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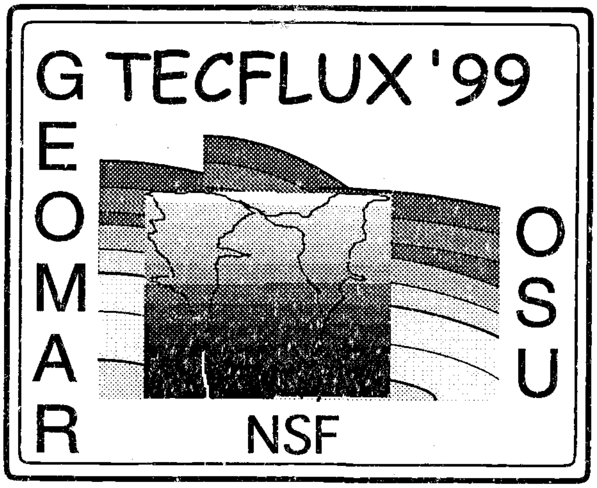

OREGON STATE UNIVERSITY

Geochemical observations on Hydrate Ridge, Cascadia Margin July 1999.

Marta E. Torres
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Data Report 174
Reference 99-3

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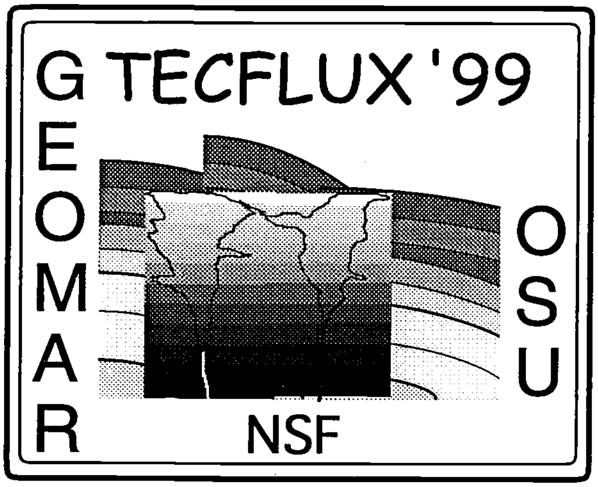

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1. INTRODUCTION AND BACKGROUND

1.1 THE TECFLUX PROGRAM

Geophysical and biogeochemical processes associated with fluid venting from active and passive continental margins will receive significant scientific and economic attention into the next century and are of major societal relevance. An important unknown among these interrelated processes is the role played by *methane gas hydrates*, at and below the seafloor, and their impact on the oceans and atmosphere.

Research scientists from institutions in the USA, Germany and Canada have developed a research project dedicated to a long-term study of continental margin gas hydrates on the Cascadia Accretionary Prism, under the acronym "TECFLUX". It is conceived as multi-stage research effort with the eventual goal of measuring the energy and chemical fluxes associated with this system, determining its temporal variability in response to tectonic and oceanographic forcing, and evaluating its impact on marine biogeochemical cycles.

TABLE 1: RESEARCH PROGRAMS CURRENTLY IN TECFLUX

"Geochemical Consequences of Extensive Gas Hydrate Formation in Sediments of the Cascadia Accretionary Prism" (funded by US-NSF to Torres, McManus and Brown).

"High-Resolution Analysis of the Nature and Volume of Gas Hydrate and Carbonate Mineralization Across the Oregon Margin Accretionary Complex." (funded by US-NSF to Goldfinger, Trehu and Torres)

"Chemical distributions and fluxes in the water column above an emerging hydrate field on the Cascadia accretionary prism" (funded by US-NSF by Collier, Klinkhammer and deAngelis).

"Long-term impact of methane hydrate on the deep-sea ecosystem at the Cascadia subduction zone" (funded by German BMBF by Suess, Linke, Bohrmann and Mienert, GEOMAR)

"Geochemistry of carbonate phases and cementation of sediments associated with near-surface gas hydrates on Cascadia". (funded by German BMBF by Bohrmann et al., GEOMAR)

"Quantifying fluid flow, solute mixing and biogeochemical turnover at vent sites of the Cascadia accretionary prism." (funded by German BMBF by Wallmann et al., GEOMAR)

"Developing a Paleoceanographic Tracer of Methane Venting" (submitted to NSF by Mix and Torres).

1.2 BENTHIC PROGRAM WITHIN TECFLUX (M.E. Torres)

During gas hydrate formation, methane and water become immobilized as a solid, reducing effective pore space and retarding the migration of fluids. Hydrate-cemented sediments act as a barrier for fluid and gas exchange. Thus, hydrate composition and distribution in the sediments influence hydrologic process within accretionary margins and affect the exchange between sediments and overlying water. Although understanding the biogeochemical processes associated with fluid seepage in continental margins has been identified as an area of scientific priority for undersea research, there is very little information on how geochemical processes in continental boundary sediments may be influenced by hydrate formation and decomposition. The direction of our research is guided by recent discoveries along the Cascadia margin of massive hydrate deposits in near surface sediments; and sites where fresh water and methane gas from hydrate decomposition are discharged at seafloor vents.

Our program is designed to examine: 1) processes that occur above the gas-hydrate sealed strata away from actively venting sites; 2) the mechanisms and consequences of hydrate decomposition at actively venting sites; and 3) the spatial and temporal variability of hydrate decomposition. Specific study sites targeted for this work include locations of known bubble ebullition at the seafloor, locations having massive hydrate blocks located within centimeters of the sediment-water interface, and locations where the hydrate lies under a few meters of sediment cover.

AT NON-VENTING SITES our main objective is to assess how near-surface formation and decomposition of a mixed CH_4-H_2S hydrate in continental margin sediments influences benthic fluxes and early diagenetic reactions.

AT VENTING SITES our main objective is to evaluate the magnitude, and the temporal and spatial variability, of elemental fluxes to the bottom water via hydrate decomposition.

To quantify the exchange of fluids and dissolved constituents from the hydrate field to the overlying water column we designed a 2-year field program to deploy benthic devices that can sample fluids and gases at stations ranging from areas characterized by diffusion-controlled transport to sites of advective fluid discharge. A number of push and multicores will be collected to assess how near-surface formation and decomposition of a mixed CH_4-H_2S hydrate in continental margin sediments influences benthic fluxes and early diagenetic reactions.

The different environments present in the Cascadia margin, along with our spatial-temporal experimental design will allow us to evaluate the effect of widespread hydrate formation in the Cascadia margin on element mobilization, transport, and release at the seafloor. This knowledge has applications on broader issues in a global scale, as hydrate geochemistry is of significant relevance in global carbon budgets, climate change models, sediment slope stability, and energy resource issues.

1.2.1 Summary of results from Tecflux 98

We had a successful field program in 1998, using the Canadian ROV ROPOS to conduct a series of experiments at the northern summit of Hydrate Ridge, OR, followed by a Wecoma cruise to recover instruments that had been deployed at the seafloor. The main results from this program have been presented in various manuscripts and scientific meetings (Table 2); and are summarized below.

Water column observations:

A massive release of methane on the Cascadia Hydrate Ridge was documented during a ROPOS program in August 1998, consistent with previously reported observations in 1996. The magnitude of this methane injection is comparable to or larger than that over oceanic spreading centers. The methane profiles suggest the presence of other methane seeps at shallower water depths on the margin. A methane profile (CTD 7) also suggests that during periods of increased storm activity some of the hydrate methane may reach surface waters. Although an observed subsurface maximum is probably due to microbial activity, comparison with methane levels in highly productive areas suggests the possibility of an added contribution to the near-surface methane concentration that originates at seafloor seeps.

***Seep observations*:**

1 Very active gas ebullition. The areas of gas discharge are discrete and highly focussed within conduits with an approximate cross-sectional area of 5 cm^2. We estimate the gas flow rate to be on the order of 5 liters/minute. The discharge is highly episodic, and suggests a tidal effect.

2. Very high Rn/CH_4 ratio in gas samples The Rn/CH_4 ratio in gas samples collected from the gas vents is very high, approximately 50 dpm/liter (stp) CH_4. If this ratio is used to calculate the Rn concentration in pore fluids that should be in equilibrium with this gas phase, the Rn should be about 1.5 dpm/cc of pore fluid. This concentration is comparable to that in groundwaters of granitic bedrock and suggests the gas must be derived from a region with high (solid)/(gas + water).

3. Hydrate precipitation at the seafloor. Methane hydrate should be stable at the temperature and pressure conditions at the seafloor on Hydrate Ridge. Indeed, solid hydrate was observed to form within the gas samplers as well as on the camera itself, supporting the conclusion that methane is rapidly transported to the seafloor from beneath the BSR within discrete conduits, most likely separated from significant amounts of pore water. When discharged at the seafloor, some of the methane precipitates as hydrate and some continues to rise within the water column. Bubbles were observed with the ROV up to 50 meters above the seafloor.

4. Benthic Barrel data supports the idea of high oxygen consumption at seep sites. The ammonium and sulfide distribution is consistent with a period (app. 40 minutes) during which the reduced species released at the vents are consumed by dissolved oxygen, after which the concentrations of these reduced species are observed to increase. This pattern was first described by Suess et al. (1998) who estimated the oxygen consumption -due to oxidation of reduced species associated with venting- to be more than 4 orders of magnitude greater than that normally found at the sea floor at comparable ocean depths. A decrease in $\delta^{13}C$ in barrel samples, and an increase in total dissolved CO_2 is also consistent with oxidation of the discharged methane. The methane oxidation rates measured in the water samples, however, do not show levels above ambient deep-water values; suggesting that methane oxidation is occurring at highly localized sites near the seafloor.

5. Seeps align in a narrow band trending 110 deg. This feature parallels larger mounds imaged by Seabeam as well as larger structures of the accretionary prism such as the Daisy bank. The area of intense bubbling is characterized by extensive bacterial mats. Large clam fields were observed ten's of meters away from the gas seeps. A third province with carbonate blocks but no clams or bacterial mats was mapped approximately 200 meters away from the seeps.

Osmotic flow meter results:

Measurements were taken over a one month period, with data being obtained from six SIO Benthic Aqueous Flux Meters. These instruments use the dilution of a chemical tracer to record a time series of flux rates. Four instruments were successfully deployed by ROPOS ROV in and around areas of microbial mats and clam colonies, indicative of areas of active flow, near the northern summit of the ridge. Preliminary results indicate that flow in this region is highly heterogeneous, with areas of both up flow and down flow in the northern deployment site. Significant changes in the magnitude of the flow also during the deployment period was also noted on one instrument. Data for two instruments deployed near the southern summit of the ridge -where extensive gas hydrates occur but with no obvious surface indicators for seepage- suggest a tidal effect on the fluid flow regime.

TABLE 2: PUBLICATIONS FROM 1998 TECFLUX PROGRAM

Suess, E., M. E. Torres, G. Bohrmann, R. W. Collier, J. Greinert, P. Linke, G. Rehder, A. Trehu, K. Wallmann, G. Winckler, E. Zuleger. Gas hydrate destabilization: Enhanced dewatering, benthic material turnover and large methane plumes at the Cascadia convergent margin. *EPSL* 170:1-15, 1999.

Trehu, A.M., Torrres, M.E., Moore, G., Suess, E. and Bohrmann, G. Dissociation of gas hydrates in response to slumping and folding on the Oregon continental margin. *Geology*, in press1999

Tryon, M.D., Brown, K. M., Torres, M.E., Trehu, A.M., McManus, J. and collier, R. W. Measurements of transience and flow cycling near episodic methane gas vents, Hydrate ridge, Cascadia. Submitted to *Geology*, 1999

Torres, M. E., K. M. Brown, R. W. Collier, M. A. de Angelis, D. Hammond, J. McManus, G. Rehder, and A. Trehu, 1998b. Geochemical observations on Hydrate Ridge, Cascadia Margin during RV-Brown-ROPOS cruise, August 1998. Oregon State University COAS-Data Report 171, Ref. 98-4

M. E. Torres, K. M. Brown, S. Colbert, R. W. Collier, M. A. deAngelis, D. E. Hammond, K. Heeschen, D. Hubbard, J. McManus, C. Moyer, G. Rehder, A. Trehu, M. Tryon, and P. Whaling (1998) Active gas discharge resulting from decomposition of gas hydrates on Hydrate Ridge, Cascadia margin. Fall AGU, San Francisco, Dec. '98.

M. E. Torres, R. W. Collier, M.A. de Angelis, J. McManus, G. Rehder and E. Suess, Isotopic Evidence for Methane Oxidation of Hydrate Methane in Water Samples Overlying Hydrate Ridge, Cascadia. In: Fluid seeps at transform and convergent margins: A symposium. AAPG Pacific Section Monterey, CA, April 28 to May 1, 1999.

C. Goldfinger, M.E. Torres, and A. M. Trehu. Possible Strike-Slip Fault Source for Hydrate Ridge Methane Vents, Cascadia Margin. In: Fluid seeps at transform and convergent margins: A symposium. AAPG Pacific Section Monterey, CA, April 28 to May 1, 1999.

M. Tryon and K. Brown, Aqueous flow measurements on Hydrate Ridge, Cascadia. In: Fluid seeps at transform and convergent margins: A symposium. AAPG Pacific Section Monterey, CA, April 28 to May 1, 1999.

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2. CRUISE NARRATIVE AND STATION SUMMARY

R/V Atlantis arrived in Newport, OR on Wednesday June 30th, 1999 for a short port call to exchange scientific personnel from Leg AT3-35A (Chief scientist: B. Carson) with the crew of Leg AT3-35B (Chief Scientist: M. Torres). The original plan was for Atlantis to depart Newport at 2000 on June 30th, however, repairs on the ship anchor system and front thruster had to be undertaken on port. These operations were not completed on time, and thus departure was delayed. We departed Newport, OR at 1000 on July 1st, 1999 and proceeded to deploy and calibrate the navigation net on Hydrate Ridge South (HRS: Figure 1). Upon completion of this operation, we began the scientific program of Leg AT3-35B, which is summarized on Table 3. It consisted of 37 stations, 10 of which correspond to Alvin dives 3421 to 3430 (see section 6.3). The Alvin dive scheduled for July 12th was cancelled due to sustained winds over 30 knots. The navigation transponders were retrieved and R/V Atlantis set sail for Astoria, OR at 1300 on July 12th. She arrived in port at 0800 on July 13, 1999.

Table 3: Station summary

Station AT9906-	Location	Date (PST)	Start Time (PST)	Time at depth	End Time (PST)	Latitude at bottom	Longitude at bottom	Latitude off bottom	Longitude off bottom	Wire out	Max. depth	Bottom depth	Remarks
1 FM	HRS	7/1/99	19:35		19:40	44°34.4508	125°08.95						Meter B
2 FM	HRS	7/1/99	19:45		20:00	44°34.2345	125°08.8884						Meter G, A
						44°34.2354	125°08.8881						Meter H, Flasher
3 MC	V4	7/1/99		21:50	22:33	44°35.889	125°05.320	44°35.871	125°05.319	1055		1042	
4 CTD 1,2		7/2/99	6:25			44°33.9503	125°09.0994					794	
5 AD 3421	HRS	7/2/99	8:00		17:00	44°34.45	125°08.95					800	
6 ESS	HRN	7/2/99				see log sheet							bubble plumes
7 MC	E. Basin	7/3/99	3:57	4:22	5:30	44°35.873	125°05.316	44°35.871	125°05.319	1029			Short cores
8 AD 3422	HRS	7/3/99	8:00		16:10	44°34.42	125°08.73					800	
9 ESS	HRN	7/4/99				see log sheet							
10 CTD 3	HRN	7/4/99	0:10			44°39.772	125°05.650					596	bubbles at 540m
11 AD 3423	HRN	7/4/99	8:00		16:10	44°40.15	125°05.75					600	
12 ESS	SEKnoll	7/4/99				see log sheet							
13 MC	HRS	7/5/99	3:50	4:21	4:58	44°35.199	125°07.00	44°35.200	125°07.00	897			
14 AD 3424	HRS	7/5/99	8:00		17:00	44°34.405	125°08.811					800	
15 ESS	N BSR outcrop	7/5/99				see log sheet							no bubbles
16 FM	HRN	7/5/99	7:00			44°40.025	125°06.005						
17 AD 3425	HRN	7/6/99	8:00		15:50	44°40.025	125°06.005					600	
18 ESS	SEKnoll	7/6/99				see log sheet							
19 CTD	SEKnoll	7/6/99				44°27.00	125°01.8					614	
20 MC	HRS	7/7/99	3:42	4:09	4:43	44°34.999	125°09.119	44°35.000	125°09.120	865		869	
21 AD 3426	HRN	7/7/99	8:00		14:30	44°40.025	125°06.005					600	
22 MC	PALEO 1	7/7/99	17:15	18:03		44°50.399	125°08.400			1824	1826	1831	
23 ESS	BSR outcrop	7/7/99				see log sheet							
24 CDT	HRN	7/8/99				44°39.63	125°05.92					605	
25 AD 3427	HRN	7/8/99	9:30		16:00	44°40.155	125°05.808					600	
26 ESS	HRN	7/8/99				see log sheet							
27 CTD	HRN	7/8/99											
28 AD 3428	HRS	7/9/99	8:00		15:30	44°34.23	125°08.89					800	
29 ESS	INCIP HEADW.	7/9/99				see log sheet							
30 MC	A2 AREA	7/10/99	4:05	4:39	5:24	44°35.889	125°05.319			1027	1024	1023	
31 FM	HRS	7/10/99	7:10			44°34.23	125°08.89					800	
32 AD 3429	HRS	7/10/99	8:15			44°34.23	125°08.89					800	
33 ESS	S' TEMPLE	7/10/99				see log sheet							
34 CTD	S' TEMPLE	7/11/99				44°17.40	125°06.05						
35 MC	SLOPE	7/11/99	5:45	6:13	6:48	44°35.950	124°55.388				731		
36 FM	HRS	7/11/99				44°34.23	125°08.89						
37 AD 3430	HRS	7/11/99	9:30		17:30	44°34.23	125°08.89						

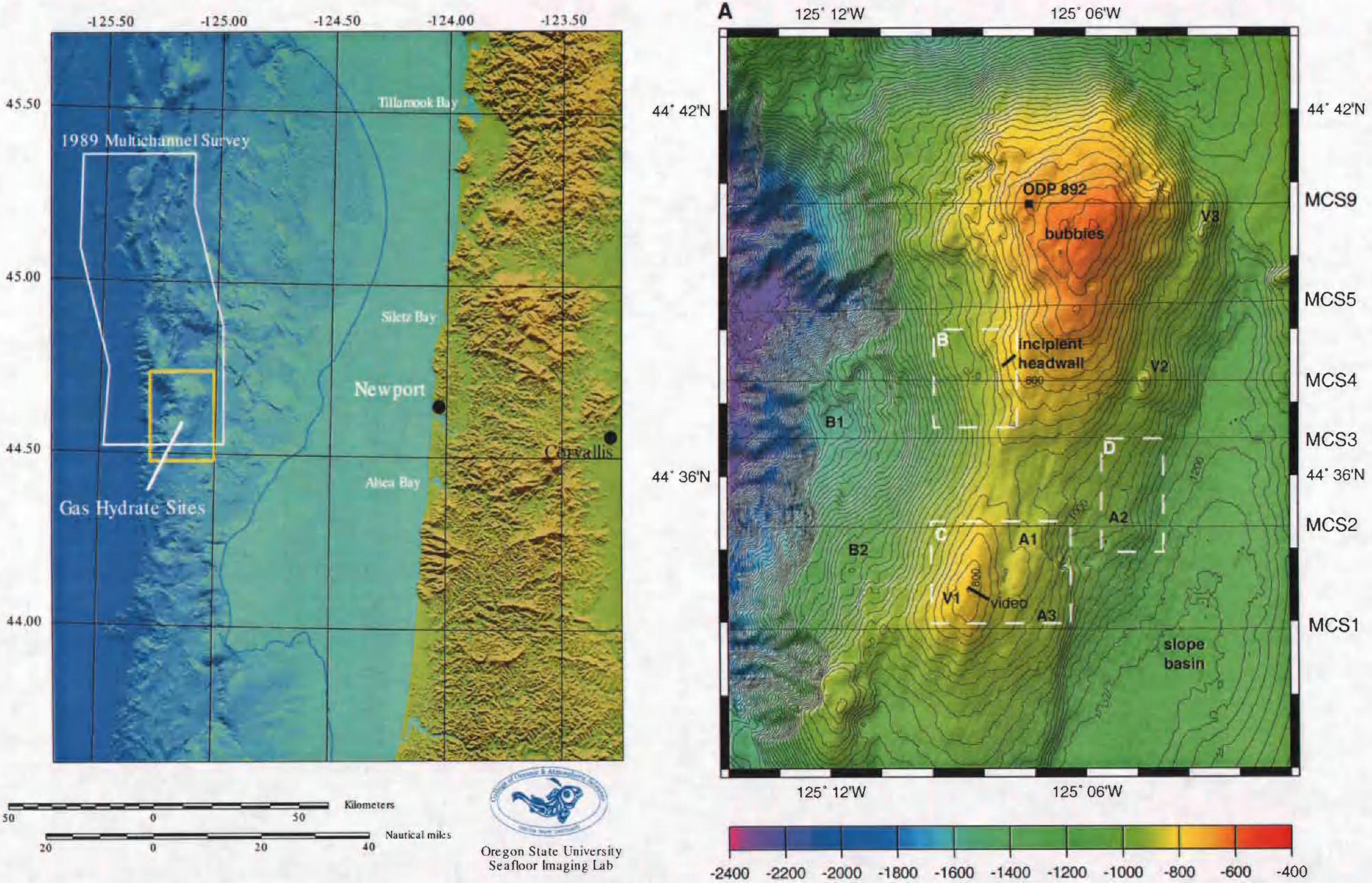


Figure 1A. Bathymetric map (left-hand panel) of the central Oregon coast and continental margin showing the location of the 1989 multichannel seismic site survey (McKay et al, 1992) and thedetail bathymetry of Hydrate Ridge area. Image produced by C. Golfinger, COAS. Right-hand panel is the Hydrosweep bathymetric map (Bohrmann et al., unpublished data) of the second accretionary ridge (now recognized as "Hydrate Ridge" by the US Board On Geographic Names) showing the location of ODP Site 892, area of bubble discharge on the north summit ("bubbles"), and the location of foccussed fluid flow on the south summit (V1).

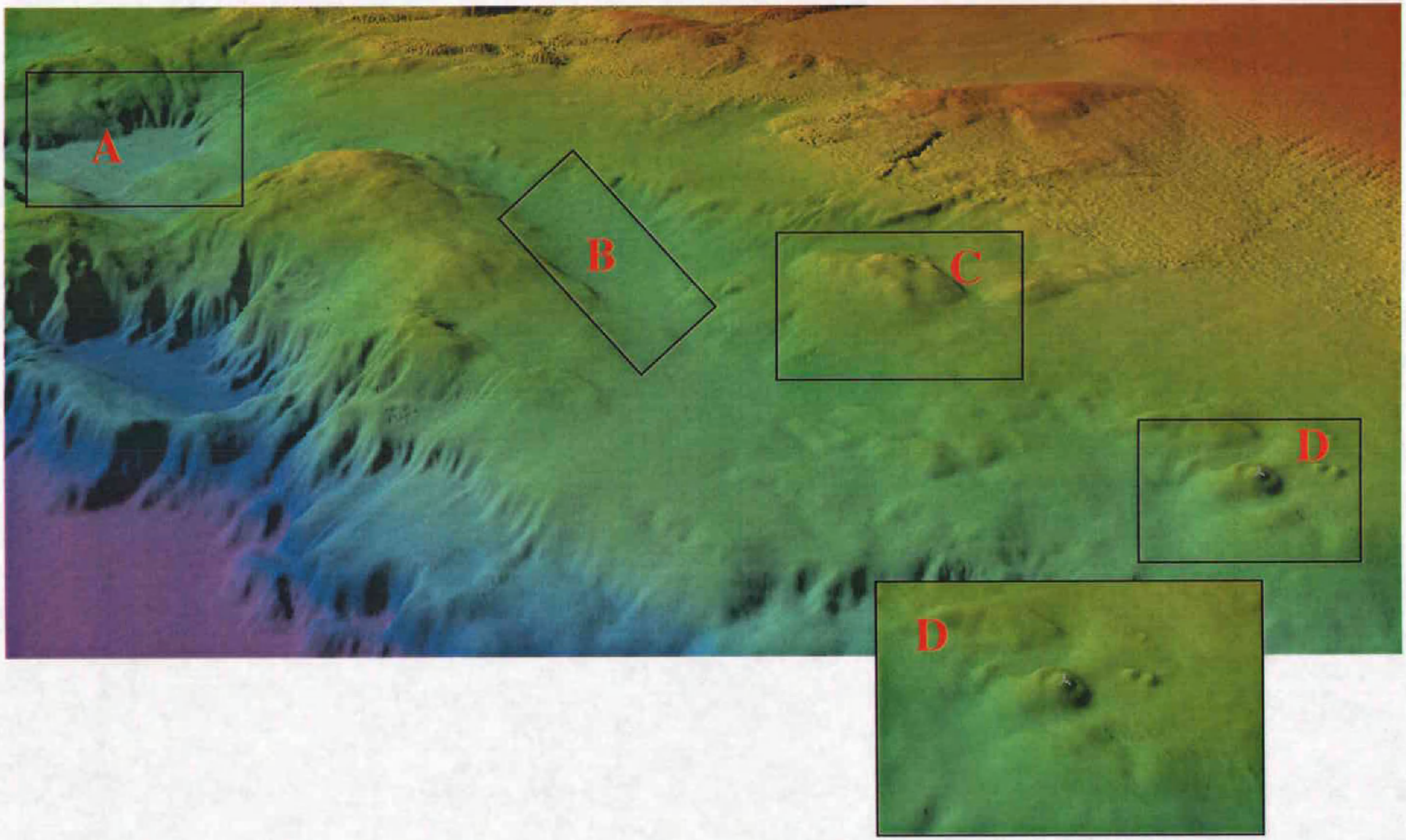


Figure1B. Hydrate Ridge and nearby areas of interest for Tecflux 99 cruise. A, Paleo Basin-1(P-1); B, Slope Basin, C, S E Knoll (high reflectivity), D possible mud volcano (Southern Temple).

3. GEOPHYSICAL SURVEY

Anne Trehu

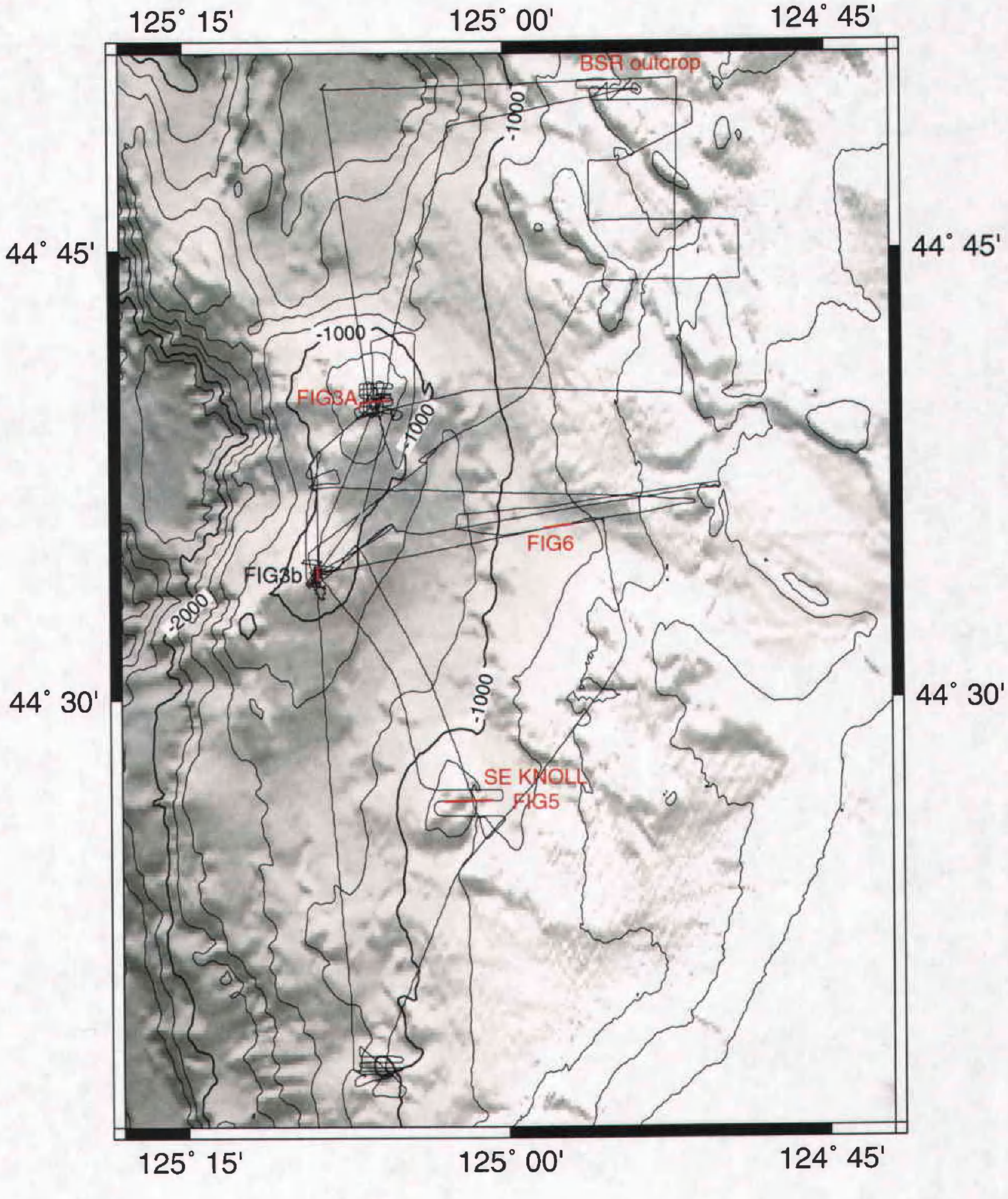
One component of the night program during cruise AT3-35B was to survey potential Hydrocast and multicore targets using the SeaBeam 2000 3.5/12 kHz echosounding system. This program was used as a substitute for the planned ZAPS (Zero Angle Photon Spectrometer) surveys when shipment of the the equipment from Antarctica was delayed and the instrument failed to arrive in time for the cruise. Unfortunately the digital acquisition system on Atlantis was not operational, and only paper records were obtained. These surveys had two primary objectives: (1) to map plumes of bubbles in the water column (12 kHz) and (2) to image the shallow subsurface beneath circular bright spots that dot the mid-slope region in the high-resolution deep-towed sidescan data collected by C. Goldfinger on a previous cruise. Figure 2 shows the location of the 3.5/12 kHz surveys run during AT3-35B.

The 12 kHz system was used to map plumes in the water column for hydrocast sampling. Distinct "clouds" of scattered acoustic energy in the water column that extend from the seafloor to a depth of about 465 m above the seafloor are interpreted to indicate the presence of bubbles in the water column. Figure 3 shows examples from northern and southern Hydrate Ridge, respectively. A detailed survey on the northern peak of Hydrate Ridge (Champagne Hill) revealed the presence of two distinct plumes (Figure 3A; Figure 4), each of which was located over a relative topographic high, suggesting that free gas in the subsurface migrated into topographic highs before being released to the water column. The strength and position of these plumes changed somewhat over the course of several days, probably in response to changes in the intensity of venting and in the direction of seafloor currents. Hydrocasts in these acoustic plumes revealed anomalies in methane content of the water located approx. 100 m above the seafloor (see section 4).

An initial, brief survey over southern Hydrate Ridge did not show any acoustic anomaly. However, after many bubbles were observed in the water column during dive 3430, we resurveyed this region and noticed a distinct acoustic anomaly over the southern crest. Unfortunately no paper record was obtained on the first pass, when the signal was strongest. We redid this profile, but weather conditions were deteriorating rapidly and the signal was less distinct (Figure 3B). Note that although the water depth is different by about 200 m between northern and southern Hydrate Ridge, the depth to the top of the water column acoustic anomaly is approximately the same, suggesting that pressure is an important factor controlling whether methane forms bubbles or is in solution.

An acoustic plume was also revealed by the 12 kHz data over a structure with a morphological resemblance to northern Hydrate Ridge that we called the SE Knoll (Fig. 5). A hydrocast that was placed based on this acoustic anomaly revealed a relatively small, but distinct, water column methane anomaly. No acoustic anomalies were seen over: (1) the carbonate pinnacle discovered SW of the southern peak (section 6.4 of this report); (2) the landward limit of the gas hydrate stability zone where a BSR intersects the seafloor (Trehu et al., 1995); (3) an unusual circular "mud volcano" located 19 miles south of Hydrate Ridge (Figs. 1B and 2); or (4) the apparent headwall of an incipient slump (Trehu et al., 1999). Because biological communities characteristic of active venting were observed over the first two of these features and are possible, if not likely,

Figure 2. Track lines for selected days during AT3-35 showing locations of geophysical surveys. Most surveys on Hydrate Ridge, SE Knoll, and on the circular feature to the south were conducted with a 12 kHz source. Except for crossings of the "BSR outcrop," most crossings of the mid-slope used the 3.5 kHz source. Locations of data samples in figures 3, 5 and 6 are also shown.



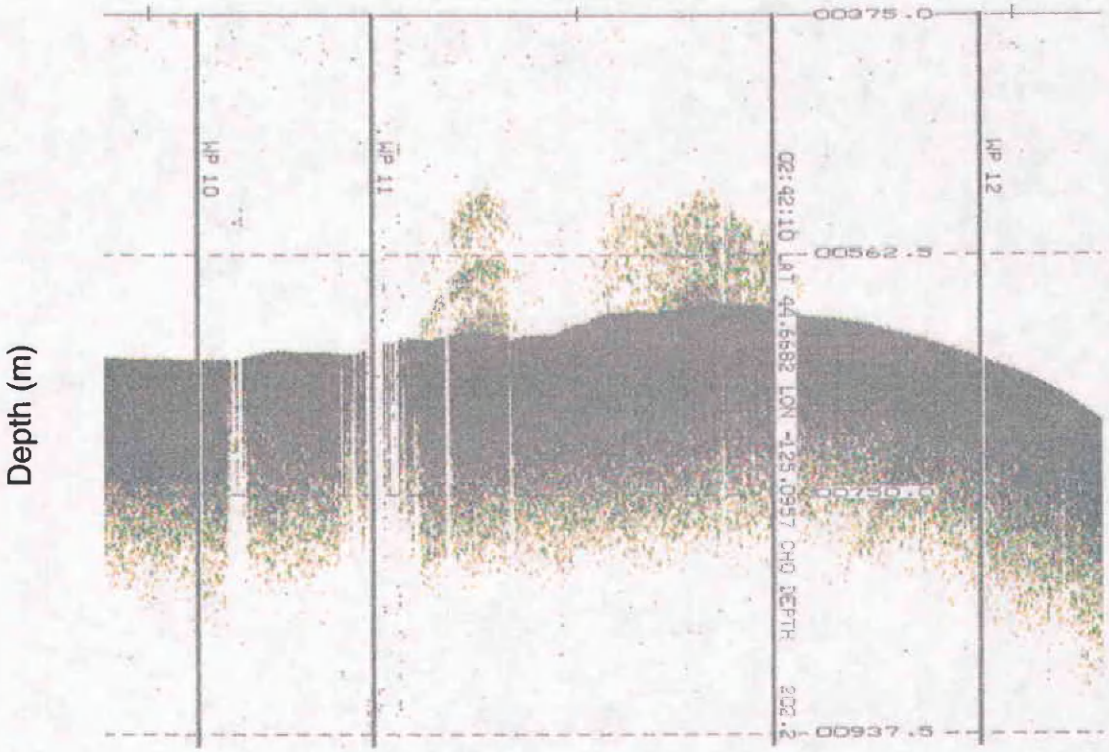


Figure 3A. Example of the acoustic anomalies observed on the northern peak of Hydrate Ridge. Map in figure 4 is based on similar observations on a grid of lines across northern Hydrate Ridge (see track in figure 2).

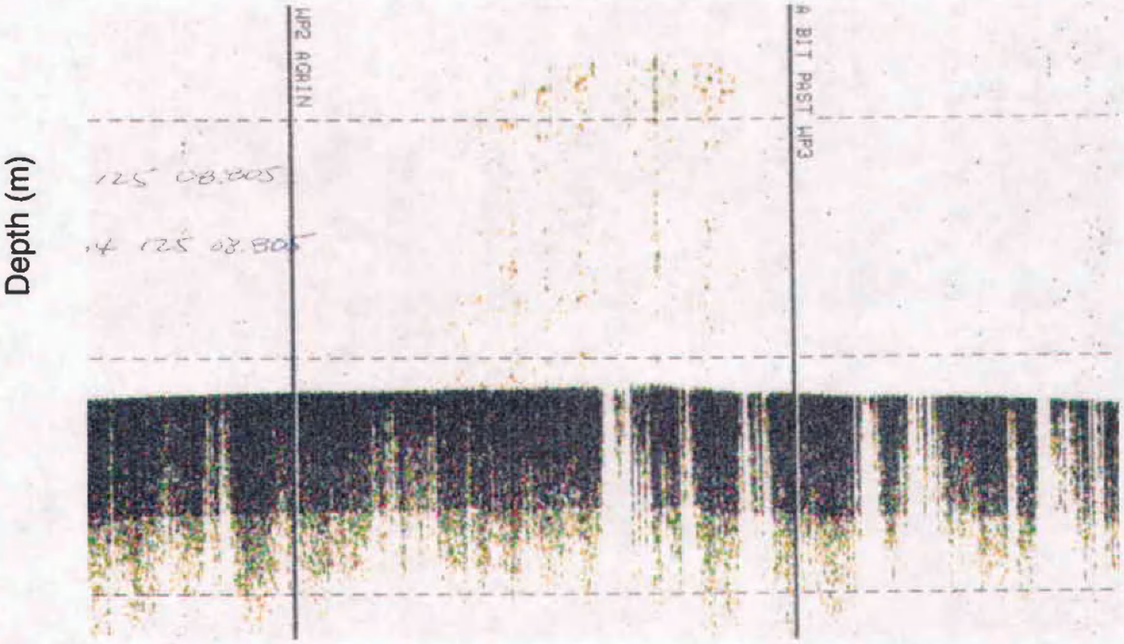


Figure 3B. Example of the acoustic anomaly observed on the southern peak of Hydrate Ridge several hours after bubbles were observed in the water column (see log of dive 3430).

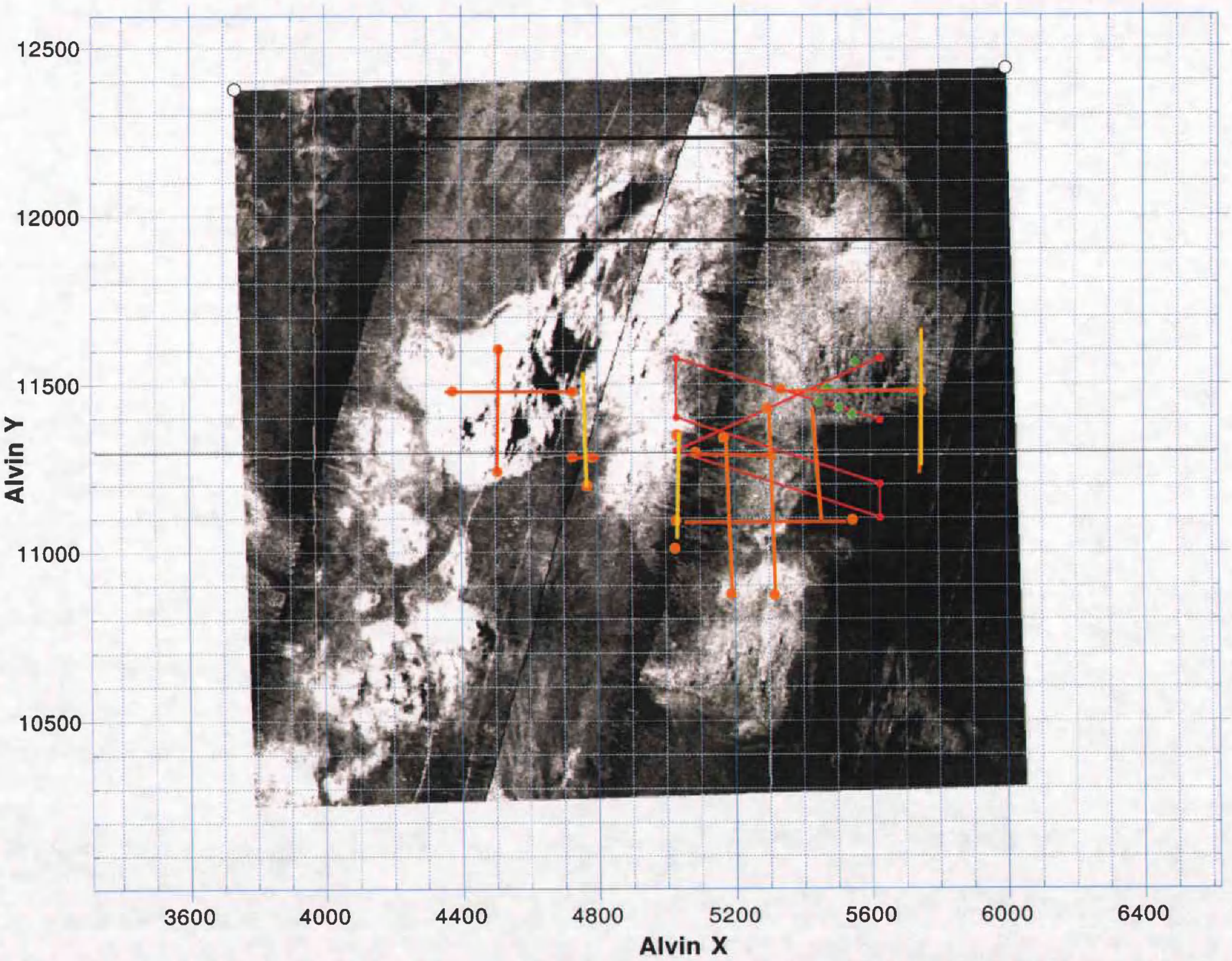


Figure 4. Location of the acoustically-imaged plume (orange and yellow lines), over the sidescan sonar data for northern Hydrate Ridge area. The red lines demark Alvin tracks and the green dots denote seep areas.

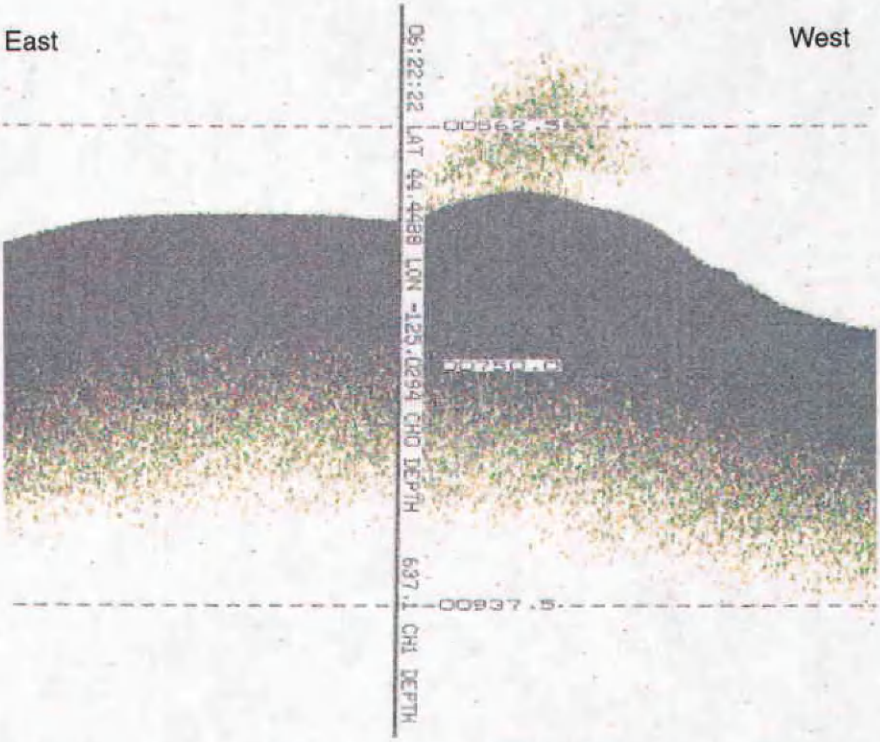
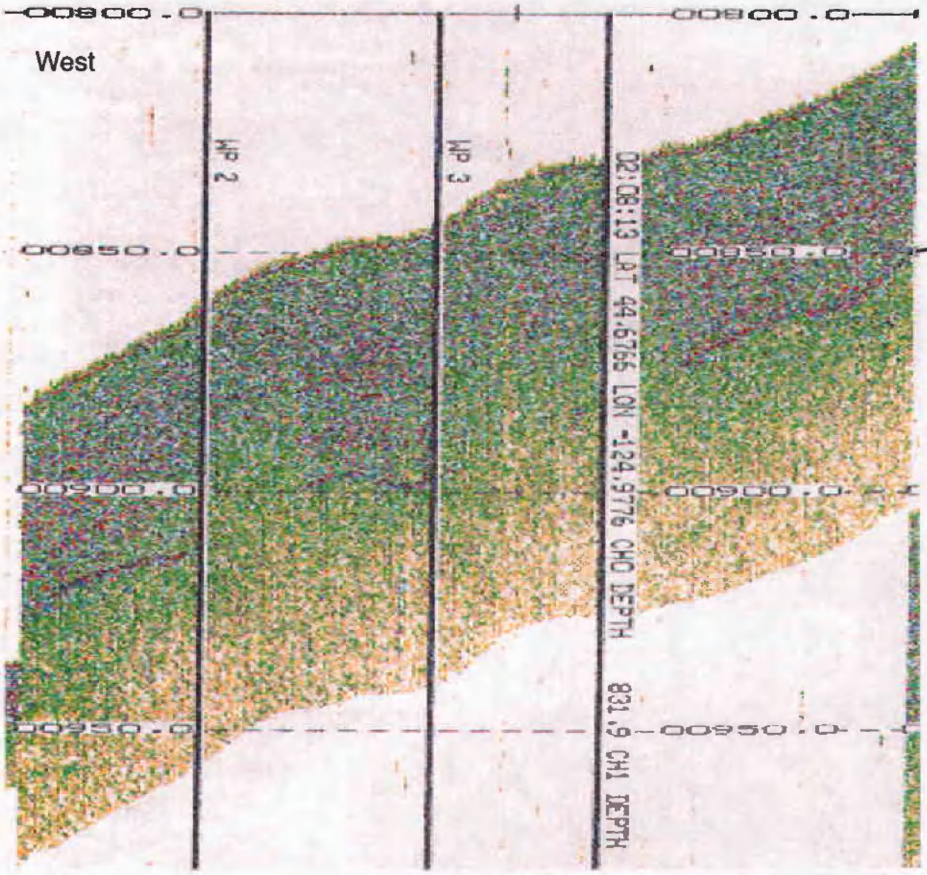


Figure 5. Acoustic signal over SE Knoll (see line location on figure 2).



reflection that is broken beneath the mounds that correspond to circular bright spots on the seafloor

Figure 6. 3.5 kHz record over a 2 bright spots on the continental slope (see line location on figure 2)

over the second two, we conclude that only vigorously bubbling seafloor vents produce water column anomalies, and that 12 kHz data are an effective tool for detecting and monitering such vents.

