GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7555

Cruise Report 2012005PGC

The Mw 7.7 Haida Gwaii Earthquake Ocean Bottom Seismometer Experiment
Instrument deployment, gas-plume acoustic imaging, and water sampling

CCG Vessel John P. Tully
7-11 December, 2012

M. Riedel, M.M. Côté, P.J. Neelands

2014

Natural Resources Canada | Ressources naturelles Canada

Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7555

Cruise Report 2012005PGC

The Mw 7.7 Haida Gwaii Earthquake Ocean Bottom Seismometer Experiment
Instrument deployment, gas-plume acoustic imaging, and water sampling
CCG Vessel John P. Tully, 7-11 December, 2012

M. Riedel, M.M. Côté, P.J. Neelands

2014

doi:10.4095/293918

This publication is available for free download through GEOSCAN (http://geoscan.nrcan.gc.ca/).

Recommended citation
Riedel, M., Côté, M.M., and Neelands, P.J., 2014. Cruise Report 2012005PGC, The Mw 7.7 Haida Gwaii Earthquake Ocean Bottom Seismometer Experiment, Instrument deployment, gas-plume acoustic imaging, and water sampling, CCG Vessel John P. Tully, 7-11 December, 2012; Geological Survey of Canada, Open File 7555, 36p. doi:10.4095/293918

Publications in this series have not been edited; they are released as submitted by the author.

TABLE OF CONTENTS

List of Tables

List of Figures

1. Introduction

1.1 General information

Canada’s second largest instrumentally recorded earthquake occurred at 8:05 p.m. PDT on October 27th, 2012, off the west coast of Moresby Island, Haida Gwaii (Figure 1). The earthquake occurred at the southern end of the rupture zone of the 1949 M 8.1 strike-slip earthquake, which was Canada’s largest instrumentally recorded event. Analysis of seismic waveforms and the pattern of aftershocks indicate that it was a “thrust” earthquake, similar to the earthquake that hit Japan off Tohoku on March 11, 2011. The tectonic margin off Haida Gwaii, extending to southern Alaska, is the transform fault boundary between the Pacific and North America plates. Off Moresby Island where the M 7.7 event occurred, there is a 20 degree oblique convergence between the Pacific and North American plates, giving rise to a small accretionary prism, referred to as the Queen Charlotte terrace, the main study area of this Ocean Bottom Seismometer (OBS) experiment. Thrust earthquakes have the potential to generate large tsunamis, and models for this event predict wave heights in some bays and inlets along the coast of Moresby Island as large as 3-5 m. Results from a post-tsunami survey along select inlets along the west coast of Haida Gwaii confirmed significant wave heights. In the first month after the earthquake more than 20,000 aftershocks were recorded. The majority of these are less than magnitude 2. The initial locations of aftershocks from this earthquake (Figure 1) cover an area 150 km along the margin and at least 50 km wide, extending seaward from beneath the west coast of Moresby Island to more than 50 km offshore. The central zone on the aftershock sequence is the target of the OBS experiment.

1.2 Objectives of the OBS experiment

To accurately locate earthquakes, recording stations need to be positioned such that they surround the epicenter and the speeds at which seismic waves travel through the earth’s crust must be known. The land stations on Haida Gwaii are all to the east of the aftershock sequence, thus making these offshore earthquake locations uncertain and making depths for those events almost impossible to calculate accurately. The OBS instruments will improve locations considerably, especially the depth. If a few earthquakes are recorded with both the land and OBS instruments, the combined data can help to improve the locations of many more aftershocks recorded on only the land stations, and will help improve the historic earthquake catalog and reduce previous biases in the earthquake locations.

The distribution of the OBS deployment locations was chosen to cover a reasonable area of the aftershock sequence centered around the epicenter, covering mostly the Queen Charlotte terrace (Figure 2). The deployment occurred in December with a recovery mission planned for January 2013, which typically restricts offshore operations due to expected heavy seas and high wind speeds in this region. Thus, the study area had to be limited in extent to avoid large distances between stations. A total of nine (9) instruments were obtained from the instrument pool at the NRCan office at the Bedford Institute of Oceanography (BIO) in Dartmouth, NS. The instruments are referred to as "NRCan" instruments throughout this report. An Additional nine (9) instruments were borrowed from Dalhousie University through collaboration with Dr. Keith Louden, but due to logistical constraints of recovery in January only five (5) of these were deployed.

The deployment pattern of these 14 instruments is further defined by the planned seismic refraction experiment in January, 2013 (Riedel et al., 2014). The seismic refraction work will help define the seismic velocity structure beneath each of the OBS instruments thus reducing uncertainty in the overall earthquake location processing.

1.3 Accomplishments and results

The expedition accomplished the deployment of 14 OBS instruments (9 instruments from NRCan and 5 instruments from Dalhousie University) as depicted in Figure 2. Due to the extreme weather forecast for the study area on Tuesday and Wednesday (December 11&12, 2012), we abbreviated the deployment procedure by not monitoring the decent of each OBS to the seafloor with the 12 kHz echo sounder. The water depths of the OBS stations vary from ~1300 m to ~2900 m, or equivalently 22 to 48 minute decent time. The monitoring would have extended the operations by approximately 6 hours and thus we would have run the risk of being offshore during bad weather and sea conditions preventing any further operations. Due to total available battery life and data storage capacity (see section 6), the OBS recording times differ between stations, with half the stations starting on December 15th (7 NRCan instruments) and the other half starting on December 22nd (2 NRCan and 5 Dalhousie instruments).

After the OBS deployment was completed we used the hull-mounted 3.5 kHz sounder to image the Queen Charlotte transform fault as well as the prominent plateau-feature and the area of known gas plumes. This was a preliminary test to prepare for the more extensive seismic work to be conducted in January. A total of 5 hours of surveying was completed with the 3.5 kHz sounder (Figure 3). Figure 4 shows several examples of the 3.5 kHz data and Figure 5 shows a close-up of the multibeam data across the plateau.

We also took this opportunity to conduct an acoustic survey over known gas plumes (Figure 6). Gas plumes up to 150 m high above the seafloor were also found over prominent seafloor knolls of the plateau (Figure 7). These features will be further explored during the January expedition. Additionally, we took water samples for gas analyses, which only were possible during this expedition in December, due to access-limitation to the water sampling rosette (to be taken off the vessel for maintenance in January). A total of 48 samples were taken and stored for gas analysis, and possible isotopic composition at the University of Victoria in collaboration with Dr. Michael Whiticar, School of Earth and Ocean Sciences.

2. Narrative of events

All times listed here are local time, Pacific Standard Time (PST).

06/12 Thursday

All day equipment was loaded and lab components were set up

07/12 Friday

09:00 Dry-run test of Conductivity-Temperature-Depth (CTD) instrumentation and rosette with S. Rose, P. Neelands, M. Côté, M. Riedel

11:00 Depart from IOS; prepare for water sampling test with CTD and rosette
Scott Rose onboard
11:30 On station in Saanich Inlet for CTD test
11:50 Test completed, break for lunch
12:15 Scott Rose departs by zodiac back to IOS
12:30 En route to port Hardy, inside passage
13:00 Safety meeting and briefing by Coast Guard, followed by life-boat station drill
13:30 Tour of the vessel and instruction of main safety rules; testing of survival suits

15:00 Discussion by B. Iuliucci, G. Standen, P. Neelands, M. Riedel on settings for OBS recordings (see details in Section 6); battery life time for the analog board (the unit with amplifiers) is most critical and most limited by battery-power levels.
From experience, the comfort zone is a maximum of 3 weeks (21 days) that full operation of the OBS unit is guaranteed. The recovery cruise is schedule for January 7-14, 2013; thus, recording on any of the OBS should not start prior to December 15, 2012; All settings are listed in Table 1.

