APPENDIX I

PART A: SITE SURVEY OF THE NORTHERN OREGON CONTINENTAL MARGIN AND ASTORIA FAN

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INTRODUCTION

A geophysical survey (gravity, magnetics, and seismic reflection profiling) was made for DSDP Sites 174 and 175 on YALOC-70 by Oregon State University's R/V *Yaquina* (Figure 1). Seismic reflection profiles were made earlier in 1970 by the U. S. Geological Survey on the USNS *Bartlett* near Site 175 (Figure 2, G-F). Detailed gravity and magnetics studies on the Oregon margin are described by Dehlinger et al. (1968) and Emilia et al. (1968), respectively. The unconsolidated and consolidated sediments were sampled in previous studies of this area (Nelson, 1968; Kulm and Fowler, 1972). These sites are located off central Oregon on the distal end of Astoria Fan (Site 174) and on the adjacent lower continental slope (Site 175) (Figures 1 and 2). DSDP Site 176, selected for shallow-water drilling at the beginning of Leg 18, was surveyed in 1969 by Oregon State's R/V *Cayuse* (Figures 1 and 3).

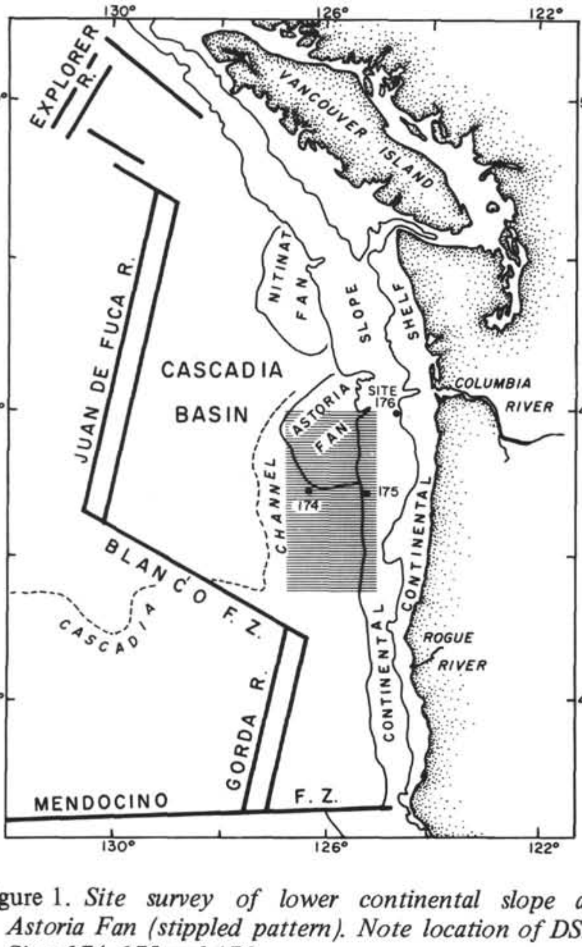

Figure 1. *Site survey of lower continental slope and Astoria Fan (stippled pattern). Note location of DSDP Sites 174, 175 and 176.*

Seismic reflection profiles were made over the distal portion of Astoria Fan to locate a prominent seismic discontinuity that separates the strongly reflecting seaward transgressive sediments of the Astoria Fan above from a landward-dipping weakly to strongly reflecting section below. The anticlinal folds on the lower continental slope are believed to be uplifted turbidites from the adjacent abyssal plain or fan (Kulm and Fowler, 1972). The lowermost folded structures on the slope were profiled to select a suitable drilling site.

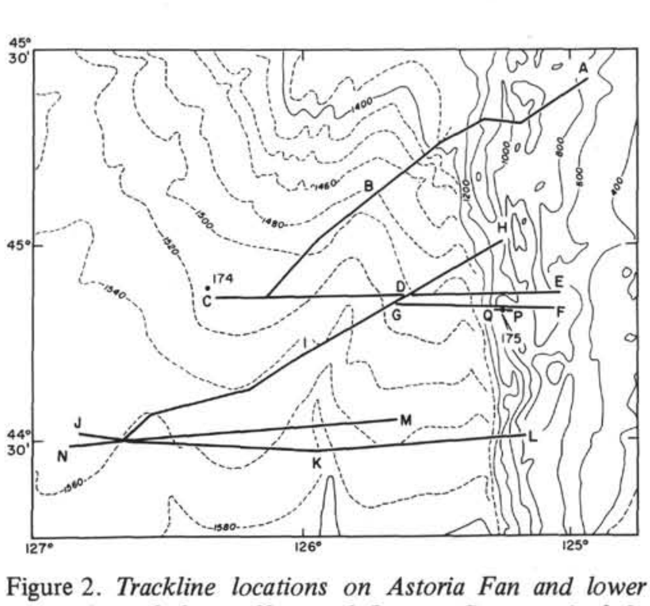

Figure 2. *Trackline locations on Astoria Fan and lower continental slope off central Oregon. Contours in fathoms. Note location of DSDP Site 174 and 175.*

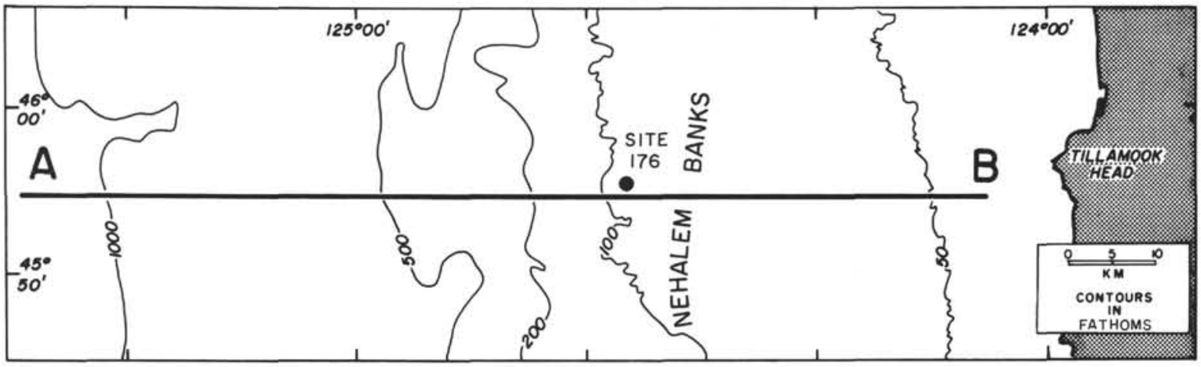

Figure 3. *Trackline location, Nehalem Banks. Contours in fathoms. Note location of DSDP Site 176.*

