Chapter 1

IMAGES VIII/PAGE 127 Gas Hydrate and Paleoclimate Cruise on the RV *Marion Dufresne* in the Gulf of Mexico, 2–18 July 2002: Introduction

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Abstract

The northern Gulf of Mexico contains many documented gas hydrate deposits near the sea floor. Although gas hydrate often is present in shallow subbottom sediment, the extent of hydrate occurrence deeper than 10 meters below sea floor in basins away from vents and other surface expressions is unknown. We obtained giant piston cores, box cores, and gravity cores and performed heat-flow analyses to study these shallow gas hydrate deposits aboard the RV *Marion Dufresne* in July 2002. This report presents measurements and interpretations from that cruise. Our results confirm the presence of gas hydrate in vent-related sediments near the sea bed. The presence of gas hydrate near the vents is governed by the complex interaction of regional and local factors, including heat flow, fluid flow, faults, pore-water salinity, gas concentrations, and sediment properties. However, conditions appropriate for extensive gas hydrate formation were not found away from the vents.

Introduction

Gas hydrate (fig. 1) is an ice-like crystalline solid containing high concentrations of methane in situ (Sloan, 1998). The amount of gas hydrate in the natural environment is thought to be enormous where conditions of high pressure, low temperature, and sufficient amounts of gas exist (Ginsburg and others, 1995; Booth and others, 1996; Kvenvolden and Lorenson, 2001a, b) (fig. 2). Gas hydrate may represent a potential source of energy (Collett, 2001), exert a control on sea-floor stability (Paull and others, 2000), represent a hazard to hydrocarbon exploration and production (Collett and others, 2000), and influence global climate change (Kennett and others, 2003). At present, however, relatively little is known about its global distribution in shallow marine sediment or even exactly how it forms.

Numerous occurrences of gas hydrate are known near (<7-meter (m) subbottom) the sea bed in the northern Gulf of Mexico (Sassen, 2001; Roberts and others, 2002). The area is characterized by high sedimentation rates, complex stratigraphy, and strata that are disrupted by salt tectonism and

Figure 1. Samples of gas hydrate recovered from Calypso giant piston core MD02-2569.

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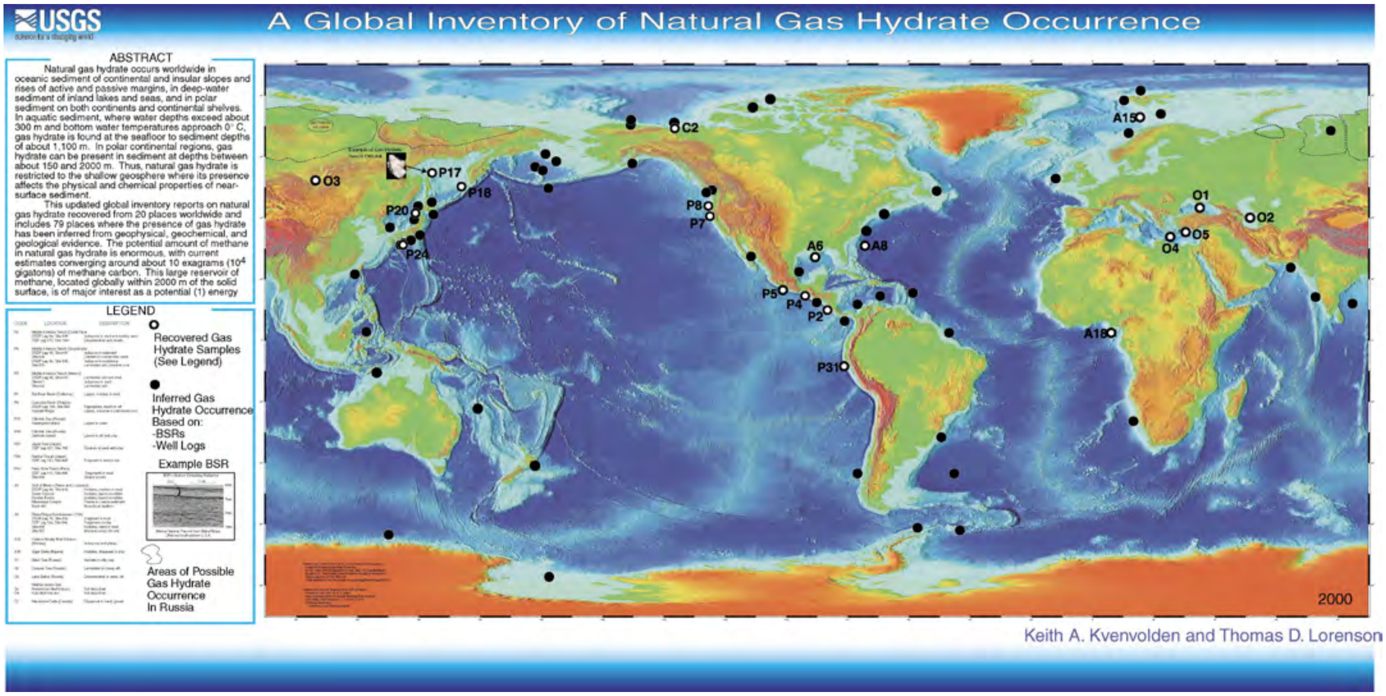

