Cruise Report *

Karen Weitemeyer, Steve Constable, and Kerry Key

September 17, 2004

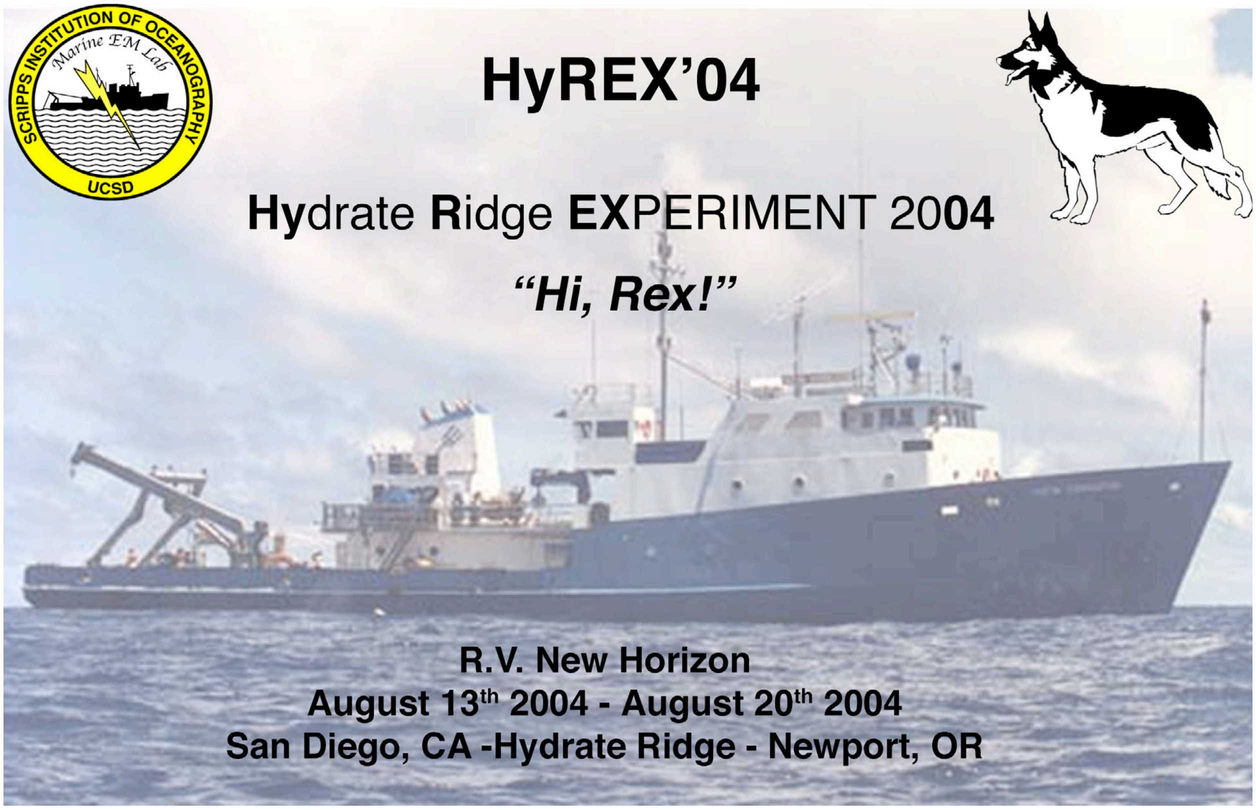

*Photo of New Horizon from: $http://shipsked.ucsd.edu/ships/new\_h/photos.html$ and clip art from Microsoft Office X

Introduction

The object of this experiment was to carry out a pilot study of the use of marine EM techniques to map the extent and quantity of gas hydrates. While the base of the gas hydrate layer often produces a distinctive seismic signature (the bottom-simulating reflector, or BSR), the gradational upper surface is less well imaged using seismology, and there are cases where hydrates are known to exist without a BSR. Well logs show that hydrate is more resistive than host sediments, providing a potential target for EM methods. The resistivity contrast observed in well logs may be quite small due to dissociation of hydrate during drilling. This study will provide preliminary data from hydrates in situ, unmodified by either drilling or collection. It is anticipated that more extensive work will be proposed based on the results of this pilot experiment.

