Reconnaissance Geology and Geologic Hazards of the Offshore Coos Bay Basin, Oregon

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By SAMUEL H. CLARKE, Jr., MICHAEL E. FIELD, and CAROL A. HIROZAWA

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Reconnaissance Geology and Geologic Hazards of the Offshore Coos Bay Basin, Oregon

By Samuel H. Clarke, Jr., Michael E. Field, and Carol A. Hirozawa

Abstract

The offshore Coos Bay basin underlies the continental shelf and upper slope between Heceta Bank and Coquille Bank, Oregon, and comprises a succession of middle Eocene and younger principally marine sedimentary rocks 5,000+ m thick. Three acoustic units have been defined within this basin on the basis of seismic-reflection and sampling data: acoustic unit 1, inferred to be Quaternary in age and to be a maximum of about 500 m thick, is widespread on the continental shelf and slope; acoustic unit 2, inferred to be late Miocene to late Pliocene in age, is exposed on Heceta Bank, on the inner shelf between Cape Blanco and Cape Arago, and, locally, in breached anticlines; and acoustic unit 3, inferred to comprise strata of Eocene to middle Miocene age, is exposed locally in breached anticlines on the inner and middle continental shelf and on the middle of the continental slope. Recurrent major episodes of deformation are evidenced by regional unconformities of late Pliocene to early Pleistocene, early late Miocene, and middle to late Eocene age; these unconformities probably reflect significant changes in the history of plate convergence along this margin.

Potential geologic hazards to offshore development include groups of short north- to northwest-trending faults that cut Quaternary (locally Holocene) deposits on the continental shelf between Cape Arago and Heceta Bank. Seismic activity appears to be low within the offshore basin area; however, a significant possibility exists of damage from tsunamis, sea-floor mass movement, and liquefaction resulting from earthquakes in adjacent regions, notably the northern California continental margin. Unstable sea-floor conditions resulting from recent subaqueous slides and flows appear to be uncommon, although the presence of locally steep slopes and thick accumulations of unconsolidated sediment with unknown engineering characteristics make site-specific studies of sea-floor stability advisable. Buried zones as large as 190 km^2 in area and 200 to 250 m thick of disrupted and rotated acoustic reflectors appear to record episodes of sea-floor failure during Pleistocene low stands of sea level. Several folds showing sea-floor relief, one of which appears to be diapiric, reflect tectonic instability of the modern upper continental slope along the west margin of the basin. Acoustic anomalies suggestive of shallow gas accumulations cover areas of as much as 120 km^2, and combined geophysical and geochemical evidence indicate that gas is being vented at the sea floor in two localities. At one locality, 25 km west of Cape Arago, samples contained high methane concentrations and equivocal indications of thermogenic hydrocarbon gas. Reduction of the bearing strength of the enclosing sediment by such gas accumulations enhances the possibility of failure; if these accumulations are of thermogenic origin, they may reflect an overpressured zone at depth.

INTRODUCTION

This investigation summarizes aspects of the offshore and onshore geology of the Coos Bay basin, Oregon, that are significant in assessing potential geologic hazards to offshore resource exploration and development. Though focused on a specific offshore basin, this study is regional in scope and is designed to provide the geologic perspective necessary for site-specific geohazard studies. The geologic phenomena investigated include faulting; seismicity; sea-floor instability resulting from active uplift, sediment slides and flows, and the presence of gas in sediment; and sediment transport and deposition.

Much of the information presented here is based on seismic-reflection and sampling data collected during three cruises to the central Oregon offshore. The first cruise (S9-77NC), funded jointly by the U.S. Geological Survey and the U.S. Bureau of Land Management, was carried out aboard the research vessel Sea Sounder during November 1977. Objectives of that cruise were to provide a geologic reconnaissance of the offshore basin and to study the regional distribution of potentially hazardous geologic processes. The second and third cruises (S12-78NC, S13-79NC), funded by the U.S. Geological Survey and completed during 1978 and 1979, were carried out to augment previously collected seismic-reflection data, to collect samples for age control, and to verify the presence of shallow gas accumulations and gas seepage from the sea floor.

The seismic-reflection data obtained during this study cover the spectrum from high-resolution profiles collected with 12-kHz, 3.5-kHz, and Uniboom systems to intermediate-penetration profiles obtained using an 80- to 140-kJ sparker system. Subsurface features greater in vertical dimension than approximately 1.0 to 1.5 m can be resolved on high-resolution data that range in subbottom penetration from 100 to more than

300 m. Intermediate-penetration sparker data used to map structures at greater subbottom depths can resolve features larger than about 15 m in vertical dimension and commonly record information at depths of 1 to 2 km beneath the sea floor. Ship positioning was accomplished using satellite-navigation and Loran C systems that were integrated by means of a dead-reckoning computer (DRC), and a shipborne electronic ranging system that employed shore-based transponders. Radar was used for positioning in areas of terrain masking and during periods of navigational-equipment malfunction. Estimated position accuracy ranges from ±50 m where positions were determined principally by electronic ranging (approximately 90 percent of the total trackline mileage) to an average of about ±400 m where DRC estimations or radar positions were used exclusively (approximately 10 percent of the total trackline mileage). Procedures of geophysical-data acquisition and navigation employed in this study were described in greater detail by Clarke and others (1981).

Acknowledgments.--We thank many colleagues who contributed to the collection and analysis of data, in particular Robert Arnal, who made microfaunal age determinations, and Keith Kvenvolden and John Rapp, who performed geochemical analyses and interpretations. Teresa Hallinan, William R. Richmond, and Michael E. White made continuing and major contributions to our efforts in data collection and analysis, and to preparation of this report. Parke D. Snavely, Jr., and Holly C. Wagner shared their ideas and made significant contributions with their reviews.

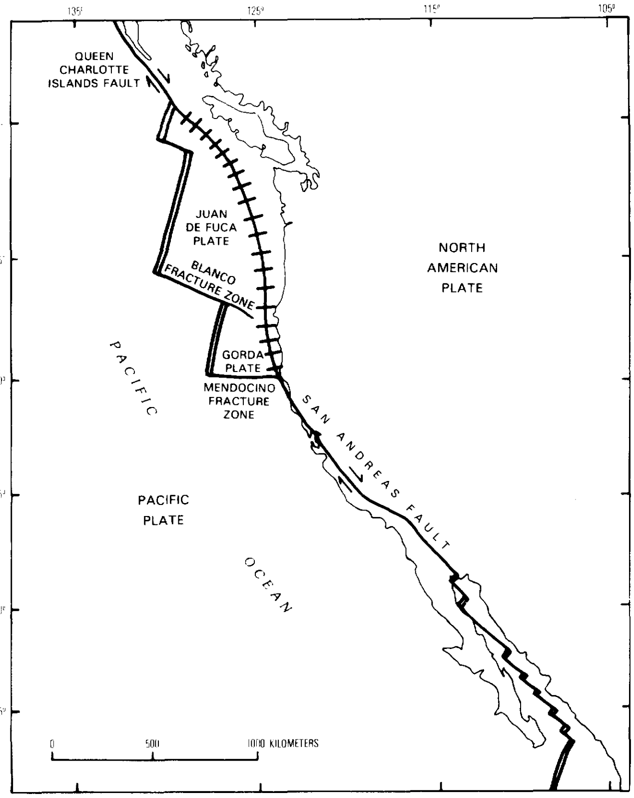

Figure 1. Generalized plate-tectonic framework of east Pacific plate margin, showing spreading ridges (double lines), major transform faults (single lines), and zones of subduction (hatched lines).

GEOLOGIC FRAMEWORK

Background

The continental margin of Oregon is situated near the boundary between the North American, Pacific, and Gorda-Juan de Fuca (a remnant of the ancestral Farallon) crustal plates (fig. 1), and the Cenozoic geologic history of this region has been shaped foremost by interactions between these plates (Morgan, 1968; Atwater, 1970; Kulm and Fowler, 1974b; Snavely and MacLeod, 1977; Snavely and others, 1977, 1980; Drake, 1982). Sea-floor spreading at the Gorda and Juan de Fuca Ridges, and underthrusting of the Gorda-Juan de Fuca plate beneath the North American Continent have resulted in long-term compression of the margin. Simultaneously, the Pacific plate has moved northwestward relative to the North American plate at a rate of about 6 cm/yr along broad zones of right shear—the San Andreas and Queen Charlotte Islands fault systems. Folding and upwarp of the outer continental margin (shelf and slope) resulting from oblique plate convergence have been accompanied by the formation of a succession of predominantly north-trending marine basins to the east, in the present area of the Oregon continental shelf and the Oregon Coast and Cascade Ranges (fig. 2); these basins were subsequently modified by episodes of strike-slip faulting (Snavely and MacLeod, 1977; Snavely and others, 1980).

West of the Cascade Range in central Oregon, terrigenous clastic sediment, volcanic rocks, and volcaniclastic rocks, with an aggregate thickness of about 8 km, have accumulated since early Tertiary time in an elongate, principally marine basin. The axis of this basin has shifted westward over time; during the middle Eocene, it probably lay about 20 to 40 km east of the present coastline in the area of the central Oregon Coast Range (Snavely and Wagner, 1963; Snavely and others, 1977, 1980). Since late Eocene time, however, deposition has been focused in a marginal basin occupying the present site of the Oregon continental shelf. The Pliocene and Pleistocene basin axis trends northward about 30 to 35 km west of the present coastline. The greatest thickness of upper Paleogene and younger sedimentary rocks lies within 50 to 60 km of the coastline at water depths of from 50 to about 1,000 m.

Geologic History

Aspects of the Cenozoic geologic history of the central Oregon continental margin were described by Snavely and Wagner (1963), Baldwin (1964, 1974), Braislin and others (1971), Baldwin and Beaulieu (1973), Kulm and Fowler (1974a, b), Snavely and others (1977, 1980), and Newton (1980); the reader is directed to these studies for a comprehensive review. Parts of the following discussion, especially those pertaining to Miocene and older units, principally concern the onshore geologic record; they are intended to provide a

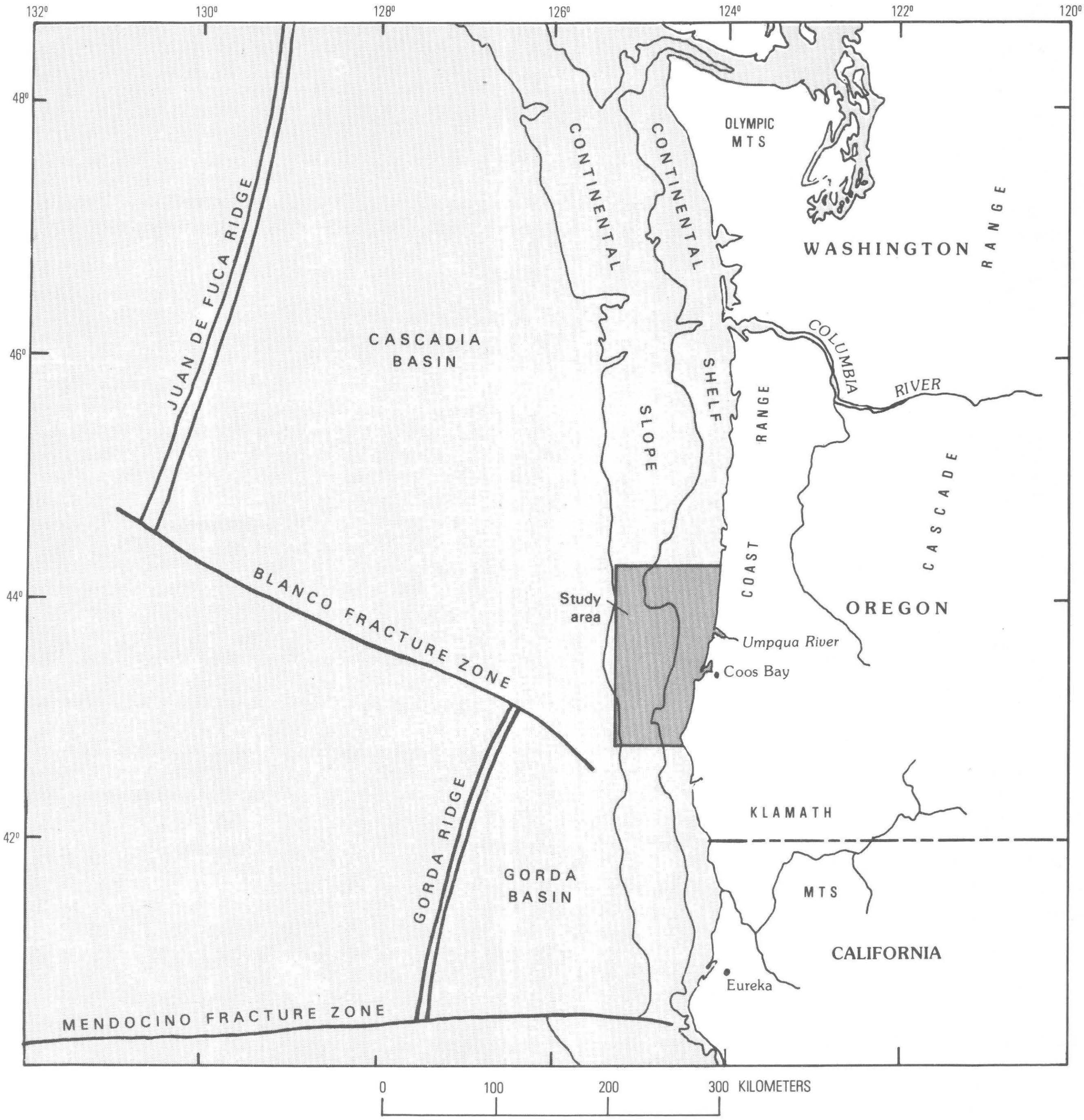

Figure 2. Major geologic and physiographic features of continental margin of the Pacific Northwest. Study area is shaded.

geologic framework within which the offshore geology can be examined.

A thick succession of Paleocene to middle Eocene tholeiitic to alkalic pillow basalt and breccia (Siletz River Volcanics, Roseburg Formation), interpreted as representing early Tertiary oceanic crust, underlies the Cenozoic sedimentary sequence in the central Oregon Coast Range and on the adjacent continental shelf (fig. 3; Snavely and Wagner, 1963; Snavely and others, 1968, 1977, 1980). The base of the volcanic succession is not exposed in the Oregon Coast Range, but the maximum thickness is estimated to be in excess of 3,000 m. Marine silt and volcanic sand (Umpqua Formation, Roseburg Formation) were deposited concurrently throughout the region in varied environments; gravel, sand, and silt (Lookingglass Formation, Flournoy Formation) were deposited in marginal marine and deltaic environments along the east and south margins of the marine basin. During middle Eocene time, an areally extensive sequence of submarine-fan and associated deposits (Tyee Formation), derived principally from uplift in the present area of the Klamath Mountains, prograded northward along the basin axis; these deposits have a maximum thickness of 3,000 m and consist mostly of massive rhythmically bedded lithic and arkosic sand-

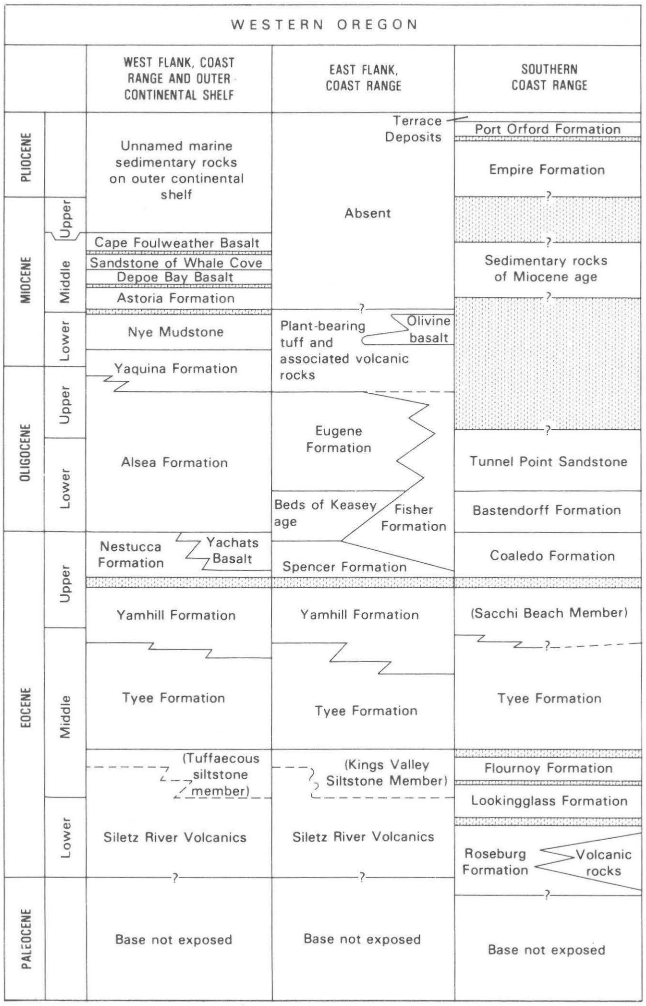

Figure 3. Correlation chart of major Tertiary units in western Oregon (from Snavely and others, 1977).

stone and siltstone (Snavely and others, 1964; Lovell, 1969). Hemipelagic mud and silt interbedded with thin sand (Yamhill Formation) were deposited elsewhere in the basin and were widespread by the beginning of late Eocene time, after deposition of the Tyee Formation.

This region was subjected to intense deformation during middle and late Eocene time, and an unconformity at the base of upper Eocene strata is widespread in the central Oregon Coast Range and offshore. This tectonism probably denotes a major episode of plate convergence, possibly related to accretion onto the North American plate of Paleogene volcanic rocks in western Oregon and accompanied by seaward migration of the Eocene subduction zone (MacLeod and Snavely, 1971; Simpson and Cox, 1977; Snavely and others, 1980). The locus of underthrusting probably occupied the middle of the present continental shelf (Snavely and others, 1977, 1980).

Late Eocene time was marked by widespread shoaling; the margin of the marine basin lay along the west edge of the present Cascade Range and the north edge of the present Klamath Mountains (Snavely and Wagner, 1963; Snavely and others, 1977). Shallow and marginal marine environments along the south margin of the basin are represented by a sequence of coal-bearing tuffaceous sandstone and siltstone (Coaledo Formation) as much as 1,000 m thick in the Coos Bay area. These deposits grade northward and westward into a thick (1,500+ m) tuffaceous siltstone, rich in organic materials, containing subordinate arkosic and volcanic sandstone (Nestucca Formation). Basalt flows and breccia (Yachats Basalt) that were erupted onto the basin floor locally near the present coastline formed islands where the accumulations were thickest. Late Eocene and Oligocene pyroclastic activity in the ancestral Cascade Range along the east margin of the basin resulted in deposition of as much as 1,500 m of tuffaceous silt and fine sand (Bastendorff Formation; Tunnel Point Sandstone; Alsea Formation). Uplift accompanied by emplacement of gabbroic to dioritic intrusive bodies during late Oligocene time limited marine deposition to areas west of the present continental shelf, the shelf itself, and the west flank of the Oregon Coast Range. Deposition of marine sediment in this area continued essentially uninterrupted into Miocene time. Along the east margin of the Coos Bay basin, which lay along the west flank of the Coast Range and near the present coastline in central Oregon (fig. 2), crustal instability and local volcanic activity are recorded by several unconformities, conspicuous upper Oligocene to middle Miocene shallow-marine clastic deposits (Yaquina Formation, Astoria Formation, and the sandstone of Whale Cove), and middle Miocene submarine and subaerial basaltic flows and breccia (Depoe Bay Basalt, Cape Foulweather Basalt). Deeper marine environments in open-margin basins are represented by deposits of clayey siltstone rich in organic material (Nye Mudstone).

Uplift and erosion, accompanying a major episode of underthrusting, occurred throughout the present area of the Oregon Coast Range and the adjacent continental shelf during late middle Miocene time, with folding principally along northeastward structural trends (Snavely and Wagner, 1963; Snavely and others, 1977, 1980). The unconformity created by this tectonism is recognizable in seismic-reflection records throughout most of the central Oregon continental shelf. Southward from Coos Bay, basin-margin deposition is represented by about 900 m of massive poorly bedded fossiliferous sandstone (Empire Formation). Partly correlative deposits in the marine basin on the present continental shelf consist of more than 1,050 m of upper Miocene tuffaceous sandy siltstone and 1,500 m of Pliocene foraminiferal siltstone and sandstone; the Pliocene deposits are thickest in the major shelf synclines (Braislin and others, 1971).

A Pliocene-Pleistocene unconformity can be traced throughout much of the central Oregon shelf. Strata beneath this unconformity are late Miocene to late Pliocene in age, whereas unconsolidated sediment overlying the unconformity at Deep Sea Drilling Project (DSDP) Site 176 is middle and late Pleistocene in age (Kulm and Fowler, 1974b). Pleistocene and Holocene deposits in this area are largely silt and sand, and are more than 500 m thick.

Marine Geology of the Coos Bay Basin

The geology of the central Oregon offshore has been mapped on a regional scale by members of the Oregon State University Department of Oceanography; their findings were presented in a series of theses and technical reports (notably Kulm, 1969; Kulm and Fowler, 1970; Fowler and Kulm, 1971) and were summarized by Kulm and Fowler (1974a, b). Mackay (1969) mapped the inner shelf between Cape Arago and Coquille Point, using a closely spaced network of single-channel seismic-reflection lines. Interpretive geologic cross sections were constructed across the offshore Coos Bay basin in the vicinity of Heceta and Coquille Banks by Couch and Braman (1980) and Couch and Pitts (1980), using combined gravity, magnetic, seismic, and well data. The geology of the adjacent area on land was mapped and described by Allen and Baldwin (1944), Wells and Peck (1961), Ramp (1972), Baldwin and Beaulieu (1973), Schlicker and Deacon (1974), and Beaulieu and Hughes (1975). Our study summarizes recent geologic and geophysical investigations conducted by the U.S. Geological Survey in the offshore Coos Bay basin (fig. 4).

