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WIDE-ANGLE SEISMIC RECORDINGS FROM THE 2002 GEORGIA BASIN GEOHAZARDS INITIATIVE, NORTHWESTERN WASHINGTON AND BRITISH COLUMBIA

By

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ABSTRACT

This report describes the acquisition and processing of shallow-crustal wide-angle seismic-reflection and refraction data obtained during a collaborative study in the Georgia Strait, western Washington and southwestern British Columbia. The study, the 2002 Georgia Strait Geohazards Initiative, was conducted in May 2002 by the Pacific Geoscience Centre, the U.S. Geological Survey, and the University of Victoria. The wide-angle recordings were designed to image shallow crustal faults and Cenozoic sedimentary basins crossing the International Border in southern Georgia basin and to add to existing wide-angle recordings there made during the 1998 SHIPS experiment. We recorded, at wide-angle, 800 km of shallow penetration multichannel seismic-reflection profiles acquired by the **Canadian Coast Guard Ship (CCGS) Tully** using an air gun with a volume of 1.967 liters (120 cu. in.). Prior to this reflection survey, we deployed 48 Refteks onshore to record the airgun signals at wide offsets. Three components of an oriented, 4.5 Hz seismometer were digitally recorded at all stations. Nearly 160,300 individual air gun shots were recorded along 180 short seismic reflection lines. In this report, we illustrate the wide-angle profiles acquired using the **CCGS Tully**, describe the land recording of the air gun signals, and summarize the processing of the land recorder data into common-receiver gathers. We also describe the format and content of the archival tapes containing the SEGY-formated, common-receiver gathers for the Reftek data. Data quality is variable but the experiment provided useful data from 42 of the 48 stations deployed. Three-fourths of all stations yielded useful first-arrivals to source-receiver offsets beyond 10 km: the average maximum source-receiver offset for first arrivals was 17 km. Six stations yielded no useful data and useful first-arrivals were limited to offsets less than 10 km at five stations. We separately archived our recordings of 86 local and regional earthquakes ranging in magnitude from 0.2 to 4.3 and 16 teleseisms ranging in magnitude 5.5 to 6.5.

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INTRODUCTION

In the past decade seismic hazards posed to northwestern Washington and southern British Columbia by crustal faulting have been recognized (e.g., Pratt et al., 1997; Cassidy et al., 2000; Mosher et al., 2000; Johnson et al., 2001). The existence of crustal faults capable of large (M~7) magnitude earthquakes within Puget Lowland has been inferred and mapped using a variety of methods including paleoseismic, seismicity, seismic reflection, and potential field geophysical data (Atwater and Moore, 1992; Bucknam et al., 1992; Johnson et al., 1994, 1996; Pratt et al., 1997; Wells et al., 1998; Blakely et al., 2002; ten Brink et al., 2002). In 1998 the Seismic Hazard Investigation in Puget Sound (SHIPS) surveyed the southern Georgia basin, yielding new crustal scale tomography velocity models for this important structure (Ramachandran, 2001; Zelt et al., 2001). Although the geology of the San Juan Islands and Lummi Peninsula have been reported (Vance, 1975, 1977; Brandon et al., 1988; Garver, 1988a,b; Droost, 1996), as well as that of the Georgia Basin (England and Bustin, 1998), few seismic studies of the Lummi Island and other crustal faults in the southern Georgia basin have been reported (Finkbeiner, 1994; Fisher et al., 2003)**.**

In this report we present wide-angle recordings obtained during a collaborative experiment between the Pacific Geoscience Centre (PGC), the U.S. Geological Survey (USGS), and the University of Victoria (Riedel, 2002; Riedel et al., 2002). The experiment, conducted using the **Canadian Coast Guard Ship (CCGS) Tully** and temporary deployments of land-based seismic recorders, was centered on the southern Georgia basin (Figure 1). The survey was designed to provide new wide-angle seismic profiles complimentary to SHIPS data and to image crustal faults. The cruise was divided into two parts, the first taking place mainly in U.S. waters (May 13-17) focusing on the Lummi Island fault and the southern extension of the Outer Island fault. The second part (May 17-May 26) was focused in Canadian waters on the location of frequent earthquake activity north-east of Gabriola Island, the northern extent of the Outer Island fault, and known recent Holocene faults in the vicinity of Vancouver, British Columbia.

DATA ACQUISITION

CCGS Tully Instrumentation and Operations

In the middle of May, 2002, we acquired nearly 180 shallow penetration marine seismic-reflection profiles in the Strait of Georgia using the **CCGS Tully** (Figure 1). Shipboard operations were described in a cruise report by Riedel (2002). The **CCGS Tully** used a single 1.967 liter (120 cu. in.) airgun as the sound source, towed at a depth of about 4 meters, and operated at a nominal air pressure of 1900 psi. Airgun shots were fired at 5 second intervals to minimize the common-midpoint spacing of the MCS data. Airgun repetition rates ranged between 5.000 and 5.492 seconds; starting at 20:21 UTC on JD 138 and for most of the cruise they were 5.384 seconds.

Signals from a blast phone (Bolt time-break solenoid valve model SV-1200-511) attached to the airgun power- and air-supply cables (Riedel, 2002) within meters of the **CCGS Tully** air gun were continuously recorded on a RefTek recorder connected to a Global Positioning System (GPS) clock. Air gun firing times were automatically picked from this record using the IRIS/PASSCAL software program **reftrig**. The resulting shot list was edited by hand to remove duplicate triggers. These air gun origin times are believed to be accurate to within one or two milliseconds. Navigation of the **CCGS Tully** was also achieved using a GPS receiver; these absolute coordinates are estimated to be accurate to within 40 m. The airgun shot locations presented here represent locations for the midpoint of the airgun having been corrected for the offset between the GPS antenna and the airgun.

For the first three days of the experiment, Julian Day (JD) 135 to JD 137 (May 15th to 17th), the **CCGS Tully** collected 36 short lines near Lummi Island, the San Juan Islands, and the Outer Islands. From Julian Day 138 to 139 the Tully collected 20 lines in the Georgia Strait. Between Julian Day 139 and 141 the Tully collected 20 lines in the epicentral region of a 1997 earthquake (Cassidy et al., 2000). From Julian Day 141 to the end of the survey on Julian Day 146, the Tully collected 100 lines in a 5-km by 10-km 3-D seismic survey of a pockmark field thought to have formed along an active crustal fault. The airgun lines were spaced 50 m apart in the 3-D grid (Fig. 1).

Figure 1 presents the **CCGS Tully** lines in map view. Appendix 1 provides an abbreviated list of the shot locations (northings, eastings, latitudes, and longitudes) and shot times for the entire **CCGS Tully** cruise given for shots acquired at hourly intervals. Appendix 2 provides start and end origin times and the beginning and ending FFIDs of the **CCGS Tully** seismic lines as numbered onboard the **CCGS Tully**. For our processing of the wide-angle Reftek data into common-receiver gathers we rearranged and reduced the number of airgun shotlines into 12 separate seismic lines, one for each Julian Day of the survey (Appendix 1).

We renumbered the airgun shot Field File Identification Numbers (FFIDs) so that each airgun shot now has a unique FFID. Appendices 1 and 2 provide the FFIDs as they were written to archival tape.

Wide-Angle Recording

The signals generated by the air gun towed by the **CCGS Tully** were recorded in a wide-angle geometry using 48 Reftek recorders deployed onshore. Given the small volume of the **CCGS Tully** airgun, most of recorders were deployed along the Strait of Georgia within 10 km of the planned ship tracks (Figure 1). Thirteen of the sites used for RefTek stations represent reoccupations of 1998 SHIPS sites (Brocher et al., 1999) (Appendix 3). The other sites selected were chosen to increase the density of SHIPS wide-angle recordings to permit the inversion for higher-resolution tomography velocity models in the southern Georgia basin. 23 stations were deployed in the Outer Islands, 12 sites were deployed on Lummi Island, Lummi Peninsula, and Orcas Island, 7 stations were deployed on the Canadian mainland, and 6 sites were deployed on the U.S. mainland. Air gun signals were recorded at ranges as close as 1 km and as far as 120 km. Appendix 3 presents the RefTek DAS number, location (northings, eastings, latitudes, and longitudes), and elevation of each Reftek station. It provides the station number of the 1998 SHIPS site previously deployed at or near the station, if any.

The digital Reftek recorders deployed consisted of five major components (PASSCAL, 1991). These components include the (1) Data Acquisition System (DAS), (2) internal or external hard disk drive, (3) internal oscillator and, in most cases, internal or external GPS Clock, (4) 3-component seismometer, and (5) external batteries. The GPS receiver clocks were typically recorded once per hour. Recording was simply halted when the instrument was retrieved.

Reftek Instrumentation

We recorded three-component data using three different RefTek models (models 06's, 07's, 07G's). Reftek 06's have external GPS receiver and antennas. DAS serial numbers for Reftek 06's had four digits starting with a 6. The Reftek 07's have either internal or external GPS receivers and antennas. DAS serial numbers for Reftek 07's had four digits starting with a 7. The Reftek 07G's have internal GPS receivers and antennas

The geophone sensors were Mark Products model L-28s, which are 4.5 Hz, 3-component seismometers. The sensors were oriented with compasses such that the N-S component was directed to **magnetic north**. Channel 1 recorded the vertical component, channel 2 recorded the N-S oriented horizontal component, and channel 3 recorded the E-W oriented horizontal component.

Power needs of the Refteks required us to deploy two 12-V, 80-Amp/Hr car batteries connected in parallel at each site. To protect them from the elements, at each station the equipment was deployed in firm plastic enclosures (Action Packers).

Station Deployment/Data Acquisition

Almost all Reftek recorders were deployed over a two-day period from JD 131 to JD 133 (May 11 to 13th).

The first airgun shots were fired at 0830 Universal Time (UTC) on JD 135 (May 15th). The last airgun shot was fired in the eastern Strait of Juan de Fuca at 2135 UTC on JD 146 (May 26th). Retrieval of the Refteks was completed on JD 147 (May 27th).

Wide-angle recorders were deployed by two teams each from the University of Victoria (stations 101-130; Fig. 1) and the U.S. Geological Survey (stations 150-167; Fig. 1). Each team was responsible for deploying and maintaining between 10 and 14 stations. The DAS at one Reftek station, 122, deployed in British Columbia, was stolen.

All Refteks were programmed to record the following parameters: (1) continuous recording with a sample rate of 100 Hz, (2) recording to start at the time of deployment, (3) recording to be halted at the time of retrieval, and (4) the continuously recorded data were divided into 60-minute-long events.

Station Locations and Elevations

The built-in or auxiliary GPS receiver at each station provided estimates of the station latitude, longitude, and elevation (Appendix 3). The GPS coordinates in Appendix 3 generally represent the average GPS location recorded once an hour (providing a median of 133 separate measurements). The median uncertainties (1 standard deviation from the average location) of the latitudes and longitudes are about 7 m (Appendix 4). The median uncertainty in elevation is 17 m (Appendix 4). To the elevations provided by these GPS receivers we added 19 m, the same correction applied by Brocher et al. (1999).

REFTEK DATA REDUCTION

Common receiver gathers

Data were cut as 20-second-long traces starting at the shot time. The data are unreduced. All three components were cut and archived. **Ref2segy** was used to extract segy traces from the raw (.ref) files. Timing corrections were computed from the log files (.log) using the **refrate** program. DAS 7296 was moved on Julian Day 140-141, resulting in two log files and two pcf files; these two pcf files were concatenated to produce a single file for the timing corrections. The timing files (.pcf) were checked visually with the '**clockview'** program to see that timing corrections were properly handled. In the cases where timing errors were not properly handled, the pcf files were hand-edited to correct the problem. Appendix 5 lists the DASes and times where corrections were edited. Timing corrections were applied by the '**segycut'** program during the data cutting stage. The trace headers contain the station number, shot number, DAS number, source and receiver elevations (in meters), and UTM coordinates of the source and receiver (in meters).

Data were written to DAT tapes as common-receiver gathers, with three gathers (three components) per day for each DAS.

Earthquakes

Eighty-six local earthquakes were saved as PASSCAL segy traces with a record length of 300 sec (5 minutes) starting 60 sec before the origin time of the earthquake (Appendix 8). Sixteen teleseisms were saved as PASSCAL segy traces with a record length of 3600 sec (1 hour) starting at the origin time of the earthquake (Appendix 9). The individual traces (3 components per DAS) are located in directories named for the start time of the traces (60 sec before the origin time).

Timing corrections were applied to all traces before cutting the earthquakes as described for the processing of the common receiver gathers. Appendix 5 lists the DASes and times where corrections were hand edited. The pcf files were then concatenated into a single file, which was used as input to the '**clockcor'** program to adjust the timing. The records were then cut using the '**eqcut'** graphic interface to the **'segycut'** program.