Traditionally, controlled source EM (CSEM) methods have been considered the tool of choice for hydrate detection (for example, see papers by Nigel Edwards of Toronto) because they are sensitive to thin resistive layers and can be configured for resolution at various depths up to several kilometers. SIO has been a pioneer in marine CSEM methods, and has recently rebuilt its deep-towed EM transmitter. SIO also has a fleet of 50 seafloor CSEM receivers.

The other common EM method, magnetotelluric (MT) sounding, has been ignored as a tool for hydrate studies because early applications of MT to the marine environment targeted deep structure (greater than 100 km). However, recent work at SIO has optimized the use of MT for shallower continental shelf exploration, and under some circumstances we can collect data at frequencies as high as 10 Hz, with a corresponding depth of resolution starting at a few 10's of meters. MT methods are incapable of detecting thin resistive layers, but some hydrate deposits have thicknesses that are comparable to their depth of burial, which could make them viable MT targets. Since the 50 SIO CSEM receivers also collect MT data, it is logistically easy to use joint CSEM and MT surveying. Four main techniques were employed on this cruise:

a) Marine magnetotelluric (MT) method. A seafloor instrument records natural variations in Earth's electric and magnetic fields for 2 days to 2 weeks. When processed, these data can be used to obtain images of seafloor conductivity up to hundreds of kilometers deep. In this case only 2-day deployments were made, and we only intend on using the high frequency data, because of a shallower target.

b) Marine controlled source EM (CSEM) sounding. An EM transmitter is deep-towed close to the seafloor to provide a man-made source of EM energy. The seafloor recorders monitor the transmitted electric fields, which provide similar information to the MT method except that (i) the CSEM method has better resolution at shallow depths and (ii) the CSEM method is better at measuring resistive (c.f. conductive) rocks.

c) Towed array. In a departure from our standard CSEM approach, which uses discretely deployed seafloor recorders, we attached a floating four channel E-field receiver behind the transmitter antenna. This consisted of a 180 m electrode array, with four dipoles attached at 10 m, 75 m, 75 m and 10 m spacing. A short baseline transponder (SBL) was attached at various points to show exactly what position the towed array was at relative to the ship. A towed array provides similar information to the seafloor CSEM recorders except that the electrodes are at a fixed distance from the transmitter.

d) Marine controlled source MT (CSMT). In an attempt to use a standard land-based technique we attempted CSMT. We towed the EM transmitter at a shallow depth near the surface, and transmitted at frequencies of 1 Hz and 0.1 Hz, creating a synthetic MT signal, which was detected by our receivers on the ocean bottom.

As a secondary project, Adam Shultz from OSU observed venting of free gas at Hydrate Ridge by using the ships 12 kHz precision depth recorder (PDR) to search for tidal influences in the character of the venting.

Research Objectives

The Hydrate Ridge region (Figure 1) has been extensively studied by seismic methods, ROV, side-scan sonar, multi-beam, well-logs, and direct sampling, providing good ground truth for hydrate distribution, extent and quantity. This makes it an ideal location for the evaluation of CSEM and MT techniques as a tool for hydrate detection. While seismics provide a good indication of hydrate location, there are reasons to augment seismic data with marine EM techniques:

a) The gradational upper surface is less constrained than the sharper lower boundary (BSR) because is difficult to map seismically. However, the resolution of EM methods is intrinsically smooth, and it should be possible to map the total thickness of the deposit, as well as the depth.

b) It is possible for hydrates to exist without a BSR, if not at Hydrate Ridge then elsewhere.

c) Well logs indicate that hydrate is more resistive then the host sediment, making it a good EM target. EM methods may be able to further enhance the understanding and properties of gas hydrate in situ, unmodified by either drilling or collection.

d) We should be able to convert estimates of hydrate resistivity into total hydrate content using binary mixing laws. Thus, EM methods are capable of mapping total hydrate reserves, rather than just lateral extent and depth.

