Preliminary Assessment of Hydrocarbon Gas Sources from the Mt. Elbert No. 1 Gas Hydrate Test Well, Milne Pt. Alaska

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ABSTRACT

Hydrocarbon gases were collected from well cuttings and core at the MtElbert-01 gas hydrate stratigraphic test well, drilled within the Milne Point field on the Alaska North Slope. Regionally, the Eileen gas hydrate deposits overlie the more deeply buried Prudhoe Bay, Milne Point, and Kuparuk River oil fields and are restricted to the up-dip portion of a series of nearshore deltaic sandstone reservoirs in the lower Tertiary (Eocene) Mikkelsen Tongue of the Canning Formation. The tested gas hydrates occur in two primary horizons; an upper zone, ("D" Unit) containing 14 meters of gas hydrate-bearing sands and a lower zone ("C" Unit), containing 16 meters of gas hydrate-bearing sands with log-interpreted gas hydrate saturations of 60 to 75 percent. The hydrocarbon gases from well cuttings from 604 to 914 meters are composed of methane with less than 1 ppm ethane. The isotopic composition of the methane ranges from -50.1 to -47.2 percent, decreasing with depth. Hydrocarbon gases collected by Modular Dynamics Testing (MDT) sampling in hydrate-bearing units C and D were similarly composed of mainly methane, with up to 270 ppm ethane. The isotopic composition of the methane ranged from -48.2 to -48.0 percent in the C sand and from 48.4 to -46.6 percent in the D sand. These results are consistent with the concept that the Eileen gas hydrates contain a mixture of deep-source thermogenic gas and shallow, microbial gas, comparing to regional methane carbon isotopic composition ranges from -54 to -46 percent in the gas hydrate zones. Thermal gases likely source from existing oil and gas accumulations that have migrated up-dip and/or up-fault and formed gas hydrate. The shallow microbial gas, likely having a biodegraded oil gas source contribution was either directly converted to gas hydrate or was first concentrated as free gas in existing conventional traps and later converted to gas hydrate in response to climate cooling or changes in surface conditions.

Keywords: gas hydrate geochemistry, Mount Elbert No. 1, Alaska

INTRODUCTION AND BACKGROUND

Large amounts of natural gas, composed mainly of methane, can occur in arctic sedimentary basins in the form of gas hydrates under appropriate temperature and pressure conditions. Northern Alaska is known to host several gas hydrate deposits that have been previously estimated to range from 6.7 to 66.8 trillion cubic feet (TCF) based on play analyses [1] In response to the need to assess the energy resource potential of gas hydrate in northern Alaska, the USGS, the U.S. Department of Energy (USDOE) and BP Exploration (Alaska), Inc. (BPXA) is teaming up to characterize and assess Alaska North Slope (ANS) gas hydrate resources and to identify technical and commercial factors that could enable government and industry to understand the future development potential of this unconventional energy resource.

In Feburary 2007, a team of scientists concluded an extensive data collection program in the Mount Elbert Gas Hydrate Stratigraphic Test Well drilled in the Milne Point area on the Alaska North

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Slope; which yielded one of the most comprehensive datasets yet compiled on a naturally-occurring gas hydrates (U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, Fire in the Ice, Methane hydrate newsletter (available at http://www.netl.doe.gov /technologies/oilgas/publications/Hydrates/Newsletter/HMNewsWinter07.pdf).

In 2005, extensive analysis of BPXA's proprietary 3-D seismic data and integration of that data with existing well log data (collaboration with the U.S. Geological Survey, the Bureau of Land Management, and Interpretation Services, Inc.), resulted in the identification of more than a dozen discrete gas hydrate accumulations within the Milne Point area. Because the most favorable of those targets was a previously undrilled, fault-bounded accumulation, BPXA and the DOE decided to drill a vertical stratigraphic test well at that location (named the "Mount Elbert" prospect) to acquire critical reservoir data needed to develop a longer-term production testing program.

