"In-Situ Sampling and Characterization of Naturally Occurring Marine Methane Hydrate Using the D/V JOIDES Resolution."

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ODP Leg 204 Shipboard Scientific Party

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ODP Leg 204 Shipboard Scientific Party* (see attached list of participants provided at the end of this report)

DISCLAIMER

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ABSTRACT

The primary accomplishments of the JOI Cooperative Agreement with DOE/NETL in this quarter were that: (1) Frank Rack, Anne Trehu, and Tim Collett presented preliminary results and operational outcomes of ODP Leg 204 at the American Association of Petroleum Geologists annual meeting in Salt Lake City, UT; (2) several Leg 204 scientists participated in special hydrate sessions at the international EGS/AGU/EUG meeting in Nice, France and presented initial science results from the cruise, which included outcomes arising from this cooperative agreement; and, (3) postcruise evaluation of the data, tools and measurement systems that were used during ODP Leg 204 continued in the preparation of deliverables under this agreement.

At the EGS/EUG/AGU meeting in Nice, France in April, Leg 204 Co-chiefs Anne Trehu and Gerhard Bohrmann, as well as ODP scientists Charlie Paull, Erwin Suess, and Jim Kennett, participated in a press conference on hydrates. The well-attended press conference entitled “Gas Hydrates: Free methane found and controversy over the "hydrate gun"” led to stories in Nature on-line and BBC radio, among others.

There were six (6) oral and fifteen (15) poster presentations on ODP Leg 204 hydrate science at the EGS/AGU/EUG Meeting in Nice, France on April 6-11, 2003. This was a very strong showing at a meeting just over six month following the completion of the drilling cruise and highlighted many of the results of the leg, including the results obtained with instruments and equipment funded under this cooperative agreement.

At the AAPG annual meeting in Salt Lake City, UT on May 11-14, 2003, Anne Trehu gave an oral presentation about the scientific results of Leg 204, and Frank Rack presented a poster outlining the operational and technical accomplishments.

Work continued on analyzing data collected during ODP Leg 204 and preparing reports on the outcomes of Phase 1 projects as well as developing plans for Phase 2.

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INTRODUCTION

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RESULTS AND DISCUSSION

Oral and Poster presentations that were made at the EGS/AGU/EUG Meeting in Nice, France on April 6-11, 2003 are provided as part of this progress report. A summary list of the oral and poster presentations is provided below, followed by the abstracts that were submitted for these presentations at the meeting.

Monday, 7 April 2003

17:00 - 17:30
ORAL EAE03-A-00947; VGP25-1MO4O-001; Room: M7
Trehu, A. M.; ODP Leg 204 Scientific Party
An introduction to ODP Leg 204: Drilling Gas Hydrates on Hydrate Ridge, (solicited)

P0511
POSTER EAE03-A-11035; VGP25-1MO3P-0511; Poster Area: Esplanade
Bohrmann, G.; Trehu, A.; Torres, M.; Rack, F.; Milkov, A.; Schultheiss, P.; Collett, T.; ODP Leg 204 Shipboard Scientific Party
Introduction to Leg 204, part II - processes at the summit of southern

OS16 Gas Hydrates and Role of Methane in the Marine Environment (co-sponsered by BG & CL) - Poster Programme
Convener: Suess, E.
Co-Convener(s): Paull, C., Reeburgh, W.
Co-Sponsorship: R&D Programme GEOTECHNOLOGIEN (Germany)

Monday, 7 April 2003 11:15 - 13:15
Poster Area: Poster Area Esplanade
Chairperson: KESSLER, J.; SCHULTHEISS, P.

P0690
EAE03-A-08884; OS16-1MO2P-0690
Papenberg, C.; Petersen, J.; Klaeschen, D.
Seismic studies of gas hydrate bearing sediments at Hydrate Ridge (Poster)

P0691
EAE03-A-00813; OS16-1MO2P-0691
Milkov, A.V.; Claypool, G.E.; Lee, Y.-J.; Borowski, W.S.; Torres, M.E.; Xu, W.; Tomaru, H.; Dickens, G.R.; Leg 204 Scientific Party, ODP
Direct evidence of free gas in the gas hydrate stability zone revealed by an ODP pressure core degassing experiment (Poster)

P0695
EAE03-A-04375; OS16-1MO2P-0695
Schultheiss, P.; Holland, M.; ODP Leg 204 Shipboard Scientific Party, .
Structure and decomposition of marine gas hydrates recovered at in situ pressures (Poster)

P0696
EAE03-A-07296; OS16-1MO2P-0696
Trehu, A. M.; Dillard III, E.; Huckemeyer, J. ; Schroeder, D. ; Leg 204 Shipboard Scientific Party
In situ temperature and thermal conductivity beneath southern Hydrate Ridge; results from Leg 204 (Poster)

P0697
EAE03-A-06948; OS16-1MO2P-0697
Riedel, M.; Long, P.; Liu, C.S.; Schultheiss, P.; ODP Leg 204 Scientific Party,
Ocean Drilling Program (ODP) Leg 204 Physical Properties: stratigraphic and structural control of hydrate formation (Poster)

P0698
EAE03-A-08241; OS16-1MO2P-0698
Lee, Y.-J.; Claypool, G.; Milkov, A.; Trehu, A.; Bohrmann, G.; Rack, F.; LEG204 Shipboard Scientific Party,
Gas geochemical detection of migration pathways and gas hydrate stability zone: preliminary results from odp leg 204 (Poster)

P0700
EAE03-A-07000; OS16-1MO2P-0700
Teichert, B.M.A; Bohrmann, G.; Gràcia, E.; Johnson, J.E.; Su, X.; Weinberger, J.L.; Leg 204 Shipboard Scientific Party
Authigenic carbonates from Hydrate Ridge (ODP Leg 204): formation processes and evidence of fluid pathways (Poster)

P0701
EAE03-A-11749; OS16-1MO2P-0701
Torres, M. E.; Wallmann, K.; Tomaru, H.; Borowski, W. S.; Trehu, A. M.; Bohrmann, G.; Leg 204 Science Party, ODP.
Constraints on gas hydrate dynamics at Hydrate Ridge based on chloride enrichment in pore fluids at the summit. (Poster)

P0702
EAE03-A-07874; OS16-1MO2P-0702
Johnson, J. E.; Chevalier, J.; Trehu, A. M.; Gracia, E.; Su, X.; Teichert, B.M.A; Weinberger, J. L.; Shipboard Scientific Party ODP Leg, 204

Stratigraphy, Sedimentology, and Depositional History At Southern Hydrate Ridge, Cascadia Margin, Interpreted from ODP Leg 204 Drill Sites and 3-D Seismic Data (Poster)

