UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

RECONNAISSANCE GEOLOGY AND GEOLOGIC HAZARDS OF OFFSHORE COOS BAY BASIN, CENTRAL OREGON CONTINENTAL MARGIN

by

S. H. Clarke Jr., M. E. Field and

C. A. Hirozawa

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS

Menlo Park, California

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INTRODUCTION

This report summarizes aspects of the offshore and onshore geology of the Coos Bay basin, Oregon, that are of importance in assessing the potential geological hazards to offshore petroleum exploration and development. Although this investigation focuses on the identification and characterization of hazards in a specific offshore basin, it should be considered regional in scope; it is designed to provide the broad geological perspective necessary to site-specific geohazards studies. The geologic phenomena investigated include faulting, seismicity, seafloor instability (e.g., submarine slides and sediment creep), seafloor erosion and deposition, hydrocarbon seepage, the presence of hydrocarbon gases in seafloor sediments, and diapirism.

Data were obtained for this report during two cruises to the northern California and southern-central Oregon OCS. The first cruise (S9-77NC), funded jointly by the U.S. Geological Survey and Bureau of Land Management, was carried out aboard the R/V SEA SOUNDER during November, 1977. Objectives of this cruise were to provide a reconnaissance of the regional distribution of potentially hazardous processes and to delineate specific hazards for future study. The second cruise (S12-78NC), funded by the U.S. Geological Survey, was completed during November, 1978.

The cruises, subsequent analytical and interpretive work, and report preparation were directed by Samuel H. Clarke, Jr. and Michael E. Field of the U.S. Geological Survey. Microfaunal age determinations were made by Robert Arnal; Keith Kvenvolden and John Rapp performed geochemical analyses and interpretations. Teresa Hallinan and William R. Richmond made continuing and major contributions to our efforts in data collection and analysis, and to preparation of this report. Michael E. White prepared many of the figures. Parke D. Snavely, Jr. shared his ideas, and contributed sigificantly to this report with his review.

GEOLOGIC FRAMEWORK

General

The continental margin of central Oregon is situated near the boundary between the North American, Pacific and Gorda-Juan de Fuca (a remnant of the ancestral Farallon plate) 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). Sea-floor spreading at the Gorda and Juan de Fuca Ridges together with underthrusting of the Gorda-Juan de Fuca plate beneath the North American continent has 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/year along broad zones of right shear--the San Andreas and Queen Charlette Islands fault systems. Folding and upwarp of the outer continental margin (shelf and slope) resulting from 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 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 sediments, volcanics and volcaniclastic rocks having 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 through time; in the middle Eocene it probably lay about 20-40 km east of the present coastline in the area of the central Oregon Coast Range (Snavely and Wagner, 1963; Snavely and others, 1977). However, since late Eocene time sedimentation has been focused in a

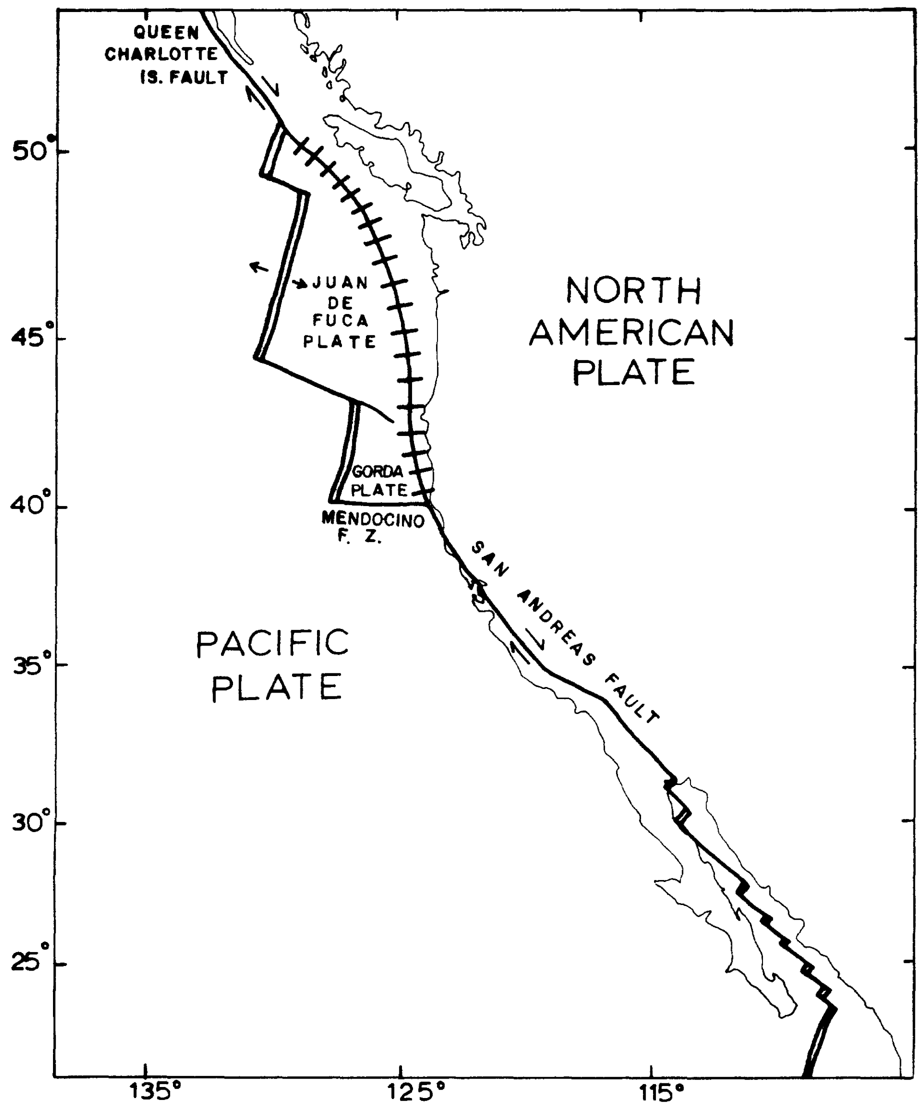

Figure 1. Generalized plate tectonic framework of the eastern Pacific margin, showing spreading ridges (double lines), major transform faults (single lines) and zones of subduction (hatched lines).

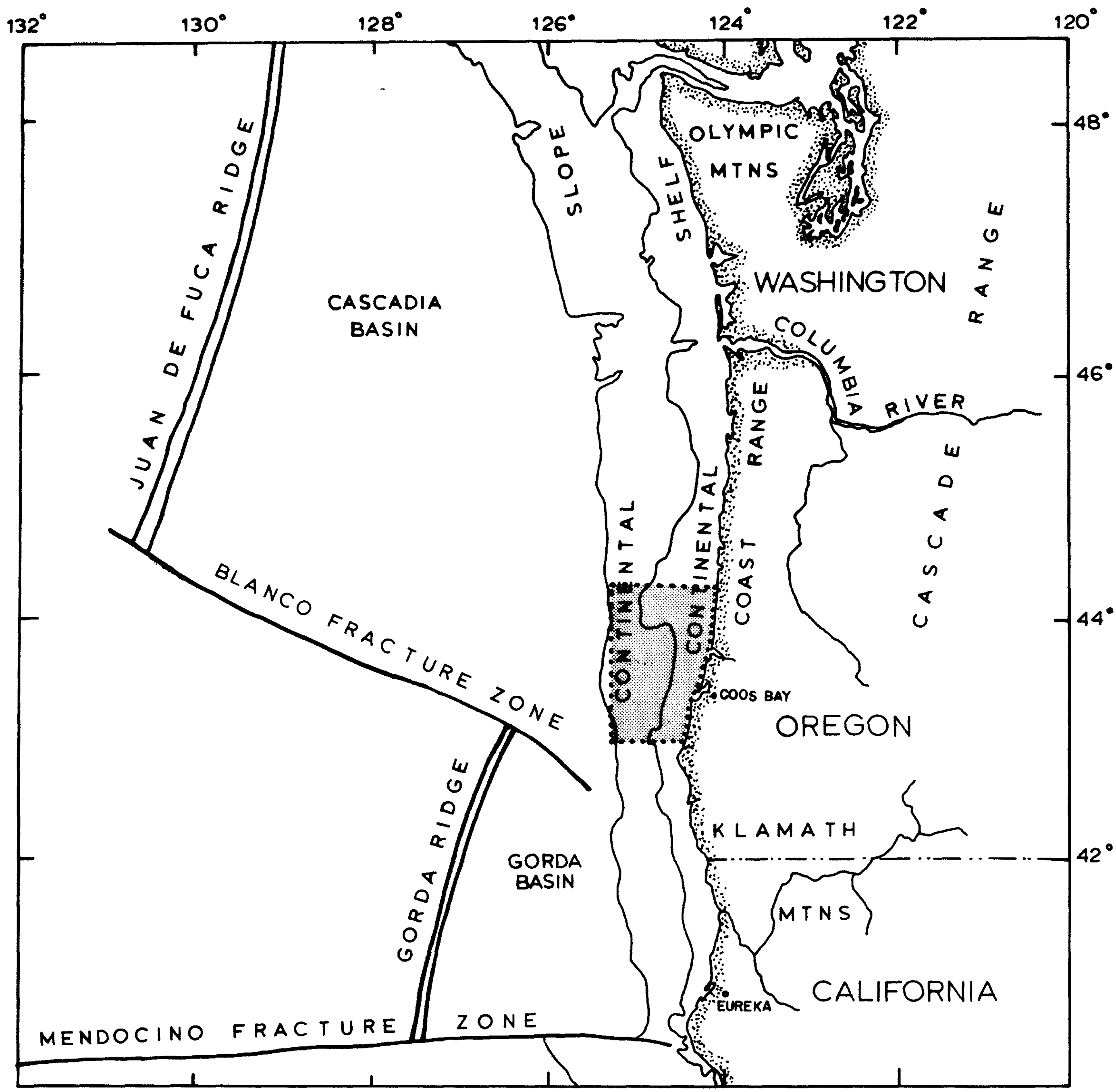

Figure 2. Major geologic and physiographic features of the continental margin of the Pacific northwest. Area of study is shown by dotted line.

marginal basin occupying the present site of the Oregon continental shelf. The Pliocene-Pleistocene basin axis trends northward about 30-35 km west of the present coastline, and the greatest thickness of upper Paleogene and younger sedimentary rocks lies within 50-60 km of the coastline at water depths ranging from 50 m up to about 1000 m.

Geologic History

The following synopsis of the Cenozoic geologic history of the central Oregon continental margin is taken largely from the work of Snavely and Wagner, (1963), Baldwin (1964, 1973, 1974), Braislin and others (1971), Kulm and Fowler (1974) and Snavely and others (1977, 1980); the reader is directed to these studies for a more comprehensive review. Parts of this discussion, especially those pertaining to Miocene and older units, principally concern the onshore geologic record; they are intended to provide geological perspective within which the offshore geology can be examined.

A thick succession of lower and middle Eocene tholeiitic to alkalic basalts and volcanic breccias (Siletz River Volcanics; Roseburg Fm) interpreted to represent 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 3000 m. Marine silts and volcanic sands (Umpqua Fm; Roseburg Fm) were deposited concurrently throughout the region in varied environments. In middle Eocene time, an areally extensive sequence of submarine fan and associated deposits (Tyee Fm) derived principally from uplift in the present area of the Klamath Mountains were carried northward along the

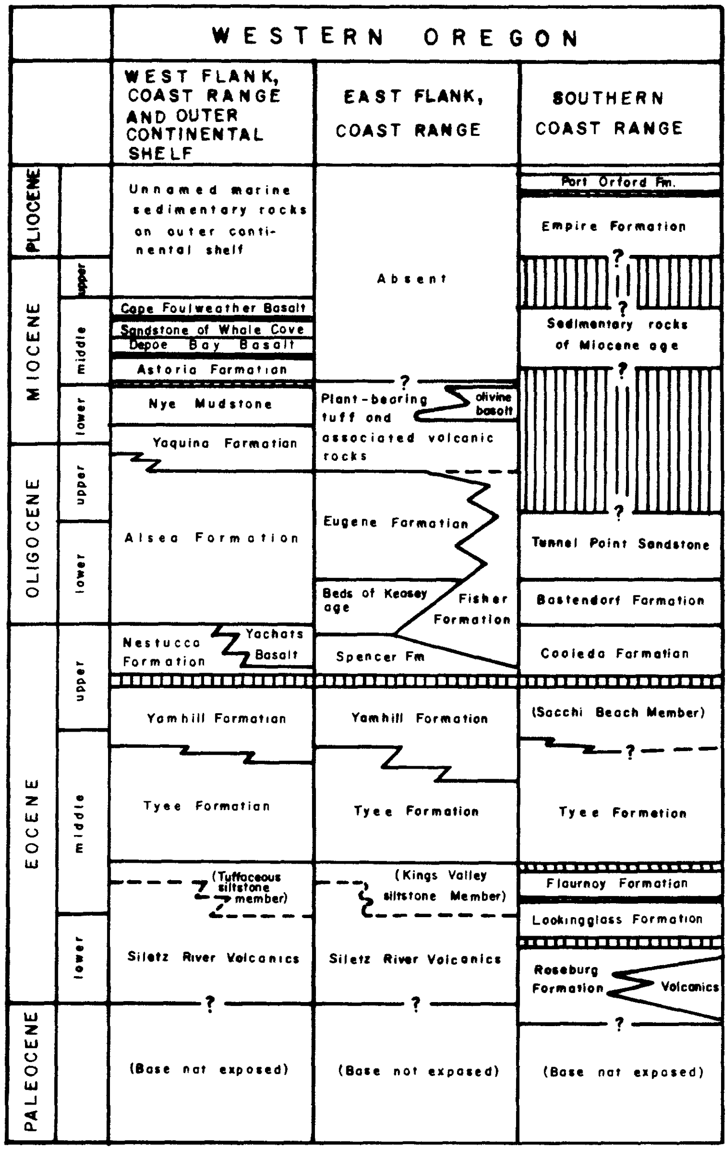

Figure 3. Correlation chart of major Tertiary units in western Oregon (from Snavely and others, 1977).

basin axis; these deposits have a maximum thickness of 3000 m and consist mostly of massive, rhythmically bedded, lithic and arkosic sandstone and siltstone (Snavely, Wagner and MacLeod, 1964; Lovell, 1969). Hemipelagic muds and silts interbedded with thin sands (Yamhill Fm) were deposited elsewhere in the basin, and were widespread by the beginning of late Eocene time following Tyee deposition.

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

The late Eocene was marked by widespread shoaling; the margin of the marine basin lay along the west edge of the present Cascade Range and northern edge of the present Klamath Mountains (Snavely and Wagner, 1963; Snavely and others, 1977). A sequence of tuffaceous sandstones and siltstones (Coaledo Fm) up to 1000 m thick that is coal-bearing in the Coos Bay area was deposited in shallow and marginal marine environments along the southern margin of the basin. These deposits grade northward and westward into a 1500 m + thick organic-rich tuffaceous siltstone containing subordinate arkosic and volcanic sandstone (Nestucca Fm). Basalt flows and breccias (Yachats Basalt) were erupted onto the basin floor in some areas, forming islands where the accumulations were thickest. Oligocene pyroclastic activity along the eastern margin of the basin resulted in deposition in the marine basin of up to about 1500 m of tuffaceous siltstone and fine sandstone (Bastendorff Fm; Tunnel Point Sandstone; Alsea Fm). Uplift accompanied by emplacement of gabbroic to dioritic intrusives during late Oligocene time limited marine deposition to the area of the present continental shelf and west flank of the Oregon Coast Range. Deposition of marine sediments in this area continued essentially uninterrupted into Miocene time. Along the eastern margin of the basin, which lay near the present coastline in central Oregon, crustal instability and local volcanic activity is recorded by several unconformities, prominant lower and middle Miocene shallow-marine clastic deposits (Yaquina Fm, Astoria Fm, Sandstone of Whale Cove), and middle Miocene submarine and subaerial basaltic flows and breccias (Depoe Bay Basalt, Cape Foulweather Basalt). Deeper marine environments in open-margin basins are represented by deposits of organic-rich, clayey siltstone (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 in late middle Miocene time, with folding principally along northeast structural trends (Snavely and Wagner, 1963; Snavely and others, 1977, 1980). The unconformity produced by this tectonism is recognizeable in seismic reflection records throughout most of the central Oregon OCS. Southward from Coos Bay, basin margin deposition is represented by about 900 m of massive, poorly-bedded, fossiliferous sandstone (Empire Fm). Correlative deposits in the marine basin on the present continental shelf comprise more than 1070 m of upper Miocene tuffaceous sandy siltstone and 1520 m of Pliocene foraminiferal siltstone and sandstone, the latter deposits being thickest in the major shelf synclines (Snavely and others, 1977).

A Pliocene-Pleistocene unconformity can be traced throughout much of the central Oregon shelf, though it is indistinct in the axes of some structural depressions. Strata beneath this unconformity are late Miocene to late Pliocene in age, whereas unconsolidated sediments overlying the unconformity at DSDP site 176 have a maximum age of 1.3 m.y. (mid-late Pleistocene) (Kulm and Fowler, 1974b). Pleistocene and Holocene deposits in this area are largely sand and silt, with gravel interbedded locally. The Quaternary section reaches a thickness of more than 500 m in major shelf synclines, and contains several unconformities reflecting continued tectonic activity (Snavely and others, 1977).

Marine Geology of 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 are presented in a series of theses and technical reports (notably Kulm, 1969; Kulm and Fowler, 1970; Fowler and Kulm, 1971), and are summarized by Kulm and Fowler (1974a, b). The reader is also referred to the M.S. thesis of A. J. Mackay (1969), who mapped the inner shelf between Cape Arago and Coquille Point using a closely spaced network of seismic reflection lines. The geology of the adjacent area on land has been 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). The report that follows presents findings of a geological and geophysical investigation of the offshore Coos Bay basin conducted during 1977-1978 by the U.S. Geological Survey.