The 3.5 KHz source was used to image the shallow sub-seafloor structure associated with the circular bright spots observed on high-resolution deep-towed sidescan data and to help identify good sites for multicores. The 3.5 kHz data revealed that many of these features are actually mounds rather than depressions (Figure 6). In several cases, subsurface reflections are "wiped out" beneath these mounds suggesting the presence of gas in the sediments. The 3.5 kHz data also indicated the presence of numerous apparent slump surfaces and other indicators of seafloor instability. Reflections may also be associated with the base of the hydrate stability zone as it shallows to intersect the seafloor. Additional analysis of these data is needed to better correlate subsurface features with seafloor morphology and reflectivity.

4. WATER COLUMN PROGRAM

G. Klinkhammer, K. Heeschen, G. Winckler, M de Angelis

4.1 INTRODUCTION (G. Klinkhammer)

The CTD program on this cruise played off work done on the New Horizon cruise from 13th to 23rd of June 1999 (Bob Collier, Chief Scientist). Collier found CH_4 anomalies that varied dramatically with space and time. Many of the highest concentrations they found were focused on the southern part of Hydrate Ridge North (HRN). Collier also observed that the 12 kHz sounder gives an acoustic image that seemed to line up with the CH_4 concentrations. The CH_4 sensor used on the New Horizon was a different sensor than the one used on this cruise. From the description of the Collier et al., profiles, these instruments behaved in a very similar manner.

There were 42 CTDs carried out on the New Horizon, we were only able to do 6 (Figure 7; Tables 4 and 5). Nevertheless, the results from these two cruises were similar as far as the CH_4 sensor and general feeling for the distribution of CH_4 plumes. The highest results we obtained were also associated with plumes on HRN. Lots of sampling as done on the New Horizon was crucial as it set a baseline and provided us with a first-cut inventory. However, this cruise pushed the water column program forward in a couple of significant ways.

Firstly, we were able to coordinate what was going on at the sea floor as seen through our Alvin dives with what we saw in the water column. These observations were very rudimentary but important. The fact that Alvin observed an increase in venting on HRN at low tide (see section 6.6) and we were able to image an intense plume at the next low tide using sonar, that this operation led to our highest CH_4 signals with the sensor, and that our highest methane concentrations were found at this time, is a step forward. This work should be expanded in the future. An ROV is perhaps the perfect platform for this type of work. With an instrumented ROV we could follow observations of bubbling with bottom-up surveying. This would allow us to link bubble flux and chemical flux directly using the water column. This work would require that we find a way to quantify the chemistry in real time. This might be an improved version of the METS sampler, although this device has a long way to go before it could be used in this way. We are going to try out several optical and opto-chemical techniques later this summer.

Secondly, we were able to demonstrate fairly conclusively that acoustic imaging is a promising exploration tool. We probably could do a better job by optimizing the acoustic equipment for this work. But even from this preliminary work, there appears to be a correlation between the intensity of the return and the occurrence of CH_4 (bubble density). What is lacking in this analysis is a way to equate the acoustic signal with standing crop. Again we need some sensor development to make this quantification possible. Also parts of the acoustic plume could be an aberration, an artifact of the sound reflection process. These problems could be dealt with from a theoretical analysis but groundtruthing will always be important. Finally we need to be careful that we don't get locked into the dramatic bubbling associated with the ridge sites. We need to maintain a balance with the wider geographic area, especially during these early days of exploration.

4.2 METS METHANE SENSOR (G. Klinkhammer)

It is clear that the METS sensor works on some level (Table 5). The greatest success of the cruise was CTD3 where the sensor went off at the same depth of the acoustic anomaly when being lowered at 5 m/min. During CTD5 the sensor gave the lowest reading near the bottom from any station and indeed the CH_4 concentrations turned out to be the lowest as well. Again during CTD6 the sensor showed large anomalies when being brought up (nothing going down) and this cast produced high concentrations at approximately the same depths. However the sensor also produced enigmatic results as exemplified by the last cast, CTD7. There was a small but distinct CH_4 anomaly at the bottom of this station but the sensor showed nothing going up or down. Also the severe memory effect of the sensor was also evident. When a large anomaly occurred it took at least 30 minutes for the signal to flush from the sensor head (apparently). This and the slow response time of the sensor make it virtually impossible to use the METS sensor as an exploration tool. For when an anomaly occurs it is never exactly clear where the parcel of water is that caused it to go off. We tried flushing the surface of the membrane by pumping water over the sensor head. At first this seemed to work and the sensor "equilibrated" faster on the way down. But this effect did not seem to be consistent or reproducible. There is no doubt that the sensor is capable of detecting CH_4 on some occasions, but overall its output is unreliable and hard to interpret.

4.3 METHANE ANALYSIS (K. Heeschen)

From earlier cruises such as SONNE 110 and TECFLUX 98 the area of the second accretionary ridge off Oregon (Hydrate Ridge) is known for very high water column methane concentrations. Methane content can be several magnitudes higher than in seawater and it is thought to have a “plume”-like distribution. This feature is due to local tectonically induced fluid expulsion, which is enhanced by decomposition of abundant gas hydrates in this area (Suess et al., 1999) 1-15). Hydrate decomposition also leads to expulsion of free gas (near 100 % methane), which was observed during this as well as earlier cruises (see section 6: Alvin dives).

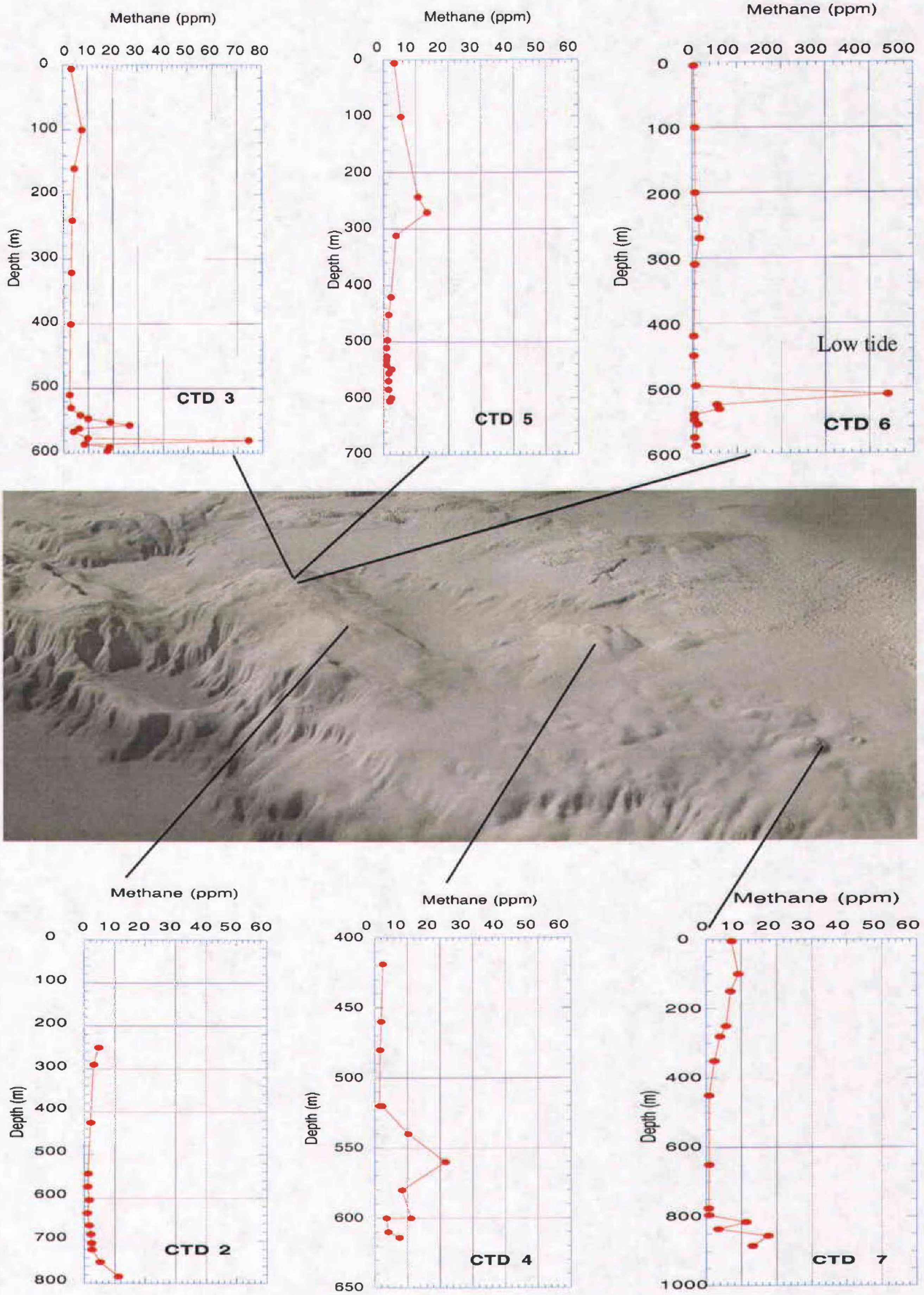


Figure 7. Methane data from hydrocast stations during AT3-35B

Table 4: Hydrocast data

Operation	Latitude	Longitude	Bottle	Date (GMT)	Depth (m)	altimeter	Marie's methane	Katja's methane	Methane isotopes	O2 ml / liter	$^3He/^4He$
335b-4CTD1	N 44 33.950	W 125 09.099	1	7/2/99	750?						
			2		705?						
335-4CTD2	N 44 33.948	W 125 9.104	1	7/2/99	784	10		11.257			
HRS			2		750			5.205			
			3		720			2.54			
			4		705			2.441			x
			5		685			2.201			
			6		664			1.721			
			7		635			1.076			
			8		605			1.719			
			9		574			1.182			
			10		544			1.283			
			11		514						
			12	no bottle							
			13		425			2.076			
			14		366						
			15		290			3.0195			
			16		250			4.788			
			17		5						
335-10CTD3	N 44 39.772	W 125 5.650	1	7/4/99	596	5		17.512		0.429	x
HRN			2		590			18.482		0.458	x
			3		586			8.2931		0.413	x
			4		580			74.303		0.466	x
			5		576			9.6702		0.521	x
			6		570					0.489	x
			7		566			4.066		0.469	
			8		561			6.152		0.567	x
			9		556			26.543		0.538	
			10		551			18.813		0.592	x
			11		546			9.866		0.559	
			13		541			6.703		0.616	x
			14		530			2.954		0.713	
			15		510			2.429		0.683	x
			16		480					0.82	x
			17		400			2.898		1.221	x
			18		320			3.288		1.609	x
			19		240			3.611		2.282	
			20		160			4.6759		2.976	x
			21		100			7.727		3.734	
			22		50					6.282	x
			23		5			3.382		6.343	
335-19CTD4	N 44 27.00	W 125 01.8	1	7/6/99	614	5		7.671		0.46	x
SE KNOLL			2		600			11.115		0.498	
			3		580			8.392		0.566	x
			4		560			21.7		0.611	
			5		540			10.276		0.6	x
			6		520			2.3744		0.757	
			7		419			2.513			
			8		610			4.127		0.417	x
			9		600			3.6205		0.456	
			10		560			1.472		0.531	x
			11		540			1.138		0.527	
			13		520			1.478		0.593	x
			14		500					0.682	x
			15		480			1.676		0.792	
			16		460			1.977		0.945	x
335-22CTD5	N 44 39.7	W 125 05.9	1	7/8/99	605	5		1.87	x		x
HRN			2		599			2.415	x		
			3		584			1.537	x		x
			4		569			1.498	x		x
			5		555			1.649	x		
			6		548			2.522	x		x
			7		540			0.967			x
			8		532			0.928	x		x
			9		525			1.011	x		x
			10		510			0.956	x		x
			11		496			1.208	x		x
			13		451			1.572	x		x
			14		420			2.256	x		
			15		311			3.862	x		x
			16		271			13.39	x		
			17		243			10.6	x		
			18		197						x
			19		100			5.347	x		x
			20		5			3.376	x		x
335-27CTD6	N 44 40.08	W 125 06.10	1	7/9/99	588	5		7.527	x		x
			2		575			4.838	x		x
HRN			3		555			11.744	x		x
start: 0200			4		548			3.449	x		x
finish: 0400			5		540			3.274	x		x
			6		532			60.336	x		x
			7		525			54.553	x		x
			8		510			442.5	x		x
			9		496			7.329	x		x
			10		450			2.555	x		x
			11		420			2.813	x		x
			13		310			5.46	x		x
			14		270			16.205	x		
			15		240			14.772	x		
			16		200			6.4	x		x
			17		100			6.653	x		x
			18		5			3.884	x		x
335-34CTD7	N 44 17.5'	W 125 05.7'	1	7/11/99	884	5		13.106	x	0.267	x
			2		855			17.653	x	0.298	x
Southern temple			3		835			3.497	x	0.283	
start: 1220			4		815			11.344		0.247	x
finish: 0230			5		795			0.848		0.274	
			6		775			0.764		0.336	x
			7		755			0.862		0.271	
			8		650					0.404	
			9		550			0.895		0.663	x
			10		450			2.397		0.947	
			11		350			3.935		1.369	x
			13		280			5.65		1.752	
			14		250			6.96			
			15		150			9.095		2.681	
			16		100			7.23		3.038	x
			17		5			3.903		6.628	

TABLE 5 CTD OPERATIONS SUMMARY

2 JULY ... CTD1 -BUT NO PROFILE

We had problems with the configuration file during this cast. Only 2 samples bottles came up closed. There is some uncertainty in the depths these samples came from.

2 JULY... CTD2 -SMALL ANOMALY

The CH4-sensor trace showed a small methane anomaly restricted to the bottom 100 meters.

3 JULY... NO CTD

Problems with the GC, no CTD this night. 12 kHz bubble survey of North Hydrate Ridge. Strong reflections above ridge summit consistent with bubbles in the bottom 100m. Also reflectors higher in the water column (200m) on some crossings. Plan to ground truth these data with CTD work later.

4 JULY ... CTD3

Finished the 12KHz survey of NHR -consistent with work the previous night. Identified two plumes, sampled one during following cast. Methane sensor showed maximum that started at depth of acoustic anomaly. Water column heavily sampled near bottom during 10CTD3.

6 JULY ... CTD4

CTD4 followed a 12 kHz survey of the "knoll" site south of HRS. A small plume was detected right over the shallowest point on the knoll. The first 6 samples were taken at this location. The CH4 sensor did not register anything that looked like a real signal. We moved 100m south and lost the plume so we moved back north and took the final 9 samples due W of our original position (about 80m).

8 JULY ... CTD5

The original idea of CTD5 was to reoccupy CTD sta.41 from the New Horizon cruise (SW of HRN summit). We crossed the ridge at this latitude with the 12KHz but we did not see a plume. We stopped directly on the sta.41 location but the sensor gave an all time low reading so we moved about 70m to the NE. The CH4 sensor reading did not change so we proceeded to close bottles at the sta.41 depths. The measured CH4 concentrations were the lowest of the cruise. Two things: we discovered during the dive program what seems to be a strong dependence on tide (>flux at low tide). This station was occupied during high tide. Also the CH4 sensor gave a reading that was definitely lower than what we saw at previous stations and the measured levels were the lowest of the cruise.

9 JULY ... CTD6

We resurveyed the top of HRN and found a plume like last time. We decided to do the CTD at low tide based on observations from the dives of a tidal influence on bubbling from the bottom. When approaching the site selected from the 12KHz survey we noticed that we passed over a darker part of the reflection somewhat south of our site. We backed down 30m from the original site to sample at this more intense part of the plume. The CH4 sensor started at the surface with a higher reading than normal and drifted downward the entire way to the bottom, even though we slowed to 5 m/min below 500m. The lowest reading was 0.828V. However on the upcast it went high on a couple of occasions and even showed two distinct maxima. This was not behavior that we had seen on previous operations. The sensor was being pumped during this cast. This operation produced the highest CH4 concentrations of the cruise.

11 JULY ... CTD7

This was a profile taken at the "south temple" feature south of Hydrate Ridge. A 12KHz survey was done of the feature immediately before this cast. No plume was detected. The CH4 sensor recorded a "classic nothing" profile with the output continually drifting downward to the bottom (0.80V,) then going even lower (0.78) in the upcast. No sensor anomalies were recorded. Subsequent CH4 measurements, however, recorded small amounts of methane in the water column. No changes were made to the sensor configuration before deployment, i.e. the sensor was pumped as before. Go figure.

Shipboard analysis of methane in water samples, supported by 12.5 kHz echosounder surveys (section 3) as well as a methane sensor on the CTD is the fastest way to find evidence for fluid and/or gas sources on the seafloor and to trace the "plume" downstream. During SONNE 110, enhanced CH_4 concentrations were traced up to a depth of 300m, apparently due to bubble transport through the water column. Hence, two different transport mechanisms for methane in the water column, i.e. advective transport of dissolved CH_4 as well as upward migration as free gas, determine the distribution of CH_4 in the research area. The C^{12}/C^{13} ratio of the dissolved methane may help to define its sources. Additionally, the isotopic signature of CH_4 allows an estimate of the amount of CH_4, which has been oxidized, as microbial oxidation leads to isotopic fractionation.

4.31 Methods

CH_4 was measured aboard using a modification of the vacuum degassing method described by Lammers and Suess (1994). The modification involved sampling of 400ml of seawater using a large glass syringe and injecting into pre-evacuated 600 ml glass bottles. The air and water phases were equilibrated by shaking for at least 30 min. The gas phase was subsequently recompressed to atmospheric pressure and the CH_4 mole fraction of the extracted gas was determined from a 1ml subsample by gas chromatography using a FID. The methane content then will be calculated on shore as the product of the mole fraction in the extracted gas phase and the amount of total gas (STP) in the sample. The total gas content of the sample will be calculated from the measured dissolved oxygen concentration and assuming that N_2 and Argon were 100% saturated relative to their atmospheric partial pressures (Weiss, 1970). The remaining gas was transferred into evacuated 5ml Wheaton bottles and stored for shorebased analysis of the carbon isotopic signature of CH_4 (CFMS).

4.32 Sampling

Samples for CH_4 analysis were taken from all CTD hydrocasts at all depths. For CTD 05 and 06 as well as some depths from CTD 07 the extracted gas which remained after analysis of the CH_4 mole fraction was trapped and stored for isotopic analysis ashore (Table 4). Samples where also taken from the OSU Benthic Barrels 1-4, the Niskin bottles closed on the Alvin dives, and from the USC bubble gas sampler (see section 6.4.7).

4.33 Preliminary results

CTD casts were performed in the area of Hydrate Ridge as well as on pockmark-like structures to the southeast (Table 4). Highest methane concentrations where detected above the northern Hydrate Ridge with up to 440 ppm in samples from CTD 06 (Figure 7). Like in CTD 03 and 04 the highest values occur in about 80 m above the bottom and can only be found within about 50 m of the water column. However, samples from CTD 04 do not show a very pronounced methane peak. In combination with the results from the former cruise with New Horizon cruise the data suggest very local and variable methane plumes in time and space. This distribution was not obvious from results of TECFLUX 98 (Torres et al., 1998). On sites 03 and 06 both the 12.5 kHz survey and the methane sensor suggested higher concentrations. CTD 07 taken above the "Southern Temple" (Research Area D, Figure 1B) showed highest concentrations right above the sea floor, which might be caused by fluid expulsion and advective transport, in contrast to transport as bubbles which are believed to produce the "plumes" observed about 100 m above the sea floor (Suess et al., 1999). CTD 05 did not show any sign of elevated methane concentration even so it was taken at a position which had 981 ppm of methane (540 mbsl) about 2 weeks before on the 22.6.1999 (New Horizon 13.6. – 23.6.1999; Station NH-53-CTD41). This observation suggests that the methane plumes in the water column are not stable but depend on sources from below, which is thought to be highly variable. CTD 02 also showed only oceanic background concentrations.

Elevated methane concentrations of up to 15 ppm at about 270 m depth were abundant in many CTD profiles (02, 05 and 06) and are thought to be related to nepheloid layers or gas expulsions on the shelf. The isotopic signature of CH4 will help to address this question. Most of the time elevated methane concentrations could be traced up to the thermocline. CTD 03 and 07 show elevated values at about 120 m. Surface values seemed to be slightly oversaturated. This feature is very rare in the open Pacific Ocean (Bates et. al., 1996).

4.4 HELIUM ISOTOPE SAMPLING (G. Winckler)

The main objective of the helium isotope program is to study the trace gas pattern of the vent-related plumes above the hydrate ridge. Radiogenic ^{4}He has been proven to be a useful tracer for cold-seep venting. ^{4}He is steadily produced by radioactive decay in the sediment matrix and quantitatively released to the fluid phase. Consequently, fluids that have circulated through a U and Th- bearing reservoir are expected to be enriched in radiogenic ^{4}He with the intensity of the enrichment being a function of the fluid's residence time. Thus, the ^{4}He excess may be used to map the injection of vent fluids into the water column.

The comparison of the helium and CH_4 data is of special interest as the mechanisms producing the methane distribution in the water column as well as the acoustic „bubble features" observed on the 12kHz-surveys are still a matter of debate. Most of the CTD casts show maximum methane concentrations in a horizon approx. 80 m above the bottom with concentrations decreasing towards the bottom. In earlier studies (TECFLUX 98, Suess et al., 1999) it has been observed that the ^{4}He excess (as the CO_2 signal) increases with depth and does not match the CH_4 plume pattern. A potential way to explain the different pattern of the two tracers is to suggest different injection mechanisms, i.e. the methane maximum is the result of dissolution of gas bubbles while ^{4}He is transported by expelled fluids. Thus, the comparison of various trace gas patterns might be useful to obtain new information regarding the (gas and fluid) venting process.

To this effect, a total of 60 samples were obtained from CTD water column casts (Table 4: stations 4CTD2, 10CTD3, 18CTD4, 22CTD5, 27CTD6, 34CTD7). Samples were transferred to 90 cm copper tubes and sealed by stainless steal pinch-off clamps. The samples will be analyzed on a sector field mass spectrometer (Type MM 3000) at the Institute of Environmental Physics (University of Heidelberg).

4.5 METHANE OXIDATION (M. de Angelis)

The objective of methane oxidation incubations and analysis is to determine the primary locations and magnitudes of bacterial consumption of methane in the sediment and water column.

Methane oxidation samples were collected and incubated for 25 Niskin samples, 22 benthic barrel water samples (representing 4 different benthic barrel deployments), 4 animal samples (2 clam shell samples, 2 snail samples (including shells, whole snails, snail soft tissue), 9 bacterial mat samples, 2 rock samples and 18 sediment samples (representing 3 push cores and 1 multicore deployment). These samples represent a total of 548 vials to be analyzed. All samples were incubated for up to 8 hours in the presence of C-14 labeled methane. All non-water samples were incubated in sterile seawater degassed with nitrogen. All samples will be analyzed for production of C-14 labeled carbon dioxide at a shore-based laboratory.

5. MULTICORE PROGRAM

5.1 INTRODUCTION

During the nigh program of Leg 3-35B, we successfully deployed the OSU multicorer on 7 stations (Table 6, Figure 8), with the aim of complementing the data obtained with the Alvin push cores at the vent sites. Sites A4, "east basin", and "slope" (Multicores 3MC, 7MC, 30MC and 35MC), were selected because they appear as "pock-mark" features on the side-scan sonar map (Goldfinger, unpublished data), which might be indicative of subsurface fluid flow on the eastern flank, basin, and slope areas east of Hydrate Ridge. The sites on Hydrate Ridge South (HRS), are intended to provide data on sites were fluid flow might be controlled by diffusive fluxes, near the active sites of fluid venting on the summit of HRS. Deployment at station 13MC, corresponds to the proposed ODP drill site HR3, which is located west of the southern peak, in a region where no coherent fluctuations are observed on the seismic records either above or below the BSR. The location of core 20MC was selected because this site was occupied by 3 SIO fluxmeters during the TECFLUX 98 program, thus providing supporting data for our results. The objective of core 22MC on Paleo-1 was twofold; to provide information on the chemistry of fluids from areas where there is no evidence for a BSR in the seismic records, as well as provide foraminifer background information from an area away from seep regions.

5.2 PORE WATER

Samples for pore water analysis were collected both by separating subsamples in a cold room followed by centrifugation and by whole-core squeezing (Table 6).

5.2.1 Centrifuged samples: (McManus with assistance from analysts)

Sediments used for pore water extraction were collected using a multi-corer (Barnett et al., 1984) or using push cores collected using the submersible. Pore waters were extracted by sectioning and centrifuging sediment slices (7-10,000 rpm). Cores for pore water analyses were processed at in situ temperatures under a nitrogen atmosphere. Cores were typically sectioned directly into acid-cleaned centrifuge tubes. Tubes were filled sequentially to full volume (50 cc) and sediment depths are back-calculated based on the volume removed and the area of the core liner (72.6 cm^2). Pore water samples

Table 6: Multicore data summary

Station number	Location	Lat	Long	Date	Water Depth (m)	Number of cores	Archive tube #'s	Foram samples*	Pore water centrifugE	Pore water squeeze	Methane oxidation	Porosity
AT9906-3MC	A4	44 35.871	125 05.319	7/1/99	1042	7	4,5	#2/15	C1/13		#3/6	#1/13
AT9906-7MC	A4	44 35.871	125 05.319	7/3/99	1040	7	8,6	#3/11	C1/10		N/A /4	#1/6
AT9906-13MC	HRS	44 35.200	125 07.000	7/5/99	912	8	5,6,7	#8/18	CA/9	WCS-3/8	#4/7	#2/11
AT9906-20MC	HRS	44 35.000	125 09.120	7/7/99	869	8	6,7	#3/18	CA/9	W-4/8	N/A /10	#5/9
AT9906-22MC	Paleo-1	44 50.399	125 08.400	7/7/99	1826	8	6,7	#5/18	CA/14	W-3/8		#2/16
AT9906-30MC	A4	44 35.87	125 05.319	7/10/99	1023	8	6,7,8	#5/18	CA/12	W-3/6		#2/15
AT9906-35MC	Slope	44 35.950	124 55.388	7/11/99	732	6	4	#5/18	CA/13	W-3/18		#1/19

* core number/ number of samples

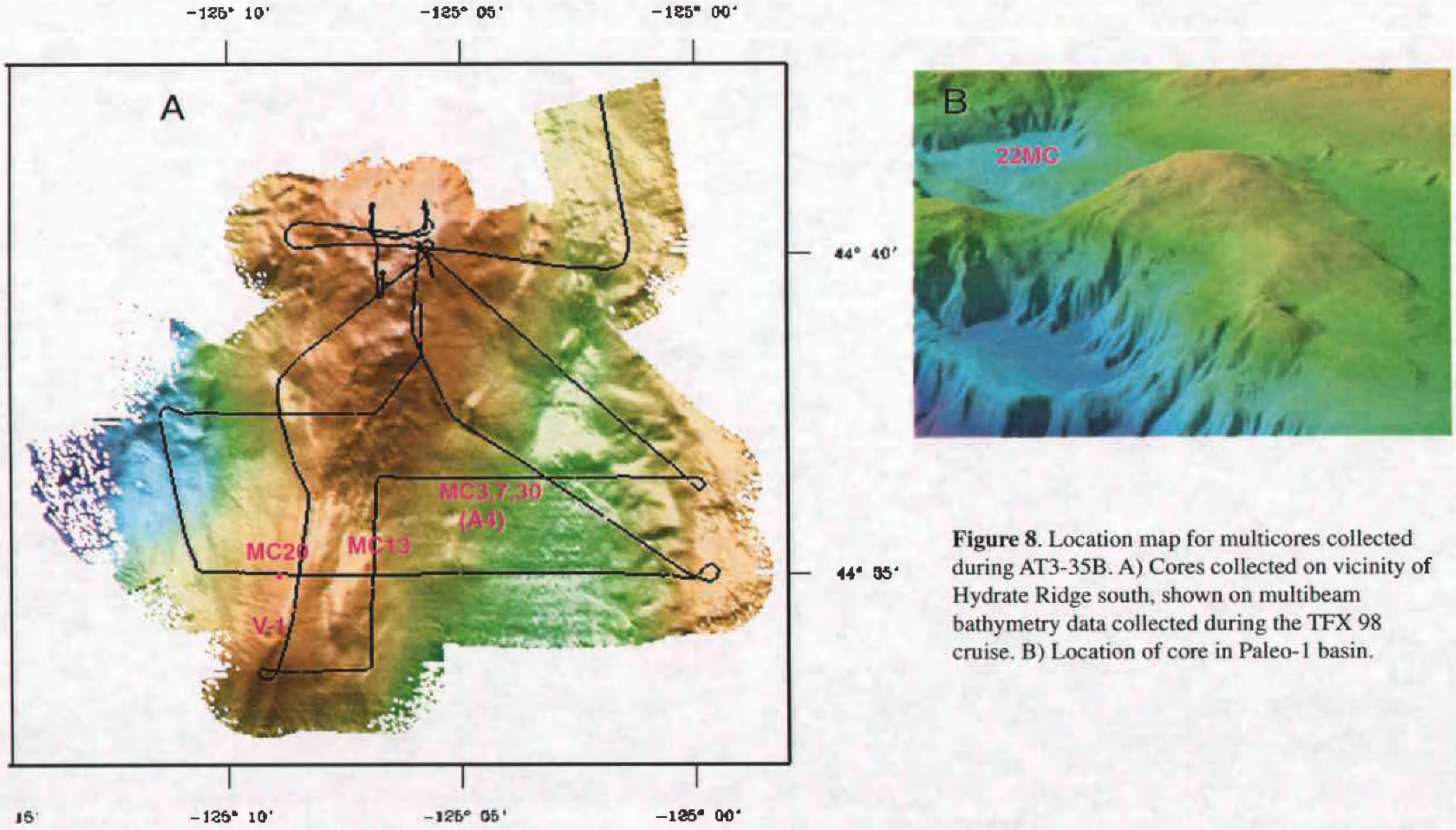


Figure 8. Location map for multicores collected during AT3-35B. A) Cores collected on vicinity of Hydrate Ridge south, shown on multibeam bathymetry data collected during the TFX 98 cruise. B) Location of core in Paleo-1 basin.

were filtered (0.45 m filter, under a nitrogen atmosphere) into HCl-leached bottles. For those samples stored for trace element analysis, samples were subsequently acidified with triple-distilled 6N HCl. A total of 9 sediment cores were processed for pore waters collected using the multi-corer and an additional 11 push cores were processed for pore waters (section 6.4.2). Pore waters were analyzed aboard ship for pH, ΣCO_2, sulfides, and alkalinity, samples for porosity and nutrients were analyzed immediately after the cruise. Results of these analyses are given in Table 7 and are illustrated in Figure 9.

5.2.2 Whole core squeezing: (Hammond, Colbert, McManus and analysts)

Description of Technique. The WCS technique utilizes a piston/filter pack unit that pushes solids downward and expels core-top water and near-surface pore water from multi-cores. Sequential aliquots of the expressed water are collected for analysis. Sample depth is calculated by assuming that pipe flow occurs with no vertical mixing, and the integral of the porosity profile is used to convert total water expressed to depth in sediment. Because we have not yet measured porosity, preliminary depths have been calculated by assuming a constant porosity of 0.90 in the upper 3 cm of sediment. In general, our WCS device worked well. Oxygen analyses of core-top water were very similar to values obtained in hydrocasts, indicating that bottom water was maintained in contact with upper sediments during sample recovery and prior to processing. No bubbles were observed in flow lines, so gas contamination should not be a problem. In addition to the coarse filter mounted on the WCS piston, an in-line filter (0.2 µm) was used to provide clean samples. During processing of cores 13,20 and the first half of 22, this filter was inserted in a reversed direction, and initial samples of uppermost water were slightly turbid suggesting that the filter was not fully effective. It is unknown if this has influenced analyses of TCO_2, nutrients, or H_2S. Later samples were processed with the filter in the correct orientation. This configuration eliminated turbidity, but back-pressure in the sample lines caused some leakage of water. This leakage has been accounted for in converting the water collected to sample depth. All squeezing was done in a cold room at temperatures of 4-6°C, within 1°C of in situ temperature.

Cores analyzed and descriptions. The first 2 multi-cores were characterized by high concentrations of methane, sufficient to cause bubble formation during recovery and extensive degassing. Because of the stratigraphic disruption and influence on dissolved gas distribution caused by this de-gassing, none of these were processed for WCS extraction of pore waters. Only 5 stations were analyzed by WCS (Table 6: MC13, MC20, MC22, MC30, MC35). Brief descriptions of each core were made after WCS processing and extrusion; these are summarized in Table 8. MC13 and MC20 on Hydrate Ridge South, and MC30 on the Eastern Domes were both characterized by an abrupt change from high porosity mud (about 15 cm thick) to a very low porosity, stiff clay below. Generally this clay prevented further core penetration. All cores contained worms, amphipods or other creatures. Irrigation features were clearly evident, sometimes resulting in oxidized rims around burrows. Significant aqueous voids were present in some cases, associated with burrows or shells collected in coring.

Table 7: Pore water data obtained in centrifuged samples from multicore deployments

AT9906-03MC-C1

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl	H2S
		ml	cm	cm	mM		mM	uM	mM	uM
1	1	50	0.69	0.34	2.367	7.48		7.93	542	1.46
2	2	50	1.38	1.03	2.408	7.53	2.416	0.00	540	1.35
3	3	50	2.07	1.72	2.400	7.51	2.435	0.00	539	1.64
4	4	50	2.75	2.41	2.497	7.4		5.24	539	1.42
5	5	50	3.44	3.10	2.552	7.37		-		1.53
6	6	50	4.13	3.79	2.616	7.41		12.40	545	1.53
7	7	50	4.82	4.48	2.691			-		1.75
8,9	8	100	6.20	5.51	2.806	7.45	2.961	21.81	547	28.25
10,11	9	100	7.58	6.89	2.989	7.52	3.127	27.63	548	113.83
12,13	10	100	8.95	8.26	3.583	7.58	3.429	36.13	548	240.98
14,15	11	100	10.33	9.64	3.802	7.54	3.663	41.06	551	338.22
16,17	12	100	11.71	11.02	4.352	7.68		51.81	549	413.01

AT9906-07MC-CA

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl	H2S
		ml	cm	cm	mM		mM	uM	mM	uM
	overlying				2.382			0.00		0.15
1	1	50	0.69	0.34	2.472	7.48	2.499	0.69	534	1.20
2	2	50	1.38	1.03	2.526	7.43	2.519	3.28	538	0.29
3	3	50	2.07	1.72	2.606	7.49	2.596	7.60	538	0.69
4,5	4	100	3.44	2.75	2.700	7.51	2.713	13.64	550	0.69
6,7	5	100	4.82	4.13	2.864	7.46	2.809	19.25	544	0.69
8,9	6	100	6.20	5.51	2.991	7.58	2.887	20.55	550	0.29
10,11	7	100	7.58	6.89	3.231	7.46	3.100	20.98	543	1.30
12,13	8	100	8.95	8.26	3.583	7.62	3.546	25.29	536	21.70
14,15	9	100	10.33	9.64	3.925	7.57	3.953	24.00	549	77.97
16	10	50	11.02	10.67			4.418	29.18	546	-

AT9906-13MC-CA

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl	H2S
		ml	cm	cm	mM		mM	uM	mM	uM
	overlying				2.336	7.4	2.325	0.00	541	0.00
1	1	50	0.69	0.34	2.358	7.38	2.344	2.63	539	2.25
2	2	50	1.38	1.03	2.396	7.36	2.344	0.67	540	0.00
3	3	50	2.07	1.72	2.474	7.35	2.296	1.53	540	0.25
4	4	50	2.75	2.41	2.492	7.36	2.364	1.75	544	0.00
5	5	50	3.44	3.10	2.526	7.45	2.451	1.53	542	0.00
6	6	50	4.13	3.79	2.489	7.36	2.499	5.20	543	0.00
7	7	50	4.82	4.48	2.551	7.42	2.441	1.53	543	0.00
8	8	50	5.51	5.17	2.537	7.32	2.490	3.04	546	0.02
9,10	9	100	6.89	6.20	2.555	7.33	2.470	1.75	544	0.39
11,12	10	100	8.26	7.58	2.565	7.39	2.490		546	
13,14	11	100	9.64	8.95	2.545	7.37	2.441		546	
15,16	12	100	11.02	10.33	2.588	7.37	2.470		549	
17,18	13	100	12.40	11.71	2.642	7.43	2.596		546	

AT9906-14MC-CA

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl	H2S
		ml	cm	cm	mM		mM	uM	mM	uM
	overlying				3.121	7.55	9.136	13.93	495	167.10
1,2	1	100	1.38	0.69	15.036	7.74	14.800	48.39	537	668.90
3,4	2	100	2.75	2.07	24.217	7.83	23.320	64.43	541	564.00
5,6	3	100	4.13	3.44	27.114	7.88	26.260	76.90	546	547.30
7,8	4	100	5.51	4.82	26.696	8.15	26.130	98.88	548	499.60
9,10	5	100	6.89	6.20	26.931	7.8	26.590	111.65	548	1193.30
11,12	6	100	8.26	7.58	29.262	7.82	28.560	94.94	548	1257.60
13,14,15	7	150	10.33	9.30	33.846	7.85	32.980	139.57	548	1192.70
16,17,18	8	150	12.40	11.36	38.598	7.79	36.740	139.06	552	1157.80

AT9906-20MC-CA

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl	H2S
		ml	cm	cm	mM		mM	uM	mM	uM
	overlying						2.315	0.00	545	
1	1	50	0.69	0.34	2.372		2.461	0.00	544	
2,3	2	100	2.07	1.38	2.481		2.441	0.00	550	0.02
4,5	3	100	3.44	2.75	2.461		2.499	0.00	546	0.00
6,7	4	100	4.82	4.13	2.418		2.480	0.00	549	0.02
8,9	5	100	6.20	5.51	2.456		2.422	0.00	547	0.00

10,11,12	6	150	8.26	7.23	2.348		2.461	1.62	548	0.14
13,14	7	100	9.64	8.95	2.538		2.480	0.00	549	0.02
15,16	8	100	11.02	10.33			2.558	0.72	551	0.02
17,18	9	100	12.40	11.71	2.545		2.596	2.08	550	0.36

AT9906-22MC-CA

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl	H2S
		ml	cm	cm	mM		mM	uM	mM	uM
	overlying		0.00	0.00	2.449	7.48	2.393	0.00	533	skip
1	1	50	0.71	0.35	2.511	7.42	2.442	1.82	532	skip
2	2	50	1.41	1.06	2.517	7.39	2.462	0.00	534	skip
3	3	50	2.12	1.76	2.467	7.45	2.462	0.00	534	skip
4	4	50	2.82	2.47	2.446	7.4	2.481	0.00	538	skip
5	5	50	3.53	3.18	2.372	7.38	2.442	0.68	534	skip
6	6	50	4.23	3.88	2.520	7.39	2.481	1.59	535	skip
7	7	50	4.94	4.59	2.491	7.36	2.481	2.50	539	skip
8	8	50	5.65	5.29	2.385	7.37	2.501	3.64	539	skip
9	9	50	6.35	6.00	2.424	7.41	2.481	6.59	536	skip
10	10	50	7.06	6.70	2.395	7.44	2.501	6.36	539	skip
11,12	11	100	8.47	7.76	2.562	7.44	2.589	10.91	535	skip
13,14	12	100	9.88	9.17	2.510	7.44	2.579	17.73	541	skip
15,16	13	100	11.29	10.59	2.638	7.48	2.599	30.68	539	skip
17,18	14	100	12.70	12.00	2.728	7.47	2.706	41.25	538	skip

AT9906-30MC-CA

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl	H2S
	overlying				2.305	7.47	2.296		532	
		ml	cm	cm	mM		mM	uM	mM	uM
1	1	50	0.69	0.34	2.416	7.4	2.384		535	0.00
2	2	50	1.38	1.03	2.462	7.38	2.462		539	0.00
3	3	50	2.07	1.72	2.610	7.36	2.559		540	0.00
4	4	50	2.75	2.41	2.604	7.34	2.579		539	0.00
5	5	50	3.44	3.10	2.625	7.38	2.540		542	0.00
6	6	50	4.13	3.79	2.689	7.39	2.442		541	0.00
7,8	7	100	5.51	4.82	2.817	7.41	2.823		538	0.00
9,10	8	100	6.89	6.20	2.920	7.51	3.058		539	0.00
11,12	9	100	8.26	7.58	4.112	7.92	4.259		544	0.00
13,14	10	100	9.64	8.95	7.040	7.73	7.493		546	1675.00
15,16	11	100	11.02	10.33	12.139	7.74	12.387		546	4012.00
17,18	12	100	12.40	11.71	17.152	7.73	17.037		547	6329.00

AT9906-35MC-CA

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl	H2S
		ml	cm	cm	mM		mM	uM	mM	uM
	overlying				2.336	7.4	2.325	0.00	541	
1	1	50	0.69	0.34	2.358	7.38	2.344	0.79	539	0.00
2	2	50	1.38	1.03	2.396	7.36	2.344	0.79	540	0.00
3	3	50	2.07	1.72	2.474	7.35	2.296	5.43	540	0.00
4	4	50	2.75	2.41	2.492	7.36	2.364	8.74	544	0.00
5	5	50	3.44	3.10	2.526	7.45	2.451	10.28	542	0.20
6	6	50	4.13	3.79	2.489	7.36	2.499	12.26	543	0.20
7	7	50	4.82	4.48	2.551	7.42	2.441	16.01	543	0.61
8	8	50	5.51	5.17	2.537	7.32	2.490	16.68	546	0.00
9,10	9	100	6.89	6.20	2.555	7.33	2.470	22.19	544	0.41
11,12	10	100	8.26	7.58	2.565	7.39	2.490	29.69	546	0.61
13,14	11	100	9.64	8.95	2.545	7.37	2.441	23.74	546	0.41
15,16	12	100	11.02	10.33	2.588	7.37	2.470	27.04	549	0.00
17,18	13	100	12.40	11.71	2.642	7.43	2.596	40.72	546	0.20

AT9906-37MC-CA

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl	H2S
		ml	cm	cm	mM		mM	uM	mM	uM
	OW				2.177	7.55		5.43		61.00
1,2	1	100	1.38	0.69	4.612	7.67		33.00		515.00
3,4	2	100	2.75	2.07	6.680	7.64		26.82		1804.00
5,6	3	100	4.13	3.44	11.961	7.74		20.65		4066.00
7,8	4	100	5.51	4.82	17.709	7.68		28.59		7283.00
9,10	5	100	6.89	6.20	24.904	7.68		61.24		10691.00
11,12	6	100	8.26	7.58	31.520	7.74		126.97		12750.00
13,14	7	100	9.64	8.95	32.469	7.76		111.31		13324.00
15,16	8	100	11.02	10.33	34.9551	7.74		84.35		16393.00
17,18	9	100	12.40	11.71	35.4828	7.75		114.35		16929.00

