FINAL CRUISE REPORT

Atwater Valley Deep-Towed Sidescan Sonar Imagery and Bathymetric Survey

R/V Pelican Cruise 14 Feb-18Feb 2005

DATE OF REPORT: November 22, 2005

DOE Award Number DE-AT26-97FT34344

CHIEF SCIENTIST/POC: Joan M. Gardner
Naval Research Laboratory, 4555 Overlook Avenue, S.W., Washington, D.C, 20375,
202-404-1094, joan.gardner@nrl.navy.mil

Participants: Mike Czarnecki, NRL Code 7420 Washington, D.C. Ocean Engineer
Rick Hagen, NRL Code 7420 Washington, D.C. Marine Geologist
Clyde Nishimura, Code 7420 Washington, D.C. Geophysicist
Warren Wood, NRL SSC Geophysicist
Chad Vaughn, NRL SSC Geologist
Jody Bruton, NRL SSC Microbiologist
Pat Hart, USGS Menlo Park, Geophysicist
Emil Bergeron, USGS WHOI Engineer
Collaborator: Deborah Hutchinson, USGS Woods Hole

Disclaimer

Abstract

The purpose of this project was to conduct detailed surface mapping of one of the areas drilled by the Joint Industry Project with ChevronTexaco to understand gas hydrates in the Gulf of Mexico. The gently sloping, mostly flat floor of the Mississippi Canyon is interrupted by mounds and depressions that presumably reflect the complex geology and geohydrology related to turbidite deposition and pervasive salt tectonism. The seafloor mounds we mapped in this study occur in approximately 1300 water depth along the floor of the Mississippi Canyon in lease block areas Atwater Valley 13 and 14. High resolution sidescan sonar (100 kHz and 500 kHz) backscatter imagery, and chirp sub-bottom profiler data were collected using the DT1 deep-towed oceanographic mapping instrument, concentrating on the region directly adjacent to and surrounding two mounds identified as, mounds D and F, and in the region directly adjacent to and surrounding the mounds. The backscatter data have been mosaiced and normalized to provide information on the shape and extent of the mounds, the possible lateral extent of fauna, such as mussel and clam fields on the mounds, possible seep related flows and the occurrence of carbonate material. The extent of a mudflow can be mapped on the southeastern side of mound F. The backscatter data show extremely high-resolution detail about the shape, relief, and morphology of the mounds. This information, coupled with porewater chemistry , DTAGS and heatflow data form a coherent picture of possible mechanics for fluid venting and flora/fauna of the seeps in this region.

Table of Contents

Introduction

An oceanographic survey was conducted in the Mississippi Canyon near Atwater Valley 13/14, Gulf of Mexico from Feb 11-18, 2005 by scientists from the Naval Research Laboratory and the US Geological Survey. High resolution sidescan sonar (100 kHz and 500 kHz) backscatter imagery, and chirp sub-bottom profiler data were collected using the DT1 deep-towed oceanographic mapping instrument, concentrating on the region directly adjacent to and surrounding two mounds identified as, mounds D and F, and in the region directly adjacent to and surrounding the mounds. These data were collected to characterize the seafloor in the area targeted for drilling by the JIP in Spring of 2005.

The presence of gas hydrates in seafloor sediments is significant from an economic, climatic and geologic hazards standpoint. Gas hydrates, also commonly referred to as clathrates or methane ice, and their association with seafloor mud volcanoes, were first documented by Ginsburg et al. (1984). Gas hydrate is a crystalline solid consisting of a gas molecule surrounded by a cage of water molecules, the entirety of which is stable at low temperatures and relatively high pressures (Booth et al., 1996; Max et al., 1997). The amount of methane, propane and other gases sequestered in gas hydrates beneath the world's oceans exceeds the volume of land based gas reserves by at least one order of magnitude (Kvenholden, 1993). Methane is a desirable alternative fuel source because it produces lower levels of carbon dioxide than oil does when burned (Dillon, 2001). Production of gas from hydrate, for use as a fuel, is presently being investigated by the Japanese along their coastal islands and by several U.S. oil companies on the North Slope of Alaska.

In addition to its potential as a future energy resource, gas hydrate also has been recognized as a possible cause of catastrophic slope failure and presents a geologic hazard to oil drilling and rig platform stability (Max et al., 1997; Baraza et al., 1999; Vogt et al., 1999; Kennett and Fackler-Adams, 2000). The presence of gas and clathrates in sediments reduces their strength, thereby making them more susceptible to failure along continental margins (Hampton et al., 1982; Lee and Baraza, 1999; Baraza et al., 1999). When hydrate in sediments breaks down into its two components, water and gas, it occupies a greater volume than it did before dissociation occurred. This greater volume increases internal pore pressure resulting in overpressurization of the sediments, which makes them more susceptible to failure (Max and Dillon, 1998; Max and Dillon 1999; Dillon, 2001). Slope failure attributed to gas in the sediments or dissociation of clathrates has been identified on the U.S. Atlantic margin (Booth et al., 1993; Driscoll et al., 2000; Holbrook, 2001), the Norwegian-Barents-Svalbard continental margin (Vogt et al., 1999), the Spanish continental margin (Lee and Baraza, 1991; Baraza et al., 1999), and the Korean continental margin (Gardner et al., 1998).