The Mount Elbert gas hydrate stratigraphic test well was designed as a 22-day program with the planned acquisition of cores, well-logs and downhole production test data. A surface hole was first drilled and cased to a depth of 595 m. The well was then continuously cored to a depth of 760 m with chilled oil-based drilling fluid using the wireline-retrievable coring system. This core system delivered 85 percent recovery through 154 m of gas hydrate and water-bearing sandstone and shale.

The coring team processed these cores on site, and collected subsamples for analyses of pore water geochemistry, microbiology, gas chemistry, petrophysical properties, and thermal and physical properties. Core samples were also stored in liquid nitrogen or transferred to pressure vessels for future study of the preserved gas hydrates. After coring, the well was reamed and deepened to a depth of 915 m, and the well was surveyed with a research-level wireline logging program including magnetic resonance and dipole acoustic logging, resistivity scanning, borehole electrical imaging, and advanced geochemistry logging. Following logging, Schlumberger Modular Dynamic Testing (MDT) was conducted at four open-hole stations in two sandstone reservoirs. Each test consisted of flow and shut-in periods of varying lengths, with one lasting for more than 13 hours. Gas was produced from the gas hydrates in each of the tests.

Gas hydrates were expected and found in two stratigraphic sections. An upper zone, (Unit D) contained ~14 m of gas hydrate-bearing reservoir-quality sandstone. A lower zone (Unit C), contained ~16 m of gas hydrate-bearing reservoir. Both zones displayed gas hydrate saturations that varied with reservoir quality as expected, with typical values between 60 percent and 75 percent.

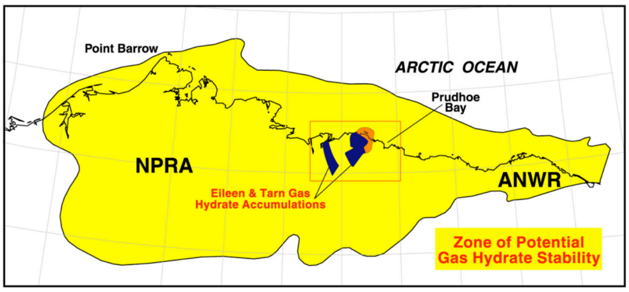

Figure 1. Zone of potential gas hydrate stability in northern Alaska, USA. Within this broad region the gas hydrate stability field exists both onshore and offshore and extends eastward into the Mackenzie Delta region of Canada. The Eileen and Tarn gas hydrate accumulations are shown in dark blue and free gas underlying the Eileen gas hydrate accumulation is shown in orange. NPRA refers the National Petroleum Reserve - Alaska, and ANWR refers to the Arctic National Wildlife Refuge. The Mount Elbert No. 1 well is located in the northern portion of the Eileen accumulation.

Gas hydrate of the Eileen accumulation

The occurrence of natural gas hydrate on the North Slope of Alaska was confirmed in 1972 with data from the ARCO/Exxon 2 Northwest Eileen State well located in the northwest part of the Prudhoe Bay field. Studies of pressurized core samples, downhole logs, and the results of formation production testing have confirmed the occurrence of three gas hydrate-bearing stratigraphic units in this well (reviewed in [2]). Gas hydrates are also inferred to occur in an additional 50 exploratory and production wells in northern Alaska based on downhole log responses calibrated to the known gas hydrate occurrences in the ARCO/Exxon 2 Northwest Eileen State well. Figure 2 shows a cross section across the Eileen area with well logs. Many of these wells have multiple gas hydrate-bearing units, with individual occurrences ranging from 3 to 30 m thick. Most of the well log-inferred gas hydrates occur in six laterally continuous sandstone and conglomerate units; all are geographically restricted to the area overlying the eastern part of the Kuparuk River field and the western part of the Prudhoe Bay field.

