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Multi-channel Seismic Analysis of Gas Hydrates and Related Geological Structure in the Northwestern Gulf of Mexico

Abstract

Gas hydrates are ice-like minerals composed of a crystal lattice of water molecules surrounding molecules of natural gas. They are found worldwide along continental slopes and are important because they may be a potential energy source, can cause slope instabilities, can affect earth's climate, and accommodate unique ecological communities. Bottom Simulating Reflectors (BSRs) are seismic reflectors commonly associated with gas hydrates. These reflectors often crosscut stratigraphic reflectors and are thought to be a result of gas trapped in sedimentary pore space beneath the zone in which gas hydrate occurs. Although BSRs are observed on many continental margins, including the northern Mexican slope, in the northern Gulf of Mexico (GOM), BSRs are either not present or have yet to be discovered. In this study, I propose a three year study incorporating ~60,198km of 2-D seismic data supplied by TGS-NOPEC. The objective of the study will be to map the geologic structure and stratigraphy in an otherwise unstudied area, determine what controls the geology has on hydrate formation, use seismic attributes to determine if hydrates exist in the study area, and if there is a hydrate transition zone between the northern GOM slope and the Mexican slope. This study will provide a better understanding of hydrate formation, distribution, and the underlying geology responsible for gas migration and accumulation. It will also yield locations of new hydrocarbon seep sites for future study and increase structural knowledge of a region that has received little geologic study in the public domain.

Introduction

Gas hydrates are ice-like crystalline solids composed of a water lattice surrounding natural gas molecules, such as methane that form under high-pressure, low-temperature conditions (Kvenvolden, 1988). Hydrate formation and accumulation is dependent upon water depth, bottom water temperature, pressure, geothermal gradients, pore water salinity, and amount of gas accumulation (Milkov *et al.*, 2000). Suitable conditions are found worldwide on continental slopes at depths >500 m (Kvenvolden, 2001). Scientists have studied hydrates for years because of the large amounts of organic carbon they contain, their potential use as an energy source, and their possible effect on climate if they were to dissociate and disperse. It is estimated that methane hydrates contain 2.103 - 4.106 Gt of carbon, more than all other fossil fuel reservoirs combined (Kvenvolden, 1988). The sudden release of methane gas into the atmosphere from dissociation of hydrate can be a cause for sudden global warming, such as the Paleocene Thermal Maximum, which saw a sharp increase in deep ocean water temperature and an increase in carbon into the atmosphere (Dickens, 2001). Dissociation of gas hydrates may also be the cause of natural hazards such as slumps, slides, and collapse structures similar to the one found on Blake Ridge (Dillon *et al.*, 2001). Hydrates also accommodate some of the planet's most interesting life forms, chemosynthetic organisms that metabolize vent fluid and gases, living in one of the harshest environments known. These organisms survive in this environment thanks to a symbiotic relationship with bacteria that feed off of the methane (MacDonald *et. Al*, 2003).

Many hydrates around the world formed from biogenic decomposition of organic matter, forming widely-dispersed layers within the sediment with low volumes of hydrates; *e.g.*, Blake Ridge (Paull *et al.*, 1995). Thermogenic methane is another type of methane, which forms from hydrocarbon reservoirs deep within the sediment column. In the GOM this gas migrates upward through faults formed in the reservoir and overlying sediment. Both biogenic and thermogenic hydrates are found in the GOM and in some locations both types form close to the surface and often outcrops at the seafloor, as seen at the Green Canyon 185 lease block (MacDonald *et al.*, 1994).

In the GOM, most hydrate locations are associated with hydrocarbon seeps, therefore locating sea-surface slicks can lead to hydrate locations (Figure 2). As gas from subsurface reservoirs rise, migrating hydrocarbons rise also. As gas escapes from the seafloor, it forms bubbles that also carry oil to the sea-surface. This gas and oil mixture collects on the sea-surface, forming natural oil slicks that are imaged from orbiting satellites. This method has proven useful for both scientists and industries in providing both starting locations for hydrate location and reservoir exploration; however, published efforts have been concentrated in the Louisiana slope region (MacDonald *et al.*, 1994, 1996). Another method for locating hydrates is through geophysical examination of multi-channel seismic data (MCS). As hydrates form, free gas becomes trapped at the base of the

hydrate stability zone (HSZ), creating a sharp difference in acoustic impedance. This difference causes a reflection called a bottom-simulating reflector (BSR), which is visible in seismic data as a horizon that mimics the sea floor, often crosscutting different sediment layers.

