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Preliminary Geologic Interpretation of USGS S. P. LEE Seismic-Reflection Profile WO 76-7 on the Continental Shelf and Upper Slope, Northwestern Oregon

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PRELIMINARY GEOLOGIC INTERPRETATION OF USGS S. P. LEE SEISMIC-REFLECTION PROFILE WO 76-7 ON THE CONTINENTAL SHELF AND UPPER SLOPE, NORTHWESTERN OREGON

By

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Introduction

In order to understand more fully the tectonic and stratigraphic framework of the Oregon and Washington continental margin, a series of land-sea geologic cross sections are being prepared. The five cross sections published to date are: Snavely and others, 1987; Snavely and Wagner, 1981, 1982; Snavely, Wagner, and Lander, 1980, 1985. These sections are based upon onshore geologic mapping, the interpretation of 24-channel seismic-reflection profiles, and the correlation of acoustical units with the subsurface stratigraphy encountered in deep exploratory test wells drilled on the continental shelf by industry in the mid-1960's (Braislin and others, 1971; Snavely, Pearl, and Lander, 1977).

Multichannel seismic-reflection profile WO 76-7, collected in 1976 aboard U.S. Geological Survey Research Vessel S. P. LEE, begins about 20 km west of Tillamook Head and extends westward across the continental shelf and upper slope near latitude 45°50' (fig. 1). The interpreted structure and stratigraphy along this profile, cross section A-A' (Plate 1), will form the western part of a land-sea geologic cross section that extends eastward across the northern part of the Oregon Coast Range to the Mist gas field (fig. 1). The onshore part of this cross section will be controlled by geologic mapping and subsurface data from deep test wells published by Niem and Niem (1985).

A single-channel seismic-reflection profile, Oregon State University line SP-106, which parallels cross section A-A', 2-3 km to the north, shows the shallow structure along this part of the Oregon continental margin. Dredge samples collected along this line provided valuable information as to ages of sea floor sedimentary rocks (Kulm and Fowler, 1974).

Our interpretation of the shallow structure along cross section A-A' was enhanced by data obtained from a single-channel high-resolution profile (UNIBOOM) collected concurrently with 24-channel seismic profile WO 76-7.

Seismic Data Collection and Processing

The seismic data for line WO 76-7 were collected using an energy source of five airguns with a combined volume of 1326 cubic inches of air compressed to approximately 1900 PSI, the airguns were fired at a 50-meter shot interval. The recording system included a 24-array streamer 2400 meters long, with a uniform 100-meter group interval, and a GUS (Global Universal Science) Model 4200 magnetic-tape recorder. Records were sampled in the field at a 2-millisecond rate, and later desampled to 4 milliseconds during the demultiplexing process. Navigational control was by a Marconi integrated satellite-doppler sonar navigational system.

