Age and Origin of Fluvial Terraces in the Central Coast Range, Western Oregon

By STEPHEN F. PERSONIUS

U.S. GEOLOGICAL SURVEY BULLETIN 2038

Radiocarbon and thermoluminescence dating methods are used to determine the ages and probable origins of fluvial terraces

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1993

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Robert M Hirsch, Acting Director

For sale by
USGS Map Distribution
Box 25286, Building 810
Denver Federal Center
Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

Personius, Stephen F.
Age and origin of fluvial terraces in the central Coast Range, western Oregon / by Stephen F. Personius.
p. cm. — (U.S. Geological Survey bulletin ; 2038)
Includes bibliographical references.
Supt. of Docs. no.: I 19.3:B2038
1. Terraces (Geology)—Oregon. 2. Terraces (Geology)—Coast Ranges. I. Title. II. Series.
QE75.B9 no. 2038
[GB595.07]
557.3 s—dc20 92–23352
[551.4'42] CIP

CONTENTS

Abstract 1
Introduction 1
Scope and Purpose 1
Geomorphic Setting 4
Climate 4
Bedrock Geology 4
Methods 4
Terrace Dating Methods 4
Radiocarbon Dating 4
Thermoluminescence Dating 5
Other Dating Methods 8
Terrace Heights and Profile Construction 10
General Characteristics of Coast Range Terraces 11
Terrace Stratigraphy 11
Controls On Terrace Formation 11
Sediment Accumulation Rates 12
Terraces Along the Umpqua River 14
Latest Pleistocene and Holocene Terraces 14
Pleistocene-Holocene Transition (PHT) Terrace Exposures Near McGee Creek 14
PHT Terrace near Elkton 16
PHT Terraces Near the Coast 16
Low Terraces Near the Coast 19
Other Holocene Terraces 19
Older Terraces 20
Marine Terraces 20
Intermediate Terraces Near Reedsport 21
High Terrace at Reedsport 23
High Terrace Along Crestview Drive 25
High Terraces Along Henderer Road 26
Terraces Along the Smith River 27
Terraces Upstream from the Island 27
Terraces in the Island 30
Terraces Between the Island and Brainard Creek 33
Terraces Near Brainard Creek 33
Terraces Downstream from Brainard Creek 34
Terraces Along the Siuslaw River 36
Holocene Terrace 36
Older Terraces 36
Marine Terraces 36
Older Fluvial Terraces 39
Terraces Along the Siletz River 41
Latest Pleistocene and Holocene Terraces 43
Late Pleistocene Terraces 43
Older Terraces 46
Marine Terraces 46
Older Fluvial Terraces 46
Terraces Along the Coquille River 48
Discussion 51
Origin of Latest Pleistocene/Early Holocene Aggradation 51

Discussion—Continued
Relations Between the PHT and Other Coast Range Terraces 52
Conclusion 52
Acknowledgments 53
References Cited 53

PLATES

[Plates are in pocket]

1. Generalized map of terraces along the lower Umpqua River, central Coast Range, western Oregon.
2. Generalized map of terraces along the lower Smith River, central Coast Range, western Oregon.
3. Generalized map of terraces along the lower Siuslaw River, central Coast Range, western Oregon.
4. Generalized map of terraces along the lower Siletz River, central Coast Range, western Oregon.

FIGURES

1. Map showing regional tectonic setting of the Pacific Northwest 2
2. Map showing the location of major rivers in western Oregon and Washington 3
3. Stratigraphic columns of three fluvial terrace exposures along the Umpqua River where both thermoluminescence (TL) and radiocarbon samples were collected 9
4. Stratigraphic columns of radiocarbon-dated fluvial sediments used to calculate sedimentation rates 13
5. Longitudinal profile of terraces along the lower reach of the Umpqua River 15
6. Photograph of PHT (Pleistocene-Holocene transition) terrace on the Umpqua River near McGee Creek 16
7. Rod-and-level profile of stripped bedrock strath and PHT (Pleistocene-Holocene transition) terrace near McGee Creek on the Umpqua River 17
8. Stratigraphic column from a PHT (Pleistocene-Holocene transition) terrace exposure near McGee Creek at station 88–U2 18
9. Stratigraphic column from a terrace exposure about 2 km downstream from the highway bridge near Scottsburg at station 87–U14 18
10. Stratigraphic column of a low terrace near the Brandy Bar on the Umpqua River at station 87–U13 19
11. Diagrammatic topographic profiles of fluvial and marine terraces in the Reedsport area 22
12. Stratigraphic column of an intermediate terrace in Reedsport at station 87–U21 23
13. Stratigraphic columns of two exposures of the high terrace underlying the town of Reedsport 24
14. Stratigraphic column of an exposure of a high terrace along Crestview Drive near Reedsport at station 87–U19 25
15. Stratigraphic column from an exposure of a high terrace along Henderer Road at station 87–U1 26
16. Stratigraphic columns of two exposures of an intermediate terrace along Henderer Road 28
17. Longitudinal profile of terraces along the lower reach of the Smith River 29
18. Stratigraphic column of a terrace exposure on Vincent Creek near the confluence with the Smith River at station 87–US7 30
19. Stratigraphic columns of two terrace exposures upstream from Smith River Falls near Bear Creek 31
20. Diagrammatic topographic profile of the present valley bottom in an abandoned meander bend on the Smith River 32
21. Stratigraphic columns of terrace exposures in The Island on the Smith River 33
22. Stratigraphic columns of terrace exposures in the abandoned mender bend near Brainard Creek on the Smith River 34
23. Stratigraphic column of an exposure of a high terrace on the Smith River at station 87–US2 35
24. Topographic profile across the Siuslaw River near river km 22.5 37
25. Longitudinal profile of terraces along the lower reach of the Siuslaw River 38
26. Stratigraphic column of an exposure of a possible PHT (Pleistocene-Holocene transition) terrace at station 88–S1 on the Siuslaw River 39

27. Stratigraphic columns of exposures of several high terraces on the Siuslaw River 40
28. Photograph of basal fluvial gravels overlying sandstone bedrock in a high terrace east of Hanson Creek at station 87–S2 41
29. Longitudinal profile of terraces along the lower reach of the Siletz River 42
30. Stratigraphic columns of exposures of Holocene terraces on the Siletz River 44
31. Stratigraphic columns of exposures of late Pleistocene terraces on the Siletz River 45
32. Examples of stratigraphic columns of exposures of older terraces on the Siletz River 47
33. Map of lower Coquille River showing locations of the towns of Bandon, Coquille, and Myrtle Point, and the confluences of the North, Middle, and South Forks of the Coquille River 48
34. Map of the flood plain of the Coquille River near Coquille 49
35. Stratigraphic columns of two auger cores in abandoned channels on the Coquille River flood plain 50

TABLES

1. List of radiocarbon ages obtained in this study 6
2. List of thermoluminescence ages obtained in this study 8

AGE AND ORIGIN OF FLUVIAL TERRACES IN THE CENTRAL COAST RANGE, WESTERN OREGON

By Stephen F. Personius

ABSTRACT

Fluvial terraces are generally poorly preserved along most rivers in the central Coast Range of western Oregon, but some terraces along the Umpqua, Smith, Siuslaw, and Siletz Rivers can be correlated and provide information about their age and origin. Most terraces on inland reaches of these rivers are underlain by a bedrock strath and have a sequence of sediments consisting of a 1- to 3-m-thick basal deposit of sandy pebble channel gravel overlain by a 2- to 7-m-thick deposit of overbank sand and silt. Terraces generally converge near the coast; along tidal reaches, terraces consist of fine sand, mud, and peat of fluvial and estuarine origin. Only a few of the older, higher terrace remnants near the coast are underlain by exposed bedrock straths.

The ages of some younger terrace sediments in the Coast Range were determined by radiocarbon dating of detrital charcoal and wood. Radiocarbon analyses from the silty overbank sediments in the lowest continuous terrace found along most Coast Range rivers provided generally consistent early Holocene (7–10 ka) ages. The regional distribution and consistent age of this terrace (herein informally referred to as the Pleistocene-Holocene transition or "PHT" terrace) indicates that climatic change was probably the cause of stream aggradation in latest Pleistocene and early Holocene time. Aggradation is thought to have been mostly related to accelerated landsliding brought on by the warmer, drier early Holocene climate rather than to base level rise related to rising sea level or an influx of glacial outwash sediment. These types of "climatic" terraces, which form extensive synchronous surfaces, are relatively rare in the Coast Range.

Older terraces are present at elevations up to 200 m or more above present river levels. Most of the stratigraphic sequences exposed in the older terraces are identical to those in the lower terraces, although clay-rich, deeply oxidized soils on the higher terraces have obscured some of the original textures and bedding. Ages from experimental thermoluminescence (TL) dating of older terrace sediments from the Umpqua and Smith Rivers generally increase with increasing terrace height and ranged from about 15 ka to >200 ka. Ages of older fluvial terraces near the coast were also estimated by tentatively correlating them to poorly preserved marine terrace deposits and assumed correlations with the marine oxygen-isotope record. Although poor terrace preservation prevented definitive correlation, reasonable projections of stream gradients similar to the modern rivers support correlation of some older fluvial terraces to marine terraces and middle to late Pleistocene sea-level high stands. The nearly continuous PHT terraces, which converge to sea level near the coast, probably are analogs of these older fluvial terraces.

Numerous isolated terrace remnants are present at various elevations along Coast Range streams, but most of these terraces probably were formed as a result of "complex responses" to periodic floods or isolated sedimentation events like localized landsliding and do not represent long-term, regional changes in stream conditions. Other isolated terraces are present on the insides of meander bends and probably formed as a result of minor vertical incision that accompanies stream meandering ("slip-off" terraces). Most of these isolated remnants were never parts of extensive terrace surfaces. Even less common in the Coast Range are "tectonic" terraces, examples of which are presently warped over an anticline in Eocene bedrock along the Siuslaw River.

INTRODUCTION

SCOPE AND PURPOSE

The Coast Range is a belt of coastal mountains of moderate elevation that lie between the Olympic Mountains of northwestern Washington and the Klamath Mountains of southern Oregon and northern California; the range forms part of the forearc of the Cascadia subduction zone, an active subduction zone that stretches from northern California to British Columbia (fig. 1). Relatively little is known about the Quaternary history of the Coast Range,

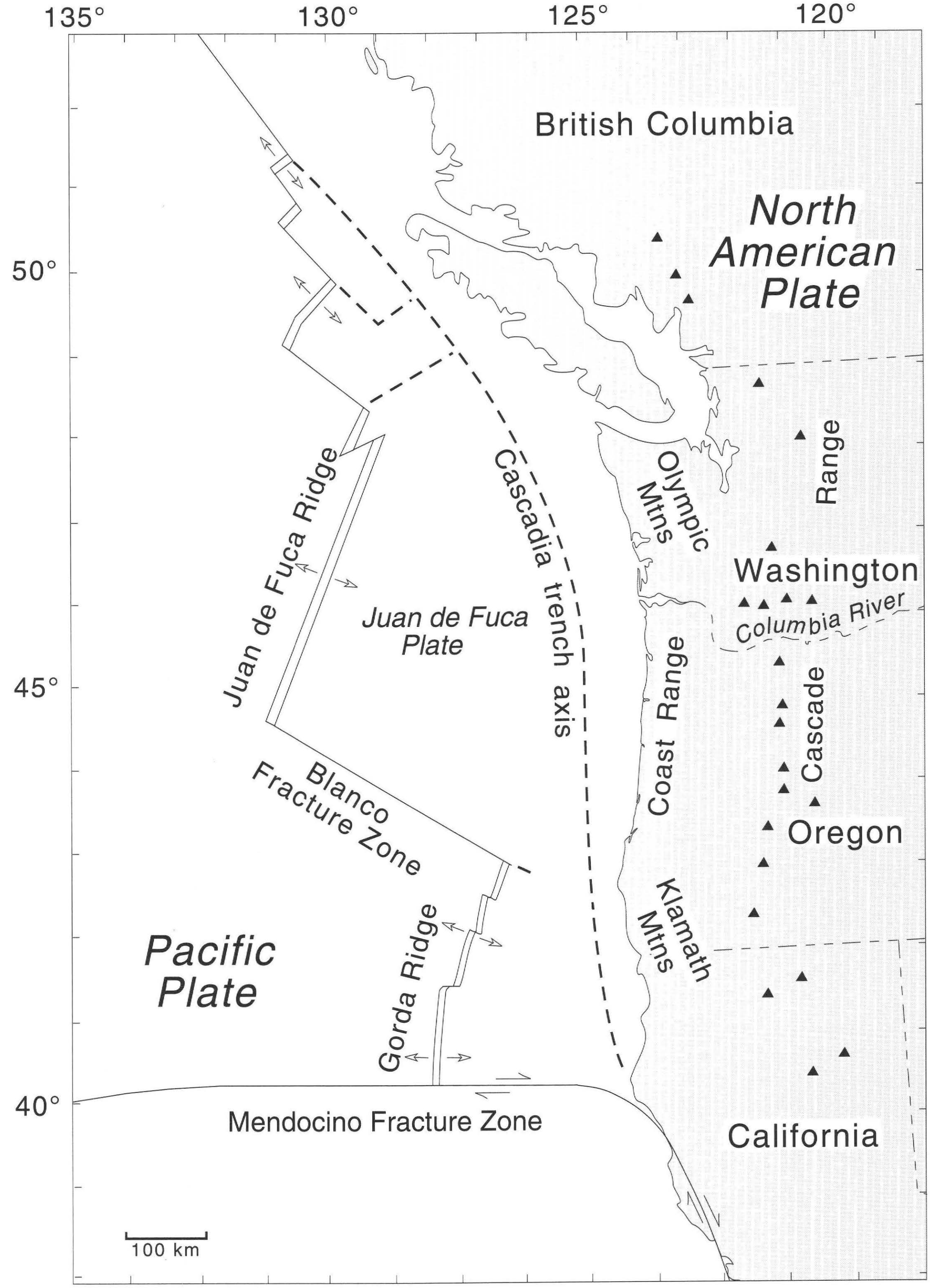


Figure 1. Map showing regional tectonic setting of the Pacific Northwest, locations of major mountain ranges, and locations of volcanoes in the Cascade Range (triangles); after Rogers (1988) and Spence (1989).

although several recent studies have addressed deformation of Quaternary deposits along the Oregon and Washington coasts (Adams, 1984; Atwater, 1987, 1992; West and McCrumb, 1988; Darienzo and Peterson, 1990; Kelsey, 1990; McInelly and Kelsey, 1990; Muhs and others, 1990; Nelson, 1992; Nelson and Personius, 1991). In this report, I discuss the distribution of terraces along several rivers in the central Coast Range of western Oregon, the methods and results of terrace dating and possible controls on terrace formation as the basis for a

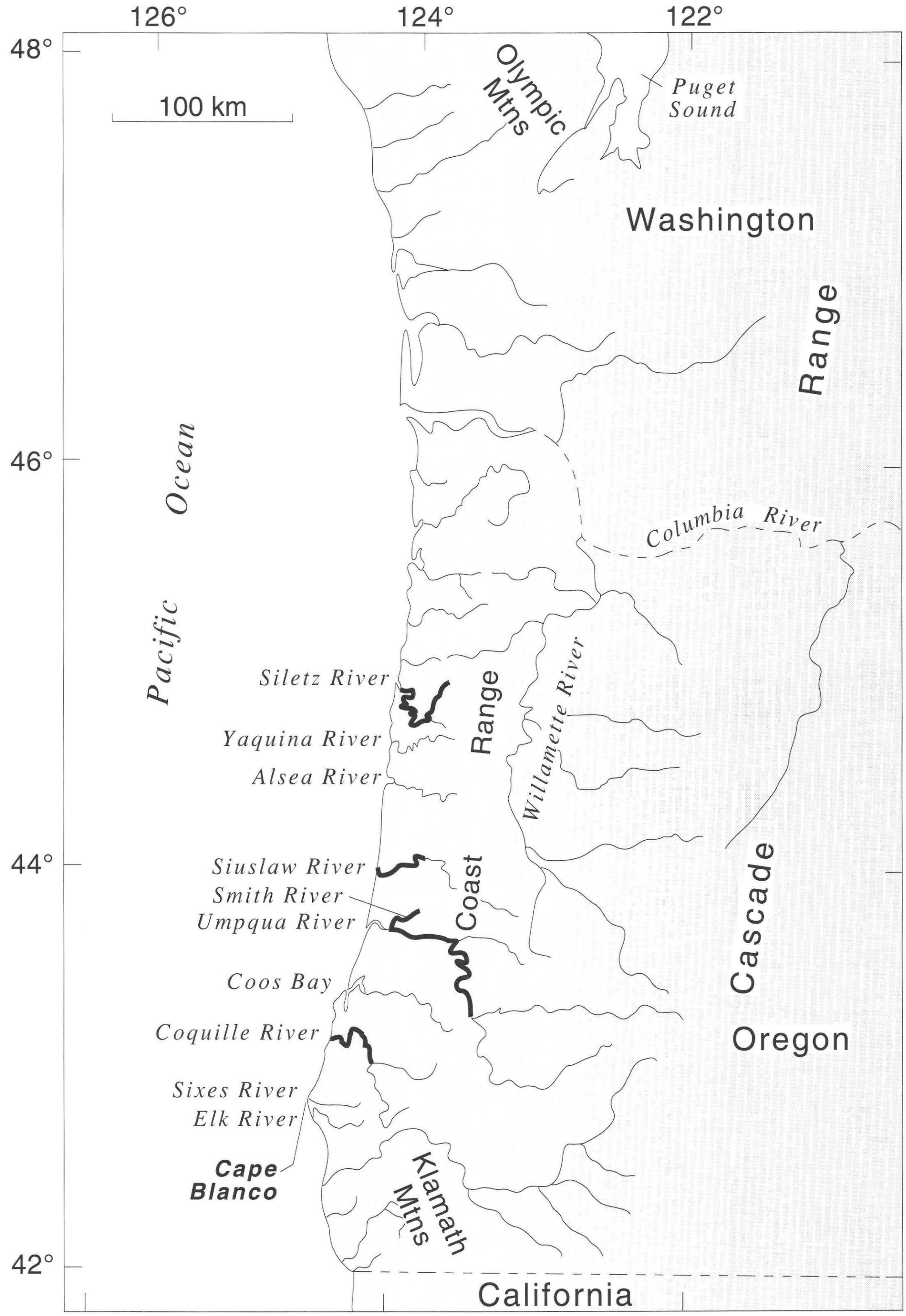


Figure 2. Map showing the location of major rivers in western Oregon and Washington. Heavier lines mark reaches of rivers examined in this study.

separate study of fluvial terraces as recorders of Quaternary deformation in this region.

The rivers chosen for this study are, from north to south, the Siletz, Siuslaw, Smith, Umpqua, and Coquille Rivers (fig. 2). The first four rivers were chosen because they all flow through similar bedrock and have several ages of fluvial terraces preserved along their lengths; the Coquille River was included in this study because of its location in a region of known Quaternary deformation. With the exception of the Smith River, which flows into the Umpqua River about 18 km from the coast, all rivers examined in this study are trunk streams that ultimately flow into the Pacific Ocean.

GEOMORPHIC SETTING

The Coast Range in Oregon is a rugged mountain range of moderate elevation that has been deeply dissected by fluvial incision. Relief is substantial although maximum elevations only reach about 1,250 m; the highest elevations in the drainages examined in this study are less than 800 m. Trunk streams in the Coast Range are usually entrenched in deep valleys, which indicates probable stream antecedence. Valley shapes and variations in river profiles (Rhea, 1993) and numerous examples of stream capture in the Coast Range (Niem, 1976; Baldwin, 1981) are probably indicative of long-term Quaternary uplift. Steep slopes and abundant rainfall aid in the formation of accumulations of colluvium on most slopes; periodic landsliding of thicker colluvial deposits from bedrock hollows is one of the dominant processes by which sediment is delivered to stream channels in the Coast Range (Pierson, 1977; Dietrich and Dunne, 1978; Benda and Dunne, 1987; McDowell, 1987; Benda, 1990). Other Quaternary features and deposits in the region include marine terraces and sand dunes along the coast, estuarine and salt marsh deposits in the tidal reaches of coastal rivers, scattered landslides, and fluvial terrace deposits along Coast Range streams.

CLIMATE

The geomorphology of the Coast Range is strongly influenced by the temperate, humid climate of the region. Rainfall is abundant and strongly influenced by elevation. Annual amounts are about 150 cm near the mouth of the Coquille River and 180–200 cm near the mouths of the Umpqua, Siuslaw, and Siletz Rivers; annual amounts are 250–300 cm in the Coast Range headwaters of the Coquille, Umpqua, Smith, and Siuslaw Rivers, and 450–500 cm in the headwaters of the Siletz River (Oregon State Water Resources Board, 1958, 1965; Beaulieu and Hughes, 1975; Schlicker and others, 1973; Schlicker and Deacon, 1974). Most precipitation occurs as rain during the winter months (November to March). Snow occurs above elevations of about 600 m, but only persists on the ground for more than a day or two above elevations of about 1,000 m. Summers are relatively dry and cool; temperatures are generally more moderate near the coast and become warmer inland away from maritime influence and summer fogs. Near the coast, mean summer temperatures are about 16°C and mean winter temperatures are about 7°C; temperatures inland in the Coast Range are also mild, but show wider variations. Despite the rugged topography, abundant rainfall and mild temperatures combine to make the Coast Range one of the most productive and heavily logged forest regions in the country.

Very little is known about Quaternary paleoclimates of the region, but the Coast Range was probably not glaciated during late Pleistocene glaciations that affected the higher parts of the Olympic Mountains to the north, the Klamath Mountains to the south, and the Cascade Mountains to the east (Porter and others, 1983). Pollen studies in southern Washington and northern California indicate cold, dry conditions during the late Wisconsin glacial maximum, followed by cool, more humid conditions in the latest Pleistocene; warmer, drier conditions than today are thought to have been prevalent during the early and middle Holocene, which were followed by cooler, wetter climatic conditions in the late Holocene (Heusser, 1983, 1985; Barnosky, 1985; Adam, 1988). These patterns are consistent with other late Quaternary paleoclimate studies in the Western United States (for example, Baker, 1983; COHMAP, 1988).

BEDROCK GEOLOGY

Most of the central Coast Range is underlain by a sequence of Eocene and younger sedimentary and volcanic rocks (Wells and Peck, 1961; Walker and Duncan, 1989) deposited in a forearc basin during an earlier phase of subduction (Snavely, 1987). Most of the study area is underlain by the Eocene Tyee Formation, a thick sequence of arkosic and lithic turbidite sandstone and siltstone. Minor felsic volcanic and intrusive rocks are found throughout the Coast Range; many of these igneous outcrops form resistant cores that underlie the highest peaks in the range. The predominant structures in bedrock are north- and northeast-trending folds and northeast- and northwest-trending high-angle faults (Wells and Peck, 1961; Peterson and others, 1986; Snavely, 1987; Walker and Duncan, 1989).

METHODS

TERRACE DATING METHODS

RADIOCARBON DATING

Because of the heavy forest cover and frequent forest fires, charcoal is relatively abundant in modern stream and younger terrace sediments in the Coast Range, so I relied heavily on conventional gas proportional and accelerator mass spectrometry (AMS) radiocarbon ages in this study (table 1). Several problems are commonly associated with radiocarbon dating of organic matter from fluvial terrace sediments. I was primarily interested in determining the age of the initiation of aggradation of terrace deposits, so I tried to obtain radiocarbon samples from the lowest parts of the terrace sediments. However, very few samples were obtained from the lower channel-facies gravel, because charcoal was either rarely deposited in these sediments or has been oxidized by subsequent pedogenesis and groundwater flow. Therefore, most of my samples were obtained from the lower part of the fine-grained overbank facies that forms the upper part of most terrace exposures.

The detrital origin of fluvial charcoal samples can cause additional problems, because detrital charcoal will sometimes have a substantial inherited age before it is deposited with fluvial sediment. Charcoal enters the fluvial system either as recently burned logs or twigs washed off the land surface, or more rarely may be recycled by erosion of previously deposited charcoal from older terrace sediments. One study in Australia showed that small (<2 mm) fragments of "modern" fluvial detrital charcoal sampled from the active stream bed had inherited ages of 1,400-1,600 radiocarbon years (Blong and Gillespie, 1978). I did not obtain multiple radiocarbon ages on charcoal from modern stream sediments as a test of this potential problem, but several of my radiocarbon analyses on charcoal from low, young terraces yielded modern ages or ages of less than a few hundred years, so inherited age is probably not a serious problem in most of my samples. Perhaps the easily eroded sandy sediment characteristic of the stream studied by Blong and Gillespie (1978) is more susceptible to charcoal reworking than the silty sediment that makes up the bulk of fluvial terraces in the Coast Range. In addition, most fragments of charcoal in Coast Range fluvial sediments are very small (<5 mm) and the climate is very conducive to rapid breakup of organic materials, so charcoal fragments of this size are likely to disintegrate quickly upon remobilization.

Some of the radiocarbon ages reported here are anomalously young. The samples may have been contaminated with small pieces of *in situ* burned roots, or partially decomposed roots and other young organic material from animal burrows, resulting in anomalous ages. Modern and decomposed roots were abundant in almost all terrace exposures examined in this study. Although extreme care was taken to avoid including such materials in the submitted samples, most of my charcoal samples were collections of small fragments of disseminated charcoal, so some contamination by younger materials was expected. Another potential source of anomalously young ages is erroneous sampling of charcoal from younger, non-fluvial sediment. Because the silty overbank sediments in the Coast Range are often devoid of characteristic fluvial bedding features, they can easily be confused with younger colluvial sediment that has similar appearance and texture. Extreme care was taken to avoid sampling exposures where fluvial features such as well-sorted sand beds were not clearly apparent or where angular colluvial clasts were present, but some samples from overlying colluvial units may have been included in the radiocarbon analyses.

A final problem with radiocarbon dating is the nonlinear relationship between the radiocarbon and calendric time scales caused by variable rates of ^{14}C production in the atmosphere (Stuiver and Quay, 1980). To overcome this problem, I used conversion data (Stuiver and Reimer, 1986; Bard and others, 1990; Becker and others, 1991; Stuiver and others, 1991) to calibrate some of my radiocarbon ages. All calibrated ages mentioned in this report are listed in "calibrated years B.P." to distinguish them from uncalibrated radiocarbon ages or age ranges, which are listed in "yr B.P." (years before present—1950) or "ka" (thousands of years ago). Modern (post-1950) samples contain some radiocarbon produced by atomic-bomb testing in the atmosphere in the 1950's, and therefore are listed as negative ages (–10 ± 70 yr B.P.) or as ages with >100 percent of modern radiocarbon (104% modern).

THERMOLUMINESCENCE DATING

I used experimental thermoluminescence (TL) dating to estimate the ages of several samples of fluvial sediment. The dates reported herein (table 2) are some of the first TL dates on fluvial sediment in the Pacific Northwest. TL dating is a relatively new technique that shows great promise for directly dating many types of Quaternary sediment (Wintle and Huntley, 1982; Berger, 1988; Forman and others, 1988). The principles behind this method are that during deposition in certain types of environments, sediments have their inherited TL signal reduced (bleached) to some low residual level by exposure to sunlight. The sediment then slowly acquires a new geological TL signal through exposure to ionizing radiation from radioactive decay of uranium, thorium, and potassium in the surrounding sediment. The accumulated TL signal in the sample is a measure of cumulative exposure to ionizing radiation. In the laboratory, the TL signal in a sample is calibrated to a known radiation level called the equivalent dose. A TL age is determined by dividing the equivalent dose by the dose rate, which is a measure of the environmental radioactivity of the surrounding sediment. Common complications to the technique include the incomplete bleaching of sediment prior to deposition (which can give the sample an inherited age), fluctuations in water content of the sediment, and physical and chemical changes in the sediment due to pedogenesis (which may tend to give anomalously young ages). All these problems have probably had an effect on the TL ages of fluvial sediment in the Coast Range.

Table 1. List of radiocarbon ages obtained in this study.

[Radiocarbon laboratory abbreviations: AA—University of Arizona/NSF Accelerator Facility; BETA—Beta Analytic, Inc., Coral Gables, Florida; ETH—Eidgenossische Technische Hochschule, Zurich (through Beta Analytic); GX—Geochron Laboratories, Cambridge, Massachusetts; PITT—University of Pittsburgh Radiocarbon Laboratory; USGS—U.S. Geological Survey, Menlo Park Radiocarbon Laboratory]

Field and laboratory sample number	Field station number	Latitude	Longitude	Geologic material and sample weight (g)	Reported Radiocarbon age (yr B.P.)	Remarks
				UMPQUA RIVER		
SP88UR1 BETA-27962	88-U2	43° 31.45'	123° 32.54'	charcoal 5.0	9,120 ± 150	Disseminated sample.
SP87UR2 BETA-22662	87-U4	43° 31.44'	123° 32.21'	charcoal 3.0	9,800 ± 410	Single fragment exposed in stream cut.
SP87UR3 PITT-0126	87-U6	43° 28.98'	123° 30.88'	charcoal 3.9	6,545 ± 75	Single fragment.
SP88UR3 USGS 2722	88-U3	43° 29.05'	123° 30.84'	charcoal 9.1	6,440 ± 60	Disseminated sample.
SP87UR4 AA-2752	87-U7	43° 38.00'	123° 34.11'	charcoal 0.24	8,630 ± 100	AMS (accelerator mass spectrometry) age on disseminated sample; 400 cm depth.
SP87UR10 USGS 2643	"	"	"	charcoal 1.0	730 ± 80	Disseminated sample; same location as SP87UR4 at 50 cm depth.
SP87UR5 BETA-22663	87-U8	43° 37.90'	123° 34.02'	charcoal 4.1	210 ± 80	Single fragment; 250 cm depth.
SP87UR6 USGS 2646	"	"	"	wood 9.5	95 ± 40	Single fragment; 180 cm depth.
SP87UR7 USGS 2645	"	"	"	wood 18.0	115 ± 40	Single fragment; 120 cm depth.
SP87UR8 USGS 2644	"	"	"	charcoal 1.0	-10 ± 70	Disseminated sample; 50 cm depth.
SP87UR15 PITT-0127	87-U14	43° 38.86'	123° 52.50'	charcoal 2.0	104% modern	Disseminated sample; probably deposited onto the terrace in a debris flow from a tributary stream.
SP87UR18 BETA-22664	87-U20	43° 40.03'	124° 05.30'	charcoal 1.8	>26,400	Disseminated sample; 425 cm depth.
SP87UR19 PITT-0186	"	"	"	charcoal 5.8	22,240 ± 630	Disseminated sample; 325 cm depth.
SP87UR21 BETA-23533	87-U22	43° 41.67'	124° 00.25'	peat 7.4	1,180 ± 130	Bulk sample from auger core; 225-250 cm depth.
				SMITH RIVER		
SP87USR2 BETA-23531 ETH-3546	87-US3	43° 44.94'	124° 01.06'	charcoal 0.3	2,685 ± 95	AMS age; disseminated sample.
SP87USR3 AA-2753	87-US5	43° 48.14'	123° 48.44'	charcoal 0.23	>43,600	AMS age; disseminated sample.
SP87USR5 BETA-23532 ETH-3547	87-US7	43° 47.45'	123° 46.39'	charcoal 0.55	7,950 ± 110	AMS age; disseminated sample from terrace on Vincent Creek, 0.25 km upstream from confluence with Smith River.
SP87USR6 PITT-0128	87-US10	43° 47.20'	123° 49.50'	charcoal 1.4	2,860 ± 215	Minimum age; disseminated sample from colluvium overlying stripped terrace.
SP87USR7 AA-2754	87-US11	43° 46.95'	123° 47.97'	charcoal 0.28	10,165 ± 85	AMS age; disseminated sample from alluvial-fan sediment.
SP87USR8 USGS 2642	87-US12	43° 47.15'	123° 48.65'	charcoal 5.6	1,020 ± 50	Minimum age on single fragment; probably a burned root.
SP87USR12 PITT-0129	87-US15	43° 44.29'	124° 04.31'	charcoal, peat, wood 4.4	123.7% modern	Mixed sample from auger core; 125 cm depth.
SP87USR13 PITT-0130	"	"	"	charcoal, wood 3-5	1,825 ± 65	Several fragments from same core as SP87USR12; 360 cm depth.

Table 1. List of radiocarbon ages obtained in this study—Continued.