08/12 Saturday

09:00 Removal of life-boat used for SAR operation for duration of OBS work to clear space on aft-deck
10:00 Arrive in Port Hardy for fuelling
10:45 Start fuelling
17:45 Fuelling completed; adjust ballast tank level
19:00 Leave Port Hard for study area

09/12 Sunday

14:00 Arrive on station for first OBS deployment
See Table 2 for sequence of deployment and final drop locations
14:38 OBS-7 (NRCan, OBS-K) deployed
14:50 Hydraulic oil leak on winch, adjusted pressure and repair winch
15:33 OBS-6 (NRCan OBS-J) deployed
16:07 OBS-5 (NRCan, OBS-H) deployed
17:11 OBS-14 (NRCan, OBS-N) deployed
17:56 OBS-13 (Dalhousie, OBS-J) deployed
18:17 OBS-4 (NRCan, OBS-F) deployed

18:45 OBS-12 (Dalhousie, OBS-D) deployed
19:26 OBS-10 (NRCan, OBS-L) deployed
20:19 OBS-9 (Dalhousie, OBS-B) deployed
21:12 OBS-8 (Dalhousie, OBS-A) deployed
22:13 OBS-3 (NRCan, OBS-E) deployed
23:08 OBS-2 (NRCan, OBS-D) deployed
23:52 OBS-1 (NRCan, OBS-A) deployed

10/12 Monday

03:30 OBS-11 (Dalhousie, OBS-C) deployed
End of all OBS deployment
Start steam to transect across Queen Charlotte Fault
06:00 Approaching first way point for survey
12/18/38 kHz system
3.5 kHz sounder
NOTE: data acquisition with AGC-Digs system produces a 16-bit SEGY-format
09:30 Transit across the "plateau"
Surface features are associated with gas plumes!
10:30 Transect across 1st gas plume
There is no gas plume seen in data
12:20 Transect across 2nd gas plume
Here we see a clear gas plume
Create a second transect in perpendicular direction and define deployment site
12:40 Rosette deployed, first 4 bottles were fired, but ship drifted out of plume. Reposition ship over plume and remaining 20 bottles were fired.
13:40 Rosette sampling completed and unit back on deck secured.
Sub-sampling of water for gas extraction
Steam to Port Hardy

11/12 Tuesday

08:00 Arrive and secure on dock, life-boat station, Granville Street
Contact Scott Rose and Fred Wright for pickup
Contact Budget for pickup with rental vehicle
09:00 NRCan truck on the road with P. Neelands, G. Standen, G. Middleton
09:30 Rental car departure: M. Ulmi, F. Wright, M. Côté, P. Meslin, B. Iuliucci, and M. Riedel
10:45 Departure of DFO truck with rosette; S. Rose, C. Stacey, and Coast Guard employee
18:00 All arrive safely back at IOS

3. OBS deployment procedures

Instrument frames with all floatation were pre-assembled at IOS prior to departure and stored onboard the vessel on the starboard breezeway (Figure 8a). OBS anchors were stored onboard the ship close to the lab and prepared individually prior to final assembly by removing rust-buildup (Figure 8b). A wooden setup-box was used for preparing OBS components by providing easy access to all components on the aft deck (Figure 8c, d). Inside the main dry-lab, the OBS pressure housings and electronic packages were stored on racks; a special setup was used for adding battery packs and to program the OBS settings (Figure 8e, f).

The OBS instruments that were ready for deployment were stored on the aft deck near the A-frame and secured for heavy sea-state. Just before reaching the designated deployment station, the OBS-recovery rope was fully removed and laid out on deck, a tag-line for controlled deployment was added and a slip-hook was attached to the metal loop on the OBS outer housing (Figure 8g). The winch (Figure 8i) lifted the OBS unit about 1.5 meter off the deck (Figure 8h) and the A-frame was extended moving the OBS off the stern by approximately 4-5 meter (Figure 8j). The OBS was then lowered slowly until it reached the water surface (Figure 8k). As the OBS entered the water the weight was lifted off the wire by the floatation spheres, the slip-hook was pulled, and the OBS released into the water (Figure 8l). Operations were (despite some heavy seas up to 5 meter swell) smooth and swift, and the deployment sequence was completed within 15 minutes after arrival on a station. All 14 instruments were deployed in a total of 14 hours.

4. Acoustic imaging of gas plumes

Prior to expedition 2012005PGC, two plumes associated with cone-shape volcano-like structures were identified (e.g. Figure 3). For this expedition, we prepared to for sample the plumes with a rosette, identical as to the sampling conducted during the 2010 SeaJade recovery mission (Riedel et al., 2014b).

The water sampling rosette (Figure 9) was tested in Saanich Inlet prior to departure, with the operational sequence of deploying and recovering the unit, firing sampling bottles and digital data acquisition reviewed with assistance from Scott Rose, DFO on Friday, December 7th, 2012.

The acoustic imaging across the two volcano-like structures on December 10 showed only one gas plume over the southern-most pinnacle (Figure 6). A plume of approximately 400 m height above seafloor was identified in the 12 kHz sounder data. The sounder system also recorded data at 18 kHz, 38 kHz, 70 kHz, 120, and 200 kHz frequencies. The best plume image is seen in the 12 kHz and 18 kHz data; a slightly lower return signal is seen at the 38 kHz frequency, which also imaged plankton layers. No plume (or plankton layers) can be identified at any of the higher frequencies ranges.

After identification of the plume, a new line, perpendicular to the original transect was designed for determining the width of the plume. After acquiring this second line, the estimated plume location from previous cruises was deemed best for deploying the rosette.

5. CTD and water sampling

A simple vertical sampling strategy was deemed best for this plume structure and the deepest sample was set to be 10 m off bottom (see Table 3). Samples were up-cast at 10 m intervals. At the beginning of the rosette deployment, the vessel drifted to the south-east and the echo-return of the plume became weaker. The first four bottles were fired and then further sampling was halted until the vessel was re-positioned. The rosette was lowered back to maximum depth and sampling continued until all bottles were fired. After the unit was secured on deck, sub-sampling of the water was conducted (Figure 10). Only one syringe was available for sub-sampling, which slowed the procedures slightly (compared to the SeaJade expedition, where three samples could be taken simultaneously). The sequence of sampling was as follows:

(a) Fill the syringe with water, then expel. Repeat three times to rinse the syringe
(b) Take 30 ml of water, then and add 30 ml of air
(c) Attempt to remove any air bubbles adhered to the inner surface of the syringe
(d) Shake syringe vigorously for 1 minute
(e) Let syringe rest for 1 minute
(f) Push headspace gas into pre-evacuated 30 ml Wheaton-bottle;
(g) Record volume of gas injected into bottle
(g) Store bottles at cold temperature (~4°C);

From each Niskin-bottle with seawater, 2 samples of headspace gas were taken. The samples where then delivered to Michael Whiticar at the University of Victoria for further analyses of gas content and potential isotopic composition of the gases.

6. Criteria for OBS recording parameters

Two different sets of OBS were deployed: 9 instruments from NRCan and 5 instruments from Dalhousie University. The main difference between these instruments is the available space for data storage: the NRCan instruments are equipped with a 16 GB flash card, whereas the Dalhousie instruments are equipped with a 4 GB flash card. All other components that influence recording time and frequency content were identical. The following criteria were evaluated before setting the recording parameters:

- Total battery life time
- Sampling rate
- Backup release time
- File size for data transfer
- Amplitude gain function
- Filter settings

6.1 Recording frequency / sampling rate

The sampling rate (sampling frequency) chosen for the OBS was determined by the maximum storage capacity of the flash disks and expected duration of recording. For the NRCan OBS with 16 GB of memory, the sampling frequency was set to 500 Hz, which is equivalent to a 2 millisecond sampling rate. This results in a Nyquist frequency of 250 Hz. The Dalhousie OBS instruments have 4 GB of memory and a primary purpose of recording data during the refraction experiment in January. Therefore, a sampling frequency of 200 Hz (5 ms sampling rate) was chosen, such that the Nyquist frequency is 100 Hz to achieve a reasonable frequency content for the passive monitoring and the active airgun refraction experiment. In addition, the duration of recording time for the Dalhousie OBS was reduced by 1 week so that the 4 GB data storage capacity is not exceeded (effectively starting on December 22, 2012). Table 1 summarizes the recording parameters of each OBS instrument.

6.2 Battery life

None of the instruments used in this experiment have been deployed for longer than 2.5 weeks. Post-deployment battery tests showed that the available voltage for the analog boards was reduced to 7.5 V (from the original 9V). A critical cut-off for the functionality of the analog board is around 5.5 - 6.0 V. Thus it was decided to limit the recording times to ensure functionality of the instruments for the seismic refraction work. As a result, seven NRCan instruments were set to begin recording on December 15, 2012 and the remaining two were set to start on December 22, 2012 with the Dalhousie instruments.

6.3 Backup release time

The acoustic transponder units on all OBS instruments are supplied with sufficient battery power for the duration of the experiment. However, the acoustic triggering of the OBS release is potentially compromised by poor data transmission caused by rough seas. To ensure recovery of the instruments, each instrument has been programmed to detach from the anchor at a specific time in January before the vessel must leave the study area and return to Port Hardy. The backup release time was calculated using water depth (equivalent to a rise-time) and distance between stations so that a continuous recovery sequence is achieved. The parameters for the backup release time are listed in Table 2.

6.4 File size for data transfer

The data from the three-component geophone and external hydrophone are recorded until a set file size is reached. The data are then transferred for permanent storage on the flash card. Data file sizes of 2, 4, 6, 8, 16, and 32 MB are available. During the data transfer, the OBS is unable to record data. Transfer times are a function of the file size itself, such that a larger file size yields a longer period of no-data acquisition, while shorter file sizes result in more frequent, but shorter periods of no-data acquisition. Testing of various file sizes and data transfer times yield an optimum file size of 16 MB. The duration of no-data acquisition is approximately 2 seconds.

6.5 Amplitude gain function

Amplitude gain functions were used for standard operations using airgun sources for refraction analyses. The size of earthquakes and energy from surface waves is likely in the same order of magnitude as the airgun operations, so we did not change the settings from the standard values.