Acknowledgments

Financial support for this survey came from several sources. The primary sponsor was the Department of Energy, who provided salary support and travel for two of the Naval

Research Laboratory (NRL) researchers, shipping expenses for the instrumentation and partial vessel support. NRL provided salary and travel expenses for five of the researchers and 80 percent of the vessel cost. The United States Geological Survey (USGS) provided scientific personnel from their offices in Woods Hole and Menlo Park, for which we are quite grateful.

We would like to thank the support personnel at the LUMCON Marine Facility, as well as the Captain and Crew of the R/V Pelican for their outstanding performance on this survey. Installation of our navigation hardware was particularly difficult and would not have been successful without the help of Jack Pennington, Ship's Engineer. Deployment and recovery of the deep-tow instrument was also quite difficult but the crew skillfully helped the scientists get the job done without injury to person or equipment.

Objectives

The purpose of this project was to conduct a detailed surface mapping survey of the area occupied by Mounds D and F in Atwater Valley. This region was selected and drilled as part of the DOE's Joint Industry Project (JIP) with Chevron-Texaco to study hydrates in the Gulf of Mexico. This data will be integrated with other data already collected in the area, including seismic, geochemical, bottom camera photographs, electromagnetic data (EM) and heat flow information. Prior to this survey, no high resolution backscatter or bathymetric maps existed in the targeted drilling area.

High resolution sidescan sonar (100 kHz and 500 kHz) backscatter imagery was collected using our deep-towed oceanographic mapping instrument over Mounds D and F, as well as the region directly adjacent to and surrounding the mounds. The backscatter data has been mosaiced, normalized and provides information on the shape of the mounds, the possible lateral extent of fauna, such as mussel and clam fields on the mounds, and the occurrence of carbonate material. Prior bottom camera data, as well as electromagnetic data, will be used to ground-truth the backscatter information. Coincident with the collection of backscatter information was the collection of very high resolution bathymetric data. This data shows the shape and relief of the mounds.

Equipment

Deep-Tow Instrument

EdgeTech's Deep Water Full Spectrum "chirp" side scan sonar is a calibrated wide band digital FM sonar that provides quantitative and qualitative, high resolution, low-noise side scan imagery at 120 and 410 kHz. It simultaneously transmits linearly swept FM pulses centered at two discrete frequencies. A number of center frequency options are available. The transmission of a longer duration, wide bandwidth pulse results in higher resolution sonar images and because more energy is projected into the water, greater signal to noise ratio (SNR) resulting in extended range.

An important feature of Full Spectrum side scan sonar is the reduction of side lobes in the effective transducer aperture. The wide band and linearity of the FM sweep smears the side lobes of the transducer and thus achieves a beam pattern with virtually no side lobes.

EdgeTech's Full Spectrum "chirp," a 2 to 16 kHz sub-bottom profiler, has a number of advantages over conventional profilers, including increased penetration and higher resolution. The tapered waveform spectrum results in images that have virtually constant resolution with depth. Another advantage is the reduction of side lobes in the effective transducer aperture. The wide bandwidth of the sweep frequency has an effect of smearing the side lobes of the transducer. The result is a beam pattern with almost no side lobes. This allows the system to be very near the bottom, minimizing destructive signal scattering caused by the sediment. The frequency range of operation is determined by the acoustic characteristics of the transmitter and receiver sensor arrays. Each sensor array can transmit acoustic pulses with different center frequencies and bandwidths. The selection of the pulse is made on-line by the operator while profiling to achieve the best imagery. The sensor array is selected based on the sub-bottom conditions at the survey site and the type of sub-bottom features that need to be imaged.

The multibeam bathymetric mapping system is an EM2000 system designed and built by Simrad. This system operates at 200 kHz with 111 beams of 2.5^{o} across track and 1.5^{o} along track. It is capable of mapping swaths of seven times the water depth below the tow vehicle; 350 meter swaths were typical for this survey.

The tow vehicle contains the side scan sonar and sub-bottom profiler sensor arrays, multibeam bathymetric mapping sensors, and all of the Full Spectrum chirp electronics required to generate, transmit, receive, and process the Full Spectrum "chirp" sonar signals. Sonar and other data are transmitted to the surface via StarMux; where a PC based data acquisition, storage, and printing processor running EdgeTech's DISCOVER software is the user interface to the underwater portion of the system. Motion and depth sensors are also integrated in the system to monitor towfish motion including pitch, roll, yaw and heave.

All the sensors are housed in a neutrally buoyant towfish which is approximately 10 feet long, 3 feet wide and 4 feet high (Figure 1). The towfish weighs 2000 lbs and requires an 1800 lb depressor weight, which is attached forward of the tow vehicle to compensate for its neutral buoyancy. The system is equipped with a pressure release system which will release the towfish if the instrument should become detached from the tow cable.

Optimum tow speed for the highest quality data acquisition was found to be about 3 knots. The tow-vehicle was towed approximately 50 meters above the seafloor.

<u>Navigation system</u>
A Sonardyne Ultra-Short Baseline (USBL) system was used for this survey. This acoustic positioning method measures the range and bearing from a vessel mounted transceiver, which was mounted on a pole extending five feet below the keel, to a single, subsea

transponder which is mounted in the tow-vehicle. The USBL system then provides a range and bearing estimate of the transponder relative to the ship's position. Range is calculated by measuring the time taken from sending a transponder interrogation signal to receiving its reply. Bearing is derived by comparing the small differences in the time of arrival of the reply signal at each receiver element within the transceiver. Such small delays (microseconds) are analyzed as 'time-phase' differences and this data is processed to provide a best fit solution. Because there are more than three receivers in the transceiver head, the redundant information can be used to get a measure of consistency and quality of the position fix.

