Anatomy of a Gas Hydrate Province:
Linking Physics and Biology on the Blake Ridge

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The Blake Ridge is one of the largest and best-characterized of the marine gas hydrate provinces within the U.S. Exclusive Economic Zone. However, the lack of commercial exploration on the Blake Ridge, coupled with the largely disseminated nature of the hydrate deposits, means that this region is often overlooked in assessments of geohazard or resource potential on U.S. continental margins. In fact, hydrates in the sediments of the Blake Ridge and nearby regions are associated with both natural hazards (e.g., submarine slope failures) and large quantities of methane. For these and other reasons, studies of the Blake Ridge remain as relevant as ever for advancing our understanding of methane hydrates. Research on the Blake Ridge continues to yield fundamental insights into the dynamics of gas hydrate reservoirs, the interaction of hydrates and the ocean-atmosphere system, and the physical, chemical, and biological processes that control concentration and accumulation of hydrates.

As a stable sediment drift composed of largely homogeneous sediments, the Blake Ridge has important advantages for gas hydrate studies, which can be more difficult to interpret in marine settings characterized by greater heterogeneity, more active flow systems, more widespread faulting, or more complicated mixtures of gases. This talk provides a bridge from direct seismic characterization of the Blake Ridge gas hydrate reservoir at a regional scale (discussed by W.S. Holbrook) to new seafloor observations at a focused methane seep (discussed by C. Van Dover). We focus here on the physical, chemical, and biological processes operating at numerous spatial and temporal scales in the Blake Ridge gas hydrate reservoir. Through a combination of observational data and numerical modeling, we (1) explore the factors controlling gas hydrate distribution; (2) discuss the dynamic response of the reservoir to climate change and to sedimentary and tectonic processes; (3) and describe linkages between the physics of the hydrologic flow systems and micro- to macroscale biology.

Drawing on disparate research, including the NOAA-sponsored Deep East Expedition in 2001, Ocean Drilling Program (ODP) Leg 164 in late 1995, and modeling research sponsored by the National Science Foundation, we apply a flux-based framework to the Blake Ridge gas hydrate province. Such a framework has natural extensions to other gas hydrate provinces, such as the high-flux Gulf of Mexico reservoir or intermediate to high flux active margins. The Blake Ridge as a whole lies at the low flux endmember and is characterized by diffuse advective flux of fluids (water and gas). Like any hydrologic system, though, heterogeneities superposed on the regional system radically alter flow regimes. Some types of heterogeneities are revealed in high-resolution seismic data collected by Holbrook. The heterogeneities, which occur at scales ranging from sediment grains to faults to regional stratigraphic horizons, impart a degree of complexity to the physical, chemical, and biological regimes that control methane production, methane migration, hydrate formation, and (sometimes) emission of methane at the seafloor.

This superposition of multiple scales of heterogeneities can be extended to a process-based interpretation of the major controls on gas hydrate distribution and reservoir dynamics. At all spatial scales, heat, methane supply rate, and fluid (water + aqueous methane) advection exercise first-order control on the formation of gas hydrate. At a regional scale, these three factors (heat, methane, and fluid flux) allow us to predict the vertical zonation of the gas hydrate reservoir into layers with free gas, layers lacking in either free gas or hydrate, and layers containing gas hydrate. When coupled with field-based observations across the Blake Ridge, these predictive models place constraints on the rate of methane production by microbial processes and thus the extent of the so-called 'deep biosphere.' The models also allow us to assess lateral variability in flow regimes and the degree of stratigraphic vs. tectonic control on fluid flow pathways.

At the more local scale, faults radically alter the flux regimes for heat, methane, and methane-laden water and lead to less stable, more dynamic, gas hydrate systems. As observed on the Blake Ridge and elsewhere, hydrate often concentrates in these high permeability conduits. Calculations show that even the very fine scale faults that are present on much of the Blake Ridge could be loci for hydrate deposition. Whether these faults might be associated with seafloor seeps is unknown, although we argue that searching for such seafloor flux indicators as chemosynthetic communities may become increasingly important as we seek to link biological, chemical, and physical processes at the top of gas hydrate reservoirs.

An extreme example of localized flux in this otherwise relatively homogeneous gas hydrate province occurs on the Blake Ridge Diapir, the southernmost of a series of 20 diapirs on the Southeastern U.S. Atlantic margin seaward of the Carolina Trough. The emplacement of the diapir has disrupted overlying sediments and led to the development of faults that serve as conduits for the transfer of gas and fluid to the ocean floor. The diapir fundamentally alters the physics and chemistry of the shallow marine hydrologic regime, and drilling on Leg 164 revealed that gas hydrate lies just below the seafloor on the diapir's crest. In September 2001, *DSV Alvin* dives conducted on NOAA's Deep East 3 expedition (C. Van Dover, Chief Scientist) revealed hydrate forming just above the seafloor (beneath a rock overhang) at this focused flux site. The presence of extensive chemosynthetic communities also testifies to the vigor of the local flux system. The Blake Ridge Diapir therefore provides a natural laboratory for the study of several common characteristics of high flux hydrate systems (e.g., chemosynthetic organisms, seafloor hydrate, widespread authigenic carbonate, and other features). The fact that the diapir is embedded within a province characterized by regional low flux and homogeneous sediments presents important advantages though: Low and high flux endmembers can be studied within the same province with the additional control of the same sediments and sedimentary processes. The perturbations associated with the diapir's focused flux system are thus largely separable from "background" physical, biological, and chemical processes.

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