U. S. DEPARTMENT OF THE INTERIOR

U. S. Geological Survey

Cruise Report for C1-94-OW: Reconnaissance High Resolution Geopulse Data Acquired for Seismic Hazard Studies along the Columbia River from July 18-22, 1994

by

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INTRODUCTION

Reconnaissance high resolution geopulse data were collected in the Columbia River between Astoria, OR and Washougal, WA from July 18-22, 1994 (Fig. 1). The data were collected as part of a feasibility study to determine if high resolution seismic reflection data of reasonable quality could be collected in the Columbia River to help assess earthquake hazards of the Portland, OR/ Vancouver, WA metropolitan area. Data were acquired in areas where faults are inferred to underlie the Columbia River and associated channels based on existing geological and geophysical data, but where fault exposures in the vicinity of the river are obscured by vegetation and cultural disturbances. This study was designed to determine whether the sedimentary fill beneath the river bed would preserve a record of recent fault activity, which proved to be the case over some sections of the river. The following areas were targeted for data acquisition:

1) Clatskanie fault zone The Clatskanie fault has been suggested to be one of the largest upper crustal fault that crosses the Columbia River (Snavely and Niem, in prep). It extends from Clatskanie, OR northwestward across the Columbia River through Wallace Island to Skamokawa, WA (Snavely and Niem, in prep). The fault is delineated by an elongate gravity anomaly and northwest trending lineations on high altitude photographs, and most likely extends west of Skamokawa to the northeast-trending Columbia River fault (Snavely and Niem, in prep). Exposures of the fault in a quarry near Skamokawa, indicate that most of the movement on the fault occurred prior to deposition of the Columbia River basalt (Snavely and Niem, in prep). However, movement on this fault may have been triggered by the 1949 Olympia M=7.1 event as evidenced by slumps, sand boils, and liquefaction features in the town of Skamokawa, WA (Chleborad and Schuster, 1990). The fault may also extend to the southeast near St. Helens, Oregon, and join the Frontal fault zone that shows up as a steep northwest-trending magnetic gradient on the anomaly map of Blakely and others (in prep). If the Clatskanie joins the Frontal fault zone, the entire length of the fault would be on the order of 150 km. A primary goal for this study was to attempt to determine if this fault is presently active, and if it can be tied to the Frontal fault zone to the east.

2) North-trending segment of the Columbia River West of the Cascades, the Columbia River generally flows east to west except for a north-trending segment between its confluence with the Willamette River, and Longview, WA (Fig. 1). It has been suggested that the north-trending segment of the river may be controlled by faulting (Blakely and others, 1995). A broad shear zone has been mapped on land near the I-5 Longview-Kelso offramp near the bend in the Columbia River (Ray Wells, pers. com., 1994), which supports the suggestion that the course of the river here is fault controlled. However, the orientation of this fault zone is not well constrained; it has been interpreted as both a north-trending fault that forms a terrane boundary parallel to the St. Helens fault zone in Washington, and as a northwest trending fault (Al Niem, pers. com., 1994). The north-trending segment of the Columbia River is also of interest since the northwest end of the Portland Basin is inferred to lie in this area.

3) Frontal Fault Zone The Frontal fault zone (FFZ) shows up as a steep northwest-trending magnetic gradient on the anomaly map of Blakely and others (in prep). This fault has been proposed to form the northeast boundary of the Portland Basin. Although this fault is not as well exposed, a surficial expression of the fault has been mapped at Lacamas Lake (Blakely and others, in prep). The FFZ has been projected southeastward to coincide with a bend in the Columbia River east of Washougal

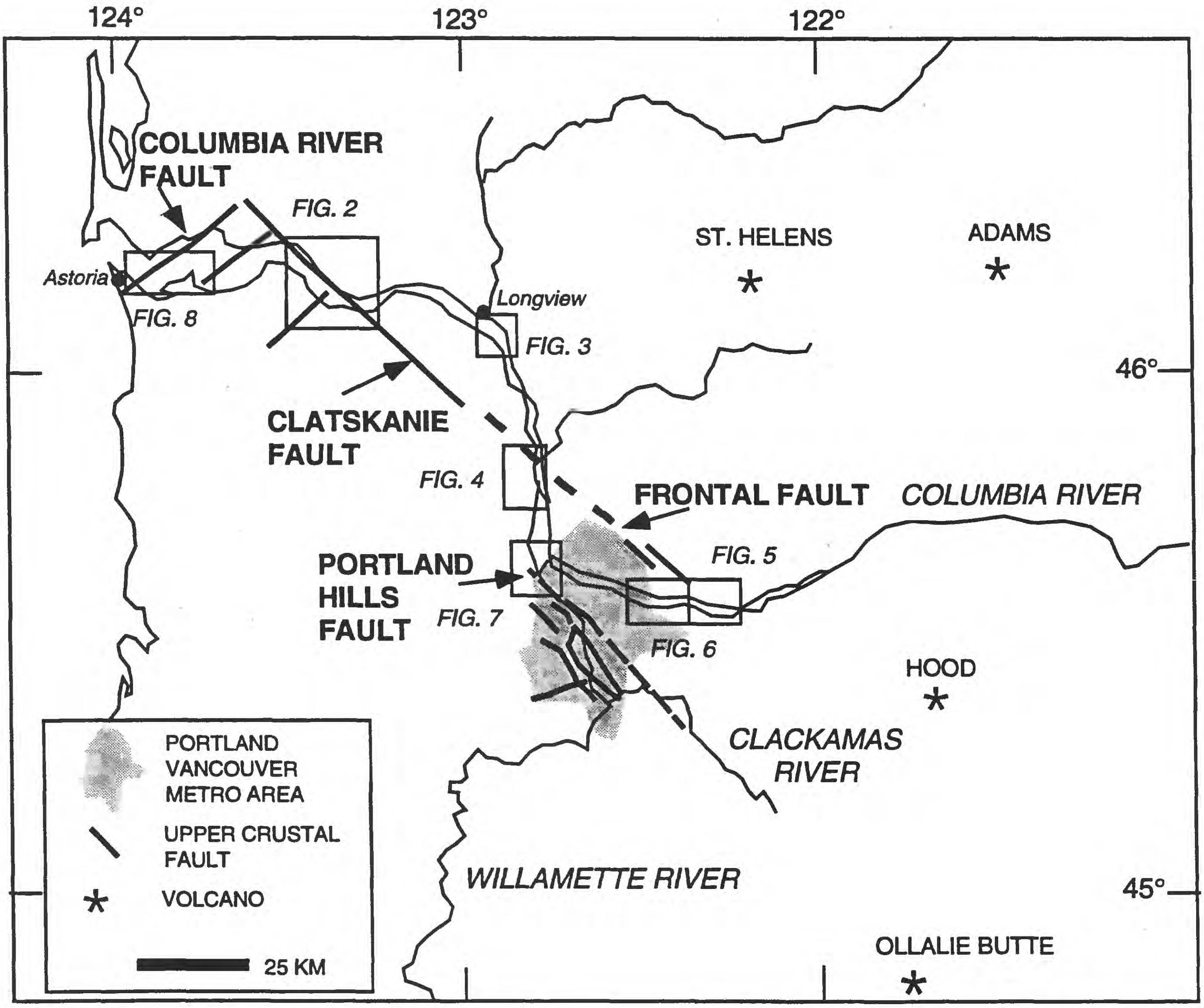

FIGURE 1. Map showing upper crustal faults near the Portland, OR/Vancouver, WA metropolitan area. The major rivers in the area are also shown. Boxes show the approximate locations where geopulse data were collected during the time period of 7/19/94 to 7/22/94 (Figs. 2-8).

based on the aeromagnetic data, and a goal of this study was to determine if offsets in river sediments would confirm the presence of the fault here.

4) Lady Island/Ryan Point An objective of collecting data south of Lady Island is to try to delineate a structure that ties Columbia River basalt exposed at the surface at Lady Island, with Columbia River basalt found at depth in wells south of the Columbia River (I. Maddin, pers. com., 1994). Further west of Lady Island near Ryan Point, WA, multichannel seismic (MCS) reflection data previously collected by Western Geophysical, show near-surface dipping reflectors off of Portland International Airport, which suggests that there may be recent fault activity in the area. Since it is difficult to resolve shallow structures using MCS data, high resolution geopulse data were collected to try to image the dipping events and determine if young river sediments are deformed.

5) Portland Hills fault zone The Portland Hills fault zone is inferred to subparallel the Frontal fault zone and trends through downtown Portland. It forms the southwest boundary of the Portland basin and has been active since at least mid-Miocene (Yelin and Patton, 1991). Offset of the Lloyd Center strand of the Portland Hills fault zone may exceed 1 km, based on magnetic modeling (Blakely and others, in prep). A swarm of earthquakes that may be related to the Portland Hills fault zone occurred beneath Sauvie Island from 1982-85 (Yeltsin and Patton, 1991). The fault zone obliquely crosses Multnomah Channel near its confluence with the Willamette River.

6) Columbia River, Chinook and Firn Hill Faults Study of the Columbia River fault zone and other faults along the lower Columbia River in western Oregon, would benefit seismic hazard assessments of the Astoria, OR area, and potentially allow a tie between the upper crustal faults in the Portland area and offshore structures. In addition, liquefaction features related to the 300-year b.p. great earthquake on the megathrust are best preserved in the lower Columbia River (Atwater, 1994). The presence of active upper crustal fault in the area could potentially impact these studies.

SCIENTIFIC STAFF

Scientific staff included Holly Ryan, Andy Stevenson, and Jim Vaughan of the USGS. Data were collected aboard the Army Corps of Engineers (ACE) vessel the *Cathlamet Bay*, expertly captained by Terry Vance from the ACE. Al Niem of Oregon State University participated in two days of data acquisition.

EQUIPMENT

Geopulse

Seismic energy was supplied by an ORE/Geopulse "boomer" transducer providing approximately 125 joules per shot. Reflected energy was received using a 20-element Benthos streamer coupled with an ORE amplifier/filter box. The total frequency content of the data was about 500-2000 Hz, although there was little frequency content at the high or low end of the spectrum. Maximum recorded subsurface depth was 1/8 second two-way travel time (about 90 m), but a static shift in the data of 1/16 second resulted in only 1/16 second (about 45 m) of actual data recorded. Since reflectors of greater than about 10-20 m sub-river bottom were rarely observed, a record length of 1/16 second was generally adequate. Based on the two-way travel time to the water-bottom multiple, an additional system delay of about 3 ms is still present in the data. The sample interval of the data was .0625 ms/sample, with 2048 samples/trace. The approximate trace spacing was .4 m based on a boat speed of about 3 kts (boat speed varied from about 2.5 to 3.5 kts). Data were recorded digitally, and often the monitor for the digital recorder showed more information than analog paper records that were collected on board the boat. The highest quality data were collected away from the main shipping channel in water depths greater than 10 m.

Mudseis/Yonav

S-code GPS position information was collected at 10 second intervals and merged with the digital acoustic data. The analog data stream from the amplifier/filter was digitized at 16 kHz using 8 bits/sample, but low signal strength resulted in values that rarely exceeded 64, a significant reduction in overall dynamic range.

OPERATIONS

The *Cathlamet Bay* has a shallow draft (1.3 m) and was therefore often able to maneuver to within a few meters of the shoreline. Data were collected during daylight hours. During the evening, the boat was tied up at the following docks: ACE in Astoria, OR, and the municipal docks at Rainier, OR and Washougal, WA. A support vehicle with spare parts and equipment transited on land between Astoria, Rainier, and Washougal, and provided onshore transport as needed.

The following abbreviations are used in this section: JD (Julian Day), Z (Zulu or Greenwich Mean Time), and PDT (Pacific Daylight Time, which corresponds to local time).

7/18/94 (JD 198)

The first day was spent at the Army Corps of Engineer dock at Tongue Point, east of Astoria, trying to mount all of the equipment in a very small protected area (a logistics nightmare). Additional problems with the power supply and the navigation and seismic recording system resulted in no data acquisition on this day.

7/19/94 (JD 199/200)

Problems with the MUDSEIS data acquisition system resulted in delays in the morning. We finally were underway at about 10:30 (PDT), and headed to Westport, OR to meet up with our support vehicle. We decided to spend this day studying the Clatskanie Fault near Puget and Wallace Islands (Fig. 2). The equipment was deployed in deep water between Wallace and Puget Islands, near where the Clatskanie Fault is mapped on MCS data (Snavely and Niem, in prep). Lines TEST through 4 were collected north and west of Wallace Island (Fig. 2) These profiles were collected near the main ship channel and subsurface penetration was not good. When it is near high tide, we proceed to try to map the Clatskanie Fault on the south side of Wallace Island in Wallace Slough, which is in quite shallow water (Fig. 2; lines 5-6). Here, the river bottom is dominated by sand waves that obscure any subsurface reflectors.

From Wallace Island, we transit back to near the area where the Clatskanie Fault is mapped on land on the Washington side of the river near Skamokawa, WA (Fig. 2; lines 7-12). There is an obvious notch in the topography on land, which we infer is related to faulting. A slightly longer hydrophone cable is used, resulting in somewhat better records. Except for line 12, few subsurface reflectors were observed on these profiles, which were also collected near the main ship channel. After attempting unsuccessfully to fuel in Cathlamet, WA (the marina closes at 1700 PDT), we collect data along the

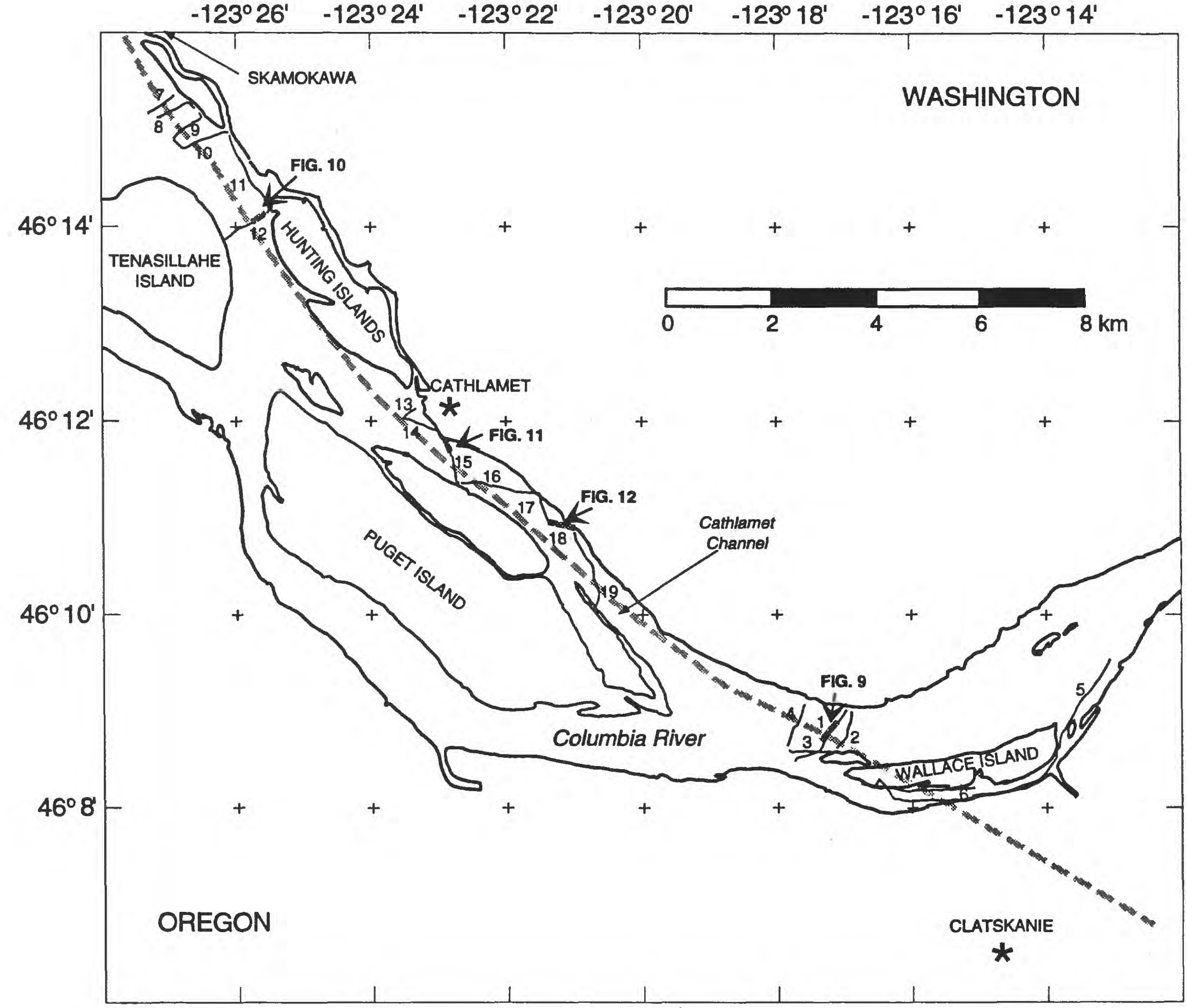

Figure 2. Trackline map of data collected in the bend of the Columbia River that may be coincident with the Clatskanie fault zone (lines 1-19). Gray dashed line shows inferred location of the fault; it has been mapped on land northeast of the town of Clatskanie, OR, and in quarry near Skamokawa, WA. Locations of seismic sections shown in Figs. 9-12 are delineated.

northeast side of Puget Island within the bend of the Columbia River that may be coincident with the Clatskanie Fault (Fig. 2; lines 13-19). Since the main ship channel runs to the southwest of Puget Island, data quality is better and sub-river-bottom reflectors are observed in this area.