Field and laboratory sample number	Field station number	Latitude	Longitude	Geologic material and sample weight (g)	Reported Radiocarbon age (yr B.P.)	Remarks
			SIUSLAW RIVER			
SP88SR1 BETA-27967 ETH-4489	88-S1	44° 03.72'	123° 52.98'	charcoal 0.2	7,010 ± 90	AMS age; disseminated sample.
			SILETZ RIVER			
SP88SZR2 BETA-28357 ETH-4746	88-SZ2	44° 42.89'	123° 55.92'	charcoal 2.0	12,110 ± 95	Minimum AMS age; disseminated sample probably contaminated with modern carbon.
SP88SZR4 BETA-27966 ETH-4488	88-SZ6	44° 44.63'	123° 47.76'	charcoal 0.3	9,030 ± 110	AMS age; disseminated sample.
SP88SZR5 BETA-27963	88-SZ7	44° 47.17'	123° 47.75'	charcoal 5.8	>36,000	Charcoal split; several fragments.
SP88SZR6 USGS 2724	"	"	"	wood 19.4	41,600 ± 1300	Wood split; several fragments from same location as SP88SZR5.
SP88SZR7 USGS 2723	88-SZ8	44° 46.70'	123° 50.07'	charcoal 2.6	2,230 ± 60	Disseminated sample.
SP89SZR1 GX-15311	89-SZ2	44° 43.79'	123° 55.42'	charcoal 3.0	9,695 ± 440	Disseminated sample.
			COQUILLE RIVER			
SP89CR4 GX-15309	89-C3	43° 09.51'	124° 11.88'	wood, charcoal 6.1	2,860 ± 155	Disseminated sample from auger core in northern abandoned channel; 350 cm depth.
SP89CR7 GX-15310	89-C4	43° 09.38'	124° 11.82'	wood, charcoal 30	2,835 ± 140	Disseminated sample from auger core in southern abandoned channel; 375-400 cm depth.

A relatively simple TL sampling technique was used in this study. The terrace exposures were first excavated about 20–50 cm to expose fresh silty overbank sediment that had not recently been exposed to sunlight. Samples were taken by screwing or pushing soup-can sized steel cans into the fresh exposure, and the cans were then sealed with aluminum foil and plastic tape to preserve moisture content and prevent exposure to sunlight.

Three TL ages were obtained on samples from radiocarbon-dated exposures on the Umpqua River in order to establish the accuracy of the technique (fig. 3). TL analysis on "modern" overbank sediment (radiocarbon age on charcoal of 210 ± 80 yr B.P.) yielded a TL age of 7.4 ± 2.6 ka (fig. 3*A*). The sampled sediment is a loosely consolidated silty sand that contains abundant well-preserved fragments of charcoal and wood. Two other radiocarbon-dated sites yielded mixed results; the TL age on sample SP87UT3 (8.9 ± 5.9 ka) was only slightly older than two radiocarbon ages on charcoal (6,440 ± 60 yr B.P. and 6,545 ± 75 yr B.P.) from the same location (fig. 3*B*); whereas, the TL age on sample SP87UT1 (18.5 ± 2.4 ka) was nearly twice as old as a radiocarbon age on charcoal of 9,800 ± 410 yr B.P. (fig. 3*C*) from the same location. The anomalously old Holocene ages indicate that inherited TL ages of 2.5–9 kyr, which are probably related to incomplete bleaching of the sediment during transport, may be characteristic of fluvial-overbank sediment from the upper reaches of Coast Range rivers. In contrast to the apparent incomplete bleaching seen in the Holocene samples, most of my TL analyses on older sediments from the tidal reaches of the Umpqua and Smith Rivers appeared to yield younger ages than geologic relations would indicate (table 2), but the geologic age estimates on these older sediments are poorly constrained. The TL ages on older sediments are discussed in more detail in sections on Umpqua and Smith River terraces.

Some dating studies have found reasonably good concordance between TL and other numerical ages of fluvial sediment (Nanson and Young, 1987; Nanson and others, 1991; Murray and others, 1992) and the effectiveness of natural zeroing of suspended fluvial sediment (Huntley, 1985; Berger and others, 1990), but other TL studies of

Table 2. List of thermoluminescence (TL) ages obtained in this study.

[All analyses were performed by Steven L. Forman at the Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, Colo.]

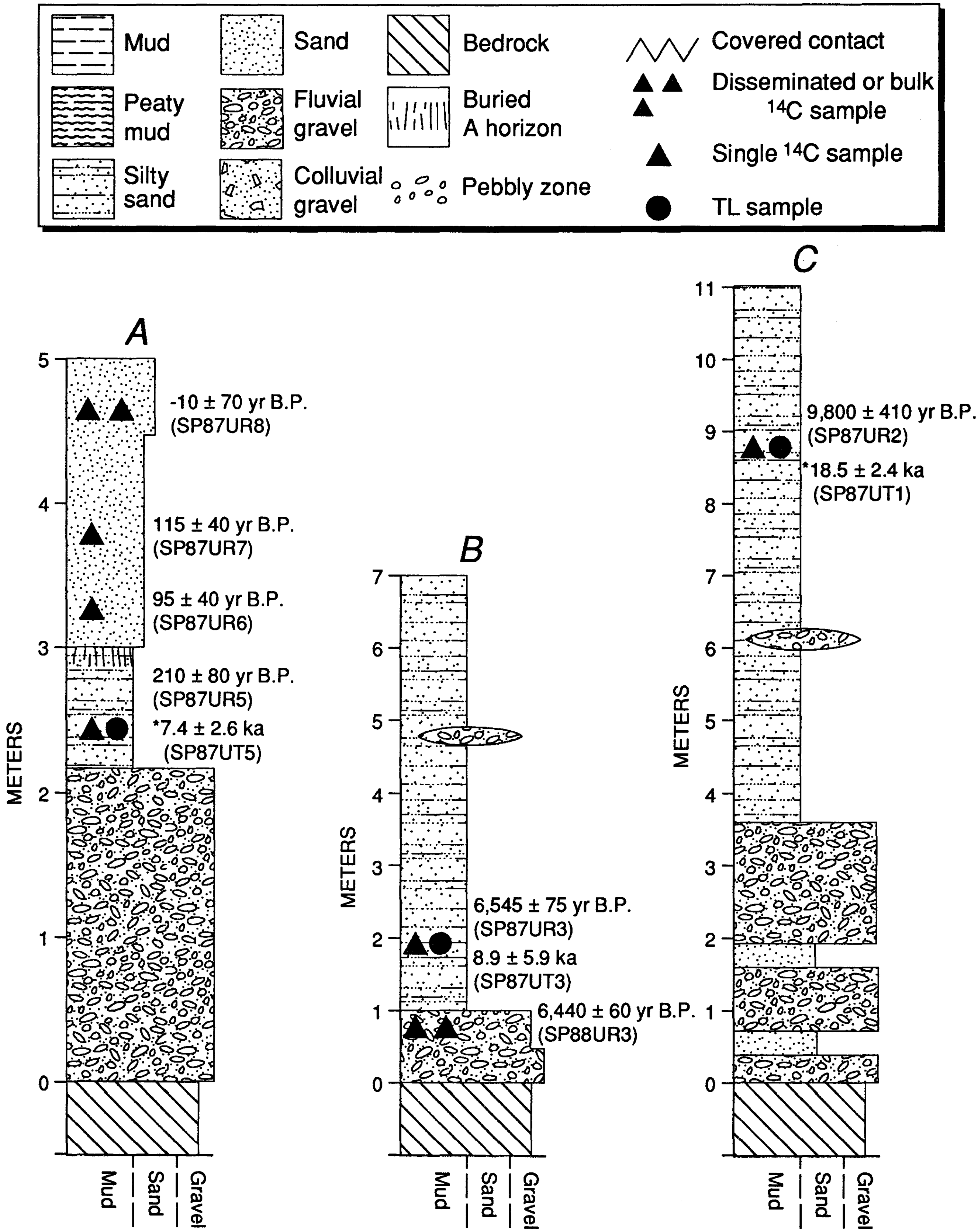
Field and laboratory sample number	Field station number	Latitude	Longitude	Geologic material	TL age (ka)	Geologic age estimate (ka)	Remarks
				UMPQUA RIVER			
SP87UT1 ITL84	87-U4	43° 31.44'	123° 32.21'	silty sand	18.5 ± 2.4	9-11	Sample located near SP87UR2 (9,800 ± 410 yr B.P.)
SP87UT3 ITL116	87-U6	43° 28.98'	123° 30.88'	silty sand	8.9 ± 5.9	6-7	Sample located near SP87UR3 (6,545 ± 75 yr B.P.)
SP87UT5 ITL85	87-U8	43° 37.90'	123° 34.02'	sandy silt	7.4 ± 2.6	0.1-0.3	Sample located near SP87UR5 (210 ± 80 yr B.P.)
SP87UT7 ITL118	87-U1	43° 38.39'	123° 36.30'	clayey, silty sand	116 ± 20	125	Sample located in lower part of Bt soil horizon; may correlate with substage 5e marine terrace.
SP87UT18 ITL117	87-U18	43° 41.82'	124° 07.52'	silt	65.2 ± 7.3	125	May correlate with substage 5e marine terrace.
SP87UT20 ITL173	87-U19	43° 41.84'	124° 05.81'	clayey, sandy silt	>200	>200	At TL saturation; may correlate with stage 7 or older marine terrace.
SP87UT22 ITL86	87-U21	43° 41.99'	124° 06.40'	sandy silt	14.9 ± 3.1	15-30	May correlate with Scholfield Creek fluvial terrace.
				SMITH RIVER			
SP87UST2 ITL174	87-US2	43° 44.12'	124° 02.92'	sandy silt	55 ± 12	125	May correlate with substage 5e marine terrace.

fluvial sediments have reported less encouraging results (Berger, 1990). While not without inconsistencies, my TL results on fluvial sediments are encouraging and, when used with other data, may be useful in determining relative ages of older fluvial terrace sediments in the Coast Range. Unfortunately, these analyses are very expensive and time consuming, so only a limited number of TL analyses were performed. I hope that demonstration projects such as this one help to establish the viability and utility of TL dating, so that additional studies that address the problems identified in the present study can be conducted.

OTHER DATING METHODS

Studies of soil development are commonly used in fluvial terrace studies (for example, Birkeland, 1984; Harden, 1987; Dethier, 1988), but I found that the steep climatic gradients (especially rainfall and summer temperatures) from the coast to inland valleys and poor terrace preservation reduced the utility of soils as a method for estimating terrace ages. In addition, most exposures of terrace sediments that I examined in this study are in roadcuts that may not be situated in stable geomorphic positions. For these reasons, I did not describe soils in detail during my studies of terraces in the Coast Range, and have not included soil profiles on the stratigraphic

Figure 3 (facing page). Stratigraphic columns of three fluvial terrace exposures along the Umpqua River where both thermoluminescence (TL) and radiocarbon samples were collected. Radiocarbon ages are listed in years before present (1950; yr B.P.) and TL ages are listed in thousands of years (ka); field sample numbers (in parentheses) are listed for reference to table 1. Column thicknesses are measured from the sediment/bedrock contact. Exposure locations are (*A*) lower terrace near Elkton at station 87–U8, (*B*) composite column from a terrace near river km 130 at stations 87–U6 and 88-U3, and (*C*) terrace near McGee Creek at station 87–U4. Legend shows patterns and labels for all stratigraphic columns in this report. Columns show complete exposures of terrace sediments, from the bedrock strath to the surface of the terrace, except where marked with covered contact symbol or where bedrock is not shown at the base of the column. Soil development is not shown in the columns. Grain size scale shows breaks between mud (silt and clay), sand, and gravel. Note differences in vertical scale.


Mud
Sand
Bedrock
Covered contact
Peaty mud
Fluvial gravel
Buried A horizon
Disseminated or bulk 14C sample
Single 14C sample
Silty sand
Colluvial gravel
Pebbly zone
TL sample
A
-10 ± 70 yr B.P.
(SP87UR8)
115 ± 40 yr B.P.
(SP87UR7)
95 ± 40 yr B.P.
(SP87UR6)
210 ± 80 yr B.P.
(SP87UR5)
*7.4 ± 2.6 ka
(SP87UT5)
METERS
B
6,545 ± 75 yr B.P.
(SP87UR3)
8.9 ± 5.9 ka
(SP87UT3)
6,440 ± 60 yr B.P.
(SP88UR3)
C
9,800 ± 410 yr B.P.
(SP87UR2)
*18.5 ± 2.4 ka
(SP87UT1)
Mud
Sand
Gravel

columns in this report. The intense rainfall induces severe oxidation and *in situ* weathering; soils were generally redder, more oxidized, contained larger amounts of clay, and contained more weathered gravel clasts (measured by hand crushing) with advancing age. However, some soil characteristics such as distinct horizonation, clay films, and soil structure were less developed than might be expected in the older soils, so some of the deeper weathering may be related to groundwater circulation.

Thicknesses of weathering rinds have been used as a relative dating technique on fluvial gravel clasts (Colman and Pierce, 1981; Knuepfer, 1988). Preliminary studies by Colman and Pierce (1981) indicated that measurement of weathering rinds on basaltic clasts might have utility as a dating technique along the Siletz River, but I found the technique unusable for several reasons. Of the five rivers examined in this study, only the Siletz River drainage basin contains enough outcrops of basaltic volcanic rocks to provide a source of clasts of suitable lithology. Unfortunately, gravels are restricted to the lower parts of most Coast Range terrace sequences, far below the upper parts of the B horizon where the most consistent weathering rinds are formed. I examined weathering rinds at several locations in the Coast Range, but most rinds were widely variable in thickness and appeared to be related to intermittent groundwater flow. Rainfall amounts also affect rind thickness (Colman and Pierce, 1981), so the steep rainfall gradients between the coast and higher parts of the Coast Range would also complicate comparisons between rind thickness and terrace age.

A final dating technique commonly used in studies of older terraces is the correlation of fluvial terraces with marine terraces and the prehistoric sea-level record. The best preserved sequence of marine terraces in the Pacific Northwest is present between Cape Blanco and Coos Bay (fig. 2) in southern Oregon. These terraces have been the subject of numerous studies but only recently have generally consistent uranium series, amino acid, and stable isotope age data become available. The youngest—Whiskey Run terrace—has been correlated with the 80 ka, oxygen-isotope substage 5a (Shackleton and Opdyke, 1973) sea-level high stand; the next older—Pioneer terrace—has been correlated with the 105 ka, substage 5c sea-level high stand (Kelsey, 1990; Muhs and others, 1990); and the next oldest—Silver Butte terrace—has been tentatively correlated with the 125 ka, substage 5e sea-level high stand (Kelsey, 1990). Detailed mapping by Kelsey (1990) indicates that all three of these terraces occupy the same wave-cut platform in the Cape Blanco region, so the lack of significant differences in altitude between the three stage-5 terraces precludes the use of elevation spacing as a precise method of correlating scattered marine terrace remnants in central Oregon to dated sites in southern Oregon. Detailed soils studies at Cape Blanco and Cape Arago (Bockheim and others, 1992), however, indicate that soil development can be used as a marine terrace correlation tool. My reconnaissance examination of soils on marine terrace sediments along the central Oregon coast has indicated that the lowest marine terraces present are more likely to have formed during one of the stage-5 high stands, (80 ka, 105 ka, or 125 ka) than during stage 7 (230 ka) or older high stands. More detailed soils studies (H.M. Kelsey, written commun., 1992) indicate that in most places along the central Oregon coast, the lowest marine terrace is correlative with the oxygen-isotope substage 5e (125 ka) sea-level high stand, and all higher terraces probably correlate with stage 7 (230 ka) or older high stands. Some tentative correlations of marine terraces with fluvial terraces near the mouths of the Umpqua, Smith, Siuslaw, and Siletz Rivers will be discussed.

TERRACE HEIGHTS AND PROFILE CONSTRUCTION

Fluvial terrace remnants were initially identified on 1:12,000-scale air photos, and most were later checked in the field. Several methods were used to measure terrace heights. Some were measured with an altimeter, especially those located within a few minutes walk or drive from a benchmark where the instrument could be accurately calibrated. Other terrace remnants were surveyed with a hand level and rod from points of known elevation; the lowest terraces were commonly measured in this fashion from the height of the river surface. Some terrace heights also were measured directly from 1:24,000-scale topographic maps. However, many high remnants were inaccessible due to thick vegetation or land ownership problems, so I employed a photogrammetric method to measure additional terrace heights. A computer-assisted photogrammetric mapping system (Dueholm and Pilmore, 1989) was used to construct detailed topographic profiles, usually measured from the river surface to the terrace surface through points of known elevation. These various methods yielded probable errors of about ±5 m for the higher terraces and ±2 m or less for the lowest terraces. In all cases, height measurements were originally made in feet and converted to meters above mean sea level.

Longitudinal profiles of the stream and terrace remnants were constructed for the Umpqua, Smith, Siuslaw, and Siletz Rivers. These profiles were constructed with the terrace height data and stream elevations taken from 1:24,000-scale topographic maps. The elevation data were plotted against stream length (in km), which was converted from river mileage values taken directly from the topographic maps. Some discrepancies occurred in plotting stream length of terraces preserved in abandoned meander bends on the Umpqua and Smith Rivers. In these cases, terrace remnant lengths were projected downstream from the location of the upstream end of the remnant. The profiles clearly show the poor preservation of terrace surfaces and the tenuous nature of most terrace correlations. Poorly constrained correlations (dotted lines) mostly were made by mimicking the gradients of the better constrained correlations (solid and dashed lines).

GENERAL CHARACTERISTICS OF COAST RANGE TERRACES

TERRACE STRATIGRAPHY

The stratigraphy of fluvial terrace deposits found along Coast Range rivers is remarkably consistent, regardless of terrace height above the present river level. Along the upper reaches above tidal influence, all terraces are strath terraces consisting of a tread cut into bedrock overlain by 3 to 10 m of unconsolidated sediment. These sediments consist of a 1- to 3-m-thick lower channel-gravel facies of sandy pebble and cobble gravel, overlain by a 2- to 7-m-thick overbank facies of sand, sandy silt or silty sand, and silt; thin, discontinuous beds of sand and sandy gravel are commonly present in the overbank facies. I found very few examples of buried soils in the more than 60 exposures of terrace sediments examined in this study. These buried soils were mostly thin (<20–30 cm), poorly developed A horizons that probably represent hiatuses in deposition of less than a few tens of years, so in most cases the sediments in both the channel-gravel and overbank facies must have been deposited fairly continuously.

The stratigraphy of fluvial terrace sediments near the coast is more variable, and probably is a reflection of short- and long-term fluctuations in sea level. The lower reaches of all rivers examined in this study are tide influenced and are flowing in deep, sediment filled, fiord-like valleys. These valleys were excavated by stream incision during periods of low sea level associated with full glacial conditions and now act as traps for fine-grained estuarine sediment. Most fluvial terrace sequences in these reaches generally consist of fine sand, mud (silt and clay), and peat, may be very thick (water wells in the Reedsport area on the Umpqua River have penetrated more than 43 m of unconsolidated fluvial sediment (Curtiss and others, 1984), and usually do not have exposed bedrock straths. Similar fluvial sequences extend up river to the tide limit of most Coast Range rivers. A few older, higher terrace remnants near the coast, however, have thinner stratigraphic sequences and bedrock straths like their upstream counterparts, supporting the conclusion that hydrologic conditions near the mouths of Coast Range rivers have not remained static through time.

CONTROLS ON TERRACE FORMATION

The modern hydrologic setting of the nontidal reaches of rivers in western Oregon is one of active stream incision driven by regional uplift of the Coast Range. Active incision is indicated by the presence of bedrock in the beds of most Coast Range streams above tide limit and by the presence of very narrow modern flood plains. Long-term Quaternary incision is implied by the presence of high strath terraces and entrenched meanders, confinement of the upstream reaches of all rivers in relatively narrow, bedrock cored, V-shaped valleys, and by numerous examples of stream capture in the Coast Range (Niem, 1976; Baldwin, 1981). Stream incision has probably dominated throughout most of the late Quaternary, and it is a condition not conducive to extensive deposition of fluvial sediment. So how do extensive fluvial terraces form in such an environment? Initial deposition of fluvial sediment requires hydrologic conditions that allow streams to migrate laterally. Periods of lateral migration can be related to short hiatuses in regional uplift or to periods of aggradation caused by an influx of sediment or a decrease in stream competence related to a rise in base (sea) level. Experimental data show that lateral migration will dominate stream incision if the sediment load of a stream is increased beyond the ability of the stream to entrain its load (see reviews in Schumm and others, 1987), so large sediment inputs not only provide the material for aggradation and are the source of terrace sediment, but large influxes of sediment also induce the lateral stream migration that cuts the bedrock straths that underlie the terrace sediments. Finally, terrace formation requires that the terrace tread eventually be abandoned by renewed incision caused by decreased sediment supply or a drop in base level caused by renewed uplift or falling sea level.

I have roughly grouped fluvial terraces in the Coast Range into four main types. The smallest, most areally restricted terraces are formed by vertical incision concurrent with minor lateral incision that accompanies meandering of the river channel. This stream behavior results in unpaired "slip-off" terraces (Cotton, 1940) preserved on the insides of meander bends. Some of these isolated remnants may correlate with more extensive terraces, but most are probably not synchronous with other terrace surfaces. Isolated "slip-off" terraces are present at many places along most Coast Range rivers.

Other aerially restricted terraces form as a result of short-lived or localized aggradation events. These are "complex response" terraces (see reviews in Schumm and others, 1987, and Bull, 1990) that form in response to minor stream perturbations; these terraces also do not form extensive synchronous terrace surfaces. At scattered locations in the Coast Range, such terrace remnants are preserved at various levels and have gradients that often are steeper than the better preserved, more extensive terraces. Most of these small terraces probably were formed as a result of transient changes in stream regime—such as aggradation related to large floods or localized landsliding—and flood plain abandonment by meander cutoff.

Another type of terrace does form major, roughly synchronous terrace surfaces in the Coast Range. These are terraces produced by regional stream aggradation events related to major changes in climate ("climatic" terraces of Bull, 1990). The best example is an extensive terrace found on all Coast Range rivers that I examined that yields consistent radiocarbon ages of 7–10 ka from the lower parts of the silty overbank facies. These terraces formed during a period of regional aggradation probably related to increased colluviation of hillslope sediment into small tributaries induced by warmer, drier post-glacial climatic conditions, and perhaps influenced to some degree along lower reaches by decreasing stream gradients induced by rapidly rising base level (see more extensive discussion under "Terraces along the Umpqua River" and "Discussion" sections). If such extensive regional aggradation is the typical response of Coast Range rivers to post-glacial climate change, then earlier climatic fluctuations probably induced the formation of similar regionally extensive fluvial terraces. TL ages and relations between scattered fluvial and marine terrace remnants near the coast indicate that some of the older, higher terraces were formed under similar climatic and hydrologic conditions.

The last type of fluvial terrace present in the Coast Range forms by episodic stream incision caused by localized tectonic movements; these "tectonic" terraces differ from others that are related to regional-uplift-induced stream incision because they are associated with active structures. Examples of tectonic terraces were examined on the Siuslaw River as part of this study; topographic profiles clearly show that terraces on the lower reach of the river have been warped over an anticline in the underlying Eocene bedrock. Although the mode of growth of this anticline (episodic versus continuous) is unknown, the presence of multiple terrace surfaces over the anticline supports the inference that localized tectonic uplift has influenced terrace formation.

In summary, fluvial terraces in the Coast Range appear to have a number of origins. At least four different types of terrace are present, but only those terraces induced by major changes in climate are likely to be extensive and synchronous along the lengths of the examined rivers. Other terraces formed by "complex response" mechanisms, river meandering, and movement on local tectonic structures in most cases did not form extensive synchronous surfaces; most isolated terrace remnants found along Coast Range rivers were probably formed by these processes. More details on terrace formation are in the following discussions.

SEDIMENT ACCUMULATION RATES

Sediment accumulation rates are useful for delineating the time spans over which different fluvial deposits accumulate and for helping to estimate the ages of terrace surfaces. For this study I was primarily interested in determining the age of initiation of terrace aggradation, so I sampled for radiocarbon from as low in the terrace sediments as possible. Unfortunately, only one radiocarbon sample was found in the basal gravel facies, so sediment accumulation rates for these deposits could not be determined. However, I found only one example of a buried soil in the gravel facies, so the gravels were probably deposited rapidly and remained entrained in active stream channels until they were abandoned by lateral stream incision and buried by fine-grained overbank deposits.

Only a few exposures yielded multiple radiocarbon ages that defined closed time intervals that could be used to determine finite sediment accumulation rates, and all the resulting ages were located in the overbank deposits. Radiocarbon ages were used to calculate long-term sediment accumulation rates from the lowest continuous terrace on the Umpqua River near Elkton at river km 80 (fig. 4*A*; station 87–U7, plate 1) and from a terrace on Scholfield Creek, a major tributary of the Umpqua about 11.5 km upstream from Reedsport (fig. 4*B*; station 87–U20, plate 1). Radiocarbon ages of 730 ± 80 yr B.P. and 8,630 ± 100 yr B.P. on charcoal collected from 0.5 m and 4.0 m, respectively, below the surface of the terrace near Elkton yielded a sediment accumulation rate of about 0.45 mm/yr. A maximum rate of about 0.25–0.3 mm/yr from the terrace on Scholfield Creek was obtained from ages on charcoal of 22,240 ± 630 yr B.P. and >26,400 yr B.P. from depths of 3.25 m and 4.25 m, respectively.

Additional sites yielded shorter term sediment accumulation rates from low terraces near the coast that are substantially higher than the rates discussed above. Near the mouth of the Smith River, data from an auger core in a low terrace at about river km 4.5 (fig. 4*C*; station 87–US15, plate 2) yielded a maximum accumulation rate of about 1.3 mm/yr from radiocarbon ages of 123.7% modern (post 1950) and 1,825 ± 65 yr B.P. at depths of 1.25 and 3.6 m, respectively. An auger core in a similar low terrace on the Umpqua River at about river km 26 (fig. 4*D*; station 87–U22, plate 1) yielded a minimum accumulation rate of about 1.9 mm/yr from a single radiocarbon age of 1,180 ± 130 yr B.P. on a peat sample from a depth of 2.25 m. Feiereisen (1981) obtained a similar rate from a shallow drill hole at about river km 23.5 on the Siuslaw River flood plain; a single radiocarbon age of 3,250 ± 70 yr B.P. on a sample of peaty wood from a depth of 5.5 m yielded a minimum sediment accumulation rate of about 1.7 mm/yr.

These data indicate that accumulation rates calculated over the life of a terrace on the upper reaches of Coast Range rivers are on the order of 0.3–0.5 mm/yr; rates are about 4 times higher (1.3–1.9 mm/yr) on lower (tidal) reaches. No other suitable sites were found for determination of sediment accumulation rates, but these rates may

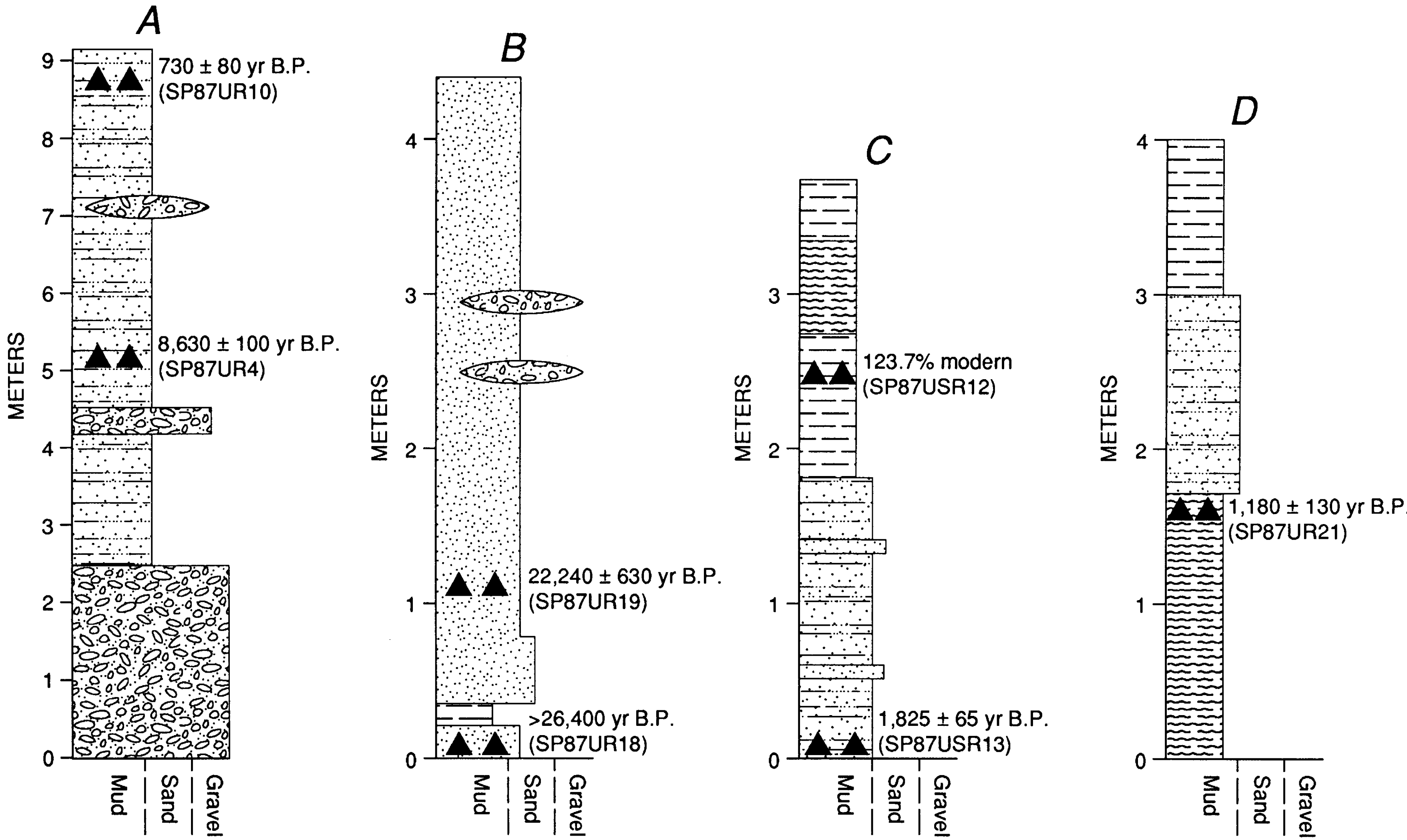


Figure 4. Stratigraphic columns of radiocarbon-dated fluvial sediments used to calculate sedimentation rates; column thicknesses are measured from the base of the exposed section or core. Exposure or core locations are (*A*) PHT (Pleistocene-Holocene transition) terrace on Umpqua River near Elkton at station 87–U7, (*B*) terrace on Scholfield Creek at station 87–U20, (*C*) 3.75-m auger core in lowest terrace on the Smith River at station 87–US15 (pl. 2), and (*D*) auger core from a low terrace on Umpqua River about 300 m west of Dean Creek at station 87–U22. Note differences in vertical scale.

be characteristic of sedimentation rates on most similar-sized rivers in the region. The variations in the accumulation rate data probably do not allow reasonable estimation of the age of terrace surfaces, but they do suggest that most of the thick terrace overbank sequences accumulated over time periods of thousands of years.

TERRACES ALONG THE UMPQUA RIVER

The Umpqua River is the largest river examined in this study (11,800 km^2 drainage area; Oregon State Water Resources Board, 1958), and it is the only river that I examined whose headwaters are in the Cascade Range of west-central Oregon. Although fluvial terraces are relatively poorly preserved along the Umpqua River (fig. 5; pl. 1), I have used age and sedimentologic data from Holocene and older terrace remnants along the lower 200 km of the river to determine some of the processes responsible for terrace formation in the Coast Range.

The only terrace that can be correlated with any certainty along the Umpqua River is a nearly continuous terrace surface that lies 2–15 m above river level. Radiocarbon dating of charcoal from this terrace indicates that sediments near the base of the terrace are latest Pleistocene to early Holocene in age, so I informally refer to this terrace as the Pleistocene-Holocene transition or "PHT" terrace. If the geomorphology of this terrace is typical of older fluvial terraces formed along the Umpqua River (and the similar stratigraphy of the terrace sediments suggests that it is), then the poor preservation of older terraces can be easily explained by the morphology of the PHT terrace. The PHT terrace is commonly unpaired, remnants are usually narrow (<600 m), and the surface is cut in places by younger terraces.

With few exceptions, the stratigraphy of older terrace deposits along the Umpqua River is almost identical to that associated with nearby Holocene terraces. Soil development, however, is progressively greater in the older deposits. Soil properties most consistent with terrace height and therefore age were degree of reddening, amount of clay and oxidation products in the B horizon, and degree of clast weathering where gravel is present in the B horizon. Soil oxidation also appeared to increase away from the coast, presumably as a response to hotter, drier summer weather and fluctuating soil-moisture conditions. Prominent terrace exposures are discussed below.

LATEST PLEISTOCENE AND HOLOCENE TERRACES

I examined the PHT terrace in detail at three sites on the upper Umpqua River, at stations 87–U4 and 88–U2 near McGee Creek, and at station 87–U7 near Elkton (pl. 1); these sites yielded charcoal for radiocarbon dating from nearly complete exposures of the terrace sediments. A fourth site downstream from the highway bridge near Scottsburg on the lower Umpqua (station 87–U14) yielded a modern age that probably is related to deposition from a tributary stream.