6.6 Filter settings

The acquisition is set to include a high-cut filter, which was set to 1 kHz for all instruments.

7. References

Riedel, M., Côté, M.M., Neelands, P.J., 2014a. Cruise Report 2013001PGC, The Mw 7.7 Haida Gwaii Earthquake Ocean Bottom Seismometer Experiment, Instrument recovery and active-source seismic refraction experiment, CCG Vessel John P. Tully, 7-14 January, 2013. Geological Survey of Canada, Open File 7556.

Riedel, M., Neelands, P.J., Taylor, S., Côté, M.M., Wania, R., Price, A., Obana, K., 2014b. Cruise Report 2010007PGC, SeaJade, Seafloor Earthquake Array - Japan Canada Cascadia Experiment, Ocean bottom seismometer recovery, methane gas-plume acoustic imaging, and CTD-water sampling program, CCG Vessel John P. Tully, 22 September - 2 October, 2010. Geological Survey of Canada, Open File 7557.

8. Tables

Table 1 Recording parameters of OBS instruments: start of recording.

OBS Station	Identifier	Original station #	Sampling frequency	Start day (UTC)	Start time (UTC)	Start day (Local)	Start time (Local)
1	NRCan-K	7	500	Dec 15	00:07	Dec 14	16:07
2	NRCan-J	6	500	Dec 15	00:06	Dec 14	16:06
3	NRCan-H	5	500	Dec 15	00:05	Dec 14	16:05
4	NRCan-N	14	500	Dec 22	00:07	Dec 21	16:07
5	Dal-J	13	200	Dec 22	00:06	Dec 21	16:06
6	NRCan-F	4	500	Dec 15	00:04	Dec 14	16:04
7	Dal-D	12	200	Dec 22	00:05	Dec 21	16:05
8	NRCan-L	10	500	Dec 22	00:03	Dec 21	16:03
9	Dal-B	9	200	Dec 22	00:02	Dec 21	16:02
10	Dal-A	8	200	Dec 22	00:01	Dec 21	16:01
11	NRCan-E	3	500	Dec 15	00:03	Dec 14	16:03
12	NRCan-D	2	500	Dec 15	00:02	Dec 14	16:02
13	NRCan-A	1	500	Dec 15	00:01	Dec 14	16:01
14	Dal-C	11	200	Dec 22	00:04	Dec 21	16:04

Table 2 Recording parameters of OBS instruments: backup release time.

OBS Station	Identifier	Release code	Backup release day (UTC)	Backup release time (UTC)	Backup release day (Local)	Backup release time (Local)
1	NRCan-K	70	Jan 12	16:55	Jan 12	08:55
2	NRCan-J	30	Jan 12	18:48	Jan 12	10:48
3	NRCan-H	20	Jan 12	20:33	Jan 12	12:33
4	NRCan-N	40	Jan 13	00:40	Jan 12	16:40
5	Dal-J	20	Jan 13	02:40	Jan 12	18:40
6	NRCan-F	50	Jan 13	04:48	Jan 12	20:48
7	Dal-D	60	Jan 13	06:48	Jan 12	22:48
8	NRCan-L	50	Jan 13	08:55	Jan 13	00:55
9	Dal-B	00	Jan 13	10:55	Jan 13	02:55
10	Dal-A	50	Jan 13	12:55	Jan 13	04:55
11	NRCan-E	70	Jan 13	14:55	Jan 13	06:55
12	NRCan-D	80	Jan 13	16:35	Jan 13	08:35
13	NRCan-A	30	Jan 13	18:30	Jan 13	10:30
14	Dal-C	80	Jan 12	14:55	Jan 12	06:55

Table 3 Final drop locations of all OBS instruments.

OBS Station	Latitude	Longitude	Water Depth (m)	OBS-identifier
1	52.169717	-132.066037	2909	NRCan-K
2	52.298262	-131.908236	2128	NRCan-J
3	52.385719	-131.811520	1518	NRCan-H
4	52.557899	-132.097616	1937	NRCan-N
5	52.512418	-132.162605	1629	Dal-J
6	52.480116	-132.214632	2070	NRCan-F
7	52.441314	-132.277701	1965	Dal-D
8	52.369217	-132.376557	2917	NRCan-L
9	52.465601	-132.519974	2901	Dal-B
10	52.565744	-132.646831	2923	Dal-A
11	52.660033	-132.808669	2908	NRCan-E
12	52.776967	-132.648549	1436	NRCan-D
13	52.854984	-132.526614	1367	NRCan-A
14	52.281435	-132.238748	2908	Dal-C

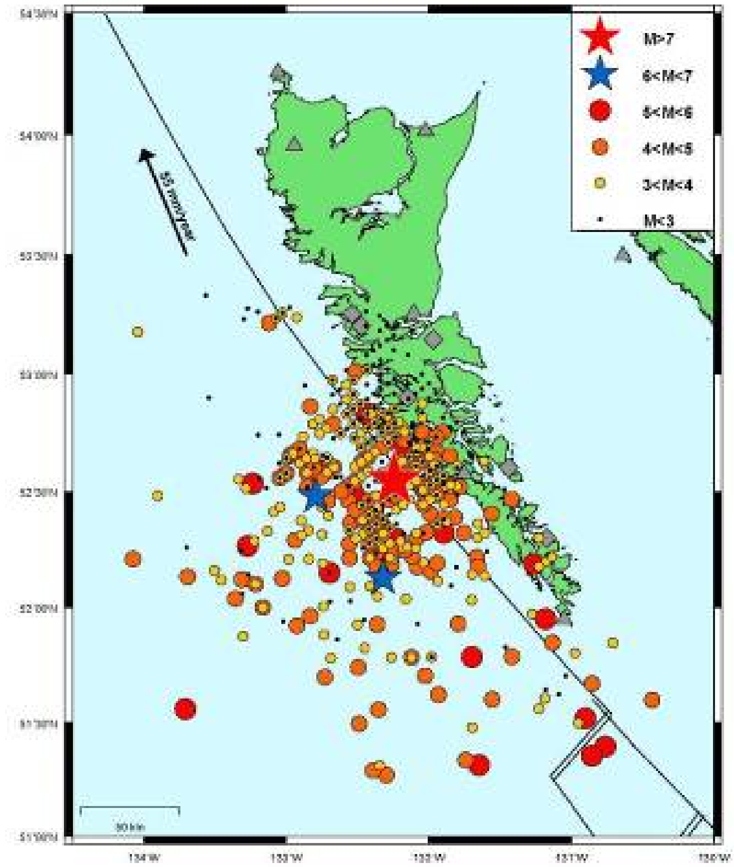
Table 4 Water samples taken from rosette (*see 12 kHz sounder data, Figure 11).

Bottle #	Target Depth (m)	Recorded Depth (m)	Notes	Volume in vial (ml)	
1	784	783.8	off station*	25	30
2	774	773	off station*	30	30
3	764	766	off station*	30	30
4	754	753.8	off station*	30	30
5	784	784	new station, in plume	28	30
6	774	773	new station, in plume	30	30
7	764	765	new station, in plume	30	30
8	754	753	new station, in plume	30	30
9	744	743	new station, in plume	30	30
10	734	735	new station, in plume	30	30
11	724	724	new station, in plume	30	30
12	714	713	new station, in plume	30	30
13	704	704	new station, in plume	30	30
14	694	695	new station, in plume	30	30
15	684	682	new station, in plume	30	30
16	674	673	new station, in plume	30	30
17	664	665	new station, in plume	30	30
18	654	655	new station, in plume	30	30
19	644	644	new station, in plume	30	30
20	634	636	new station, in plume	30	30
21	624	623	new station, in plume	30	30
22	614	614	new station, in plume	30	30
23	604	605	new station, in plume	30	30
24	594	593	new station, in plume	28	30

<u>Table 5</u> Science crew

Name	Affiliation	Function onboard
Michael Riedel	GSC-Pacific	Chief scientist
Greg Middleton	GSC-Pacific	Deck supervision
Peter Neelands	GSC-Pacific	Lab supervision
Graham Standen	Geoforce	OBS technician
Robert (Bob) Iuliucci	Dalhousie-U.	OBS technician
Patrick Meslin	GSC-Atlantic	OBS technician
Michelle Côté	GSC-Pacific	Navigation
Malaika Ulmi	GSC-Pacific	Watch keeper
Cooper Stacey	GSC-Pacific	Watch keeper

9. Figures



<u>Figure 1</u> Preliminary locations of aftershocks with magnitude 3.0 and above for the first 30 days after the M 7.7 Haida Gwaii earthquake. The epicentre of the main event is shown by the red star and the two largest aftershocks of magnitude 6.0 and above are shown as blue stars (from Cassidy et al., 2012[+]).