CRUISE LOG

1030 PDT	*depart ACE dock at Tongue Point, OR*
1045 PDT	*boat overheated causing 15 minute delay*
1150 PDT	*pick up Andy Stevenson at Westport, OR*
1210 PDT	*geopulse sled in the water/ BOL TEST*
1942 Z	*BOL 1 (Columbia River, between Wallace and Puget Islands)*
1959 Z	*BOL 2*
2008 Z	*BOL 3*
2015 Z	*BOL 4*
2025 Z	*EOL 4/ pull sled onto boat for transit to Wallace Island*
2044 Z	*BOL 5 (Wallace Slough, south of Wallace Island)*
2137 Z	*BOL 6*
2201 Z	*EOL 6/ pull sled onto boat for transit to near Skamakowa, WA*
2247 Z	*BOL 7 (Columbia River, NE of Welch and Tenasillahe Islands)*
2255 Z	*BOL 8*
2306 Z	*BOL 9*
2315 Z	*BOL 10*
2329 Z	*BOL 11*
2342 Z	*BOL 12*
2352 Z	*EOL 12/ pull sled to fuel at Cathlamet, WA*
0044 Z	*BOL 13/ (Columbia River, NE of Puget Island)*
	MUDSEIS is not operational, proceed only with paper record
0048 Z	*BOL 14/ MUDSEIS up and running*
0100 Z	*BOL 15*
0110 Z	*BOL 16*
0130 Z	*BOL 17*
0137 Z	*BOL 18*
0143 Z	*BOL 19*
0202 Z	*EOL 19/ end of operations for day/ transit to Westport*
1930 PDT	*arrive in Westport, OR for transit in support vehicle to Rainier, OR*

7/20/94 (JD 200)

One of the major targets for this day is the area of the big bend in the Columbia River at Rainier, OR (Fig. 3). An attempt was made to collect data up the Cowlitz River, to try to intersect the fault mapped on land near the I-5 Longview-Kelso offramp. Unfortunately, the main channel was too shallow to collect any data (we had to pull in the gear), probably as the result of large deposits of ash following the Mt. St. Helens

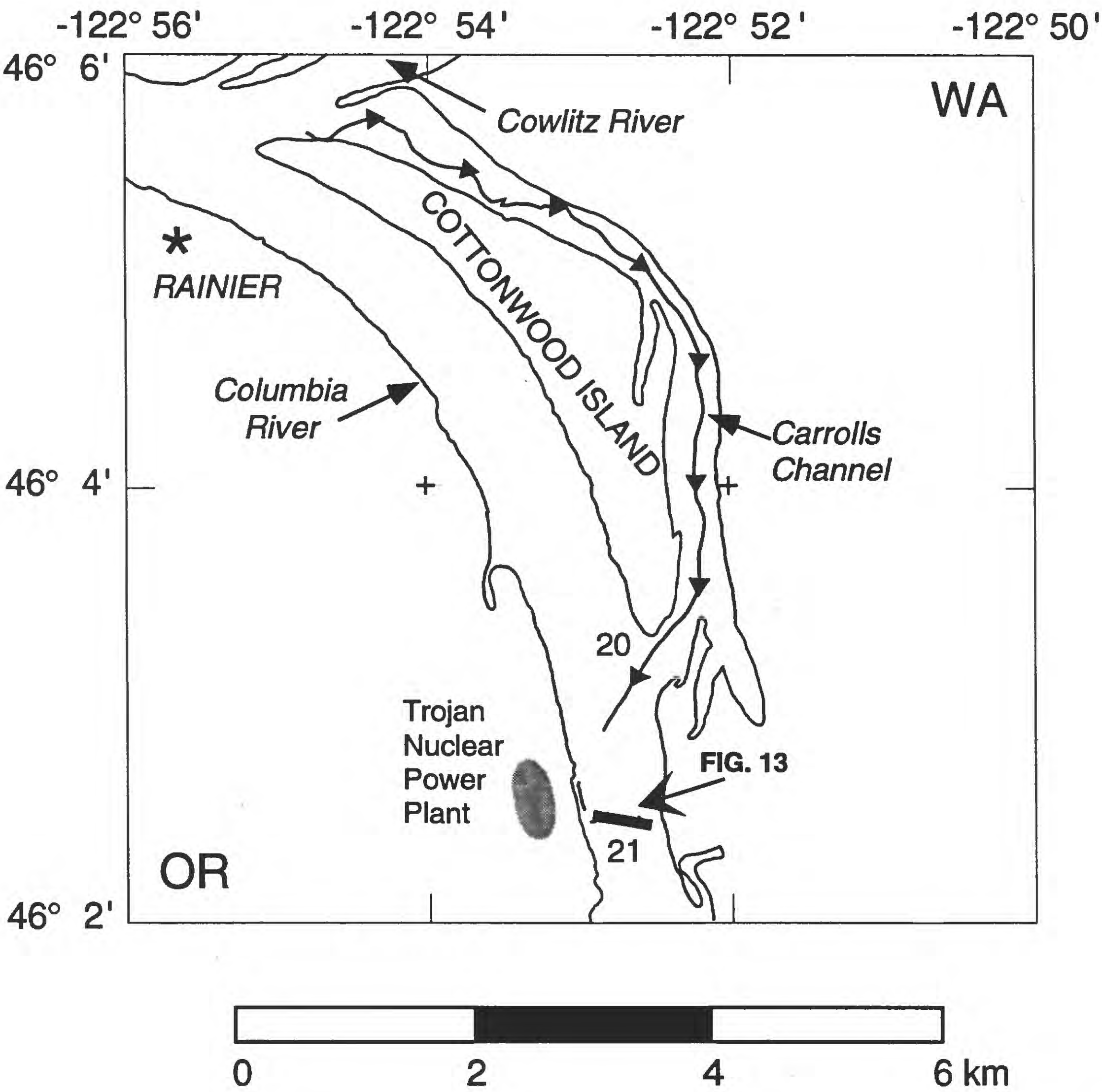

Figure 3. Trackline map of data collected in the area where the Columbia River changes from a northerly to a westerly direction (lines 20 and 21). Location of figure 13 is shown.

eruption. Since this fault may also project along Carrolls Channel on the back side of Cottonwood Island, line 20 (Fig. 3) was collected. No subsurface reflectors were observed within Carrolls Channel itself, perhaps also the result of ash deposition. In the main Columbia River Channel, better subsurface penetration revealed some strong reflectors on the end of line 20 and line 21 (Fig. 3). Unfortunately, the seismic acquisition system failed about halfway through line 20, and we only have digital data for line 21.

From Trojan nuclear power plant, we pulled the gear and transited south to near St. Helens, OR, to collect data in the northern part of Multnomah Channel, as far south as Scappoose, OR (Fig. 4; lines 22-23). Line 22 was collected along the northernmost end of Sauvie Island near the northwestward projection of the Frontal fault zone, and line 23 was collected in an area of Multnomah Channel characterized by unusual sharp bends along strike with a fault mapped on land along Scappoose Creek. Before the long transit up river to Washougal, WA, data were collected immediately north of St. Helens, OR in the Columbia River west of St. Helens bar near a possible projection of the Clatskanie Fault (Fig. 4; line 24). Lines 22-24 all showed reflectors from beneath the river bottom.

CRUISE LOG

0800 PDT	*boat departs Rainier to fuel*
0910 PDT	*boat arrives back in Rainier, Al Niem from OSU joins operations*
1629 Z	*start test line/ search for main Cowlitz Channel/*
1649 Z	*pull gear out of the water, as too shallow to collect any data transit to Carolls Channel*
1653 Z	*BOL 20 (Carolls Channel)*
1819 Z	*generator died, lost power (needed oil)*
1825 Z	*geopulse back up and running, but MUDSEIS is still down*
1829 Z	*BOL 21/ MUDSEIS is back up*
1834 Z	*EOL 21/ pull in gear and transit back to Rainier, OR*
1150 PDT	*arrive in Rainier, transit in support vehicle to St. Helens, OR*
1249 PDT	*depart St. Helens, OR*
1955 Z	*BOL 22 (Multnomah Channel)*
2038 Z	*EOL 22/ pull gear to transit further up channel*
2108 Z	*BOL 23 (Multnomah Channel)*
2138 Z	*EOL 23/ pull in gear to transit back to St. Helens, OR*
2224 Z	*BOL 24 (Columbia River near St. Helens, OR)*
2249 Z	*EOL 24 / pull in gear for transit to St. Helens*
1600 PDT	*Leave St. Helens in support vehicle for transit to Washougal, WA*

<u>7/21/94 (JD 201)</u>

Data acquisition today is concentrated in the Portland, OR/ Vancouver, WA metropolitan area. The geopulse system was deployed immediately outside of the Washougal, WA Marina (Fig. 5). We collected data in the bend of the Columbia River

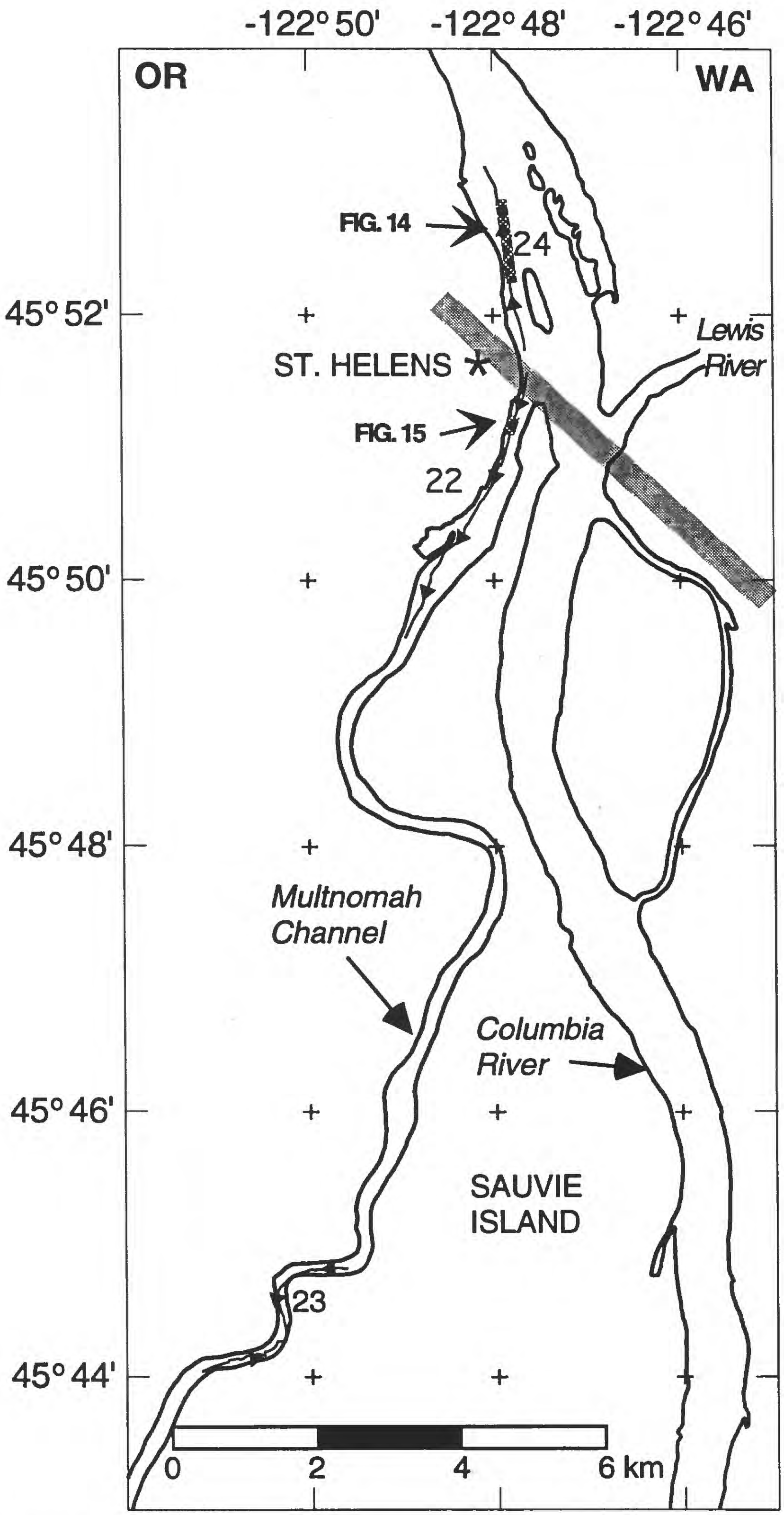

Figure 4. Trackline map of data collected near St. Helens, OR along the north-trending segment of the the Columbia River and northern part of Multnomah Channel (lines 22-24). Several faults are inferred to cross the Columbia River and/or Multnomah Channel in this region including the northwest projection of the Frontal Fault Zone; the approximate trend of the Frontal Fault Zone is shown by the gray dashed line. The locations of Figs. 14 and 15 are shown.

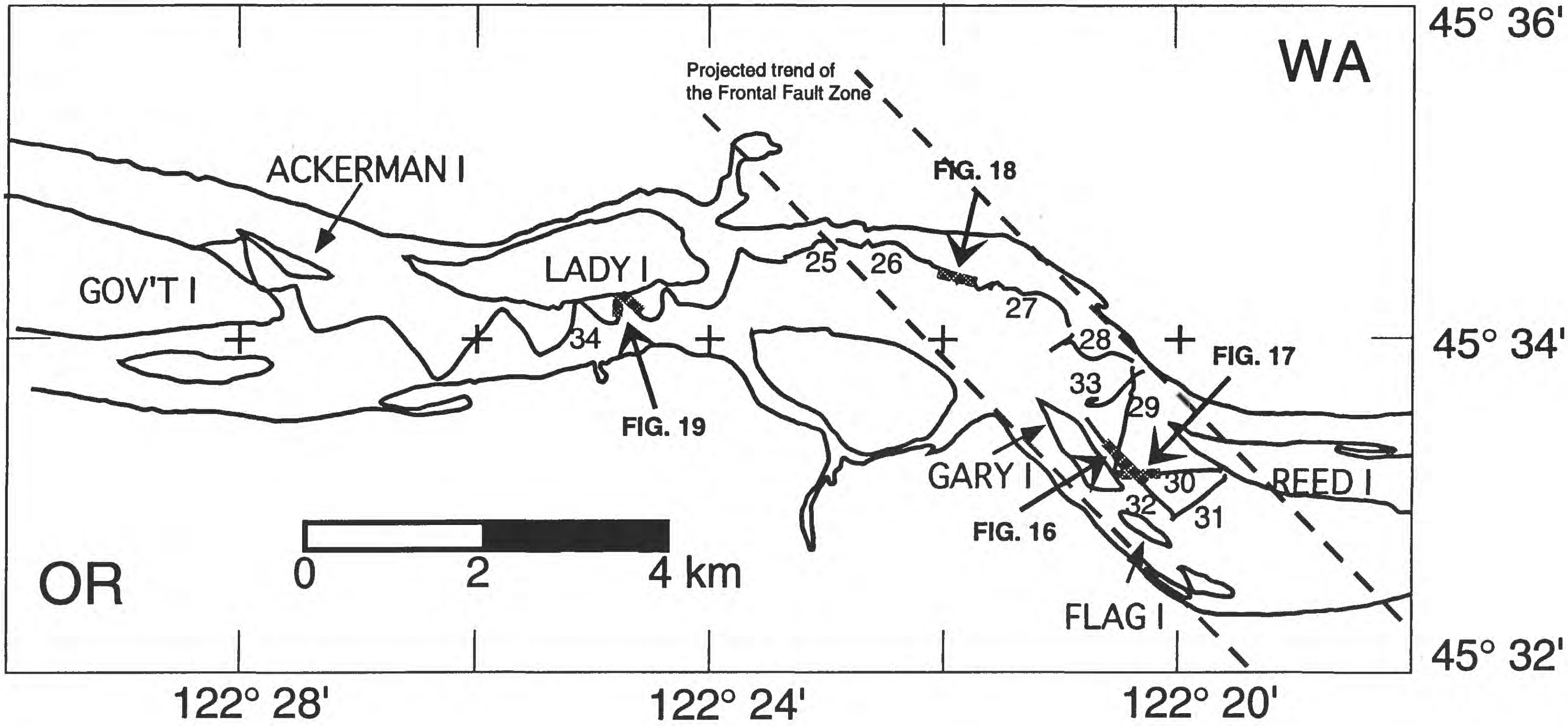

Figure 5. Trackline map of data collected in the bend of the Columbia River that may be coincident with the Frontal Fault Zone (lines 25-33) and south of Lady Island (line 34). The dashed lines show the projection of the fault zone through the river bend. The location of Figs. 17-19 are shown.

east of Lady Island to attempt to image the Frontal Fault Zone (Fig. 5, lines 25-33). Water depths were too shallow to collect data near the southern river bank at the northwest end of the bend. The data with the best subsurface penetration were collected within the bend to the northeast of Gary and Flag Islands, where a strong subsurface reflector was mapped.