AT9906-03MC-C1

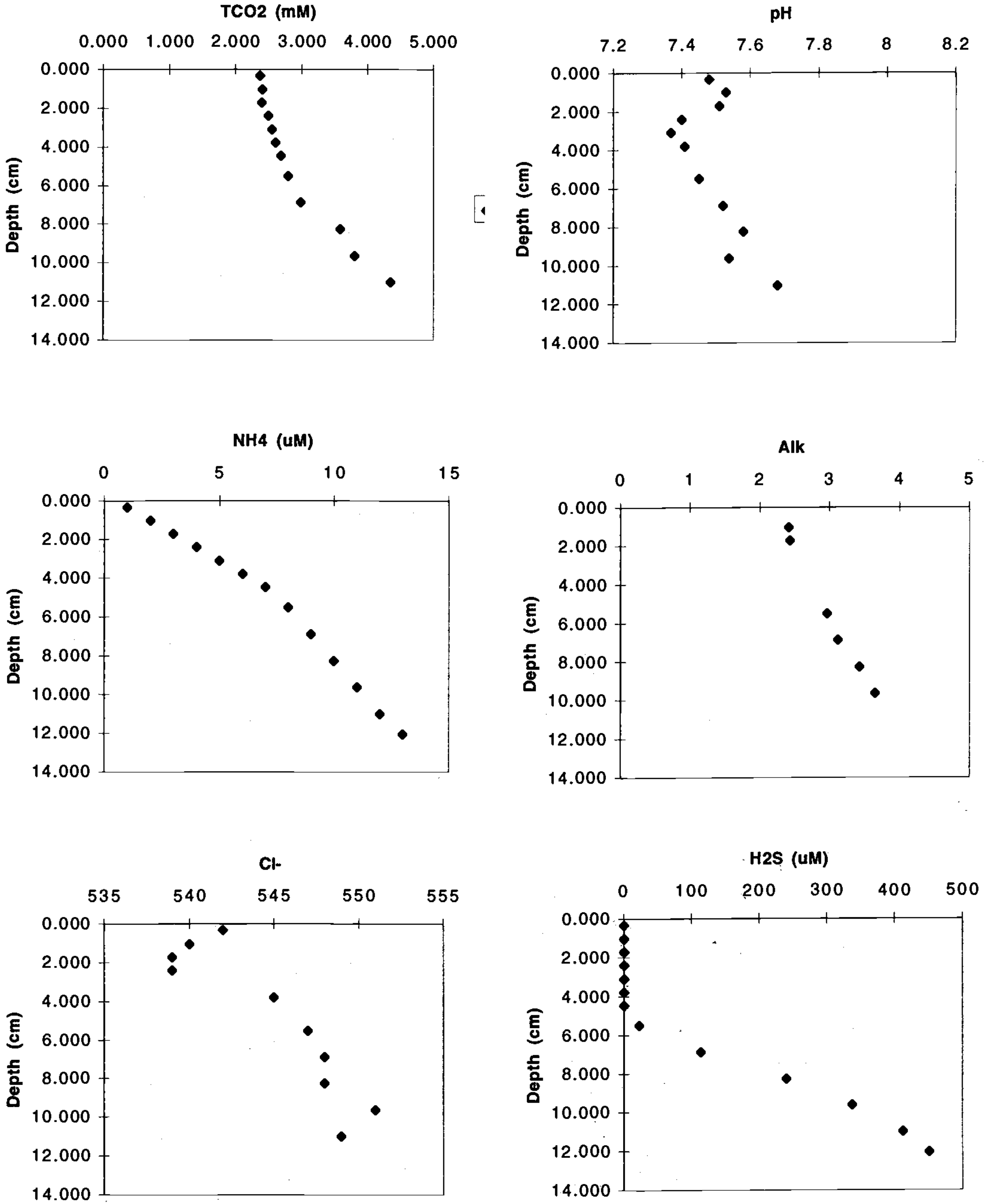
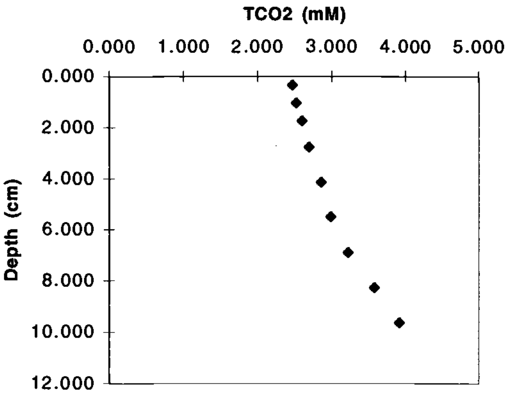
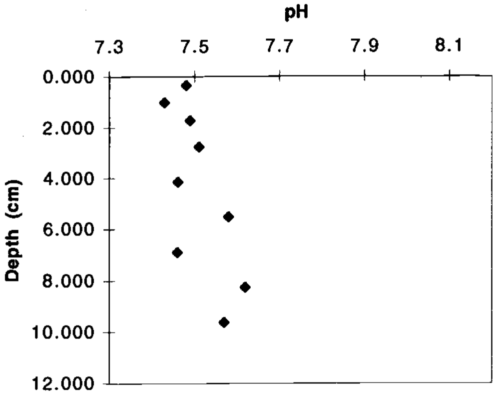
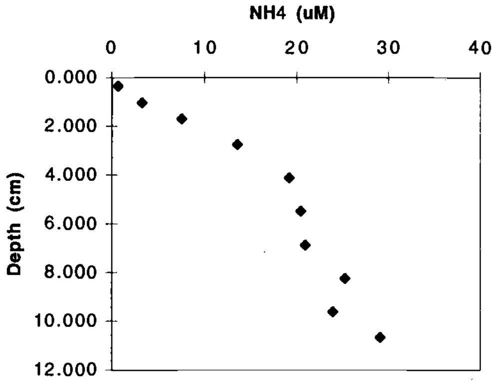


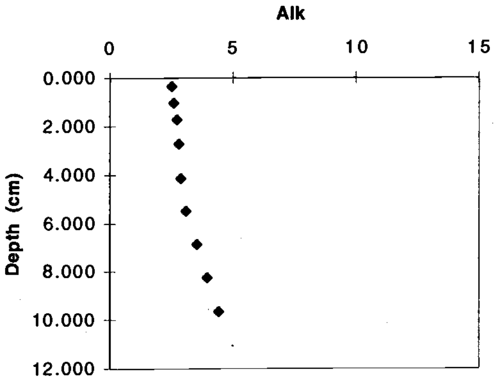
Figure 9. Pore water profiles for AT3-35B multicores

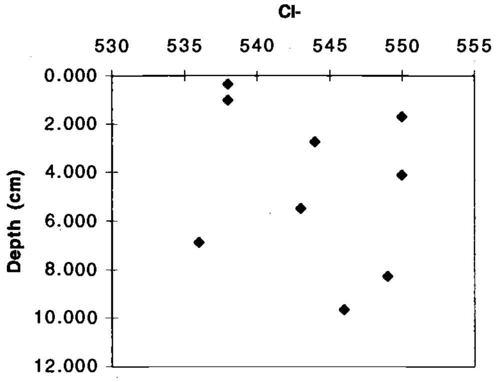
AT9906-07MC-C1

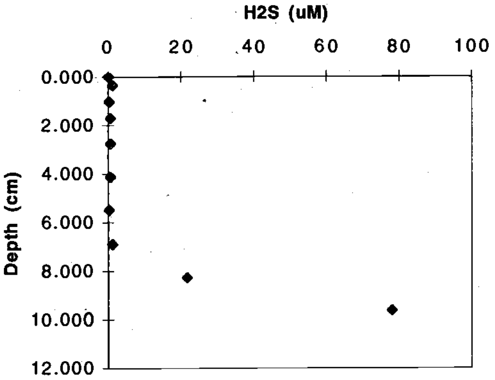












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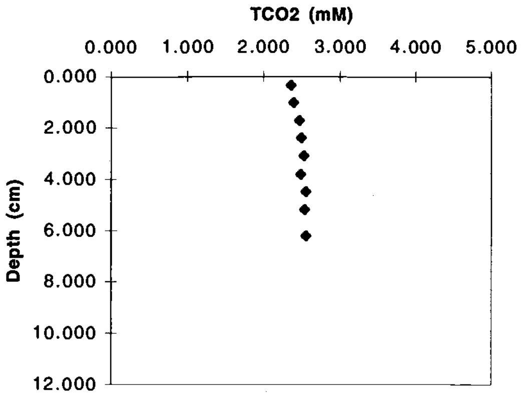

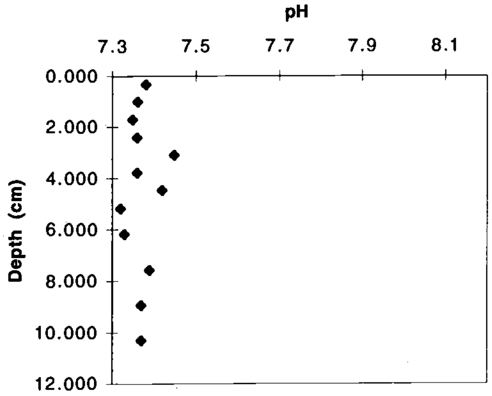

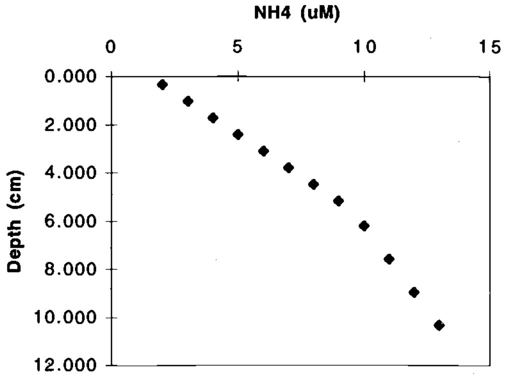

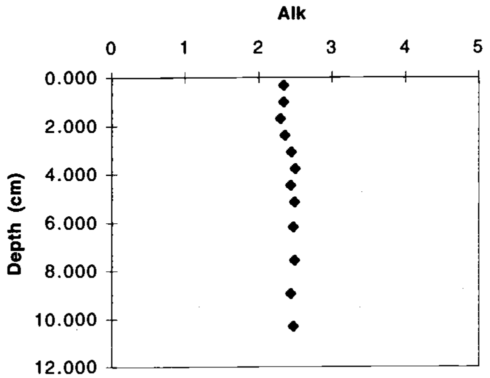

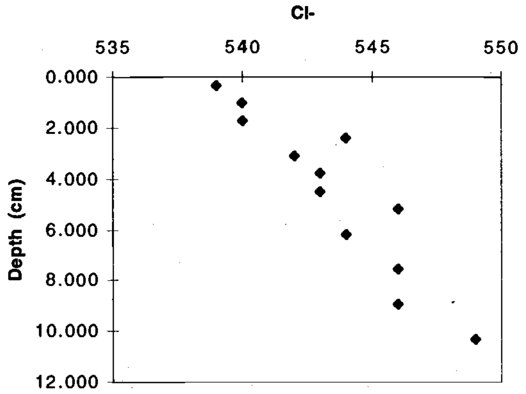

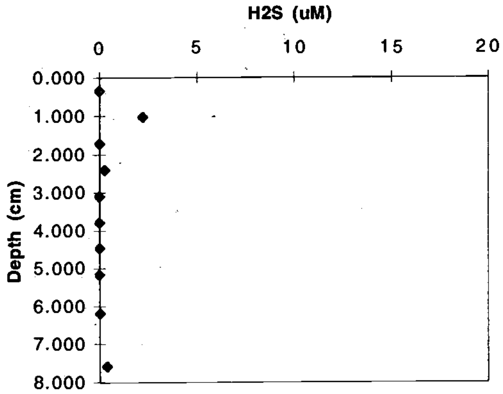

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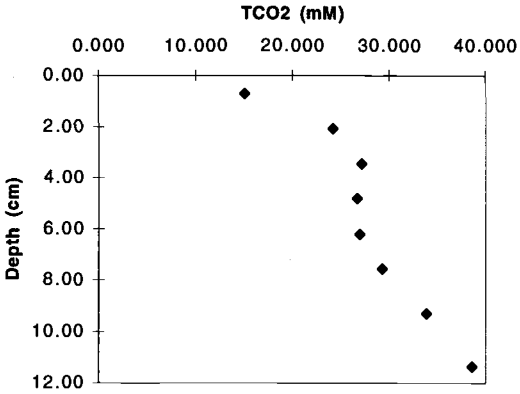

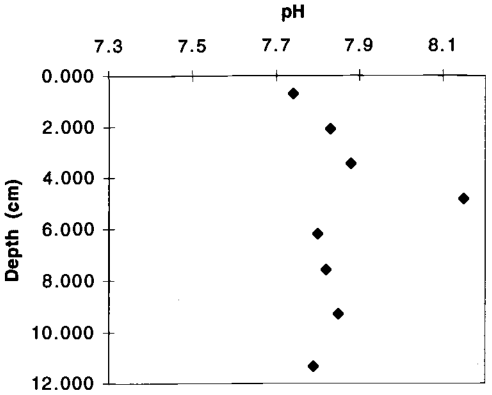

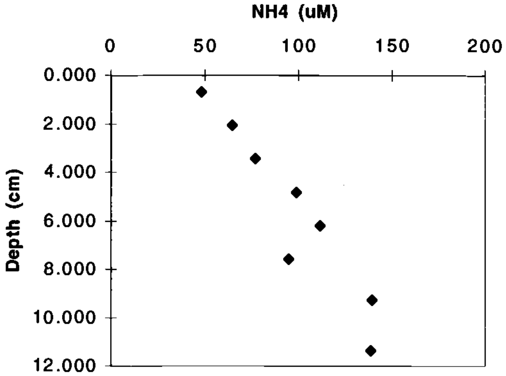

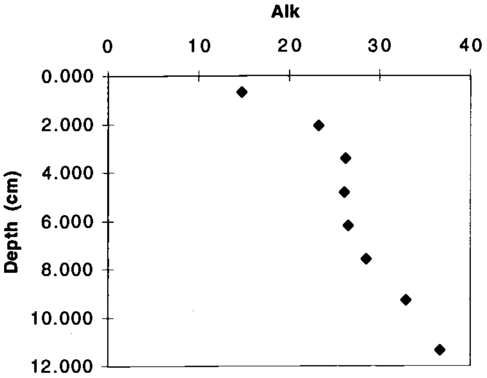

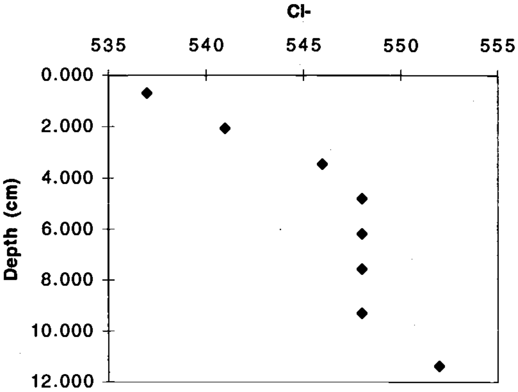

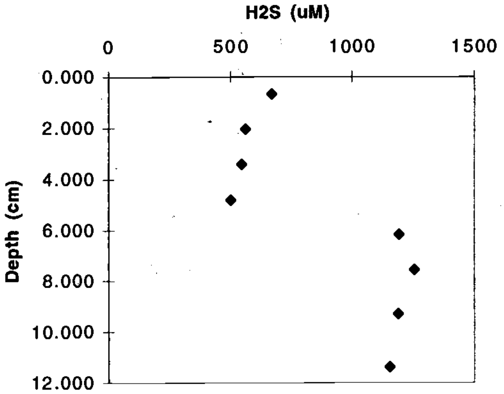

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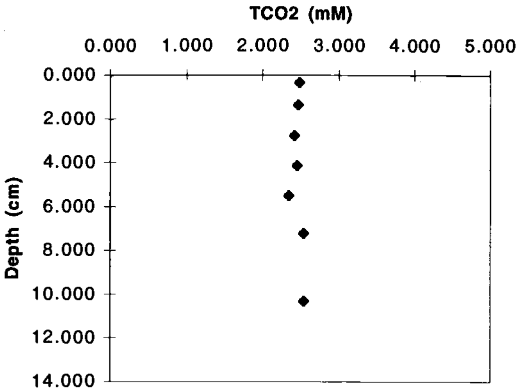
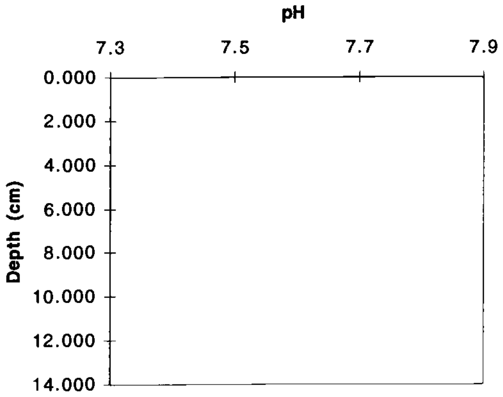
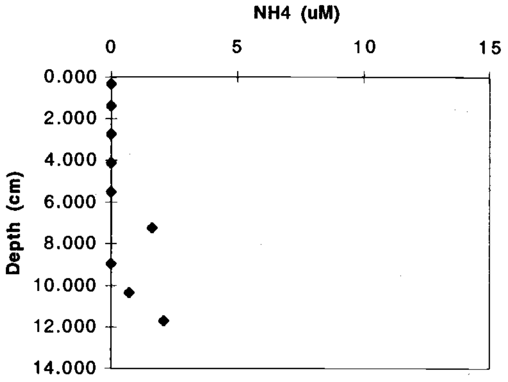
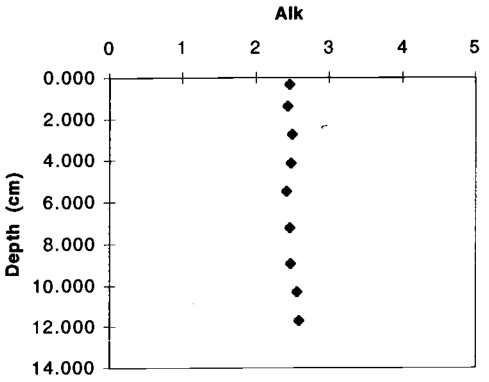
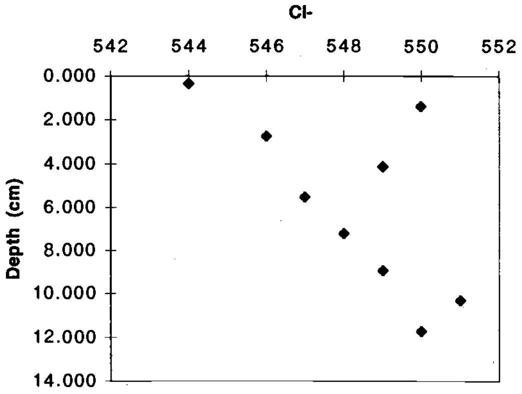
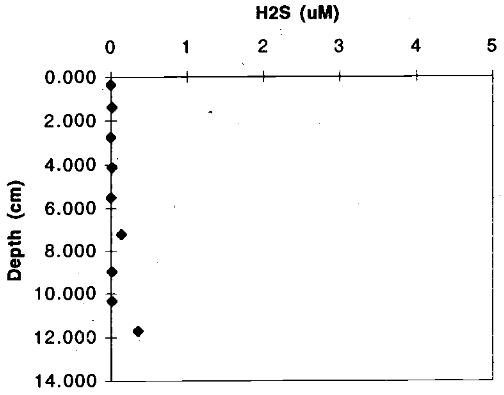


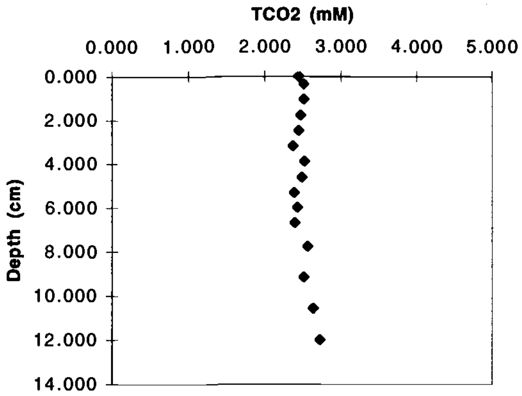


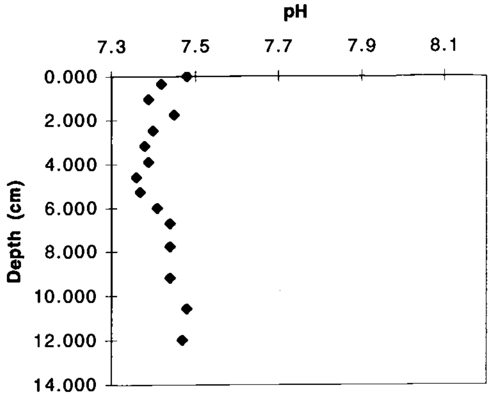









TCO2 (mM)
0.000
1.000
2.000
3.000
4.000
5.000
Depth (cm)
0.000
2.000
4.000
6.000
8.000
10.000
12.000
14.000


pH
7.3
7.5
7.7
7.9
8.1
Depth (cm)
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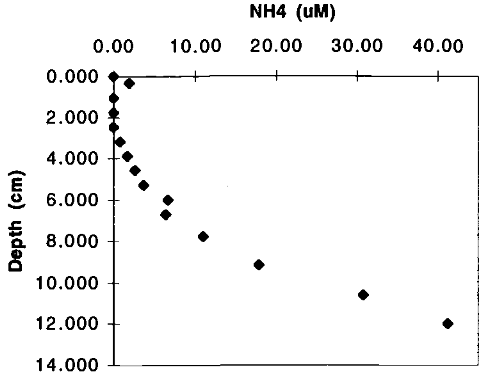
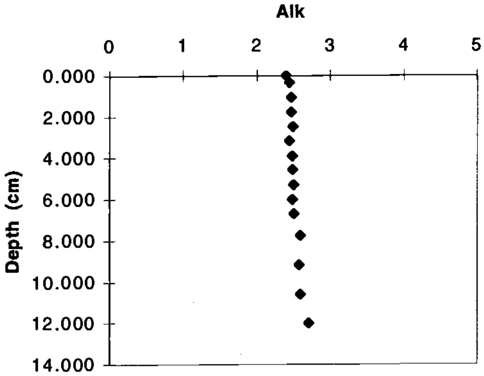
2.000
4.000
6.000
8.000
10.000
12.000
14.000


NH4 (uM)
0.00
10.00
20.00
30.00
40.00
Depth (cm)
0.000
2.000
4.000
6.000
8.000
10.000
12.000
14.000


Alk
0
1
2
3
4
5
Depth (cm)
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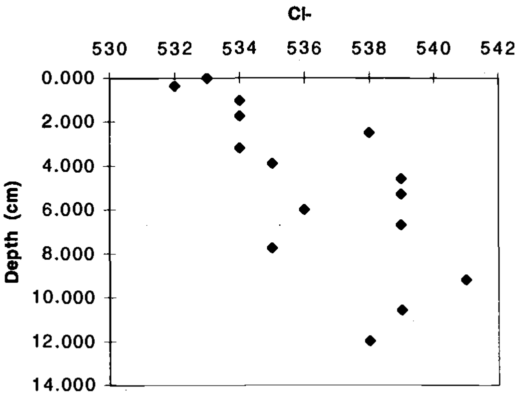
2.000
4.000
6.000
8.000
10.000
12.000
14.000


Cl-
530
532
534
536
538
540
542
Depth (cm)
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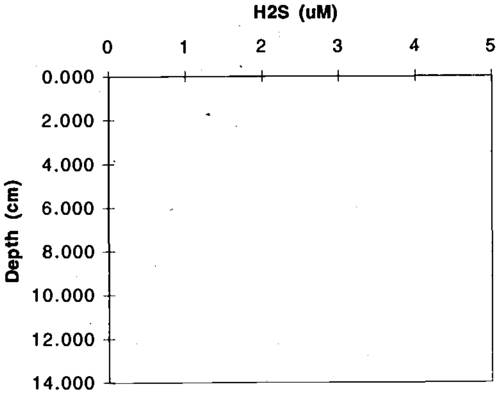
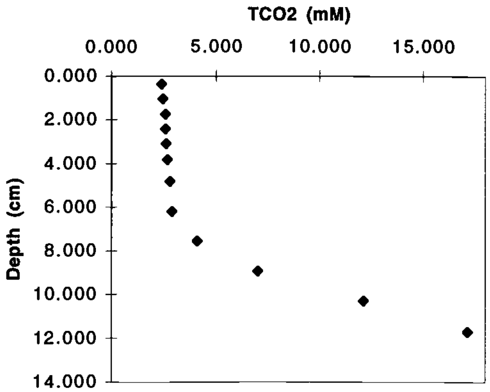
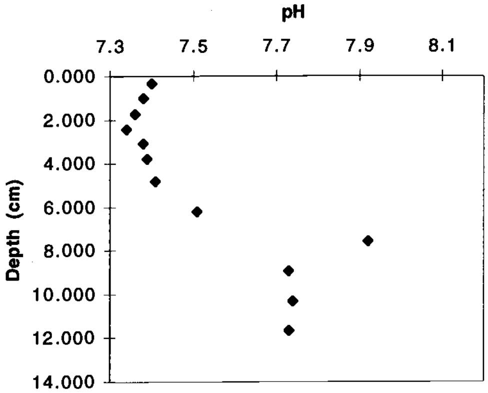
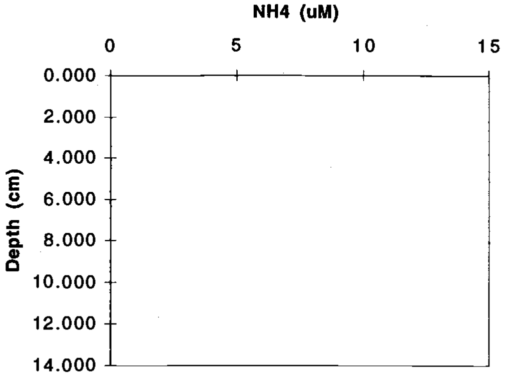
2.000
4.000
6.000
8.000
10.000
12.000
14.000

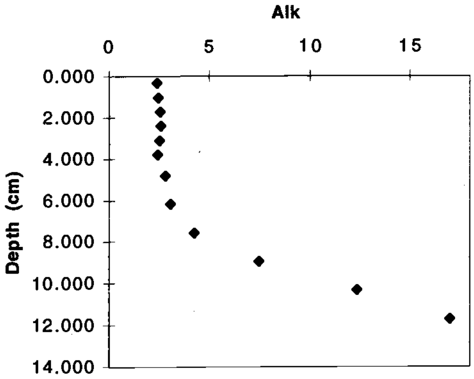

H2S (uM)
0
1
2
3
4
5
Depth (cm)
0.000
2.000
4.000
6.000
8.000
10.000
12.000
14.000

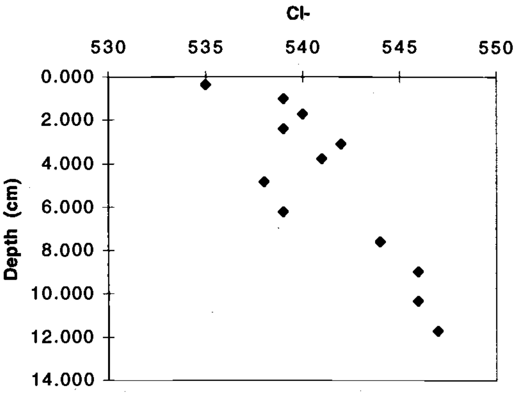
AT9906-30MC-CA

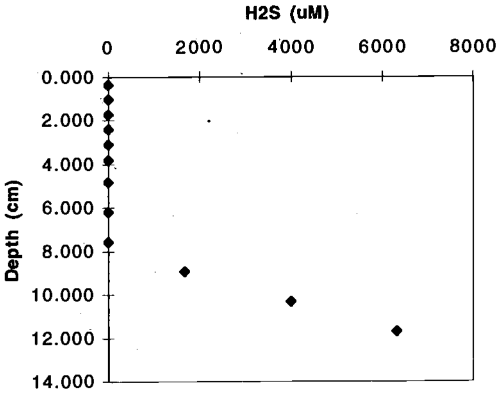




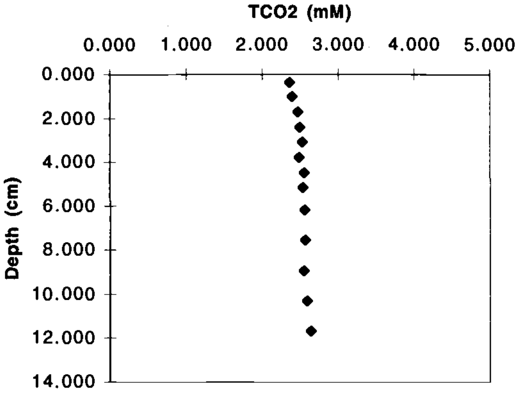


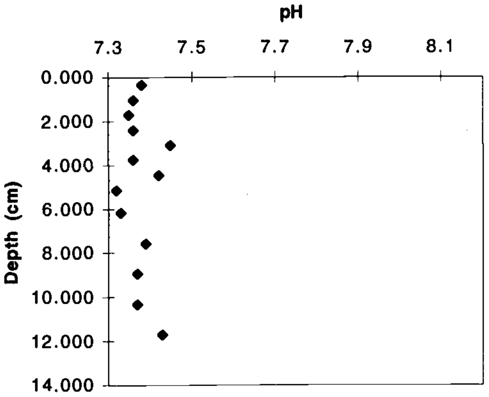


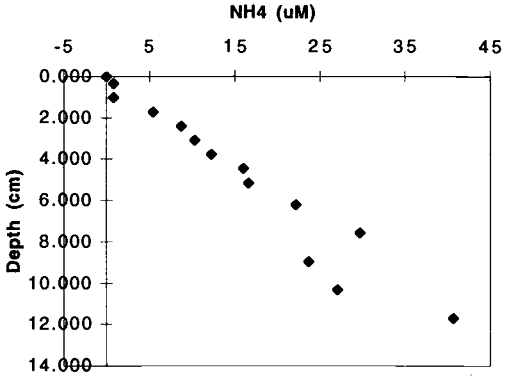


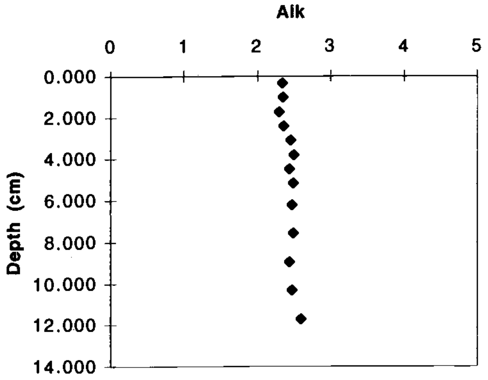


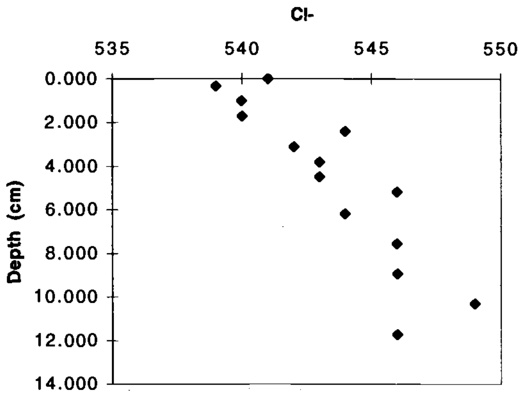
AT9906-35MC-CA

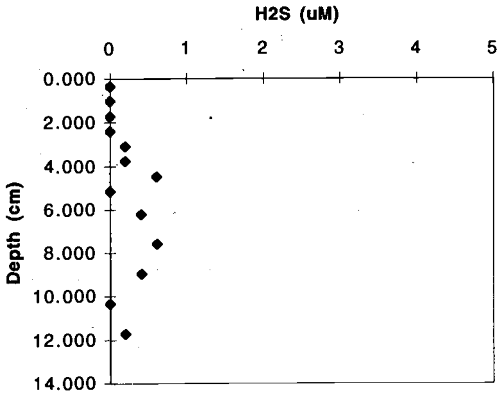




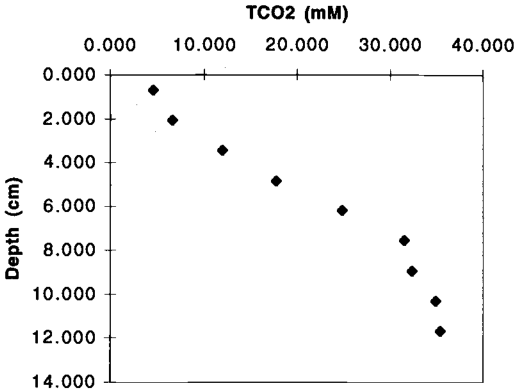


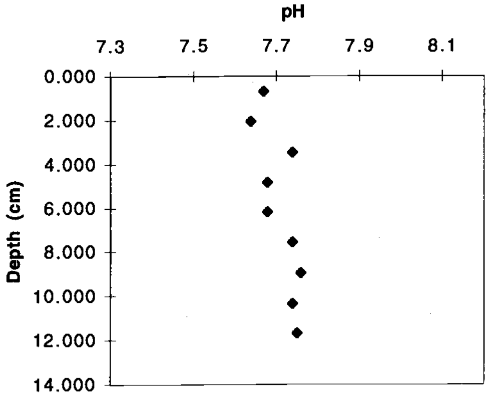


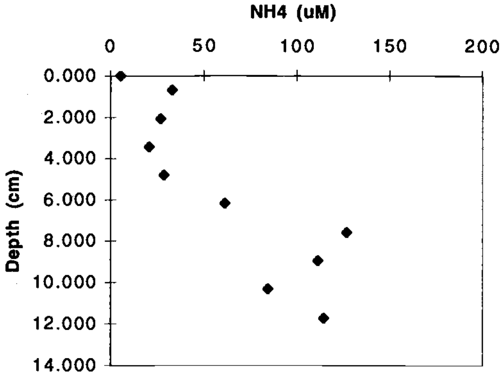


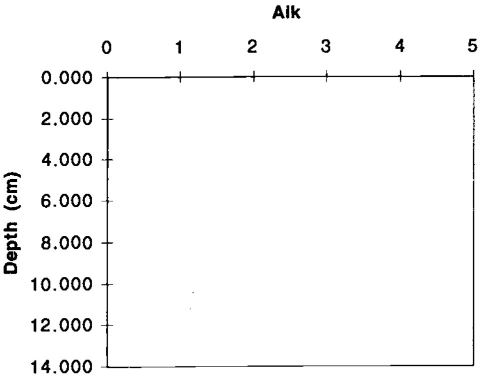


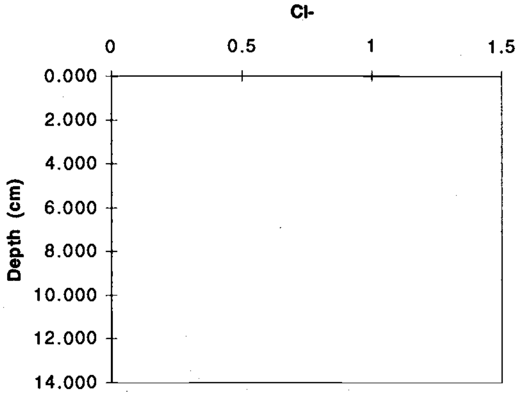
AT9906-37MC-CA

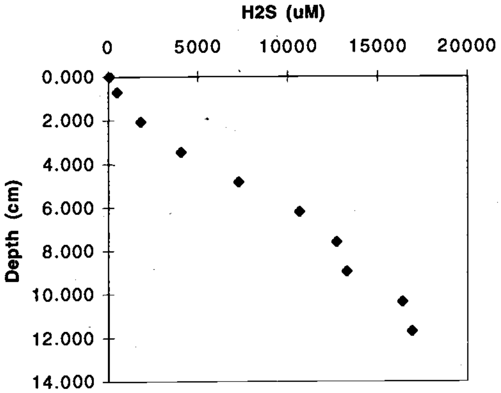

TCO2 (mM)


pH


NH4 (uM)


Alk


Cl-


H2S (uM)

Oxygen analysis. Oxygen was measured with a flow-thru oxygen electrode (Microelectrodes, Inc) mounted in line prior to the filter. The voltage output from their O2-ADPT unit was measured with a digital voltmeter to ±1 mv. This signal is relatively insensitive to flow rate as long as rates are above 1 cc/min. Oxygen-free water gives a blank of 3 mv, and the sensitivity is about 1 mv/µM at 5 °C. For the first core processed (MC13), some oxygen contamination was introduced by the tygon tubing used in the flow line. A correction has been made for this blank. Later extractions utilized nylon tubing that did not have a significant oxygen blank. Calibration was done by equilibrating DIW with the atmosphere at known temperature, cooling the water to the temperature of the cold room, and measuring the signal generated. Conversion of measured signal to a seawater scale was made by dividing by 1.293, the activity coefficient of oxygen in 34.5‰ seawater at 5°C. Temperature of standards and expressed pore waters was measured periodically and the signal was corrected to a reference temperature of 5°C. The temperature sensitivity of the signal was 4.2%/°C in this temperature range. Based on precision of calibration and uncertainties in signal and blanks, the accuracy of this analysis is estimated to be ±2.5 µM.

Other analyses. In addition to oxygen, samples were taken for analyses of TCO_2 and pH (run on same split by C. Meredith and D. Colbert), methane (run using head-space equilibration technique by M. deAngelis), H_2S (sometimes taken, run by S. Kohlbry) radon (alpha scintillation, run by S. Colbert) and nitrate (stored cold for analysis at OSU).

Results of WCS are presented in Table 8, and summarized in the sections below.

Rn results. Radon increased with depth to a relatively constant concentration, as expected from a simple diffusion-reaction profile. An exponential function of the form

$$C = Ceq*(1 - \exp(-bz))$$

was fit to all profiles, and it was expected that b = sqrt(λ/Ds), where λ = Rn decay constant and Ds is the Rn diffusivity corrected for tortuosity. While this function appeared to provide a reasonable fit to the profiles, the values of b obtained were quite high, ranging from 1.5 to 3.0 cm^{-1}, with an expected value of 0.6 cm^{-1}. Several factors might increase b above the expected value:

1. Significant upward advection. This is unlikely, however, as the very stiff clay at some sites must have very low permeability and would prevent advection.

2. Substantial irrigation. To make b so large, rates of irrigation would need to occur at 2-3 times the Rn decay rate, resulting in a porewater turnover time of about 2 days due to irrigation. This seems unreasonably high.

3. Changes in Rn emanation with depth. If a Mn-rich zone exists in the upper 1 cm of oxygenated sediments, it could influence Ra-226 distribution and Rn emanation, causing emanation rates in the upper 1-2 cm to be greater than below. Solid phase samples from each core were saved for measurement in the lab to test this hypothesis.

4. Artifacts in the WCS processing. If voids contain high Rn water, and these are expressed preferentially during the early part of the squeezing, this might influence the measured profile. While voids did exist, their Rn content was expected to be lower than the near-surface pore water, but this may play some role.

Table 8. Results from WCS analysis of multicore samples

Core ID: AT9906-20mc-4

Date Collected: 7/7/99 **Date Squeezed:** 7/7/99

Notes: Sample depths preliminary, assume 63 ml/cm.
First samples cloudy - filter not working well.
BW O2 measured in coretop water; BW Rn assumed.

Core Description: Brown/olive mud; fluffy, level interface; top 3 cm w/ black dots; 13 cm down change to a compact olive clay

ID	Total corr ml	Depth (cm)	O2 µM	TCO2 µM	pH	H2S µM	CH4 nM	Rn dpm/l	± 1 sig	Notes
Sample 1				2228	7.42	1.270	55			
Sample 2				2236	7.42	0.250	34			
Average BW		0	24.1	2232	7.42		45	0.1		
Oxy	12.0	0.11	11.5							
tCO2-3	14.5	0.15		2272	7.39					
Oxy	17.0	0.19	11.5							
Sulfide-3	19.3	0.23				1.390				
Rn-1	25.0	0.32						76	9	
Methane-3	32.3	0.43					90			
Oxy	35.0	0.48	9.6							
Nutrient-3	37.3	0.51								
tCO2-4	44.3	0.62		2358	7.38					
Sulfide-4	48.5	0.69				0.93				
Rn-2	55.8	0.81						121	10	
Oxy	58.5	0.85	7.2							
Methane-4	63.3	0.92					43			
Oxy	66.0	0.97	4.8							
Nutrient-4	68.3	1.00								
tCO2-5	75.3	1.12		2447	7.37					
Oxy	78.0	1.16	6.7							
Sulfide-5	79.5	1.18				0.590				
Rn-3	85.8	1.28						130	12	
Methane-5	93.0	1.40					30			
Oxy	95.5	1.44	3.8							
Nutrient-5	97.8	1.47								
tCO2-6	104.8	1.58		2420	7.41					
Oxy	107.5	1.63	2.9							
Sulfide-6	109.3	1.65				0.14				
Rn-4	115.8	1.76						139	16	
Oxy	118.5	1.80	1.9							
Methane -6	124.3	1.89					30			
Oxy	127.0	1.94	1.0							
Nutrient-6	129.3	1.97								
tCO2-7	137.3	2.10		2338	7.38					
Sulfide-7	141.5	2.17				0.02				
Rn-5	147.8	2.27						145	20	
Oxy	150.5	2.31	1.0							
Methane-7	155.3	2.38					63			
Oxy	158.0	2.43	0.0							
Nutrient-7	160.3	2.46								
tCO2-8	167.3	2.58		2335	7.39					
Sulfide-8	171.5	2.64				0				
Rn-6	177.8	2.74						110	11	Rn suck air on fill. Low?
Methane-8	185.3	2.86					41			
Nutrient-8	190.3	2.94								
Oxy	192.5	2.98	0.0							
Sulfide-9	198.5	3.07				0				

Table 8. Cont.

Core ID: AT9906-22MC-3

Date Collected: 7/7/99 **Date Squeezed:** 7/7/99

Notes: Sample depths preliminary, assume 63 ml/cm.
First samples cloudy - filter not working well.
BW O2 measured in coretop water; BW Rn assumed.
Corrected depth calculated by assuming 15 ml leakage based on later cores.

Core Descrip 1.5 cm relief at top; fluffy interface; brown mud;
slight gas trapped against liner @ ~30cm; ~3ml void@ 2cm depth; Large Clam @~10 cm w/voids at the core liner
**When core was opened, found a 1 cm polycheate @ ~10 cm depth;
oxidized patch ~ 2 cm diam. about 6 cm down, empty articulated clam shell ~ 10 cm long ~8cm down,
one more little polycheate

ID	Total corr ml	Depth (cm)	O2 µM	TCO2 µM	pH	H2S µM	CH4 nM	Rn dpm/l	± 1sig	Notes
Sample 1				2413	7.48		112			
Sample 2				2410	7.46		54			
Average BW		0	24.1	2411	7.47		83	0.1		
tCO2-3	13.8	0.14		2510	7.40					Cloudy
Rn-1	21.3	0.26						51	7	
Oxy	24.0	0.30	9.6							
Methane-3	28.8	0.38					293			
Oxy	31.5	0.42	6.7							
Nutrient-3	33.8	0.46								
tCO2-4	40.5	0.56		2559	7.39					
Oxy	43.0	0.60	5.8							
Rn-2	47.8	0.68						69	9	
Methane-4	55.3	0.80					91			
Oxy	58.0	0.84	5.8							Large pocket gone
Nutrient-4	60.3	0.88								New Filter, corr. position.
tCO2-5	80.0	1.19		2559	7.34					Start leakage correction
Rn-3	90.4	1.36						104	11	
Oxy	93.6	1.41	1.9							
Methane-5	99.3	1.50					108			
Oxy	102.5	1.55	1.0							
Nutrient-5	108.7	1.65								
tCO2-6	115.9	1.76		2591	7.36					
Oxy	119.1	1.81	0.0							
Rn-4	124.7	1.90						116	13	
Methane -6	134.8	2.06					184			
Nutrient-6	140.7	2.15								
tCO2-7	147.6	2.26		2584	7.35					
Oxy	150.5	2.31	-1.0							
Rn-5	155.0	2.38						113	19	
Methane-7	162.7	2.50					145			
Nutrient-7	168.6	2.60								
Oxy	171.3	2.64	-1.0							

Table 8 Cont

Core ID: AT9906-30mc-3

Date Collected: 7/10/99 **Date Squeezed:** 7/10/99

Core Descrip ~1.5 cm relief; fluffy interface; few tubes sticking up; several 1-2cc voids in upper 5 cm. Top 5 cm light brown, then olive w/black grains for 10cm, then olive below.

Notes: Assume Temp correction is 1.4°C (5.9%). O2 calc as: 1.059*(mv-3)*1.028*0.899
Depth calculated as: (Corr ml - 5)/63. Leakage correction made as noted below
Filter (was in reversed position?) and allowed cloudy sediment in early samples
Nylaflow tubing used.
BW O2 was measured in coretop water; BW Rn was assumed.