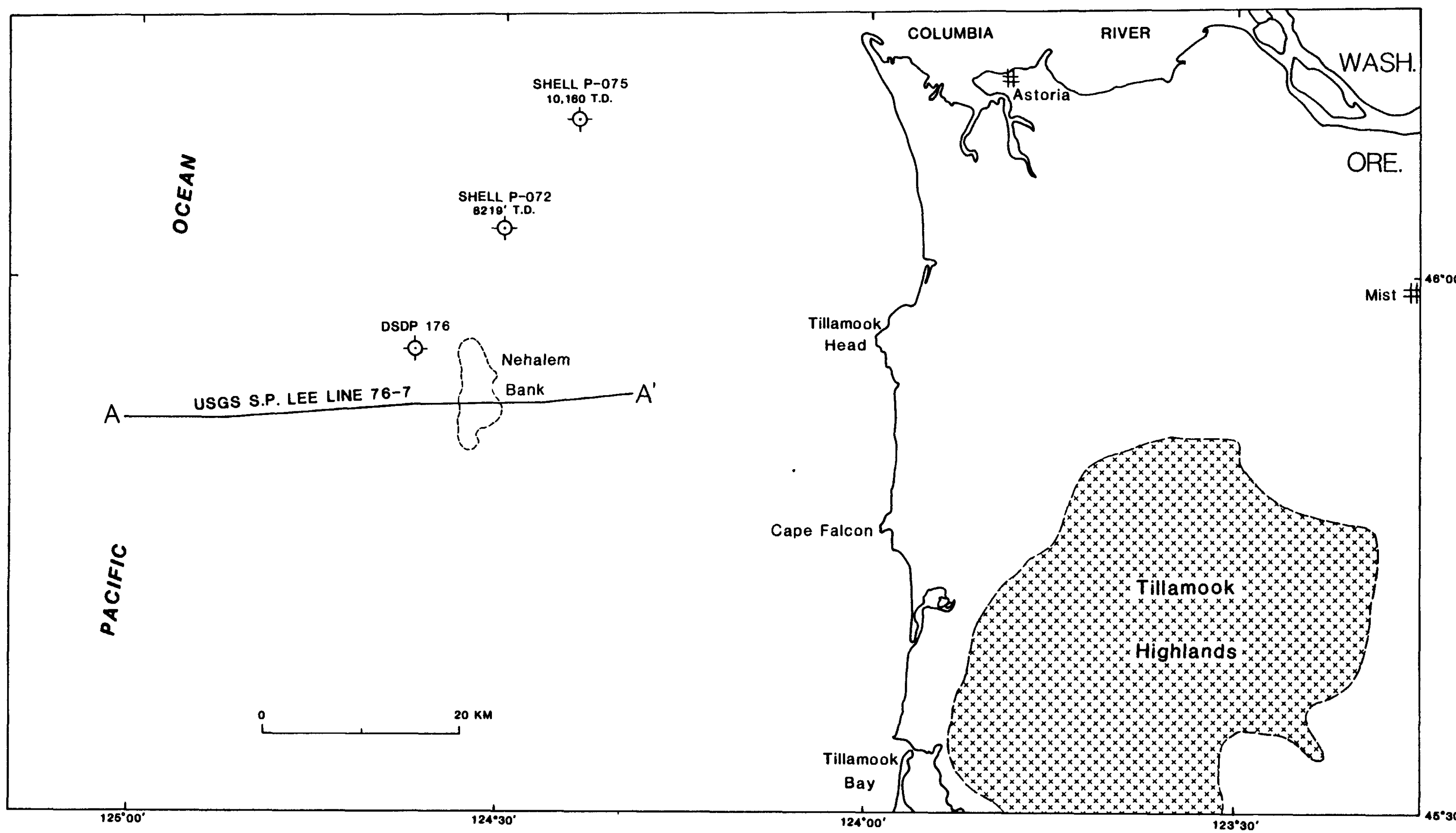

Figure 1.--Index map showing location of land-sea geologic cross section A-A' along S.P. LEE line 76-7.

The seismic processing sequence included editing-demultiplexing, automatic gain control, deconvolution filtering, velocity analysis and normal-moveout correction, trace balancing, and bandpass filtering. In areas of shallow sea floor, the early arrivals on far-channel traces were muted to remove refracted energy. In areas of deeper water, the near-channel traces were muted at and below approximately twice the water-bottom time, to suppress the amplitude of water-bottom multiples in the stacked traces. The 24-fold data were then stacked with a normalizing stacking program. The stacked data were migrated using a finite-difference time-migration routine, with a migration velocity model prepared from constant-velocity migration analyses. Processing was done at the USGS Marine Geology Multichannel Processing Center in Menlo Park, California.