The Coos Bay basin occupies the shelf and upper slope of the central Oregon continental margin between Heceta and Coquille Banks (from about 43^{o} N to $44^{o}15'$ N) (fig. 4). The continental shelf in this area ranges in breadth from 20-25 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 having up to about 50 meters of relief. The shelf break occurs at a depth of about 140 m, estimated from bathymetric profiles

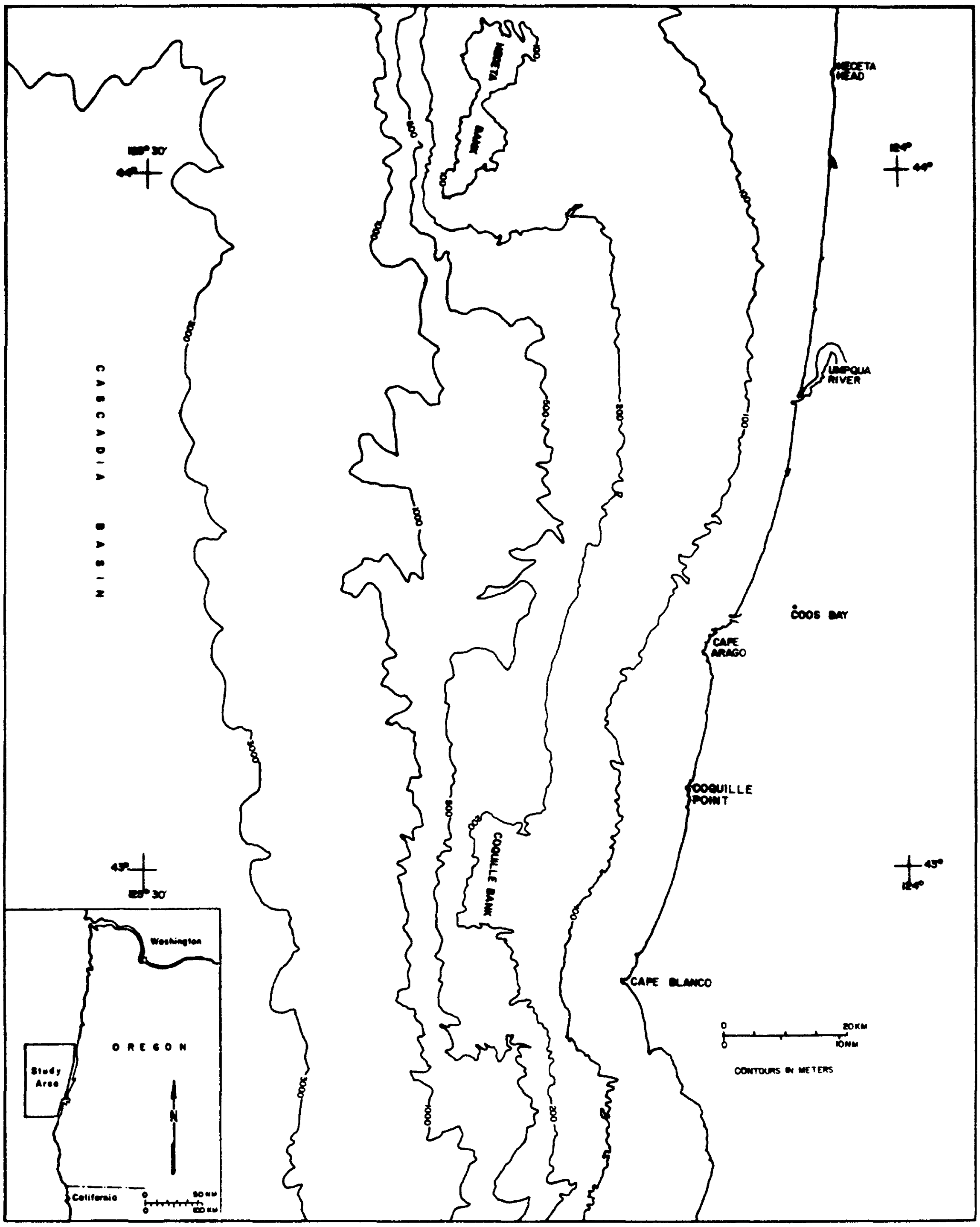

Figure 4. Area of the offshore Coos Bay basin. Bathymetry from C & GS 1308N-17 (1968) and 1308N-22 (1968), scale 1:250,000.

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°, being steepest in the vicinity of the banks, and slopes westward to depths of 3000 m - 3100 m in the Cascadia Basin. The lower part of the slope is conspicuously steep, with declivites of 7° - 14° being common between the depths of 2000 m and 3000 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 (fig. 4; pl. 2). Age control for these units is provided by dart core samples collected during this study (pl. 2; app. 2), age dates reported by Fowler and Kulm (1971) and Kulm and Fowler (1974b), and well sections reported by Snavely and others (1977). Acoustic unit 1 overlies a prominent unconformity on the east flank of Heceta Bank (fig. 5, 6), where it comprises strata dated as Pleistocene in age (pl. 2; Kulm and Fowler, 1974b). This unconformity marks a major tectonic event; it can be traced throughout much of the Oregon continental shelf and cuts strata of late Miocene to late Pliocene age. About 200 km north of the study area at DSDP site 176 on Nehalem Bank, it separates Pliocene siltstone from strata dated as mid-late Pleistocene (1.3 m.y. old) in age (Kulm and others, 1973).

This unconformity can be identified elsewhere on the banks and inner shelf (e.g., see figs. 13, 17), but is indistinct in the centers of major synclines. The sedimentary sequence comprising acoustic unit 1 is stratigraphically the

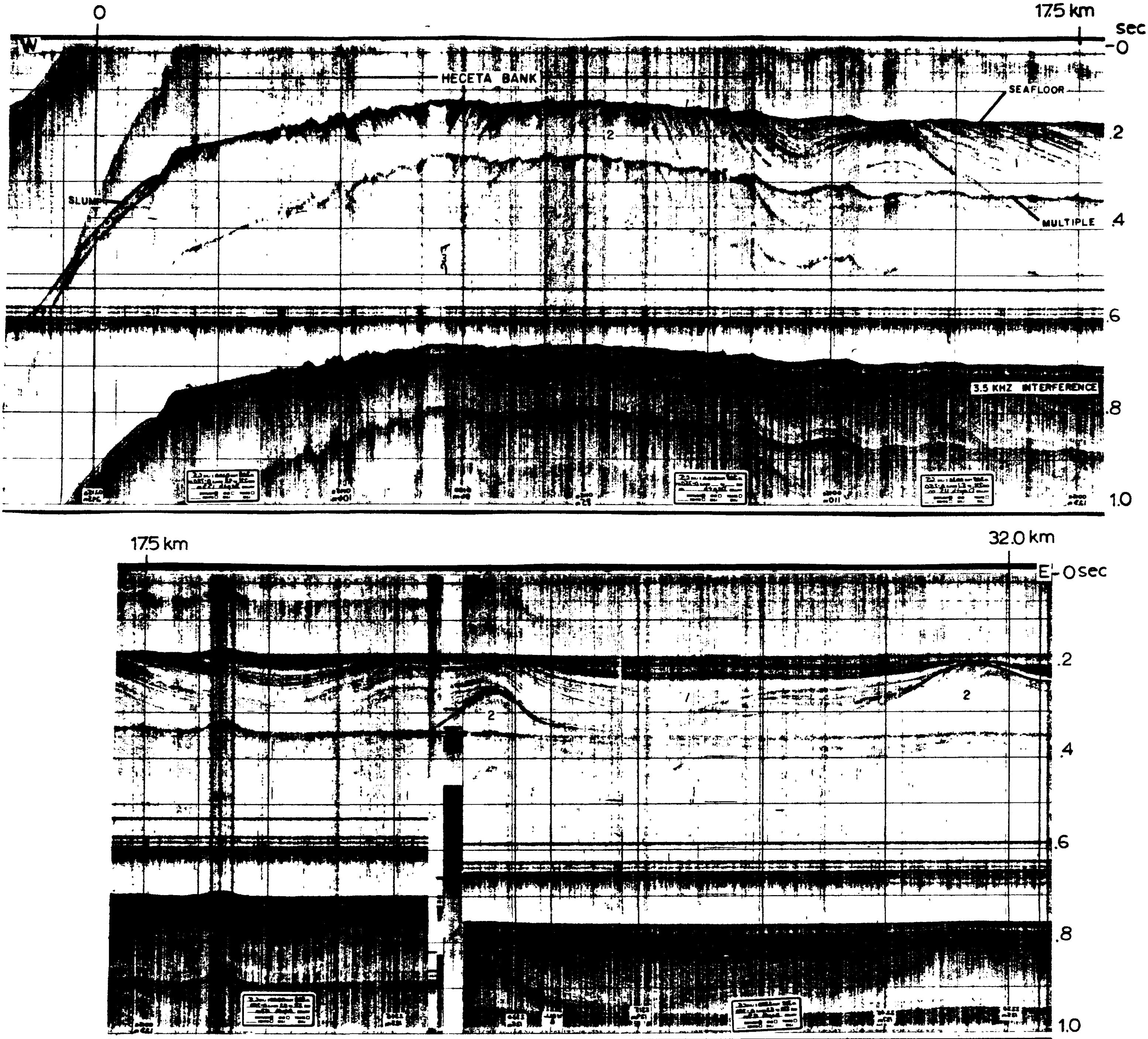

Figure 5. High resolution seismic reflection record (77-05) extending eastward across Heceta Bank and the adjacent shelf. Note contact between acoustic units 1 and 2, evidence of Quaternary deformation, and slump on west side of bank. See Plate 1 for location of profile.

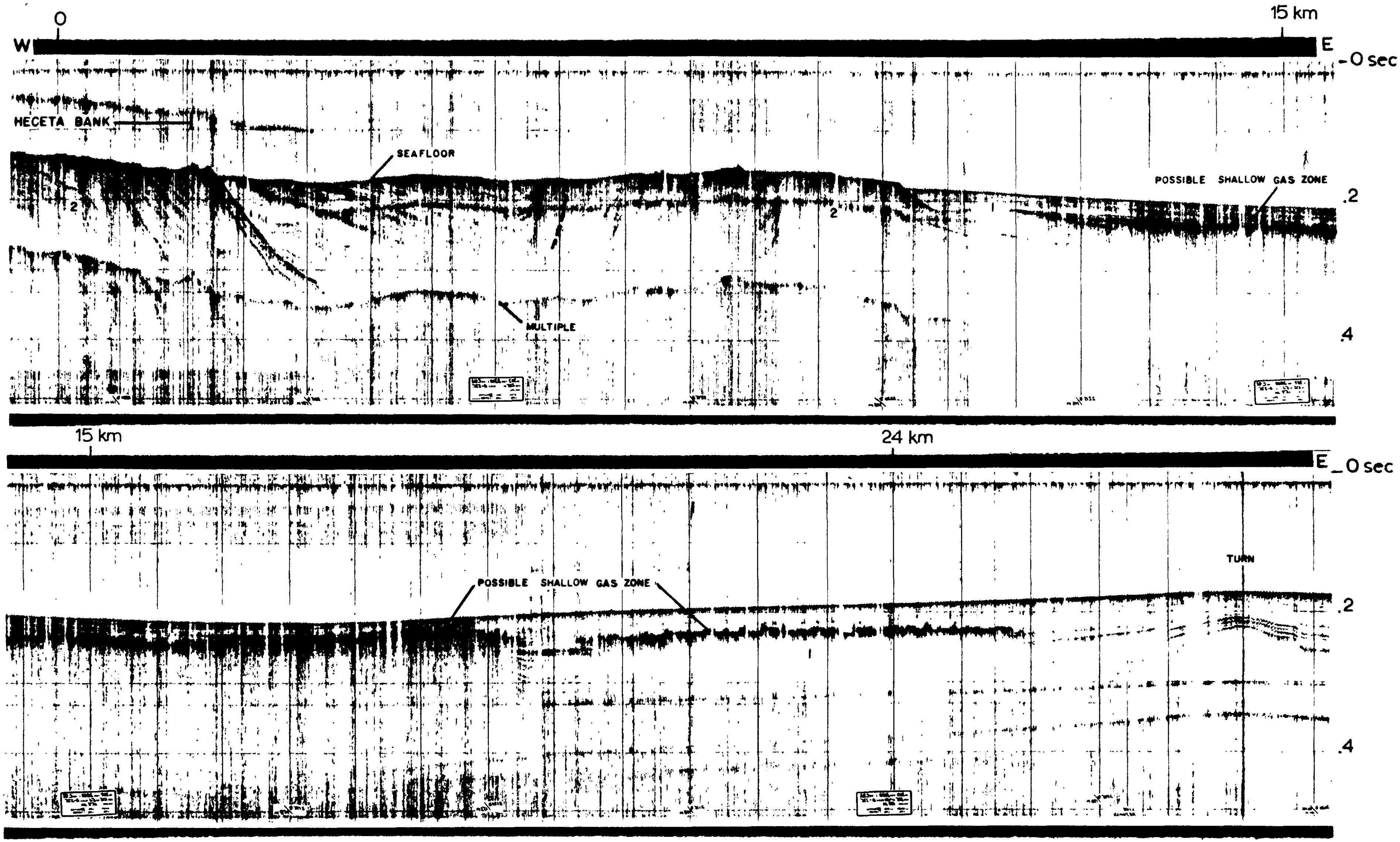

Figure 6. High resolution seismic reflection record (78-42) extending eastward from Heceta Bank across the adjacent shelf. Note contact between acoustic units 1 and 2, deformation of acoustic unit 1, and evidence of possible shallow gas accumulation.

uppermost (youngest) unit defined over most of the central Oregon shelf and slope. However, locally on the inner shelf it is overlain unconformably by a seaward-thinning sediment wedge as much as 15 m thick (fig. 7); this wedge of sediment is thought to represent Holocene deposits derived largely from rivers draining the adjacent Coast Range and coastal plain. These deposits are included with acoustic unit 1 on Plates 2 and 5, as they cannot be traced with confidence between adjacent seismic profiles.

Acoustic unit 1 is widespread on the shelf and upper and (locally) mid slope of the central Oregon offshore (pl. 2). Within the study area, it is thickest in the axis of the broad, relatively shallow syncline near the shelf edge between Cape Arago and Heceta Bank (pls. 3 and 5; fig. 8). Substantial seaward progradation of the shelf edge here appears to have accompanied erosion of the inner shelf during Pleistocene low stands of sea level. Sediments of acoustic unit 1 overlap older strata on the east flank of Heceta Bank, and on the upper and mid slope are ponded landward of anticlinal folds in strata inferred to be of late Miocene and Pliocene age. Unconformities of limited extent occur within acoustic unit 1 (fig. 5), reflecting recurrent episodes of uplift and erosion coupled with downwarp of the adjacent basin during Pleistocene time.

Pleistocene sediments of the central Oregon offshore are described as sand and silt interbedded with minor gravel (Snavely and others, 1977). The Pleistocene section penetrated at DSDP site 176 on Nehalem Bank consists of greenish-gray clayey silts containing abundant coarse debris and shallow-water megafossils (Kulm and others, 1973). Sediments of this age cored during the present study are typically fine-grained silts and clays.

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 (pl. 2). Acoustic unit 2 underwent wide-

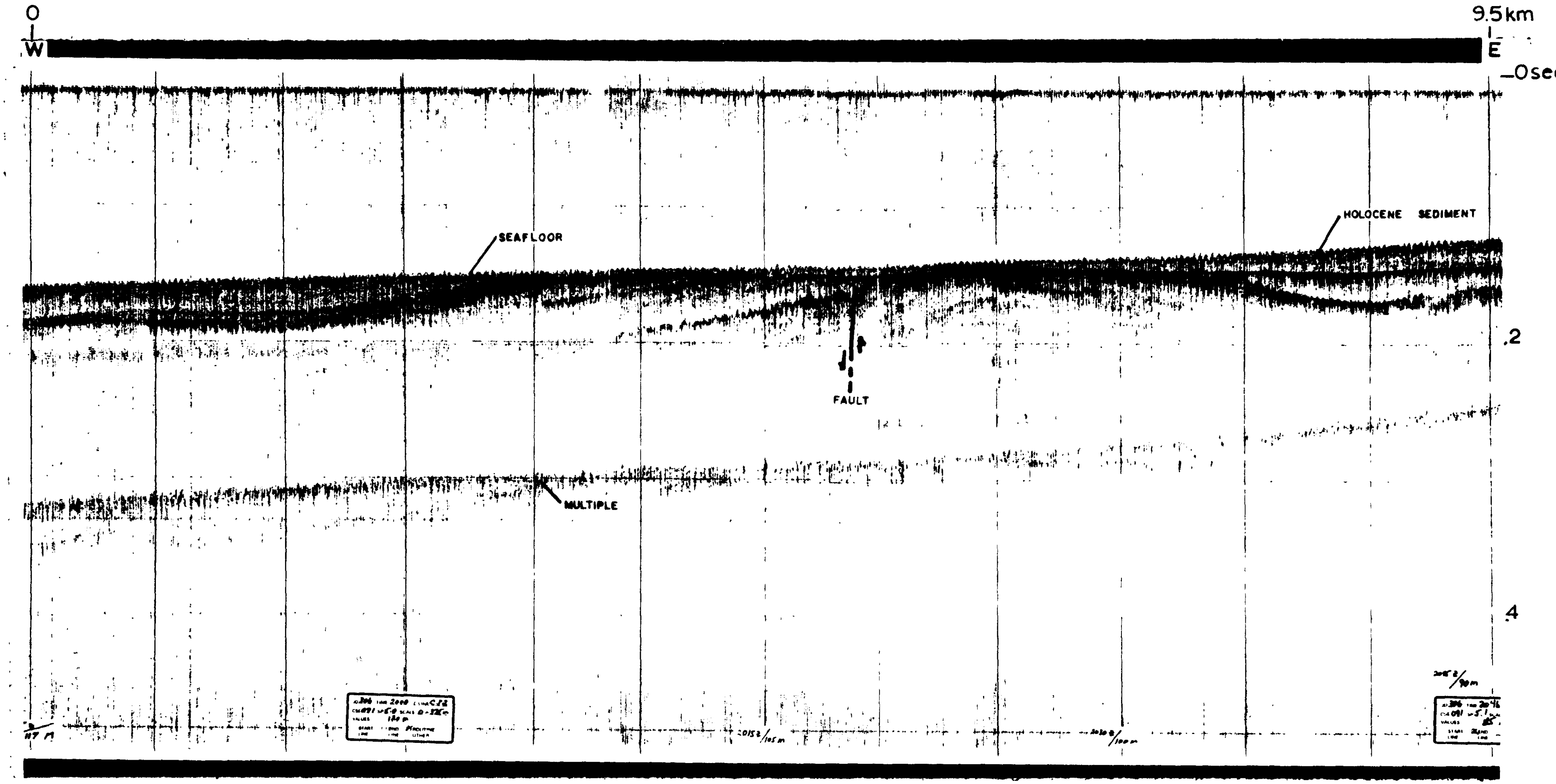

Figure 7 High resolution seismic reflection record (78-32) across the inner shelf north of Cape Arago. Note seaward-thinning wedge of Holocene sediment overlying acoustic unit 1, and fault at 2018Z; fault cuts unit 1 but not the overlying sediment.

