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STUDY TITLE: Improving the Predictive Capability of 3D Seismic Surface Amplitude Data for Identifying Chemosynthetic Communities Sites

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BACKGROUND: A very promising approach for utilizing regional 3-D seismic data for enhanced predictability of the sea floor and shallow subsurface is application of surface reflectivity or surface amplitude mapping. This process involves mapping the reflection strength associated with a narrow window of data centered on the sea floor. An interval of about 10 ms is commonly used. This technique is valuable for quickly mapping large areas of sea floor and identifying those local zones which differ in reflection strength from ambient conditions. However, a variety of conditions can account for reflectivity or amplitude that deviates from the "norm." These conditions range from hard bottoms associated with rock outcrops, (mineralized mounds, hardgrounds, other cemented bottom types, as well as, surface-to-shallow subsurface gas hydrate) to very soft bottoms that are charged with gas (biogenic, thermogenic, or a combination of the two). The hard bottom areas constitute a medium through which acoustic energy travels slightly faster than the surrounding sea floor while gas-charged sediment have just the opposite response of slower velocities. Therefore, the identification of these slightly different velocities of seismic energy moving through the surface sediment can help discriminate hard and soft bottoms. This classification can be accomplished through phase analysis, phase being a product of velocity of the acoustic energy and density of the medium. Results of this analysis which identifies a polarity shift in the data can help distinguish one end-member bottom type from another. These techniques have previously been used to help interpret site-specific sea

floor conditions and features, particularly those that are associated with hydrocarbon seepage or more rapid venting of fluids and gases to the modern sea floor. Amplitude mapping has also been employed successfully in a broader range of geohazards assessments. However, for the project described in this report, the emphasis is placed on improving the use of 3-D seismic data, particularly surface amplitude or reflectivity data, for predicting sea floor geology and biology, which can be used in the regulatory framework. The project specifically focuses on developing links between surface reflectivity data and areas that support chemosynthetic communities. This project contributes to field verification of 3-D seismic surface reflectivity signatures. This step is absolutely crucial to developing reliable predictors of sea floor characteristics from remotely sensed data. Because of the high degree of geologic complexity of the northern Gulf of Mexico continental slope, understanding the range of sea floor geologic/biologic features and areas that give rise to 3-D seismic amplitude anomalies is a challenging task that has required a determined effort on the part of both academic and BOEM personnel associated with this project.

OBJECTIVES: Analysis of 3-D seismic surface reflectivity or amplitude data coupled with direct field verification data in a matrix of known geologic configurations will lead to the development of a scheme for predicting the sites of various hydrocarbon seep-vent features and particularly the probable sites for occurrence of chemosynthetic communities. The presence or absence of chemosynthetic communities is directly dependent on delivery of hydrocarbons to the sea floor. This delivery system is a product of the continental slope's geologic framework. Therefore, understanding the geology of hydrocarbon seep-venting sites is viewed in this study as fundamental to being able to predict general biologic response.

DESCRIPTION: The five sections of this report set the stage for interpreting datasets and results of the case histories for individual sites for fluid-gas expulsion that were analyzed remotely using 3-D seismic data and then verified with direct observation sampling using manned submersibles. These five sections provide geologic framework summary information on the sash-sediment relationships that create a unique structural framework that promotes fluid and gas expulsion and associated seafloor responses. In addition, the evolution of technology advances that currently allow us to interpret seafloor geology with a high degree of confidence as well as the methodologies directly applied to this project are also discussed.

The report is discusses ten case investigations where both field and data are combined for making informed identifications of hydrocarbon seep and vent sites that impact the modern sea floor. As stated in the introductory sections of this report, the primary objective of this study is to improve the predictive use of 3-D seismic surface reflectivity or surface amplitude data for enhanced interpretation of sea floor geology and biology associated with sites where fluid and gas expulsion is taking place. The laboratory data consist of industry-acquired 3-D seismic data analyzed under proprietary guidelines at the Bureau of Ocean Energy Management (BOEM) office in New Orleans, Louisiana. In conjunction with BOEM geoscientists, each site was geophysically characterized using both surface attributes and stratigraphic-structural properties of the shallow subsurface interpreted from 3-D seismic data. Interpretations about the character of the sea floor derived from these data were field "calibrated" using observational data (video

tape and 35mm photographs) from the Harbor Branch Oceanographic Institute's Johnson Sea-Link submersible and sea floor sampling (grab samples and short cores).

