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Evidence of naturally occurring Gas Hydrates on the North Slope of Alaska

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ABSTRACT

Significant quantities of natural gas hydrates have been detected in many arctic regions of the world, including western Siberia, the Mackenzie Delta of Canada, and the North Slope of Alaska. Direct evidence for gas hydrates on the North Slope comes from a gas-hydrate-containing core, and indirect evidence has been obtained from drilling and open-hole geophysical logs which appear to indicate the presence of a number of gas-hydrate-containing layers occurring mainly in the Kuparuk Oil Field. The identified gas hydrates appear to be laterally continuous and extensive; this widespread distribution of in-situ gas hydrates on the North Slope suggests that they may be an unconventional source of natural gas.

INTRODUCTION

Gas hydrates are crystalline compounds of water and gas in which the solid-water lattice accommodates the gas molecules in a cage-like structure, or clathrate. Gas hydrates have been known as laboratory curiosities since about 1810. Detailed studies of hydrates and their physical properties however, were not undertaken until Hammerschmidt (1934) published data pertaining to the plugging of natural gas pipelines due to gas hydrate formation. The geological occurrence of gas hydrates has been known since the mid 1960's, when gas hydrate fields were discovered in the U.S.S.R. (see Makogon, 1981 for a review).

The pressure and temperature conditions suitable for the formation of gas hydrates are found in arctic regions of permafrost and beneath the sea in outer continental margins and ocean basins (Kvenvolden and McMenamin, 1980). The fact that temperatures and pressures associated with permafrost may fall within the stability field of gas hydrates was first recognized by Katz (1971). Gas hydrates can occur not only in permafrost but also below the base of permafrost at temperatures above the freezing point of water.

Significant quantities of gas hydrates have been detected in several permafrost regions of the world, including western Siberia (Makogon, 1981), the Mackenzie Delta of Canada (Bily and Dick, 1974), and the North Slope of Alaska (Collett, 1983; Galate and Goodman, 1982). Estimates of worldwide gas hydrate resources in permafrost regions are as high as 10^{16} m^3 (Potential Gas Agency, 1981), an estimate large enough to stimulate interest in gas hydrates as a possible energy source. Gas hydrates also may be a potential drilling hazard; as such their delineation is important for minimizing drilling risks. In this paper we review the publicly available information on the occurrence of gas hydrates on the North Slope of Alaska.

RECOVERED HYDRATES

The only known confirmation of the presencee of in-situ natural gas hydrates on the North Slope of Alaska was obtained in 1972, when ARCO and EXXON were successful in recovering the first sample of a natural gas hydrate in a solid state (Kvenvolden and McMenamin, 1980). This sample was from a depth of 666 m in the North-West Eileen State Number 2 well at Prudhoe Bay. The well was drilled with cool drilling muds in an attempt to reduce thawing of the permafrost and decomposition of the gas hydrate. A sample of methane hydrate was recovered in a pressurized core barrel. The presence of gas in a hydrated state was confirmed by a pressure test of the core while it was maintained in the barrel at a temperature of about 1° C. As gas was withdrawn from the core barrel, the pressure dropped, but it subsequently rose toward the gas hydrate equilibrium pressure when the system was closed. This pressure response has been discussed by Hunt (1979, p. 167). If the core had contained only free gas, the pressure in the barrel would have decreased linearly as gas was withdrawn.

Data from driller's and open-hole geophysical logs also strongly suggested the presence of naturally occurring in-situ gas hydrates. The mud log indicates that a significant amount of free gas was liberated from the hydrate-containing interval during drilling. Logs such as the Dual Induction and the Compensated Sonic devices indicate the presence of gas hydrates with anomalously high resistivities and transit times within the suspected gas hydrate occurrence. The recovered gas hydrate sample had a gas composition of 92.79% methane, 7.19% nitrogen, and also had minor traces of carbon dioxide, ethane, and propane (P. Barker, personal commun., ARCO Alaska Inc., Anchorage, Alaska).