The six gas hydrate-bearing sedimentary units have each been assigned a reference letter, units A-F, with unit A being the stratigraphically deepest (Figure 2). Three-dimensional seismic surveys and downhole logs from wells in the western part of the Prudhoe Bay field indicate the presence of several large free-gas accumulations trapped stratigraphically downdip below four of the log-inferred gas hydrate units. The total mapped area (Figure 3) of the six gas hydrate occurrences is about 1643 km^2; the areal extent of the individual units ranges from 3 to 404 km^2. The volume of gas within the gas hydrates of the Prudhoe Bay- Kuparuk River area is estimated to be about 37 to 44 TCF (1.0-1.2 trillion m^3) or about twice the volume of known conventional gas in the Prudhoe Bay field [2, 3].

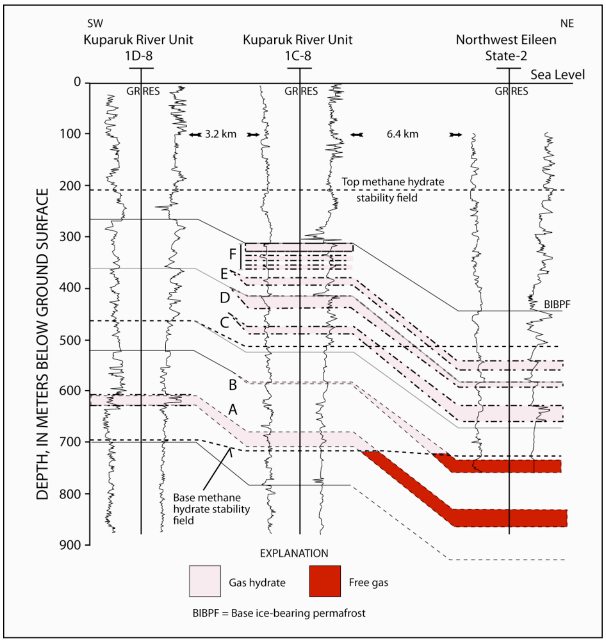

Figure 2. Cross section showing the lateral and vertical extent of gas hydrates and underlying free-gas occurrences in the Prudhoe Bay-Kuparuk River area in northern Alaska. See Figure 3 for location of cross section. The gas-hydrate-bearing units are identified with the reference letters A through F from [2].

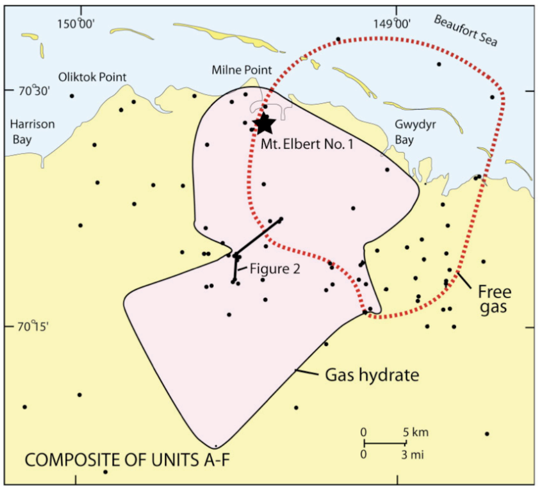

Figure 3. Composite map of the six gas-hydrate/free-gas units (Units A-F) from the Prudhoe Bay-Kuparuk River area in northern Alaska. Also shown is the location of the cross section in Figure 2. Dots indicate wells studied in [2]. The Mount Elbert No. 1well is located north of the cross section in Figure 2, but penetrates an identical stratigraphy.

EXPERIMENTAL METHODS

Well bore cuttings samples were collected at 30-foot intervals from each well for gas analyses. Each sample was collected in a 1-pint paint can modified with a septum. The cans were filled approximately to one half full, salt was added as a preservative, sealed and weighed. Flowed gas samples were taken directly from the shaker table and mud-degassing manifold and channeled into evacuated aluminum cylinders. All gas analysis were preformed at Isotech Laboratories in Champaign, Illinois and are accurate to within 2%.

RESULTS AND DISCUSSION

The hydrocarbon gas concentration, relative distribution and isotopic composition define two main gas zones; microbial methane overlying thermogenic gas, mainly methane, that reflects and origin from anerobic oil biodegradation. Typically microbial gas is noted as low concentrations of hydrocarbon gas, mainly methane, very low concentrations of higher molecular weight hydrocarbons, and a light carbon isotopic composition of methane, generally lighter than -50‰.