SIGNIFICANT CONCLUSIONS:

1. The structural frameworks for most of the cases investigated in this study (7 out of 10) were defined by extensional faulting either at the margins of intraslope basin or as families of faults above the crests of shallow subsurface salt bodies. Many of these faults clearly provided pathways for fluid-gas migration from the subsurface. However, nearly half of the sites investigated (4 of 10) displayed vertical buoyancy-driven migration routes, mostly at the edges of salt bodies characterized by acoustic blanking on seismic profiles.

2. The 3-D seismic sea floor amplitude methodology for identifying exposed hard bottom areas on the seabed is very successful. Hard bottom was interpreted and confirmed by "ground truth" observations in 7 of 10 cases considered in this investigation. However, the method is not infallible. In the 3 cases where little or no hard bottom was found by direct observation in areas defined by medium-to-high positive acoustic amplitudes, the acoustically reflective surfaces were interpreted as being covered by unconsolidated sediment. Because of the frequency content of the 3-D seismic data, the sea floor amplitude response is integrated over approximately 5-7 m (15-25 ft) of the sediment column. Therefore, acoustically reflective surfaces can occur anywhere in that interval and result in a positive acoustic sea floor amplitude.

3. Considering the limited options for "hard bottom" on the northern Gulf of Mexico continental slope (shallow sands, salt, and seep-related carbonates), the 3-D seismic sea floor amplitude methodology is well-suited for identifying sites of hydrocarbon seepage or more rapid venting. High positive acoustic amplitudes have the highest probability of correlating to areas of authigenic carbonate development (nodular masses in the sediment, slabs, boulders and large outcrops) and/or lucinid-vesycomyid clam shell beds. Chemosynthetic communities, outcropping gas hydrate, and deep water corals are also frequently encountered in these sea floor areas of moderate-to-high acoustic amplitude response.

4. Patterns of 3-D seismic acoustic amplitudes or acoustic reflectivity from the sea floor are meaningful. For example linear patterns of moderate-to-high acoustic amplitudes are usually sediment flows from mounded expulsion centers with crestal areas of low positive values (below the regional background values). The low positive areas usually represent gas-charged sediment. Small scattered "spots" of high positive acoustic amplitude have been found to represent discrete authigenic carbonate outcrops of low relief separated by unconsolidated sediments.

5. The 3-D seismic sea floor amplitude method is limited and should only be considered a first-level approach to interpreting details of the seabed. However, this methodology has proved to be of immense value in locating probable sites of chemosynthetic communities, deep water corals, and gas hydrates. Furthermore, the methodology has provided a way to efficiently apply more specific and costly methods of collecting detailed data from the sea floor. An ideal investigation would include 3-D seismic sea floor amplitude mapping for identifying areas of

interest, high resolution multibeam bathymetry to obtain details of seabed relief, and manned submersibles or ROVs for direct observation and sampling of specific areas within the field of sea floor amplitudes and specific seabed features identified in the multibeam bathymetry dataset.