Twin 20 cu. in. air guns were used on the *Yaquina* and *Cayuse* cruises. A 160,000 joule sparker was used on the USNS *Bartlett* cruise. Satellite navigation was used on the *Yaquina* and *Bartlett*, and Loran A on the *Cayuse.*

GEOLOGIC SETTING

Astoria Fan is one of two prominent submarine fans in Cascadia Basin (Figure 1). It lies at the mouth of Astoria Canyon which has its head on the outer continental shelf off the Columbia River. The fan is a wedge of sediments radiating to the southwest of the mouth of the canyon (Nelson et al., 1970) and lies between the base of the continental slope on the east and Cascadia Channel on the west. Studies of the sand and clay mineralogy of the fan sediments indicate that the late Pleistocene and Holocene deposits were derived from the various sub-basins of the extensive Columbia River drainage system (Nelson, 1968; Duncan and Kulm, 1970; Duncan et al., 1970).

The lower continental slope off northern and central Oregon displays a change in morphology at approximately 45° N latitude (Figure 2). North of this point, a series of prominent ridges parallel the north trend of the slope. The ridges with their intervening trough-and-basin topography are characteristic of the lower continental slope off northern Oregon and continue along the Washington slope. In contrast, the slope south of 45°N is marked by a rather steep escarpment with a series of isolated hills, particularly where submarine banks occur near the edge of the adjacent continental shelf.

Pliocene and Pleistocene turbidites and mudstones were dredged from these lower continental slope ridges and hills near 44°39'N latitude. Paleodepths determined from the benthic foraminiferal assemblages indicate that these deposits have been uplifted as much as 1100 meters from abyssal plain depths to their present position on the lower slope (Kulm and Fowler, 1972). Sediments on the outer edge of the continental shelf have also been uplifted as much as 1000 meters (Byrne et al., 1966).

STRUCTURE

Eastern Cascadia Basin

The eastern part of Cascadia Basin is characterized by a thick wedge of sediment which lies upon an acoustic basement. The wedge is approximately 2.0 seconds near the base of the continental slope at 44°40'N (Figure 4, G-F) and increases to more than 2 seconds near the mouth of Astoria Canyon (46°10'N)' The wedge thins southward away from the apex of the fan and westward towards Cascadia Channel (Figures 5 and 6 J-H and J-L, respectively). A similar wedge-shaped body of sediment occurs elsewhere along the eastern edge of the Juan de Fuca-Gorda Plate, such as off the Straits of Juan de Fuca (Ewing et al., 1968) and in other areas of the northern Cascadia Basin (McManus et al., 1972). Seismic reflection profiles made off northern California (Silver, 1969) show a reflecting sediment wedge which is underlain by a somewhat transparent zone directly above acoustic basement. These rather thick sediment wedges may represent a filled marginal trench at the base of the continental slope (Ewing et al., 1968), occupying the entire eastern margin of the Gorda-Juan de Fuca Plate.

Within the sedimentary wedge, a seismic discontinuity can be traced across the basin from the eastern wall of Cascadia Channel to the base of the Oregon continental slope (Figures 5, 6 and 7) where the discordance is more difficult to detect (Figure 4, G-F). Reflectors below the discontinuity generally dip eastward toward the continental margin.

In Figure 4 (f-e), the sediment wedge can be separated into an upper acoustic unit consisting of strong, somewhat discontinuous reflectors and a lower acoustic unit of weak reflectors. The boundary between the two units is somewhat indistinct, but is picked approximately midway in the section where reflectors below are dipping and those above are flat lying. In this reflection profile, the upper unit is about 1.25 seconds thick at the base of the continental slope. The sediments of Astoria Fan onlap this dipping

