Procurement and reprocessing of an industry marine seismic reflection profile from the Columbia River, Oregon and Washington

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ABSTRACT

This report summarizes seismic reflection results from reprocessing an industry seismic profile along the Columbia River. I integrated the seismic-reflection data with combined high- and low- resolution aeromagnetic data and geologic maps to characterize the tectonic framework along the Columbia River. I identify a number of basins along the river and offshore and I identify several potentially active northwest- to northeast-trending faults that cross and perhaps control the Columbia River channel. The reprocessed 24-channel industry seismic-reflection data, with an emphasis on the upper 2 km, help identify and characterize the vertical offsets related to faulting. The aeromagnetic data identify lineaments that may be fault related, further constrain the regional extent of identified faults, and help characterize deeper geologic structures. Geologic map data provide the ground-truth and age control necessary to characterize seismic hazards identified with the geophysical data.

Miocene and Eocene volcanic rocks define the largest boundaries along the seismic transect. Offshore, the seismic data characterize a faulted sedimentary basin that contains more than 2 km of sediment on Eocene bedrock. The Astoria basin contains large, regionally folded sediments with unconformities and laterally terminating reflection packages. The unconformities likely correspond to changing sea-level conditions, while the laterally terminating reflections signify Neogene or younger faulting. Onshore, I characterize two deep basins that contain Eocene and younger sedimentary and volcanic rocks. These basins are fault controlled and correlate with magnetic anomalies and mapped faults. Further integration of geological and geophysical data will allow a better understanding of the risks associated with the potentially active fault structures in the region.

INTRODUCTION

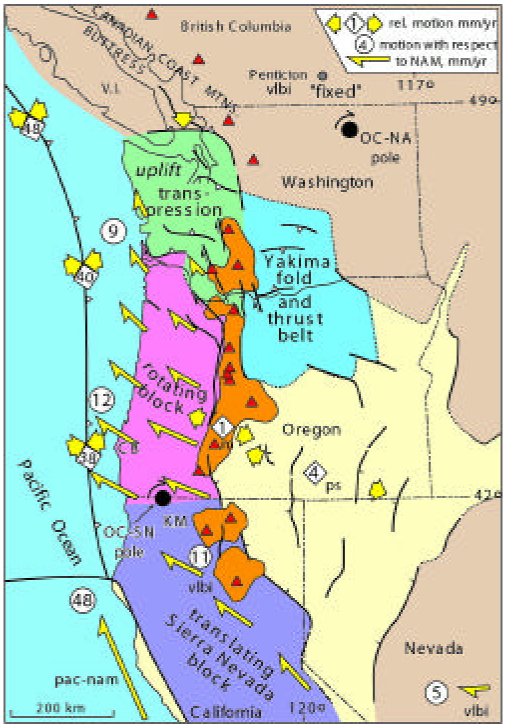

FIGURE 1. Schematic showing generalized geologic blocks for the region. Note the Columbia River west of the Cascade mountain range roughly separates the rotating Oregon block from the transpressional Washington block. Figure from Wells et al. (1998).

The Columbia River establishes the border between Oregon and Washington almost 500 km. The river is a major shipping channel to upstream ports and provides a migration route for salmon. The western portion of the Columbia River also roughly separates the Washington fore-arc block to the north from the Oregon fore-arc block to the south (Wells et. al, 1998; Figure 1). The north-to-south change in tectonic regimes separates compressional tectonics from extensional tectonics, marks a decrease in seismicity (Weaver and Michaelson, 1985), an increase in volcanism (Sherrod and Smith, 1990), and an apparent change in accreted Eocene-age crust (Trehu et al., 1994). The Columbia River generally flows from east to west for 500 km, with a major northward turn immediately downstream from the Portland/Vancouver metropolitan area (Figure 1). Blakely et al. (1995) postulated that the major northward turn in the Columbia River may actually be a fault controlled structure. A minor river bend in the Portland/Vancouver region closely matches the projection of the potentially active Frontal fault. New seismic reflection results from the Columbia River (Liberty, 2003; Pratt et al., 2001) support the hypothesis of a structurally controlled river channel in the Portland metropolitan area and potentially along other downstream reaches.