Results

Thirteen survey lines were driven over the Atwater site. Survey line spacing was laid at 200 meters apart, with lines being extended beyond the Mounds by a minimum of 2 km to ensure the tow-vehicle passed over them before a turn was initiated. Survey lines were approximately 8 km in length. The navigation system performed only marginally well due to problems with the transponder mounting in the towfish. Navigation data collected with this system was only usable on half of the survey lines.

<u>Sidescan data</u>
Three sidescan sonar imagery charts have been constructed over the primary areas of focus: Mounds D; F; and the region between the mounds where two of the JIP sites have been proposed. These charts (Figures 2, 3, 4) are constructed of backscatter imagery tracks which have been mosaiced together and a line-drawn interpretation of the important features has been done. The imagery has been normalized so that the greyscale is representative of textural changes in the seafloor surface which affects the backscatter intensity. High or strong regions of backscatter are represented by darker pixels on the charts and low or weak regions of backscatter are represented by lighter pixels. Sidescan imagery was gridded at a 0.6 meter pixel resolution. Approximate swath width was 300 meters per side for the survey.

<u>Bathymetry data</u>
Bathymetric charts have not been constructed for this dataset due to a problem with the datafiles.

<u>Sub-bottom Profiler data</u>
Sub-bottom profiler data was believed to be of poor resolution and quality until some tests were run with the system in a region to the northeast of Atwater Valley. The sensors were determined to be operating correctly; therefore it was the geology, specifically the presence of fluid and gas in the sediments that made for the poor appearance and subsurface reflector definition in the data. (Figure 5).

Discussion

Sidescan data was collected and mosaiced over the three areas that the JIP was planning to drill. The left panel in Figure 2 is a mosaiced 100 kHz sidescan image of Mound F.

The right panel is a line-drawn interpretation of the important features in the sidescan image. The top of the mound is flanked by a series of curved faults and cracks which are slightly arcuate in shape. Additionally, there is a higher backscatter region on the southern flank of the mound that may be a small mud flow or vent site. Heat flow and piston core sites have been plotted on the map for reference. The overall higher backscatter of the sidescan image which covers the mound is an artifact of a instrument induced gain change that we are still trying to compensate for, although it is likely that the mound itself returns an overall higher backscatter signature due to the presence of thin carbonate crust deposits.

Figure 3 represents the region between the two mounds. Two JIP sites are proposed here. The only features of note on this image are the small network of faults that form wrinkles on the seafloor. These faults are very small (2 to 5 meters of throw) and show some signs of erosion by bottom current forces. There are a few dark patches in the image that may also represent coral or clam communities.

Mound F can be seen in Figure 4. An area of venting with associated mud flows is very apparent in the image. There are also several areas of sand/mud waves that are the result of bottom water currents in the area. In the southwest corner of the image there are a series of small faults similar to the ones in Figure 3. The JIP site is positioned to the southeast of what appears to be a vent site. Heatflow data were collected over this site on a previous cruise, and the data shows high values in this region of high backscatter which suggests fluid flow and venting.

Figure 5 is an example of the sub-bottom profiler data that was collected in the region. Very little sub-seafloor information can be extracted from this data. We confirmed during the cruise that the sensor was performing within specifications. Therefore the lack of definition in this image is most likely due to gas or fluids entrained in the sediments.

Figure 6 combines newly acquired deep-towed acoustic geophysics system (DTAGS) data collected during a February 21-25, 2005 cruise which directly followed our DT1 cruise,() over and between the mounds with results from the porewater chloride levels (green line), the thermal data (color bands), the top of gas as interpreted directly from the DTAGS data (blue line) and the base of the gas hydrate stability (BGHS) zone (red line) as modeled using the thermal data. The modeled BGHS very closely follows the interpreted top of gas. Additionally, the increase of chloride values and thermal values under the mounds indicated these are regions of high fluid flux. These results are quite encouraging since it is the first time, to our knowledge, that a plunging or perturbed BSR has been successfully modeled.

Summary

Sidescan sonar imagery, bathymetry and sub-bottom data were collected in the Atwater Valley with the Naval Research Laboratories DT1 instrument. This report contains examples of the imagery data and interpretations of the data. Sub-bottom data were of poor quality and did not give any definitive information about the sub-seafloor.

Bathymetric data could not be processed due to a problem with the data logger. Thermal and geochemical data collected by NRL have been successfully processed and appear to support the hypothesis that high fluid flow exists in the center of both mounds and is contributing to the perturbations of the BSR observed in the seismic images. Additionally, the thermal data have been successfully extrapolated and used to model the BSR in this region. This is an important achievement. This is the first time a model has been successfully used and demonstrates how mineralizing solutions can migrate into porous horizons within the GHSZ where the geological strata are essentially parallel to the seafloor, as is the case in much of the Gulf of Mexico.

The position of the BGHSZ is believed to be affected by the pressure and temperature of the seafloor and the geothermal gradient. Results of this survey clearly demonstrate that the BGHSZ is an active element, whose position can be strongly affected by groundwater movement. Movement of the BGHSZ is important in allowing mineralizing solutions to pass laterally into porous horizons that are the best hosts of high grade hydrate deposits, as the BGHSZ and the porous strata must intersect for this to happen. While this may seem intuitive, it has been an unsubstantiated hypothesis up to this point.