The Coos Bay basin occupies the shelf and upper slope of the central Oregon continental margin between Heceta and Coquille Banks (from about lat 43° to 44°15'N.) (fig. 5). The continental shelf in this area ranges in breadth from 20 to 25 km off Cape Arago and Coquille Point, to a maximum of nearly 70 km at Heceta Bank. The most prominent features of this shelf segment are Heceta and Coquille Banks, which are exposed bedrock highs on the outer shelf with about 50 m of sea-floor relief. The shelf break occurs at a depth of about 140 m, estimated from bathymetric profiles and from the depth of deposits interpreted as late Pleistocene progradational sequences, and is best defined in the vicinity of the banks. The continental slope has a northward trend in this region and ranges in breadth from 35 km seaward of Heceta and Coquille Banks to 55-75 km in the area between the banks. It has an average declivity of 2°-4°, is steepest in the vicinity of the banks, and slopes westward to depths of 3,000 to 3,100 m in the Cascadia Basin. The lower part of the slope is conspicuously steep; declivities of 7°-14° are common between depths of 2,000 and 3,000 m. Large canyons do not cut the continental slope off central Oregon, although smaller submarine valleys and gullies are numerous.

Three acoustic units separated by unconformities were defined in seismic-reflection profiles across the continental shelf between Heceta and Coquille Banks (figs. 5, 6). Age control for these units is provided by paleontologic analysis of samples collected during this study (fig. 6); by the age dates reported by Fowler and Kulm (1971), Kulm and Fowler (1974b), and Kulm (1980); and by the exploratory-well data reported by Snavely and others (1977, 1981). Acoustic unit 1 overlies a conspicuous unconformity on the east flank of Heceta Bank (figs. 7, 8) and consists of sediment dated as Pleistocene in age (fig. 6; Kulm and Fowler, 1974b). This unconformity marks a major tectonic event because it is traceable throughout much of the Oregon continental shelf and truncates strata of late Miocene to late Pliocene age. About 200 km north of the study area, at DSDP Site 176 on Nehalem Bank, the unconformity separates Pliocene siltstone from deposits dated as middle and late Pleistocene (maximum age 1.3 Ma) (Kulm and others, 1973). This unconformity can be identified elsewhere on the banks and inner shelf (see figs. 16, 23) but is indistinct in the centers of major synclines. Acoustic unit 1 is stratigraphically the uppermost (youngest) unit defined over most of the central Oregon shelf and slope. Locally on the inner shelf, however, it is overlain unconformably by a seaward-thinning sediment wedge as much as 15 m thick (fig. 9). This wedge of sediment is thought to represent Holocene deposits derived mostly from rivers draining the adjacent Coast Range and coastal plain. These deposits are included in acoustic unit 1 on figures 6 and 27 because they cannot be traced with confidence between adjacent seismic profiles.

Acoustic unit 1 is widespread on the central Oregon continental shelf and upper slope, and is present locally on the midslope (fig. 6). Within the study area, it reaches a maximum thickness of about 500 m in the axis of the broad, shallow syncline near the shelf edge between Cape Arago and Heceta Bank (fig. 10; see fig. 27). Substantial seaward progradation of the shelf edge apparently accompanied erosion of the inner shelf during Pleistocene low stands of sea level. Sediment of acoustic unit 1 overlaps older strata on the east flank of Heceta Bank, and on the upper slope and midslope is ponded landward of anticlinal folds in strata inferred to be of late Miocene and Pliocene age. Unconformities of limited extent that occur within acoustic unit 1 (fig. 7) reflect recurrent episodes of uplift and erosion coupled with downwarp of the adjacent basin during Pleistocene time.

Pleistocene sediment of the central Oregon offshore area is described as sand and silt interbedded with minor gravel (Snavely and others, 1977, 1981). Deposits of this age penetrated at DSDP Site 176 consist of greenish-gray clayey silt containing abundant coarse debris and shallow-water megafossils (Kulm and others, 1973). Pleistocene sediment cored during the present study is typically fine silt and clay.

Acoustic unit 2 is widely exposed on Heceta Bank, on the inner continental shelf between Cape Blanco and Cape Arago, and in anticlinal axes elsewhere on the continental shelf and upper slope (fig. 6). Acoustic unit 2 underwent widespread deformation by folding before the deposition of acoustic unit 1, which unconformably overlies it (fig. 7; see figs. 16, 23). In turn, acoustic unit 2 unconformably overlies more intensely deformed strata of acoustic unit 3 (fig. 10; see figs. 11, 15, 16).

Strata of acoustic unit 2 on Heceta Bank have been dated as late Miocene and early and middle Pliocene (Fowler and Kulm, 1971; Kulm and Fowler, 1974b). Samples collected from acoustic unit 2 on Heceta Bank and from a youthful fold 45 km northwest of Cape Arago have been dated as late Pliocene (fig. 6). Thus, acoustic unit 2 on Heceta Bank is correlative with upper Miocene and Pliocene marine sedimentary strata that crop out locally along the southern Oregon coast. Pleistocene sediment (acoustic unit 1) directly

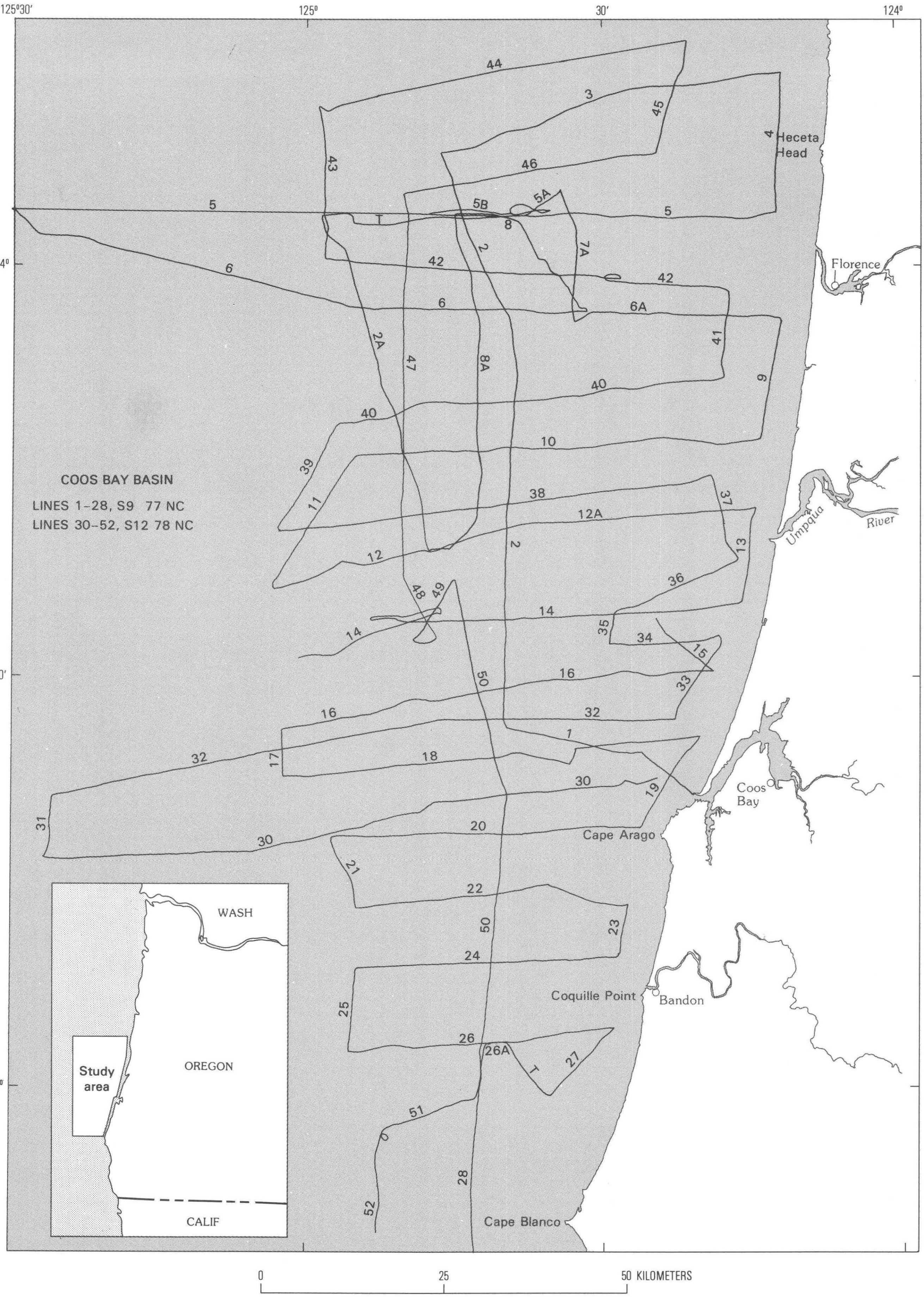

Figure 4. Geophysical tracklines in Coos Bay basin for 1977 and 1978 cruises of research vessel *Sea Sounder.*

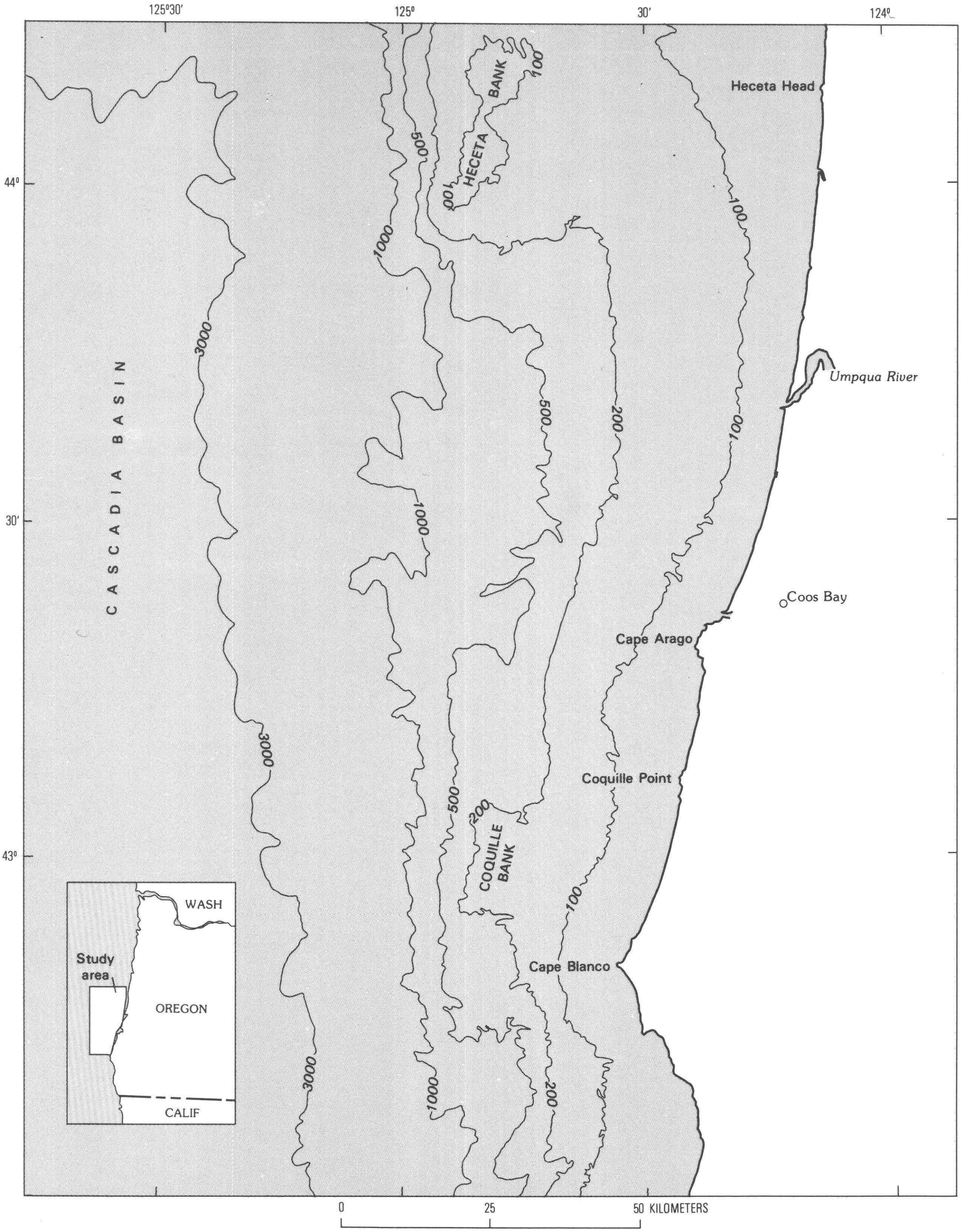

Figure 5. Offshore area of Coos Bay basin. Bathymetry from U.S. Coast and Geodetic Survey 1308N-17 (1968) and 1308N-22 (1968).

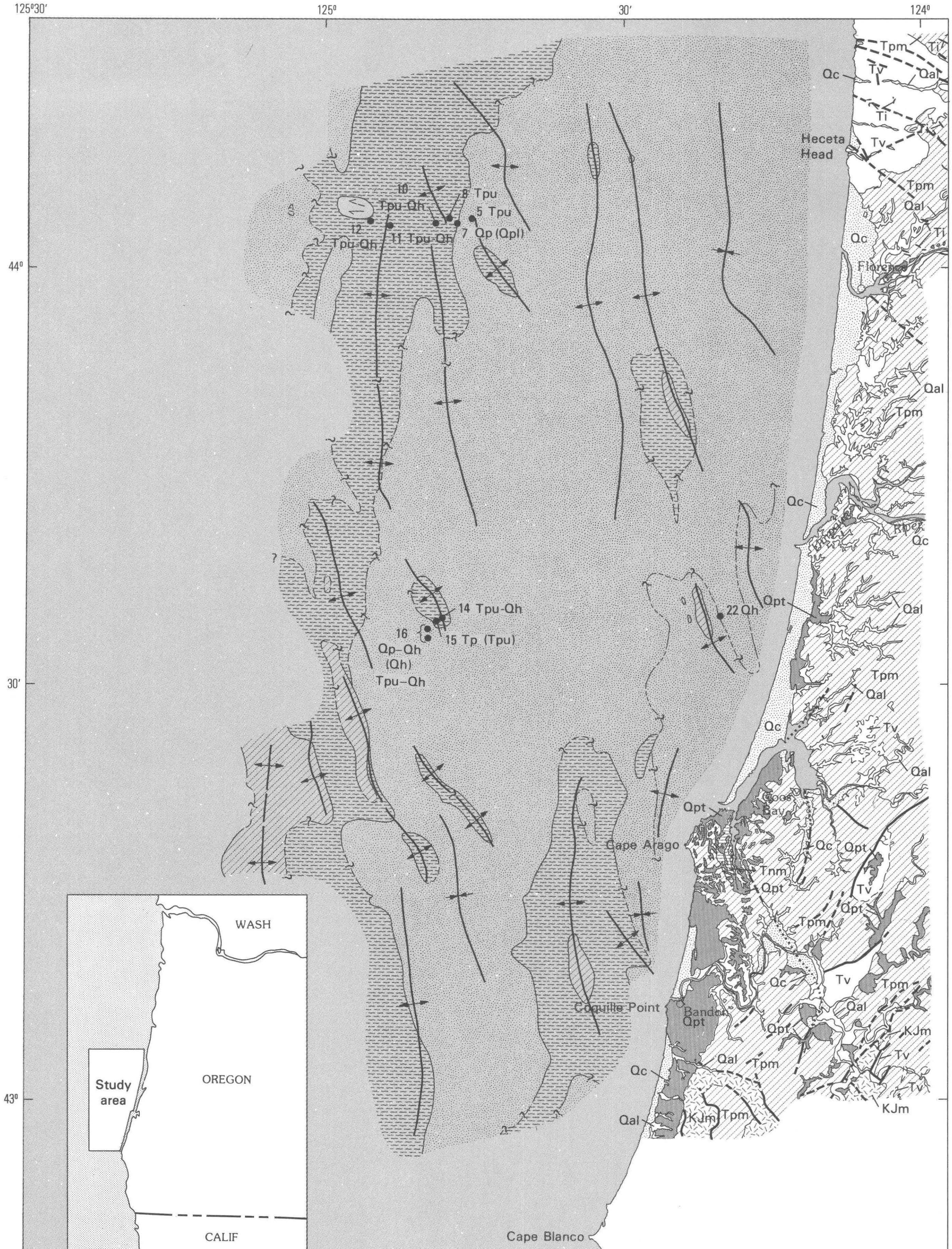

Figure 6. Generalized geologic map of southern Oregon continental margin. The geologic map-unit symbols used on this figure may not conform to standards set by the U.S. Geological Survey.

EXPLANATION

ONSHORE GEOLOGY

(From Beaulieu and Hughes, 1975, and Schlicker and Deacon, 1974)

Qc	MODERN COASTAL SEDIMENTS—Principally deposits of active and stabilized dunes and inter-dune areas and tidal flats
Qal	MODERN ALLUVIAL DEPOSITS
Qpt	PLEISTOCENE MARINE AND FLUVIAL TERRACE DEPOSITS
Tnm	MIOCENE AND PLIOCENE MARINE SEDIMENTARY ROCKS
Ti	EOCENE(?) TO MIOCENE INTRUSIVE ROCKS—Principally gabbro, diabase, and diorite
Tpm	PALEOCENE, EOCENE, AND OLIGOCENE MARINE SEDIMENTARY ROCKS—Includes lesser nonmarine and volcanic rocks
Tv	PALEOCENE AND EOCENE VOLCANIC ROCKS—Principally basalt and associated volcaniclastic rocks
KJm	MESOZOIC MELANGE—Fine- to coarse-grained marine sedimentary and volcanic rocks
	CONTACT—Dashed where approximate; dotted where concealed
	FAULT—Dashed where approximate; dotted where concealed

OFFSHORE GEOLOGY

	ACOUSTIC UNIT 1—Inferred to comprise Quaternary shelf, slope, and basin deposits
	ACOUSTIC UNIT 2—Inferred to comprise strata of late Miocene and Pliocene age; principally siltstone and claystone
	ACOUSTIC UNIT 3—Inferred to comprise strata of Eocene through middle Miocene age; principally siltstone and sandstone with some interbedded volcanic and volcaniclastic rocks and lesser intrusive rocks
•16 Tpu-Qh	SAMPLE LOCATION—Ages shown are based principally on benthic foraminiferal faunas; age ranges are shown where greater resolution was not obtained; ages in parentheses are probable ages within the range indicated; faunal identifications and age determinations by R. E. Arnal. Q, indicates Quaternary, undifferentiated; Qh, Holocene; Qp, Pleistocene; Tp, Pliocene, undifferentiated; Tpu, upper Pliocene; Tpl, lower Pliocene
	CONTACT—Dashed where approximate; queried where uncertain
	CONTACT BETWEEN ACOUSTIC UNITS 2 AND 3 WHERE COVERED BY VENEER OF QUATERNARY SEDIMENTS ON INNER SHELF—Queried where uncertain
	AXIS OF MAJOR ANTICLINE
	AXIS OF MAJOR SYNCLINE
	SLUMP

Figure 6. Continued

overlies upper Miocene rocks (acoustic unit 2) on the inner continental shelf between Cape Arago and Coquille Point (Kulm and Fowler, 1970, 1974b), and acoustic unit 2 is missing owing to pre-Pleistocene erosion on much of the inner shelf north of Cape Arago. Strata of late Miocene and Pliocene age also appear to be missing onshore, adjacent to the Coos Bay basin, except for a small area where Pliocene marine sediment is exposed east of Cape Arago (fig. 6; Beaulieu and Hughes, 1975).

Braislin and others (1971) described upper Miocene (Mohnian and Delmontian) rocks of the central Oregon offshore as tuffaceous sandy siltstone; those of Pliocene age were described as a monotonous sequence of massive foraminifer-rich olive-gray siltstone and claystone that is similar biostratigraphically to Pliocene strata of the Ventura and Los Angeles basins of southern California. Kulm and Fowler (1974a) reported that upper Miocene strata are principally fine-grained sandstone; MacKay (1969) speculated, on the basis of reflector characteristics and analogy to Pliocene rocks on land nearby, that the late Neogene strata on the inner shelf between Cape Arago and Coquille Point consist of massive sandstone of relatively uniform lithology. Indurated olive-gray mudstone of probable late Pliocene age was cored during this study on Heceta Bank at a water depth of 115 m and on the crest of a piercement structure 45 km northwest of Cape Arago at a depth of 491 m (fig. 11).

Acoustic unit 3 is exposed in the cores of breached anticlines on the inner to middle continental shelf seaward of the mouth of the Umpqua River and Coquille Point, and on the middle of the continental slope seaward of Cape Arago (fig. 6). Acoustic unit 3 is unconformably overlain by acoustic unit 2 (fig. 10; see figs. 11, 13, 15, 16) and is much more intensely deformed than are younger strata on the central Oregon continental shelf. The unconformity separating acoustic units 2 and 3 is thought to be correlative with the regional unconformity representing widespread late middle Miocene deformation on the continental margin off Oregon and Washington (Snavely and others, 1977, 1980). This unconformity separates upper Miocene and younger rocks from strata ranging in age from Eocene to middle Miocene (Beaulieu and Hughes, 1975; Snavely and others, 1977). Acoustic unit 3 was not sampled during this study, nor do published references show samples from these exposures; however, this unit is inferred to consist of upper Eocene to middle Miocene strata, on the basis of its stratigraphic position and presumed equivalence to upper Eocene to middle Miocene rocks that are bounded by regional unconformities onshore. Strata of this age were reported by Snavely and others (1977, 1980) to consist principally of siltstone interbedded with some turbidite sandstone, and volcanic rocks.

Upper Eocene to middle Miocene rocks overlie older Tertiary strata along a regional unconformity in the central Oregon Coast Range and in the offshore well sections reported by Snavely and others (1977,1980). Beneath the inner shelf and Heceta Bank, these older strata appear to underlie acoustic unit 3 unconformably. Because they do not crop out on the sea floor within the study area, however, and cannot be traced with confidence between adjacent lines, these older strata have not been mapped separately in this study.