The relative scarcity of continuous terraces below the PHT terrace (fig. 5) indicates that the latest period of extensive terrace formation on the upper Umpqua River occurred in latest Pleistocene and early Holocene time, and only a few scattered terraces have developed since then. I examined lower, younger terraces at three sites on the upper Umpqua River, at stations 87–U6 and 88–U3 near the Bullock Bridge and at station 87–U8 near Elkton. I also examined low terraces on the lower Umpqua River near Reedsport at stations 87–U13 and 87–U22.

PLEISTOCENE-HOLOCENE TRANSITION (PHT) TERRACE EXPOSURES NEAR MCGEE CREEK

The PHT terrace near McGee Creek has the longest continuous exposure of fluvial terrace sediments along the length of the Umpqua River examined in this study (fig. 6). Part of the bedrock strath has been exhumed and the sediments have been completely removed on part of the terrace; the excellent exposures at this location probably resulted from scour by recent flooding. A topographic survey across the stripped bedrock strath with rod and Abney level documents the height of the strath beneath the terrace surface and shows the morphology of the site (fig. 7). Shallow abandoned channels and other minor surface irregularities are not shown on the profile, but a 0.5–1.0 m-high scarp preserved along one of several strike-slip faults exposed in the bedrock strath is included. This and other similar scarps are not related to recent surface faulting but are the result of differential erosion of softer siltstone in fault contact with more resistant massive sandstone. Other examples of exhumed bedrock surfaces are common along this reach of the Umpqua River.

The stratigraphy in the McGee Creek terrace is typical of that seen along most of the PHT terraces, and the radiocarbon results illustrate the types of problems associated with dating fluvial sediments (figs. 3*C*, 7, 8). The two exposures at stations 87–U4 and 88–U2 are about 500 m apart, consist of basal sandy gravel channel deposits overlain by silty overbank deposits, and yield inverted radiocarbon ages of 9,800 ± 410 yr B.P. (station 87–U4) and 9,120 ± 150 yr B.P. (station 88–U2). The charcoal sampled at station 87–U4 (fig. 3*C*) was a single fragment found protruding from the silty overbank deposits. This sample may have been exposed to growth of fungi or molds; but the fragment was probably only recently

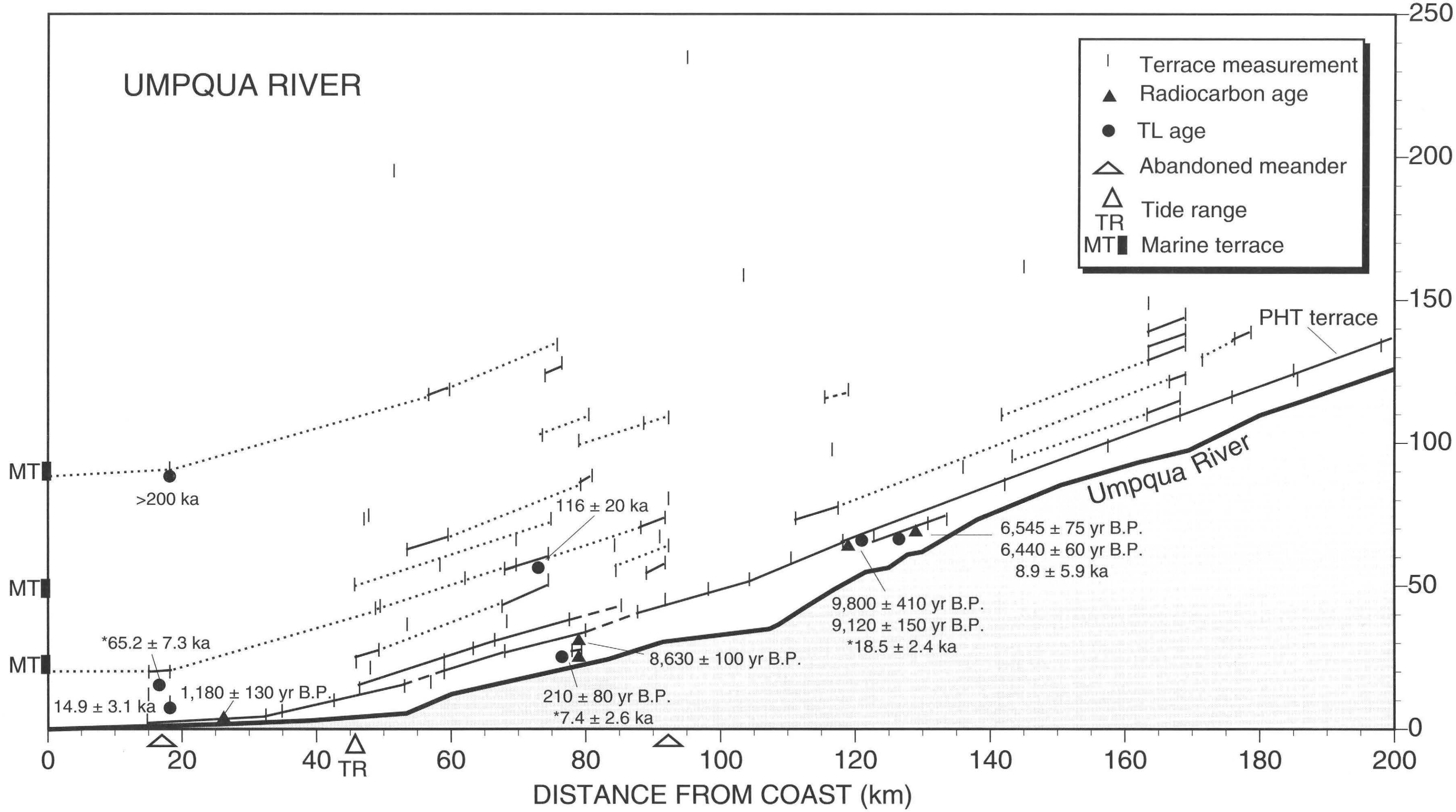


Figure 5. Longitudinal profile of terraces along the lower reach of the Umpqua River. Heavier solid line is elevation of the Umpqua River and lighter solid lines connect terraces that can be physically correlated; dashed lines connect terraces that are probably correlative, and dotted lines are speculative correlations. Terrace heights may have vertical errors of ±5 m for the higher terraces and ±2 m for the lower terraces. Radiocarbon ages are located with triangles and listed in years B.P., and TL (thermoluminescence) ages are located with solid circles and listed in ka (thousands of years ago); ages thought to be seriously in error are marked with asterisks. The heights of marine terraces, with bars approximating estimated vertical errors, are labelled "MT" on the left side of the figure. Locations of abandoned meander bends (arrowheads) and the tide range ("TR") are shown along the distance axis.

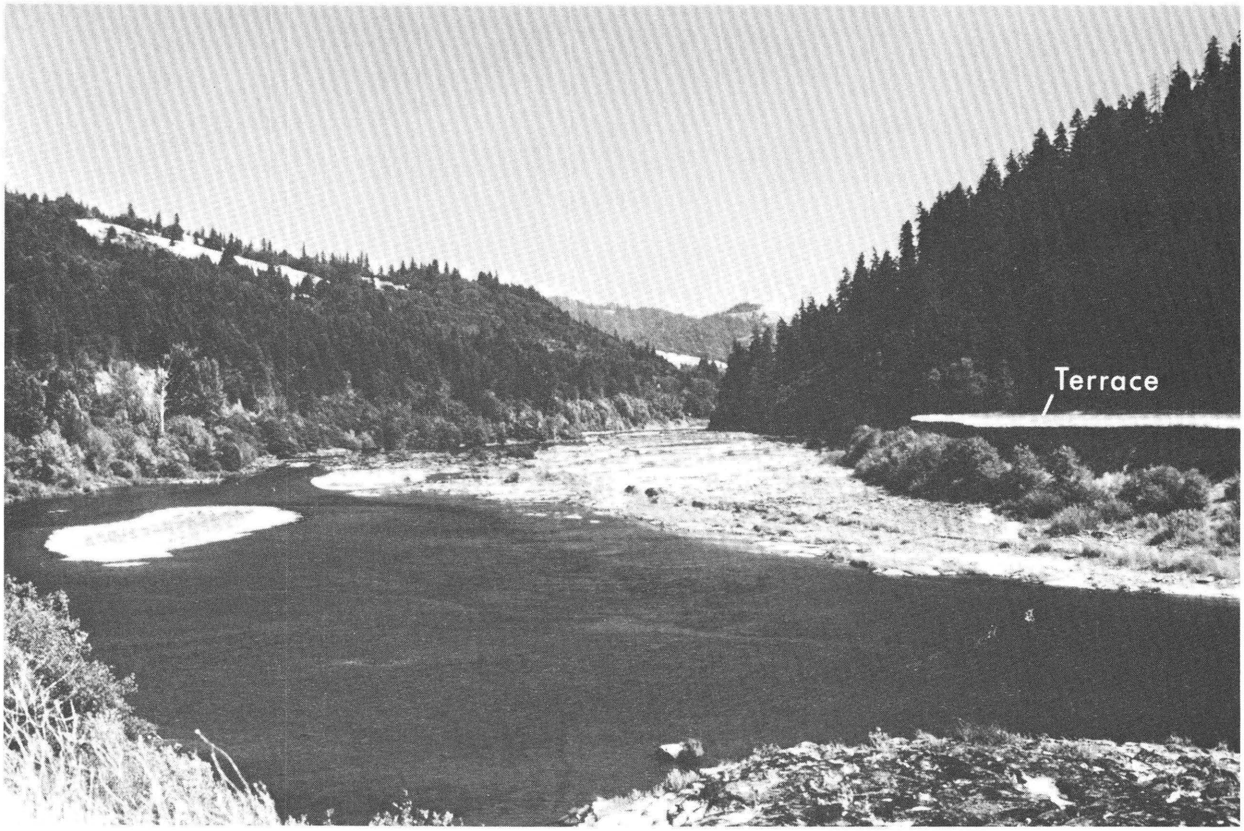


Figure 6. Photograph of PHT (Pleistocene-Holocene transition) terrace at about river km 121 on the Umpqua River near McGee Creek; station 87–U4 is located at right edge of photograph. Note extensive exhumed bedrock strath to the left of the terrace and in the foreground. Profile shown in figure 7 was measured across the strath near the center of the photograph.

exposed by flooding, and sample pretreatments should have removed such contaminants. At station 88–U2 (fig. 8), numerous small pieces of charcoal were sampled from a silty interbed in the basal gravel; this sample was not exposed prior to excavation, but the enclosing sediments contained abundant modern roots and rootlets, so the sample was carefully picked prior to dating. Although slight contamination of one or both samples is possible, the ages nearly overlap within their laboratory error limits. Thus, the radiocarbon results indicate that the basal McGee Creek terrace sediments were deposited a minimum of 9,000–10,000 radiocarbon years ago. Radiocarbon ages in this range have been corrected to 9,900–11,000 calibrated years B.P. on the dendrochronological time scale (Becker and others, 1991; Stuiver and others, 1991).

PHT TERRACE NEAR ELKTON

I examined a similar exposure of the PHT terrace near Elkton at river km 77.5 (station 87–U7, plate 1). Small fragments of charcoal from the lower part of the overbank facies yielded an accelerator (AMS) radiocarbon age of 8,630 ± 100 yr B.P., and fragments from the upper part of the overbank facies yielded a conventional radiocarbon age of 730 ± 80 yr B.P. (fig. 4*A*). The consistent surface height and early Holocene age of the sample near the middle of the overbank facies indicate that the PHT terraces at McGee Creek and Elkton can be correlated with confidence.

PHT TERRACES NEAR THE COAST

A somewhat unusual stratigraphic sequence was exposed in a tributary stream cut in the PHT terrace near river km 42 (fig. 9; station 87–U14, plate 1). The terrace surface is about 7 m above river level at this site and is continuous with the PHT terrace upstream. The stream cut exposed a basal unit of coarse (clasts to boulders in size), angular, matrix-supported gravel, overlain by a pebbly silt and sand unit that has a weak soil formed on its surface. A sandy pebble gravel that contains stream-rounded fragments of brick is present at the surface of the exposure. The texture of the coarse basal gravel indicates that it probably was deposited as a debris flow from the

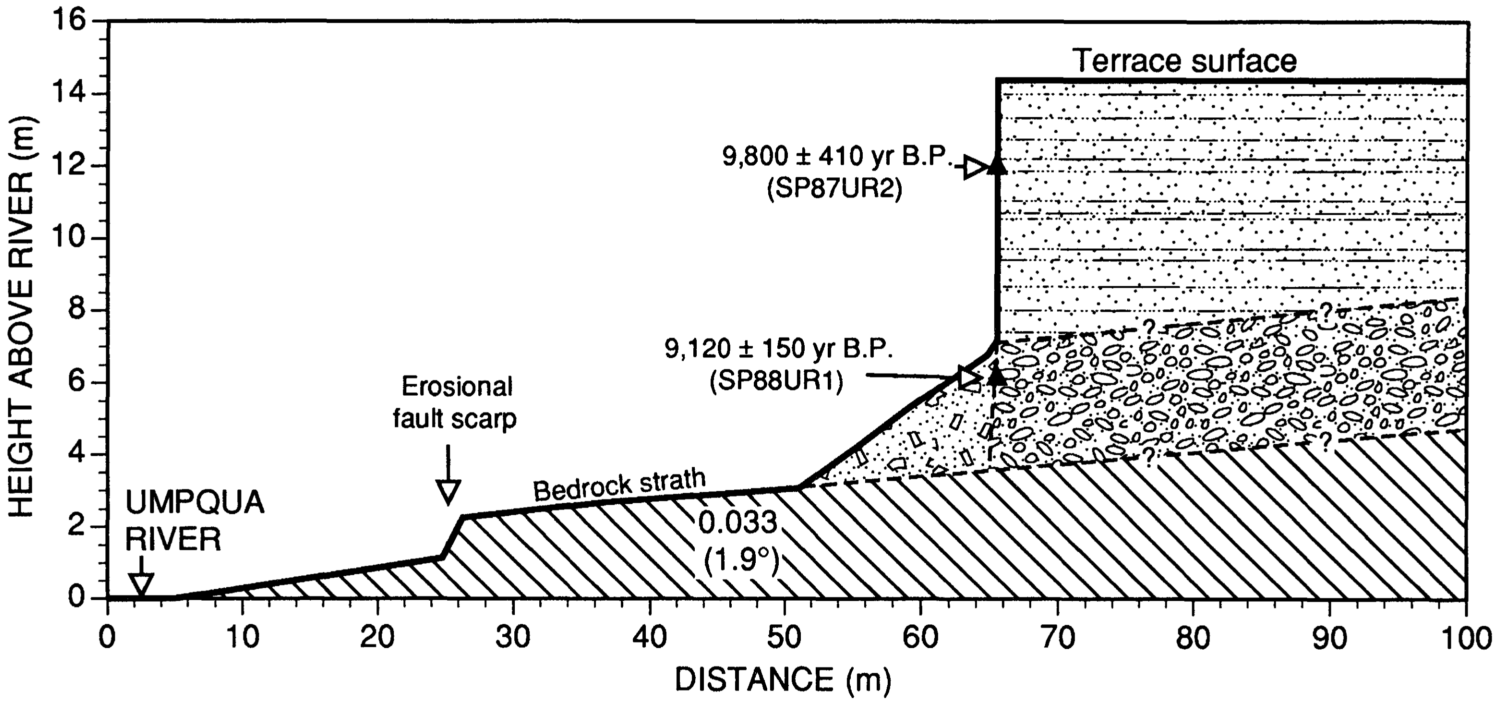


Figure 7. Rod-and-level profile of stripped bedrock strath and PHT (Pleistocene-Holocene transition) terrace near McGee Creek on the Umpqua River. See legend in figure 3 for explanation of lithologic patterns. Note the projected locations of two radiocarbon ages (see figs. 3*C* and 8) and the gradient of the exposed strath surface. The step in the strath profile at about 25 m marks the location of a fault in bedrock that has been accentuated by differential erosion.

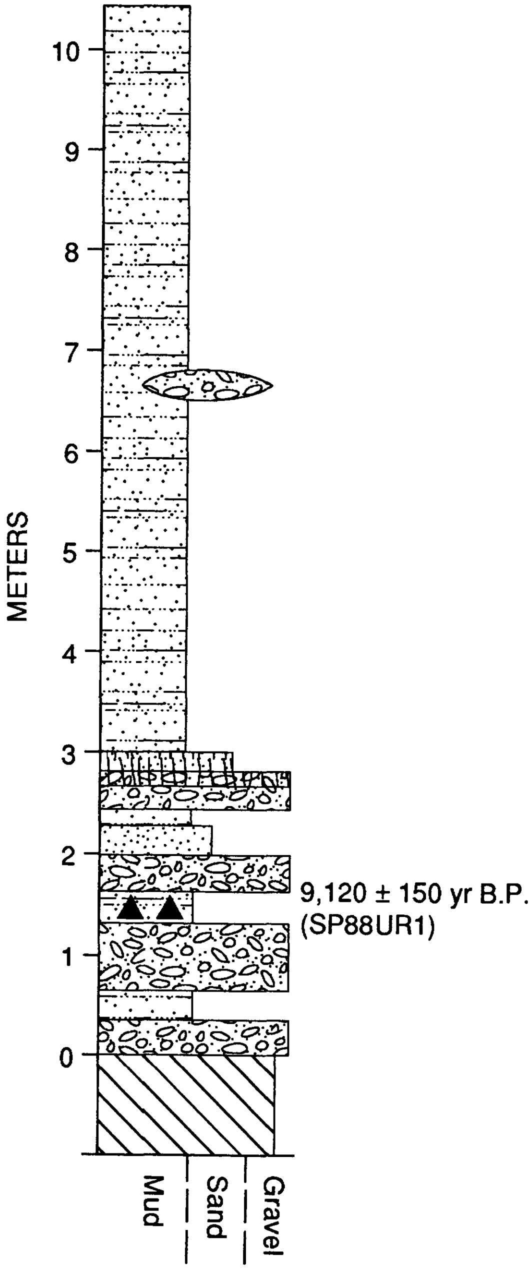


Figure 8. Stratigraphic column of a PHT (Pleistocene-Holocene transition) terrace exposure near McGee Creek on the Umpqua River at station 88–U2. See legend in figure 3 for explanation of lithologic patterns and symbols.

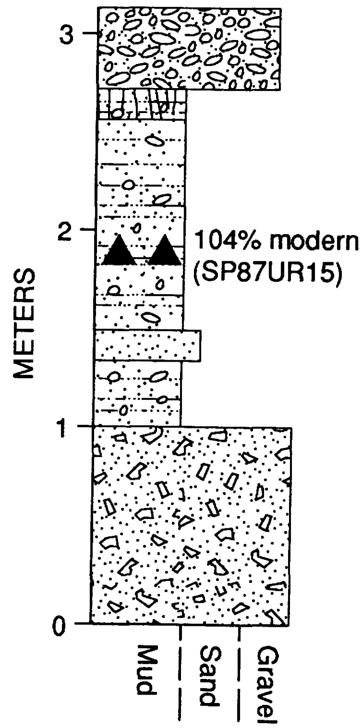


Figure 9. Stratigraphic column from a terrace exposure about 2 km downstream from the highway bridge near Scottsburg on the Umpqua River at station 87–U14. See legend in figure 3 for explanation of lithologic patterns and symbols. Note presence of colluvial gravel at base of the exposure and fluvial gravel at the top of the exposure.

unnamed tributary stream flowing northward into the river through the site. The modern radiocarbon age (104% modern) in the silt indicates that these sediments were deposited after 1950, probably during a period of increased precipitation or flooding. This conclusion is supported by the presence of brick fragments in the upper gravel. The unusual stratigraphy exposed at the site and evidence of extensive modern deposition indicate that the PHT terrace surface is commonly reoccupied by flood waters along tidal reaches of the Umpqua River.

Another exposure of the PHT terrace was examined along the lower Umpqua River near the Brandy Bar at river km 32.5 (fig. 10; station 87–U13, plate 1). The terrace surface is only about 2.5 m above river level at the site and consists of about 1.0 m of sandy silt overlying a minimum of 1.0 m of sandy pebble and cobble gravel. No radiocarbon ages were obtained from this exposure, but only minimal oxidation was visible so the terrace sediments are probably very young. The stratigraphy exposed at the site is significant because this is the last exposure of an "upper reach" fluvial sequence (silty overbank sediment overlying basal channel gravel) that I observed in the tidal reach of the Umpqua River. At all other sites downstream, exposed sediments in the low terraces consist of estuarine sand and mud. However, water wells drilled near the Brandy Bar site show that thick sequences of sandy gravel are present beneath the fine overbank sediment in this terrace; two wells about 0.5 km downstream from station 87–U13 penetrated about 5.5 m of overbank sediment and a minimum of 13 and 19 m of sandy gravel, respectively, without intersecting bedrock (Curtiss and others, 1984).

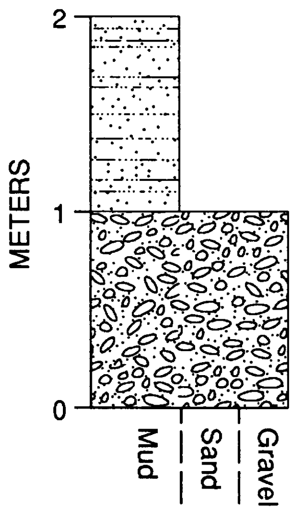


Figure 10. Stratigraphic column of a low terrace near the Brandy Bar on the Umpqua River at station 87–U13. See legend in figure 3 for explanation of lithologic patterns and symbols. Nearby water wells have penetrated as much as 19 m of sandy gravel without encountering bedrock.

LOW TERRACES NEAR THE COAST

As is obvious from the preceding discussion, the height of the PHT terrace decreases rapidly as the river nears the coast. By about river km 26, the terrace is only 1 m above river level, and by about river km 19 the terrace merges with salt marshes in the estuary of the Umpqua River. The transition from fluvial terrace to salt marsh marks the culmination of terrace convergence that is evident along the lower reaches of all rivers examined in this study. While fluvial terraces commonly converge downstream, convergence on Coast Range rivers may be accentuated by some combination of coastal subsidence and rising sea level in the late Holocene. Some estuaries in northern Oregon and Washington apparently have been subject to coseismic subsidence associated with regionally extensive earthquakes on the Cascadia subduction zone (Atwater, 1987, 1992; Darienzo and Peterson, 1990, Atwater and Yamaguchi, 1991; Nelson and Personius, 1991), but regional coseismic subsidence along the central Oregon coast is equivocal (Nelson, 1992; Nelson and Personius, 1991).

Several cores in the lowest terrace and in nearby salt marshes revealed sequences of interbedded peat, mud, and minor sand. A 4-m-deep auger core in a terrace about 1 m above river level near Dean Creek at river km 26 (fig. 4*D*; station 87–U22, plate 1) exposed the muddy sediments that typify most low terraces near the coast. A similar sequence was obtained in a 3.75-m-deep auger core in a low terrace also about 1 m above river level on the Smith River (fig. 4*C*; station 87–US15, plate 2) about 4.5 km upstream from its confluence with the Umpqua River. Nelson (1992) found similar sequences of peat and mud in several cores in salt marshes along the lower Umpqua River. The muddy sediments in the lowest terraces are finer grained, contain peats that are not present in fluvial sequences upriver, and reflect the estuarine influence on sedimentation in the lower reaches of the river. The total thickness of these deposits is unknown, because I could find no records of water wells in these deposits and because only the upper 4–5 m of these sediments could be observed in natural exposures and cores. The presence of fine-grained estuarine sediments in the lowest terraces is an important clue to past climatic conditions, because most of the older, higher terraces near the coast have similar sequences of thick, fine-grained deposits. Some (most?) of these older terraces were probably deposited during periods of high sea level similar to present conditions, and therefore correlate with past sea-level high stands. Thus, the present low terraces are modern analogs to some of the older fluvial terraces.

OTHER HOLOCENE TERRACES

Although younger fluvial terraces are not well developed below the PHT terrace, lower terraces are present at a few places along the Umpqua River. The most extensive younger terrace is about 8 m above river level and is inset into the 12- to 13-m-high PHT terrace from about river km 133.5 to km 123 (fig. 5). Two natural exposures of the lower terrace sediments yielded charcoal for radiocarbon analysis (fig. 3*B*; stations 87–U6 and 88-U3, plate 1). The consistent radiocarbon ages from these sites (6,545 ± 75 yr B.P. and 6,440 ± 60 yr B.P., respectively, fig. 3*B*) support the conclusion that this is a younger terrace surface inset into the older PHT terrace, rather than a stripped PHT terrace. Inset terraces of this age are not part of a widespread middle Holocene terrace surface because relatively few terraces of this height are present along the Umpqua River.

One intriguing idea about the origin of this terrace is the possible association of aggradation of this terrace with the eruption of Mt. Mazama in the headwaters of the North Umpqua River (D.R. Sherrod, oral commun., 1991). Mt. Mazama erupted 6.7–7 ka (Bacon, 1983; Sarna-Wojcicki and others, 1983), and this eruption must have dumped large quantities of debris-flow sediment into the North Umpqua River (Sherrod, 1991). No detailed sedimentologic studies were done on the sediments in this terrace, but the radiocarbon ages that indicate that the terrace sediments are just a few hundred years younger than the eruption are at least suggestive of a genetic relationship.

A lower, much younger terrace consisting of basal gravels and sandy overbank sediment extends for about 1.5 km upstream from Elkton (fig. 3*A*; station 87–U8, plate 1). Four radiocarbon ages on charcoal and wood collected from the loosely consolidated sandy sediment in this terrace indicate that the overbank sediment is less than 300 years old.

The radiocarbon ages and textural differences in the young terrace deposits near Elkton indicate that the overbank sediments were deposited in three discrete units: (1) a lower, siltier unit that yielded a radiocarbon age of 210 ± 80 yr B.P. and is capped by a thin buried A horizon, (2) a middle sandy unit that yielded radiocarbon ages of 95 ± 40 yr B.P. and 115 ± 40 yr B.P., and (3) an upper sandy unit that yielded a modern radiocarbon age (–10 ± 70 yr B.P.). If each of these overbank units was deposited during a major flood, then the radiocarbon ages may be useful in establishing the frequency of such events in the past few hundred years. The highest sample yielded a modern (post 1950) age that indicates recent deposition on the surface of this terrace, perhaps from the latest large flood event in the region which occurred in December, 1964 (Rantz and Moore, 1965). Analysis of all the radiocarbon ages obtained at this site indicates that major depositional events have taken place on average about every 105–120 radiocarbon years for the last two cycles, with depositional events at about 210 yr B.P., 105 yr B.P. (average of 95 yr B.P. and 115 yr B.P.), and post-1950 (1964?).

Unfortunately, when these radiocarbon ages are dendrochronologically calibrated (Stuiver and Reimer, 1986), the resulting ages are not usable for calculating discrete recurrence intervals. For example, averaging and calibration of the 95 ± 40 yr B.P. and 115 ± 40 yr B.P. ages yields at least 5 calibrated age choices ranging from 0 to 243 calibrated years B.P., and a 1 sigma error range of 0 to 262 calibrated years B.P. Calibration of the 210 ± 80 yr B.P. age yields a single age of 288 calibrated years B.P., but this age has a 1 sigma error range of 0 to 311 calibrated years B.P. So a more conservative approach to calculating recurrence intervals from these deposits would indicate that there have been 3 depositional (flood) events in about the last 300 years, with an average recurrence interval of about 150 years.

A comparison of radiocarbon ages from the low terrace at Elkton with the historic record of large floods in the Pacific Northwest (Helley and LaMarche, 1973) indicates that the last two depositional events at Elkton might be related to major floods in 1860–61 and 1964. Studies of deposits related to the 1964 and earlier floods in northern California yielded recurrence intervals estimates of 60–80 yr (Kelsey, 1987) to 100–200 yr (Helley and LaMarche, 1973) for large landscape-altering floods.

The intense floods of December 1964 (Rantz and Moore, 1965) may be a recent analog for the flooding events responsible for the creation of other small Coast Range terrace remnants, but the restricted distribution of the Elkton and similar isolated terraces (fig. 5) indicates that large floods may be more often recorded in the stratigraphic record as discrete beds in the overbank deposits of other terraces. Thus, small, isolated terraces like the low Elkton terrace are examples of terraces formed as "complex responses" to relatively minor changes in river hydrology, rather than the regional, climatic changes associated with aggradation of the PHT terrace.

OLDER TERRACES

Although less well preserved than the younger terraces, numerous exposures of older fluvial terrace sediments are present throughout the Coast Range. Only one older terrace on a small tributary of the Umpqua River yielded materials suitable for radiocarbon dating, so experimental thermoluminescence (TL) dating was attempted on sediments from several older terraces. These results for the individual sites will be discussed later. Correlation of fluvial terraces to the marine terrace record can be a useful relative-dating tool, so a discussion of marine terrace remnants present near the mouth of the Umpqua River will precede discussion of older fluvial terraces.

MARINE TERRACES

Marine terrace cover sediments consist primarily of thick sequences of eolian and minor beach sand and are present at various elevations at several places near the mouth of the Umpqua River; I measured surface elevations on some of these deposits but did not map or examine the sediments in detail. In most cases terrace back edges are not preserved and no exposures of wave-cut platforms were observed, so the elevations of shoreline angles could not be determined. Golder Associates (1986, table 6) list, but do not locate, heights of marine terraces along the Oregon coast, including an elevation of 18.8 m for a Whiskey Run-equivalent marine terrace (isotope substage 5a, 80 ka) near Winchester Bay. West and McCrumb (1988, fig. 6) apparently used this and other elevations in their calculation of uplift rates along the Oregon coast. I found no terrace back edges and only one exposure of possible marine terrace sediments in the Winchester Bay area, in a roadcut on a dirt road on the north side of Winchester Creek about 0.5 km from U.S. Highway 101. Although I found no evidence of a preserved terrace, the elevation of these sediments is consistent with that given by Golder Associates (1986).

Marine terrace deposits are more abundant on the north side of the Umpqua River, where several exposures of sandy terrace sediments are found along the road that parallels Threemile Creek. Above the east shore of Threemile Lake an apparent terrace surface and back edge are preserved at an elevation of 24–28 m. Several meters of parallel bedded eolian sand are visible in an exposure of this surface near the southern end of the lake. No evidence of a wave-out platform or lower terraces was observed below the Threemile Lake surface, but most of the topographically low areas in this region are covered by sand dunes (Beaulieu and Hughes, 1975) that may have buried such features. Preliminary soils correlations (H.M. Kelsey, written commun., 1992) indicate that the lowest preserved marine terrace along this part of the Oregon coast is no younger than oxygen-isotope substage 5e (125 ka), so I have concluded that marine terrace sediments at both Winchester Bay and Threemile Lake probably are parts of the same substage 5e, 125 ka terrace.

Sandy marine terrace sediments are exposed at elevations of 44–54 m along the Threemile Creek road, but unequivocal terrace surfaces or wave cut platforms were not observed. Similar deposits at even higher elevations are exposed in a borrow pit near the intersection of the Threemile Creek road and U.S. Highway 101, at an elevation of 85–95 m. Some speculative but geologically reasonable correlations between marine terrace deposits near the mouth of the Umpqua River and older fluvial terraces will be discussed.

INTERMEDIATE TERRACES NEAR REEDSPORT

I found a single exposure of charcoal-bearing sediment in an intermediate-aged fluvial terrace on Scholfield Creek, a tributary that joins the Umpqua River at Reedsport (station 87–U20, plate 1). This exposure is in a small terrace remnant whose surface stands about 13.5 m above Scholfield Creek at an elevation of 16.5 m. Two charcoal samples were collected for radiocarbon dating from the upper 4 m of the terrace exposure, which consisted of fine to medium sand with minor silt and sandy gravel interbeds (fig. 4*B*). The resulting radiocarbon ages (22,240 ± 630 yr B.P. and >26,400 yr B.P.) are somewhat problematic because they correlate the Scholfield Creek terrace with a period of fluctuating sea level that was not conducive to fluvial terrace aggradation.

Formation and preservation of a 22 ka fluvial terrace near the coast is unusual because sea level is thought to have fallen from an interstadial high stand of about 35–40 m below present sea level, between 25 and 30 ka (Bloom and others, 1974; Chappell and Veeh, 1978; Pinter and Gardner, 1989) to a late Wisconsin minimum about 17–18 ka that may have been 100–150 m below present sea level (Bloom, 1983; Chappell and Shackleton, 1986; Tushingham and Peltier, 1991). The apparent age of the Scholfield Creek terrace does not fit well with these changes in global sea level because fluvial terrace treads near the coast that may have aggraded during the interstadial high stand should have been abandoned by incision brought about by the steep, post-25 ka drop in sea level to the late Wisconsin minimum. Examples of stream terraces that may correlate with the 25–30 ka interstadial high stand have been described in central and southern California by Alexander (1953) and Birkeland (1972), and in northern California by Merritts and Vincent (1989, fig. 5), but 20–25 ka terraces are uncommon and appear to be restricted to areas undergoing very high rates of uplift, such as near Ventura in southern California (Rockwell and others, 1988).