Recent efforts by the earthquake hazards community has been to map potentially active faults in the Pacific Northwest using both geologic and geophysical methods. Undifferentiated Quaternary sediments and massive volcanic rocks have made geologic mapping along portions of the Columbia River difficult. The presence of Miocene and older massive volcanic rocks in the subsurface have provided the opportunity for regional aeromagnetic surveys to identify lineaments that may be related to previously unmapped, potentially active faults. Large-scale seismic reflection surveys are expensive, yet seismic profiling provides one of the few methods of deriving a cross-section view of subsurface geology. Providing images of subsurface stratigraphy, preferably to depths of known volcanic rocks for age control and longer-term structural control is critical in determining the seismic hazards of the mapped faults and locating possibly unmapped faults.

GEOLOGIC SETTING

Earthquakes in the Pacific Northwest are related to intraplate and interplate stresses of active Juan de Fuca plate subduction. Offshore earthquakes may correlate with the location of fore arc basins that can be mapped with gravity and seismic methods (Wells et al., 2002). One of the largest of such basins lies immediately offshore the Oregon and Washington coast, where a near-continuous record of Cenozoic sedimentation appears (Snavely and Wells, 1996). Numerous industry and academic seismic reflection profiles have been examined along the continental shelf near the Columbia River (e.g., Niem et al., 1992; McNeill et al., 1997; 2000; Snavely and Wells, 1996) and have identified evidence for active faulting. Yet these basin and the underlying crustal structures are only broadly understood. A seismic profile extending from the mouth of the Columbia River adds a considerable information regarding the structural style for the region in general and the Astoria Basin in particular.

Onshore, a significant hazard also exists from shallow earthquakes in the crust of the North American plate. Upper plate earthquakes occur on crustal faults at relatively shallow depths (<25 km) and are of particular concern to the populated areas of western Oregon and Washington, where ground shaking from crustal faults may result in more damage than subduction-related seismicity. The Columbia River, along the Oregon/Washington border, loosely defines the northern boundary of the Oregon fore arc block, a boundary that marks a north-south transition in seismicity, volcanism, and crustal thickness (Figure 1). Many northwest-trending potentially active faults may cross and perhaps control the drainage of the Columbia River (Figure 2). Surficial evidence for active fault-

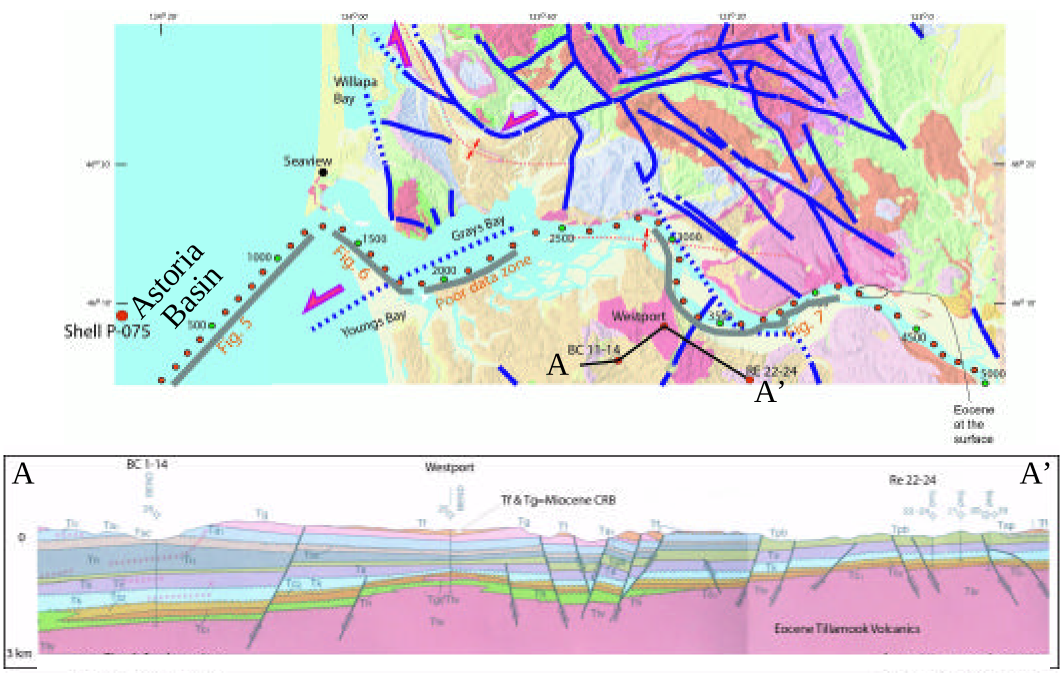

FIGURE 2. Generalized geologic map and cross section for the region near the mouth of the Columbia River with seismic shot locations, mapped faults, nearby oil industry wells, and location of figures presented in this report. Map modified from R. Wells (personal comm.). Cross section from Niem et al. (1992).

ing across the Columbia River is lacking due to the presence of thick channel fill and overbank flood sediments and a significant amount of lateral slip that may occur on regional faults.