The headers of all traces in the earthquake data contain the receiver (station) number, receiver elevation in meters, and receiver latitude and longitude. The latitude and longitude are given as integer values, and need to be divided by 3600 to obtain decimal degrees.

Notes:

1) A total of approximately 15 Gbytes of rawrefdump-formatted data were acquired. During the data reformatting data volumes were expanded by a factor of 4. Twenty-second records of unreduced data were archived for each airgun shot.

2) GPS locks recorded in the logfiles for each station were averaged to provide GPS estimates of the station location and elevation using the program **position** (Appendix 3). Statistics of these estimates are given in Appendix 4.

3) A file containing the receiver (station) number, DAS number, the receiver UTMs (in meters), decimal longitude and latitude, and receiver elevation (in meters) was compiled (Appendix 3).

4) The more than 160,300 airgun shots were divided into 12 separate shot files; one file for each Julian Day.

SEGY Trace Format

The common receiver gathers were written in an unreduced travel time format in industry-standard SEGY format. Twenty-seconds of data were saved for each trace, starting at the airgun origin time. At a sample rate of 10 ms, there are 2001 samples per trace, for a block length, including header, of 8244 bytes per trace (including the 240-byte SEGY trace header). The time interval between airgun shots is approximately 5 s.

SEGY trace header formats are described by Barry et al. (1975) and in Appendix 6. The modification comes from the fact that we use some of the unspecified header words to store information pertinent to the PASSCAL data. The data values for each trace are preceded by a 240 byte header. The format of the header is given in Appendix 6. All integer values are stored with the most significant byte first. Data values are 32 bit, IEEE floating point numbers. Tape copies are available from the IRIS/PASSCAL Data Management Center.

Earthquake data are written in PASSCAL SEGY format, which is a modified version of the SEGY format. In the PASSCAL format, each trace is a separate file, and the data are either 16-bit integers (06 DAS) or 32-bit integers (07 DAS). The trace header locations are shown in Appendix 6. In the earthquake data, the source location is not in the header, and the receiver location is given in latitude and longitude (decimal degrees times 3600).

DESCRIPTION OF THE DATA

The data show several seismic arrivals. First arrivals consisting of direct arrivals and refractions from the sedimentary basin fill were well recorded (e.g., Figs. 2 to 7). Strong secondary arrivals were routinely recorded (Figs. 2, 3, and 7). Water waves are also commonly observed (e.g., Figs. 2 and 5).

Examples of local earthquakes recorded during our two-week deployment are shown in Figures 8 and 9. In these plots, the traces are ordered from nearest to farthest from the earthquake epicenter, and traces from all three components are plotted.

DATA QUALITY

Useful first arrivals were recorded at 42 of the 48 stations. Examples of the common-receiver gathers that we obtained are provided in Figures 2 to 7. First arrivals are typically low frequency, approximately 10 Hz. The 5-second airgun repetition rate causes a great deal of sound to be in the water column on these records (e.g., Fig. 2), particularly at the smallest source-receiver separations (less than 10 km). In addition, very strong secondary arrivals, possibly shear-waves, interfere with the first arrivals when source-receiver offsets are small (e.g., Figs. 3 and 5). In some cases, these secondary arrivals can be traced to greater offsets than the first arrivals (e.g., Fig. 6).

Appendix 3 presents an estimate to the maximum range that useful first-arrivals can be observed for each RefTek station, for the Julian Day of the closest approach of the Tully to the receiver. For the 46 stations that yielded data, the average maximum range for which useful first arrivals could be observed was 17 km. Thirty-seven out of 48 stations (77%) provided usable first arrival data to source-receiver offsets of at least 10 km (Appendix 3). First arrivals could be traced to offsets less than 10 km for only 5 stations (Appendix 3). 17 stations recorded useful first arrivals to offsets between 10 and 20 km (Appendix 3). First arrivals were observed to offsets of or beyond 20 km for 20 stations (Appendix 3). No first arrivals were observed in data from stations near urban centers on the mainland in Canadian and U.S. (stations 125, 126, 156, and 157). No data were recorded at Stations 119 and 122.

Eleven local earthquakes occurring within the map area of Figure 1 were recorded by our RefTek array (Appendix 8). The largest of these events, 300010, had a magnitude of 2.7 and originated 44 km below Victoria. Because it occurred early in our deployment, it was recorded by 25 stations at the southern end of our RefTek array (Fig. 8). Event 300047 also had a magnitude of 2.7 and originated just SE of Figure 1. It was recorded by 37 of our stations (Fig. 9). The remaining 10 local events had magnitudes ranging from 0.2 to 1.8.

The magnitudes of the 16 teleseisms that we recorded ranged from 5.5 to 6.5. Only three teleseisms had magnitudes greater than 6.0 (Appendix 9). None of these teleseisms were obvious on records filtered with a low-frequency bandpass. The largest teleseism, 400016, had a magnitude of 6.5, occurred at a depth of 109 km just north of the Banda Sea (Appendix 9). This teleseism occurred in the later stages of our recording interval, and as consequence was recorded only by 17 stations at the northern end of our deployment.

Favorable weather conditions were encountered, and this favorable weather undoubtedly contributed to the data quality. There were few extended periods of high winds during the experiment.

DATA AVAILABILITY

Copies of the SEGY common receiver gathers may be ordered via email from the IRIS/PASSCAL Data Management Center (DMC) in Seattle, Washington. The current email address of the Incorporated Research Institutions for Seismology (IRIS) Consortium is: www.iris.edu. The current general email address for the IRIS DMC is webmaster@iris.washington.edu. The current address of the IRIS DMC is: 1408 NE 45th St., Suite 201, Seattle, WA 98105. telephone (206) 547-0393. Tim Ahern is currently the Program Manger of the IRIS Data Management System at Seattle.

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The IRIS/PASSCAL Instrument Facility loaned the RefTeks used to record the airgun shots. Mike Fort of IRIS/PASSCAL prepared the RefTek instruments for deployment in Canada. Russell Sell made cables allowing us to record the airgun blast phone signal on a RefTek recorder, and generated the airgun shottime list using PASSCAL software.

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Appendix 1. Abbreviated list of airgun shotpoint FFID numbers, shot times, and locations

FFID	Year	JD	Hr	Mn	Second	Easting, m	Northing, m	Depth, m	Latitude NAD 83	Longitude NAD 83
110175	2002	135	8	25	53.598	517889	5382931	-4	48.5992	-122.7574
110575	2002	135	10	0	2.082	524018	5389497	-4	48.6581	-122.6739
111295	2002	135	11	0	1.110	529860	5382241	-4	48.5925	-122.5950
111983	2002	135	12	0	0.138	528584	5391179	-4	48.6730	-122.6117
112704	2002	135	13	0	4.158	522856	5399928	-4	48.7519	-122.6891
113424	2002	135	14	0	3.184	518041	5404943	-4	48.7972	-122.7543
114144	2002	135	15	0	2.210	515778	5395352	-4	48.7110	-122.7855
114864	2002	135	16	0	1.238	509084	5396196	-4	48.7187	-122.8765
115547	2002	135	17	0	0.274	510869	5402445	-4	48.7749	-122.8521
116188	2002	135	18	0	4.506	507933	5406771	-4	48.8139	-122.8919
116843	2002	135	19	0	2.442	502525	5412586	-4	48.8662	-122.9656
117489	2002	135	20	0	0.360	498170	5418223	-4	48.9169	-123.0250
118103	2002	135	21	0	3.792	492540	5424488	-4	48.9733	-123.1019
118623	2002	135	22	0	10.512	488701	5417630	-4	48.9115	-123.1542
119137	2002	135	23	0	2.936	484354	5411287	-4	48.8543	-123.2133
119779	2002	136	0	0	0.860	482531	5418431	-4	48.9186	-123.2384
120396	2002	136	1	0	4.280	487169	5425417	-4	48.9815	-123.1754
120571	2002	136	1	18	39.362	488533	5424649	-4	48.9746	-123.1567
120618	2002	136	7	13	51.392	515259	5404455	-4	48.7929	-122.7922
121145	2002	136	8	0	3.224	517053	5398694	-4	48.7410	-122.7681
121865	2002	136	9	0	2.248	521329	5390786	-4	48.6698	-122.7103
122585	2002	136	10	0	1.272	528747	5386792	-4	48.6335	-122.6098
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254512	2002	145	19	0	1.286	469478	5454020	-4	49.2382	-123.4193
255181	2002	145	20	0	2.618	467543	5449037	-4	49.1933	-123.4455
255850	2002	145	21	0	3.950	468553	5452293	-4	49.2226	-123.4319
256519	2002	145	22	0	5.282	468396	5450368	-4	49.2053	-123.4339
257187	2002	145	23	0	1.232	467699	5450947	-4	49.2105	-123.4435
257856	2002	146	0	0	2.564	469118	5451435	-4	49.2149	-123.4240
258525	2002	146	1	0	3.896	467156	5449903	-4	49.2010	-123.4509
259194	2002	146	2	0	5.228	469521	5452017	-4	49.2202	-123.4186
259862	2002	146	3	0	1.178	465191	5446547	-4	49.1707	-123.4775
260531	2002	146	4	0	2.510	470022	5454496	-4	49.2425	-123.4119
261200	2002	146	5	0	3.842	466741	5447342	-4	49.1780	-123.4563
261869	2002	146	6	0	5.174	469531	5453670	-4	49.2350	-123.4185
262537	2002	146	7	0	1.122	468644	5450404	-4	49.2056	-123.4305
263206	2002	146	8	0	2.454	468217	5451402	-4	49.2146	-123.4364
263875	2002	146	9	0	3.786	468559	5450153	-4	49.2034	-123.4316
264544	2002	146	10	0	5.118	468150	5451207	-4	49.2128	-123.4373
265201	2002	146	11	0	1.068	468515	5449991	-4	49.2019	-123.4322
265870	2002	146	12	0	2.400	469076	5452611	-4	49.2255	-123.4247
266539	2002	146	13	0	3.732	467682	5448521	-4	49.1886	-123.4435
267208	2002	146	14	0	5.064	468788	5452076	-4	49.2207	-123.4286
267876	2002	146	15	0	1.012	468384	5449595	-4	49.1983	-123.4340

268545	2002	146	16	0	2.344	468446	5451421	-4	49.2148	-123.4333
269214	2002	146	17	0	3.676	468615	5449846	-4	49.2006	-123.4308
269883	2002	146	18	0	5.008	467175	5449216	-4	49.1949	-123.4505
270551	2002	146	19	0	0.956	471248	5452367	-4	49.2234	-123.3949
271220	2002	146	20	0	2.288	466016	5454717	-4	49.2443	-123.4669
271889	2002	146	21	0	3.620	467590	5448218	-4	49.1859	-123.4448
272006	2002	146	21	10	33.450	466853	5447072	-4	49.1756	-123.4548