Natural gas hydrate occurs worldwide in oceanic sediment of continental and insular slopes and rises of active and passive margins, in deep-water sediment of inland lakes and seas, and in polar sediment on both continents and continental shelves. In aquatic sediment, where water depths exceed about 300 m and bottom water temperatures approach 0° C, gas hydrate is found at the seafloor to sediment depths of about 1,100 m. In polar continental regions, gas hydrate can be present in sediment at depths between about 150 and 2000 m. Thus, natural gas hydrate is restricted to the shallow geosphere where its presence affects the physical and chemical properties of near-surface sediment.

This updated global inventory reports on natural gas hydrate recovered from 20 places worldwide and includes 79 places where the presence of gas hydrate has been inferred from geophysical, geochemical, and geological evidence. The potential amount of methane in natural gas hydrate is enormous, with current estimates converging around about 10 exagrams (10^4 gigatons) of methane carbon. This large reservoir of methane, located globally within 2000 m of the solid surface, is of major interest as a potential (1) energy

Figure 2. Global inventory map of gas hydrate occurrences (Kvenvolden and Lorenson, 2001b) (*http://walrus.wr.usgs.gov/globalhydrate/index.html*).

common sea-floor failures (Cooper and Hart, 2002). Natural oil and gas seeps also are abundant, usually associated with fault conduits. The resulting numerous hydrocarbon vents are often capped by gas hydrate when the seeps are within the hydrate stability zone. Whereas gas hydrate is relatively common near the sea floor as indicated by extensive sample recovery of hydrate, the lack of diagnostic geophysical indicators on seismic records leaves the existence of deeper gas hydrate unresolved. Thus, we do not know if significant gas hydrate accumulations are present in sediments away from structural conduits inferred to underlie sea-floor mounds. To address this and other questions, we collected samples with the International Marine Past Global Changes Study (IMAGES) and Paleoceanography of the Atlantic and Geochemistry (PAGE) programs aboard the research vessel (RV) *Marion Dufresne* (fig. 3) in July 2002, within four continental-slope regions of the northern Gulf of Mexico (Tunica Mound, Orca and Pigmy Basins, Bush Hill, and the Mississippi Canyon region).

Figure 3. RV *Marion Dufresne* is 120.5 meters in overall length and is 20.6 meters in beam amidships. It has a draft of 6.95 meters and displaces 10,380 tonnes. Coring operations are conducted using the starboard stern A frame.

Scientific Objectives and Conclusions

We recovered 17 giant piston cores, up to 38 m long, two giant box cores up to 10 m long, and four gravity cores up to 9 m long. Gas hydrate-related coring sites were selected along seismic-reflection transects in widely different geologic environments in water depths ranging from about 560 to 1,320 m (table 1). The transects were designed to extend from known sea-floor gas hydrate occurrences across the adjacent basin to thick sediments away from any gas-venting sites. We recovered gas hydrate in four cores from previously known venting areas in subbottom depths of about 3 to 9 m, but none was found in adjacent basins. We made 17 successful passive heat-flow measurements to subbottom depths of 17 m in conjunction with hundreds of pore-water and gas-chemistry measurements to better understand the thermal and geochemical regimes in the sediments and their relations to gas hydrate formation and occurrence.