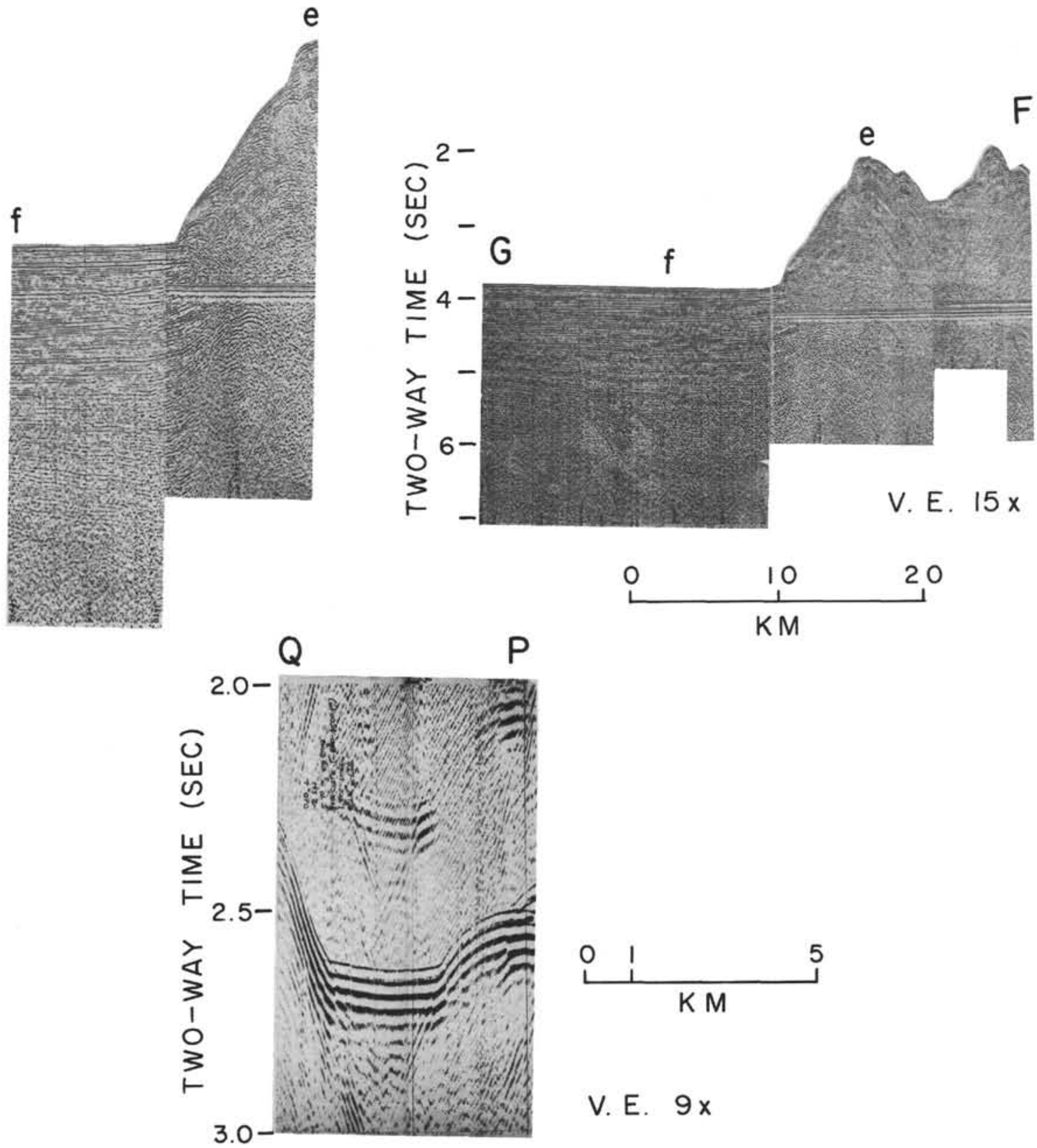

Figure 4. *Seismic reflection profiles G-F (USNS* Bartlett, *Sparker record) and Q-P (R/V* Yaquina, *post-drilling airgun record). Multiple iw shown at the top of Q-P record to define small basin. See Figure 2 for location of profiles.*

surface in a time-transgressive sequence that is thickest at the base of the continental slope and thins to the west and south. A complex sedimentary sequence is seen in the seismic record when its dimensions are squeezed to accentuate the deposits of the fan (Figure 7) and may result from the deposition associated with shifting distributary channels on the fan. A similar discontinuity was observed beneath Nitinat Fan (Carson, 1971) which is located just to the north of Astoria Fan (Figure 1).

Continental Slope

Continuous seismic reflection profiles over the northern Oregon continental slope (not all records are shown here) show a series of broad anticlinal folds with intervening synclinal basins or troughs (Kulm and Fowler, 1971) (Figure 8, A-B). Some basins appear to be graben-like features with faults on either side. Some basins contain only flat-lying sediments; in others, flat-lying sediments are separated from underlying folded or gently dipping sediments by a discordant contact. Some of these anticlinal folds have the morphological expression of small hills or ridges within the basins.

It is difficult to determine from the reflection profiles whether the deeper folded sediments in these basins represent a pre-orogenic sequence followed by post-orogenic sediment ponding or whether the tectonism is continuing but is being masked by the very high sedimentation rates of the late Pleistocene. However,