Appendix 2. R/V Tully Lines, Times, RefTek FFID numbers, and line locations

Tully Line No.	Start JD	UTC HrMin	End JD	UTC HrMin	Start FFID	End FFID	No. of Shots	Location
1	135	8:25	135	9:47	110175	110430	256	Lummi/San Juan/Outer Isl.
2	135	9:48	135	11:06	110431	111386	956	Lummi/San Juan/Outer Isl.
3	135	11:06	135	13:48	111387	113288	1902	Lummi/San Juan/Outer Isl.
4	135	13:48	135	15:12	113289	114290	1002	Lummi/San Juan/Outer Isl.
5	135	15:12	135	16:03	114291	114906	616	Lummi/San Juan/Outer Isl.
6	135	16:03	135	17:05	114907	115596	690	Lummi/San Juan/Outer Isl.
7	135	17:05	135	21:09	115597	118171	2575	Lummi/San Juan/Outer Isl.
8	135	21:09	135	22:51	118172	119035	864	Lummi/San Juan/Outer Isl.
9	135	22:51	135	23:32	119036	119478	443	Lummi/San Juan/Outer Isl.
10	135	23:32	136	1:18	119479	120571	1093	Lummi/San Juan/Outer Isl.
11	136	7:13	136	8:46	120618	121697	1080	Lummi/San Juan/Outer Isl.
12	136	8:46	136	9:58	121698	122569	872	Lummi/San Juan/Outer Isl.
13	136	9:58	136	14:04	122570	125514	2945	Lummi/San Juan/Outer Isl.
14	136	14:04	136	14:44	125515	125994	480	Lummi/San Juan/Outer Isl.
15	136	14:44	136	15:38	125995	126610	616	Lummi/San Juan/Outer Isl.
16	136	15:38	136	16:12	126611	126973	363	Lummi/San Juan/Outer Isl.
17	136	16:12	136	17:56	126974	128143	1170	Lummi/San Juan/Outer Isl.
18	136	17:56	136	19:24	128144	129070	927	Lummi/San Juan/Outer Isl.
19	136	19:24	136	20:16	129071	129658	588	Lummi/San Juan/Outer Isl.
20	136	20:16	136	20:52	129659	130031	373	Lummi/San Juan/Outer Isl.
21	136	20:52	136	21:51	130032	130682	651	Lummi/San Juan/Outer Isl.
22	136	21:51	137	0:59	130683	132729	2047	Lummi/San Juan/Outer Isl.
23	137	0:59	137	2:12	132730	133535	806	Lummi/San Juan/Outer Isl.
24	137	2:12	137	6:01	133536	136027	2492	Lummi/San Juan/Outer Isl.
25a	137	6:01	137	6:34	136028	136394	367	Lummi/San Juan/Outer Isl.
25b	137	6:34	137	6:53	136395	136596	202	Lummi/San Juan/Outer Isl.
26	137	6:53	137	12:56	136597	140561	3965	Lummi/San Juan/Outer Isl.
27	137	12:56	137	15:39	140562	142343	1782	Lummi/San Juan/Outer Isl.
28	137	16:35	137	17:49	142344	143129	786	Gulf Islands
29	137	17:49	137	18:43	143130	143717	588	Gulf Islands
30	137	18:43	137	19:03	143718	143936	219	Gulf Islands
31	137	19:03	137	19:52	143937	144471	535	Gulf Islands
32	137	19:52	137	20:45	144472	145050	579	Gulf Islands
33	137	20:45	137	21:54	145051	145804	754	Gulf Islands
34	137	21:54	138	2:11	145805	148611	2807	Gulf Islands
35	138	2:11	138	3:30	148612	149482	871	Gulf Islands
36	138	7:41	138	9:20	149483	150519	1037	Georgia Strait
37	138	9:20	138	9:59	150528	150946	419	Georgia Strait
38	138	10:37	138	11:31	-	-	-	Georgia Strait
39	138	11:31	138	11:43	-	-	-	Georgia Strait
40	138	12:22	138	12:22	150947	150948	2	Georgia Strait
41	138	12:33	138	12:47	150949	151071	123	Georgia Strait
42	138	12:47	138	13:48	151072	151766	695	Georgia Strait
43	138	13:48	138	13:54	151767	151831	65	Georgia Strait
44	138	13:54	138	15:13	151832	152694	863	Georgia Strait
45a	138	15:13	138	15:17	152695	152737	43	Georgia Strait
45b	138	15:17	138	16:24	152738	153469	732	Georgia Strait
46	138	16:24	138	17:34	153470	154239	770	Georgia Strait
47	138	17:43	138	18:32	154240	154770	531	Georgia Strait
48	138	18:32	138	21:15	154771	156525	1755	Georgia Strait
49	138	21:43	138	23:27	156832	158125	1294	Georgia Strait
50	138	23:27	138	23:39	158008	158125	118	Georgia Strait
51	138	23:39	139	1:33	158126	159360	1235	Georgia Strait
52	139	1:33	139	2:17	159361	159840	480	Georgia Strait
53	139	2:17	139	4:16	159841	161157	1317	Georgia Strait
54	139	4:16	139	6:24	161158	162876	1719	Georgia Strait
55	139	6:24	139	9:21	162877	164527	1651	Georgia Strait
56	139	9:21	139	11:48	164528	166173	1646	Earthquake Epi. N-S line.
57	139	11:48	139	14:05	166174	167690	1517	Earthquake Epi. N-S line.
58	139	14:05	139	14:18	167691	167835	145	Earthquake Epi. N-S line.
59	139	14:35	139	16:57	167836	169429	1594	Earthquake Epi. N-S line.

60	139	16:57	139	19:14	169430	170961	1532	Earthquake Epi. N-S line.
61	140	1:06	140	3:40	170962	172670	1709	Earthquake Epi. N-S line.
62	140	3:40	140	6:13	172671	174381	1711	Earthquake Epi. N-S line.
63	140	6:13	140	8:25	174382	175850	1469	Earthquake Epi. N-S line.
64	140	8:25	140	10:19	175851	177122	1272	Earthquake Epi. N-S line.
65	140	10:19	140	12:40	177123	178693	1571	Earthquake Epi. N-S line.
66	140	12:40	140	15:00	178694	180252	1559	Earthquake Epi. N-S line.
66b	140	15:00	140	15:11	180253	180374	122	Earthquake Epi. N-S line.
67	140	22:03	141	0:09	180375	181781	1407	Earthquake Epi. N-S line.
68	141	0:09	141	1:27	181782	182649	868	Earthquake Epi. E-W line.
69	141	1:27	141	2:50	182650	183575	926	Earthquake Epi. E-W line.
70	141	2:50	141	4:39	183576	184789	1214	Earthquake Epi. E-W line.
71	141	4:39	141	6:07	184790	185776	987	Earthquake Epi. E-W line.
72	141	6:07	141	8:37	185777	187444	1668	Earthquake Epi. E-W line.
73	141	8:37	141	10:32	187445	188732	1288	Earthquake Epi. E-W line.
74	141	10:32	141	12:09	188733	189811	1079	Earthquake Epi. E-W line.
75	141	12:09	141	13:40	189812	190821	1010	Earthquake Epi. E-W line.
3D-01	141	13:40	141	14:45	190822	191545	724	Pockmark field.
3D-31	141	14:45	141	16:01	191546	192391	846	Pockmark field.
3D-02	141	16:01	141	17:04	192392	193098	707	Pockmark field.
3D-32	141	17:04	141	18:13	193099	193866	768	Pockmark field.
3D-03	141	18:13	141	19:10	193867	194497	631	Pockmark field.
3D-33	141	21:23	141	22:34	194498	195298	801	Pockmark field.
3D-04a	141	22:34	141	22:48	195299	195366	68	Pockmark field.
3D-04b	141	22:39	141	23:26	-	-	-	Pockmark field.
3D-34	141	23:59	142	0:54	196162	196766	605	Pockmark field.
3D-05	142	0:54	142	1:59	196767	197500	734	Pockmark field.
3D-35	142	1:59	142	3:10	197501	198284	784	Pockmark field.
3D-06	142	3:10	142	4:12	198285	198975	691	Pockmark field.
3D-36	142	4:12	142	5:22	198976	199755	780	Pockmark field.
3D-07	142	5:22	142	6:25	199756	200459	704	Pockmark field.
3D-37	142	6:25	142	8:20	200460	201738	1279	Pockmark field.
3D-08	142	8:20	142	10:25	201739	203133	1395	Pockmark field.
3D-38	142	10:25	142	11:34	203134	203905	772	Pockmark field.
3D-09	142	11:34	142	12:35	203906	204587	682	Pockmark field.
3D-39	142	12:35	142	13:45	204588	205363	776	Pockmark field.
3D-10	142	13:45	142	14:48	205364	206067	704	Pockmark field.
3D-40	142	14:48	142	15:54	206068	206804	737	Pockmark field.
3D-11	142	15:54	142	16:57	206805	207500	696	Pockmark field.
3D-41	142	16:57	142	17:57	207501	208173	673	Pockmark field.
3D-12	142	17:57	142	19:01	208174	208890	717	Pockmark field.
3D-42	142	19:01	142	20:59	208891	210041	1151	Pockmark field.
3D-13	142	20:59	142	23:12	210042	211529	1488	Pockmark field.
3D-43	142	23:12	143	0:19	211530	212259	730	Pockmark field.
3D-14	143	0:19	143	1:23	212260	212972	713	Pockmark field.
3D-44	143	1:23	143	2:28	212973	213695	723	Pockmark field.
3D-15	143	2:28	143	3:01	213696	214064	369	Pockmark field.
3D-45	143	3:10	143	4:46	214065	215131	1067	Pockmark field.
3D-16	143	4:46	143	5:50	215132	215845	714	Pockmark field.
3D-46	143	5:50	143	6:56	215846	216587	742	Pockmark field.
3D-17	143	6:56	143	7:55	216588	217239	652	Pockmark field.
X-1	143	7:55	143	9:23	217240	218219	980	Pockmark field.
3D-47	143	9:23	143	11:11	218220	219426	1207	Pockmark field.
3D-18	143	11:11	143	12:13	219427	220116	690	Pockmark field.
3D-48	143	12:13	143	13:12	220117	220777	661	Pockmark field.
3D-19	143	13:12	143	14:20	220778	221533	756	Pockmark field.
3D-49	143	14:20	143	15:20	221534	222197	664	Pockmark field.
3D-20	143	15:20	143	16:23	222198	222791	594	Pockmark field.
3D-50a	143	16:23	143	16:28	222792	222842	51	Pockmark field.
3D-50b	143	16:28	143	17:24	222843	223467	625	Pockmark field.
3D-21	143	17:24	143	18:22	223468	224124	657	Pockmark field.
3D-51	143	18:22	143	19:28	224125	224853	729	Pockmark field.
3D-22	143	19:28	143	20:27	224854	225513	660	Pockmark field.
3D-52	143	20:27	143	21:34	225514	226264	751	Pockmark field.

3D-23	143	21:34	143	22:42	226265	227020	756	Pockmark field.
3D-53	143	22:42	143	23:45	227021	227722	702	Pockmark field.
3D-24	143	23:45	144	0:54	227723	228482	760	Pockmark field.
3D-54	144	0:54	144	2:00	228483	229215	733	Pockmark field.
3D-25	144	2:00	144	3:06	229216	229955	740	Pockmark field.
3D-55	144	3:06	144	4:13	229956	230706	751	Pockmark field.
3D-26	144	4:13	144	5:15	230707	231394	688	Pockmark field.
3D-56	144	5:15	144	6:24	231395	232161	767	Pockmark field.
3D-27	144	6:24	144	7:22	232162	232813	652	Pockmark field.
3D-57	144	7:22	144	8:30	232814	233569	756	Pockmark field.
3D-28	144	8:30	144	9:28	233570	234219	650	Pockmark field.
3D-58a	144	9:28	144	10:29	234220	234893	674	Pockmark field.
3d-58b	144	10:10	144	10:16	-	-	-	Pockmark field.
3D-29	144	10:29	144	11:31	234894	235589	696	Pockmark field.
3D-59	144	11:31	144	12:28	235590	236226	637	Pockmark field.
3D-30	144	12:28	144	13:26	236227	236873	647	Pockmark field.
3D-60	144	13:26	144	14:33	236874	237613	740	Pockmark field.
3D-15r	144	14:33	144	15:34	237614	238289	676	Pockmark field.
3D-20r	144	15:34	144	16:37	238290	239002	713	Pockmark field.
3D-4r	144	16:37	144	17:36	239003	239649	647	Pockmark field.
3D-18r	144	17:36	144	18:41	239650	240376	727	Pockmark field.
3D-17r	144	18:41	144	19:44	240377	241075	699	Pockmark field.
3D-24r	144	19:44	144	20:30	241076	241587	512	Pockmark field.
3d-23r	144	20:30	144	21:14	241588	242056	469	Pockmark field.
3D-54r	144	21:14	144	21:48	242057	242442	386	Pockmark field.
H-09	144	22:16	144	22:45	-	-	-	Extra Huntec Line
H-10	144	22:45	144	23:35	-	-	-	Extra Huntec Line
3D-81	145	0:06	145	1:28	242443	243355	913	Pockmark field.
3D-61	145	1:28	145	2:27	243356	244017	662	Pockmark field.
3D-82	145	2:27	145	3:29	244018	244710	693	Pockmark field.
3D-62	145	3:29	145	4:28	244711	245362	652	Pockmark field.
3D-83	145	4:28	145	5:32	245363	246081	719	Pockmark field.
3D-63	145	5:32	145	6:37	246082	246806	725	Pockmark field.
3D-84	145	6:37	145	7:46	246807	247568	762	Pockmark field.
3D-64	145	7:46	145	8:46	247569	248245	677	Pockmark field.
3D-85	145	8:46	145	9:17	248246	248581	336	Pockmark field.
3D-65	145	10:08	145	11:06	248582	249236	655	Pockmark field.
3D-85r	145	11:06	145	12:06	249237	249907	671	Pockmark field.
3D-66	145	12:06	145	13:09	249908	250600	693	Pockmark field.
3D-86	145	13:09	145	14:11	250601	251291	691	Pockmark field.
3D-67	145	14:11	145	15:12	251292	251978	687	Pockmark field.
3D-87	145	15:12	145	16:08	251979	252605	627	Pockmark field.
3D-68	145	16:08	145	17:13	252606	253319	714	Pockmark field.
3D-88	145	17:13	145	18:13	253320	253989	670	Pockmark field.
3D-69	145	18:13	145	19:14	253990	254673	684	Pockmark field.
3D-89	145	19:14	145	20:26	254674	255475	802	Pockmark field.
3D-71	145	20:26	145	21:25	255476	256136	661	Pockmark field.
3D-90	145	21:25	145	22:38	256137	256942	806	Pockmark field.
3D-70	145	22:38	145	23:35	256943	257580	638	Pockmark field.
3D-91	145	23:35	146	0:44	257581	258350	770	Pockmark field.
3D-72	146	0:44	146	1:41	258351	258989	639	Pockmark field.
3D-92	146	1:41	146	2:56	258990	259823	834	Pockmark field.
3D-73	146	2:56	146	4:08	259824	260628	805	Pockmark field.
3D-93	146	4:08	146	5:10	260629	261317	689	Pockmark field.
3D-74	146	5:10	146	6:21	261318	262111	794	Pockmark field.
3D-94	146	6:21	146	7:29	262112	262866	755	Pockmark field.
3D-75	146	7:29	146	8:30	262867	263542	676	Pockmark field.
3D-95	146	8:30	146	9:29	263543	264203	661	Pockmark field.
3D-76	146	9:29	146	10:32	264204	264902	699	Pockmark field.
3D-96	146	10:32	146	11:25	264903	265485	583	Pockmark field.
3D-77	146	11:25	146	12:21	265486	266101	616	Pockmark field.
3D-97	146	12:21	146	13:22	266102	266784	683	Pockmark field.
3D-78	146	13:22	146	14:27	266785	267509	725	Pockmark field.
3D-98	146	14:27	146	15:27	267510	268177	668	Pockmark field.