MAGNETIC AND GRAVITY DATA

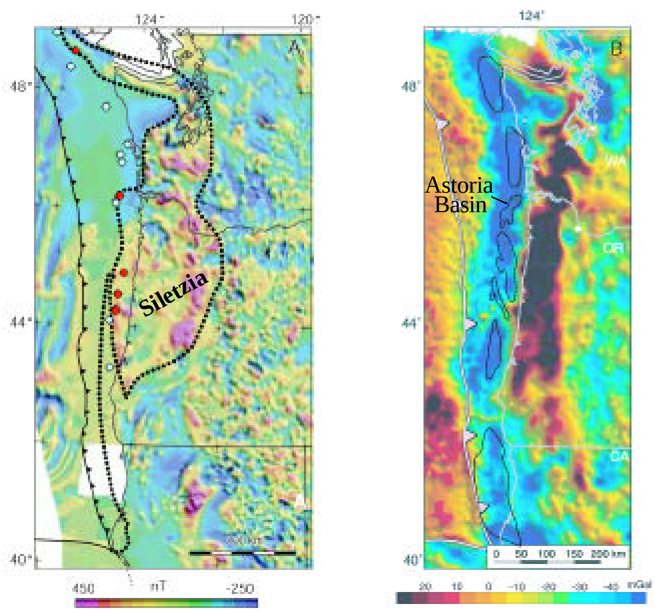

FIGURE 3. Magnetic and isostatic residual gravity maps for the Cascadia fore arc (from Wells et al., 1998; 2002). A) Siletzia accreted basalt basement (stippled area). Offshore wells bottoming in basalt basement (red) and sediment (blue). B) Offshore Cascadia fore arc basins (black outlines) shown as gravity lows adjacent to the gravity high associated with accreted.

Regional potential field data (Figure 3) define the outline for the accreted basalt terrane of Siletzia as broad magnetic and gravity highs (Wells et al., 1998; 2002). Offshore, fore arc basins are observed as gravity lows. Immediately offshore of the Columbia River, the Astoria Basin (Figure 2), and adjacent basins to the north and south, may be a proxy for long-term coseismic slip and may represent the offshore region with the largest asperity along the Cascadia margin (Wells et al., 2002).

High resolution aeromagnetic surveys have recently been acquired by the U.S. Geological Survey for the onshore region along the Columbia River. R. Blakely (personal comm.) merged these new data with existing offshore data to produce a detailed aeromagnetic map (Figure 4). This map contains many anomalies and lineaments worth discussion. Anomaly A correlates with a north-plunging anticline of Eocene basalt offset to the north by a northeast trending sinistral fault (R. Wells, personal comm.). Anomaly B is the large, high-amplitude magnetic anomaly likely representing a shallow Eocene basement with a major sill complex, intruded by late Eocene plutons. Anomaly C is an east-west magnetic lineament that correlates with Middle Miocene volcanic rocks exposures and anomaly D correlates with a northwest trending lineament that matches a mapped fault in Washington displacing Miocene and older units. Figure 4B shows the discrete vertical derivative of Figure 4A that highlights near-surface magnetic sources. This map was created by upward continuing the original data by 100 m, then treated subtract the results from the original data (R. Blakely, personal comm.). The high frequency, northwest-trending magnetic pattern that dominates the eastern portion of the map defines the shallow volcanic rocks, mostly Columbia River Basalt (CRB). The filtered data display several short-wavelength lineations. Lineation E marks a boundary between contrasting frequency content, indicating a vertical offset across a magnetic body. Lineations F, G, and H may also indicate near-surface faults. Although many of these magnetic features may be fault related, not all cross the Columbia River. The lineaments that do cross the