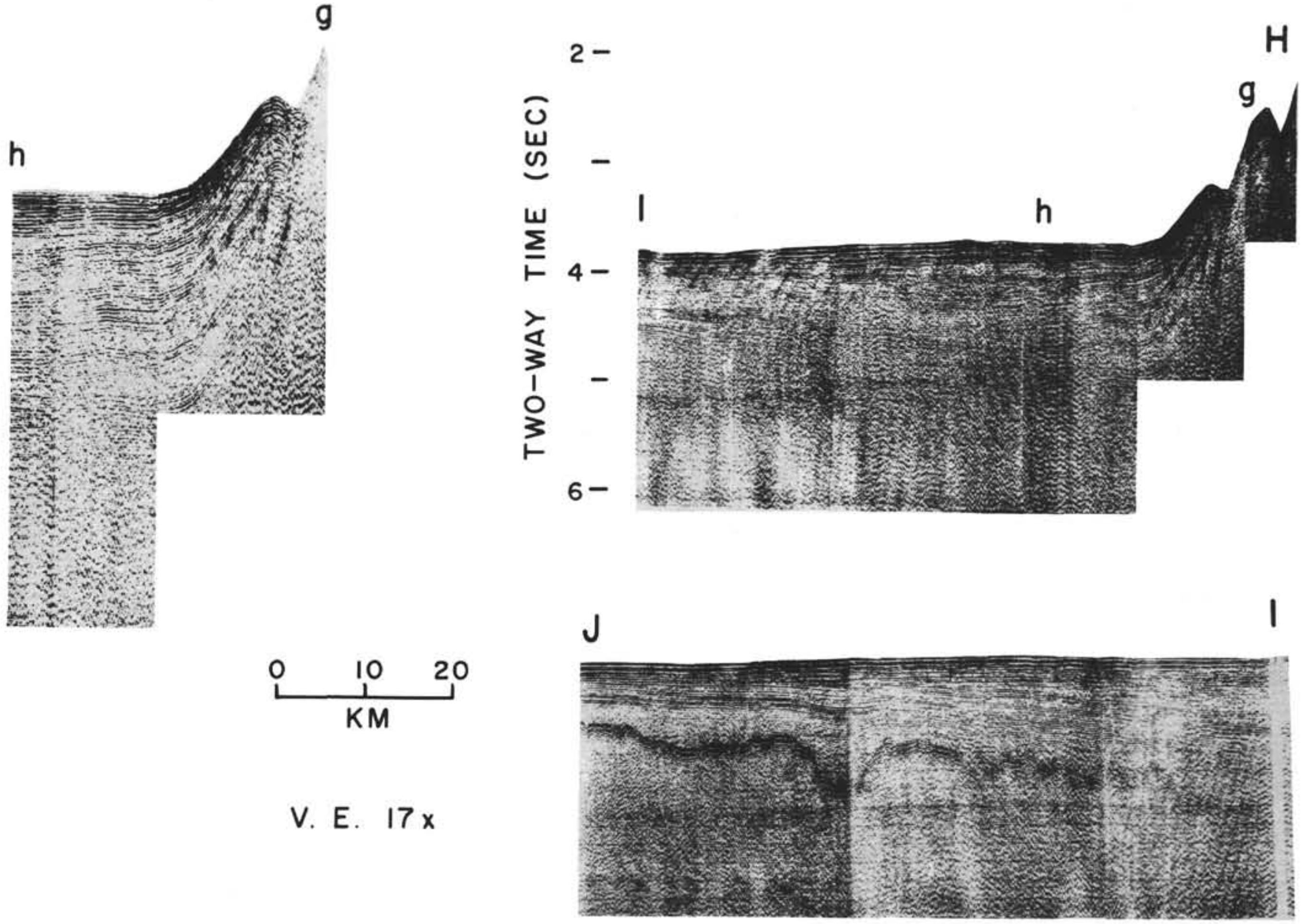

Figure 5. *Seismic reflection profile J-H. See Figure 1 for location.*

continued tectonism is more likely since the uplift of the lower slope folded structure cored at Site 175 is as recent as a few hundred thousand years (see Site 175, Chapter 6). Furthermore, a number of small anticlinal structures apparently are developing on the abyssal plain immediately adjacent to the continental slope (Figure 9, c-b). Similar structures were noted at the base of the slope on the southern Oregon margin (Spigai, 1971, Figure 18).

In most reflection profiles across the steeply dipping lower continental slope-abyssal plain interface, there is a complex seismic signal and the nature of the contact is therefore uncertain. The lower slope and abyssal plain may be either in fault contact, especially where a steep escarpment is present (Figure 6, i-L), or linked together in a continuous sequence but undetected due to the loss of signal. The acoustic character and thickness of similar anticlinal folds at the base of the slope off northern California and southern Oregon lead Silver (1969) to suggest that the upper portion of the Gorda Plate is being scraped off into the lower continental slope as the lithospheric plate descends beneath the continental block.

In marked contrast to the example described above, the continuous reflectors of profile I-H (Figure 5) clearly demonstrate that the sediments of Astoria Fan extend onto the lower continental slope where they are folded. The continuity of fan and folded lower slope sediments was also noted by Silver (Silver and Barnard, 1971) off Washington. A small but similar anticlinal structure occurs along profile D-E (Figure 9, see c-b) and appears to be deformed Astoria Fan sediments. Seismic reflectors can be traced continuously from the fan onto the continental slope, however, in only these two profiles. Interestingly, profiles between I-H and D-E show the typical steep interface with no detectable continuity of reflectors at the slope-plain interface. Perhaps at some stage in the folding, a fault developed at the interface or the strata dip at an angle too steep to be detected. Such a tectonic setting may be represented on the continental slope in profile i-L (Figure 6).

Continental Shelf

The survey for Site 176 was made earlier in 1969 by the R/V *Cayuse* (Figure 3). Seismic reflection profiles across the northern Oregon continental shelf and slope show the shallow structure consists of relatively gentle folds and faults (Figure 10). A prominent syncline lies between the shoreline and the banks on the shelf. An angular unconformity occurs within this sedimentary section and a shallow acoustic basement underlies the thin covering of inner shelf deposits. Large magnetic anomalies were