Stratigraphy

The discussion of the stratigraphy along seismic profile line WO 76-7 is presented in a chronostratigraphic sense because onshore formations that crop out in the northern part of the Coast Range cannot be correlated directly with offshore acoustical units. Also, many of the onshore formations lose their characteristic lithologies seaward due to facies changes that reflect deeper-water depositional environments. However, provisional correlations have been made between offshore chronostratigraphic units and onshore formations in the Oregon Coast Range (fig. 2). The closest deep subsurface control to line 76-7 is Shell Oil Company well P-072 drilled 18 km north of the profile to a depth of 8219 feet (2505 m). The ages of the strata penetrated in this well were determined from a study of foraminifers by W. W. Rau (written commun., 1976).

The stratigraphic units interpreted in cross section A-A' are discussed under three major tectono-stratigraphic terranes, (1) the deep marginal basin Tertiary sequence beneath the continental shelf, (2) the (?)late Oligocene to middle Miocene accretionary terrane beneath the upper slope west of fault C (which may have been thrust under the deep marginal basin strata), and (3) the thrust faulted and folded abyssal sediments west of fault A.

Deep Marginal Basin Sequence

Middle to Late Eocene.--The top of basaltic rock of the Tillamook Volcanics may be represented by a few high-amplitude reflections near the east end of Profile A-A' and in an anticlinal structure east of fault E (unit Tev). Onshore this suite of chiefly subaerial porphyritic basalt and basaltic andesite flows and breccia forms the Tillamook Highlands (fig. 1) in the northwestern part of the Oregon Coast Range (Wells and others, 1983; Niem and Niem, 1985). Whole-rock K/Ar age determinations for these basalts range from about 38 m.y. to 44 m.y. (R. Wells, oral commun., 1987). South of the main eruptive centers, in the central part of the highlands, these flows grade into pillow lavas and breccia, and basaltic sedimentary rocks. Offshore where they are inferred to be present in cross section A-A', we would expect these volcanic rocks to consist of interbedded basalt breccias, with minor pillow lava flows and basaltic sandstone and siltstone.

The Tillamook Volcanics (Wells and others, 1983) correlate in part with the Yachats Basalt (Snavely and MacLeod, 1974) that crops out near the coast 160 km south of Tillamook Head. Offshore, the Yachats Basalt extends beneath the shelf in the subsurface and was penetrated by several test wells in this