Subsequently, data were collected south of Lady Island (Fig. 5, line 34). In areas opposite to where Columbia River basalt are exposed on the island, the river has a rough bottom topography, and eddies and boils are common in the river. A strong subsurface reflector is observed south of the basalt exposure. The southern bank of the river is too shallow for data collection, which precludes obtaining data across the entire width of the river. The Columbia River is also too shallow to collect much data in the area between Government and Lady Islands. We did attempt to collect data between Government and Ackerman Islands in the main ship channel, but did not record much subsurface penetration as is typical of areas where the main ship channel is routinely dredged.

Line 35 (Fig. 6) was collected in the vicinity of Ryan Point, WA, to try to confirm the existence of a near-surface structure imaged on previously acquired multichannel seismic reflection data. The geopulse sled was deployed at buoy 16, opposite the control tower at Portland International Airport. Data were collected back and forth across the river between the buoy and a railroad bridge west of the I-5 overpass (Fig. 6). Strong subsurface reflectors are observed on most of the passes across the river, including strong dipping reflectors near the shore at both the I-5 overpass and the railroad bridge.

Data were collected in the Columbia River near the confluence with the Willamette River in the vicinity where the Columbia River changes direction from westerly to northerly (Fig. 7, lines 36-40). Unfortunately, this is a heavily dredged area and no subsurface reflectors were observed. We collected data in the Willamette River immediately north of Multnomah Channel (Fig. 7, lines 41-43). This is also a dredged area and subsurface penetration was poor.

Subsequently, data were collected in the southern part of Multnomah Channel, which intersects the Portland Hills Fault at a very oblique angle (Fig. 7, line 44). Subsurface penetration within Multnomah Channel, which is not dredged, was good and we obtained reflection data over one crossing of the fault zone. Unfortunately, since the ambient air temperature was greater than 100°F, the power supply overheated and we were forced to suspend operations immediately down channel from the Sauvie Island Bridge.

CRUISE LOG

1555 Z	*BOL 25 (Columbia River bend, east of Washougal, WA)*
1603 Z	*BOL 26 (parallels river course)*
1611 Z	*abrupt change in record quality -- data are much noisier adjust gain in data*
1645 Z	*BOL 27/ must end line early as river shallows abruptly*
1650 Z	*BOL 28*
1701 Z	*BOL 29*
1713 Z	*BOL 30*
1725 Z	*BOL 31*
1734 Z	*BOL 32/ this is a test line to see if good data can be collected running down river (we had only been collecting data up river)*
1747 Z	*BOL 33/ line is aborted, head back to restart line*
1752 Z	*BOL 33*

1800 Z	*EOL 33/ pull gear to transit back to near Washougal marina*
1811 Z	*BOL 34 (Columbia River, south of Lady Island) this is a long line composed of 14 segments -- we essentially zig-zag across the river between Lady and Government Islands*
1931 Z	*EOL 34/ pull in gear*
1235 PDT	*stop at Bartlett Landing for a lunch break*
1310 PDT	*head for next site near Portland International Airport*
2028 Z	*BOL 35 (Columbia River, between buoy 16 and Hayden Island) this is a long line composed of 9 segments heading back and forth across the river*
2141 Z	*EOL 35/ pull gear and transit to western end of Hayden Island*
2153 Z	*BOL 36 (confluence Willamette and Columbia Rivers)*
2200 Z	*BOL 37*
2210 Z	*BOL 38*
2221 Z	*BOL 39*
2230 Z	*BOL 40*
2239 Z	*EOL 40/ pull in gear to transit down Willamette River towards Multnomah Channel*
2252 Z	*BOL 41 (Willamette River)*
2258 Z	*BOL 42*
2303 Z	*BOL 43*
2308 Z	*BOL 44*
2313 Z	*enter Multnomah Channel*
2331 Z	*power supply trips off due to overheating*
2332 Z	*power supply back up*
2336 Z	*power supply trips off again / decide to stop operations EOL 44/ transit back to Washougal, WA*

7/22/94 (JD 202)

We depart the Washougal Marina at 6:30 a.m. (PDT) on the *Cathlamet Bay* and transit back to Astoria, OR, arriving at the ACE dock at about 11:00 a.m. (PDT). Our objectives are to attempt to image the Columbia River fault zone, particularly in the vicinity of the bridge connecting Oregon and Washington. Time permitting, data are to be collected across the projections of other faults in the area.

The fog lifted at about 11:00 a.m. (PDT), but the winds had picked up and the seas were choppy. There are many shoals near the mouth of the Columbia River, and it was necessary to stay in the main channel on the southern side of the Columbia River estuary to collect data (Fig. 8, line 45). Line 45 crossed projections of both the Columbia River and Chinook faults, however, the profiles were dominated by large sand waves with little subsurface penetration. An attempt was made to collect data along the northern end of the Astoria bridge to also try to image the Columbia River fault (Fig. 8, line 46); the fault also projects into Grays Bay, which is unfortunately too shallow to be able to collect any data. However, since the waters were too choppy to acquire any data of reasonable quality, we decided to pull the gear in, and head back to near the ACE docks. The final profiles were collected across the Firn Hill Fault (Fig. 8, line 47), where data of

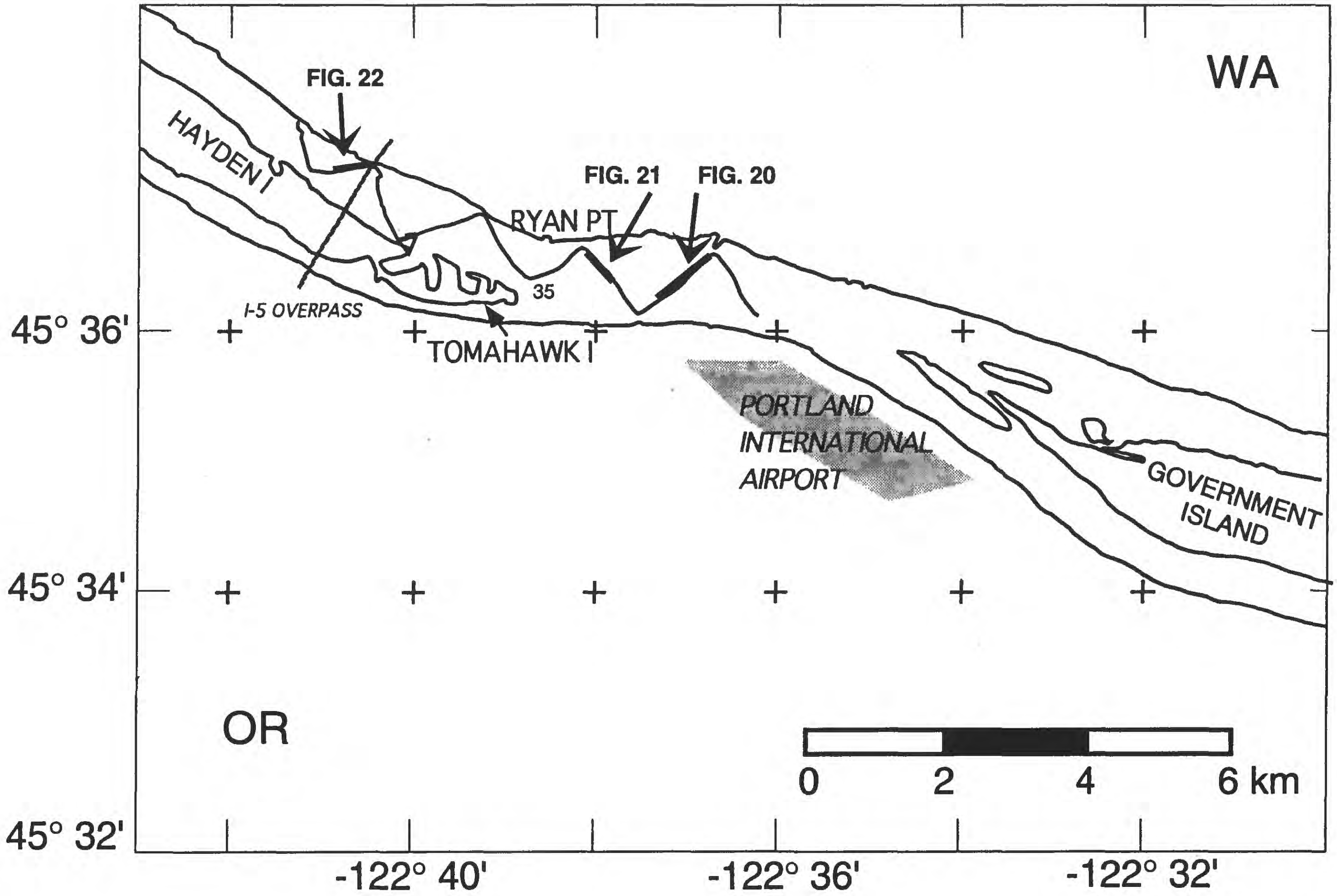

Figure 6. Trackline map of data collected near Ryan Point, WA (line 35). Location of Figs. 20-22 are shown.

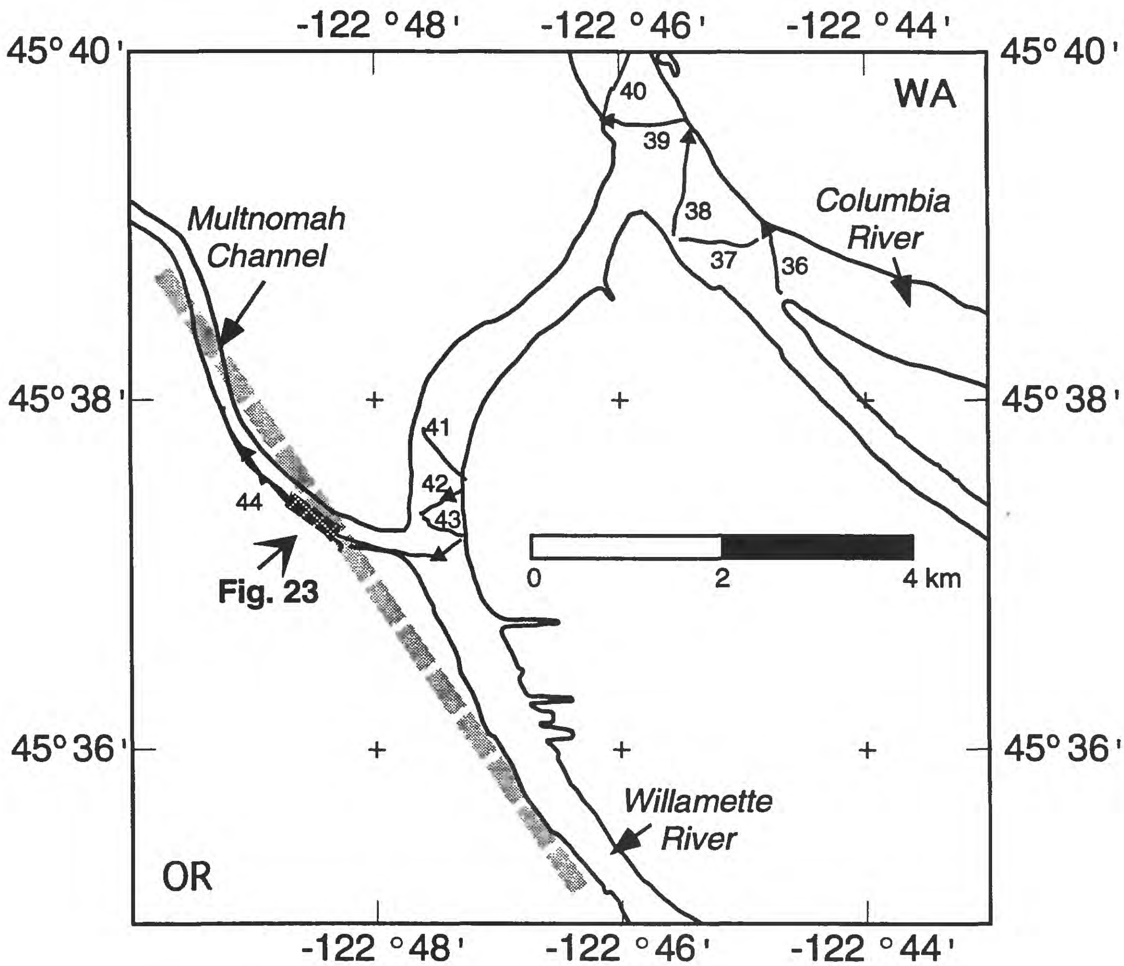

Figure 7. Trackline map of data collected near the confluence of the Columbia and Willamette Rivers (lines 36-40), and near the southern end of Multnomah Channel (lines 41-44). The gray-dashed line shows the approximate trace of a strand of the Portland Hills fault zone. The location of Fig. 23, which obliquely crosses the fault zone, is shown.