STUDY RESULTS: Although 3-D seismic sea floor amplitude mapping has become an accepted methodology for identifying sites of hydrocarbon seepage, mainly because of acoustic reflectivity associated authigenic carbonates, the use of these data is not without limitations. The primary purpose of 3-D seismic data is to image the stratigraphic and structural complexities of the subsurface. The frequency content of the seismic energy to accomplish this task does not allow for just the sediment-water interface to be imaged. Therefore, the first reflected return from the sea floor integrates information from approximately the upper 5-7 m (15-25 ft) of the sediment column. Buried hardgrounds, shell layers, sand deposits, salt, and other acoustically reflective materials may therefore be represented in the amplitude of the "sea floor" reflector. The case examples demonstrate this limitation of the 3-D seismic surface amplitude methodology for predicting areas of hard bottom. Although all but one case exhibited areas of moderate-to-high positive 3-D seismic sea floor amplitudes, three of these cases (GB 535, GC 238, and EW 1001) had either no surface evidence of "hard bottom" or very few indicators. In these cases, it is highly suggestive that the acoustically reflective surfaces imaged in the 3-D seismic sea floor amplitude data are in the subsurface covered with sediment. In the EW 1001 case, fluidized sediment expulsion from two separate expulsion centers is burying chemosynthetic communities (e.g. tubeworms) and areas interpreted as lithified zones on the flanks of the mounded expulsion centers.

STUDY PRODUCTS: Roberts, H.H. 2013. Improving the Predictive Capability of 3-D Seismic Surface Amplitude Data For Identifying Chemosynthetic Communities. US Dept. of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico Region, New Orleans, LA. OCS Study BOEM 2013-222. 190 pp.

Publications:

Chen, D.F., L.M. Cathles, III, and H.H. Roberts, (2004), The geochemical signatures of variable gas venting at gas hydrate sites: marine and Petroleum Geology, v. 21, p. 317-326.

Sassen, R., H.H. Roberts, R. Carney, A.V. Milkov, D.A. DeFreitas, B. Lanoil, C. Zhang, (2004), Free hydrocarbon gas, gas hydrate, and authigenic minerals in chemosynthetic communities of the northern Gulf of Mexico continental slope: relation to microbial processes. Chemical Geology, v. 205, p. 195-217.

Sassen, R., A.V. Milkov, H.H. Roberts, S.T. Sweet, and D.A. DeFreitas, (2003), Geochemical evidence of rapid hydrocarbon venting from a seafloor-piercing mud diapir, Gulf of Mexico continental shelf: Marine Geology, v. 198, p. 319-329.

Rogers, R.E., J.L. Dearman, and H.H. Roberts, (2003), Enhancement of gas hydrate formation in Gulf of Mexico sediments: Proceedings, Offshore Technology Conference, OTC 15393, p. 1-7.

Roberts, H.H., J.L. Hunt, W.W. Shedd, and R. Sassen, (2002), Surficial gas hydrates, part of the fluid and gas expulsion response spectrum: Identification from 3D seismic data: Proceedings Offshore Technology Conference, OTC 14033, May 6-9, 2002, p. 1-10.

Roberts, H.H., R. Sassen, and A.V. Milkov (2001) Seafloor expression of fluid and gas expulsion from deep petroleum systems, continental slope of the northern Gulf of Mexico: 2001 GCSSEPM research Foundation, 21st Ann. Res. Conf., Petroleum Systems of Deep-Water Basin, p. 407-421.

Roberts, H.H., (2001), Fluid and gas expulsion on the northern Gulf of Mexico continental slope: Mud-prone to mineral-prone responses. *In:* C.K. Paull and W.P. Dillon (eds.), Natural gas hydrates: Occurrences, distribution, and dynamics: American Geophysical Union, Geophysical Monograph, No. 124, p. 145-161.

Sassen, R., H.H. Roberts, A.V. Milkov, and D.A. DeFreita (2001) Seafloor vents, seeps, gas hydrate: Relation to flux rate from the deep Gulf of Mexico petroleum system: 2001 GCSSEPM Research Foundation, 21st Ann. Res. Conf., Petroleum Systems of Deep-Water Basins, p. 489-505.

Roberts, H.H., J.M. Coleman, J. Hunt, Jr., and W.W. Shedd, (2000), 3D-seismic surface amplitude mapping for unproved interpretation of seafloor geology and biology: Offshore Magazine, September Issue, p. 126-128, 181.