P0703
EAE03-A-14012; OS16-1MO2P-0703
Su, X.; Watanabe, M.; Trehu, A.; Bohrmann, G.; Rack, F.; and LEG 204 Shipbord Scientific Party
Biostratigraphy of Late Pliocene to Holocene sediments from Southern Hydrate Ridge, ODP LEG 204 (Poster)

P0704
EAE03-A-11089; OS16-1MO2P-0704
Guerin, G; Goldberg, D; Collett, T; Barr, S; Leg 204 shipboard scientific party, ODP
Acoustic energy dissipation in gas hydrate bearing sediments, ODP leg 204, Hydrate Ridge (Poster)

P0727
EAE03-A-07754; OS16-1MO3P-0727
Collett, T.; Goldberg, D.; Guerin, G.; Barr, S.; Leg 204 shipboard scientific party, I.
Assessment of gas hydrate concentrations (saturations) with downhole electrical resistivity logs on Hydrate Ridge (Poster)

P0752
POSTER EAE03-A-11745; OS19-1MO4P-0752; Poster Area: Esplanade
Torres, M. E.; Bangs, N. L.; Bohrmann, G.; Borowski, W. S.; Chan, L-H.; Chevalier, J.; Tomaru, H.; Trehu, A. M.; Leg 204 Science Party, ODP.
Dissolved lithium and chloride distributions at Hydrate Ridge: Implications for reaction zones, fluid sources and flow pathways. (Poster)

P0761
POSTER EAE03-A-14075; OS19-1MO4P-0761; Poster Area: Esplanade
Flemings, P. B.; Dugan, B.; Rack, F. R.; Schroeder, D.; Trehu, A.; Germain, J.; Shipboard Scientific Party ODP LEG 204
Interpretation of pore pressure and permeability at Hydrate Ridge with piezoprobe and DVTP-P penetrometers and consolidation experiments (Poster)

Tuesday, 8 April 2003

OS16 Gas Hydrates and Role of Methane in the Marine Environment
(co-sponsered by BG & CL)
Oral Programme
Convener: Suess, E.
Co-Convener(s): Paull, C., Reeburgh, W.
Co-Sponsorship: R&D Programme GEOTECHNOLOGIEN (Germany)
Tuesday, 8 April 2003
Lecture Room: Euterpe

Chairperson: SUESS, E.; LONG, P.

8:45 - 9:00
EAE03-A-00179; OS16-1TU1O-002
Milkov, A.V.; Claypool, G.E.; Lee, Y.-J.; Dickens, G.R.; Xu, W.; Borowski, W.S.; the ODP Leg 204 Scientific Party, ODP
Direct measurements of in situ methane concentrations at Hydrate Ridge offshore Oregon: Implications for global gas hydrate inventory

9:00 - 9:15
EAE03-A-02964; OS16-1TU1O-003
Ussler III, W.; Paull, C.; McGill, P.; Schroeder, D.; Ferrell, D.; Leg 201 and 204 Scientific Parties,
Estimates of in situ Sediment Gas Concentrations in ODP Boreholes from Records of Core Temperature Obtained During Core Recovery

9:15 - 9:30
EAE03-A-07999; OS16-1TU1O-004
Long, P. ; Riedel, M. ; Trehu, A.; Collett, T.; Weinberger, J.; Torres, M.; Rack, F.; Bohrmann, G.; Liu, C.; ODP Leg 204 Shipboard Scientific Party,
Abundance and texture of gas hydrate beneath Hydrate Ridge, offshore Oregon, USA from infrared imaging

9:30 - 9:45
EAE03-A-03922; OS16-1TU1O-005
Francis, T.
The hyacinth project

Chairperson: SUESS, E., PAULL, C.

18:00 - 18:15
EAE03-A-02358; OS16-1TU4O-005
Goldberg, D; Janik, A; Johnson, J E; Moos, D; Flemings, P; Barr, S; Leg 204 Shipboard Scientific Party, ODP
Stress orientations and estimated in situ strength of gas hydrate — evidence from borehole breakouts at ODP Leg 204 sites, Hydrate Ridge

EGS/AGU/EUG ABSTRACTS

(see following pages)

Geophysical Research Abstracts, Vol. 5, 00947, 2003

AN INTRODUCTION TO ODP LEG 204, PART I: DISTRIBUTION AND CONCENTRATION OF GAS HYDRATE BENEATH HYDRATE RIDGE

ODP Leg 204 Shipboard Science Party (1), presented by **A. M. Trehu** (2)

(1) Ocean Drilling Program, College Station TX, (2) College of Oceanic and Atmospheric Sciences, Oregon State Un., Corvallis OR [trehu@coas.oregonstate.edu]

During Leg 204, we cored and logged 9 sites on the Oregon continental margin. Our objectives were to determine the distribution and concentration of gas hydrates in an accretionary ridge and adjacent slope basin, investigate the mechanisms that transport methane and other gases into the gas hydrate stability zone (GHSZ), and obtain constraints on physical properties of hydrates in situ. Here we present an overview of the major highlights of the cruise, with a focus on the relationship between the stratigraphic and structural setting and the distribution and concentration of gas hydrate. Constraints on the stratigraphic setting are derived from combining stratigraphic analysis of the cores with 3D seismic data. Constraints on hydrate distribution are derived from a variety of physical and chemical measurements. In general, geochemical techniques provide direct measures of hydrate concentration but only in limited, discrete intervals. Geophysical techniques provide good vertical resolution but require other assumptions to estimate concentration. Hydrate concentration is greatest in a 600x400x30 m region at the summit in which hydrate occupies a significant fraction of the total volume (estimated to be $>$30%). Away from the summit, visible hydrate is distributed along bedding planes and fractures in lenses up to several cm thick, which occur from ˜50 mbsf to the base of the GHSZ (114-134 mbsf). Grain size and composition are important controls on fluid flow and hydrate concentration and character, with volcanic-ash-rich horizons acting as conduits. Integrated hydrate concentration within the zone of gas hydrate occurrence in this region is estimated to be 1-2% of total volume. In a slope basin to the east of Hydrate Ridge, gas hydrate concentration is high in a 12 m-thick-layer just above the BSR (filling ˜20% of the pore space). Gas hydrate is rare above this layer, and the integrated concentration in the basin above the

basal layer is estimated to be $<1\%$. These patterns of hydrate distribution and concentration place constraints on models of methane generation, fluid flow and hydrate formation in accretionary complexes and on mechanisms for transporting methane from beneath the seafloor to the ocean and atmosphere. Other talks and posters at this meeting provide detailed discussions of the various types of data acquired during Leg 204 and of the physical, chemical and biological processes controlling the dynamics of hydrate formation. Additional information is available in the Leg 204 Preliminary Report (www-odp.tamu.edu).