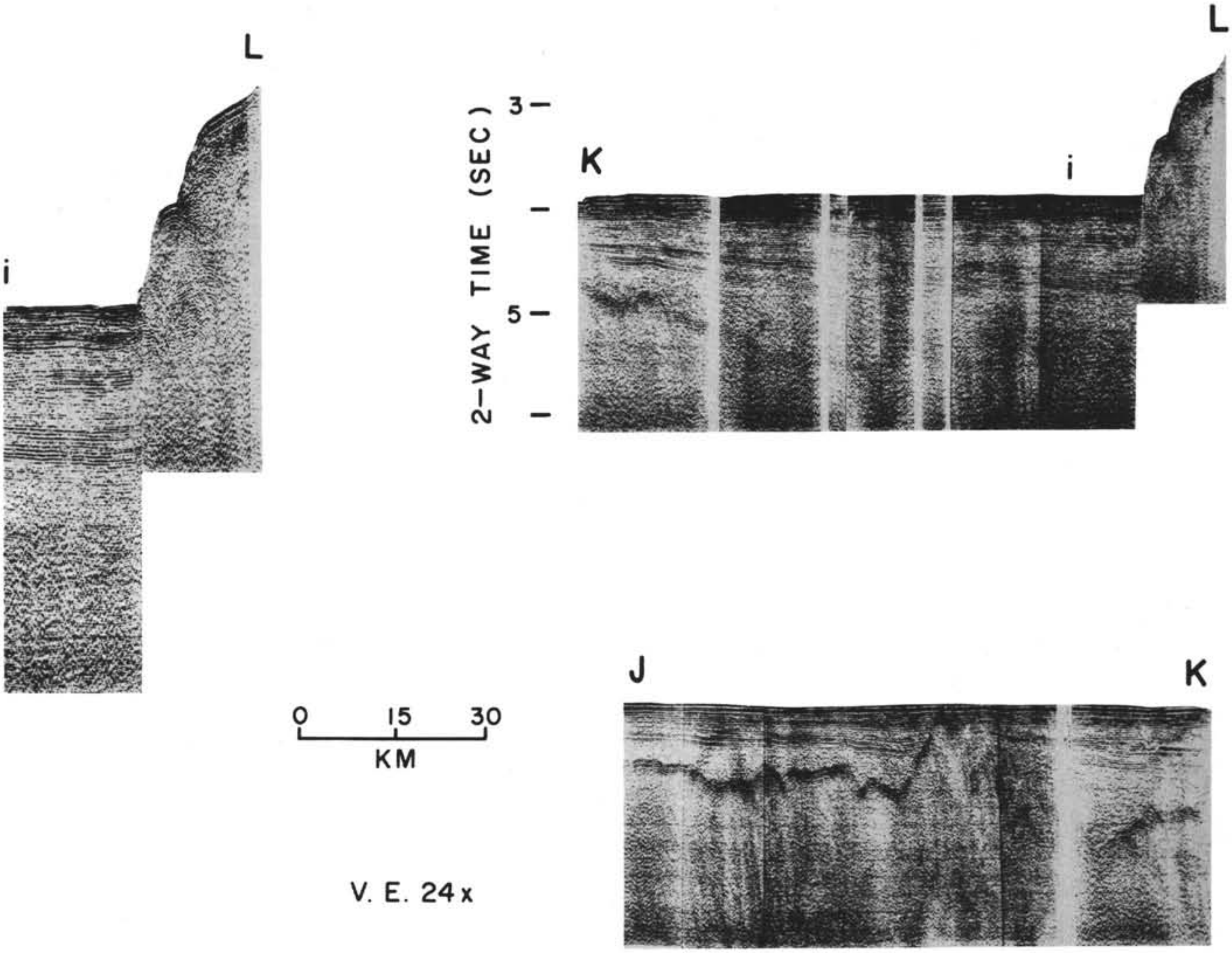

Figure 6. *Seismic reflection profile J-L. See Figure 1 for location.*

reported by Emilia et al. (1968) for this part of the shelf and the acoustic basement is probably a shelf extension of middle Miocene extrusive and intrusive basalt that crop out in the coastal region (Snavely and others, in press).

A younger unconformity, which truncates folded structures, is present on the outer edge of the shelf and appears to be exposed on the westernmost limb of Nehalem Banks. Gravity cores taken in the area suggest that the deposits below the unconformity are Pliocene whereas those above are Pleistocene.

Immediately to the east of Site 176, the dip of the strata on Nehalem Banks is too steep to be recorded. Faulting is implied from the reflection profiles and substantiated by biostratigraphic studies of the mudstones collected in the vicinity of the banks.

DISCUSSION

One of the primary objectives of the survey for Site 174 and 175 was to determine if the abyssal sediments of Cascadia Basin, including those that comprise the Astoria Fan, are folded to form the lower continental slope off central Oregon. The continuous reflectors of seismic profile I-H (Figure 5) show the sediments of the distal portion of Astoria Fan extend onto the slope where they are folded. Although the time that this folding was initiated is not known, it probably is continuing today.

Site 175 was drilled in the vicinity of profile Q-P (Figure 4). In this region, the abyssal plain reflectors cannot be traced into the lower slope anticlinal structure, but paleodepth determinations made from the benthic foraminiferal assemblages at Site 175 indicate that the turbidites below 72 meters in the hole were originally at abyssal plain depth and have since been uplifted 500 to 1000 meters above the plain (see Site 175 summary for a complete discussion). Based upon diatom stratigraphy (Schrader, Chapter 17, this volume), the uplift is late Pleistocene, between 0.3 and 0.45 million years ago. Heavy mineral suites from the turbidites at Site 175 have the same provenance as the Astoria Fan sand turbidites (those deposits above the seismic discontinuity) at Site 174 (Scheidegger et al., this volume). This mineral assemblage also is found below the seismic discontinuity to a depth of 370 meters, but it is incorporated in a more distal abyssal plain facies.

From the DSDP drilling data, it is clear that the folding on the lowermost continental slope has been active in