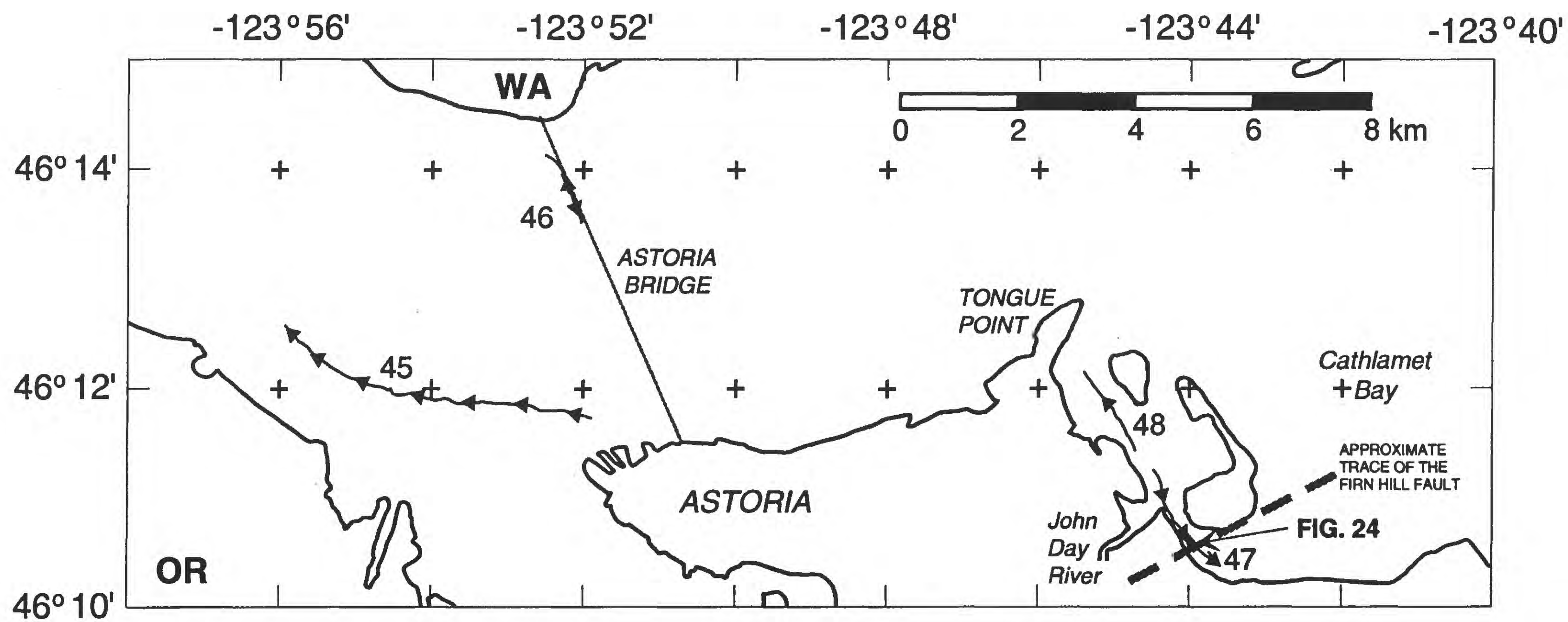

Figure 8. Trackline map of data collected near Astoria, OR (lines 45-48). The dashed line shows the approximate trace of the Firn Hill Fault. The location of Fig. 24, is shown.

reasonable quality were obtained across the fault zone, and the informally named Mill Creek fault (Fig. 8, line 48), which showed few subsurface reflectors.

CRUISE LOG

0630 PDT	*leave Washougal on Cathlamet Bay for transit to Astoria* *Jim Vaughan drives support vehicle to meet boat at ACE dock*
1045 PDT	*arrive at ACE dock, take care of boat logistics*
1140 PDT	*Al Niem joins operations; leave ACE dock to fuel in Astoria*
1927 Z	*BOL 45 (lower Columbia River, main ship channel)* *MUDSEIS not running*
1937 Z	*MUDSEIS up and running*
2011 Z	*streamer pulled in a few feet -- no improvement in data*
2012 Z	*streamer let back out*
2020 Z	*data drops owing to interference sled and hydrophone*
2035 Z	*EOL 45/ pull in gear to transit to north side of Astoria Bridge*
2102 Z	*BOL 46 (lower Columbia River, Astoria Bridge)* *Optical Disk # 1 complete*
2108 Z	*MUDSEIS back up after disk change*
2122 Z	*EOL 46/ water too rough to collect good data* *transit back toward ACE dock*
2225 Z	*BOL 47 (John Day Channel)*
2253 Z	*EOL 47/ pull in gear to transit back down channel*
2300 Z	*BOL 48 (channel near ACE dock)*
2307 Z	*redeployed streamer as tangled with sled*
2317 Z	*EOL 48* *END OF CRUISE OPERATIONS*

DATA PROCESSING

The digitally-recorded geopulse data were translated into a standard SEGY format for processing using the DISCO software package. The following processing was done to a selected portion of the data that showed subsurface reflectors, including all of the data shown in this report: resample data to .125 ms, static shift of 62.5 ms, water-bottom mute, band-pass filter from 500-1900 Hz, AGC (automatic gain control) over 60 ms window, and weighted trace averaging (over 3 traces). An unsuccessful attempt was made to develop a good deconvolution filter to enhance the sharpness of the signal. Reflection profiles that showed prominent diffractions were migrated at a velocity of 1500 m/s using a FK migration algorithm. Data were replotted at a low vertical exaggeration (V. E.), generally less than 5 to 1, to aid in interpretation. The processed records show a significant improvement in data resolution over the analog records collected aboard the boat.

PRELIMINARY SCIENTIFIC RESULTS

The quality of the geopulse data was highly variable and dependent upon the location of data acquisition within the main and side river channels. In areas near the main shipping channel, particularly where regularly dredged, few if any subsurface reflectors were present in the data (e.g. Fig. 9). Where the river bottom was dominated by large-scale sand waves, subsurface penetration was also minimal. The highest quality data were collected away from the main ship channel, especially in lower-flow areas.

Even in areas where subsurface penetration was sufficient, the difficulty in interpreting subsurface reflectors in a fluvial environment should be emphasized. Complex depositional patterns and the constant reworking of sediments can result in a stratigraphy that may obscure evidence for faulting. In addition, abundant Pleistocene flood deposits in the Columbia River valley attest to catastrophic flooding, which resulted in a complex paleotopography. The Columbia River Basalt (CRB), which forms basement to much of the area, has an irregular topography. Differentiating between changes in elevation of a basement surface related to faulting versus related to erosional processes can be difficult.

Clatskanie Fault

Reflection profiles were collected in the bend of the Columbia River between Skamokawa, WA and Clatskanie, OR to find evidence for recent faulting along the Clatskanie fault zone (Fig. 2). Lines 1-4 and 7-11 were all collected across the main ship channel and do not show evidence for disruption or truncation of reflectors, which might be indicative of faulting. However, this lack of evidence for faulting may be related to poor subsurface penetration within the ship channel and does not preclude the possibility that a fault is present. Only line 12, collected near the north end of Hunting Island where we were able to traverse the entire width of the river, shows subsurface reflectors. A strong reflector appears truncated and perhaps folded near the projection of the fault (Fig. 10, at about ping 800). However, no river-bed disruption is associated with this event, which may be the result of river re-working or may indicate that this feature is not related to active faulting.

Additional data were collected away from the main shipping channel on the south side of Wallace Island and in Cathlamet Channel on the northeast side of Puget Island (the main shipping channel runs south of Puget Island) (Fig. 2). Although the Clatskanie fault zone is projected to cross Wallace Island, we observed no evidence for faulting in the reflection profiles. However, the river is very shallow here and we primarily observed sand waves that may obscure any subsurface features. In addition, recent known floods from tributary creeks probably caused substantial reworking of sediment south of Wallace Island. Near Puget Island, dipping reflectors are observed, although whether these events are related to faulting is equivocal. A strong, dipping event is observed at the end of line 14 and onto the start of line 15, which nears the river bed near ping 350 (Fig. 11) along the northeast bank of the river. This event may be a reflection off the top of the CRB. Dipping reflectors are also observed on lines 16, 17, and 18 (e.g. Fig. 12), although these events are most likely attributed to depositional processes. The river shallows abruptly in the middle of Cathlamet Channel, which resulted in the early termination of line 17. These data allow for the suggestion that the Clatskanie fault zone may trend near the northeast bank of the river, however, the data are inconclusive. Deeper penetration reflection data are needed to verify faulting in this area.

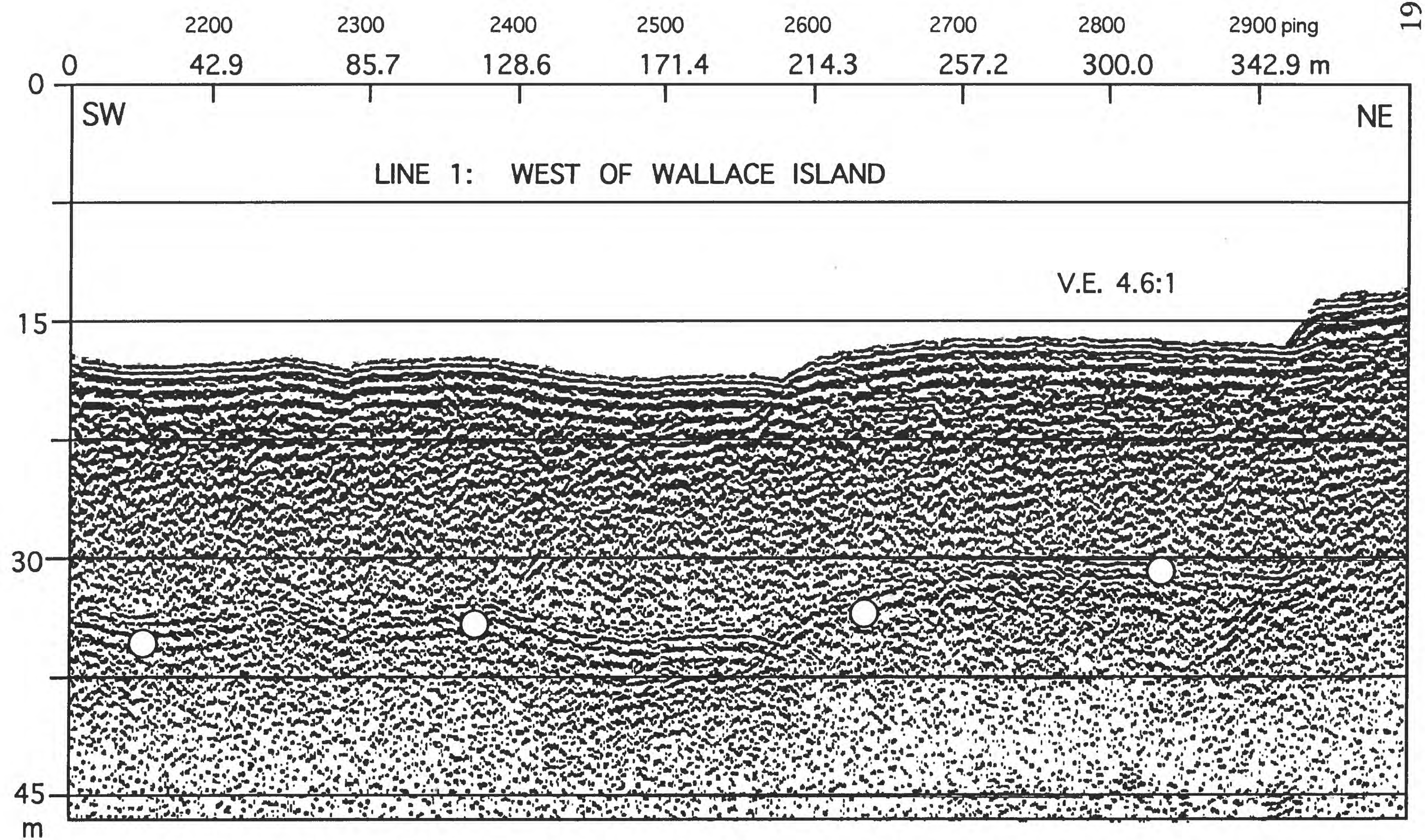

Figure 9. Reflection data collected near the main shipping channel west of Wallace Island. This profile is an example of the lack of subsurface penetration in areas of the Columbia River that are dredged. The location of the section is shown in Fig. 2. Dots denote water-bottom multiple.

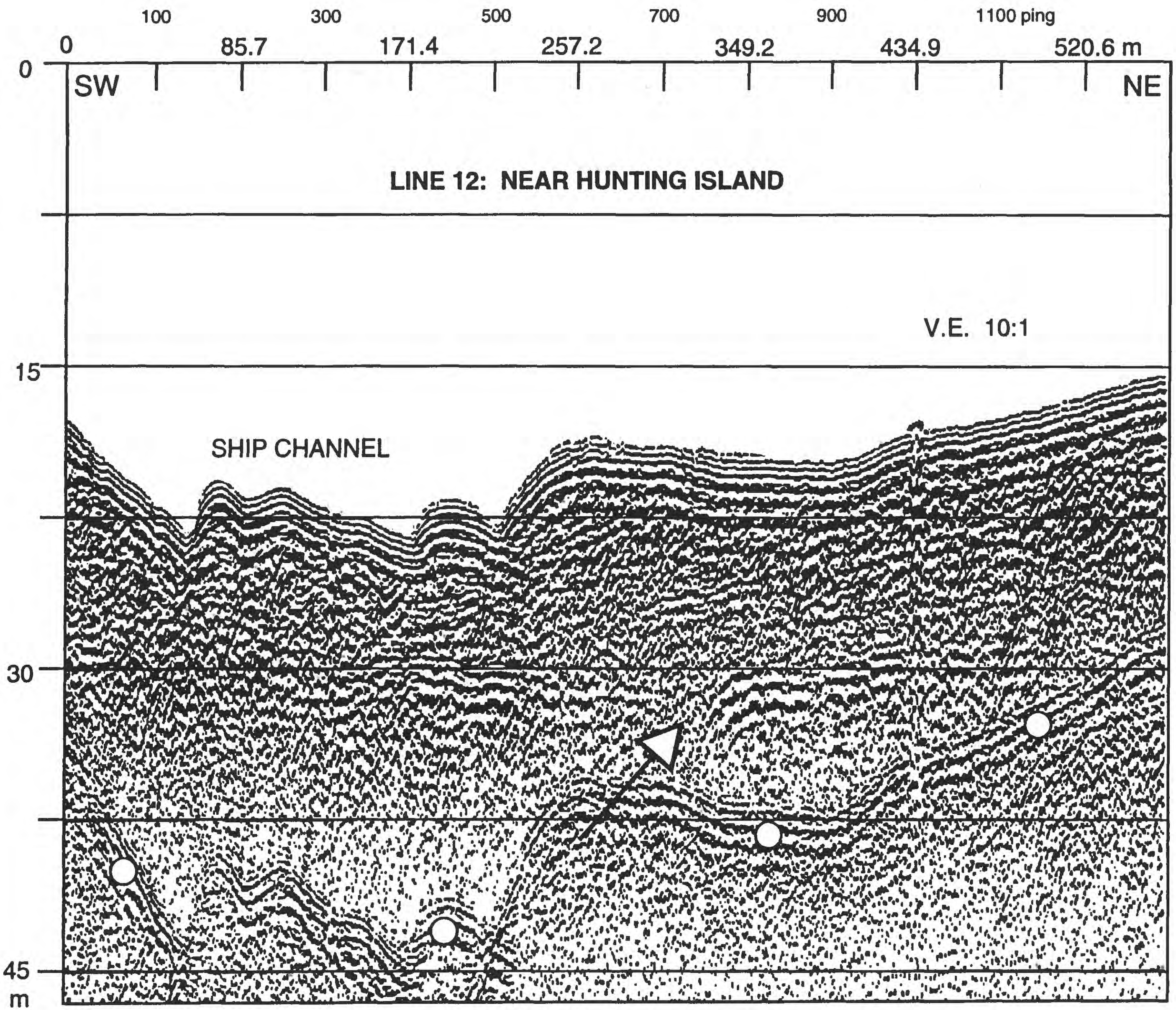

Figure 10. Reflection profile collected near the projection of the Clatskanie fault zone within a bend of the Columbia River. The arrow points to a disrupted and truncated reflector. Note the large sand waves within the ship channel. Location of profile shown in Fig. 2. Dots denote water-bottom multiple