The history and extent of late Pleistocene sea-level fluctuations are poorly known along the Oregon coast, so I searched for evidence of a late Wisconsin sea-level minimum by examining the bathymetry of the region off the mouth of the Umpqua River on the U.S. Geological Survey Reedsport, Oregon, 1:100,000 scale topographic-bathymetric map. Numerous minor irregularities are apparent on the sea bottom, but a major break in slope that might be related to a sea-level low stand is present at an elevation of −104 m (fig. 11), a depth that is consistent with recent models of sea-level change in the late Quaternary (Tushingham and Peltier, 1991). However, I found no evidence of a submarine canyon or an Umpqua River paleochannel on the continental shelf, so either rapid sedimentation has obliterated any traces of such features or the drop to the late Wisconsin sea-level minimum had only temporary effects on the lower reaches of the Umpqua River and its tributaries. Thus, one possible explanation for the problematic age of the Scholfield Creek terrace is that the creek was isolated from any incision brought on by the post-25 ka drop in sea level until 20–22 ka, when entrenchment of the Umpqua River system retreated upstream to the vicinity of the Scholfield Creek terrace.

The Scholfield Creek terrace ages have also been affected by the recently documented systematic errors in the radiocarbon time scale determined from comparisons with geomagnetic intensities (Stuiver and others, 1991) and precise uranium-series dating of fossil corals (Bard and others, 1990). These studies indicate that radiocarbon ages in the 20- to 30-ka range are 2,500–4,000 years too young. Thus, the two Scholfield Creek radiocarbon ages yield calibrated ages of 25–30 ka, which are more compatible with a period of aggradation during an interstadial sea-level high stand, rather than to the period of rapidly falling sea level following this high stand.

Terraces are poorly preserved along Scholfield Creek, so correlation of the dated terrace with surfaces on the lower part of Scholfield Creek and on the Umpqua River near the confluence is uncertain. However, the dated terrace might correlate with a small terrace remnant at an elevation of about 9 m in the town of Reedsport, just upstream from the confluence with the Umpqua River (station 87–U21, plate 1). About 5 m of sandy silt and silty sand, oxidized to 7.5YR hues (color terminology of Munsell Color Co., 1954), were exposed in an old roadcut in this intermediate terrace (fig. 12). Unfortunately, no charcoal for radiocarbon dating was found, but a TL age of 14.9 ± 3.1 ka was

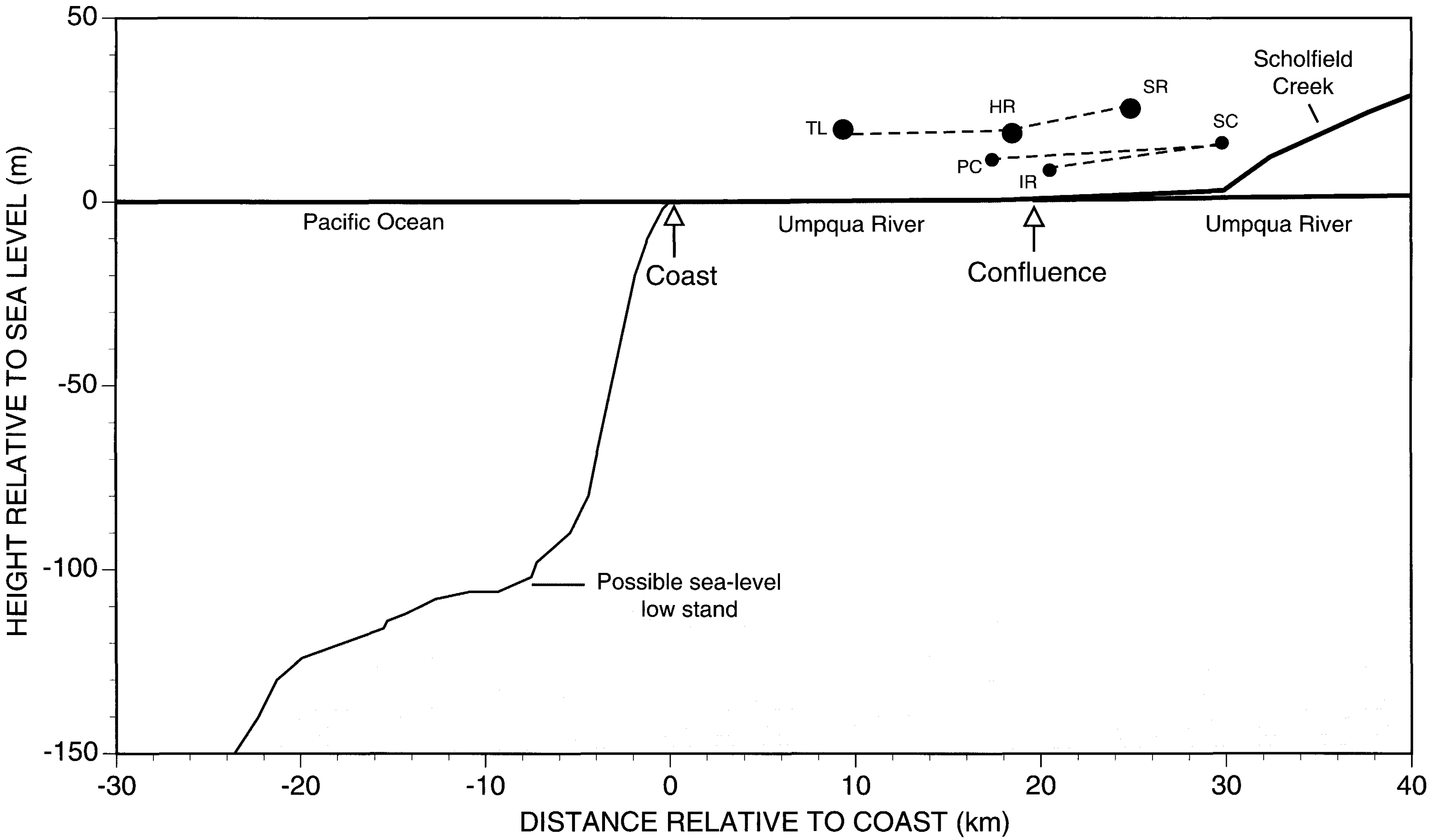


Figure 11. Diagrammatic topographic profiles of fluvial and marine terraces in the Reedsport area. Heavy lines are profiles of the Pacific Ocean, Umpqua River, and Scholfield Creek; the coast and confluence of Umpqua River and Scholfield Creek are marked with arrows. The Umpqua River and the low-gradient part of Scholfield Creek are in the tide range. Locations of terrace remnants discussed in text are shown with filled circles: HR—high fluvial terrace at Reedsport, IR—intermediate fluvial terrace at Reedsport, PC—terraces on Providence Creek, SC—terrace on Scholfield Creek, TL—marine terrace at Threemile Lake, SR—high terrace on the Smith River. Dashed lines are tentative terrace correlations; gradients between the correlated terraces are discussed in the text. Topographic data are from altimeter readings, several photogrammetric profiles (see discussion of methods) and 1:24,000-and 1:100,00-scale topographic maps; variations in size of terrace symbols (filled circles) reflect greater measurement errors in heights of higher terraces. Note vertical exaggeration.

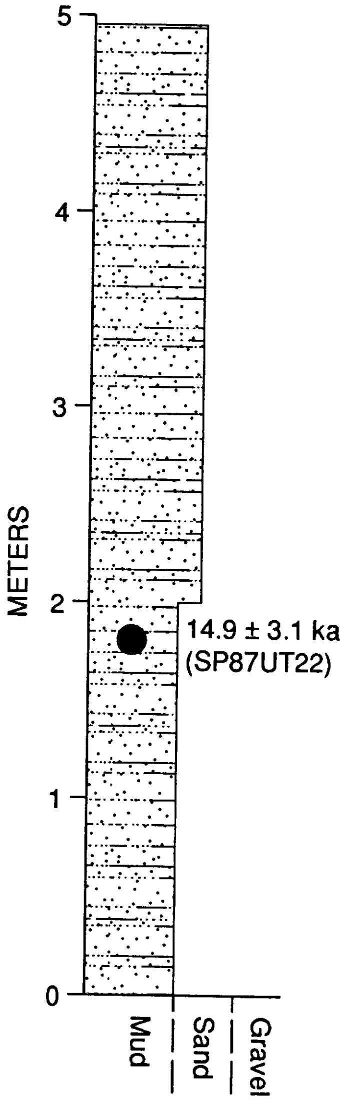


Figure 12. Stratigraphic column of an intermediate terrace in Reedsport at station 87–U21. See legend in figure 3 for explanation of lithologic patterns and symbols.

obtained on sediment from this exposure. The projected gradient between the intermediate Reedsport terrace and the terrace on Scholfield Creek (0.0008) is substantially higher than the tide influenced gradient of modern Scholfield Creek (0.0002) in the same reach (fig. 11); gradients on the upper part of Scholfield Creek are 0.0027–0.0036. If these two terrace remnants are correlative, then the calibrated Scholfield Creek radiocarbon ages indicate that the TL age on the intermediate terrace at Reedsport is too young by 10,000 to 15,000 years.

The Scholfield Creek terrace might also correlate with other intermediate terrace remnants located near Providence Creek, 1–1.5 km north of station 87–U18. These terraces are mapped as two narrow, northwest-trending surfaces with elevations of about 12 m on plate 1. No exposures were found in these terraces. The projected gradient between the Scholfield Creek terrace and the intermediate terrace remnants near Providence Creek is about 0.0004. This gradient is less steep than the projected gradient to the 9-m-high intermediate Reedsport terrace, but no age information was obtained from the Providence Creek terraces, so either the Providence Creek or intermediate Reedsport terraces might reasonably be correlated with the Scholfield Creek terrace (fig. 11).

My limited age and gradient data indicate that fluvial sediments in a late Pleistocene terrace remnant on Scholfield Creek, and possibly in one or more intermediate terraces on the Umpqua River near Reedsport, may have aggraded during an interstadial sea-level high stand 25–30 ka, and were subsequently abandoned during the fall of sea level to the late Wisconsin minimum.

HIGH TERRACE AT REEDSPORT

An extensive high terrace surface underlies much of the western part of the town of Reedsport at about river km 18 (stations 87–U15 and 87–U18, plate 1), and occupies an abandoned meander bend of the Umpqua River at an elevation of 18–20 m. Water wells in the high Reedsport terrace about 0.6 km northwest of station 87–U18 have penetrated more than 40 m of unconsolidated sediment without encountering bedrock (Curtiss and others, 1984), so a very thick sequence of unconsolidated fluvial and estuarine sediment must underlie the meander bend. Two exposures in the high Reedsport terrace revealed similar stratigraphic sequences of massive silts overlying fine to medium sand and pebbly sand (fig. 13); these sediments are similar to most other fluvial and estuarine terrace sediments exposed along the lower reaches of all rivers examined in this study. Charcoal was not found in the two exposures, but a TL age of 65.2 ± 7.3 ka was obtained on silt from the station 87–U18 site (fig. 13*A*).

The TL age is somewhat problematic, because it indicates that the high terrace at Reedsport correlates with a sea-level low stand at oxygen-isotope stage 4 (Shackleton and Opdyke, 1973; Chappell and Shackleton, 1986; Martinson and others, 1987). I cannot substantiate the TL age with other numerical dates, but the presence of marine terrace remnants near the mouth of the Umpqua River suggests correlation of the Reedsport terrace to a different part of the oxygen-isotope record. The surface of the possible substage 5e (125 ka) marine terrace remnant at Threemile Lake is 4–6 m higher than the surface of the high fluvial terrace at Reedsport, but common variations of ±2 m in the original altitude of the shoreline angle (Wright, 1970), the presence of an unknown thickness of marine and eolian sediment on the marine terrace surface, or minor tilting of folding could easily allow the correlation of these terrace surfaces.

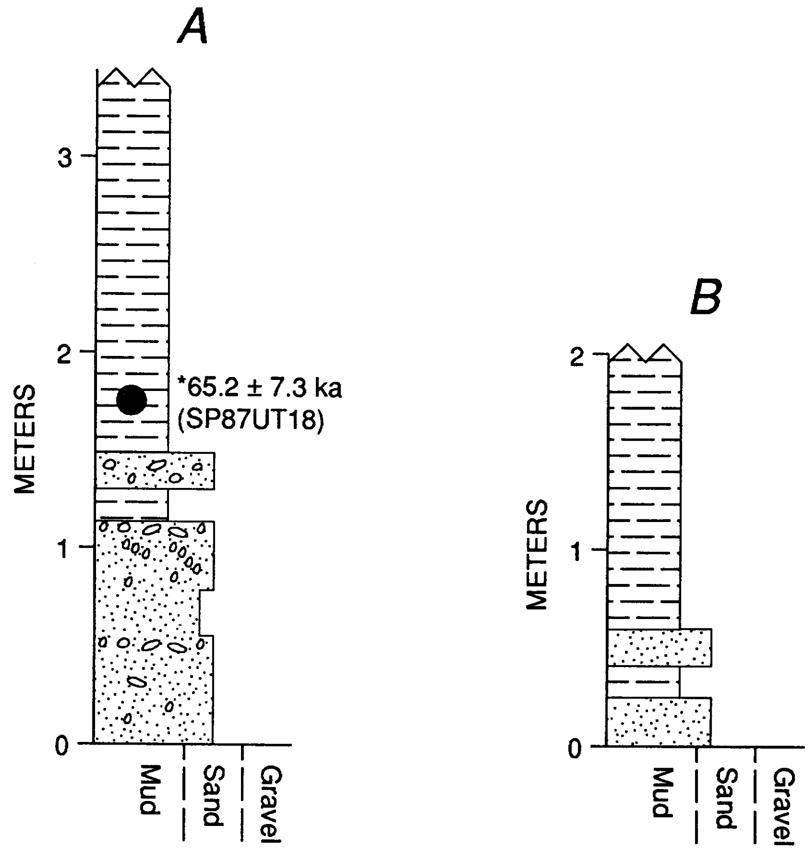


Figure 13. Stratigraphic columns of two exposures of the high terrace underlying the town of Reedsport: (*A*) station 87–U18 and (*B*) station 87–U15. See legend in figure 3 for explanation of lithologic patterns and symbols.

The two possible terrace ages discussed above (65 ka from the TL age or 125 ka from correlation with the marine terrace record) associate the high terrace at Reedsport with very different sea-level positions and geomorphic settings. A 125 ka age would correlate the fluvial terrace with a time period in which sea level stood about 6 m above present sea level (Chappell and Shackleton, 1986), so fluvial conditions near the mouth of the Umpqua River were probably similar to those of today. In contrast, a 65 ka age would correlate the Reedsport terrace with a sea-level low stand (oxygen-isotope stage 4) at a time when the heights and ages of uplifted coral reefs on the Huon Peninsula in New Guinea indicate that sea level stood more than 60 m below present sea level (Chappell and Shackleton, 1986). The lower Umpqua River must have been flowing in a deeply entrenched canyon under such conditions. Marine and near-coastal fluvial terraces formed during sea-level low stands are rarely preserved above sea level except in areas of very high uplift (Lajoie, 1986). No studies of coastal uplift have shown uplift rates of more than about 0.4 mm/yr for the central Oregon coast (Adams, 1984; West and McCrumb, 1988), and more recent studies (H.M. Kelsey, written commun., 1992) indicate coastal uplift rates are <0.2 mm/yr in this region, so high uplift rates are an unlikely cause of preservation of a 65 ka aged fluvial terrace at Reedsport.

The geomorphology and sedimentology of the high terrace at Reedsport support the inference that the terrace formed during a sea-level high stand. The terrace tread nearly fills its ancestral valley (pl. 1), a pattern which geomorphically resembles the present valley of the Umpqua River—that is, a relatively flat, steep-walled valley filled with fine-grained fluvial and estuarine sediment. If the present morphology of the lower Umpqua is typical of valleys formed during sea-level high stands, then it seems highly unlikely that an extensive fluvial terrace formed during a sea-level low stand could be preserved above the modern river. Therefore, I conclude that the TL age of about 65 ka for the Reedsport terrace deposits has underestimated the age of this terrace by about 60,000 years, and that the terrace is correlative with possible 125 ka marine terrace sediments near the mouth of the Umpqua River (fig. 11).

If the high fluvial terrace at Reedsport is correlative with a 125 ka marine terrace, then the rapid drop in base (sea) level that followed the substage 5e high stand is a likely mechanism for initiating the incision that cut off the Reedsport meander and stranded the high Reedsport fluvial terrace. Drastic drops in base level (on the order of many tens of meters) may be the most likely mechanism for vertical incision and abandonment of most terrace treads located within a few tens of kilometers of the coast.

HIGH TERRACE ALONG CRESTVIEW DRIVE

A very high (90- to 92-m elevation) fluvial terrace is preserved along Crestview Drive in the southeastern part of Reedsport near river km 18.5 (station 87–U19, plate 1). A deep roadcut in this terrace revealed a 6-m-thick basal channel facies of sandy pebble and cobble gravel with minor interbeds of fine sand, overlain by a 3-m-thick overbank facies of sandy silt (fig. 14). The stratigraphy in this exposure is similar to that seen in terraces along the upper reaches of the Umpqua River, but the gravel facies is thicker and the clasts are somewhat coarser than in upstream exposures. Although an unknown amount of the upper surface of the Crestview terrace may have been removed by erosion, the Crestview sequence is considerably coarser than other terrace sequences near the coast (compare figs. 13 and 14). The sedimentologic differences between the Crestview and other Reedsport area terrace exposures are so striking that depositional environments near the coast may have changed considerably since the Crestview terrace was deposited. The sediments in the high Reedsport terrace described previously appear to have been deposited in an estuarine-dominated environment similar to the present tidal reach of the Umpqua River; however, the coarser Crestview sediments are clearly a product of a higher energy fluvial environment similar to the present Umpqua River upstream from tidal influence.

The height of the Crestview terrace indicates that the age of this terrace is well beyond the range of radiocarbon dating, so a TL age was obtained on the silty overbank deposits (fig. 14). The TL analysis determined that the Crestview sediments are at TL saturation and indicates a probable age of greater than 200 ka. This minimum age is consistent with the height of the terrace and the soil development found in the deposit (oxidation extends through the entire 10-m-deep exposure, and 2.5YR hues are present in the B horizon). An age of >200 ka is also consistent with tentative correlation with the marine terrace record. Although poorly preserved, marine terrace sediments are present about 7 km downstream at about the same elevation as the Crestview terrace. The 85–95 m elevation of these marine deposits indicates that they are substantially older than the 24- to 28-m-high, isotope-stage 5 terrace at Threemile Lake, so they most likely correlate with a stage 7 (230 ka) or older sea-level high stand. Some aspects of soil development on the Crestview terrace, particularly soil hues, are consistent with soils on the highest marine terrace at Cape Blanco—the Poverty Ridge terrace—(Bockheim and others, 1992), which is thought to be >500 ka (H.M. Kelsey, written commun., 1992).

If the Crestview terrace correlates with marine terrace deposits, then the coarse texture of the fluvial sediments implies high stream gradients and the absence of a well-established estuary at the mouth of the Umpqua River at the time of terrace aggradation. Perhaps the mouth of the Umpqua River during "Crestview" time was similar to the mouths of the present day Elk and Sixes Rivers in the Cape Blanco area of southern Oregon (fig. 2); these rivers are nontidal, gravel-dominated fluvial systems that empty

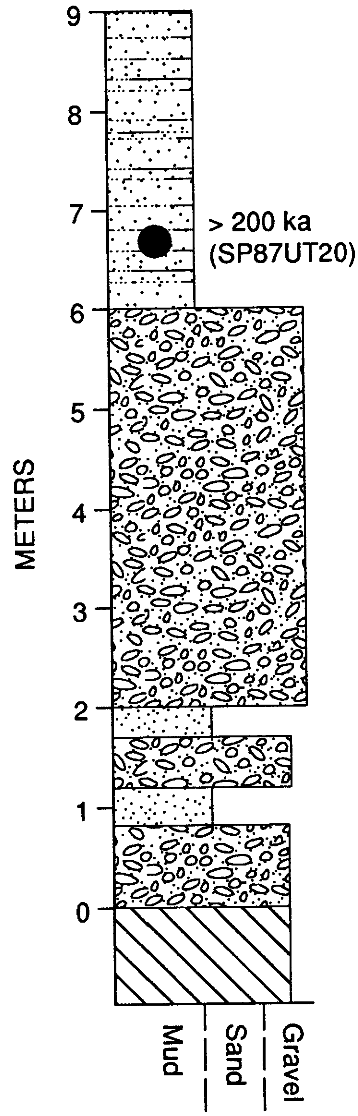


Figure 14. Stratigraphic column of an exposure of a high terrace along Crestview Drive near Reedsport at station 87–U19. See legend in figure 3 for explanation of lithologic patterns and symbols.

into the Pacific Ocean through relatively narrow (1- to 2-km-wide), flat-bottomed valleys. The gradients of the present-day lower portions of the Elk and Sixes Rivers (0.0009 and 0.0007, respectively) are much higher than the gradient of the tidal reach of the Umpqua River (0.0001). Unfortunately, the gradient between the Crestview terrace and possibly correlative marine terrace deposits cannot be calculated because of the poor preservation of both the marine and fluvial terrace surfaces, but the coarse texture of the Crestview terrace sediments indicates a steeper gradient on the ancestral lower Umpqua River. The inferred higher gradient indicates that either the whole ancestral Umpqua River had higher gradients or the rate of uplift of this part of the Coast Range was higher during "Crestview" time. High uplift rates certainly have affected the hydrology of the Elk and Sixes Rivers, because the Cape Blanco region has the highest uplift rates (0.8–1.5 mm/yr) determined along the entire Oregon coast (West and McCrumb, 1988; Kelsey, 1990; Muhs and others, 1990). Because stream gradients commonly decrease as stream discharge increases, a presumably smaller ancestral Umpqua River should have had a higher gradient at its mouth than the present river. So both greater uplift and a smaller discharge may have contributed to higher gradients when the Crestview terrace was formed. Some rivers in the Pacific Northwest have demonstrated similar patterns of increasing gradients with older terraces, such as the Cowlitz River in western Washington (Dethier, 1988, fig. 4), while others have essentially parallel older terraces, such as the Mattole River in northern California (Merritts and Vincent, 1989, fig. 5). Unfortunately, the preservation of older fluvial terraces is so poor that longitudinal profiles of older terrace remnants (fig. 5) must be considered speculative, and therefore yield relatively little conclusive information about the gradients of the ancestral Umpqua River.

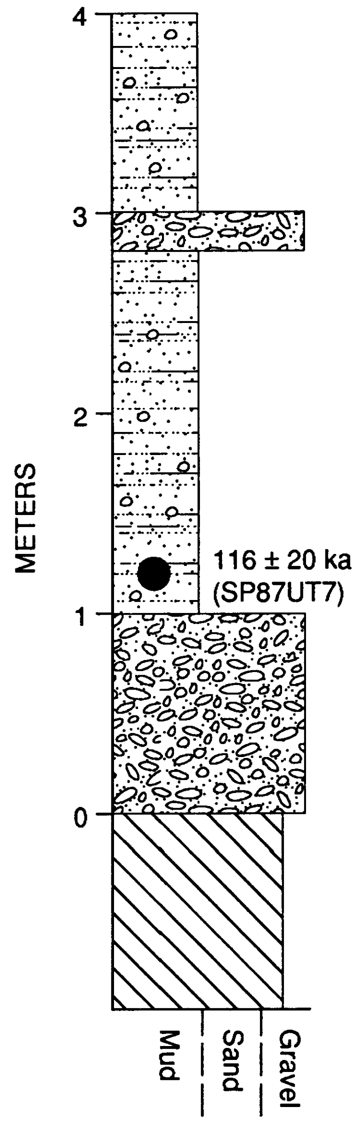


Figure 15. Stratigraphic column from an exposure of a high terrace along Henderer Road about 3 km west of Elkton at station 87–U1. See legend in figure 3 for explanation of lithologic patterns and symbols.

HIGH TERRACES ALONG HENDERER ROAD

Several high terraces are relatively well preserved along the Umpqua River in the area around Elkton between river km 65 and 95 (fig. 5; pl. 1). About 4 meters of extremely weathered fluvial sediment is exposed in one of the high terraces in a roadcut near the upstream end of the terrace at river km 75 (fig. 15; station 87–U1, plate 1). The exposed sediments differ from the usual fluvial stratigraphy found in upper Umpqua River terraces in that the sandy gravel at the base of the section is thinner than basal gravels at most other sites. The thin gravel is overlain by sandy silt that contains thin gravelly interbeds and some gravel clasts floating in the sandy silt matrix. Soils on this terrace are extremely well developed, with 2.5YR hues in the B horizon, and obliteration of most depositional fabric. In addition, all gravel clasts are crushable in hand specimen. Strong oxidation extends through the entire exposure and into several meters of exposed saprolitic sandstone bedrock.

Soils are better developed on the Henderer Road terrace than on the previously described Crestview terrace, even though the difference in height of these terraces above the Umpqua River (41 m versus 90 m, respectively) indicates that the Henderer Road terrace is much younger. I believe the apparent change in rates of soil development between these two sites is related to differences in climate, in particular to the occurrence of the "summer dry," the hotter, drier, sunnier weather experienced some distance inland from maritime influence along the Oregon coast.

Coastal soils develop under cooler, moister, and foggier summer conditions than do soils in inland parts of the Coast Range, so the drier summer soil conditions inland may be more conducive to increased oxidation. The increased oxidation is clearly apparent in the Henderer Road and other terrace exposures on the Umpqua River that lie more than about 40 km from the coast. However, this apparent limit of coastal influence on soil development may not extend as far inland on other parts of the Oregon coast, because coastal fogs often move farther inland along major river valleys than they do across unbroken mountains. Additional variations in coastal influence on soil development through time may exist as a result of changes in climate related to fluctuating sea levels. Such variations in soil development are examples of the problems inherent in using soils as a tool for correlating terrace remnants along Coast Range rivers.

A TL age of 116 ± 20 ka was obtained on silty sediment from one of the higher terrace exposures along Henderer Road (fig. 15). As with the other TL sites, I attempted to sample unweathered sediment for analysis, but this proved to be impossible because soil development extended through the entire exposure. The affect of pedogenesis on the TL signal preserved in these sediments is unknown, but oxidation, influx of illuviated silt and clay, and fluctuating groundwater conditions probably have altered the amounts and types of radioactive sources in the sediment. However, the TL age obtained on the higher Henderer Road terrace may be geologically reasonable, especially if the TL age of 65.2 ± 7.3 ka on the high terrace at Reedsport, to which the Henderer Road terrace might be correlated (fig. 5), is a minimum age. The TL age of 116 ± 20 ka on the Henderer Road terrace appears to be accurate within its laboratory error limits if both fluvial terraces are graded to the Threemile Lake marine terrace, which in turn is correlative with a substage 5e, 125-ka sea-level high stand. This is a reasonable interpretation, but the advanced soil development on the high Henderer Road terrace, lack of physical continuity, and poor preservation of both fluvial and marine terraces suggests that other correlations cannot be ruled out.

Several roadcuts in a lower terrace along Henderer Road at about river km 68–70 (stations 87–U3 and 87–U23, plate 1) exposed similar sequences of sandy silts overlying sandy pebble and cobble gravels (fig. 16). The elevation of the lower Henderer Road terrace surface near these exposures is about 43 m, about 26 m above the Umpqua River. No age information was obtained on this terrace, but comparable well-developed soils are present on the deposits at both sites. Strong oxidation extends through the entire exposures, most gravel clasts are crushable in hand specimen, and colors reach 5YR hues in the B horizons. If the higher Henderer Road terrace correlates with a possible substage 5e (125 ka) marine terrace at Threemile Lake, then the lower Henderer Road terrace surface might be graded to sea-level high stands at 80 or 105 ka, but marine terraces of this age are probably below sea level along this part of the Oregon coast (H.M. Kelsey, written commun., 1992).

TERRACES ALONG THE SMITH RIVER

The Smith River, one of the largest (900 km^2 drainage area; Oregon State Water Resources Board, 1958) tributaries of the Umpqua River, enters the Umpqua River near Reedsport (fig. 2). Unfortunately, fluvial terraces along the Smith River are even less well preserved than along the Umpqua River (fig. 17; pl. 2). Most terraces are small, but at four locations terraces are better preserved in abandoned meander bends. As with the Umpqua River, terrace sediments are found at heights as much as 100 m above present river level, but lower, younger terraces are more common.

The only terrace that can be physically correlated with any certainty along the Smith River is a mostly continuous terrace, 2–10 m above river level, that probably is correlative with the PHT terrace on the Umpqua River. Unfortunately, no radiocarbon ages were obtained from upstream exposures of this terrace on the Smith River that could be compared to dated sites on the Umpqua River. Several radiocarbon ages were determined on charcoal from terraces in abandoned meander bends near Brainard Creek and in The Island near Smith River Falls, and near the confluence of Vincent Creek and Smith River; a single TL age was obtained from a high terrace near the mouth of the river. Most of these ages are not consistent with other ages on the Smith River or with the better established chronology on the Umpqua River. The dated sites and several other terraces are discussed below.

TERRACES UPSTREAM FROM THE ISLAND

Fluvial sediments are exposed in a logging roadcut along Vincent Creek, just upstream from the confluence of the creek with the Smith River near river km 53 (station 87–US7, plate 2). In the exposure about 1 m of fluvial sandy silt overlies about 0.75 m of sandy gravel (fig. 18); an accelerator (AMS) radiocarbon analysis on small fragments of charcoal from the sandy silt yielded an age of 7,950 ± 110 yr B.P. This age seems anomalously young because the terrace surface is about 19 m above the elevation of Vincent Creek and about 24 m above the elevation of Smith River, 250 m downstream. An infinite radiocarbon age (>43,600 yr B.P.) on a lower terrace near Bear Creek about 4 km downstream and the presence of abundant decomposed roots, worm casts, and animal burrows

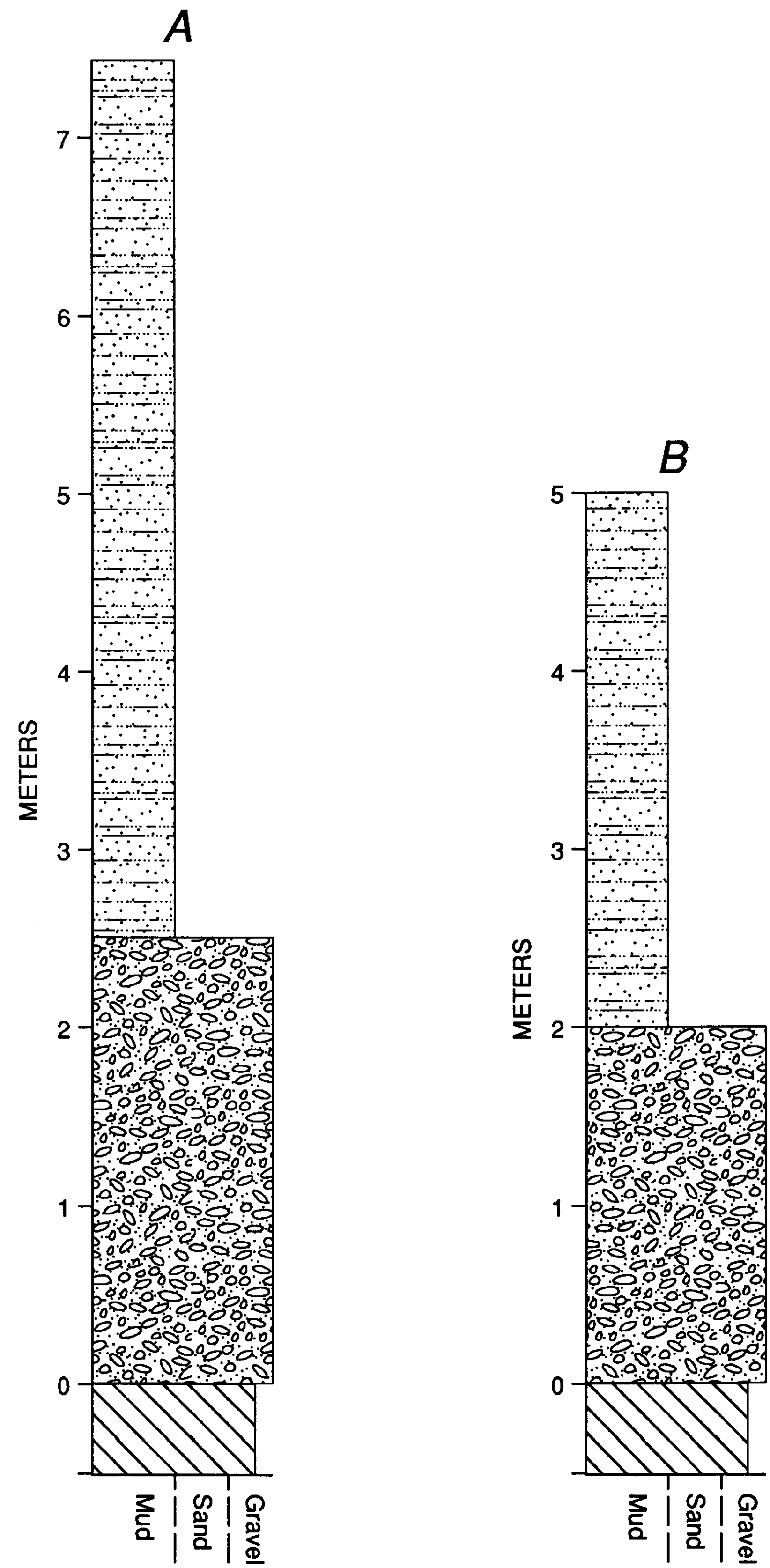


Figure 16. Stratigraphic columns of two exposures of an intermediate terrace along Henderer Road, 6–8 km west of Elkton: (*A*) station 87–U3 and (*B*) station 87–U23. See legend in figure 3 for explanation of lithologic patterns and symbols.