STRUCTURE

Background

Folds and faults in the offshore Coos Bay basin are shown on Figure 12. The vertical scale of the seismic profiles shown here as figures is greatly exaggerated, typically 4:1 to 5:1 for intermediate-

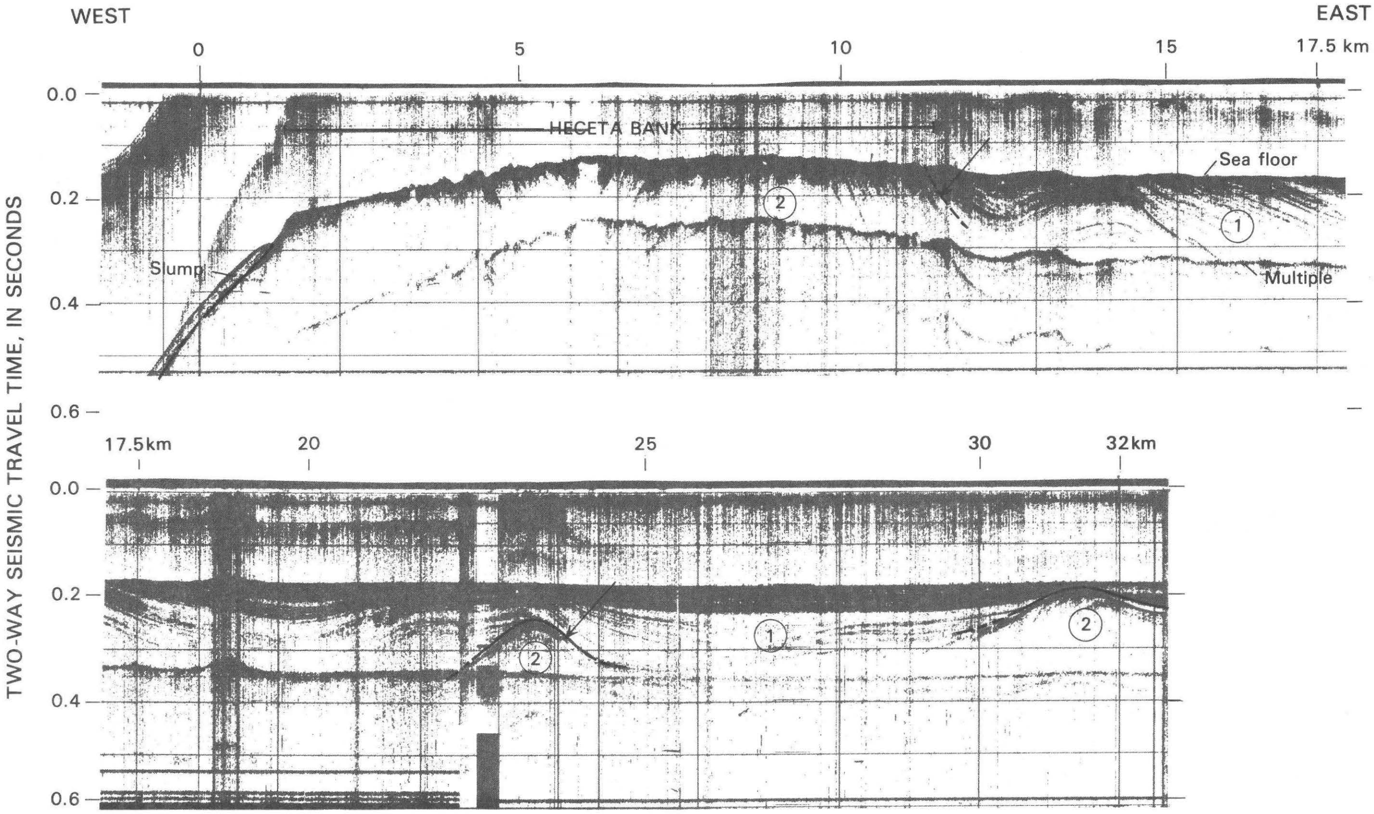

Figure 7. High-resolution seismic-reflection profile (77-05) extending eastward across Heceta Bank and adjacent shelf. Note contact between acoustic units 1 and 2 (arrows), evidence of Quaternary deformation, and slump on west side of bank. See figure 4 for location of profile.

penetration sparker records and 12:1 to 14:1 for high-resolution records. Little acoustic energy is returned from reflectors dipping more than 15°-20°, and so areas of steep dips and structural complexity, such as parts of Heceta Bank, are characterized by an absence of coherent reflectors. Masking of subbottom structure by water-bottom multiples in shallow water, such as on the inner continental shelf, makes interpretation difficult and interpretative results more subjective than elsewhere.

Three classes of folds are identified on Figure 12: (1) Folds that create sea-floor relief, typically in the form of irregular or smoothly rounded, linear ridges; (2) folds that are breached at the sea floor; and (3) folds that are buried beneath younger, characteristically less deformed deposits. Folds that create sea-floor relief are generally the youngest folds present and show as much as 250 m of sea-floor relief (see figs. 11, 16); most reflect Quaternary deformation and some appear to be active. Breached folds, which predominate on the inner shelf and banks at depths less than about 200 m, were truncated during Pleistocene low stands of sea level. Sea-floor outcrops associated with breached folds commonly involve strata of acoustic unit 2, inferred to be late Miocene and Pliocene in age, on the inner shelf and on Heceta Bank (fig. 7), and strata of acoustic unit 3, interpreted as middle Miocene and older, on the inner continental shelf (fig. 13). Some breached folds on the shelf and bank margins are overlapped along trend by strata of acoustic unit 1. Breached folds probably reflect deformation principally during early late Miocene or Pliocene to Pleistocene time. Buried folds are seen both in acoustic unit 3, in which folds commonly appear to have been truncated by erosion before the deposition of acoustic unit 2, and in acoustic unit 2.

Faulting is indicated on seismic-reflection records by the displacement of reflectors, the termination of conspicuous reflectors or an abrupt change in the appearance of the seismic section, or by an abrupt change in apparent dip. Faults that are identified by using two or more of these criteria are considered to be well defined and are shown by solid lines on figure 12; those identified by using a single criterion are inferred and are shown by dashed lines. The orientation of faults was determined principally by correlation between seismic-reflection lines. Faults are queried where their existence, trend, or connection between adjacent lines is questionable.

The ages of faults are based on the youngest acoustic unit they offset. The resolution of ages assigned to faults in the Coos Bay basin is limited by the absence of geologic-age information in some parts of the basin and by the rather long time span represented by each acoustic unit. Faults extending to the sea floor and those cutting sediment inferred to be Holocene in age on the inner shelf are significant in that they may be active. Faults that reach the sea floor, however, also may be old faults exhumed by post-Tertiary erosion. Because Pleistocene and Holocene strata have not been differentiated beyond the inner shelf, faults that reach the sea floor or terminate within acoustic unit 1 are probably Quaternary in age. Faults terminating near the boundary between acoustic units 1 and 2 in basins where the Pliocene-Pleistocene boundary is ill defined are identified as Pliocene-Pleistocene in age. Faults mapped on land adjacent to the offshore Coos Bay basin were compiled from Schlicker and Deacon (1974) and Beaulieu and Hughes (1975).

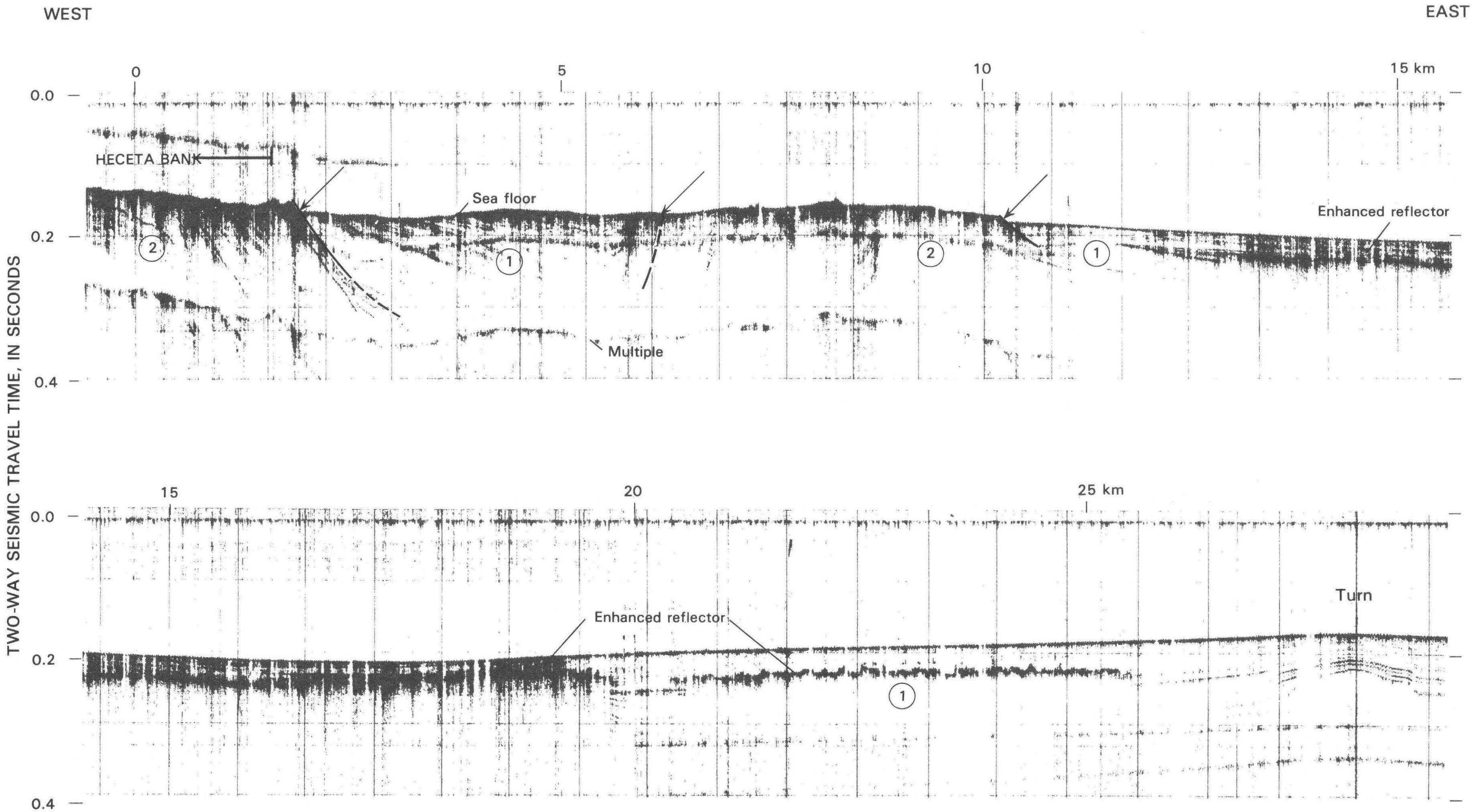

Figure 8. High-resolution seismic-reflection profile (78-42) extending eastward from Heceta Bank across adjacent shelf. Note contact between acoustic units 1 and 2 (arrows), deformation of acoustic unit 1, and enhanced reflector indicating possible shallow gas accumulation.

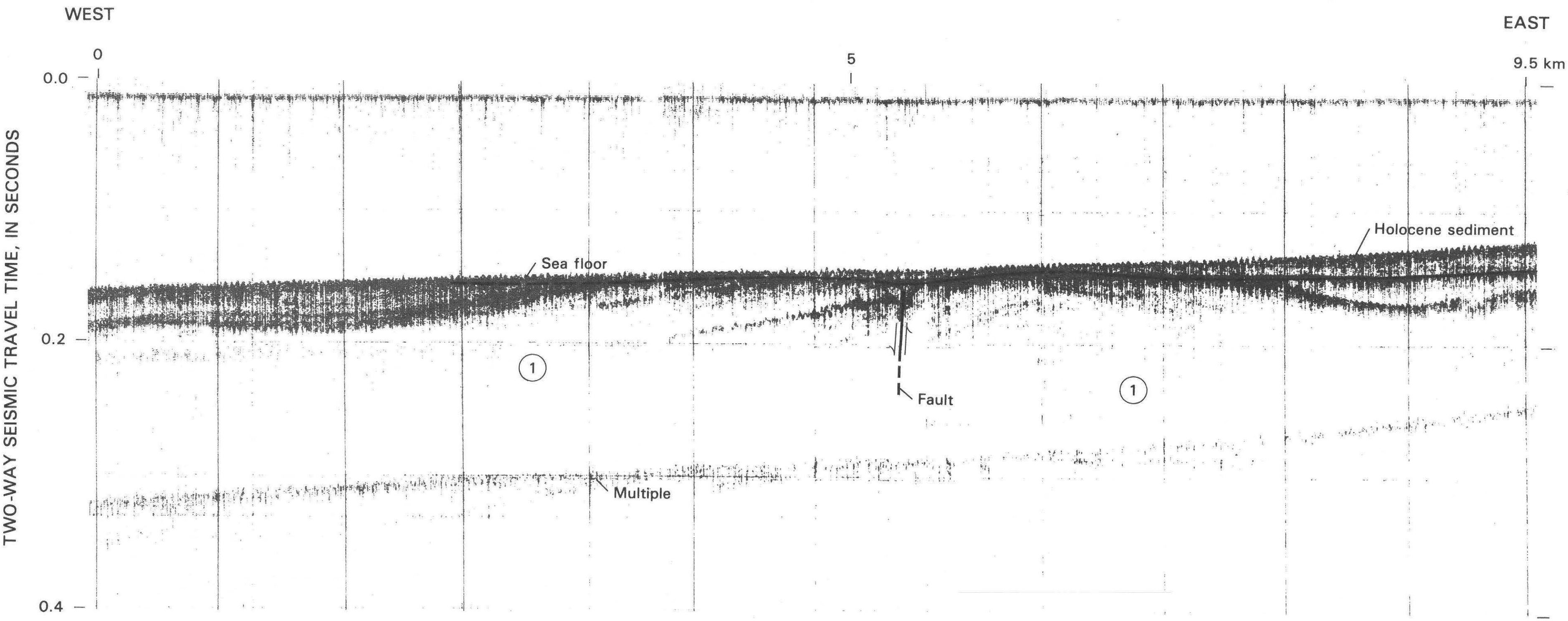

Figure 9. High-resolution seismic-reflection profile (78-32) across inner shelf north of Cape Arago. Note seaward-thinning wedge of Holocene sediment overlying acoustic unit 1; fault cuts unit 1 but not overlying Holocene sediment.

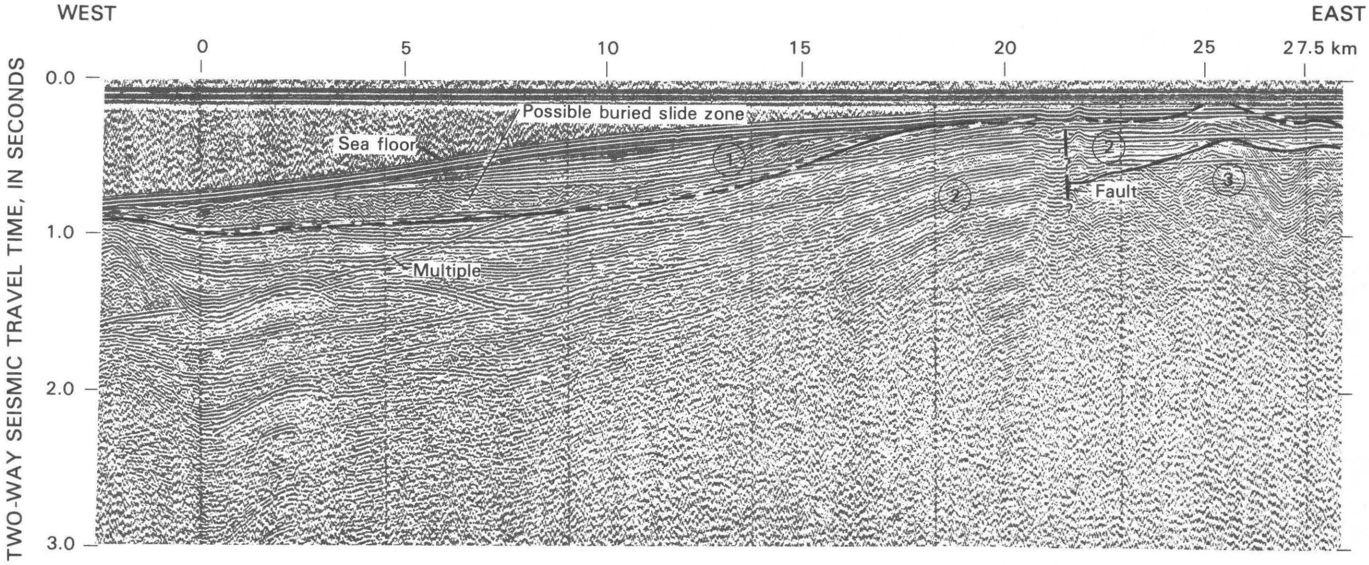

Figure 10. Deep-penetration seismic-reflection profile (78-38) across shelf and slope between Heceta Bank and Cape Arago. Note thickening of acoustic unit 1 in shallow syncline on upper slope; also note contacts between acoustic units 1 and 2, 2 and 3, and possible buried slide zone in acoustic unit 1.

Folds

The axial trend of the Coos Bay basin is approximately north (fig. 12). Fold axes in acoustic units 1 and 2 have nearly the same trend, about N.10°W. Locally, as on the upper slope west of Cape Arago, folds trend north for most of their length but swing to a more northwesterly trend (about N.40°W.) near their south end. Folds in the Coos Bay basin are 2 to 12 km in breadth (avg 5 km), and several have a mappable length of 25 km (max 40 km). Folds involving acoustic units 1 and 2 are mainly symmetrical or asymmetrical with east-dipping axial planes that suggest a principal compressive stress from the west; some folds have west-dipping axial planes. Although most folds on the Oregon continental margin appear to be of "a normal compressional type" (Braislin and others, 1971; Snavely and others, 1980), reflecting underthrusting at the continental margin, some symmetrical folds on the upper slope (fig. 11) appear to be diapiric in origin.

The outer continental shelf and slope off central Oregon have a history of Tertiary and Quaternary deformation that extends to the present time. Modern rates of uplift estimated for the Oregon continental margin range from 100 to 1,000 mm/m.y.; the most rapid rate is associated with uplift of the coastal terraces at Cape Blanco and with the uplift of abyssal deposits on the lower continental slope of central Oregon (Kulm and Fowler, 1974b; Snavely and others, 1980). Assemblages of benthic foraminifers reflect depths greater than those from which they were collected and thus indicate uplift of the enclosing rocks subsequent to deposition. The upper Miocene and lower Pliocene rocks on Heceta Bank appear to have been uplifted 900 to 1,000 m, and the middle Pliocene strata on Coquille Bank as much as 500 to 600 m (Kulm and Fowler, 1974b).

Three discrete episodes of deformation are indicated by major unconformities apparent in seismic-reflection profiles collected from the inner continental shelf (see figs. 10, 15, 16). The youngest unconformities separate acoustic units 1 and 2, and acoustic units 2 and 3; the oldest is within acoustic unit 3. These unconformities are inferred to be Pliocene-Pleistocene, early late Miocene, and middle to late Eocene in age, respectively. Angular discordance between acoustic units is greatest on the inner shelf and in the vicinity of Heceta and Coquille Banks. The area between the banks and shoreline consists of a series of generally north-trending synclines (fig. 12) filled with Quaternary sediment that onlaps folded Pliocene and older rocks on the adjacent banks and shelf (fig. 7). Some of these synclines may be superimposed on basins in older rocks. A thick sedimentary sequence beneath the outer shelf and inner continental slope is also suggested by the presence of a large negative free-air gravity anomaly (Dehlinger and others, 1968; Kulm and Fowler, 1974b).

A multichannel seismic-reflection profile across the continental shelf and slope near the south end of Heceta Bank suggests that this bank was formed by a shoreward-steepening series of thrust faults associated with east-west compression of the continental margin (Seely and others, 1974). The average strike of upper Miocene to middle Pliocene strata on Heceta Bank is N.55°E. Pleistocene strata, however, strike N.30°E., perhaps reflecting a change in the direction of subduction during Pliocene to Pleistocene time. Heceta and Coquille Banks are characterized by positive free-air gravity anomalies (Dehlinger and others, 1968), consistent with the presence of Paleogene strata at shallow depths.

Acoustic unit 2 on Heceta Bank is folded and truncated and is onlapped locally by acoustic unit 1. Deformation of the bank continued during deposition of acoustic unit 1, as this unit is folded and contains a local unconformity on the east side of the bank (fig. 7). Seismic-reflection profiles suggest that acoustic unit 3 crops out locally on the bank along the axes of anticlinal folds, although this suggestion has not been verified by sampling. Thus, our data indicate that the most recent episode of deformation on Heceta Bank began during the Pliocene (probably late Pliocene) and continued into the Pleistocene. The bank was

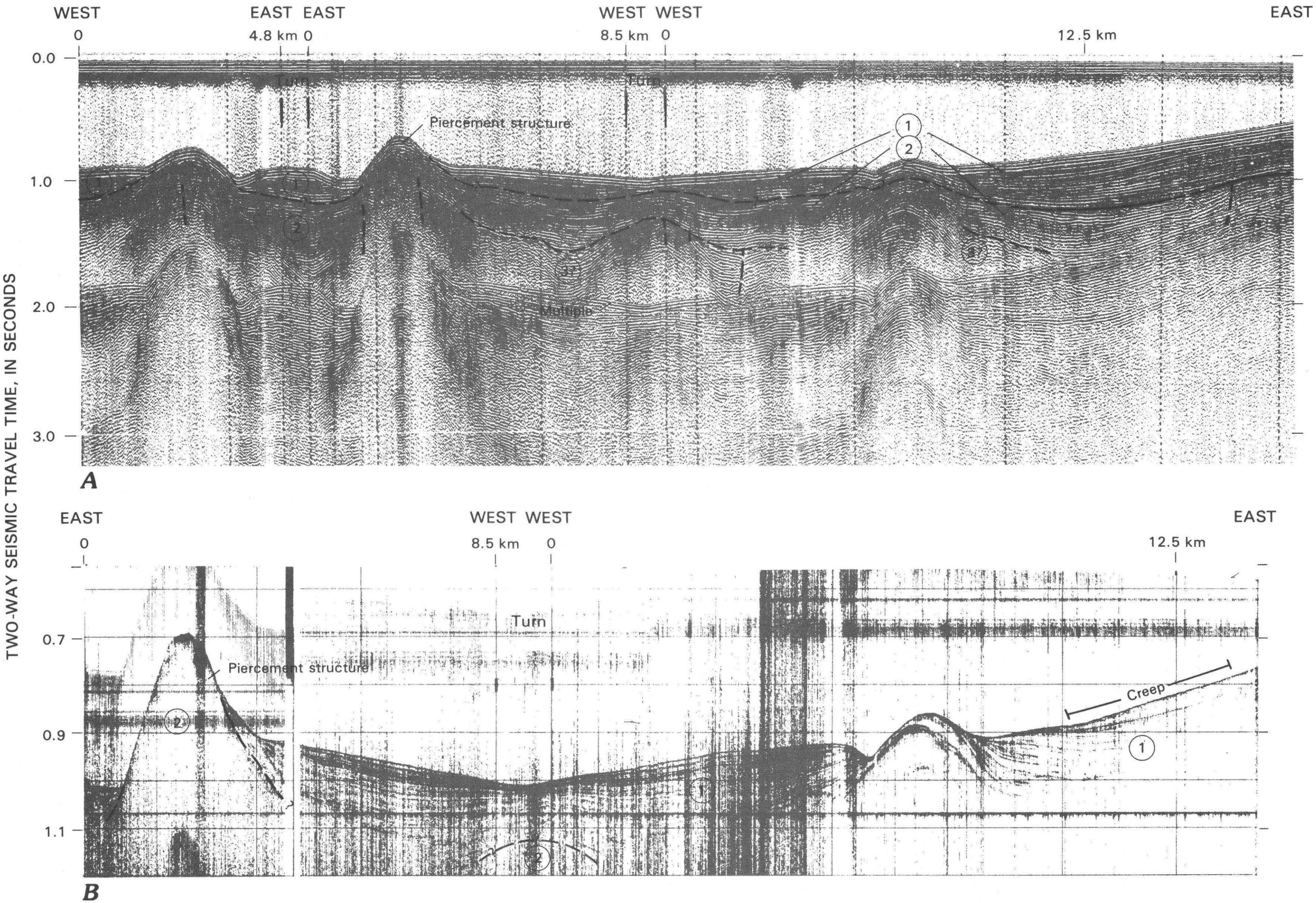

Figure 11. Deep-penetration (A) and high-resolution (B) seismic-reflection profiles (77-14) across slope northwest of Cape Arago. Note contacts between acoustic units 1 and 2, 2 and 3, and apparent creep of surface sediment at east end of high-resolution record; also note young fold with as much as 250 m of sea-floor relief and showing evidence of piercement. Two course reversals appear in figure 11A, and so diapiric fold is crossed three times; one course reversal and two crossings of diapir appear in figure 11B.