3D-79	146	15:27	146	16:31	268178	268892	715	Pockmark field.
3D-99	146	16:31	146	17:37	268893	269624	732	Pockmark field.
3D-80	146	17:37	146	18:47	269625	270413	789	Pockmark field.
H-11	146	18:47	146	19:50	270414	271112	699	Extra Huntec Line
H-12	146	19:50	146	20:35	271113	271612	500	Extra Huntec Line
3D-99a	146	20:35	146	21:10	271613	272006	394	Pockmark field.

Appendix 3. Reftek receiver station locations and elevations, reoccupations of 1998 SHIPS sites, and estimates of signal propagation.

Receiver No.	DAS No.	Easting UTM 10, meters	Northing UTM 10, meters	Final Elev. (m)	Reftek Latitude NAD 83	Reftek Longitude WGS 84	1998 SHIPS Station. No.	Maximum Range of First-Arrivals, kilometers
101	6088	494405	5403417	25	48.78373	-123.07616		20
102	6119	480466	5409221	17	48.83566	-123.26619		10
103	7591	475727	5414486	49	48.88285	-123.33108		7
104	7595	469887	5417552	84	48.91018	-123.41097	11019	18
105	7333	463293	5422214	111	48.95176	-123.50137		35
106	7599	457521	5427083	42	48.99519	-123.58071	11020	20
107	7602	453010	5432388	4	49.04258	-123.64300		16
108	7620	449671	5438036	8	49.09312	-123.68938		30
109	7601	448830	5442502	15	49.13322	-123.70147	11021	16
110	7280	441701	5444971	125	49.15479	-123.79954		14
111	7619	438614	5448859	61	49.18946	-123.84247	11022	20
112	6019	482782	5398262	26	48.73714	-123.23418		30
113	6107	478026	5406911	35	48.81480	-123.29932		30
114	7605	468466	5403310	72	48.78199	-123.42926		35
115	7296	464229	5413337	21	48.87196	-123.48781		20
116	7344	456777	5420400	52	48.93502	-123.59017		20
117	7451	450804	5424432	6	48.97084	-123.67222		20
118	7288	448403	5429685	29	49.01790	-123.70568		25
119	6096	452601	5407667	66	48.82018	-123.64572		-
120	7319	446362	5419053	59	48.92209	-123.73219		12
121	7316	442343	5432294	43	49.04083	-123.78893		20
122	7453	438582	5439378	-	-	-		-
123	7296	428352	5445783	240	49.16068	-123.98274		35
124	7048	493531	5427519	46	49.00054	-123.08845	11030	8
125	7064	487875	5438311	2	49.09753	-123.16610	11031	0
126	7604	485365	5450590	3	49.20793	-123.20093	11032	0
127	7081	480943	5465214	79	49.33935	-123.26233		18
128	7283	460532	5473272	138	49.41085	-123.54409		20
129	7065	454848	5475735	158	49.43261	-123.62273	11043	18
130	7091	443425	5479935	28	49.46943	-123.78086	11044	28
150	7103	505804	5394539	52	48.70386	-122.92112		5
151	7284	509693	5394708	15	48.70533	-122.86825		24
152	7443	517818	5388641	40	48.65057	-122.75808		26
153	7317	516468	5390745	131	48.66954	-122.77632		24
154	7462	532891	5380536	23	48.57705	-122.55408	1007	5
155	7458	537483	5388744	44	48.65063	-122.49108	1006	12
156	7098	537541	5394552	23	48.70287	-122.48977		13
157	6111	538475	5405909	71	48.80498	-122.47602		0
158	7433	526075	5403273	30	48.78191	-122.64505		7
159	7613	527261	5400627	36	48.75806	-122.62908		10
160	7596	524372	5398200	19	48.73634	-122.66854		10
161	7611	525831	5396160	5	48.71793	-122.64882		10
162	7336	521418	5398669	68	48.74067	-122.70869	1004	11
163	7429	522982	5395687	31	48.71379	-122.68758		13
164	7445	524902	5393778	5	48.69654	-122.66159		16
165	7457	526332	5392614	64	48.68601	-122.64223	1005	26
166	7594	515907	5414821	26	48.88614	-122.78301		13
167	7448	513656	5420978	32	48.94158	-122.81351		10

Appendix 4. Statistics of GPS Reftek station locations and elevations

Station No.	DAS No.	Time of First Lock Dy:Hr:Mn	Time of Last Time Dy:Hr:Mn	No. of Locks Used	No. of Locks Rejected	Location St. Dev. (m)	Elev. St. Dev. (m)
101	6088	134:21:06	140:22:46	89	30	9.3	15.1
102	6119	135:15:09	140:17:47	51	14	5.9	14.9
103	7591	134:19:01	140:18:46	110	34	6.1	14.3
104	7595	134:21:08	140:20:46	107	37	5.7	13.2
105	7333	134:21:45	146:14:57	208	72	4.4	11.5
106	7599	134:22:34	146:14:43	215	56	5.6	14.2
107	7602	134:17:56	147:23:46	250	69	6.4	16.1
108	7620	134:17:07	147:22:55	239	68	9.9	24.7
109	7601	134:22:38	147:20:47	228	78	6.4	16.5
110	7280	134:23:42	147:20:26	243	67	6.3	16.4
111	7619	134:21:44	147:19:52	239	68	6.5	18.3
112	6019	134:00:43	140:00:46	107	36	5.8	12.7
113	6107	134:15:36	136:20:46	49	20	5.6	17.4
114	7605	134:01:50	140:22:48	123	31	8.6	20.4
115	7296	134:00:23	140:19:49	124	40		
116	7344	133:23:39	147:17:00	249	81	7.9	20.1
117	7451	133:21:21	147:16:48	259	74	6.3	18.2
118	7288	133:20:32	147:17:47	262	70	6.8	16.4
119	6096	130:23:34	135:05:46	39	2	68.1	82.2
120	7319	133:18:51	139:15:16	112	30	6.3	18.3
121	7316	133:18:03	147:17:48	253	75	7.6	17.0
122	7453	133:17:00	-	-	-	-	-
123	7296	141:23:33	147:17:00	104	29	9.5	25.2
124	7048	134:02:49	141:00:59	138	12	13.6	634.2
125	7064	133:23:51	146:16:46	209	64	4.6	12.1
126	7604	133:22:41	143:15:46	74	27	4.9	10.9
127	7081	133:21:15	146:22:49	160	45	10.9	20.0
128	7283	133:18:01	146:22:46	242	76	7.5	19.7
129	7065	133:17:11	146:21:45	235	76	6.3	14.6
130	7091	133:15:50	146:21:46	246	73	6.8	15.7
150	7103	131:19:54	139:16:59	131	39	6.8	16.7
151	7284	131:18:32	139:16:46	139	47	7.1	16.3
152	7443	131:16:27	139:17:42	149	45	11.7	30.0
153	7317	131:15:06	139:17:48	156	36	6.6	15.1
154	7462	131:23:13	140:02:00	144	52	6.6	14.3
155	7458	132:01:40	138:23:55	163	1	13.1	1959.7
156	7098	132:03:27	138:23:55	116	39	6.6	15.5
157	6111	132:02:26	139:01:41	129	40	7.4	16.9
158	7433	133:19:38	138:18:48	4	1	8.8	53.3
159	7613	133:19:05	139:21:46	110	38	5.2	13.7
160	7596	133:18:26	139:19:46	110	37	9.9	27.0
161	7611	133:19:26	139:20:46	116	32	5.9	14.6
162	7336	132:21:36	139:19:49	127	40	5.0	13.0
163	7429	132:20:28	139:18:47	133	33	5.2	13.2
164	7445	132:19:10	139:18:48	136	33	8.0	15.8
165	7457	132:20:08	139:17:53	116	38	5.3	16.3
166	7594	132:15:43	139:14:46	124	44	5.4	13.4
167	7448	132:17:26	139:15:48	129	39	6.8	19.3
		Median		133	39	6.6	16.4

Appendix 5: Receiver DAS numbers, quality of timing, tape numbers, and comments.

Station No.	DAS No.	Quality of Timing	DDS-3 3-comp. tapes (IRIS)	Comments
101	6088	good	1/15	
102	6119	**errors**	1/30a	Fixed timing error, 139:23:47 to 140:03:42
103	7591	good	1/17	
104	7595	good	2/5	
105	7333	good	2/5	
106	7599	good	1/17	
107	7602	good	1/17	
108	7620	good	1/17	
109	7601	**errors**	1/17	Possible 1-sec error from 141:17:00 to 141:19:00
110	7280	good	2/5	
111	7619	good	1/30a	
112	6019	**errors**	1/30a	Short data segments; GPS failed at 139:11:30
113	6107	good	1/15	
114	7605	**errors**	1/30a	Fixed timing error, 138:09 to 138:10 (still 8-msec error?)
115	7296	good	2/10	
116	7344	good	2/5	
117	7451	good	1/30a	
118	7288	good	2/10	
119	6096	good	1/15	
120	7319	good	2/5	
121	7316	good	2/5	
122	7453	-	-	-
123	7296	good	2/10	
124	7048	**errors**	1/15	GPS failed at 141:01:02
125	7064	good	1/15	
126	7604	**errors**	1/30a	136:18:46-139:18:00 missing; no GPS locks after 141:00:54
127	7081	good	1/15	
128	7283	good	2/5	
129	7065	good	1/15	
130	7091	good	1/17	
150	7103	good	1/13	
151	7284	good	1/13	
152	7443	good	1/13	
153	7317	good	1/13	
154	7462	good	1/30a	
155	7458	good	1/13	
156	7098	good	1/13	
157	6111	good	1/13	
158	7433	**errors**	1/30a	Fixed timing error, 133:19:43 to 135:18:38
159	7613	good	1/13	
160	7596	good	1/13	
161	7611	good	1/13	
162	7336	good	1/13	
163	7429	good	1/13	
164	7445	**errors**	1/30a	Fixed 2 timing errors at 136:11:45 and 138:13:46
165	7457	good	1/13	Missing header - manually set sample rate, gains and format
166	7594	good	1/13	Errors during ref2segy
167	7448	good	1/13	

Appendix 6. PASSCAL SEGY Trace Header Format

Byte #	Description
1 - 4	Trace sequence number within data stream
5 - 8	Trace sequence number within reel (same as above)
9 - 12	Event number (FFID number)
13 - 16	Channel number = 1 or 4 for the vertical component, 2 or 5 for the N-S horizontal component, 3 or 6 for the E-W horizontal component
17 - 20	Energy Point number (FFID)
|	
29 - 30	Trace identification code = 1 for seismic data
|	
33 - 36	Source-receiver offset (m)
37 - 40	Receiver elevation (m)
41 - 44	Source Elevation (depth) (m)
|	
69 - 72	Source X coordinate (UTM Easting)
73 - 76	Source Y coordinate (UTM Northing)
77 - 80	Receiver X coordinate (UTM Easting)
81 - 84	Receiver Y coordinate (UTM Northing)
|	
89 - 90	Coordinate units = 2 for Lat/Long
|	
103 - 104	Low 2 bytes of the total shift in milliseconds
|	
115 - 116	Number of samples in this trace (note if equal 32767 see bytes 229 - 232)
117 - 118	Sample interval in microsecs for this trace (note if equal 1 see bytes 201 - 204)
119 - 120	Fixed gain flag = 1
121 - 122	Gain of amplifier
|	
157 - 158	Year data recorded
159 - 160	Day of year
161 - 162	Hour of day (24 hour clock)
163 - 164	Minute of hour
165 - 166	Second of minute
167 - 168	Time basis code: 1=local 2=GMT 3=other
|	
174 - 174	Stake number index
|	
181 - 186*	Station Name code (5 chars + 1 for termination)
187 - 194*	Sensor Serial code (7 chars + 1 for termination)
195 - 198*	Channel Name code (3 chars +1 for termination)
199 - 200*	Extra bytes (2 chars)
201 - 204*	Sample interval in microsecs as a 32 bit integer
205 - 206*	Data format flag: 0=16 bit integer 1=32 bit integer
207 - 208*	Milliseconds of second for first sample
209 - 210*	Trigger time year
211 - 212*	Trigger time Julian day
213 - 214*	Trigger time hour
215 - 216*	Trigger time minutes
217 - 218*	Trigger time seconds
219 - 220*	Trigger time milliseconds
221 - 224*	Scale factor (IEEE 32 bit float) (true amplitude = (data value)*(scale factor)/gain
225 - 226*	Instrument Serial Number
229 - 232*	Number of Samples as a 32 bit integer
233 - 236*	Max value in counts.
237 - 240*	Min value in counts.