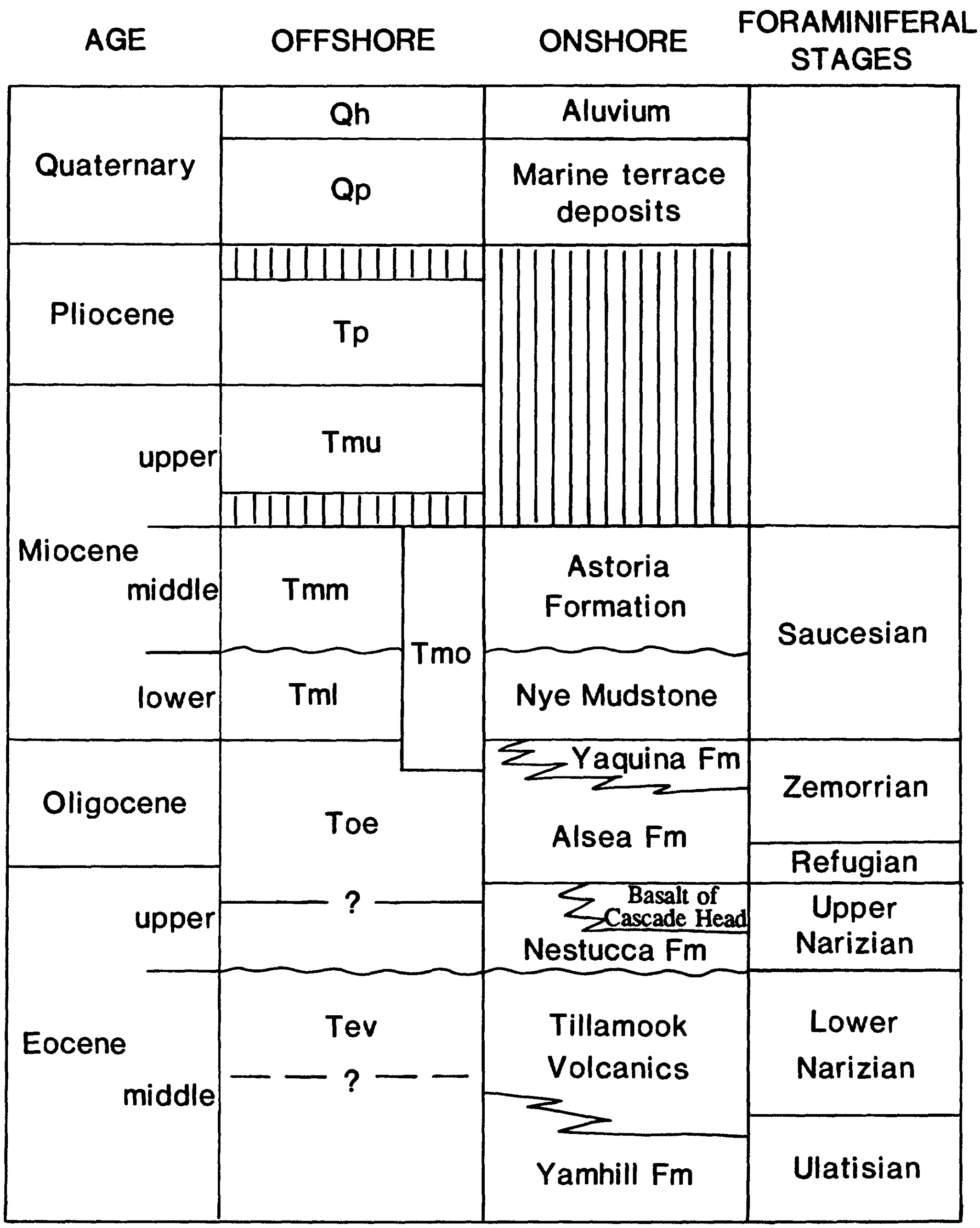

Figure 2.--Generalized stratigraphic section showing correlations between onshore formations and offshore chronostratigraphic units. Benthic foraminiferal stages are modified from Rau, 1981. Middle Miocene basalt sills and dikes are not shown.

area (Snavely, Wagner, and Rau, 1982). Shell Oil Company well P-075, drilled about 30 km north of cross section A-A' (fig. 1), penetrated palagonitic basalt and basaltic sedimentary rocks from a depth of about 9750 feet (2972 m) to the total depth of 10,160 feet (3097 m). Petrographic studies of these basalts suggest they are lateral equivalents of the Tillamook Volcanics.

The Tillamook Volcanics grade southward into massive- to thin-bedded concretionary finely micaceous siltstone with massive and cross-bedded channel deposits of micaceous arkosic and lithic sandstone of the upper middle and lower upper Eocene Yamhill Formation. The Yamhill Formation contains interbeds of tuff-breccia where it grades northward into the Tillamook Volcanics. On the outer continental shelf, far west of the centers of Tillamook volcanism, siltstone of the Yamhill Formation may constitute the entire upper middle to lower upper Eocene sequence.

A unit of thin-bedded tuffaceous siltstone with interbeds of fine-grained arkosic and basaltic sandstone unconformably overlies the Yamhill Formation and its lateral equivalent, the Tillamook Volcanics. This sedimentary unit, the Nestucca Formation of late Eocene (upper Narizian) age, underlies the subaerial basalt flows that form Cascade Head. North of Cascade Head, these volcanic rocks grade laterally into lapilli-tuff and tuffaceous siltstone in the upper part of the Nestucca Formation which, in turn, grades northward into the Cowlitz Formation. Figure 3 shows the general stratigraphic relationships between the Eocene volcanic and sedimentary rocks in the northern part of the Oregon Coast Range.

