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THE POTENTIAL FOR ABIOTIC METHANE IN ARCTIC GAS HYDRATES

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Most methane enclosed in gas hydrates is biotic in origin, formed by microbial degradation of sedimentary organic matter. Increasingly, there is evidence that substantial gas hydrate may also be sourced from thermogenic decomposition of organic matter and subsequent migration of this gas into the gas hydrate stability zone. In addition, there is a third potential source of methane that does not involve organic matter at all—abiotic methane, which can be generated by magmatic processes or gas-water-rock reactions in the crust and upper mantle.

Abiotic Methane in Slow and Ultraslow Spreading Environments

The Earth produces abiotic methane in a variety of geologic settings and at a range of temperatures and pressures from chemical reactions that do not directly involve organic matter. Experimental studies and field observations in modern slow and ultraslow spreading mid-ocean ridge environments have shown that serpentinization reactions occur during the high temperature (>200 °C) hydrothermal alteration of ultramafic rocks, resulting in significant hydrogen production. The hydrogen produced during serpentinization can react with CO or CO_2, via Fischer-Tropsch Type Reactions, to produce abiotic methane.

During the last 25 years, studies at modern ultramafic-hosted seafloor hydrothermal vents along the Mid-Atlantic Ridge provide clear evidence for high hydrogen and methane concentrations. Serpentinization in slow and ultraslow spreading ridge environments is focused along large detachment faults that can exhume deeper crustal and upper mantle rocks and accommodate a significant portion of the extension along magma-limited ridge segments. Such detachments are often well developed at the inside corners of ridge-transform intersections and are believed to be active for 1 to 4 million years, limiting active serpentinization and abiotic methane venting to the youngest crust near the ridge axis.

In the north Atlantic and Arctic ocean basins, spreading ridge rates are transitional from slow to ultraslow spreading (Figure 1). As spreading rates decrease, extension is accommodated mainly by detachment faulting, with minimal volcanism. Low-angle detachment faults and exhumed serpentinized peridotites have been observed and sampled on Gakkel Ridge; serpentinite and peridotite have been sampled on Lena Trough and Molloy Ridge; and black smokers and vent fauna have been observed at the junction of the Mohns and Knipovich Ridges, near exhumed detachment surfaces. Bottom simulating reflectors (BSRs), identified in seismic sections above interpreted serpentinized ultramafic diapirs, also exist on the sediment-covered eastern flank of Knipovich Ridge. These