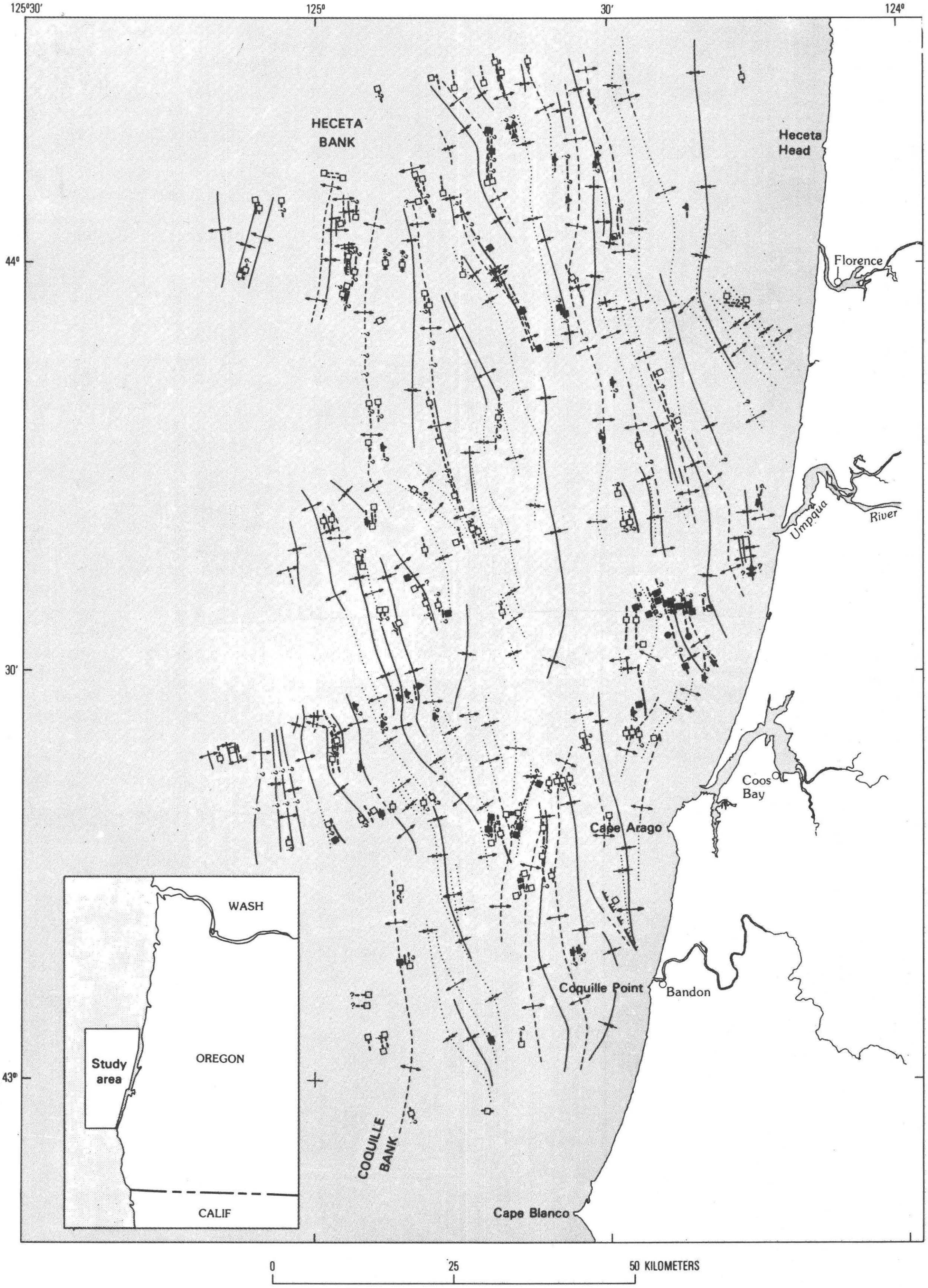

Figure 12. Structural geologic map of southern Oregon continental margin. Explanation is on next page.

EXPLANATION

FOLDS—Solid lines indicate folds that produce sea-floor relief; dashed where folds are breached at sea floor; dotted where folds are buried; queried where continuity is inferred

FAULT TRACES—Solid where well located; dashed where inferred; queried where questionable

FAULT SURFACE EXPRESSION AND AGE—Symbol appears on downthrown side of fault where relative movement could be determined; symbol centered on fault trace where movement not determined

Bars on downthrown side indicate sea-floor offset; bars centered on trace indicate fault reaches sea floor, but offset was not evident

Fault cuts sediment interpreted to be Holocene in age

Fault cuts acoustic unit 1, interpreted as Quaternary in age

Fault cuts acoustic units 1 and 2 (undifferentiated), where contact could not be determined; cuts inferred to be Pliocene and (or) Pleistocene in age

Fault cuts acoustic unit 2, inferred to be late Miocene to Pliocene in age

Fault cuts acoustic unit 3, inferred to be Eocene to middle Miocene in age

Figure 12. Continued

truncated during Pleistocene low stands of sea level and does not appear to have been uplifted substantially since that time, suggesting that the intensity of deformation diminished during the late Quaternary.

Coquille Bank is a north-trending asymmetric doubly plunging anticline. The west limb is inferred by Kulm and Fowler (1974b) to be downfaulted, on the basis of bathymetry and the absence of the thick Pliocene and Pleistocene section present on the east limb. The youngest pre-Quaternary rocks exposed in the axial parts of Coquille Bank are siltstone and claystone of middle Pliocene age (Kulm and Fowler, 1970, 1974b; Kulm, 1980). Local thinning of the lower part of acoustic unit 1 from the base by onlap onto uparched strata of acoustic unit 2 suggests that the banks had positive sea-floor relief during the deposition of acoustic unit 1 (fig. 14). Acoustic unit 1 is truncated on Coquille Bank, and strata in the upper part of this unit within the structural saddle east of the bank thin toward the west and are upwarped along the bank margin (see figs. 23, 24), a relation suggesting that deformation continued well into the time of deposition of this unit. Additionally, Coquille Bank stands 60 to 90 m above the depth that would be expected if it were beveled concurrently with the wave-cut platform on the inner shelf east of the bank (see fig. 24). This platform presumably was cut during the late Wisconsin low stand of sea level. Either Coquille Bank stood above sea level as an island and resisted erosion during late Pleistocene time—seemingly unlikely because the core of the bank consists of poorly indurated and easily eroded siltstone and claystone—or it has been uplifted differentially since the last Pleistocene low stand. The amount of Holocene uplift (60 to 90 m) suggested for acoustic unit 1 is generally consistent with previous estimates (Kulm and Fowler, 1974b) of as much as 100 m uplift of Pleistocene deposits on the outer banks based on assemblages of benthic foraminifers. These observations suggest that the latest major episode of deformation on Coquille Bank commenced during late Pliocene time, increased in intensity during Pleistocene time, and continued into Holocene time.

Piercement structures in coastal Washington with cores of Miocene siltstone were described by Rau and Grocock (1974). Snavely and others (1977) estimated that 50 to 100 such diapiric intrusions are present on the Washington and Oregon continental shelf. Several folds on the upper continental slope between Heceta and Coquille Banks appear to be recently active because they have sea-floor relief. One such fold, approximately 60 km northwest of Coquille Point, that was crossed by tracklines 77-14 (fig. 11), 78-48, and 78-49 may be diapiric in origin. This fold shows evidence of piercement and about 250 m of sea-floor relief. The lower part of acoustic unit 1 is uplifted and truncated against the east flank of

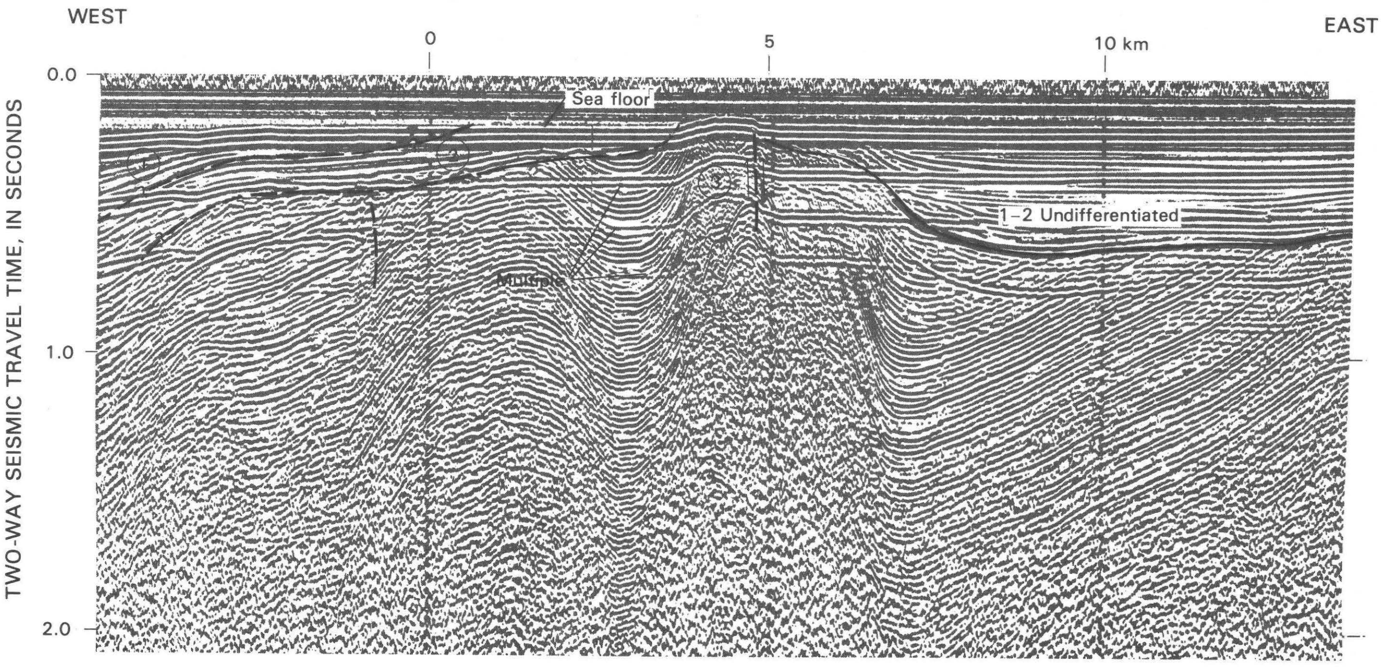

Figure 13. Deep-penetration seismic-reflection profile (78-40) across inner shelf southeast of Heceta Bank. Note breached fold in which acoustic unit 3 is exposed at sea floor.

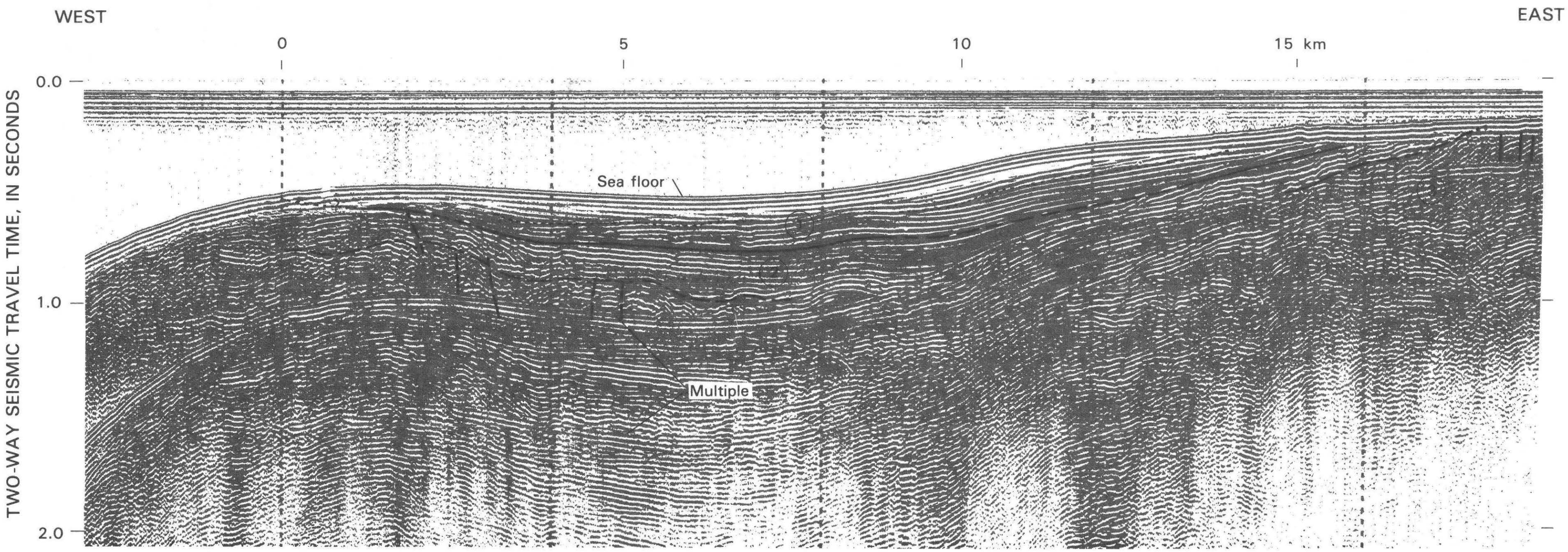

Figure 14. Deep-penetration seismic-reflection profile (77-22) across shelf and slope north of Coquille Bank. Note contacts between acoustic units 1 and 2, 2 and 3, and onlap of lower part of acoustic unit 1 (below dotted line) onto acoustic unit 2 on east flank of Coquille Bank.

the fold (fig. 11), and the upper part of acoustic unit 1, probably late Quaternary in age and the youngest sedimentary unit mapped here, thins depositionally as it approaches this feature. The core lacks coherent internal structure in seismic-reflection records, and samples indicate that it is composed of Pliocene (probably late Pliocene) mudstone (samples 14, 15, fig. 6). Uplift apparently began during Quaternary (Pleistocene) time. The great sea-floor relief, thinning of young sediment against the flanks of the fold, and absence of sediment on the crest of the fold suggest that this structure may be undergoing uplift at present.

Recent deformation without piercement or other evidence of diapirism is shown by other folds on the upper slope. For example, a fold crossed by tracklines 77-18 and 78-30 (fig. 4) 20 to 25 km south of the piercement structure described above shows as much as about 150 m of sea-floor relief. Acoustic unit 1 thins abruptly and is upturned along the east flank of this fold, and it is absent from the fold crest (figs. 15, 16). This deformation appears to be wholly of Quaternary age.

Faults

Although Quaternary faults are not so common as in the northern California continental margin, several have been mapped from seismic-reflection records in the vicinity of the offshore Coos Bay basin. Snavely and others (1977, 1980) noted that many north-trending faults on the Oregon coast offset geologically youthful strata and may be part of a north-trending group of faults mapped on seismic records from the inner shelf. Kulm and Fowler (1974b) suggested that the steep linear escarpments west of Heceta and Coquille Banks are fault controlled. Most of the faults mapped during this study cannot be correlated with certainty between adjacent seismic-reflection lines (fig. 12). A few faults, however, can be traced between two adjacent lines, a distance of 5 to 8 km, and several can be traced for as much as 12 to 15 km. Faults that terminate in acoustic unit 1, inferred to be Quaternary, and those that terminate in acoustic unit 2, inferred to be late Miocene and Pliocene, are about equal in number. Those faults cutting acoustic unit 2 are generally evenly distributed on the middle to inner continental shelf, upper slope, and banks, whereas those cutting acoustic unit 1 are most common on the shelf and bank tops. Faults on the inner shelf and bank tops commonly trend between N.30°W. and north; on the upper slope, faults terminating in acoustic unit 2 have trends between about N.15°W. and N.5°E.

A group of faults trending slightly west of north cuts acoustic unit 1 on the inner continental shelf about 15 to 25 km north of Cape Arago (figs. 9, 12, 17). One 13-km-long fault of this group cuts deposits of presumed Holocene age, and several others may reach the sea floor. Further study of faults in this area is warranted as they appear to have been active during Quaternary time and are near the Coos Bay-North Bend-Empire area.

Acoustic unit 1 is cut by a fault (fig. 18) with possible major displacement on the southeast side of Heceta Bank (Kulm and Fowler, 1974b). This fault trends N.30°W., is downthrown to the northeast, and is at least 15 km long (fig. 12). It and the cluster of faults north of Cape Arago have the same apparent age and trend; although those faults have not been traced between Cape Arago and Heceta Bank, the similarity in style of faulting suggests that they may be part of the same fault system.

South-southwest of Cape Arago, acoustic unit 2 is cut by a fault with a substantial vertical offset (fig. 19). This fault trends about N.30°W., is downthrown to the east, and has sea-floor expression that suggests recent movement.

The Port Orford shear zone, a north-northwest-trending fault zone as much as 3 km wide that shows evidence of right slip, extends offshore from a point just northeast of Cape Blanco (Dott, 1962, 1965, 1971; Koch, 1966). This zone was active in post-middle Eocene and post-Miocene time. Pliocene and (or) Pleistocene activity on this fault zone is suggested by a possibly related north-trending fault at Cape Blanco that juxtaposes lower Pliocene marine sandstone with Mesozoic and Eocene strata and is capped by Pleistocene marine-terrace deposits (Dott, 1971). Recent tectonic activity in the Cape Blanco-Coos Bay area is also indicated by uplifted and faulted marine terraces of Pliocene and Pleistocene age (Janda, 1969). Dott (1979) proposed that the Port Orford shear zone and similar northwest-trending, approximately echelon shear zones that cut the Pacific margin of Oregon and northern California are part of the east boundary of the "Humboldt plate" (Herd, 1978). This plate, possibly more appropriately termed the "Humboldt block," is a narrow intracontinental structural block situated at the complex boundary between the North American, Pacific, and Gorda crustal plates; its proposed east boundary comprises a series of northwest-trending strike-slip faults.