Roberts, H.H., J.M. Coleman, J. Hunt, Jr., and W.W. Shedd, (2000), Surface amplitude mapping of 3D-seismic for improved interpretations of seafloor geology and biology from remotely sensed data: Transactions Gulf Coast Association of Geological Societies, v. 50, p. 495-504.

Presentations at Local, Regional, National, and International Meetings:

Roberts, H.H., J.L. Hunt, Jr., and W. Shedd, 2005, Seafloor and subsurface geology of gas hydrate sites—northern Gulf of Mexico continental slope: SGS Geophysical Symposium, New Orleans, LA, June 9 (Poster).

Roberts, H.H., 2004, Gas hydrates in the Gulf of Mexico's complex geologic setting: Future resource or just another geohazard? Houston Geological Society, Houston, TX, April 28, (Invited Talk).

Roberts, H.H., J.M. Coleman, J.L. Hunt, Jr., W.W. Shedd, and R. Sassen, 2003, Seafloor and subsurface geology of gas hydrate exposure sites-Northern Gulf of Mexico Continental Slope: American Association of Petroleum Geologists Annual Meeting, Official Abstract Volume, p. A146 (Poster).

Roberts, H.H. and J.M. Coleman, 2003, Improving the predicitive capability of 3D-seismic surface amplitude data for identifying chemosynthetic communities: MMS-Information Transfer Meeting, Jan. 14-16, New Orleans, LA. (Talk).

Roberts, H.H., J.M. Coleman, and H. Peele, 2003, Mapping areas of hard bottom and other important bottom types-outer continental shelf and upper continental slope (northern Gulf of Mexico): MMS-Information Transfer Meeting, Jan. 14-16, New Orleans, LA. (Talk).

Sassen R., H.H. Roberts, J.P. Chanton, A.V. Milkov, D.A. DeFreitas, and S.T. Sweet, 2003, Evidence of a deep source of bacterial methane in the Gulf of Mexico continental slope: American Chemical Society Meeting, New Orleans (Talk)

Roberts, H.H., J.L. Hunt, W.W. Shedd, and R. Sassen, 2002, Surficial gas hydrates, part of the fluid and gas expulsion response spectrum: Identification from 3D seismic data: 2002 Offshore Technology Conference, OTC 14033, 10 p.

Roberts, H.H., J.M. Coleman, J.L. Hunt, W.W. Shedd, R. Sassen, and A. Milkov, 2002, Gas hydrate deposits in a complex geologic setting northern Gulf of Mexico slope: Gulf Coast Association of Geological Societies Annual Convention, October 30 – November 1, Austin, TX., Official Program, p. 101 (Poster).

Roberts, H.H., 2002, Geologic and biologic responses to varying rates of fluid and gas expulsion – Northern Gulf of Mexico, American Association of Petroleum Geologists Hedberg Conference, Vanconver, April 7-10, 2002 (Talk).

Roberts, H.H., J.M. Coleman, J.L. Hunt, W.W. Shedd, A.V. Milkov, and R. Sassen, 2002, Fluid and gas expulsion on the continental slope, northern Gulf of Mexico: 2001 GCSSEPM Research Foundation, 21st Ann. Res. Conf., Petroleum Systems of Deep-Water Basin, (Poster).

Roberts, H.H., J.L. Hunt, W.W. Shedd, and R. Sassen, 2002, Surficial gas hydrates, part of the fluid and gas expulsion response spectrum: Identification from 3D-seismic: Proceedings Offshore Technology Conference, OTC 14033, May 6-9, 2002, p. 1-10, (Talk).

Roberts, H.H., J.M. Coleman, J.L. Hunt, W.W. Shedd, R. Sassen, and A. Milkov, 2002, Gas hydrate deposits in a complex geologic province (GOM): Linkage to fluid-gas expulsion: Gulf Coast Association of Geological Societies Annual Convention, Austin, TX, (Poster).

