Cascadia Region Seismic Experiment

Cruise Report for R/V Sonne cruise SO108

Summary

The main goal of The R/V Sonne cruise SO108 was to investigate the large-scale structure of the Cascadia subduction zone to better assess the earthquake hazard it presents to the Pacific Northwest. The cruise was carried out in April and May of 1996 cooperatively by GEOMAR, Kiel, Germany and the USGS, Marine Program, Menlo Park and Woods Hole. Our *ocean bottom seismometers* (OBS) and the *German hydrophones* (OBH) were deployed at 116 stations and collected wide-angle reflection and refraction seismic data along 12 profiles across and along the continental margin off Washington and Central Oregon and on the adjacent ocean floor of the Juan de Fuca plate. 1532 km of multichannel seismic reflection (MCS) data along 13 lines were collected over the Washington continental margin with two of the lines being coincident with wide-angle seismic profiles. Additionally, the largest earthquake to hit Seattle in the last 15 years was recorded by our OBS and OBH. All the wide-angle seismic data and two of the MCS lines have been processed, plotted, and analyzed on board for quality control and for initial scientific interpretations. The cruise ran smoothly and efficiently with the exception of a major storm and the loss of one OBS in the first week of operations. Data quality is good to excellent.

Both wide-angle reflection and refraction data and the MCS data could detect the subducting oceanic crust under the continental margin to a distance of 20 km from shore. Three major differences between the continental margins of Washington and Oregon were discovered. The Oregon margin is much narrower than the Washington margin but the depth of the bottom of the subducting plate near the coast is similar in both areas (18-20 km), hence the dip of the subducting plate is higher under Oregon than under Washington. The dip of the subducting plate may also decrease from south to north under the Washington margin. The second major difference is the average velocity of the sedimentary and crustal rocks overlying the subducting plate. Offshore Washington, the rock velocity never exceeds 5.3 km/s even at depths as large as 10-12 km. Offshore Oregon, the rock velocity is up to 6.5 km/s and is 5 km/s or larger below 5 km depth. These differences represent differences in crustal composition. In Oregon, the Siletz River basalts are thought to extend offshore. In Washington, crustal rocks are probably broken and fractured Eocene to Middle Miocene melange. The boundary between these crustal domain is probably south of the mouth of the Columbia River where the sediment and upper crustal structure

change dramatically. The third difference is in the thickness of sediments underlying the continental shelves. Offshore Oregon sediment thickness does not exceed 3 km, whereas offshore Washington a deep (up to 8 km) partly fault-controlled elongate basin underlies the shelf.

The MCS sections show that thrust faults within the accretionary wedge extend downward to the level of the igneous oceanic crust, so the entire 3-km thickness of sedimentary rocks on the ocean plate is being accreted. The frontal thrust verges landward and locally returns a high amplitude reflection, which probably reveals focused flow of fluids. Major thrust faults in the outer 40 km of this wedge verge landward, and at their landward limit, they stack fault blocks of accreted sediment against what may be a backstop of older, indurated rock.

INTRODUCTION - USGS OCEAN BOTTOM SEISMOMETERS

Nine US Geological Survey Ocean Bottom Seismometers (OBS) were used aboard the RV Sonne cruise SO108 offshore Oregon and Washington to record wide-angle seismic reflection and refraction information. Each OBS is housed in a 24-inch aluminum sphere *(Figure1)* and contains data-acquisition system designed to record continuous data from a vertical geophone, 2 horizontal geophones, and a pressure compensated hydrophone. The OBS is designed to free-fall to the ocean bottom with an anchor plate attached and to stay at depths of up to 5000 meters for up to 10 days. An acoustic release is incorporated in the instrument to allow release from its anchor upon command from the surface, permitting the buoyant OBS sphere to ascend. Once on the surface, a light strobe and a radio beacon help locate the instrument.