Geophysical Research Abstracts, Vol. 5, 11035, 2003

INTRODUCTION TO LEG 204, PART II - PROCESSES AT THE SUMMIT OF SOUTHERN

ODP Leg 204 Shipboard Scientific Party (1) presented by **G. Bohrmann** (2)

(1) Ocean Drilling Program, Colleg Station TX, (2) Fachbereich Geowissenschaften University Bremen, Germany [gbohrmann@geomar.de]

Since 1996, it has been known that the summit of Hydrate Ridge is a dynamic environment in which massive hydrate is forming at and near the seafloor and free gas is escaping vigorously into the ocean. In this presentation we summarize new data on subseafloor processes in this region obtained during ODP Leg 204. Several other presentations at this meeting provided additional discussion of the Leg 204 data and of the subseafloor processes they imply.

During Leg 204, two sites were drilled at the summit. Integration of data from pressure core samples (PCS and HYACINTH autoclave system) with porewater chloride concentrations, electrical resistivity from logging while drilling (LWD) and infrared (IR) thermal imaging of cores on retrieval indicate that gas hydrate comprises as much as 30-40% of the total core volume in the upper 20-30 m. In addition, very high pore water chloride concentrations place constraints on rates of hydrate formation. The data imply high gas flux and movement of free gas through the gas hydrate stability zone (GHSZ). One possible explanation for the presence of free gas in the GHSZ is that water is locally exhausted during hydrate formation, leading to the presence free gas in the pore space. Although the occurrence of free gas associated with gas hydrates had been documented prior to Leg 204, Leg 204 is the first time that free gas at in situ conditions has been documented, an observation made possible by the the first use of the integrated HYACINTH pressure coring and density logging system.

Geophysical Research Abstracts, Vol. 5, 08884, 2003

SEISMIC STUDIES OF GAS HYDRATE BEARING SEDIMENTS AT HYDRATE RIDGE

C. Papenberg, J. Petersen, D. Klaeschen

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In recent years, gas hydrates have become the focus of many research projects, since their economic potential, their role as a natural hazard and their impact on climate is yet not well known. To shed more light on these complex gas hydrate environments and to give rise to possible answers, a broad range of seismic experiments were carried out across Hydrate ridge.

Simultaneous recordings of near-angle (single-channel surface streamer) and wide-angle reflection seismics (ocean bottom seismometers) were conducted within a broad frequency range, covering a dense grid of seismic profiles across and around Hydrate ridge.

A well pronounced bottom simulating reflector (BSR), marking the base of the gas hydrate stability zone (GHSZ), has been imaged and its amplitude and frequency behavior investigated in more detail. AVA (amplitude variations with offset) analysis of both P- and S- waves were the key elements of quantifying the amount of gas hydrates within the sediments and/or the amount of free gas beneath the GHSZ. A pinnacle-like structure on the southwestern flank of the southern summit of Hydrate ridge was covered with high-resolution seismic sparker lines. The observed variations in the BSR`s amplitude and its discontinuity suggest possible pathways for fluids and/or methane below the pinnacle. Drill site information of ODP (Ocean Drilling Program) Leg 146 and recent Leg 204, covering the northern and southern summit of Hydrate ridge, provide additional and necessary information that was implemented in our investigations.

Geophysical Research Abstracts, Vol. 5, 00813, 2003

DIRECT EVIDENCE OF FREE GAS IN THE GAS HYDRATE STABILITY ZONE REVEALED BY AN ODP PRESSURE CORE DEGASSING EXPERIMENT

A.V. Milkov (1), G.E. Claypool (2), Y.-J. Lee (3), W.S. Borowski (4), M.E. Torres (5), W. Xu (6), H. Tomaru (7), G.R. Dickens (8) and the ODP Leg 204 Scientific Party

(1) Woods Hole Oceanographic Institution (amilkov@whoi.edu), (2) Lakewood, CO, (3) Korea Institute of Geoscience and Mineral Resources, (4) Eastern Kentucky University, (5) Oregon State University, (6) Georgia Institute of Technology, (7) University of Tokyo, (8) Rice University

The Ocean Drilling Program (ODP) Pressure Core Sampler (PCS) was extensively used during Leg 204 on Hydrate Ridge offshore Oregon. One PCS was deployed within the gas hydrate stability zone (GHSZ) at ˜14 meters subbottom depth in a location near seafloor gas vents, seafloor hydrates, and chemosynthetic organisms (ODP Site 1249). Approximately 95 L of natural gas (dominantly methane) was collected during the degassing experiment, which is the greatest volume of gas ever measured with the PCS. Variation in the composition of released gases suggests that free gas and gas hydrate co-exist in sediment. Geochemical measurements and mass-balance calculations imply that water in the pore space outside of gas hydrate has salinity at least 106 g kg-1. We propose that a hydrate-brine-free gas equilibrium is reached at shallow depth as salt is excluded during gas hydrate crystallization, is not effectively removed from the pore space, and inhibits further gas hydrate crystallization. Formation of a gas phase should facilitate methane transport within the GHSZ. Free gas in the pore space may also influence physical properties of the bulk sediment (e.g., electrical resistivity and acoustic velocity) and must be taken into account by remote and indirect techniques for estimating in situ gas hydrate concentration.

Geophysical Research Abstracts, Vol. 5, 04375, 2003

STRUCTURE AND DECOMPOSITION OF MARINE GAS HYDRATES RECOVERED AT IN SITU PRESSURES

P.J. Schultheiss (1), M.E. Holland (2), & ODP Leg 204 Shipboard Scientific Party
(1) GEOTEK, Daventry, UK, (2) ASU Geology, Tempe, AZ, USA (peter@geotek.co.uk)