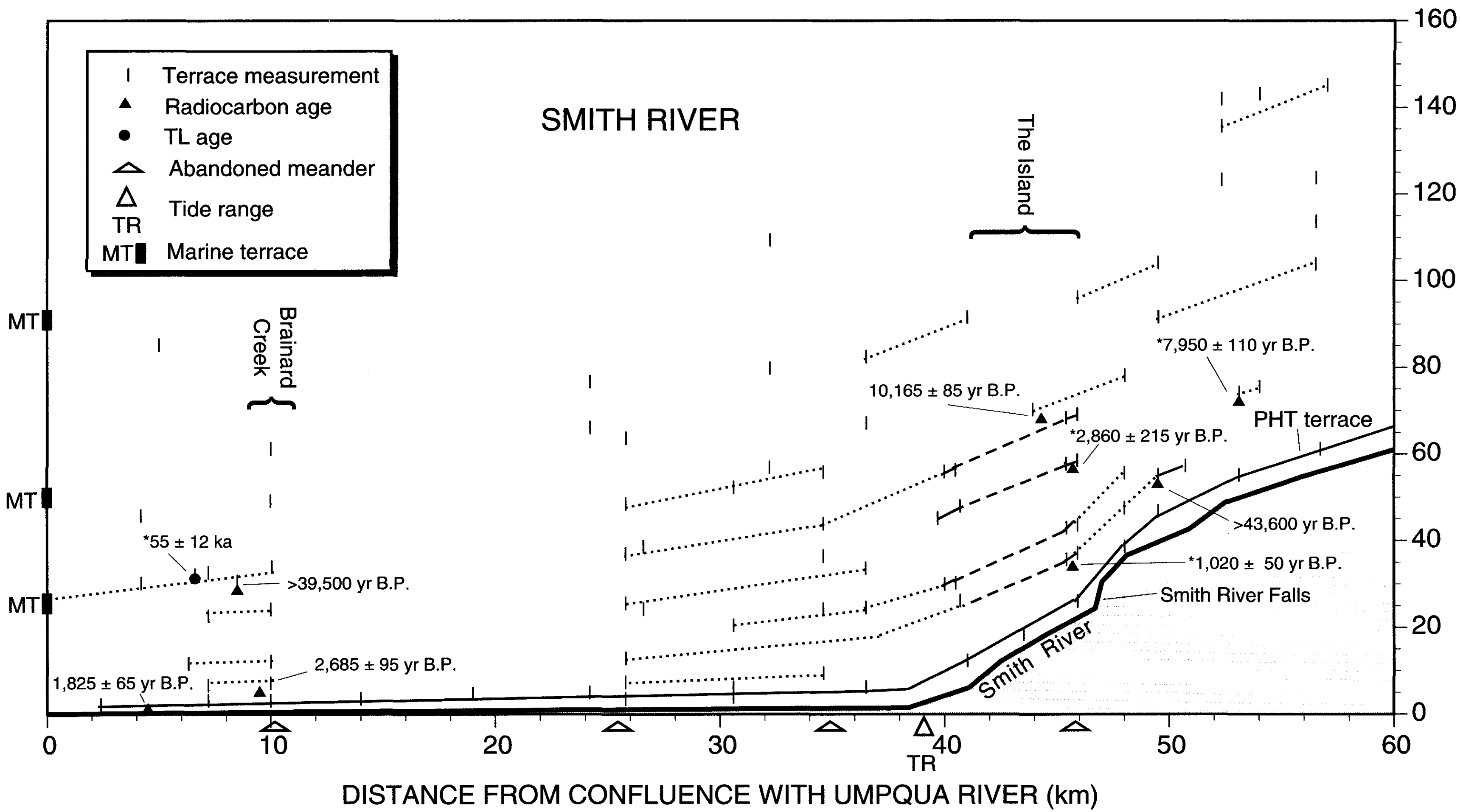


Figure 17. Longitudinal profile of terraces along the lower reach of the Smith River; see figure 5 for explanation of symbols. Radiocarbon age of 10,165 ± 85 yr B.P. is on charcoal from alluvial-fan sediment in The Island area. Marine terraces are projected from near the mouth of the Umpqua River a few km downstream from the confluence.

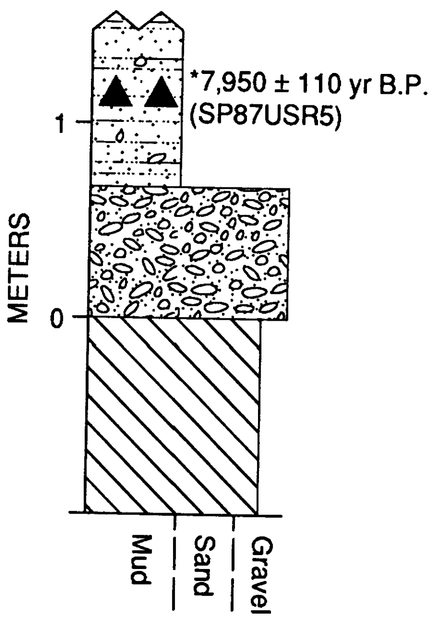


Figure 18. Stratigraphic column of a terrace exposure on Vincent Creek near the confluence with the Smith River at station 87–US7; the radiocarbon age is probably too young (see text). See legend in figure 3 for explanation of lithologic patterns and symbols.

in the exposure indicate that the Vincent Creek radiocarbon sample may have been contaminated with younger carbon.

Soil development cannot be used with much confidence at this site because the upper meter or two of the terrace was not exposed and the roadcut was located in a partially eroded part of the terrace surface. The present soil at the site is weakly developed, with only minor oxidation and clast weathering visible in the exposure; moist colors in the sediments are 10YR 5/4 to 10YR 5/6, so little reddening of the soil is apparent. A terrace of similar height along Henderer Road on the Umpqua River is more oxidized, has 5YR hues in the B horizon and hand crushable gravel clasts, so the height of the Vincent Creek terrace may be related to higher incision rates on Vincent Creek rather than to advanced age. As with several other sites on the Smith River, the geologic and radiocarbon data are somewhat contradictory. The height of the Vincent Creek terrace indicates that the radiocarbon age from the site is too young, but the weak soil development in the deposit supports a relatively young age. The gradient of Vincent Creek is four times as steep as the Smith River in this area (0.008 versus 0.002), thus, both sample contamination and higher incision rates may be the cause of the apparent anomalously young age of the Vincent Creek terrace.

Several terrace surfaces are preserved along a fairly straight stretch of the Smith River near Bear Creek, 3–4 km upstream from Smith River Falls (stations 87–US5 and 87–US6, plate 2). Exposures in two of these terraces revealed similar sequences of basal sandy pebble and cobble gravel overlain by pebbly sand and pebbly sandy silts and silty sands (fig. 19). An infinite AMS radiocarbon age (>43,600 yr B.P.) was obtained on disseminated charcoal collected from an exposure of the lower terrace that stands about 15 m above the Smith River (fig. 19*A*). This radiocarbon age is important because it casts doubt on the accuracy of several Holocene radiocarbon ages on terraces presently found at greater heights above the Smith River. As previously discussed, young organic materials (roots, filled animal burrows) are abundant in most terrace exposures, so some anomalously young radiocarbon ages were expected. Anomalously old ages, however, are more difficult to explain because sources of dead carbon, such as fragments of coal or organic-rich shale, are rare in the underlying bedrock in this part of the Coast Range. Older fragments of charcoal could be a source, but the very small fragments preserved in the station 87–US5 exposure could not have been transported very far by the Smith River without disintegrating. Therefore, I conclude that the infinite radiocarbon age from the lower terrace is accurate, and that most of the Holocene ages on nearby terraces, including Vincent Creek and most of the terraces in The Island (to be discussed) are probably not accurate estimates of terrace age.

An exposure in the higher terrace near Bear Creek, which stands about 50 m above the Smith River (fig. 19*B*), revealed a stratigraphic sequence similar to but somewhat coarser than the nearby lower terrace. Soil development was better in the upper terrace (higher clay content and the sand had a firmer consistence in the B horizon), but in both exposures the soils are only oxidized to 10YR hues and the gravel clasts in the exposures are only slightly weathered and not crushable in hand specimen. This degree of weathering is substantially less than terraces of similar height on the nearby Umpqua River (for example, the Henderer Road terraces), which implies either that incision rates on the Smith River are very high, or that soil development at this site has been inhibited by coastal weather patterns. The Bear Creek terraces are located about 30 km from the coast and the Henderer Road terraces are located about 45 km from the coast, so the limit of coastal climatic suppression of soil oxidation may lie somewhere between 30–45 km along major stream valleys in this part of the Coast Range.

TERRACES IN THE ISLAND

The Island is a large abandoned meander bend located at about river km 46 on the Smith River (stations 87–US10, 11, and 12, plate 2). Smith River Falls is located about 0.6 km upstream from the meander cutoff and probably is a retreating knickpoint created by the

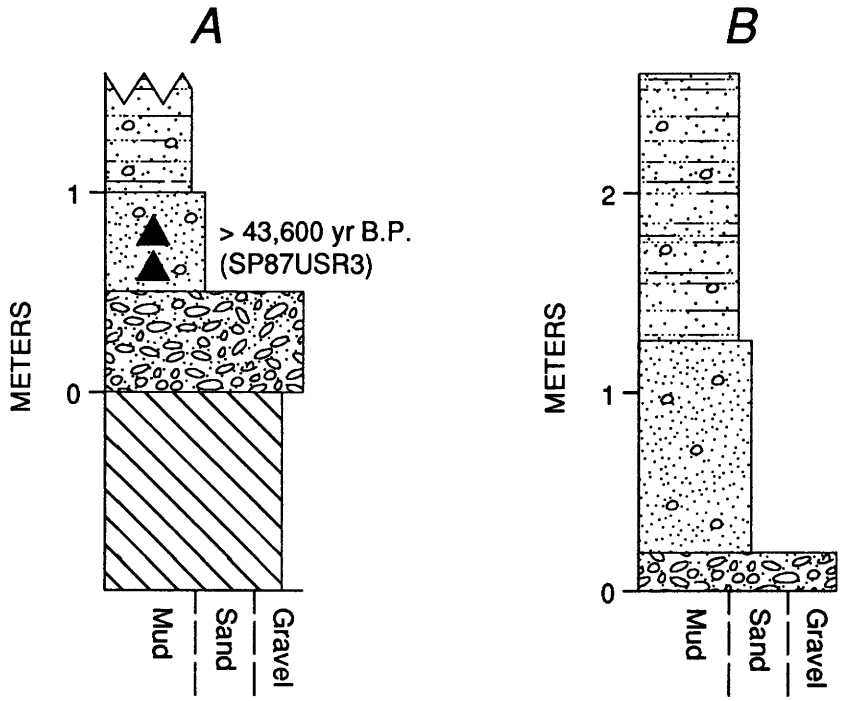


Figure 19. Stratigraphic columns of two terrace exposures upstream from Smith River Falls near Bear Creek: (*A*) exposure of lower terrace at station 87–US5, and (*B*) exposure of higher terrace at station 87–US6. See legend in figure 3 for explanation of lithologic patterns and symbols.

abandonment of about 6 km of former channel of the Smith River now isolated in The Island. Several fluvial terraces are preserved in the area as a result of abandonment, but the present geomorphology of the bend has been complicated by subsequent landsliding, drainage reversals, and alluvial deposition by small streams. A topographic profile measured along the present valley bottom of The Island illustrates some of the pertinent aspects of the geomorphology of the area (fig. 20): (1) remnants of at least four pre-abandonment terraces are preserved in the bend; (2) a substantial amount of colluvial and alluvial sediment has been deposited in the bend since abandonment; (3) the gradient of the modern Smith River (0.0029) in the vicinity of The Island is only slightly higher than the projected gradients of the four terraces in the bend (average of four values=0.0023); and (4) two radiocarbon ages yielded unexpectedly young ages and probably are only minimum ages.

The timing of the abandonment of the The Island is unknown because of inconsistent radiocarbon ages. Charcoal from the lowest abandoned terrace (station 87–US12, plate 2), which probably was the Smith River flood plain at the time of abandonment (dashed line in fig. 20), yielded an age of 1,020 ± 50 yr B.P., but this age is almost certainly a minimum value. This sample was taken from a wedge-shaped zone of reddish-brown silty sand containing abundant angular wood and charcoal fragments in the sandy overbank facies (fig. 21*A*). The shape and color of this zone and the abundance of apparently nonfluvial organic debris indicate that this zone is probably a burned tree root or tree-throw cavity filled with sediment and organic material that post-dates the fluvial terrace surface. Therefore, the radiocarbon age yields only a minimum age for the abandonment of this terrace.

A roadcut in a fluvial terrace about 21 m above the lowest terrace (station 87–US10, plate 2) exposed an apparently eroded section of fine sand and sandy silt overlying bedrock (fig. 21*B*). This sediment has probably been reworked by colluvial processes because the exposed section is very thin, does not include the basal sandy gravel found in almost all other exposures of fluvial sediments in the area, and contains some angular pebbles. The exposure also appears to have been extensively bioturbated by rodents and contains abundant decomposed roots, so some decomposed roots may have been included in the radiocarbon sample. Thus, the radiocarbon age of 2,860 ± 215 yr B.P. also yields only a minimum age of this terrace.

A third radiocarbon age (10,165 ± 85 yr B.P.) from a roadcut exposure at station 87–US11 (pl. 2) gives a better assessment of the antiquity of terraces in The Island. As is evident from its position on the topographic profile (fig. 20) and on plate 2, the dated sediments lie near the top of a thick sequence of post-abandonment colluvial and alluvial sediment. The stratigraphy in the exposure (fig. 21*C*)

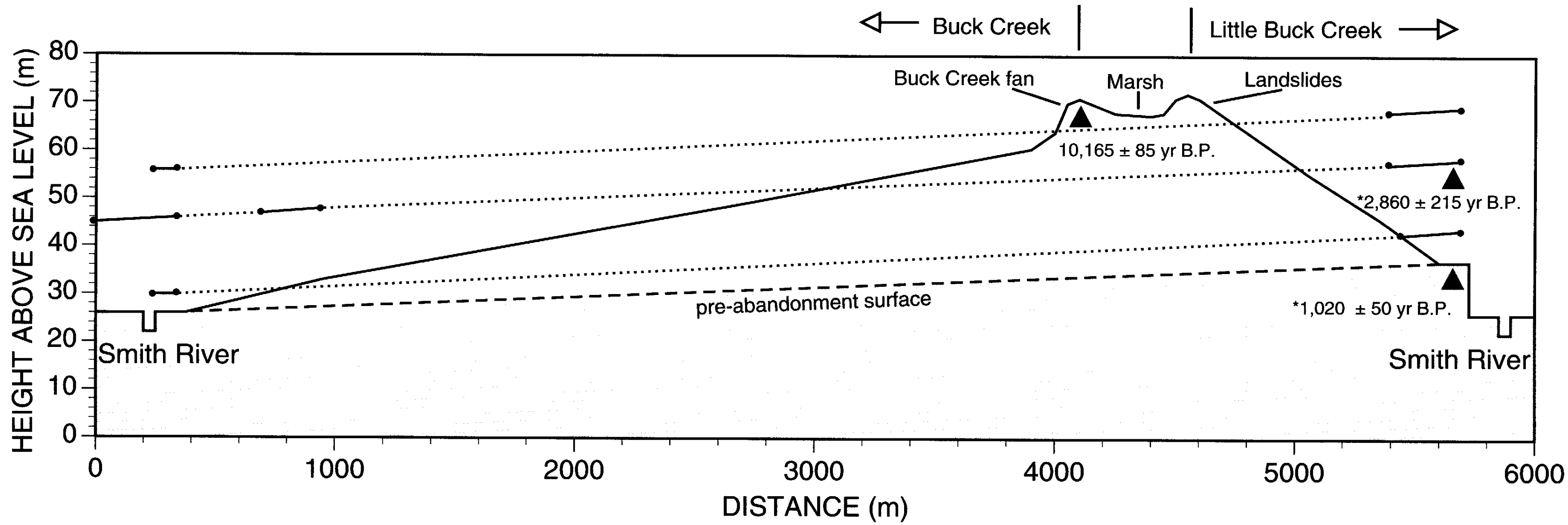


Figure 20. Diagrammatic topographic profile of the present valley bottom (solid line) in an abandoned meander bend on the Smith River (labelled "The Island" on plate 2). Also shown are several pre-abandonment terrace remnants (short solid lines), and probable correlations (dotted lines) between these surfaces. The gradients of the correlated surfaces (average 0.0023) are only slightly less steep than the gradient of the modern Smith River in this reach (0.0029). The lowest projected terrace surface (dashed line) approximates the flood plain of the Smith River at the time of meander abandonment; note the large volume of post-abandonment sediment (unshaded area) overlying this surface. The two youngest radiocarbon ages (marked with asterisks) are probably in error; the radiocarbon age from the Buck Creek fan is on charcoal from alluvial-fan sediment near the top of the post-abandonment sequence, so it yields a minimum age of meander cutoff. An infinite radiocarbon age (>43,600 yr B.P.) from a terrace near Bear Creek, a few km upstream (fig. 19*A*) probably correlates with the pre-abandonment terrace in The Island and gives a better estimate of the age of the abandoned meander. Note the small marsh located where drainage is trapped between the Buck Creek fan and downstream landslides; this area forms the modern drainage divide between Buck Creek and Little Buck Creek. Topographic data are from altimeter readings, several photogrammetric profiles and 1:24,000 scale-topographic maps.

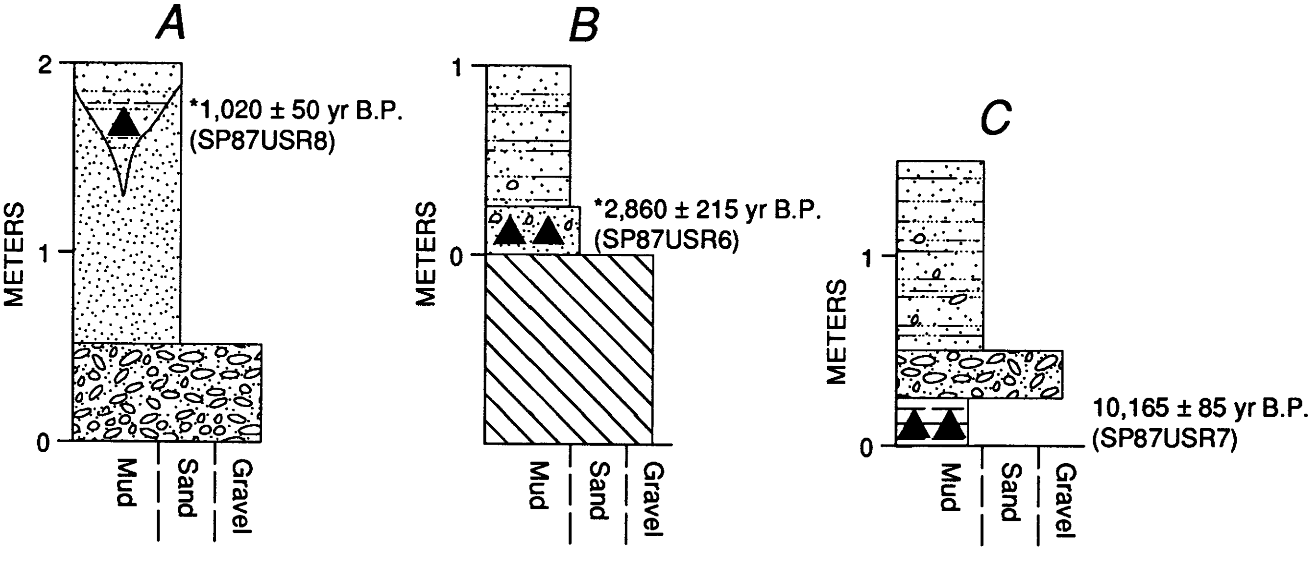


Figure 21. Stratigraphic columns of terrace exposures in The Island: (*A*) exposure of lowest terrace at station 87–US12, (*B*) exposure of intermediate terrace at station 87–US10, and (*C*) exposure of Buck Creek alluvial-fan sediments at station 87–US11. See legend in figure 3 for explanation of lithologic patterns and symbols.

is somewhat unusual because a thin bed of sandy pebble and cobble gravel is interbedded with pebbly sandy silt and silt. This stratigraphy and the geomorphology at the site indicate that the exposed sediments were deposited in an alluvial or debris fan formed where Buck Creek enters the abandoned cutoff and are not part of a Smith River fluvial terrace. This conclusion is supported by the characteristic fan shape of the ground surface where Buck Creek enters the meander, and lack of older fluvial terrace surfaces in the area (pl. 2). In addition, the roadcut in the Buck Creek fan is located near the center of the valley, where preservation of a high Smith River terrace remnant is unlikely. Projection of the lowest Island terrace (dashed line in fig. 20) beneath the colluvial and alluvial sediments now present in the cutoff shows that as much as 38 m of post-abandonment sediment has been deposited at the apex of the Buck Creek fan. Such a large amount of sediment has accumulated in the meander because Buck Creek, which now occupies most of the former valley of the Smith River, is underfit and incapable of carrying the large sediment loads supplied to the valley bottom from adjacent slopes. The location of the Buck Creek radiocarbon sample near the surface of the fan sequence may indicate that the latest period of significant alluviation in this part of The Island occurred in latest Pleistocene or early Holocene time, coincident with aggradation of PHT terraces along several Coast Range rivers (see "Discussion" section).

The radiocarbon age from the previously described lower terrace near Bear Creek (>43,600 yr B.P.) may be a more reasonable constraint on the minimum age of meander abandonment than the three radiocarbon ages from The Island, because the lowest Island terrace and the Bear Creek terrace are at about the same height above the Smith River (fig. 17), and because the infinite radiocarbon age is more consistent with the large amount of post-abandonment sediment present in The Island (fig. 20).

TERRACES BETWEEN THE ISLAND AND BRAINARD CREEK

Downstream from The Island, fluvial terraces are best preserved on the insides of meander bends and in abandoned meanders near Sulphur Springs at about river km 35 and near North Fork at about river km 26 (fig. 17). Both abandoned meanders contain high, old terraces that are mostly covered by colluvium. No exposures were apparent so these terraces were not examined in detail. However, the terrace spacing at these and other scattered sites was regular and consistent, so tentative correlations have been made between the scattered remnants (fig. 17). The gradients of these correlated surfaces roughly parallel the better constrained terrace surfaces in The Island but are somewhat steeper than the modern Smith River and low terraces along the same reach. Most terraces are not correlated downstream from the North Fork area because almost no terraces are preserved in a 15-km-long gap between North Fork and Brainard Creek (fig. 17).

TERRACES NEAR BRAINARD CREEK

Several terraces are preserved in a large abandoned meander near Brainard Creek at about river km 9.5

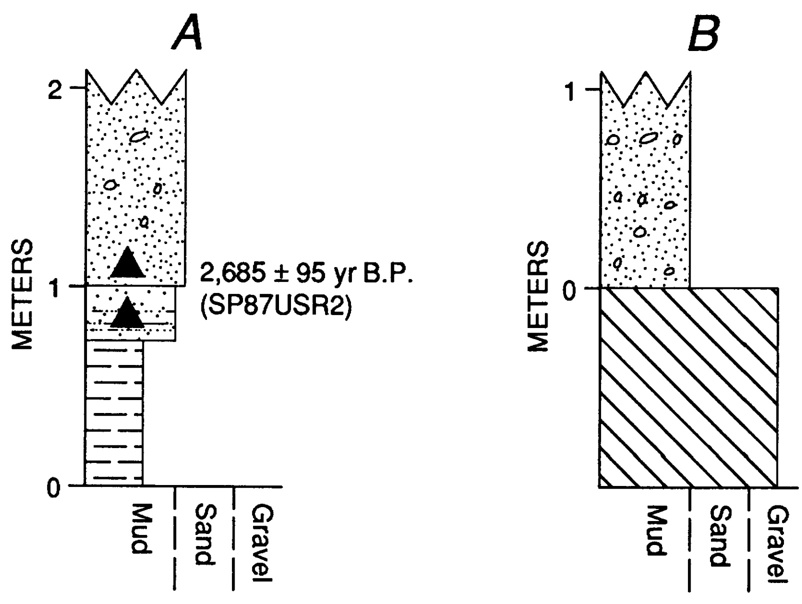


Figure 22. Stratigraphic columns of terrace exposures in the abandoned meander bend near Brainard Creek: (*A*) exposure of the lowest terrace at station 87–US3, and (*B*) exposure of the highest terrace at station 87–US4. See legend in figure 3 for explanation of lithologic patterns and symbols.

(fig. 17). The surface of the lowest terrace in the meander is at an elevation of about 7 m and is dissected, but enough of this surface is preserved to show the extent of the pre-abandonment path of the Smith River. A roadcut in this surface (fig. 22*A*; station 87–US3, plate 2) exposed about 1.25 m of overbank silty sand overlying at least 0.75 m of silty clay that may be estuarine sediment, quiet-water sediment deposited in an oxbow lake, or lacustrine sediment deposited behind a landslide dam. No landslide scars large enough to dam the Smith River are evident downstream from this exposure, so the muddy sediment was probably deposited in an oxbow lake or by estuarine processes. An AMS radiocarbon age of 2,685 ± 95 yr B.P. was obtained on small fragments of charcoal from the base of the sand and the top of the underlying silt. The exposure contained numerous decomposed roots and worm burrows that could be sources of younger organics, but the sample was picked carefully to remove such materials before submission. The lowest terrace in the Brainard Creek meander is about 4 m higher than the lowest terrace along the Smith River, which has yielded radiocarbon ages of 123.7% of modern at 1.25 m depth and 1,825 ± 65 yr B.P. at 3.6 m depth from an auger core about 5 km downstream at station 87–US15 (fig. 4*C*; pl. 2). The lowest Brainard Creek terrace is also about 2 m lower than an intermediate terrace near the confluence at Reedsport that yielded a TL age of 14.9 ± 3.1 ka. Thus, the radiocarbon age from the lowest terrace in the Brainard Creek meander is bracketed in correct stratigraphic order by radiocarbon and TL ages from nearby terrace sediments and may be a reasonable maximum age for the age of meander abandonment.

An eroded exposure of fluvial sediment in the highest terrace near Brainard Creek was visible in a driveway roadcut (fig. 22*B*; station 87–US4, plate 2). Only the lower 1 m of this exposure appeared to be in place, and the sediment was extremely weathered (all gravel clasts crushable in hand specimen, extensive oxidation and clay alteration, 5YR hues) but fluvial bedding was still apparent in the sediment. Although the age of this terrace is unknown, the height (61 m), extensive weathering of the terrace sediments, and relations to marine terraces at the mouth of the Umpqua River (fig. 17) indicate that this terrace is more than 125 ka. Four other terrace surfaces are preserved in the Brainard Creek meander between the two terraces discussed here, but no exposures of these surfaces were found.

TERRACES DOWNSTREAM FROM BRAINARD CREEK

A roadcut in a 32-m-high terrace on the south side of the Smith River at about river km 6.5 (station 87–US2, plate 2) exposed about 2 m of sandy silt and pebbly sand (fig. 23). A TL age obtained on these sediments (55 ± 12 ka) is younger than the TL age obtained on fluvial sediment from the high terrace at Reedsport (65.2 ± 7.3 ka), but these ages overlap within their laboratory error limits (table 2). The high terrace at Reedsport may correlate with possible 125 ka marine terrace deposits near the mouth of the Umpqua River, so if these terraces are correlative, then both TL ages on these terraces are too young.

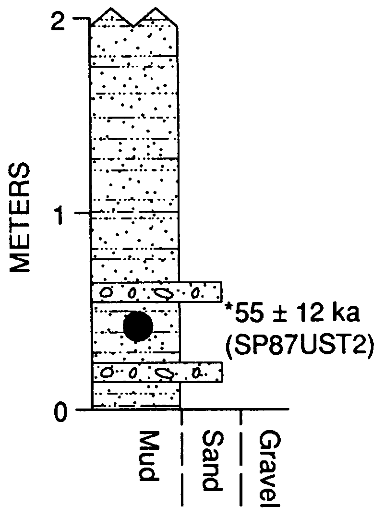


Figure 23. Stratigraphic column of an exposure of a high terrace on the Smith River at station 87–US2. See legend in figure 3 for explanation of lithologic patterns and symbols.

Comparisons between projected terrace gradients and the present gradients of the Smith and Umpqua Rivers do not conclusively indicate whether the high terraces at Reedsport and on the Smith River are correlative. The present tide-influenced gradients of the lower Smith and Umpqua Rivers are both about 0.0001; gradients upstream from tidal influence are variable, but generally average about 0.003 for the next 45 km of the Smith River and about 0.0006 for the next 45 km of the Umpqua River. The projected gradient between the high Smith River and Reedsport terraces is 0.002, and the average gradient projected between the Smith River terrace and the marine terrace surface at Threemile Lake is about 0.0004. The anomalously high gradient between the Smith River and Reedsport terraces may indicate that they are not correlative, it may be an artifact of vertical errors in measuring the height of one or both of these terraces, or it could indicate that the high Smith River terrace formed at a time when the lower reach of the Smith River was substantially steeper than at present, perhaps similar to conditions on the modern nontidal reach of Scholfield Creek (fig. 11). A steeper gradient also would be consistent with nontidal conditions during a period of lower sea level, as indicated by the TL ages. However, the fine sand and silt in the two high terraces and the geomorphic setting of the Reedsport terrace indicate that both terraces were probably formed under estuarine conditions similar to those of today.

Thus, the heights, projected gradients, TL ages, and relations to marine terrace deposits indicate at least three possible scenarios for the age and correlation of the two high terrace remnants on the lower Smith and Umpqua Rivers. The terraces may not be correlative, but TL ages on these sediments overlap within their laboratory error limits. If the terraces are the same age, then they were aggraded either about 55–65 ka during a sea-level low stand, or about 125 ka during a sea-level high stand. Fluvial terraces formed during sea-level low stands near the coast are rarely preserved in the emergent geologic record (Lajoie, 1986), and the deep exposures of the Reedsport terrace show no evidence of coarse sediment that should be associated with steeper stream gradients. So while the geologic evidence and TL ages are somewhat contradictory, I conclude that the Reedsport and Smith River terraces are probably the same age, and that they correlate with marine terrace deposits near Threemile Lake that may be 125 ka. The variations in projected gradients between these terrace surfaces (fig. 11) are probably related to errors in the measurement of the heights of terrace surfaces and the presence of an unknown thickness of marine and eolian sediment on the marine terrace platform at Threemile Lake. If these correlations are correct, then TL ages determined on sediment from the fluvial terraces are too young by 60,000 years for the Reedsport terrace and by 70,000 years for the Smith River terrace. The TL age discrepancies may be related to pedogenic changes in the fluvial sediments, because at both sample locations, extensive soil oxidation extended throughout the exposures.

Charcoal from a fluvial terrace on Hudson Slough, a tributary that enters the Smith River at about river km 5.5, has been radiocarbon dated as part of a recent study of colluvial deposits and erosion rates in the Coast Range (Reneau, 1988). The terrace surface is about 15 m above the bed of Hudson Slough at an elevation of 25–30 m; charcoal from about 1 m below the terrace surface at a site 3 km upstream from the Smith River yielded a radiocarbon age of >39,500 yr B.P. (Reneau, 1988, p. 220). Several other apparently correlative terrace remnants are at the same elevation in the Hudson Slough drainage (pl. 2), apparently indicating that a fairly extensive terrace surface existed in the slough sometime prior to 40 ka. This terrace may have been similar to the modern surface of low relief in Hudson Slough and therefore may have formed during a sea-level high stand similar to present sea-level conditions. The height of this terrace indicates that it might be correlative with TL-dated terraces on the south side of the river just upstream (fig. 17) and at Reedsport on the Umpqua River. All these terraces are probably correlative with the marine terrace at Threemile Lake, which may be related to the oxygen-isotope substage 5e (125 ka) sea-level high stand, although Reneau (1988) suggested that erosion rates calculated in his study indicated that the Hudson Slough terrace might be related to a Whiskey-Run equivalent (80 ka) sea-level high stand.