The offshore extension of the Port Orford shear zone was not identified in this study. Although Mackay (1969) may have crossed this zone about 10 km north of Cape Blanco, he speculated that it is covered by post-Miocene strata farther northwest on the shelf. However, shear associated with this zone may also be transferred to other northwest-trending faults in the offshore, such as those mapped during this study north of Cape Arago and on Heceta Bank that show evidence of Quaternary offset. Such a transfer of shear between echelon faults would accord with Herd's (1978, p. 725) observation that the line of faults forming the east boundary of the "Humboldt plate" is so young geologically "that there has been insufficient time to integrate the fault zones into a single surficial break." The possible existence in the Coos Bay basin of a zone of echelon strike-slip faults forming the boundary of a major structural block has obvious import to offshore development in the area. Tectonic activity associated with such a zone would probably be low in comparison with that farther south, judging from the present low level of seismicity and tectonic activity associated with the boundary between the Juan de Fuca and North American plates (Smith and Knapp, 1980). Nonetheless, additional study is required to determine the style and significance of Quaternary faults in the Coos Bay basin, their relation

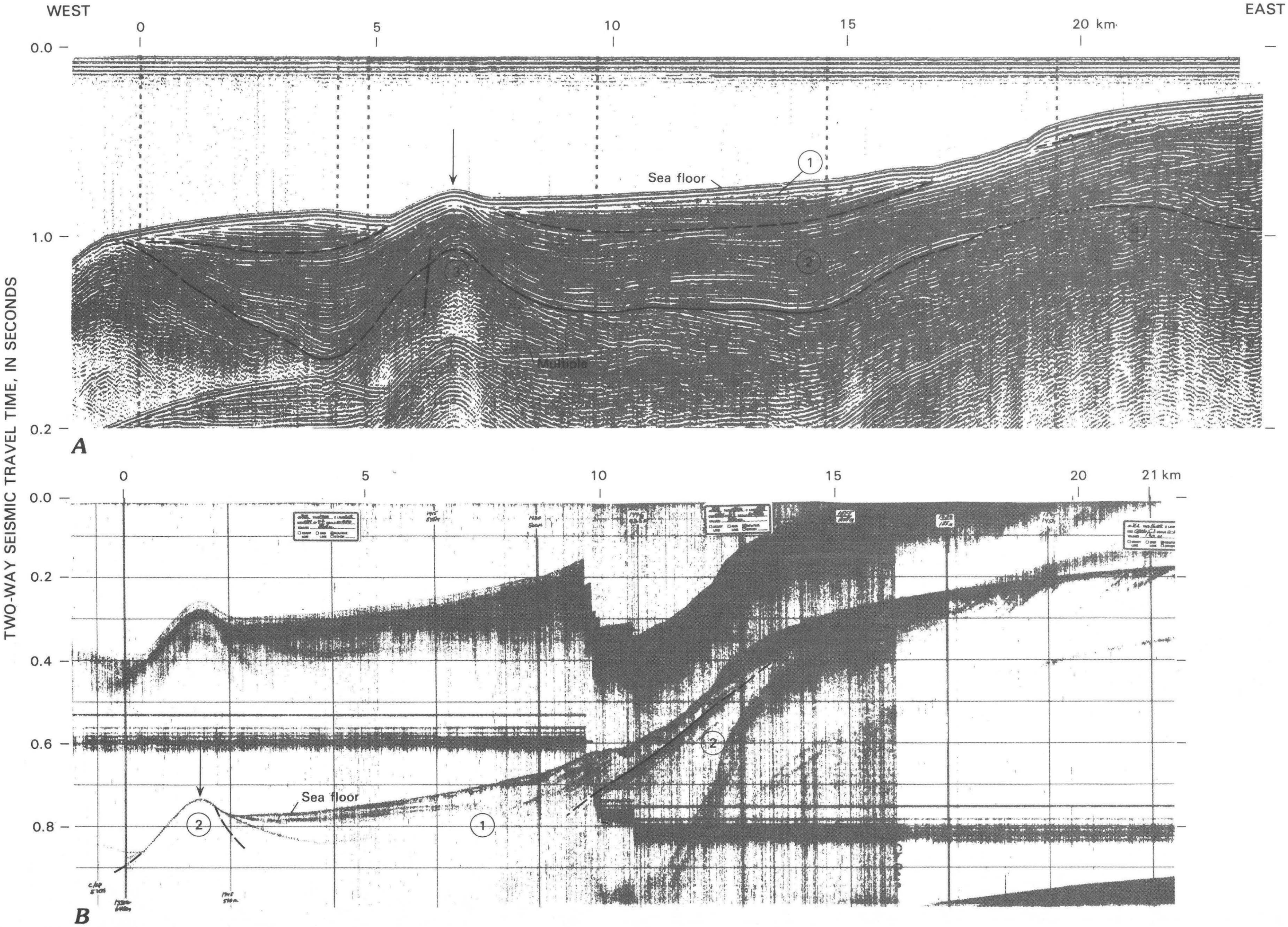

Figure 15. Deep-penetration (A) and high-resolution (B) seismic-reflection profiles (77-18) across shelf and slope west of Cape Arago. Note contacts between acoustic units 1 and 2, 2 and 3, and youthful (active?) fold (arrows); also note apparent depositional thinning of unit 1 against flanks of this fold.

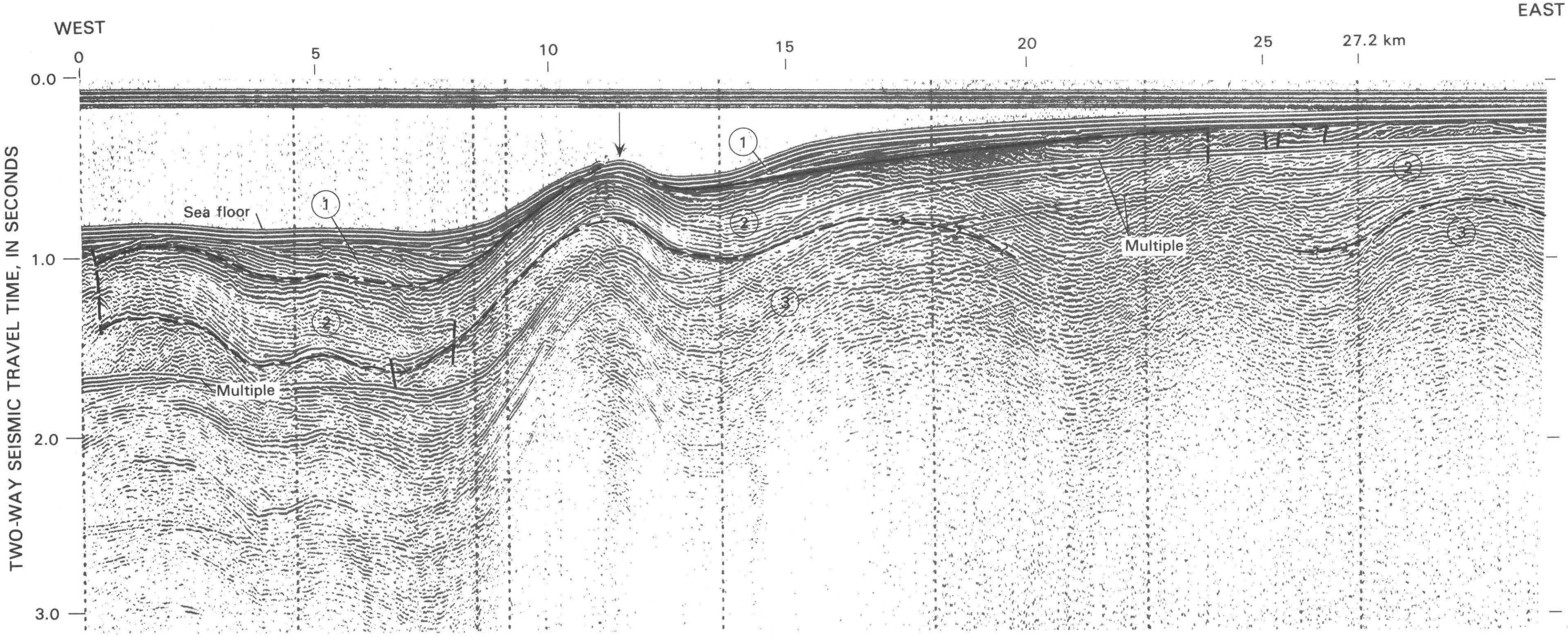

Figure 16. Deep-penetration seismic-reflection profile (78-30) across shelf and upper slope west of Cape Arago. Note contacts between acoustic units 1 and 2, and 2 and 3; also note evidence of youthful (active?) fold (arrow), and apparent depositional thinning and deformation of acoustic unit 1 along flanks of this fold.

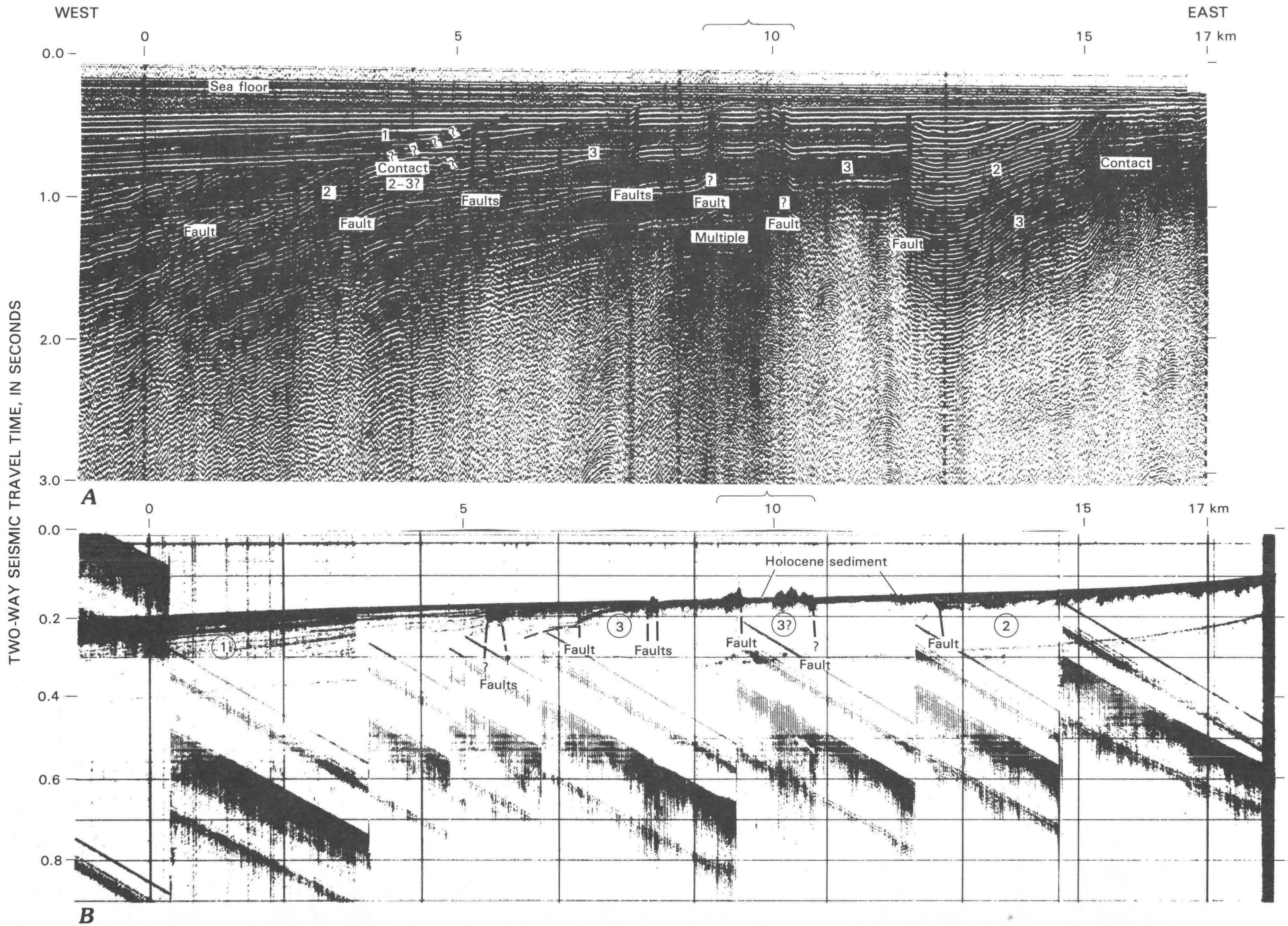

Figure 17. Deep-penetration (A) and high-resolution (B) seismic-reflection profiles (77-14) across inner shelf north of Cape Arago. Note series of faults extending to, or near, sea floor in acoustic units 1 and 2. Acoustic unit 3 may crop out on sea floor in the area indicated by the brackets.

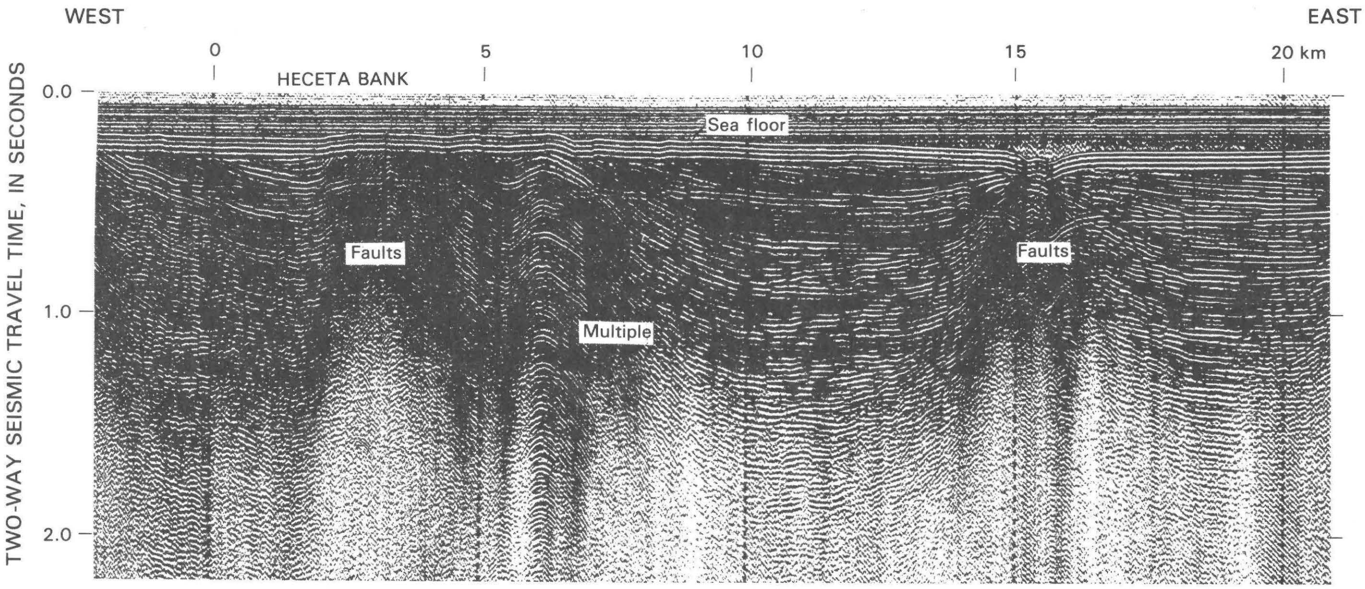

Figure 18. Deep-penetration seismic-reflection profile (77-06) across southeastern Heceta Bank and adjacent shelf. Note faults extending to sea floor in acoustic unit 1.

to the Port Orford and similar shear zones farther south, and the relation of these zones to the "Humboldt plate."

SEISMICITY

Oregon is less active seismically than other Pacific coast States and has no record of major earthquake destruction. The record of seismic events, however, extends back only to the late 1800's and thus is too short to be an accurate predictor of future earthquake size or frequency.

The major seismic zones in this region lie 200 to 300 km or more off the coast of southern Oregon and northern California and are related to a series of growing oceanic ridges connected by transform faults. Plots of epicenters recorded conventionally from the Northeast Pacific for the period 1954-63 show that earthquake activity off northern California and Oregon is located along the Gorda Ridge, the Mendocino Fracture Zone east of the Gorda Ridge, the Blanco Fracture Zone between the Gorda and Juan de Fuca Ridges, and within the Gorda Basin (fig. 2) (Bolt and others, 1968; Tobin and Sykes, 1968; Couch, 1980; Smith and Knapp, 1980). Relatively little seismic activity is associated with the Juan de Fuca Ridge or with the continental margin of Oregon north of Cape Blanco (Couch, 1980). A plot of 1,025 events recorded by hydroacoustic methods reveals a concentration of epicenters along the Gorda Ridge and the Blanco Fracture Zone (Northrup and others, 1968). Fault-plane solutions for the Blanco Fracture Zone, the Gorda Basin, the Gorda Escarpment, and the Cascadia Basin (fig. 2) are consistent with right slip along southeast-trending faults; those for the Gorda Ridge are consistent with normal faulting along a plane parallel to the ridge (Couch and Pietrafesa, 1968; Tobin and Sykes, 1968). These solutions suggest that the regional seismicity is dominated by spreading at the Gorda Ridge, accompanied by displacement along dextral transform faults (Blanco and Mendocino Fracture Zones) and by underthrusting at the northern California-southern Oregon continental margin. Right-lateral motions in the Gorda Basin may reflect the transfer of motion by transcurrent faulting from the San Andreas fault across the basin to the Blanco Fracture Zone (Bolt and others, 1968). The low level of seismic activity associated with the Juan de Fuca Ridge and the absence of an oceanic trench and Benioff zone along the continental margin of central-northern Oregon and Washington suggest that subduction is episodic.

The locations of earthquakes that occurred during the period 1841-1975 in the area extending from lat 42°30' to 44°10' N. and from long 124°00' to 126°00' W. are plotted on figure 20. Location accuracy of earthquakes in this region before 1962 is estimated at 8 km. Since 1963, five recording stations in Oregon (Corvallis/OSU, Portland/OMSI, Klamath Falls/OTI, Blue Mountain/NOS, and Pine Mountain/UO-NASA) and improved traveltime curves have reduced the average uncertainty to about 4 km for earthquakes of $\underline{M}$ 3.5 (Couch and Lowell, 1971). Reported depths of earthquakes in Oregon indicate shallow foci, although data are scant. Several workers estimate an average focal depth of 5 to 15 km for earthquakes in that part of Oregon west of the Cascade Range (Couch and Lowell, 1971). Focal depths of earthquakes associated with the Gorda Ridge and the Blanco Fracture Zone are largely unknown but are considered to be shallow—approximately 5 km (Brune, 1968).

Only one earthquake has been recorded within the offshore Coos Bay basin and none has been recorded for more than 100 years within the adjacent coastal area (fig. 20; Schlicker and Deacon, 1974; Beaulieu and Hughes, 1975). Beaulieu and Hughes (1975), however, suggested that the earthquake potential for the area surrounding and south of Coos Bay is at least moderate and that earthquakes of modified Mercalli intensity (MMI) V to VII are to be expected. The total seismic-energy release in the western Oregon Coast Range province for the 100-year period from 1870 to 1970 has been computed as approximately equivalent to one $\underline{M}$ = 5.0 earthquake per decade (Couch and Lowell, 1971). The maximum MMI reported for an earthquake in this region is VI,

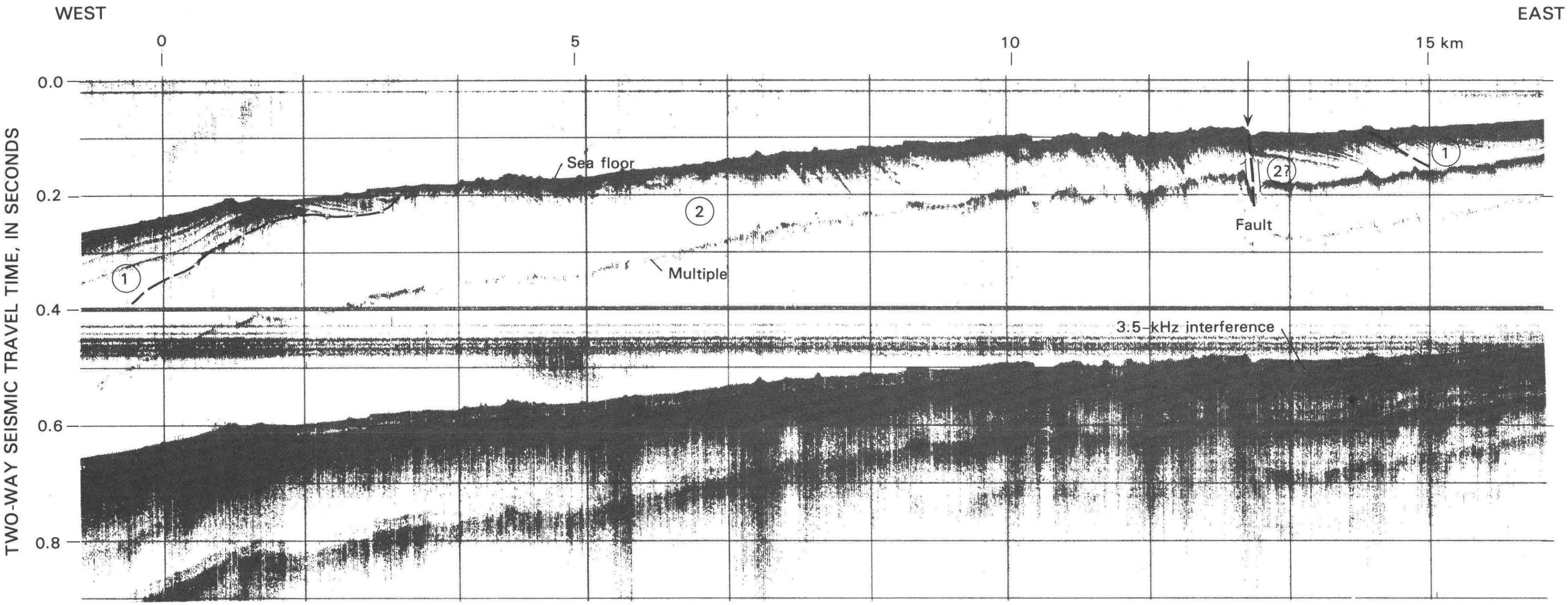

Figure 19. High-resolution seismic-reflection profile (77-22) across shelf southwest of Cape Arago. Note fault (arrow) in acoustic unit 2 that offsets sea floor. Also note apparent onlap of acoustic unit 1 onto unit 2, and deformation of unit 1 on shelf edge at west side of record.