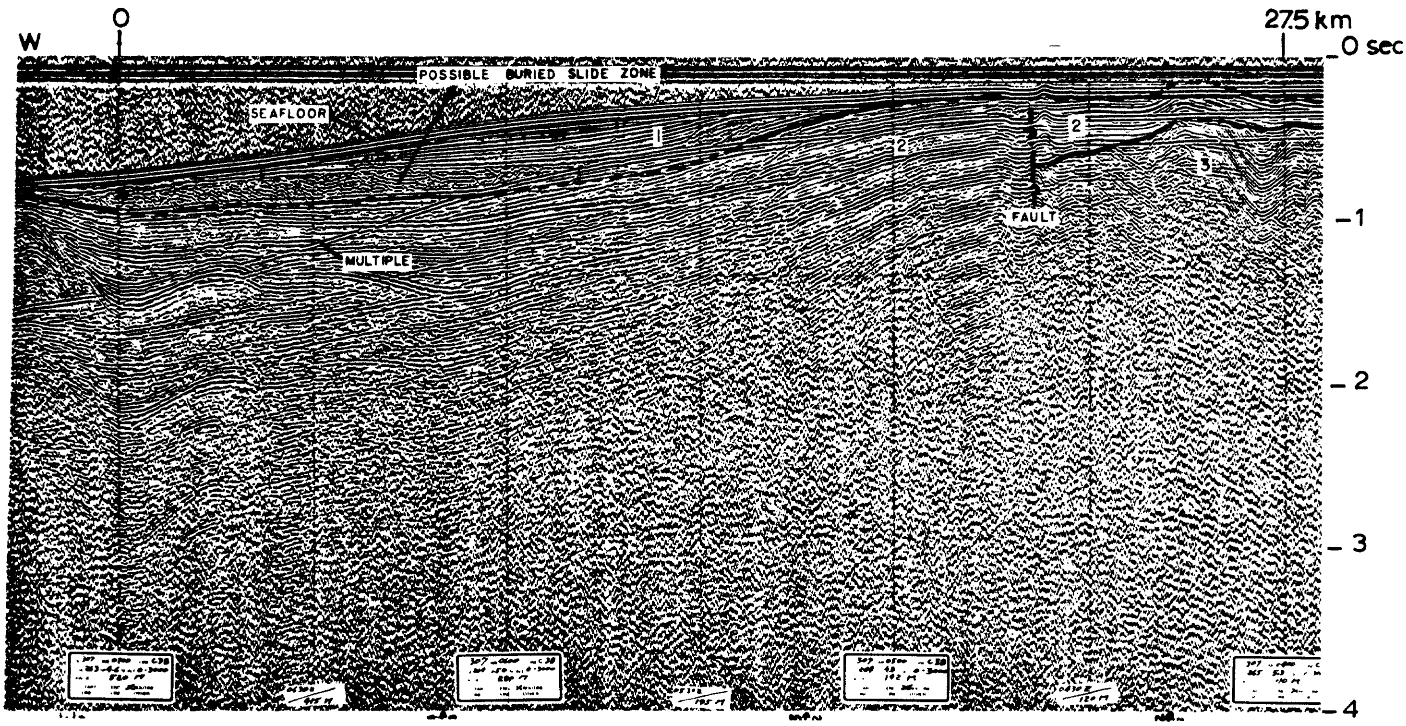

Figure 8. Deep penetration seismic reflection record (78-38) across shelf and slope between Heceta Bank and Cape Arago. Note thickening of acoustic unit 1 in the shallow syncline on the upper slope; contacts between acoustic units 1 and 2, and 2 and 3; buried slump in unit 1.

spread deformation by folding prior to deposition of unit 1, and is unconformably overlain by that unit (fig. 5; see also figs. 13, 17). It unconformably overlies more intensely deformed strata of acoustic unit 3 (fig. 8; see also figs. 10, 12, 13).

Strata of acoustic unit 2 have been dated as late Miocene and early to mid Pliocene on Heceta Bank (Fowler and Kulm, 1971; Kulm and Fowler, 1974b). Samples collected from unit 2 on Heceta Bank and from a young fold located 45 km northwest of Cape Arago during this study have been dated as late Pliocene (pl. 2; R. Arnal, written commun., 1978). Unit 2 on Heceta Bank thus is correlative with the unconformity-bounded composite sedimentary sequence of late Miocene and Pliocene age exposed in the Oregon Coast Range. Pleistocene sediments directly overlie upper Miocene rocks on the inner continental shelf between Cape Arago and Coquille Point (Kulm and Fowler, 1970; 1974b), and unit 2 appears to be missing due to pre-Pleistocene erosional truncation on much of the inner shelf north of Cape Arago, with unit 1 unconformably overlying unit 3. Correlative strata of late Miocene and Pliocene age also appear to be missing due to unconformity onshore adjacent the Coos Bay basin, except for a small area in which Pliocene marine sediments are exposed east of Cape Arago (pl. 2; Beaulieu and Hughes, 1975).

Braislin and others (1971) describe upper Miocene (Mohnian and Delmontian) rocks of the central Oregon offshore as tuffaceous sandy siltstone; those of Pliocene age are 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) record fine-grained sandstone in the upper Miocene section, and MacKay (1969) speculates on the basis of reflector characteristics and analogy to Pliocene rocks on land nearby that late Neogene strata on the inner shelf between Cape Arago and Coquille Point comprise a sequence 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 diapiric structure 45 km northwest of Cape Arago at a depth of 491 m.

Acoustic unit 3 is exposed in the cores of anticlines breached at the surface on the inner to mid continental shelf seaward of the mouth of the Umpqua River and Coquille Point, and on the mid continental slope seaward of Cape Arago (pl. 2). Unit 3 is unconformably overlain by acoustic unit 2 (fig. 8, see also figs. 10, 12, 13), and is much more intensely deformed than younger strata on the central Oregon OCS. The unconformity separating 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, and present in three wells drilled within the study area in the Oregon OCS (Snavely and others, 1977). This unconformity separates upper Miocene and younger rocks from strata ranging in age from middle Miocene to as old as Eocene (Snavely and others, 1977; Beaulieu and Hughes, 1975). Acoustic unit 3 was not sampled during this study, nor do published references show samples from these exposures; however, it is thought to be late Eocene to middle Miocene in age, based on its stratigraphic position and presumed equivalance to late Eocene-middle Miocene rocks that are bounded by regional unconformities onshore. Strata of this age are reported by Snavely and others (1977, 1980) to consist principally of siltstone interbedded with some turbidite sandstone, and volcanic rock.

Upper Eocene to middle Miocene rocks overlie with regional unconformity an older Tertiary unit in the central Oregon Coast Ranges as well as in offshore well sections reported by Snavely and others (1977, 1980). This older unit appears to unconformably underlie acoustic unit 3 beneath the inner shelf and Heceta Bank.

It does not crop out on the seafloor within the study area nor can it be traced with confidence between adjacent lines and, consequently, was not mapped separately in this study.

STRUCTURE

General

Folds and faults in the offshore Coos Bay basin are compiled on Plate 3. Standard techniques (see Moore, 1969) were employed in the interpretation of reflection records. The vertical scale of records shown as figures is greatly exaggerated, typically 4:1 to 5:1 for sparker records and 12:1 to 14:1 for high resolution records. Little acoustic energy is returned from reflectors dipping more than 15° - 20°, so that areas of steep dips and structural complexity, such as parts of Heceta Bank, are characterized by an absence of coherent reflectors. Water-bottom multiples tend to mask subbottom structure in shallow water, such as on the inner continental shelf, making interpretation difficult and interpretive results more subjective than elsewhere.

Three classes of folds are identified on Plate 3. These are: a) folds that create seafloor relief, typically in the form of irregular or smoothly rounded, linear ridges. These are, in general, the youngest folds present and show as much as 250 m of seafloor relief (e.g., see figs. 10, 13); most reflect Quaternary deformation and some appear to be active; b) folds that are breached at the seafloor. These folds are located on the inner shelf and banks at depths less than about 200 m, and were truncated during Pleistocene low stands of sea level. Seafloor outcrops associated with breached folds commonly involve strata of acoustic unit 2, thought to be upper Miocene and Pliocene, on the inner shelf and on Heceta Bank (fig. 5), and acoustic unit 3, thought to be middle Miocene and older, on the inner continental shelf (fig. 9). 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 Pliocene-Pleistocene or early late Miocene time; c) folds that are buried beneath younger, characteristically less deformed sediments. Buried folds are seen both in acoustic unit 3, in which folds commonly appear truncated by erosion prior to deposition of acoustic unit 2, and in unit 2.

Displacement of reflectors, the discontinuation of prominent reflectors or an abrupt change in the character of the seismic section, and an abrupt change in apparent dip are considered to be evidence of faulting on seismic reflection records. Generally, faults identified using two or more of these criteria are shown by solid lines on Plate 3; those identified using a single criterion are shown by dashed lines. Faults are queried where their existance, trend or connection between adjacent lines is questionable. The orientation of faults was determined by correlation between seismic reflection lines. Faults identified on only one line are drawn perpendicular to the line on which they were identified, or parallel to nearby faults or prominent bathymetric features.

Faults are dated according to the youngest acoustic unit cut. The resolution of ages assigned to faults in the Coos Bay basin is limited by the lack of geologic age information in some parts of the basin and the rather long span of time represented by each acoustic unit. Faults extending to the seafloor and those cutting sediments inferred to be Holocene in age are noteworthy in that they may represent recent fault movement, although the former may be old faults exhumed by post-Tertiary erosion. Sediments identified as Holocene on the inner shelf are those that locally form a seaward-thinning wedge that unconformably overlies older strata of acoustic unit 1. Faults cutting these

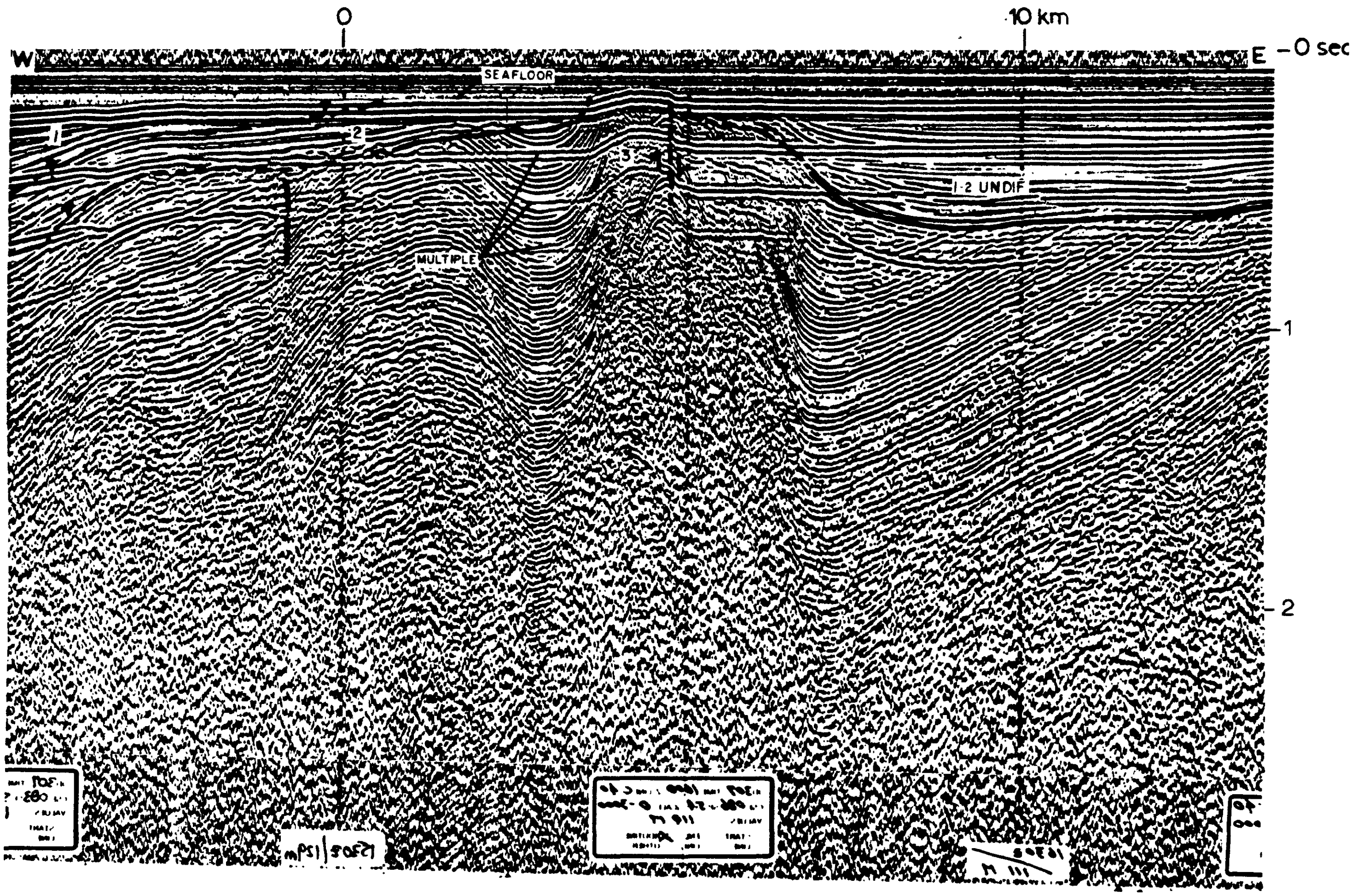

Figure 9. Deep penetration seismic reflection record (78-40) across inner shelf southeast of Heceta Bank. Note breached fold in which acoustic unit 3 is exposed at seafloor.

sediments are interpreted as having been active in Holocene time. The Pleistocene and Holocene have not been separated elsewhere, and faults that reach the surface or terminate within acoustic unit 1 are probably Quaternary in age. Faults terminating near the boundary between units 1 and 2 in basins where this boundary is ill defined are identified as probably Pliocene - Pleistocene (undifferentiated) in age. Faults on land adjacent to the offshore Coos Bay basin were compiled from maps by Schlicker and Deacon (1974) and Beaulieu and Hughes (1975).

FOLDS

The axial trend of the Coos Bay basin is approximately north. The trend of fold axes in acoustic units 1 and 2 is nearly the same, 350 degrees; locally, as on the upper slope west of Cape Arago, folds trending north-south for most of their length swing to a northwesterly trend (about 320^{o}) near their southern end. Folds in the Coos Bay basin are 2 to 12 km in breadth, averaging about 5 km, and several have a mappable length of 25 km (longest 40 km). Folds involving units 1 and 2 appear to be either broadly symmetrical or asymmetrical with east-dipping axial planes, suggesting a principal compressive stress from the west. A subordinate number have westerly axial plane dips. 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 of the upper slope (e.g., fig. 10) appear diapiric in origin.

The outer 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 average 100 to 1000 mm/m.y., with the most rapid uplift associated with the coastal terraces at Cape Blanco and deposits on the lower continental slope of central Oregon (Kulm and Fowler, 1974b).

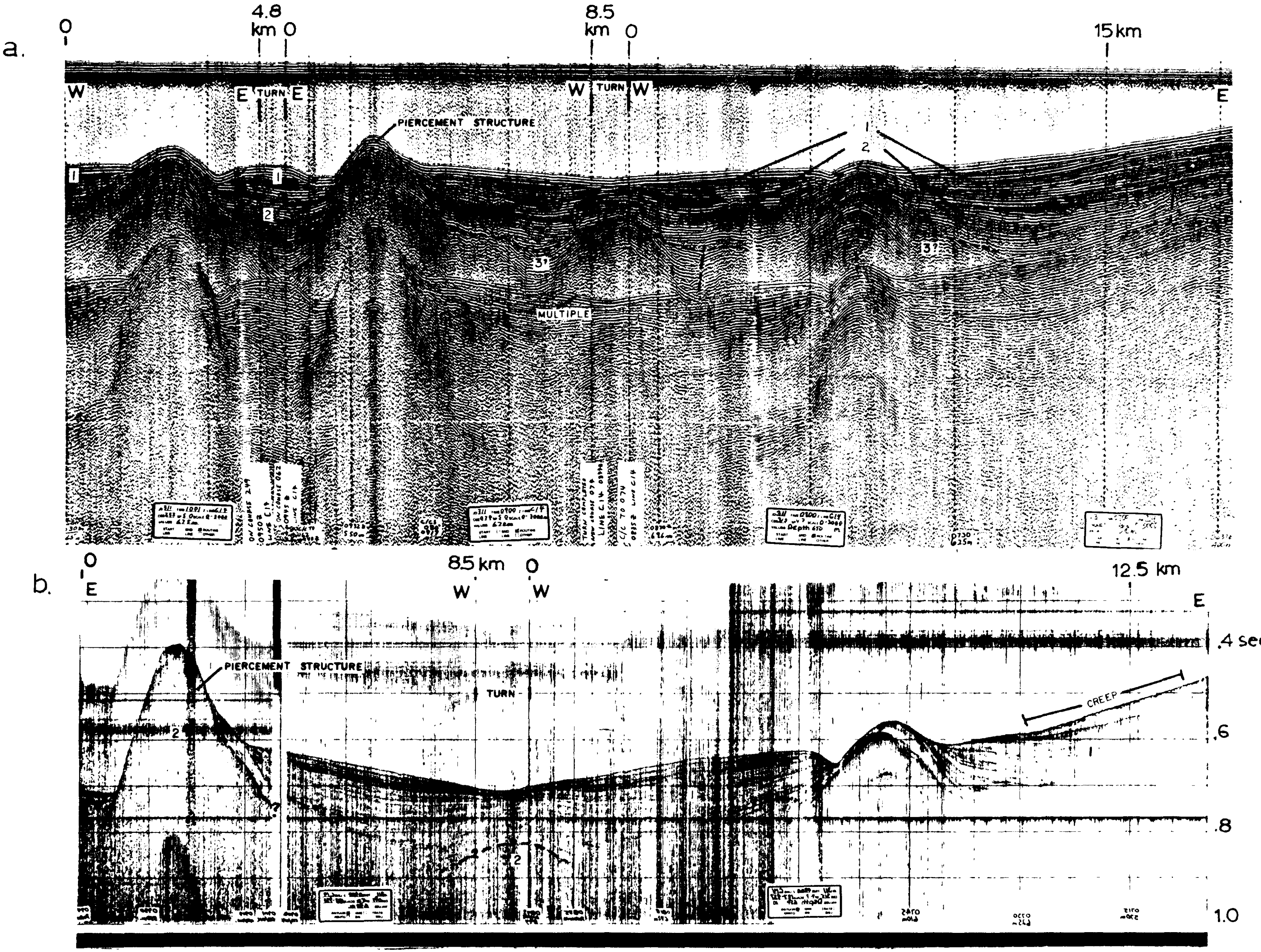

Figure 10. Deep penetration (a) and high resolution (b) seismic reflection records (77-14) across slope northwest of Cape Arago. Note contacts between acoustic units 1 and 2, 2 and 3; apparent creep of surface sediment at east end of the high resolution record (10b); and young fold having up to 250 m of seafloor relief and showing evidence of piercement. Note that two course reversals appear on 10a, so that diapiric fold is crossed three times; one course reversal and two crossings of diapir appear on 10b.

Assemblages of benthic Foraminifera reflect depths greater than those from which they were collected, indicating uplift of the enclosing rocks subsequent to deposition; upper Miocene and lower Pliocene rocks on Heceta Bank appear to have been elevated 900-1000 m, and lower to middle Pliocene strata on Coquille Bank have been uplifted as much as 500-600 m (Kulm and Fowler, 1974b).

Three discrete episodes of deformation are indicated by major unconformities in seismic reflection records from the inner continental shelf (e.g. see figs. 5, 8, 12, 13). The youngest unconformities separate acoustic units 1 and 2, and units 2 and 3; the oldest is within unit 3. These unconformities are believed to be Pliocene-Pleistocene, early late Miocene and middle to late Eocene in age, respectively. Angular discordance between units is greatest on the inner shelf and in the vicinity of Heceta and Coquille Banks. Between the banks and shoreline are a series of generally north-trending synclines filled with Quaternary sediments that onlap folded Pliocene and older rocks on the adjacent banks and shelf. Some of these synclines appear from seismic reflection records to have formed on the sites of 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 anomaly (Dehlinger and others, 1968; Kulm and Fowler, 1974b).

A CDP profile near the south end of Heceta Bank suggests that the 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 055 degrees (N55E); Pleistocene strata strike 030 (N30E), perhaps reflecting a change in the direction of deformation during Pliocene-Pleistocene time (Fowler and Kulm, 1971). Heceta and Coquille Banks are characterized by positive free air anomalies (Dehlinger and others, 1968), perhaps reflecting the presence of Paleogene strata at relatively shallow depths.