Microbial gas is found within the upper ~1500 feet (457m) of section. Methane in from the cuttings samples ranged from $\delta^{13}C_1$ -86 to -42‰ and from -86 to -53‰ above the gas hydrate zone (Figure 4) Below the transition occurring at about 1500 feet (~457m) the methane isotopic composition becomes nearly constant, with values between -48 to -42‰.

Gas characteristic of microbial origin likely has many sources. Possible sources for microbial gas are the bacterially mediated production of methane in the continuum of reactions that take place during early diagenesis. The dominant hydrocarbon generating process in the upper 1000 feet is CO_2 reduction as shown by the carbon isotopic fractionation between coexisting methane and CO_2 with fractionation factors of about 1.04 to 1.06 [5].

Another likely source of microbial gas in the study area is the anaerobic biodegradation of oil and gas as evidenced by the carbon isotopic composition of methane, and studies of gases in other wells on the North Slope [5].

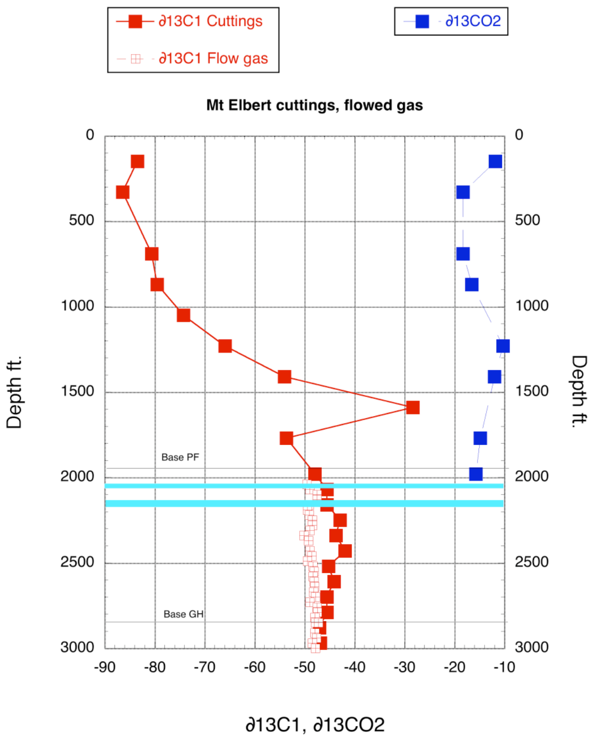

Figure 4. Profiles of methane and carbon dioxide isotopic composition with depth of cuttings and flowed gas from the Mount Elbert No. 1 well. Base of permafrost (base PF) and the base of the gas hydrate stability zone (base GH) are given. Light blue lines denote the D and C gas hydrate occurrences.

Mixed or modified thermal gas is found in the gas hydrate-bearing sediment, gas hydrate, and deeper strata through to the depth near oil and gas deposits. This zone is characterized by heavier carbon isotopic composition of methane (-48 to –42‰), higher concentrations of higher molecular weight hydrocarbons, concentrations of hydrocarbon gas, mainly methane. Thermogenic sources of gas and oil are typically encountered at depths below 3000 feet in the study area. Other thermal sources for gas maybe local areas rich in coal or lignite.

Lighter carbon isotopic composition of C_1-C_4 hydrocarbon gases reflect secondary processes studied in other North Slope wells [5]. Vertical migration of gas likely occurs from depth along north-to northeast-striking high-angle fault systems that include the Eileen fault. An analogous scenario occurs in the Mackenzie Delta of Canada where thermogenic gas migrates up faults and is emplacement as gas hydrate in permeable deltaic sediments [6].