Cruise Report for R/V Sonne cruise SO108 Deployment Information

The experiment included 5 deployments of 7-8 instruments each :

Deployment 1 - Lines 1, 2, 4, 5, 6, 102, 506 - Rosette

#OBS	Latitude	Longitude	Depth	BTime	BShift	ETime	EShift	Drift	TT#
A2	44 30.036	126 28.655	2898	96:04:22:01:27	4.5	-	-	-	-
A4	-	-	-	-	-	-	-	-	-
A1	44 30.004	126 21.582	2889	96:04:22:01:56	6.0	96:04:26:06:48	0.9	-5.1	A1
C3	44 27.513	126 22.012	2901	96:04:22:01:47	2.2	96:04:26:07:55	-3.9	-6.1	C3
A3	44 28.187	126 14.666	2898	96:04:22:02:00	-0.3	96:04:26:09:10	-0.2	0.1	A3
C9	44 34.100	126 14.337	2871	96:04:22:01:32	-1.5	96:04:26:10:18	-5.8	-4.3	C9
C1	44 30.867	126 09.043	2895	96:04:22:01:54	3.1	96:04:26:12:23	1.5	-1.6	C1
C4	44 35.915	126 06.358	2892	96:04:22:01:59	3.9	96:04:26:13:42	2.3	-1.6	C4
A8	44 41.123	126 06.673	2871	96:04:22:01:41	8.7	96:04:26:14:28	20.8	12.1	A8

Deployment 2 - Lines 7, 8, and 9 - Oregon E-W, N-S coastal, N-S seaward

#OBS	Latitude	Longitude	Depth	BTime	BShift	ETime	EShift	Drift	TT#
A4	44 38.276	124 41.798	234	96:04:26:22:46	2.1	96:05:01:12:30	-2.1	-4.2	C4
C1	44 38.343	124 35.990	193	96:04:26:22:50	1.4	96:05:01:12:46	0.8	-0.6	C1
A3	44 38.353	124 30.195	127	96:04:26:23:02	-0.7	96:04:29:07:07	-1.1	-0.4	A3
A8	44 38.439	124 23.957	75	96:04:26:22:39	2.3	96:04:29:08:09	4.8	2.5	A8
A1	44 38.343	124 17.911	79	96:04:26:23:12	0.3	96:04:29:09:15	-2.4	-2.7	A1
C9	44 38.279	124 11.407	59	96:04:26:22:56	3.8	96:04:29:10:34	1.2	-2.6	C9
C4	44 38.302	124 27.129	100	96:04:29:00:21	2.7	96:05:01:19:59	-1.9	-4.7	C3

Deployment 3 - Line 10 - SW Washington

#OBS	Latitude	Longitude	Depth	BTime	BShift	ETime	EShift	Drift	TT#
A4	46 38.987	125 38.931	1989	96:05:02:02:28	5.4	96:05:04:11:18	5.8	0.4	C3
C1	46 38.987	125 31.588	2129	96:05:02:02:31	0.6	96:05:04:12:54	0.8	0.2	C1
C4	46 38.992	125 24.936	1913	96:05:02:02:34	-2.2	96:05:04:13:54	-1.3	0.9	C4
C9	46 38.981	124 29.004	108	96:05:02:02:40	1.3	96:05:05:08:28	0.9	-0.4	C9
A1	46 38.992	124 24.003	84	96:05:02:15:25	8.4	96:05:05:06:46	8.1	-0.3	A1
A8	46 38.984	124 18.995	68	96:05:02:15:30	8.1	96:05:05:07:24	14.1	6.0	A8
A3	46 38.996	124 14.028	48	96:05:02:15:36	-2.1	96:05:05:05:17	-2.7	-0.6	A3

Deployment 4 - Line 11 - Washington N-S

#OBS	Latitude	Longitude	Depth	BTime	BShift	ETime	EShift	Drift	TT#
A4	45 50.969	124 10.285	99	96:05:04:21:04	3.7	96:05:07:19:19	1.1	-2.6	C3
C1	45 56.586	124 13.036	105	96:05:04:21:08	0.8	96:05:07:20:08	1.1	0.3	C1
C4	46 03.282	124 16.698	105	96:05:04:21:14	-1.4	96:05:07:21:33	-0.9	-0.5	C4
C9	47 42.495	125 05.971	376	96:05:05:08:45	0.9	96:05:08:10:50	0.6	-0.3	C9
A8	47 49.939	125 09.787	353	96:05:05:07:52	0.5	96:05:08:12:03	14.4	13.9	A8
A1	47 56.335	125 13.045	176	96:05:05:07:01	8.2	96:05:08:13:08	7.6	-0.6	A1
A3	48 03.297	125 16.574	150	96:05:05:06:21	-2.7	96:05:08:14:06	-3.3	-0.6	A3