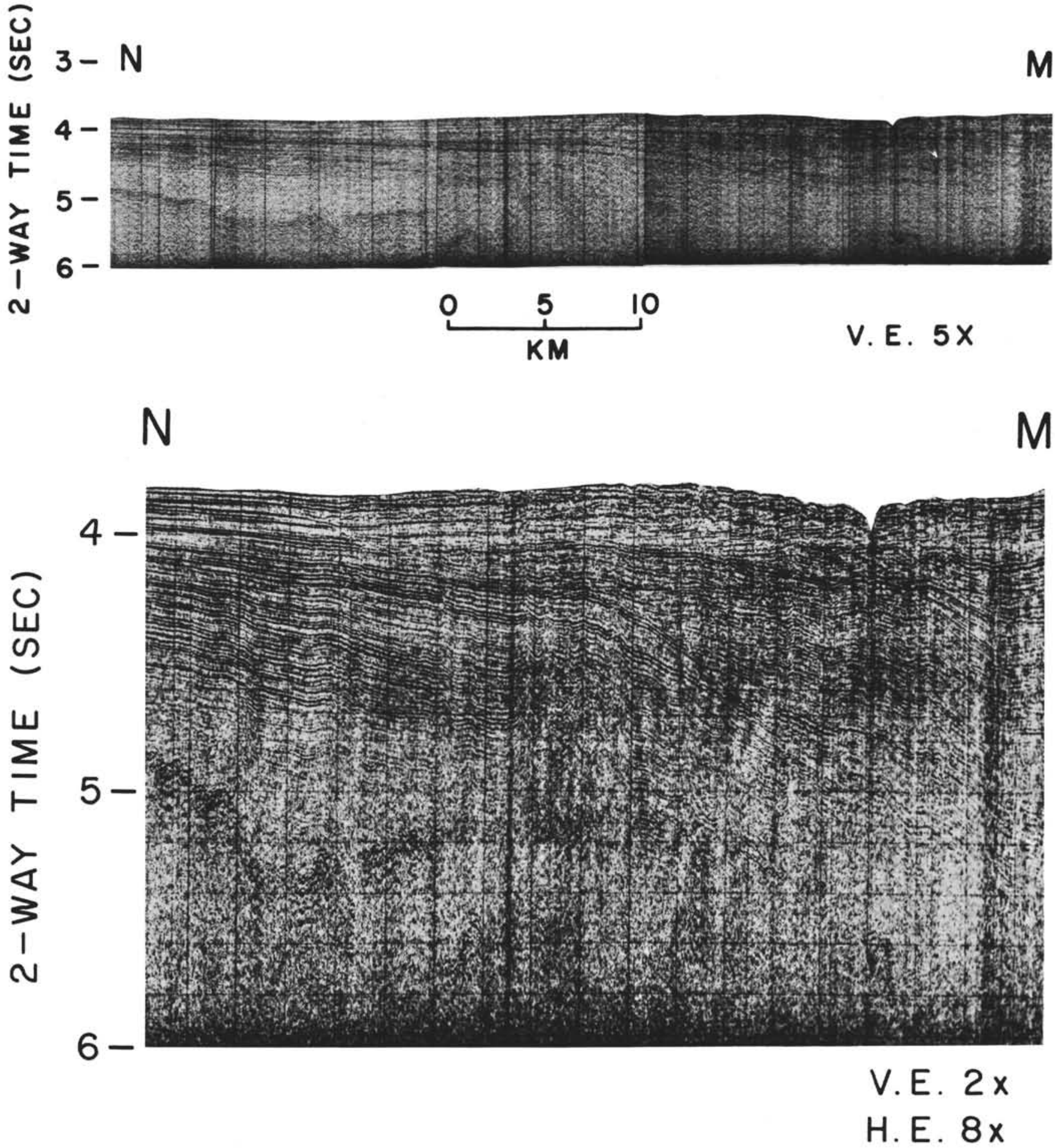

Figure 7. *(Top) Seismic reflection profile N-M. (Bottom) Squeezed record of profile N-M showing seismic discontinuity between overlying Astoria Fan sediments and underlying landward-dipping abyssal plain sediments. Exaggerations given are the amounts of distortion in the original record (top). See Figure 1 for location.*

recent time and that Astoria Fan sediments are folded to form the lower continental slope off central Oregon. In areas where the nature of the continental slope-abyssal plain interface is acoustically obscure (profiles G-F; A-B; K-L), a fault may be present near the interface or the strata may be dipping too steeply to detect with seismic reflection methods.

If the Juan de Fuca Plate is underthrusting the North American block, at least the upper portion of the plate is being scraped off onto the adjacent continental margin. It