Results of this work confirm the presence of gas hydrate in vent-related near-sea-bed sediments. However, if results from our limited coring effort can be extrapolated to other Gulf of Mexico sites, it appears that gas hydrate is not pervasive between hydrate outcrops.

Table 1. Core information, including location, water depth, recovered core length, and core type.

[ID, identification; deg, degrees; m, meters; PC, piston core; C2 (box), square box core; GHF, gravity core with heat-flow temperature sensors attached; Grav, gravity core without thermal sensors; **, denotes successful determination of geothermal gradient]

Core ID	Latitude (deg)	Longitude (deg)	Site name	Water depth (m)	Core length (m)	PC	C2 (box)	GHF	Grav	Comments
MD02-2535	27.6198	-92.2410	Tunica Mound	605	37.84	*				
MD02-2536GHF-1	27.6198	-92.2410	Tunica Mound	608	8.88			**		
MD02-2536GHF-2	27.6253	-92.2460	Tunica Mound	564	8.88			**		
MD02-2536GHF-3	27.6270	-92.2375	Tunica Mound	585	8.88			**		
MD02-2537	27.6160	-92.2487	Tunica Mound	600	33.58	*				
MD02-2538G	27.6167	-92.2472	Tunica Mound	599	7.76				*	
MD02-2539	27.6397	-92.1922	Tunica Mound	622	31.1	*				
MD02-2540GHF-1	27.6403	-92.1920	Tunica Mound	617	5.65			**		
MD02-2540GHF-2	27.6402	-92.1952	Tunica Mound	620	-			*		
MD02-2541	27.6325	-92.2123	Tunica Mound	615	35.34	*				
MD02-2542GHF	27.6322	-92.2120	Tunica Mound	617	7.7			**		
MD02-2543G	27.6123	-92.2555	Tunica Mound	579	0.15				*	
MD02-2544G	27.6130	-92.2535	Tunica Mound	584	0.1				*	
MD02-2545G	27.6140	-92.2517	Tunica Mound	588	9.27				*	
MD02-2546	27.6157	-92.2470	Tunica Mound	595	31.21	*				
MD02-2547GHF	27.6165	-92.2483	Tunica Mound	607	5.73			**		
MD02-2548	27.6375	-92.1995	Tunica Mound	610	32.92	*				
MD02-2550C2	26.9462	-91.3457	Orca Basin	2,249	9.09		*			
MD02-2553C2	27.1835	-91.4167	Pigmy Basin	2,259	10.03		*			
MD02-2554	27.7833	-91.4990	Bush Hill Basin	602	31.05	*				
MD02-2555	27.7832	-91.4892	Bush Hill Basin	636	35.68	*				
MD02-2556	27.7830	-91.4775	Bush Hill Basin	654	34.25	*				
MD02-2557GHF-1	27.7830	-91.4987	Bush Hill Basin	613	7.59			**		
MD02-2557GHF-2	27.7830	-91.4890	Bush Hill Basin	639	-			**		
MD02-2557GHF-3	27.7828	-91.4805	Bush Hill Basin	659	-			**		
MD02-2559	28.2225	-89.0882	Kane Spur	1,132	33.39	*				
MD02-2560	28.2433	-89.1550	Kane Spur	1,029	28.24	*				
MD02-2561	28.2052	-89.0202	Kane Spur	1,268	28.8	*				

Table 1. Core information, including location, water depth, recovered core length, and core type. — Continued

[ID, identification; deg, degrees; m, meters; PC, piston core; C2 (box), square box core; GHF, gravity core with heat-flow temperature sensors attached; Grav, gravity core without thermal sensors; **, denotes successful determination of geothermal gradient]