It has be previously observed that gases from the Kuparuk River oil field may have leaked gas and condensate that subsequently followed fault conduits to oil and gas traps higher in the section (Figure 5) [5]. This gas was trapped in the previously biodegraded oil of the West Sak field and recharged this field with lighter hydrocarbon components. Evidence for this includes the dry molecular composition of hydrocarbon gases from methane up to heptane, high iC_4/nC_4 ratios, isotopically light methane, and isotopically heavy CO_2 [5].

Specifically [5] saw evidence for the anaerobic biodegradation of methane to CO_2 resulting in isotopically heavy CO_2 (+13.8‰). Our results for the isotopic composition of CO_2 range from –10 to -18‰ for cuttings, and -14 to +9‰ for core gas (Figure 6) and thus we do not see isotopic evidence for the in-place biodegradation of methane. Rather we think that the methane was generated at depth by anaerobic processes, and then migrated up to the gas hydrate stability field where it then formed gas hydrate. We do however note the production of methane from CO_2 in the upper 1400 feet (~427m) (Figure 4). Within and below the gas hydrate bearing sands the carbon fractionation factor ranges from 1.00 to 1.025, indicative of methane oxidation to CO_2 [4]. However, because multiple sources of methane are likely to occur in this zone and other sources

of CO_2 are possible in hydrocarbon-prone areas (e.g. catagenesis, and solution gas), this observation must be considered with caution.
We some evidence for isotopic fractionation of methane and carbon dioxide just below hydrate sand D but this observation is not confirmed by the isotopic composition of methane from gas hydrate which has a value of ~-46‰ nor the isotopic composition of methane from cuttings at the same depth (~46‰). There is some evidence for the oxidation of methane in the interval of about 2420 to 2350 feet (738 – 717m) where the carbon isotopic composition of methane becomes anomalously heavy while that of carbon dioxide is concurrently light (Figure 6).

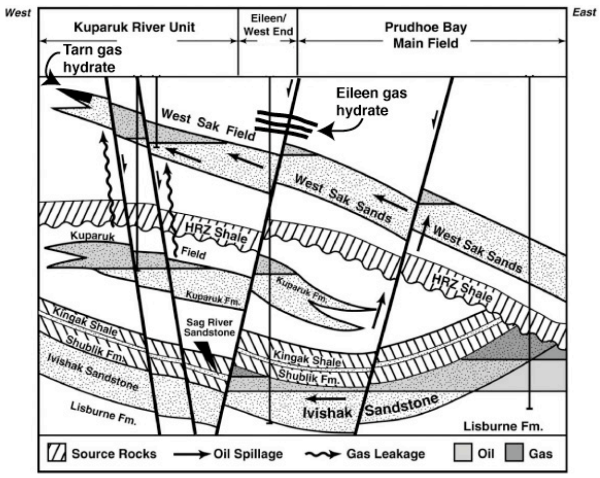

Figure 5. Schematic cross-section of the Prudhoe-Kuparuk area showing the proposed filling history of the West Sak oil field (Modified from [5]) Gas hydrate has been added to the model at the upper left hand corner and reflects the relative position and origin of gas hydrate. Gas hydrate represents the up-dip "frozen" extension of gas from leaking oil fields. The ultimate source of gas is thermogenic; however, the gas has undergone modification mainly by biodegradation of some hydrocarbons and evaporative fractionation enhancing the lighter fraction of hydrocarbons and lightening their isotopic composition.