Fully-pressurized cores containing methane hydrate were recovered on ODP Leg 204 at Hydrate Ridge, Cascadia Margin, by the HYACE Rotary Corer (HRC) and the Fugro Pressure Corer (FPC). Both the HRC and the FPC were developed as part of the European HYACE and subsequent HYACINTH projects to collect 1 m-long cores at in-situ pressure and to enable further analysis by transferring these cores in their plastic liners under full pressure into specialized chambers. Two hydrate-bearing pressure cores were dissociated over a period of many hours. During this time, multiple gamma density profiles were acquired and evolved gas was measured and analysed. Core 204-1249F-2E, 80 cm long, released over 100 L of methane (1000 ppm ethane, 5 ppm propane) and contained several centimeter-thick layers of massive hydrate. Based on an analysis of total gas and core volume, the hydrate content of this core was calculated to be 38% of the total core volume. In comparison, Core 204-1244E-8Y, 75 cm long, released only 3.8 L of methane (10 ppm ethane, 5 ppm propane) and had only 2 individual layers of gas hydrate. The depressurized core was X-rayed and sampled for pore water chlorinity analysis which confirmed the existence of hydrate layers. The hydrate content of this core was calculated at 0.2% of the total volume, with all the hydrate contained within the 2 identified layers. There was no evidence for any disseminated hydrate distributed throughout the clay sediment structure. Core 204-1249G-2E, which was frozen and then preserved in liquid nitrogen, had multiple layers of massive gas hydrate, similar to Core 204-1249F-2E. Core 204-1249H-2Y was stored under in situ temperature and pressure for further analysis, including CT scanning. This core also contained centimeter-scale low density intervals consistent with massive hydrate. Spikes of extremely low density within these hydrate layers are conclusive evidence for the existence of free gas within the massive hydrate structure.

Geophysical Research Abstracts, Vol. 5, 07296, 2003

IN SITU TEMPERATURE AND THERMAL CONDUCTIVITY BENEATH SOUTHERN HYDRATE RIDGE; RESULTS FROM LEG 204

A. M. Trehu (1), E. Dillard III (2), J. Huckemeyer (2), D. Schroeder (2), and the Leg 204 Shipboard Science Party (2)

(1) College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis OR 97331, USA, trehu@coas.oregonstate.edu; (2) Ocean Drilling Program, College Station TX

Temperature is a major parameter affecting gas hydrate stability beneath the seafloor. In order to constrain the thermal state of the gas hydrate reservoir beneath Hydrate Ridge, we made 85 in situ temperature measurements during ODP Leg 204. To first order, measured subsurface temperatures increase linearly with depth and are consistent with temperatures predicted from seismic estimates of the depth to the base of the gas hydrate stability field (BSR depth) combined with laboratory measurements of gas hydrate stability in seawater. However, after detailed analysis of possible biases due to instrument calibration, short-term temporal variations in bottom water temperature, and uncertainties in situ thermal conductivity, some systematic variations can be resolved. At sites in water depths $>$ 1000 m, the thermal gradient is ˜0.06 K/m and in situ temperatures are consistent with BSR depth. As the summit is approached, the apparent thermal gradient decreases slightly (0.049-0.057 K/m) and the predicted depth to the stability boundary is 12-35 m deeper than indicated by the BSR depth. This is not the pattern expected for a thermal perturbation caused by upward flow of aqueous fluids, which should increase the apparent thermal gradient. Alternative explanations (e.g, bias in the equation used to predict temperature based on BSR depth; hydrate dissociation in situ due to friction from the temperature probe; variable pore water chemistry) will be explored. Evidence is also presented for in situ thermal conductivities of as low as 0.4 W/mK for a few measurements made near the summit. This low value of thermal conductivity, which contrasts with thermal conductivities of ˜1 W/mK measured on sediments in the lab, suggests that hydrate is present in very high concentration where the measurement was made.

Geophysical Research Abstracts, Vol. 5, 06948, 2003

OCEAN DRILLING PROGRAM (ODP) LEG 204 PHYSICAL PROPERTIES: STRATIGRAPHIC AND STRUCTURAL CONTROL OF HYDRATE FORMATION

M. Riedel (1), P. Long (2), C.S. Liu (3), P. Schultheiss (4) and ODP Leg 204 Scientific Party

(1) Geological Survey of Canada, (2) Pacific Northwest Laboratory, (3) Institute of Oceanography, National Taiwan University, (4) Geotek Ltd.

Physical characteristics of the subsurface environment play an important role in determining the nature of fluid and gas migration, which in turn impact the nature of microbial communities as well as gas and hydrate formation. Bulk sediment physical properties were routinely measured during ODP Leg 204 using the multisensor track (MST) on whole-round cores and using discrete samples to measure bulk density (BD), porosity, grain density, P-wave velocity and magnetic susceptibility (MS). In addition, thermal conductivity was measured on whole cores. The data from the discrete index samples were in very good agreement with the logging-while-drilling (LWD) data taken prior to coring at each site and were also subsequently used to calibrate estimates of hydrate-concentration using the Archie law from the LWD-resistivity data. Automated infrared (IR) images of the complete core were taken on the catwalk to identify and quantify the presence of hydrate in the cores.
Combining bulk physical property data with IR images, LWD data, 3D seismic data and sediment lithology, reveal both stratigraphic and structural control of gas hydrate formation at Southern Hydrate Ridge (SHR). Several strong seismic reflectors (horizon A and B) that connect flanking basins to the summit of SHR probably represent conduits for upward migrating fluids.
Seismic reflector B is characterized by a series of turbidites as identified by sediment lithology description and magnetic susceptibility. The bottom of each turbidite shows high MS and coarse-grained sediments and was associated with strong IR cold-

anomalies indicative of the presence of gas hydrate.

Seismic reflector A has been identified as an ash-rich layer, which shows a double-peaked low bulk density. This reflector has been cored four times at Sites 1245, 1247, 1248, and 1250, mainly below BSR depth. It serves as a fluid pathway transporting methane and higher hydrocarbons up dip from the accretionary complex to the summit of Hydrate Ridge.

During Leg 204, the accretionary complex was cored three times at Sites 1244, 1251 and 1252. The transition from slope sediments to the accretionary complex appears as a relatively sharp decrease in bulk density in MAD, GRA and LWD data. This transition is also marked by a change of slope in the generally decreasing porosity-depth function.

Sediments of the accretionary complex have relatively higher porosities or are characterized by almost constant porosity over the cored depth range.

Geophysical Research Abstracts, Vol. 5, 08241, 2003

GAS GEOCHEMICAL DETECTION OF MIGRATION PATHWAYS AND GAS HYDRATE STABILITY ZONE: PRELIMINARY RESULTS FROM ODP LEG 204

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ODP Leg 204 cored nine sites on the Cascadia continental margin to investigate the distribution and concentration of gas hydrates in an accretionary ridge and adjacent slope basin.

Hydrocarbon gases in sediments were analyzed in shipboard laboratories by two different sampling methods, headspace and core gas void sampling. Preliminary results of the gas geochemistry on board are as follows: 1) Conduits of gas migration were identified by analyzing methane/ethane ratios and contents of other heavier hydrocarbons. 2) The base of the gas hydrate stability zone was correlated with a shift to lower methane/ethane ratios. 3) The top of the gas hydrate stability zone was characterized by relative ethane enrichment and propane depletion in core gas voids produced from dissociation of gas hydrate. Gas geochemistry proxies to detect gas hydrate stability zone were consistent with other data such as chlorinity, infrared thermal imaging, and wire line logging. Both headspace and void gas analysis can provide information to detect presence of gas hydrates on board.