Core ID	Latitude (deg)	Longitude (deg)	Site name	Water depth (m)	Core length (m)	PC	C2 (box)	GHF	Grav	Comments
MD02-2562	28.0798	-89.1402	Kane Spur	1,051	26.09	*				
MD02-2563C2	28.1233	-89.1363	MC853 Diapir	1,070	3.86		*			recovered hydrate (gas bubbles)
MD02-2564GHF-1	28.2433	-89.1545	Kane Spur	1,027	7.63			**		
MD02-2564GHF-2	28.2223	-89.0883	Kane Spur	1,261	-			**		
MD02-2564GHF-3	28.2052	-89.0200	Kane Spur	1,269	-			**		
MD02-2564GHF-4	28.2070	-89.0200	Kane Spur	1,269	-			**		
MD02-2565	28.1235	-89.1395	MC853 Diapir	1,068	22.5	*				recovered hydrate
MD02-2566	28.1192	-89.1032	Kane Spur	1,186	26.05	*				
MD02-2567	28.1002	-89.0198	Kane Spur	1,318	26.65	*				
MD02-2568GHF-1	28.0790	-89.1400	MC853 Diapir	1,049	6.96			**		
MD02-2568GHF-2	28.0810	-89.1370	MC853 Diapir	1,057	-			**		
MD02-2568GHF-3	28.1193	-89.1030	MC853 Diapir	1,190	-			**		
MD02-2568GHF-4	28.1233	-89.1395	MC853 Diapir	1,068	-			*		
MD02-2568GHF-5	28.1235	-89.1362	MC853 Diapir	1,049	-			*		
MD02-2569	28.1522	-89.4797	Mississippi Canyon	1,032	10.35	*				recovered hydrate
MD02-2570	28.0710	-89.6898	West Mississippi	631	28.35	*				
MD02-2571C2	28.0667	-89.7192	West Mississippi	664	10.38		*			
MD02-2572GHF	28.0710	-89.6897	West Mississippi	628	4.9			**		
MD02-2573GHF	28.1520	-89.4798	Mississippi Canyon	1,027	4.2			*		recovered hydrate
MD02-2574	28.6267	-88.2248	East Mississippi	1,963	32.28	*				

Note: Cores obtained during the cruise that are not listed in this table and cores MD02-2548 in Tunica Mound, MD02-2550C2 in Orca Basin, and MD02-2574 in East Mississippi region are IMAGES/PAGE cores, not dedicated USGS cores.

Report Format and Chapter Descriptions

Part 1

This report contains three main sections. The first part (Chapters 2 through 9) describes the interpretation of measurements integrated across all of our sample sites in the northern Gulf of Mexico.

Chapter 2, Geologic Setting: Results of prior USGS seismic-reflection cruises conducted in the northern Gulf of Mexico that provided the stratigraphic framework for the present coring program. Site characteristics of Tunica Mound, Bush Hill, the Mississippi Canyon region, and Pigmy and Orca Basins are discussed.

Chapter 3, Coring and Gas Hydrate Operations: An illustrated record of the procedures used to acquire, subsample, and process sediment samples from the various sampling devices used during the cruise. Special emphasis is placed on safety-related aspects dealing with dissociating gas hydrates.

Chapter 4, Physical Properties: Results of shear strength, electrical resistivity, texture, carbon content, and index property tests performed at sea and in a shore-based laboratory.

Chapter 5, Sedimentology: Sedimentologic descriptions and discussion of longitudinally split cores obtained during the cruise. In addition, techniques used to obtain Multi-Sensor Core Logs (MSCL), core photographs, and spectrophotometric logs are presented.

Chapter 6, Heat Flow: Results of instrumented gravity core penetrations of the sea floor. Geothermal gradients and heat-flow parameters at 17 locations distributed throughout the three main study areas.

Chapter 7, Thermal Conductivity: Methods and results of thermal conductivity (TC) tests performed on whole-round sections from 23 cores.

Chapter 8, Pore-Water Geochemistry: Interpretations of chloride, sulfate, and methane concentration in relation to subbottom depth of 483 water samples squeezed from sediment of Tunica Mound, Bush Hill, and the Mississippi Canyon region.

Chapter 9, Sediment Gas Geochemistry: Results of hydrocarbon and carbon dioxide gas analyses of sediment samples taken from four distinct regions in order to constrain concentrations and sources of gas that may form gas hydrate. Gas from dissociated hydrate, gas dissolved in sediment pore water, and gas from voids in the core were analyzed.

Part 2

The second part of this report (Chapters 10 through 14) is related to analyses that were performed on just one or a limited number of cores.