Deployment 5 - Line 12 - Olympic

#OBS	Latitude	Longitude	Depth	BTime	BShift	ETime	EShift	Drift	TT#
A1	47 34.343	124 39.949	67	96:05:08:13:25	7.6	96:05:10:16:07	7.1	-0.5	A1
A3	47 33.336	124 45.195	93	96:05:08:15:23	-3.3	96:05:10:16:15	(-3.9)	-0.6	A3
A8	47 32.463	124 49.746	121	96:05:08:12:33	4.5	96:05:10:16:58	1.7	-2.8	A8
C1	47 31.581	124 54.815	171	96:05:08:01:24	0.6	NO DATA	-	-	A2
C4	47 26.262	125 22.896	1492	96:05:07:21:52	-0.9	96:05:10:21:45	-0.5	0.4	C4
C9	47 25.271	125 28.287	1484	96:05:08:11:07	0.6	96:05:10:23:01	0.1	-0.5	C9
A4	47 24.247	125 33.942	1478	96:05:07:19:39	1.1	96:05:10:23:49	-1.8	-2.9	C3

GMT = Data logger_time + Shift ; A negative Shift means GPS clock pulse behind (is later than) Data logger Time in UTC (7 hours ahead of local time).
Drift = (EShift - BShift) in milliseconds.
Correction_Shift = BShift + [Drift * (Orig_Starttime - Btime)] in milliseconds.
Corrected_Trace_Starttime = Orig_Starttime + Correction_shift.
The value of Correction_shift for each SEGY trace is (added to the value) stored in the trace header under Total_Static

During the Rosette and the Oregon deployments, hence a total of 75 records were generated. All instruments recorded 4 channels on all the lines except for 6 instruments on the Oregon deployment, which were programmed to record only channels 1 and 4. Sadly, the first OBS deployed in this experiment has not been recovered, and this represents a real loss to the USGS OBS program. Another instrument did not record data on one deployment.

Data quality were good on at least one channel in each instrument in each deployment . Several sedimentary and crustal arrivals can be identified on all but 4 OBS records from shallow waters.

OPERATIONS

The instruments were brought into the seismic laboratory approximately 4 hours prior to deployment where the battery power was connected, all components of the system were tested, the data logger were programmed, and the spheres were sealed and vacuumed. Deployment was done through the starboard-side crane at mid-ship. A small stand was set on deck and the anchor was placed on top of it. The OBS was placed on top of the anchor and the two were bolted together. During later deployments, a floating ("swimming") line with an end-float was wrapped tightly around the base of the sphere, and the end of the floating line was tucked between the base of the sphere and the anchor. Once on location, the OBS and its anchor were lifted up by the crane and into the water where it was released using a slip knot and a pin.

Recovery was done using the same starboard-side crane which lifted the OBS on board. A tag line was attached to the OBS with a Happy Hooker or a lifting hook. In later deployments, the floating line was caught by throwing a rope with a hook, and

dragging the floating line with the OBS closer to the side of the ship. The use of the floating line shortened considerably the time needed for the 3000-ton ship to maneuver alongside the OBS. The OBS was lifted to deck, was washed in fresh water, and carried back to the lab, where the post-deployment checks were done. The data logger was brought to the lower-deck lab, checked for time drift against the GPS clock, and attached to the computer. While the data, recorded on the data logger, were being downloaded, new batteries were installed into the OBS in anticipation of redeployment at a later time. The sphere was then closed and tied down to the main deck. Once the data was recovered, the data logger was placed on a charging station to recharge the gelcell battery and to keep the oven-controlled oscillator at operating temperature. Some data loggers were programmed and immediately placed back into their sphere, because of the short time between recovery and the next deployment.

DATA REDUCTION AND PROCESSING

Step 1 - Data were down loaded from the data logger to a PC computer, one file per data logger. The raw data were written on one 8 mm Exabyte tape for each deployment, and a duplicate tape of the raw data was made.
Step 2 - Shot instance and navigation data, supplied by GEOMAR, were converted from UKO format to our format.
Step 3 - OBS location and depth from our log were entered to NAVD file, and *.src files with trace header information were created for each OBS for each seismic line.
Step 4 - *.src files were used in program OBSTOOLS to create SEGY files from the raw data. Specifically, the header file was edited to give the length of each trace, the project number and location, OBS name etc. The program uses shot instant from the *.src files to determine the start of each trace, and the difference between shot location and the OBS location to determine shot-receiver offset. SEGY files for each deployment were written as a SEGY binary tar tape.
Step 5 - The SEGY tapes were read into Promax processing software and processed. The processing sequence included:

1. tar tape into UNIX workstation hard disk.
2. Read SEGY disk input file..
3. Spiking deconvolution with an operator length of 80 ms..
4. Bandpass filter (Butterworth) - 4-7-18-32 Hz..
5. 2-D spatial filtering (not used in this cruise because of poor navigation)..
6. Trace equalization (not used in this cruise)..
7. Linear moveout correction (6 km/sec)..
8. Automatic gain control with a window of 2000 msec..
9. Trace header math with the equation.
cdp = offset in meters + no. in meters; where no. > total length of line..
Trace header math with Line no. and OBS no..
10. Plot data by cdp (effectively by offset)..