ID	Total corr ml	Depth (cm)	O2 µM	TCO2 µM	pH	H2S µM	CH4 nM	Rn dpm/l	± 1sig	Notes
Sample 1				2344	7.45		45			
Sample 2				2357	7.46		45			
Average BW		0	28.4	2350	7.46		45	0.1		
Oxy	7.29	0.04	4.9							
tCO2-3	10.63	0.09		2506	7.46					
Oxy	16.39	0.18	2.0							
Methane-3	19.43	0.23					2010			
Sulfide-3	24.29	0.31								
Rn-1	31.57	0.42						68	15	
Oxy	34.61	0.47	2.0							
Nutrient-3	37.34	0.51								Large pocket gone
tCO2-4	45.23	0.64		2657	7.41					
Sulfide-4	50.39	0.72								
Rn-2	57.07	0.83						81	9	
Oxy	60.11	0.87	1.0							
Methane-4	65.57	0.96					3117			
Nutrient-4	71.34	1.05								
Oxy	74.07	1.10	0.0							
tCO2-5	78.32	1.16		2671	7.40					
Sulfide-5	83.18	1.24								
Oxy	85.00	1.27	0.0							
Rn-3	90.02	1.35						85	15	
Methane-5	97.84	1.47					2927			
Nutrient-5	103.14	1.56								
tCO2-6	109.56	1.66		2711	7.37					
Sulfide-6	114.02	1.73								
Rn-4	119.60	1.82						97	25	
Oxy	122.40	1.86	0.0							
Methane -6	126.30	1.93					3497			
Nutrient-6	131.60	2.01								

Table 8 Cont

Core ID: AT9906-35mc-3
Date Collected: 7/11/99 **Date Squeezed:** 7/11/99
Core Descrip 1.5 cm relief at top; fluffy interface; brown mud w/black dots throughout;
About 7cm from the bottom, it changes to very stiff olive clay w/no sulfide granules
Notes: Temp correction is -0.6°C (-2.5%). O2 calc as: 0.975*(mv-3)*1.028*1.153
Depth calculated as: (Corr ml - 5)/63. 30 ml Leakage correction= ((30+148)/148)
No H2S drawn; BW O2 measured in coretop water; BW Rn assumed.
Check to see if methane order is correct.

ID	Total corr ml	Depth (cm)	O2 µM	TCO2 µM	pH	H2S µM	CH4 nM	Rn dpm/l	± 1sig	Notes
Sample 1				2291	7.43		167			
Sample 2				2307	7.42		177			
Average BW		0.00	23.4	2299	7.43		172	0.1		
Waste	3.01	-0.03								
tCO2-3	9.32	0.07		2387	7.37					
Waste	13.83	0.14								
Rn-1	18.04	0.21						29	6	
Oxy	21.05	0.25	13.9							
Waste	22.25	0.27								
Methane-3	26.76	0.35					1067			
Oxy	30.07	0.40	11.6							
Nutrient-3	32.77	0.44								
Oxy	35.48	0.48	9.2							
Waste	36.68	0.50								Large pocket gone
tCO2-4	41.19	0.57		2427	7.36					New Filter (reversed). Start correction
Waste	45.70	0.65								
Rn-2	49.91	0.71						41	3	
Waste	55.02	0.79								
Methane-4	60.44	0.88					102			
Oxy	63.74	0.93	8.1							
Nutrient-4	66.45	0.98								
Waste	70.36	1.04								
tCO2-5	74.87	1.11		2511	7.36					
Oxy	78.18	1.16	4.6							
Waste	79.38	1.18								
Rn-3	83.89	1.25						65	8	
Waste	88.40	1.32								
Methane-5	92.91	1.40					54			
Nutrient-5	98.92	1.49								
Oxy	101.63	1.53	2.3							
Waste	103.13	1.56								
tCO2-6	107.94	1.63		2582	7.51					
Waste	112.45	1.71								
Rn-4	116.66	1.77						71	37	
Oxy	119.67	1.82	1.2							
Waste	120.27	1.83								
Methane -6	124.18	1.89					81			
Nutrient-6	130.19	1.99								
Waste	133.50	2.04								
tCO2-7	137.41	2.10		2459	7.36					
Oxy	140.72	2.15	0.0							
Waste	141.92	2.17								
Rn-5	146.13	2.24						70	22	
Waste	150.34	2.31								
Methane-7	154.85	2.38					92			
Oxy	158.16	2.43	-1							
Nutrient-7	160.86	2.47								
Waste	164.77	2.54								
tCO2-8	169.28	2.61		2423	7.38					
Nutrient-8	175.29	2.70								

Measurements of porosity and solid phase Rn emanation must be made in the lab to properly constrain variables influencing Rn profiles. Factors 3 and 4 (above) are most likely to cause the high values of b. Results from Rn should be useful in determining if the presence of voids and burrows has created severe artifacts in profiles of other parameters.

Oxygen results. Profiles were fit with an exponential function:

$$C = Co*exp(-bz)$$

While this function describes the general decrease, it tended to predict concentrations too high at shallow depth and too low at greater depth. This failure may reflect the existence of multi-G organic matter that is highly reactive in near-surface sediments, or it may reflect irrigation. The latter is certainly an influence, as a few cores show some sub-surface maximum, requiring non-local transport of oxygenated water. Fits to the profiles were used to estimate the oxygen flux into sediments, which ranged from 0.2 to 0.5 mmol/m2-day, except MC30 that indicated a flux 30 times greater. The former range is considered a lower limit estimate due to the presence of irrigation; if only the overlying water value and first data point are used, fluxes of 0.5-0.6 mmol/m2-day would be predicted for the cores other than MC30. The very large oxygen gradient at MC30 corresponds to a significant upward flux of methane. This was the only core showing substantial concentrations of pore water methane, and it appears that the high oxygen flux calculated may be related to high fluxes of oxidizable material from below. This core also had the highest TCO_2 gradient.

TCO_2 results. Cores from deeper water showed an increase in TCO_2 to a relatively constant value. The 2 sites shallower than 900 m showed clear evidence of irrigation, with a subsurface maximum. pH decreased with depth in each core, sometimes passing through a minimum. $CaCO_3$ saturation calculations will be carried out to determine if an artifact is present in the TCO_2 data due to carbonate precipitation during recovery. The variation in core-top values among the cores is larger than expected based on the oxygen measurements. It is possible that more cleaning of TCO_2 data will be required to see if daily variation in blanks may be a factor here. Fitting a function that increases to a constant value at depth:

$$C = Cd - \Delta C*exp(-bz)$$

provides parameters to permit a rough estimate of fluxes. Results indicate a range of 0.5-4.2 mmol/m2-day at all sites except MC-30, which predicts a flux of 9.4 mmol/m2-day. This range is greater than the O_2 fluxes and demonstrates that oxidants other than O_2 are significant. We have not yet evaluated the contribution of carbonate dissolution/precipitation to the TCO_2 budget.

CH_4 results. In all cores except MC-30, the concentration of methane was rather variable and erratic. One notable consistency is that the uppermost sample always had the greatest concentration, suggesting that the methane source is rapidly decomposing organics present in near-surface sediments. This maximum ranged from 0.1 to 1 µM above background values. In MC-30, methane increased from 2 to 3 µM from 0.2 cm to 2 cm depth. This gradient is insufficient to account for a significant fraction of the oxygen consumption, but perhaps a story will be evident in the H_2S profile.

TABLE 9: Sampling for foraminifer studies

AT9906-3MC-2
Date: July 1-99
Core Diameter: 9.5cm
Number of samples: 15
Sample Depths: 0-12cm at 1cm intervals
12-18cm at 2cm intervals

Notes:
Observed at channel-looking feature beginning at 5.5cm and at 1cm diameter. Black/sandy possibly containing of iron or manganese.

AT 9906-7MC-3
Date: July 3-99
Core Diameter: 9.5cm
Number of Samples: 11
Sample Depths: 0-10cm at 1cm intervals
10-10.5cm

Notes:
Beginning at 6cm core was split down the middle. One side was harder, lighter in color, and clay. The other side was darker, softer, and containing more water.

AT 9906-13MC-8
Date: July 5-99
Core Diameter: 9.5cm
Number of Samples: 18
Sample Depths: 0-6cm at 1/2cm intervals
6-12cm at 1cm intervals

Notes:
Core was virtually containing no observable life on surface.
No clams or carbonates. Clay appeared from 10cm on out.

AT 9906-20MC-3
Date: July 7-99
Core Diameter: 9.5cm
Number of samples: 18
Sample Depths: 0-6cm at 1/2cm intervals
6-12cm at 1cm intervals

Notes:
Removed a red-orange colored Amphipod/Crustacea. Mud turned to clay at 8cm.

AT 9906-22MC-5
Date: July 7-99
Core Diameter: 9.5cm
Number of Samples: 18
Sample Depths: 0-6cm at 1/2cm intervals
6-12cm at 1cm intervals

Notes:
A lot of mud in this core, saved the remaining. AT 7-8cm observed an orange rust-colored cylinder about 1/3cm in diameter. It stood vertical and was hollow.

AT 9906-30MC-5
Date: July 10-99
Core Diameter: 9.5cm
Number of samples: 18
Sample Depths: 0-6cm at 1/2cm intervals
6-12cm at 1cm intervals

Notes:
Mud became firmer about 6cm down. Also saved remaining core.

AT 9906-35MC-5
Date: July 11-99
Core Diameter: 9.5cm
Number of Samples: 18
Sample Depths: 0-6cm at 1/2cm intervals
6-12cm at 1cm intervals

Notes:
Sample a little disturbed, water was drained in freezer. Saved remaining mud and stored in cold room.

Summary. WCS results suggest that at most sites, oxygen consumption is 0.5-0.6 mmol/m2-day. The role of other oxidants is expected to be significant as TCO_2 fluxes are several times greater than those for oxygen. Irrigation plays a significant role in determining pore water profiles. Radon may be of some help in determining if artifacts in the WCS are important, but cannot be used until measurements of solid phase Rn emanation rates are made. MC30 is distinct from the other 4 sites in having significant quantities of methane in the upper 3 cm and extremely high oxygen consumption. However, sediments at this site are underlain by a very stiff clay that would appear to preclude upward advection

5.3 FORAM SAMPLING (K. Kinports)

On the whole a total of 7 multicores were used in sampling for microscopic foraminifer as described in Table 9. This accounts for one core from every multicore site on this cruise. Aside from the first two coring sites each core was sliced up into 1/2cm intervals for the first 6cm and then at 1cm intervals from 6-12cm. A piston and measuring rings aided in this process. No samples were taken after 12cm. From each slice the sediment was placed into 125ml nalgene bottles labeled with coring site and depth in core. After all samples were taken formalin containing Rose Bengal was added, about a half an inch per bottle, to preserve and stain the live forams. Each bottle was then stored in the cold room, sample analysis will be conducted at OSU.

6. ALVIN OPERATIONS

6.1 INTRODUCTION

We had a total of 10 Alvin dives: 6 on HRS, and 4 on HRN. The main objectives were to: 1) asses how near surface formation of decomposition of a near-surface gas hydrate influences benthic fluxes and early diagenetic reactions, and 2) evaluate the magnitude, temporal and spatial variability of methane fluxes to the bottom water via hydrate decomposition.

6.2 NAVIGATION

During this cruise we utilized the ACNAV long baseline navigation system, using two nets of two acoustic transponders each. This nets allowed tracking of ALVIN's position from the support ship and from within the submersible. ALVIN is equipped with an in-hull navigation transceiver which allows the submersible to utilize the long baseline transponder net to navigate independently of ATLANTIS and thus more accurately (<5 meters). This transceiver is capable of transmitting on any one frequency and receiving on any four frequencies between 5.0 and 15.0KHz in 100 Hz steps. The acoustic travel times measured by this transceiver are fed to the ALVIN computer for further interpretation and display.

The acoustic transmitter/receiver (Benthos 455 ASP) on the ATLANTIS receives 16 of the 17 frequencies from 7.0 to 15.0 KHz simultaneously with 500 Hz spacing (normally no reception on 12.5 KHz). Additionally, it can interrogate on 16 frequencies (excluding 12.5 KHz). This system can provide precision navigation of the support ship with an accuracy of within 10 meters relative to the transponder net. The uncertainty is primarily due to errors inherent in the system such as imprecise sound velocity information and instability of the transponder moorings. However, since these errors are relatively constant for a particular net, the precision of the system is quite good and a repeatability of 5 meters can be expected. The preferred baseline distance between transponders is approximately 1.5 times the site depth, and reliable fixes may generally be obtained at distances up to one baseline length away from any two transponders. The Alvin positions are given on XY coordinates relative to an XY origin, which for this cruise was located at 44° 34.0'N and 125° 10.0'W.

6.3 DIVE SUMMARIES

The location and specific objectives of each dive are summarized in Table 10. Details of objectives, dive logs, navigation information, samples collected and dive-specific maps for each dive are given in Appendix 1.

TABLE 10: Alvin Dives during cruise AT3-35B

Station	Dive	Location	Objectives
5	3421	HRS	Deploy SIOFM, and benthic chambers
8	3422	HRS	Survey area, deploy thermal blanket and recover benthic chambers
11	3423	HRN	Survey area, collect hydrates in clathrate bucket, sample
14	3424	HRS	Recover OSU lander, deploy benthic barrel, survey and sample
17	3425	HRN	Position SIOFM, survey and sample
21	3426	HRN	Deploy barrel, collect gas, sediments and organisms
25	3427	HRN	Deploy barrel, collect hydrates observe bubbling episodicity
28	3428	HRS	Deploy barrel, OSU lander and USC landers. Pick up thermal blanket and survey area
32	3429	HRS	Reposition SIOFM, recover landers survey Beaver mounds
37	3430	HRS	Reposition SIOFM, collect hydrates sediments and bacterial mats

6.4 MAPPING SUMMARY

6.4.1 Hydrate Ridge North (Mike Tryon, Thomas Naehr, Gerhard Bohrmann)

An area between approximately 44° 36' and 44° 42' N and 125° 06' and 125° 10' W, in the eastern and highest part of Hydrate Ridge North, was visited during five Alvin (Table 10, Appendix 1 and Figure 10A). Based on side scan sonar data (Figure 10B), observations during the dives, analysis of the dive video tapes, and Alvin navigation data, a morphological and geological map of the area was created Figure 10C). The dives generally characterize a southwestern region ("Chemoherm") which is dominated by massive, fractured carbonate outcrops with little to no sediment with infrequent seep indicators. North and northeast of here the area is a mix of carbonate pavement and rocky sediment cover with occasional patches of clams and bacterial mats. In the northeast of the survey area is a hill, dubbed "Champagne Hill", which is dominated by rocky outcrops and rubble with patches of rocky sediment with clams and/or microbial mats. The highpoint of this hill is the location of the "gusher" methane vent site. Extending SSW from the top of this hill is a lower, roughly linear ridge which marks the eastern boundary of the carbonates. The southeastern portion of the survey area is dominated by flat lying sediment cover with no indicators of seep activity.

In four transects, dive 3423 surveyed approximately 3000 m of ocean floor. The interpretation of live and video observations indicates areas of extensive carbonate cementation in the northeastern and western part of the surveyed area ("Champagne Hill" and "Chemoherm", respectively). The "Chemoherm" area in particular is characterized by several-meter thick massive carbonates with deep, bacterial-lined fractures and collapse structures. Between these two zones lies a NNE - SSW trending area marked by patches of chemosynthetic clams and bacterial mats. Carbonate cementation seems to be less extensive, however, when trying to take push cores, we frequently encountered firm sediments at shallow depth. The NNE – SSW alignment of chemosynthetic communities seems to indicate a structural control over the fluid flow in the surveyed area.

Dive 3425 concentrated on surveying the NNE - SSW trending ridge extending SSW from the bubble site. This ridge is characterized by linear outcrops of layered rock and linear zones of rocky sediment containing biological seep indicators. These outcrops had a typical strike of ~335° and dip of ~30-45°. The linear seep zones also were aligned ~335°. The southern portion of the ridge had more sediment cover than rocky outcrop, however the proportion of sediment cover steadily diminished northward, until there was essentially no sediment cover at the base of the rise up Champagne Hill. The hill is dominated by rocky outcrops with no discernible alignment. Patches of rocky sediment with clams and microbial mats are found primarily near the top of the hill. Overall the transect reveals a roughly linear "seep zone" which strikes 030° paralleling the ridge and passing through the southern instrument deployment site, the gusher, Clam 1-2, and Clam 3. Dives 3426 and 3427 were primarily concerned with local observations and instrument deployments, however they confirmed and refined the above observations.

6.4.2 Mapping: Hydrate Ridge South (Anne Trehu and Kevin Brown)

The Southern Hydrate Ridge Alvin Dive sites where chosen on the basis of the discovery of gas hydrates in a TV-guided grab sample (TVG-18) taken by R/V SONNE

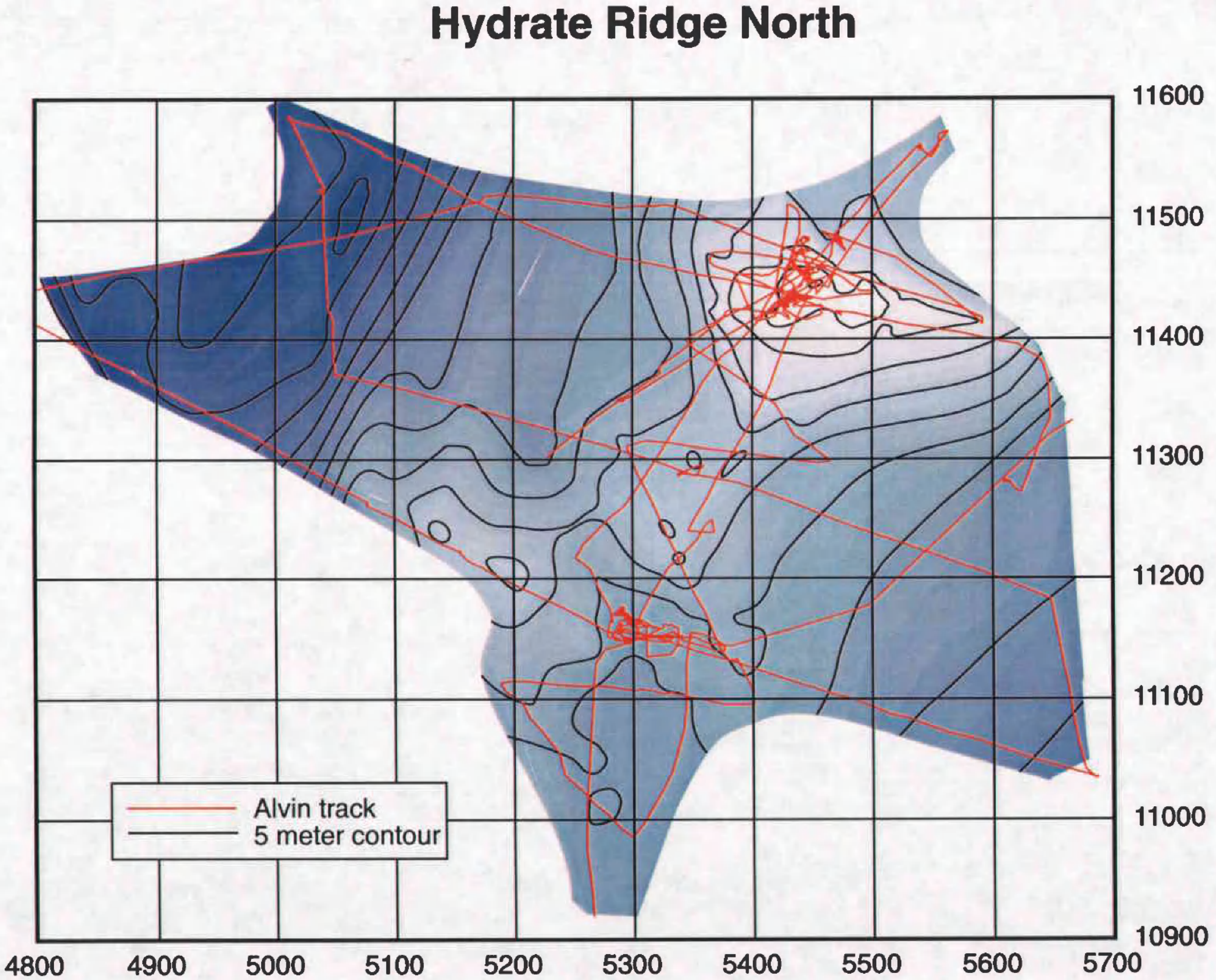


Figure 10A. Summary of Alvin dive tracks on Hydrate Ridge North on a bathymetric background

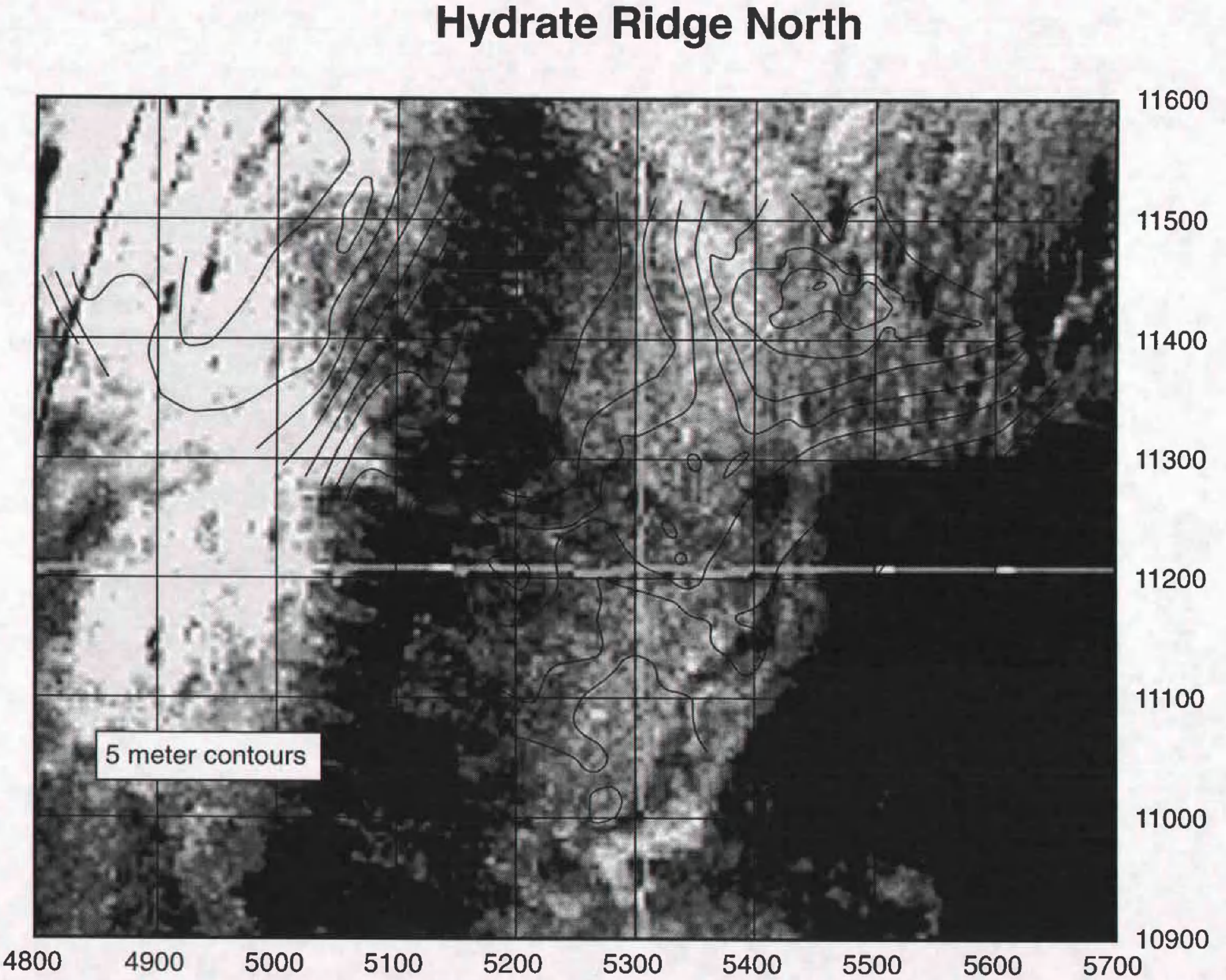


Figure 10B. Bathymetry of the Hydrate Ridge North area overlaid on a side-scan sonar image from Goldfinger et al. (unplublished data)

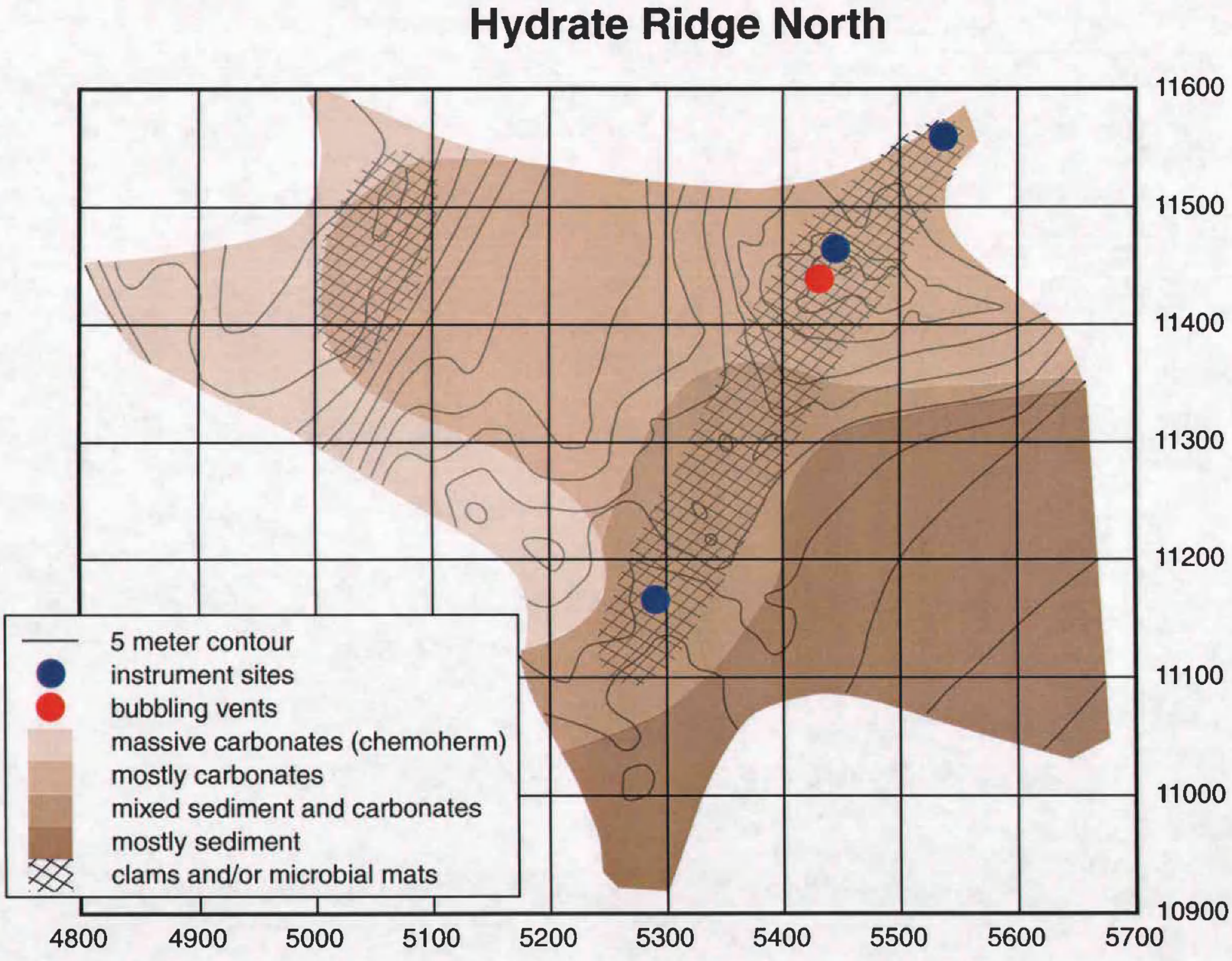


Figure 10C. Summary of bottom observations from Alvin dives on Hydrate Ridge North

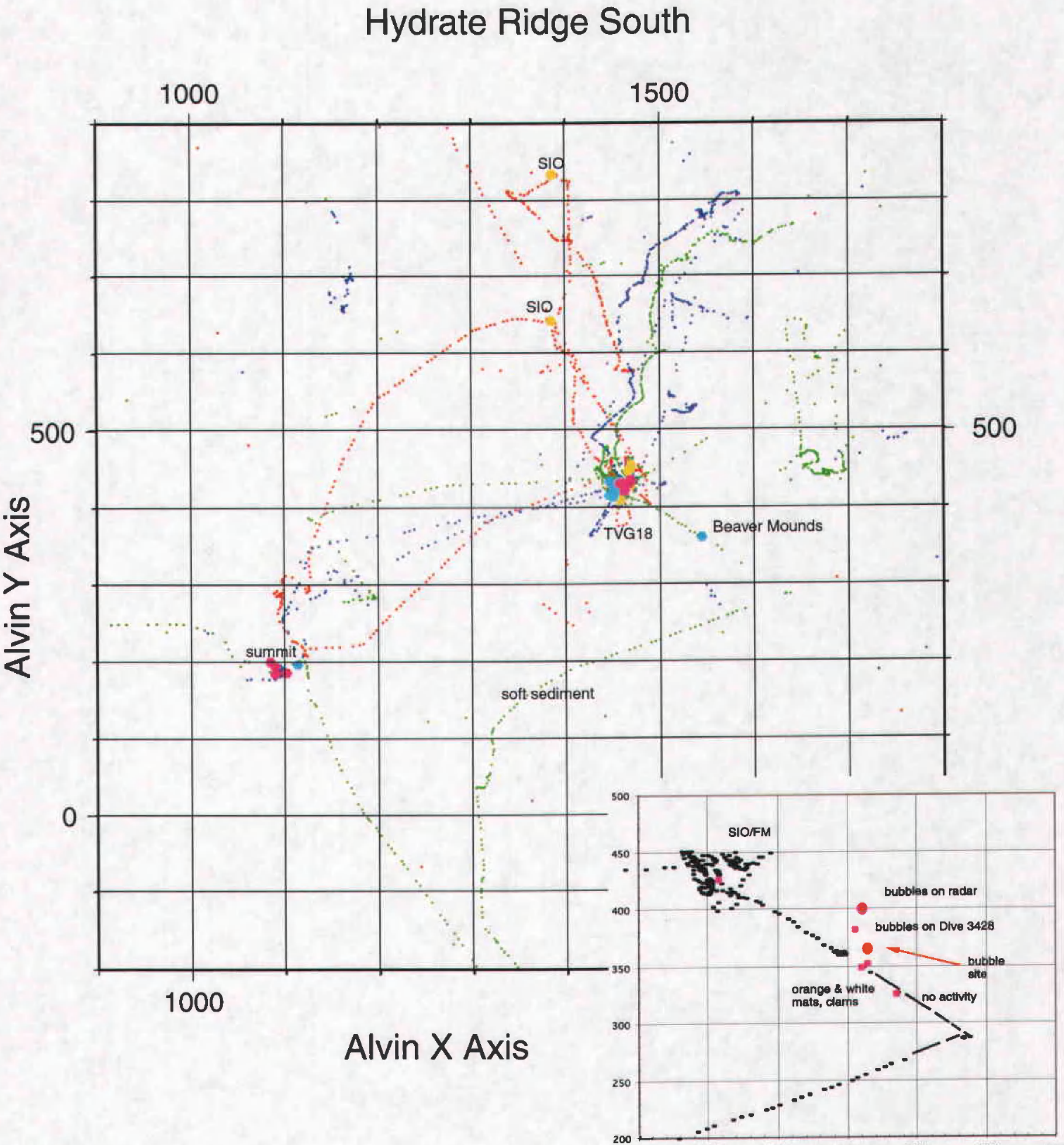


Figure 11: Location of the Alvin tracks during dives on Hydrate Ridge South, showing locations of near-surface hydrate (TVG-18), SIO flowmeters (SIO), the carbonate pinnacle (summit), and Beaver Mounds area. Insert shows location ofgas discharge sites on Beaver Mounds area.

in 1996. The shallow depth below seafloor and abundance of hydrates in the grab sample suggested that seepage of water and methane was extensive enough in this location to form hydrates close to the sediment water interface. A number of circular highly reflective regions up to ~700 m diameter were observed in the southern region within in the Side Scan Sonar data of Goldfinger (New Horizon Cruise June, 1999). The hydrate bearing region (TVG-18) lay in the partly reflective region just 400m to the NE of the center of one of largest of these in a region of moderate irregular reflectivity.

The 6 dives to the southern summit of Hydrate Ridge (Table 10, Figure 11, Appendix 1) reveal a very active venting system that has generated two very different environments. 1) A region of undulating topography (pit-ridge/mound morphology) and extensive seep communities encompassing the central summit region at depth < 775 m, that was named "Beaver Mounds"; and 2) A substantial carbonate chemoherm, represented by a tall pinnacle-like edifice which stands more than 50m above the surrounding seafloor. This structure, named "Pinnacle", likely represents an early stage in the development of the types of structures that presently cover the northern summit of Hydrate Ridge.

Beaver Mounds area: The region of pit-ridge/mound morphology and extensive seep communities occurred within the TVG-18 region stretching ~150m to the SE towards the summit of the local topographic high of the S. Hydrate Ridge. The surface of this region contains mud mounds and shallow depressions with carbonates that may well be locally paved or intercalated with hydrate and is unlike any other sea floor environment yet described. This region was found to vigorously emit streams of methane in at least 4 sites at one location and may represent a very early stage in the development of a sea floor vent system that precedes the development of massive carbonate formation.

This 700m diameter high reflectivity region was characterized at the surface by a predominately muddy bottom with scattered small carbonate blocks. The seep-related communities included abundant white bacterial mats and clam fields in the TVG-18 locality with increasing abundance of orange/red bacterial mats towards the summit of the southern ridge. The shallow depressions appeared to contain a concentric pattern of patches of bacterial mats in the center surrounded by extensive clam colonies; few large individual specimens of clams (2 species of *Calyptogena* sp.) seem to be present within the bacterial mats. Dead *Solemya* mussels (*Acharax* sp.) are present throughout the sea floor in all stages of disintegration as evident by their characteristic dark brown periostrucum which survives long after the carbonate has been dissolved. Probing of the bacterial mats released gas bubbles and samples of hydrate carbonate (bubble pseudomorphs and brecciated cemented mud clasts) were recovered in the uppermost sediment layers. Some Alvin push cores were also observed to degas vigorously on recovery. Vigorous active gas venting was discovered during the last dive in the summit region of the ridge. The active gas venting allowed hydrates to be produced at the sea floor and brought to the surface in the MBARI hydrate pressurized container (section 6.4.4).

Much of the main region of seepage was characterized by a low amplitude ridge/mound and shallow depression morphology. Diameters of these features varied from <1m up to ~10-15m and locally reached depths of up to several meters. The morphology of these mounds was initially described as resembling sand dunes. Later dives, however, indicated that these mounds were covered with a cracked and broken crust. When the Alvin touched this crust, large numbers of bubbles were released, leading to the conclusion that these crusts were formed, in large part, from hydrate, which is immediately underlies a thin layer of soft sediment and bacterial mats. It is conceivable that the hummocky topography is generated by floating up of hydrate slabs at irregular intervals. Such a process could be the result of continuously accreting of hydrate beneath bacterial mats and within the near-surface sediment layers until increasingly positive buoyancy lifts up the interlayered hydrate-carbonate-sediment mixture. Trapping of free methane bubbles within the hydrate structure, as has been observed in the TVG-18 material as well as artificially produced by catching a stream of methane, would greatly add to the positive buoyancy.

Pinnacle area: The central topographic high of the southern summit was revealed to be a dramatic 50 meter high constructional carbonate tower set in shallow topographic bowl. We named this feature the "Pinnacle." Topographic data collected during 6 dives indicate that the base of the Pinnacle has a diameter of 150 m at a depth of about 805-815 m. The sides increase in slope upwards to near vertical to form the edifice which rises to a depth of ~775 m. The top of the Pinnacle is approximately flat, with an area of ~50 m^2. The upper part of the Pinnacle is highly porous and appears to have been formed by precipitation of carbonate from fluids venting from the top of the structure, similar to the carbonate deposits found onshore in the tuffa towers of Mono Lake, California (Figure 12). Numerous bacterial mats and clam colonies in holes in the summit region suggest it is currently active. The lower slopes are covered with large talus blocks (several meters across), which decrease in size with distance from the main structure; they are derived from the tower. A series of long, remarkably prominent fissures, striking ~10-20°, break through the SSW and NNE flanks of this structure and are lined with clam beds, bacterial mats, and possibly hydrate deposits. More details on the approach to the tower, the nature and contents of the fissure, and the apparent layering of the deposits near the top of the are described in the individual dive logs (see Table 10 and Appendix 1).

In summary, relatively extensive submersible investigation of the S. Hydrate Ridge indicated that the summit region is hydrogeologically highly active with significant regions of seepage, seep related biological communities, local vigorous gas venting and chemoherm development. The hydrogeologically active region is delineated by a higher backscatter reflectivity in side scan images. There is also every indication that while hydrates are present close to the sediment surface, free methane gas is also present just beneath the sediment water interface trapped beneath bacterial mats.

6.5 BOTTOM SAMPLING

6.5.1 Authigenic carbonates (G. Bohrmann)

Authigenic carbonates are widely distributed at the sediment surface along the Cascadia continental slope and shelf (Kulm and Suess, 1990). These carbonate structures are prominent features associated with fluid venting, which is well known to occur in this area (Kulm et al., 1996). Recent studies have discovered a great variety of authigenic carbonates along the Cascadia Margin (Greinert, 1999) and have documented the large influence of gas hydrates on the formation of carbonates (Suess et al. 1999). Based on their mineralogical composition, structure and isotopic composition, a close connection between gas hydrates and the formation of carbonates (so-called „gas hydrate carbonates") has been established (Bohrmann et al., 1998).

During ATLANTIS cruise 3-35B, authigenic carbonates were recovered from several areas using ALVIN's manipulator arms. Other samples were found in push cores or in scoop samples and include a great variety of carbonate buildups, crusts, concretions, slabs, and irregular edifices. The samples will be investigated with regard to their microtexture, as well as their mineralogical, geochemical and isotopic composition at GEOMAR and OSU within the frame of the TECFLUX program. Dive numbers, sample locations, approximate sizes and brief descriptions are given in Table 11. Based on their shape, texture and structural context, the carbonates were separated into three distinct groups.

Group 1 includes diagenetic carbonates that are principally carbonate-cemented sediments and show a large variety of shapes. The gray to dark gray rocks are dominantly (>60%) composed of terrigenous sediment components, such as quartz, feldspar and clay minerals, which are cemented by micritic carbonate. Large amounts of these carbonates are exposed at the northern summit of Hydrate Ridge and were observed during ALVIN dives 3423, 3424, 3425 and 3426. Although only a few rock samples of that type were taken during dives 3423 and 3426, several group 1 carbonates were recovered from a number of multicorer stations in both areas of Hydrate Ridge.

Chemoherm carbonates **of group 2** were sampled at the newly discovered "pinnacle" on the upper western flank of the southern summit of Hydrate Ridge. This unusual morphologic structure seems to be predominately composed of carbonate. At the lower part of the pinnacle, polymict breccias were sampled, which are composed of angular clasts, shells of vent clams, and micritic debris. Between these components, pure aragonite crystals seem to form a rim cement that shows several generations of precipitation. During ALVIN dives 3422, 3424, 3428, and 3429 rocks from the topmost area of the chemoherm were sampled from a massive outcrop (Figure 12). These rocks are composed of very pure white carbonate, presumably aragonite, which seems to have precipitated from fluids originating from below. Active fluid flow on top of the „pinnacle", probably along a NNE - SSW trending fracture zone was observed during the dives. The outer shape of the rocks is very irregular and numerous open tubes seem to be part of a plumping system for fluid circulation on Hydrate Ridge South.

Carbonate **group 3** is represented by presumably gas hydrate-related carbonates and includes two different types. One type is characterized by a carbonate-cemented breccia composed of angular clasts. The clasts are Mg-calcite cemented, fine-grained sediment chips of variable sizes and occur in distinct layers. Detailed investigations of gas hydrate/ sediment intercalations from the southern summit of Hydrate Ridge have shown that this fabric is clearly related to the gas hydrate formation (Bohrmann et al. 1998). Unconsolidated layers of soft sediment act as a seal for free gas from below. Here, gas bubbles crystallize as gas hydrate, often forming bedding-parallel gas hydrate layers of up to 10 cm thickness. During this process sediment clasts form, which often float in a matrix of pure gas hydrate. During destabilization of the hydrate layers the clasts are

Table 11: Carbonate samples recovered by Alvin dives to Hydrate Ridge

ALVIN Dive #	Stat.#	specimen/ size	Description
3421 (HRS) Brown/Hammond	-1	1/s	1 cemented clam
3422 (HRS) Torres/Bohrmann	-3	2/m, .../s	carbonate slab/ sharp edges from a bacterial mat area/ gas hydrate breccia
	-10	2/s	push corer samples: cemented sediment and 2 clams
	-14	1/m	white carbonate broken from the rim of chemoherm chemohermcarbonate
3423 (HRN) Sahling/Nähr	-1	1/m	in clam box: carbonate with greyish coat of bacteria; rounded edges approx. 20 cm long
	-5	1/l	block of carbonate
3424 (HRS) Suess/de Angelis	-1	1/m	in box #1: rock with bacterial mat collected near the top of the spire
	-3	1/xxl	large rock: collected midway downslope from top of the spire
	-4	1/xl, 5/m	in box#2: rock broken off large rock at talus base of the carbonate spire
	-5	... /s	scoop sample: firm cemented sediment pieces
	-6	2/s	Push core : aragonite precipitates/pseudomorphs to gas hydrate bubbles
	-8	.../s	Push core : firm cemented sediment pieces
	-9	.../s	Push core : firm cemented sediment pieces
3425 (HRN) Tryon/Bruce			no samples
3426 (HRN) Torres/Winckler	-7		carbonate slab, from the gusher rim
	-13	..../s	push corer from a bacterial mat area:
3427 (HRN) Bohrm./Gottschall	-5	2/m	clam box: rock from the gusher site, covered by bacterial mats
	-7	..../s	push corer in clam field:
3428 (HRS) Trehu/Colbert	-6	2/xl, .../s	carbonate broken off from in-situ slab at top of the pinnacle
3429 (HRS) Klinkham./Phil	-1	1/m, .../s	hand-sized carbonate and smaller pieces from top of the chemoherm
	-2	1/xl	carbonate broken off from in-situ slab at top of the chemoherm
	-3	1/s	carbonate from a scoop sample (mud, clam and orange mat)
3430 (HRS) Suess/Moser			no samples
Carbonate samples		size: s=small, m=middle, l=large; xl=extra large	

Figure 20: Carbonate sample recovered from pinnacle structure on Hydrate Ridge South

being deposited and cemented forming the observed brecciated layers. Numerous such breccias were recovered from the southern summit of Hydrate Ridge during ALVIN dive 3422. A second type of gas hydrate related carbonates are pure aragonite layers, which precipitate within gas hydrate layers. One sample from a push core taken during ALVIN dive 3424 in fact seems to be a pseudomorph after the bubble-shaped pores of gas hydrate, indicating the latter mechanism of formation.

6.4.2 Alvin push cores (M. Torres)

We collected Alvin and USC push cores for pore water analysis, foraminifer and biology studies, as described in the sections below. Detail descriptions of the collection sitesand sampling scheme are included in each dive summary (Appendix 1).

Pore water analysis (McManus). Alvin push cores were contained high concentrations of methane, sufficient to cause bubble formation during recovery and extensive degassing. Because of the stratigraphic disruption and influence on dissolved gas distribution caused by this de-gassing, none of these were processed for WCS extraction of pore waters. Samples for pore water analysis were obtained by centrifugation only, as described in section 5.2.1. Results of these analyses are summarized in Table 12.

Biology (H. Sahling). The main objective of the biological investigation was the collection of animals for taxonomic, isotopic, and chemical studies. The biological characterization of different areas within the chemoautotrophic communities was used to determine and sample different geochemical provinces. Most obvious indication of venting, beside the massive appearance of authigenic carbonates, is the occurrence of Vesicomyid clams (*Calyptogena* sp., *Vesicomya* sp.) and bacterial mats. The nutrition of the symbiontic clams in this area is based on the oxidation of hydrogen sulfide, the bacterial mats are not well characterized yet.

Samples have been taken qualitatively by removing epilithic animals from rock samples or collections made by Alvin's shuffle, scoop or claw. Quantitative samples have been taken with push cores. All organisms have been preserved adequately in formaldehyde, ethanol, or have been frozen and will be analyzed at GEOMAR. Special attention has been paid to cores from areas with clams or bacterial mats. In combination with the sampling scheme for methane and porewater, macrofauna was hand selected from the surface of the sediments and/or the very few first millimeters of the sediment were collected as a bulk and preserved for further studies. In combination with the field notes of the observers, the videos, and the abundances of organisms we should be able to correlate the macrofauna with characteristic geochemical settings.