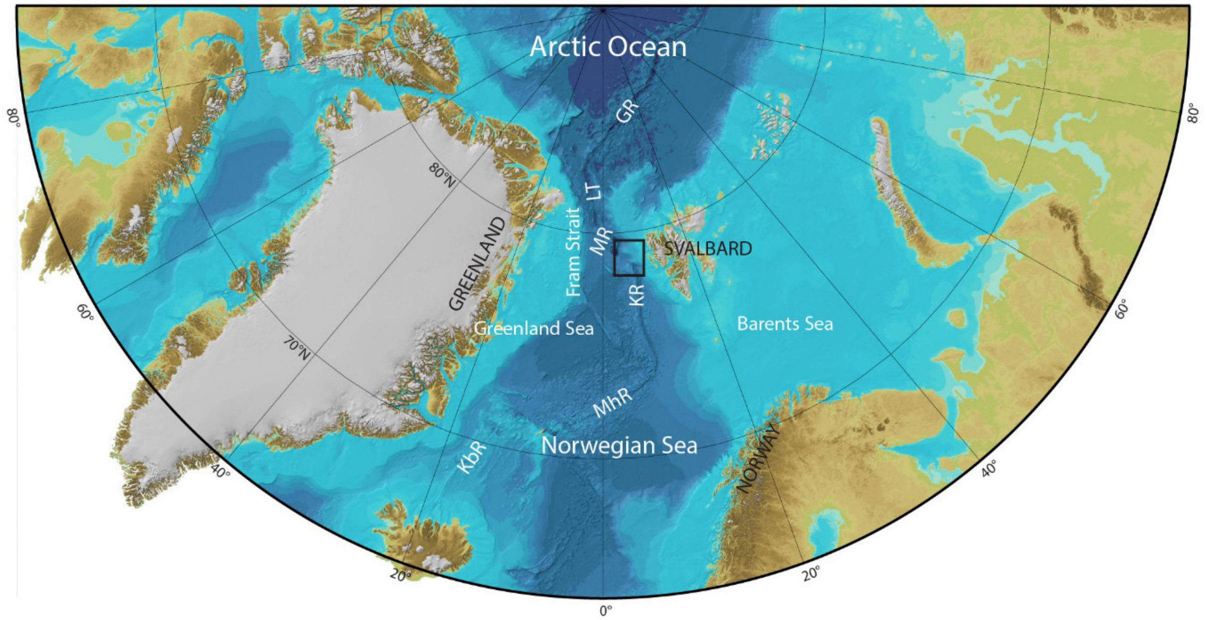

Figure 1. Arctic Ocean Bathymetry (IBCAO Version 3.0). Labels identify the slow to ultraslow spreading ridges that extend northward from Iceland; KbR-Kolbeinsey Ridge, MhR-Mohns Ridge, KR-Knipovich Ridge, MR-Molloy Ridge, LT-Lena Trough, and GR-Gakkel Ridge. Black box outlines the study area near the Vestnesa Ridge, described below and in Figures 2 and 3.

observations establish the possibility of methane delivery for gas hydrates from an abiotic, serpentinized mantle source throughout sediment-covered portions of the Arctic Ocean ultraslow spreading ridge system.

Sediment-Covered Ultraslow Ridges in Fram Strait

The potential for gas hydrate systems to be charged by serpentinized mantle sources of methane is high in Fram Strait, where young portions of ultraslow spreading ridge flanks are sediment covered and lie within the gas hydrate stability zone. Water mass transport through Fram Strait since the early Miocene created an environment for the formation of sediment drifts. These drift deposits grow during northern hemisphere glaciations and are sustained throughout the ultraslow separation of Greenland and Svalbard.

The most well known gas hydrate-bearing drift in the Fram Strait is the Vestnesa Ridge. It is a >100-km-long and 50-km wide sediment drift between the northwest Svalbard margin and the Molloy Transform fault (Figure 1). It contains a gas hydrate reservoir and active free gas system that creates vents that release gas through the seafloor and into the ocean. Isotope measurements of gas from hydrates at this location are indicative of biotic sources (thermogenic methane). Abiotic sources are not present, likely due to the old age (10-20 million years old) of the crust beneath the drift.

Just south of the Molloy Transform fault, however, on significantly younger crust (0-10 million years old), an offset portion of the Vestnesa drift shows an equally well-established gas hydrate system. Its underlying crustal structure suggests that, in addition to biotic gases, abiotic gases formed by