Chapter 10, Microbiology: An analysis of the archaeal small-subunit ribosomal RNA gene diversity from core MD02-2571C2, located near a gas chimney at a site west of the Mississippi Canyon.

Chapter 11, Biostratigraphy: A preliminary age-depth model for core MD02-2570 (west flank of the Mississippi Canyon), based on datums defined by the regional biostratigraphic zonation of planktonic foraminifers.

Chapter 12, Scanning Electron Microscopy (SEM): SEM analyses of natural gas hydrate nodules from core MD02-2569, from a site west of the Mississippi Canyon. Similarities in grain and pore structure were compared with images of laboratory-synthesized gas hydrates.

Chapter 13, Pollution Transport: Results of textural analyses of samples from Pigmy Basin and from low-oxygen, hyper-saline Orca Basin. Trace metal compositions of basin sediments were determined using a variable-pressure scanning electron microscope (SEM) equipped with energy-dispersive spectroscopy (EDS).

Chapter 14, Carbonate Mineralogy and Isotopes: Analyses of carbonates sampled from various subbottom depths at Tunica Mound and the Mississippi Canyon.

Part 3

The third part of this report consists of appendixes that typically, but not exclusively, present information and data produced at sea. Most of the at-sea data sets required the use of proprietary software that was not available for post-cruise editing and, thus, are in their original, unedited formats.

Appendix A, Cruise Logistics: A table of core information, core and sediment recovery statistics, photographs, and contact information for cruise participants.

Appendix B, Maps: Regional and local bathymetric maps showing core locations.

Appendix C, Combined Station Results: Compiled, measured properties, and information for individual core sites.

Appendix D, Seismic profiles/Track lines: Regional and local core-specific seismic profiles and track lines.

Appendix E, Core Summaries: Information about individual core recovery and sediment observations.

Appendix F, Lithologic Descriptions: Unedited lithologic descriptions produced at sea of longitudinally split cores.

Appendix G, Core Photographs: At-sea photographs of freshly exposed longitudinally split cores (combined from individual digital files representing 0.5-m long core sections).

Appendix H, Multi-Sensor Core Logger (MSCL) Results: Individual core at-sea records of unedited acoustic velocity and amplitude, density, magnetic susceptibility, and related properties.

Appendix I, Spectrophotometry Results: Unedited, at-sea spectrophotometry records of individual cores.

Appendix J, Photographs: Digital photographs of shipboard activities.

Appendix K, U.S. Geological Survey (USGS) Video Press Release: Produced for the USGS in Tampa Bay.

Appendix L, Gas Hydrate Stability Models: Gas hydrate stability models related to gas type and geothermal conditions.

Appendix M, Metadata: Cruise logistics and information.

Appendix N, Abbreviations and Symbols: Selected abbreviations and symbols used in this report.

There is some redundancy in information between chapters so that readers can concentrate on those chapters that are of primary interest. Thus, readers may not need to read the chapters in numerical order.

USGS Cruise Participants

Participants of the USGS-supported part of the cruise: USGS, Menlo Park; USGS, Woods Hole; USGS, St. Petersburg; Monterey Bay Aquarium Research Institute (MBARI); University of Victoria, British Columbia, Canada; College of William and Mary; Moscow State University; University of Tokyo; and Texas A&M University.

Acknowledgments and Notes

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Considerable at-sea help was provided by an international group of about 40 scientists working under the IMAGES (International Marine Past Global Changes Study) and PAGE (Paleoceanography of the Atlantic and Geochemistry) programs. The IMAGES program is an international effort to understand the mechanisms and consequences of climatic changes using the oceanic sedimentary record.

Financial support of USGS-related activities was provided by the USGS Coastal and Marine Geology Program, the USGS Energy Program, and the U.S. Department of Energy's Gas Hydrate Program.

The U.S. Minerals Management Service provided information used to determine core locations and avoid existing sea-floor infrastructure (pipelines, etc.).

The Integrated Ocean Drilling Program (IODP) provided facilities to store and archive recovered cores.

Metadata from the cruise, including navigation, personnel, core locations, are available on the Internet at the USGS Web site: *http://walrus.wr.usgs.gov/infobank/d/d102gm/html/d-1-02-gm.meta.html* .

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