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Geologic controls on gas hydrate occurrence in the Mount Elbert prospect, Alaska North Slope

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ABSTRACT

Data acquired at the BPXA-DOE-USGS Mount Elbert Gas Hydrate Stratigraphic Test Well, drilled in the Milne Point area of the Alaska North Slope in February, 2007, indicates two zones of high gas hydrate saturation within the Eocene Sagavanirktok Formation. Gas hydrate is observed in two separate sand reservoirs (the D and C units), in the stratigraphically highest portions of those sands, and is not detected in non-sand lithologies. In the younger D unit, gas hydrate appears to fill much of the available reservoir space at the top of the unit. The degree of vertical fill with the D unit is closely related to the unit reservoir quality. A thick, low-permeability clay-dominated unit serves as an upper seal, whereas a subtle transition to more clay-rich, and interbedded sand, silt, and clay units is associated with the base of gas hydrate occurrence. In the underlying C unit, the reservoir is similarly capped by a clay-dominated section, with gas hydrate filling the relatively lower-quality sands at the top of the unit leaving an underlying thick section of high-reservoir quality sands devoid of gas hydrate. Evaluation of well log, core, and seismic data indicate that the gas hydrate occurs within complex combination stratigraphic/structural traps. Structural trapping is provided by a four-way fold closure augmented by a large western bounding fault. Lithologic variation is also a likely strong control on lateral extent of the reservoirs, particularly in the D unit accumulation, where gas hydrate appears to extend beyond the limits of the structural closure. Porous and permeable zones within the C unit sand are only partially charged due most likely to limited structural trapping in the reservoir lithofacies during the period of primary charging. The occurrence of the gas hydrate within the sands in the upper portions of both the C and D units and along the crest of the fold is consistent with an interpretation that these deposits are converted free gas accumulations formed prior to the imposition of gas hydrate stability conditions.

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1. Introduction

Gas hydrate is a common term used to describe clathrate compounds consisting of a solid lattice of water molecules that efficiently encapsulate molecules of various natural gases – most commonly methane. The pressure-temperature conditions that are necessary (but not sufficient) for gas hydrate formation (see Sloan and Koh, 2008) limit the occurrence of gas hydrates to arctic sediments (typically where the geothermal gradient is impacted by permafrost), to sediments within deep lakes and seas, and to shallow oceanic sediments on outer continental shelves and slopes where water depths exceed approximately 500 m. Gas hydrate occurs in a variety of forms and a range of geologic settings. In the marine environment, gas hydrate has been documented to occur as disseminated grains filling pores within sands (Riedel et al., 2006; Fujii et al., 2008) and muds (Paull et al., 1996; Yang et al., 2008), as well as complex networks of fracture fills, veins, and nodules primarily in fine-grained sediments (Holland et al., 2008; Collett et al., 2008a; Park, 2008; Hadley et al., 2008). In contrast, permafrost-associated gas hydrates have commonly been reported to be primarily restricted to pore-filling morphologies within sandy sediments (Dallimore and Collett, 2005).

The factors that control the occurrence and distribution of gas hydrate continue to be the subject of much investigation. Primary controls include conditions unique to gas hydrates, including specific ranges of temperature and pressure conditions that vary

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with the geochemistry of both the gas and the water (Sloan and Koh, 2008). In addition, the development of methane hydrate systems require adequate supplies of water, as well as many of the same elements as other hydrocarbon accumulations, including migration pathways for gases in volumes sufficient to exceed the solubility of methane in water at the given pressure and temperature conditions. In addition to adequate sourcing, the ultimate nature and richness of gas hydrate systems appear to be profoundly impacted by the nature of the host sediment, including grain and pore sizes as well as mineralogy. Overall, it appears that deposits of pore-filling hydrate at high saturations (herein considered to be 50% or more of pore space) require the high intrinsic formation permeability that is only provided in high-porosity sands and sandstones (Dallimore and Collett, 2005; Torres et al., 2008; Uchida et al., 2009).

The formation processes for gas hydrate accumulations in nature are also not well understood. The most commonly invoked mechanisms include 1) formation from dissolved phase methane as it exsolves due to changing solubility as methane-saturated pore waters migrate upward through sediment columns (Hyndman and Davis, 1992); and 2) advection of bubble-phase methane into the gas hydrate stability zone along preferential permeability pathways (faults, inclined permeable strata, and in vent/chimney structures; see Milkov and Sassen, 2002). In addition, conversion of free gas accumulations to gas hydrate by late-stage imposition of gas hydrate stability conditions has been a favored interpretation for gas hydrate accumulations on the Alaska North Slope (Collett, 1993, 2002).