Acoustic unit 2 on Heceta Bank is folded and truncated, and is onlapped locally by unit 1. Deformation of the bank continued during deposition of unit 1, as it contains an unconformity locally on the east side of the bank and is itself folded (figs. 5, 6). Acoustic unit 3 may crop out on the bank locally in the axes of anticlinal folds, but this has not been verified. These data indicate that the most recent episode of deformation on Heceta Bank began during Pliocene (probably late Pliocene) time and continued into the Pleistocene. The bank was truncated during Pleistocene low stands of sea level; it does not appear to have been uparched substantially since that time, suggesting that the intensity of deformation has diminished during the late Quaternary.

Coquille Bank is a north-trending, asymmetrical, doubly plunging anticline (Mackay, 1969). The west side is inferred by Kulm and Fowler (1974b) to be faulted down, based on bathymetry and on the absence there of the thick Pliocene-Pleistocene section present on the east limb. The youngest pre-Quaternary rocks exposed in the core of Coquille Bank are siltstone and claystone of middle Pliocene age (Kulm and Fowler, 1970, 1974b). The lower part of acoustic unit 1 locally thins from the base by onlap onto uparched strata of acoustic unit 2, suggesting that the banks had positive seafloor relief early during deposition of unit 1 (fig. 11). Unit 1 is truncated on Coquille Bank, and strata in the upper part of unit 1 in the structural saddle east of the bank thin depositionally toward the west and are upwarped along the bank margin (see figs. 17, 18), suggesting that deformation continued well into the time of deposition of this unit. Additionally, Coquille Bank stands 60-90 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, presumed to have been cut during the late Wisconsin low stand of sea level (see fig. 18). Either it stood above sea level as an island and resisted erosion during

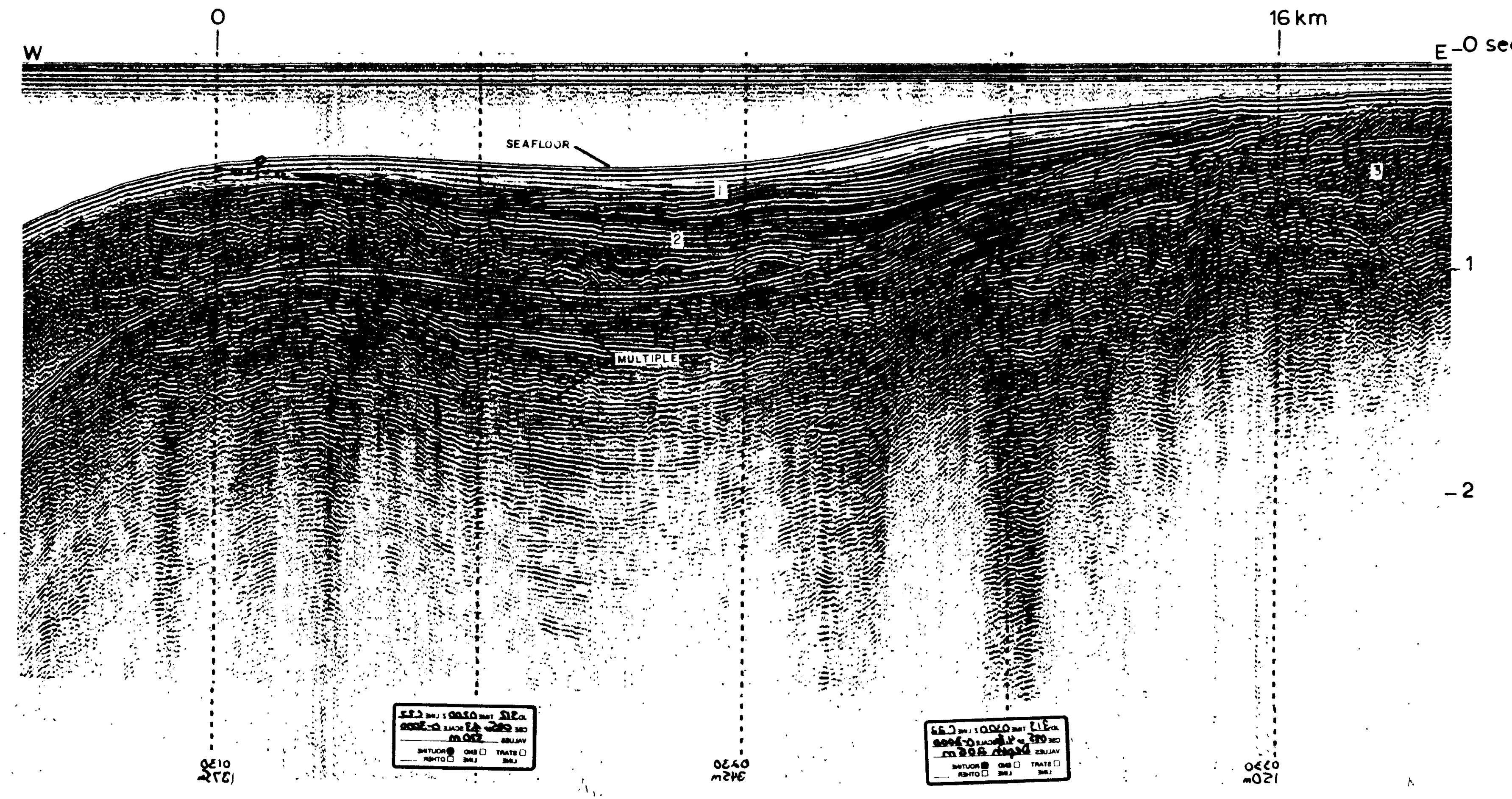

Figure 11 Deep penetration seismic reflection record (77-22) across shelf and slope north of Coquille Bank.
Note contacts between acoustic units 1 and 2; 2 and 3; apparent onlap of lower part of unit 1 (bounded by dotted line) onto unit 2 on east flank of Coquille Bank.

late Pleistocene time, seemingly unlikely as the core material is relatively 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 suggested for unit 1 (60-90 m) is generally consistent with previous estimates (Kulm and Fowler, 1974b) from assemblages of benthic Foraminifera of up to 100 m uplift of Pleistocene deposits on the outer banks. These observations suggest that the latest major episode of tectonic activity on Coquille Bank commenced in late Pliocene time, with deformation increasing in intensity during Quaternary, and continuing into Holocene time.

Piercement structures with cores of Miocene siltstone have been described from coastal Washington by Rau and Grocock (1974), and Snavely and others (1977) estimate that 50-100 such diapiric intrusions are present on the Washington and Oregon OCS. Several folds showing seafloor relief on the upper continental slope between Heceta and Coquille Banks appear recently active; one of these, crossed by lines 77-14 (fig. 10), and 78-48 and 49, may be diapiric in origin. This fold shows evidence of piercement and about 250 m of seafloor relief. The lower part of acoustic unit 1 is uplifted and truncated against the east flank of the fold (fig. 10, 0745Z), and the upper part of 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 sheared olive-gray mudstone of Pliocene (probably late Pliocene) age, (pl. 2; app. 3, sample nos. 77-14, 77-15). Uplift appears to have commenced during Quaternary (Pleistocene) time; judging from the amount of seafloor relief, thinning of young sediments against the flanks of the fold and their absence on the crest of the structure, it 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 lines 77-18 and 78-30 and located 20-25 km south of the piercement structure described above shows up to about 150 m of seafloor relief (pls. 1, 3). Acoustic unit 1 thins abruptly and is upturned along the flank of this fold, and is absent from the fold crest (figs. 12, 13). This deformation appears to be wholly Quaternary in age.

Faults

Faulting, though not so prevalent as in the California offshore, remains a potential hazard to offshore development in the Coos Bay basin. Snavely and others (1977, 1980) note that many north-trending faults cutting geologically young strata have been mapped in coastal Oregon and appear on seismic records on the inner shelf. Kulm and Fowler (1974b) suggest that the steep, linear escarpments west of Heceta and Coquille Banks may be fault controlled. Most faults mapped during this study in the Coos Bay basin are short, and cannot be traced between adjacent seismic reflection lines (pl. 3). Some faults can be traced between two lines, a distance of 5-8 km, and a few can be traced for as much as 12-15 km. Faults terminating in acoustic unit 1, inferred to be Quaternary, and in acoustic unit 2, inferred to be late Miocene and Pliocene in age, are about equal in number. Those cutting unit 2 are more-or-less evenly distributed on the mid to inner continental shelf, upper slope and banks, whereas those cutting unit 1 are most common on the shelf and bank tops. Faults on the inner shelf and bank tops commonly trend between 330 and 360 degrees (NNW to N); on the upper slope, faults terminating in unit 2 have a slightly more northerly trend, between about 345 and 005 degrees. Faults that appear to be high angle are most common.

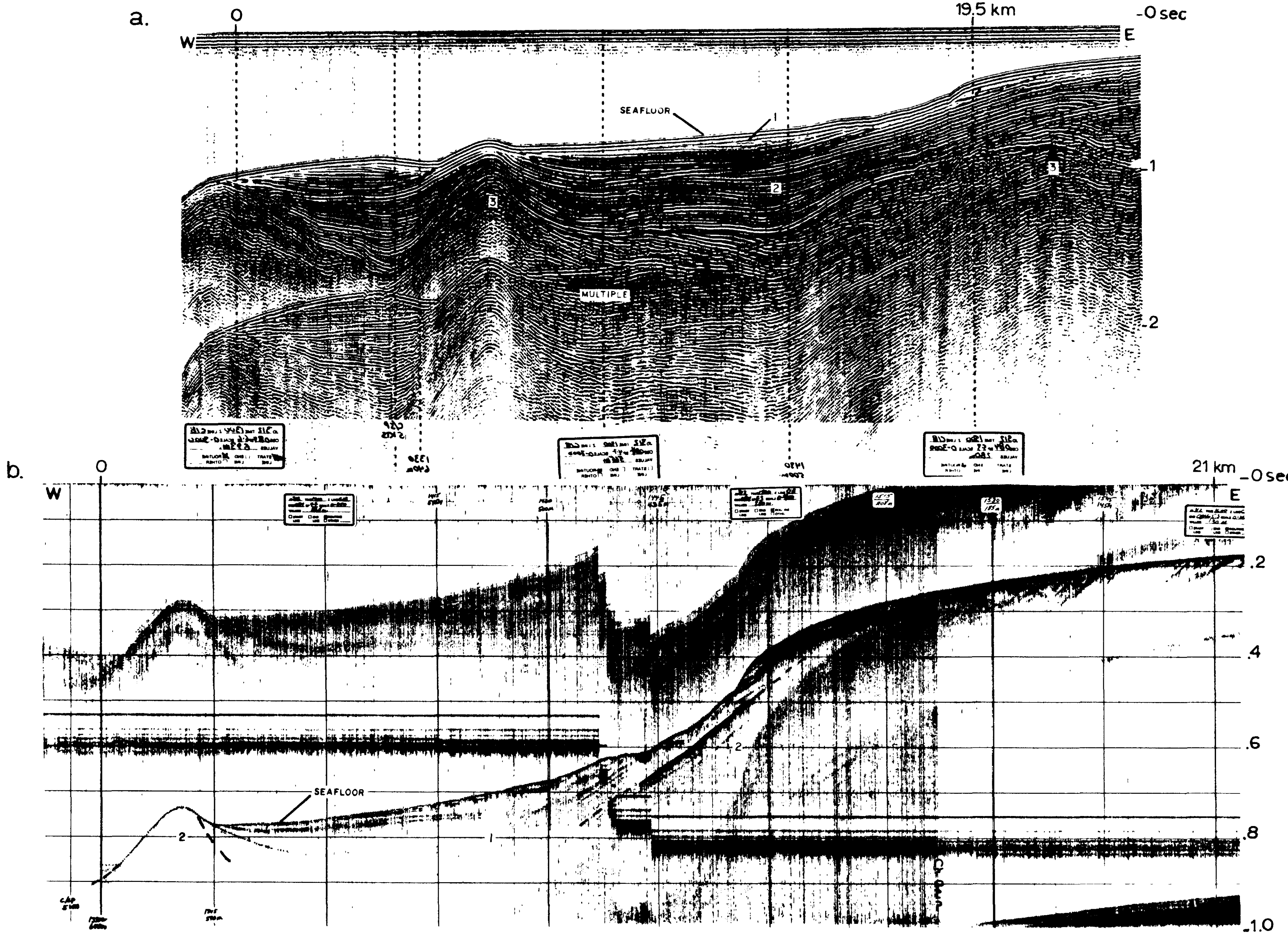

Figure 12. Deep penetration (a) and high resolution (b) seismic reflection records (77-18) across outer shelf and slope west of Cape Arago. Note contacts between acoustic units 1 and 2, 2 and 3; youthful (active?) fold at 1340Z; and apparent depositional thinning of unit 1 against flanks of this fold.

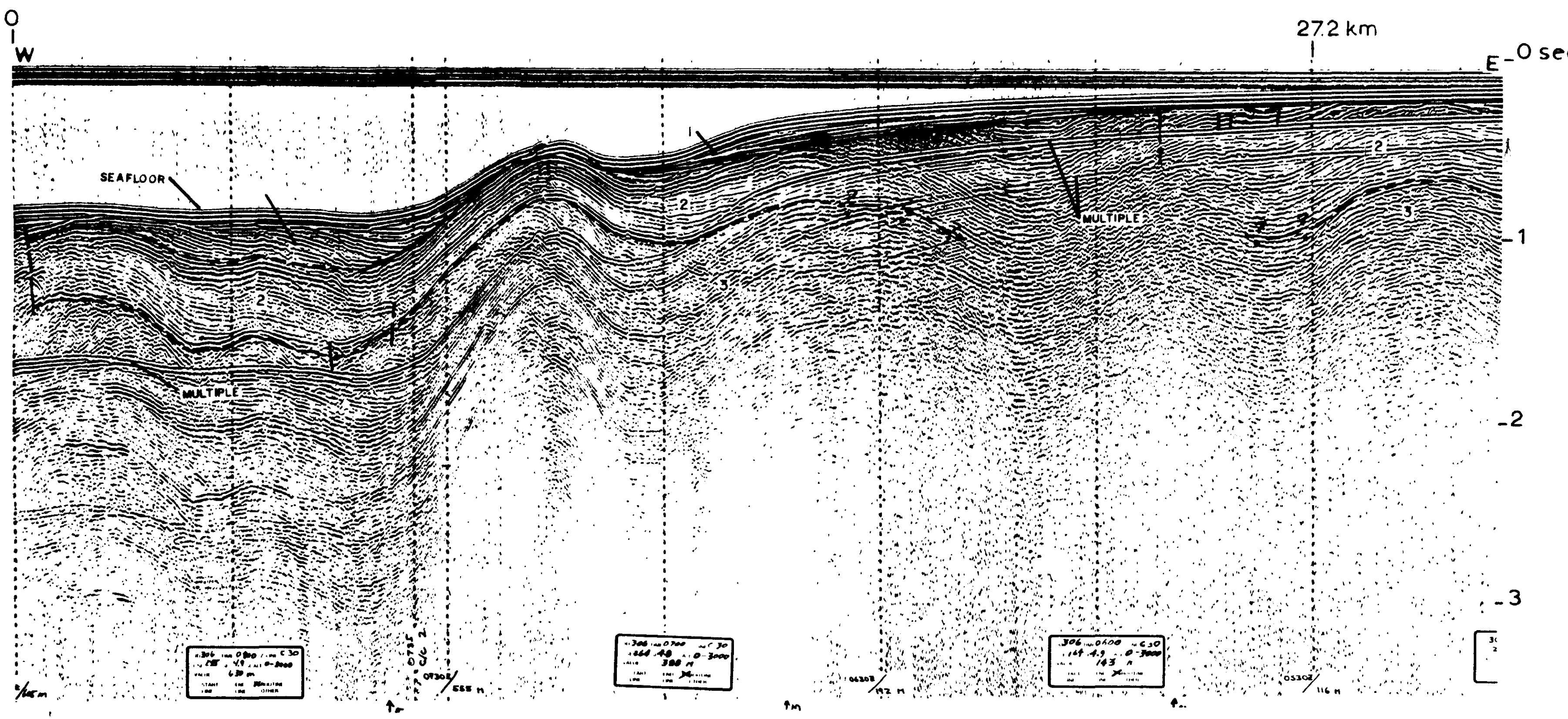

Figure 13. Deep penetration seismic reflection profile (78-30) across shelf and upper slope west of Cape Arago.
Note contacts between acoustic units 1 and 2, 2 and 3; evidence of youthful (active?) fold at 0715Z; and apparent depositional thinning and deformation of unit 1 along flanks of this fold.

A group of faults trending approximately 350 - 360 degrees cuts acoustic unit 1 on the inner continental shelf about 15 - 25 km north of Cape Arago (figs. 7, 14). One fault cuts deposits of presumed Holocene age (fig. 7); this fault trends 342 degrees, is downthrown to the west, and has been traced for 13 km. Several other faults may reach the sea floor. Further study of these faults is warranted by the indications of Quaternary activity and by their proximity (approx. 20 km) to the Coos Bay - North Bend-Empire area.

Acoustic unit 1 is cut by a fault of possibly major displacement on the south side of Heceta Bank (pl. 3; Kulm and Fowler, 1974b). This fault trends 330 - 335 degrees, is downthrown to the northeast and is at least 15 km in length (fig. 15). This fault and the cluster of faults north of Cape Arago described above have the same apparent age and lie on the same trend. Although they have not been traced through the intervening area, the similarity in style of faulting suggests that they may have a common origin.

Acoustic unit 2 is cut by a fault having substantial vertical offset 12 - 15 km south-southwest of Cape Arago (fig. 16); this fault trends about 330 degrees, is downthrown to the east, and has seafloor expression suggestive of recent movement.