*Header values not specified in the standard SEGY format

Appendix 7. Minimum source-receiver offset (in meters) for each station for every Julian Day

JD	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116
135	10997	4172	4642	10829	18604	25919	32492	38250	41405	48687	53418	12496	7509	16390	16194	24240
136	3171	9438	7864	12674	19606	26464	32654	38256	41156	48641	53117	6749	12369	20651	18997	25829
137	2697	5287	4904	3717	2295	6615	13528	20072	24313	30399	35363	1514		6781	3285	4213
138	25160	12520	5644	3508	2443	1061	2083	5348	9589	13031	17874	23332		17189	8730	3436
139	46375	34875	27913	22290	15334	9832	7228	5893	4713	9874	12811	45462		34927	24148	16556
140	52637	40052	33212	28218	22347	17849	12953	8066	3934	8688	11770			41766	31272	24542
141					25387	21628	17501	12017	7901	10996	12860					28240
142					20408	15418	12018	10883	10749	18036	21868					22139
143					25618	21778	18987	17282	15899	22090	24828					28402
144					25474	21440	18339	16413	14934	21211	24058					28109
145					24869	21596	19395	18272	17181	23679	26645					28099
146					23436	20092	18029	17216	16508	23297	26525					26600

JD	117	118	119	120	121	122	123	124	125	126	127	128	129	130	150	151
135	31085	35247		34268	41843			2909	13605	26121	41384	57194	62435	72852	3674	930
136	32289	35936		36174	42512			5764	12748	25007	40010	54323	59328	69370	4381	8264
137	10522	14983		14698	21506			5747	11863		37128	49730	54487	61098	9126	7084
138	2985	1769		4313	4418			15356	16612		28342	32553	36264	44735	39481	42257
139	14711	12542		21651	15186			27500	17466	12338	14439	8962	10071	17236	60025	62215
140	21174	16508			16006		21923	36246	26758	23014	18604	8993	11001	16596		
141	25466	20463			19895		23467	35173	24966	17685	15615	12087	16385	22219		
142	20017	16993			20043		31392		24876		15310	18274	23116	33650		
143	26909	23936			26586		35227		20721		14688	17648	22431	32925		
144	26349	23217			25722		34400		24272		15109	18178	23044	33600		
145	27115	24498			27541		36925		22881		14398	20179	24813	35038		
146	25687	23172			26413		36627		21674		13273	19032	23366	33283		

JD	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167
135	3885	2955	2764	7859	9549	16612	4069	4444	813	1161	1692	1562	898	795	8601	13798
136	3677	3512	6887	8925	11696	21260	9460	9108	5380	5465	3130	2849	3086	3334	5744	7470
137	3267	3443	15041	15625	15785	21331	9059	8969	5260	5529	2858	2855	3505	4419	4943	9052
138	52382	50008	69249	68656	66095	62756	52038	54227	52642	54877	49803	52614	55235	57059	38614	35330
139	72055	69578	88206	86022	82486	77093	68081	70619	69901	72338	67369	70533	73239	75079	53150	48086

Yellow boxes denote closest approaches less than 10 km.
Red lettering denotes ranges between 10 and 20 km.
Gray lettering denotes ranges between 30 and 40 km.

Appendix 8. Local and regional earthquakes archived.

FFID No.	Year:JD:Hr:Mn:Sec	Latitude	Longitude	Mag-nitude	Depth, km	Source
300001	2002:131:19:10:01.09	47.7962	-122.7728	2.3	23.0	UW
300002	2002:131:19:56:49.46	46.7040	-122.7677	3.2	6.4	UW
300003	2002:131:21:22:00.54	46.8270	-117.1817	2.7	0.1	UW
300004	2002:132:06:10:36.00	48.9200	-123.0500	0.4	22.0	PGC
300005	2002:132:14:28:29.72	48.5392	-121.5993	0.5	5.9	UW
300006	2002:132:18:39:31.76	46.7145	-122.7638	3.0	6.8	UW
300007	2002:132:20:54:16.44	46.4798	-121.3413	2.1	2.2	UW
300008	2002:133:04:22:15.00	49.1800	-128.9400	3.2	10.0	PGC
300009	2002:133:13:47:32.00	49.1500	-122.6600	0.9	18.0	PGC
300010	2002:133:21:00:37.00	48.4000	-123.5100	2.7	44.2	PGC
300011	2002:133:21:21:47.19	46.7065	-122.7703	3.5	46.0	UW
300012	2002:133:21:58:33.73	48.0845	-121.9243	2.0	0.0	UW
300013	2002:133:23:29:14.43	47.9192	-122.7103	1.3	27.8	UW
300014	2002:134:15:26:46.48	48.7395	-121.7677	1.3	20.9	UW
300015	2002:134:17:05:30.21	46.9098	-122.3005	1.2	6.2	UW
300016	2002:134:17:13:10.55	47.8505	-123.0602	2.1	47.7	UW
300017	2002:134:21:33:16.76	46.7085	-122.7700	2.3	8.8	UW
300018	2002:134:21:53:74.82	44.2462	-120.8962	2.7	0.0	UW
300019	2002:134:22:50:19.23	47.0095	-122.0057	1.8	15.3	UW
300020	2002:135:00:29:10.19	47.7810	-122.8283	1.0	24.2	UW
300021	2002:135:01:28:42.65	48.2935	-122.2082	1.0	11.9	UW
300022	2002:135:05:48:21.27	48.6750	-122.0358	0.9	5.3	UW
300023	2002:135:06:26:53.94	47.6607	-121.8197	0.5	12.7	UW
300024	2002:135:08:48:51.09	47.8182	-121.9462	0.1	27.6	UW
300025	2002:135:11:15:14.00	49.5500	-127.1000	1.0	29.0	PGC
300026	2002:135:17:54:48.60	42.2313	-121.9012	4.3	42.0	UW
300027	2002:135:19:00:37.72	47.7977	-121.9865	0.2	0.0	UW
300028	2002:135:21:11:57.72	47.4587	-120.6523	0.9	8.3	UW
300029	2002:135:21:31:32.60	46.7000	-122.7532	2.7	10.0	UW
300030	2002:136:04:19:33.60	46.9978	-122.0055	1.2	14.1	UW
300031	2002:136:05:36:05.00	48.9300	-123.0500	0.3	24.0	PGC
300032	2002:136:05:36:27.85	47.6323	-122.5677	0.9	22.4	UW
300033	2002:136:05:52:27.00	49.3900	-128.7200	2.8	10.0	PGC
300034	2002:136:05:59:55.89	42.2318	-121.9067	2.0	9.5	UW
300035	2002:136:06:54:54.35	47.6860	-123.6775	0.8	38.5	UW
300036	2002:136:20:31:54.48	46.6928	-122.7928	2.3	16.4	UW
300037	2002:137:05:41:52.34	42.2223	-121.9042	2.1	3.8	UW
300038	2002:137:06:39:34.58	47.7075	-123.6640	0.2	29.8	UW
300039	2002:137:07:46:19.82	47.0080	-122.0008	1.4	15.7	UW
300040	2002:137:21:12:13.17	46.7115	-122.7763	2.3	4.4	UW
300041	2002:138:06:31:19.00	48.7900	-123.3600	0.4	18.0	PGC
300042	2002:138:09:09:14.00	48.9200	-123.0500	0.6	23.0	PGC
300043	2002:138:12:06:34.00	49.3300	-123.7200	1.0	2.0	PGC
300044	2002:139:06:02:35.00	49.1800	-127.7800	1.6	10.0	PGC
300045	2002:139:07:47:30.08	47.7313	-122.6242	0.2	26.3	UW
300046	2002:139:10:50:43.00	49.6800	-127.0800	3.9	20.0	PGC
300047	2002:139:17:05:27.65	48.3000	-122.1948	2.7	13.7	UW
300048	2002:140:08:33:38.41	47.6792	-121.8775	0.1	12.1	UW
300049	2002:140:10:44:38.96	47.7783	-122.8637	2.0	20.2	UW
300050	2002:140:12:07:35.31	47.7708	-122.8493	1.4	20.5	UW
300051	2002:141:00:13:56.20	47.8323	-122.0428	0.9	17.3	UW
300052	2002:141:00:30:21.01	47.6525	-120.1918	0.9	0.5	UW
300053	2002:141:10:40:47.00	49.9200	-127.8400	1.0	30.0	PGC
300054	2002:141:19:06:40.46	48.0923	-121.9127	1.5	48.0	UW

300055	2002:141:19:31:74.08	48.4665	-122.1773	0.5	0.0	UW
300056	2002:141:21:03:20.83	46.7063	-122.7738	2.4	7.0	UW
300057	2002:141:22:25:43.00	48.7200	-128.6300	2.7	10.0	PGC
300058	2002:142:00:29:43.10	47.8135	-123.0588	1.5	24.8	UW
300059	2002:142:03:41:52.00	48.6400	-124.7400	1.3	34.0	PGC
300060	2002:142:05:58:39.01	47.0435	-121.9200	0.4	19.9	UW
300061	2002:142:18:44:26.14	46.6220	-120.5438	2.1	8.0	UW
300062	2002:142:19:59:02.00	49.1500	-127.7400	1.7	10.0	PGC
300063	2002:142:20:55:15.31	46.7070	-122.7623	3.2	10.7	UW
300064	2002:143:01:19:09.11	49.0073	-122.5328	1.8	11.0	UW
300065	2002:143:10:49:16.58	48.4393	-123.0828	1.1	17.1	UW
300066	2002:143:18:04:35.34	47.7775	-122.8445	0.7	20.5	UW
300067	2002:143:21:02:10.14	46.7010	-122.7628	3.0	8.8	UW
300068	2002:143:21:43:49.86	45.5573	-123.3645	2.1	0.0	UW
300069	2002:143:22:34:58.41	46.9803	-122.2022	1.3	1.5	UW
300070	2002:143:23:05:37.67	47.7708	-122.8438	1.1	19.4	UW
300071	2002:144:11:17:29.06	48.0527	-122.6175	1.0	29.5	UW
300072	2002:144:13:57:17.00	49.6900	-127.0700	1.0	22.0	PGC
300073	2002:144:14:09:29.00	49.3600	-123.9400	1.3	64.0	PGC
300074	2002:144:20:32:37.46	46.5898	-123.0228	2.5	4.0	UW
300075	2002:144:21:07:56.73	46.7002	-122.7678	3.3	7.0	UW
300076	2002:144:22:40:76.31	45.3330	-121.6828	2.0	3.2	UW
300077	2002:146:02:17:32.00	48.8700	-123.4500	0.2	20.0	PGC
300078	2002:146:10:21:53.82	47.7048	-120.1128	2.0	2.4	UW
300079	2002:146:14:04:21.43	48.1825	-120.1703	1.8	0.6	UW
300080	2002:147:08:43:58.61	48.2040	-120.1717	2.4	1.3	UW
300081	2002:147:11:41:37.19	47.7842	-122.8223	0.9	23.4	UW
300082	2002:147:17:41:21.00	48.6300	-128.8800	2.6	10.0	PGC
300083	2002:147:17:52:33.38	46.7082	-122.7568	2.9	8.2	UW
300084	2002:147:19:33:38.77	46.9372	-121.9682	2.4	13.2	UW
300085	2002:147:21:47:39.00	48.7600	-128.5700	2.3	10.0	PGC
300086	2002:147:22:56:56.00	48.8100	-128.5200	2.6	10.0	PGC

Sources: Pacific Geoscience Centre (PGC), University of Washington (UW).