A 3.75-m-deep auger core was obtained from a low terrace about 4.5 km upstream from the mouth of the Smith River (station 87–US15, plate 2) near the mouth of Franz Creek. The core contained several layers of peaty and silty sediment (fig. 4*C*). Two radiocarbon ages on mixtures of peat, detrital charcoal, and wood were obtained from depths of 1.25 and 3.6 m; as previously discussed, these ages (123.7% modern and 1,825 ± 65 yr B.P., respectively) yielded a maximum sediment accumulation rate of about 1.3 mm/yr at this site.

TERRACES ALONG THE SIUSLAW RIVER

The Siuslaw River has a drainage basin of about 2,000 km^2 (Oregon State Water Resources Board, 1965) and is located 30–35 km north of the Umpqua River (fig. 2). Extensive older fluvial terraces initially were recognized along the lower Siuslaw River by Baldwin (1956), but Schlicker and Deacon (1974) modified Baldwin's mapping by removing terraces mapped on the meander bend west of Mapleton. My mapping generally confirms Baldwin's original work in this area (pl. 3). The distribution of fluvial terraces along the lower Siuslaw River is unusual because almost all older terraces are preserved on a high bench on the north side of the river. The present topography of the valley is U-shaped, with a flat, sediment-filled floor and steep sides (fig. 24). Because extensive high terraces are not evident on the south side of the river, the river appears to have migrated unidirectionally to the south in Quaternary time. Another unusual feature of the Siuslaw terraces is the apparent anticlinal warping of older terraces near river km 25 (fig. 25). This warping coincides with an anticline in the underlying bedrock (Baldwin, 1956; Schlicker and Deacon, 1974). The anomalously high gradients of the terraces on the downstream limb of the anticline were attributed by Schlicker and Deacon (1974) and Adams (1984) to folding, but neither noted the presence of multiple terraces or the terrace gradient reversals on the upstream limb of the anticline. The multiple terraces present above the Siuslaw River anticline appear to be examples of "tectonic" terraces formed as a result of repeated movements on the anticline.

HOLOCENE TERRACE

A single low terrace is found along much of the lower Siuslaw River at about 2–10 m above river level; a radiocarbon determination on charcoal from an exposure in this terrace near river km 38 (fig. 26; station 88–S1, plate 3) yielded an age of 7,010 ± 90 yr B.P. The radiocarbon sample was taken from near the base of sandy overbank sediment that overlies about a meter of basal sandy gravel. The small exposure of overbank sediment was covered at this location by slumped sands that may be inset into the older terrace surface. At the exposure site, the terrace surface is at an elevation of 8.5 m and is about 6.5 m above river level. The age and height of this terrace are similar to those of the PHT terrace on the Umpqua River, which yielded slightly older radiocarbon ages from similar positions in the silty overbank deposits. The younger apparent age of the Siuslaw terrace may be related to the location of the present tide limit, which is only 2 km downstream from the sample site. Terrace aggradation in such locations may have been more affected by changes in sea level than terraces located farther upstream. The Holocene terrace on the Siuslaw River converges with the river downstream and eventually merges with tidal marshes near the coast.

In an earlier study, Feiereisen (1981) conducted an investigation of the geomorphology, sedimentology, and stratigraphy of the modern flood plain along the lower Siuslaw River, which included most of the Holocene terrace described above. He identified cyclical patterns of fluvial sedimentation and attributed these patterns to forest fires and large floods in the watershed. Feiereisen obtained a single radiocarbon age of 3,250 ± 70 yr B.P. on peat and wood from a depth of about 5.5 m in a core in the flood plain sediments near river km 23.5.

OLDER TERRACES

Several exposures of older, higher terraces on the north side of the Siuslaw River revealed extensively weathered fluvial sequences that were commonly partially stripped and overlain by colluvium. Because most of the exposures were clustered in a group of high surfaces, only subtle differences in weathering characteristics were evident. The most apparent differences in weathering characteristics were degree of reddening, oxidation, and preservation of gravel clasts. I did not obtain any numerical age information from the older Siuslaw River fluvial terraces, so correlation with marine terraces at the coast may be the best means of estimating fluvial terrace ages. A discussion of marine terraces present near the mouth of the river will precede discussion of the older fluvial terraces.

MARINE TERRACES

Marine terrace deposits are present at several elevations near the mouth of the Siuslaw River. Golder Associates (1986, table 6) listed an elevation of 18.2 m for a Whiskey Run-equivalent terrace (80 ka) and an elevation of 48.5 m for a Pioneer(?)-equivalent terrace (105 ka) at Florence. Golder Associates (1986) also listed an elevation of 30.3 m for a Pioneer-equivalent terrace at Sutton Lake, about 10 km north of the Siuslaw River. This terrace may extend southward to Florence as a relatively flat, sand

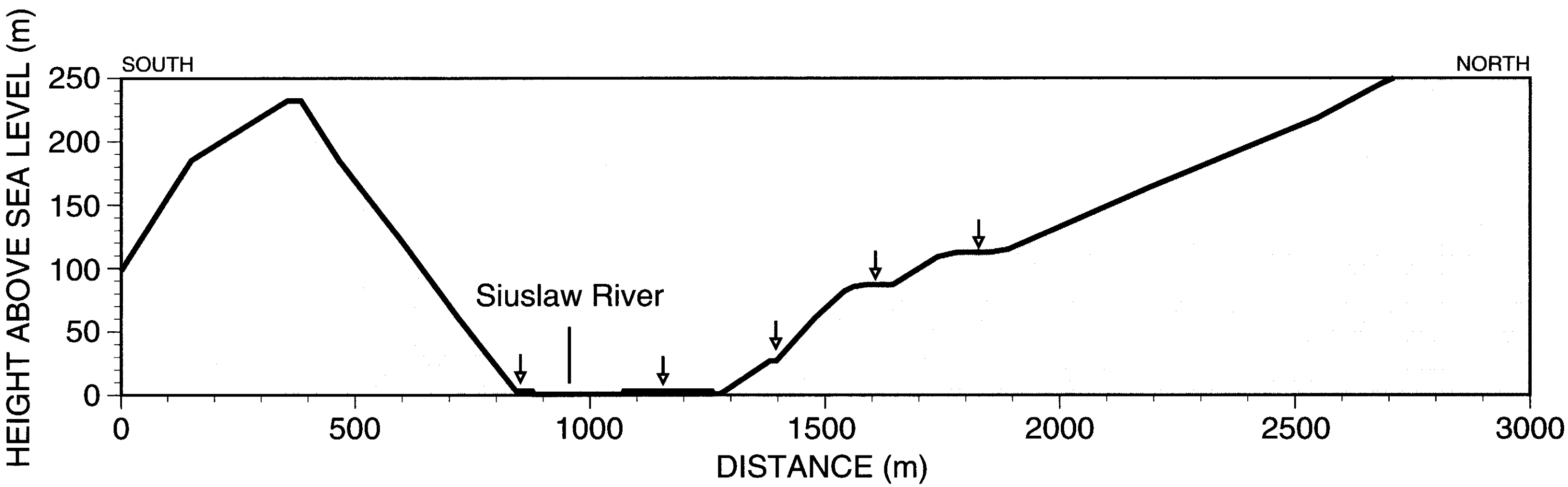


Figure 24. Topographic profile (from 1:24,000-scale topographic map) across the Siuslaw River near river km 22.5; fluvial terraces are marked with arrows. Note U-shaped, flat-floored valley and preservation of older fluvial terraces only on the north side of the river.

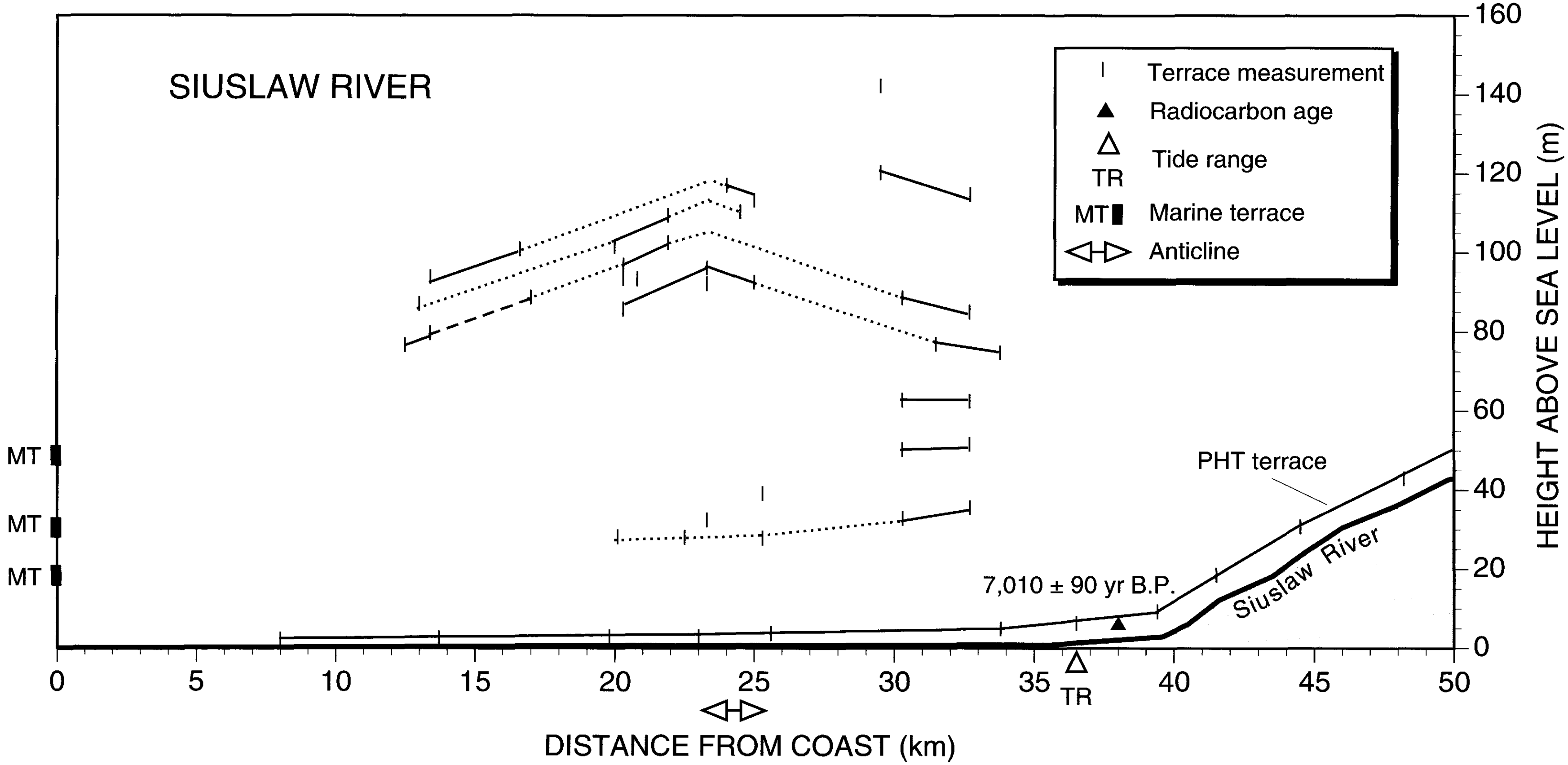


Figure 25. Longitudinal profile of terraces along the lower reach of the Siuslaw River; see figure 5 for explanation of symbols. Note warping of higher terraces over an anticline; double arrow symbol indicates location of fold axis in the underlying bedrock.

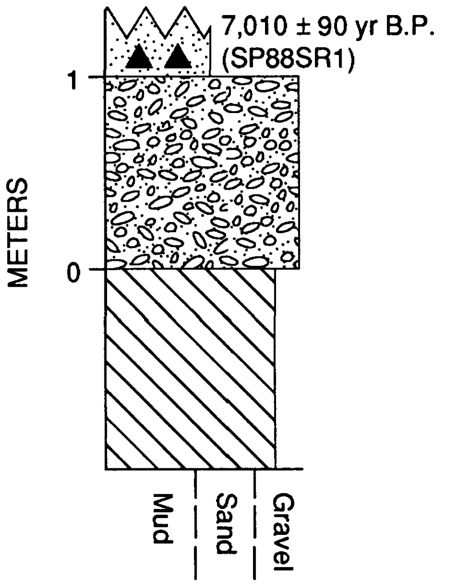


Figure 26. Stratigraphic column of an exposure of a possible PHT (Pleistocene-Holocene transition) terrace at station 88–S1 on the Siuslaw River. See legend in figure 3 for explanation of lithologic patterns and symbols.

covered surface at 30–35 m elevation. Although marine terrace deposits are not shown on recent geologic maps (Schlicker and Deacon, 1974), deposits are present near the elevations of Golder Associates (1986) in roadcuts south of Florence. Recent soils work in the region (H.M. Kelsey, written commun., 1992) indicates that an age of 125 ka is most reasonable for the 18.2 m terrace, so the higher terraces probably do not correlate with the 105 ka Pioneer terrace, but they are related to stage 7 (230 ka) or older sea-level high stands. Older and higher marine terrace sediments are also present northeast and east of Woahink Lake, a few kilometers southeast of Florence. The heights of the three marine terraces of Golder Associates (1986) have been plotted in figure 25 for comparison with fluvial terraces on the Siuslaw River.

OLDER FLUVIAL TERRACES

Several exposures of fluvial sediment were visible in logging roadcuts at an elevation of about 109 m about 0.5 km east of Hanson Creek near river km 22.5 (station 87–S2, plate 3). A composite stratigraphic column of two exposures shows about 3 m of sandy silt overlying about 2 m of sandy gravel (fig. 27*A*). Strong oxidation extends through the entire profile, soil hues reach 2.5YR in the upper part of the B horizon, and 30- to 40-cm-deep solution pits are developed in the saprolitic bedrock strath surface (fig. 28). All sandstone gravel clasts are easily crushable in hand specimen, but a few clasts of quartzite are still relatively unweathered.

A similar sequence, with an upper unit of silt, was revealed in a not as well exposed section of fluvial sediment in a terrace a few kilometers upstream, about 1 km west-northwest of Beck Station near river km 24.5 (fig. 27*B*; station 87–S3, plate 3). Soil development, colors, and depth and degree of oxidation are all similar to that seen at station 87–S2, but this terrace is about 6 m higher in elevation (115 m) and probably correlates with the highest terrace surface on the downstream limb of the anticline.

A lower terrace at about 88 m elevation was exposed in a roadcut about 1 km northwest of Wendson near river km 16.5 (fig. 27*C*; station 87–S4, plate 3). The fluvial sediments exposed in this roadcut are similar to the sediments described at stations 87–S2 and 87–S3, but soil development is not as extensive as that seen in the higher terraces. Strong oxidation is present throughout the profile, but soil reddening only reaches a maximum of 5YR hues in the B horizon. Most gravel clasts are crushable in hand specimen but solution pits are not evident in the underlying bedrock strath surface.

A much lower terrace at about 35 m elevation was exposed in a roadcut about 1.5 km south of Mapleton near river km 32 (fig. 27*D*; station 87–S5, plate 3). This terrace is the lowest in an extensive flight of high terraces preserved on the inside of a major bend in the Siuslaw River. The exposure revealed a basal channel facies of sandy pebble gravel overlain by an overbank facies of pebbly fine sand and sandy silt. The soil in this exposure is less well developed than on the higher terraces; soil reddening reaches 5YR hues in the upper part of the B horizon, but the sediment has 10YR hues just below the B horizon. Oxidation extends throughout the profile, but clasts in the basal gravel are not crushable in hand specimen.

The ages of the older fluvial terraces are unknown. Adams (1984) recognized a single deformed terrace on the lower Siuslaw River that he correlated with a hypothetical 100 ka marine terrace at the coast. My studies have delineated multiple older terraces, rather than a single terrace, along the same reach of the Siuslaw River (fig. 25; compare with Adams, 1984, fig. 8). The exact relations between the deformed fluvial terraces and marine terraces at the coast are unknown. However, unless the terrace gradients on the downstream limb of the anticline get steeper near the coast, which is unlikely, these terraces cannot be reasonably correlated with the lowest marine terrace and therefore must predate the probable 125 ka age of the lowest marine terrace. An age of >200 ka is consistent with the degree of weathering and soil development of the highest fluvial terraces and with comparisons to a TL age on the 90-m-high Crestview terrace on the Umpqua River, 30–35 km to the south. The lowest fluvial terrace in the sequence near Mapleton (station 87–S5, plate 3) appears to be relatively undeformed, and it is at an elevation (35 m) that could reasonably be projected to the 18.2 m or 30– to 35-m-high

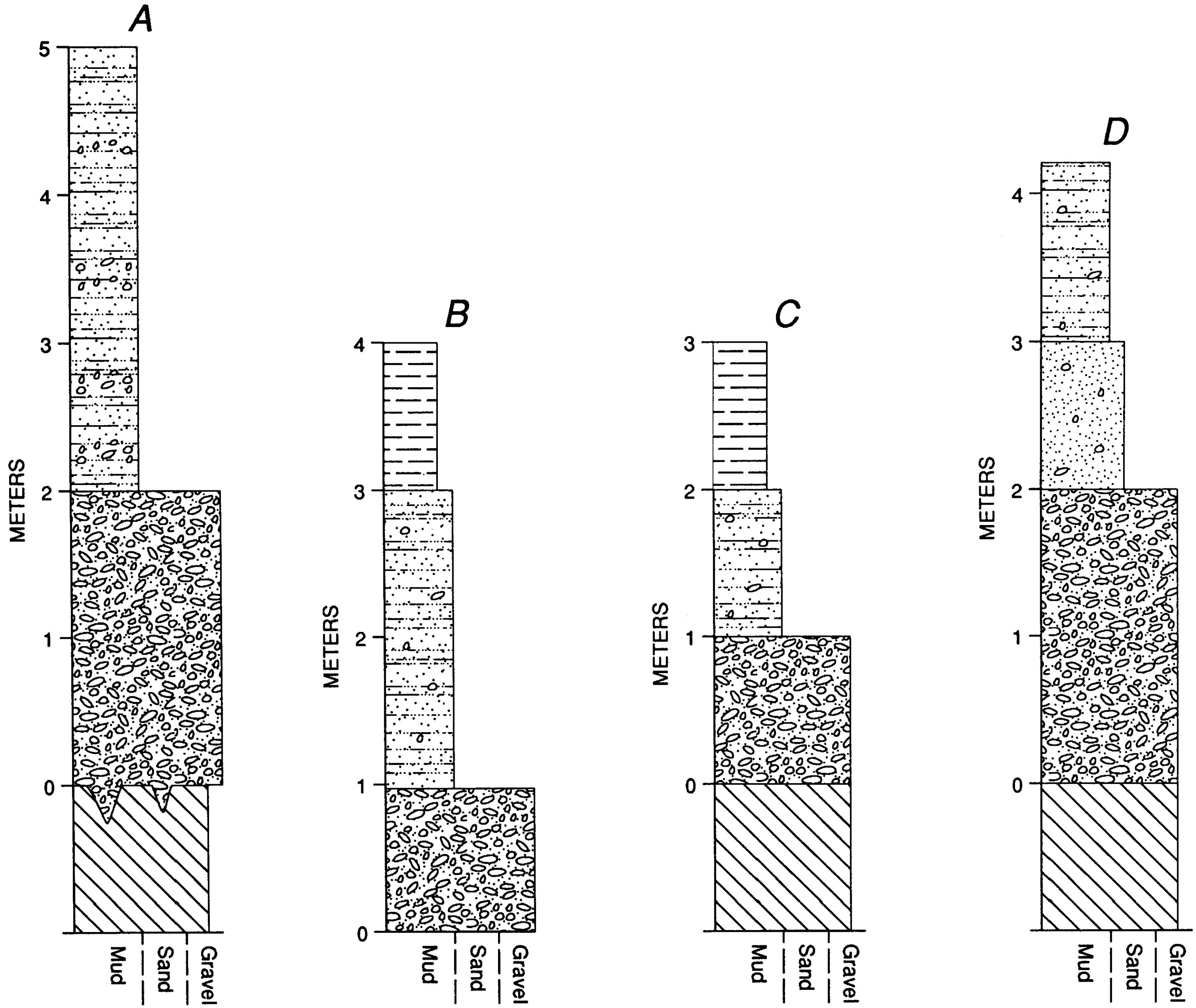


Figure 27. Stratigraphic columns of exposures of several high terraces on the Siuslaw River: (*A*) composite column of several exposures of a high terrace east of Hanson Creek at station 87–S2, (*B*) exposure of high terrace near Beck Station at station 87–S3, (*C*) exposure of high terrace near Wendson at station 87–S4, and (*D*) exposure of high terrace near Mapleton at station 87–S5. See legend in figure 3 for explanation of lithologic patterns and symbols.

Figure 28. Photograph of basal fluvial gravels overlying sandstone bedrock in a high terrace east of Hanson Creek at station 87–S2; see fig. 27*A*. Note probable solution pits in bedrock (arrows) and weathering of fluvial clasts. Pocket knife handle at right center (circled) is 10 cm long.

marine terraces near Florence. If one of these correlations is accurate, then this fluvial terrace is 125 ka or older.

I do not have enough age information to confirm a relationship between the multiple high fluvial terraces on the Siuslaw River and sea-level high stands, but the preservation of at least six older fluvial terraces near Mapleton indicates that some of these individual terraces may have formed as a result of episodic tectonic uplift rather than climatic perturbations and accompanying fluctuations in sea level.

TERRACES ALONG THE SILETZ RIVER

The lower reaches of the Umpqua, Smith, and Siuslaw Rivers are located within about 30 km of each other and flow through similar bedrock. The Siletz River has a slightly smaller drainage area than the Smith River (800 km^2; Oregon State Water Resources Board, 1965) is located about 80 km north of the Siuslaw River (fig. 2), and flows through more heterogeneous bedrock than the other Coast Range rivers examined in this study. Fluvial terraces and bedrock geology have been mapped along the lower reach of the Siletz River by Schlicker and others (1973) and Snavely and others (1976a, 1976b); Niem (1976) discussed additional information on the geologic history and hydrology of the Siletz River drainage basin. The lower 86 km of the Siletz River flows through Tertiary sandstone and siltstone of the Yaquina, Alsea, Nestucca, Yamhill, and Tyee Formations. These rocks are perhaps a bit finer grained and less massively bedded but are otherwise similar to the bedrock of the Tyee Formation underlying the Siuslaw, Smith, and Umpqua Rivers.

Above river km 86 (pl. 4), however, the Siletz River is flowing on basalts and volcaniclastic sedimentary rocks of the Eocene Siletz River Volcanics, which have been intruded in places by dikes and sills of granophyric gabbro (Schlicker and others, 1973; Snavely and others, 1976b). These rocks appear to be considerably more resistant to fluvial erosion than the sedimentary rocks downstream. Extensive fluvial terraces are not present along the river where it flows on the volcanic rocks, and the contact between the Siletz River Volcanics and the sedimentary rocks downstream coincides with the mouth of a narrow gorge (fig. 29; labelled "Lower Gorge" on plate 4).

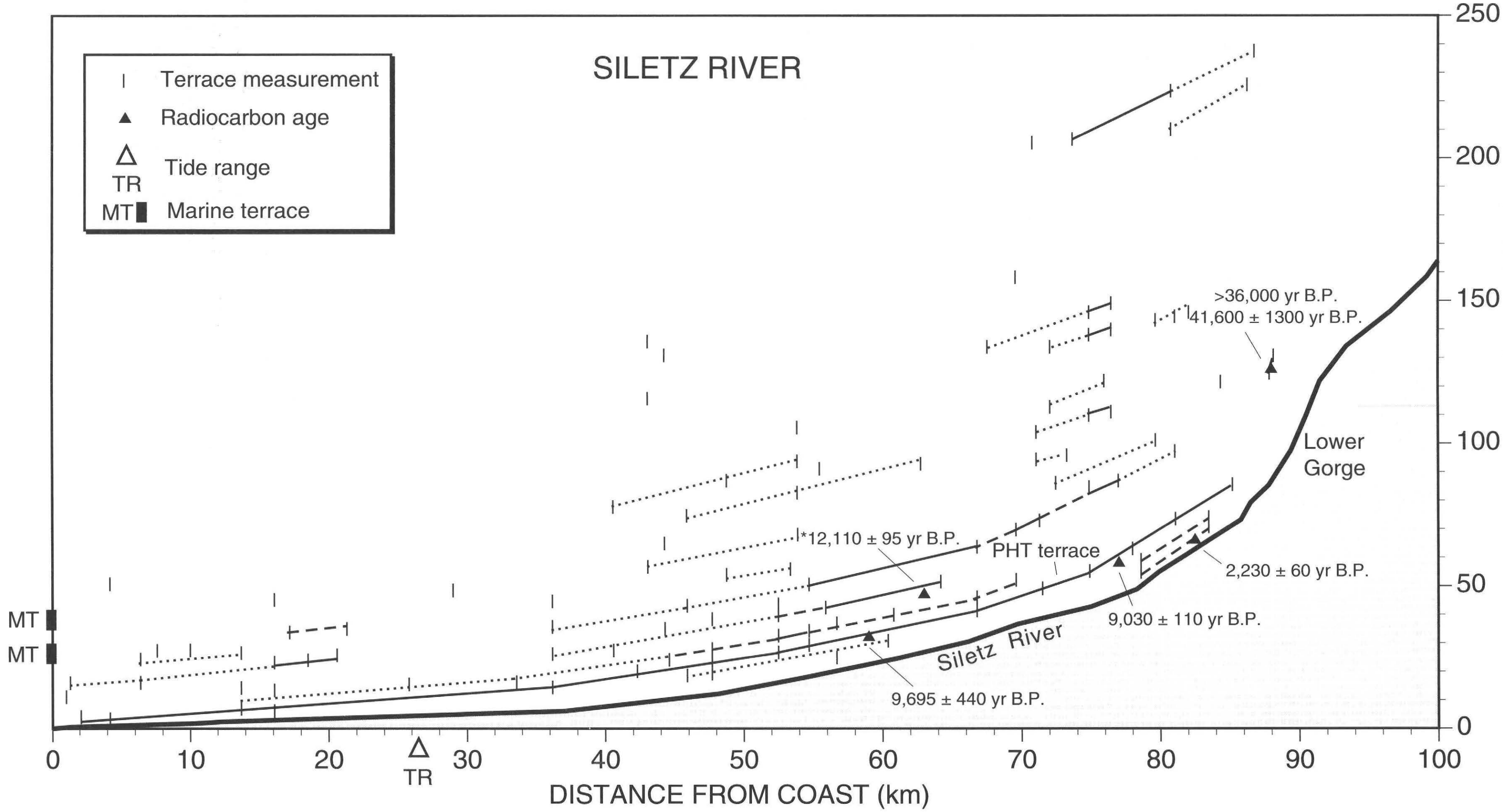


Figure 29. Longitudinal profile of terraces along the lower reach of the Siletz River; see figure 5 for explanation of symbols.

Terraces are rare above the mouth of the gorge because the basalts of the Siletz River Volcanics and younger intrusive gabbroic rocks are much more resistant to the lateral stream incision that is necessary for formation of extensive fluvial terraces. The gradient of the Siletz River steepens above the mouth of the gorge (from 0.003 to 0.008), so vertical stream incision has also been inhibited by the more resistant bedrock of the Siletz River Volcanics. These changes in stream incision are classic examples of bedrock control on stream behavior.

Holocene terraces are well preserved along the Siletz from near the mouth of Lower Gorge to the coast (pl. 4). The lowest continuous terrace has yielded two early Holocene radiocarbon ages (fig. 29) and is equivalent to the PHT terrace on the Umpqua River. Late Pleistocene and older terraces are less well preserved, but they are present at various elevations downstream from Lower Gorge. Prominent terrace exposures are discussed below.

LATEST PLEISTOCENE AND HOLOCENE TERRACES

The low, nearly continuous PHT terrace is 2.5–15 m above river level and has been sampled for radiocarbon dating at two sites. A cut in a large gravel pit a few hundred meters northwest of Logsden (fig. 30*A*; station 88-SZ6, plate 4) near river km 78.5 exposed a minimum of 2 m of sandy silt overlying 0.25 m of medium to coarse sand and 1.75 m of sandy gravel. An AMS radiocarbon determination on small fragments of charcoal from near the base of the sandy silt yielded an age of 9,030 ± 110 yr B.P. A second exposure of the PHT terrace was examined in a natural stream cut near river km 60, northwest of the town of Siletz (fig. 30*B*; station 89–SZ2, plate 4). This stream cut exposed an overbank sequence of fine to medium sand with thin stringers of sandy silt, overlying channel facies sandy pebble and cobble gravel; charcoal from the lower part of the overbank sands also yielded an early Holocene age (9,695 ± 440 yr B.P.). The similar early Holocene ages support the physical correlation of the terrace surface between these sites (fig. 29) and also supports the correlation of this terrace to the PHT terrace on the Umpqua River. The presence of PHT-equivalent terraces on the Umpqua, Siletz, and probably the Smith and Siuslaw Rivers strongly implies a regional, probably climatic cause for stream aggradation in latest Pleistocene and early Holocene time.

Scattered younger terrace remnants are present at lower elevations along much of the Siletz River. Most of these remnants are on the insides of meander bends and none form surfaces that are continuous for more than a few hundred meters. In one low terrace at river km 84.5 near the confluence with Palmer Creek (fig. 30*C*; station 88–SZ8, plate 4), charcoal from an exposure of pebbly, sandy silt and sandy pebble and cobble gravel had a radiocarbon age of 2,230 ± 60 yr B.P. Small, isolated terraces like these probably formed as "complex responses" to relatively minor changes in river hydrology and sediment supply, rather than to the regional, climatic changes associated with aggradation of the PHT terrace.

LATE PLEISTOCENE TERRACES

Radiocarbon analyses on charcoal collected from two higher terrace exposures indicate that stream aggradation also occurred in the late Pleistocene. A roadcut in a well-preserved terrace surface southwest of Siletz near river km 64 (fig. 31*A*; station 88–SZ2, plate 4) exposed about 2 m of overbank pebbly fine sand overlying about 0.5 m of channel facies sandy pebble and cobble gravel. A sample of disseminated charcoal from near the base of the overbank sand yielded an AMS radiocarbon age of 12,110 ± 95 yr B.P. This age is younger than expected because the terrace is twice as high above the river (24 m versus 12 m) as the 10 ka PHT terrace at the same location. No other examples of 12 ka terraces have been found in the Coast Range, so the anomalously young age may be the result of inclusion of small fragments of modern and decayed roots in the radiocarbon sample. Alternatively, if the radiocarbon age is accurate, then the height and age of this terrace indicate that rates of stream incision were very high in latest Pleistocene time, just prior to deposition of the PHT terrace sediments. My dating results from other Coast Range rivers indicate that inclusion of younger carbon in the radiocarbon sample may be the best explanation for the anomalously young age at this site.

A complex sequence of fluvial and colluvial sediments was examined in a quarry exposure of a 40-m-high late Pleistocene terrace near river km 88.5 in the Lower Gorge (fig. 31*B*; station 88–SZ7, plate 4). A typical sequence of channel-facies sandy pebble and cobble gravel, overlain by overbank medium sand, is present at the base of the exposure. The sand is in turn overlain by 0.6 m of organic-rich silt and 0.3 m of sandy, pebbly silt. The silts are unusual because such fine sediment is not presently being deposited along this steep reach (gradient of 0.008) of the Siletz River. The silts are overlain by 2 m of matrix-supported, sandy, silty, colluvial gravel, which contains abundant angular pebbles and cobbles of Tyee Formation siltstone. The presence of Tyee Formation clasts indicates that this gravel was not fluvially transported, because upstream from the terrace exposure, the Siletz River has incised more than 200 m below the base of the overlying Tyee Formation into basalts and volcaniclastic rocks in the underlying Siletz River Volcanics (Schlicker and others, 1973; Snavely and others, 1976b). The colluvial gravel is overlain by a 1.5-m-thick sequence of fluvial sandy pebble gravel, sandy silts, and silts.