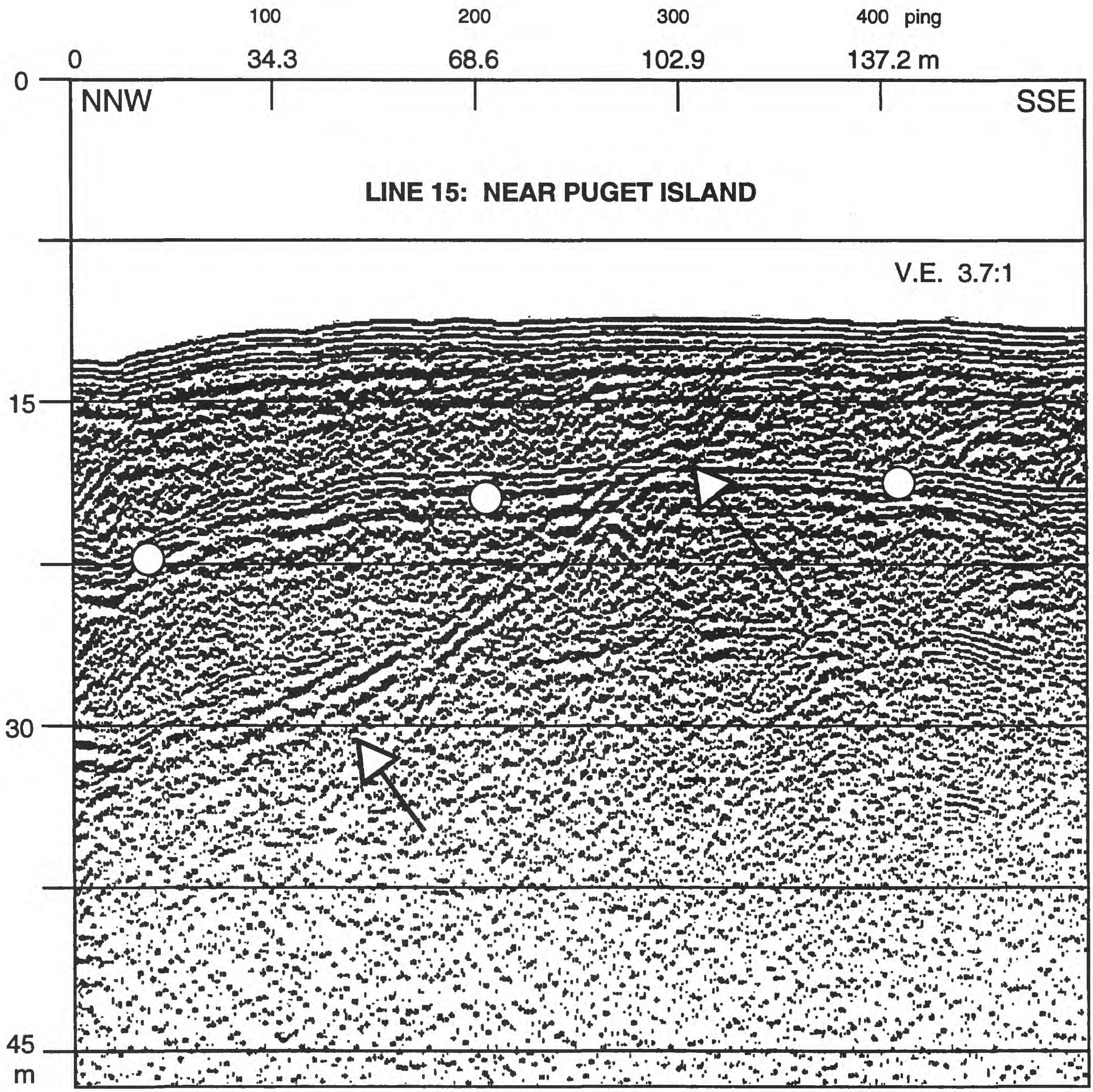

Figure 11. Reflection data collected near the northeast bank of the Columbia River showing a strong reflector dipping into the river bank (arrows point to the event). This event nears the river bed near ping 350, however no disruption of the river bed is evident. Location of the profile is shown in Fig. 2. Dots denote top of water-bottom multiple.

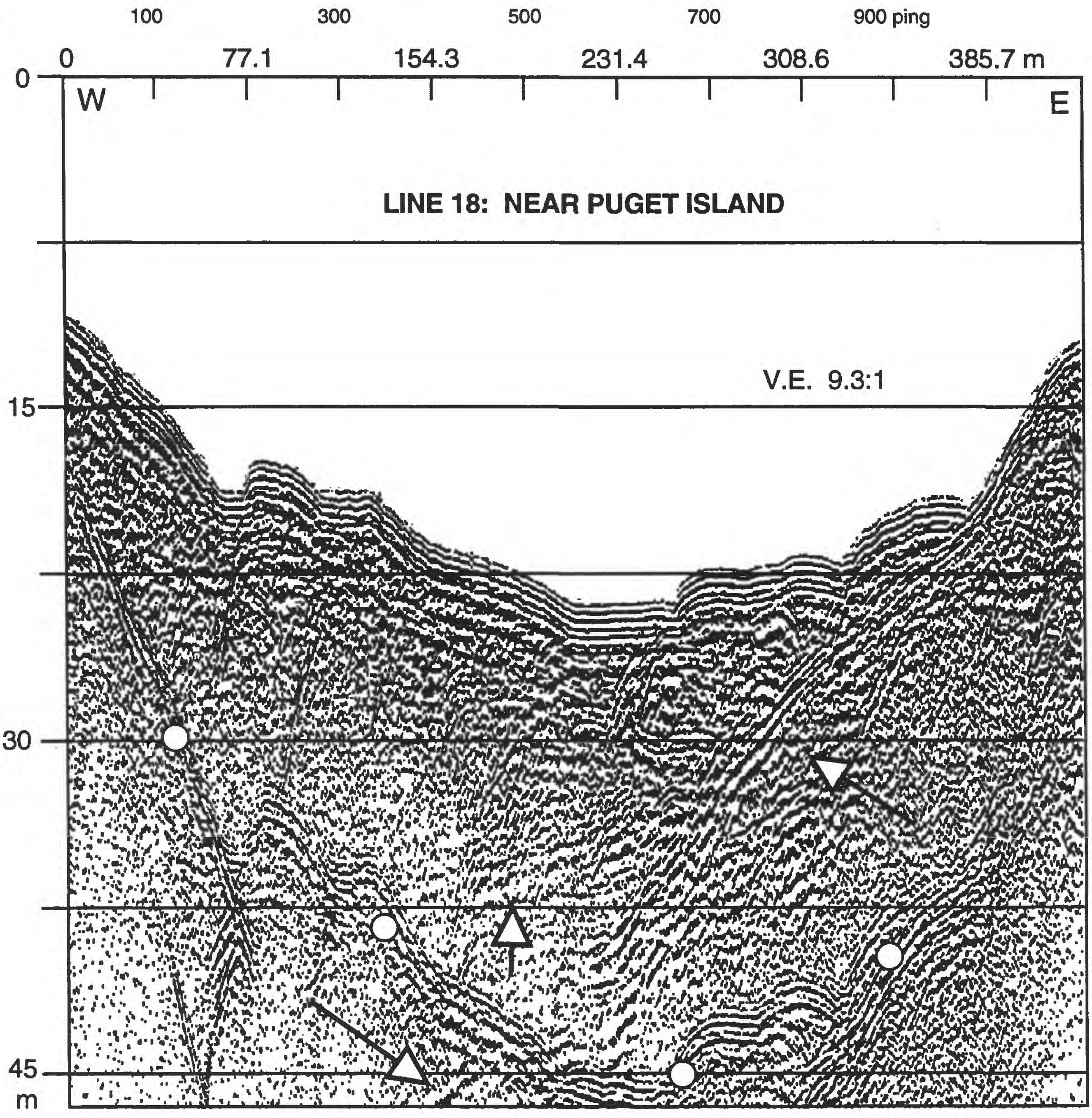

Figure 12. Reflection data collected between the northeast bank of the Columbia River and a mid-river shoal off of Puget Island. The arrows point to reflectors dipping at variable angles beneath the channel. These reflectors are most likely related to complex depositional patterns. Location of the profile is shown in Fig. 2. Dots denote top of water-bottom multiple.

North-trending segment of the Columbia River

The north-trending segment of the Columbia River between Portland, OR and Longview, WA has been interpreted to be fault controlled, although direct evidence for active faulting is lacking. Reflection data were collected to try to image a southward projection of a fault mapped north of the confluence of the Cowlitz and Columbia River (Fig. 3). No indication of faulting is evident at the confluence or within Carrolls Channel. However, massive inundation of Mt. St. Helens-derived ash down the Cowlitz River could have obscured any evidence for faulting. Data collected at the end of line 20 and on line 21 suggest that a fault may exist south of Cottonwood Island. Line 21 shows both a steep scarp at ping 700 and the truncation of a strong, east-dipping reflector (Fig. 13). It is unclear how this structure may relate to the fault mapped at the I-5 offramp.

Both the Clatskanie Fault and the Frontal Fault Zone (FFZ) are projected to cross the north-trending segment of the Columbia River near the confluence of the Lewis River (Fig. 4). Data were acquired within the Columbia River north of St. Helens (Fig. 4, line 24) and in the northern part of Multnomah Channel (Fig. 4, line 22) to assess the possibility that these faults are somehow connected. Despite the presence of large sand waves, high amplitude dipping and truncated reflectors are observed in the subsurface north of St. Helens, OR (e.g. Fig. 14). However, direct evidence for faulting, such as disruption of the river bed, is lacking. In addition, scarps that may be related to offset in basement are observed along the projection of the FFZ (Fig. 15 near ping 2000). However, there were few subsurface reflectors in the data, and the basement offset may be related to paleotopography. Lack of time precluded collection of data along the projection of these faults across the Columbia River itself.

Additional data were collected in Multnomah Channel east of Scappoose, OR (Fig. 4, line 23) where sharp bends in the channel could be related to faulting. Evidence for faulting here is unconvincing. However, a poorly defined reflection event near a bend in the channel that *may* be structurally related.

Frontal Fault Zone

Geopulse data were collected in the Columbia River east of Washougal, WA to find evidence that the Frontal fault zone (FFZ) controls a prominent bend in the Columbia River. A strong reflection event can be observed throughout the bend in the Columbia River, and is especially prominent northeast of Gary and Flag Islands (Fig. 5; lines 29-32). This event is observed to gradually deepen from about .02 sec TWTT near the northwest of the river bend to about .04 sec TWTT near Flag Island (Fig. 16). This corresponds to a change in depth of about 15 m over a distance of about 2 km (an apparent dip of less than 0.5°). This strong reflector is observed to be disrupted near Gary and Flag Islands (Fig. 17), along strike with observed breaks in the topography on land. However, it is uncertain whether this disruption is the result of faulting, or is related to difficulties in imaging reflectors in close proximity to the river bank.

The location of where the FFZ crosses the Washington bank of the Columbia River is more equivocal. Most of line 26 was collected near the edge of the main ship channel (Fig. 5), which makes interpretations difficult. An area of diffractions is imaged near the bend in the Columbia River at Ough Reef (Fig. 18). Based on analyses of migration velocities, the reef is composed of higher velocity outcrop and may expose Columbia River Basalt , which may outcrop along the fault zone. However, the fault zone may project further to the west and perhaps be associated with gently dipping reflectors observed at the beginning of line 25.

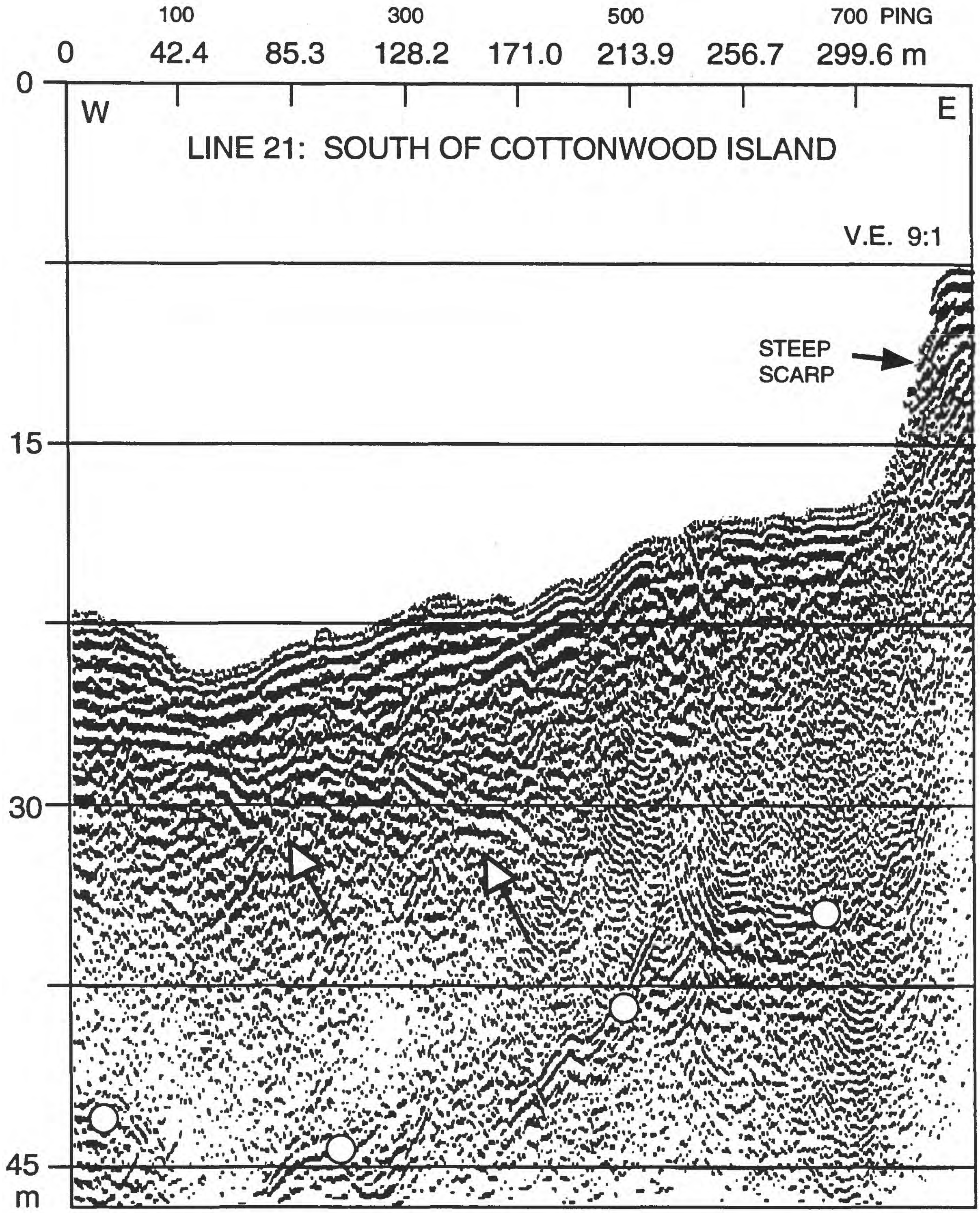

Figure 13. Reflection profile collected across the Columbia River near the now defunct Trojan Nuclear Power Plant. A strong, irregular reflector (shown by arrows) is dipping into and may be truncated at a steep scarp. These data are migrated at 1500 m/s. The location of the profile is shown in Fig. 3. Dots denote top of water-bottom multiple.

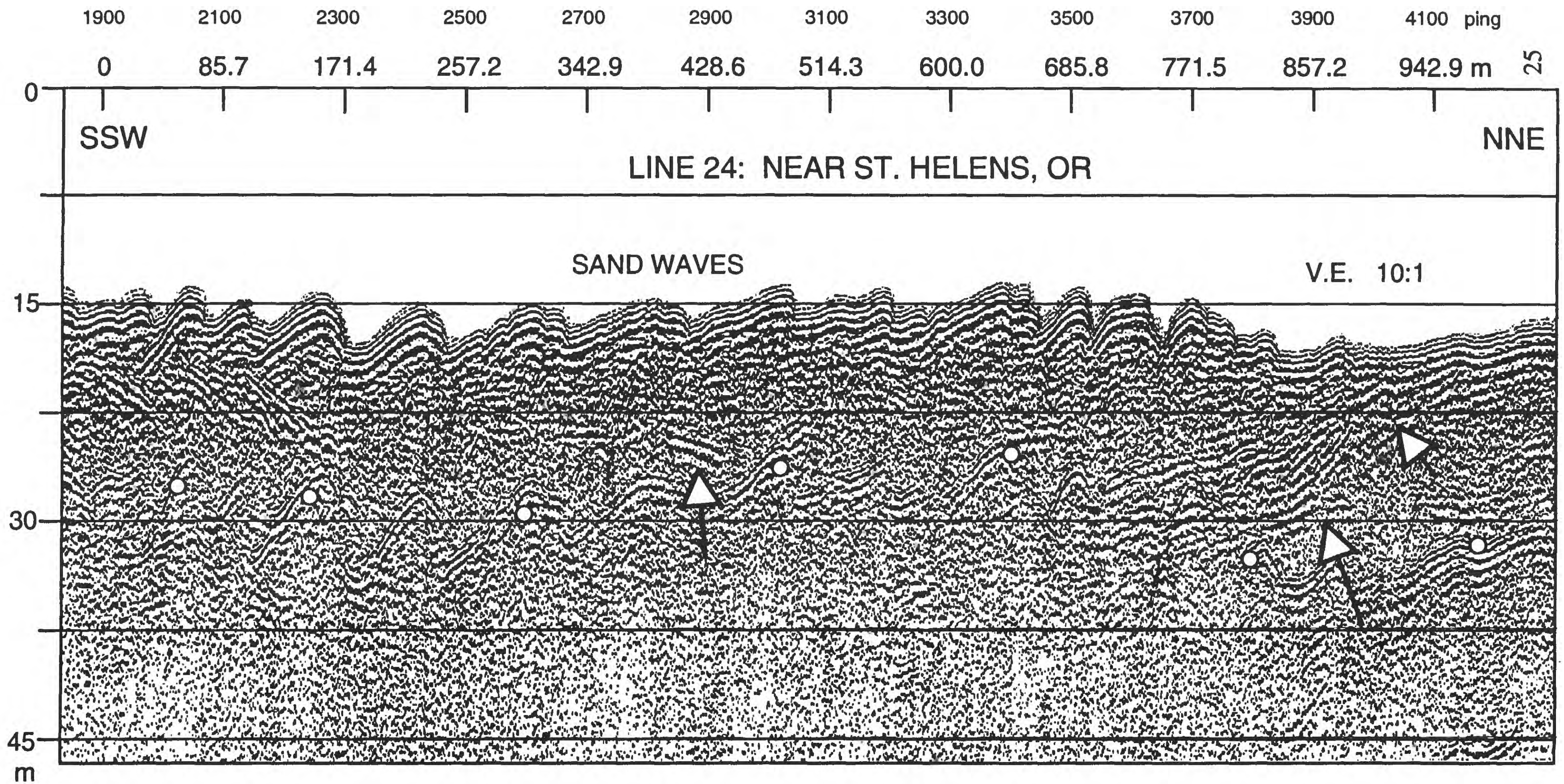

Figure 14. Reflection profile collected north of St. Helens, OR in the vicinity of the southeastward projection of the Clatskanie fault zone. Despite the presence of large sand waves along the river bed, strong reflectors (shown by arrows) are observed above the water-bottom multiple (denoted by dots). These events are somewhat discontinuous with low apparent dips. Location of profile shown in fig. 4.