Appendix 9. Teleseisms archived to tape.

FFID	YR	JD	Hr:Mn	Sec	Latitude	Longitude	Mag.	Depth
400001	2002	132	23:12	52.91	-1.1430	127.0870	5.5	33.0
400002	2002	133	19:54	43.12	19.1410	121.2380	5.5	33.0
400003	2002	133	19:57	22.90	19.1320	121.2380	5.5	33.0
400004	2002	134	14:19	03.38	3.5070	125.3770	5.5	33.0
400005	2002	134	16:56	10.42	-36.5180	78.9320	5.6	10.0
400006	2002	135	03:27	35.58	-21.4050	-174.2610	5.7	10.0
400007	2002	135	03:46	05.76	24.6360	121.9220	5.7	10.0
400008	2002	137	10:40	10.77	48.1680	-27.8080	5.7	10.0
400009	2002	138	15:15	08.80	-2.9070	33.7330	5.8	10.0
400010	2002	141	06:02	59.94	17.7790	-81.9110	5.9	10.0
400011	2002	141	20:04	16.16	44.4300	146.6190	5.9	149.8
400012	2002	143	15:52	15.28	-30.7490	-71.1970	5.9	52.1
400013	2002	143	22:05	51.82	-5.8160	102.0640	6.0	10.0
400014	2002	144	00:23	15.93	-31.9710	-70.9470	6.2	60.2
400015	2002	145	05:36	31.97	53.8150	-161.1160	6.3	33.0
400016	2002	146	00:10	21.04	1.8320	127.2380	6.5	109.0

Source: National Earthquake Information Center (NEIC)

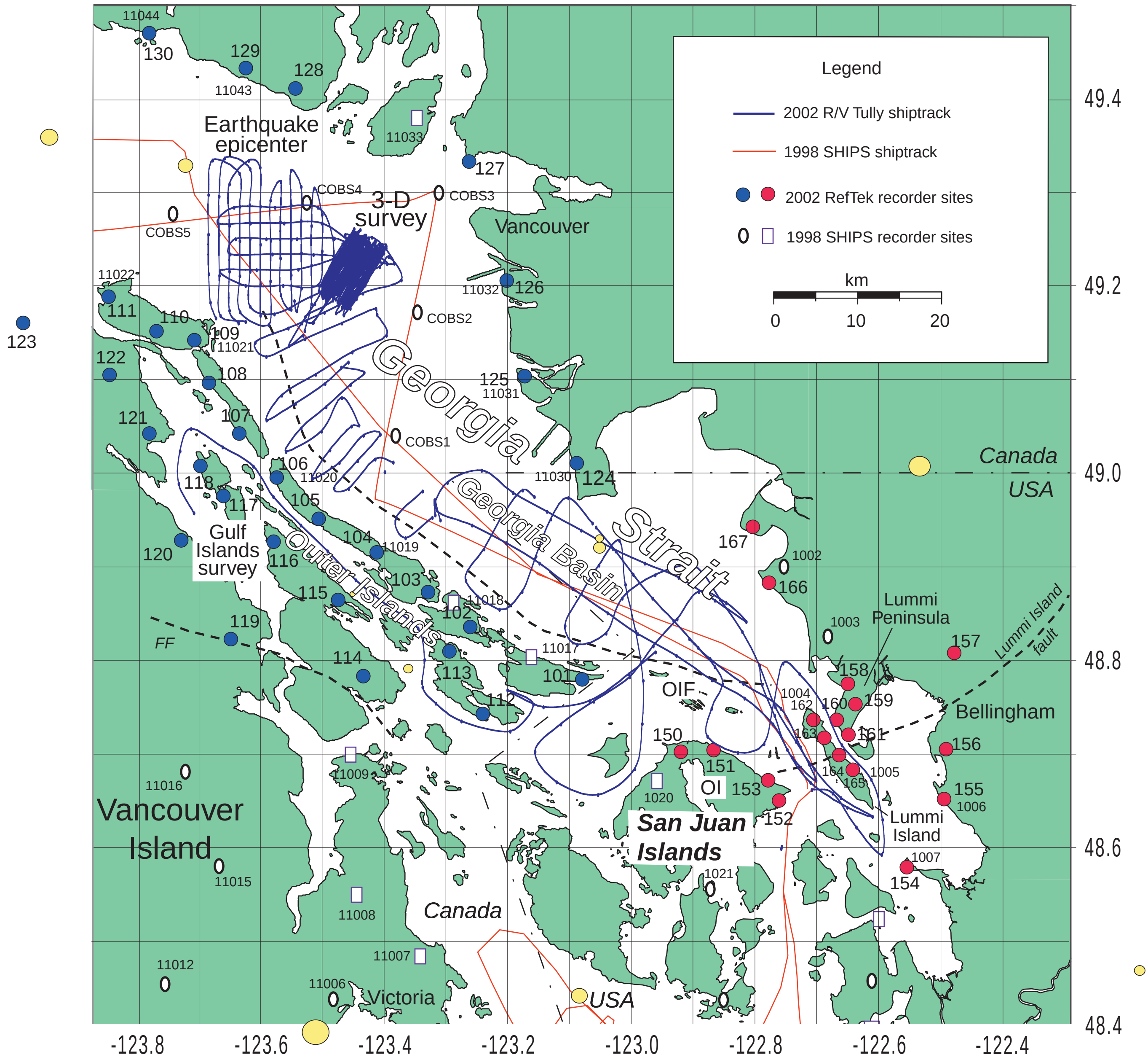

Figure 1. Map showing location of Tully tracklines and RefTek receivers, 1998 SHIPS tracks and receivers, and earthquakes (yellow dots) that were recorded during the 2002 Georgia Basin Geohazards Initiative study. Blue filled circles show Canadian stations, red filled circles show U.S. stations. For 1998 SHIPS ellipses show vertical-component stations whereas rectangles show three-component stations. Abbreviations: FF-Fulford fault, OI-Orcas Island, OIF-Outer Islands fault.

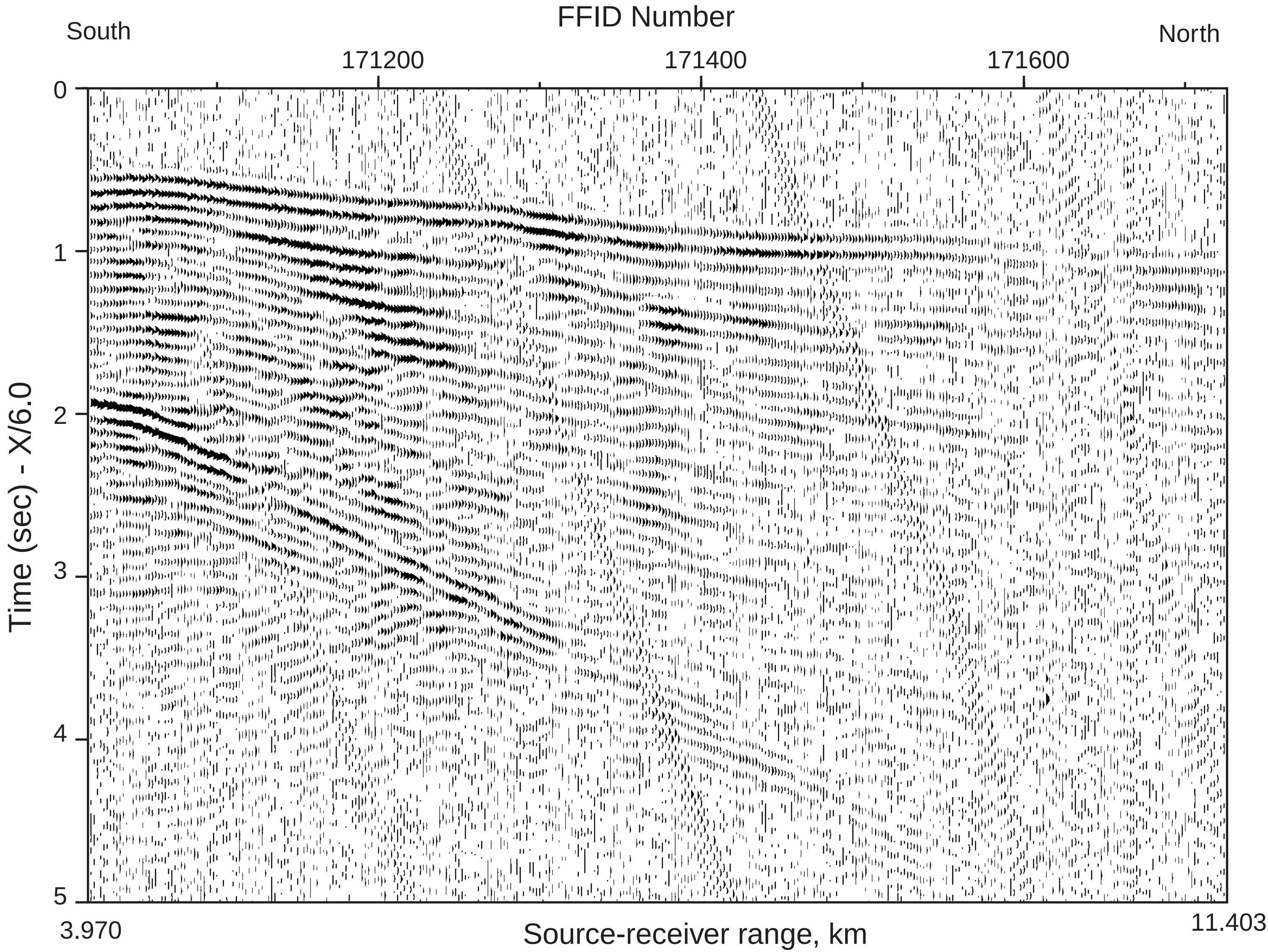

Figure 2. Common-receiver gather for site 109 (DAS 7601), for line 61, Julian Day 140. Traces have been bandpass filtered and only every other trace is plotted. Line 61 is a N-trending line in the 2-D Earthquake Epicenter survey.

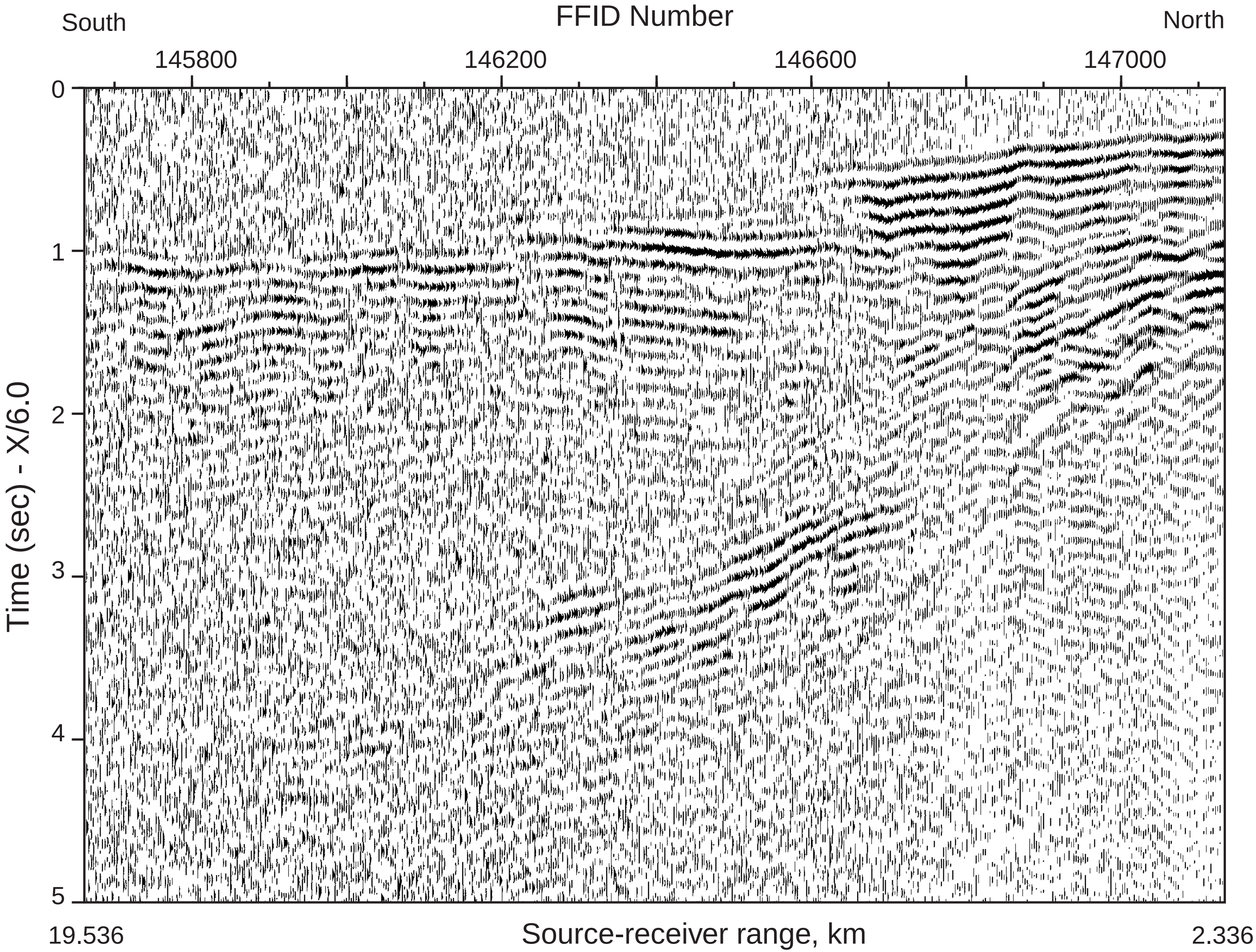

Figure 3. Common-receiver gather for site 105 (DAS 7333), for lines 33-34, Julian Day 137. Traces have been bandpass filtered and only every third trace is plotted. Line 33-34 are NW-trending lines in the Gulf Islands survey.