Key issues addressed by this project are:

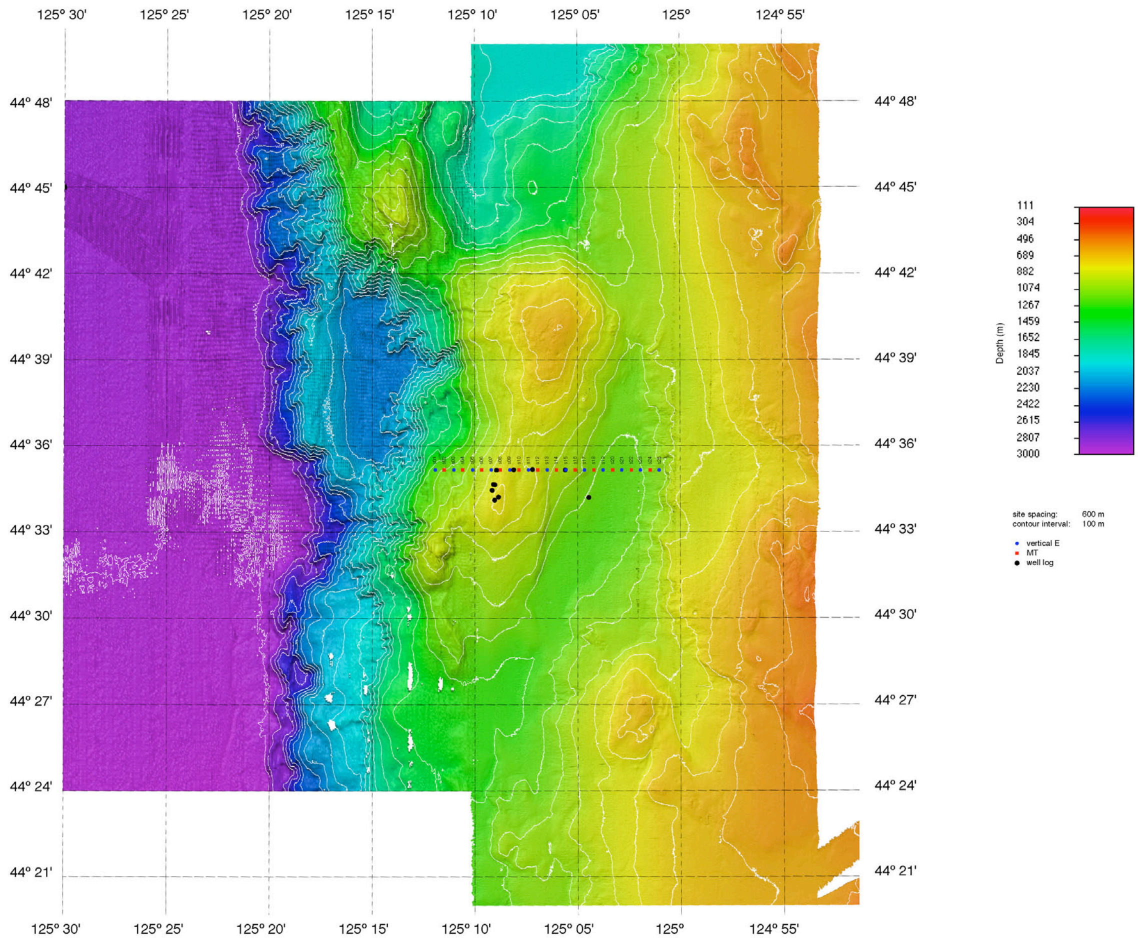

Figure 1: Bathymetry map of Hydrate Ridge from high resolution EM300 data compiled by MBARI (east of 125° 10') and lower resolution NOAA data from SeaBeam data base *http://autochart.pmel.noaa.gov:1776/autochart/ASC.html* (elsewhere). Site locations are indicated by red (MT) and blue (Vertical E). The black dots are ODP 204 drilling locations.

- What is the distribution, vertical extent and volume fraction of hydrate in the region? Recent seismic and ODP drilling will act as a constraint on our results to determine the viability of marine EM for gas hydrate detection.

- To determine the suitability of and the logistics involved in deploying the towed array and CSMT, and to assess their usefulness in other projects.

- Electrical resistivity images of the sediments from this experiment will complement existing results from other geophysical methods used at this segment of Hydrate Ridge. Estimates of the amount and distribution of hydrate, as well as the porosity and permeability of the structure, will support the interpretation of a wide variety of other experiments in the region.