Because a plotter was not connected to the SUN workstation with the Promax system during cruise SO108, data were written to a DAT tape in SEGY format, read by a different SUN workstation into GEOMAR`s GEOSYS software and plotted by D. Klaeschen using this software.

Steps 1-4 were performed on a 386-PC. Step 5 was performed on a SUN Sparc-10 workstation on board.

NARRATIVE OF THE USGS OBS COMPONENT

Predeployment - In initial testing, an oscillator on one data logger failed, prohibiting one OBS from being deployed during each of the subsequent deployments. That OBS was used for spare parts during the experiment.

Deployment 1 - 8 OBS were deployed along 6 lines in a rosette shape. Only 5 lines were shot due to severe weather. The gun arrays were battered and we were forced to stop shooting twice. Guns operated at partial capacity for periods of time. One OBS (A2) could not be ranged and was never recovered and is either at the bottom or floating. 3 hours at night and 4 hours in daylight were spent looking for it. >40 release commands were sent from 4 azimuths and the ship searched in a ~4 x 4 n.m. area around the deployment location. It was the first OBS deployed in the experiment. Weather during shooting was stormy with winds of up to 50 knots and 8-12 ft. waves. Windy but calm seas during deployment and calm weather during recovery.

Deployment 2 - Oregon lines - 6 OBS were deployed at intervals of 4 n.m. along the landward end of the E-W line (Line 7). Calm seas and light wind during deployment, shooting, and recovery. Guns fired at almost full capacity. Ship navigation froze during deployment as we approached shore and at the 3-mile limit we were 2.5 miles off, hence, we did not deploy the planned seventh instrument. Exact positions of instruments were found during recovery. 4 instruments were recovered, 2 instruments near the junction with Line 9 were left at the bottom after locating and ranging on them. The instrument, not deployed on the E-W line, was deployed at the crossing with Line 8. The remaining 3 OBS were recovered without incident after the shootings of Lines 8 and 9.

Deployment 3 - SW Washington line - 3 OBS were deployed in the lower continental slope and 4 instruments were deployed along the landward end of the line. The 3 instruments in the lower continental slope were recovered before we left the line to meet a supply boat. The remaining 4 OBS were recovered when the ship reached the area again after deploying some OBS and OBH along the N-S Washington line. All guns fired. Calm seas and light wind during deployment, shooting, and recovery.

Deployment 4 - From the meeting point with the supply boat off Astoria, we continued south to the southern end of the N-S line and deployed our 3 OBS already on board. The remaining OBS, picked from the SW Washington line during the deployment, were deployed at the northern end of the line. Deployment, shooting, and recovery was carried out amidst fishing boats and crab buoys. Two of the guns (a 580 and a 500 cu.in.) ceased shortly after beginning of shooting so we had only 5200 cu.in. of air for shooting. The northern end of the line was relocated slightly farther offshore at the shelf edge to avoid deploying in waters that are too shallow.

Deployment 5 - Olympic Line- Upon the recovery of the last OBS from Deployment 4, the ship sailed to the eastern end of the Olympic Line, and within 3 hours, the first

OBS was deployed. 3 more OBS were deployed in shallow waters (67-171 m), and 3 OBS were deployed in a flat section of the continental slope. The line was shot at full gun capacity. Recovery of the OBS started from the eastern end of the line. The sea was very calm during deployment, shooting, and recovery.