Figures

Figure 1. NRL's Deep-towed sidescan sonar, bathymetric and sub-bottom mapping instrument DT1.

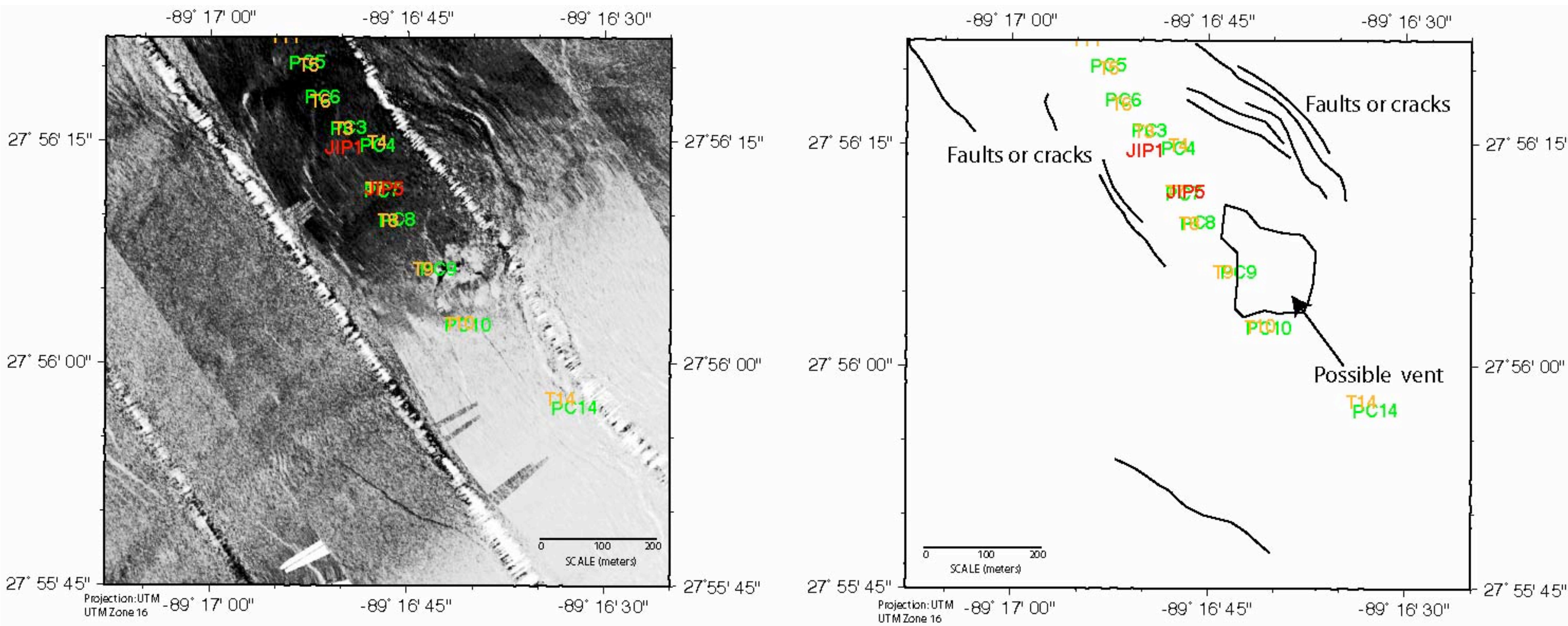

Figure 2: Mound F 100 kHz sidescan sonar image of the proposed JIP sites 1 and 5 (left panel) and interpretation of features of interest in the image (right panel). Piston cores (PC) and heat flow (T) stations are annotated on the image. Sidescan convention: High backscatter dark, low backscatter light.