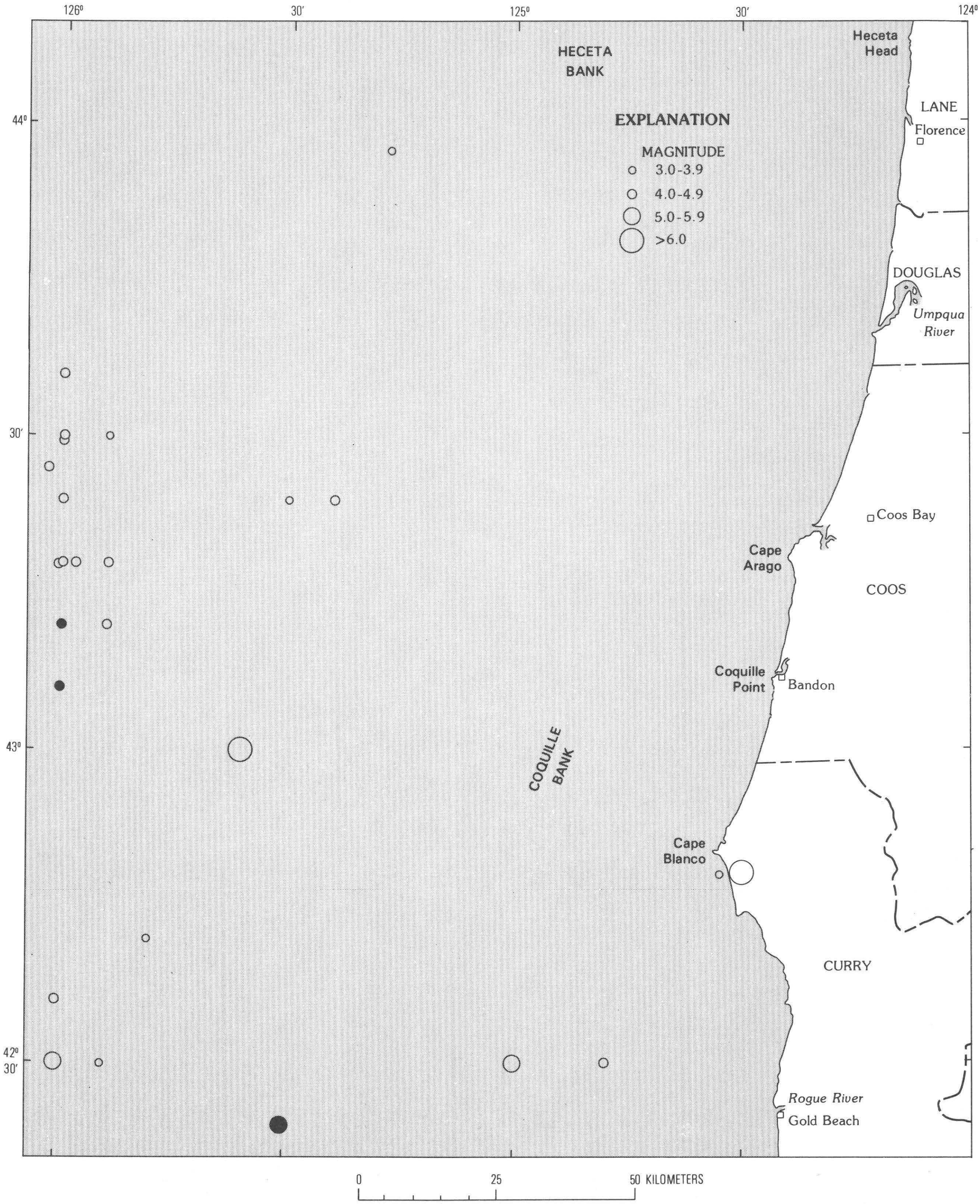

Figure 20. Sketch map of southern Oregon continental margin, showing locations and magnitudes of seismic events. Dots from NOAA Earthquake Data File, 1841-1975 (NGSDC); circles from Couch and others (1974).

and the corresponding expected maximum ground acceleration is 31.6 cm/s^2. Although the offshore Coos Bay basin is devoid of epicenters for the period 1841-1974, the Port Orford earthquake of 1973, centered near Cape Blanco, had a magnitude of about 6.3 (computed from observed intensity). An earthquake of $\underline{M}$ = 6.0, centered at sea about 90 km west of Cape Blanco, was recorded in 1938 (fig. 20; Couch and others, 1974).

The possibility of damage resulting from an earthquake in adjacent areas, notably the northern California continental margin, should be considered in an assessment of the geologic hazards to development in the Coos Bay basin. The effects, other than ground motion, of such earthquakes may include sea-floor mass movement, liquefaction, differential subsidence, and tsunamis. Couch and Deacon (1972) indicated that the recurrence interval of an $\underline{M}$ = 8.0 earthquake in the Gorda Basin is 130 years, and earthquakes as large as $\underline{M}$ = 7.3 have been recorded along the Mendocino Escarpment. A 1922 earthquake of $\underline{M}$ = 7.3 (calculated maximum intensity X) centered in the Gorda Basin about 90 km northwest of Cape Mendocino (Couch and others, 1974) had an MMI of V in Coos Bay; Beaulieu and Hughes (1975), assuming similar attenuation of seismic waves, estimated that the "largest possible" earthquake along the Mendocino Escarpment would generate an MMI of VII in the Coos Bay area and that the corresponding ground acceleration would be less than 0.10 $\underline{g}$ (48.8 cm/s^2).

SEA-FLOOR INSTABILITY

Sea-floor instability here refers to conditions that result from sea-floor failure due to mass movement, liquefaction, or tectonic deformation of sea-floor sediment. Potentially unstable sea-floor conditions identified in the offshore Coos Bay basin are associated with subaqueous sediment slides (both surficial and buried), sediment creep, active uplift and possible diapirism, accumulations of shallow gas, and possible gas hydrates. Additional information concerning instability in the coastal area adjacent to the Coos Bay basin, and the engineering properties of geologic units exposed in this region, is contained in the reports by Schlicker and Deacon (1974) and Beaulieu and Hughes (1975).

Sediment Slides, Flows, and Creep

Subaqueous slides are mass movements of rigid or semiconsolidated masses along discrete shear surfaces, with relatively little internal deformation (Dott, 1963). Slides are commonly identifiable on seismic-reflection records by the presence of some or all of the following major characteristics: (1) A head-scarp where the slip surface extends upward to the sea floor, (2) compressional ridges and folded and contorted subbottom reflectors resulting from small-scale thrusting and folding at the toe of the slide, (3) transverse (tensional) cracks in the body of the slide, (4) evidence of rotation with limited internal deformation of reflectors, and (5) the presence of a slip surface, which may be concave upward or planar, represented by a discrete failure plane or by an intensely deformed zone beneath the slide mass. The term "slump" is commonly applied to a slide that shows evidence of rotational movement along a curved slip surface. Subaqueous slides have been documented on slopes of less than 1° and range upward in size from simple failures covering tens of square meters to composite failure zones thousands of square kilometers in area and hundreds of meters thick (Moore, 1961; Heezen and Drake, 1964; Lewis, 1971; Hampton and Bouma, 1977). Subaqueous mass flows involve the gravitational downslope movement of water-saturated unconsolidated sediment; the moving mass may behave plastically or as a highly viscous fluid, and movement may be slow or rapid (Dott, 1963). The velocity and displacement of flow characteristically decrease with depth below the sea floor, so that the deposit lacks a distinct slip surface. Subaqueous-flow deposits are identifiable on seismic-reflection records by (1) the presence of anomalously thick sediment masses apparently detached from underlying strata, (2) the absence of an identifiable slip plane, and (3) acoustic transparency or chaotic internal structure. Sediment creep in the marine environment is a poorly understood and poorly documented phenomenon. As used here, this term refers to the slow more or less continuous downslope movement of the upper layers of unconsolidated sediment. The occurrence of creep is inferred from seismic-reflection records by the presence of hummocky sea-floor topography, deformed but identifiable acoustic bedding in the upper sediment layers, a downward decrease in the degree of deformation, and the apparent absence of a slip surface. Creep may affect large areas and is commonly associated with other types of failure. Zones of past sea-floor failure should be viewed as having an unknown potential for renewed movement. Some of these zones may have become more stable as a consequence of having failed, whereas others may have unchanged or even reduced stability. Consequently, the geologic and engineering properties of zones of past failure and of adjacent deposits require study on a case-by-case basis.

Few areas of modern sea-floor mass movement were identified in seismic reflection records from the offshore Coos Bay basin (fig. 21). This is surprising considering the large areas of sea-floor failure present about 100 km south in the Eel River basin (Field and others, 1980), a geologic setting that is similar in many respects to the Coos Bay basin, and also considering the locally thick accumulations of Quaternary sediment (see fig. 27) in the basin on relatively steep (2°-4°) slopes. The very high rate of sediment influx from the Klamath and Eel Rivers and the more active seismic environment of the northern California region may be responsible for the abundance of modern slope failures in that area. Failures may also be more prevalent on the middle to lower continental slope west of the study area, where thick sections of faulted upper Tertiary and Quaternary sediment are present and slopes of 7°-14° are common. In addition, peat and devitrified volcanic ash, both of which are present in Cenozoic deposits onshore and on the continental shelf, may contribute to failure by reducing shear resistance. It is noteworthy that ground failure is common in water-saturated upper Tertiary and Quaternary deposits along the Oregon coast and on

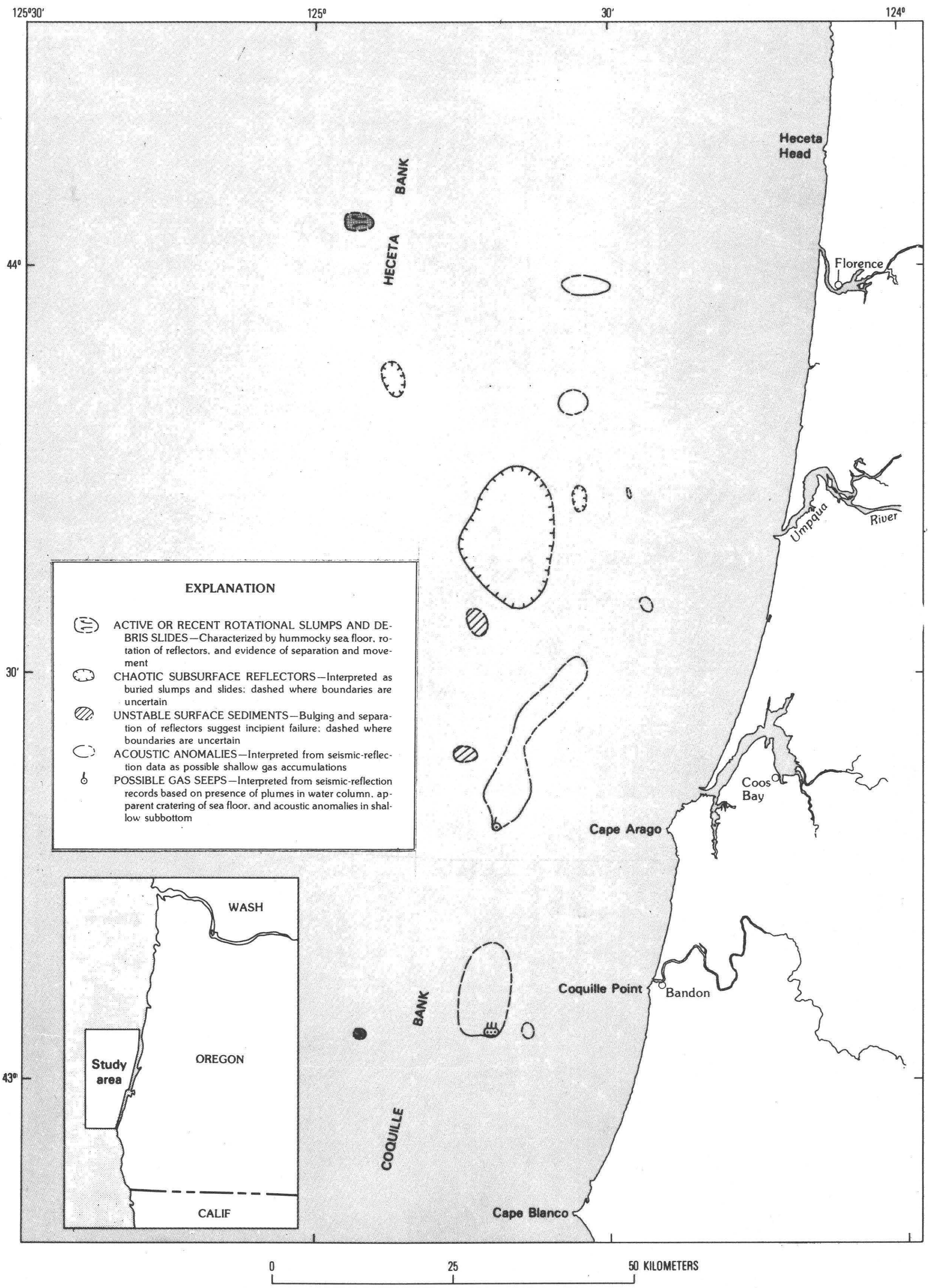

Figure 21. Sketch map of Coos Bay basin, showing areas of sea-floor failure, hydrocarbon seepage, and shallow gas accumulation.

steep slopes elsewhere in the Oregon and Washington offshore region.

Slides were identified in the Coos Bay basin on the west flanks of Heceta Bank and Coquille Bank (fig. 21), areas having relatively steep slopes but generally lacking thick deposits of Quaternary sediment. These slides occur in water depths of 150 to 450 m and 700 to 900 m, respectively, and each is about 15 m thick. The deposit west of Heceta Bank appears to be a rotational slump about 4 km long (fig. 7), and the deposit west of Coquille Bank is a slide of undetermined type about 2 km across.

Two areas of possible sediment creep were mapped on slopes at depths of 500 to 600 m. The southern area appears to be about 3.5 km long and has a zone of disturbance extending about 10 m below the sea floor. This area of creep may be superimposed on an older buried slide, and so the unstable zone could extend considerably deeper. The northern area, 40 km northwest of Cape Arago, is crossed by two seismic lines. The disturbed zone is about 2.8 by 4 km, and extends to a depth of 5 to 8 m below the sea floor (fig. 11).

Buried zones of chaotically disrupted (broken and rotated) reflectors stratigraphically low in acoustic unit 1 were identified in the central part of the basin south of Heceta Bank (fig. 21). Similar zones have been mapped in the Eel River basin (Field and others, 1980), where they are associated with extensive modern slump deposits which they resemble in acoustic character. These buried failure zones are interpreted as slides in Quaternary sediment, possibly associated with rapid sediment influx during a low stand of sea level in Pleistocene time. The largest zone (fig. 10) is in central Coos Bay basin below the edge of the modern shelf at water depths of 250 to 600 m; it is nearly 20 km long and 13 km wide at its widest point, and covers an estimated area of 190 km^2. Reflectors in the lower part of this zone are backrotated, and the degree of disruption of reflectors increases downslope. The upper surface of the zone ranges from 150 to 300 ms in acoustic depth below the sea floor (equivalent to a subbottom depth of about 125-250 m, at an assumed velocity of 1,650 m/s), and the zone is as much as 250 to 300 ms (about 200 to 250 m) thick. Smaller zones of disrupted subsurface reflectors occur south of Heceta Bank and east of the buried slump area described above. These areas, which are crossed by only one seismic line each, are 5 and 2 km across, respectively.

Areas of Uplift

Several folds that show sea-floor relief on the upper continental slope between Heceta and Coquille Banks appear to be active; one of these folds, 60 km northwest of Coquille Point, shows evidence of piercement (figs. 11, 12; see subsection above entitled "Folds"). The uppermost (youngest) strata of acoustic unit 1 thin depositionally and are deformed against the flanks of these features and are absent from their crests. Subjacent strata are uparched over the folds, and sea-floor relief of as much as 250 m is apparent on seismic-reflection profiles (figs. 11, 15, 16). Piercement occurs locally along the axis of a fold about 45 km northwest of Cape Arago (fig. 11). The core of this fold is acoustically incoherent, and the irregularity of topography on the ridge crest, where core material is exposed, is consistent with recent flowage. Samples of sheared olive-gray mudstone of Pliocene (probably late Pliocene) age were obtained from the ridge crest (samples 14, 15, fig. 6). Uplift here apparently commenced in Quaternary time and may be presently active.

Diapirism has been documented from the northern California continental margin (Field and others, 1980; Field and Gardner, 1980), and diapiric intrusions are thought to be abundant on the Washington and Oregon continental shelf (Snavely and others, 1977) and along the Washington coast. In the latter area, Pliocene strata are intruded locally by a pervasively sheared melange of volcanic and sedimentary rocks in a mudlike matrix of clay and siltstone fragments which contain Miocene foraminifers (Rau and Grocock, 1974). The association of gas seeps and abnormally high subsurface gas pressures with the coastal Washington intrusions suggests that diapirism there is associated with overpressured zones in the subsurface. Geochemical analyses for hydrocarbon gases were performed on four sediment samples collected on and adjacent to the piercement structure mapped in the offshore Coos Bay basin; these analyses did not reveal evidence of gas leakage into near-surface sediment (fig. 22; samples 15G, 16G, 17G, and 18G, table 1; Kvenvolden and Rapp, 1981). However, a sample from Quaternary sediment ponded on the crest of a piercement structure in the offshore Eel River basin of northern California contained anomalously high concentrations of high-molecular-weight hydrocarbon gases and gasoline-range hydrocarbons (Field and others, 1979; Kvenvolden and others, 1980). These gases are interpreted to have had a thermogenic origin within the underlying Neogene sedimentary section and to have leaked through fractures into unconsolidated sediment ponded locally on the ridge crest. This occurrence of thermogenic hydrocarbons in the Eel River basin and the association of gas seepage with diapirism in coastal Washington suggest that further sampling of diapiric structures might also reveal the presence of thermogenic hydrocarbons in the offshore Coos Bay basin.

These youthful folds clearly reflect recent tectonic instability and thus merit careful study. Their potential as hazards to offshore development, however, cannot be assessed without additional information concerning their distribution, manner of emplacement, rate and style of uplift, relation to overpressured zones, and association with other forms of sea-floor instability.

Shallow Gas Accumulation

Natural gas of biogenic and thermogenic origin may be present in marine sediment. Biogenic gas, principally methane, is derived from bacterial alteration of organic material in the sediment (Claypool and Kaplan, 1974). Thermogenic gas, containing methane as well as heavier hydrocarbon gases, is a byproduct of petroleum formation (Bernard and others, 1976). The

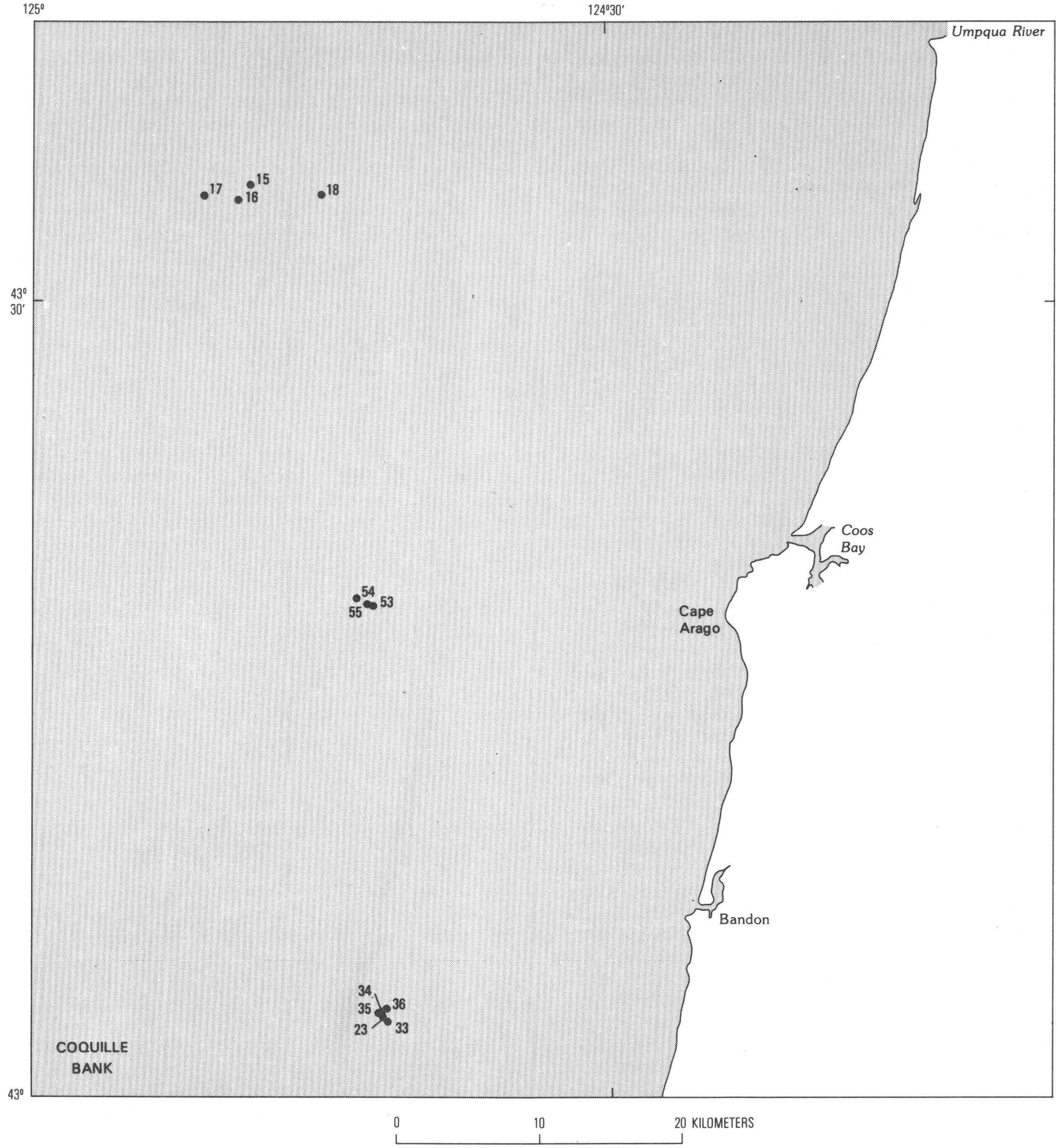

Figure 22. Sketch map of Coos Bay basin, showing locations of cores analyzed for hydrocarbon-gas content.

presence of thermogenic gas in sediment can reflect an overpressured (that is, in excess of hydrostatic pressure) zone that is discharging gas into the overlying strata either directly or by way of a conduit such as a fault or bedding plane. Inadvertent penetration of an overpressured zone or gas-escape conduit accompanied by sudden venting of gas at the surface can pose a hazard to drilling operations. Additionally, gas of either type present as bubbles in the pore space of unconsolidated sediment can reduce the shear strength of the enclosing sediment, thereby increasing the likelihood of failure; under some circumstances gas-charged sediment can liquefy spontaneously when subjected to cyclic loading, as from earthquake shaking (Hall and Ensiminger, 1979). Consequently, the identification of areas of possible shallow gas accumulation is an important adjunct to studies of sediment instability in the offshore.