Mobilization and Logistics

This cruise was opportunistic - taking advantage of the New Horizon's presence at Newport for an Office of Navel Research (ONR) funded project. Because we had very limited funds for ship time, we had to compress as much work as possible into 3 days on station. All equipment and staff were loaded in San Diego. A three and a half day transit at good speed in good weather put us on station in a timely manner. This experiment benefited a great deal by having a scientists and technicians previously trained for the East Pacific Rise (EPR) cruise, which took place in the winter of 2004. Thus, very few people required training, and those that did were able to learn quickly from the experienced staff.

Efficient use of ship time was achieved by dividing the personnel into two 12 hour shifts for deployments and recoveries (see shift list in appendix). Each shift was led by an experienced Scripps scientist capable of mitigating most situations (Key and Behrens) and consisted of 4 other persons to carry out the work. Crane operations were carried out by two Resident Technicians (Gainther and Riemer), who also followed the 12 hour shifts. During the deep-tow operations watches were formed for the winch control and monitoring deep-tow vital signs. Constable, Winther, Key, and Behrens oversaw the deep-tow operations while the other personnel took turns at "flying" sessions at the winch control station (Figure 2).

A forecast gale prompted us to terminate the experiment a few hours ahead of schedule, and to recover instrumentation at an accelerated pace (special thanks to Jim!), resulting in a slightly earlier arrival in Newport.

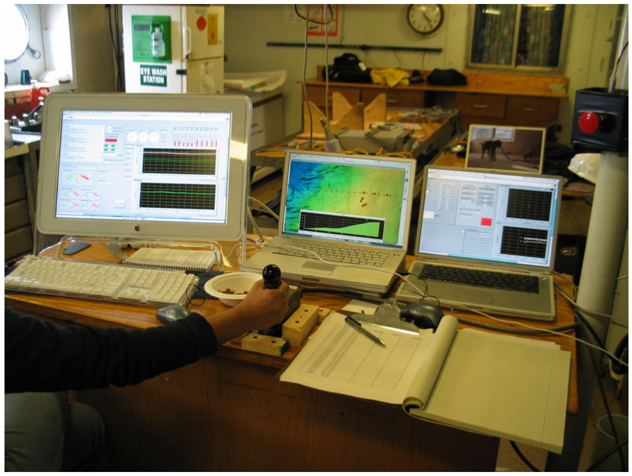

Figure 2: Control console for SUESI 's Labview interface showing vital signs and flight height, with winch controller, Fledermaus visualization of depth profile, and acoustic navigation (also controlled by LabView).

Instrumentation

Receivers

Twenty-five seafloor electromagnetic recorders were used in this experiment. There are two types of loggers (Mk II and Mk III) differing only by details of mass storage devices. The loggers are configured in one of two ways (Figure 3):

i) MT (12 instruments). This consisted of two orthogonal horizontal magnetometers and two orthogonal horizontal 10 m electric dipoles.
ii) Vertical E (13 instruments). This consisted of two orthogonal 10 m electric dipoles and one vertical 1.5 m electric dipole.

A brief list of specifications follows:

The seafloor receivers were placed along a 14.4 km line that coincides with seismic line 230 (Trehu, pers. comm.), as well as four ODP holes from ODP Leg 204 (Figure 1). The two types of instrument configurations were placed alternately, at a 600 m spacing, starting and ending with the vertical arm configuration. All loggers were set to a sample rate of 125 Hz.

Things to consider in processing are:
a) One or two of the Mk II loggers may have skipped disk writes as batteries reached their limit.

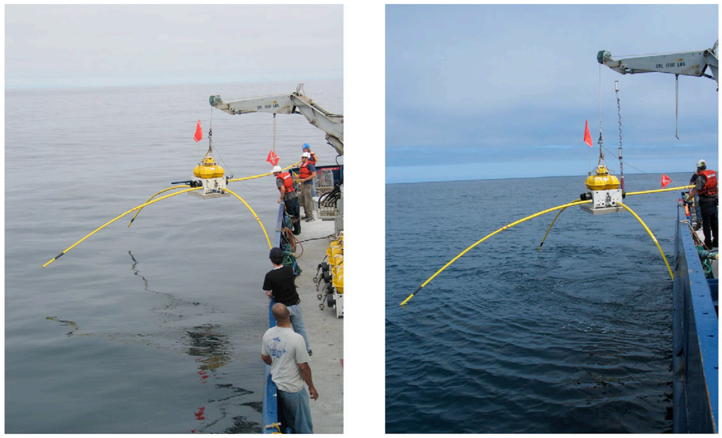

Figure 3: Two receiver configurations used MT (left) and vertical E (right)