[+]J. Cassidy, T. James, R. Hyndman, M. Riedel, G. Rogers, M. Schmidt, K. Wang, and T. Mulder, 2012. The M 7.7 Haida Gwaii Earthquake of October 27, 2012, Simon Fraser University Newsletter December 2012

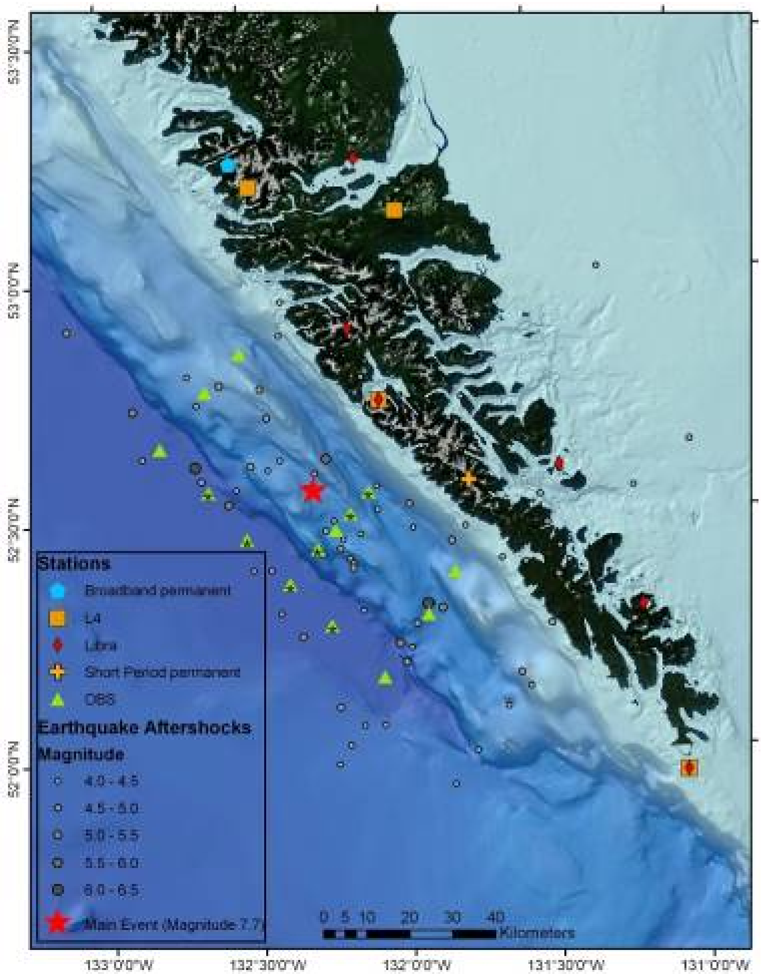


Figure 2 OBS and land stations deployed during cruise 2012005PGC. OBS Stations that start recording on midnight, December 22nd (UTC time) are labelled with an asterisk. All other OBS start recording on midnight, December 15 (UTC). Co-ordinates of OBS deployment locations are provided in Table 3.

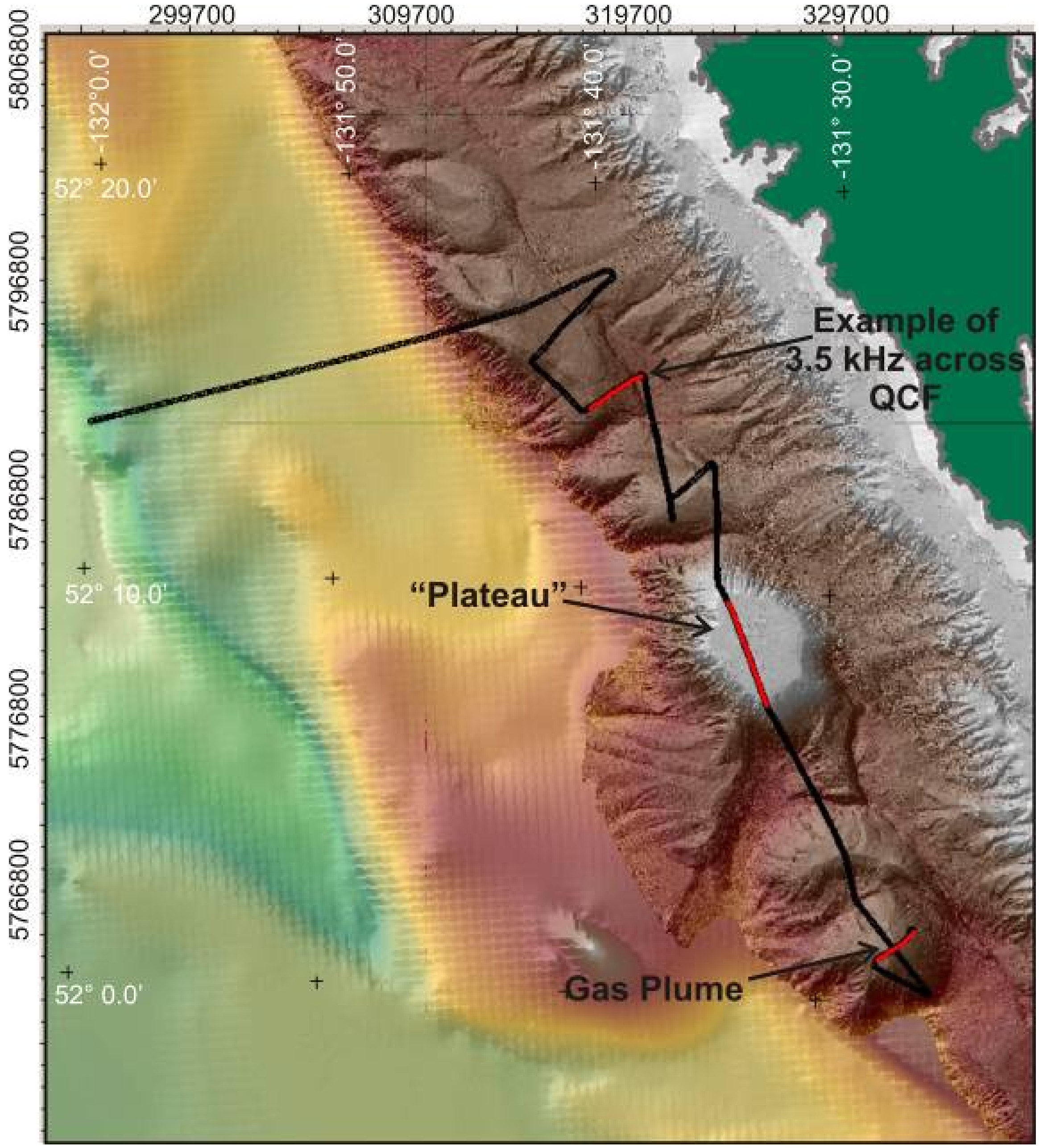


Figure 3 Map showing survey area of 3.5 kHz data acquisition across the Queen Charlotte Transform Fault (QCF), "Plateau" and gas plume. Sections of 3.5 kHz data shown in Figure 4 are highlighted in red.