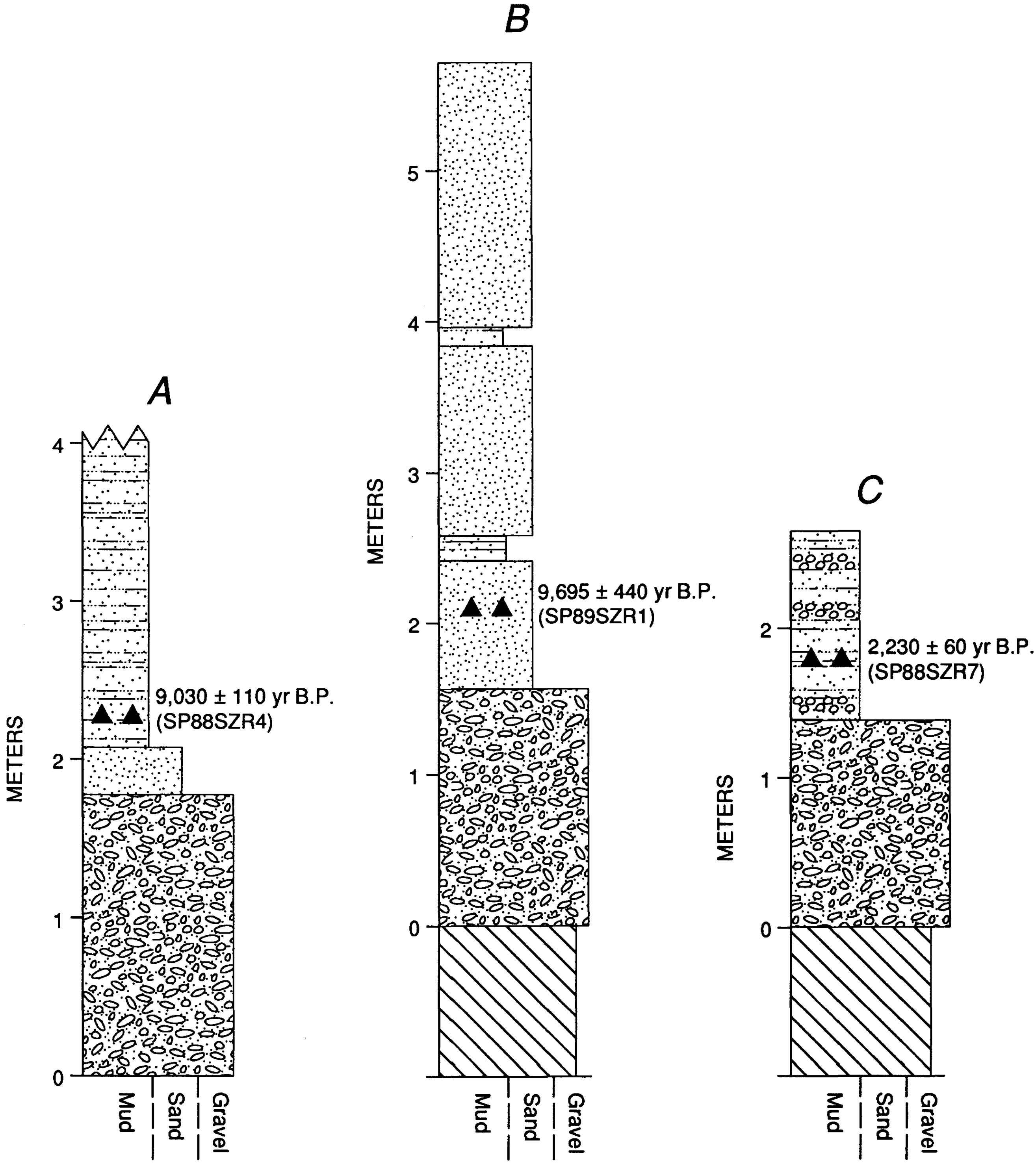


Figure 30. Stratigraphic columns of exposures of Holocene terraces on Siletz River: (*A*) exposure of a PHT (Pleistocene-Holocene transition) terrace in gravel pit near Logsden at station 88–SZ6, (*B*) PHT terrace exposure northwest of Siletz at station 89–SZ2, and (*C*) exposure of low terrace near the confluence of Palmer Creek at station 88–SZ8. See legend in figure 3 for explanation of lithologic patterns and symbols.

The complex stratigraphy exposed at this site appears to be the result of one or more episodes of landsliding and possible damming of the Siletz River in the Lower Gorge. The bowl-shaped ridge at the head and hummocky topography in the floor of the drainage in which the site is located (pl. 4) indicate that the colluvial gravel probably was deposited as a debris flow. It is not clear if this debris flow dammed the Siletz River, but the colluvium was

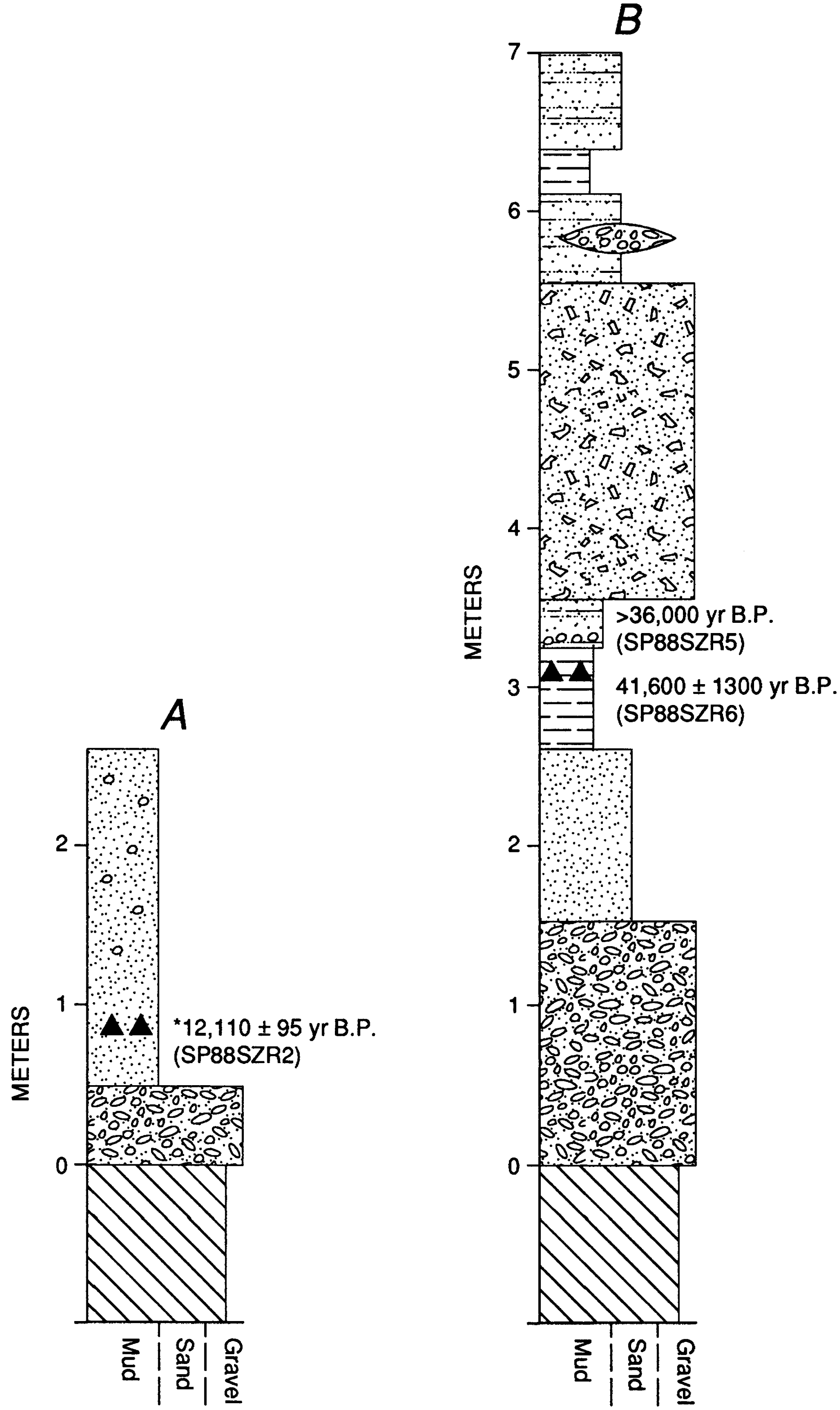


Figure 31. Stratigraphic columns of exposures of late Pleistocene terraces on Siletz River: (*A*) terrace exposure southwest of Siletz at station 88–SZ2, and (*B*) terrace exposure in rock quarry in the Lower Gorge at station 88–SZ7. See legend in figure 3 for explanation of lithologic patterns and symbols.

subsequently buried by fluvial sediment before the terrace surface was abandoned. The fine silty sediment that underlies the colluvium may have been deposited as a result of an earlier period of landsliding that dammed the river downstream from the quarry site. The sediment that formed this dam could have originated as debris flows either from colluvium-filled hollows located on both sides of the lower reach of Lower Gorge, or from two small southward-flowing streams that enter the river a few kilometers downstream from the terrace site. The presence of fluvial sediments at the top of the exposed sequence indicates that any landslide dams formed during the aggradation of the quarry terrace were eventually breached and fluvial deposition was re-established before the terrace surface was finally abandoned. Such temporary landslide damming has probably been a common process in the narrow confines of the Lower Gorge.

Radiocarbon samples were taken from 1- to 2-cm-thick mats of mixed detrital charcoal and wood from the organic-rich silt unit at the Lower Gorge site (fig. 31*B*). The charcoal and wood fragments were separated in the field and submitted to different radiocarbon laboratories; the charcoal fraction yielded an age of >36,000 yr B.P., and the wood fraction yielded an age of 41,600 ± 1,300 yr B.P. (table 1). Although the wood fraction yielded a finite age, the presence of decayed roots in the surrounding sediment could have caused contamination of the sample and as a result yields a minimum age for the terrace sediments.

OLDER TERRACES

Numerous older, higher terrace remnants are preserved along the Siletz River (fig. 29) but as with other Coast Range rivers, most remnants are widely scattered so terrace correlations are tenuous. No numerical age data are available from any of the older terraces, but some age information can be inferred from comparisons between the heights of these older surfaces and the heights of radiocarbon-dated terraces and from relations to marine terraces at the coast. A discussion of marine terraces present near the mouth of the Siletz River will precede discussion of older fluvial terrace exposures.

MARINE TERRACES

Correlation of Siletz River terraces with the marine terrace record is very tenuous because few fluvial and marine terraces are preserved near the coast (fig. 29). Golder Associates (1986) listed an elevation of 24.2 m for a Whiskey Run-equivalent marine terrace at Glenenden Beach, a few kilometers south of the mouth of the Siletz River. My reconnaissance in the Lincoln City and Glenenden Beach areas (pl. 4) confirmed that marine terrace remnants are present at 24–28 m in this area. Kennedy (1978) used amino-acid ratios on shells to establish an oxygen-isotope substage 5a (80 ka) age on a terrace of similar height at Yaquina Bay, 30 km south of the Siletz River, but recent soils work (H.M. Kelsey, written commun., 1992) indicates that several major structures are present between Yaquina Bay and the Siletz River, and that the lowest marine terrace at Glenenden Beach is most reasonably correlated to the substage 5e (125 ka) sea-level high stand. Marine terrace deposits are also present at 36–40 m in Lincoln City and just south of the mouth of the Siletz River in Glenenden Beach. These deposits are probably related to stage 7 (230 ka) or older sea-level high stands. Some scattered fluvial terraces near the coast may correlate with these marine deposits, but the preservation of both types of terraces is so poor that such correlations are very tentative.

OLDER FLUVIAL TERRACES

Older fluvial terraces are well developed in two locations downstream from Lower Gorge, but poor access and a lack of good exposures hampered examination of most older fluvial terraces along the Siletz River. The best preserved terrace flight is located west of Logsden (river km 70–80) and has terrace remnants from 40 m to over 100 m above present river level. The longest terrace remnants have surface gradients that are somewhat less steep than lower terraces and the modern river in this reach (fig. 29). The lower gradients may be an artifact of the methods used to measure terrace heights, or they could signify rejuvenation and steepening of the Siletz River in late Pleistocene time. Unfortunately, the poor preservation of older terraces elsewhere along most of the river prevents terrace correlation over enough distance to determine whether rejuvenation has taken place. No good exposures of these sediments was observed.

Older terraces are also fairly well developed near Siletz. A deeply weathered exposure of fluvial sediment in one of these terraces was examined in a logging roadcut west of Siletz at about river km 63 (fig. 32*A*; station 88-SZ3, plate 4). The dissected terrace surface is at an elevation of about 93 m and has been covered by colluvium. Examination of the sediment exposed in the roadcut revealed about 1 m of sandy, pebbly colluvium overlying an overbank sequence of pebbly, sandy silt; a well preserved buried A horizon present in the upper 0.15 m of the silt probably marks the original terrace surface. The lower part of the sandy silt and about 1.7 m of clayey silt and silt were observed in a 3-m-deep core at this site. I was unable to penetrate the entire thickness of the fluvial sediment with the corer, so the character of the lower part of

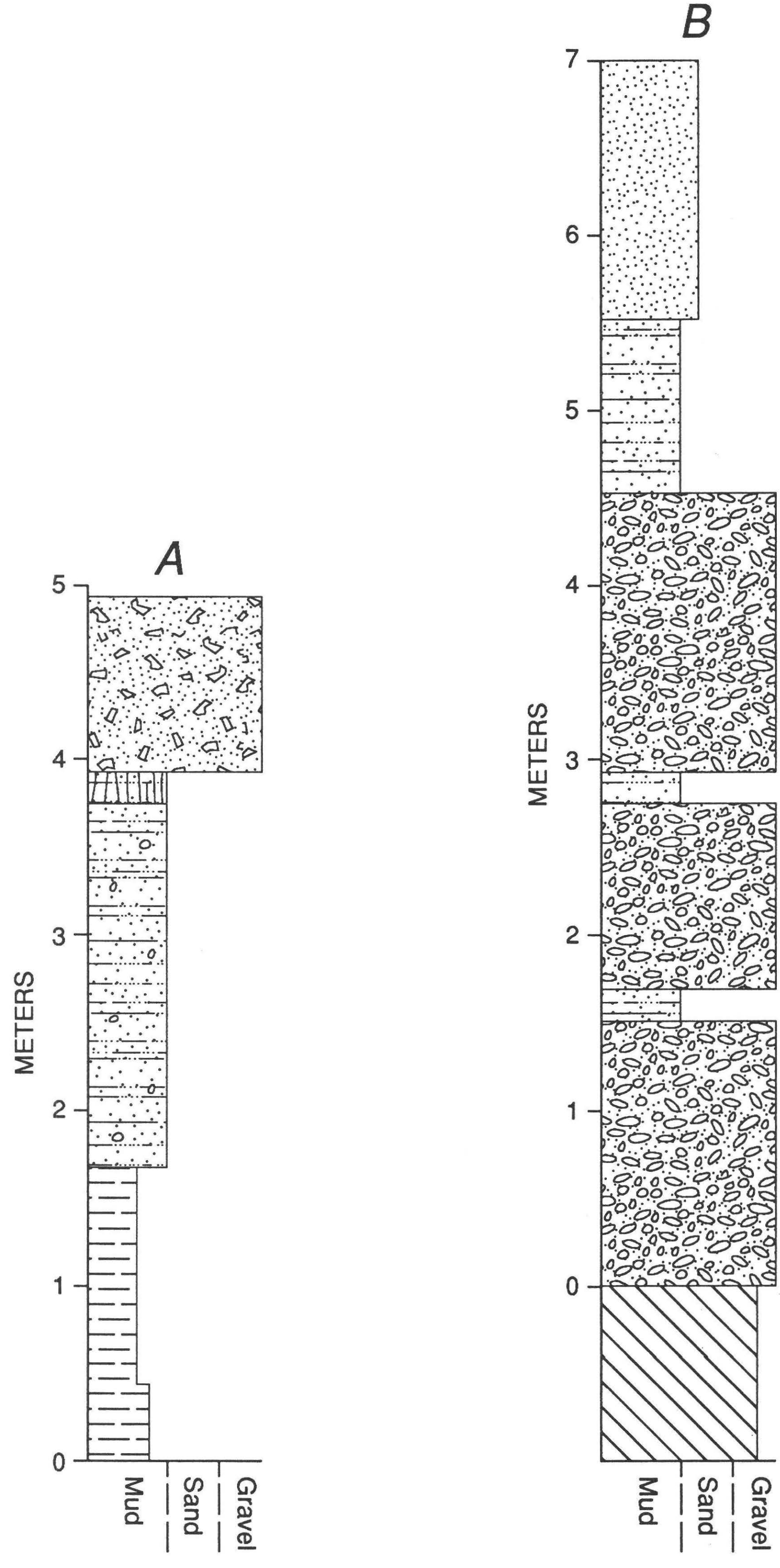


Figure 32. Examples of stratigraphic columns of exposures of older terraces on the Siletz River: (*A*) exposure of high terrace west of Siletz at station 88–SZ3; lower 3 m of section from an auger core, and (*B*) terrace exposure near Melco Landing at station 88–SZ9. See legend in figure 3 for explanation of lithologic patterns and symbols.

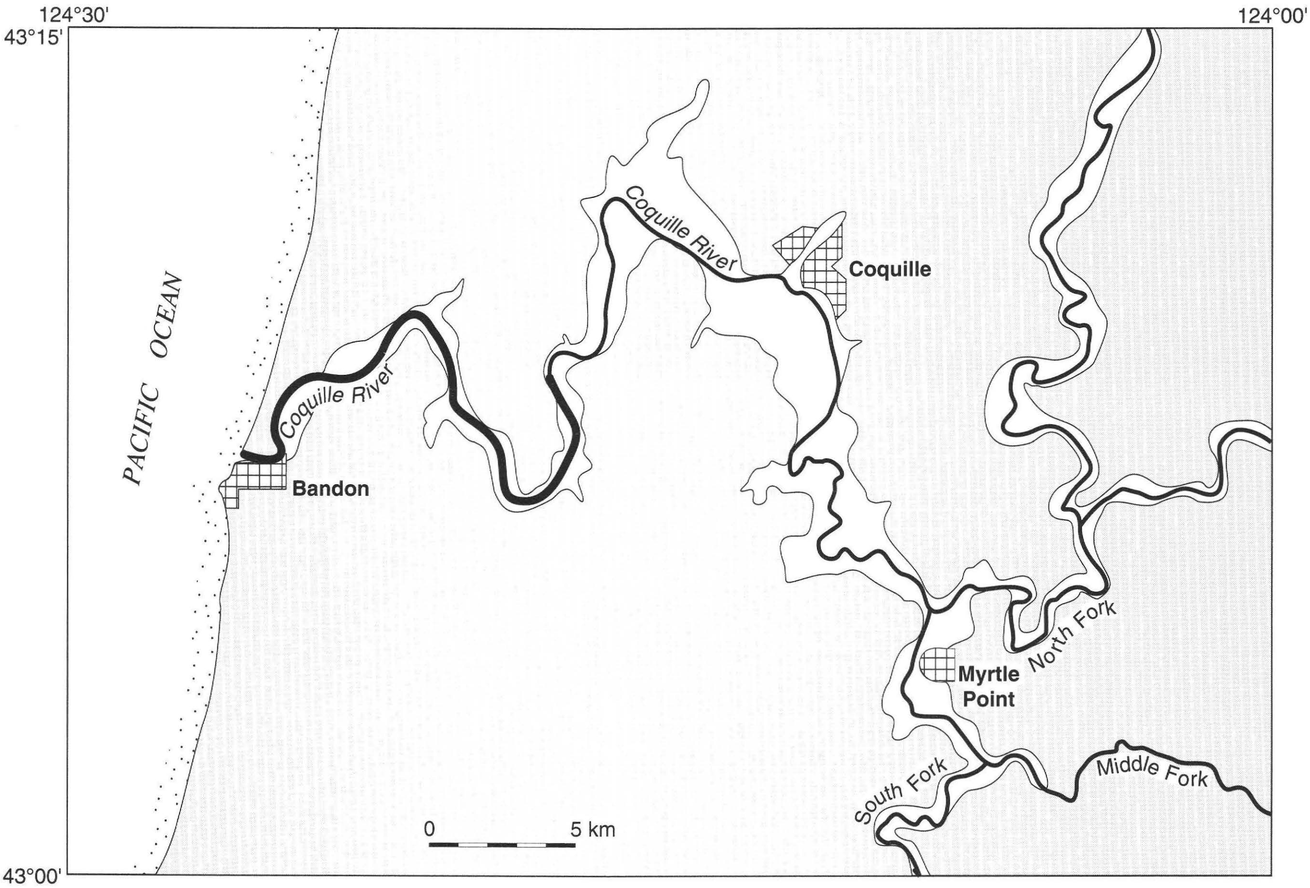


Figure 33. Map of lower Coquille River showing locations of the towns of Bandon, Coquille and Myrtle Point, and the confluences of the North, Middle, and South Forks of the Coquille River; shaded area denotes uplands.

the terrace sequence is unknown. The fluvial sediments underlying the colluvium are oxidized to 5YR hues in the B horizon and sedimentary and volcanic gravel clasts in the sandy silt are crushable in hand specimen.

A few very high terrace remnants are present at elevations of 150–175 m above river level near the mouth of Lower Gorge (pl. 4). These terraces have straths formed in the Tyee Formation, so they predate incision of the river into the more resistant Siletz River Volcanics and subsequent formation of the gorge. No good exposures of these older terrace sediments were observed.

Most older terraces are poorly preserved along the lower reach of the Siletz River, but two terrace surfaces are fairly well preserved at elevations of 23–25.5 m and 33.5–35 m near Melco Landing (pl. 4). A landslide scar just west of Melco Landing near river km 17 (fig. 32*B*; station 88–SZ9, plate 4) exposed a sequence of fluvial sediments consisting of 4.5 m of sandy pebble gravel interbedded with thin stringers of sandy silts, which is overlain by 1 m of silty sand and 1.5 m of fine to medium sand. The terrace sediments are oxidized to 7.5YR hues and the gravel clasts are not crushable in hand specimen. Few other exposures of older terrace sediments were observed along the lower reach of the river.

TERRACES ALONG THE COQUILLE RIVER

The Coquille River is located about 60 km south of the Umpqua River (fig. 2) and enters the Pacific Ocean at Bandon in an area that has recently been the subject of several marine terrace studies (Kelsey, 1990; McInelly and Kelsey, 1990; Muhs and others, 1990). My initial work in the area consisted of a search for fluvial terraces along the lower 60 km of the Coquille River, downstream from the town of Myrtle Point and the confluence of the North and South Forks of the river (fig. 33). Unfortunately, fluvial terrace sediments are present in only a few places along the lower Coquille (Beaulieu and Hughes, 1975), and I found no evidence of multiple Holocene terraces downstream from Myrtle Point. Because of the dearth of preserved terraces, I examined the extensive flood plain in the vicinity of the town of Coquille (fig. 34), where the flood

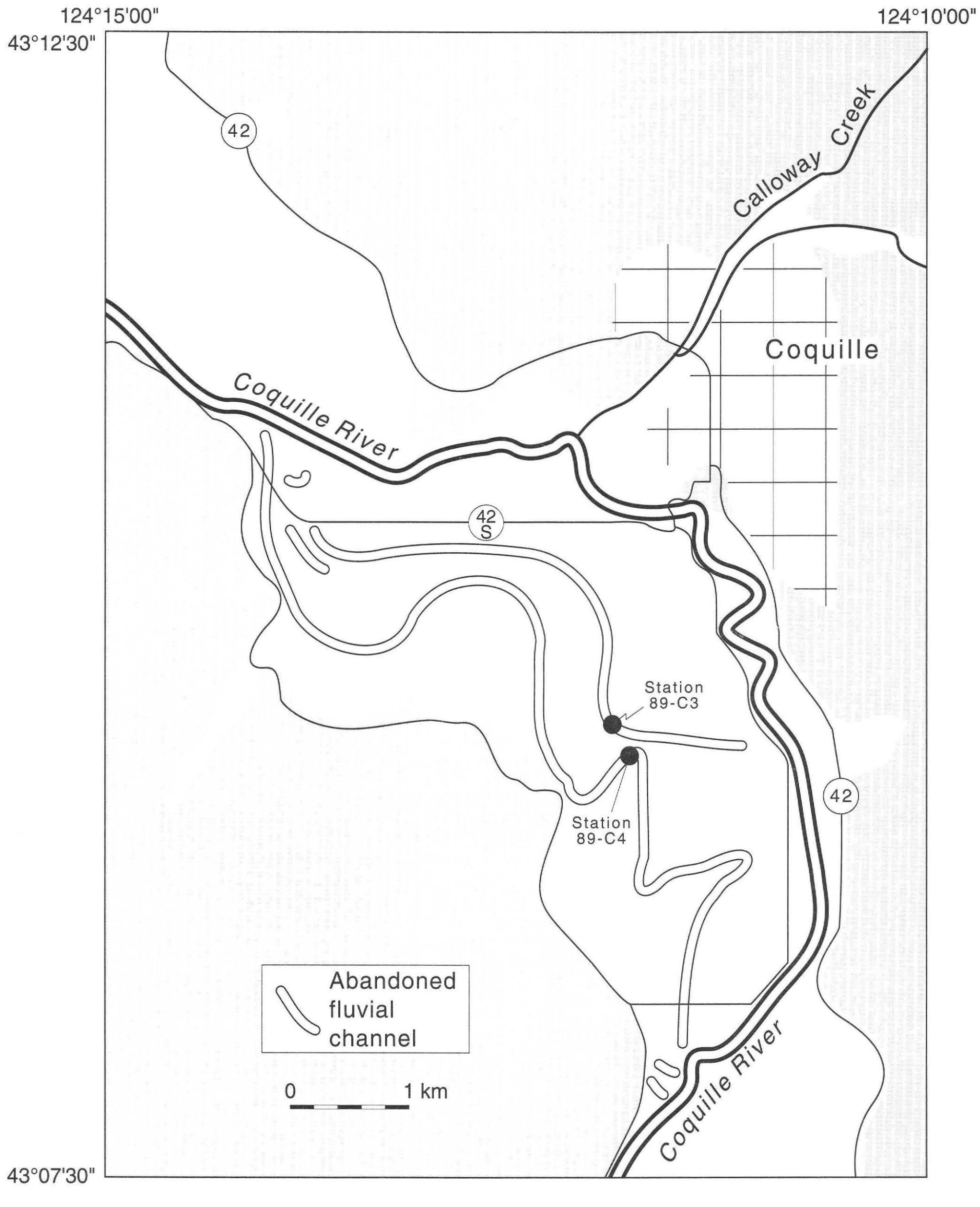


Figure 34. Map of the flood plain of the Coquille River near Coquille; shaded areas denote uplands. Note presence of two extensive abandoned channels on the flood plain southwest of Coquille and locations of two auger cores (stations 89–C3 and 89–C4) shown in figure 35 and discussed in the text.

plain is as much as 3 km wide and presently used as pasture land. Prior to drainage and diking associated with agricultural development, the flood plain had extensive areas of freshwater marsh and was frequently covered with ponded flood waters. The flood plain and the surrounding towns are still flooded during periods of extended rainfall in the winter months (Beaulieu and Hughes, 1975).

One of the most interesting features on the flood plain are extensive, well preserved abandoned channels of the ancestral Coquille River (fig. 34). These channels are clearly visible in air photos and are expressed in the field as 25- to 40-m-wide linear depressions that lie less than a meter below the general elevation of the flood plain and are flanked by 50- to 100-m-wide levees. The southernmost abandoned river channel extends continuously across the Coquille Valley for about 10 km, and represents a major prehistoric shift in the course of the river. A second abandoned river channel is preserved a couple of hundred meters north of the more extensive abandoned channel. The northern channel

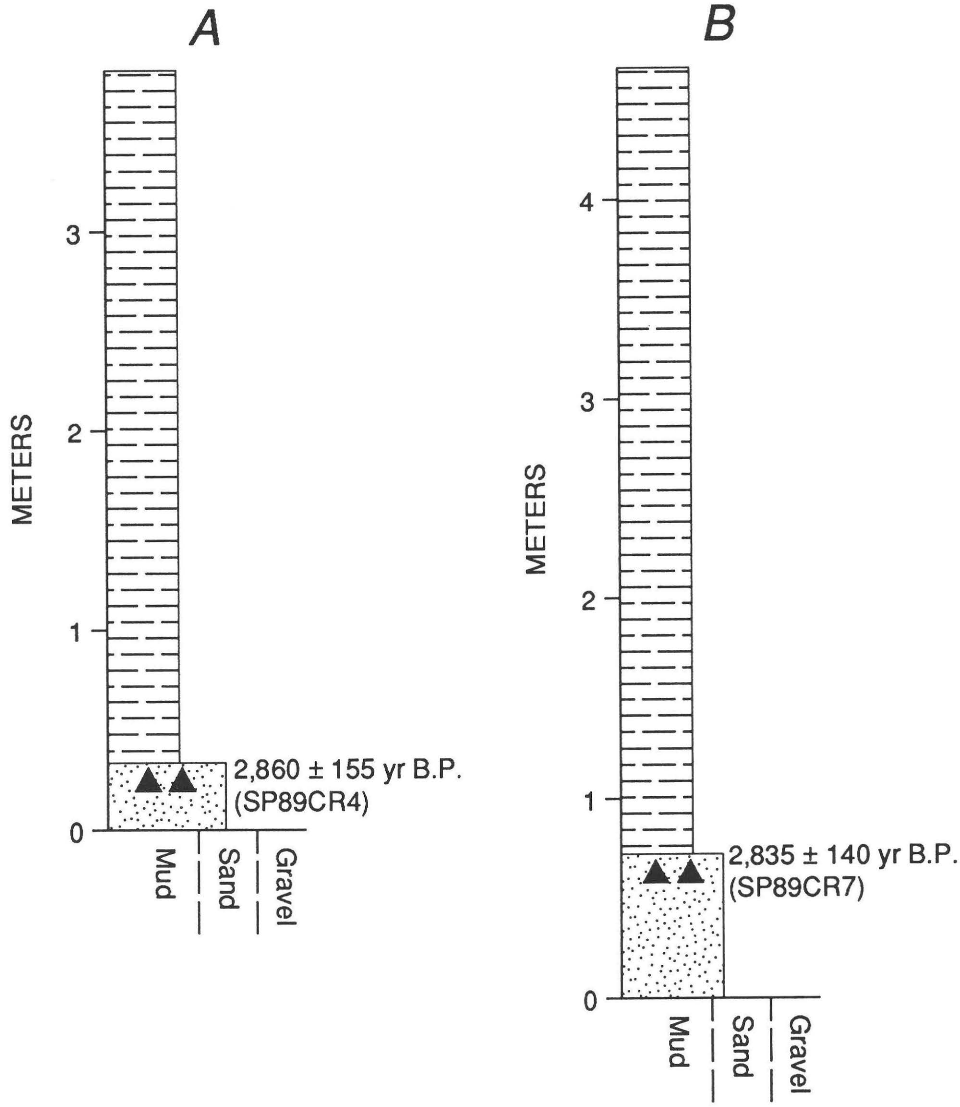


Figure 35. Stratigraphic columns of two auger cores in abandoned channels on the Coquille River flood plain: (*A*) core in southern abandoned channel at station 89–C4, and (*B*) core in northern abandoned channel at station 89–C3. Stations are located in figure 34. See legend in figure 3 for explanation of lithologic patterns and symbols.

apparently was not occupied as long because its central channel is shallower and it has low levees that have been breached by numerous small tidal channels.

No exposures of flood plain or channel sediments were found near Coquille, so I obtained several 4- to 5-m-deep auger cores in both abandoned channels. The simple stratigraphy found in these cores is illustrated by examples from each of the channels (stations 89–C3 and 89–C4, fig. 34). The two cores contained sandy channel deposits that were overlain by more than 3 m of overbank silt (fig. 35). Radiocarbon analyses on detrital charcoal and wood from the upper parts of the channel sands from the two cores yielded nearly identical ages of 2,860 ± 155 yr B.P. and 2,835 ± 140 yr B.P.

These radiocarbon ages and the geomorphology of the Coquille River flood plain can be used to estimate the relative position of late Holocene sea level. The present low-water (summer) elevation of the surface of the nearby Coquille River is less than 1 m above sea level, and the elevation of the top of the channel deposits in the two cores (about 2 m below sea level) is about the same as the present elevation of the channel bottom of the modern river in the vicinity of Coquille. This relation implies that little if any change in relative sea level has occurred in the last 3,000 years in this area. The preservation of numerous abandoned tidal and river channels on the present flood plain and lack of multiple fluvial terraces also indicate stable relative sea-level conditions.

DISCUSSION

ORIGIN OF LATEST PLEISTOCENE/EARLY HOLOCENE AGGRADATION

Radiocarbon ages and the distribution of Pleistocene/-Holocene transition (PHT) terraces are remarkably similar along the Umpqua, Siletz, and probably the Smith and Siuslaw Rivers. In addition, Grabau (1990) identified what appears to be a PHT equivalent, 10 ka terrace on Drift Creek, a tributary of the Alsea River located about equidistant between the Siuslaw and Siletz Rivers. Understanding the genesis of the PHT terraces is important because they are the best preserved terraces in the Coast Range and may be analogs for some of the older fluvial terraces in the region. The consistent ages and regional distribution of PHT terrace sediments indicate a linkage between the formation of extensive fluvial terraces and some regional control, such as climatic change.