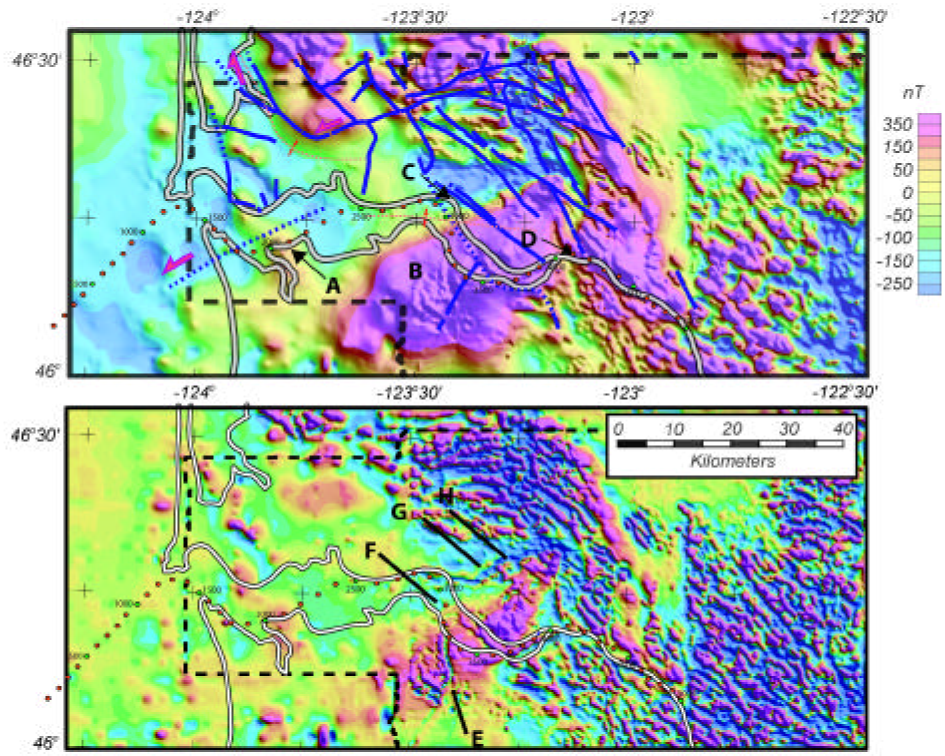

FIGURE 4. A) Magnetic anomaly map showing shoreline and Columbia River location, seismic shot locations, and presumed fault locations (from Fig. 2). Selected anomalies that cross the river are labeled and discussed below. B) Discrete vertical derivative of (A) to emphasize near-surface structures. Figures from R. Blakely (personal comm.)

river can be further characterized by the seismic data. The other magnetic lineaments may require an independent analysis to identify potentially active structures.

SEISMIC RESULTS

Data Acquisition

The seismic reflection data were acquired on an industry seismic vessel using 16 airguns totalling 600 cu in (4600 psi). A 25 m shot interval and a 24-channel streamer (20 hydrophones per group) with a 25 m group generated offsets from 255-830 m behind the airgun array. Both the airgun and streamer arrays were deployed at 6 m depth. Seismic data were recorded for 6 seconds at a 2 ms sample rate with a 5-128 Hz analog filter. The acquisition parameters were adequate to image depths of more than 2.5 km offshore and nearly 2 km inland. The seismic data quality were strongly controlled by the geologic and water bottom conditions along the Columbia River. Additional acquisition and processing parameters are summarized by Liberty (2003).

Offshore seismic profile

Offshore, the seismic data extend approximately 30 km across the Astoria Basin (Figures 2 and 3). This region appears as a gravity and magnetic low (Figures 3 and 4), suggesting a large package of sediments lies upon basement rocks. Eocene Tillamook volcanic rocks appear as the acoustic basement across the offshore seismic section (Figure 5). The reflector representing basement correlates to both surface outcrops along the Washington and Oregon coast (Figure 2; Niem and Niem, 1985) and also to nearby borehole information (Niem et al., 1992). The 3000 m deep Shell Oil Co. P-075 was drilled approximately 10 km northwest of position 150 (Niem et al., 1992). The major seismic boundaries appear to match the changes in lithology observed in the borehole (Figure 5). In the borehole and the seismic section, Pleistocene through Eocene sediments extend to approximately 2.5 km depth. Major unconformities extend across the basin and may also extend throughout the region (McNeil et al., 2000). The seismic data suggest the sediments are folded and faulted across the basin. The sag basin that appears in Figure 5 contrasts with a listric normal faulted basin that appears approximately 30 km to the north (McNeil et al., 1997).