Geophysical Research Abstracts, Vol. 5, 07000, 2003

AUTHIGENIC CARBONATES FROM HYDRATE RIDGE (ODP LEG 204): FORMATION PROCESSES AND EVIDENCE OF FLUID PATHWAYS

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During Ocean Drilling Program (ODP) Leg 204 at Hydrate Ridge (HR), gas hydrates and authigenic carbonates related to the discharge of methane were sampled at eight of the nine sites. The sampled carbonates show different states of lithification (from semi-lithified, light colored sediments to lithified carbonate rocks) and were found at different depth intervals in the boreholes, which can be attributed to different mechanisms of carbonate formation. Microbially mediated anaerobic methane oxidation (AMO) is an important process for the carbonates found in an interval between 0-42 mbsf at the summit of southern HR and the eastern- and western flank of HR. These carbonates have a calcitic mineralogy often bearing different phases of Mg-calcite and occur as semi-lithified sediments as well as lithified rocks. Carbonates related to methane production, gas hydrate formation and decomposition were found at a depth of about 70 mbsf beneath the eastern flank of HR. These carbonates have a calcitic mineralogy and occur as semi-lithified sediments, which might indicate ongoing carbonate formation and active pathways of methane-rich fluids. Carbonates found deeper in the boreholes (92-427 mbsf) within the accretionary complex east of HR have a mixed composition of dolomite and calcite. These carbonates are probably related to diagenetic processes or possibly represent carbonates related to AMO that occurred much shallower in the sedimentary succession during their time of formation.

Geophysical Research Abstracts, Vol. 5, 11749, 2003

CONSTRAINTS ON GAS HYDRATE DYNAMICS AT HYDRATE RIDGE BASED ON CHLORIDE ENRICHMENT IN PORE FLUIDS AT THE SUMMIT.

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At the summit of Hydrate Ridge (ODP Sites 1249 and 1250) the pore fluids are highly enriched in dissolved chloride (up to 1360 mM) in a zone that extends from the near the sediment surface ($\sim$1 mbsf) to depths of 20-30mbsf. The presence of this brine indicates that gas hydrate formation here must be very recent and rapid. Below 30 mbsf, high chloride brines give way to the low chloride anomalies characteristic of dissociation of hydrate relative to background interstitial waters in which the ions excluded during hydrate formation have been removed by advection or diffusion. The observed chloride distribution at Site 1249 can be reproduced by a one dimensional, non-steady state, transport-reaction model if upward advection of methane-bearing fluids at this site is 1-10 cm/yr. Such rapid advection rates are consistent with the distribution of other dissolved metabolites (e.g. sulfate and barium) at this site. At these advection rates, the gas hydrate currently present at the Hydrate Ridge summit could have been generated in less than 5,000 years, which highlights the dynamic nature of this system. In addition, the model predicts the ascent of a fluid-gas mixture, since the observed Cl enrichment cannot be generated exclusively from methane dissolved in the pore fluids.

Geophysical Research Abstracts, Vol. 5, 07874, 2003

STRATIGRAPHY, SEDIMENTOLOGY, AND DEPOSITIONAL HISTORY AT SOUTHERN HYDRATE RIDGE, CASCADIA MARGIN, INTERPRETED FROM ODP LEG 204 DRILL SITES AND 3-D SEISMIC DATA

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Hydrate Ridge, a gas hydrate-bearing thrust anticline located on the lower slope of the Cascadia accretionary wedge, was the site of Ocean Drilling Program (ODP) Leg 204 drilling in 2002. Drill sites were focused along transects over the southern summit of the ridge and into the adjoining eastern slope basin. 3-D seismic data, obtained in 2000, provide the high-resolution structural and stratigraphic context for each of the drill sites and detailed lithologic description, multi-sensor track (MST) logging, and logging while drilling (LWD) data characterize the sedimentology of the recovered cores and of the in situ stratigraphy. Sedimentological description and interpretation of the cores reveals a history of sedimentation dominated by turbidites and occasional debris flows, as well as intermittent volcanic glass emplacement, either as air fall ash or detrital glass in turbidites. Downhole variability in the micropaleontology data and abrupt changes in stratal geometry in the 3-D seismic data also suggest a history punctuated by both depositional hiatuses and erosion. Post-depositional compaction, biologic activity, deformation, dewatering, and diagenesis have overprinted the stratigraphy with bioturbation, iron-sulfide and authigenic carbonate precipitation, glauconite occurrences, and gas hydrate. Turbidite sands and silts and zones with concentrated volcanic glass shards provide the greatest porosity in the section and com-

monly contain overpressured gas and gas hydrate. Gas hydrate was also observed in the microfractures of some clay-rich sediments as well. Initial stratigraphic correlation across sites is encouraging, however, further integration of the lithologic, MST, LWD, and 3-D seismic data across the region will be presented and help to better decipher the geologic history of this region and to quantify the stratigraphic, structural, and sedimentological framework within which the gas hydrate system on Hydrate Ridge exists.

Geophysical Research Abstracts, Vol. 5, 14012, 2003

BIOSTRATIGRAPHY OF LATE PLIOCENE TO HOLOCENE SEDIMENTS FROM SOUTHERN HYDRATE RIDGE, ODP LEG 204

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Hydrate Ridge is located in the Cascadia accretionary complex (offshore northwest North America) and recently has been investigated by a number of geological and geophysical cruises because of cold seeps and gas hydrates there. However, we knew little about the age sequences of the hydrate-bearing sediments on the southern Hydrate Ridge prior to ODP Leg 204, when we drilled 9 sites on the southern Hydrate Ridge. Diatoms and calcareous nannofossils from sediments recovered were studied to assign preliminary ages for these sediments. Thirteen late Pliocene to Pleistocene microfossil events (5 diatom and 8 calcareous nannofossil events) were recognized. The oldest is the last occurrence of *Neodenticula seminae* (diatom) found in bottom sediments at Site 1244, indicating an age of late Pliocene (younger than 2.6 Ma) for the sediments. Bottom sediments at Sites 1251 and 1252 were also assigned to Upper Pliocene. At all other sites, the oldest sediments recovered are Quaternary. Sedimentation rates estimated by linear interpolation range from 2 cm/k.y. to 163 cm/k.y. and vary in time and space. The highest sedimentation rate (163 cm/k.y.) was found at the basin Site 1251 and the slowest one (2 cm/k.y.) at Site 1249 on the summit of the ridge. Further study of these biostratigraphical records and correlation with seismic records will provide detailed information for constraining the history of tectonic uplift of this accretionary ridge, which presumably is a driving force for hydrate formation in this region.