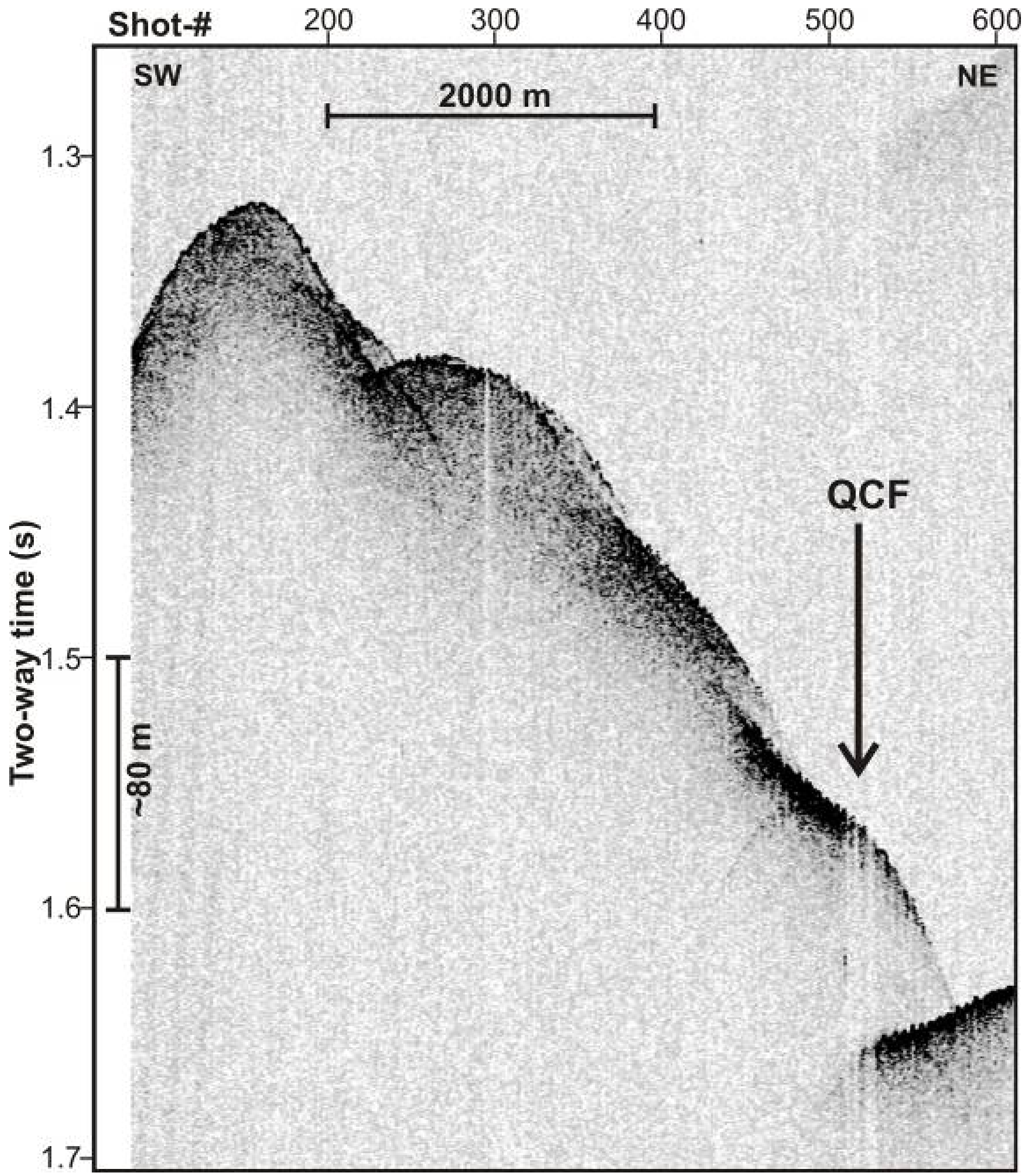


Figure 4a Example of 3.5 kHz data across fault showing an offset of about 60 m across the fault-step (identified by arrow).

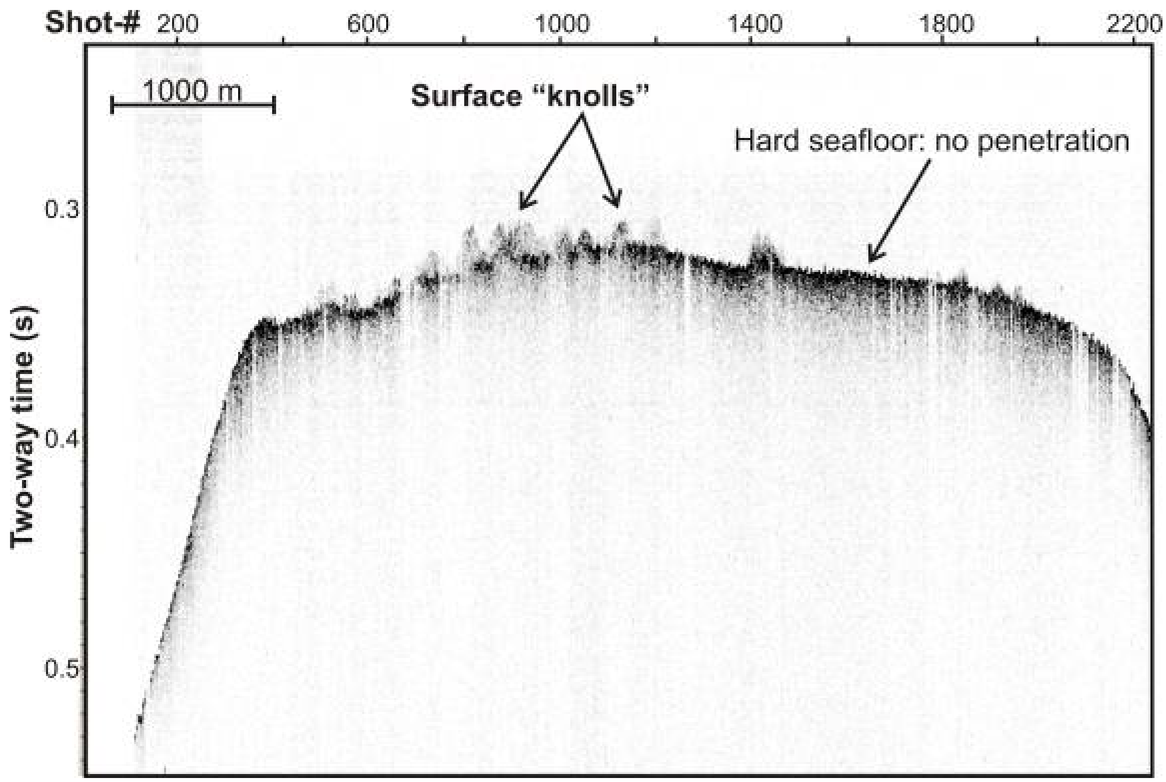


Figure 4b Example of 3.5 kHz data across elevated "plateau". The data show that the seafloor is hard with no penetration. The seafloor "knolls" seen in the multi-beam image (Figure 5) are associated with gas plumes (Figure 10).

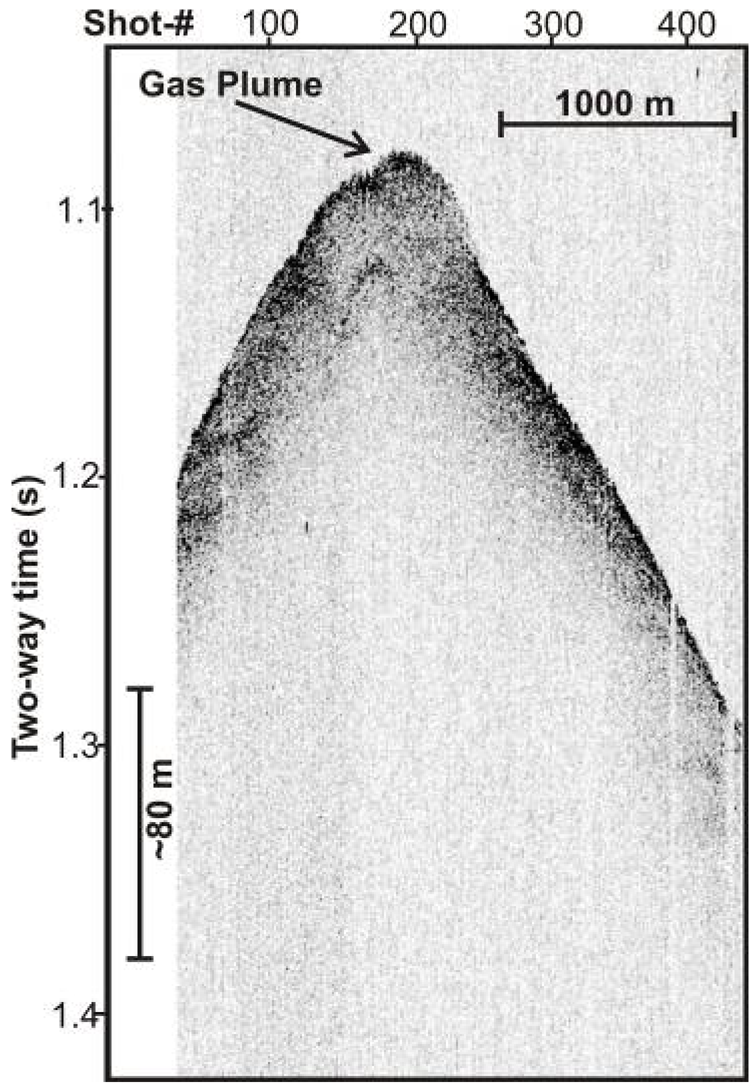


Figure 4c Example of 3.5 kHz data across gas plume location (indicated by arrow) where water sampling was conducted.