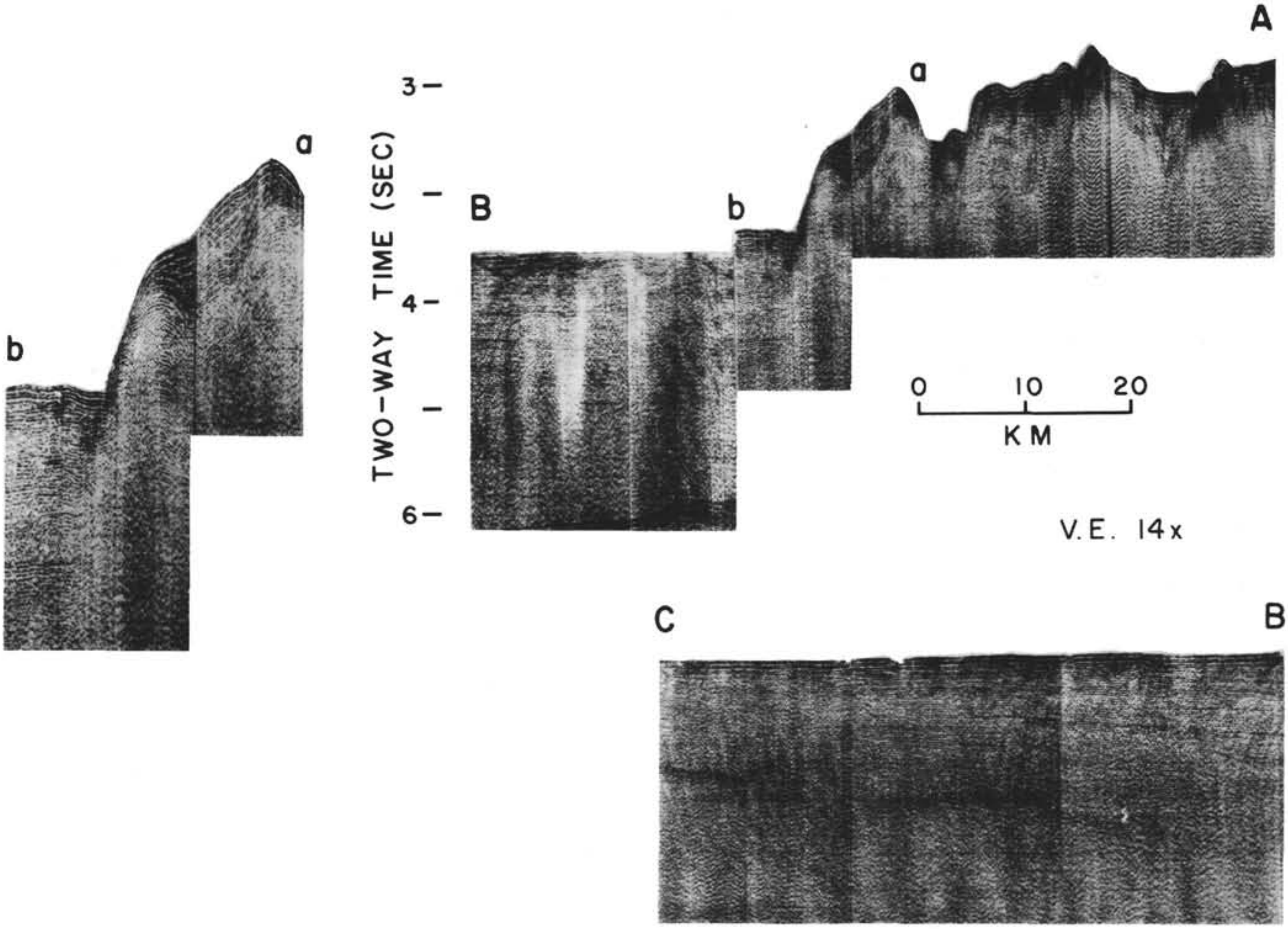

Figure 8. *Seismic reflection profile C-A. See Figure 1 for location.*

appears that the zone of deformation most frequently is obscured in the folded structures of the lower continental slope where a combination of factors preclude detection.

The relationship of the seismic discontinuity to the tectonism on the continental slope will be discussed elsewhere in this volume (see von Huene and Kulm, Chapter 33).

The angular unconformity on the western limb of Nehalem Banks was penetrated at a depth of 234 meters below sea level (see Site 176, Chapter 7). The Pliocene sediments are deeper-water deposits that have been uplifted and apparently truncated by a lower stand of sea level. Because this erosional surface presently occurs much deeper than the minus 125 meters commonly accepted for the late Wisconsin lowering of sea level, substantial subsidence is inferred for the outer edge of the northern Oregon shelf (see Site 176, Chapter 7).

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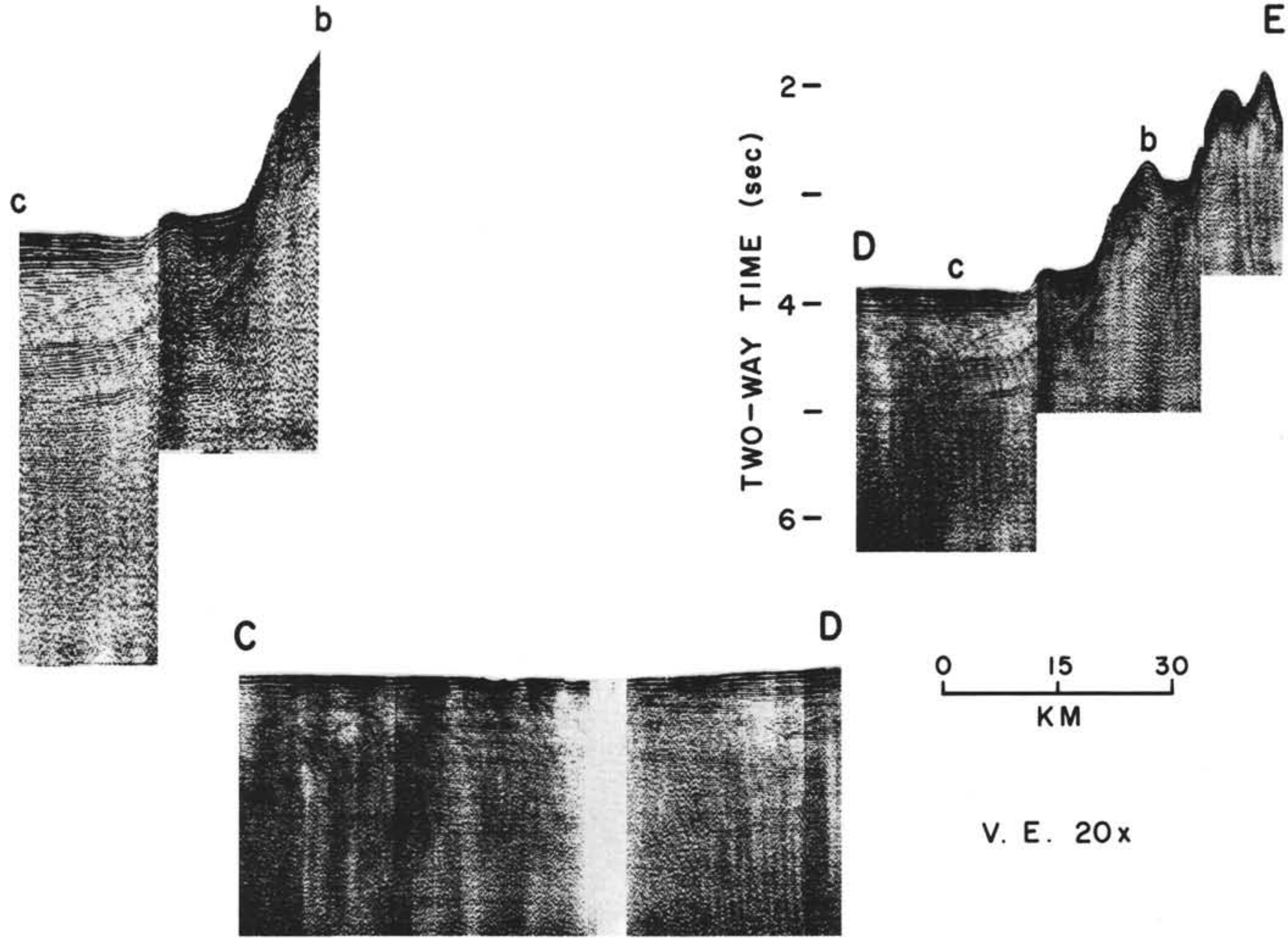