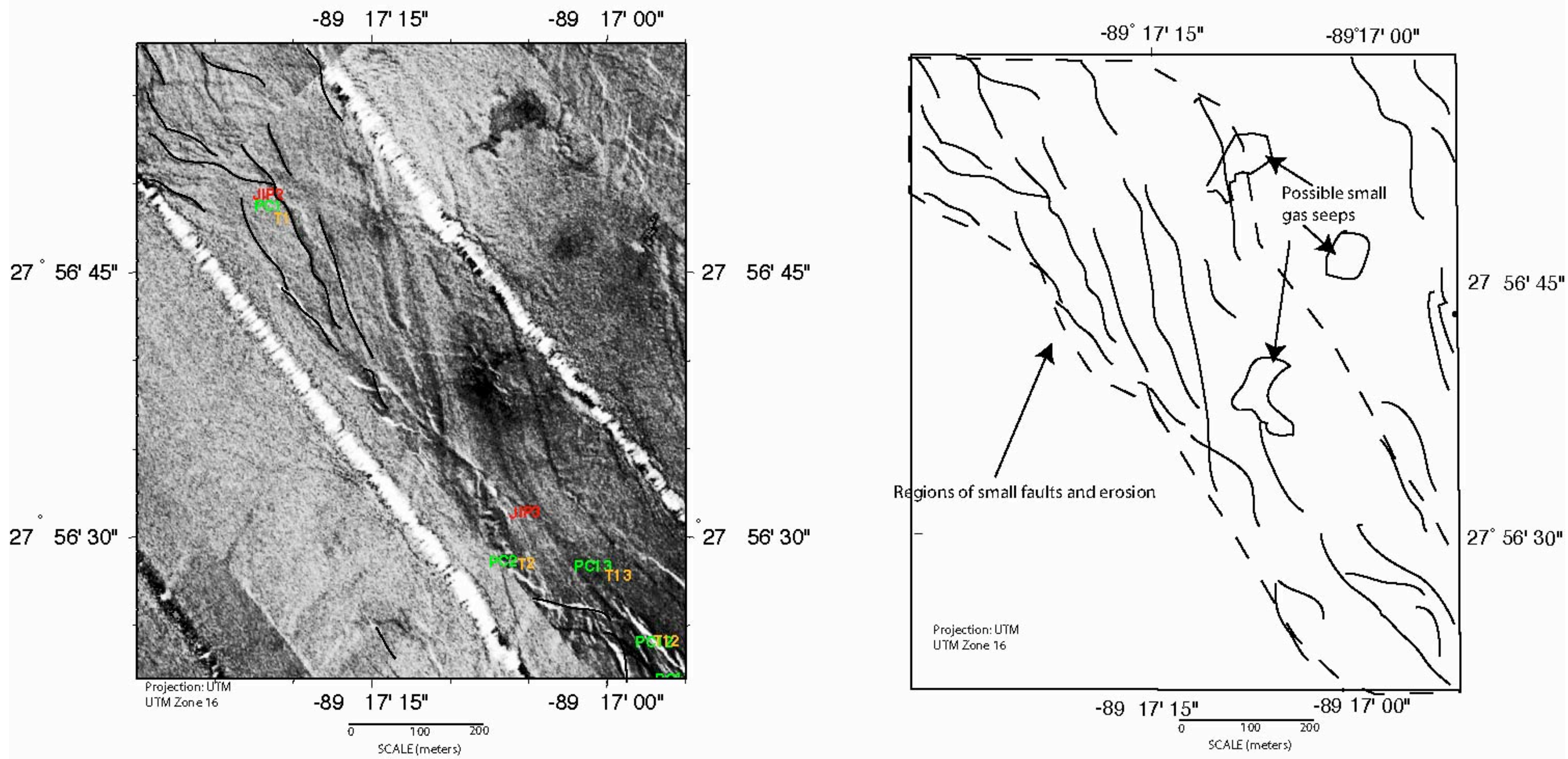

Figure 3: 100 kHz sidescan sonar image of the proposed JIP sites 2 and 3 (left panel) and interpretation of features of interest in the image (right panel) piston cores (PC) and Heat flow (T) stations are annotated on the image. Sidescan convention: High backscatter dark, low backscatter light.