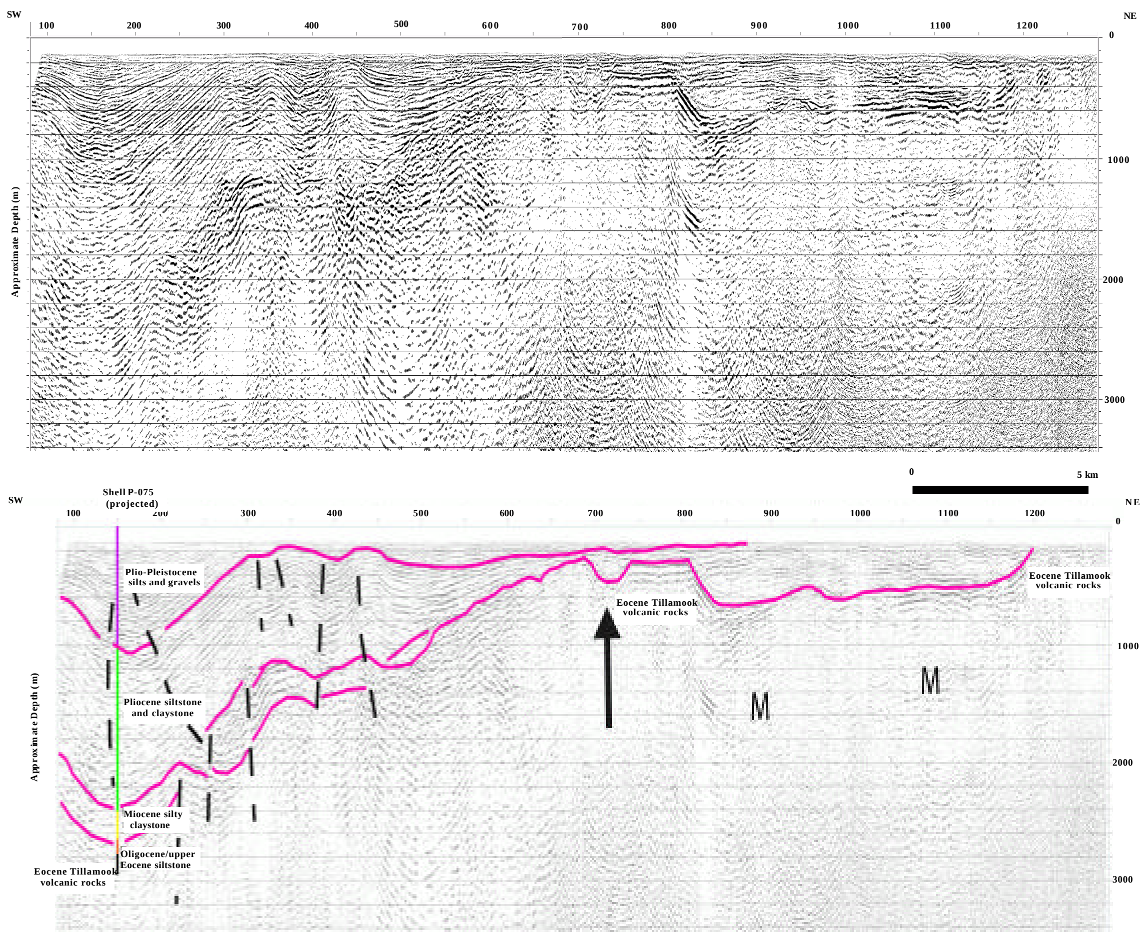

FIGURE 5. The migrated seismic reflection profile from the shoreline to approximately 30 km southwest across the inner continental shelf of the Astoria Basin (Fig. 3). Approximately 10 km northwest of position 150, the 3 km deep Shell Oil Co. P-075 bottoms in Eocene Tillamook volcanic rocks (Niem et al., 1992). Above the volcanic basement, Pleistocene to upper Eocene sedimentary rocks appear folded and faulted. To the east, bedrock rises to ~300 m depth along an erosional surface (position 740-810) and paleochannel. (position 710) Eocene volcanic rocks outcrop along south of Seaview (Fig. 3) and define the acoustic seismic basement both offshore and onshore. M=multiple.