The GOM is an interesting site for the study of gas hydrates because of its unique structures. The GOM opened with rifting as North America and South America separated in the Jurassic (Pindell *et al.*, 1985). An inter-continental sea was formed, which deposited a thick layer of salt on the northern syn-rift sediments. The salt layer was later buried by late Jurassic, Cretaceous, and Cenozoic sediments creating a thick continental-margin sedimentary wedge (McGookey *et al.*, 1975). Because of the mobility of salt under pressure, the salt has risen in diapirs and sheets, disrupting the sediment column in the northern and southwestern GOM. These structures have formed faults that cut through deep hydrocarbon reservoirs, allowing for the migration of hydrocarbons to the seafloor. They have also created sea-floor structures of domes and basins as salt diapirs and withdrawal basins form (Figure 1). Hydrates in the GOM tend to form around the edges of salt domes due to the faulting associated with the salt migration (Sasson *et al.*, 2001). Hydrates have been cored and visually examined in these environments through the use of submersibles; however BSRs are absent or patchy in these areas so there may be no extensive sheets of hydrates in this area. This is thought to be a result of structural focusing of hydrocarbons in the region due to the salt diapirs and faulting (Milkov *et al.*, 2000). However, the southwestern GOM on the Mexican slope contains multiple BSRs imaged by the Department of Energy in the early 1980's. The BSRs were mapped using multi-channel 2-D seismic data and covered an area from Campeche Knolls to Tampico, Mexico (Krason *et al.*, 1985). This leaves a large section of the western GOM, the Texas slope, which may be the transition between these regimes (Figure 1).

Objectives

- *Use MCS data to determine extent and transition of BSRs in the GOM.* BSRs are known to exist in the southwestern GOM and not in the northern GOM. MCS data will allow for the mapping of BSRs from the western GOM as far as possible to determine where the transitional zone is from no BSRs to many BSRs, why this transition exists, and its relationship to seeps and sea surface slicks.

- *Use MCS data to examine subsurface structures related to hydrocarbon seeps and hydrate formation.* MCS data will be used to create a regional structural map to examine hydrocarbon migration pathways, sea-floor structures, top salt structure, and structural transitions across the northwest GOM slope.

Methods

This study will be based on MCS data from TGS-NOPEC (Houston, TX). The ata will be interpreted with Kingdom Suite SMT seismic interpretation program. The geophysical data will contain regional gridded seismic data (2 mile x 2 mile grids) containing the upper 7 seconds of sediment containing record. Well log data will be purchased from A2D and the Mineral Management Service in order to support the geophysical interpretation.

Geophysical interpretation of hydrocarbon seeps is accomplished by examination of the subsurface structures and acoustic anomalies in the sediment column. Salt domes are commonly associated with hydrocarbon seeps due to the fracturing of overlying sedimentary layers as the salt rises. Common features associated with hydrocarbon seeps are gas chimneys, acoustic wipeouts, BSRs, and bright spots (Figure 3; e.g., Corthay, 1997; Sager *et al.*, 2003; Reilly *et al.*, 1996). Gas related features appear in MCS data because of the acoustic scattering of the acoustic wave as it travels through gassy sediment. Gas "chimneys" and acoustic wipeouts are anomalies that appear in seismic records as a column of acoustic scattering, often underneath a mud volcano or seafloor seep as hydrocarbons rise along fault pathways (Sager *et al.*, 2003). BSRs and bright spots can also be used to identify gas hydrates in geophysical records. BSRs occur due to the change from a higher velocity medium (hydrate) to a lower velocity medium (gas saturated sediment) and appear at the base of the HSZ. Bright spots often occur below BSRs where large accumulations of gas occur and appear as a bright area, or area without data, on a seismic record (Krason *et al.*, 1985). Using these geophysical signatures of hydrocarbon seeps and gas hydrates allows for the mapping of hydrates, interpreting the corresponding geology, better understand hydrate formation and extent, and determine where and if there is a transition zone between the southwest GOM and northern GOM. Once the data are interpreted, geological maps will be created. Maps will be placed into a GIS format for further interpretation. Once data are fully interpreted, data and maps will be prepared for publication.