The BPXA-DOE-USGS Mount Elbert Gas Hydrate Stratigraphic Test Well (Mount Elbert Well) was drilled, logged, cored, and pressure tested in February 2007 as part of an ongoing cooperative research and development effort between the Department of Energy's National Energy Technology Laboratory (NETL), BP Exploration (Alaska), Inc., (BPXA), and the U.S. Geological Survey (USGS). This research program aims to better understand the nature and occurrence of gas hydrate on the Alaska North Slope (ANS) and to assess gas hydrate's part in, and impact on, the ANS energy resources (Hunter et al., 2011). The data collection effort at the Mount Elbert site was designed to evaluate and advance geological/geophysical detection and characterization methodologies, improve confidence in regional assessments of gas hydrate resource volumes, and provide additional reservoir evaluation and numerical simulations to support the selection of a location and operation plans for extended term gas hydrate production testing.

This report attempts to draw additional insights regarding the process of formation and the geologic controls on the areal extent and internal saturation distribution of gas hydrate at the Mount Elbert accumulation using data acquired at the Mount Elbert well in conjunction with features observed in industry seismic data.

2. Setting

The Mount Elbert well was drilled vertically from a temporary ice pad within the southeastern portion of the Milne Point Unit (MPU), within the greater ANS infrastructure area (Fig. 1). The ANS has produced large quantities of oil from Permian to Triassic and younger-aged sand and carbonate reservoirs at producing depths greater than ∼2000 m (∼6500 ft) since initial field discovery in 1968. The ANS also has large natural gas resources which are primarily associated with the oil fields. Three major oil fields have been established with the greater Prudhoe Bay region (the Milne Point, Kuparuk River, and Prudhoe Bay oil fields), resulting in the development of extensive infrastructure and geological/geophysical databases. A key aspect of the BPXA-DOE-USGS project is to leverage this data, knowledge, and infrastructure to explore the occurrence and resource potential of gas hydrates.

Within the MPU, hydrocarbons are produced from complex structural/stratigraphic traps within the Lower Cretaceous Kuparuk sand (Carman and Hardwick, 1983; Werner, 1987). The area also contains vast resources in the form of viscous oil within cold and shallow (∼1200 m: ∼3940 ft) Tertiary Schrader Bluff and Ugnu

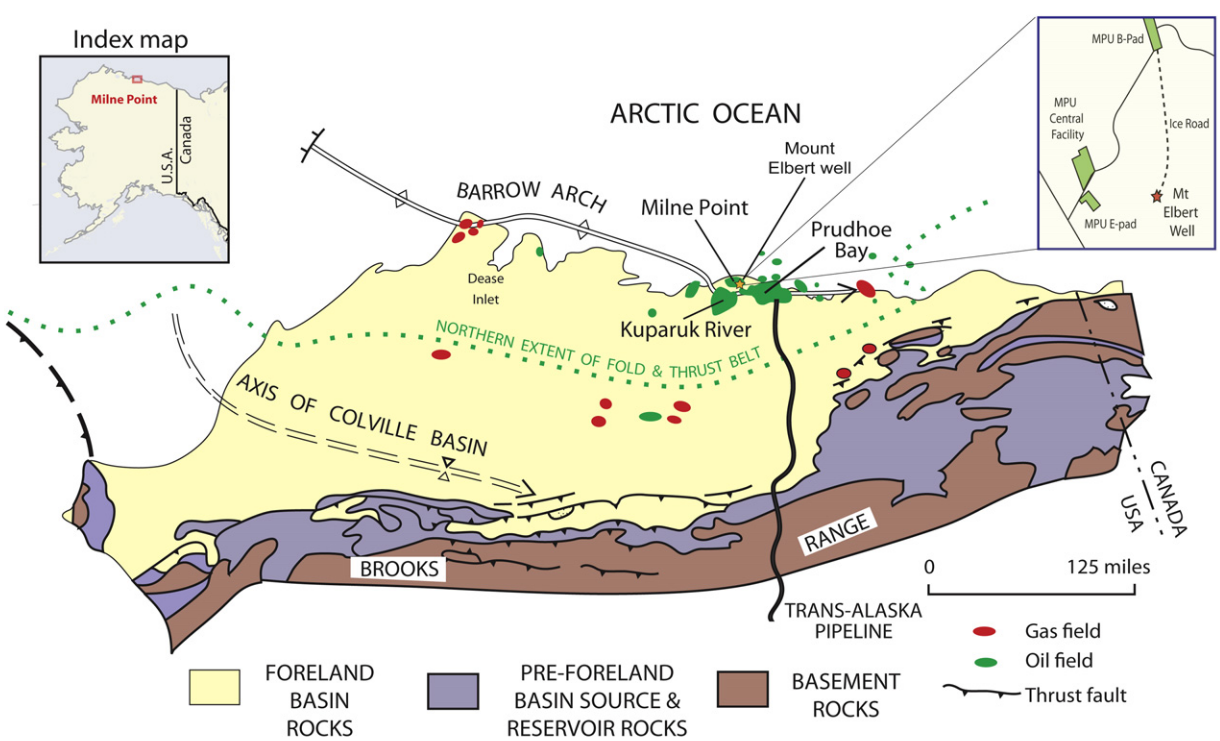

Fig. 1. The location of the Mount Elbert well within the Milne Point Unit (MPU) on the North Slope of Alaska. Inset shows the position of the nearest offset wells on the MPU E and MPU B production pads.