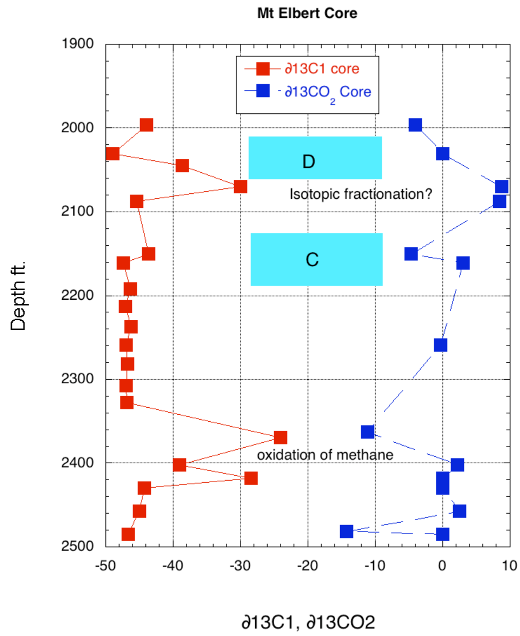

Figure 6. Profiles of methane and carbon dioxide isotopic composition with depth of core gas from the Mount Elbert No. 1 well. Light blue bars denote the D and C gas hydrate occurrences. The range of methane isotopic values are similar to the cuttings and flowed gas samples. Post-sampling oxidation of methane may have occurred in the interval of about 2420 to 2350 feet (738 – 717m), while some potential isotopic fractionation maybe occurring at and 2080 to 2050 feet (634 -625m).

The composition of hydrocarbon gases, specifically the diagnostic ratio of C_1/C_2+C_3, and the carbon isotopic composition of methane help determine the origin of light hydrocarbons. Figure 7 shows the results for gas hydrate derived gases. MDT (Modular Dynamic Testing) gas, similar to a drill stem are plotted relative to gases derived gas hydrate dissociation from samples (QD). The gas wetness ratio C_1/C_2+C_3 is useful because methane hydrate in this hydrocarbon environment concentrates methane relative to other hydrocarbon gases resulting in higher values relative to the surrounding sediment [6]. The gas composition of the gas hydrate constrains the majority, if not all of the gas hydrate to the Structure I form [7].

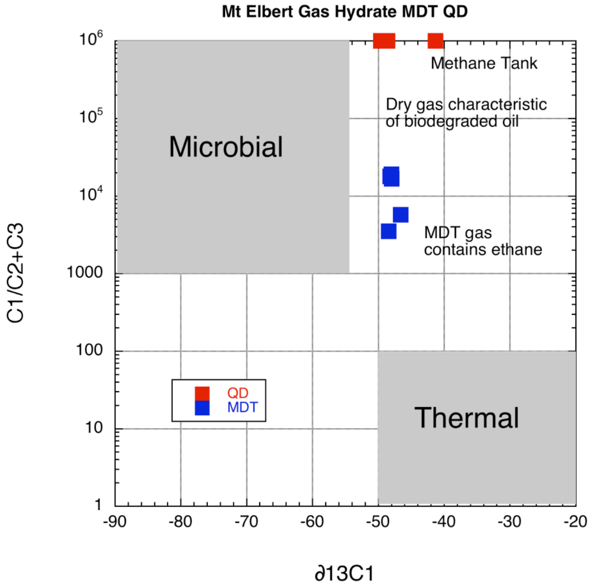

Figure 7. Bernard plot showing the proposed origin of gases. MDT (Modular Dynamic Tester) gas, similar to a drill stem test are plotted in blue, while plotted in red (QD) are gases derived gas hydrate dissociation from samples. Methane tank refers to the isotopic composition of gas from a methane cylinder used to pressurize gas hydrate shipping containers. All of the samples plot outside standard microbial and thermal gas composition. We propose that the lack of ethane results from the generation of the methane from the anerobic degradation of oil at depth. MDT sampled gases may contain more ethane than gas hydrate samples and may reflect more accurate in-situ concentrations of ethane in gas hydrate.

CONCLUSIONS

- The USGS, BPXA, USDOE and industry have embarked on a multiyear program to assess the energy resource potential of gas hydrate in northern Alaska. The results indicate that the gas hydrates of northern Alaska can be related to leaking petroleum deposits that migrate up fault conduits from depth. The Alaskan hydrate petroleum system shows evidence of oil migration, oil biodegradation, and generation of C_1 to C_3 from biodegraded oil. Mount Elbert did not contain enough ethane or propane to isotopically characterize. The hydrocarbon gas composition found in gas hydrate requires that the hydrate must be Structure I. As elsewhere there is some evidence that permafrost and gas hydrate layers act as traps similar to previous observations at Mallik and other North Slope Alaska wells.

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