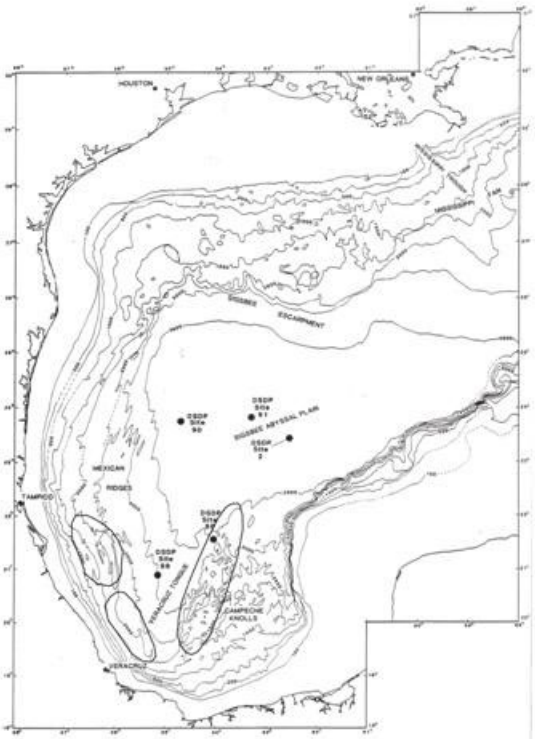

Figure 1: Multibeam map of the Gulf of Mexico. Elliptical objects on the SW represent areas of known BSRs (Krason et al. 1985)

Figure 2: Spaceborne Imaging Radar - C/X - Band Synthetic Aperture Radar (SIR - C/X - SAR) image of oil slicks in the Arabian Sea (http://southport.jpl.nasa.gov/pio/srl2/sirc/oilsk.html)

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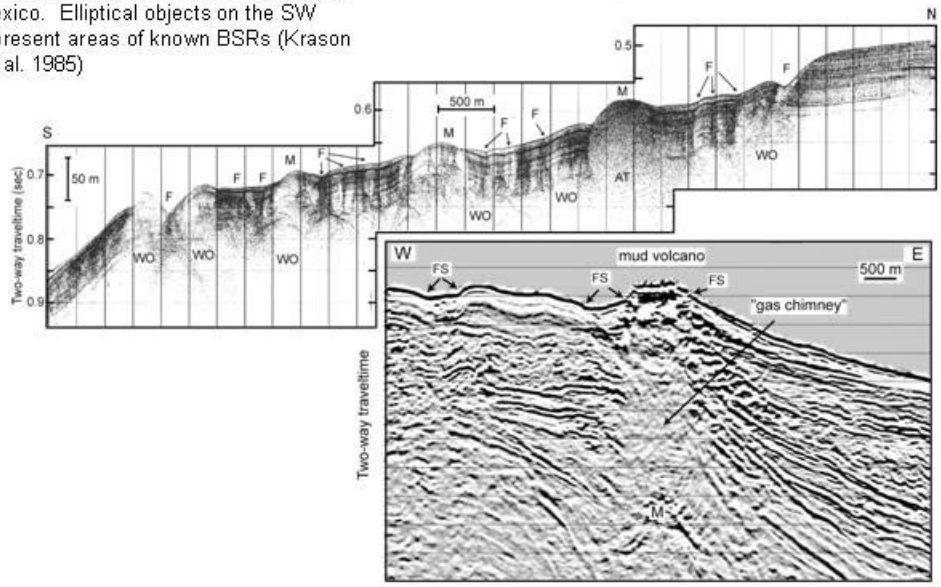

Figure 3: High resolution chrip section and MCS section displaying common features found at hydrocarbon seeps. Note the gas "chimney" and mud volcanoin the MCS data, and the acoustic wipeouts (WO), faults (F), and mounds (M) in the chirp section (Sager et al. 2003).

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