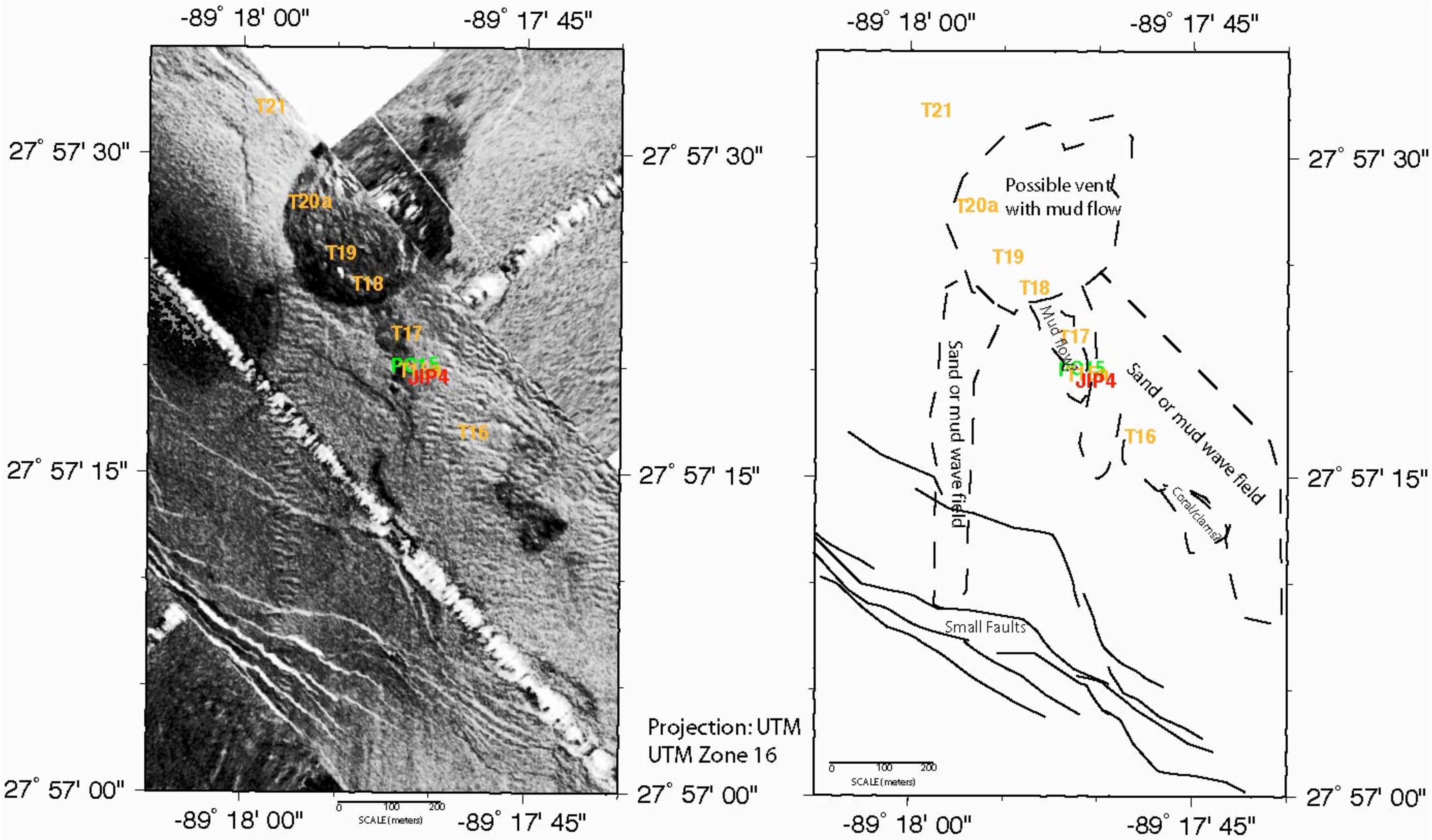

Figure 4: Mound D. 100 kHz sidescan sonar image of the proposed JIP site 4. (left panel) and interpretation of features of interest in the image (right panel). Piston cores (PC) and heat flow (T) stations are annotated on the image. Sidescan convention: High backscatter dark, low backscatter light.

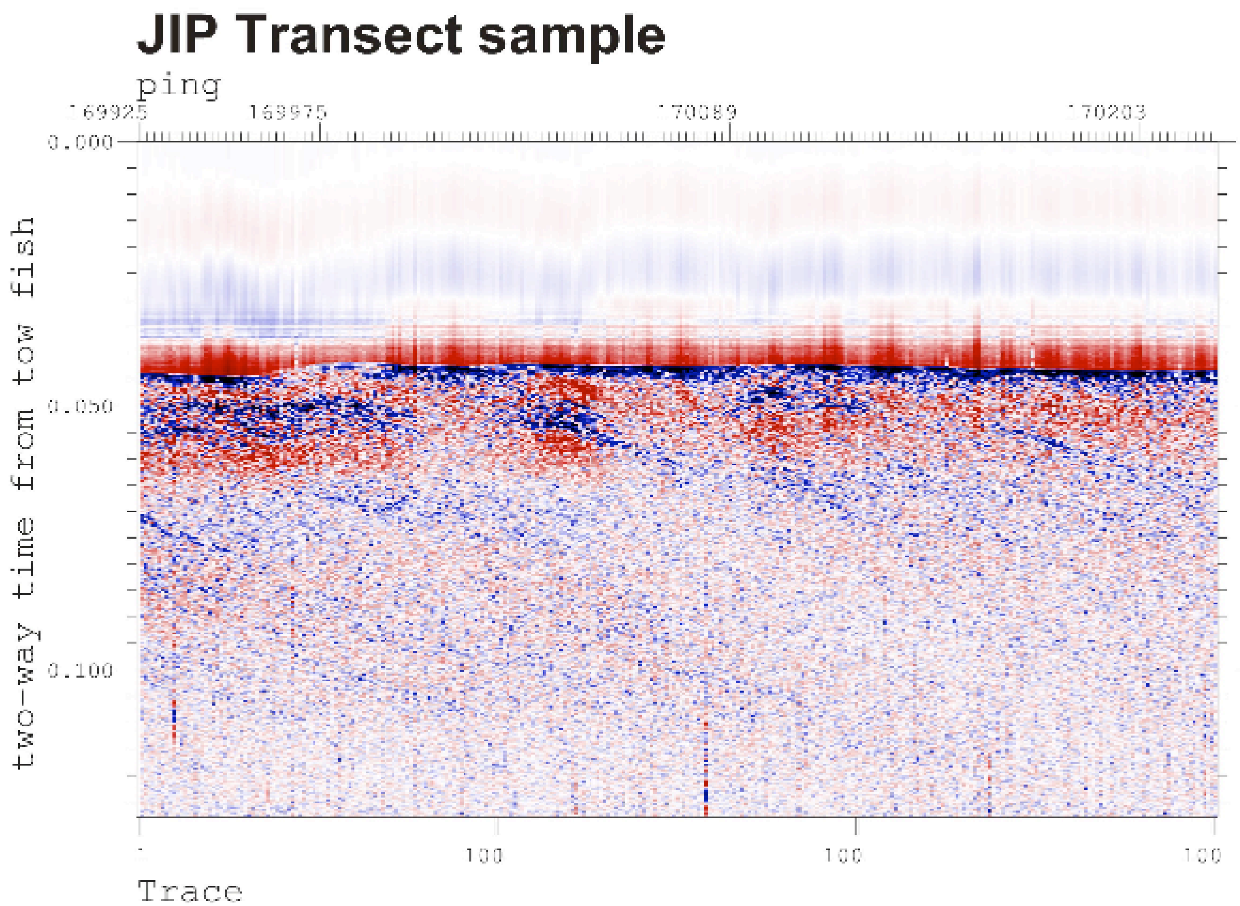

Figure 5. Sample of the chirp sub-bottom profiler data collected in the Atwater Valley. Note how the sub-bottom reflectors are poorly defined. The sensor was later proven to be operating as it should and the poor appearance of this record is most likely due to fluid and gas entrained in the subsurface sediments which are absorbing and scattering the signal. Data processed by Warren Wood.