Changes in stream behavior associated with formation of PHT terraces most likely include rapidly rising base (sea) level associated with late Wisconsin deglaciation and/or increased sediment load in streams. Tidal reaches of Coast Range streams were certainly affected by base-level changes, but rises in base level may not have strongly affected fluvial systems very far inland from the coast (McDowell, 1987, p. 549). This conclusion is supported by studies of river behavior upstream from recently flooded reservoirs (Leopold and others, 1964; Leopold and Bull, 1979), by studies of fluvial response to late Quaternary climate and base-level change in the Texas Gulf Coast (Blum, 1990), and by the lack of radiocarbon-dated terraces in the Coast Range associated with the steep sea-level rise that accompanied worldwide late Wisconsin deglaciation. A recent modelling study of post-Wisconsin sea-level changes (Tushingham and Peltier, 1991) indicates that about 40 m of sea-level rise occurred between the late Wisconsin minimum (18 ka) and 11 ka, but no well-documented examples of extensive fluvial terraces of this age have been found in the Coast Range. I conclude that effects of base-level rise were restricted to the lower (presently tidal) reaches of Coast Range streams, and had no significant impact on aggradation of the upstream reaches.

Thus, the aggradation of PHT terrace sediments appears to be driven by increased sediment inputs into Coast Range streams. Late Pleistocene stream aggradation is commonly attributed to sediment inputs from glaciers, but only one river in this study (the Umpqua) had late Pleistocene glaciers in its headwaters, and I observed no sedimentologic differences between terrace sediments on the Umpqua and other Coast Range rivers. Therefore, the PHT terraces in the Coast Range are not aggradational outwash terraces similar to those commonly found downstream from glaciated headwaters in the Western United States (for example, Moss, 1974; Dethier, 1988) but rather are the result of stream aggradation related to the input of large sediment loads from other sources. As suggested by Grabau (1990), the most likely source of this sediment is increased frequency of mass movements in the Coast Range.

The most important source of sediment input into modern Coast Range streams is mass movements (usually debris flows) that originate from colluvium-filled hollows (Pierson, 1977; Dietrich and Dunne, 1978; Benda and Dunne, 1987; Benda, 1990), but the upper reaches of most modern Coast Range streams are not rapidly aggrading, so present rates of sediment input into streams are not sufficient to deposit extensive alluvial sediments. Formation of the PHT and other extensive terraces must have required much higher rates of sediment input, and the most likely source of this sediment is increased debris-flow activity originating from colluvium-filled hollows. Studies of the ages of basal colluvial deposits from hollows in Washington suggest a period of accelerated evacuation of colluvium in the early Holocene (Reneau and others, 1989; Reneau and Dietrich, 1990), and studies from central and northern California suggest a similar period during the Pleistocene/Holocene transition (Marron, 1985; Reneau and others, 1986, 1990; Rypins and others, 1989). The occurrence of accelerated mass movements in other parts of the Pacific Northwest at the same time as initial deposition of PHT terrace sediments in the Coast Range points to climatically induced mass movements as the most likely source of sediment in these terraces. Colluvium-filled hollows are widely dispersed along all drainages in the Coast Range, so climatically controlled, accelerated evacuation of these hollows could have provided the regionally distributed sediment supply needed for extensive alluvial aggradation at the Pleistocene/Holocene transition.

Unfortunately, a recent study of hollows in the Coast Range (Reneau, 1988; Reneau and Dietrich, 1990, 1991) did not identify an early Holocene period of landsliding but rather found basal colluvial ages clustering in the middle Holocene (4–7.5 ka). However, at least one sample from this study (Reneau, 1988) and one sample from another study in the Siuslaw River drainage (Benda and Dunne, 1987) yielded early Holocene and latest Pleistocene basal colluvial ages. I interpret these latter ages, and the radiocarbon age of about 10 ka from the Buck Creek alluvial/debris fan on the Smith River, as evidence of an earlier period of colluvial evacuation and debris fan formation that produced the large volume of sediment now present in the PHT terraces. The relative dearth of middle Holocene fluvial terraces in the Coast Range indicates that the "PHT" episode must have evacuated significantly greater volumes of colluvium than the middle Holocene event postulated by Reneau (1988). The relative lack of basal colluvial ages of latest Pleistocene and early

Holocene age in the Coast Range is probably related to the small number of radiocarbon ages on basal colluvial deposits in the region and to the removal of older coluvium during subsequent landsliding episodes.

The exact causes of the postulated periods of accelerated landsliding are not known. In historic time, periods of accelerated landsliding have usually been caused by short-term, localized perturbations, such as large forest fires, and by periods of flooding related to intense precipitation and rapid snowmelt. The late Pleistocene/early Holocene periods of accelerated landsliding in California and Washington have generally been attributed to longer-term late Quaternary climatic changes, such as increased storm intensities in latest Pleistocene time and/or vegetation changes and increased frequency of forest fires induced by warmer, drier early Holocene climates (Reneau and others, 1986, 1989, 1990; Reneau, 1988; Rypins and others, 1989; Reneau and Dietrich, 1990). Such processes, if active for many hundreds to thousands of years, probably are responsible for the large inputs of sediment into Coast Range streams near the Pleistocene/Holocene transition.

RELATIONS BETWEEN THE PHT AND OTHER COAST RANGE TERRACES

The PHT terraces are excellent examples of "climatic" terraces and can be viewed as analogs for some of the older terraces in the Coast Range, but most isolated older terrace remnants probably were formed by processes other than aggradation induced by regional climate and never formed extensive synchronous terrace surfaces. Those that did form extensive surfaces probably shared several characteristics with the PHT terraces: the older climatic terraces originally formed fairly extensive, nearly continuous surfaces that converged and correlated with marine terrace sediments (proxies for high sea level) near the coast, and the terraces consisted of sediments whose age ranges may have spanned 10,000 years or more.

Most older terraces are presently very poorly preserved in the Coast Range, but I have made some very tentative correlations between some older fluvial terraces and marine terrace deposits near the coast. The connection between eustatic sea-level changes and fluvial terraces near the coast is geologically reasonable, because with the exception of a single terrace exposure on the Umpqua River, older fluvial terraces near the coast mostly consist of fine-grained sediments deposited under fluvial and estuarine conditions similar to those affecting the lower reaches of modern rivers. Examples of probable older climatic terraces include the two extensive older terraces along Henderer Road on the Umpqua River (river kms 68–75), and the extensive high terraces just downstream from Logsden at about river km 75 on the Siletz River.

Most other Coast Range terraces of all ages are probably either slip-off terraces, such as the numerous terraces present on the insides of meander bends along the Smith River, or formed as "complex responses" to major floods or other short-duration sedimentation events. Examples of the latter are the discontinuous terraces below the PHT terrace near Elkton and at river km 123–133 on the Umpqua River, and terraces below the PHT terrace at river kms 46–60 and 78–84 on the Siletz River. Many (most?) isolated older terrace remnants on all Coast Range rivers are probably "complex response" terraces that never formed continuous, synchronous surfaces.

Examples of older "tectonic" terraces are preserved on the lower reach of the Siuslaw River. Although the older terraces near Mapleton have been described by Reneau (1988, p. 219) as slip-off terraces, the anticlinal warping of these surfaces indicates that tectonic uplift probably forced the abandonment of at least some terrace surfaces. The Siuslaw River anticline plunges to the south (Baldwin, 1956), so perhaps the terraces are localized on the north side of the river because the river has periodically "slipped" southward off the anticline in the direction of fold plunge. Some of the older Siuslaw terraces probably correlate with marine terraces near the coast, but uplift has masked any climatic signal in this terrace sequence.

CONCLUSION

Fluvial terraces are mostly discontinuous and small in the Coast Range of western Oregon, but I have made some inferences about terrace origin based on the distribution and age of terrace deposits on the Siletz, Siuslaw, Smith, Umpqua, and Coquille Rivers. Widespread, nearly continuous Pleistocene/Holocene transition (PHT) terraces are 2–15 m above the present level of most Coast Range rivers and began to aggrade in nontidal reaches in latest Pleistocene and early Holocene time; radiocarbon analysis of charcoal from terrace sediments on the Siletz, Siuslaw, and Umpqua Rivers yielded ages of 7–10 ka. The ubiquitous distribution of the PHT terraces implies a regional, probably climatic cause of initial terrace formation. The most likely cause of terrace aggradation at the Pleistocene/Holocene transition is accelerated landsliding associated with regional climatic change and its effects on vegetation and sediment yield, rather than rising base level or an influx of glacial outwash sediment. Similar periods of accelerated colluviation in Washington and California have been attributed to increased storm intensities in latest Pleistocene time and vegetation changes and increased intensity of forest fires induced by warmer, drier early Holocene climates, but the exact cause of accelerated landsliding in Oregon is unknown.

Most of the late Holocene, aerially restricted fluvial terraces in the Coast Range probably formed as "complex responses" to major floods or localized landsliding. These terraces represent short-duration interruptions in what appears to be a long term trend of stream incision since the PHT terrace sediments were aggraded.

Older terrace remnants are scattered along the lengths of Coast Range rivers up to 200 m or more above present river levels, but they are less frequent as the rivers approach the coast. Tentative correlations of these terraces with poorly preserved marine terrace deposits indicate that some of the older fluvial terraces were formed during sea-level high stands in the middle and late Pleistocene.

With the exception of the Smith River, I obtained generally consistent results from radiocarbon dating of detrital charcoal and wood from the lower terrace sediments. Anomalously young ages are thought to be related to contamination of the samples with young carbon from the inclusion of root material or from sampling in younger colluvial sediment. Experimental TL dating of older terrace sediments yielded mixed results; the TL dates on Holocene deposits generally yielded maximum ages and most of the TL dates on older deposits appeared to yield minimum ages. However, the TL ages were in stratigraphic order and may be useful as relative age indicators. Problems with TL ages are poorly understood, but they may be related to some combination of incomplete light bleaching during deposition and to post-depositional hydrologic or pedogenic changes. Examination of soils proved to be less useful as a relative-dating technique because of apparent changes in rates of soil development inland from the coast. Apparent differences in oxidation in soils on terraces of similar age indicate that soils which formed under the cooler, foggier summer weather near the coast developed more slowly than inland soils, where hotter, drier conditions prevail during the summer months.

ACKNOWLEDGMENTS

The author wishes to thank the numerous landowners who allowed free access to their property in the Coast Range, Steve McDuffy for assistance in the field, Danelle Alloway and especially Lee-Ann Bradley for drafting assistance, Kathy Haller and Sherry Agard for manuscript reviews, Steve Reneau for comments on erosion rates in the Coast Range, and Harvey Kelsey for comments on marine terraces along the central Oregon coast. This work was supported by the National Earthquake Hazards Reduction Program of the U.S. Geological Survey and the U.S. Nuclear Regulatory Commission.

REFERENCES CITED

Adam, D.P., 1988, Pollen zonation and proposed informal climatic units for Clear Lake, California, cores CL–73–4 and CL–73–7, *in* Sims, J.D., ed., Late Quaternary climate, tectonism, and sedimentation in Clear Lake, northern California Coast Ranges: Geological Society of America Special Paper 214, p. 63–80.

Adams, John, 1984, Active deformation of the Pacific Northwest continental margin: Tectonics, v. 3, no. 4, p. 449–472.

Alexander, C.S., 1953, The marine and stream terraces of the Capitola-Watsonville area: University of California Publications in Geography, v. 10, no. 1, p. 1–44.

Atwater, B.F., 1987, Evidence for great Holocene earthquakes along the outer coast of Washington State: Science, v. 36, p. 942–944.

———1992, Geologic evidence for earthquakes during the past 2000 years along the Copalis River, southern coastal Washington: Journal of Geophysical Research, v. 97, p. 1901–1919.

Atwater, B.F., and Yamaguchi, D.K., 1991, Sudden, probably coseismic submergence of Holocene trees and grass in coastal Washington State: Geology, v. 19, p. 706–709.

Bacon, C.R., 1983, Eruptive history of Mount Mazama and Crater Lake caldera, Cascade Range, U.S.A.: Journal of Volcanology and Geothermal Research, v. 18, p. 57–115.

Baker, R.G., 1983, Holocene vegetation history of the western United States, *in* Wright, H.E., Jr., ed., The Holocene, Vol. 2 *of* Wright, H.E., Jr., ed., Late Quaternary environments of the United States: Minneapolis, University of Minnesota Press, p. 109–127.

Baldwin, E.M., 1956, Geologic map of the lower Siuslaw River area, Oregon: U.S. Geological Survey Oil and Gas Investigations Series Map OM–186, scale 1:62,500.

———1981, Geology of Oregon (third edition): Dubuque, Iowa, Kendall/Hunt, 170 p.

Bard, Edouard, Hamelin, Bruno, Fairbanks, R.G., and Zindler, Alan, 1990, Calibration of the ^{14}C timescale over the past 30,000 years using mass spectrometric U-Th ages from Barbados corals: Nature, v. 345, no. 6274, p. 405–410.

Barnosky, C.W., 1985, Late Quaternary vegetation near Battle Ground Lake, southern Puget Trough, Washington: Geological Society of America Bulletin, v. 96, p. 263–271.

Beaulieu, J.D., and Hughes, P.W., 1975, Environmental geology of western Coos and Douglas Counties, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 87, 148 p.

Becker, Bernd, Kromer, Bernd, and Trimhorn, Peter, 1991, A stable-isotope tree-ring timescale of the Late Glacial/Holocene boundary: Nature, v. 353, p. 647–649.

Benda, Lee, 1990, The influence of debris flows on channels and valley floors in the Oregon Coast Range, U.S.A.: Earth Surface Processes and Landforms, v. 15, p. 457–466.

Benda, Lee, and Dunne, Thomas, 1987, Sediment routing by debris flow, *in* Beschta, R.L., Blinn, T., Grant, G.E., Swanson, F.J., and Ice, G.G., eds., Erosion and sedimentation in the Pacific Rim: International Association of Hydrological Sciences Publication no. 165, p. 213–223.

Berger, G.W., 1988, Dating Quaternary sediments by luminescence, *in* Easterbrook, D.J., ed., Dating Quaternary Sediments: Geological Society of America Special Paper 227, p. 13–50.

———1990, Effectiveness of natural zeroing of the thermoluminescence in sediments: Journal of Geophysical Research, v. 95, no. B8, p. 12,375–12,397.

Berger, G.W., Luternauer, J.L., and Clague, J.J., 1990, Zeroing tests and application of thermoluminescence dating to Fraser River Delta sediments: Canadian Journal of Earth Sciences, v. 27, p. 1737–1745.

Birkeland, P.W., 1972, Late Quaternary eustatic sea-level changes along the Malibu coast, Los Angeles County, California: Journal of Geology, v. 80, p. 432–448.

———1984, Soils and geomorphology: New York, Oxford University Press, 372 p.

Blong, R.J., and Gillespie, R., 1978, Fluvially transported charcoal gives erroneous ^{14}C ages for recent deposits: Nature, v. 271, p. 739–741.

Bloom, A.L., 1983, Sea level and coastal morphology of the United States through the late Wisconsin glacial maximum, *in* Porter, S.C., ed.,The Late Pleistocene, Vol. 1 *of* Wright, H.E., Jr., ed., Late Quaternary environments of the United States: Minneapolis, University of Minnesota Press, p. 215–229.

Bloom, A.L., Broecker, W.S., Chappell, J.M.A., Matthews, R.K., and Mesolella, K.J., 1974, Quaternary sea level fluctuations on a tectonic coast—New $^{230}Th/^{234}U$ dates from the Huon Peninsula, New Guinea: Quaternary Research, v. 4, p. 185–205.

Blum, M.D., 1990, Climatic and eustatic controls on Gulf Coastal Plain fluvial sedimentation—An example from the Late Quaternary of the Colorado River, Texas: Gulf Coast Section, Society of Economic Paleontologists Foundation Eleventh Annual Research Conference, Programs and Abstracts, p. 71–83.

Bockheim, J.G., Kelsey, H.M., and Marshall, J.G. III, 1992, Soil development, relative dating, and correlation of late Quaternary marine terraces in southwestern Oregon: Quaternary Research, v. 37, p. 60–74.

Bull, W.B., 1990, Stream-terrace genesis—Implications for soil development, *in* Knuepfer, P.L.K. and McFadden, L.D., eds., Soils and landscape evolution: Geomorphology, v. 3, p. 351–367.

Chappell, J., and Shackleton, N.J., 1986, Oxygen isotopes and sea level: Nature, v. 324, p. 137–140.

Chappell, J., and Veeh, H.H., 1978, $^{230}Th/^{234}U$ age support of an interstadial sea level of -40 m at 30,000 yr B.P.: Nature, v. 276, p. 602–603.

COHMAP, 1988, Climatic changes of the last 18,000 years—Observations and model simulations: Science, v. 241, p. 1043–1052.

Colman, S.M., and Pierce, K.L., 1981, Weathering rinds on andesitic and basaltic stones as a Quaternary age indicator, western United States: U.S. Geological Survey Professional Paper 1210, 56 p.

Cotton, C.A., 1940, Classification and correlation of river terraces: Journal of Geomorphology, v. 3, p. 27–37.

Curtiss, D.A., Collins, C.A., and Oster, E.A., 1984, Water resources of western Douglas County, Oregon: U.S. Geological Survey Water-Resources Investigations Report 83–4017, 81 p.

Darienzo, M.E., and Peterson, C.D., 1990, Episodic tectonic subsidence of late Holocene salt marshes, northern Oregon coast, central Cascadia margin, U.S.A.: Tectonics, v. 9, p. 1–22.

Dethier, D.P., 1988, The soil chronosequence along the Cowlitz River, Washington: U.S. Geological Survey Bulletin 1590–Für, p. F1–F47.

Dietrich, W.E., and Dunne, Thomas, 1978, Sediment budget for a small catchment in mountainous terrain: Zeitzschrift für Geomorphologie, Supplementband 29, p. 191–206.

Dueholm, K.S., and Pilmore, C.L., 1989, Computer-assisted geologic photogrammetry: Photogrammetric Engineering and Remote Sensing, v. 55, no. 8, p. 1191–1196.

Feiereisen, J.J., 1981, Geomorphology, alluvial stratigraphy, and sediments—Lower Siuslaw and Alsea River valleys, Oregon: Eugene, University of Oregon, Ph.D. dissertation, 281 p.

Forman, S.L., Jackson, M.E., McCalpin, J., and Maat, P., 1988, The potential of using thermoluminescence to date buried soils developed on colluvial and fluvial sediments from Utah and Colorado, U.S.A.—Preliminary results: Quaternary Science Reviews, v. 7, p. 287–293.

Golder Associates, 1986, WNP-3 geologic support services, coastal terrace study: Richland, Washington, *unpublished report prepared for* Washington Public Power Supply System, 106 p.

Grabau, P.C., 1990, Floodplain aggradation in an intermontane area of the Oregon Coast Range as a geomorphic response to the Pleistocene-Holocene transition: Bellingham, Western Washington University, M.S. thesis, 45 p.

Harden, J.W., 1987, Soils developed in granitic alluvium near Merced, California: U.S. Geological Survey Bulletin 1590–A, 65 p.

Helley, E.J., and LaMarche, V.C., Jr., 1973, Historic flood information for northern California streams from geological and botanical evidence: U.S. Geological Survey Professional Paper 485–E, p. E1–E16.

Heusser, C.J., 1983, Vegetation history of the northwestern United States including Alaska, *in* Porter, S.C., ed., The Late Pleistocene, Vol. 1 *of* Wright, H.E., Jr., ed., Late Quaternary environments of the United States: Minneapolis, University of Minnesota Press, p. 239–258.

———1985, Quaternary pollen records from the Pacific Northwest Coast—Aleutians to the Oregon-California boundary, *in* Bryant, V.M., Jr., and Holloway, R.G., eds., Pollen records of Late-Quaternary North American sediments: Dallas, American Association of Stratigraphic Palynologists, p. 141–165.

Huntley, D.J., 1985, On the zeroing of the thermoluminescence of sediments: Physics and Chemistry of Minerals, v. 12, p. 122–127.

Kelsey, H.M., 1987, Geomorphic processes in the recently uplifted coast ranges of northern California, *in* Graf, W.L., ed., Geomorphic systems of North America, *part of* Chapter 13, Pacific Coast and Mountain System: Geological Society of America Centennial Special Volume 2, p. 550–560.

———1990, Late Quaternary deformation of marine terraces on the Cascadia subduction zone near Cape Blanco, Oregon: Tectonics, v. 9, p. 983–1014.

Kennedy, G.L., 1978, Pleistocene paleoecology, zoogeography and geochronology of marine invertebrate faunas of the Pacific Northwest coast (San Francisco to Puget Sound): Davis, University of California, Ph.D. thesis, 824 p.

Knuepfer, P.L.K., 1988, Estimating ages of late Quaternary stream terraces from analysis of weathering rinds and soils: Geological Society of America Bulletin, v. 100, p. 1224–1236.

Lajoie, K.R., 1986, Coastal tectonics, *in* Wallace, R.E., panel chairman, Active Tectonics: Washington, D.C., National Research Council, Studies in Geophysics, National Academy Press, p. 95–125.

Leopold, L.B., and Bull, W.B., 1979, Base level, aggradation, and grade: Proceedings of the American Philosophical Society, v. 123, p. 168–202.

Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964, Fluvial processes in geomorphology: San Francisco, W.H. Freeman and Company, 522 p.

Marron, D.C., 1985, Colluvium in bedrock hollows on steep slopes, Redwood Creek drainage basin, northwestern California, *in* Jungerius, P.D., ed., Soils and Geomorphology: Catena Supplement 6, p. 59–68.

Martinson, D.C., Pisias, N.G., Hays, J.D., Imbrie, John, Moore, T.C., Jr., and Shackleton, N.J., 1987, Age dating and the orbital theory of the ice ages—Development of a high-resolution 0 to 300,000-year chronostratigraphy: Quaternary Research, v. 27, p. 1–29.

McDowell, P.F., 1987, Geomorphic processes in the Pacific coast and mountain system of Oregon and Washington, *in* Graf, W.L., ed., Geomorphic systems of North America, *part of* Chapter 13, Pacific Coast and Mountain System: Geological Society of America Centennial Special Volume 2, p. 539–549.

McInelly, G.W., and Kelsey, H.M., 1990, Late Quaternary deformation in the Cape Arago-Bandon region of coastal Oregon as deduced from wave-cut platforms: Journal of Geophysical Research, v. 95, no. B5, p. 6699-6713.

Merritts, Dorothy, and Vincent, K.R., 1989, Geomorphic response of coastal streams to low, intermediate, and high rates of uplift, Mendocino triple junction region, northern California: Geological Society of America Bulletin, v. 101, p. 1373- 1388.

Moss, J.H., 1974, The relation of river terrace formation to glaciation in the Shoshone River basin, western Wyoming, *in* Coates, D.R., ed., Glacial Geomorphology: Binghamton, State University of New York, Publications in Geomorphology, p. 293–314.

Muhs, D.R., Kelsey, H.M., Miller, G.H., Kennedy, G.L., Whelan, J.F., and McInelly, G.W., 1990, Age estimates and uplift rates for Late Pleistocene marine terraces—Southern Oregon portion of the Cascadia forearc: Journal of Geophysical Research, v. 95, no. B5, p. 6685–6698.

Munsell Color Company, 1954, Munsell soil color chart: Baltimore, Maryland, Munsell Color Company, Inc.

Murray, Andrew, Wohl, Ellen, and East, Jon, 1992, Thermoluminescence and excess ^{226}Ra dating of late Quaternary fluvial sands, East Alligator River, Australia: Quaternary Research, v. 37, p. 29–41.

Nanson, G.C., Price, D.M., Short, S.A., Young, R.W., and Jones, B.G., 1991, Comparative Uranium-Thorium and thermoluminescence dating of weathered Quaternary alluvium in the tropics of northern Australia: Quaternary Research, v. 35, p. 347–366.

Nanson, G.C., and Young, R.W., 1987, Comparison of thermoluminescence and radiocarbon age determinations from Late-Pleistocene alluvial deposits near Sydney, Australia: Quaternary Research, v. 27, p. 263–269.

Nelson, A.R., 1992, Holocene tidal-marsh stratigraphy in south-central Oregon—Evidence for localized sudden submergence in the Cascadia subduction zone, *in* Fletcher, C.P., and Wehmiller, J.F., eds., Quaternary coasts of the United States—Marine and lacustrine systems: SEPM Special Publication 48, p. 287–301.

Nelson, A.R., and Personius, S.F., 1991, The potential for great earthquakes in Oregon and Washington—An overview of recent coastal geologic studies and their bearing on segmentation of Holocene ruptures, central Cascadia subduction zone, *in* Rogers, A.M., Walsh, T.J., Kockelman, W.J., and Priest, G.R. compilers, Earthquake hazards in the Pacific Northwest of the United States : U.S. Geological Survey Open-File report 91–441–A, 29 p.

Niem, W.A., 1976, Drainage basin morphology in the central Coast Range of Oregon: Corvallis, Oregon State University, M.S. thesis, 99 p.

Oregon State Water Resources Board, 1958, Umpqua River basin: Salem, Oregon State Water Resources Board, 200 p.

———1965, Mid-coast basin: Salem, Oregon State Water Resources Board, 122 p.

Peterson, C.P., Kulm, L.D., and Gray, J.J., 1986, Geologic map of the ocean floor off Oregon and the adjacent continental margin: Oregon Department of Geology and Mineral Industries Geologic Map Series map GMS–42, scale 1:500,000.

Pierson, T.C., 1977, Factors controlling debris-flow initiation on forested hillslopes in the Oregon Coast Range: Seattle, University of Washington, Ph.D. thesis, 166 p.

Pinter, Nicholas, and Gardner, T.W., 1989, Construction of a polynomial model of glacio-eustatic fluctuation—estimating paleo-sea levels continuously through time: Geology, v. 17, p. 295–298.

Porter, S.C., Pierce, K.L., and Hamilton, T.D., 1983, Late Wisconsin mountain glaciation in the western United States, *in* Porter, S.C., ed., The Late Pleistocene, Vol. 1 *of* Wright, H.E., Jr., ed., Late Quaternary environments of the United States: Minneapolis, University of Minnesota Press, p. 71–111.

Rantz, S.E., and Moore, A.M., 1965, Floods of December 1964 in the far western United States: U.S. Geological Survey Open-File Report, 205 p.

Reneau, S.L., 1988, Depositional and erosional history of hollows—Application to landslide location and frequency, long-term erosion rates, and the effects of climatic change: Berkeley, University of California, Ph.D. dissertation, 327 p.

Reneau, S.L., and Dietrich, W.E., 1990, Depositional history of hollows on steep hillslopes, coastal Oregon and Washington: National Geographic Research, v. 6, p. 220–230.

———1991, Erosion rates in the southern Oregon Coast Range—Evidence for an equilibrium between hillslope erosion and sediment yield: Earth Surface Processes and Landforms, v. 16, p. 307–322.

Reneau, S.L., Dietrich, W.E., Donahue, D.J., Jull, A.J.T., and Rubin, Meyer, 1990, Late Quaternary history of colluvial deposition and erosion in hollows, central California Coast Ranges: Geological Society of America Bulletin, v. 102, p. 969–982.

Reneau, S.L., Dietrich, W.E., Dorn, R.I., Berger, C.R., and Rubin, Meyer, 1986, Geomorphic and paleoclimatic implications of latest Pleistocene radiocarbon dates from colluvium-mantled hollows, California: Geology, v. 14, p. 655–658.

Reneau, S.L., Dietrich, W.E., Rubin, Meyer, Donahue, D.J., and Jull, A.J.T., 1989, Analysis of hillslope erosion rates using dated colluvial deposits: Journal of Geology, v. 97, p. 45–63.

Rhea, Susan, 1993, Geomorphic observations of rivers in the Oregon Coast Range from a regional reconnaissance perspective: Geomorphology, v. 6, p. 135–150.

Rockwell, T.K., Keller, E.A., and Dembroff, G.R., 1988, Quaternary rate of folding of the Ventura Avenue anticline, western Transverse Ranges, southern California: Geological Society of America Bulletin, v. 100, p. 850–858.

Rogers, G.C., 1988, An assessment of the megathrust earthquake potential of the Cascadia subduction zone: Canadian Journal of Earth Science, v. 25, p. 844–852.

Rypins, Steven, Reneau, S.L., Byrne, Roger, and Montgomery, D.R., 1989, Palynologic and geomorphic evidence for environmental change during the Pleistocene-Holocene transition at Point Reyes Peninsula, central coastal California: Quaternary Research, v. 32, p. 72–87.

Sarna-Wojcicki, A.M., Champion, D.C., and Davis, J.O., 1983, Holocene volcanism in the conterminous United States and the role of silicic volcanic ash layers in correlation of latest-Pleistocene and Holocene deposits, *in* Wright, H.E., Jr., ed., The Holocene, Vol. 2 *of* Wright, H.E., Jr., ed., Late Quaternary environments of the United States: Minneapolis, University of Minnesota Press, p. 52–77.

Schlicker, H.G., and Deacon, R.J., 1974, Environmental geology of coastal Lane County Oregon: Oregon Department of Geology and Mineral Industries Bulletin 85, 116 p.

Schlicker, H.G., Deacon, R.J., Olcot, G.W., and Beaulieu, J.D., 1973, Environmental geology of Lincoln County, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 81, 171 p.

Schumm, S.A., Mosley, M.P., and Weaver, W.E., 1987, Experimental fluvial geomorphology: New York, John Wiley and Sons, 413 p.

Shackleton N.J., and Opdyke, N.D., 1973, Oxygen isotope and paleomagnetic stratigraphy of Equatorial Pacific core V28-238—Oxygen isotope temperatures and ice volumes on a 10^5 and 10^6 year scale: Quaternary Research, v. 3, p. 39–55.

Sherrod, D.R., 1991, Geologic map of a part of the Cascade Range between latitudes 43°–44°, central Oregon: U.S. Geological Survey Miscellaneous Investigations Series Map I–1891, scale 1:125,000.

Snavely, P.D., Jr., 1987, Tertiary geologic framework, neotectonics, and petroleum potential of the Oregon-Washington continental margin, *in* Scholl, D.W., Grantz, A., and Vedder, J.G., eds., Geology and resource potential of the continental margin of western North America and adjacent ocean basins—Beaufort Sea to Baja California: Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, v. 6, p. 305–335.

Snavely, P.D., Jr., MacLeod, N.S., Wagner, H.C., and Rau, W.W., 1976a, Geologic map of the Yaquina and Toledo quadrangles, Lincoln County, Oregon: U.S. Geological Survey Miscellaneous Investigations Series Map I–867, scale 1:62,500.

———1976b, Geologic map of the Cape Foulweather and Euchre Mountain quadrangles, Lincoln County, Oregon: U.S. Geological Survey Miscellaneous Investigations Series Map I–868, scale 1:62,500.

Spence, William, 1989, Stress origins and earthquake potentials in Cascadia: Journal of Geophysical Research, v. 94, no. B3, p. 3076–3088.

Stuiver, Minze, Braziunas T.F., Becker, Bernd, and Kromer, Bernd, 1991, Climatic, solar, oceanic, and geomagnetic influences on Late-glacial and Holocene atmospheric $^{14}C/^{12}C$ change: Quaternary Research, v. 35, p. 1–24.

Stuiver, Minze, and Quay, P.D., 1980, Changes in atmospheric carbon-14 attributed to a variable sun: Science, v. 207, p. 11–19.

Stuiver, Minze, and Reimer, P.J., 1986, A computer program for radiocarbon age calibration: Radiocarbon, v. 28, p. 1022–1030.

Tushingham, A.M., and Peltier, W.R., 1991, Ice-3G—A new global model of Late Pleistocene deglaciation based upon geophysical predictions of post-glacial relative sea level change: Journal of Geophysical Research, v. 96, p. 4497–4523.

Walker, G.W., and Duncan, R.A., 1989, Geologic map of the Salem 1° by 2° quadrangle, western Oregon: U.S. Geological Survey Miscellaneous Investigations Series Map I–1893, scale 1:250,000.

Wells, F.G., and Peck, D.L., 1961, Geologic map of Oregon west of the 121st meridian: U.S. Geological Survey Miscellaneous Investigations Series Map I–325, scale 1:500,000.

West, D.O., and McCrumb, D.R., 1988, Coastline uplift in Oregon and Washington and the nature of Cascadia subduction-zone tectonics: Geology, v. 16, p. 169–172.

Wintle, A.G., and Huntley, D.J., 1982, Thermoluminescence dating of sediments: Quaternary Science Reviews, v. 1, p. 31–53.

Wright, L.W., 1970, Variation in the level of the cliff/shore platform junction along the south coast of Great Britain: Marine Geology, v. 9, p. 347–353.

Published in the Central Region, Denver, Colorado
Manuscript approved for publication June 11, 1992
Edited by Tom Kohnen
Graphics by Stephen F. Personius and Roger Highland
Photocomposition by Shelly A. Fields

☆U.S. GOVERNMENT PRINTING OFFICE: 1993-573-038/86000