Foraminifer sampling (K. Kinports). A total of 6 push cores were used in sampling for microscopic foraminifera (Appendix 1 and Table 13). This accounts for 5 of the Alvin dives during this cruise, two cores were sampled from the first dive.. Aside from the first three Alvin cores used in this data each core was sliced up into 1/2cm intervals for the first

Dive: 5 AD 3421
Date: 7/2/99

Sample No.	No.	Push Core	Position	Foraminifera	Porewater	McManus Label	Methan	Methanoxidation	Macrofauna	Radon	Length	sample site	description	comments
	1	USC	port mid	x				x	x		17 cm	within bacterial mat, site 1	many gas bubbles in sediment	
	2	USC	port aft						x	x		within bacterial mat, site 1	many gas bubbles in sediment	1/4 of 0-6 cm for Radon
	3	APC	port forward		x	CA			x			within bacterial mat, site 1	many gas bubbles in sediment	
	4	USC	stb. aft						x			just off the bacterial mat, site 2	few gas bubbles, living clams	
	5	USC	stb. mid	x							20 cm	within bacterial mat, site 2	many gas bubbles in sediment	
	6	APC	stb. forward		x	CB						within bacterial mat, site 2	many gas bubbles in sediment	

Alvin Push Core APC: 6.5 cm inner diameter
UCS Push Core: 9.6 cm inner diameter

8 AD 3422

Dive: 8 AD 3422
Date: 7/3/99

Sample No.	No.	Push Core	Position	Foraminifera	Porewater	McManus Label	Methan	Methanoxidation	Macrofauna	Radon	Length	sample site	description	comments
7	1	APC	port front		x	CB						clam-rich area, site 1	with clams	
6	2	USC	port mid	x							12 cm	clam-rich area, site 1	without overlaying water	
5	3	USC	port aft				x		x			clam-rich area, site 1		
8	4	USC	stb. mid						x			outsite clam area	with gas in sediment, without overlaying water	
10	5	APC	stb. front						x			outsite clam area	with gas in sediment, disturbed sediment	
9	6	USC	stb. aft		x	CA	x		x			outsite clam area	with gas in sediment	

Alvin Push Core APC: 6.5 cm inner diameter
UCS Push Core: 9.6 cm inner diameter

Dive: 11 AD 3423
Date: 7/4/99

Sample No.	No.	Push Core	Position	Foraminifera	Porewater	McManus Label	Methan	Methanoxidation	Macrofauna	Radon	Length	sample site	description	comments
3	1	APC	aft	x								in clam field	without overlaying water	
2	2	APC	mid		x	CB	x		x			in clam field	clams	
7	3	APC	fron		x	CA						within sea urchin aggregation, 10 m outsite clamfield		

Alvin Push Core APC: 6.5 cm inner diameter
UCS Push Core: 9.6 cm inner diameter

Dive: 14 AD 3424
Date: 7/5/99

Sample No.	No.	Push Core	Position	Foraminifera	Porewater	McManus Label	Methan	Methanoxidation	Macrofauna	Radon	Length	sample site	description	comments
	1	USC	front	x								within bacterial mat, next to bare zone		
	2	USC	2nd front				x		x			within bacterial mat, on other side of barrel, compared to No. 3	homogenes gray-green sediment, white bacterial filaments on surface, very few bubbles in sediment	
	3	USC	2nd aft		x	CA						within bacterial mat, near benthic barrel		
	4	USC	furthest aft		x	CB			x			at rim of bacterial mat, near (in) clam field	gas in sediment from 10 cm down, slightly decreasing with depth, clams on top	

Alvin Push Core APC: 6.5 cm inner diameter
UCS Push Core: 9.6 cm inner diameter

Push Core summary

Dive: 16 AD 3425
Date: 7/6/99

Sample No.	No.	Push Core	Position	Foraminifera	Porewater	McManus Label	Methan	Methanoxidation	Macrofauna	Radon	Length	sample site	description
recovered marked clams but lost at surface													
no pushcores													

UCS Push Core: 9.6 cm inner diameter
Alvin Push Core APC: 6.5 cm inner diameter

Push Core summary

Dive: 21 AD 3426
Date: 7/7/99

Sample No.	No.	type	Position	Foraminifera	Porewater	McManus Label	Methan	Methanoxidation	Macrofauna	Radon	Length	sample site	description	comments
13		UCS	port		x				x			in bacterial mat, 3 m from barrel	bacterial mat on top	
14		UCS	2nd port						x			used as grab to get carbonates and bacteria	some carbonates and bacteria	

Alvin Push Core APC: 6.5 cm inner diameter
UCS Push Core: 9.6 cm inner diameter

Push Core summary

Dive: 25 AD 3427
Date: ###

Sample No.	No.	Type	Position	Foraminifera	Porewater	McManus Label	Methan	Methanoxidation	Macrofauna	Radon	Length	x	y	z	sample site	description	comments
7		MBARI Push Core	in Hydrate sampler									5447	11539	593	clam area (clam 1 in 1998)	no hydrate/gas, sediment sliped out of tube	

Alvin Push Core APC: 6.5 cm inner diameter
UCS Push Core: 9.6 cm inner diameter

Push Core summary

Dive: 28 AD 3428
Date: ###

Sample No.	No.	Typ	Position	Foraminifera	Porewater	McManus Label	Methan	Methanoxidation	Macrofauna	Radon	Length	x	y	z	sample site	description	comments
		no push cores															

Alvin Push Core APC: 6.5 cm inner diameter
UCS Push Core: 9.6 cm inner diameter

Push Core summary

Dive: 32 AD 3429
Date: ###

Sample No.	No.	Push Core	Position	Foraminifera	Porewater	McManus Label	Methan	Methanoxidation	Macrofauna	Radon	Length	sample site	description	comments
5	1	MBARI-core	hydrate sampler						x			on top of a beaver mount (?)	no significant amount of gas, core felt off the tube when opened, no living macrofauna found	

Alvin Push Core APC: 6.5 cm inner diameter
UCS Push Core: 9.6 cm inner diameter

Push Core summary

Dive: 37 AD 3430
Date: ###

Sample No.	No.	Push Core	Position	Foraminifera	Porewater	McManus Label	Methan	Methanoxidation	Macrofauna	Radon	Length	sample site	description	comments
6		MBARI-core	hydrate sampler									after making gashydrate over the methane bubble site, not recovered		
7		MBARI-core	hydrate sampler									after making gashydrate over the methane bubble site	significant amounts of gas, many subsamples taken	
10	1	USC	port front	x			x					in bacterial mat		
11	2	USC	stb. front		x	CA						in bacterial mat		
12	3	APC	stb. aft				x					for clam collection in clam site		
13	4	APC	port aft									for clam collection in clam site	strongly disturbed	

Alvin Push Core APC: 6.5 cm inner diameter
UCS Push Core: 9.6 cm inner diameter

Table 12: Pore water data obtained from centrifuged samples of Alvin push cores

AT99006-05AD3421-CA

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl	H2S	PO4	Silicate
		cc	cm	cm	mM		mM	uM	mM	uM		
	overlying		0.00	0.00	3.093	7.62	3.01	36.52	545	240	6.22	103.32
1	1	50	1.51	0.75	16.165	8.07	15.8	64.58	555	3374	93.75	334.84
2,3	2	100	4.52	3.01	32.814	8.08	30.4	82.27	564	10811	31.69	319.15
4,5	3	100	7.53	6.02	37.101	8.13	33.7	75.37	562	11004	28.91	309.11
6,7,8	4	150	12.05	9.79	40.542	7.99	37.1	61.55	566	12959	24.68	290.59
9,10,11	5	150	16.57	14.31	37.733	7.94	32.9	81.84	565	9959	14.45	281.97

AT99006-05AD3421-CB

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl	H2S	PO4	Silicate
		cc	cm	cm	mM		mM	uM	mM	uM		
	overlying		0.00	0.00	3.827	7.58	3.300	48.6	545	281	6.66	113.68
1,2	1	50	1.51	0.75	21.952	7.98	20.60	50.76	556	6261	25.97	297.2
3,4	2	100	4.52	3.01	30.388	7.77	28.29	67.6	565	10209	21.29	308.36
5,6	3	100	7.53	6.02	36.335	7.74	33.08	94.79	563	13936	16.49	288.42
7,8	4	150	12.05	9.79	38.381	7.73	35.36	97.38	567	13482	13.67	291.1
9,10,11	5	150	16.57	14.31	39.223	7.69	35.56	100.4	565	15368	14.78	285.29

AT99006-08AD3422-CA

Tube#	Sample#	vol of mud	Depth int	Depth	ΣCO2	pH	Alk	NH4	Cl		PO4	Silicate
		cc	cm	cm	mM		mM	uM	mM			
	overlying			0.00			2.38	2.48	444		0.69	26.53
	1		0 - 2	1.00			4.4	17.26	546		20.96	299.12
	2		2 - 4	3.00			6.58	28.78	547		20.53	332.89
	3		4 - 6	5.00			12.8	20.96	554		16.95	293.16
	4		6 - 8	7.00			14.5	18.78	555		15.49	280.29
	5		8 - 10	9.00			14.5	21.17	554		12.76	250.46
	6		10 - 12	11.00			11.9	20.96	555		11.39	233.34
	7		12 - 14	13.00			14.5	29.87	554		11.96	230.36
	8		14 - 16	15.00			14.7	28.13	554		11.31	225.97
	9		16 - 18	17.00			14.3	23.78	555		1.93	208.85
	10		18 - 20	19.00			18.8	49.22	555		12.08	227.07
	11		20 - 22	21.00			18.1	44	552		10.89	214.2
	12		22 - 24	23.00			19.9	30.3	555		12.85	247.97

AT99006-08AD3422-CB

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl	H2S	PO4	Silicate
		cc	cm	cm	mM		mM	uM	mM	uM		
	overlying		0.00	0.00	2.373	7.54	2.44	20.52	506	11.91	1.430	75.18
1	1	50	1.51	0.75	2.666	7.56	2.77	7.7	553	0.25	7.370	202.89
2,3	2	100	4.52	3.01	2.762	7.67	2.67	10.74	552	31.05	9.510	180.22
4,5	3	100	7.53	6.02	3.557	7.72	3.55	28.51	554	91.48	9.510	177.41
6,7	4	100	10.54	9.04	5.889	8.00	5.86	33.57	556	272.15	8.660	183.11
8,9	5	100	13.55	12.05	10.616	7.88	10.3	21.61	552	240.29	10.840	195.92
10,11,12	6	150	18.07	15.81	18.985	7.91	16.2	26.39	557	205.84	10.800	187.43

AT99006-11AD3423-CA

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl	H2S	PO4	Silicate
		cc	cm	cm	mM		mM	uM	mM	uM		
	overlying		0.00	0.00	2.358	7.52	2.328	1.32	543	0.44	2.810	95.15
1,2	1	100	3.01	1.51	2.664	7.23	2.731	9.11	542	0.44	7.040	154.83
3,4,5,6	2	200	9.04	6.02			2.869	12.56	538	0.75	6.19	163.37
7,8,9,10	3	200	15.06	12.05			8.90	46.23	541	66	4.23	194.66

AT99006-11AD3423-CB

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl	H2S	Phosphate	silicate
		cc	cm	cm	mM		mM	uM	mM	uM		
	overlying		0.00	0.00			2.348	1.53	528	43	2.32	107.76
1	1	50	1.51	0.75			2.869	39.52	537	43	7.61	162.75
2	2	50	3.01	2.26			6.327	82.06	540	986	11.67	175.34
3	3	50	4.52	3.77			10.89	48.82	541	2687	7.65	190.74
4	4	50	6.02	5.27			13.46	41.05	542	3517	5.7	196.26
5	5	50	7.53	6.78			17.07	40.19	541	4593	5.84	203.18
6	6	50	9.04	8.28			23.53	55.26	541	3790	8.5	234.15

AT99006-14AD3424-CA

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl!	H2S	PO4	Silicate	NOTES
		cc	cm	cm	mM		mM	uM	mM	uM			
	overlying		0.00	0.00	1.812	8.14	6.942	11.55	448	130	0.51	20.9	1. TCO2 data with trap
1	1	50	0.71	0.35	6.951	8.42	9.038	34.43	503	0	CS	297.08	2.large diameter push core
2	2	50	1.41	1.06	11.628	8.26	15.8	28.19	525	2357	119.92	333.27	
3	3	50	2.12	1.76	14.210	8.21	22.3	100.96	556	5532	36.93	354.34	

4,5	4	100	3.53	2.82	16.393	8.14	27.1	100.07	560	8728	20.78	361.27	3. OS indicates off scale
6,7	5	100	4.94	4.23	18.484	7.96	31.6	165.12	560	7429	20.64	351.23	
8,9	6	100	6.35	5.65	18.980	7.91	33.4	134.65	557	11202	24.58	345.44	
10,11	7	100	7.76	7.06	19.989	8	36	141.71	560	12790	26.19	359.44	
12	8	50	8.47	8.12			37.2	142.59	561	14130	27.84	376.27	

AT99006-14AD3424-CB

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl!	H2S	PO4	Silicate
		cc	cm	cm	mM		mM	uM	mM	uM		
	1	100	1.41	0.71	15.036	7.74	14.8	48.39	537	5449	13.06	206.28
	2	100	2.82	2.12	24.217	7.83	23.32	64.43	541	8233	9.83	225.94
	3	100	4.23	3.53	27.114	7.88	26.26	76.9	546	8357	13.68	238.52
	4	100	5.65	4.94	26.696	8.15	26.13	98.88	548	9738	13.45	232.73
	5	100	7.06	6.35	26.931	7.8	26.59	111.65	548	10522	14.21	238.24
	6	100	8.47	7.76	29.262	7.82	28.56	94.94	548	10295	8.12	238.1
	7	150	10.59	9.53	33.846	7.85	32.98	139.57	548	13161	12.05	247.86
	8	150	12.70	11.65	38.598	7.79	36.74	139.06	552	14470	13.39	260.45

AT99006-21AD3426-CA

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl!		PO4	Silicate
		cc	cm	cm	mM		mM	uM	mM			
	overlying		0.00	0.00	2.042	7.82	2.11	0.36	493		0.11	49.89
	1	50	0.71	0.35	2.588	7.54	2.501	17	531		7.06	217.98
	2	100	2.12	1.41	2.722	7.57	2.755	28.62	541		7.94	230.55
	3	100	3.53	2.82	2.766	7.51	2.853	36.58	543		6.62	209.18
	4	100	4.94	4.23	2.709	7.64	2.833	41.91	542		2.65	170.85
	5	100	6.35	5.65	2.682	7.59	2.853	40.32	543		1.29	146.66
	6	100	7.76	7.06	2.684	7.54	2.813	40.32	545		1.05	142.26
	7	50	8.47	8.12	2.695		2.95	41.22	542		1.17	142.1
	8	100	9.88	9.17	2.687	7.67	2.892	42.36	544		1.19	136.29
	9	100	11.29	10.59	2.798	7.7	2.794	38.08	545		1.27	137.54
	10	100	12.70	12.00	2.802	7.6	2.921	44.01	544		1.07	144.46

AT99006-32AD3429-CA

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl!	H2S	PO4	Silicate
		cc	cm	cm	mM		mM	uM	mM	uM		
	OW						2.592	8.07	534	5301	2.18	109.58
	1	100	3.01	1.51	14.199	7.81	13.91	29.91	543	12170	16.47	229.62
	2	100	6.02	4.52	28.300	7.87	25.69	116.82	548	12350	17.77	213.93
	3	100	9.04	7.53	25.182	7.86	23.35	83.07	553	10593	21.1	233.58
	4	100	12.05	10.54	34.499	7.85	32.92	128.47	555	14001	22.13	282.93
	5	100	15.06	13.55	40.152	7.92	36.55	166.41	560	18630	22.93	240.37
	6	100	18.07	16.57	38.870	7.85	35.838	184.94	559	18144	21.44	221.84

AT99006-37AD3430-CA

Tube#	Sample#	vol of mud	ΣDepth	Depth	ΣCO2	pH	Alk	NH4	Cl!	H2S	PO4	Silicate
		cc	cm	cm	mM		mM	uM	mM	uM		
	overlying		0.00	0.00	2.177	7.55	2.141	5.43	482	61	0.17	38.37
	1	100	1.41	0.71	4.612	7.67	4.679	33	533	515	18.95	208.94
	2	100	2.82	2.12	6.680	7.64	6.814	26.82	539	1804	16.09	201.86
	3	100	4.23	3.53	11.961	7.74	11.59	20.65	550	4066	13.01	201.9
	4	100	5.65	4.94	17.709	7.68	16.53	28.559	550	7283	11.36	194.82
	5	100	7.06	6.35	24.904	7.68	2.341	61.24	550	10691	12.38	221.88
	6	100	8.47	7.76	31.520	7.74	30.16	126.97	557	12750	15.54	241.83
	7	100	9.88	9.17	32.469	7.76	30.19	111.31	555	13324	15.19	236.18
	8	100	11.29	10.59	34.955	7.74	33.07	84.35	555	16393	18.48	246.18
	9	100	12.70	12.00	35.483	7.75	33.39	114.35	557	16929	17.95	243.37

Table 13. Summary of foraminifera sampling in Alvin push cores

AT 9906-5dive#3421-APC-1

Date: July 2-99
Core Diameter: 9.5cm
Number of Samples: 15
Sample Depths: 0-12cm at 1cm intervals
12-16cm at 2cm intervals
16-17cm

Notes:
Sampled 1 live Calyptogena /Bivalvia, 6 live Provanna/Sastropoda, 1 Bivalve-shell, 1 carbonate piece. Large calcium carbonates present.

AT 9906-5dive#3421-APC-5

Date: July 2-99
Core Diameter: 9.5cm
Number of Samples: 16
Sample Depths: 0-12cm at 1cm intervals
12-20cm at 2cm intervals

Notes:
Large carbonates present in this sample.

AT 9906-8dive#3422-APC-2

Date: July 3-99
Core Diameter: 9.5cm
Number of Samples: 12
Sample Depths: 0-12cm at 1cm intervals

Notes:
Originally core was waterless when placed into cold room. Also had real problems with piston, it didn't fit and could have disturbed sample. One clam and several carbonates present.

AT 9906-11dive#3423-APC-1

Date: July 4-99
Core Diameter: 6.5cm
Number of Samples: 18
Sample Depths: 0-6cm at 1/2cm intervals
6-12cm at 1cm intervals

Notes:
Water drained from core when Alvin came up. 3 big clams on top and 1 live snail. Parts of the mud on one side was hard, looked like solidified clay that could be crushed with pressure.

AT 9906-14dive#3423-APC-1

Date: July 5-99
Core Diameter: 9.5cm

Notes:
Lost entire core due to loosened plug.

AT 9906-37dive#3430-APC-1

Date: July 11-99
Core Diameter: 9.5cm
Number of Samples: 15
Sample Depths: 0-6cm at 1/2cm intervals
6-9cm at 1cm intervals

Notes:
Shared core with Katja and Marie. Core was very rocky and had a strong H_2S smell.

6cm and then at 1cm intervals from 6-12cm. A piston and measuring rings aided in this process. No samples were taken after 12cm. From each slice the sediment was placed into 125ml nalgene bottles and labeled with coring site and depth from core. After all samples were taken formalin containing Rose Bengal was added, about a half an inch per bottle, to preserve and stain the live forams. Each bottle was then stored in the cold room waiting to be analyzed at OSU.

6.4.3 Bottom water samples

Two to four (1.7 l) Niskin bottles were mounted on Alvin, aft of the sampling basket, with the purpose of sampling bottom water at the seep sites. Data from these samples are listed in Table 14.

Table 14: Analysis of water samples collected by Niskin bottles during Alvin dives

Sample ID		ΣCO_2	O_2	CH_4	NH_4	H_2S	Notes
		mM	ml/l	ppm	uM	uM	
5AD3421-1	(5)		0.33	52		0.00	HRS, over clam field
5AD3421-2	(2)	2.416	0.36	1158	0.30	0.00	HRS, over bact mat, UCS blue station
5AD3421-3	(1)	2.409	0.37	4039	0.30	0.00	over bact mat, after coring
8AD3422-1	(1)	2.420	0.39	58	1.39	0.00	TVG 18 area, 5 meters above seafloor
8AD3422-2	(2)	2.416	0.31	38	0.30	0.00	right over Jim's chamber, undisturbed sed
8AD3422-3	(3)	2.407	0.340	113	0.74	0.00	over bact mat, undisturbed bottom
8AD3422-4	(5)	2.410	0.39	1606	1.61	0.00	HRS, over live clams, TVG18 area
11AD3423-1	(1)	2.383	0.16	285	1.83	0.00	HRN, over bact mat, 2 m from core 2&3
11AD3423-2	(3)	2.332	0.17	173	2.26		over large clam area
		with trap					
21AD3426-1	(2)	2.392	0.49	124	0.00	0.17	2 or 3 m from bubbling hole
21AD3426-2	(1)	2.390	0.49	179	0.00	0.07	3 m above bottom, ref site
21AD3426-3	(3)	2.399	0.54	95	0.00	0.07	HRN, over meters area
21AD3426-4	(5)	2.397	0.59	99	0.00	0.12	over meter and barrel site, before deployment
25AD3427-1	(1)	2.405	0.48	801	0.00	0.27	Close to marker 6, gusher site, low bubbling
25AD3427-2	(2)	2.414	0.43	>17000	0.00	0.27	At marker 6, gusher, highest activity
25AD3427-3	(3)	2.406	0.41	847	0.00	0.12	Barrel station, after retrieval
25AD3427-4	(5)	2.409	0.44	210	0.00	0.17	at barrel station, before deployment
32AD3429-1	(1)	2.409	0.31	3140	1.07	1.07	Beaver mounds, after coring. 771m
32AD3429-2	(2)	2.455	0.30	14722	0.00	0.00	774m
32AD3429-3	(3)	2.397	0.26	10621	0.00	0.00	772.00
32AD3429-4	(5)	2.435	0.31	leaky bottle	0.00	0.00	770.00
37AD3430-1	(1)	2.441	0.36	230717	2.12	2.12	gas vents, high activity
37AD3430-2	(2)	2.437	0.39	7482	0.13	0.13	gas vents ,beaver mounds, fast hydrate growth

6.4.4 Clathrate bucket (T. Naher)

The "Clathrate Bucket", which was designed at the Monterey Bay Aquarium Research Institute (MBARI), was deployed during Alvin dives 3423, 3427, 3429, and 3430. It consists of an aluminum casing with a hydraulically operated lid, which can be closed under water using Alvin's hydraulic system. A sample inside the bucket can be brought to the surface under *in situ* pressure conditions from water depths up to 1000 m. A polycarbonate housing around the pressure casing encloses a volume of sea water, which provides relative temperature constancy during ascend. The system is designed for the recovery of gas hydrates under *in situ* pressure and temperature conditions, preventing partial or complete decomposition of the hydrate sample during the slow ascend of submarines or remotely operated vehicles.

Samples were brought back to the surface from dives 3427, 3429, and 3430. Samples from dives 3427 and 3429 contained no gas hydrate, however, during dive 3430 approximately 230 cm^3 of gas hydrate were precipitated from a gas vent using a push core and put in the clathrate bucket. Back on the surface, the internal pressure of the bucket was close to 1000 psi (67.5 bar), which was about 200 psi less than the *in situ* pressure at the sampling depth of 800 m below sea level. On board, pressure was released as quickly as possible and about 8 liters of gas were collected. When the bucket was opened up, the hydrate sample had already completely decomposed and no hydrate could be collected. However, video observations during the dive and the volume of the evolved gas, which exceeded the expected volume if the water in the bucket would have been saturated with methane, prove the initial presence of gas hydrate in the sample container. Preliminary shipboard analysis indicates that the gas is predominately methane. Operation of the tool was smooth, however the difference between *in situ* pressure and internal pressure of the bucket when brought back on board indicates a problem with the accumulator system, which should provide pressure compensation for the volume increase due to material expansion during ascend.

Gas analysis (Hammond): On 7/11/99, hydrate was made in a small tube by trapping gas flowing from a gas seep. It was sealed in the MBARI pressurized vessel (bomb) and returned to the ship. As pressure was released, the gas volume was measured and aliquots were collected. The initial pressure was about 850 psi, and a total of about 8±1 liter of gas was evolved. Methane analyses showed the gas to be nearly pure methane. Rn/CH_4 ratios were 5-6 times smaller than in the in situ gas samples obtained directly. This is attributed to the greater solubility (about 7x) of Rn in the water as gas evolved from the sampler during depressurization. However, fractionation during hydrate formation may have also played a role. Aliquots were also taken for rare gases (bags #80, #6, #159).

6.4.5 Benthic Barrel (OSU)

The OSU benthic barrel (Fig. 13) is a cylindrical chamber with a large opening at the bottom and a small opening at the top. The barrel is designed to sample sites that have active fluid flow, by placing the barrel over a vent site thereby channeling the effluent from the seafloor into a semiclosed environment. The bottom of the barrel is open and can be pushed into the sediments to assure a seal over the vent sites. The barrel encloses 0.26 m^2 of the bottom surface area and has an internal displaceable


Figure 13. OSU benthic barrel deployed on HRN

volume of 180 l. The internal volume of the barrel is initially flooded with ambient seawater and is slowly replaced by venting fluids. Six Niskin water bottles (2 L) are mounted vertically around a cylindrical polycarbonate frame, and they are tripped sequentially by a motor located in the center of the frame. Changes in the concentration of dissolved components in the sequentially timed water samples are then used to calculate their flux rates (Carson et al., 1990). The exhaust port at the top of the chamber is designed to accept a thermistor flowmeter. A complete description of this instrument and its operation can be found in Linke et al., 1994.

Results: Analysis of water samples from the Niskin bottles inside the barrel are summarized in Table 15, and discussed in the following sections.

CH4 analysis (Heeschen, Torres) Samples for methane analysis were taken from each of the Niskin bottles and the analysis was conducted as described in section 4.3.1. Changes in methane concentration with time (Figure 14) can be used to calculate methane fluxes during the barrel deployments. The two deployments at HRN (AD3426 and 3427), show extreme changes on methane flux. Whereas the methane flux estimated from the barrel deployed on a bacterial mat, south of the Gusher (AD3426) gives values as high as 14 mol/m^2 day, the deployment on the clam fields northwest of the Gusher (Clam 1) show no positive methane flux at this site. Data collected by two SIO Fluxmeters at the Clam 1 location during Tecflux 98, show the fluid flow to be negative, i.e. into the sediments, at this site during the 30 day deployment period (Tryon et al., 1999). Such downflow episodes are consistent with the barrel data obtained on Clam 1 during AT3-35B (AD3427). The barrel data clearly document the extreme variability of methane fluxes at the northern site.

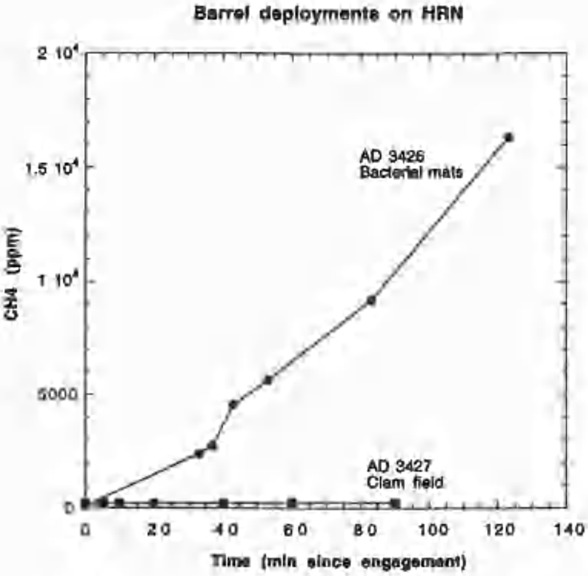


Figure 14: Methane release measured in two separate deployments of the benthic barrel at HRN, illustrating the large variability of methane flux rates at these sites.

Table 15: Analysis of samples from barrel deployments

Deployment 14-AD3424, on HRS **(X=1462; Y= 429; Z=777)**
Barrel was deployed on a thick bacterial mat partly upslope and inside.
a large depression (2 to 4 m diameter, 777 m depth)

Bottle# Deployment	Time	Oxygen ml/l	ΣCO2 mM	pH	Alk mM	NH4 uM	Cl mM	CH4 ppm	H2S uM	PO4 uM	silicate uM	nitrate uM
	10:28											
1	10:33	1.449	2.383	7.45	2.38	0.86		28262.8	12.4	3.3	119.2	43.02
2	10:43	1.118		7.43	2.38	0.00	538	42096.8	19.2			
3	10:53	1.409	2.438		2.37	0.00		43769.8	18.1	3.22	119.7	42.56
4	11:13	0.878	2.445	7.42	2.36	0.00	537		22.1	3.26	119.2	42.09
5	11:28		2.436	7.46			539	45300.4	19.7	3.19	119.2	41.86
6	11:58	0.847	2.439	7.43			535	37275.3	16.8			

Deployment 21-AD3426, on HRN **(X=5297; Y=11166; Z=599)**
Barrel was deployed on a thick bacterial mat next to
SIO flowmeter "C", at 599 m, about 250m south of The Gusher

Bottle Deployment	Time	Oxygen ml/l	ΣCO2 mM	pH	Alk mM	NH4 uM	Cl mM	CH4 ppm	H2S uM	PO4 uM	silicate uM	nitrate uM
	9:30											
1	10:23:47	1.142	2.443	7.13	2.315	nd	540	2389	0.53	3.06	101.4	42.25
2	10:27:14	1.139	2.423	7.29	2.305	nd	544	2761	0.27	3.02	101.4	42.14
3	10:33:59	1.113	2.418	7.22	2.325	nd	541	4552	0.22	3.05	101.7	42.37
4	10:44:20	0.970	2.424	7.21	2.364	nd	538	5646	0.27	3.08	101.7	42.37
5	11:13:53	1.044	2.423	7.26	2.345	nd	538	9175	0.48	2.98	101.7	41.44
6	11:53:38	1.007	2.428	7.14	2.354	nd	538	16318	0.69	3.09	101.7	42.2

Deployment 25-AD3427, on HRN **(X=5447; Y=11483; Z=593)**
Barrel was deployed on a clam field (Clam 1), an area
where SIO FM were deployed in TFX 98

Bottle#	Time	Oxygen (ml/l)	ΣCO2 mM	pH	Alk meq/l	NH4 uM	Cl mM	CH4 ppm	H2S uM	PO4 uM	silicate uM	nitrate uM
Deployed	12:50											
1	13:22:50	0.750	2.400	7.44	2.289	0.47	540	206	0.32	3.23	101.2	43.04
2	13:32:52	0.734	2.411	7.15				207	0.27			
3	13:49:30	0.733	2.393	7.40	2.309	0	540	219	0.32	3.2	101.2	42.8
4	14:19:20	0.745	2.410	7.33	2.27	0	541	201	0.38	3.16	101.4	42.51
5	14:52:28	0.830	2.389	7.41	2.289	0	543	254	0.48	3.17	100.4	42.34
6	15:38:48	0.700	2.405	7.21	2.289	0	542	225	0.43	3.14	101	42.22

Deployment 28-AD3428, on HRS
Barrel was deployed on a bacterial mat as part of a multi-lander **(X=1482; Y= 442; Z=779)**
experiment, where 3 chambers were simultaneously deployed
in clams and mudd (background) sites

Bottle#	Time	Oxygen ml/l	ΣCO2 mM	pH	Alk meq/l	NH4 uM	Cl mM	CH4 ppm	H2S uM	PO4 uM	silicate uM	nitrate uM
Deployed	9:33											
1		bottle did not trip										
2	10:14:44	0.697	2.427	7.45	2.315	3.64	543	1627	0	3.32	115.6	44.04
3	10:21:28	0.846	2.422	7.45	2.354	0.19	541	2462	0.01	3.28	115.4	43.4
4	10:31:30	0.840	2.442	7.29	2.296	0	543	2783	0.01	3.28	115.6	43.57
5	11:01:20	0.871	2.434	7.24	2.315	0	544	2965	0.25	3.21	115.4	43.34
6	11:41:40	0.785	2.426	7.40	2.286	0	542	3725	0.61	3.21	115.6	43.23

At Hydrate Ridge South, the barrel was deployed on the TVG 18 area on dives 3424 and 3428 (four days apart). The two deployment sites lie within 20 meters of each other in very similar topographic sites. In both cases the barrels were deployed over bacterial mats. The methane flux estimates based on these deployments vary by an order of magnitude (Figure 15). More significantly, the AD3428 deployment is part of a multi-lander experiment in which fluxes at sites covering bacterial mats, clam fields and muddy background sediments were collected simultaneously to isolate the spatial and temporal variability. The results of the USC landers deployed over the clams and muddy sites are given in section 6.4.6. These results show that the methane fluxes to be 0.45 and <0 mmol/m^{2}day in the clams and background sediments respectively; highlighting the extreme spatial variability of the methane flux in these environments. The only other flux data over clam fields in this area is given by Linke et al., 1994. At a clam site over an active gas hydrate site on the HRN, the methane flux measured with the benthic barrel in 1990 was estimated to be 125 mmol/m^{2}day.

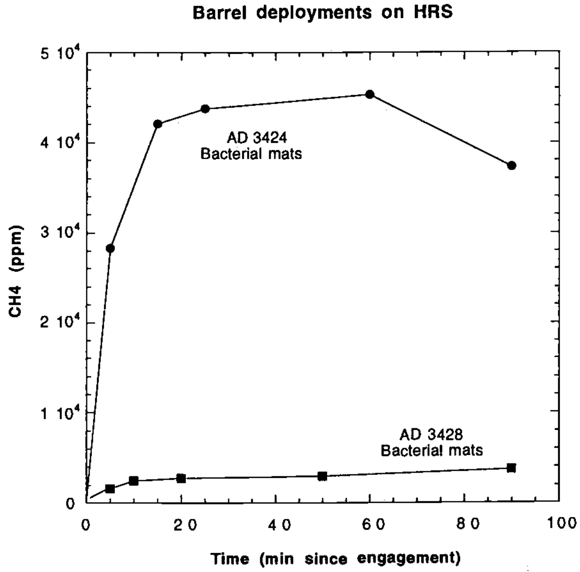


Figure 16: Methane release measured in two separate deployments of the benthic barrel at HRS, illustrating the large variability of methane flux rates at these sites

Benthic Barrel Measurements of Rn (Hammond, Colbert) Aliquots of water were drawn for Rn analysis from Niskins in Benthic Barrels. The lack of water limited draws to Niskins 1, 3, and 5. Unfortunately, any increase in Rn during the deployments was undetectable (Table 19). This lack of increase allows an upper limit for flow to be calculated, based on the assumption that the Rn concentration in pore waters under the deployment sites is similar to that measured at depth in the whole core squeezer profiles (150 dpm/l). Some additional work must be done to evaluate the validity of this assumption. A change of 0.6 dpm/l during the course of the experiments should have been detectable. If we assume that the water in the barrel was well-mixed, no more than 0.4% of the barrel water was replaced during the experiment. If the barrel was 100 cm high and the average length of time spanned by the samples was 1 hour, this constrains the upper limit for flow to be 4 mm/hr or 10 cm/day. While the assumptions about good mixing and the concentration of Rn in pore water could be invalid, it should be interesting to compare this result to the flow velocity measured at the barrel exit.

Helium isotopes (Winckler). Three helium isotope samples (bottle #2, #4, #6) were collected from each of the four barrel deployments. Due to the limited volume of the barrel's Niskin bottles a new sampling method designed by W. Roether (U Bremen) was used. The water was transferred into a pre-evacuated glass ampoule that was subseqently sealed. The radiogenic helium excess (see chapter 4.5.1) will be used to characterize the endmember fluid and to obtain new information on the fluid's flow path and typical residence times in the matrix prior to expulsion.

6.4.6 Benthic Flux Measurements with landers (Hammond, S. Colbert, McManus, D. Colbert, deAngelis, Meredith, Kohlbry, Richert)

Instrument design. The benthic chamber used (Figure 16) is similar to that designed by Berelson and Hammond (1986). This design is relatively simple. It has an aluminum frame, PVC-constructed chamber, a stirring motor, and gasket material for sealing the chamber lid to the chamber. 6 - 8 samples can be collected during incubation—including one for bottom water. Samples are collected at preprogrammed times via a computer housed inside a pressure case. Sample collection is initiated by an electrical signal originating from the computer (i.e. a burn wire). Chamber volume is determined by injection of a CsBr "tracer" spike of known concentration, followed by subsequent sampling of the chamber water. Oxygen concentration throughout the course of an experiment is monitored using a pulsed electrode system (Langdon, 1984).

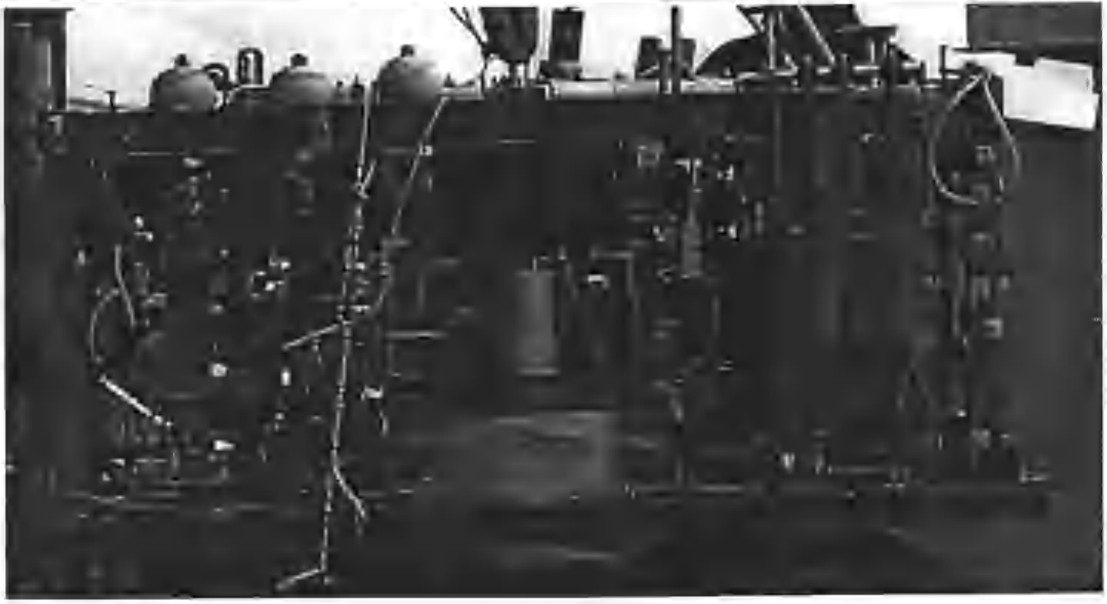


Figure 16. USC lander in Alvin basket prior to deployment

Sampling Three successful flux chamber deployments were carried out, one in each of three biogeochemical environments that were separated by 10 to 70 meters. The mechanical aspects of the chamber operations at each site appeared to be satisfactory, with 5 or 6 samples drawn during each deployment. Aliquots of samples were analyzed on board for O_2, TCO_2, alkalinity, ammonia, methane, H_2S, Cl, and Rn. Additional analyses for nutrients, C-13, and selected metals will be carried out later. In addition, a tracer containing Cs and Br was added to define chamber volume. The tracers can also be used to assess if leakage and/or advection occurred. Each chamber contained an electrode to measure O_2 in situ at 6 minute intervals during the deployment. Unfortunately, this probe failed in 2 of the 3 experiments. However, O_2 changes were also determined from analyses on discrete draws. A summary of the deployments and preliminary estimates of several fluxes is given in Table 16. Several interesting observations are apparent as noted below.

Table 16. Flux chamber deployments

Recovery Dive #	Chamber	Site characteristics	X	Y	O2	CH4	Rn	Notes
AD-08-HB	Blue	Bacterial Mat	1468	439	-	0.1	128±16	2nd half only
AD-32-HG	Green	Clams	1479	440	12	0.45	37±9	
AD-32-HB	Blue	Soft Sediment	1344	455	6	(<0)	50±11	

X, Y refer to m in transponder grid (section 6.2); O_2, CH_4 fluxes mmol/m^2-day; Rn fluxes atoms/m^2-s.

Preliminary Interpretation

1. The deployment on the bacterial mat did not produce a pattern that is easy to interpret. Solutes expected to escape from sediments (CH_4, NH_3, H_2S, TCO_2, alkalinity) increased enormously from the first to second draws, but then decreased to near bottom water values in the 3rd and 4th draws. From the fourth through sixth draw, these solutes increased steadily again. Video tape of the chamber before and after sample draws did not reveal any problems in sealing that would lead to massive leakage. Our preliminary interpretation of this pattern is that the chamber was strongly influenced by advection, with rapid upward flow during the first 5 hours of deployment, downward flow during the next 7 hours, and upward flow during the last 10 hours. These changes are only weakly correlated with tidal heights recorded at nearby South Beach of the Yaquina River, so the mechanism that might cause flow reversal is enigmatic. Alternatively, we cannot rule out the possibility that a leak was present; however, it must have been quite variable in time to produce the changes observed. An interesting observation is that the chlorinity of these samples appears to be greater than in the other two deployments. Whether this is real, an artifact of DIW dilution during sample draws, or daily variability in standardization will require additional measurements.

2. The deployment over the clams showed very rapid changes in oxygen during the initial part of the deployment, with smaller changes during the later stages. Radon also showed a larger flux during the initial portion of the deployment, but the overall flux was rather similar to that expected for molecular diffusion, indicating that macrofaunal irrigation and advection must play relatively minor roles at this site. Ammonia only

appeared in the last two draws, after O_2 was largely consumed. This site was characterized by a very high flux of methane, but the methane flux must be largely diffusive and indicates that the clams are not fully efficient in removing methane from pore waters. The methane flux was not strongly dependent on chamber O_2. TCO_2 fluxes exceeded O_2 fluxes, indicating the importance of other electron acceptors, but alkalinity fluxes are surprisingly low.

3. Fluxes at the soft sediment site chosen as a background station were also rather high. Oxygen fluxes were within the range of values calculated from the WCS multicore measurements, but about 5 times the median estimate for the WCS results. TCO_2 fluxes were comparable to O_2 fluxes, and no ammonia flux was observed despite the rather low O_2. Methane fluxes were erratic as concentrations rose and then fell. Alkalinity fluxes were also remarkably low. Rn fluxes are slightly above values expected for molecular diffusion, indicating that some irrigation may occur.

Additional work in progress Further interpretation will require measurement of the Cs and Br tracers added, nitrate and other nutrients, and selected major and minor cations. A careful comparison of TCO_2 measurements and that calculated from alkalinity and pH must be carried out. Small corrections for dilution during sample draws must be done, and then the stoichiometry of fluxes may constrain the relative importance of the major diagenetic reactions occurring in sediments.

6.4.7 Gas samplers (Hammond)

***Sampler design and Collection*:** Gas samples were collected in situ on the sea floor using USC collectors. This design incorporates a funnel, attached to a PVC tube that passes through a 3 way stopcock (used later as a port to draw samples), into a plexiglass cylinder, through a 2 way plastic stopcock at the base, and into a length of PVC tubing (Figure 17). The cylinder contains a 60cc Nalgene bottle filled with oil (Crisco vegetable oil =Soybean, chosen because it has a low specific gravity). The bottle is epoxied into a plexiglass base and will float in water so that only plexiglass touches the gas phase if water remains in the sampler. Initially, the tubing and cylinder are filled with DIW that has been purged with N2. In practice, small bubbles were always noted after filling with DIW. The sampler is mounted on a base, with a rubber stopper bolted to the base serving as a mounting bracket and sealing the funnel. The stopcocks were deployed so that flow through the device could occur if the sampler was removed from the rubber stopper. A small hole drilled in the side of the funnel allows for escape of any air trapped in the funnel during entry into the ocean. To collect samples on the sea floor, a bungie securing the sampler was removed, the sampler was held over a seep only a few cm above the sea floor, and gas bubbles entering the funnel could flow up the tube, enter the cylinder, and displace DIW until the desired gas was collected. The float indicated how much gas had been collected and minimized any contact between water in the cylinder and gas collected. In all cases but one, samplers were fully filled with gas on the sea floor. After obtaining the sample, the sampler was returned to the rack and re-bungied into position. The rubber stopper served as a check valve to prevent flow of water into the funnel or escape of gas from the cylinder top. As the sampler came to the surface, gas expanded and could escape from the cylinder bottom. The tubing attached to the bottom returned filled with water and prevented exchange between air and the cylinder after the sampler left the ocean. Once on deck, the lower and upper cylinder valves were closed to isolate the gas.


Figure 17. Gas samplers in Alvin basket prior to deployment.

Summary Samples of gas seeping from the sea floor were collected in two general locations, emanating from a rocky environment at HRN (on 7/7/99, from 2 different seeps about 587 m depth) and from a mat environment near HRS (on 7/11/99, from 1 seepage area at 775 m depth). Samples were analyzed for CH_4, CO_2, H_2S, and Rn while at sea and aliquots were taken that will be analyzed for both He isotopes (He-3 and He-4) and heavier noble gases (Ne, Ar, Kr, Xe). The main objective of the helium isotope analysis is to see if samples are enriched in He-4 to determine if a radiogenic He signature has accumulated during their residence in a radiogenically dominated reservoir. The main objective of the heavy rare gas analysis is to obtain insight into the processes involved in the formation of the gas phase. Aliquots were also taken for analysis of carbon isotopes in the methane. Some analytical problems were encountered with several analyses as noted below. The gas is nearly pure methane, with a CO_2 fraction of about 0.5‰ measured in a sample from HRN. This CO_2 fraction is an indicator of the carbonate chemistry of the source area, as a rough calculation shows that if gas had equilibrated with a solution containing 2 mM calcium and saturated with calcite, the (HCO_3^-) of water in the source area should be about 30 mM. The Rn measurements can put some constraints on physical characteristics of the source area. It must have a free gas fraction <20% and porosity <70%. If the source region porosity is 50% and gas resides in planar cracks, the crack dimension should be approximately 0.5 cm. The Rn content of different seeps varied by a factor of 2, showing lowest concentrations in the most slowly flowing seepage areas. This may be evidence that conduits to the source area seal while the seep is active, increasing transit times, decreasing flow rates, and resulting in the episodic nature of flow. Further modeling work must be done to explore alternative scenarios.

Sample Draw: Most samples were drawn about 4 hours after they reached the surface. Samples were drawn into plastic syringes through the 3-way valve at the top. As gas was removed, DIW previously purged with N_2 was introduced into the bottom to keep pressure near atmospheric. Draws for noble gases were usually taken prior to adding this DIW, and the sample was quickly transferred into an Al bag for storage until analysis can be done. Next, splits were taken for Rn, methane, and CO_2. These were often drawn into a 140 cc syringe and aliquots were transferred into smaller syringes for methane, methane isotopes, or CO_2. To determine methane, 0.1 ml was drawn into a gas-tight glass syringe, injected into a glass syringe containing 20 cc of room air, and 0.1 cc of the diluted mixture was drawn for methane analysis. Several gas cylinders were sampled for H_2S. After the initial draws, samples were stored in the cylinders (with the DIW) and splits were later drawn to repeat methane and CO_2 analyses.