The Port Orford shear zone, a north-northwest trending fault zone up to 3 km wide that shows evidence of right slip extends offshore just northeast of Cape Blanco (Dott, 1962, 1965, 1971; Koch, 1966). This zone is known to have been active in post-middle Eocene and post-Miocene time; Plio-Pleistocene activity 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

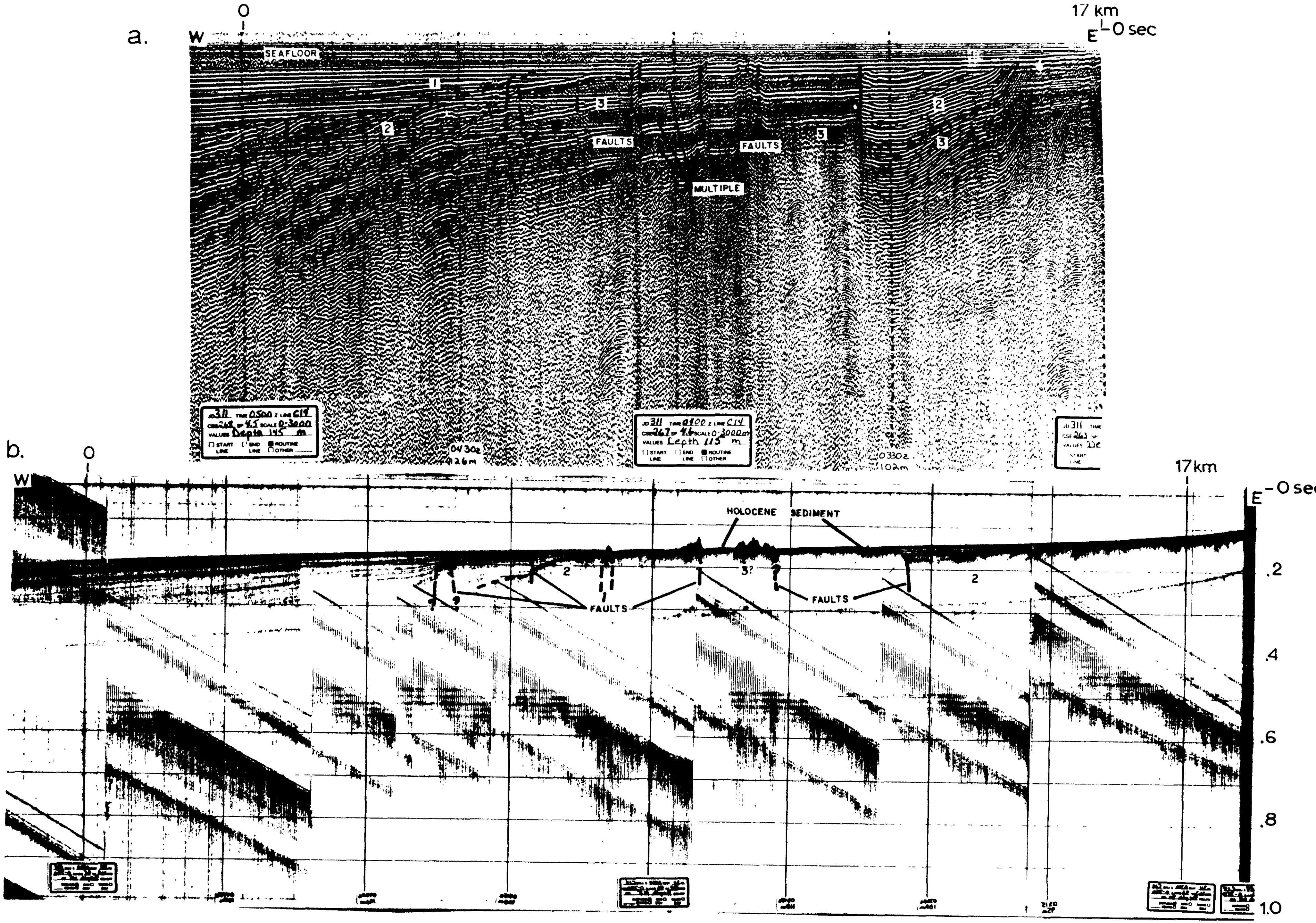

Figure 14. Deep penetration (a) and high resolution (b) seismic reflection record (77-14) across inner shelf north of Cape Arago. Note series of faults extending to or near the seafloor in acoustic units 1 and 2. Acoustic unit 3 may crop out on the seafloor between about 0346Z and 0357Z.

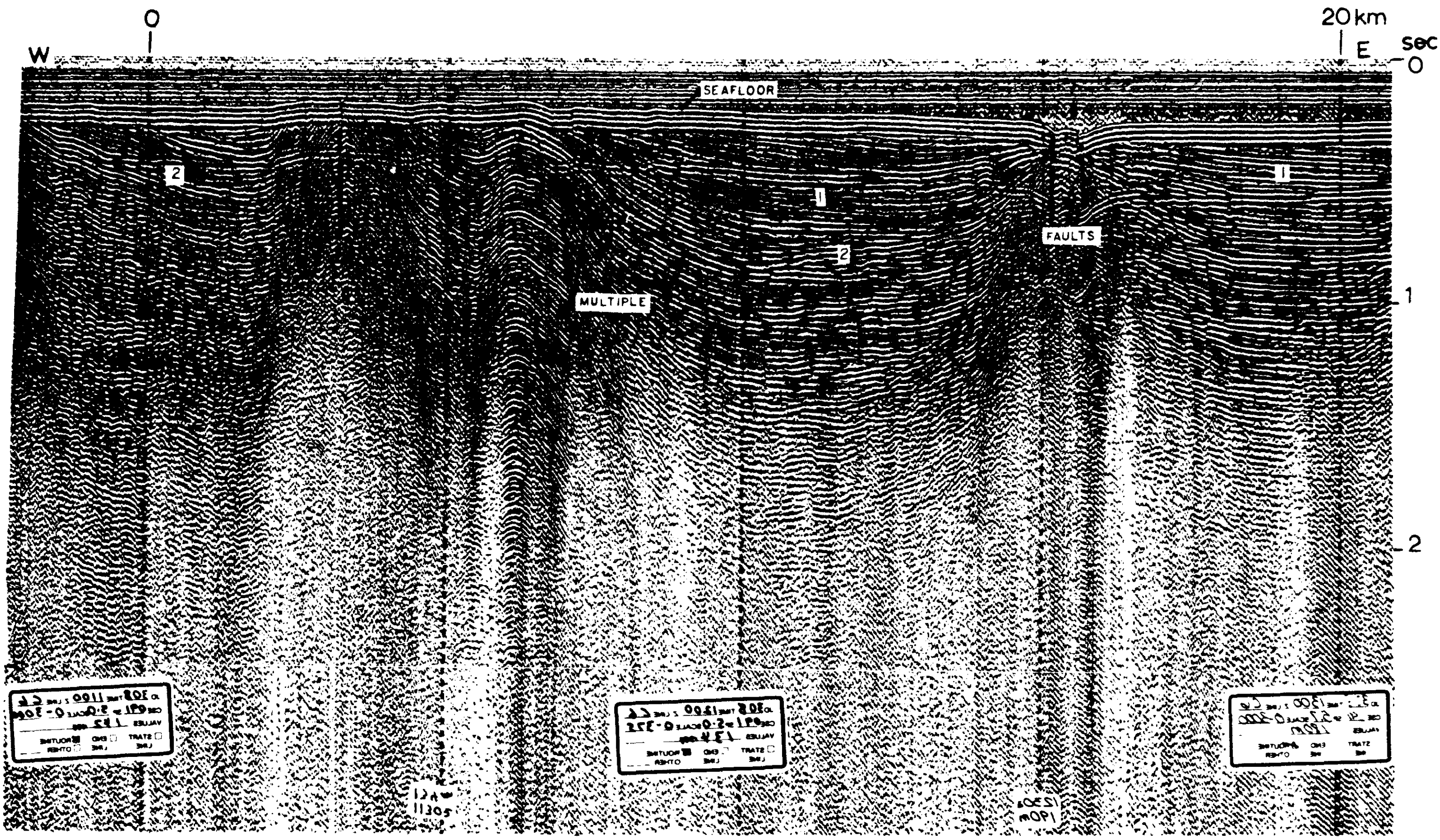

Figure 15. Deep penetration seismic reflection record (77-06) across southeastern Heceta Bank and adjacent shelf. Note faults extending to the seafloor is acoustic unit 1 at about 1230Z.

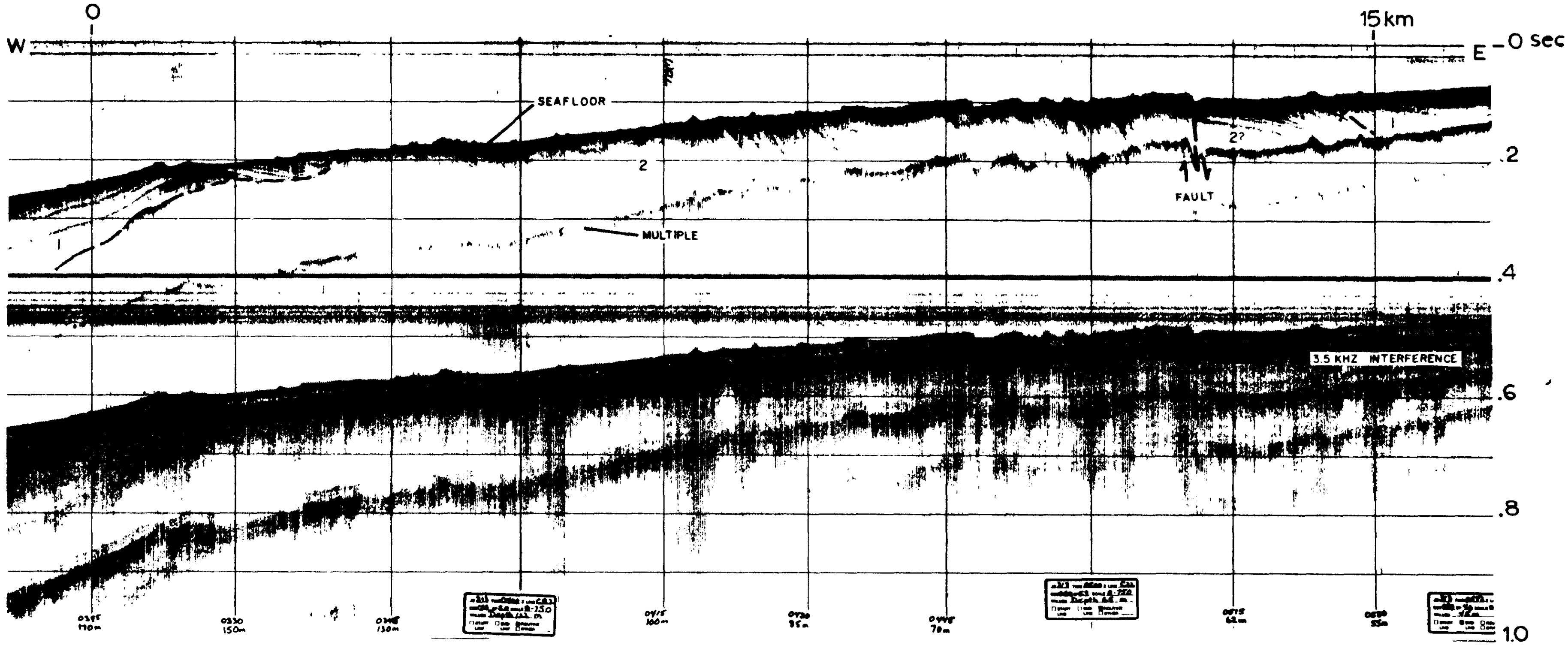

Figure 16. High resolution seismic reflection record (77-22) across shelf southwest of Cape Arago. Note fault offsetting the seafloor in acoustic unit 2 at about 0510Z. Note also apparent onlap of unit 1 onto unit 2, and deformation of unit 1 on shelf edge at west side of record.

Cape Blanco - Coos Bay area is also indicated by uplifted and faulted marine terraces of Pliocene and Pleistocene age (Janda, 1969). Dott (1979) recently proposed that the Port Orford shear zone and similar northwest-trending, roughly en-echelon shear zones that cut the Pacific margin of Oregon and northern California are part of the eastern boundary of the "Humboldt plate" (Herd, 1978). This plate (perhaps more appropriately termed the "Humboldt block") is a narrow, intracontinental structural block located at the complex boundary between the North American, Pacific and Gorda crustal plates; its proposed eastern boundary comprises a series of northwest-trending strike-slip faults.

The Port Orford shear zone zone cannot be traced far into the offshore and was not identified, as such, in this study; Mackay (1969) may have crossed the zone about 10 km north of Cape Blanco, but speculated that it is covered by post-Miocene strata farther northwest on the shelf. However, it is also possible that shear associated with this zone is transferred to other northwest trending faults in the offshore, perhaps those here described as showing evidence of Quaternary offset north of Cape Arago and on Heceta Bank. Such a transfer of shear between en-echelon faults would be in accord with Herd's (1978) observation that the line of faults comprising the eastern boundary of the "Humboldt plate" is so young geologically "that there has been insufficient time to integrate the faults into a single surficial break", and this regime of faulting would extend the eastern boundary of the 'Humboldt plate", if its existance is established, as far north as Heceta Bank. The existance in the Coos Bay basin of a zone of en-echelon strike-slip faults marking a plate boundary, and whose present level of tectonic activity is unknown, has obvious import to offshore development in the area. Tectonic activity associated with such a zone would probably be low relative to 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 and the likelihood that shear would be accomodated along several faults. Nonetheless, additional study is in order to determine the nature and significance of Quaternary faults in the Coos Bay basin, their relationship to the Port Orford and similar shear zones farther south, and the relationship 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. However, the record of seismic events extends 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 200-300 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 1954-1963 show that earthquake activity off northern California and Oregon is focused along the Gorda Ridge, the Mendocino Escarpment 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). Relatively little activity is associated with the Juan de Fuca Ridge or with the continental margin of Oregon north of Cape Blanco. A plot of 1025 events recorded by hydroacoustic methods shows a concentration of epicenters along the Gorda Ridge and Blanco fracture zone (Northrup and others, 1968). Fault plane solutions for the Blanco fracture zone, Gorda Basin, Gorda Escarpment and Cascadia Basin 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 underthrusting of the continental margin off northern California and southern Oregon. 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 relative lack of seismic activity associated with the Juan de Fuca Ridge and absence of an oceanic trench and Benioff zone along the continental margin of central-northern Oregon and Washington suggests that subduction has slowed or stopped.

The locations of earthquakes that occurred during the period 1841-1975 in the area extending from latitude 42°30'N to 45°00'N and from longitude 124°00'W to 126°00'W are plotted on Plate 4. Location accuracy of earthquakes in this region prior to 1962 is estimated to be 8 km. Since 1963, the use of five recording stations in Oregon (Corvallis/OSU, Portland/OMSI, Klamath Falls/OTI, Blue Mountain/NOS and Pine Mountain/UO-NASA) and improved travel-time curves have reduced the average uncertainty to about 4 km for earthquakes greater than M3.5 (Couch and Lowell, 1971). Reported depths of earthquakes in Oregon indicate shallow foci, although data are scant. An average focal depth of 5-15 km is estimated by several workers for earthquakes in the portion of Oregon west of the Cascade Range (Couch and Lowell, 1971). Focal depths of earthquakes associated with the Gorda Ridge and Blanco fracture zone are largely unknown, but are thought to be shallow - perhaps approximately 5 km (Brune, 1968).

Only one earthquake has been recorded within the offshore Coos Bay basin and none have been recorded within the adjacent coastal area of Coos, Douglas and Lane Counties, Oregon, for more than 100 years (pl. 4 ; Schlicker and Deacon, 1974; Beaulieu and Hughes, 1975). Beaulieu and Hughes (1975), however, suggest that the earthquake potential for the area surrounding and south of Coos Bay is at least moderate, with earthquakes of (modified Mercalli) intensity V to VII 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 roughly equivalent to one M5.0 earthquake per decade (Couch and Lowell, 1971). The maximum intensity reported for an earthquake in this region is VI, and the corresponding expected maximum ground acceleration is 31.6 cm/sec^2. Although the offshore Coos Bay basin is devoid of epicenters for the 1841-1974 period, the Port Orford earthquake of 1973, centered near Cape Blanco, had a magnitude of about 6.3 (computed from observed intensity), and an earthquake of magnitude 6.0 centered at sea about 90 km west of Cape Blanco was recorded in 1938 (pl. 4 ; Couch and others, 1974).

The possibility of damage resulting from an earthquake in adjacent areas, notably the northern California continental margin, should be taken into consideration in assessing geological hazards to development in the Coos Bay basin. The effects, other than ground motion, of such earthquakes may include seafloor mass movement, sediment flowage, liquefaction, differential subsidence, and tsunamis. Couch and Deacon (1972) indicate that the recurrence interval of a M8.0 earthquake in the Gorda Basin is 130 years, and large earthquakes (up to M7.3) have been recorded along the Mendocino Escarpment. A 1922 earthquake of M7.3 (calculated intensity X) centered in the Gorda Basin about 90 km northwest of Cape Mendocino (Couch and others, 1974) was felt with an intensity of V in Coos Bay; Beaulieu and Hughes (1975), assuming similar attenuation of seismic waves, have estimated that the "largest possible" earthquake along the Mendocino Escarpment would produce a quake of intensity VII in the Coos Bay area, with the corresponding ground acceleration less than 0.10 g (48.8 cm/sec^2).

SEAFLOOR INSTABILITY

Seafloor instability here refers to conditions that could lead to seafloor failure from mass movement, liquefaction or tectonic deformation, and to evidence of past seafloor failure. Unstable and potentially unstable seafloor conditions identified in the offshore Coos Bay basin are associated with subaqueous slides (both surficial and buried), sediment creep, active uplift and possible diapirism, possible accumulations of shallow gas, and possible clathrates; each of these is treated in the following paragraphs. 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 reports by Schlicker and Deacon (1974) and Beaulieu and Hughes (1975).

Slides, Flows and Creep

Subaqueous slides are mass movements of rigid or semi-consolidated masses along discrete shear surfaces, which may be concave upward or planar, with relatively little internal deformation (Dott, 1963). Slides are commonly identified on seismic reflection records by the presence (in longitudinal sections) some or all of the following characteristics: 1) a headscarp where the slip surface extends upward to the seabottom, 2) compressional ridges resulting from small-scale thrusting and folding at the toe of the slide, 3) transverse (tensional) cracks in the body of the slide, 4) limited internal deformation of reflectors, and 5) the presence of a slip surface 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 may occur on slopes of less than 1 degree (under special circumstances as low as 0.2 degree), and range upward in size from 10s of meters to square kilometers in area and more than 100 m in thickness (Moore, 1961; Heezen and Drake, 1964; Lewis, 1971; Hampton and Bouma, 1978). Subaqueous flows involve the downslope movement under gravity of water saturated, unconsolidated sediment; the moving mass may behave plastically or as a very viscous fluid, and movement may be slow or rapid (Dott, 1963). The velocity and displacement of flow characteristically decrease gradually with depth below the surface, so that the deposit lacks a distinct slip surface. Subaqueous flow deposits are suggested on seismic reflection records by the presence of 1) anomalously thick, apparently detached sediment masses that 2) lack an identifiable slip plane and 3) show acoustic transparency or chaotic internal structure. Creep, a form of flow, is the slow, more-or-less continuous, downslope movement of the upper layers of unconsolidated sediment and is characterized by 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 extend to depths of 15-20 m, and may affect large areas.

Little evidence of sediment mass movement was identified in seismic reflection records from the Coos Bay basin (pl. 6). This is somewhat surprising in view of the large areas of slumping present only about 100 km to the south in the Eel River basin (Field and others, 1980) in a geologic setting that is similar in many respects, and of the presence of 2-4 degree slopes below the shelf edge - slopes seemingly adequate to cause failures in the locally thick accumulations of Quaternary sediment (pl. 5) present in the basin. The very high rate of sediment influx from the Klamath River and much more active seismic environment of the northern Calfornia region probably are responsible for the much greater abundance of modern slope failures in that area. Slides may be more prevalent on the mid to lower continental slope west of the study area, as thick sections of faulted late Tertiary and Quaternary sediments are present and slopes of 7 to 14 degrees are common. The presence of peat and devitrified volcanic ash, both of which are present in deposits of this age onshore and on the continental shelf, can greatly reduce shear resistance and contribute to failure. It is noteworthy that ground failure is relatively common in water-saturated late Tertiary and Quaternary deposits along the Oregon coast and on steep slopes elsewhere in the Oregon and Washington offshore.

Slides were identified in the Coos Bay basin on the west flanks of Heceta Bank (fig. 5) and Coquille Bank, both areas of relatively steep slopes but generally lacking thick deposits of Quaternary sediments (pl. 6). These slides occur in water depths of 150-450 m and 700-900 m, respectively, and each is about 15 m thick. The deposit west of Heceta Bank appears to be a rotational slump 4 km or less in length, and the one west of Coquille Bank is a slide of undetermined type about 2 km in breadth.