Eocene to Oligocene.--A sedimentary sequence, unit Toe on cross section A-A', is correlated with the Alsea Formation (Snavely and others, 1975), which consists principally of uppermost Eocene (Refugian) and Oligocene (Zemorrian) massive to thin-bedded tuffaceous siltstone and very fine grained sandstone with interbeds of thick-bedded arkosic sandstone and minor conglomerate. Onshore, the basal part of the sequence is characterized by shallow-water massive to thick-bedded basaltic sandstone underlain by cobble and boulder conglomerate eroded from the underlying Tillamook Volcanics and Basalt of Cascade Head. Turbidite sandstone, tuff beds, and zones of penecontemporaneously deformed strata occur in places.

In Shell Oil Company well P-072, strata of Oligocene (Zemorrian) age were encountered below a depth of about 6000 feet (1829 m). This sequence which is cut by shear zones apparently extends at least to a depth of 6870 feet (2095 m). As no age diagnostic microfossils were found below the depth of 6870 feet, the lower part of this test well may have encountered strata of late Eocene age.

Early to Middle Miocene.--South of Tillamook Bay (fig. 1), deep-water strata, which are correlative to the Nye Mudstone of early Miocene age, are unconformably overlain by shallow-water marine sandstone and siltstone of the Astoria Formation of middle Miocene age; these strata form two distinct lithologic sequences (Wells and others, 1983; Wells and Snavely, unpublished data). However, on the continental shelf strata correlative to the Astoria Formation are predominantly siltstone, and a lithologic distinction between the Nye and Astoria is difficult to discern (Snavely, Wagner, and Lander, 1980). In cross section A-A', strata correlated with the Astoria Formation (unit Tmm) appear to be widespread, extending from the eastern end of the section westward to