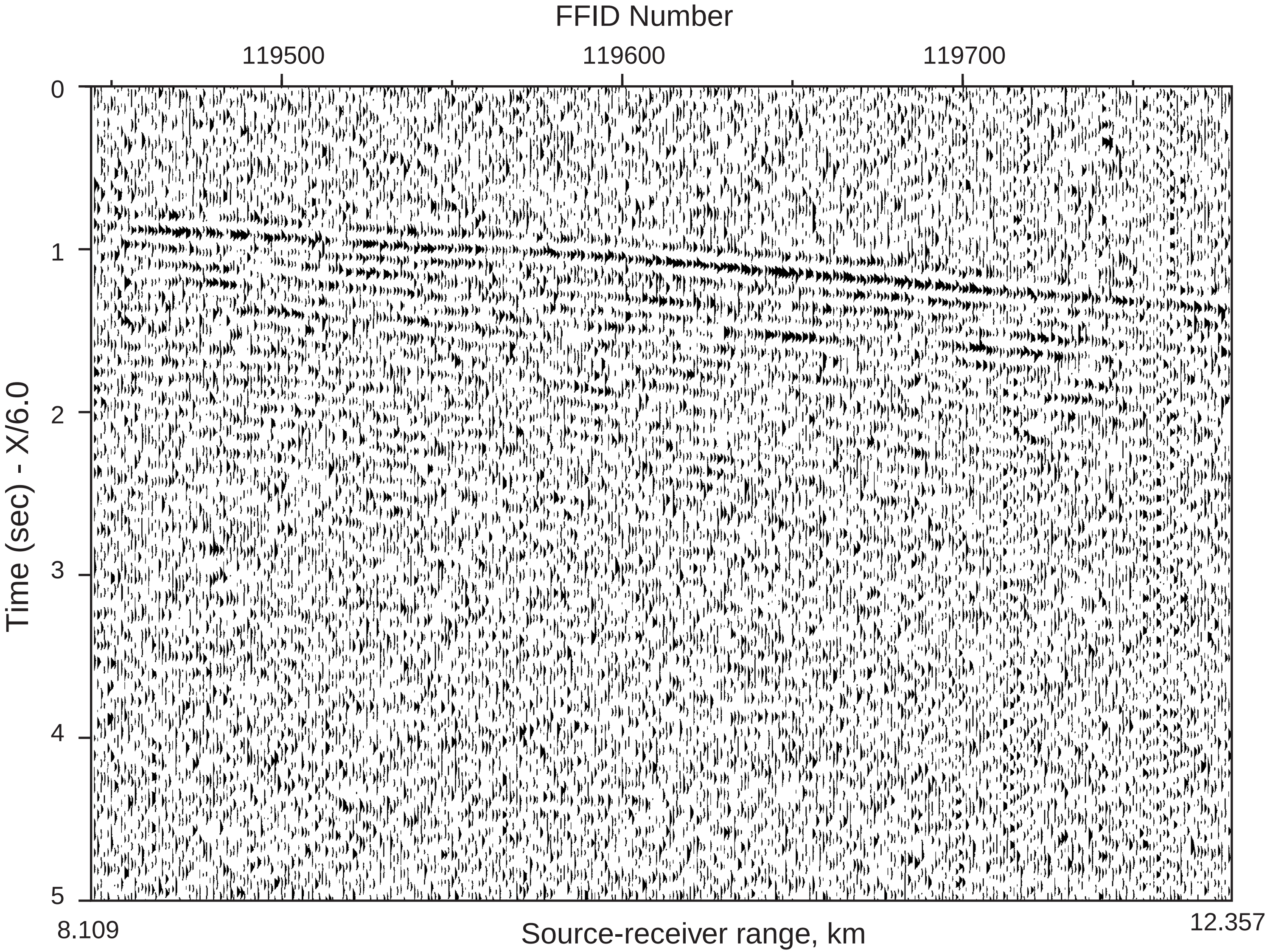

Figure 4. Common-receiver gather for site 113 (DAS 6107), for line 10, Julian Day 135. Traces have been bandpass filtered and only every other trace is plotted. Line 10 is a line in the Outer Islands survey.

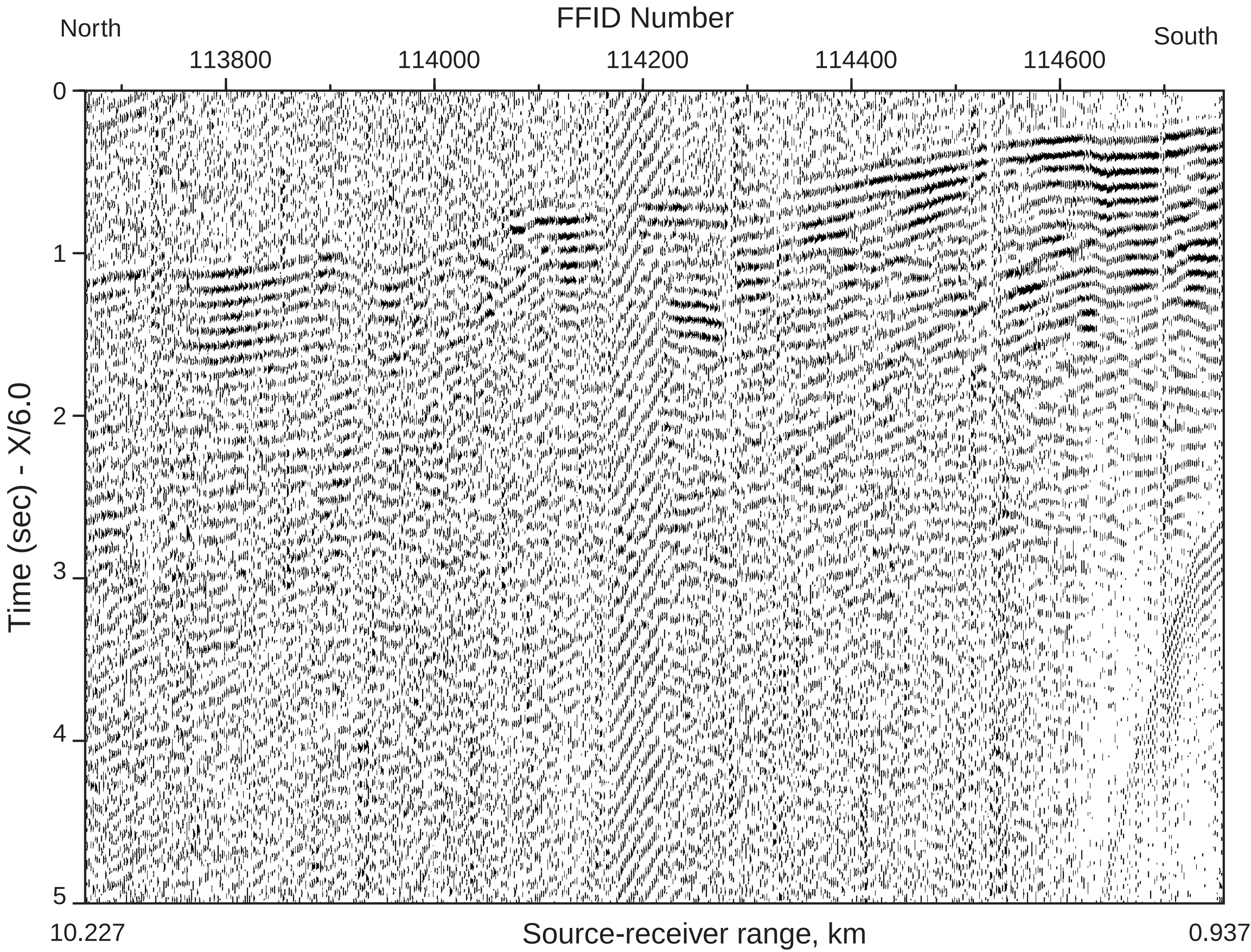

Figure 5. Common-receiver gather for site 151 (DAS 7284), for line 4, Julian Day 135. Traces have been bandpass filtered and only every other trace is plotted. Line 4 is a line running along the north end of Orcas Island.

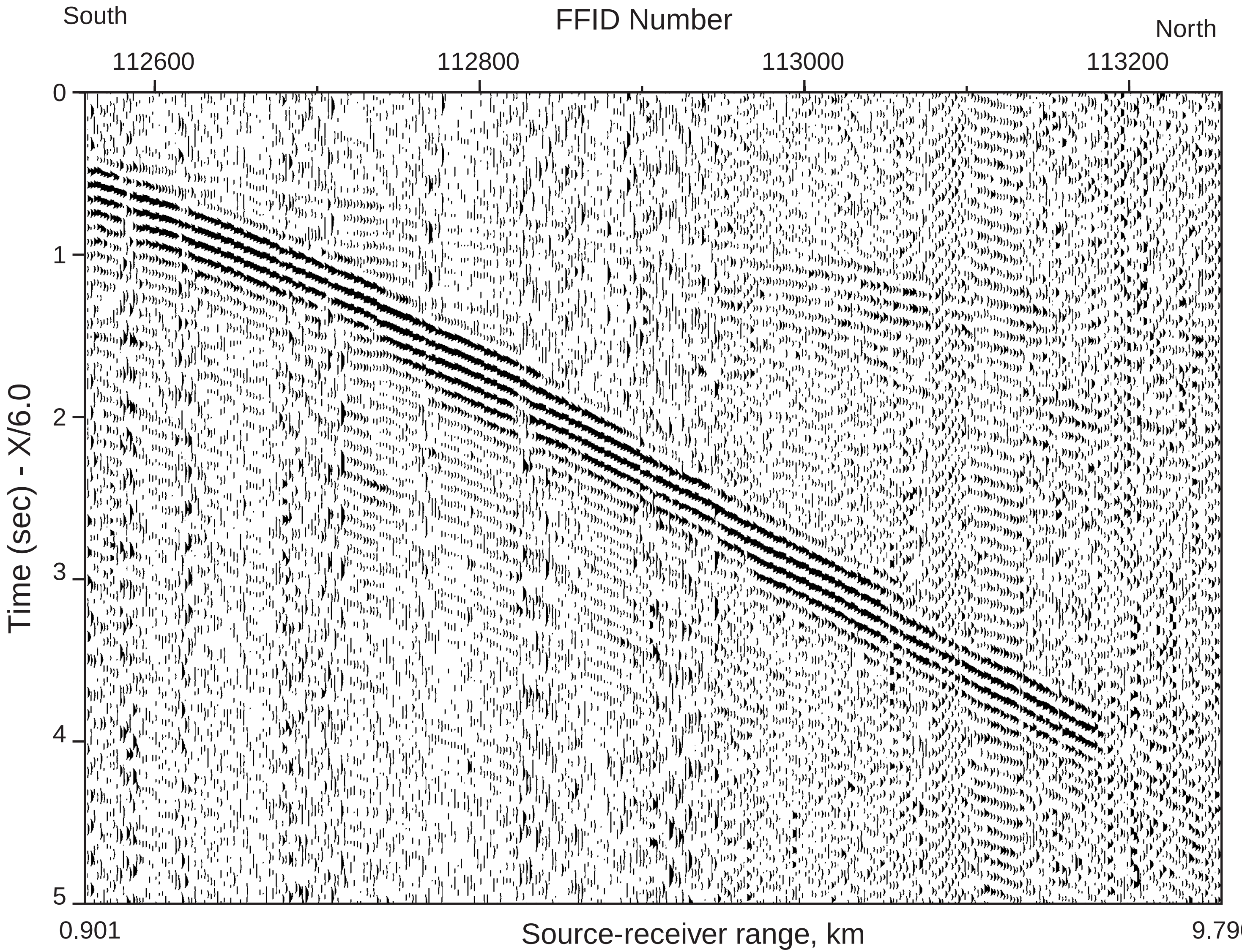

Figure 6. Common-receiver gather for site 160 (DAS 7596), for line 3, Julian Day 135. Traces have been bandpass filtered and only every other trace is plotted. Line 3 is a N-trending line in between Lummi Island and Lummi Peninsula.