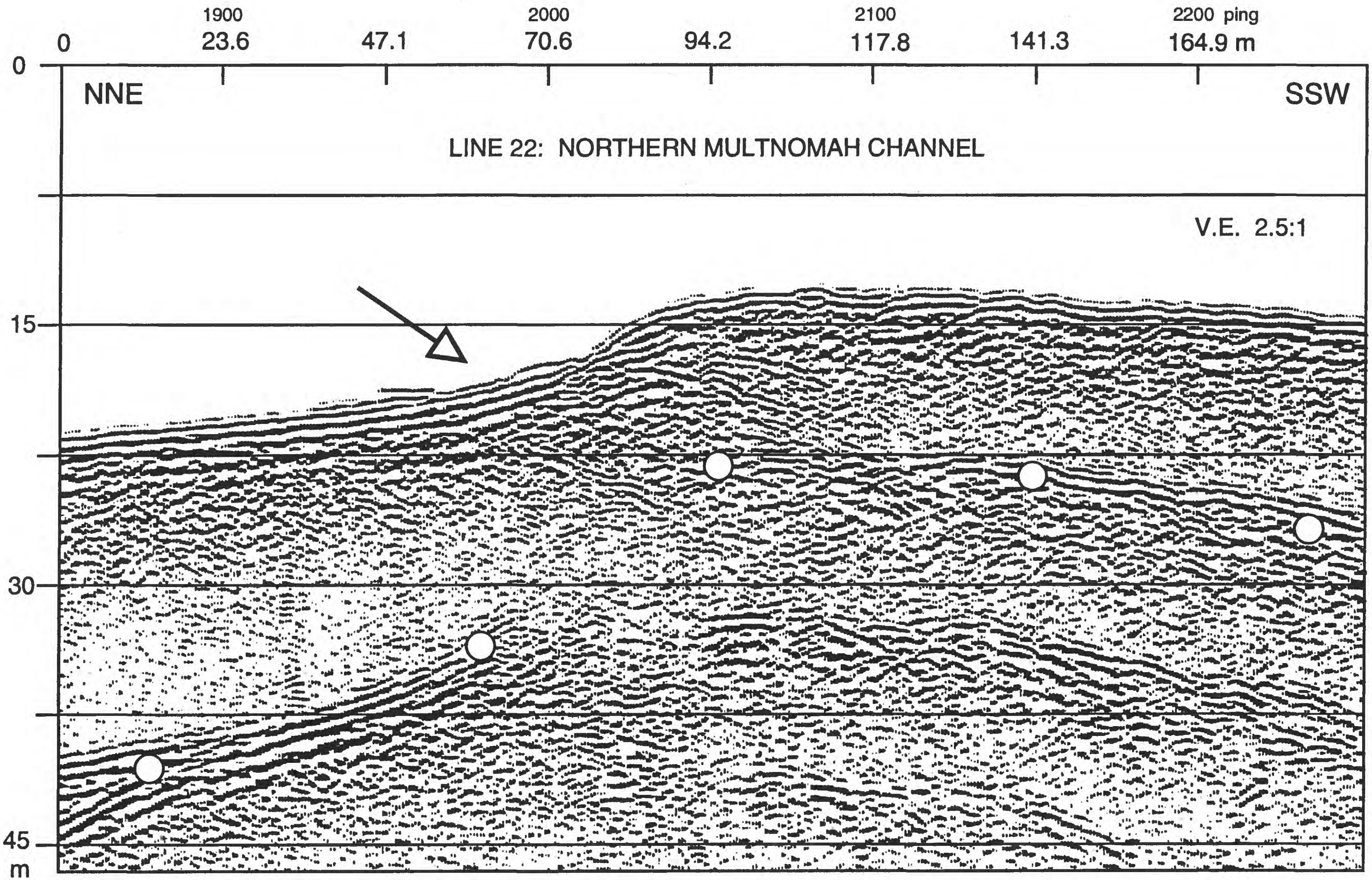

Figure 15. Reflection profile collected in the vicinity of the northwestward projection of the Frontal fault zone. Basement is offset (at arrow) and reflectors dip back away from the scarp to the south. Location of profile is shown in Fig. 4. Water-bottom multiple denoted by dots.

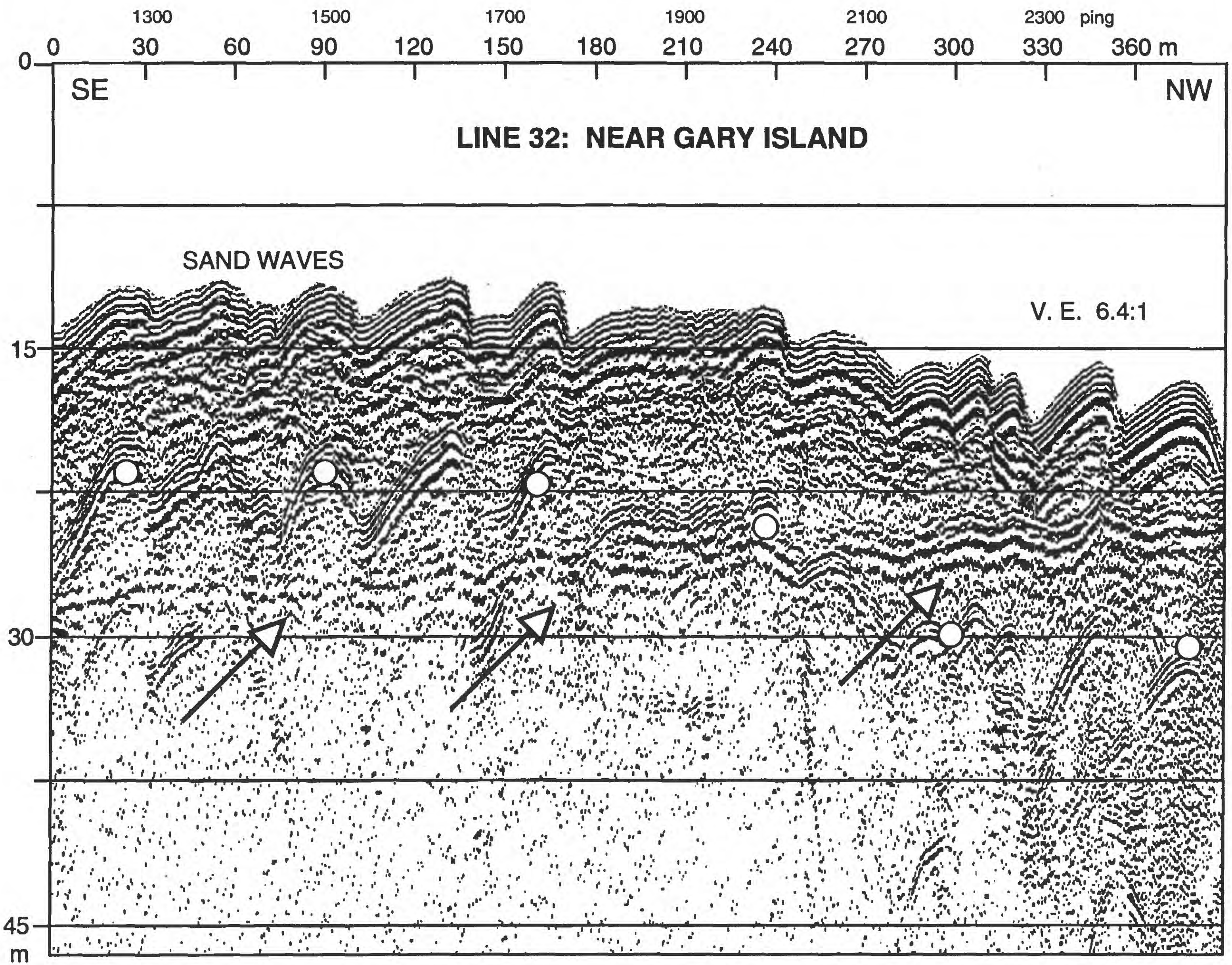

Figure 16. Reflection profile collected in the area of the bend in the Columbia River that shows a strong reflector (delimited by arrows), which cuts the water-bottom multiple (shown by dots). This reflector dips gently to the south and is disrupted at Gary Island (see Fig. 17). The location of the profile is shown in Fig. 5.

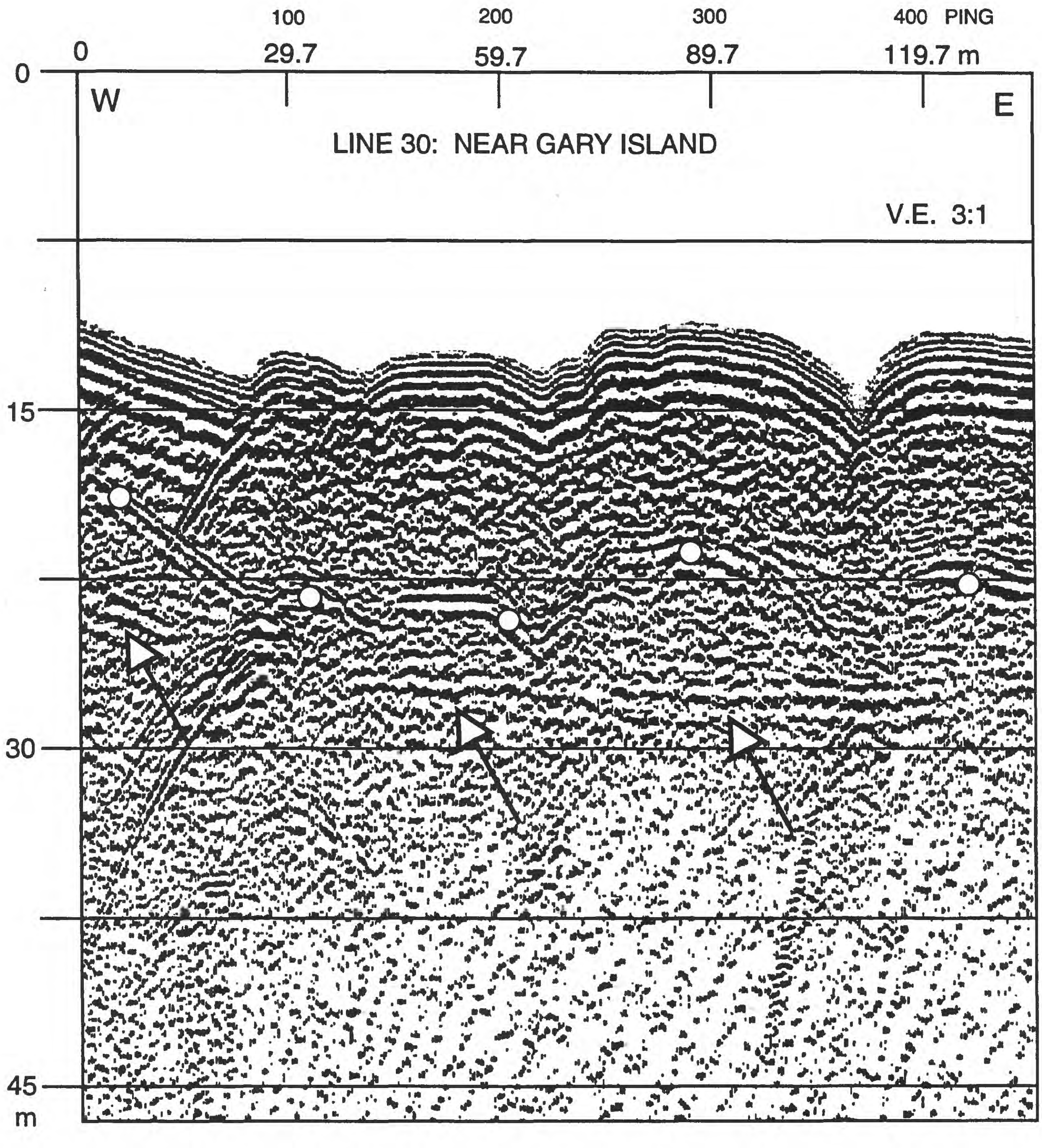

Figure 17. Reflection profile collected at Gary Island that shows the disruption of strong reflector near ping 75 that may be coincident with the Frontal Fault Zone (arrow points at reflector, which is also shown in Fig. 16). This feature is along strike with breaks in topography on land. Location of the profile is shown in Fig. 5. Dots denote water-bottom multiple.

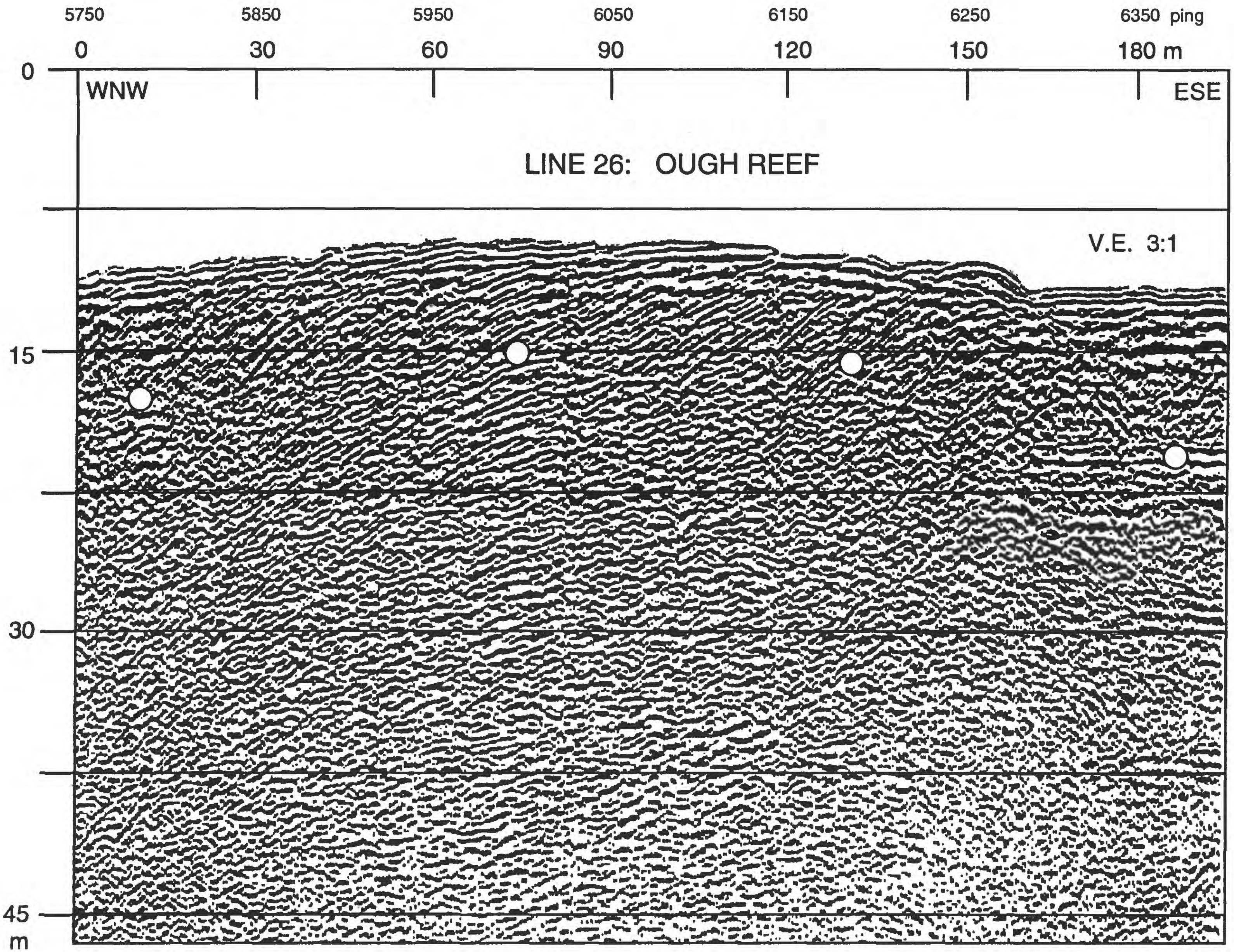

Figure 18. Reflection profile collected the near northern bend in the Columbia River associated with the Frontal Fault Zone. The diffractions, which migrate at higher than expected velocities (higher than 1500 m/s), may be from outcropping Columbia River Basalt that lies along the trend of the fault. The location of the profile is shown in Fig. 5. Water-bottom multiple denoted by dots.