Results

Methane. Analyses for methane are listed in Table 17. These were run on a Shimadzu gas chromatograph using a FID detector standardized against a standard containing 1% CH_4. Several combinations of range and attenuations were used. It appears that either dilutions or the instrument linearity response varied a bit from day to day. Analyses for the first day indicated 75-92% methane, and later analyses indicated averages of 108.4, 104.8, and 108.1%. An analysis of the gas escaping from the MBARI 'bomb' were 110.9%. The interpretation is that analyses from the first day were low because of some unidentified technical or standardization problem on that day. Standards and samples were run on different ranges. Samples should have been 2.7% H_2O (water vapor pressure at 23°C). If the MBARI bomb gas is assumed to be pure methane, it can be used to remove any systematic error caused by dilution; these normalized results indicate the gas samplers contained nearly pure methane with a few percent water vapor making up the balance.

TABLE 17. Methane Analyses (%) from different analysis dates. Uncertainties are sample standard deviations for number of analyses indicated in parentheses.

AD 3426 on 7/7/99				
ID	7/7	7/9	7/11	Normalize to MBARI
GS-1	78.3,74.0,73.3	117.8, 112.8	102.4,104.0	98.5±7.7
GS-2	84.2	100.1,104.9	108.0	94.8±3.5
GS-3	92.0	116.2,98.7	?	96.8±11.1
GS-4	89.9	-	-	
Ave.	85.3±7.5	108.4±8.3	104.8±2.9	
n	(4)	(6)	(3)	
AD 3430 on 7/11/99				
ID	7/11			Normalize to MBARI
GS-1	107.4			96.8
GS-2	109.6			98.7
GS-3	104.7			94.3
GS-4	110.8			99.9
Ave.	108.1±2.7			
n	(4)			
MBARI 'bomb'	110.9			

Table 18. TCO_2 Analyses (*‰*) from different analysis dates. Note that the samplers from AD3430 are all different from those used on AD3426 except GS-4.

AD 3426 on 7/7/99				
ID	7/7	7/9	7/11	Best estimate
GS-1	1.23	5.12	10.22	<1
GS-2	0.55	0.70	1.08	0.50
GS-3	1.25	5.95	12.48	<1
GS-4	1.08	-	-	<1
AD 3430 on 7/11/99				
ID	7/11	7/12		
GS-1	2.99	4.27		<2
GS-2	<0	4.94		-
GS-3	3.48	-		<3.5
GS-4	2.54	3.83		<2
MBARI 'bomb'	10.36			
MBARI 'bomb'	0.41			

Table 19. Radon Analyses. Uncertainties are based on counting statistics only. Concentrations are given in dpm/l in sampler at room temperature for measured values or in dpm/cc under in situ conditions, calculated by multiplying by: (295/278)*(depth in m)/(10*1000).

AD 3426 on 7/7/99				
ID	Seep Char.	1st anal.	2nd anal.	in situ (dpm/cc)
GS-1	Seep A, slow	26.1±1.5		
GS-2	Seep A, moderate	26.7±1.5		
GS-3	Seep B, fast	50.1±2.0	54.4±3.9	
GS-4	Seep B, fast	45.8±1.8		
Ave.	Seep A	26.4±1.0		1.63±0.06
	Seep B	49.1±4.6		3.06±0.30
AD 3430 on 7/11/99				
ID	Seep Char.	7/11		
GS-1	Seep C	29.6±1.5		
GS-2	Seep C	28.4±1.6		
GS-3	Seep C	36.3±1.5		
GS-4	Seep C	28.0±1.8		
Ave.	Seep C	30.6±3.9		2.51±0.32
MBARI 'bomb-1'		5.13±0.6		(first 140 ml)
MBARI 'bomb-2'		4.3±0.5		(after 1.4 liters)

CO_2. Measurements of CO_2 were made shortly after samples were collected and at intervals of 1-2 days following the initial analysis. Analyses were done by subsampling gas samplers using a plastic syringe and injecting a known volume of gas into the OSU coulometer. Injections were either into the sampling loop (including a 20 ml glass pipet bulb, done only on 7/7 analyses) or injecting directly into the stripper. Results are given in Table 18. These results show a systematic increase in CO_2 concentration with time during storage. It seems unlikely that this CO_2 should come from the DIW introduced as samples were drawn, because the DIW was purged with N2 prior to filling the samplers. Furthermore, the blanks for both GS-2 samplers were quite different than for the other samplers. It seems unlikely that methane would be oxidized to CO_2 during storage because we made efforts to exclude oxygen. A test of the samplers for blanks was carried out by filling two samplers (GS-1 and GS-2) from AD3426 with N2 and storing them for one day. The oil-filled bottle was removed from GS-1 for this test because it was suspected as a likely source of the blank. Results of this test showed an increase from zero (assumed) to 0.76 ‰ in GS-1 and to 0.095‰ in GS-2. Our interpretation of these results is that a significant CO_2 blank exists and is specific to each sampler. The blank for GS-2 on 7/7 appears to be small. Extrapolation of the GS-2 results to time of arrival on deck using either the measured blank or using the observed increase from 7/7 to 7/11 indicates a CO_2 fraction of 0.5‰. For all other gas samplers, the contribution of the blank has overwhelmed the initial signal, and only an upper limit for CO_2 can be estimated. Some additional uncertainty exists due to the contribution of the coulometer blank to the signal (30±10% of the total signal for this sample) and because samples for this run were analyzed by first injecting the sample gas into the 20 ml sample loop. About 30 ml of gas was injected through this loop; assumption of instantaneous mixing suggests that it should have been 77% sample. This factor introduces another 10% uncertainty (estimated). Consequently, we estimate that the CO_2 fraction in GS-2 was 0.5±0.2‰. The CO_2 blank is quite problematic. While some may come from CO_2 released by oil in the float, this cannot be the only source. Some must come from the acrylic or possibly the epoxy used to cement the PVC stopcocks in place. Neither of these sources seems like a likely source, however, and why some of the samplers lack a large blank is a further enigma. Additional work will need to be done to confirm the origin and magnitude of the blank.

Radon: Rn-222 was analyzed by alpha scintillation techniques. Aliquots of gas from the samplers were injected into the RRES stripping system and transferred to counting cells. Results are presented in dpm/l as measured at the surface and corrected to in situ concentrations by assuming ideal gas behavior (Table 19). Several features are notable. First, the concentrations in different seeps vary, with the area having the lowest seepage rate (seep A) also having the lowest Rn. Second, gas from the more rapidly flowing seep at HRN (seep B) has a concentration very similar to the value of 54±3 dpm/l measured in August, 1998 from a very rapidly flowing seep. Third, the in situ concentrations are large, and demonstrate good communication between solid phases producing Rn and the gas phase. In the lab, we have measured the Rn emanation rate from solids collected at ODP site 892 as about 0.9 dpm/g when immersed in water (should be an upper limit). Several interpretations of this data are possible, but the high Rn concentrations indicate that the gas has most recently been in contact with sediments characterized by a relatively high solids/gas ratio. An alternative interpretation of the high Rn is that as gas moves from its source area to the seep, a large fraction of the migrating methane has been converted into hydrate and this hydrate has excluded Rn. However, this seems unlikely because the size of Rn suggests that it should be readily incorporated into the hydrate structure. The similarity of the measurements from the more rapidly-flowing seep B to the 1998 results suggests that the structure of the system has not undergone any large change, and that the transit time from source area to the sediment surface is small. Consequently, the lower Rn in the slowly flowing seep A may be due to decay during transit from its source area. Seep C in HRS has Rn in situ that is similar to Seep B, suggesting a general similarity of the gas/solid ratio in the two regions. We cannot use Rn to uniquely determine the gas/solid ratio because the calculation depends on the water content and the degree to which Rn has equilibrated with pore waters. However, if water content measurements at ODP 892 (water/sold volume ratio =1) are appropriate and the gas has fully equilibrated, the fraction of free gas in the source region is <20%. Alternatively, if gas only resides in fractures and Rn must diffuse through sediment pore waters to reach the fractures, the fracture size can be estimated from mass balance considerations. Based on the water content estimate above and assuming a planar geometry for gas filled fractures, their aperture is about 0.5 cm.

$\underline{H_2S}$: An attempt to measure H_2S was made by adding 2.5 ml zinc acetate to syringes containing about 20 ml of gas and allowing contact for about 20 minutes with occasional shaking. The solution was then removed and carried through the normal procedures for sulfide analysis. No detectable H_2S was observed. The sensitivity for this technique is approximately 2 μM in the 2.5 ml zinc solution. Consequently we estimate an upper limit for H_2S in the gas samples as (5 nanomoles)(24 nanoliters/nanomole)/(20 ml) = 6 ppm. This is far greater than the sensitivity of the human nose which is about 3 ppb.

6.4.8 Osmotic flowmeters (Brown and Tryon)

The SIO osmotic flux meters (Fig. 18) use the dilution of a chemical tracer to determine flux rates. An osmotic pump, injects a tracer at a constant rate into the water stream as it moves through the outlet tubing (Tryon et al.,1999b). A portion of the fluids moving out of the top of the chamber are collected in sample coils, giving a unique pattern of chemical tracer distribution. The two sample coils allow both positive and negative flow to be measured and give a serial record of the flow rates. The RbCl tracer is analyzed by optical emission spectrometry and can resolve flux rates ranging of over four orders of magnitude. The SIO flux meters

Figure 18. SIO FM deployed on clam field during the Tecflux 98 experiment

can be configured with the specific purpose of measuring surface aqueous fluxes that occur at slow to intermediate rates (i.e. minimum rates of ~ 0.1 mm/y and maximum rates of several 10,s m/y). This technique has proven to be very robust in terms of the tracer's conservative nature. The use of the tracer also allows for the measurement of the fluxes of other major dissolved chemical constituents to be undertaken where appropriate (i.e. regions of elevated rates of out flow).

During the TECFLUX '99 Alvin dives, 10 SIO flux meters were deployed in and around seep areas on Hydrate Ridge (Table 20). The instruments were set up to measure aqueous flux across the sediment-water interface of approximately 0.1 mm/yr to 15 m/yr. They will also maintain a temporal resolution of ~4 hours in the latter portion of the record in order to resolve tidal period variations in the flow. The duration of the deployment will be about seven weeks with recovery to take place August 20-25 aboard the R/V Sonne.

All the deployments were initially made from the surface and subsequently recovered and repositioned on the seafloor with Alvin. The initial four deployments were completed during Alvin dive 3421 on July 1 on southern Hydrate Ridge. Instruments G and H were placed a few 10s of meters inside a widespread seep area. This is approximately 100 m WNW of the area of active methane venting seen during a subsequent dive. Meter A was placed NNW ~200 m and meter B ~400m NNW of the initial 2 meters. The latter two are in an area which is not indicative of fluid advection, i.e. sediment cover relatively devoid of life.

TABLE 20: Deployment of SIO flowmeters

Instrument number	Latitude 44° +	Longitude 125° +	Depth (meters)	Comment
G	34.221	8.899	778	seep
H	34.22	8.90	778	seep
B	34.450	8.954	798	non-seep
A	34.347	8.955	790	non-seep
C	40.034	6.007	603	seep
F	40.029	6.006	604	seep
D	40.024	6.006	605	seep
E	40.243	5.817	602	seep
I	40.203	5.871	598	seep
J	34.264	8.885	780	non-seep

Meters C, F, D, E, and I were deployed on July 6 on northern Hydrate Ridge during Alvin dive 3425. The initial target area was found during Alvin dive 2423 survey and exhibited rocky sediment cover with patches of clams and microbial mats. This area is ~300 m SSW of the TECFLUX '98 ROPOS dives along a relatively continuous linear region of biological seep indicators extending between these two. C, F, and D were deployed in this target region in an area of thick, dense, white microbial mats. C and F were placed directly on mats at the top of a small sediment covered ridge and D was placed on a patch of clams downslope ~10 m away and ~2 m deeper. The other two meters were moved to the TECFLUX '98 area for deployment. E was placed at Clam 3 in the same position as last year and I was placed at Clam 2. These positions are approximately 100 m and 25 m NNE respectively of the gas vent site.

Meter J was deployed during Alvin dive 3429 on July 10 on southern Hydrate Ridge. It was placed ~50 m north of meters G and H, just outside the active seep area. On reviewing the video tapes it was found that meter H has shifted on its base and may not function properly. We recovered the meter and redeployed it prior to dive 3430. Time constraints prevented it from being repositioned during the dive, however we believe it is very near meter G in the seep area.

6.4.9 Thermal blanket (Johnson, Hutnak and Torres)

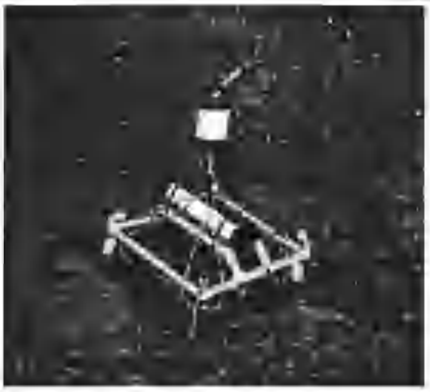


Figure 19. UW thermal blanket deployed on Baby Bear seamount

The University of Washington thermal blanket was designed to accurately measure heat flow in a volcanic or carbonate 'hard rock' environment that cannot be penetrated by traditional heat flow probes. This blanket consists of an insulating layer of water-saturated urethane open cell foam, with four pairs of thermistors that measure the temperature difference between the seafloor and the overlying water (Fig. 19). Two sets of unpaired thermistors on the top and bottom of the blanket allow correction for water temperature variations during the deployment period. Thermal gradient data are stored in a data logger (Alvin certified to 4000 meters) that is supported directly above the blanket. The blanket requires a minimum of approximately 6 hours of deployment time on the seafloor for a valid heat flow measurement, but can be deployed for periods as long as a year for time series data. The UW thermal blanket has been deployed on newly erupted lava flows on the Juan de Fuca Ridge to determine the rate of cooling of volcanic events, and has measured the general evolutionary cooling of oceanic crust (Johnson and Hutnak, 1997). Recently, the thermal blanket was deployed on Baby Bare Seamount in Cascadia Basin (Figure 19), and determined that there was a substantial tidal modulation (10% of total heat flow) that was due to tidal motions of the overlying water column (Hutnak and Johnson, Dec, 1998, AGU meeting).

Results. We deployed the UW Bare Rock Heat Flow blanket to measure surface heat flow in an area of the South Hydrate Ridge where hydrates occur very near to the sediment surface and traditional heat flow probe data is not available. Deployment was only for 8 days, but obtained the surprising result that at this location there were long periods of time (on the order of 10 hours) where the bottom water was warmer than the surface sediments and heat flow was **negative** (i.e., into the sediments; Figure 20). The average heat flow for this 1999 deployment was – 250 mW/m^2, which was due largely to the high amplitude temperature reversals between the warm bottom water and the cooler surface sediments. Calculation of the thermal diffusivity for the upper sediments of this site indicates that the thermal diffusion distance is approximately 15 cm for a 10-hour temperature disturbance, and this length scale includes the near-surface occurrence of solid hydrate in the adjacent area. These pulses of warm bottom water on the Oregon margin have been observed previously using CTD moorings (R. Collier, unpubl. data.) and the resulting periodically-elevated temperatures within the sediments due to the negative heat flow may constitute a possible source of time-dependent destabilization of the gas hydrates deposits at the seafloor into gaseous methane. If heat flows into the sediments during (tidally-forced?) circulation of warm bottom water, the resulting elevated temperatures for the near-equilibrium gas-hydrate could be responsible for the periodic appearance of methane bubbles. Our 8-day deployment in 1999 was not long enough to establish if this was a short, transient or seasonal phenomena, or if the thermal fluctuations are a regular feature of the margin environment.

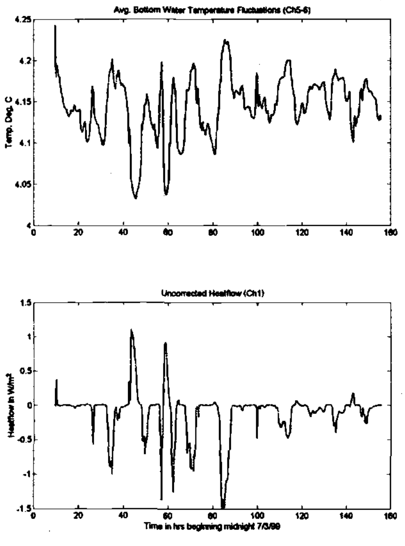


Fig. 20. Data from UW Blanket from an 8-day deployment (July, 1999) on the southern Hydrate Ridge. Upper figure shows the bottom water temperature variation from un-paired thermistors on the top of the blanket. The initial rapid decrease at 10 hours is the deployment through the water column by ALVIN. The lower figure shows the un-corrected (for water temperature variations) heat flow from this deployment from the thermistor pairs.

6.6 GAS FLOW EPISODICITY, Alvin observations

Repeated observations of a site of known gas discharge were made during several Alvin dives. Gas discharge on HRN was first identified during the Sonne expedition in 1996. Subsequently episodic gas discharge on the flanks of this depression was documented during the Tecflux 98 expedition (Gusher site, Torres et al., 1998). A bottom marker was left at this location in 1998. Venting at this site was observed again in 1999, both in the bottom of the pit (where marker #6 was positioned) as well as on its flanks. On HRS, vigorous gas venting was also documented during our last dives in the Beaver Mounds area (marker #7). These observations are summarized in Table 21, and discussed in the following sections. Detailed observations and sampling procedures at these sites are given in each of the dive summaries (Appendix 1).

Table 21: Gas discharge observations on Hydrate Ridge

Visits to Marker 6 area (The Gusher), on HRN

Alvin Dive #	Date	Time at marker 6	Observations
3425	6-Jul-99	15:17	Few bubbles observed at Gusher site
3426	7-Jul-99	10:10	At marker #6. Only a few very sporadic bubbles observed coming from a hole among carbonate rubble
		10:27	More steady bubble flow
		10:39	The Gusher is gushing
		12:39	Vigorous discharge observed on flank and at the bottom of the depression continuously from 10:40 til 12:40.
3427	8-Jul-99	11:30	Bubbling observed at 5 discrete sites on depression
		13:00	Highest gas discharge rates from 13:00 to 13:30

Visits to Marker 7 area (Beaver Mounds), on HRS

Alvin Dive #	Date	Time at marker 7	Observations
3422	3-Jul-99		First visit to Beaver mounds, bacteri mats described but no bubbling obsen
3424			No visits to Beaver mounds
3428	9-Jul-99	14:14	Bubbles rising from orange mats documented for the first time
3429	10-Jul-99	12:22	Bubbles observed only when bottom is disturbed by sub
3430	11-Jul-99		Bubbles observed on Alvin's sonar during descend, app. 50 m off bottom
		11:52	Observe vigorous bubble discharge from at least 4 sites, on a depression in Beaver mounds area. Deploy marker 7
		15:26	Terminate work on bubble site.

Hydrate Ridge North: The temporal changes in the aqueous flow regime at this site can vary significantly on time-scales of days to weeks (Torres et al., 1998; Tryon et al., 1999). ROPOS and Alvin investigations respectively in 1998 and 1999 also indicate the highly variable rates of methane gas venting from the ridge. During our Alvin dives, several vents were observed to go from dormancy to active discharge in a period of a few hours, highlighting the transient nature of these systems (Table 21, Appendix 1). At present we don't have a good understanding of the various mechanisms driving the fluid discharge; nevertheless, several mechanisms including: temperature changes at depth; tidal loading; and dynamics of two-phase flow systems, are likely to be contributing to the observed transience of the gas discharge.

Data from the osmotic flowmeter deployments during TFX 98 have been used to postulate that the longer period (week to monthly) variations in aqueous flow can be coupled to the action of a gas-driven pump (Tryon et al.,1999). In this recently postulated mechanism, the timing flux rates of gas discharge events relate to the complex interplay between the rate of gas charging of localized reservoirs (probably fractured sediments) at depth, the resulting changes in the buoyant force at the top the low density gas column, and the non-linear changes in the permeability of the two phase (gas/water) system. In this hypothesis, the expected local heterogeneity in plumbing and reservoir characteristics between different gas vent regions on the ridge could result in widely varying timing and rate, and longevity of gas discharge between different gas vent sites. Some of the mechanisms involved are somewhat analogous to the mechanisms driving transient fluid discharge at geysers (Ingebritsen and Sanford, 1998).

Data obtained from underwater observations (ROPOS and Alvin), indicate that gas bubbling is highly episodic, suggesting a tidal component to the fluid discharge (Figure 21). Tidal modulation of fluid flow has been reported in a variety of environments ranging from hydrothermal systems (Hutnak and Johnson, Dec, 1998, AGU meeting) to cold seeps at continental margins (Orange et al., 1997) and estuarine systems (Brown, unpublished data). Sub-seafloor pore pressure variations with transient loading imposed at the seafloor by ocean tides have been recorded by marine pore pressure probes and by borehole observatory instruments (e.g. Fang et al., 1993; Davis and Becker, 1994, Davis et al., 1995). In ODP Hole 892B, the tidal signals were observed to be attenuated by 55%, with several degree phase lead probably due to the presence of an opening on the sealed borehole (Wang and Davis, 1996). Tidal forcing causes pressure cycles on the order of 10-20 kPa with ~12 or 24 hour cycles that can be responsible for flow reversals (Wang and Davis, 1996) and might be responsible for destabilization of gas hydrates at depth. In low-permeability, clay-rich sediments the rates of oscillatory flow this generates are negligible; however in sands or sediments dominated by fracture permeability, such as those present at Hydrate Ridge, more significant cycling can occur.

Hydrate Ridge South. In the southern Hydrate Ridge area there are no significant departures in BSR depth from that predicted by the seawater/gas hydrate phase boundary in existing seismic data (Zwart et al., 1996). Our Alvin documented for the first time the presence of vigorous gas discharge at the southern end of Hydrate Ridge, which was previously thought to be dominated by diffuse fluid flow. The crest of the ridge is characterized by the presence of mounds covered by bacterial mats in which large amounts of gas hydrate and free methane gas seem to coexist. The mounds appear to be covered by a crust of nearly pure gas hydrate. These observations have been confirmed by the recovery of gas hydrate blocks from these mounds using a TV-guided grab deployed from the German RV Sonne during a cruise that immediately followed the Atlantis expedition. From Alvin we observed a tremendous amount of free methane gas, previously trapped beneath a hydrate cap, being released suddenly to the bottom water. Positive buoyancy of naturally formed hydrate may contribute to sediment instabilities; periodically floating up of large blocks of hydrate. These processes could be responsible for the hummocky morphology of the Beaver Mound area.

Summary: Results from our field work on 1998 and 1999 have documented that gas venting on Hydrate Ridge is highly episodic. Various mechanisms: temperature changes at depth and on the seafloor; tidal loading; gas hydrate buoyancy; and dynamics of two-phase flow systems, may be driving the gas discharge. The processes leading to gas discharge seem to be different in the northern and southern summits of the ridge. We believe that the northern summit represents a more mature stage in the evolution of these ridges (Trehu et al., 1999) as evidenced by extensive carbonate pavement and chemoherm development, and upward deflections of the BSR where it is cut by faulting. The methane discharging at this site seems to originate below the BSR (Suess et al., 1999). In contrast, the southern Hydrate Ridge region is less evolved, exhibiting only limited and localized carbonate build up and no significant departures in BSR depth from that predicted by the seawater/gas hydrate phase boundary in existing seismic data. Preliminary observations indicate that gas discharge here is driven by more localized phenomena, possibly associated with destabilization of gas hydrate deposits at the seafloor.

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Appendix 1

Alvin Dive Logs

Alvin Dive log

Dive number: **3421**

Area: **TVG18+ Pinnacle**

Date: 2 July 1999
Observers: Brown and Hammond
Pilot: D. Foster
Launch: 44°34.00N 125°094W, in water about 8:20. Reach bottom about 0900.

Tape start times:tape 1=0900, tape 2=1103, tape 3=1308
Tape times recorded on sample log are approximate within a few minutes.

Summary

The principal objectives of dive 3421 were to a) locate and survey the TVG 18 grab site were gas hydrates were located in a cold seep region on the previous Sonna cruise, b) Locate and place four SIO flux meters at different locations around the area of seepage, c) deploy two benthic chambers from OSU and USC on the seeps, d) obtains slurp, push core and Niskin water samples. These objectives were successfully accomplished. The TVG 18 site was found to comprise a series of mounds and shallow pits with amplitudes ranging up to 2 m. Evidence for large and vigorous clam and bacterial colonies were observed in a region at least 30m in diameter. bacterial mats seem particularly well developed along the side and top of 2-3m high ridges. The white bacterial mats had diameters that ranged locally up to 2m but were very irregular in shape. Well over 20 different patches were observed. Abundant small clams (<2-3cm) were located in the regions immediately around the bacterial mats. There appeared to be a negative correlation between bacterial mats and the immediate presence of clams. Gas was released when the bacterial mats were probed the gas appeared to originate from immediately under the bacterial mats. Bubbles were also observed to rise around Alvin when in set down of bacterial mat sites. Probing around the edges of the bacterial mats also suggested the surface 1-2cm of weakly cemented crust that broke easily. The later portions of the dive were spent undertaking preliminary investigations of features determined in sidscan sonar images including the discovery of the Pinnacle; a large seepage related chemoherm that forms a 30-50m tall carbonate tower.

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Alvin on bottom ~ 8:30 am

Video start 8:58 am (x:y: 1375 774)- Heading NNW: Dominant bottom type -Muddy with many burrows.

9:19 am, Depth 798m (x:y: 1375 774 1372 821) -Muddy with many burrows.

9:18 am, Depth 798 (x:y 1383 828) - SIO flux meter B found (box 17). Muddy with many burrows. Flat and feature less, no boulders no evidence of seep communities. Occasional star fish and sea pens. Made sure base of meter was well coupled. Left meter in position.

9:56 am, Heading south to TVG 18. Have been traveling across muddy sediment bottom. Start of scatter carbonate boulders continuing south.

10:00 am, (x:y 1426 473) - Start of mostly carbonates boulders with some mud in between.
(x:y 1426 473) -small seep (1m diameter) live clams. Carbonates become abundant.

10:03 am, Arrived TVG 18 - A major seep site. At meter G (x:y 1426 473) three meters can be seen where they were dropped from ship in a line.

10:10 am, (x:y 1445 426, Depth 778 m) - At large bacterial mat site (>2-3) irregular shape on the side of a large pit. Probed around the live clams around the edge of the bacterial mat no gas bubbles seen. Probed within the white area of the bacterial mat released numerous bubbles from just under the mat. Probed gray region close to white bacterial mat with bubble and the probe broke through a soft crust ~1-2 cm thick no bubbles released. Strange texture possible gas hydrate cemented sediment.

10:36 am, (x:y 1458 426)- Deployed OSU bethic chamber on a bacterial mat that was on a flat area on edge of pit. Some bubbles seen during deployment . It appeared to be on the edge of the mat, so we repositioned it into the center. The seal appeared to be good and the lower frame was approximately half buried in the mud. The lid appeared to be closed when we left, but it is not clear when this happened. 10:49 am niskin water sample taken (1) at this location plus three push cores (APC 1-3). Slurp sample taken of bacterial mat. Three cores were collected, a slurp sample and a Niskin. Temp probes were inserted to roughly measure the gradient in the mat and on the edge of the mat. The sensor drifted after insertion, so we took reading after 1-2 min. when it seemed more stable.

10:51 am, (x:y 1469 431, depth 778m) - Placed USC benthic chamber on algal mat that was surrounded by live clams and other white bacterial mats. Bubbles seen coming up from under Alvin. Niskin bottle (2) taken + three push cores (APC 4-6) on the edge of the bacterial mat. USC chamber was planted in center of mat, on a small topographic high. Seal appeared to be good, lid was open, chamber stirring. Niskin was tripped, 3 cores were taken. APC-4 was just off mat, APC-5 was in mat. Consistency was like jello, with interface inside core about 15 cm depressed relative to sediment surface.

12:27 pm, (x:y, 1456: 412, depth 778m), SIO Flux meter G, placed on a white algal mat 1 m diameter surrounded on all sides by live clams, whole seep Site 3-4 meters wide. Looks very active. (Did it seal on the up slope side?).

12:54 pm, Two SIO Meters H & A, picked up and put on Alvin to carry to new site.

12:59 left TVG 18 site to the SW to go to Pinnacle. Carbonate blocks seen all the way out from TVG 18 until (x:y, 1316:373 depth 795) after which scattered blocks only. To the pinnacle site. Traveling on heading 204° scattered carbonate blocks seen between TVG 18 and Pinnacle, depth 798 m.

13:12am, Base of the Pinnacle ~30 high at the point we went over later learnt it was 50m high. At base depth 792m (x:y 1183, 233). Went up to 774m still had a way to go to top. Had electrical problems with steering motor. Returned to base at x:y 1095:272 depth 806 m. Base is rubbly. Internal layering light carbonate cemented breccia and less brecciated zones layers vary in thickness from ~1-1.5m down to perhaps a few 10 cm. The near vertical face we climbed of the Pinnacle had a lot of the internal layering exposed with a dip of 50° to east. Perhaps a portion had collapsed to reveal internal structure. Also a caves 3-4 meter deep 1-3m wide and 10 m long elongate in direction of layering. On decent the layering seemed to be subparallel to the outer surface of the pinnacle. On the decent the water depth at base was 806m x:y, 1096, 276. A dead clam field close to the base of the tower which had the appears of a rubbly scree slope sloping at 20° away from the base of the pinnacle.

14:04 pm, Depth 790m, x:y 642:1383, Deployed SIO meter A (box 18) muddy bottom featureless.

14:13 pm, Depth 784 m (x:y, 1386:630) Heading back to TVG18, Start of scattered carbonate boulders. Progressively increases southward. Denser cluster of carbonate boulders at x:y, 1419:565.

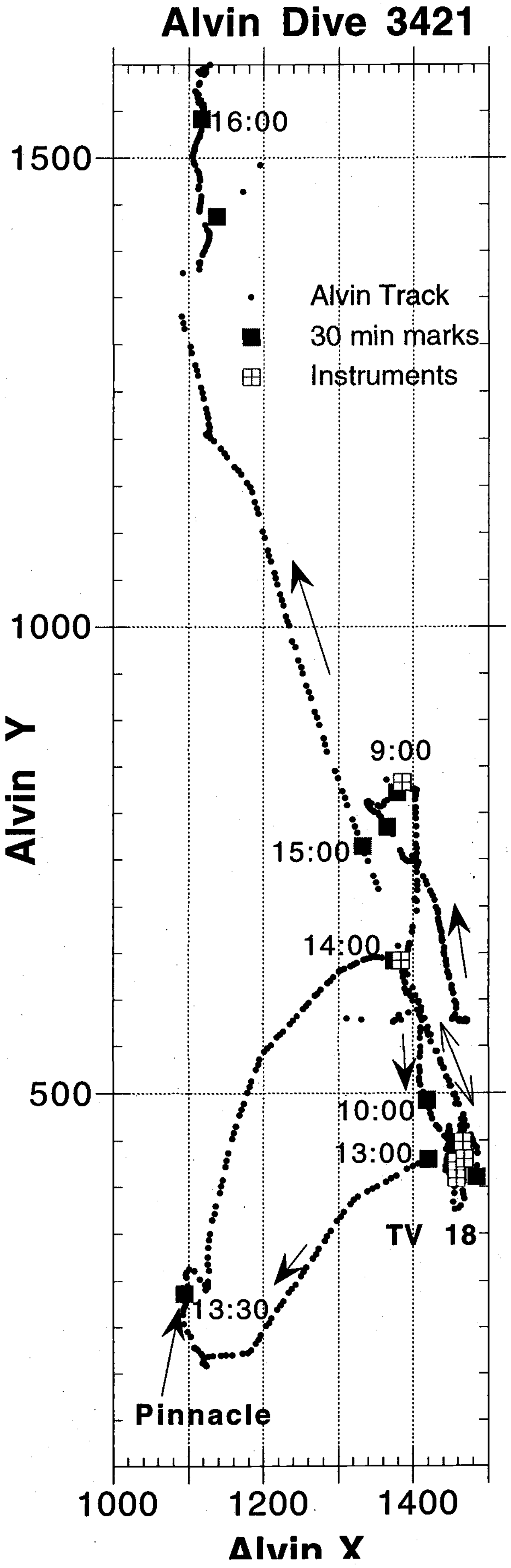
14:26pm, Depth 780m, (x:y, 1478:451). First clams sited, carbonate blocks very abundant.

14:32 pm, Depth 780m, (x:y, 1466:447) SIO Meter H, deployed at the foot of a slope covered in live clams. Live clams cover an area > 20m diameter, very abundant. No bacterial mats visible, no bubbles disturbed during deployments. The plunger connection was shifted slightly on the base of the meter possible that the connection with the base was unseated. (niskin sample 5 taken at this site).

14:50 pm, Left TVG 18 heading north to small bright patch to the NW of the Pinnacle and TVG18 region.

15: 28 pm, Depth 858m, (x:y 1090:1330) on the bright patch covered with starfish on a muddy featureless bottom. We steamed across a muddy bottom looking for the bright region in the side scan sonar north of TVG 18. The bright spot was filed with many brittle stars (1-3 per m2) but it was unclear why this was so bright.

End Dive


Alvin Dive 3421
Alvin Track
30 min marks
Instruments
16:00
9:00
15:00
14:00
10:00
13:00
TV
18
13:30
Pinnacle
1500
1000
500
1000
1200
1400
Alvin Y
Alvin X

List of samples recovered

Sample#	Operation	Time	Depth	X	Y	3 chip cam tape/time	basket spot	Notes
1	SIO Meter B	922	798	1385	833	1/0:25	Muddy sed.; improve sea	
2	OSU brown	1033	778	1458	426	1/1:34	On white microbe mat	
							Deployed 2x, lid was closed	
3	3PC(was APC1)	1056	778	1458	426	1/1:34	port aft	large
4	4PC(was APC2)	1057	778	1458	426	1/1:35	port mid	large
5	4PC(was APC3)	1059	778	1458	426	1/1:37	port fwd	small
6	Niskin-1	1049	778	1458	426	1/1:49	port	
7	Bio Slurp	1101-1109	778	1458	426	end1/start 2	At OSU flux chamber	
8	Temp Probe measurements at OSU flux chamber site						start tape 2	
	bottom water	4.152						
	In mat	4.214	3 cm of probe showing = about 35 cm depth					
	bottom water	4.147						
	in mud, mat edge	4.184	3 cm of probe showing = about 35 cm depth					
		Waited about 1-2 min for drift to stop before reading.						
9	USC blue	1143	778	1468	430	2/0:40	On white microbe mat	
							Seals look good for both	
10	Niskin -2	1154	778	1468	430	2/0:51	mid-port	
11	11PC(was APC4)	1156	778	1468	430	2/0:53	star aft	large
12	12PC(was APC 5)	1159	778	1468	430	2/0:56	star mid	large
13	13PC(was APC6)	1202	778	1468	430	2/0:59	star fwd	small
14	SIO Meter G	1240	778	1458	409	2/1:36	Clams- vent site?	
15	SIO Meter A	1405	790	1384	642	3/0:58	Muddy sediment	
16	SIO Meter H	1432	780	1466	448	3/1:25	Many clams	
17	Niskin-5	1448	780	1469	454	3/1:40	starboard	

Alvin Dive Log Draft; video observations will be included

Dive number: **3422**
Area: **Southern Hydrate Ridge; area of high Side-Scan-Sonar reflectivity; TV-G 18**
Date: 3 July 1999
Bottom time: 8:47 - 14:50
Pilot: Bob Waters
Port observer: Marta Torres
Starbord observer: Gerhard Bohrmann
Origin of XY coord.: 44° 34'N; 125° 10'W

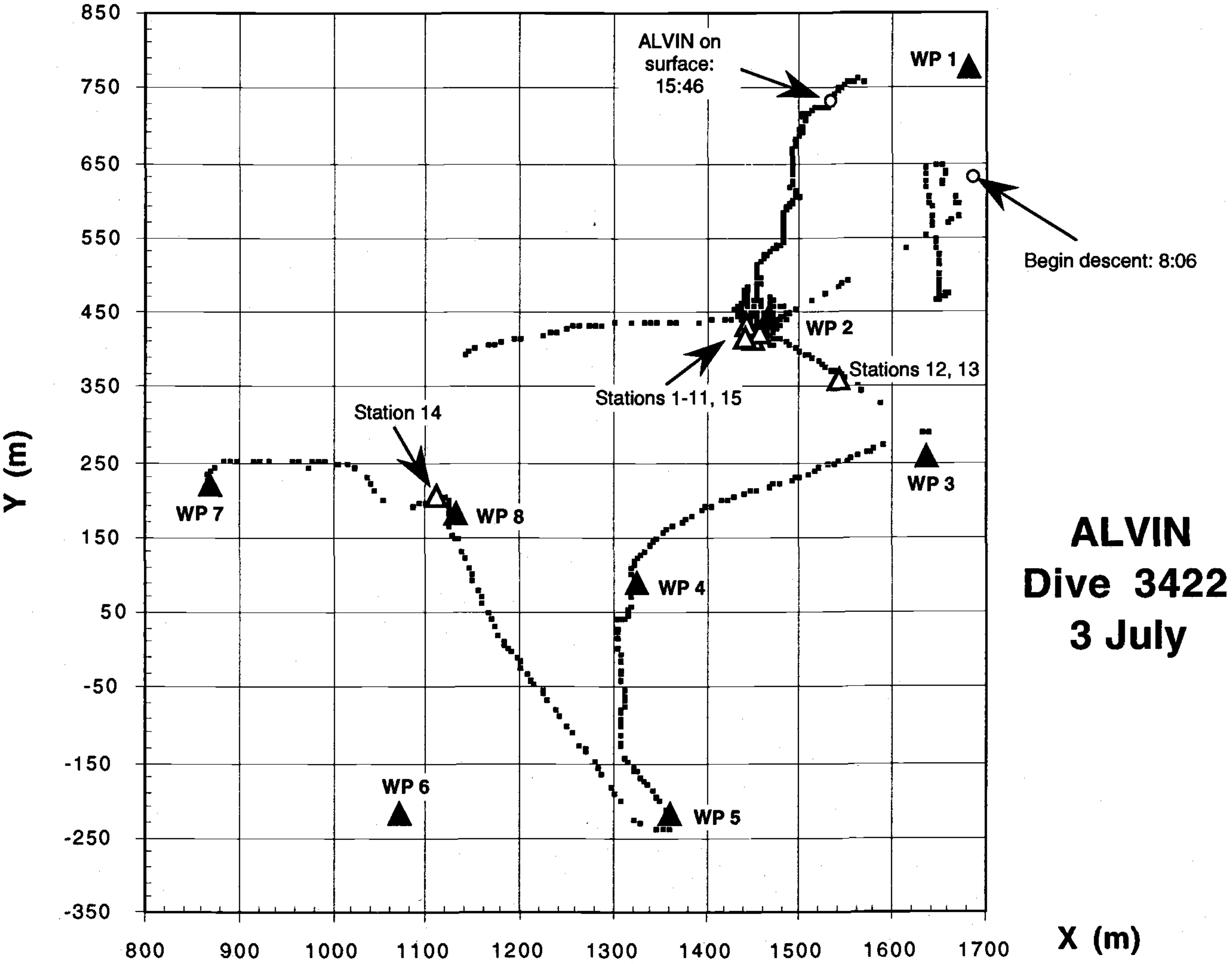
Objectives: Conduct survey of the area; search for evidence of active venting (live clam colonies, gas hydrate exposed at seafloor, carbonate deposition). Deploy thermal blanket (UW), recover two benthic chambers (OSU, USC) and collect bottom water samples (4 Niskin bottles), slurp samples of vent bacteria, push cores (6), clams and carbonates.

Summary: Thermal blanket deployed; 3 push cores from two areas: from a clam-covered surface and outside the clam area with no obvious fluid activity; sampling of clams, gas hydrate carbonates as well as water samples in the area from and around the bacterial mats. Found orange bacterial mats (sampling by slurp gun). Survey of the high reflectivity area comming from the N to the E, SE and to the W. Observation of active venting (white and orange bacterial mats, few clams) near the top of the 50m high chemoherm. Sampled the chemoherm carbonates; recovered two benthic chambers from OSU and USC; OSU chamber was lost on the way back to the surface.