b) There is 25 Hz and 50 Hz noise on Mk III loggers.
c) There were some cases when we had a GPS blackout, which affected the ships navigation and stopped deployments. This will be evident in the EM Lab GPS acoustic navigation data, where the field "TFDAA" will be larger than 4 (4 = best, 9 = worst).

The performance of the instruments was overall excellent. One instrument, Devil, had batteries that ran down prematurely so we had to extract the data upon return to Scripps.

The data quality was generally very good with a few sites which appear to be affected by environmental noise.

In total we collected approximately 20 hours of CSEM and 6 hours of CSMT data.

Towed Array

This was a first attempt by the Scripps Marine EM lab to have an additional array of receivers behind the transmitter. The receiver consisted of a 4-channel logger in E-field mode with the gains turned down (10,000 c.f. 1,000,000). A pair of 10 m dipoles were run, to avoid saturating signals, and a pair of 75 m dipoles, which will give a better signal to noise ratio

Channels	8 (MkIII), 4 (MkII)
ADC	24 bit
ADC noise floor	10^{-13} V^2/Hz at 0.01 Hz to nyquist
Power consumption	450mW (4 channels at 32 Hz sampling)
Maximum sample rate	1,000 Hz on 4 (MkIII) channels or 2 (Mk II)
Time base drift	1-5 ms/day, correctable to <1 ms
E and B amplifiers	Chopper-stabilized
Bandwidth	10,000 s to 1,000 Hz
E sensors	AgCl electrodes
Voltage noise floor	10^{-18} V^2/Hz at 1 Hz
E-field noise floor on 10m antenna	10^{-10} V/m/$\sqrt{Hz}$ at 1 Hz
B sensors	Multi-turn, mu-metal core
B noise floor	10^{-8} nT^2/Hz at 1 Hz
Weight of assembly in air	125 kg
in water	-14 kg
Endurance on one set of NiMH rechargeable batteries	2 weeks
Data capacity	1 Gbyte (Mk III), 20 Gbyte (Mk II)
Depth rating	6000m
Acoustic navigation/release	SIO custom (SIO) or EG& G (Industry)
Long term loss rate	$<$ 1% per deployment
Deployments to date	$> 1,000$

but maybe saturated by motional noise or self potential (SP). The goal was to have the system past the end of the SUESI antenna to be buoyant, so (a) we did not dredge and (b) if we did and broke something, it would come back and be easily found on the surface because of the tail float (Figure 4 and 5 and 6).

Unfortunately the SBL system, mounted in the ship's well, broke during transit. Because the well could not be opened at sea, this could not be repaired. Further, the data logger, Bunyip, in the towed array, failed shortly after deployment due to a small water leak. Embarrassingly, we had commissioned a new endcap/logger assembly that had earlier been used as a display piece at an SEG meeting. An unused encap perforation (reserved for a future battery charging connection) had been covered by a seal screw without an installed 'o'-ring, and this was not caught during checkout because that seal screw is not normally used.