Lady Island/ Ryan Point

Reflection data were collected near Lady Island to attempt to image a structure that would tie Columbia River Basalt mapped on Lady Island to Columbia River Basalt found at depth in wells south of the Columbia River (Fig. 5, line 34). Near the eastern end of Lady Island, strong south-dipping reflectors are observed immediately offshore of the island in the vicinity where Columbia River Basalt are exposed on the shoreline of the island (Fig. 19). These reflectors may be from the top of the basalt.

Data were collected back and forth across the Columbia River in the vicinity of Ryan Point, WA (Fig. 6), where previously collected MCS data indicated that a fault may be present (Ian Maddin, pers. com. 1994). During the first river crossing, a smooth, coherent, high amplitude reflector that cuts the water-bottom multiple is observed. This reflector dips gently to the south (apparent dip of about 1°) to a maximum depth of about .035 s two-way travel time (TWTT) (or about 26 m). This reflector is also observed on the next river crossing, however, the reflector steepens in dip about 2/3 of the way across the river (Fig. 20). The reflector may be truncated based on the presence of diffractors at its southernmost image near a depth of .042 s TWTT (Fig. 20; near ping 4000). Further west near Ryan Point, the river has cut deeper into the section and the reflector outcrops at ping 6350; the reflector is observed over a distance of about 110 m with an apparent dip of about 6°. There is no clear indication of this strong event during the next two river crossings, although reflectors are observed at depths less than .03 s TWTT.

Further down river near the I-5 overpass on the Washington side of the river, a strong, high amplitude event that dips to the south is observed (Fig. 22). This event cuts the river bottom at pings 14200 and 14400, with a maximum apparent dip of 9.° The event is clearly observable over distances of about 200 m, but may be present at the maximum depth of the profile (.0625 s TWTT or 47 m) near ping 15150 (Fig. 22). This event was also observed at the final crossing of the Columbia River near the railroad trestle down river from the I-5 overpass, also on the Washington side of the river. The reflector changes dip along strike, and appears to be slightly folded. The maximum apparent dip is about 6° and the reflector is observed over a distance of 250 m.

The strong reflector imaged near Ryan Point is proposed to be structurally-controlled versus erosionally formed because the dipping surface is smooth, which would probably not be the case if it were eroded. In addition, because the reflector imaged with the high-resolution geopulse system is coincident with deeper dipping events imaged with a multichannel seismic-reflection system, a case can be made for a structural origin. However, no fault was imaged and additional data need to be collected to assess whether this proposed structure poses a seismic hazard for the area.

Portland Hills Fault Zone

Geopulse data collected in Multnomah Channel near its confluence with the Willamette River crosses a strand of the Portland Hills fault zone (PHFZ) at a highly oblique angle (Fig. 7). A zone of both disrupted, and dipping and truncated reflectors is observed between pings 3150 and 3625 over a distance of about 0.2 km (Fig. 23). We interpret this zone as the location of the PHFZ, although the obliquity of the fault crossing makes interpretation of individual structures difficult. The disruption of the river bed indicates that this fault has been recently active. Unfortunately, equipment failures precluded the collection of any additional data across this fault zone.

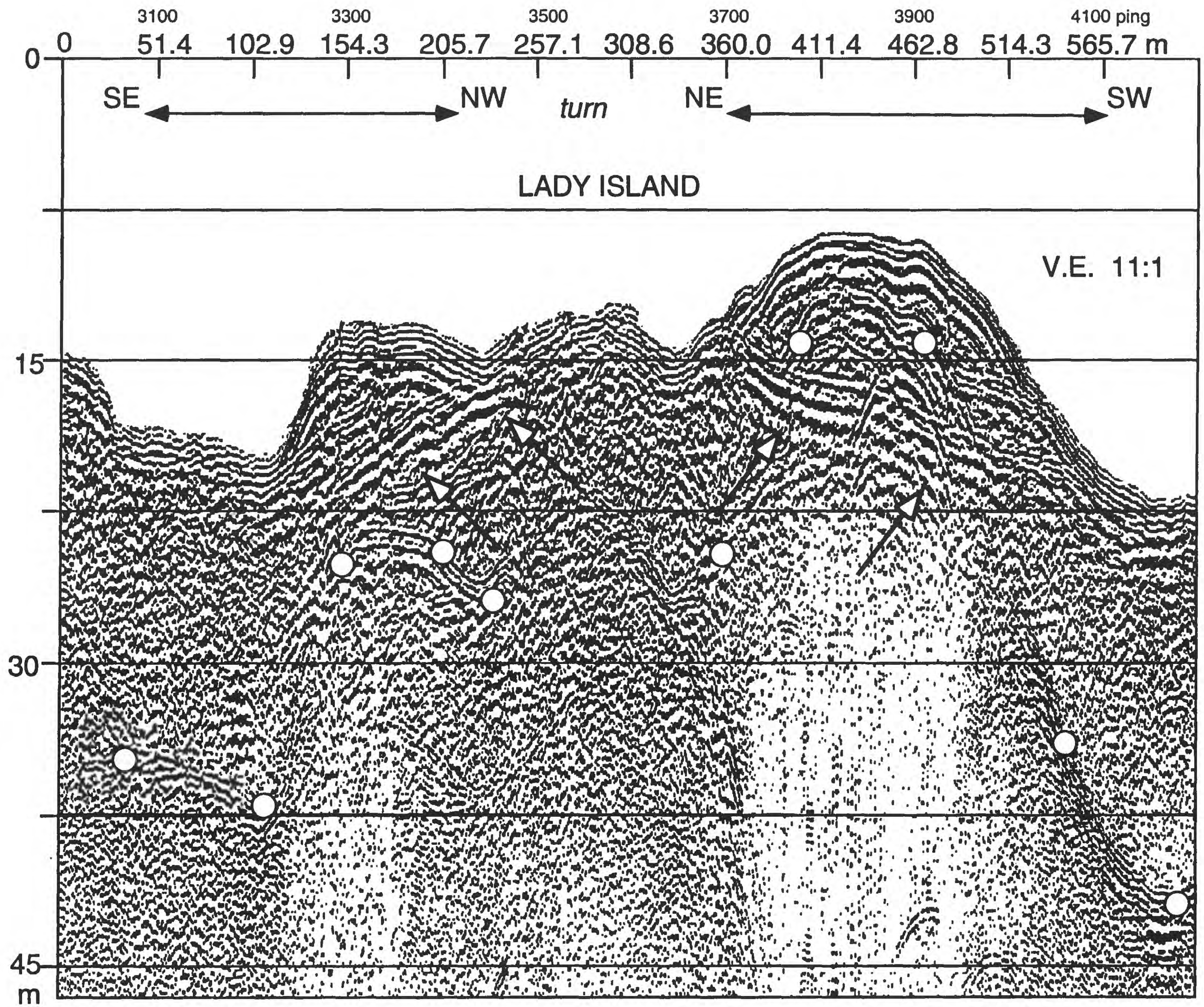

Figure 19. Reflection profile collected at turn near the shore of Lady Island. A strong reflector, dipping to the south is observed both approaching and going away from the island. This reflector may be from the top of Columbia River Basalt. The location of the profile is shown in Fig. 5. Water-bottom multiple denoted by dots.

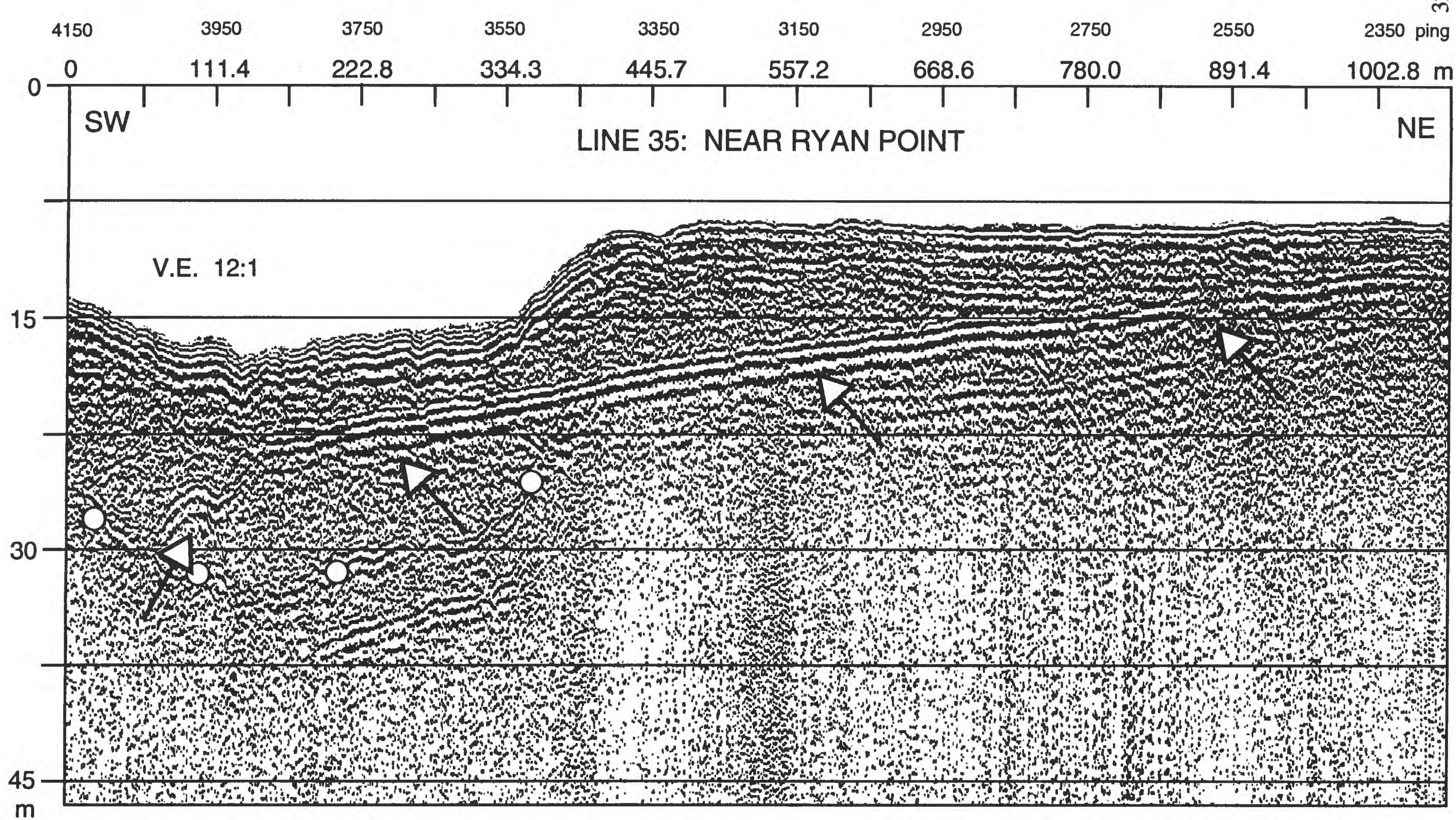

Figure 20. Reflection profile showing strong reflector observed beneath the Columbia River near Ryan Point, WA. This reflector dips gently to the south, but appears to be disturbed near ping 4000. Location of the profile is shown in Fig. 6. Dots denote water-bottom multiple.

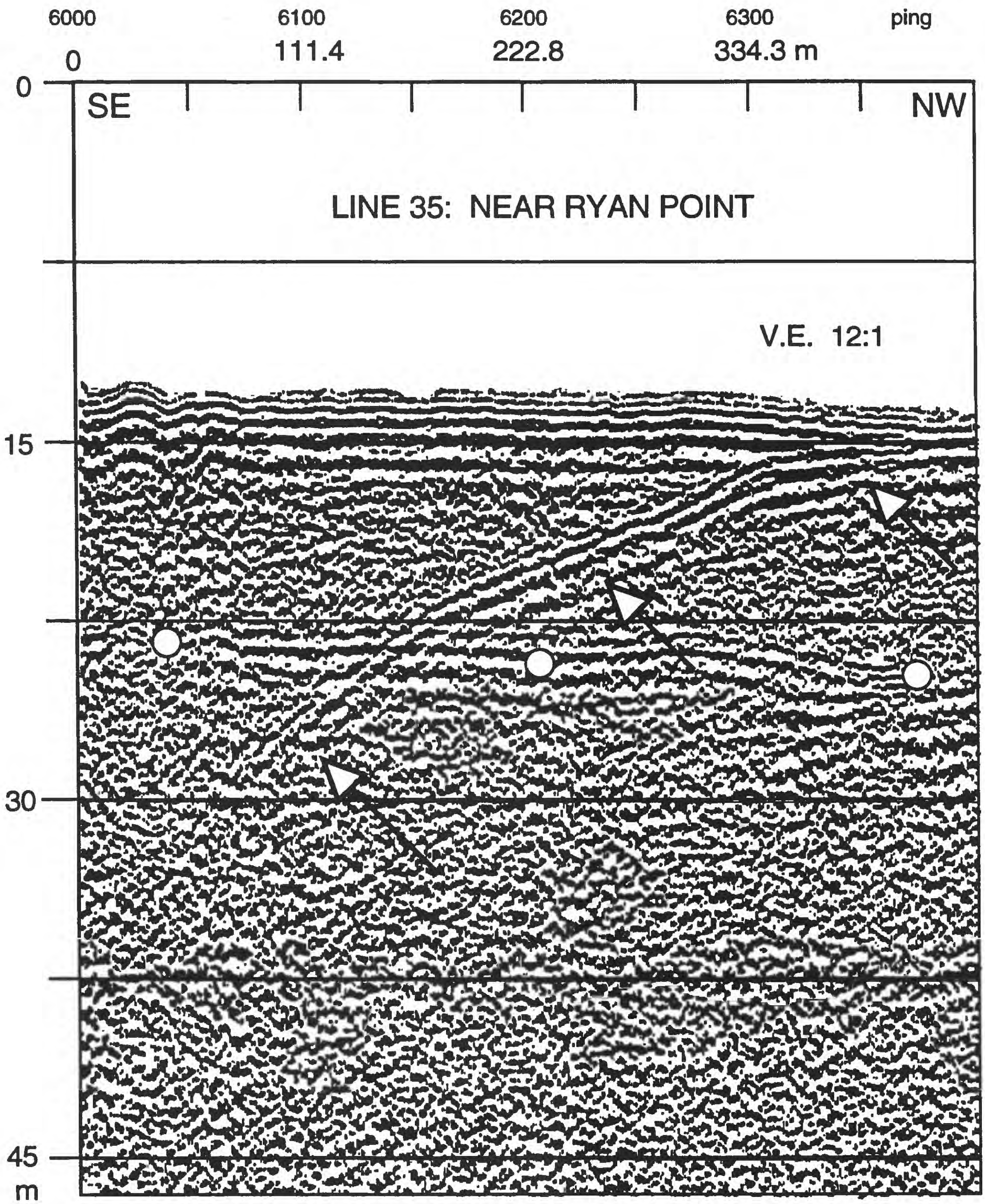

Figure 21. Reflection profile collected on the next river crossing adjacent to Fig. 20. Here, the strong reflector (shown by arrows) dips more steeply to the south, although it cannot be traced much beneath the water-bottom multiple (shown by dots). Location of profile is shown in Fig. 6.