HYDRATE STABILITY

As discussed earlier, gas hydrates exist under a limited range of temperatures and pressures. The depth and thickness of the zone of potential gas hydrate stability in permafrost regions can be calculated if the geothermal gradient, pressure gradient, and gas density are known (Bily and Dick, 1974). The geothermal gradients needed to predict the thickness of the gas hydrate stability zone are not easily obtained, especially if permafrost is present. Lachenbruch et al., (1982) published a series of geothermal gradients recorded on the North Slope. Their reported gradients varied greatly laterally in the Prudhoe Bay region; this variance indicates that an average regional gradient can not be used to calculate the thickness of the gas hydrate stability field. A new method was developed to evaluate local geothermal gradients on a well-by-well basis (Collett, 1983). In this procedure, individual geothermal gradients for each well were projected from the base of the ice-bearing permafrost to the surface. Because of a change in thermal conductivity, the geothermal gradient changes abruptly at the base of the ice-bearing permafrost, and this change in the gradient must be accounted for in any gas hydrate stability calculation. To correct for this change in gradient, a factor, developed by Lachenbruch et al., (1982), has been used to establish the geothermal gradient within the permafrost and below the base of the permafrost.

The methane hydrate-stability curve and the depth to the base of the permafrost can be used to determine the depth and thickness of the potential methane hydrate zone (Figure 1). In the example from the North-West Eileen State Number 2 well, no effort was made to correct for the effect of the 7% nitrogen in the methane. The following calculations were made using Collett's (1983) method: the depth to the base of the permafrost is 532 m and the suspected zone of methane hydrate stability extends from a depth of 177 m to a lower boundary at 957 m, a total thickness of 780 m.

After evaluating logs from 125 wells on the North Slope, it was determined that in order to have an intersection between the methane hydrate stability curve and a geothermal gradient, the projected gradient within the ice-bearing permafrost must be equal to or less than 4.32°C/100 m (Collett, 1983). If the geothermal gradient and the methane hydrate stability curve do not intersect, in-situ gas hydrates will not be stable and most likely will not be present. Given this geothermal gradient, a minimum permafrost depth would be 232 m. In other words, methane hydrate should not be present in North Slope sediment if the permafrost is less than 232 m thick. The shaded area in Figure 2 indicates the region in which methane hydrates would be potentially stable, and the dashed line represents the 232 m permafrost depth contour. The northern boundary of the shaded area is uncertain.

The results of recent subsurface geochemical sampling within the gas hydrate stability field in the Kuparuk Oil Field indicates that the composition of the free gases within these shallow horizons is more complex then previously believed. Gas analyses indicated the presence of significant amounts of methane and heavier gases such as ethane and propane. The depth and thickness of the gas hydrate stability field is directly related to the gas composition of the gas hydrates. Minor amounts of heavier gases such as propane could alter the gas hydrate structural form leading to a more extensive hydrate stability field than that of a pure methane hydrate system. Conversely, nitrogen would decrease the stability of a gas hydrate system and reduce the thickness of the gas hydrate stability field. The recovered gas hydrate core from the Eileen well contained nitrogen; thus the delineated gas hydrate stability field in Figure 2 may not be accurate and only represents an approximation. More geochemical analyses of the gases within the gas hydrate horizons are needed to determine the actual extent of the natural gas hydrate stability field on the North Slope.

INFERRED HYDRATE OCCURRENCES

Detailed analyses of a series of open-hole geophysical well logs from 125 wells in the Prudhoe Bay and Kuparuk oil fields suggests the presence of 102 gas hydrate occurrences in 32 different wells (Collett, 1983). Gas hydrates are present in relatively porous, discrete sedimentary units and in many wells in multiple zones; the individual zones range from 2 to 28 m in thickness. Most of the gas hydrate occurrences appear to be geographically restricted to the Kuparuk Field, west of Prudhoe Bay (Figure 3).

In Kuparuk Oil Field, gas hydrates are present in about four to six laterally continuous units that can be delineated in cross section. The gas hydrates are restricted to a series of sands and gravels which are interbedded with multiple thick silt units. The gas hydrate bearing sands and gravels represent a non-marine delta front to delta plane depositional package (Collett, 1983).