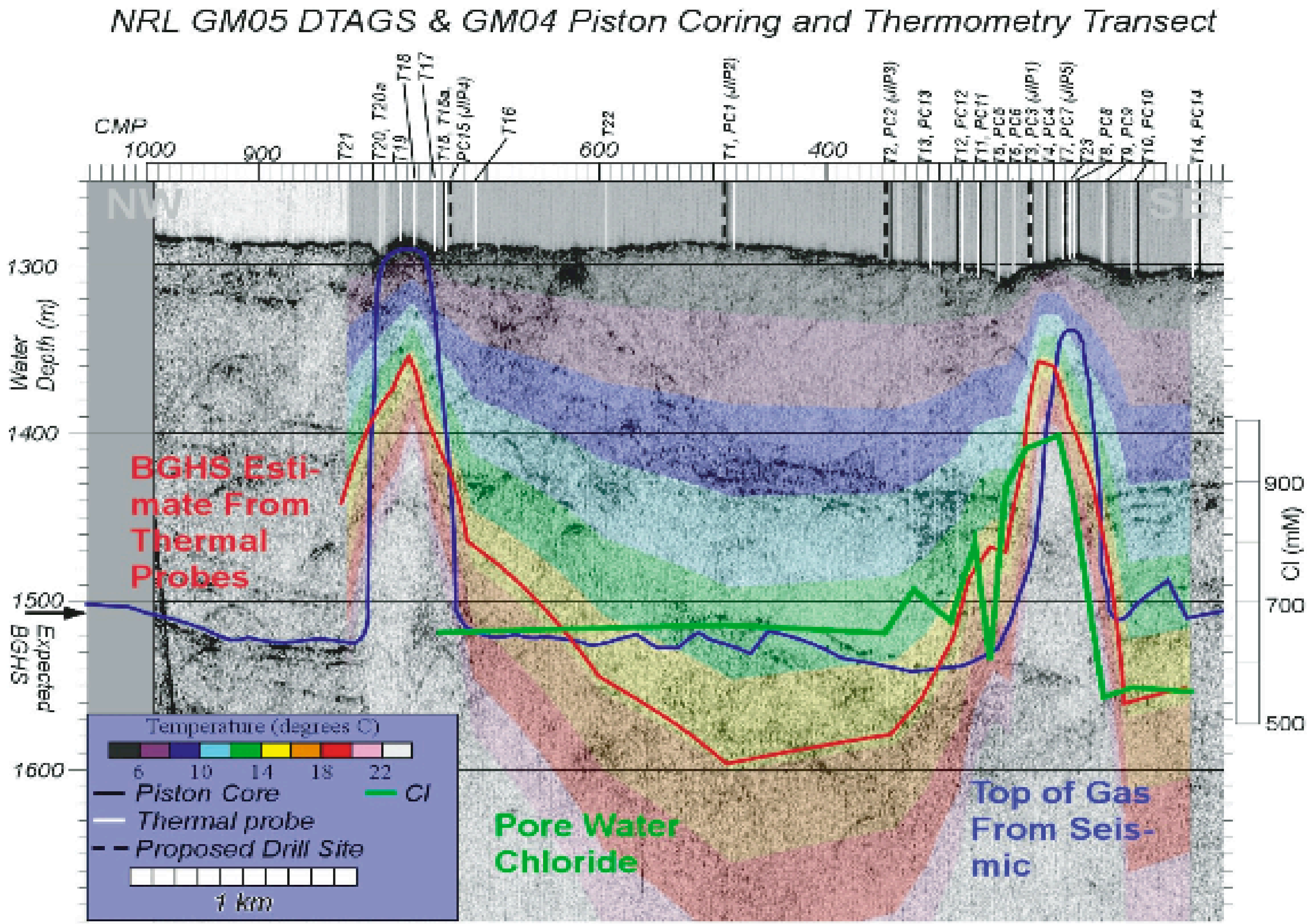

Figure 6. This figure illustrates the base of the gas hydrate stability zone (BGHS) estimated using the thermal data in the SUTRA model. (red) Pore water chloride variations are denoted by the green line and the top of the gas picked directly from the DTAGS data is denoted in blue. Figure by Warren Wood.

References

Baraza, J., Ercilla, G., and Nelson, C.H., Potential geologic hazards on the eastern Gulf of Cadiz slope (SW Spain) (1999)., Marine Geology (155), p. 191-215

Booth, J. S., Rowe, M., and Fischer, K.M. (1996). Offshore gas hydrate sample database with an overview and preliminary analysis. USGS Open-file Report 96-272, pp.17.

Dillon, W.P., (2001). Gas hydrate in the ocean environment. In: Meyers, R.A. (Ed.) Encyclopedia of Physical Science and Technology, Third Edition, Academic Press, (6), p. 473-486.

Driscoll, N. W., J. K. Weissel, and J. A. Goff, (2000). En echelon cracks along the outer continental shelf: Implications for submarine landslides and tsunamis, Geology, (28), p. 407-410.

Holbrook, W.S., (2001). Seismic studies of the Blake Ridge: Implications for hydrate distribution, methane expulsion and free gas dynamics. In: Paull, C.K. and Dillon, W.P., (Eds) Natural gas hydrates. Occurrence, distribution and detection. American Geophysical Union Press, p. 235-256.