The basin terminates to the northeast near position 700, where a high-amplitude reflection appears at approximately 300 m depth (Figure 5). This reflection likely represents the top of the Eocene volcanic sequence and may represent an erosional surface that marked the late Pleistocene sea level position. To the northeast, another small basin is centered at position 900 on the seismic profile. The bedrock reflection here is approximately 600 m deep. This small basin correlates to a local magnetic low centered to the south (Figure 4A). Along the seismic profile to the northeast, the bedrock reflection again shallows. At position 1200, bedrock appears shallower than the seismic data can image (<200 m). The near-surface position of bedrock correlates with a string of high-amplitude magnetic anomalies that trend to the north-northwest (Figure 4B) that likely mark the boundary of Tillamook volcanic rocks immediately below sea floor elevations.

Columbia River mouth seismic profile

Onshore, the mapped geology is complex (Niem et al., 1985; Figure 2). Middle Eocene volcanic rocks outcrop at the mouth of the Columbia River at position 1300 and again at position 1700-1800 (Figure 2). Between bedrock exposures, a 1.5 km deep basin appears in the seismic section (Figure 6). Reflections within the basin are poorly resolved, suggesting that either coarse-grained sediments fill the basin or the basin sediments are not laterally continuous and perhaps faulted. The surface sediments are mapped as Quaternary beach and dune sands, likely not extending into the subsurface any measurable depth. The eastern edge of this basin correlates with the mapped extent of a fault to the north (Figure 2) and magnetic anomaly A (Figure 4A). The interpretation of a north-plunging anticline of Eocene basalt suggests the basin may deepen to the northwest. A mapped east-west fault that extends through Grays Bay cuts the seismic section at position 1800 (Figure 2). Position 1800 marks the transition from Eocene volcanic rock outcrops to the east and younger sediments to the west (Niem and Niem, 1985) with an offset across Eocene volcanic rocks that exceeds 1000 m. This location also marks a transition where seismic data are poorly imaged to the east. The seismic and geologic data suggest Eocene volcanic rocks appear at the near-surface east of position 1800. Since the seismic data do not clearly image the geology below Eocene volcanic rocks, the seismic data provide no additional geologic or tectonic information immediately to the east. The seismic data between positions 1800 and 2900 will not be discussed in this report.

Westport seismic section

Near of the town of Westport, the seismic data show reflections dipping to the northwest near position 3200 and reflections that appear more flat-lying to the east and south (Figure 7). This region is near the Mist gas field and contains numerous oil and gas wells to tie to the seismic data (Figure 2). Also, a few noted magnetic lineaments (Figure 4B) appear to rest upon the deep-seeded magnetic high associated with Eocene basement and associated sills and plutons (Figure 4A). The Westport borehole is a 1500 m deep well that bottoms in Eocene Tillamook volcanic rocks at position 3290 (projected). Above the Eocene basement, late Miocene through upper Eocene volcanic and sedimentary rocks appear (Niem et al., 1992). The upper Eocene section appears to tie to a zone of strong reflectivity (Figure 7). This reflection package appears folded and faulted. Near the surface, Miocene