Time	**X**	**Y**	
07:59			Sealing the hatch
08:03			ALVIN free of ship (44°34.352'N 125°08.253'W)
08:06	1689	620	Begin descent
08:09	1691	468	Lost the thermal blanket
08:47	1658	471	At the bottom (765m), going to the north looking for the thermal blanket; pretty benthic life (grabs, snails, fishs); soft sediment with few carbonate slabs; slurp gun also loose from basket.
09:04	1665	593	Thermal blanket found approximately 16 m from the drop point;
09:10	1665	592	Recovered blanket proceed to target; based on the observed seafloor along the last 200m decided to go not to WP 1 (X=1681; Y=777; 125°08.73'W 44°34.42'N) instead go to WP 2 (X=1458; Y=426; 125°08.89'W 44°34.23'N)
09:13	1656	566	Few dead clams of Acharax on soft sediment surface
09:22	1475	439	USC chamber was observed
09:36	1446	433	Found white patch approx. 10m away from the instruments; thermal planket deployed on a white mat (station 1)
09:42	1442	438	Waiting for mud to settle
09:49	1445	433	Deploy path finder/sonar transponder
09:55	1432	453	Sonar test was ok; steaming to a clam hash area next to the mat;
10:08	1450	425	Lots of live clams
10:11	1451	425	Collect clams by a scoop (station 2);

10:30	1451	423	Sampling of a carbonates with the port manipulator (station 3)
10:45	1452	419	Bottom water sample/ Niskin bottle 1 (port inside; station 4)
10:50	1452	421	Push core (USC) from a clam-rich area (port aft 3; station 5)
10:51	1452	422	Push core (USC) from the same area; short core (port mid 2; station 6)
10:53	1452	421	Push core (Alvin) from the same area (port front 1; station 7)
10:58	1450	414	Push core (USC) from outside a clam-rich area (starboard mid 4; station 8)
11:00	1450	413	Push core (USC) from the same area (starboard aft 6; station 9)
11:02	1450	413	Push core (Alvin) from the same area (starboard front 5; station 10)
11:06	1445	415	Bottom water sample/ Niskin bottle 5 (port outside; station 11) 5m above seafloor
11:08	1444	419	Flowmeter was observed; heading to WP 3 (X=1641; Y=259; 125°8.76'W 44°34.14'N)
11:16	1543	360	Big patch of orange mats observed on a mound approx. 1.5 m high
11:19	1544	361	Bottom water sample/ Niskin bottle 3 was taken above the bacterial mat (starboard inside; station 12)
11:21	1544	360	Slurp sample from the orange and white mats (station13)
11:29	1560	349	Relief on seafloor; heading to WP 3 (X=1641; Y=259; 125°08.76'W 44°34.14'N)
11:32	1632	293	Sediment surface was just soft sediment; 16m away from WP 4
11:36	1632	287	Navigation errors; waiting for better navigation; starfish cluster
11:42	1636	287	Soft mud, some carbonate slabs.
11:59	1321	86	Heading to the south to WP 5 (X=1363; Y=-222; 125°8.97'W 44°33.88'W)
12:03	1312	37	Still muddy sediment; used probe to see how deep it can penetrate: 3-4 cm penetration in soft sediment, no rocks or hydrate.
12:15	1321	-160	Sediment has more evidence of bioturbation; few carbonate slabs
12:22	1360	-241	Heading for WP 8 (X=1138; Y=185; 125°09.14'W 44°34,10'N)
12:27	1263	-129	Came to a scarp 4m deep step
			Sediment surface without strong fluid activity;
12:40	1124	179	Carbonate mound was reached; steaming 25m up to the top of the chemoherm; flanks show a lot of huge carbonate blocks that form debris at the lower slope. The top of the chemoherm is fractured and some blocks seem to fall down. Rough area; Venting activity in a small area was documented on top of the mound by bacterial mats and a few live clams.
12:43	1120	201	Reache the summit of the chemoherm
12:53	1113	196	Sample of a carbonate piece with mats on it from top of the chemoherm (station 14); loose bottom contact during descent of the mound to SE
13:15			Heading back to WP 7, bad navigation
13:23			Upslope soft sediment, bad navigation
13:43			Using temperature probe in the water: 4.13°C
13:43			Temperature probe in the sediment: algal mat with small clams surrounded by carbonates: initial temperature 4.41°C; waiting with probe in the mud; went in to 5-7cm. Temperature reading after 5 min: 4.16°C
13:57			Temperature measurement in a muddy area (background); water reading: 4.13-4.14°C; temperature change during insertion in the sediment up to 4.14°C.
14:01			Head to pick up the chambers
14:05	1456	433	Bottom water sample/ Niskin bottle 2 (starboard ouside) (station 15)

14:08	1455	433	pick up OSU chamber
14:30	1465	451	USC chamber checked; stirring okay, door was closed
14:34	1467	438	pick up the USC chambe
14:48	1468	437	A few bubbles were observed
14:50	1468	436	Ready to go to the surface
14:51	1466	437	Leave the bottom (764m)
14:57	1452	478	700m --> 11m/min
15:21	1493	610	482m --> 16m/min
15:46	1532	732	ALVIN on the surface
15:52	1574	750	Lost the OSU chamber
16:06			ALVIN on deck



ALVIN
Dive 3422
3 July

Bottom sample sediment record summary sheet								
DIVE 3422		HYDRATE RIDGE SOUTH						
Station #	Type	Time	Depth	Lat (N)	Long (W)	X	Y	Comments
1	Thermal Blanket	936	777	44 34.234'	125 08.908'	1446	433	Blanket deployed
2	Clam scoop	1011	778	44 34.230'	125 08.900'	1451	425	
3	Carbonate slabs	1030	778	44 34.228'	125 08.904'	1451	423	Carbonate slabs with sharp edges from clam patch area
4	Niskin Bottle (P-I)	1044	778	44 34.228'	125 08.900'	1451	422	bottom water sample, bottle #1
5	Push core USC	1050	778	44 34.227'	125 08.903'	1452	421	from clam area- port aft #3
6	Push core USC	1051	778	44 34.234'	125 08.903'	1452	422	from clam bed, short core- port mid #2
7	Push Core Alvin	1053	778	44 34.234'	125 08.903'	1452	421	from clam area-port front #1
8	Push Core USC	1058	779	44 34.223'	125 08.905'	1450	414	from sediment on rim of clam patch -starboard mid #4
9	Push Core USC	1100	778	44 34.223'	125 08.905'	1450	413	from sediment on rim of clam patch -starboard aft #6
10	Push Core Alvin	1102	779	44 34.223'	125 08.905'	1450	413	from sediment on rim of clam patch -starboard front #5
11	Niskin Bottle (P-O)	1106	773	44 34.224'	125 08.909'	1445	415	5 meters above bottom, over clam patch, bottle #5
12	Niskin Bottle (S-I)	1119	771	44 34.195'	125 08.833'	1544	361	Over bacterial mats, undisturbed bottom, bottle#3
13	Slurp Gun	1121	772	44 34.195'	125 08.834'	1544	360	Orange and white mats
14	Carbonate slab	1253	774	44 34.106'	125 09.160'	1113	196	Carbonate slab from top of pinnacle, with mats on them
15	Niskin Bottle (S-O)	1405	778	44 34.234'	125 08.900'	1456	433	Tripped right over chamber, bottle #2

Alvin Dive Log

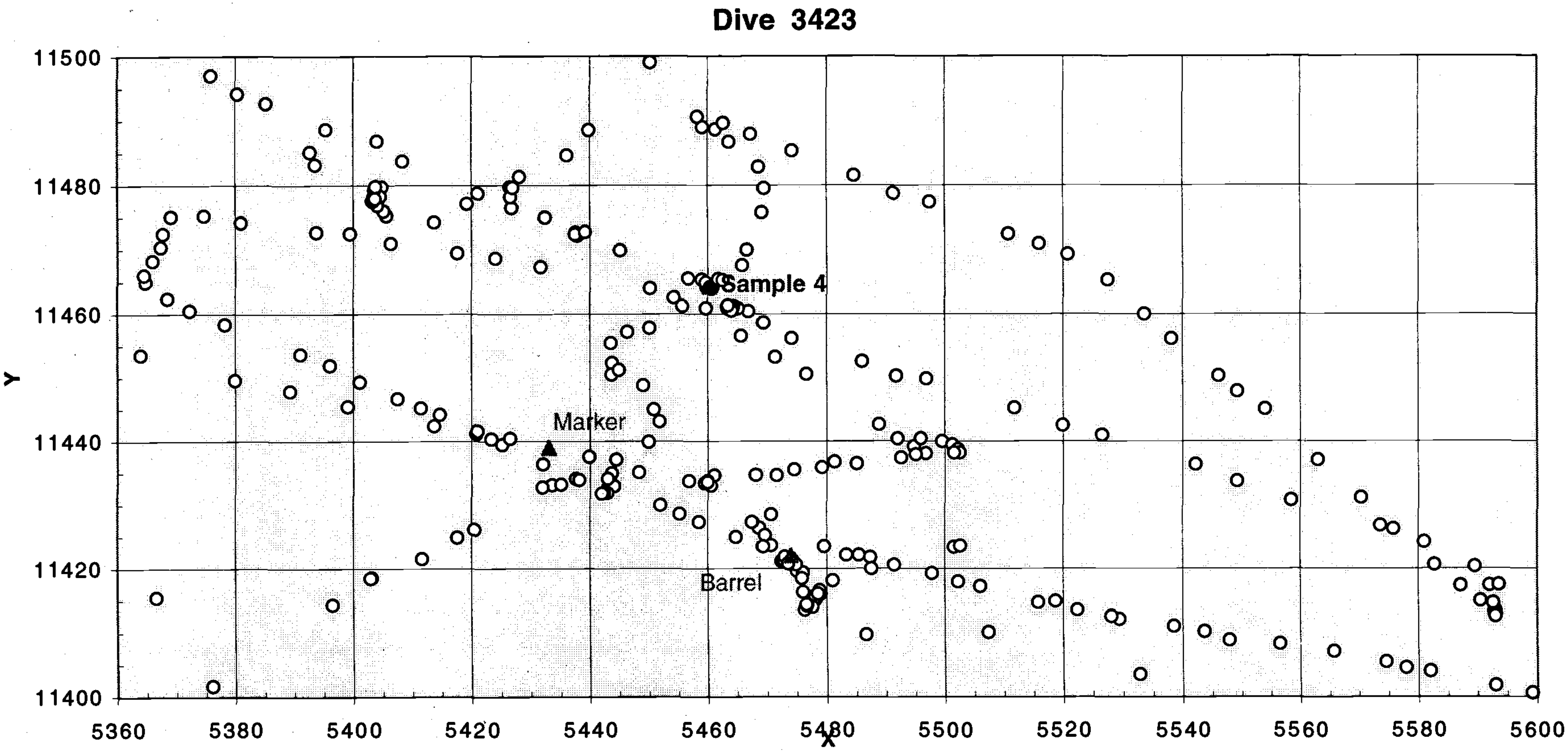
Dive number:	**3423**
Area:	**Northern Hydrate Ridge; area of high Side-Scan-Sonar reflectivity and known gas venting sites**
Date:	4 July 1999
Bottom time:	8:36 - 15:16
Pilot:	Bob Brown
Port observer:	Heiko Sahling
Starboard observer:	Thomas Naehr
Origin of XY coord.:	44° 34'N; 125° 10'W

Objectives: Conduct survey of the area; search for sites with gas venting and other evidences of fluid flow. Measure gas flow rates, collect gas samples (4 gas sampler), produce or collect gas hydrate and store it in hydrate sampler, collect bottom water samples (4 Niskin bottles), slurp samples of vent bacteria, push cores (4), box core (1), clams and carbonates. Photoprofile along dive track.

Summary: Venting of gas was not observed although ESS 6 and ESS 9 had shown flares, and bubbles had been documented during SO 110 and TECFLUX 1998. Extension of fluid venting based on biological and geological observations was mapped.
ESE-WNW transects across the area showed variations in the extent of carbonate cementation and in the distribution of clam patches and bacterial mats. Apparently, the clams follow a linear structure (fault?) trending approximately 30 degree SW-NE. In this area, carbonate cementation seems to be less extensive. The distribution of the carbonate pavement is less evident. However, extensive carbonate formation resulting in > 5m thick slabs was observed in the western part of the survey area. Cracks on the cm to m scale separate the slabs into large blocks.
Samples: 2 Niskin over clam sites, 2 pushcores in clam field, 1 pushcore some 10 Meters outside of clam field, 2 rock samples (Carbonates). Photoprofile along dive track (860 pictures taken by outside still camera).

Time	**X**	**Y**	
08:05			Alvin in the water
08:33			Start recording videos
08:36	5616	11284	At the bottom, landing on inactive seep with clamshells, start with photoprofile (port camera first photo no. 121)
08:50			Heading for WP 1, 1-2 m big carbonate blocks
08:59	5623	11396	At WP 1, heading for WP 2, small fields with clamshells, school of fish (cod?)
09:11	5474	11421	barrel (needs to be recovered?)
09:18	5425	11439	metal frame, cone-shaped
09:22	5365	11466	circle around the area close to the barrel to look for gas bubbles
09:37	5460	11433	heading to WP 2 as no barrel/ gas bubbles could be found
09:42			less carbonates, more sediment
09:54			many purple sea urchins
10:00	5011	11586	at WP 2, around this area some small depressions and ridges with very gentle slopes and heights of a few meters, heading to WP 3

10:06	5036	11535	clamshells
10:10	5039	11524	**Sample 1**, grabbing carbonate with rounded edges, and grayish coat of bacteria, looking around with 3-chip camera
10:25			continue heading to WP 3
10:28			clamshells, at rim of slope
10:32			changing videotapes, sitting on bottom
10:36	5052	11371	at WP 3, heading for WP 4
10:49	5352	11285	very large area with living (?) clams
11:00			sitting down, need to wait until sediment cloud has gone, trying to take a pushcore within clams, ground below too hard to penetrate, probably cemented by precipitates, stop video recording from 11:20 to 11:30
11:30			continue heading to WP 4
11:34			big clam field, many alive (?)
11:39			Thomas sees an octopus on starboard, dead spider crabs all over the place!
11:45	5647	11184	at WP 4, heading south to WP 5
			soft sediment with loads of purple sea urchins
11:51	5676	11050	at WP 5
12:00			heading for WP 6
12:14	5432	11117	carbonates and clamshells, big area with bacterial mats on port
12:22	5290	11159	small depression of about 15 m in diameter, whole area is full of clamshells, some bacterial mats
12:23			sitting down, waiting for the water to clear, stop video tape for some minutes
12:28			start video and looking around with 3-chip camera
			taking 2 Alvin pushcores within the clam field (**sample 2 & 3**) and 1 Niskin bottle over a bacterial mat (**sample 4**)
12:56			change of video tapes (now no. 3)
			Trying to get carbonate sample but were unable to break off a sample
13:18			heading for WP 6
13:26			**sample 5**: getting carbonate sample
13:38			heading E to get to active venting area (bubble site) again
13:50			still carbonates but more sediment now
14:10	5438	11472	large area with clams, weights from "Scripps" flow meter
14:15			**sample 6**, taking Niskin over very big clam area
14:26			loop around the field, heading to WP 1
14:35			trying to close Niskin bottles but box core in the way
14:47			at site of "gusher" observed during ROPOS-dive in 1998 but no evidence for gas venting, heading SW 225° to follow active area
14:55			**sample 7**: sitting down to take APC to catch one of the purple sea urchins which are very abundant here.
15:10			continue heading 225°
15:16	5404	11480	need to surface as battery power now too low.


Dive 3423
Sample 4
Marker
Barrel
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A3423.sample summary

Bottom sample sediment record summary sheet									
DIVE 3423		HYDRATE RIDGE NORTH							
Station #	Type	Time	Depth	Lat (N)	Long (W)	X	Y	Comments	
1	Rock Sample	10:10	612	44°40.2224	125°06.1942	5039	11524	Carbonate with grey bacteria	
2	Alvin Push Core	12:44	603	44°40.0231	125°06.0040	5291	11155	within clam field, in big clam area, APC 2=CB	
3	Alvin Push Core	12:44	603	44°40.0231	125°06.0040	5291	11155	within clam field, in big clam area, APC 1	
4	Niskin Bottle	12:44	603	44°40.0231	125°06.0040	5291	11155	over bacterial mat, in big clam area	
5	Rock Sample	13:10	600	44°40.0814	125°06.1540	5079	11263	block of carbonate	
6	Niskin Bottle	14:15	594	44°40.1899	125°05.8754	5461	11464	water sample within very big clam area	
7	Alvin Push Core	14:55	602	44°40.1284	125°06.0054	5289	11350	within pink sea urchin colony, ca. 10 m outsite active vent site, APC 3=CA	

10/28/99

Alvin Dive Log

Dive number: **3424**

Area: **Southern Hydrate Ridge; Area of high Side-Scan-Sonar reflectivity; TV-G 18 and carbonate spire**

Date:	5 July 1999
Start down:	08:18
Bottom time:	09:00 - 14:25
Pilot:	Steve
Port observer:	Erwin Suess
Starbord observer:	Marie de Angelis
Origin of XY coord.:	44° 34'N; 125° 10'W

Objectives:

- Locate Lander (McManus) and take it to Barrel site (WP 2);
- Deploy Barrel (Torres) inside bacterial mat field near WP 2;
- Visit carbonate spire (WP 8) via WP 3 and/or WP 7; map structure, pick up carbonate slabs, crusts; look for fluid exits on summit; document extent of live biota; observe strike, dip, and bedding;
- Return to Barrel site (WP 2);
- Take 2 push/box core transects: bacterial mat - clam field - mud; with box cores in center of bacterial mat;
- Collect representative organisms in relation to bacterial mat field;
- Load Barrel and Lander.

Summary:

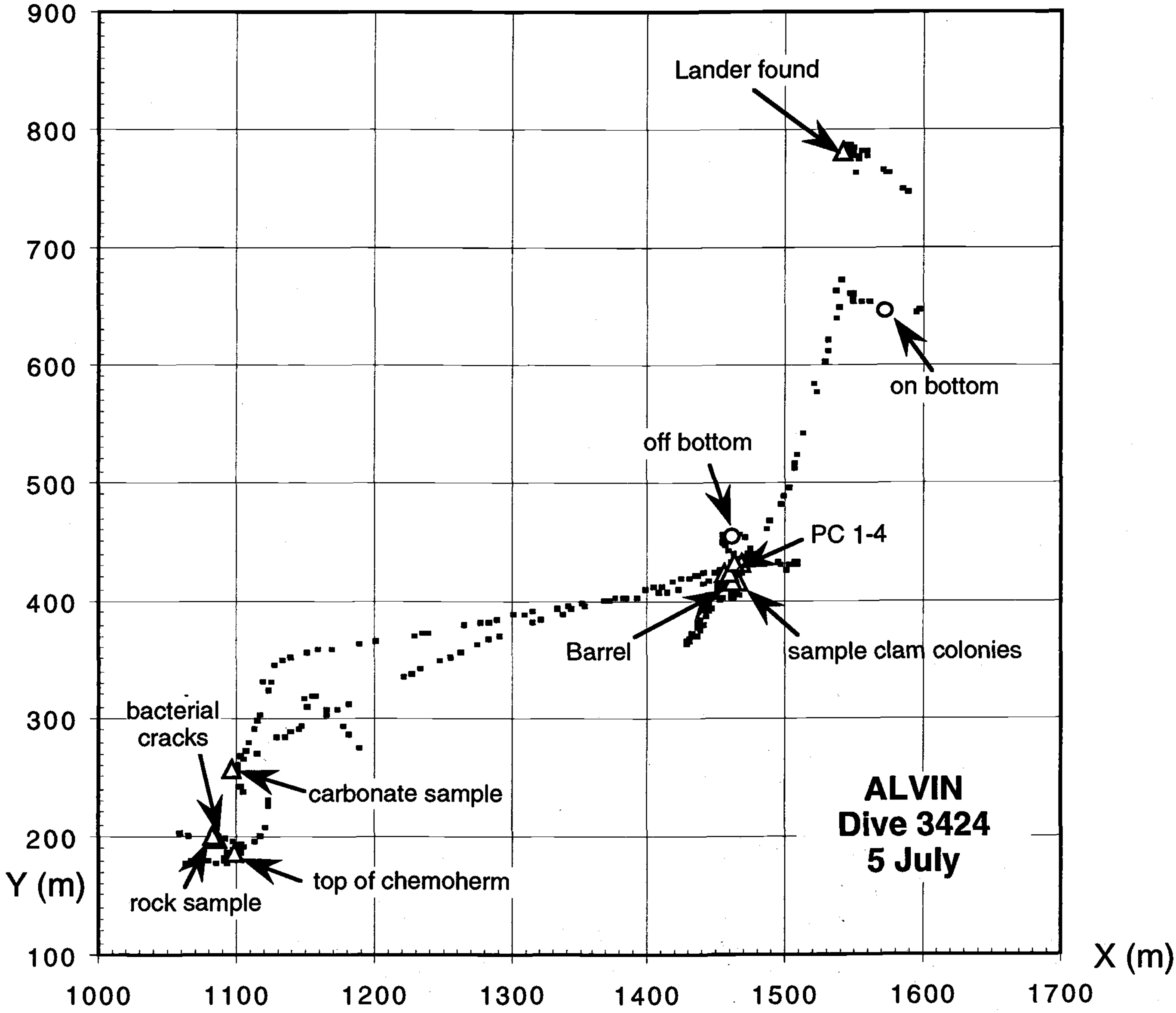
Located lander with radar; picked up lander and searched for active vent/gas hydrate site near TV-G 18; deployed barrel inside depression with several patches of bacteria and isolated clams; numerous clam colonies of small individuals around slightly elaveted rim around depression;

Headed for Carbonate Spire directly without surveying sea floor; ascended carbonate spire from talus slope to summit (shallowest depth 774m); explored summit area; descended 4 m and sampled slab of carbonate with biota; descended 20 m and picked up big slab with conglomerates and cemented breccia; descended 15 m (deepest depth 810m) and picked up loose sample from talus slope.

Returned to barrel directly without surveying sea floor; passed over thermal blanket, active flasher, and flux meter G; sampled clam colonies and 1 push core from rim above depression; 3 push cores from bacterial mats around barrel; observed small mounds of greyish material with sugary texture, not resembling bacteria, suspected hydrate; attempted 1 box core but experienced problems with closing shutters (how many turns ?); loaded and tied up barrel; headed for lander; loaded and tied down lander and all gear and headed for the surface.

Time	X	Y	
09:00	1534	669	Stopped 20 m above bottom to trim boat; depth = 761m Descended to bottom; muddy surface few organisms; conspicuous burrows; turned on radar; spotted strong return at 150 m 310 degr.
09:05	1572	645	Start tapes
09:08	1591	644	Bottom sighted; mostly mud, some brittle stars, small rattails
09:23	1541	782	At 785 m depth reached lander; upside down with T-bar partially buried; no apparent damage; tipped up lander and loaded aboard;
10:00	1460	402	Deposited lander near prospective barrel deployment site; small clams present
10:28	1461	429	Placed barrel on thick bacterial mat partly up slope and inside a large depression (2-4 m diameter; 777 m depth)
10:35			Attempted to pull switch; bumped barrel slighly
10:37			Several attempts to pull switch needed because rubber bands twice pulled switch magnets back together;
10:38			Barrel cycle starts; window temperature = 4.1°C
10:39	1461	428	Head 280 degr. until y = 1130; change course 180;
10:50	1198	365	
			Field of carbonate blocks; fractures; ascend 90 degr. wall over fractures and thinly banked carbonate strata (no bedding but appeared chemical layering)
11:00	1101	186	Reached top of spire (774 m);
11:05			Explored top platform ca. 5 x 15 m (773) no higher spot around;
11:07	1089	185	Observed thickly matted bacterial covers (orange); white (long fibrous) hairy bacterial mats and solidly cemented bivalve shells in live position; orange bacterial mat with center hole (2 cm diameter); few organisms except for anemone-like items; very thick white feathery filaments observed primarily around cracks and openings
11:11			Changed tape
11:25	1089	195	Sampled rock ledge witrh heavy bacteria mat and other biota; placed sample in BOX 1 (portside); Attempted to determine strike: 300 degr. and dip 30° Descended 20 m through tensional fracture patterns; disticntly less biota moving downslope At 783 m bolders start top appear
11:34	1084	200	At 784 m 5-meter long crack, horizontal, ca. 10 cm wide filled with white bacteria; going off in the distance At 790 m huge vertical crack 10 m deep up to 2 m wide;
11:35	---	---	Losing navigation at 794 m; stop for sampling piece of large flat slab; observe banking of cemented sediment, conglomerates and pure carbonate (chemical ppts.?); place sample on rack between basket and Alvin; Descend down talus slope; no longer vertical
11:45	---	---	Still no navigation fixes; 810 m muddy floor with boulders; heading 126 facing slope; dead Solemya shells heavily corroded; sample rock from base of talus slope; place in BOX 2 (starboard); depth = 812m
12:01	1098	255	Completed work on Carbonate Spire; headed back for barrel;
12:20	1462	428	Reached barrel; passed over thermal blanket and flux meter G; also observed in the vicinity one sole active flasher with short white barrel;

12:22	1462 429	Clam colonies of small densely populated locations on top of slightly elevated rim surrounding depression; place 2 big scoops on BOX 2 (starboard on top of rock sample); depth = 777 m.
12:42	1457 431	Depth 778 m; Push core 1 from elevated rim surrounding depression; placed aft 1
12:47	1458 431	Push core 2 from bacteria mat next to barrel (about 20 cm distance); placed aft 2; depth = 778 m.
12:52	1468 436	Changed position to opposite rim of depression near large bacterial mat. Nice bullseye pattern of bacterial mat surrounded by clams. Bare "bullseye" in middle but slightly off-center; depth = 777 m. Push core 3 from bacterial mat; placed aft 3.
12:59	1469 435	Push core 4 from middle of bacterial mat near bare bullseye; placed aft 4. Observed suspected hydrate on small mounds inside depressions as whitish-grey material with sugary texture -not resembling bacteria-; no organisms in vicinity of mounds.
13:07	1505 432	Changed position to outside depression; looked for muddy surface without clams or bacterial for background sample; attempted box core several times but failed to close shutter
13:35	1467 432	Returned to benthic barrel. Deployed temperature probe under barrel. T=4.195 °C @13:36, 4.139 °C@13:38, 4.131 °C@ 13:39, 4.135°C @13:39; ambient T (probe) in front of sub = 4.154 °C
13:41	1465 431	Picked up barrel; lat 44N34.235 long 125W 8.895
14:25	1452 454	Left bottom
15:45		Arrived at surface
16:10		Alvin out of water and on board Atlantis


Lander found
on bottom
off bottom
PC 1-4
Barrel
sample clam colonies
bacterial cracks
carbonate sample
top of chemoherm
rock sample
ALVIN
Dive 3424
5 July
Y (m)
X (m)
900
800
700
600
500
400
300
200
100
1000
1100
1200
1300
1400
1500
1600
1700

Bottom sample sediment record summary sheet

DIVE 3424		**Southern HYDRATE RIDGE**						
Station #	Type	Time	Depth	Lat (N)	Long (W)	X	Y	Comments
1	Carbonate rock	11:31	773	44 34.104	125 09.170	1099	192	Baseball-glove-size rock taken near top of spire; placed in BOX #1
2	Carbonate rock		797			no fix	no fix	Large conglomeratic rock; midway downslope; placed on rack
3	Carbonate rock	11:51	812			no fix	no fix	Rock brocken off large boulder at talus base; placed in BOX #2
4	Clam scoop	12:22	777	44 34.232	125 08.896	1462	429	Clams from general area of Benthic barrel; 3 scoops; BOX #2
5	USC-push core	12:47	777	44 34.233	125 08.899	1458	431	From bacterial mat near Benthic barrel site; placed 2nd aft.
6	USC-push core	12:42	778	44 34.233	125 08.899	1458	432	From rim of depression near clams; quiver aft;
7	USC-push core	12:52	777	44 34.235	125 08.891	1468	436	From bacterial mat opposite Benthic barrel; placed 3rd aft.;
8	USC-push core	12:59	777	44 34.235	125 08.891	1469	435	From middle of bacterial mat opposite Benthic barrel; placed #4;
9								
10								
11								
12								
13								

Alvin Dive Log

Dive number: **3425**

Area: **Northern Hydrate Ridge;**
Area at eastern rim of "Champagne Hill" including TECFLUX '98 area

Date: 6 July 1999
Start down: 07:58
Bottom time: 08:41 - 1
Pilot: Bruce
Port observer: Mike Tryon
Starboard observer: Dudley Foster
Origin of XY coord.: 44° 34'N; 125° 10'W

Objectives:

- Locate 5 flux meters deployed from ship at WP 1 (dive site);
- Deploy 3 flux meters near WP 1 (dive site);
- Carry remaining 2 flux meters and survey eastern border of ring feature (WP 2 thru WP 13);
- Deploy remaining 2 flux meters somewhere along the way;
- Collect 6 push cores;
- Collect temperature probe measurements;
- Collect 4 water samples;
- Collect gas samples if significant bubbling vent found;
- Collect live clams from seep sites;
- After last flux meters positioned, retrieve "Teapot" when convenient;
- If no suitable site for 2 carried flux meters are found they will return to WP 1 for deployment;
- If all above completed we will survey along the "ring fault":

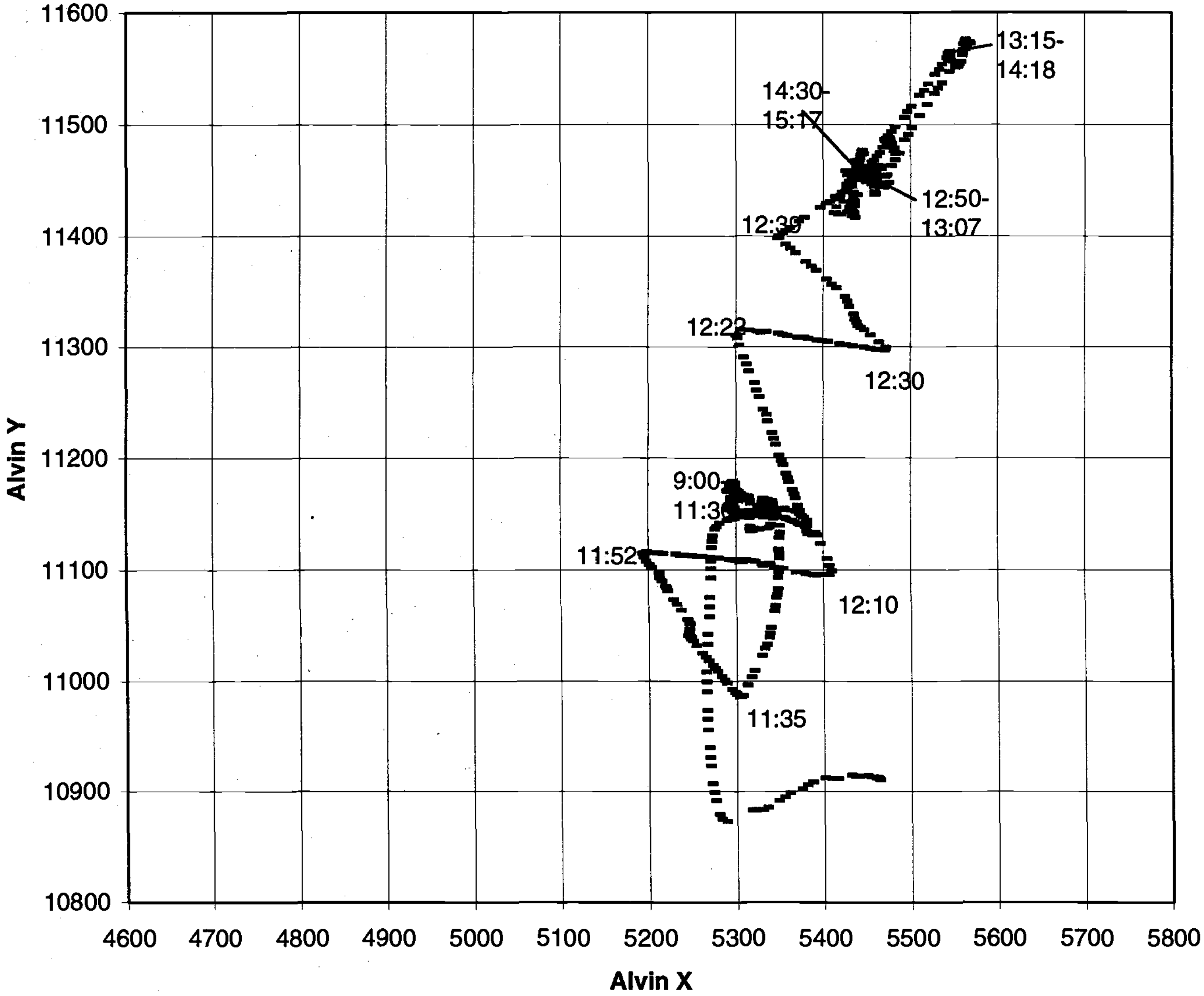
Summary:

The flux meters were quickly located and two of them were loaded onto the basket. We continued west to the site seen on dive 3423 where suitable deployment sites were found on and around both live and dead clams and exceptionally thick microbial mats. The site was along the top of a sedimented ridge line roughly aligned N-S. A few bubbles were released when the sediment was disturbed by the deployments. We continued surveying the eastern rim of the structure noted on the side-scan survey. To the east and south there is fairly uniform sediment with typical non-seep life (urchins, anemones, various fish). There is a rise to the west, at times stepped and marked by prominent rocky outcrops, generally striking approximately N-S and dipping W ~30-45°. A "seep zone" generally parallels this trend and is located near the top of the rise. It consists of generally patchy clam fields which are sometimes roughly linear, and/or patches of white microbial mat. The clam fields appear to consist of predominantly dead clams and disarticulated shell but some signs of live ones are there (most are presumed buried). The mats in the southern deployment area are exceptionally thick and opaque. On arriving at the TECFLUX '98 "gusher" site we attempted to relocate the gas vent and site marker, but were unsuccessful. We continued to "clam 3" where we recovered some of the marked clams and deployed one of the flux meters. While returning to the gusher site, the last meter was deployed at "clam 2". The "gusher" site marker was found and recovered and some bubbling was seen at the site but at a barely perceptible rate. Two niskin bottles were tripped. A new marker was deployed and we returned to the surface.

Time	**X**	**Y**	
08:41	5457	10912	on bottom, beginning search for flux meters
9:07	5331	11161	found flux meters, picking up meters C, F, depth 601m
9:30			looking for deployment sites near WP1
			found area of many clam fields which appear mostly dead ones (shell) on surface, also many thick white microbial mats 1-3 m across
10:21	5290	11171	C placed in thick white microbial mat
10:45	5290	11163	F placed in thick white microbial mat
10:59	5287	11155	D placed in clams in depression downslope of others
			a few bubbles are released when the mats are disturbed but we didn't see this until reviewing the tapes
			going to pick up last two meters
11:30	5350	11154	begin surveying, heading to WP2
			initially heading down gentle rock covered slope to south
			few snails, no seep indicators
11:38	5308	10996	at WP2, 604m, fairly flat and rocky
			climbing rise, ridge off to right, increasing shell but no life signs
11:45	5242	11040	seeing mats similar to deployment site, clams (mostly dead)
11:52	5191	11113	passing over ridge with carbonate rock outcrop at top ~1m high striking ~45°
11:53	5189	11114	WP3
11:54	5197	11115	passing over same ridge as above, some shell & thin mats on other side
12:00	5303	11107	passing depression with larger clams in it, no mats
			after this becomes mostly sediment with no seep indicators
12:10	5402	11096	WP4
12:12	5387	11133	passing linear shelly area with some carbonate outcrops striking ~335°

12:14	5375	11139	crossing an Alvin track from dive 3423, starting to see pockets of clams, still mostly sediment
12:17	5353	11186	getting rocky, looks like lots of burrow casts on surface, lots of snails nearby but no seep indicators, most of the vicinity looks like rocky sediment with widely scattered shells and no seep indicators
12:21	5316	11267	getting rockier, linear shelly area striking ~335°
12:22	5305	11290	WP5
12:25	5331	11314	passing over ridge with carbonate outcrop on top striking ~335°, followed by numerous similarly aligned carbonates, widely scattered shell
12:29	5429	11301	passing over ~1m vertical drop-off aligned ~335° followed by slope down to sediment
12:30	5457	11297	WP6, don't see step back up as expected so it must be a local feature as we should be within ~25m of it
12:34	5430	11330	passing area of what appears to be burrow casts on surface again followed by some sparse shelly areas, then outcropping planar rock dipping ~45° and striking ~000°, this outcrop is quite extensive and fairly devoid of shell
12:38	5352	11392	WP7, we've dropped ~5m in above described outcrop, now turning to run across this grain, outcrop may strike a little more to west of north than previously thought (or it has changed)
12:41	5374	11416	passing over top of ~N-S aligned ridge and have climbed 7m, large patches of clams and some very small microbial mats in amongst rocks
12:43	5417	11439	we appear to be following the strike of an outcrop (060°) that dips to the left ~30°
12:44	5441	11453	WP8, beginning search for "teapot" site marker and "gusher"
			we are unsuccessful and head for WP9 (Clam 3)
13:20	5540	11560	at WP9, remove clam corral and take two scoops of clams, replace corral, move last year's base to side and place new meter (E) on approximately the same spot
14:17			heading back to WP8
14:49	5479	11484	last flux meter deployed at last years Clam 2 site, very near Clam 1
15:17	5431	11427	"teapot" seen, few bubbles seen at last years "gusher" site, two niskin bottles tripped, marker 6 deployed, "teapot" recovered
			heading to surface

Dive 3425



11600
11500
11400
11300
11200
11100
11000
10900
10800
Alvin Y
4600
4700
4800
4900
5000
5100
5200
5300
5400
5500
5600
5700
5800
Alvin X
13:15-
14:18
14:30-
15:17
12:50-
13:07
12:39
12:22
12:30
9:00-
11:30
11:52
12:10
11:35

Sample record summary sheet										
DIVE 3425		HYDRATE RIDGE NORTH								
Station #	Type	Time	Depth	Lat (N)	Long (W)	X	Y	Comments		
1	SIO flux meter C	10:21	603	44° 40.031	125° 6.005	5290	11171	C placed in thick white microbial mat		
2	SIO flux meter F	10:45	604	44° 40.027	125° 6.005	5290	11163	F placed in thick white microbial mat		
3	SIO flux meter D	10:59	605	44° 40.023	125° 6.007	5287	11155	D placed in clams in depression downslope of others		
4	clams	13:00	602	44° 40.242	125° 5.816	5540	11560	lost on the way up		
5	SIO flux meter E	13:20	602	44° 40.242	125° 5.816	5540	11560	E placed in clams at last year's Clam 3		
6	SIO flux meter I	14:49	598	44° 40.201	125° 5.862	5479	11484	I placed in clams at last year's Clam 2		
7	2 niskin bottles	15:17	588	44° 40.170	125° 5.898	5431	11427	gusher site, valves open, samples lost		

Alvin Dive Log Draft; video observations will be included

Dive number: **3426**
Area: **Northern Hydrate Ridge; Gusher area**
Date: 7 July 1999
Bottom time: 8:45 - 13:40
Pilot: Bob Waters
Port observer: Marta Torres
Starbord observer: Gisela Winckler
Origin of XY coord.: 44° 34'N; 125° 10'W

Objectives: Deploy Barrel (Torres) inside bacterial mat south of the gusher site Find bubbling site from TFX98 cruise, record episodicity of flow, Collect gas samples, as well as sediments, carbonates and representative organisms in relation to bacterial mat field.

Summary: Deploy benthic barrel on algal mat, nest to SIO FM C; approximately 200 meters southwest of the gusher site. Arrived at Gusher site (now marker 6) at 10:10, noticed very few bubbles, released from a conduit at about 15 second intervals. The rate os flow increased dramatically within the next hour. Collected Gas samples, obseved venting on three distinct localities at this site, sampled carbonates on the rim of the gusher, made temperature measurements, and collected water samples. Recovered Barrel, cored the area around barrel. Returned to the surface.

Time	**X**	**Y**	
07:55			Sealing the hatch
08:10	5575	11151	ALVIN cleared for diving
08:41	5624	11232	tapes started
08:45	5567	11206	At the bottom soft mud
08:50	5591	11292	Carbonate rubble;
08:51	5561	11270	Back to soft sediment
08:55	5352	11151	Carbonate patches, this sediment cover. Depresion in seafloor
08:58	5303	11150	Find flowmeters on seafloor, look for a patch to deploy barrel
09:16	5293	11169	Collect water samples in Niskins (2) over flow meter and barrel sites, before deploying the barrel (stations 1&2)
09:30	5297	11166	Deployed benthic barrel on algal mat next to SIO Flowmeter "C". (station 3)
09:45	5304	11166	Engage Barrel
09:48	5306	11162	On route to Gusher site, off the port side observe clam fields which align in narrow bands, also small circular patches of clams among sediment and carbonate rubble.
10:00	5345	11240	More rubble
10:08	5422	11381	small clam field among large slabs of carbonate
10:10	5438	11417	Big depression about 3 to 4 meters deep, algal mats at the bottom. This is the location of Marker 6.
10:14	5451	11435	Observe few bubbles comming from a hole among carbonates. Bubble discharge is slow, with about 15 seconds between discharge episodes
10:21	5451	11434	Collect water sample in Niskin bottle, 2 to 3 meters away from the bubbling hole (station 4)
10:23	5448	11434	Observe another discharge site with the Pan and Tilt camera.

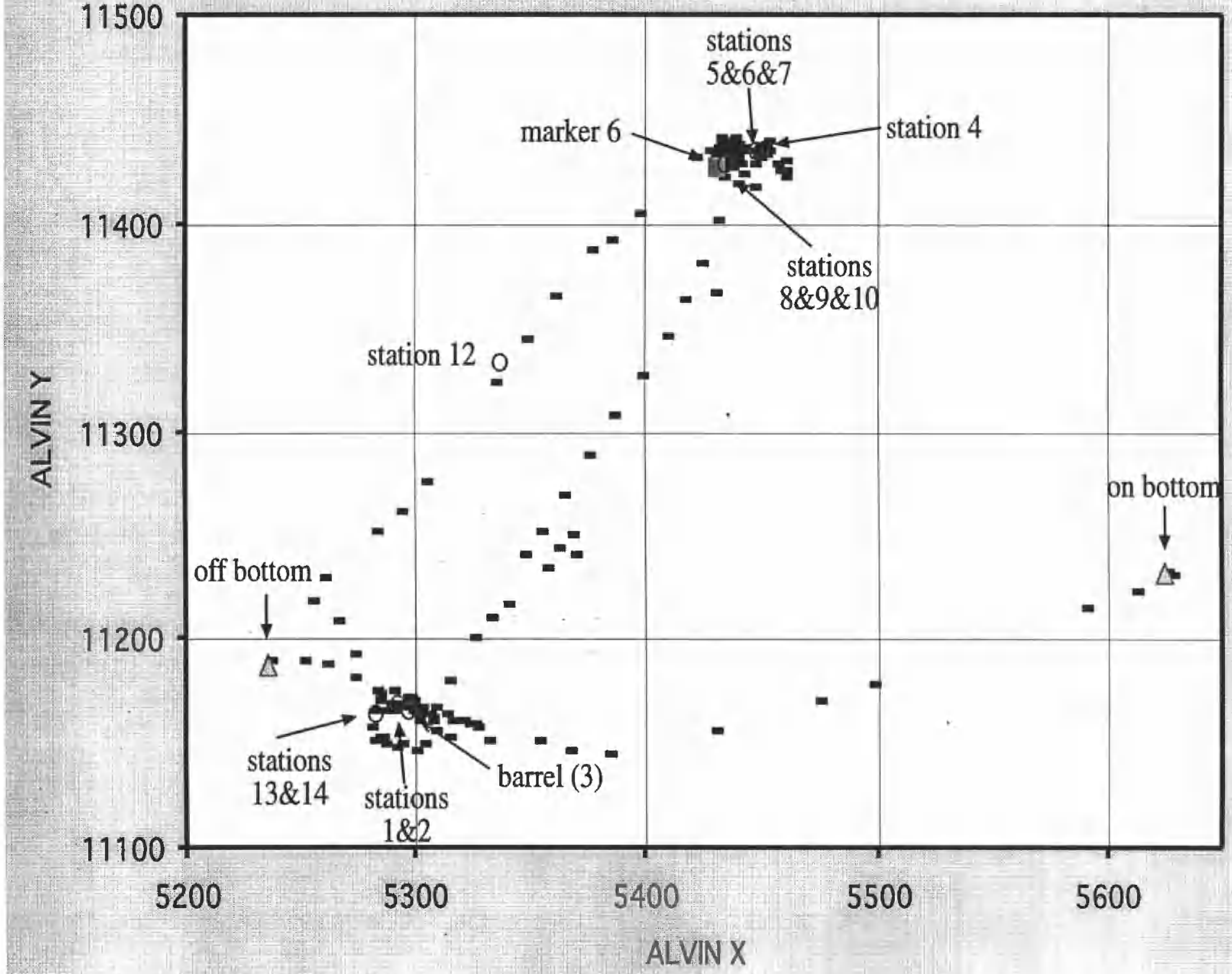
10:24	5448	11435	Collect gas sample (one red stripe sampler, station 5)
10:27	5448	11435	More steady flow of bubbles from hole in carbonates
10:31	5448	11435	Collect gas sample over vent site (station 6). Flow of gas is much steadier
10:38	5448	11435	change tapes
10:39	5448	11435	The gusher is gushing!
10:40	5448	11435	Collect bubbles with a push core to see if we can form hydrate.
10:50	5448	11435	Hydrate deposit observed in camera
10:55	5448	11433	Collect carbonate/hydrate slab from the gusher rim (station 7)
11:00	5451	11434	went to collect marker 6 to place in front of Gusher.
11:02	5439	11436	Observe gas discharging rapidly from various (up to six) point sources over the bacterial mats at the bottom of the depresion, approximately 6 meters away from gusher site.
11:05	5435	11428	Collect gas sample (3 green stripes) over active vent on bacterial mat. High rate of fluid flow. Pilot observed hydrate forming in the gas sampler (station 8)
11:08	5435	11429	Second gas sample over gas vent on bacterial mats. High discharge rate (station 9)
11:15	5436	11428	Tried to poke into the bottom, surface looks quite hard
11:17	5436	11428	Tried to grab sample from the sediment (hydrate?) underneath mats. The sample decomposes as it is picked up from the seafloor. No luck (station 10)
11:24	5437	11429	Tried to scube with push core, failed
11:34	5435	11429	Grab sample (carbonate?) with Alvin's arm and put it in the tube-core quiver.
11:37	5435	11429	Measure temperature in the bacterial-mat area. No different from the seawater value of 4.64 C
11:50	5455	11428	Back to gusher and survey the area
11:55	5459	11425	Observe old barrel on the seafloor
12:21	5431	11425	Have trouble finding gusher again
12:27	5429	11433	Back to marker 6. Noticed that the flow rate diminished a bit and pick-ed up again to a steady flow
12:29	5438	11433	Found a new bubbling spot, 10 meters due 240 from marker 6. High flow rate.
12:34	5430	11433	tapes changed
12:39	5434	11430	Temperature measurements on the venting hole, show no variation from bottom seawater values (4.57C)
13:02	5383	11392	En route to recover benthic barrel
13:05	5338	11332	Trip Starboard Niskin bottle 3 meters above bottom over soft sediment (background value) Z=596m. (station 12)
13:17	5282	11165	Push core over bacterial mat, only 3 meters from the barrel (station 13)
13:20	5283	11165	Push core on clam field next to mat (station 14)
13:25	5297	11168	arrived at barrel deployment site
13:32	5297	11165	barrel recovered
13:40	5235	11188	left bottom
14:30			arrived at surface ALVIN on deck

Bottom sample sediment record summary sheet

DIVE 3426 **NORTHERN HYDRATE RIDGE, GUSHER AREA**

Station #	Type	Time	Depth	Lat (N)	Long (W)	X	Y	Comments
1	Niskin Bottle (port)	9:18	602	44 40.031	125 06.002	5297	11167	Niskin#5, bottom water sample over barrel site before deploymen
2	Niskin Bottle (port-mid)	9:18	602	44 40.031	125 06.002	5297	11167	Niskin#3, bottom water sample over barrel site before deploymen
3	Benthic Barrel	9:30	599	44 40.031	125 06.001	5297	11166	deployed on algal mat nect to flowmeter C
4	Niskin Bottle (stbd-mid)	10:21	587	44 40.176	125 05.885	5451	11434	Niskin #1, 2-3m from bubbling hole
5	Gas sample (port)	10:24	587	44 40.176	125 05.887	5447	11435	collected over bubbling vent site (1 red stripe)
6	Gas sample (port-mid)	10:31	587	44 40.176	125 05.887	5447	11435	collected over bubbling vent site, steadier gas flow (2 red stripes)
7	Carbonate slab	10:55	587	44 40.175	125 05.89	5448	11433	taken from the gusher rim
8	Gas sample (stbd-mid)	11:05	587	44 40.175	125 05.89	5438	11432	collected over active vent, high flow rate (3 green stripes)
9	Gas sample (stbd)	11:08	587	44 40.175	125 05.89	5438	11432	collected over active vent, high flow rate (4 red stripes)
10	Grab sample	11:17	587	44 40.173	125 05.90	5436	11428	no luck, clam box broken
11	Grab sample	11:34	587	44 40.172	125 05.90	5435	11429	sampled over bacterial mats
12	Niskin bottle (stbd)	13:05	596	44 40.115	125 05.97	5338	11332	3m above bottom over soft mud (reference site)
13	push core (port)	13:17	601	44 40.03	125 06.01	5282	11165	on bacterial mat only near barrel site
14	push core (port-mid)	13:20	600	44 40.031	125 06.01	5283	11165	on clams next to bacterial mat

ALVIN DIVE 3426



Alvin Dive Log Draft; video observations will be included

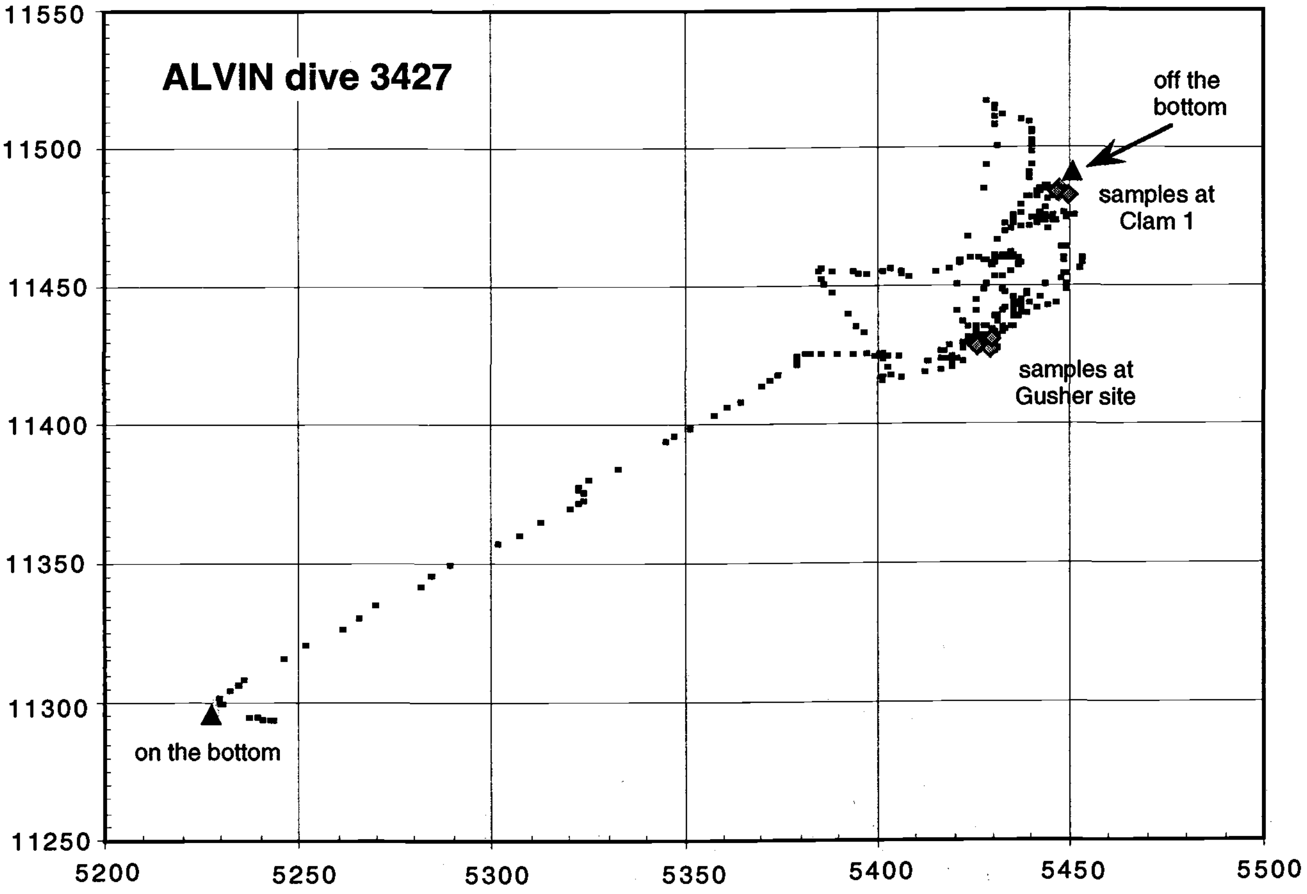
Dive number:	**3427**
Area:	**Northern Hydrate Ridge; Gusher Garden; Clam 1**
Date:	8 July 1999
Bottom time:	10:37 - 14:26
Pilot:	Bob Brown
Port observer:	Gerhard Bohrmann
Starbord observer:	Claus Gottschall/ german TV crew
Origin of XY coord.:	44° 34'N; 125° 10'W

Objectives: Conduct survey of the area; search for evidence of gas hydrate exposed on the sea floor and sampling of gas hydrates; transport back within the hydrate bucket; study the activity of emanating gas bubbles at the gusher site. Deploy barrel at clam one station (from 1998) and collect bottom water samples (4 Niskin bottles); exploration of the „SONNE" chemoherm

Summary: Due to wether conditions ALVIN dive 3427 started later and ended earlier and bottom time was limited. Two sites were investigated: Site Clam 1 and the Gusher. At clam 1 the barrel was deployed for approximately 2 hours. In addition 2 Niskin bottles and a push core was recovered. At gusher site changes in bubbleing activity were documented. Highest activity was between 13:00 and 13:30: up to ten gas vents in a line were observd. Two niskin bottle samples were taken.