The presence of thick coal units in this sequence also suggests a deltaic environment of deposition. The coal may also serve as a source of the free methane gas necessary for the formation of gas hydrate. Heavy oil, also present within this shallow sequence, may also have been a source of methane and heavier gases such as propane since dissolved gases are commonly associated with oil accumulations.

Galate and Goodman (1982) evaluated 17 National Petroleum Reserve of Alaska (NPRA) wells for evidence of in-situ gas hydrates. For this study, they used all available records such as drilling plans, well histories, daily drilling reports, mud reports, geologic data for the area, coring information, and geophysical well logs. Of the 17 wells investigated, 8 showed significant evidence of gas hydrates. All the potential hydrate intervals identified by Galate and Goodman (1982) fall within the methane hydrate stability field (shown Figure 2) at Point Barrow, Cape Simpson and along the northern coast of NPRA.

CONCLUSION

In-situ natural gas hydrates are known to be present in many Arctic environments. In northern Alaska, pressure and temperature conditions within which gas hydrates should be stable appear to be widespread. Core samples, drilling operations, and open-hole geophysical logs provide evidence of probable gas hydrate occurrences on the North Slope of Alaska. At this time the extent of these hydrate occurrences is not known, but preliminary research has indicated that a substantial amount of in-place natural gas hydrates is present in this region.

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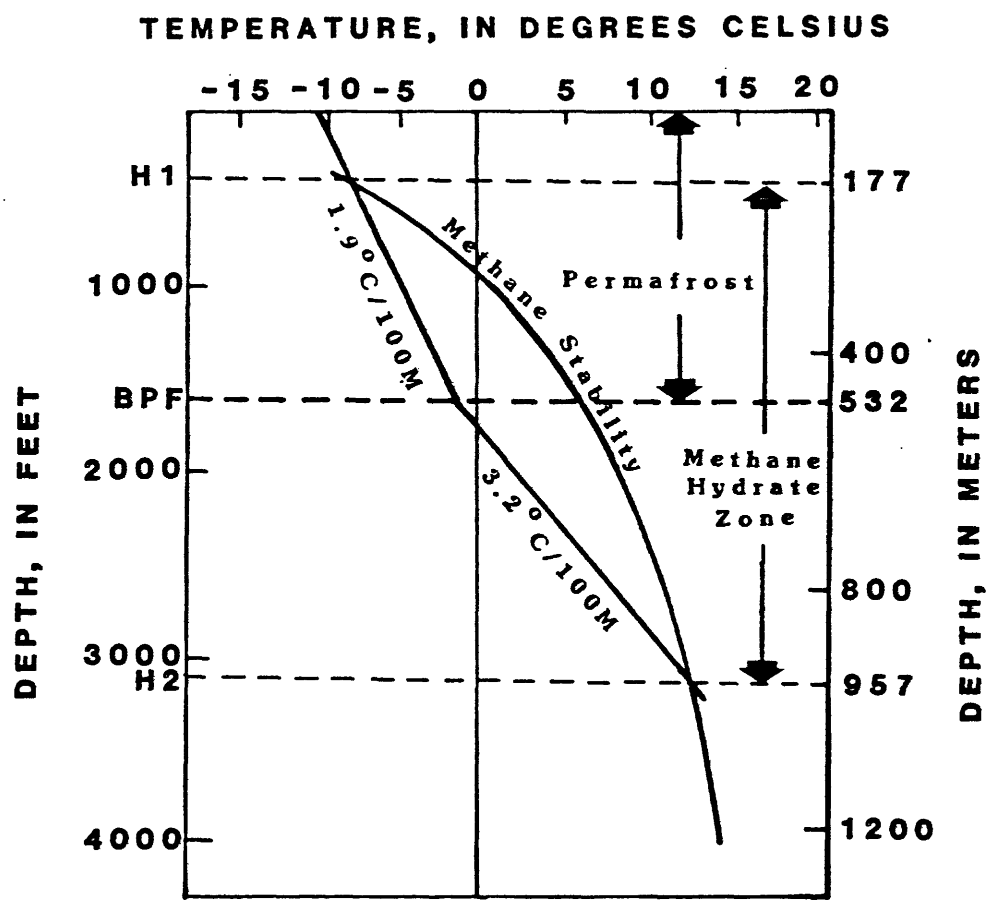

Figure 1--Phase diagram of the methane hydrate stability zone in the North-West Eileen State Number 2 well in Prudhoe Bay, Alaska (Collett, 1983).