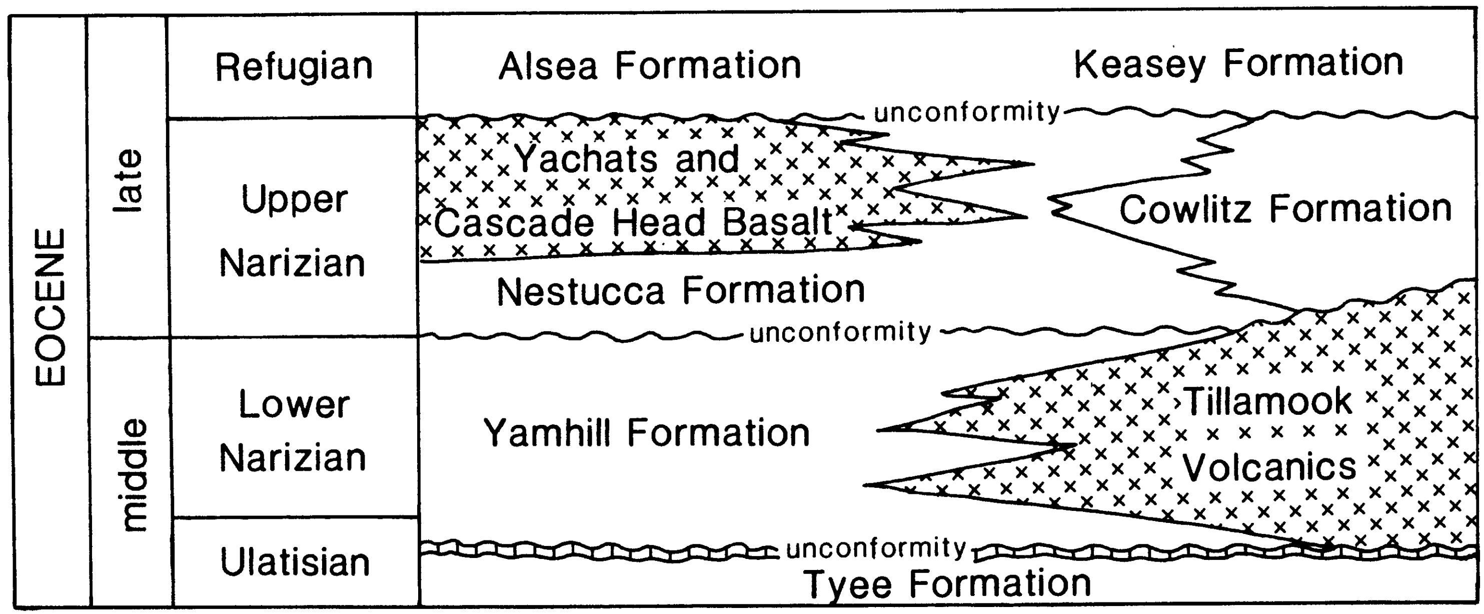

Figure 3.--Diagram showing relationship between Eocene sedimentary rocks and the Tillamook Volcanics, Basalt of Cascade Head, and the Yachats Basalt.

fault C. Strata assigned to the Astoria Formation on the cross section are intruded by basalt sills and dikes (unit Tb shown by small x's) which have extremely high amplitude reflections. These intrusive basalts are equivalent in age to the middle Miocene sills and flows that form prominant headlands at Cape Lookout, Cape Mears, Cape Falcon, and Tillamook Head. K/Ar ages of about 15 m.y. have been obtained for these onland basalt sills; hence, they only intrude strata of middle Miocene age or older. These intrusive and extrusive rocks, which are widespread on the northern Oregon continental margin (Snavely, MacLeod, and Wagner, 1973; Snavely and Wells, 1984; Niem and Niem, 1985), are readily recognized on seismic profiles by their high-amplitude, their multiple reflections, and their cross-cutting relationships to older strata.

Near the eastern end of the cross section, an acoustical unit that unconformably underlies strata assigned to the middle Miocene Astoria Formation (unit Tmm) is inferred to correlate with the lower and middle Miocene age Nye Mudstone (unit Tml). Elsewhere on the cross section unit Tml appears to be absent, perhaps cut out by the unconformity at the base of the Astoria Formation. In Shell Oil Company well P-072, however, strata assigned an early and middle Miocene age occur between the depths of about 5100 to 6000 feet (1555 to 1830 m).

Late Miocene.--A well defined acoustical sequence that unconformably overlies the Astoria Formation (Tmm) and shows an eastward depositional downlap (between shot-points 150 and 580) is interpreted to consist of strata of late Miocene age (unit Tmu). This sequence has a maximum thickness of about 550 m in the axial part of the deep marginal basin and thins both to the east and west away from the basin axis. The eastward downlap of these inferred late Miocene strata indicates a western source for these sediments; they perhaps eroded off a structural high uplifted along fault D.

Beds of late Miocene age do not crop out along the northern Oregon coast and are absent at the eastern end of cross section A-A'. Although basalt sills and dikes are common in the middle Miocene Astoria Formation onshore, they are absent in overlying upper Miocene strata. Likewise, high-amplitude reflections from sills and dikes offshore are present in the inferred Astoria equivalent (Tmm) and older strata, but are absent in the overlying upper Miocene unit (Tmu).

Although the thickness of late Miocene strata is estimated to be about 550 m, only 70 m of late Miocene siltstone was penetrated in Shell Oil Company well P-072. This pronounced thickness difference is probably due to thinning of the late Miocene strata against the structural high of older strata penetrated in the Shell well.

Pliocene.--Strata of Pliocene age (unit Tp) are interpreted to be present across the entire shelf, but are of variable thickness due to episodic periods of vertical tectonic movement during deposition and, in places, due to erosion along the unconformity at the base of Pleistocene strata. In Shell Oil Company well P-072, the Pliocene section is about 1600 feet (485 m) thick and consists of olive-gray claystone and siltstone. DSDP core hole 176 (Kulm and others, 1973), located 6 km north of cross section A-A' (fig. 1), encountered fissile siltstone of Pliocene age at a depth of 41 m. The DSDP well was drilled in a geologic setting similar to that just west of fault E in cross section A-A'.