Geophysical Research Abstracts, Vol. 5, 11089, 2003

ACOUSTIC ENERGY DISSIPATION IN GAS HYDRATE BEARING SEDIMENTS, ODP LEG 204, HYDRATE RIDGE

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While it has been well documented that the presence of hydrate increases sonic velocity in the host sediment, recent work on sonic logging data from the Blake Ridge and the Mackenzie delta show that sonic waveforms amplitude are also significantly affected by the presence of gas hydrate. The data suggest that this effect is dependent not only on hydrate concentration, but also on the nature and on the frequency of the acoustic source used. Based on these observations, we use sonic waveform amplitudes and attenuation to investigate in situ the nature of the interaction between gas hydrate and its host sediment. During Leg 204, an extensive logging program was conducted in nine sites to characterize gas hydrate distribution near the crest of the Southern Hydrate Ridge. Six of the wells were logged with the Dipole Sonic Imager tool. In order to document the energy loss in these sediments, two sources (monopole and dipole) were each used at two different frequencies in every hole. We use a spectral method to calculate attenuation and quantify energy loss. The results show strong energy dissipation where hydrate concentrations are the highest, near the crest of the ridge (Sites 1250 and 1247). Monopole waveforms have the greatest attenuation. Attenuation of the high-frequency dipole waveforms is generally greater than at low frequency. At Site 1252, however, where hydrate concentration is low, energy loss is greater for the low-frequency dipole. Below the gas hydrate stability field, low energies of both monopole and dipole data are associated with free gas migration pathways. An elastic wave propagation model using percolation theory for frozen porous media and multiple-phase fluids can explain our observations at these frequencies in the Hydrate Ridge sediments.

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ASSESSMENT OF GAS HYDRATE CONCENTRATIONS (SATURATIONS) WITH DOWNHOLE ELECTRICAL RESISTIVITY LOGS ON HYDRATE RIDGE

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The downhole logging program on Ocean Drilling Program (ODP) Leg 204 was designed to obtain the data needed to assess the occurrence and concentration of gas hydrates beneath Hydrate Ridge off the northwest coast of the United States. During Leg 204, logging-while-drilling (LWD) tools were deployed at eight of the nine sites cored on Hydrate Ridge. The LWD tools used during Leg 204 were provided by Schlumberger, they included the resistivity-at-the-bit (RAB-GVR) tool, the magnetic resonance while drilling (MRWD) tool, and the azimuthal density-neutron (VDN) tool. It has been shown that it is possible to obtain gas-hydrate saturations (percent of pore space occupied by gas hydrate) by using the Archie relation to analyze the electrical resistivity of gas-hydrate-bearing sediments. In this study, the Archie relation was used with resistivity data from the GVR tool and porosity data from the VDN density tool to calculate water saturations at all eight LWD log sites on Hydrate Ridge.

The downhole log inferred distribution of gas hydrate beneath Hydrate Ridge and the adjacent slope basin is heterogeneous, with downhole RAB images showing gas hydrate occupying fractures and occurring as a disseminated pore-filling material within flat lying stratigraphic units with thicknesses varying from several centimeters to as much as 10 m. The Archie relation yielded water saturations ranging from low values near the crest of the ridge, of about 10% in Hole 1249A, to a more common value of about 90% along the flanks of the ridge. It is generally accepted that with the zone of gas hydrate stability, gas hydrate saturations (S_h) are the mathematical complement

of Archie derived water saturations (S_w), with S_h=1-S_w. Thus, the Archie derived gas hydrate saturations at the crest of the ridge exceed 90%. It should be noted that the Archie relation cannot distinguish between the occurrence of free-gas and gas hydrate. But, neutron porosity logs from the VDN tool, which are sensitive to the occurrence of free gas, did not reveal the presence of any significant free-gas occurrence above the depth of the BSR on Hydrate Ridge.

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DISSOLVED LITHIUM AND CHLORIDE DISTRIBUTIONS AT HYDRATE RIDGE: IMPLICATIONS FOR REACTION ZONES, FLUID SOURCES AND FLOW PATHWAYS

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The composition of pore fluids, particularly the Li^+ and Cl^- distributions, are known to be useful indicators of fluid sources and migration patterns in accretionary margins, and can provide clues to the source and flux of methane to the gas hydrate stability zone (GHSZ). The distribution of dissolved Li+ in pore waters from Leg 204 is characterized by an initial lithium uptake in the uppermost 20 mbsf, followed by a generally smooth increase with depth. Superimposed on this trend, Li^+ shows excursions to higher concentrations at the depth of a seismic reflector (Horizon A) that images thick intervals of volcanic ash. The higher permeability of these volcanogenic sequences may represent a path for fluids and hydrate-forming gases migrating from deeper intervals within the accretionary wedge.

A Li^+ increase with depth, usually accompanied by a decrease in the Cl^- concentration, is thought to reflect dehydration of subducted oceanic crust and sediment at depth. Interstitial waters from the Leg 204 sites drilled on the eastern flank of Hydrate Ridge do indeed show a Cl^- decrease and a Li^+ increase with depth, consistent with a mechanism whereby lithium-enriched fresh water migrates from deeper in the accretionary complex. However, at all sites drilled west of the summit, there is no change in the Cl^- distribution below the GHSZ, even though an increase in Li^+ is observed.

These data reveal a decoupling of the processes releasing Li^+ and water to the pore fluids. We postulate that emplacement of a thick sediment package on the western flank of the ridge has severed communication with deep sequences where dehydration reactions occur.