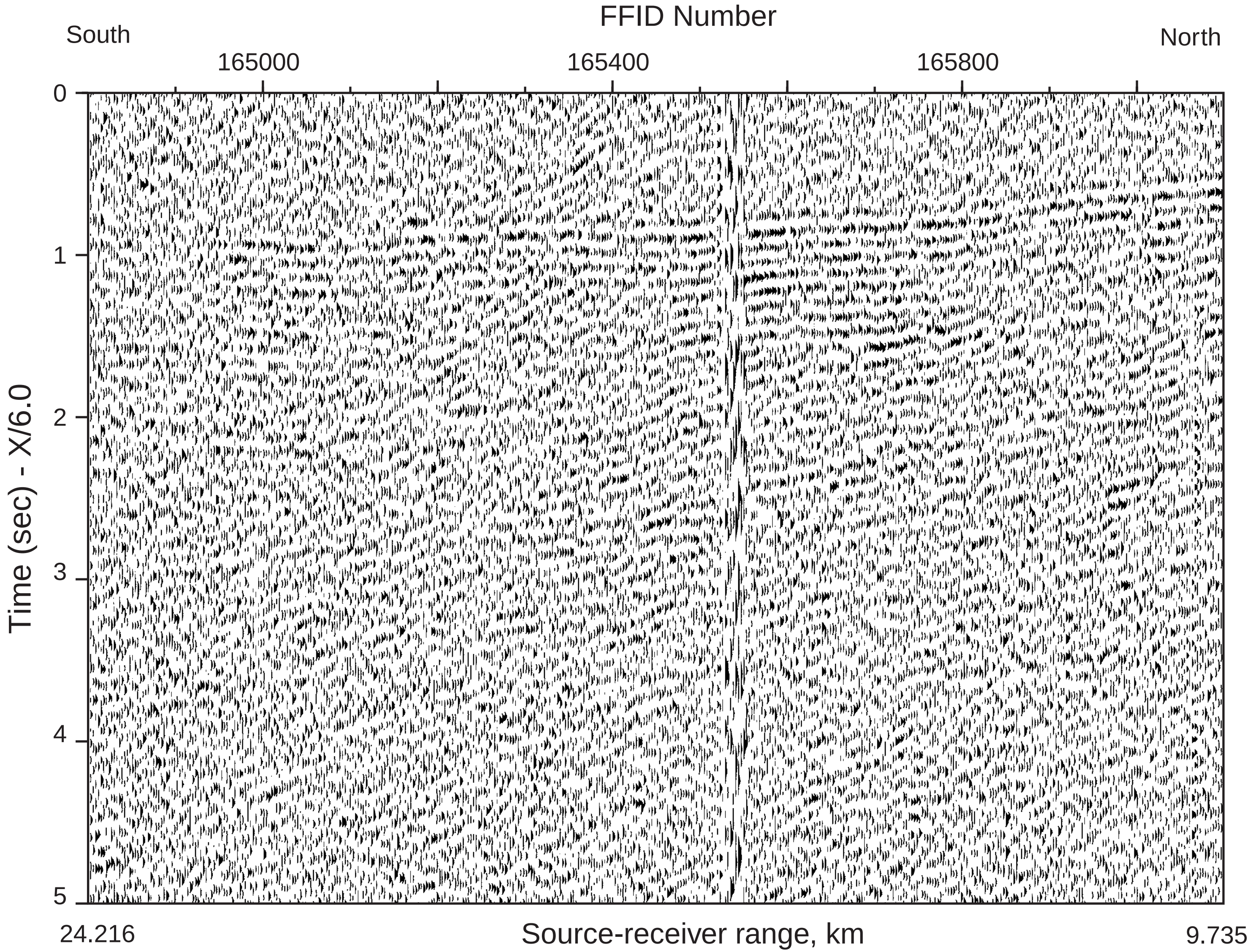

Figure 7. Common-receiver gather for site 128 (DAS 7283), for line 56, Julian Day 139. Traces have been bandpass filtered and only every third trace is plotted. Line 56 is a N-trending line in the 2-D Earthquake Epicenter survey.

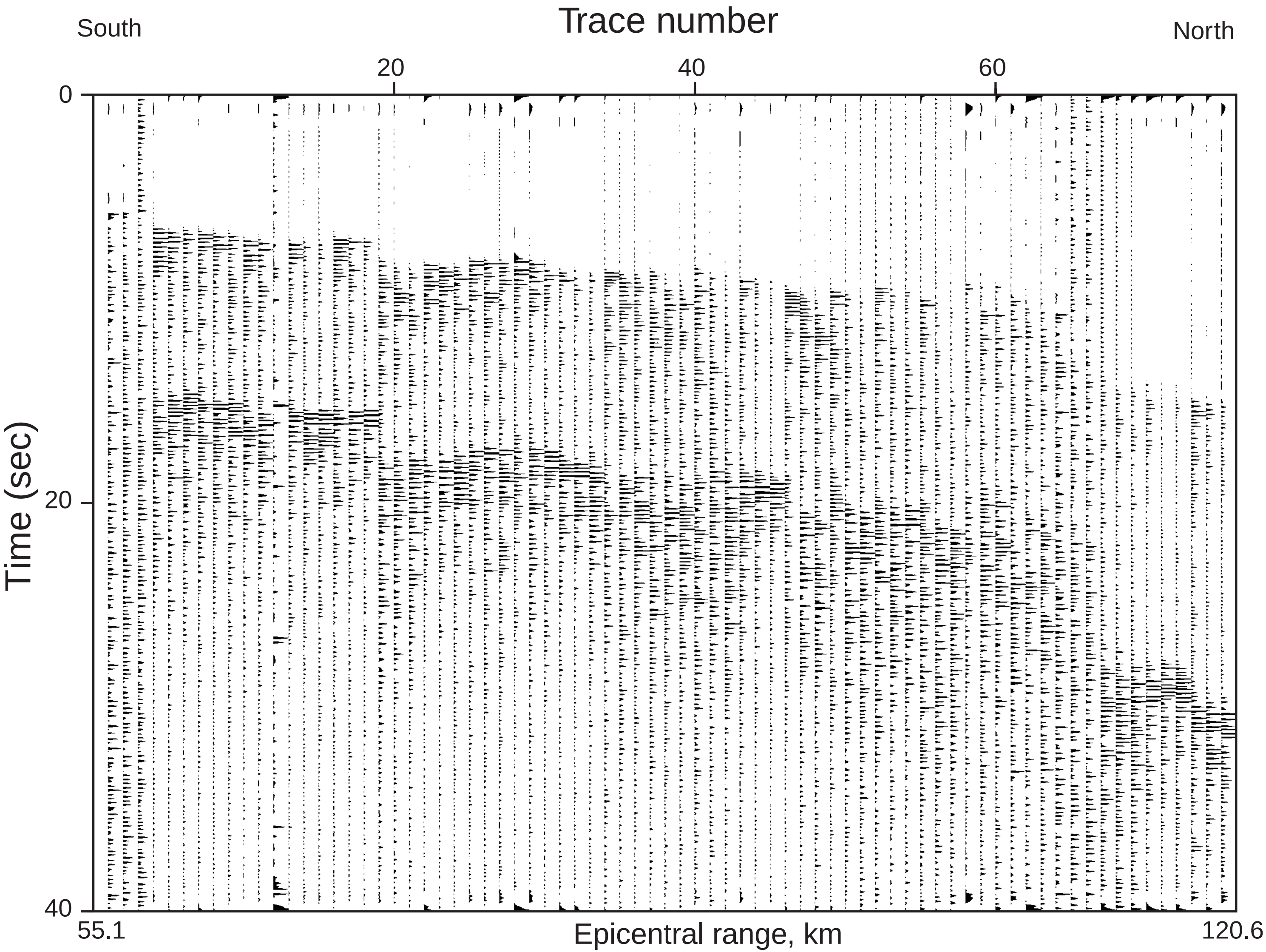

Figure 8. Three-component recordings of local earthquake 300010 , at 20:59 on Julian Day 133 (see Appendix 8). Traces have been bandpass filtered. This M2.7 earthquake originated about 44 km beneath Victoria.

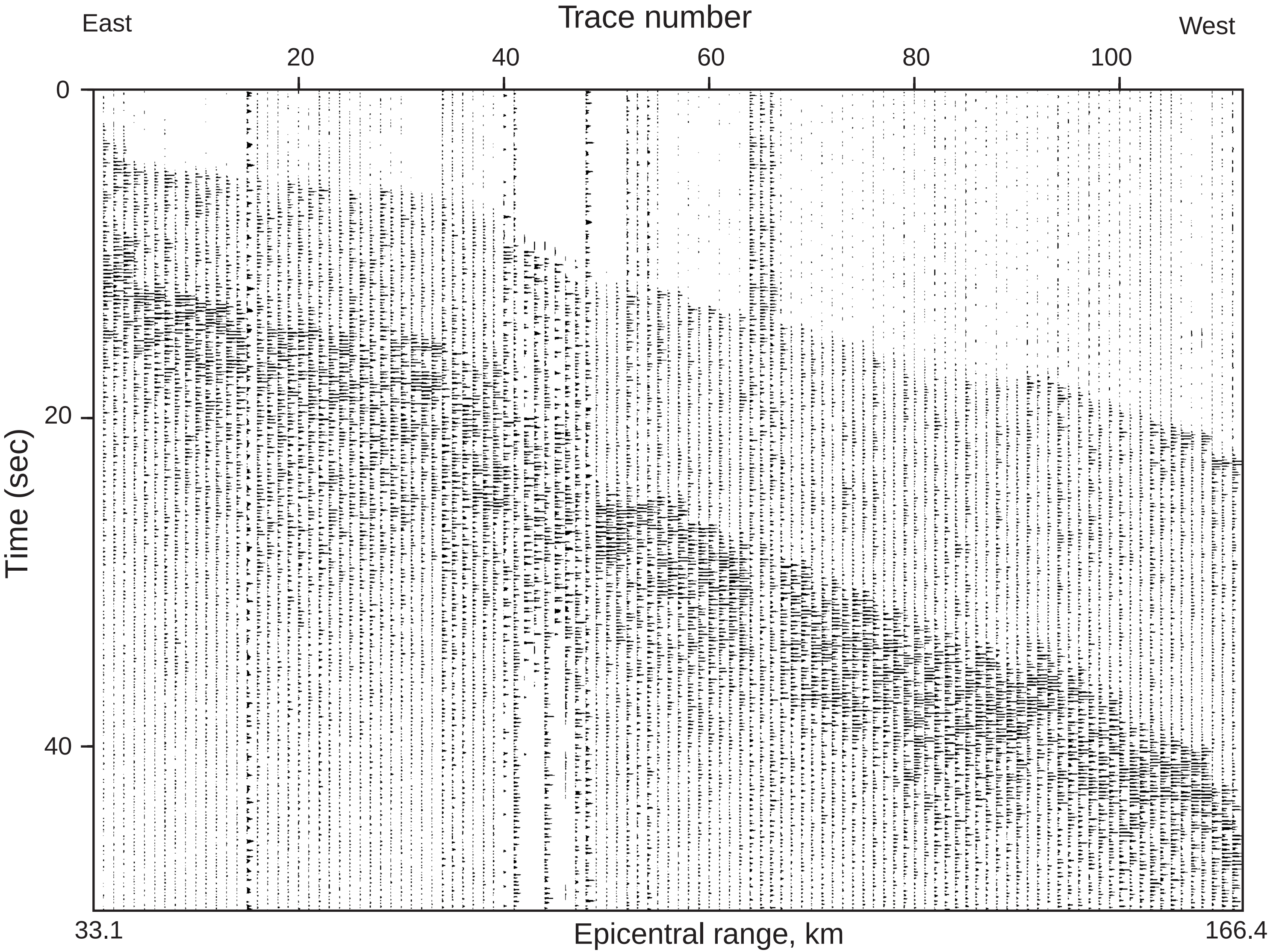

Figure 9. Three-component recordings of local earthquake 300047, at 17:05 on Julian Day 139 (see Appendix 8). Traces have been bandpass filtered. This M2.7 earthquake originated just SE of Figure 1.