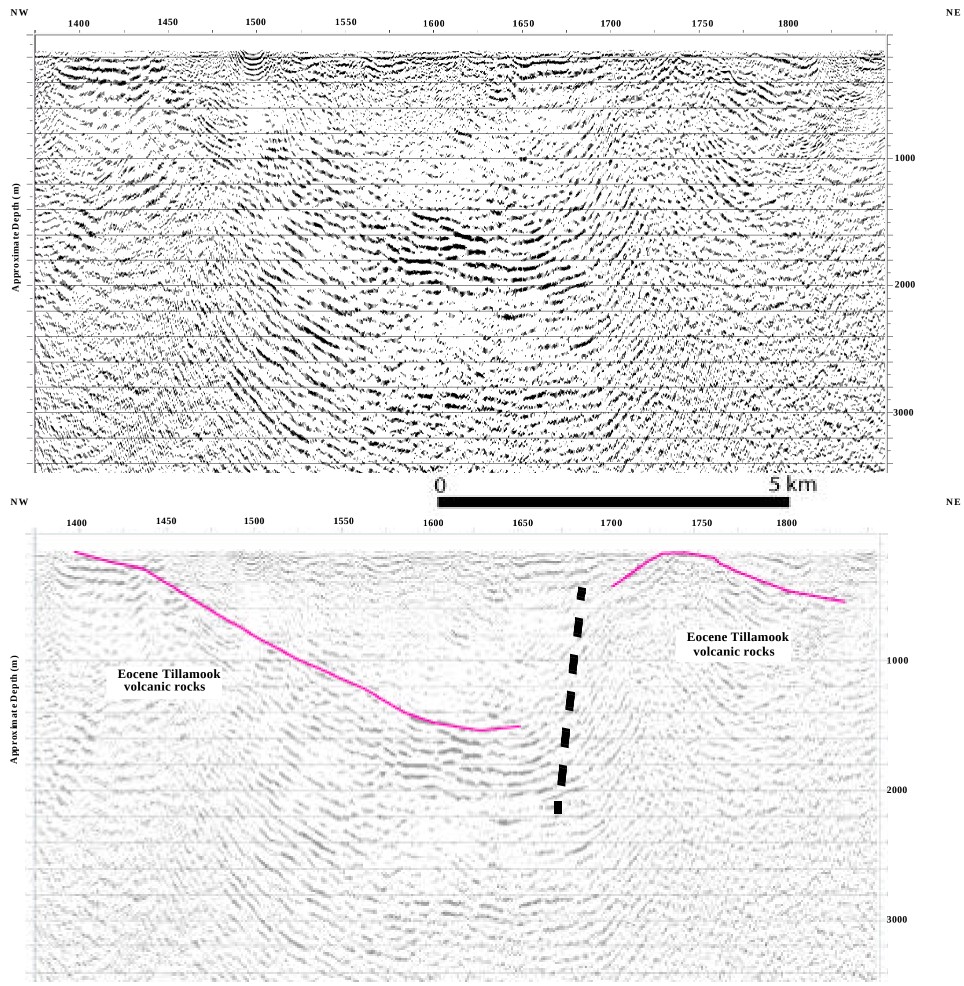

FIGURE 6. Migrated seismic profile near the mouth of the Columbia River showing a 5 km wide syncline and adjacent anticline. Eocene volcanic rocks outcrop near 1300 and 1800 on the adjacent Washington shore (Fig. 3) and suggest the prominent seismic boundary that extends to ~1600 m depth represents the top of the Eocene Tillamook volcanic rocks. Coherent reflections from the overlying Eocene to Miocene sedimentary rocks do not appear on the section.

CRB volcanic rocks appear in outcrop and can be mapped on the seismic data. The CRB section is thin enough to allow seismic energy to penetrate through and return from deeper sources. This is a contrast from the downstream section near Portland, where a thick package of Miocene volcanic rocks form the acoustic basement for this same data set (Liberty, 2003).

Magnetic anomaly E crosses the Columbia River near seismic position 3300 (Figure 2). This location marks a contrast in the seismic character and also a large bend in the Columbia River. To the northwest, the reflections dip steeply to the northwest. South of this lineament, the seismic data appear near flat lying (Figure 7). Although this change in apparent dip corresponds with a change in river orientation, a step in the CRB reflection and the underlying Eocene volcanic rocks is present, suggesting a fault is present. Although offsets in the Miocene and older volcanic rocks does not imply modern fault activity, it does suggest this fault or region may warrant further neotectonic investigations.