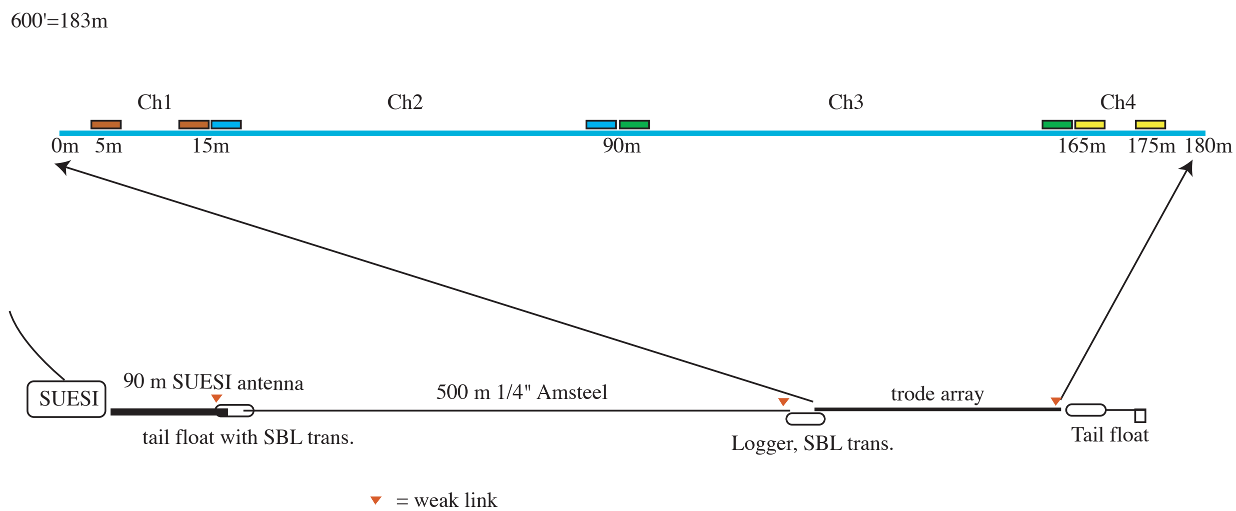

Figure 4: Schematic of the towed array designed.

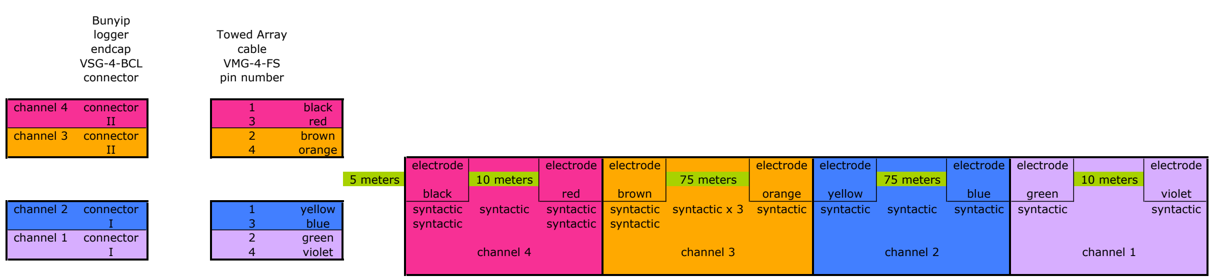

Figure 5: Electrical configuration of towed array.

Figure 6: Photos of the towed array deployment. From left to right: stray-line buoy with float and acoustic transponder, stray-line buoy in water, attaching electrodes and feeding out the array (next two), Bunyip recorder in case with syntactic foam and SBL transponder attached, and lastly, the SUESI deployment.

Scripps Undersea Electromagnetic Source Instrument

Specifications for SUESI transmitter system, first deployed on the EPR experiment in March 2004, are as follows:

Dipole moment at full power	50,000 Am
Square wave zero- peak current	200 A
Tow cable	Standard 0.680" (17 mm) UNOLS copper coaxial
Tow cable voltage	2000 V RMS/400Hz
Input power supply	30 kVA, 208-480 VAC, 3-phase
Telemetry	9600 baud bidirectional on copper
Noise floor of system with SIO recorder	10^{-15} V/m per Am
Output frequency	DC to 100 Hz, GPS stabilized
Depth rating	6,000m
Top-side interface	Serial port / LabView GUI

A LabView GUI (Figure 7) gave the operator temperature, voltage, current and altimeter data to assess the vital signs of SUESI while being towed and to keep SUESI about 100 m above the seafloor.