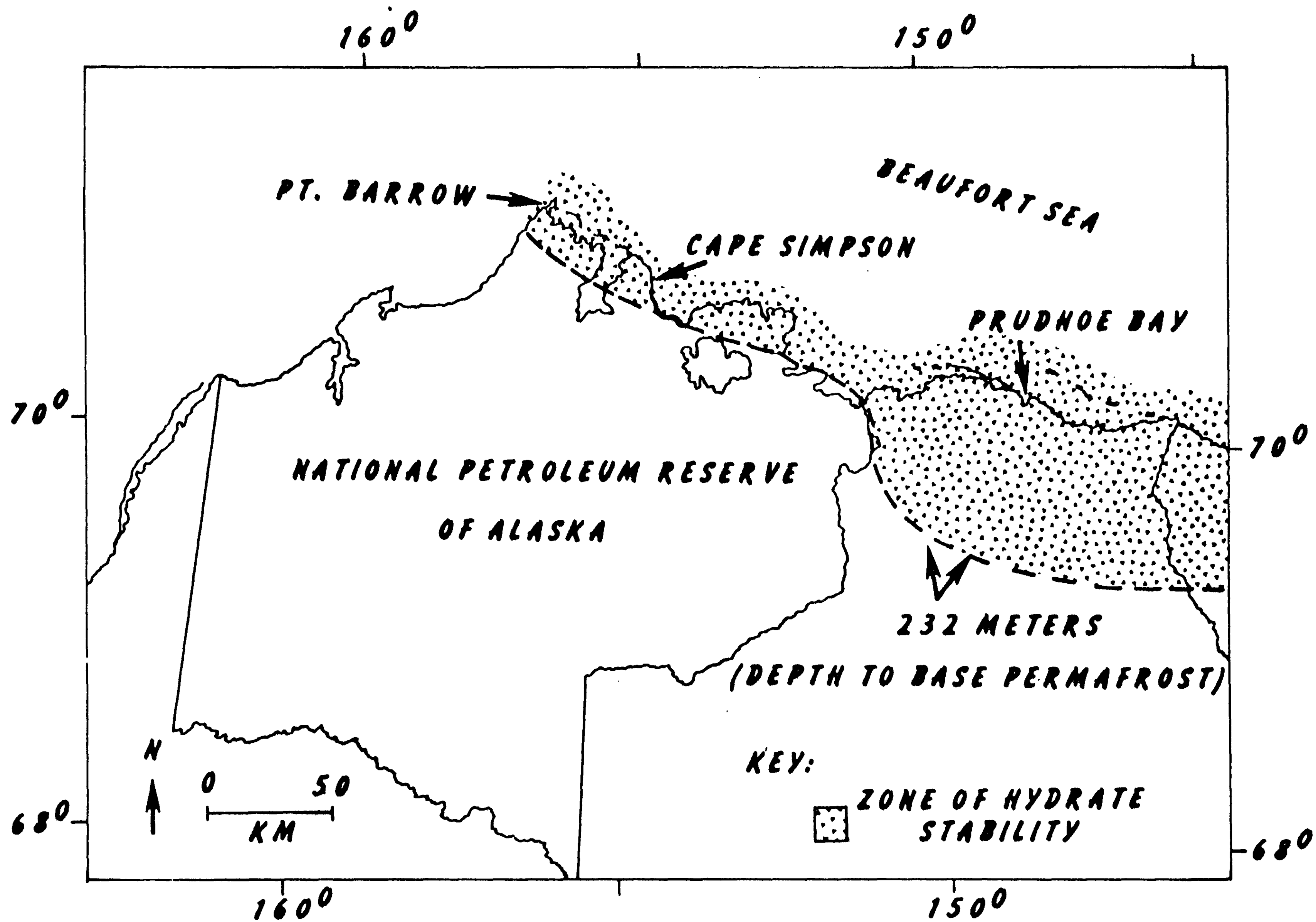

Figure 2--Geographic distribution of the methane hydrate stability field on the North Slope, Alaska. Northern boundary of shaded area is uncertain.