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INTERPRETATION OF PORE PRESSURE AND PERMEABILITY AT HYDRATE RIDGE WITH PIEZOPROBE AND DVTP-P PENETROMETERS AND CONSOLIDATION EXPERIMENTS

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Fugro-McClelland Marine Geosciences Inc.'s piezoprobe, a penetration-based tool used to determine pore pressure and hydrologic properties within a borehole, was deployed for the first time in the Ocean Drilling Program (ODP) on ODP Leg 204. The piezoprobe was deployed at approximately 53 mbsf. The initial peak pressure reached 10.3 Mpa and declined to 9.6 MPa at the end of the test (~40 minutes). Analysis of these data suggests that in situ pore pressure is 9.5 MPa, which is approximately the hydrostatic pressure (9.53 MPa). From the dissipation data, we estimate $in\,situ$ permeability of ~1.5 x10^{-17} m^2 for the hemipelagic clay, whereas laboratory-measured permeability is considerably greater (~1x10^{-16} m^2). We interpret that the $in\,situ$ permeability is reduced by the presence of hydrate. The piezoprobe data were compared to a Davis-Villinger Temperature/Pressure Probe (DVTP-P) measurement made at the same depth in the same lithology. The DVTP- P is also a penetration-based tool, however, it has a much wider probe diameter (~18.0 mm vs. 6.0 mm). The DVTP-P generated a higher peak pressure (10.55 MPa) that did not dissipate as much as the piezoprobe pressure (9.8 MPa @ ~38 minutes). This resulted in a DVTP-P estimate of $in\,situ$ pressure that nearly equals the overburden stress. The results suggest that the comparison of laboratory-derived information with $in-situ$ measurements can be used to infer how hydrates affect hydraulic properties. In the future, a narrow diameter probe like the piezoprobe could be used to rapidly determine $in\,situ$ pressure and hydrologic properties in sites investigated by the Ocean Drilling Program.

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DIRECT MEASUREMENTS OF IN SITU METHANE CONCENTRATIONS AT HYDRATE RIDGE OFFSHORE OREGON: IMPLICATIONS FOR GLOBAL GAS HYDRATE INVENTORY

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Gas hydrate is thought to be a large global reservoir of carbon containing ˜15,000 Gt of methane. However, the volume of hydrate-bound gas is poorly constrained by direct measurements. Ocean Drilling Program (ODP) Pressure Core Sampler (PCS) was extensively used during Leg 204 at Hydrate Ridge on a tectonically active margin offshore Oregon. Thirty direct measurements of methane concentration in sediments were made above and below the estimated depth of the bottom simulating reflector (BSR). High methane concentrations (71-3127 mM) indicate abundant gas hydrate (average ˜11.3% of porosity) within the gas hydrate stability zone (GHSZ) above the BSR and free gas (˜4.3% of porosity) below the BSR in a restricted area where hydrocarbon gases migrate from the deep accretionary complex to the seafloor. In a larger area lacking this supply of migrating hydrocarbons, lower methane concentrations (10-893 mM) indicate less gas hydrate (average ˜1.2% of porosity) within the GHSZ above the BSR and little or no free gas below the BSR. The in situ methane concentrations from Hydrate Ridge are generally lower than those determined for the crest of the Blake Ridge, which range between 70 and 1900 mM and support abundant gas hydrate and free gas over a 400 m interval. If gas hydrate concentrations at Hydrate Ridge and the Blake Ridge are typical of continental margins, and if ˜30% of continental margins contain gas hydrate, then the global volume of hydrate-bound methane is probably closer to 2,100-3,600 Gt, or five times less than widely cited estimates.

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ESTIMATES OF IN SITU SEDIMENT GAS CONCENTRATIONS IN ODP BOREHOLES FROM RECORDS OF CORE TEMPERATURE OBTAINED DURING CORE RECOVERY

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Anomalously cold core temperatures have been frequently observed for freshly recovered gas-rich continental margin cores collected during the Deep Sea Drilling Project and the Ocean Drilling Program (ODP). These measurements are made by inserting thermistors into the core after it has been removed from the core barrel and delivered to scientists on the catwalk. These "catwalk core temperature" measurements show that some core sections arrived on deck at distinctly lower temperatures (5-10 deg C cooler) than other cores recovered from the same drill site. In some sections pore water along the interior wall of the core liner was frozen when the core arrived on deck. These observations clearly show that there are significant temperature differences between adjacent cores apparently produced during the coring process. Thermal modeling indicates that the observed temperature anomalies can be explained by a combination of the cooling effects caused by gas expansion, gas exsolution, and gas hydrate decomposition. To better quantify the thermal changes that occur in gas-rich cores, we have developed a tool to continuously monitor the temperature, pressure, and conductivity (TPC) changes during ODP coring. The TPC sensors are located on the face of a modified ODP advanced piston corer's piston and the data logging electronics are embedded within the piston. This system is designed to require little shipboard attention. By establishing families of ascent curves comprising data from successive cores, the stratigraphic variations in the relative amounts of gas stored in sediments can be determined at individual sites and variations between sites can be

assessed. Testing and validation of tool function was obtained using an ROV. Methane was bubbled over the TPC sensors while the ROV was moved up and down in the water column. These tests provided visual confirmation that measured thermal anomalies corresponded with gas expansion and with methane gas hydrate formation and decomposition. The temperature anomalies were distinct from the background water column profiles measured without gas being present. The TPC tool was used during ODP Legs 201 and 204. The temperature anomalies and ascent profiles are consistent with model predictions and these data are providing new and unique insight into the distribution of gas within continental margin sediments.

Geophysical Research Abstracts, Vol. 5, 07999, 2003

ABUNDANCE AND TEXTURE OF GAS HYDRATE BENEATH HYDRATE RIDGE, OFFSHORE OREGON, USA FROM INFRARED IMAGING

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The strongly endothermic dissociation of gas hydrate cools sediment samples containing gas hydrates once they are out of hydrate stability conditions. Previously, multiple thermistors have been used on cores to detect such cooling as a proxy for gas hydrate occurrence. On Leg 204 of the Ocean Drilling Program (ODP), infrared (IR) imaging cameras (FLIR SC-2000, 320 x 240 pixels) were used make continuous images of cores while they were still in plastic liners. Resulting images facilitated on-catwalk identification and sampling of core sections likely to contain hydrate. Temperature data extracted from the images were used to map hydrate occurrence as a function of depth at each of 9 sites on or near southern Hydrate Ridge (ODP Sites 1244-1252). Down-core temperature anomalies ranging from -0.3 to -9°C were compared to other proxies for hydrate occurrence such as resistivity logs using the Archie Relationship to estimate pore water saturation (Sw), chloride concentration of interstitial water, and gas composition. The IR images also provide information on cm-scale textures of hydrate occurrences. Observed textures include lenses or veins (conformable and cross-cutting), nodular, and disseminated features. Dissection of selected samples revealed that individual hydrate lenses commonly have adjacent fine ($<$1 mm) veinlets oriented in 2 to 3 mutually orthogonal directions.