Table 1. Hydrocarbon gases in sediment, offshore Oregon

[From Kvenvolden and Rapp (1981)]

Station and sample	Interval (cm)	Water depth (m)	Concentrations in wet sediment (nL/L) C_1	C_2	$C_{2:1}$	C_3	$C_{3:1}$	$i-C_4$	$\underline{n}-C_4$	$\frac{C_1}{C_2+C_3}$
			1977							
15G	0-10	543	2,060	95	82	67	126	7	18	13
15G	50-60	543	397	--	--	--	--	--	--	--
15G	100-110	543	80	--	--	--	--	--	--	--
16G	0-10	679	42	--	--	--	--	--	--	--
16G	50-60	679	3,930	70	88	49	98	7	11	33
16G	100-110	679	418	--	--	--	--	--	--	--
16G	150-160	679	28	--	--	--	--	--	--	--
16G	200-210	679	5,650	32	22	15	42	--	--	120
17G	0-10	675	1,740	45	82	43	84	--	--	20
17G	100-110	675	3,341	35	28	21	59	--	--	59
17G	200-210	675	251	--	--	--	--	--	--	--
18G	0-10	610	1,040	22	35	18	66	--	--	26
18G	100-110	610	306	--	--	--	--	--	--	--
18G	200-210	610	271	--	--	--	--	--	--	--
23G1	0-10	157	2,900	56	53	36	120	10	10	31
23G1	65-75	157	11,000	59	31	24	82	7	3	132
23G3	0-10	157	5,010	106	43	54	120	17	17	31
23G3	18-28	157	4,480	106	50	48	113	14	14	29
			1979							
33G1	44-54	150	12,500	153	40	57	75	11	15	60
33G3	76-86	149	1,950	26	37	14	59	0	0	49
34G1	65-75	150	3,610	96	49	42	79	11	16	26
34G2	65-75	150	85,700	808	35	50	63	10	12	100
35G1	42-52	150	1,980	43	31	13	72	0	0	35
36G1	77-87	150	8,810	82	44	49	94	9	14	67
53G1	100-110	217	5,830	37	21	19	48	0	0	100
53G2	100-110	213	6,480	26	24	12	57	0	0	170
54G1	140-150	259	36,200,000	4,270	34	130	37	66	14	8,200
[1]54G1	225-235	259	31,000,000	3,180	53	142	60	80	12	9,300
54G2	140-150	260	17,800	1,860	31	165	56	43	12	9
54G2	219-229	260	25,300,000	2,520	46	134	0	59	13	9,500
54G3	140-150	259	4,510,000	3,870	18	194	57	59	12	1,100
[1]54G3	255-265	259	35,000,000	2,990	18	98	50	75	15	11,000
55G	113-123	237	119,000	1,280	77	62	102	0	0	89

[1]Isotope sample taken.

Gas in sediment is inferred from medium- and high-resolution seismic-reflection records on the basis of one or more of the following criteria: (1) Amplitude anomalies, apparent as enhanced or "bright" subbottom reflectors, that denote significant acoustic velocity contrasts (fig. 8); (2) the sharp termination or apparent displacement of reflectors, commonly associated with acoustically turbid zones; (3) the absence of surface multiples, indicating absorption of the acoustic signal (Nelson and others, 1978) and (4) the presence in reflectors of "pulldowns," apparent depressions resulting from the decreased velocity of sound in gaseous sediment and consequent delayed arrivals of acoustic returns. Side-scan sonographs and underwater video or photographic coverage can show seep mounds or craters on the sea floor and gas bubbles in the water column. In all cases, sampling and geochemical analyses are needed to verify the presence of gas and identify its origin.

Areas of inferred shallow gas accumulation in the Coos Bay basin range in size from about 0.5 km across (crossed by a single line) to as much as about 120 km^2 (fig. 21). The largest zones, 20 to 25 km west of Cape Arago and Coquille Point, lie in areas of Quaternary sedimentation on the lower shelf and upper slope, at water depths ranging from 135 m to about 400 m (fig. 21). Sampling was conducted in these two large areas and on and adjacent to the piercement structure northwest of Cape Arago (see fig. 22) to determine if gas is present in sea-floor sediment and, if so, to identify its origin. The analytical procedures and results of this sampling program were reported by Kvenvolden and Rapp (1981); table 1 summarizes the results.

Several mapped areas of gas-charged sediment are associated with faults that cut Quaternary deposits. One such area, 22 to 23 km southwest of the mouth of the Umpqua River (fig. 21), appears to be bounded on the east and west by faults (fig. 12). Seepage in an area west of Coquille Point appears to reach the surface along a fault that cuts the Quaternary section (figs. 23, 24). Depth below the sea bottom of the upper surface of the gassy zones ranges from 10 to 40 ms (approx 8 to 33 m) and averages about 24 ms (approx 20 m). The sea floor 20 to 25 km southwest of Coquille Point appears to be cratered where the apparent gassy zone extends to the surface, and high-resolution seismic-reflection records suggest bubbles in the water column above the crater (fig. 24). A side-scan sonograph taken in this area appears to show a northwest-trending linear crater field, which may represent seepage along a fault or faults. The inability to obtain long cores hampered attempts to confirm the presence of gas in this area. Short cores taken from the vicinity of this apparent gas seep area and subjected to chromatographic analysis at sea to determine their gas content did not contain unusually high concentrations of hydrocarbon gases (fig. 22; samples 23G, 33G-36G, table 1). There is evidence in one sample (34G2), however, that gas concentrations may increase with depth, and so gas-charging, though not confirmed, is a possibility. Longer cores are required for further testing at this site. In addition, sample 34G2 contains nearly 10 times more methane (C_1) than do other samples collected in this vicinity, although the significance of such an indication from a single core is unclear.

Samples 54G1, 54G2, and 54G3, from a possible seep area 25 km west of Cape Arago, contain anomalously high concentrations of hydrocarbon gases (fig. 22; table 1). These samples were collected within and adjacent to a crater that may be associated with geologically youthful faults near the shelf edge (fig. 25). The high methane (C_1) concentrations in these samples suggest that they may be gas charged. The methane (C_1) to ethane (C_2) ratio, about 10,000, suggests the methane is biogenic in origin (Bernard and others, 1976). However, carbon-isotopic compositions of methane in samples 54G1 and 54G3 are -56.4 and -53.3 permil, respectively, at the heavy end of the range of values (-89 to -50 permil) observed for bacterially generated methane from natural sources (Fuex, 1977), but within the range of values (-58 to -40 permil) observed for gas associated with petroleum generation (Kvenvolden and Rapp, 1981). The large ethane (C_2) to ethene ($C_{2:1}$) ratios (apprx 60 to 220) also reflect a possible thermogenic source for the ethane (Kvenvolden and others, 1981). Thus, although the major source of methane resides in bacterial alteration of organic matter, the gas mixture may also have a thermogenic component (Kvenvolden and Rapp, 1981). In addition, we note that core penetration at sample site 54 was nearly twice that at sites 53 and 55, located outside the crater, approximately 900 m east of site 54 and containing relatively little methane. The greater core penetration at site 54 may directly reflect the effect of gas in reducing the bearing strength of sediment at this site.

Possible Gas Hydrates

Bottom-simulating reflectors (BSR's) (Scholl and Creager, 1973) are conspicuous reflecting horizons that cross coherent reflections from bedding planes and are approximately concordant with the overlying sea bottom. BSR's are present on sparker records across the middle and lower continental slope (depth of water approx 650 - 2,000 m) seaward of the Coos Bay basin, where they characteristically occur at depths ranging from 250 to 400 ms below the sea floor. Although their origin is uncertain, the BSR's may indicate the presence of gas hydrates composed of solid, icelike mixtures of natural gas and water (Milton, 1976; Kvenvolden and McMenamin, 1980). If gas is present in quantity and if extraction proves feasible, such zones could become economically important. Gas hydrates also may form impenetrable barriers to the upward migration of free natural gas. Inadvertent penetration of such a barrier presumably could result in the sudden, uncontrolled venting of gas to the surface, a condition that would be hazardous to drilling operations.

CHARACTERISTICS OF SURFACE SEDIMENT

Sampling in the Coos Bay basin was directed primarily toward obtaining geochemical data and geologic-age information to facilitate interpretation of seismic records; table 2 lists the locations, water depths, and lengths of cores, and table 3 gives textural data for selected core samples. Procedures employed in sampling and textural analyses are described by Clarke and others (1981, app. A).

The reader is directed to the report by Kulm and others (1975) for the type and distribution of sediment facies and the factors affecting sediment transport on the Oregon shelf. Scheidegger and others (1971) mapped sediment provenance and dispersal patterns, and Byrne and Panshin (1977) showed the distribution of shelf-sediment types. Spigai (1971) and Kulm and others (1968a, b) reported on the heavy minerals of Oregon shelf and beach sands, and Komar and others (1972) described the wave climate on the Oregon shelf. The following section summarizes of the characteristics of surface sediment on the central Oregon shelf, incorporating data from these reports and from samples collected during the present study.

Sediment Sources and Lithology

The principal sources of sediment along the southern and central Oregon shelf are the Rogue and Klamath Rivers. These and eight other rivers draining the Klamath Mountains as far north as the Millecoma River of the Coos Bay area have a combined annual flow of 38.6 km^3 (Scheidegger and others, 1971). The Umpqua River, which has an annual flow of 8.4 km^3 and drains parts of the Cascade Range, Klamath Mountains, and the southern Oregon Coast Range, supplies sediment to the inner shelf of central Oregon. In addition, erosion of uplifted Pleistocene marine-terrace deposits along the central and southern Oregon coast provides a locally important source of

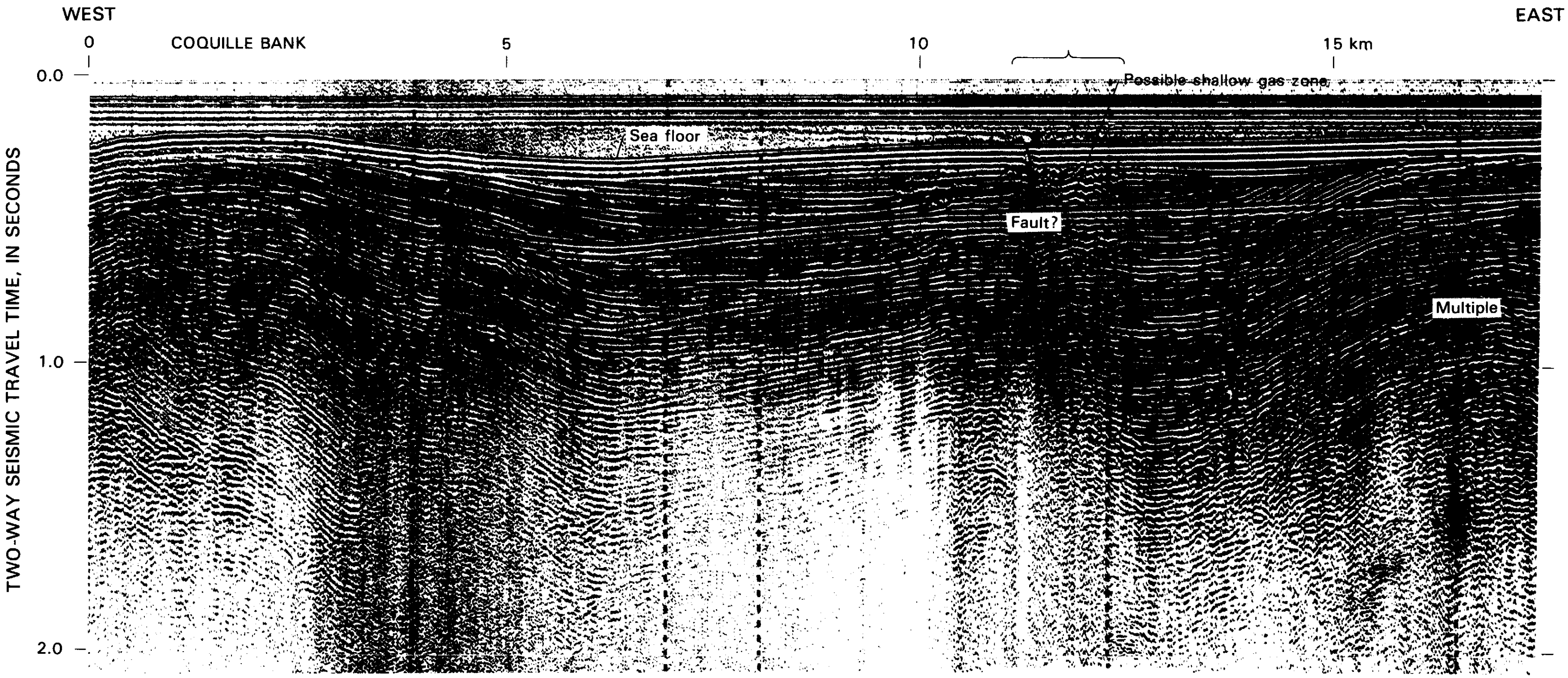

Figure 23. Deep-penetration seismic-reflection profile (77-26) across Coquille Bank and adjacent shelf. Note contacts between acoustic units 1 and 2, and 2 and 3; also note fault and deformation of reflectors thought to be associated with shallow gas in acoustic unit 1 (area indicated by bracket). Compare with figure 24.

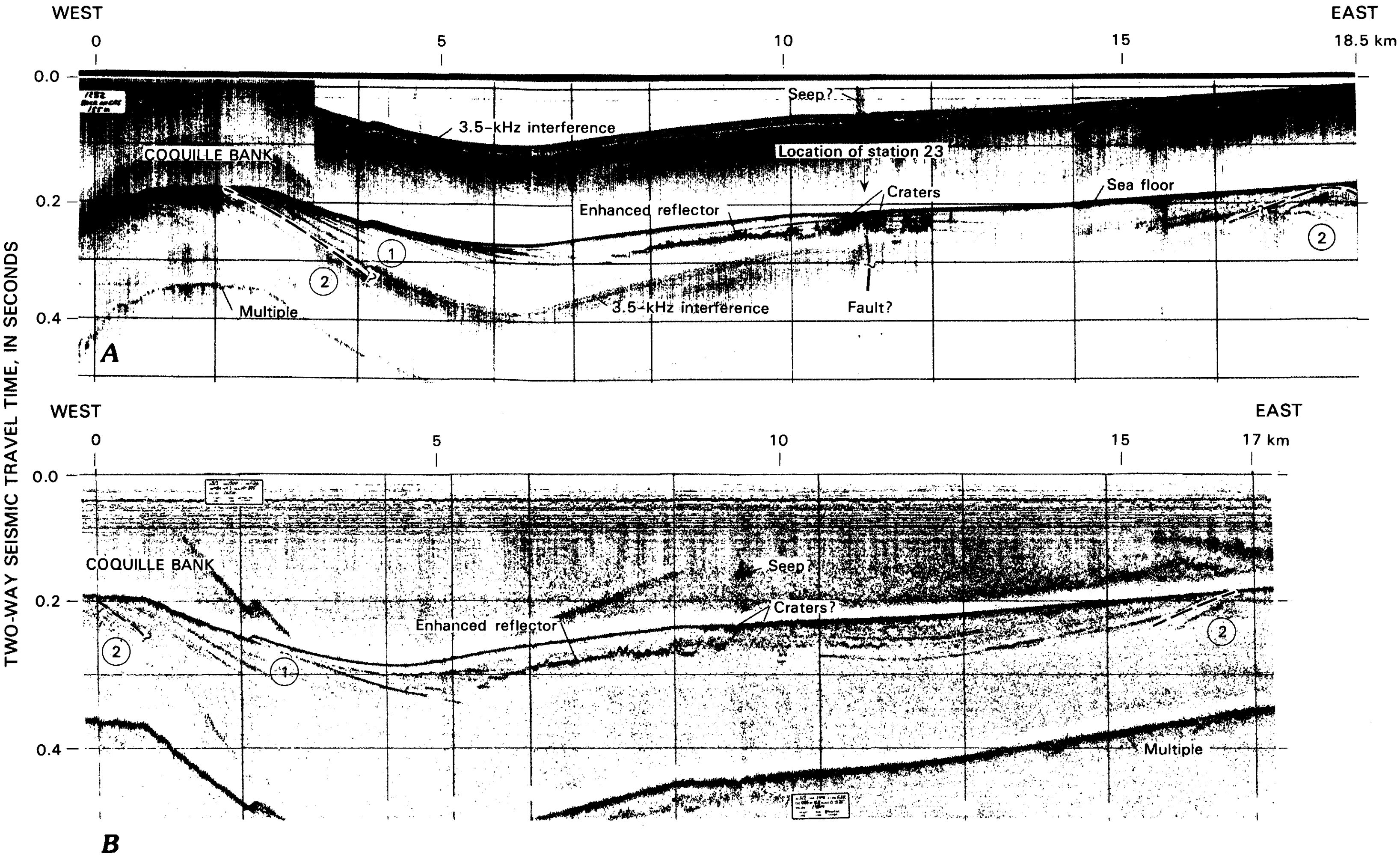

Figure 24. High-resolution seismic-reflection profile (77-26) across Coquille Bank and adjacent shelf. A, 1.2-kJ "boomer" record. B, 3.5-kHz profiler record. Note contact between acoustic units 1 and 2, depositional thinning of strata in upper part of acoustic unit 1 east of Coquille Bank, truncation of acoustic unit 1 on bank margin, and sea-floor relief of bank above adjacent shelf, indicating recent uplift. Also note enhanced or "bright" reflector above acoustically turbid zone in acoustic unit 1, apparent cratering of sea floor above this zone, and possible gas bubbles in water column above craters—all features suggesting the presence of shallow gas in acoustic unit 1. Sampling station 23 is within cratered zone; stations 33-36 are nearby.

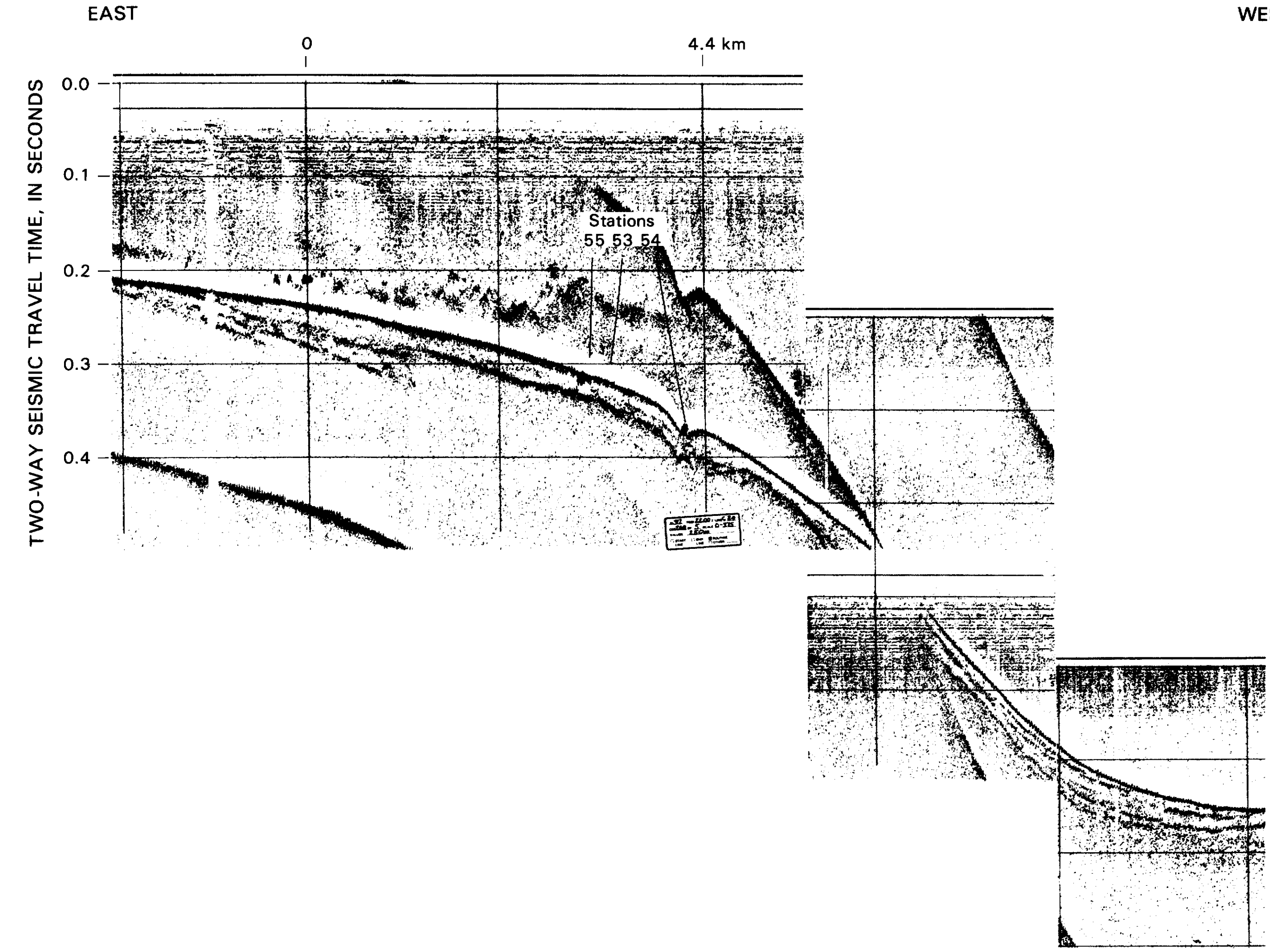

Figure 25. High-resolution seismic-reflection profile (77-20), showing location of sampling station 54 and projected locations of stations 53 and 55, approximately 24 km west of Cape Arago. Note sea-floor crater (station 54) and underlying acoustically turbid zone.

sand. Byrne (1963) estimated that erosion rates on the north coast of Oregon range from 0.6 m/yr for sedimentary rocks overlain by terrace gravel to 16 m/yr for unconsolidated gravel and sand.

Sand predominates along the inner continental shelf seaward to a depth of 50 to 100 m within the study area (fig. 26; Byrne and Panshin, 1977). These deposits are in large part modern and are of characteristically clean and well-sorted fine to very fine sand (approx 2.75 - 3.25∅), arkosic in composition (Scheidegger and others, 1971; Kulm and others, 1975). Sediment coarser than very fine sand, as well as some silt and clay from fluvial sources, tends to be trapped in the numerous coastal estuaries, and so the coarse sediment on the continental shelf is mostly relict (Kulm and others, 1975). Relict fine to coarse sand and gravel are characteristically iron stained, solution pitted, and altered, and are probably late Pleistocene in age. Deposits of relict sand are most common off erosionally resistant headlands and along parts of the coast where small rivers provide a relatively minor supply of sediment to the marine environment (Kulm and others, 1975).

Sediment flanking submarine outcrops appears to consist of mixtures of reworked residual material from the outcrops, relict sand and gravel, and possibly fine modern sediment as well (Kulm and others, 1975). Relatively coarse relict sand is also found in isolated patches near the shelf edge. Submerged deposits of heavy minerals, probably formed during Pleistocene low stands of sea level, are present on the shelf between Coos Bay and the Oregon-California State line (Kulm and others, 1968a). Biogenic components, principally sponge spicules and microfossils, make up a minor part of the shelf sand but locally are important constituents of fine mud. Authigenic glauconite occurs locally in concentrations exceeding 50 percent of the coarse fraction along the outer edge of the shelf and on the flanks of topographic highs (Kulm and others, 1975). Clays in modern sediment north of Coquille Bank consist of approximately equal proportions of chlorite, illite, and montmorillonite. However, clays in samples from Coquille Bank southward to northern California consist principally of chlorite (reflecting derivation from the Klamath Mountains), lesser amounts of illite, and minor amounts of montmorillonite (Kulm and Fowler, 1970).