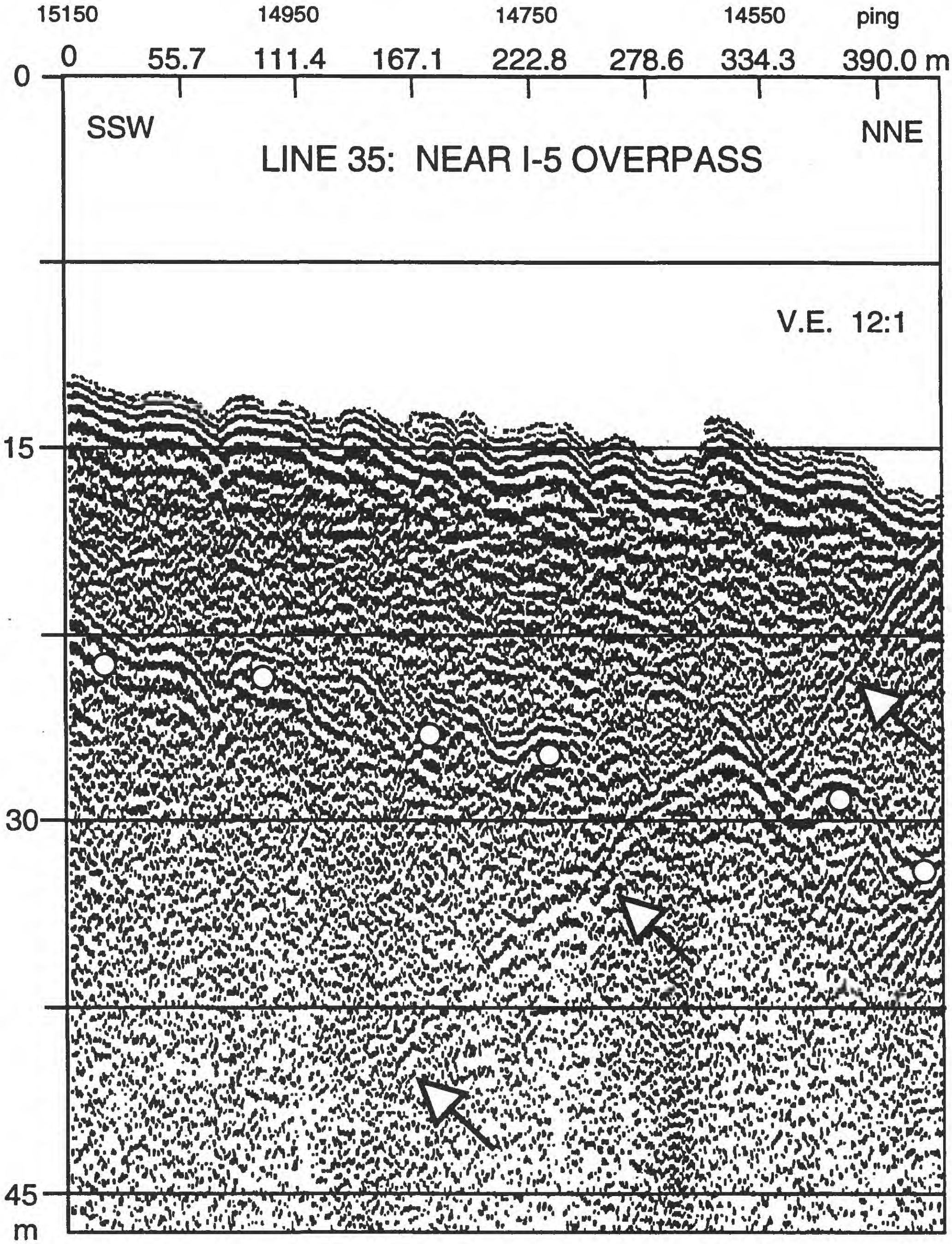

Figure 22. Reflection profile collected near the I-5 overpass across the Columbia River. This profile shows a strong reflector dipping to the south (shown by arrows). The reflector is obscured by the water-bottom multiple (denoted by dots) near ping 14600. Location of the profile is shown in Fig. 6.

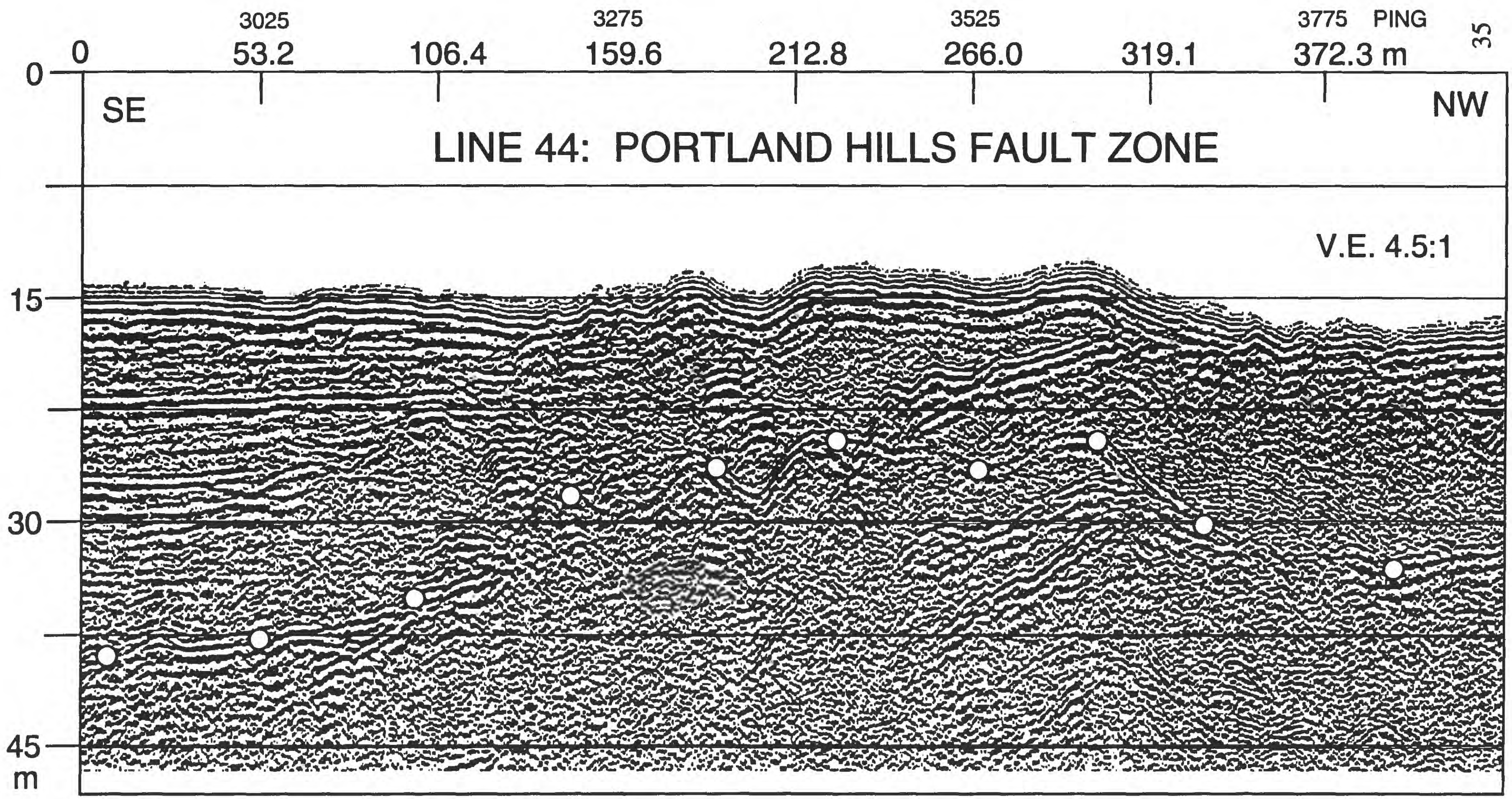

Figure 23. Reflection profile collected obliquely across a strand of the Portland Hills Fault Zone near the confluence of the Multnomah Channel and Willamette River. A zone of both disrupted, and dipping and truncated reflectors is observed (pings 3150-3625). However, the obliquity of the fault crossing makes the interpretation of individual fault structures difficult. The disruption of the river bed suggests that this fault has been recently active. The location of the profile is shown in Fig. 7. Dots denote top of water-bottom multiple.

Firn Hill Fault

The Firn Hill Fault (Fig. 8) is mapped on land as a left-lateral oblique slip fault zone of Miocene age (Snavely and Niem, in prep). This fault is well imaged on our reflection profiles as evidenced by the presence of truncated and dipping beds (Fig. 24; pings 4840-5250). Additional offset is observed to the west (near ping 4500 on Fig. 24), which suggests that this is a broad fault zone. The offset of the river bed indicates that the fault has been active relatively recently (although there are no age constraints). Prior to this study, it was not known that this fault was still active.

CONCLUSIONS AND RECOMMENDATIONS

Despite problems with the dynamic range of the data and the lack of subsurface penetration of the Geopulse system, it is encouraging that we were able to obtain data of reasonable quality in the Columbia River and associated channels to help assess the seismic hazards of northern Oregon and southern Washington. Reflection profiles collected from the Portland Hills fault zone (Fig. 23) and the Firn Hill Fault (Fig. 24) show the best evidence for faulting of recent river deposits. Other indicators of the structural disruption of recent deposits are less clear.

Relatively recent faulting is suggested, but not confirmed, by the presence of dipping and/or truncated reflectors in a number of areas. These areas include the Frontal fault zone, which is postulated to form the northeast margin of Portland basin (Figs. 16-17); the Clatskanie fault, a major northwest trending upper crustal fault that crosses the lower Columbia River (Figs. 10-12); an unnamed fault inferred to coincide with a major bend in the Columbia River opposite the Trojan nuclear power plant (Fig. 13); and an area where dipping reflectors are imaged near Ryan Point, WA (Figs. 20-22) . In addition, limited data support the suggestion that the Frontal fault zone and Clatskanie Fault may join together in the area near St. Helens, OR (Figs 14-15), although additional data are needed to confirm this idea.

It is still not possible to accurately assess the maximum magnitude of upper crustal earthquakes let alone determine any sort of recurrence intervals for these faults. The length and geometry of upper crustal faults, especially at depth, are not known. Abundant vegetation and urban development make on land mapping of these faults very difficult. Results from this preliminary survey support the need to continue a program of using deeper penetration marine geophysical combined with sampling techniques in the Columbia River and other water bodies to improve estimates of the earthquake hazards of the Portland, OR, Vancouver, WA, and Astoria, OR urban areas.

As a first order priority, this data set needs to be tied into the on going work that the Oregon Department of Geology and Mineral Industries (DOGAMI) is involved with related to both on-land mapping investigations and the analyses of well and other geophysical data (Madin, 1990). Subsequently, a program should be developed to collect high-resolution seismic-reflection data across additional sites within the Columbia River and its environs to study such faults as the Nicolai Mountain Fault, the Portland Hills Fault south of downtown Portland, and the Hood River Fault among others. Even more importantly, a deeper penetration seismic acquisition system is needed to be able to determine basement offsets in the fault zones that were imaged during this study. Geophysical studies should then be followed by a sampling program to determine the age of dipping or truncated reflectors, in order to be able to determine the recency of upper crustal faulting.

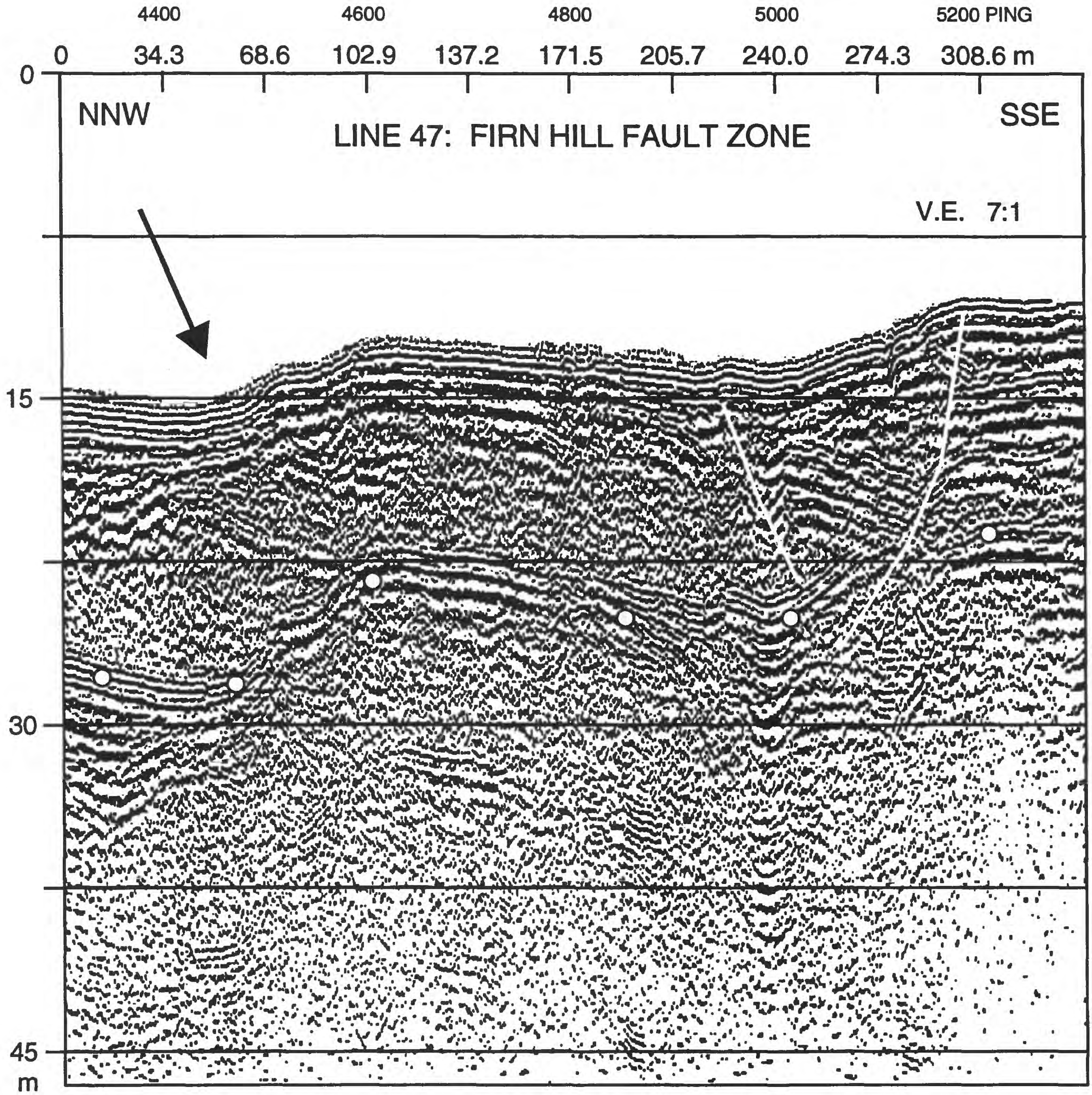

Figure 24. Reflection data collected across the Firn Hill Fault that crosses the lower Columbia River. The fault is mapped on land as a left-lateral oblique slip fault of Miocene age (Snavely and Niem, in prep.) It is delineated on this profile by truncated and dipping reflectors (pings 4850-5250). Additional offset occurs near ping 4400 (beneath the arrow). The offset of the river bed suggests that the fault is active. Location of the profile is shown in Fig. 8. The dots denote the water-bottom multiple.

ACKNOWLEDGMENTS

We would like to thank Terry Vance of the Army Corps of Engineers for expertly navigating us through the shoals and channels of the Columbia River; this project would not have been nearly as successful without his advice, assistance, and willingness to work long hours in record-breaking heat and still manage to keep a smile on his face.

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