Geophysical Research Abstracts, Vol. 5, 03922, 2003

THE HYACINTH PROJECT

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HYACINTH is the acronym for "Development of HYACE tools in new tests on Hydrates". The project is being carried out by a consortium of six companies and academic institutions from Germany, The Netherlands and the United Kingdom. It is a European Framework Five project whose objective is to bring the pressure corers developed in the earlier HYACE project, together with new core handling technology developed in the HYACINTH project, to the operational stage. Our philosophy is that if all one does with a pressure core is to bleed off the gas it contains, a major scientific opportunity has been missed. The current system enables pressure cores to be acquired, then transferred, without loss of pressure, into laboratory chambers so that they can be geophysically logged. The suite of equipment - HYACE Rotary Corer (HRC), Fugro Pressure Corer (FPC), Shear Transfer Chamber (STC), Logging Chamber (LC), Storage Chamber (SC) and Vertical Multi-Sensor Core Logger (V-MSCL) - will be briefly described. Other developments currently in progress to extend the capabilities of the system will be summarised: - to allow electrical resistivity logging of the pressure cores - to enable pressurised sub-samples to be taken from the cores - to facilitate microbiological experiments on pressurised sub-samples

The first scientific results obtained with the HYACE/HYACINTH technology were achieved on ODP Leg 204 and are the subject of another talk at this meeting.

Geophysical Research Abstracts, Vol. 5, 02358, 2003

STRESS ORIENTATIONS AND ESTIMATED IN SITU STRENGTH OF GAS HYDRATE - EVIDENCE FROM BOREHOLE BREAKOUTS AT ODP LEG 204 SITES, HYDRATE RIDGE

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Ocean Drilling Program (ODP) Leg 204 collected the first recordings of in situ borehole breakouts in natural marine gas hydrates near Hydrate Ridge off the coast of Oregon. Schlumberger's logging-while-drilling GeoVision^{TM} resistivity imaging tool was used to make these observations. Breakouts are borehole enlargements that occur on opposite sides of the hole by failure of the formation under differential horizontal stresses that exceed its in situ strength. They can be used to estimate the orientation and magnitude of the horizontal stresses, as well as a relative estimate of in situ formation strength. Breakouts were observed at four of nine sites drilled through hydrate-bearing and non-hydrate-bearing sediments on and around the southern summit of Hydrate Ridge. They indicate that the maximum horizontal stress is NE-SW (ridge-parallel) at the summit and NW-SE (ridge-perpendicular) towards the east. No breakouts are observed at sites to the west of Hydrate Ridge. These orientations are interpreted in conjunction with the mapped subsurface structures from regional seismic surveys and lead to a better understanding of the tectonic setting in the area. At the ridge summit, the presence of breakouts in hydrate-bearing rocks allows for computation of their in situ strength relative to the host formation. Laboratory tests on core samples yield compressive strength estimates for the formation and provide constraints on the horizontal differential stresses that form the breakouts. Assuming that this differential remains constant in the shallow seafloor at Hydrate Ridge, the breakouts yield an es-

timate of in situ strength for the hydrate-bearing sediment. The implication of having greater in situ strength than the host formation is that hydrate dissociation would locally weaken the environment in the vicinity of the borehole; likewise, on a broader scale, hydrate dissociation and formation weakening may induce landslides in some submarine settings.

CONCLUSION

The primary accomplishments of the JOI Cooperative Agreement with DOE/NETL in this quarter were that: (1) Frank Rack, Anne Trehu, and Tim Collett presented preliminary results and operational outcomes of ODP Leg 204 at the American Association of Petroleum Geologists annual meeting in Salt Lake City, UT; (2) several Leg 204 scientists participated in special hydrate sessions at the international EGS/AGU/EUG meeting in Nice, France and presented initial science results from the cruise, which included outcomes arising from this cooperative agreement; and, (3) postcruise evaluation of the data, tools and measurement systems that were used during ODP Leg 204 continued in the preparation of deliverables under this agreement.

At the EGS/EUG/AGU meeting in Nice, France in April, Leg 204 Co-chiefs Anne Trehu and Gerhard Bohrmann, as well as ODP scientists Charlie Paull, Erwin Suess, and Jim Kennett, participated in a press conference on hydrates. The well-attended press conference entitled “Gas Hydrates: Free methane found and controversy over the "hydrate gun"” led to stories in Nature on-line and BBC radio, among others.

There were six (6) oral and fifteen (15) poster presentations on ODP Leg 204 hydrate science at the EGS/AGU/EUG Meeting in Nice, France on April 6-11, 2003. This was a very strong showing at a meeting just over six month following the completion of the drilling cruise and highlighted many of the results of the leg, including the results obtained with instruments and equipment funded under this cooperative agreement.

At the AAPG annual meeting in Salt Lake City, UT on May 11-14, 2003, Anne Trehu gave an oral presentation about the scientific results of Leg 204, and Frank Rack presented a poster outlining the operational and technical accomplishments.

Work continued on analyzing data collected during ODP Leg 204 and preparing reports on the outcomes of Phase 1 projects as well as developing plans for Phase 2.

LIST OF ACRONYMS AND ABBREVIATIONS

APC	Advanced Piston Corer
APC-M	Advanced Piston Corer-methane tool
APC-T	Advanced Piston Corer-temperature tool
BHA	Bottom Hole Assembly
BSR	Bottom Simulating Reflector
DOE	Department of Energy
DVTP	Davis Villinger Temperature Probe
DVTP-P	Davis Villinger Temperature Probe with Pressure
FMMG	Fugro-McCleland Marine Geosciences
FPC	Fugro Pressure Corer
GHSZ	Gas Hydrate Stability Zone
HR	Hydrate Ridge
HRC	HYACE Rotary Corer
HYACE	Hydrate Autoclave Coring Equipment
HYACINTH	Deployment of HYACE tools In New Tests on Hydrates
IR-TIS	Infrared Thermal Imaging System
JOI	Joint Oceanographic Institutions
JOIDES	Joint Oceanographic Institutions for Deep Earth Sampling
LDEO	Lamont Doherty Earth Observatory (Columbia University)
L/L	Liters per Liter
LTC	Laboratory Transfer Chamber
LWD	Logging While Drilling
MBRF	Meters Below Rig Floor
MBSF	Meters Below Sea Floor
MH	Methane Hydrate
MPa	Mega-Pascals
MSCL-V	Multi-Sensor Core Logger - Vertical
NETL	National Energy Technology Laboratory
NSF	National Science Foundation
ODP	Ocean Drilling Program
ODP-LC	Ocean Drilling Program – Logging Chamber
PCS	Pressure Core Sampler
PSI	Pounds per Square Inch
RAB	Resistivity at the Bit
RAB-c	Resistivity at the Bit with Coring
RCB	Rotary Core Barrel
R/V	Research Vessel
TAMU	Texas A&M University
XCB	Extended Core Barrel

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