Two areas of sediment creep were mapped on slopes at depths between 500-600 m. The southern area appears to be about 3.5 km long, with the zone of disturbance extending to a depth of about 10 m below the seafloor. This area of creep may be superimposed on an older, buried slide, in which case the unstable zone would extend considerably deeper. The northern area is located 40 km northwest of Cape Arago, and was crossed by two seismic lines (fig. 10). The disturbed zone is about 2.8 by 4 km in size, and extends to a depth of about 5-8 m below the seafloor.

Buried zones of moderately to extremely disrupted (broken and rotated) reflectors were identified stratigraphically low in acoustic unit 1 in the central part of the basin south of Heceta Bank (pl. 6). Similar appearing zones have been mapped in the Eel River basin (Field and others, 1980) where they are clearly associated with extensive modern slump deposits which they resemble in acoustic character. Consequently, these zones are interpreted as slides in Quaternary sediments, perhaps associated with rapid sediment influx during a low stand of sea level in Pleistocene time. The largest zone (fig. 8) is located in the central part of Coos Bay basin below the edge of the modern shelf at water depths of 250-600 m; it is nearly 20 km long and 13 km wide at its widest point, and covers an estimated area of 190 km^2. The upper surface of the zone ranges from 150 to 300 ms in depth below the seafloor, equivalent to a subbottom depth of about 125-250 m (at an assumed velocity of 1650 m/sec), and the zone is as much as 250-300 ms, or about 200-250 m thick. Smaller zones of disrupted subsurface reflectors are located south of Heceta Bank and east of the buried slump area described above. These areas are crossed by only one seismic line each, and are 5 km and 2 km across, respectively.

Areas of Uplift

Several folds that show seafloor relief on the upper continental slope between Heceta and Coquille Banks appear to be active, and one of these shows evidence of piercement (pl. 3; also see "STRUCTURE - Folds"). The uppermost (youngest) strata of acoustic unit 1 thin depositionally and are deformed against the flanks of these features and are absent from the crests. Subjacent strata are uparched over the folds and seafloor relief of up to 250 m has been observed (figs. 10, 12, 13). Piercement has occurred locally along the axis of one fold, located about 44 km northwest of Cape Arago (fig. 10). The core of this fold lacks coherent internal structure in seismic reflection records, and the irregularity of topography on the ridge crest where core material is exposed is consistent with recent flowage. Samples show the core material to be sheared olive-gray mudstone of Pliocene (probably late Pliocene) age (pl. 2; app. 3 , samples 77-14, 77-15). Uplift here appears to have commenced in Quaternary (Pleistocene) time and may be active at present.

Diapiric intrusions are thought to be abundant on the Washington and Oregon OCS (Snavely and others, 1977) and, along the Washington coast, Pliocene strata are intruded locally by a pervasively sheared melange of volcanic and sedimentary rocks in a "mudlike matrix of clays and siltstone fragments" containing Miocene Foraminifera (Rau and Grocock, 1974). Gas seeps and abnormally high subsurface gas pressures are associated with the latter intrusions, suggesting that diapirism in coastal Washington is associated with overpressured zones in subsurface. Geochemical analyses for hydrocarbon gases were made of four sediment samples collected on and adjacent the piercement structure mapped in the offshore Coos Bay basin; however, no evidence was detected of gas leakage from this structure into near-surface sediments (see app. 4, samples 15G, 16G2, 17G1, and 18G).

These features clearly reflect recent tectonic instability and so merit careful study. However, their potential as hazards to offshore development can not be assessed without additional information concerning their manner of emplacement, rate and nature of uplift, relationship to overpressured zones and association with other forms of seafloor instability.

Shallow Gas Accumulations

Natural gases of biogenic and/or thermogenic origin may be present in marine sediments. Biogenic gases, principally methane, are derived from bacterial alteration of organic material in sediments. Thermogenic gases, dominated by hydrocarbons heavier than methane, are by-products of petroleum formation. The presence of thermogenic gases in sediments can reflect an over-pressured zone that is discharging gas into the overlying strata either directly or via a conduit such as a fault or bedding plane. Inadvertant penetration of an over-pressured 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 dissolved in the interstitial pore space of sediment lowers the shear strength of the enclosing sediment and increases likelihood of failure; under some circumstances dissolved gas can liquefy spontaneously when subjected to cyclic loading (Hall and Ensiminger, 1979).

The presence of gas in sediments is suggested on medium and high resolution seismic reflection records by the presence of amplitude anomalies (apparent as enhanced or "bright" reflectors); the sharp termination or displacement of reflectors, commonly associated with acoustically turbid zones; the absence of surface multiples indicating absorption of the seismic signal (Nelson and others, 1978); the presence of "pull-downs" from the decreased velocity of sound in gas charged sediments; and the presence of bubbles in the water column. Side-scan sonographs and underwater video or photographic coverage may show seep mounds or craters on the sea floor, and bubbles. In all cases, sampling and geochemical analyses are needed to verify the presence of gas and identify its origin.

Several possible accumulations of gas in sediments were identified at shallow subbottom depths in the Coos Bay basin. These gassy zones are indicated on high-resolution seismic reflection records by an abrupt discontinuation of subbottom reflectors accompanied by zones of acoustic turbidity; the turbid zones are overlain by an "enhanced" reflector marking a significant velocity contrast (fig. 6). This "enhanced" reflector typically appears randomly displaced along its length.

Possible gas accumulations mapped in the Coos Bay basin range in size from about 0.5 km across (crossed by a single line) up to about 120 km^2; the largest zones lie in areas of active Quaternary sedimentation on the lower shelf and upper slope, at water depths ranging from 135 m to about 400 m. Several of the areas are associated with faults that cut Quaternary sediments. One area, located 22-23 km off the mouth of the Umpqua River, appears to be bounded on the east and west by faults; seepage in another area (fig. 17) appears to reach the surface along a fault that cuts the Quaternary section. Depth below

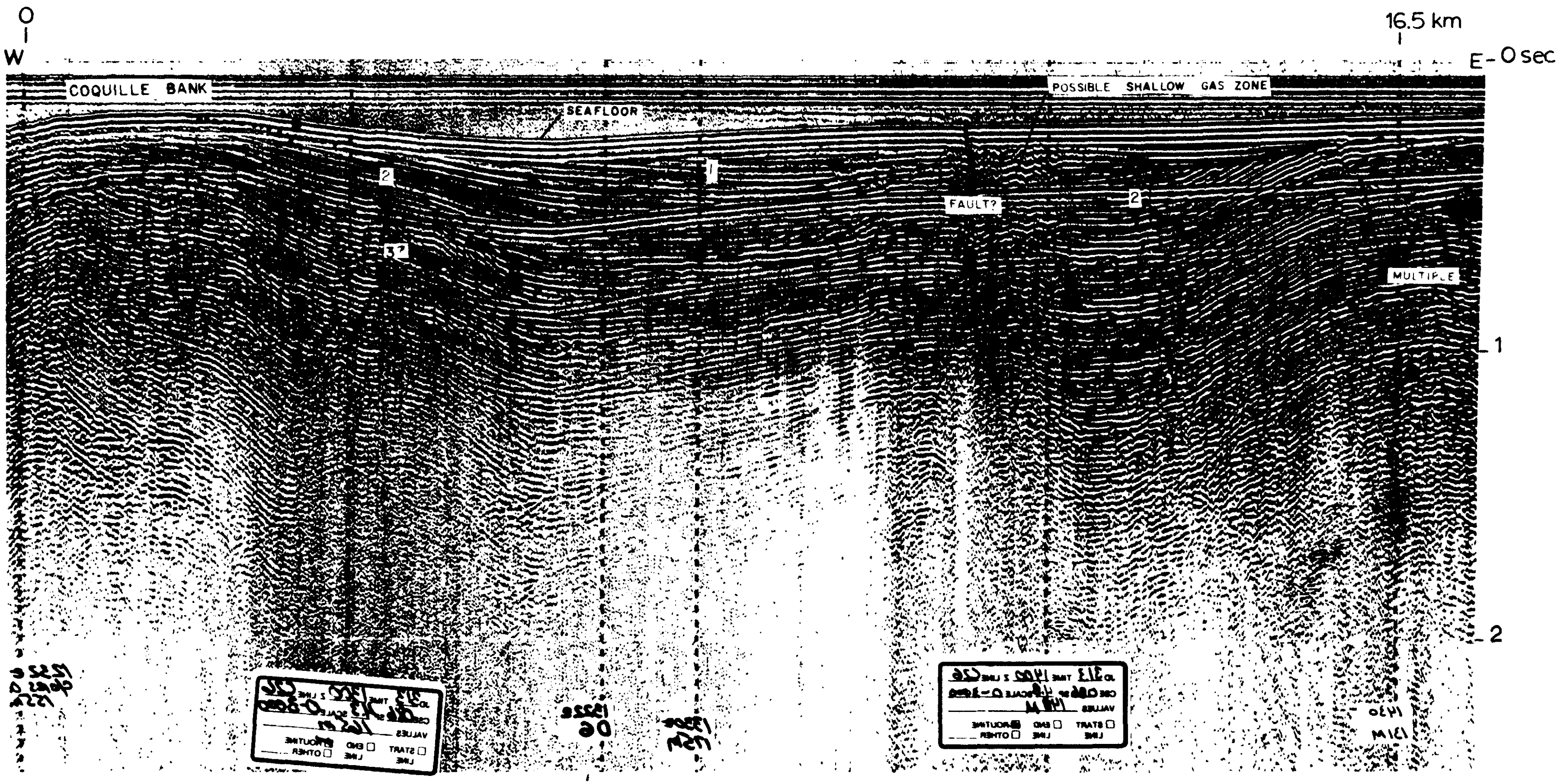

Figure 17. Deep penetration seismic reflection record (77-26), across Coquille Bank and adjacent shelf. Note contacts between acoustic units 1 and 2, 2 and 3; also note deformation of reflectors thought to be associated with shallow gas in acoustic unit 1 between about 1350Z and 1400Z, and fault at 1352Z.

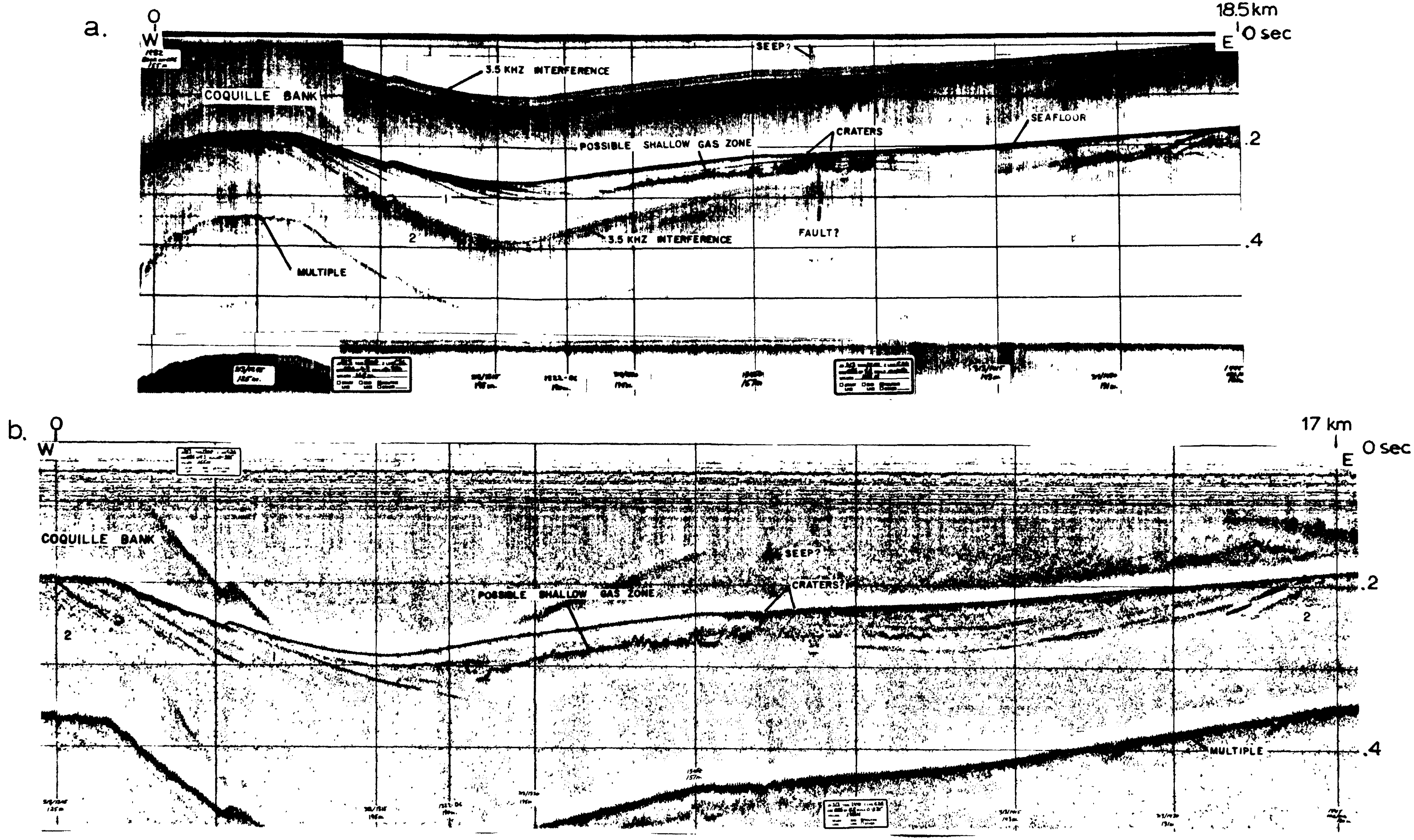

Figure 18. High resolution seismic reflection records (77-26) across Coquille Bank and adjacent shelf. Figure 18a is 1.2 kJ "boomer" record; 18b is 3.5 kHz profiler record. Note contact between acoustic units 1 and 2. Depositional thinning of strata in upper part of unit 1 east of Coquille Bank, truncation of unit 1 on bank margin and seafloor relief of bank above adjacent shelf indicate recent uplift. Note also evidence of shallow gas in acoustic unit 1, apparent cratering of seafloor associated with this zone, and possible gas bubbles in water column above crater.

the sea bottom of the upper surface of the gassy zones ranges from 10 to 40 ms, (about 8 to 33 m) and averages 20-25 ms (about 20 m). The seafloor at one location appears to be cratered where the gassy zone extends to the surface, and there is a suggestion on high resolution seismic reflection records of bubbles in the water column above the crater (fig. 18). Samples taken in the vicinity of this apparent gas seep and analyzed at sea to determine their gas content did not contain unusually high concentrations of hydrocarbon gases; however, there is evidence that gas concentrations may increase with depth, so that gas-charging, while not confirmed, remains a possibility (app. 4, samples 23G1 and 23G3).

Possible Clathrates

Bottom Simulating Reflectors (BSR's) are prominent 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 mid and lower continental slope (about 650 m to 2000 m water depth) seaward of the Coos Bay basin, characteristically occurring at depths ranging from 250 to 400 milliseconds below the sea floor. Their origin is uncertain, but they may indicate the presence of clathrates-frozen gas hydrates comprising solid, ice-like mixtures of natural gas and water (Kvenvolden and McMenamin, 1980). If gas is present in quantity and if extraction proves feasible, such zones could become energy resources. Clathrates may also form impenetrable barriers to the upward migration of free natural gas. Inadvertant 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 SEDIMENTS

Sampling in the Coos Bay basin was aimed at obtaining a limited amount of geochemical data and geological age information to faciliate interpretation of seismic records; location, water depth and length of cores obtained in 1977 are shown in Appendix 2, and textural data for selected core samples are shown in Appendix 5 . A sampling program to characterize surface sediments was not carried on because of time constraints, the need to collect a large amount of other geological and geohazards data, and the availability from institutions such as Oregon State University of a large amount of surface sediment data and interpretive reports, some published, derived from these data. The reader is directed to studies by Kulm and others (1975) of the nature and distribution of sediment facies and factors affecting sediment transport on the Oregon shelf; Scheidegger and others (1971) of sediment provenance and dispersal; Byrne and Panshin (1977) of the distribution of shelf sediment types; Spigai (1967) and Kulm and others, (1968a, b) of the heavy mineralogy of Oregon shelf and beach sands; and Komar and others (1972) of the wave climate on the Oregon shelf. The following is a synopsis of the chracteristics of surface sediments on the central Oregon shelf, incorporating data from these reports as well as from samples collected by the U.S. Geological Survey.

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 31.3 million acre feet (Scheidegger and others, 1971). The Umpqua River, which has an annual flow at 6.8 million acre feet and drains parts of the Cascade Range, Klamath Mountains and southern Oregon Coast Range, supplies sediment to the inner shelf of central Oregon. Erosion of uplifted Pleistocene marine terrace deposits along the central and southern Oregon coast provides a locally important source of sand. Byrne (1963) has estimated that erosion rates on the northern Oregon coast range from 0.6 m/year for sedimentary rocks overlain by terrace gravels to 16 m/year for unconsolidated gravels and sands.

Sand predominates along the inner continental shelf seaward to a depth of about 50-100 m within the study area (fig. 19; Byrne and Panshin, 1977). These deposits are in large part modern and are characteristically clean and well sorted, arkosic in composition, and have median diameters in the fine to very fine sand range (about 2.75 ϕ to 3.25 ϕ) (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, so that coarse sediment on the continental shelf is mostly relict (Kulm and others, 1975). Relict fine to coarse grained sands and gravels are characteristically iron stained, solution pitted and altered, and are probably late Pleistocene in age. Deposits of relict sand are most prominant 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).