A mud facies composed of materials with mean sizes finer than 4∅ is present on the middle shelf off the Umpqua River and is irregularly distributed on parts of the outer shelf and inner continental slope (fig. 26; Byrne and Panshin, 1977; Kulm and others, 1975). The net rate of mud accumulation on the central Oregon shelf is slow; fines tend to be

Table 2. Location, depth, length, type, and purpose of selected samples

Station	Sample number	Sample type	Purpose	Latitude	Longitude	Water depth(m)	Sample length (m)
			1977				
1	1G	Gravity core	Stratigraphic and sedimentologic information	+44.0500	-124.6621	125	2.00
2	2G	do..........	do................	+44.0594	-124.7032	115	1.62
3	3G	do..........	do................	+44.0577	-124.7358	140	.38
4	4G	do..........	do................	+44.0561	-124.7342	140	.45
5	5G	do..........	do................	+44.0599	-124.7551	135	Core catcher
6	6G	do..........	do................	+44.0595	-124.7655	130	Do
7	7G1	do..........	do................	+44.0536	-124.7824	120	Do
7	7G2	do..........	do................	+44.0551	-124.7802	120	Do
8	8G1	do..........	do................	+44.0574	-124.7902	115	Do
8	8G2	do..........	do................	+44.0598	-124.7903	115	Do
9	9G	do..........	do................	+44.0534	-124.8018	105	.27
10	10G	do..........	do................	+44.0542	-124.8132	080	.19
11	11G	do..........	do................	+44.0508	-124.8913	133	.36
12	12G	do..........	do................	+44.0564	-124.9246	182	.37
13	13G	do..........	do................	+44.0604	-124.9284	212	1.96
14	14G	do..........	do................	+43.6480	-124.8523	491	Core catcher
15	15G	do........	do................	+43.6205	-124.8196	543	1.45
16	16G1	do........	do................	+43.5677	-124.8259	670	2.65
16	16G2	do........	Gas analysis	+43.5568	-124.8272	679	2.62
17	17G1	do........	do................	+43.5792	-124.8294	675	2.84
17	17G2	do........	Stratigraphic and sedimentologic information	+43.5775	-124.8122	685	3.00
18	18G	do........	Gas analysis	+43.5721	-124.7577	610	2.24
19	19G	do........	Stratigraphic and sedimentologic information	+43.5676	-124.7376	540	2.27
21	21G	do........	do................	+43.5778	-124.3803	115	.05
22	22G	do........	do................	+43.5815	-124.3398	100	2.00
23	23G1	do........	Gas analysis	+43.0525	-124.7042	157	.85
23	23G2	do........	Stratigraphic and sedimentologic information	+43.0528	-124.6975	155	Core catcher
23	23G3	do........	Gas analysis	+43.0537	-124.6967	157	.30
			1979				
33	33G1	Gravity core	Gas analysis	+43.0493	-124.6953	150	.54
33	33G2	do..........	do................	+43.0492	-124.6963	155	.25
33	33G3	do..........	do................	+43.0497	-124.6952	149	.86
34	34G1	do..........	do................	+43.0523	-124.6967	150	.75
34	34G2	Gravity Core	Gas Analysis	+43.0523	-124.6972	151	.75
35	35G	do..........	do................	+43.0533	-124.7018	150	.52
36	36G	do..........	do................	+43.0540	-124.6963	150	.87
53	53G1	do..........	do................	+43.3095	-124.7013	217	1.33
53	53G2	do..........	do................	+43.3132	-124.6963	213	1.59
54	54G1	do..........	do................	+43.3123	-124.7118	259	2.35
54	54G2	do..........	do................	+43.3122	-124.7123	260	2.29
54	54G3	do..........	do................	+43.3120	-124.7123	259	2.65
55	55G	do..........	do................	+43.3130	-124.7025	237	1.23

resuspended by wave action and then transported seaward into progressively deeper water. This wave stirring controls the landward extent of the mud facies, and shelf-edge turbulence and sediment bypassing limit its seaward growth (Kulm and others, 1975). Mixing by benthic organisms of this river-supplied mud with relict and modern sand has created a mixed mud-and-sand facies that covers much of the middle and outer shelf and parts of the upper slope off central Oregon (fig. 26).

Sediment Transport

Modern littoral transport of sand-size material is northward, and this has been the dominant transport direction since late Wisconsin time (approx 18,000 yr B.P.) (Scheidegger and others, 1971; Kulm and others, 1975). However, littoral drift along the outer edge of the modern continental shelf during the late Wisconsin regression apparently was more effective than at present; as much as 315 km of northward transport

Table 3. Textural parameters of selected sediment samples

[See table 2 for sample locations]

Station	Sample	Sand (gravel) (pct)	Mud (pct)	Mean (Inman) (Ø)	Median (Inman) (Ø)	Sorting (Inman) (Ø)	Skewness 16/84 (Inman)	Kurtosis (Inman)
1	1G	52 (12)	36	3.22	2.16	2.76	0.39	0.88
3	3G	84	16	2.65	2.01	.96	.68	1.78
4	4G	74	26	3.35	2.57	1.61	.49	1.07
11	11G	66 (23)	11	.96	1.49	2.03	-.26	1.12
16	16G	1	99	7.29	6.62	2.07	.32	.83
17	17G2	2	98	6.52	6.00	1.94	.27	.90
19	19G	1	99	4.57	4.30	.48	.56	2.67
22	22G	32	68	5.48	4.73	1.99	.38	.90

occurred during the Wisconsin low stand of sea level (Kulm and others, 1975). The modern strandline has been relatively stationary since the Holocene transgression, and littoral transport has been limited by numerous coastal estuaries that tend to trap material coarser than very fine sand and by erosionally resistant headlands that hinder the northward movement of sand along the coast (Kulm and others, 1975).

The wave climate off the Oregon coast, especially during the winter months, is vigorous. Fine terrigenous and biogenic sediment deposited from suspension on the Oregon shelf is resuspended by wave and current action and is moved seaward as a low-density bottom flow concentrated in swales and small valleys on the middle to outer shelf as it is transported toward the continental slope and abyssal plain (Kulm and others, 1975). Studies by Komar and others (1972) showed that surface waves associated with winter storms off the Oregon coast should generate bottom orbital velocities sufficient to form ripples in very fine sand at water depths as great as 150 to 200 m. Photographic observation confirms that oscillatory ripple marks are present across the shelf to depths as great as 200 m and that ripples formed by summer waves extend to depths of 50 to 100 m. In addition, near-bottom currents associated with intense winter storms, with velocities as high as 75 cm/s, sufficient to erode and transport sand, have been measured off the Columbia River at a depth of about 50 m (Smith and Hopkins, 1972). The origin of these currents and their influence on sediment dispersal are unclear. Current-velocity measurements 50 to 210 cm above the bottom at middle- and outer-shelf depths (90 to 165 m) indicate velocities as high as about 25 cm/s in currents that partly are tidally induced (Harlett, 1972; Komar and others, 1972). Near-bottom (1-2 m above the seabed) current velocities have been measured as high as 40 cm/s on the upper continental slope (500 to 1,000 m), and as high as 10 cm/s on the lower continental slope (1,000 to 2,800 m) off central Oregon (Korgen and others, 1970).

Fine sediment accumulates on the lower continental slope in this region at rates estimated at as much as 70 cm/1,000 yr, and a sedimentation rate of about 10 cm/1,000 yr has been calculated for the upper continental slope (Carlson, 1968; Spigai, 1971). Relict sand, probably late Pleistocene in age and exposed locally at depths as great as 500 m on benches on the continental slope, indicates that little or no sedimentation has occurred on some parts of the Oregon slope since the Holocene transgression (Spigai, 1971).

Geometry of Quaternary Deposits

The distribution and thickness of acoustic unit 1, interpreted to be of Quaternary age and the youngest sedimentary sequence that could be traced throughout the study area, are shown as Figure 27. An unconformity at the base of this unit can be traced with fair confidence along the margins of banks and on the inner shelf. This unconformity is indistinct in the centers of major synclines, and so the thickness of acoustic unit 1 in shelf-and-slope basins should be considered a minimum. The age, lithology and stratigraphic relations of acoustic unit 1 were discussed above in the subsection entitled "Marine Geology of the Coos Bay Basin."

Organic-Carbon and Calcium Carbonate Content

A total of ten samples from 8 stations on the central Oregon shelf were analyzed for organic carbon and $CaCO_3$ content; analytical procedures were described by Clarke and others (1981, app. A), and table 4 lists the results. The trends apparent in the values obtained are questionable owing to the small number and wide geographic distribution of samples.

Organic-carbon content averages 1.5 weight percent but ranges from about 0.4 to 3.0 weight percent; only one sample (with 3.04 weight percent) contains more than 2 weight percent. Generally, high organic-carbon content appears to be associated with deeper water and with decreasing grain size. Calcium carbonate content is characteristically low; eight of

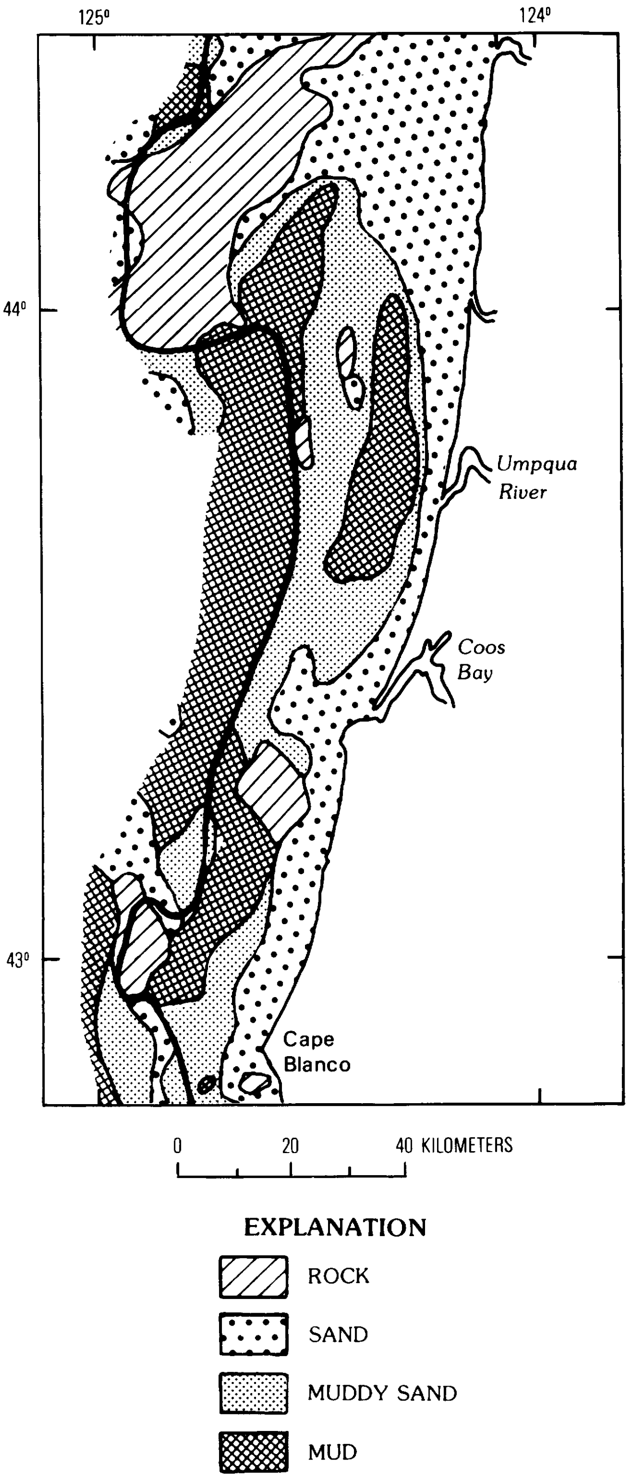

Figure 26. Map showing distribution of major sediment types on continental shelf and slope off central Oregon (from Byrne and Panshin, 1977). Heavy line denotes approximate location of shelf edge. Sand consists of sediment with mean sizes coarser than 4∅; mud consists of silt and clay with mean sizes finer than 4∅.

the samples (from seven stations) contain less than 1 weight percent $CaCO_3$. Two samples have anomalously high calcium carbonate contents (11.3 and 18.6 weight percent), probably reflecting the presence of small fragments of shelly material. The calcium carbonate appears to be derived principally from calcareous nannofossils and tests of foraminifers, with a secondary contribution from mollusk and echinoderm fragments.

SUMMARY OF GEOLOGIC HAZARDS

Active faulting in the offshore Coos Bay basin poses a potential hazard to sea-floor installations. Groups of geologically youthful north- to northwest-trending faults are present on the inner shelf north of Cape Arago and on Heceta Bank. Individual faults can be traced for at least 15 km, and these groups of faults may reflect a broad zone of active shear (fig. 12). In addition, a northwest-trending fault 10 km long that has sea-floor expression cuts the inner shelf south-southwest of Cape Arago. Additional detailed study of these faults is recommended to determine the type and history of offset and their relation to faults onshore, and to assess their potential hazard to structures offshore.

Little seismic activity has been recorded in the immediate vicinity of the Coos Bay basin during the period 1841-1975 (fig. 20). Seismic hazards are probably associated principally with ground shaking, earthquake-induced sea-floor mass movement and liquefaction, and tsunamis resulting from earthquakes in adjacent regions, notably along the Gorda Ridge, the Mendocino Escarpment, the Blanco Fracture Zone, and in the Gorda Basin. Beaulieu and Hughes (1975) estimated that a major earthquake in the vicinity of the Mendocino Escarpment could generate an MMI of VII in the Coos Bay area, with a corresponding ground acceleration of 0.10 g. The tsunami hazard associated with such an earthquake would be minimized by the predominately horizontal motions accompanying faulting in the northern California-southern Oregon continental margin. The Alaskan earthquake of 1964, however, generated wave heights along the Oregon coast of 1.2 and 4.2 m above the prevailing mean high water, and wave heights greater than 6 m were recorded at Crescent City, Calif. Substantial damage to coastal structures was done in Oregon, and catastrophic losses of property occurred locally in northern California. Thus, the tsunami hazard to facilities constructed in shallow areas on Heceta and Coquille Banks and on the inner shelf adjoining the Coos Bay basin could be significant (Beaulieu and Hughes, 1975).

Evidence of modern sea-floor mass movement (fig. 21) is uncommon on the seismic-reflection records collected during this study. However, Quaternary sediment of largely unknown engineering properties is locally thick (fig. 27) and in some areas contains peat and devitrified volcanic ash, which can reduce shear resistance. Slopes sufficiently steep to promote failure in unconsolidated sediment are prevalent below the shelf edge in the Coos Bay basin. Evidence of older, buried slides is present in areas of apparently high sediment influx during Pleistocene time. In

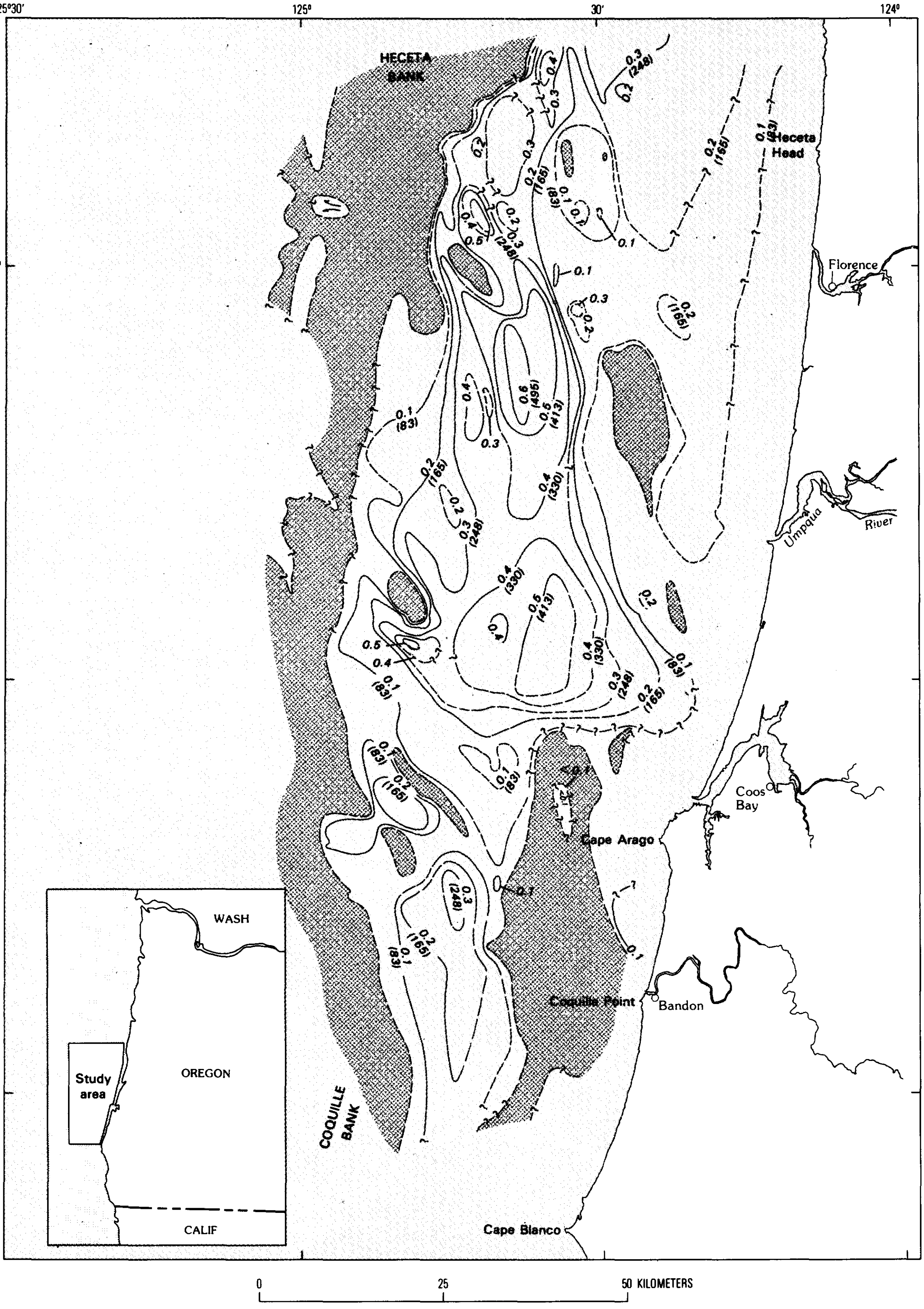

Figure 27. Isopach map showing thickness of Quaternary sediment in the Coos Bay basin. Explanation is on next page.

EXPLANATION

AREAS DEVOID OF QUATERNARY SEDIMENT—Determined from high-resolution seismic-reflection profiles. Contacts dashed where inferred; queried where control limited

ISOPACHS SHOWING THICKNESS OF QUATERNARY SEDIMENT—In seconds of penetration (2-way travel time). Approximate thickness in meters, assuming an acoustic velocity of 1650 m/s, is shown in parentheses. Contours dashed where inferred; queried where control limited

SLUMP

Figure 27. Continued

Table 4. Carbon and calcium carbonate contents of selected samples

[All analyses in weight percent, according to the procedure of Clarke and others (1981, app. A). See table 2 for sample locations]

Sample	Interval (cm)	Depth (m)	Organic carbon	Inorganic carbon	$CaCO_3$	Total carbon
01G	2-4	125	1.73	2.23	18.60	3.96
01G	12-14	125	.95	.02	.13	.97
03G	1-3	140	.43	.02	.18	.45
04G	1-3	140	.70	.07	.60	.77
11G	1-3	133	3.04	1.35	11.27	4.40
16G	1-3	670	1.69	.11	.88	1.80
17G2	2-4	685	1.97	.07	.59	2.04
17G2	19-21	685	1.79	.07	.59	1.86
19G	1-3	540	1.57	.10	.80	1.66
22G	1-3	100	1.14	.09	.73	1.23

addition, sea-floor failures are widespread in a similar geologic setting about 100 km south in the offshore Eel River basin of northern California, although their distribution may reflect the significantly greater level of seismic activity and sediment influx in that region. Thus, in spite of the paucity of evidence of modern failures, sea-floor mass movement should be considered a potential hazard unless site-specific studies indicate otherwise. Our research did not emphasize modern sediment transport and deposition. A survey of literature, however, shows that storm waves and bottom currents are strong enough locally to erode and transport bottom sediment and thus may pose a hazard to some types of sea-floor installation.

Diapirs and areas of active uplift have been mapped throughout the northern California, Oregon, and Washington continental margin, and also are present in the offshore Coos Bay basin. These features reflect recent tectonic activity, but the hazard they pose to offshore development is uncertain because little is known of the rate and type of uplift, the relation of these features to overpressured zones, and their relation to other types of sea-floor instability. These aspects of diapirism merit further study, and the hazard posed by such features should be judged on a site-specific basis. No evidence was obtained of gas seepage into sediment on and surrounding one diapir sampled off central Oregon; however, diapirs on the Washington continental margin are probably asociated with overpressured zones and shallow gas pockets, which themselves may constitute a hazard to development.

Gas in sediment reduces bearing strength and, if it is of thermogenic origin, may reflect an overpressured zone at depth. Acoustic anomalies suggestive of shallow gas zones are extensive in the offshore Coos Bay basin (fig. 21). Side-scan sonographs, high-resolution seismic-reflection profiles, and samples from the area of one suspected shallow gas zone indicate that gas is being vented at the sea floor along a linear northwest-trending zone that may be associated with youthful faults. High concentrations of biogenic methane were confirmed in a second area, which also bore evidence suggestive of gas venting and faulting. The degree of hazard posed by shallow gas in this area cannot be assessed without confirmation of the presence of gas in other areas and without determination of the type of gas present, the occurrence of associated faulting, and the effect of gas in the bearing properties of the enclosing sediment. Such assessment would entail additional seismic-reflection profiling—preferably with records processed to preserve true relative amplitudes—and sampling of sediment above suspected gas zones to confirm the presence of gas, determine its origin, and measure its concentration.

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