Data were collected from the following tows:

TOW 1 (on receiver line west to east):

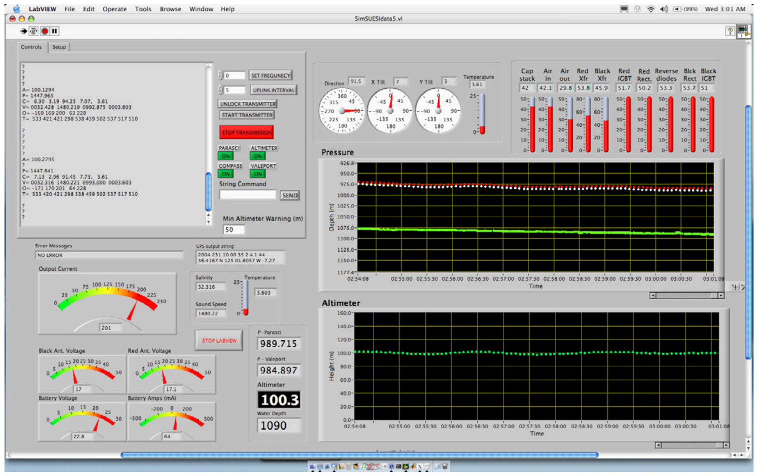

Figure 7: LabView GUI.

08/17/2004 14:21 local, start transmission, 5 Hz, 90 m dipole 102 amps 08/17/2004 23:55 local, hauling in for turn, 2-3 km past s25.

TOW 2 (1500 m to the north of the line, east to west):
08/18/2004 02:56 local, start transmission, 5 Hz, 90 m dipole 200 amps 08/18/2004 08:04 local, stopping transmission.

CSMT TOWS (north of line going west to east):
08/18/2004 12:39 local, start transmission, 200 m dipole, 200 amps 08/18/2004 14:49 local, current lowered to 100 amps 08/18/2004 18:30 local, stopped transmission.

Acknowlegements

We would like to thank Captain Murray Stein, the crew of the R.V. New Horizon, and resident technicians Michelle Gainther and Brent Riemer for assistance with the seagoing operations. They allowed us to take advantage of a good weather window and accomplish a tremendous amount of work in just a few days. Thanks to Anne Trehu for making the seismic data available to us, and for helpful discussions during the cruise planning. She also promised us excellent weather, and by and large delivered on this.

We also thank GERD Japan, the Seafloor Electromagnetics Consortium (SEMC), Exxon-Mobil, and RPSEA for funding various aspects of this study.

References

Bathymetry Data:
Monterey Bay Aquarium Research Institute. 2001. MBARI Northern California and Oregon Margin Multibeam Survey. Moss Landing. [CD-ROM].

NOAA Vents Program Acoustic Monitoring. Monitoring the global ocean through underwater acoustics Autochart Bathymetric/Seismic Map Production. SeaBeam website: http://www.pmel.noaa.gov/vents/data/index.html

Seismic Data:
Trehu, Anne. pers. comm. May 2003. Hydrate Ridge Seismic Line 230.

ODP Leg 204 data:
Trehu, A.M., Bohrmann, G., Rack, F.R., Torres, M.E., et al., 2003. Proc ODP, Init. Repts., 2004 [CD-ROM]. Available from: Ocean Drilling Program, Texas A&M University, College Station TX 77845-9547, USA.

Appendix

Cruise Personal:		
Steve Constable	Scripps Inst. Oceanography	Chief Scientist
Kerry Key	Scripps Inst. Oceanography	Co-Chief Scientist
James Behrens	Scripps Inst. Oceanography	Student
Karen Weitemeyer	Scripps Inst. Oceanography	Student
Courtney Schatzman	Scripps Inst. Oceanography	Student
Chester Weiss	Sandia National Laboratories	Scientist
Christian Winther	Scripps Inst. Oceanography	Engineer
Patricia Cheng	Scripps Inst. Oceanography	Engineer
Chris Armerding	Scripps Inst. Oceanography	Technician
Garth Engelhorn	Scripps Inst. Oceanography	Technician
David Wright	Simrad	Technician
Kazunobu Yamane	GERD	Observer
Adam Shultz	OSU	Scientist
Phillip	OSU	Engineer
Brent Riemer	Scripps Inst. Oceanography	Res Tech
Michelle Gainther	Scripps Inst. Oceanography	Res Tech

Pre-cruise Personal:		
Jacques Lemire	Scripps Inst. Oceanography	Engineer
John Saunders	Scripps Inst. Oceanography	Engineer
Pat Walsh	Scripps Inst. Oceanography	Technician