Sediments flanking submarine outcrops appear to comprise mixtures of reworked residual material from the outcrops, relict sand and gravel, and possibly fine-grained modern sediments as well (Kulm and others, 1975). Relatively coarse relict sands are also found in isolated patches near the shelf edge, and submerged placer deposits of heavy minerals thought to have formed during Pleistocene low stands of sea level are present on the shelf between Coos Bay and the

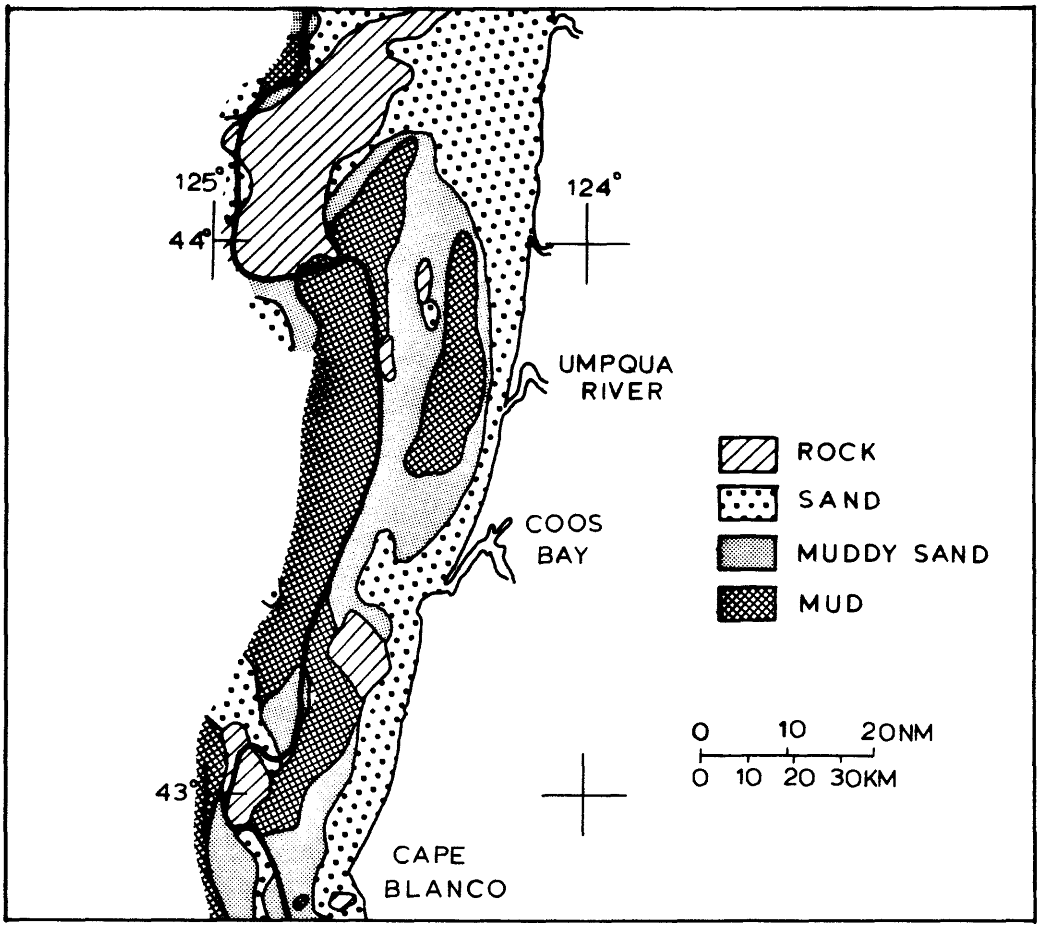

Figure 19. Distribution of major sediment types on the continental shelf and slope off central Oregon (from Byrne and Panshin, 1977). Heavy line indicates the approximate location of the shelf edge. Sand comprises sediments having mean sizes coarser than 4ϕ; mud comprises silt and clay having mean sizes finer than 4ϕ.

California border (Kulm and others, 1968a). Biogenic components, principally sponge spicules and microfossils, make up a minor part of the shelf sands but locally are important constituents of fine-grained muds. Authigenic glauconite is present 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 sediments north of Coquille Bank comprise approximately equal proportions of chlorite, illite and montmorillonite. However, clays in samples from Coquille Bank south to California consist principally of chlorite (reflecting derivation from the Klamath Mountains), with lesser illite and minor amounts of montmorillonite (Kulm and Fowler, 1970).

A mud facies comprising materials with mean sizes finer than 4ϕ is present on the mid shelf off the Umpqua River, and is irregularly distributed on parts of the outer shelf and inner continental slope (fig. 19; 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 resuspended by wave action then transported seaward into progressively deeper marine environments. This wave stirring is thought to control the landward extent of the mud facies, while shelf-edge turbulence and sediment bypassing limit its seaward growth (Kulm and others, 1975). Mixing by benthic organisms of these river supplied muds with relict and modern sands has created a mixed mud and sand facies that covers much of the mid and outer shelf and parts of the upper slope off central Oregon (fig. 19).

Transport

Modern littoral transport of sand-size material is northward, and this has been the dominant transport direction since late Wisconsin time (about 18,000 y.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 appears to have been much more effective than at present; as much as 315 km of northward transport 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 reduce sediment supply to the littoral zone by trapping 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 Oregon, 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 moved seaward as a low density bottom flow concentrated in swales and small valleys on the mid to outer shelf toward the continental slope and abyssal plain (Kulm and others, 1975). Studies by Komar and others (1972) show that surface waves associated with winter storms off the Oregon coast should produce bottom orbital velocities sufficient to ripple very fine sand at water depths of as much as 150-200 m, and photographic observation confirms that oscillatory ripple marks are present across the shelf to depths as great as 200 m. Summer waves produce ripples to depths of 50 to 100 m. In addition, near-bottom currents associated with intense winter storms and having velocities up to 75 cm/sec, sufficient for the erosion and transport of sand, have been measured off the Columbia River at a depth of about 50 m (Smith and Hopkins, 1972). The origin of such currents and their influence on sediment dispersal is not known. Current velocity measurements made 50-210 cm above the bottom at mid- (90 m) and outer- (165 m) shelf depths indicate velocities ranging up to about 25 cm/sec in currents that are thought to be in part tidally induced (Harlett, 1972; Komar and others, 1972). Near-bottom (1-2 m above the bed) current velocities of up to 40 cm/sec have been measured on the upper continental slope (500-1000 m), and of up to 10 cm/sec on the lower continental slope (1000-2800 m) off central Oregon (Korgen and others, 1970).

Fine sediments accumulate on the lower continental slope in this region at rates up to about 70 cm/1000 years, and sedimentation rates of about 10 cm/1000 years have been calculated for the upper continental slope (Carlson, 1968; Spigai, 1971). Relict sands thought to be late Pleistocene in age are exposed locally at depths up to 500 m on benches on the continental slope, indicating that little or no sedimentation has occurred on some parts of the Oregon slope since the Holocene transgression (Spigai, 1971).

Geometry

The distribution and thickness of acoustic unit 1, thought to comprise strata of Quaternary age, are shown as Plate 5. 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 characteristically indistinct in the centers of major synclines so that the thickness shown for acoustic unit 1 in shelf and slope basins should be considered a minimum figure. Characteristics of this unit (age, lithology, stratigraphic relations, etc.) are discussed in "Marine Geology of the Coos Bay Basin".

Acoustic unit 1 is the youngest sedimentary sequence that could be traced throughout the study area and, in general, sediments of Holocene age could not be separated on seismic reflection records from the older strata of this unit. However, a seaward-thinning wedge of sediment unconformably overlies acoustic unit 1 on parts of the inner shelf. This sediment wedge is a maximum of about 15 m thick (fig. 7), and is thought to represent Holocene deposits derived chiefly from rivers draining the adjacent Oregon Coast Range and coastal plain.

Organic Carbon and Calcium Carbonate Content

Ten samples from eight stations on the central Oregon shelf were analyzed for organic carbon and $CaCO_3$ content; the analytical results are shown in Appendix 6. Such trends and patterns as appear in the values obtained may not be valid due to the small number and rather wide geographical distribution of samples.

Organic carbon content ranges from about 0.4 to 3.0 percent, and averages about 1.5 percent. Only one sample has a value (3.04%) greater than 2.0 percent. Generally, high organic carbon content appears to be associated with greater water depths, and organic carbon content increases with decreased grain size in these samples. Calcium carbonate content is characteristically low, with eight of the samples (from seven stations) having less than 1 percent $CaCO_3$. Two samples show anomalously high values (11.3%) and 18.6%), but these probably reflect the presence of small fragments of shell material. Calcium carbonate appears to be derived principally from calcarious nannofossils and tests of Foraminifera, with a secondary contribution from mollusc and echinoderm fragments.

SUMMARY OF GEOLOGIC HAZARDS

Several geological features and conditions that are potentially hazardous to offshore development in the Coos Bay basin merit special attention. Perhaps foremost among these is active faulting. Groups of geologically young, 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 it is possible that these groups of faults reflect a broad zone of active shear (pl. 3). In addition, a northwest-trending fault 10 km long and having seafloor expression cuts the inner shelf south-southwest of Cape Arago. Additional detailed study of these faults is necessary to determine their relations, relationship to faults onshore, nature and history of offset, and to assess their potential threat to development structures offshore.

Little seismic activity has been recorded in the immediate vicinity of the Coos Bay basin over the 100-plus years during which records have been kept (pl. 4). The seismicity hazard appears to be associated principally with ground shaking and seafloor mass movement, liquefaction and tsunamis resulting from earthquakes in adjacent regions, notably along the Gorda Ridge, Mendocino Escarpment, Blanco fracture zone, and in the Gorda Basin. Beaulieu and Hughes (1975) estimate that a major earthquake in the vicinity of the Mendocino Escarpment could produce a shock of intensity VII in the Coos Bay area, with a corresponding ground acceleration of 0.10 g. The tsunami hazard associated with such an earthquake is minimized by the predominately horizontal motions accompanying faulting in the northern California-southern Oregon continental margin. However, the Alaskan earthquake of 1964 produced wave heights along the Oregon coast of 1.2 m to 4.2 m above the prevailing mean high water, and wave heights greater than 6 m were recorded at Crescent City, California. Substantial damage to coastal structures was done in Oregon, and catastrophic losses occurred locally in northern California. Consequently, the hazard to facilities in shallow areas of Heceta and Coquille Banks and on the inner shelf adjoining the Coos Bay basin appears to be a significant one; this threat is discussed in some detail by Beaulieu and Hughes (1975).

Evidence of modern seafloor mass movement is uncommon on the seismic reflection records collected during this study (pl. 6). However, seafloor failures are widespread in a similar geological setting only about 100 km south in the offshore Eel River basin, although the rate of sediment influx and seismic activity here are much greater (Field and others, 1980). Slopes sufficient to promote failure in unconsolidated sediments are present below the shelf edge in the Coos Bay basin. Quaternary sediments of largely unknown engineering characteristics are locally thick (pl. 5); in some areas these sediments contain peat and devitrified volcanic ash, which reduces shear resistance. Evidence of older, buried slides is present in areas of apparently high Pleistocene sediment influx. Seafloor mass movement should, therefore, be considered a potential hazard unless site-specific studies indicate otherwise.

Diapirism and active uplift have been mapped throughout the northern California-Oregon-Washington continental margin and are present in the offshore Coos Bay basin. They reflect modern tectonic activity, but the hazard they pose to offshore development is uncertain because so little is known of the rate and nature of uplift, relationship of these features to overpressured zones, and their association with other forms of seafloor instability. These aspects of diapirism merit further study as they pertain to this region, and the hazard posed by such features must be judged on a site-specific basis. No evidence was obtained of gas seepage into sediments on and surrounding the diapir sampled off central Oregon; however, diapirs on the Washington continental margin are thought to be associated with overpressured zones and shallow gas pockets, which themselves may constitute a hazard to development.

Gas in sediments reduces their bearing strength and, if of thermogenic origin, may reflect an over-pressured zone at depth. Acoustic anomalies suggestive of shallow gas zones are extensive in the offshore Coos Bay basin (pl. 6). Sampling in the vicinity of these zones failed to confirm the presence of hydrocarbon gases, although at one location gas charging was suspected. Assessment of the hazard posed by shallow gas in this area is not possible without positive confirmation of the presence of gas and more information concerning the extent of these zones, the type of gas present, associated faulting and the effect of gas on the bearing properties of the enclosing sediments. This would entail additional seismic reflection profiling, preferably with records processed to preserve true relative amplitudes, and sampling of sediments above suspected gas zones to confirm the presence of gas, determine its origin, and measure its concentration in sediments.

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APPENDIX 1: PROCEDURES

Navigation

Positioning data were obtained at sea using satellite navigation and Loran C systems, and a shipborne electronic ranging system employing shore-based transponders. Radar was used infrequently for positioning where terrain masking or equipment malfunctions were encountered. Data from the satellite and Loran C systems were integrated by means of a Dead Reckoning Computer (DRC). Positions derived from the DRC and electronic ranging systems initially were plotted separately and weighted according to their relative accuracy; subsequently these data were corrected and merged to produce maps of position location for geophysical tracklines and sampling stations. Estimated position accuracy ranges from $\pm$ 50 m where positions were determined principally by electronic ranging (approximately 90 percent of the cruise) to an average of about $\pm$ 500 m where DRC or radar positions were used exclusively (approximately 10 percent of the cruise).

Geophysical Profiling

A variety of profiling equipment were used to obtain a spectrum of data ranging from relatively high resolution, shallow penetration to low resolution, intermediate to deep penetration seismic reflection records. Precision bathymetric and shallow subbottom records were obtained using 12 kHz and 3.5 kHz profiling systems employing hull-mounted transducers and hydrophones. A boomer system was used to obtain high resolution, shallow penetration subbottom profiles. This system employed 4 hull-mounted transducers and a hydrophone streamer towed 3 m off the starboard beam approximately 0.3 m below the sea surface. Power output ranged from 800 to 1200 J and the incoming signal was filtered between 400-500 Hz (low cut) and 1200-1500 Hz (high cut). Fire and sweep rates of 0.5

second and 1 second were used depending on the geological conditions encountered and the character of the records.

A sparker system operated at 80-140 kJ was used to obtain low resolution, intermediate to deep penetration records. This system has a fundamental frequency of approximately 80 Hz, and was filtered between 50 Hz and 98-125 Hz; fire and sweep rates were 4 seconds. Four sparker ladders were towed astern at a depth of 3 m; two ladders were located approximately 3 m outboard from the ship and 45 m astern, and two were towed approximately 6 m outboard from the ship and 60 m astern. The hydrophone streamer consisted of a 45 m-long active section containing 100 elements; the streamer was towed at a depth of 3 m directly astern, with the lead hydrophone approximately 60 m aft of the ship.

In addition to the primary geophysical equipment noted above, data were obtained using a La Coste-Romberg 3-axis gravimeter and a proton precession marine magnetometer. Side-scanning sonar records were obtained to provide detailed information on the geologic structure in two relatively small areas off Coos Bay, Oregon.

Additional geophysical profiles were run in the fall, 1978 to fill gaps in existing coverage, and to address specific geologic problems revealed during interpretation of records collected in 1977. A preliminary interpretation was made of these seismic reflection data and the results are included in this report.

Sampling and Shipboard Sample Processing

Bedrock outcrops and sediments were sampled using dart and gravity coring equipment. The dart coring device consists of a thick-walled steel pipe approximately 5 cm ID x 0.6 m long attached to a heavy weight (680-900 kg), and is dropped onto the seafloor at velocities of 100-150 m/min; it is employed principally in areas of hard bedrock outcrop. The gravity corer employs the same weight, but the coring device consists of a thick-walled steel barrel containing a clear plastic liner approximately 7.6 cm ID x 3 m long. A core retainer and cutter are employed, and the device is dropped onto the seafloor at velocities of 100-150 m/min. It is used to collect samples from areas of sediment cover and relatively poorly indurated bedrock.

Sampling off Oregon was directed toward collecting geochemical data and geologic age information to facilitate interpretation of seismic records; sample was recovered from 21 of 23 stations attempted. Location, water depth and recovery results at each sampling station are listed in Appendix 2; station locations are shown in Plate 2.

Dart and gravity cores were removed from the core barrels and taken to the sedimentology laboratory aboard ship. There they were split, with one half being designated for archive purposes and the other for various analytical procedures. The half designated for analysis was subsampled at top (the uppermost sediment layer not disturbed by coring), bottom, and appropriate intermediate levels for microfaunal, lithologic and geochemical data; the core half designated for archive was photographed, x-rayed (if appropriate), subsampled for smear slides and described. Smear slides from selected cores were studied to obtain detailed information concerning sediment texture and composition. Both core halves and all subsamples were then placed in a refrigerated (40°F) core storage area for the duration of the cruise.

Fourteen subsamples from 12 cores were processed and submitted upon return to Menlo Park to Robert Arnal (USGS) for identification of benthic Foraminifera (app. 3). All other core sections and subsamples are now stored in the refrigerated (40°F) core storage area at the Pacific-Arctic Branch of Marine Geology, U.S. Geological Survey, 3475 Deer Creek Road, Palo Alto, California.

Laboratory Analysis

Grain Size Determination: Subsamples from the surface of 8 gravity cores were analyzed for grain size distribution. About 5 grams of each sample were placed in individual 1000 ml beakers, diluted with about 100 ml of 10% hydrogen peroxide (to remove particulate organic material) and allowed to stand overnight. The solution was boiled until about 10 ml remained and the sediment was wet seived through a 0.063 mm sieve to separate the sand and mud fractions. The sand fraction ($>$ 0.063 mm) was oven dried and split into 0.5 gram fractions for size analysis. A single fraction from each sample was analyzed for grain size by using settling velocity techniques with a rapid sediment analyzer (RSA) settling tube. Duplicates were run for every tenth machine run. Mud fractions ($<$ 0.063 mm) were diluted to 100 ml in a graduated cylinder and dispersed with sodium hexametaphosphate (calgon). The slurry was mixed and a 10 to 25 ml split was taken for grain size analysis using light transmission techniques on a hydrophotometer (Jordan and others, 1971: Tilly, 1977: Jordan, 1977).

These data were entered into a computer file and used to calculate and graph particle size distribution and to calculate modal, median and mean size, sorting, skewness and kurtosis (using both the methods of moments and graphical statistics). Duplicate analyses show no major discrepancies.

Calcium Carbonate and Carbon Analyses: Ten subsamples from 8 cores were analyzed for total, inorganic (carbonate) and organic carbon. Approximately 1-2 grams of sediment from each subsample was washed twice with distilled water by centrifuging and decanting to remove flouride and chloride salts that might affect the results of carbon analysis. Washed sediment was oven dried, ground to fine powder with mortar and pestle, and stored in airtight glass vials at room temperature. Total carbon content was determined by combustion of 0.02 gram samples for 55 seconds in a LECO tube induction furnace. Evolved carbon dioxide gas was measured in a LECO model WR 12 carbon determinator modified after Kolpack and Bell (1968). Carbon content was determined by averaging three analytical runs for each procedure, and the organic carbon fraction was calculated as the difference between total carbon and inorganic carbon.

Calcium carbonate content was derived from the analyses by multiplying the amount of inorganic carbon by the ratio of molecular weight of $CaCo_3$ (100) to the atomic weight of carbon (12). Thus a value of 0.25% inorganic carbon would equate to a value of 0.25 x 100/12 or 2.08% calcium carbonate.

References Cited

Jordan, C. F., 1977, Size analysis of silt and clay by hydrophotometer (reply): Jour. Sed. Petrology, v. 47, no. 2, p. 931-932.

Jordan, C. F., Fryer, G. E., and Hemmen, E. H., 1971, Size analysis of silt and clay by hydrophotometer: Jour. Sed. Petrology, v. 41, no. 2, p. 489-496.

Kolpack, R. L. and Bell, S. A., 1968, Gasometric determination of carbon in sediments by hydroxide absorption: Jour. Sed. Petrology, v. 38, no. 2, p. 617-620.

Tilly, C. R., 1977, Size analysis of silt and clay by hydrophotometer (discussion): Jour. Sed. Petrology, v. 47, no. 2, p. 930-931.