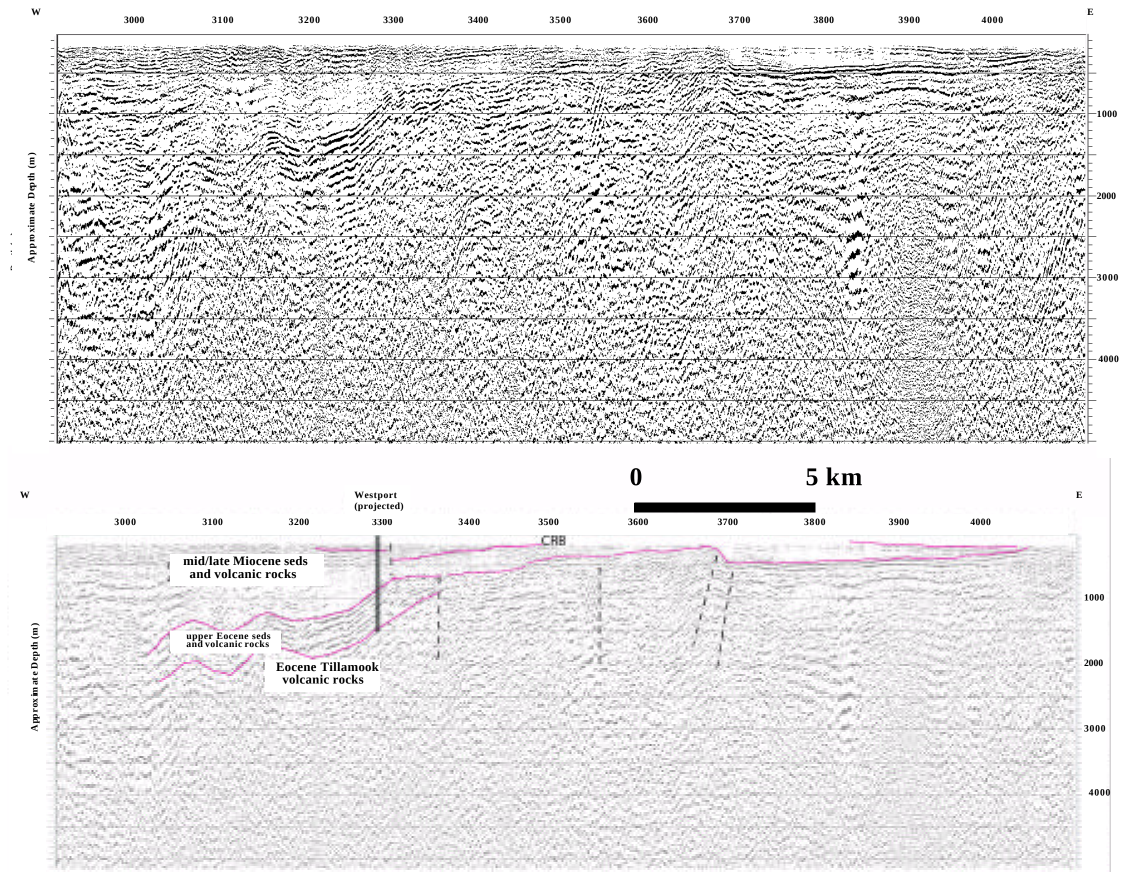

FIGURE 7. Migrated seismic profile from position 2900 to 4100 showing a prominent package of reflections shallowing to the southeast. (3100-3300) This section crosses magnetic Anomaly B (Fig. 4). The nearby Westport borehole (Fig. 3) suggests Eocene sedimentary and volcanic rocks comprise the reflection package that is truncated at 700 m depth (3300). Miocene-age CRB volcanic rocks appear at the surface across much of this profile. Further east, the flat reflection between 3700-4000 likely represents an Eocene volcanic rock eroded surface. Eocene volcanic rock outcrops appear near position 4200.

Further east, the bedrock surface appears at depths that range from 200-500 m depth. This surface may be faulted in places, but the surface also appears as an erosional surface from times of lower sea level. The amount of vertical relief on the bedrock reflection does not suggest large-scale faulting is present, but erosion and strike-slip motion may mask major crustal faults that cross the river.

CONCLUSIONS

Seismic reflection data from the Columbia River provide insight into the offshore and onshore geologic and tectonic structures that may be related to modern fault activity. The 30 km offshore profile shows a folded and faulted basin that contains more than 2.5 km of Eocene and younger sediment. A high-amplitude, flat surface immediately offshore is likely an erosional surface. Onshore, the seismic data quality diminish due to laterally changing geologic conditions and slow sedimentation rates compared to the offshore section. Two basins are mapped along the seismic profile between the shoreline and Rainier, Oregon. These basins are faulted, folded, and bottom in Eocene Tillamook volcanic rocks. The regional nature of the magnetic lineaments that match the observed seismic data suggest many of the faults are regionally significant and they warrent further exploration to determine whether fault activity continues. Other magnetic lineaments that do not cross the Columbia River may contain similar structures and may warrent further exploration.

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