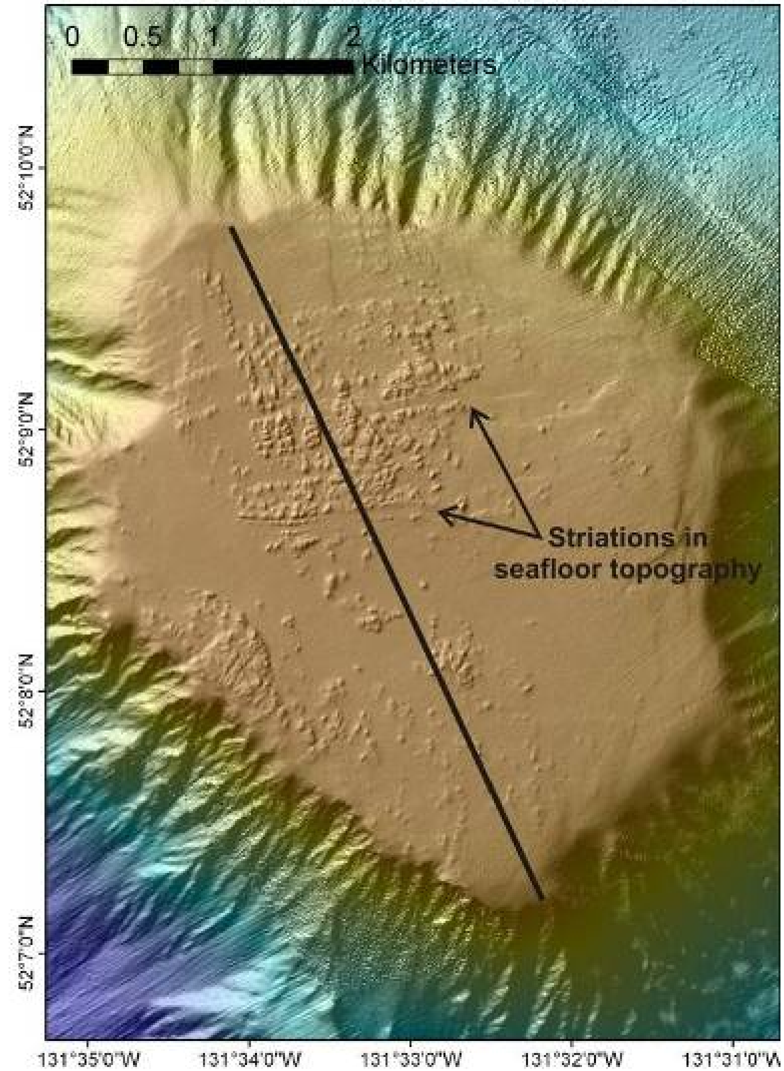


Figure 5 Multibeam image of "Plateau" with rough surface expression (referred to as "knolls" in Figure 4b) resembling an eroded seafloor, potentially from glacial activity. Black line outlines extent 3.5 kHz survey line.

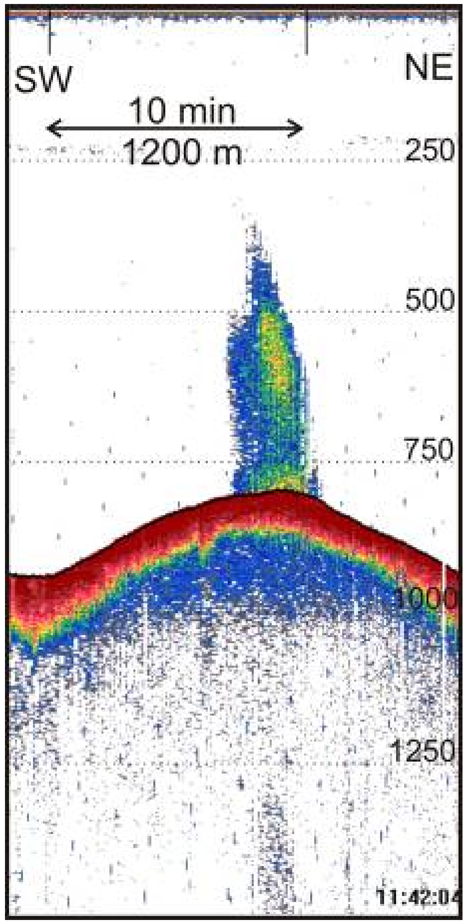


Figure 6 Example of 12 kHz data over gas-plume location where water sampling was conducted.

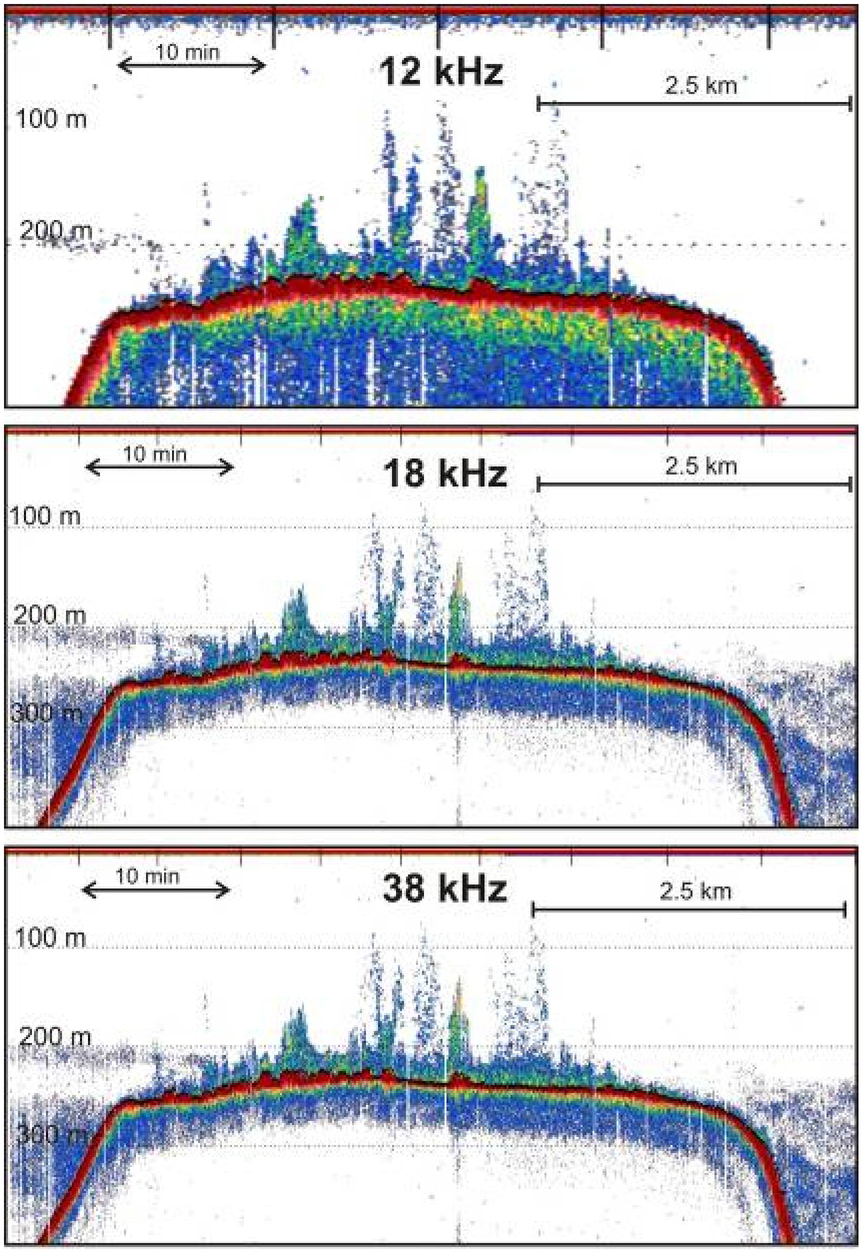


Figure 7 Additional evidence for degassing over "Plateau" showing rough seafloor surface ("knolls") associated with gas plumes (~150 m in height) in the 12, 18, and 38 kHz echo sounder data.