Gardner, J., Shor, A., and Jung, W., (1998). Acoustic Imagery Evidence for methane Hydrates in the Ulleung Basin, Marine Geophys. Res., (20), p. 495-503

Ginsburg, G.D., Ivanov, V.L. and Soloviev, V.A., (1984). Natural gas hydrates in the world's oceans. In: Oil and Gas Content of the World's Oceans, Leningrad, PGO Sevmorgelogia. Translated from Russian., p. 141-158

Ginsburg, G.D. and Soloviev, V.A., (1998). Submarine Gas Hydrates. V.L. Ivanov (Ed)., VNIIOkeangeologia, St Petersburg. Translated from Russian. 216 pp.

Ginsburg, G.D. Guseinov, R.A., Dadashev, AA., Ivanova, G.A., Kazantsesv, S.A., Soloviev, V.A., Telepnev, Ye.V., Askery-Nasirov, R.E., Yesikov, A.D., Maltseva , V.I., Mashirov, Yu.G, ans Sahbayeva, I.Yu., (1992). Gas Hydrates in the southern Caspian Sea. Izv. Akad. Nauk, Ser. Geol., (7), translated from Russian, p. 5-10.

Hampton, M.A., Lee, H., and Beard, R.M., (1982). Geological interpretation of cone penetrometer tests in Norton Sound, Alaska. Geo-Mar. Lett. (2), p. 223-231.

Kennett, J.P. and Fackler-Adams, B., (2000). Relationship of clathrate instability to sediment deformation in the upper Neogene of California. Geology (28) n. 3, p.215-218.

Kvenholden, K.A., (1993). A primer on gas hydrate, In: Howell, D.G. et al. (Eds). The Future of Energy Gases. USGS Professional Paper 1570, p. 279-291.

Lee, H., and Baraza, J., (1999). Geotechnical characteristics and slope stability in the Gulf of Cadiz. Mar. Geol. (155), p. 173-190.

Max, M.D., Pellanbarg, R.E., and Hurdle, B.G., (1997). Methane Hydrate, a special clathrate: its attributes and potential. NRL Memoradium Report/6101-97-7926, pp.77.

Max, M.D. and Dillon, W.P., (1998). Oceanic methane hydrate: Character of the Blake Ridge hydrate stability zone and potential for methane extraction. Journal of Petroleum Geology, (21), p. 343-358.

Max, M.D. and Dillon, W.P., (1999). Oceanic methane hydrate: Character of the Blake Ridge hydrate stability zone and potential for methane extraction: Author correction. Journal of Petroleum Geology, (22), p. 227-228.

Vogt, P.R., Gardner, J.M. and Crane, K., (1999). High latitude mass wasting and gas venting. Geo-Marine Lett. Spec. Issue, (19), n 1/2, pp. 169.

Appendix

Chronological Order of Events

14 Feb 0800 local: Depart LUMCON for Atwater site. 12 hour transit. Seas are sloppy.
2157 local: On site at Atwater Valley. Sonardyne calibration beacon deployed at 27 56.468N 89 16.844W.

15 Feb 0056 local: Calibration finished and beacon is recovered.
0245 local: Deep-towed fish in the water.
0430 local: Start data logging. Water depth about 1268 m. Towfish range 2211m towfish depth is 100 m above the bottom. Tow fish is towing about 100 m to port side of ship.
0530 local: end of line 1
0620 local: begin line 2, towfish tracking 100 m to port, range is 2143 m
0752 local: end of line 2, cable shorted during turn. Depressor on board at 0911 local for electrical cable repair.
1026 local: Depressor deployed.
1111 local: Begin line 3, layback about 1600 m, range 1983m, towfish towing about 200m to port.
1311 local: End of line 3
1459 local: Begin of line 4, towfish 75 m off bottom, layback about 1600 m, towfish still crabbing about 100-200m to port
1609 local: End of line 4
1719 local: Begin line 5
1854 local: End line 5
1952 local: Begin line 6, water depth 1240 m towfish about 60 m above seafloor
2130 local: End line 6
2228 local: Begin line 7, fighting current, fish about 200 m to port, cable out several times to keep fish about 65 m above bottom. End of line 7 at 2353 local
Additional comments: Oil company drill ship is camped out to the northwest of our survey area and called on the radio to alert us to a 1.5 mile radius of safety that they'd established. This altered our survey plan slightly. Seas have been almost dead flat calm today with light winds. Navigation system not tracking well. Bathymetry processing software not working properly so the data will have to be processed back at the lab. Sidescan processing is making progress.

16 Feb: Continue surveying. Begin line 8 at 0144 local. End of line 8 at 0335 local. Completed through line 13 which is the end of Atwater Canyon. Transited to IODP drill sites to test sub-bottom profiler quality. Lines 14 (transit), 15 and 16 completed. Sub-bottom data looks beautiful. What we believed was poor sensor operation on the Atwater lines, due to little sub-bottom definition, was actually due to the geology and gas entrained in the sediments.

17 Feb. Line 17 transit line. Line 18 turn. Line 19 completed over headwall scarp near Dufresne core sites. Survey lines had to be shortened due to safety zone established for drill rig activity in the area. Weather beginning to deteriorate so survey was ended and the towfish was recovered at 0931 local.
Towfish onboard at 1030 local. Transit to Gulfport, MS.

18 Feb. 0430 local. Arrive Gulfport, MS. 0800 local pack up gear. 1100 local, truck

with DTAGS gear arrives. Deep-tow gear offloaded and DTAGS onloaded. 1400 local Leg 1 science party departs.