Sassen, R., A.V. Milkov, D.A. DeFreitas, and H.H. Roberts, 2002, Gas venting and gas hydrate stability in the northwestern Gulf of Mexico-significance to sediment deformation: Proceedings Offshore Technology Conference, OTC 14034, May 6-9, 2002, p 1-7, (Talk).

Roberts, H.H., J.M. Coleman, J.L. Hunt, W.W. Shedd, A.V. Milkov, and R. Sassen, 2001, Gas hydrates in a complex geologic province, Northern Gulf of Mexico: AAPG Annual Convention, Official Program, v. 10, p. A170, (Poster).

Roberts, H.H., 2001, A new source of energy from deep water – The potential of gas hydrates: Lafayette Geological Society, November 28, 2001 (Talk).

Roberts, H.H., 2001, Gas hydrates – Can they be produced from the Gulf of Mexico slope? Society of Independent Professional Earth Scientists (SIPES), April 17, 2001. (Invited Talk)

Roberts, H.H., J.M. Coleman, J.L. Hunt Jr., W.W. Shedd, A.V. Milkov, and R. Sassen, 2001, Gas hydrates in a complex geologic province, northern Gulf of Mexico: American Association of Petroleum Geologists Annual convention, Denver, Co., May 2-6, 2001. (Invited Poster).

Roberts, H.H., J.M. Coleman, J.L. Hunt, W.W. Shedd, A.V. Milkov, and R. Sassen, (Accepted), Gas hydrates in a complex geologic province, northern Gulf of Mexico:

American Association of Petroleum Geologists Convention, Denver, CO., June 3-6, 2001, Abst. (Poster).

Sassen, R., S.T. Sweet, A.V. Milkov, D.A. DeFreitas, and H.H. Roberts, Thermogenic gas venting and gas hydrate in the Gulf of Mexico potential significance to climate change: American Association of Petroleum Geologists Convention, Denver, CO., June 3-6, 2001, Abst. (Poster).

Sassen, R., S.T. Sweet, A.V. Milkov, D.A. DeFreitas, and H.H. Roberts, 2001, Thermogenic gas venting and gas hydrate in the Gulf of Mexico-potential significance to climate change: American Association of Petroleum Geologists Annual Convention, Denver, Co, May 2-6, 2001. (Poster).

Roberts, H.H., J. Coleman, J. Hunt Jr., and W. Shedd, 2000, Surface amplitude mapping of 3D-seismic data for improved interpretations of seafloor geology and biology from remotely sensed data: 50th Annual Gulf Coast Association of Geological Societies convention, October 25-27, 2000. (Talk).

Roberts, H.H., 2000, Fluid and gas expulsion on the northern Gulf of Mexico slope: American Association of Petroleum Geologists Annual Convention, April 16-19, New Orleans, LA., Program and Abstracts, p. A126. (Talk).

Roberts, H.H., Wm. J. Wiseman, Jr., J. Hooper, and G. Humphrey, 2000, Gas hydrate at or near the modern seafloor: Effects of water column temperature variations on hydrate stability: American Association of Petroleum Geologists Annual Convention, April 16-19, New Orleans, LA., Program and Abstracts, p. A126. (Talk).

Sassen, R., H.H. Roberts, and A.V. Milkov, 2000, Oil and gas fields, seafloor vents, seeps, and gas hydrate deposits as products of the Gulf of Mexico Petroleum System: 20th Annual GCSSEPM Research Conference, Deep Water Petroleum System, Houston, Texas, December 2-5, 2001, Abst. (Talk).

Roberts, H.H., R. Sassen, and A.V. Milkov, 2000, Seafloor expressions of fluid and gas expulsion from deep petroleum systems, continental slope of the northern Gulf of Mexico: 20th Annual GCSSEPM Research Conference, Deep Water Petroleum Systems, Houston Texas, December 2-5, 2001.

Roberts, H.H., 2000, Fluid and gas expulsion on the northern Gulf of Mexico continental slope: Mud-prone to mineral-prone responses: American Geophysical Union, Fall Meeting, San Francisco, CA., Abst. (Talk).