In cross section A-A', the Pliocene strata are thickest in the deep marginal basin beneath the shelf and in a narrow fault-bounded, extensional basin beneath the upper slope where strata assigned to the Pliocene are more than 800 m in maximum thickness. The Pliocene strata thin landward and do not crop out in coastal northwestern Oregon; however, the Quinault Formation, of Pliocene age, crops out farther north in places along the west side of the Olympic Peninsula (Rau, 1975).

Pleistocene and Holocene Deposits.--The two uppermost acoustical units differentiated on the cross section are interpreted to represent a thick sequence of Quaternary sediments (units Qp and Qh). These deposits are widespread on the Oregon and Washington continental shelves and are thickest in broad synclines formed by folding of older strata. Ages of these two youngest acoustical units on the cross section were interpreted chiefly from superposition and relation to unconformities; however, Oregon State University dredged Pleistocene and Holocene sediment along their line SP-106 (Kulm and Fowler, 1974) that parallels cross section A-A' 2-1/2 km to the north. Also, DSDP core hole 176 (Kulm and others, 1973), drilled 6 km north of the cross section A-A' (at a projected location that would lie just west of fault E on section A-A'), penetrated 41 m of Pleistocene clayey silt separated by an unconformity with Pliocene(?) fissile siltstone encountered at the bottom of the hole.

Accretionary Complex on the Continental Slope

The complex structure on the upper continental slope along cross section A-A' reflects periods of compressive deformation resulting from the subduction of the Juan de Fuca plate beneath the continental margin. As interpreted from our 24-channel profile, the structure consists of a landward-dipping thrust fault (e.g., fault C) and a younger set of seaward-dipping thrust faults (e.g., fault A). Between these thrust faults (shot-points 800 and 1000), two west-dipping normal faults bound narrow basins that contain thick sequences of upper Miocene and Pliocene strata. The presence of these normal faults in an overall compressive tectonic regime appears anomalous; however, they may represent periods of extension or extension-related dextral faulting of strata in the upper plate above the downgoing Juan de Fuca plate.

Late Oligocene to Middle Miocene Melange and Broken Formation.--Although there is no direct evidence of what constitutes the acoustical basement beneath the upper slope between faults A and C, the rock sequence may consist of an accretionary wedge of upper Oligocene to middle Miocene melange and broken formation. This unit (Tmo on cross section A-A') may be correlative with the tectonically complex Hoh assemblage (Rau, 1975) that crops out along the west side of the Olympic Peninsula. As unit Tmo is, in places, unconformably overlain by strata assigned to a late Miocene age, it supports a pre-late Miocene age for these acoustical basement rocks.

Shell Oil Company well P-072 penetrated sheared, well-cemented, quartzose arkosic sandstone and indurated siltstone with veins of zeolite minerals and quartz between depths of about 5100 feet (1555 m) and at least 8219 feet (2505 m). These sheared strata range in age from middle Miocene to late Oligocene (Zemorrian) (W. W. Rau, written commun., 1976) and may be equivalent to unit Tmo in cross section A-A'. If this stratigraphic correlation is valid, fault

C on our cross section would have to strike northeastward, in order to lie east of well P-072.

Pliocene and Pleistocene.--The westernnmost part of cross section A-A' consists of a sequence of Pliocene(?) (Tp) and Pleistocene (Qp) abyssal strata that have been uplifted along seaward-dipping thrust faults and associated folds. These abyssal strata appear to be thrust over the accretionary wedge of late Oligocene to middle Miocene strata (unit Tmo). Upper(?) Pleistocene and Holocene deposits (Qp and Qh) blanket the older strata in most places on the continental shelf and slope and are thickest in basinal areas between anticlinal folds in the older strata.