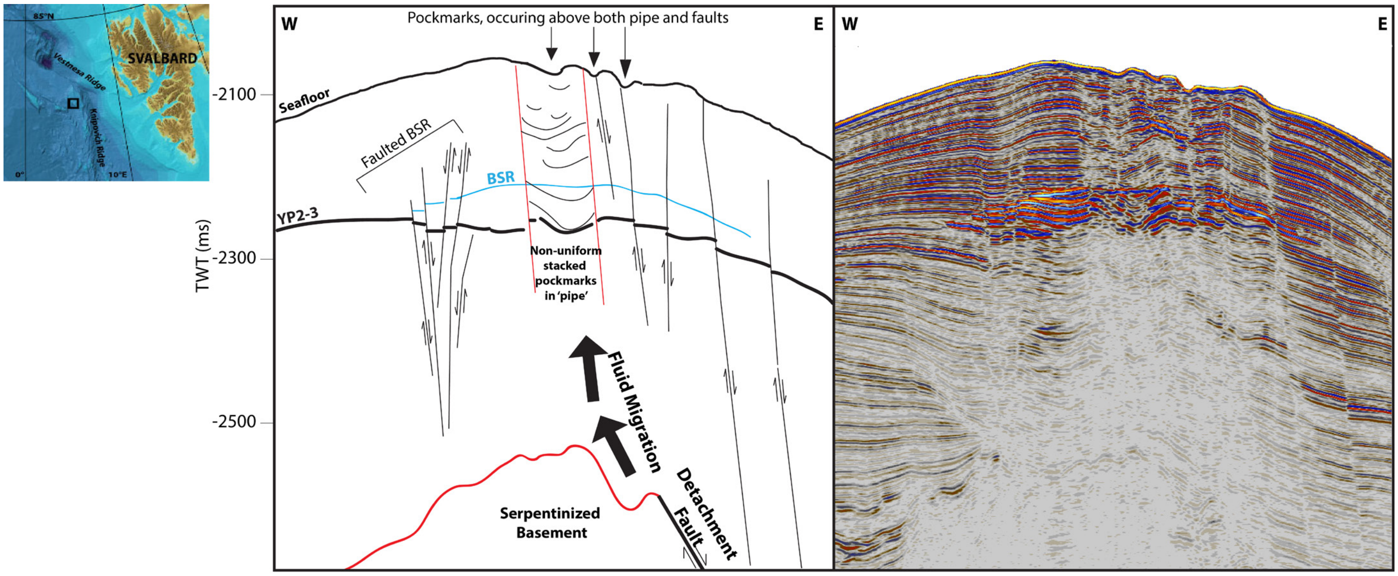

Figure 2. Location map (left) and interpreted seismic section (middle) of the gas hydrate system, including (from bottom to top) gas migration blank areas, the BSR, faults, and depressions at the seabed, across the crest of the offset Vestnesa drift south of the Molloy transform fault.

serpentinization also charge this gas hydrate system (Figures 2 and 3).

Abiotic Methane Window

In a 2015 paper, we presented the concept of an abiotic methane window for ocean basins characterized by ultraslow spreading. The extent of the abiotic methane window depends on the age of the oceanic crust, typical activity along detachment faults, and the optimum temperature range for serpentinization reactions (Figure 3).

Active detachment faults that accommodate the majority of plate motion in ultraslow spreading environments are a key component of this conceptual model. Such faults exhume ultramafic mantle rocks and

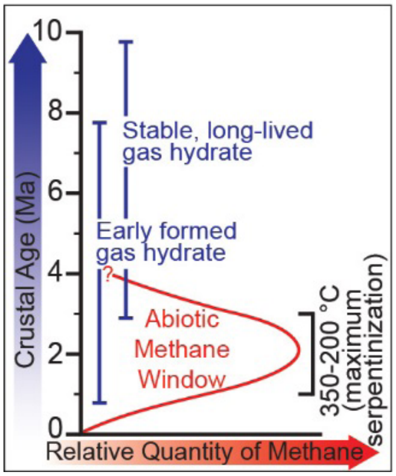

Figure 3. Conceptual diagram of an abiotic methane window for serpentinized ocean crust in a sediment-covered ultraslow spreading ridge environment (modified after Johnson et al., 2015). Abiotic charged gas hydrate is most likely to form in sediments that cover ultraslow spreading ridges early, near the ridge axis, when detachment faults are active, and the temperature regime is optimized for serpentinization. Progressive translation of gas hydrated drifts into deeper water with continued ultraslow spreading, increases the stability of the gas hydrate system, contributing to its potential longevity.

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provide conduits for seawater, thereby promoting serpentinization. With continued seafloor spreading, these faults become less active and more mineralized—and therefore less permeable—as new detachments form closer to the ridge. Typical activity along spreading ridge detachments ranges from 1-4 million years, restricting the most effective serpentinization to the youngest and warmest crust closest to the ridge axis. In the case where sediment drifts in Fram Strait offset along mid-ocean ridge transform faults, early abiotic gas charge could contribute to early gas hydrate formation.

Future Directions

Realizing the proportion of abiotic and biotic gases stored as gas and gas hydrate on sedimented, ultraslow spreading ridge flanks throughout the Arctic will require: (1) seismic reflection reconnaissance surveys to map the gas hydrate and free gas systems that likely exist within the largely underexplored Arctic and subarctic seafloor environments; and (2) future scientific drilling to directly sample, quantify, and isotopically characterize the gases in these likely mixed biotic and abiotic gas hydrate systems.

Acknowledgments

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