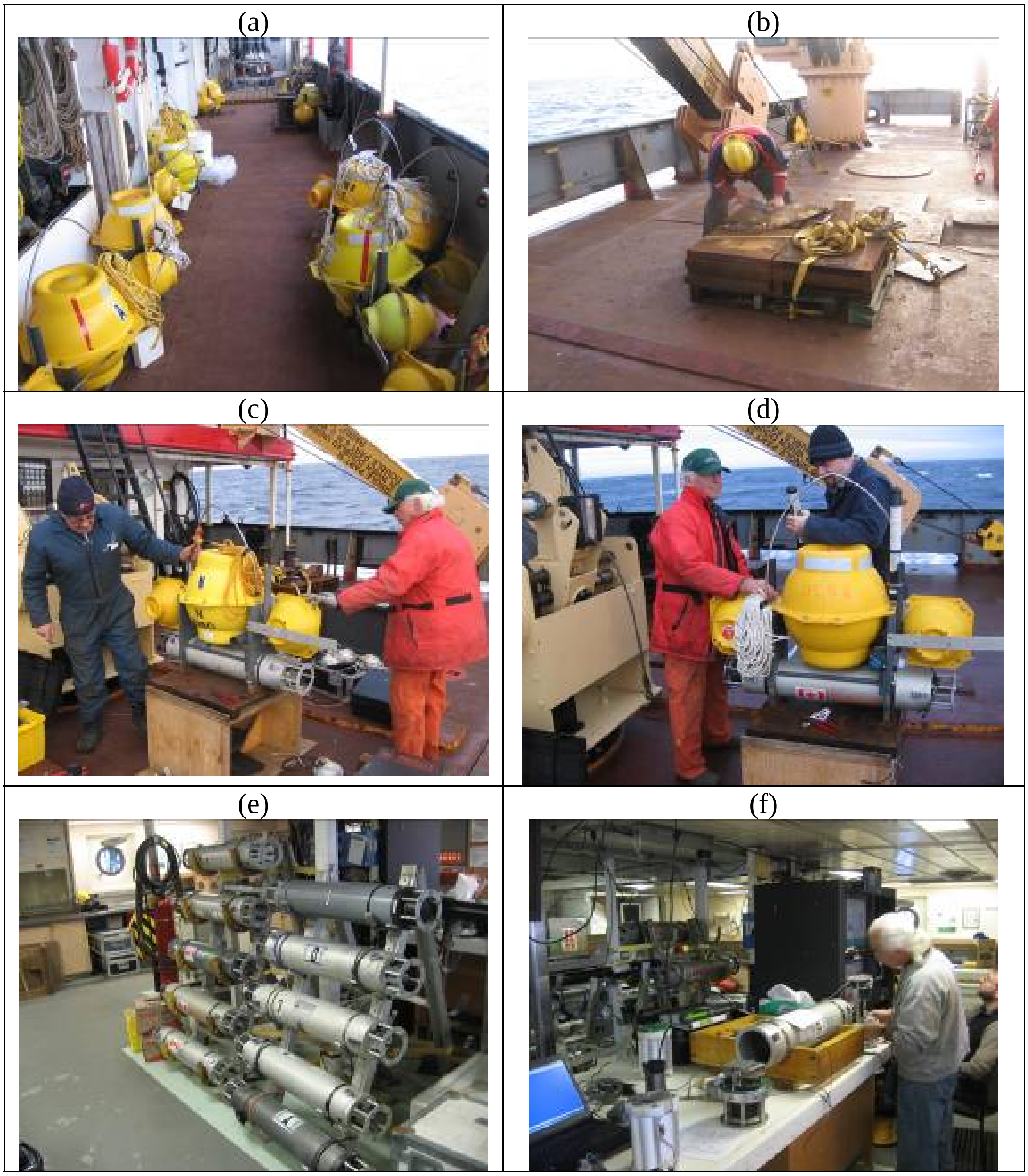


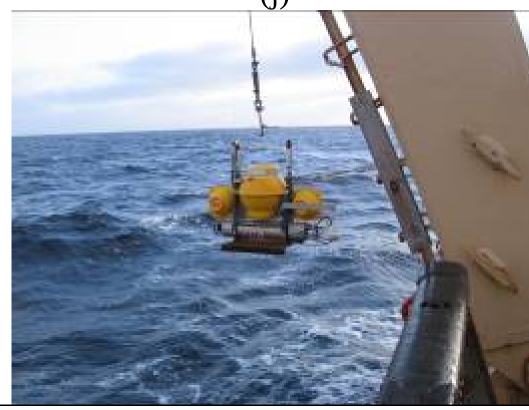
Figure 8 OBS assembly (a) OBS floatation stored at the starboard breezeway; (b) removing rust from anchors for final assembly; (c) wooden box for easy access to OBS unit, (d) adding strobe, antenna, and satellite communication; (e) storage of OBS pressure housing inside lab; (f) setup inside lab for assembling electronic components of OBS.

(g)

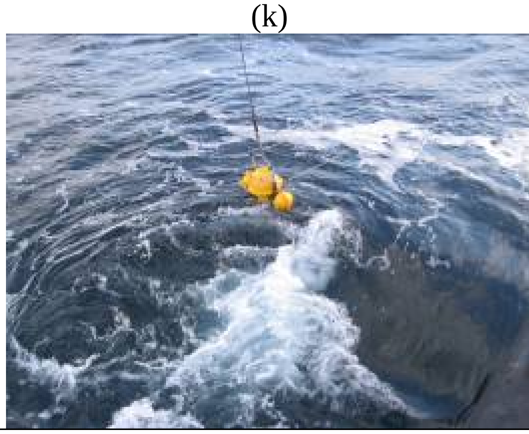
(h)

(i)

(j)



(k)



(l)

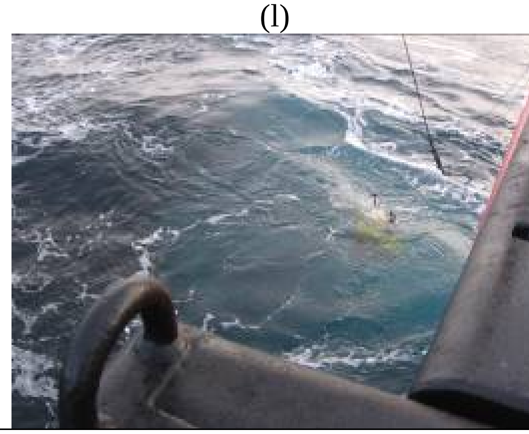
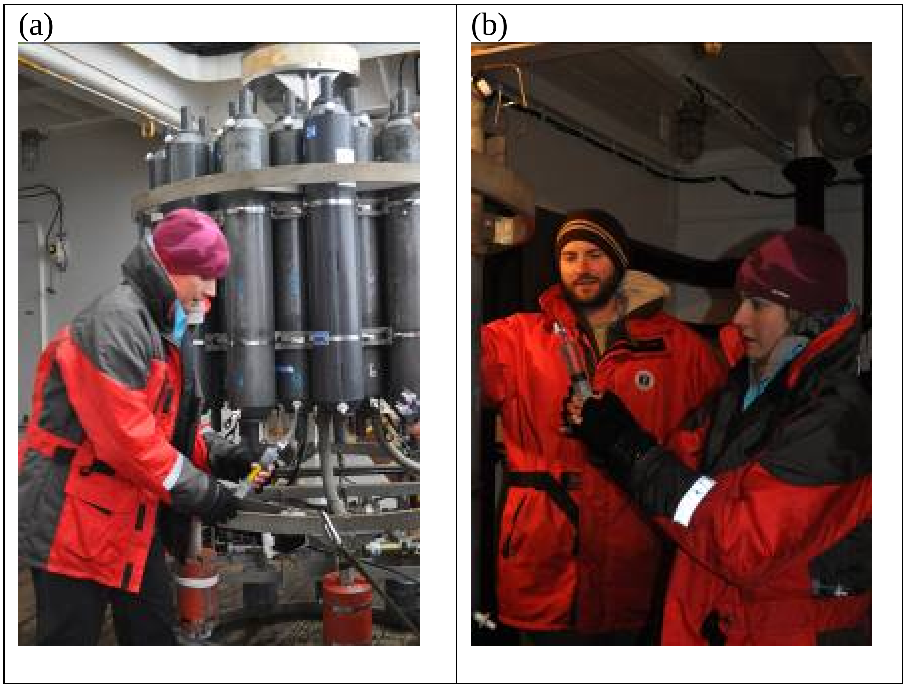


Figure 8 (contd.) (g) OBS deployment with aft A-frame; (h) OBS-recovery rope is laid out next to instrument and tag-lines are attached; (i) OBS is lifted with winch; (j) A-frame is extended so that the OBS is about 4 meters off stern; (k) OBS is lowered to the surface and (l) release by pulling the line with hook.

Figure 9 Water sampling rosette and CTD deployed during cruise 2012005PGC.



<u>Figure 10</u> Sub-sampling of water from the rosette by M. Ulmi and C. Stacey.

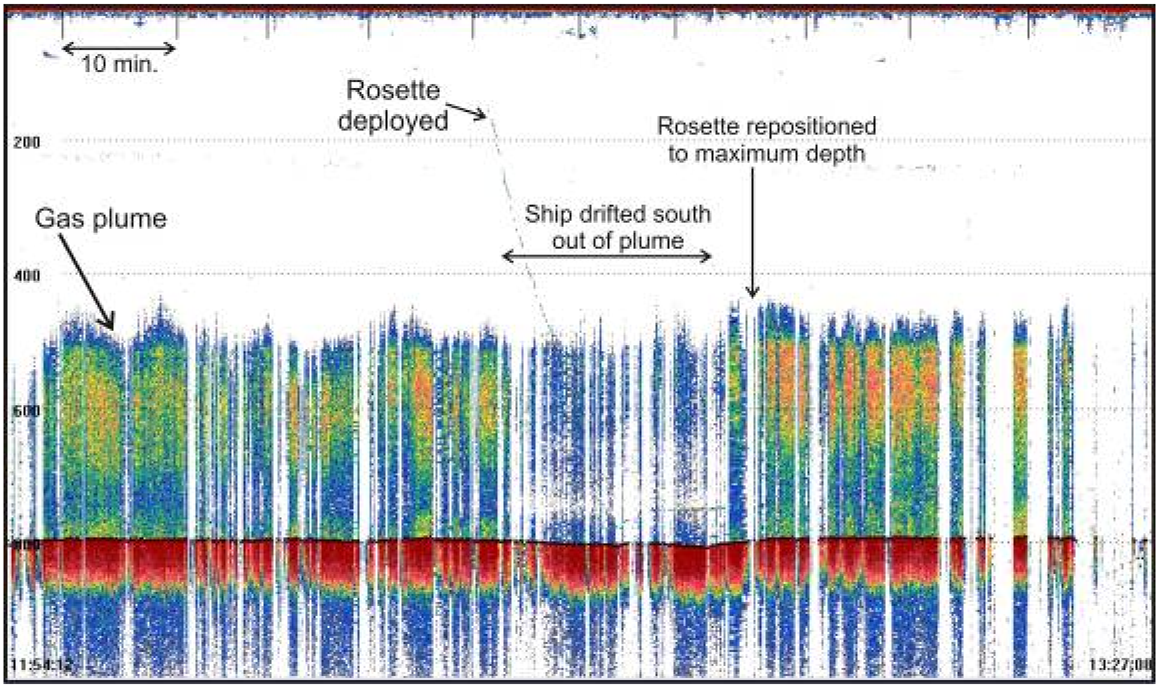


Figure 11 12 kHz echo sounder data acquired during water sampling. Note the period of 20 minutes, when ship had drifted out of gas plume. After re-positioning the vessel into the centre of the plume, sampling recommenced.