Time	**X**	**Y**	
09:30			Sealing the hatch
09:46			Barrel was fixed in the basket with the help of a diver
09:57	5145	11093	Begin descent
10:37	5242	11293	at the bottom (593 m), soft sediment covered by single diagenetic carbonates mostly burrow infillings and concretions; heading to WP 1 (44°40.171'N; 125°5.895'W)
10:45	5289	11340	yellow fishery rope was observed
10:45			small slope with carbonate outcrops
10:49	5347	11395	occurrence of carbonate slabs increased
10:51	5363	11408	bacterial mats with dispersed clams around the mats
10:55	5400	11424	large clam field areas
11:18	5414	11454	white rope with balls
11:19	5406	11453	anchor was observed
11:25	5395	11432	large areas of clam fields
11:31	5422	11428	white marker 6 was reached in a flat area with pavement of cobblestones that was covered by white orange bacterial mats
11:33			Approximately 5 bubble sites were oberserved along a line close to marker 6; survey for additional bubble sites
11:39	5425	11428	Niskin bottle # 1 was closed at the Gusher site
11:52	5436	11435	Bacterial mat area without bubbles
11:56	5425	11431	Again back at marker 6; bubbling slowed down; still at 2-5 vent sites
12:03			Bubbleing slowed down and was restricted to only one site
12:04	5424	11431	Heading to WP 2 (44°40.198'N; 125°05.895'W)

12:12	5440	11497	Reached the area of „clam 1"; the area is a small depression showing dispersed clams in live and dead clam shells; three white anchor plates are to see close together
12:32	5447	11482	Niskinbottle # 5 was taken;
12:50	5447	11483	The OSU benthic barrel was deployed in an area of clams; heading back to WP 1/Gusher site
13:01	5424	11435	Reached marker 6 again; very strong degasing at 7 well pronounced vent sites; oberservation of the bubble activity with three chip camera; outgasing remained very strong during at least half an hour. At the bubbling sites bacterial mats are blown in the water, due to the escape of bubbles.
13:14	5428	11429	Niskin bottle # 2 was deployed at approximately the same position
	as		before; sediment and gas hydrate recovery was tried serveral
	times, but		failed. Scooping around for gas hydrates was also difficult
	and not		successful.
13:52	5430	11427	A rock sample directly from the area of outgassing was sampled
	that was		covered by thick bacterial mats.
13:40			Bubbleing activity already decreased down to a few pulses of
	degassing:		
14:46	5447	11484	barrel retrieved
15:02	5447	11484	Niskin bottle # 3
15:11	5455	11539	push core
15:04	5448	11484	of the bottom
15:55			ALVIN back at water surface


ALVIN dive 3427
off the bottom
samples at Clam 1
samples at Gusher site
on the bottom
11550
11500
11450
11400
11350
11300
11250
5200
5250
5300
5350
5400
5450
5500

Bottom sample sediment record; summary sheet								
Dive 3427: Hydrate Ridge North								
Sample #	**Type**	**Time**	**X**	**Y**	**Lat. (N)**	**Long. (W)**	**Depth (m)**	**Comments**
1	Niskin (first port)	11:39	###	11428	44°40.173	125°05.904	587	Bottle #1; close to marker 6/Gusher
2	Niskin (second por	12:32	###	11482	44°40.202	125°05.887	593	Bottle #5; at barrel station
3	Barrel	12:50	###	11483	44°40.202	125°05.888	593	Barrel retrieved from the bottom at 14:46
4	Niskin (third port)	13:14	###	11429	44°40.173	125°05.902	586	Bottle #2; at marker 6/gusher
5	Rock sample	13:52	###	11427	44°40.172	125°05.900	586	from the gusher site, contains bacterial ma
6	Niskin (fourth port)	15:02	###	11484	44°40.203	125°05.888	594	Bottle #3; at barrel site
7	Push Core	15:11	###	11485	44°40.233	125°05.881	593	close to the barrel, stored in the
								MBARI pressure chamber

Alvin Dive Log

Dive number:	**3428**
Area:	Hydrate Ridge South
Date:	9 July 1999
Bottom time:	8:39 - 14:22
Pilot:	Steve ?
Port observer:	Anne Trehu
Starboard observer:	Debbie Colbert
Origin of XY coord.:	44 34N; 125 10E
Objectives:	Deploy barrel over bacterial mat near TVG18 area. Deploy OSU lander and one USC lander on clam beds near the same site. Deploy one USC lander on soft sediment. Survey pinnacle from 2 different directions.

Summary: The primary objective of this dive was to deploy one Benthic Barrel and 3 Landers (1 McManus; 2 USC) across a clam field and bacterial mats near TVG18 site on the southern crest of Hydrate Ridge. Other objective were to map the circumference of the pinnacle, observe the orange mounds (subsequently named "Beaver mounds."), and groundtruth T5, a reflective spot falling north of the primary "pinnacle" reflective spot. We accomplished all objectives, although the observation of the "Beaver mounds" was very brief because it fell at the end of dive. Bubbles were seen on the Beaver mounds. It was clear that this was a very exciting area that should be the site of future dives.

Time	X	Y	
08:39	1660	286	On bottom. Scattered flounders, rock fish, clams, starfish, etc.
08:42			Sighted colonies of glass sponges growing on flat slabs of rock.
08:45	1595	150	Scattered carbonate blocks and clams.
08:58	1452	410	Sighted flow meter, blanket, old Alvin track, possible TVG scar.
~09:00	1467	429	Glimpse of mounds a bit to the side for possible revisit. These are morphologically similar to the mounds capped by orange bacterial mats further south, but no orange mats were noted here. Note1: this area was not looked at closely. AT saw it out of the corner of her eye. Note2: prior to 09:00 the Alvin video is badly out of focus. 3-chip is better.
09:08	1481	443	Surveying area with bacterial mats and clams for possible deployment sites.
09:15	1481	439	Alvin adjusting ballast for deploying OSU lander.
09:16	1481	440	Deployed OSU lander over clams. Checked seal.
09:29	1482	442	Closeup shots of bacterial mats.
09:33	1482	442	Deployed barrel over patch of bacterial mat. Checked seal.
09:59	1474	449	Started looking for elevator.
10:16	1444	450	Located elevator.
10:23	1422	459	Picked up USC lander B from elevator platform.
10:36			Change to tape 2.
10:38	1344	455	Deployed USC lander B in soft sediment.
10:55	1340	464	Leaving USC lander B to return to elevator.
11:01	1421	454	At elevator to pick up USC lander C.
11:15	1479	440	Camera shot of clam area for USC lander C.
11:21	1479	440	Placed USC lander C in clam area near OSU lander and barrel. Noted mounds covered with whitish material nearby.

			This whitish material, in closeup, looks crystalline - is maybbe hydrate rather than bacterial mats. Also a small white mound.
11:34	1450	433	Picked up thermal blanket and secured it.
11:35	1448	432	Near the blanket, there are mounds topped with a crust covered by bacterial mats. When ground was disturbed, sediment "vents" from holes in the crust. Suggests crust is relatively impermiable.
11:40	1406	370	Sediment covered blocks on seafloor; lots of burrows.
11:51	1261	206	Heading to WP5. Original plan was to head across area of mounds with orange caps. We decided to postpone this to the end of the dive and head to the Pinnacle. Seafloor covered with soft sediment.
11:53	1221	168	Start to see bits of talus.
11:55	1156	177	Start seeing big carbonate blocks.
11:57	1138	186	On flank of Pinnacle. Start heading north around Pinnacle to circle it completely along the ~785m contour.
12:00	1134	238	First see crack at depth of 784m on flank of Pinnacle.
12:05	1125	238	Took clam sample from crack on flank of Pinnacle. This crack is amazingly linear, about 20 cm wide, and has clam colonies and bacterial mats at the base. Its trend is estimated to be ~195 degrees, based on the angle of the crack to the Alvin and Alvin's heading at the time of 171 degrees. This is probably the same crack seen on dive 3424, although no clams were sampled on 3424. We took a sample of clams and sediment from this crack. On return, one large live clam and many clam shells were found in this sample. Good panoramic view of crack on 3-chip
	1105	221	Curved bedding, resembling carbonate wrapped around a sediment concretion (?)
	1263	170	Large (several meters) stratified talus blocks appear to have fallen off pinnacle.
12:23	1121	338	Continuing to circle pinnacle.
12:31	1129	186	Completed circle.
12:34	1115	197	Arrived at top of Pinnacle; lots of anemones.
13:39	1078	508(?)	Change to tape 3.
12:44	1119	196	774m. Broke off a large piece of carbonate from the top of the pinnacle. Started toward WP9
12:57	1227	231	802m Thought we were are WP9 but then passed over carbonate blocks and were back at the Pinnacle. Realized that navigation was not stable, so we headed north to reach WP10.
13:00	1097	187	777m Long, straight white crack visible in the distance.
13:02	1103	222	781m. Still seeing crack.
13:25	1153	975	828m water depth. Arrived at WP10, which is in the middle of the T5 reflective feature on the sidescan. Seafloor covered by soft mud with several types of starfish and other bottom dwellers. No trace of what may be causing the reflective feature.
13:27	1163	1010	828m. Arrived at WP11; no structure evident that correlates with image on sidescan.
1343	1824	673	Heading back to barrel.
1348	1487	446	Arrived at barrel to pick it up.
1357	1496	427	Barrel secure in Alvin basket.

1413	1555	363	769m (note: this is the shallowest depth of the survey) Went SE of barrel towards WP3. Seafloor covered by large undulationg mounds (amplitude ~1-2 m, wavelength ~5-10 m) which seem to be capped by crusty material that is cracked and broken in places. Orange bacterial mats are found on the top of the mounds.
1414	1569	354	Bubbles rising from orange mounds and streaming past windows. Try to find the source but Alvin has kicked up sediment and we are low on power and must depart.
1426			Alvin departed from bottom.

Bottom sample sediment record summary sheet

DIVE 3428 **SOUTHERN HYDRATE RIDGE**

Station #	Type	Time	Depth	Lat (N)	Long (W)	X	Y	Comments
1	McManus Lander	1.486	779	44 34.238	125 08.881	1481	440	deployed on field of small clams
2	Benthic Barrel	9:33	779	44 34.239	125 08.881	1482	442	deployed covering white baterial mat within clam field
3	USC Lander B	10:38	791	44 34.246	125 08.985	1344	455	deployed on soft sediment as background site
4	USC Lander C	11:21	779	44 34.238	125 08.883	1479	440	deployed on clam field near McManus Lander and Barrel
5	clam sample	12:05	784	44 34.129	125 09.150	1125	238	collected from bottom of large crack floored by clams and hydrate
6	carbonate slabs	0:00	774	44 34.092	125 09.046	1263	170	sample broken off from in-situ slab at top of pinnacle. Navigation not reliable

Alvin Dive Log

Dive number:	**3429**
Area:	**Southern Hydrate Ridge** **Area of High Side-Scan-Sonar Reflectivity** **TV-G 18 and Carbonate Pinnacle**
Date:	10 July 1999
Start down:	08:25
Bottom time:	09:15 - 15:02
Pilot:	Phil
Port observer:	Gary Klinkhammer
Starbord observer:	Dudley Foster... Training Dive
Origin of XY coord.:	44° 34'N; 125° 10'W

Objectives: **Equipment to be loaded on elevator:**

- 2 Landers USC (Hammond) ---- 65 lbs each

Equipment on basket:

- 1 Hydrate bucket ----63 lbs
- 1 Temperature probe
- 1 Sediment Probe
- Space for Benthic lander (McManus)------62 lbs
- 1 Temperature probe
- 2 Large push cores
- Hydrate push core
- Hydrate generator

Operations:

- Recover and reposition SIOFM J at WP 2 (TVG18)
- Release Alvin Pathfinder Transponder
- Pick up USC Landers, position on elevator and release elevator
- Survey the Beaver mounds
- Survey and sample pinnacle. Sample clams on top
- Return to Beaver Mounds and core (push cores and hydrate core)
- Recover McManus Lander
- Niskin bottle profile on the way up
- 1 Clam net/Scoop

Summary:

This was a training dive which affected what we could accomplish, but overall the pilots did a great job and the dive was a success.

After we attained trim we proceeded to the drop off point for SIO Flux Meter J. We located the meter and moved it north. After two attempts we got it seated properly in the sediment.

We used sonar to locate the transponder buoy and pulled the pin.

We had passed USC Lander C and the OSU lander when we were searching for SIO-J. We returned to this location and picked up the USC lander. We found the elevator close to the drop point and after some effort secured the lander to the elevator.

We then headed to the location of USC-B. We found this lander without difficulty, returned it to the elevator and secured it without difficulty. We then released the elevator without incident.

We then returned to the OSU lander and secured it in the basket. We were originally going to do this later in the mission but we were having problems with sub steering and didn't want to risk surfacing without the package.

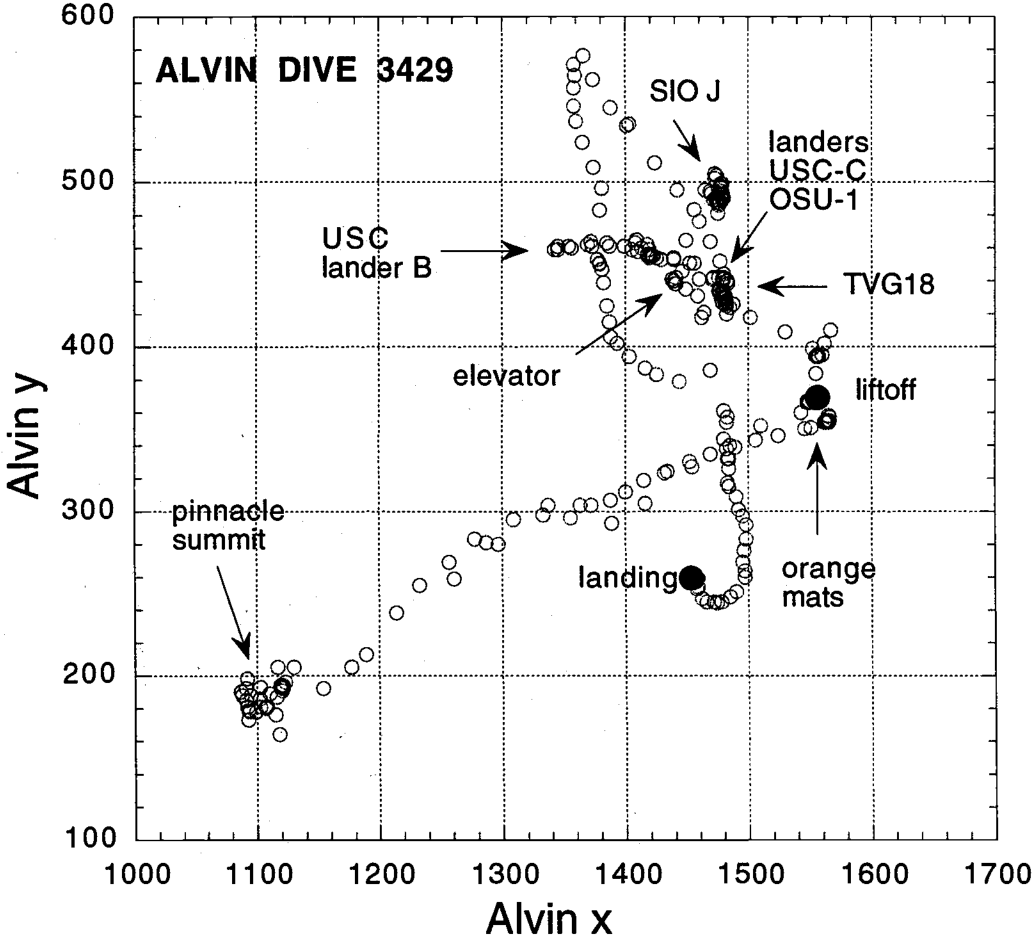
We then went to the orange mats area, observed bubbles when the sub skid hit the bottom, and did a brief survey of the area.

We then transited to the top of the carbonate pinnacle. We traveled a few meters off the bottom on the way to save energy. When we arrived we took pictures and recovered two carbonate samples. We then proceeded back to the orange mats area on the seafloor.

When we arrived in the mounds area the pilot had trouble keeping the sub off the sea floor. This was a problem because it was approaching slack tide and the currents were low so it took a long time for the disturbed sediment to dissipate. After two attempts to relocate we had exhausted the batteries. We took a sample with the hydrate push core but we not able to locate the preferred target because of poor visibility. We did take a core in the blind with this device and a grab sample with the clam scoop. We placed the core in the hydrate bucket, closed the lid, and dumped the clams and sediment on top.

TIME	X	Y	DEPTH	COMMENTS
0816				sealing hatch
0820				in water
0825				dive in 787m
0831				bottom of photic zone (>100m)
0910	1416	387	+48	driving to flux meter position
0915	1385	426	+10	bottom in site, muddy
0930	1358	557	786	trimmed and searching
0939	1442	496	782	in transition area
0942	1480	438	778	at flow meter J, also USC lander C and the OSU lander
0953				J in hand, moving north
0956	1463	419		passed white mat area
1011	1479	489	781	deployed meter J but not seated
1032	1476	487	782	redeployed SIO flux meter J
1036				leave flux meter site
1045	1441	438	780	at transponder, transponder
away				
1104	1429	454	783	at elevator
1115				USC-C lander secured
1122	1343	460	781	USC-B in hand
1135	1419	456	783	lander USC-B secured
1138				elevator released
1156	1483	442	779	at WP3, OSU lander placed in basket
1222	1558	373	774	at orange mats, bubbles, probed bottom

1241	1549	368	773	left for pinnacle
1301 n	1109	182	772	arrived at pinnacle top, observed and photographed orange mats, no clams observed
1340				recovered one small and one large carbonate sample
1346				survey bottom back to orange mats
1400	1355	297		muddy
1402	1372	304		muddy
1406	1463	334		mud, but more carbonate
	1516	345		start of mats
1416	1565	356	774	parked at orange mats
1443	1584	363	774	hydrate push core
				clam grab
1500			774	closed stbd outside Niskin
			772	closed stbd inside Niskin
			771	closed port inside Niskin
			770	closed port outside Niskin
1502				coming up
1503				one weight away
1549				light at 150m
1600				surface
1617				deck


ALVIN DIVE 3429
SIO J
landers
USC-C
OSU-1
USC
lander B
TVG18
elevator
liftoff
pinnacle
summit
landing
orange
mats
Alvin y
Alvin x
600
500
400
300
200
100
1000
1100
1200
1300
1400
1500
1600
1700

BOTTOM SAMPLE RECORD AD3429 -Hydrate Ridge South

Sample #	Type	Time	x	y	Lat. (N)	Long. (W)	Depth (m)	Comments
1	small carbonate slab	1305	1109	182	44 34.10	125 9.17	772	from top of pinnacle
2	large carbonate slab	1340			44 34.10	125 9.17	772	from top of pinnacle
3	stbd outboard Niskin	1500	1584	363	44 34.205	125 9.128	774	1 of 4 profile
4	stbd inboard Niskin	1500	1584	363	44 34.205	125 9.128	772	2 of 4 profile
5	port inboard Niskin	1501	1584	363	44 34.205	125 9.128	771	3 of 4 profile
6	port outboard Niskin	1501	1584	363	44 34.205	125 9.128	770	4 of 4 profile
7	grab of clams	1455	1584	363	44 34.205	125 9.128	774	

Alvin Dive Log

Dive number: **3430**
Area: **Southern Hydrate Ridge; Beaver mounds area**
Date: 11 July 1999
Bottom time: 10:36 - 16:15
Pilot: Bob Waters
Port observer: Erwin Suess
Starboard observer: Chris Moser
Origin of XY coord.: 44° 34'N; 125° 10'W

Objectives:

- Recover and reposition SIO/FM H between WP 1 and WP 3
- Find bubble site - survey surrounding area in great detail;
- Determine the extent of active area which includes TVG-18 and Beaver mound(s);
- Survey fracture, document and sample hydrate;
- Sample water/clams/bacterial mats in and around fractures;
- Sample water/clams/bacterial mats in and around gas vent site;
- Survey for evidence of hydrate outcrops;
- Sample hydrate core;
- Observe bubble site from about 15:00 to maximum high tide (16:15)

Summary:

In order to observe maximum gas venting at the lowest tidal flux (expected at 16:15 local time), start of the dive was delayed to 09:30. During descent at approximately 50 meters off the bottom, radar detected an elongated object > 20 meters in diameter with extraordinary strong reflections in the water column; most probably coming from a large gas plume. In spite of very erratic navigation ALVIN found 4 vigorously flowing gas vents inside one of several depressions in the Beaver Mounds area, having a slightly elevated rim and being covered with patches of white bacterial mats and colonies of clams and single specimens . Gas sampling as well as production of artificial gas hydrate from emanating streams of gas was accomplished as well as water samples taken from the near-saturated bottom waters.

The gas hydrate and the enclosed methane bubbles in the porous hydrate fabric generate enough positive buoyancy which leads to the escape of the core while securing it inside the pressure vessel. Design change of the pressure vessel and/or extra weight added to handle of hydrate corer is needed to prevent losses in the future.

Positive buoyancy of naturally formed hydrate may contribute to sediment instabilities; periodically floating up of large blocks of hydrate could be responsible for the hummocky morphology of the Beaver Mound area.

Time	X	Y	
09:45	1516	280	Clear for diving At approx. 50m off bottom very strong radar reflection in water column, 20 m-diameter object; probably bubble cloud;
10:28	1560	406	At approx. 38 m off the bottom (depth 727m) visible bubble trains passing by forward of ALVIN observed by pilot;
10:33	1564	440	Attempting to relocate bubble train, unsuccessful;
10:36	1566	435	On bottom at 755m, muddy sediment, few carbonate rocks;heading 203°; sighted . strobe flashes on stbd. side - probably SIO/FM-H (SIO/FM-H target coor. = 1457, 403)
10:43	1566	473	Searching for flux meter; target on radar approx. 150m 270degr.
10:44			Navigation problems; bad fixes;

10:58	1562	426	Good fix; 774 m
			Bad fixes
11:03	1550	384	Attempting to locate ALVIN on bottom;
11:06 - 11:09			Bad fixes; white bacterial mats; sub heading = ~ 030° - 045°
11:13	1567	413	Attempting to locate ALVIN; mud;
11:17	1556	408	Attempting to locate ALVIN; mud;
11:20			Bad fixes;
11:31	1625	433	Attempting to locate ALVIN; mud; 765m. depth
11:41	1643	518	Questionable fix;
11:47	1620	445	Questionable fix; ;
11:51	1568	371	Good fix;
11:52	1565	366	Observe bubbles rising from bacterial mat at 774 m;
11:54	1565	366	Move closer to gas vent; appear to be sitting on rim surrounding morphological depression; dune area; Beaver mounds; Observe at least 4 very active gas vents aligned inside depression; covered with patches of mostly white bacterial mats; orange mats appear on stbd. side; small clams in (live?) colonies and (dead?) individuals all over the place;
12:00			Closed Niskin #1 on stbd. side;
12:02	1564	365	Begin sampling gases; Gas sampler #1; Observe hydrate forming inside sampler;
12:05	1564	365	Start Gas sampler #2; Observe bubbles passing through sampler with periodic puffs of hydrate crystals emitted through the opening of tube; Observe very strong shimmering water passing in front of pushcores; horizontal schlieren pattern rising upward; no entrained bubbles;
12:07	1563	365	Start Gas sampler #3;
12:09			Complete Gas sampler #3;
12:10.17			Start tape
12:11			Start Gas sampler #4; floater stops moving about halfway down; stop sampling;
12:17			probed bacterial mat for crusts with metal rod - negative result, no crusts
12:18			Start making hydrate with mesh core; rapid downward growth of hydrate interface; observe bubbles coalesce and freeze as hydrate;
12:22			Still making hydrate;
12:30			Bubbling activity diminishes noticeably;
12:39			Move to next bubbling site about 1 m away towards the inside of depression;
12:40			Rapid growth of hydrate core
12:55			Finish hydrate production;
12:56			Photo session; document hydrate core from all sides; tilt and view inside bottom; observe mesh being surrounded by solid hydrate;
12:58			Hydrate core escapes rapidly upward leaving a puff of bubbles; while placing it into pressure bucket; strong positive buoyancy due to hydrate plus captured bubbles; DESIGN CHANGES NEEDED on hydrate bucket or extra weight added to hydrate corer handle.
13:00			Start hydrate production with short push core; but see little evidence for growing hydrate;
13:08			Stop production because progress appears too slow;
13:11			Close Niskin #2 (second from stbd. side)
13:14			Attempt to measure temperature inside gas vent to decide if shimmering water is due to thermal or salinity gradient;

			Experience difficulty with reaching temperature probe inside basket;
13:30			Lose bubble site; bad fixes;
13:40			Still maneuvering to find bubble site;
			No fixes; leave bottom and rise to approx. 760m
13:49	1527	353	Good fix; descend to 773 m course 45°
13:52	1528	346	Good fix;
	1534	357	Good fix;
	1543	365	Good fix;
13:59	1545	366	Good fix;
14:03	1553	357	Good fix;
	1551	355	Good fix;
14:09	1561	366	Reach bubble site;
14:15			Bad fixes
14:16			Attempt to free probe;
14:22	1566	370	Temperature probe free;
14:25	1564	368	Good fix;
	1570	372	Good fix
14:27			Probe failed; grounded due to damaged cable;
14:29			Place marker #7 on gas vent;
14:33	1563	367	Start hydrate production with short push core; very rapid growth of hydrate core;
14:35			Stopped hydrate production because of poor weather developing at the surface; placed inside pressure basket; close lid;
14:37			Close Niskin #3 (3rd from stbd. side)
14:38			Take push core (USC) in bubble area with bacterial mat;
			about one-half full;
14:46	1546	361	
14:57	1557	368	Take push core (USC) bubble site, bacterial mat;
15:02	1550	366	
15:04	1526	375	Lost bubble site;
			Bad fixes; relocate
15:26			Approach bubble site; attempt to collect clams; experience difficulties due to suspended particles; thick clouds;
			Clam scoop (new design) is damaged;
			Attempt to collect individual clams with claws; cumbersome and time consuming; decide to use ALVIN push cores for clam collection; take 2 cores on colonies;
15:30			Terminate work on bubble site and head for SIO/FM-H;
15:45	1457	403	Drop site, search with radar; circle area generally muddy surface; approach clam and carbonate mounds; white bacterial mats; look for flasher;
15:52			Search with radar; no target within 50m; getting low on power;
16:00			Top lab advises to leave bottom by 16:15 at the latest; weather deteriorating;
16:03			Close Niskin #4; portside;
16:			Getting ready to leave bottom; very low on power;
16:15			Leave bottom , continue to search for SIO/FM-H with radar;
16:50			Arrive at surface;
17:25			ALVIN on deck.

Appendix 2

Nutrient Data

Nutrient Samples analyzed July 23rd- 29th 1999
Aross

Multi Core run 1	PO4(uM)	Si(OH)4(uM)	NO3+NO2(uM)	NO2(uM)
MC7-C0W	3.13	130.63	42.14	0.29
MC7-C1	5.33	215.67	27.17	2.15
MC7-C2	8.76	283.03	4.19	0.79
MC7-C3	13.03	303.68	3.96	0.89
MC7-C4	13.75	345.58	6.40	1.15
MC7-C5	19.78	364.13	3.72	1.07
MC7-C6	22.00	342.99	2.60	0.61
MC7-C7	22.40	319.72	1.48	0.32
MC7-C8	20.14	304.95	2.14	0.28
MC7-C9	17.58	299.39	1.25	0.15
MC7-C10	16.97	295.95	1.24	0.12
20MC-CA0W	3.42	112.34	45.53	0.09
20MC-CA1	5.06	207.49	31.05	0.35
20MC-CA2	6.72	282.09	10.12	0.32
20MC-CA3	7.03	285.75	4.55	0.26
20MC-CA4	5.78	253.91	3.88	0.23
20MC-CA5	5.84	239.81	3.21	0.23
20MC-CA6	5.91	235.65	2.53	0.14
20MC-CA7	5.35	233.62	0.75	0.09
20MC-CA8	4.92	233.01	1.41	0.11
20MC-CA9	3.96	240.21	1.40	0.08
3MC-C1	2.41	208.11	8.50	0.06
3MC-C2	4.84	221.40	8.90	0.18
3MC-C3	6.47	261.18	0.12	0.08
3MC-C4	8.89	306.63	0.30	0.05
3MC-C6	12.54	344.87	3.22	0.66
3MC-C8	21.36	376.98	0.43	0.23
3MC-C9	20.29	350.85	0.38	0.10
3MC-C10	19.93	348.82	0.78	0.07
3MC-C11	19.85	356.71	0.29	0.06
3MC-C12	20.41	342.79	1.20	0.06
13MC-CA0W	2.91	117.98	40.93	0.09
13MC-CA1	3.63	193.93	27.01	0.27
13MC-CA2	5.51	240.10	13.08	0.11
13MC-CA3	5.89	245.86	7.21	0.32
13MC-CA4	5.62	250.21	5.15	0.27
13MC-CA5	5.78	253.84	2.64	0.35
13MC-CA6	6.72	255.35	6.18	0.24
13MC-CA7	6.00	246.22	3.67	0.13
13MC-CA8	5.28	242.06	2.50	0.23
13MC-CA9	5.13	228.67	1.56	0.10
35MC-CA0W	3.38	106.04	44.01	0.02
35MC-CA1	3.56	205.44	22.71	0.18
35MC-CA2	5.30	245.96	8.13	0.82
35MC-CA3	9.27	282.94	4.73	0.98
35MC-CA4	10.21	309.28	5.35	1.24
35MC-CA5	10.48	322.86	3.97	1.00
35MC-CA6	9.79	335.01	4.14	1.35
35MC-CA7	9.25	358.52	1.19	0.35
35MC-CA8	9.90	357.91	4.05	0.65
35MC-CA9	7.75	397.74	0.87	0.11
35MC-CA10	7.41	373.71	1.72	0.75

35MC-CA11	7.30	358.90	2.34	0.56	
35MC-CA12	6.45	361.84	3.41	1.26	
35MC-CA13	9.14	444.98	1.80	0.15	
22MC-0W	3.36	158.36	43.30	0.11	
22MC-CA1	5.15	271.97	41.48	0.35	
22MC-CA2	5.31	309.60	26.27	0.59	
22MC-CA3	5.53	335.87	19.55	0.80	
22MC-CA4	5.67	347.22	12.15	1.31	
22MC-CA5	5.94	351.47	12.79	1.18	
22MC-CA6	5.62	352.88	8.97	1.04	
22MC-CA7	4.88	377.01	6.04	0.29	
22MC-CA8	4.77	385.52	5.79	0.29	
22MC-CA9	4.39	387.65	4.64	0.10	
22MC-CA10	3.49	369.18	4.17	0.10	
22MC-CA11	5.37	356.39	4.14	0.15	
22MC-CA12	4.39	418.14	4.11	0.12	
22MC-CA13	10.33	474.22	4.52	0.12	
22MC-CA14	7.28	508.28	3.82	0.06	
30MC-CA0W	0.61	127.78	16.04	0.63	
30MC-CA1	4.79	210.12	19.13	1.13	
30MC-CA2	11.61	271.87	13.75	1.46	
30MC-CA3	16.17	283.93	11.50	0.76	
30MC-CA4	17.67	295.99	8.79	0.97	
30MC-CA5	18.82	303.79	7.65	0.67	
30MC-CA6	14.91	298.10	9.62	1.21	
30MC-CA7	16.91	277.51	6.70	0.32	
30MC-CA8	15.18	266.86	6.45	0.37	
30MC-CA9	4.54	242.72	28.88	5.13	
30MC-CA10	12.13	281.02	4.65	0.00	These last three had a
30MC-CA11	11.09	286.70	8.15	0.00	strong odor of HSulfide
30MC-CA12	7.68	300.88	0.53	0.00	

Deep Water Niskins

	PO4 (uM)	Si(OH)4 (uM)	NO3+NO2 (uM)	NO2 (uM)
5AD 1	3.00	115.09	41.86	0.56
5AD 2	2.93	114.44	41.38	0.00
8AD 1	3.30	113.99	44.33	0.07
8AD 2	3.26	115.84	43.96	0.02
8AD 3	3.22	115.77	43.97	0.03
8AD 4	3.22	115.12	44.08	0.07
11AD 1	3.26	104.29	43.33	0.04
11AD 2	3.19	98.84	42.13	0.05
21AD 1	3.13	100.31	42.03	0.03
21AD 2	3.18	101.00	42.69	0.15
21AD 3	3.13	101.12	42.37	0.17
21AD 4	3.14	101.82	42.76	0.05
32AD 1	3.25	114.81	43.97	0.03
32AD 2	3.21	115.13	43.65	0.09
32AD 3	3.20	114.09	43.60	0.03
32AD 4	3.16	113.64	43.17	0.05
37AD 1	3.26	117.22	44.27	0.04
37AD 2	3.23	116.38	43.84	0.04
37AD 3	3.23	116.31	43.74	0.04
37AD 4	3.23	113.74	43.80	0.00

Barrel and Landers

	PO4 (uM)	Si(OH)4 (uM)	NO3+NO2 (uM)	NO2 (uM)
25AD N1	3.16	101.11	43.20	0.00
25AD N2	3.13	100.35	42.50	0.10
25AD N3	3.14	100.36	42.51	0.11
25AD N4	3.15	101.15	42.62	0.10
25AD BB1	3.23	101.16	43.04	0.05
25AD BB3	3.20	101.17	42.80	0.06
25AD BB4	3.16	101.44	42.51	0.06
25AD BB5	3.17	100.42	42.34	0.06
25AD BB6	3.14	100.95	42.22	0.04
28AD BB2	3.32	115.59	44.04	0.11
28AD BB3	3.28	115.35	43.40	0.10
28AD BB4	3.28	115.62	43.57	0.06
28AD BB5	3.21	115.37	43.34	0.05
28AD BB6	3.21	115.64	43.23	0.06
32ADHL G1	3.09	114.11	42.82	0.18
32ADHL G3	3.04	114.13	41.42	0.40
32ADHL G4	3.09	115.16	38.44	0.90
32ADHL G5	3.10	116.46	33.58	1.66
32ADHL G6	3.18	118.27	30.07	2.26
32ADHL B1	3.14	113.15	43.47	0.00
32ADHL B2	3.14	113.42	43.18	0.03
32ADHL B3	3.08	115.48	41.37	0.09
32ADHL B4	3.09	114.73	42.36	0.08
32ADHL B5	3.05	114.48	40.90	0.08
32ADHL B6	3.07	117.32	40.32	0.10
21AD BB1	3.06	101.41	42.25	0.09
21AD BB2	3.02	101.42	42.14	0.12

Nutrient Samples analyzed July 23rd- 29th 1999
Aross

WCS run1

	Si(OH)4 (uM)	NO3+NO2 (uM)	NO2 (uM)
35MCW1	113.82	43.10	0.09
35MCW1	113.74	42.91	0.08
35MCW2	114.26	42.20	0.04
35MCW3	227.46	15.16	2.37
35MCW4	255.56	6.44	0.60
35MCW5	269.87	4.34	0.40
35MCW6	273.40	4.28	0.49
35MCW7	267.64	7.73	0.95
35MCW8	269.06	7.68	1.21

WCS run 2

	Si(OH)4 (uM)	NO3+NO2 (uM)	NO2 (uM)
MC13 1	125.16	42.02	0.04
MC13 2	126.00	42.12	0.09
MC20 W1	120.55	43.01	0.05
MC20 W2	120.19	43.75	0.09
MC22 1	166.32	43.33	0.12
MC22 2	166.57	43.12	0.10
MC30 W1	134.71	43.12	0.19
MC30 W2	135.25	42.54	0.15
MC13 3	230.61	11.29	0.06
MC13 4	244.96	7.99	0.48
MC13 5	261.11	5.58	0.64
MC13 6	268.26	4.33	0.61
MC13 7	270.91	2.76	0.40
MC13 8	276.56	2.45	0.46
MC20 W3	245.00	7.37	0.34
MC20 W4	253.65	6.27	0.07
MC20 W5	253.30	2.87	0.23
MC20 W6	246.34	3.23	0.24
MC20 W7	245.09	3.70	0.31
MC20 W8	246.24	5.38	0.48
MC22 3	298.43	18.10	2.81
MC22 4	322.70	9.62	1.96
MC22 5	332.26	9.25	1.16
MC22 6	344.52	5.80	0.65
MC22 7	338.47	9.93	0.89
MC30 W3	239.02	93.16	2.40
MC30 W4	255.18	115.88	6.78
MC30 W5	263.84	108.11	12.06
MC30 W6	271.00	85.56	17.11
MC30 W8	197.05	81.22	2.38

21AD BB3	3.05	101.69	42.37	0.14
21AD BB4	3.08	101.70	42.37	0.16
21AD BB5	2.98	101.71	41.44	0.21
21AD BB6	3.09	101.73	42.20	0.25
14AD BB2	3.30	119.20	43.02	0.12
14AD BB4	3.22	119.73	42.56	0.13
14AD BB5	3.26	119.23	42.09	0.13
14AD BB6	3.19	119.24	41.86	0.13
8ADHB 1	3.28	117.71	42.78	0.08
8ADHB 2	3.69	117.98	40.43	0.00
8ADHB 3	3.14	117.99	42.81	0.12
8ADHB 4	2.94	116.21	42.80	0.16
8ADHB 5	4.60	119.30	40.93	0.02
8ADHB 6	3.99	119.32	39.07	0.03

Dive cores

	PO4 (uM)	Si(OH)4 (uM)
5AD CA0W	6.22	103.32
5AD CA1	93.75	334.84
5AD CA2	31.69	319.15
5AD CA3	28.91	309.11
5AD CA4	24.68	290.59
5AD CA5	14.45	281.97
5AD CB0W	6.66	113.68
5AD CB1	25.97	297.20
5AD CB2	21.29	308.36
5AD CB3	16.49	288.42
5AD CB4	13.67	291.10
5AD CB5	14.78	285.29
8AD CA0W	0.69	26.53
8AD CA1	20.96	299.12
8AD CA2	20.53	332.89
8AD CA3	16.95	293.16
8AD CA4	15.49	280.29
8AD CA5	12.76	250.46
8AD CA6	11.39	233.34
8AD CA7	11.96	230.36
8AD CA8	11.31	225.97
8AD CA9	1.93	208.85
8AD CA10	12.08	227.07
8AD CA11	10.89	214.20
8AD CA12	12.85	247.97
21AD CA0W	0.11	49.89
21AD CA1	7.06	217.98
21AD CA2	7.94	230.55
21AD CA3	6.62	209.18
21AD CA4	2.65	170.85
21AD CA5	1.29	146.66
21AD CA6	1.05	142.26
21AD CA7	1.17	142.10
21AD CA8	1.19	136.29
21AD CA9	1.27	137.54

21AD CA10	1.07	144.46

Dive cores

	PO4 (uM)	Si(OH)4 (uM)	
11AD CB0W	2.32	107.76	
11AD CB1	7.61	162.75	
11AD CB2	11.67	175.34	
11AD CB3	7.65	190.74	
11AD CB4	5.70	196.26	
11AD CB5	5.84	203.18	
11AD CB6	8.50	234.15	
32AD CA0W	2.18	109.58	
32AD CA1	16.47	229.62	
32AD CA2	17.77	213.93	
32AD CA3	21.10	233.58	
32AD CA4	22.13	282.93	
32AD CA5	22.93	240.37	
32AD CA6	21.44	221.84	
14AD CA0W	0.51	20.90	
14AD CA1	-99.00	297.08	yellow color. PO4 way offscale
14AD CA2	119.92	333.27	
14AD CA3	36.93	354.34	
14AD CA4	20.78	361.27	
14AD CA5	20.64	351.23	
14AD CA6	24.58	345.44	
14AD CA7	26.19	359.44	
14AD CA8	27.84	376.27	
14AD CB0W	3.29	86.21	
14AD CB1	13.06	206.28	
14AD CB2	9.83	225.94	
14AD CB3	13.68	238.52	
14AD CB4	13.45	232.73	
14AD CB5	14.21	238.24	
14AD CB6	8.12	238.10	
14AD CB7	12.05	247.86	
14AD CB8	13.39	260.45	

Dive cores

	PO4 (uM)	Si(OH)4 (uM)
8AD CB0W	1.43	75.18
8AD CB1	7.37	202.89
8AD CB2	9.51	180.22
8AD CB3	9.51	177.41
8AD CB4	8.66	183.11
8AD CB5	10.84	195.92
8AD CB6	10.80	187.43
11AD CA0W	2.81	95.15
11AD CA1	7.04	154.83
11AD CA2	6.19	163.37
11AD CA3	4.23	194.66
37AD CA0W	0.17	38.37
37AD CA1	18.95	208.94

37AD CA2	16.09	201.86
37AD CA3	13.01	201.90
37AD CA4	11.36	194.82
37AD CA5	12.38	221.88
37AD CA6	15.54	241.83
37AD CA7	15.19	236.18
37AD CA8	18.48	246.18
37AD CA9	17.95	243.37