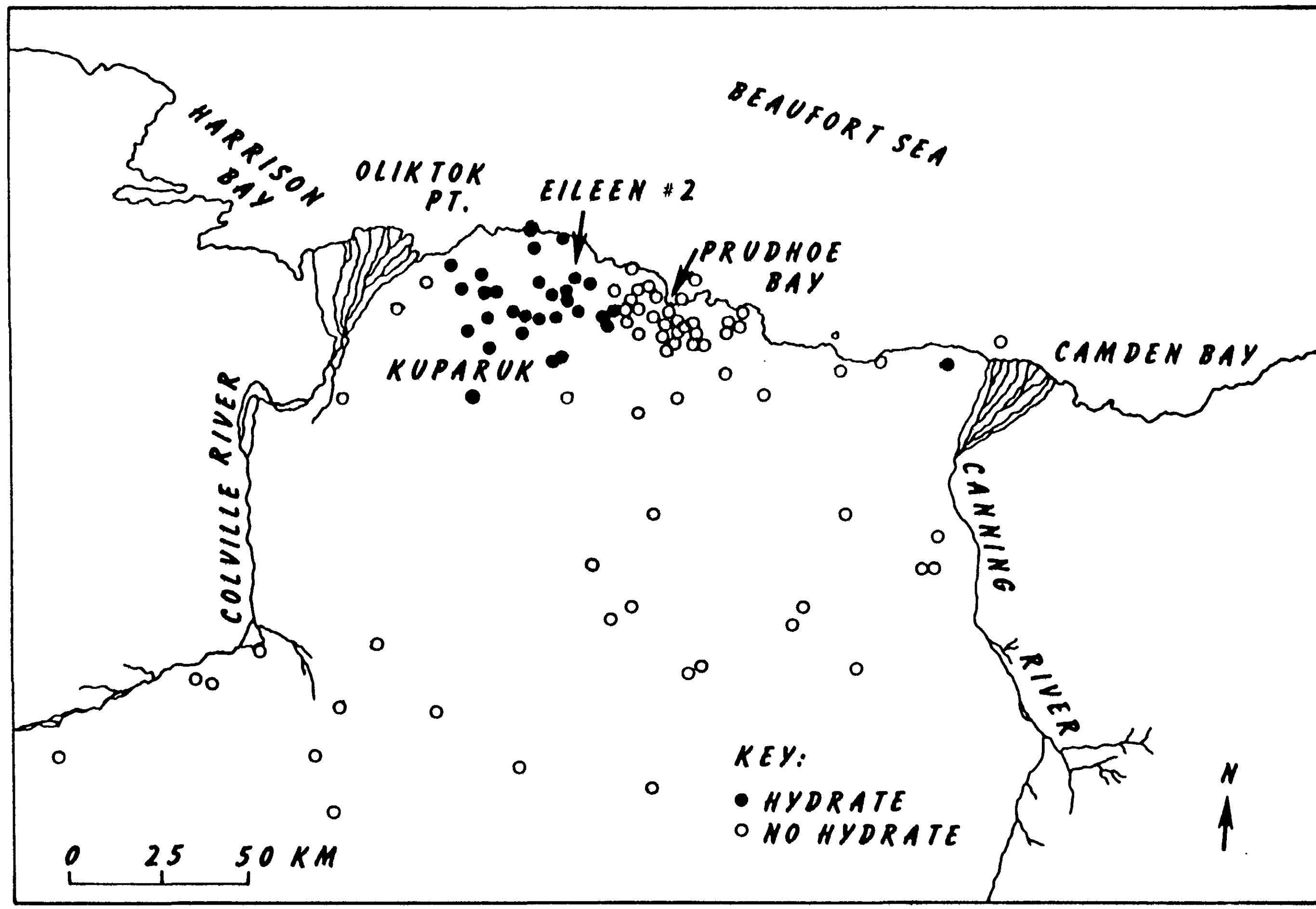

Figure 3--Geographic distribution of gas hydrate occurrences on the North Slope, Alaska (Collett, 1983).