Shift List

12pm-12am	**12am-12pm**	**SUESI Team**
Key	Behrens	Constable
Cheng	Weiss	Winther
Engelhorn	Armerding	Key
Yamane	Weitemeyer	Cheng
Constable/Winther	Schatzman	
Gainther	Riemer	

Daily Log

August 10	New Horizon arrives in port at Marfec, San Diego
August 11	Loading
August 12	Loading and instrument preparations
August 13	Underway on schedule at 08:00 depart from SIO's Nimitz Marine Facility
August 14	Transit to station
August 15	Transit to station
August 16	14:00 arrive on station. Start deployments.
August 17	14:00 Transmitter tow 1
August 18	01:00 transmitter tow 2; 08:00 stop transmitter tow 2; 13:00 CSMT; 19:00 recover instruments
August 19	10:30 finish recoveries; 13:00 head to port; 17:00 arrive Newport, OR.
August 20	off-loading at Hatfield Marine Science Center, Newport

Site Locations

Instrument	Site	Position Latitude	Longitude	Depth	Wake up Date	(local) Time	Release Date	(local) Time
Bullant	s01	44 35.162'	125 11.928'	1278	8/17/04	04:00:00	8/19/04	10:15:00
Stingray	s02	44 35.173'	125 11.088'	1220	8/17/04	04:00:00	8/19/04	09:47:00
Roo	s03	44 35.167'	125 11.031'	1200	8/17/04	04:00:00	8/19/04	09:30:00
Occie	s04	44 35.149'	125 10.534'	1134	8/17/04	04:00:00	8/19/04	09:11:00
Galah	s05	44 35.151'	125 10.174'	1079	8/17/04	04:00:00	8/19/04	08:48:56
Taipan	s06	44 35.172'	125 9.641'	992.25	8/17/04	04:00:00	8/19/04	08:20:00
Wobby	s07	44 35.160'	125 9.207'	930	8/17/04	04:00:00	8/19/04	08:08:00
Camel	s08	44 35.169'	125 8.674'	892.5	8/17/04	00:00:00	8/19/04	07:43:00
Magpie	s09	44 35.166'	125 8.294'	892.5	8/17/04	00:00:00	8/19/04	06:59:00
Lorrie	s10	44 35.160'	125 7.843'	876	8/17/04	00:00:00	8/19/04	05:46:00
Possum	s11	44 35.160'	125 7.389'	902.25	8/17/04	00:00:00	8/19/04	05:28:00
Rabbit	s12	44 35.160'	125 6.934'	915	8/17/04	00:00:00	8/19/04	04:49:00
Echidna	s13	44 35.160'	125 6.480'	986.25	8/16/04	20:00:00	8/19/04	04:18:00
Shark	s14	44 35.159'	125 6.017'	1020	8/16/04	20:00:00	8/19/04	03:41:00
Devil	s15	44 35.180'	125 5.587'	1056?	8/16/04	20:00:00	8/19/04	03:08:00
Kooka	s16	44 35.168'	125 5.122'	1065	8/16/04	20:00:00	8/19/04	02:27:00
Joey	s17	44 35.192'	125 4.655'	1120	8/16/04	20:00:00	8/19/04	01:57:00
Rosella	s18	44 35.215'	125 4.243'	1195	8/16/04	20:00:00	8/19/04	01:23:00
Emu	s19	44 35.160'	125 3.752'	1232	8/16/04	20:00:00	8/19/04	00:36:00
Skink	s20	44 35.160'	125 3.297'	1240	8/16/04	22:00:00	8/18/04	23:56:00
Spit	s21	44 35.160'	125 2.843'	1255	8/16/04	22:00:00	8/18/04	23:19:00
Mantis	s22	44 35.160'	125 2.388'	1240	8/16/04	16:00:00	8/18/04	22:15:00
Platypus	s23	44 35.160'	125 1.934'	1218	8/16/04	16:00:00	8/18/04	21:44:00
Corella	s24	44 35.160'	125 1.479'	1165	8/16/04	16:00:00	8/18/04	21:02:00
Wallaby	s25	44 35.162'	125 0.966'	1135	8/16/04	16:00:00	8/18/04	20:11:00