Appendix-A

COUNCIL OF THE HAIDA NATION

December 6, 2012

Dr. Michael Riedel
Natural Resources Canada
Geological Survey of Canada - Pacific
9860 West Saanich Road
Sidney, BC
V8L 4B2 Canada

Email: mriedel@nrcan.gc.ca

Dear Sir,

We have reviewed the project proposal "Haida Gwaii Earthquake Response – Ocean Bottom Seismometer and Refraction/reflection Seismic Experiment" that we received from Ernie Gladstone, the Gwaii Haanas Superintendent. We understand that the Archipelago Management Board (that includes Council of the Haida Nation representatives) has supported the project within Gwaii Haanas. The Council of the Haida Nation supports the project in the area outside the Gwaii Haanas marine area boundary and gives our permission for the project to proceed.

You have proposed to do surveys on the west coast of Haida Gwaii in the vicinity of the recent 7.7 magnitude earthquake. The surveys will take place both within the Gwaii Haanas marine area and in deeper water to the west of Gwaii Haanas during two cruises on December 7-12, 2012 and January 4-12, 2013 (tentative). The second cruise will involve experiments involving air guns and measures are proposed to avoid encounters with marine mammals.

We understand that you have invited us to place an observer on the vessel to work with two marine mammal observers. We accept the invitation. Brad Setso, the Haida Fisheries Program Manager, can work with you to identify a suitable observer and make the necessary arrangements. He can be contacted at 250 626-3302 or by email at brad.setso@haidanation.ca.

Sincerely

April Churchill
April Churchill
Vice President of the Haida Nation

cc: Ernie Gladstone
Brad Setso

☑ Box 98 Queen Charlotte City, Haida Gwaii, BC V0T 1S0 • Phone (250)559-4468 • Fax (250)559-8951
Toll Free Queen Charlotte City 1-877-559-4468

☐ Box 589 Massett, Haida Gwaii, BC V0T 1M0 • Phone (250)626-5252 • Fax (250)626-3403
Toll Free Massett 1-888-638-7778

Appendix-B

Fisheries and Oceans | Pêches et Océans

Pacific Region
Suite 200 - 401 Burrard Street
Vancouver, B.C.
V6C 3S4

November 29, 2012

Dr. Michael Riedel
Natural Resources Canada
Geological Survey of Canada - Pacific
9860 W. Saanich Road
Sidney, BC V8L 4B2

Dear Dr. Riedel:

RE: January 7 - 18, 2013
Natural Resources Canada Seismic Survey

The Fisheries Management Branch of Fisheries and Oceans Canada has a legal obligation to protect marine mammals under the *Fisheries Act* for any project that could disturb or harm marine mammals under the Marine Mammal Regulations and/or the *Species at Risk Act* (SARA).

We have reviewed the proposal and understand that a vessel cruise is proposed from January 7 – 18, 2013 to undertake active source seismic experiments and to retrieve 9 ocean bottom seismometers

There are two separate components to the proposed active source seismic airgun experiments:

(a) A refraction seismic experiment using a single 520 cubic inch airgun (G-gun).

(b) A high-resolution reflection seismic experiment using a single 210 cubic inch GI-gun.

Estimated sound pressure levels of these air guns are equivalent to 215 dB re 1µPa-m_{rms} and 217 dB re 1µPa-m_{rms}, respectively. These are above the sound pressure level considered to cause temporary threshold shifts and behavioural disturbance in marine mammals.

Due to the likely presence of marine mammals including long diving species such as sperm and beaked whales, enhanced mitigation measures are required to prevent disturbance or harm.

Canadä

1

Marine Mammal Mitigations Measures:

All participants should be reminded of their obligation to comply at all times with Section 7 of the *Marine Mammal Regulations*, which specifically prohibits the disturbance of marine mammals.

1. Marine Mammal Observers:

   Two trained DFO-approved marine mammal observers dedicated to maintaining constant observations for marine mammals during daytime operations in the ship's vicinity prior to and during seismic array operations. The marine mammal observers shall submit a written report containing the following information within 90 days of research completion to the Marine Mammal Coordinator:

   a. Date, time and position of seismic operations of each seismic array at start-up and shut down;
   b. Date, time, position, species and numbers of all marine mammal sightings;
   c. Date, time, and position of all seismic array shut-downs or start-up delays required because of marine mammals in the area of study; and the species and numbers of marine mammals causing the shut-down or start-up delay.
   d. In the unlikely event that a marine mammal is impacted, detailed description(s) of any observations of marine mammal impacts in the area of study should be recorded.

2. Exclusion Zone:

   A marine mammal exclusion zone having a radius of 1,500 m will be established and monitored to ensure under water sound pressure levels are less than 160 dB re 1μPa outside of this radius.

3. Pre-Operations Monitoring:

   The marine mammal exclusion zone must be visible to the marine mammal observer and is to be monitored for 60 minutes prior to initial start-up of the airgun or upon resumption of operations following a shut-down due to a marine mammal sighting within the exclusion zone.

4. Power-down and Shut-down Triggers:

   The air gun will be shut down should a marine mammal be observed within or about to enter the 1,500 m exclusion zone.

5. Start-up Procedures following Shut-downs and Power-downs:

   Airgun operations are not to start unless the zone is visible to the marine mammal observers and has been monitored for 60 minutes immediately prior to start-up. Procedures for ramp up to full power should occur over a 30-minute period as stated in the proposal. Should a shut-down be required for maintenance or other operational reasons when the exclusion zone is not visible (e.g., in thick fog or at night), no start-up will be initiated until the zone is visible.

6. These mitigation measures are valid for this survey as proposed. After this time, if the subject works have not been completed, this letter will be void. This will ensure that the proposed project will conform to current management policy, guidelines, and legislation.

7. It is understood that by proceeding with the proposed seismic activities, you, your contractors, agents or partners have indicated you understand and have agreed to the foregoing mitigation measures. In addition, a copy of this letter is to be available on board the vessel for the duration of the project.

8. All materials and equipment used for the purpose of project completion shall be operated in a manner that prevents any deleterious substances (e.g. petroleum products, etc.) from entering the water.

9. Any variances must be submitted to the DFO Marine Mammal Coordinator's office for review and approval, prior to any changes being implemented.

Please note that this Letter of Advice does not absolve the proponent from the responsibility of securing any other permits as may be required by federal or provincial legislation. If a disturbance occurs as a result of a change in the plans for the proposed activity, or failure to implement the mitigation measures specified above, contravention of Subsection (7) of the *Marine Mammal Regulations* or SARA could occur.

If you wish to discuss the mitigation measures, or you have any other questions, please contact the undersigned at 604-666-9965. If you propose to undertake the above marine mammal mitigation measures, please confirm by signing and returning a copy of the Letter of Advice attached to this letter.

Sincerely,

Paul Cottrell
A/Marine Mammal Coordinator
Fisheries and Aquaculture Management
Fisheries and Oceans Canada – Pacific Region

cc: J. Ford, L. Nichol DFO

Please sign this page and fax or scan a copy to: Annely.Greene@dfo-mpo.gc.ca

Fisheries and Aquaculture Management – Pacific Region
Marine Mammal Program
Suite 1420 - 401 Burrard Street
Vancouver, BC V6C 3S4

Attention: Paul Cottrell

RE: **January 7 - 18, 2013**
Natural Resources Canada Seismic Survey

LETTER OF ADVICE

I, Carmel Lowe, having authority to commit funds and activities on behalf of **Natural Resources Canada** have read and understood correspondence from DFO dated November 29, 12, outlining recommended marine mammal mitigation measures for the proposed seismic research.

Response:

(✓) I agree to the recommended mitigation measures in the above-referenced correspondence and commit to apply them during the proposed work or undertaking.

Signed Carmel Lowe
Title Director, GSC-Pacific
Dated Dec. 3rd 2012

Note: Failure to show due diligence in the protection of Marine Mammals could result in violation(s) of the *Fisheries Act* or *the Species at Risk Act*. In addition, this correspondence addresses only the concerns of DFO-FAM. It is the obligation of the proponent to meet any other regulatory requirements.

4