Tectonic Framework

The interpretation of the stratigraphy and structure along cross section A-A' across the northern Oregon continental shelf and upper slope is speculative, as our 24-channel seismic profile varies in quality and critical subsurface data are absent. Despite these limiting factors, the cross section clearly indicates that the continental margin has been subjected to both compressional and extensional tectonics during Cenozoic time. Convergence between Pacific oceanic plates and the North American plate have resulted in episodic periods of underthrusting, dextral transcurrent faulting and extension (Snavely, Wagner, and Lander, 1980; Snavely, 1987).

Two major faults, D and E, offset Tertiary strata on the continental shelf and probably extend to the sea floor. Fault D displays a positive flower structure indicating transpressional strike-slip (dextral?) movement (Harding, 1985). The thickness difference of middle and upper Miocene strata east and west of fault D also supports strike-slip movement along this fault. Fault E also is most likely a strike-slip fault with a major component of vertical displacement (up on the east), as the thickness of middle Miocene strata (unit Tmm) is twice as much to the east of the fault as to its west, also the sequence is offset across the fault with an apparent vertical separation of about 800 m. On our high-resolution profile (UNIBOOM), fault E appears to be overlapped by Quaternary sediments which, in turn, onlap the uplifted middle Miocene strata that form Nehalem Bank (fig. 1). A major north-trending dextral fault, the Fulmar fault (Snavely, 1980), has been mapped on the southern Oregon shelf. Although its trace north of latitude 45° is unclear, this fault may be related to fault D.

In the eastern part of the cross section, near shot-point 135, a listric fault offsets Holocene strata but not the sea floor. This westward-dipping thrust fault flattens at depth and appears to be a bedding plane fault that lies immediately above a middle Miocene sill (Tb) and cuts unit Tmm (Astoria Formation?). This listric fault indicates that compressional forces were active on the continental shelf during Holocene time. Numerous normal faults and several thrust faults offset late Oligocene and older strata in the deep marginal basin; however, most of these faults do not extend above the unconformity at the base of middle Miocene strata (Tmm).

A major episode of underthrusting occurred in late middle Miocene time (Snavely, Wagner, and Lander, 1980; Snavely, 1987), and is interpreted to have resulted in the subduction of Oligocene and Eocene strata (Toe) west of fault C. A widespread unconformity at the base of upper Miocene strata on the

Oregon and Washington continental shelf may record regional uplift that occurred in response to this period of plate convergence. Middle Miocene and older strata were uplifted and folded on the inner shelf and later were truncated by erosion before downwarping and deposition of upper Miocene and Pliocene marine strata (Snavely, Wagner, and Lander, 1980). A major unconformity between upper Miocene and older strata has been recorded in many Circum-Pacific basins and correlates with the major 10.2 m.y. sequence boundary between supercycles TB2 and TB3 as defined by Haq, Hardenbol, and Vail (1987).

Near the west end of cross section A-A', fault A thrusts a folded sequence of Pliocene (Tp) and Pleistocene (Qp) abyssal strata over late Oligocene and middle Miocene melange (Tmo). West of fault A, and probably extending to the base of the slope beyond our cross section, a series of imbricate, west-dipping, low-angle thrust faults and associated folds (thrust-folds) have uplifted abyssal sediments as much as 1000 m above their original site of deposition (Kulm and Fowler, 1974; Snavely, Wagner, and Lander, 1980). This compressive deformation is inferred to occur in upper-plate strata that lie above a major decollement within Pliocene strata. Below this decollement, near latitude 45° (Snavely and others, 1987), Pliocene strata and late Miocene oceanic basalts of the Juan de Fuca plate are being subducted and possibly underplated.

Although the quality of the seismic profile below 4 seconds is poor, discontinuous strong sub-horizontal reflectors are evident below the structurally complex Pliocene to Eocene strata along the entire cross section. One might speculate that these reflectors represent underplated sediment between the accretionary prism and the subducting Juan de Fuca plate.

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