Figure 9. *Seismic reflection profile C-E. DSDP Site 174 was located just northwest of the beginning of this line. See Figure 1 for location.*

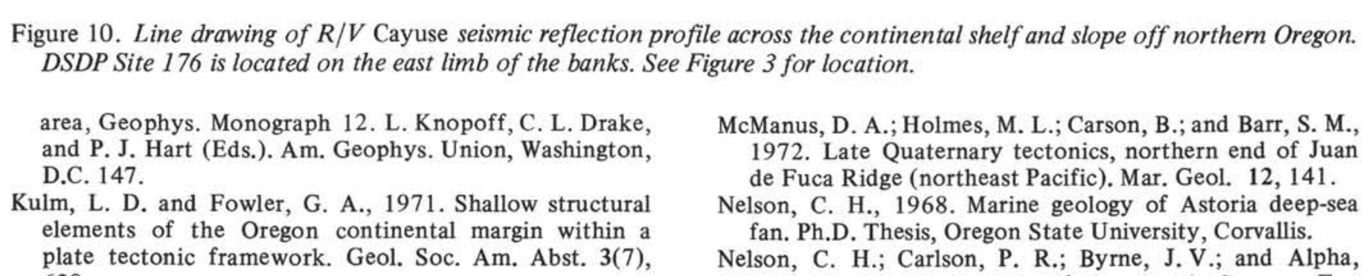

Figure 10. *Line drawing of R/V* Cayuse *seismic reflection profile across the continental shelf and slope off northern Oregon. DSDP Site 176 is located on the east limb of the banks. See Figure 3 for location.*

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PART B: SITE SURVEY OF PAUL REVERE RIDGE WEST OF NORTHERN VANCOUVER ISLAND

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Figure 1 shows the location of DSDP Site 177 and the site survey area off the northwest coast of Vancouver Island. The site is located in the Scott Islands fracture zone physiographic province (McManus, 1967a-b; Couch, 1969a-b; Dehlinger et al., 1971). The Scott Islands fracture zone, approximately 200 km long and 80 km wide, generally parallels the continental shelf and extends from on the continental shelf to the abyssal sea floor. Bathymetric studies of the region (Gibson, 1960; Hurley, 1960; McManus, 1964; Chase, Menard, and Mammerickx, 1970) show two long narrow ridges trending northwest-southeast with relatively flat floor between (Figure 2). The westernmost ridge, Paul Revere Ridge (McManus, 1964), extends approximately 130 km northwest from 40°50′N, 129°00′W to 50°30′N, 130°15′W and delineates the western boundary of the fracture zone. The region between Paul Revere Ridge and the continental shelf, termed the *Winona Basin* (Tiffen, Cameron, and Murray, 1972), is approximately 2000 meters below sea level and contains Winona Ridge, a broad ridge of relatively gentle relief subparalleling Paul Revere Ridge.

At its northwestern end, Paul Revere Ridge merges into the southeastern end of the two Dellwood knolls. Bertrand (1972) postulates the northwestern knoll to be an active center of sea floor spreading. Explorer Ridge, also a postulated active center of sea floor spreading, terminates at its northeastern end at approximately the mid-point of Paul Revere Ridge. At the southeastern end, Paul Revere Ridge diminishes in height and terminates in the vicinity of a submarine channel which runs south out of Winona Basin. DSDP Site 177 is located at the north end of Paul Revere Ridge.

Figure 3 shows that the pronounced magnetic anomalies (Raff and Mason, 1961; Couch, 1969) associated with sea floor spreading terminate along the west flank of Paul Revere Ridge and that the Scott Islands fracture zone exhibits very small amplitude magnetic anomalies. Vine's (1966) interpretation of the magnetic ages of these anomalies suggests the oceanic crust southwest of Paul Revere Ridge is late Pliocene or younger.

Sea floor spreading adjacent to Paul Revere Ridge appears to occur at a center approximately 10 km south of Site 177 and approximately 30 km north of the main axial trough of Explorer Ridge. The high heat-flow values observed by Lister and Davis (Srivastava et al., 1971) and very fresh basalt dredged from a valley near 50°20′N latitude, 130°10′W longitude support this interpretation. Although high heat-flow values are observed in postulated spreading centers immediately west of Paul Revere Ridge, (Couch, 1970; Srivastava et al., 1971) approximately normal heat flow is observed in Winona Basin (Couch et al., 1970, unpublished).

The Scott Islands fracture zone (Figure 4) exhibits free-air gravity anomalies between -80 and -160 mgl. Couch (1969b) interpreted the gravity anomaly magnitudes and pattern as suggesting a complex graben or a group of downfaulted blocks which were subjected to right-lateral shear. Figure 5 shows a crustal and subcrustal cross section which passes approximately through the gravity minimum and intersects Paul Revere Ridge and the continent approximately orthogonally. The anomaly is interpreted as caused by a crustal block downdropped approximately 6 km with the resulting graben filled with light sediments, possibly glacial till. The magnitude of the anomaly suggests the fracture zone is a major structural feature which may extend into the upper mantle. The relatively light (ρ = 3.18) material postulated in the upper mantle in the section is associated with the Explorer Ridge complex.

Continuous seismic profiling shows Paul Revere Ridge changes its character from north to south. On the north, in the area of Site 177 (Figure 6), it appears to form part of the Revere-Dellwood transform-fault zone joining Explorer Ridge to the Dellwood spreading center. Here, it is cut by numerous faults, steeply dipping or vertical, and probably