APPENDIX 2: LOCATION, DEPTH, LENGTH, TYPE, AND PURPOSE OF SAMPLES COLLECTED ON CRUISE S9-77NC

Sta.	Sample Number	Sample Type	Purpose	Location	Latitude	Longitude	Water Depth (m)	Sample Length (m)
01	01G	Gravity Core	Stratigraphic and Sedimentologic Information	Oregon OCS	+44.0500	-124.6621	125	2.00
02	02G	"		"	+44.0594	-124.7032	115	1.62
03	03G	"	"	"	+44.0577	-124.7358	140	0.38
04	04G	"	"	"	+44.0561	-124.7342	140	0.45
05	05G	"	"	"	+44.0599	-124.7551	135	Core Catcher
06	06G	"	"	"	+44.0595	-124.7655	130	Core Catcher
07	07G	"	"	"	+44.0536	-124.7824	120	Core Catcher
07	07G2	"	"	"	+44.0551	-124.7802	120	Core Catcher
08	08G	"	"	"	+44.0574	-124.7902	115	Core Catcher
08	08G2	"	"	"	+44.0598	-124.7903	115	Core Catcher
09	09G	"	"	"	+44.0534	-124.8018	105	0.27
10	10G	"	"	"	+44.0542	-124.8132	080	0.19
11	11G	"	"	"	+44.0508	-124.8913	133	0.36
12	12G	"	"	"	+44.0564	-124.9246	182	0.37
13	13G	"	"	"	+44.0604	-124.9284	212	1.96
14	14G	"	"	"	+43.6480	-124.8523	491	Core Catcher
15	15G	"	"	"	+43.6205	-124.8196	543	1.45
16	16G	"	"	"	+43.5677	-124.8259	670	2.65
16	16G2	"	Gas Analysis	"	+43.5568	-124.8272	679	2.62

APPENDIX 2. LOCATION, DEPTH, LENGTH, TYPE, AND PURPOSE OF SAMPLES COLLECTED ON CRUISE S9-77NC (cont'd.)

Sta.	Sample Number	Sample Type	Purpose	Location	Latitude	Longitude	Water Depth(m)	Sample Length(m)
17	17G	Gravity Core	Gas Analysis	Oregon OCS	+43.5792	-124.8294	675	2.84
17	17G2	"	Strat./Sed. Info.	"	+43.5775	-124.8122	685	3.00
18	18G	"	Gas Analysis	"	+43.5721	-124.7577	610	2.24
19	19G	"	Strat./Sed. Info.	"	+43.5676	-124.7376	540	2.27
20	No Recovery				+43.5782	-124.3796	112	
21	21G	Gravity Core	"	"	+43.5778	-124.3803	115	0.05
22	22G	"	"	"	+43.5815	-124.3398	100	2.00
23	23G	"	Gas Analysis	"	+43.0525	-124.7042	157	0.85
23	23G2	"	Strat./Sed. Info.	"	+43.0528	-124.6975	155	Core Catcher
23	23G3	"	Gas Analysis	"	+43.0537	-124.6967	157	0.30

APPENDIX 3

INFORMAL REPORT ON THE AGE OF SELECTED CORE SAMPLES FROM CRUISE S9-77NC

Prepared by

Robert E. Arnal

REPORT ON REFERRED FOSSILS

STRATIGRAPHIC RANGE	Pliocene to Recent	SHIPMENT NUMBER	
GENERAL LOCALITY	Northern California Offshore	REGION	Pacific Coast
QUADRANGLE OR AREA	Unknown; Cruise code S9-77-NC	DATE RECEIVED	02 15 78
KINDS OF FOSSILS	Foraminifera	STATUS OF WORK	Complete
REFERRED BY	Sam Clarke	DATE REPORTED	04 05 78
REPORT PREPARED BY	Robert E. Arnal		

Sample 5G

Age: Late Pliocene to Recent; cold water environment.

7G2

Age: Pleistocene, probably late Pleistocene.

8G2

Age: Probably late Pliocene, there are also some Holocene forams; cold water environment.

9G

Abundant large diatoms and Radiolaria also sponge spicules.
Age: indeterminate, no forams.

10 G

Rare Forams but flood of diatoms.

Age: Late Pliocene to Recent.

11 G

Age: Late Pliocene to Recent.

12 G

Age: Late Pliocene to Recent.

14 G

Age: Late Pleistocene to Recent.

15 G

Age: Pliocene, not Pleistocene, probably Late Pliocene.

REPORT ON REFERRED FOSSILS

STRATIGRAPHIC RANGE	Pliocene to Recent	SHIPMENT NUMBER	
GENERAL LOCALITY	Northern California Offshore	REGION	Pacific Coast
QUADRANGLE OR AREA	Unknown; Cruise code S9-77-NC	DATE RECEIVED	02 15 78
KINDS OF FOSSILS	Foraminifera	STATUS OF WORK	Complete
REFERRED BY	Sam Clarke	DATE REPORTED	04 05 78
REPORT PREPARED BY	Robert E. Arnal		

Sample 16 G1, 1 to 3 cm

Age: Pleistocene to Recent, probably Holocene.

16 G1, 244 to 266 cm

Age: Pleistocene to Recent, probably Holocene, same fauna as top of core.

16 G2

Age: Late Pliocene to Recent.

22 G, 1 to 3 cm

Age: Holocene.

22 G, 187 to 189 cm

Age: Holocene. Abundant pine tar and lignite, maybe terestrial or lagunal shallower water than the top of the core; indication of subsidence or else rise in sea level.

APPENDIX 4

HYDROCARBON GAS IN SEDIMENTS OFFSHORE OREGON

K.A. Kvenvolden and J.B. Rapp

Hydrocarbon gases were measured in 23 surface and near-surface sediment samples recovered at five stations located off the coast of southern Oregon (fig. 1). Four stations (15, 16, 17 and 18) were located at various positions relative to a major diapiric structure. Station 15 was on the top of the diapir. Stations 16 and 18 were on the south and east flanks, respectively. Station 17 was positioned well off of the west flank. At station 23, sediments were analyzed for hydrocarbon gases to determine if the shallow acoustic anomaly noted at this station could be related to high concentrations of gases in the sediments.

The analytical procedure was designed to analyze for methane (C_1), ethane (C_2), ethene ($C_{2:1}$), propane (C_3), propene ($C_{3:1}$), isobutane (C-D_4), and n-butane (n-C_4). Sediment samples for gas analyses were recovered by gravity coring. The 8-cm (I.D.) core liner was cut into 10-cm segments of various depths down the core. The sediment core from each segment was extruded into a preweighed, 1-qt. can which had two septa-covered entry ports near the top. The can was filled with distilled water that had been purged with helium to remove any dissolved hydrocarbon gases. For the can 100-ml of water was removed. A double friction top was sealed in place, and the 100-ml headspace was purged with helium through the septa. The cans were shaken for ten minutes to extract gases into the headspace. From the can about 5-ml of gas mixture was removed, and exactly one ml of this mixture was analyzed on a modified Carle 311 Analytical Gas Chromatograph equipped with both flame ionization and thermal conductivity detectors. The instrument was calibrated with a standard mixture of hydrocarbon gases prepared by the Matheson Gas Company. Calculations of concentrations of gases were determined from chromatograms by measuring heights of peaks representing each gas. Partition coefficients were used to correct for the different solubilities of each gas. Concentrations are reported as nL/L of wet sediment.

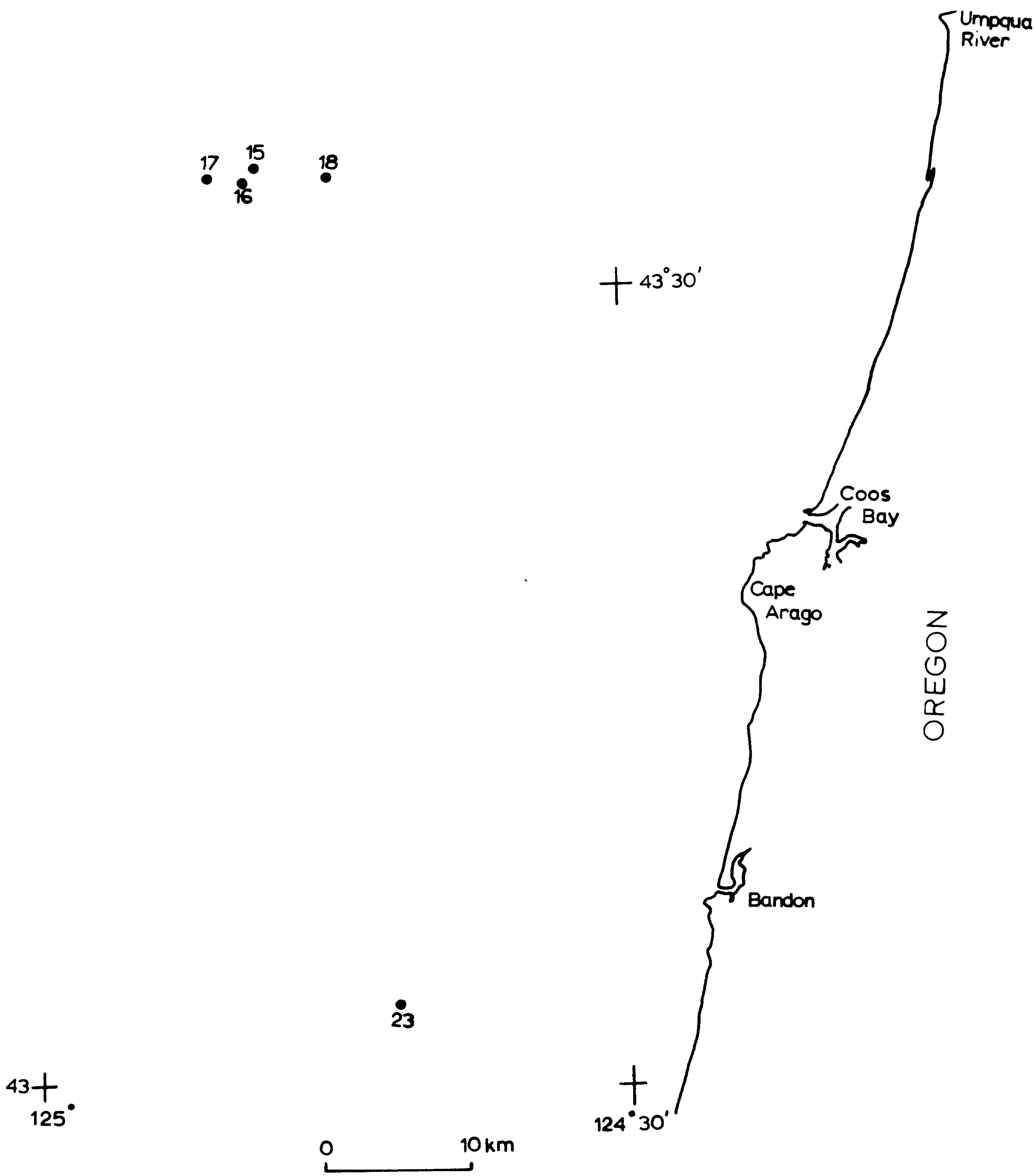
The results of the gas analyses are summarized in Table 1. Samples from stations 15, 16, 17 and 18 contained low concentrations of hydrocarbon gases. At three of the four stations, the content of C_1 decreased with depth, an observation contrary to what has been measured, for example, in most near-surface marine sediments offshore Alaska. At station 16, the concentration of C_1 is variable with no obvious trend although the deepest sample has the highest content of C_1. The other hydrocarbons that were detected show no significant trends. These results suggest that the diapiric structure on and near which these stations were located is not leaking hydrocarbon gases into the near-surface sediments associated with it.

Station 23 was located on a shallow acoustic anomaly. This anomaly was manifest by broken reflectors in the sediments and noise in the water column. These manifestations suggested the possibility of high concentrations of gas. Samples from this station did not contain unusually high concentrations of hydrocarbon gases, but trends in the results suggest that at depth higher concentrations may be found. For example, sample 23 - G1 (65-75) has the highest C_1 concentration observed at the 65-75 cm interval in this survey. Likewise, both samples 23 -G3 have higher concentrations of C_1 than do other samples of comparable interval.

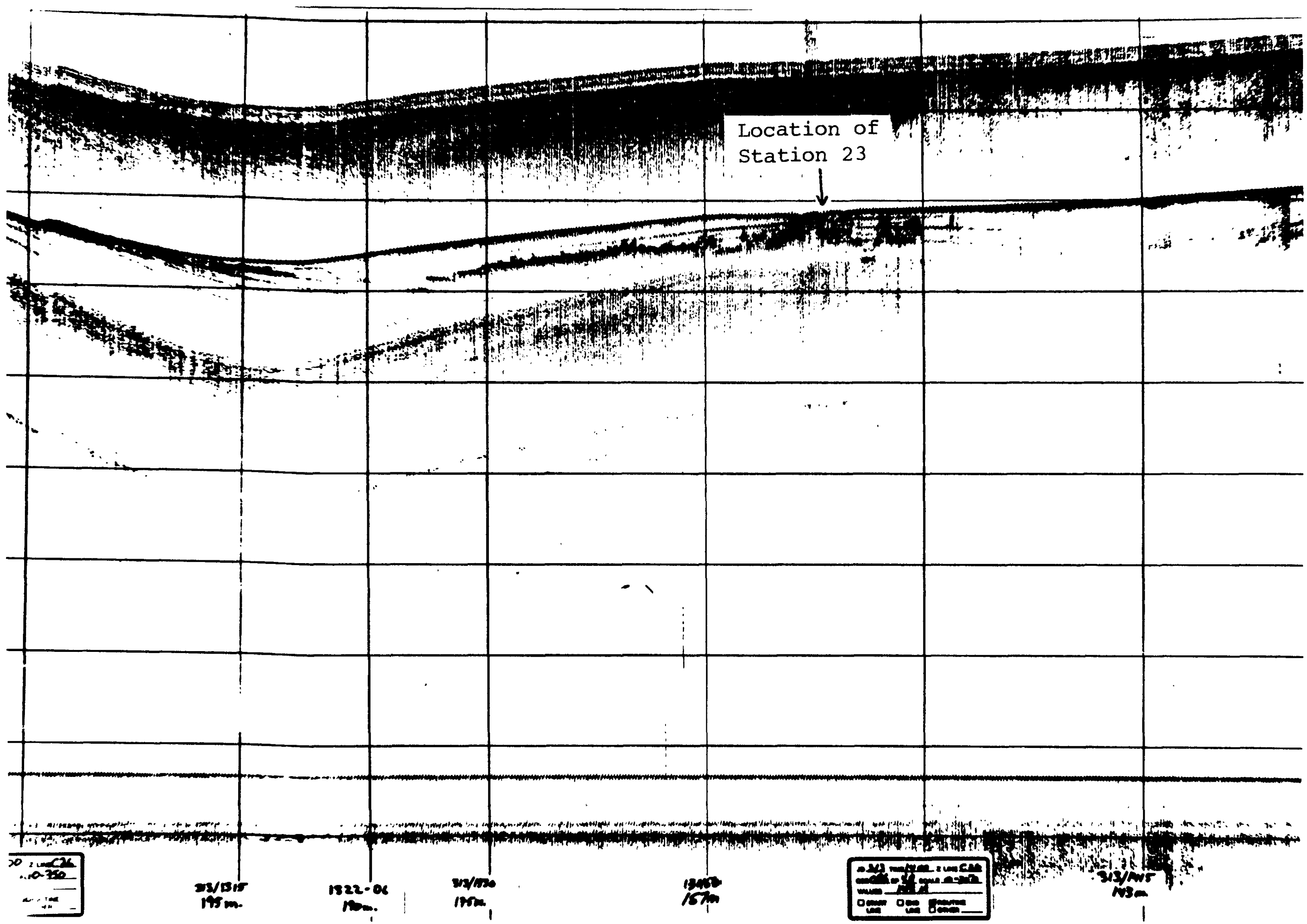
These hydrocarbon gases measured in this survey are likely all of biological origin. There is no evidence that the diapiric structures tested are leaking hydrocarbon gases into the near-surface sediments covering them. There is no dramatic, chemical evidence that the acoustic anomaly seen at station 23 is caused by gas-charged sediments. On the other hand, there is subtle evidence that the gas concentrations here may increase with depth, and gas-charging remains a possibility not directly confirmed by our results. Deeper samples are required for further testing at this site.

Table 1. Hydrocarbon Gases in Sediments Offshore Oregon S9-77

Sta/Sam	Interval (cm)	Water Depth (m)	Concentrations nL/L wet sediment C_1	C_2	$C_{2:1}$	C_3	$C_{3:1}$	$i\text{-}C_4$	$\underline{n}\text{-}C_4$	$\frac{C_1}{C_2 + C_3}$
15 G	0-10	543	2060	95	82	67	126	7	18	13
"	50-60	"	397	-	-	-	-	-	-	-
"	100-110	"	80	-	-	-	-	-	-	-
16 G	0-10	679	42	-	-	-	-	-	-	-
"	50-60	"	3930	70	88	49	98	7	11	33
"	100-110	"	418	-	-	-	-	-	-	-
"	150-160	"	28	-	-	-	-	-	-	-
"	200-210	"	5650	32	22	15	42	-	-	120
17 G	0-10	675	1740	45	32	43	84	-	-	20
"	100-110	"	3341	35	28	21	59	-	-	59
"	200-210	"	251	-	-	-	-	-	-	-
18 G	0-10	610	1040	22	35	18	66	-	-	26
"	100-110	"	306	-	-	-	-	-	-	-
"	200-210	"	271	-	-	-	-	-	-	-
23 G 1	0-10	157	2900	56	53	36	120	10	10	31
"	65-75	"	11000	59	31	24	82	7	3	132
23 G 3	0-10	157	5010	106	43	54	120	17	17	31
"	18-28	"	4480	106	50	48	113	14	14	29



GRAVITY CORE STATIONS
HYDROCARBON GAS ANALYSES
S9-77


Location of
Station 23
313/1315
195 m.
1322-06
190m.
313/1330
195m.
1345
167m
313/1415
143m.

APPENDIX 5: TEXTURAL PARAMETERS OF SELECTED SEDIMENT SAMPLES FROM CRUISE S9-77NC

STA.	SAMPLE NUMBER	DEPTH IN SAMPLE (CM)	(GRAVEL) PERCENT SAND	PERCENT MUD	Phi MEAN (INMAN)	Phi MEDIAN (INMAN)	Phi SORTING (INMAN)	SKEWNESS 16/84 (INMAN)	KURTOSIS (INMAN)
01	01G	03.0	52 (12)	36	3.22	2.16	2.76	0.39	0.88
03	03G	02.0	84	16	2.65	2.01	0.96	0.68	1.78
04	04G	02.0	74	26	3.35	2.57	1.61	0.49	1.07
11	11G	02.0	66 (23)	11	0.96	1.49	2.03	-0.26	1.12
16	16G	02.0	01	99	7.29	6.62	2.07	0.32	0.83
17	17G2	03.0	02	98	6.52	6.00	1.94	0.27	0.90
19	19G	02.0	01	99	4.57	4.30	0.48	0.56	2.67
22	22G	02.0	32	68	5.48	4.73	1.99	0.38	0.90

Ref: Inman, D. L., 1952, Measures for describing the size distribution of sediments: Jour. Sed. Petrology, vol. 22, no. 3, p. 125-145.

APPENDIX 6: ORGANIC CARBON AND CALCIUM CARBONATE CONTENT OF SAMPLES FROM COOS BAY BASIN

Sample	Interval	Depth	Percent Organic Carbon	Percent Inorganic Carbon	Percent $CaCO_3$	Total Carbon
01G	2-4	125	1.729	2.232	18.600	3.961
01G	12-14	125	0.950	0.015	0.125	0.965
03G	1-3	140	0.428	0.021	0.175	0.449
04G	1-3	140	0.696	0.072	0.600	0.768
11G	1-3	133	3.044	1.352	11.267	4.396
16G	1-3	670	1.691	0.105	0.875	1.796
17G2	2-4	685	1.972	0.071	0.592	2.043
17G2	19-21	685	1.791	0.071	0.592	1.862
19G	1-3	540	1.567	0.096	0.800	1.663
22G	1-3	100	1.139	0.087	0.725	1.226