Cruise Participants

RV Sonne

- **Dr. Uri tenBrink** - USGS- Atlantic Marine Geology - Chief Scientist
- **Bob Busby** - USGS- Atlantic Marine Geology - technician
- **Dave Foster** - USGS- Atlantic Marine Geology - technician

Cruise Data

Deployment Map

Record Sections for Line1

- *OBS A1*
- *OBS C1*
- *OBS C3*
- *OBS C9*

Record Sections for Line2

- *OBS A3*

Record Sections for Line4

- *OBS C4*

Record Sections for Line5

- *OBS A8*

Record Sections for Line7

- *OBS A4*
- *OBS A8*

- *OBS C1*

Record Sections for Line8

- *OBS A4*

Record Sections for Line 9

- *OBS A4*

Record Sections for Line10

- *OBS A4*
- *OBS A8*
- *OBS C1*

Record Sections for Line11

- *OBS A1*
- *OBS A3*
- *OBSA4*
- *OBS C1*
- *OBS C4*
- *OBS C9*

Record Sections for Line 12b

- *OBS A1*
- *OBS A3*
- *OBS A4*
- *OBSA8*
- *OBS C4*
- *OBS C9*

TECHNICAL PROBLEMS AFFECTING OPERATIONS AND DATA QUALITY

Deployment 1

1. A2 not recovered. 3 hours at night and 4 hours in daylight spent looking for it. >40 release commands sent from 4 azimuths. No clear response from ranges or releases. It was the first OBS deployed in the experiment.
2. C4 strobe leaked, strobe damaged and replaced with fresh unit. This delayed sighting upon recovery.

Deployment 2

1. On recovery C4 geophone pack found to be knocked off gimbals, reassembled.
2. C9 vertical geophone wire broken in sensor pack, found and fixed after recovery. Channel known to be bad on deployment but no time to fix it. Data QC does not indicate a problem.

3. After recovery, A1 hydrophone found to be wired to RS-232 in upper sphere. Fixed.
4. A4 no signal from hydrophone at preamp board. Fixed, FM.
5. C3 could not be deployed during deployment 2-5 because of a bad oscillator.

Deployment 3

1. A8 vertical examined with scope for any noise problem. No problem found.
2. A1 low signal at data logger input for horizontal 1. No repair attempted.

Deployment 4

1. A8 vertical still bad. Swapping sensor pack with C3 during deployment 5 remedied the problem. Problem appears to be with geophone pack. Probably the vertical geophone has a damaged suspension and must be replaced.
2. A1 has weak hydro and low horz1.

Deployment 5

1. C1 with datalogger from A2 did not record anything. It was in acquisition mode but the time was way off and no tracks were recorded. Probably the clock was glitched installing datalogger into sphere.
2. A3 lost time reference at recovery or more likely during a frequency check. Estimate drift at +0.3 msecs on the basis of previous deployments.

DATA FORMAT

Trace header format on SEGY files of all OBS files are as follows:

Byte position 1 = trace # (a number from 1 to the # traces in the file).
Byte position 5 = trace # as above.
Byte position 9 = channel # (1 = vertical geophone, 2 and 3 = horizontal geophones, and 4 = hydrophone).
Byte position 13 = shot # (from navigation data).
Byte position 29 = trace id code (1 for seismic data)
Byte position 31 = # of vertically stacked traces (1 for 1 trace)
Byte position 33 = # of horizontally stacked traces (1 for 1 trace)
Byte position 35 = data use (1 for production)
Byte position 37 = Shot-receiver offset (Offsets are negative for all shots occurring south/west of each OBS location and positive for all shots occurring north/east of each OBS location)
Byte position 41 = receiver elevation (negative value of the OBS depth)
Byte position 65 = water depth of receiver (OBS depth)
Byte position 73 = source longitude (in seconds)
Byte position 77 = source latitude (in seconds)
Byte position 81 = OBS longitude (in seconds)
Byte position 85 = OBS latitude (in seconds)
Byte position 89 = coordinate units (2 for seconds of arc)
Byte position 109 = delay recording time (0 in this case)

Byte position 115 = # samples in this trace
Byte position 117 = sample interval (in microsec, 10,000)
Byte position 119 = gain type (1 for fixed)
Byte position 125 = correlated (1 for not correlated)
Byte position 141 = alias filter frequency (in hertz)
Byte position 143 = alias filter slope (dB/octave)
Byte position 157 = year of shot
Byte position 159 = day of year (Julian)
Byte position 161 = hour of day
Byte position 163 = minute
Byte position 165 = second
Byte position 167 = time basis code (2 for GMT - GMT used for all time references)
Byte position 169 = trace weighting factor (data values are recorded with the least significant bit corresponding to 10`s of microvolts for a weight factor of 14)
Byte position 181 = milliseconds of the shot time

User provided:

Byte position 221 = Line no. (4 Byte integer)
Byte position 225 = OBS no. (4 Byte integer), Examples: A8 = 18; C4 = 34.