Relation between Gas Hydrate and Physical Properties at the Mallik 2L-38 Research Well in the Mackenzie Delta

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ABSTRACT: **As part of an interdisciplinary field program, a 1150-m deep well was drilled in the Canadian Arctic to determine, among other goals, the location, characteristics, and properties of gas hydrate. Numerous physical properties of the host sediment were measured in the laboratory and are presented in relation to the lithology and quantity of *in situ* gas hydrate. Profiles of measured and derived properties presented from that investigation include: sediment wet bulk density, water content, porosity, grain density, salinity, gas hydrate content (percent occupancy of non-sediment grain void space), grain size, porosity, and post-recovery core temperature. The greatest concentration of gas hydrate is located within sand and gravel deposits between 897 and 922 m. Silty sediment between 926 and 952 m contained substantially less, or no, gas hydrate perhaps because of smaller pore size.**

INTRODUCTION

The Japan Petroleum Exploration Co. Ltd./Japan National Oil Corporation/Geological Survey of Canada Mallik 2L-38 gas hydrate research well was drilled in February and March 1998, at latitude 69° 27′ 40.71″N, longitude 134° 39′ 30.37″W, on the Northeastern edge of the Mackenzie Delta, Northwest Territories, Canada. A primary goal of the 1,150-m deep well was the collection of core samples to document an occurrence of Arctic gas-hydrate.[1] The sediment physical properties determined from the Mallik well were used to verify well log data and to relate the location of gas hydrate to the physical nature of the host material. These data also complement sedimentology studies,[2] petrophysical analyses,[3] and a variety of modeling investigations.

Water content, grain density, and Atterberg limits (water contents that separate different remolded sediment consistency states) were measured from core subsamples collected between 109 and 175 m and between 886 and 952 m, from widely

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differing sediments. Other parameters, such as porosity, wet and dry bulk density, void ratio, and total unit weight were calculated from the index properties. The physical property measurements discussed in this report are supplemented by other data[4] and by Winters *et al.*[5]

GAS HYDRATE LOCATION AND GEOLOGICAL SETTING

Unconsolidated and lithified sediments from three stratigraphic sequences, which range from Pleistocene to Oligocene (Iperk Sequence 0–346 m, Mackenzie Bay Sequence 346–926.5 m, and Kugmallit Sequence 926.5–1,150 m),[2] were penetrated during drilling. Permafrost is present from slightly below ground surface to a depth of 640 m (relative to the kelly bushing on the drill rig, which was 8.31 m above ground surface). In total, 37.3 m of core were obtained between the depths of 886 and 952 m to document a thick gas hydrate zone that had been identified at a nearby site (Mallik L-38) during exploration drilling by Imperial Oil Ltd. in 1972.[6]

Gas hydrate typically either filled sediment voids or coated grains within coarse sand and gravel deposits in samples obtained at depths between 897 and 922 m.[1,7] Nodules less than 1 cm in diameter and thin veins less than 1 mm thick were also observed. In addition, the presence of hydrate indicated by resistivity well logs suggest that hydrates exist below the level of sample recovery to a depth of about 1,110 m.[7] The "standard" Archie relation used for interpretation of electrical resistivity measurements indicates that hydrates occupy an average of 47% of the void space. Well logs from the nearby Mallik L-38 well indicate that gas hydrate occupies more void space (about 67%) than is present at the 2L-38 well.[8]

METHODS

A number of different coring systems and techniques were used during the project. A wireline retrievable system produced 50 mm diameter cores in permafrost. A conventional core barrel was typically used in the gas hydrate interval to obtain larger (133 and 89 mm) diameter cores. Pore water near gas hydrate deposits occasionally froze during recovery due to endothermic cooling caused by gas-hydrate dissociation. This process probably stabilized the sandy sections. Considerable care was taken at the drill site to characterize the physical properties of core samples with emphasis on time-critical observations such as bonding or strength, gas hydrate or permafrost characteristics, and core temperatures. Subsamples were taken directly at the drill site for water content, pore-water geochemistry, petrophysical studies, and a variety of other investigations. Four 26-cm long, large-diameter samples containing gas hydrate were also preserved for specialized physical-property studies.[9] Detailed physical property measurements and geochemical analyses were conducted at a field laboratory in Inuvik, located approximately 170 km south of the drill site where additional subsamples were obtained.

Core subsamples, used for physical-property measurements, were obtained using two methods. A plunger or syringe, which produced a cylindrical plug, provided a uniform specimen from which volume was calculated using measured sample

dimensions. A larger number of irregularly shaped specimens were also collected. Volumes of components in these samples were corrected for pore water salinity and were back calculated using density values, assuming 100% saturation of the pore voids by either ice or by a combination of water and gas hydrate according to interpretation of the resistivity log.

The specimens were dried, typically after gas hydrate dissociation, at a temperature of 90°C for at least 24 hours in order to determine the amount of fresh water and solids present. The dried specimen was then broken into granule-size pieces, and the volume of dried solids was determined with an automatic gas pycnometer, using helium as the purge and expansion gas.[10]

Sediment pores are filled with a combination of water or gas hydrate *in situ* (and ice in the permafrost zone). The physical property calculations were adjusted to account for the *in situ* gas hydrate quantities interpreted by Collett *et al.*[7] from resistivity well log data. Grain sizes were determined using two methods. Dry sieving was used to measure the size of coarse material and a Brinkmann particle size analyzer using time of transition theory was used for the fine fraction.

RESULTS AND DISCUSSION

Measurements of water content and porosity are important to understanding host sediment conditions. These characteristics indicate the quantity of water and void space available to form hydrate, provided that gas concentration is not a limiting factor. Water contents (mass of pore water/mass of sediment grains, M_w/M_s) in the zone beneath permafrost vary from 35.5% to about 1% in a thin cemented sandstone encountered at 926 m. Porosities change from 50% to 3% over the same interval. Most of the samples from the deeper section exhibit porosities less than 44%.[4]

Physical property index measurements on sediment cores and derived geotechnical parameters are summarized for the gas hydrate interval in FIGURE 1 and are plotted with profiles of well-log-derived bulk density, porosity, and gas hydrate concentration. Petrophysical determinations of porosity and bulk density using a helium porosimeter are also presented. In general, within the gas-hydrate interval from 897 m to 922 m, the core-measured values and the values derived from well logs are strongly correlated. For some samples, a difference exists between the index-derived values and the measured helium porosimetry values. Good agreement between all techniques is observed in a thin layer at 926 m, which has porosity values between 2% and 4% (dolomite cemented sandstone).

Salinity determinations on pore water extracted from core samples beneath permafrost reveal pronounced changes, ranging from 60 to 4 ppt. Within the gas hydrate interval, many sediment specimens containing high hydrate concentrations had values less than 10 ppt and usually less than 5 ppt. However, other core samples within this interval had salinity values from 26 ppt to over 50 ppt. These samples generally correlate with apparent interbeds having lower gas hydrate concentrations and may imply solute migration associated with gas hydrate formation. Salinity in finer grained sediments above and below this interval had more consistent salinity values in the range of 25 to 35 ppt.

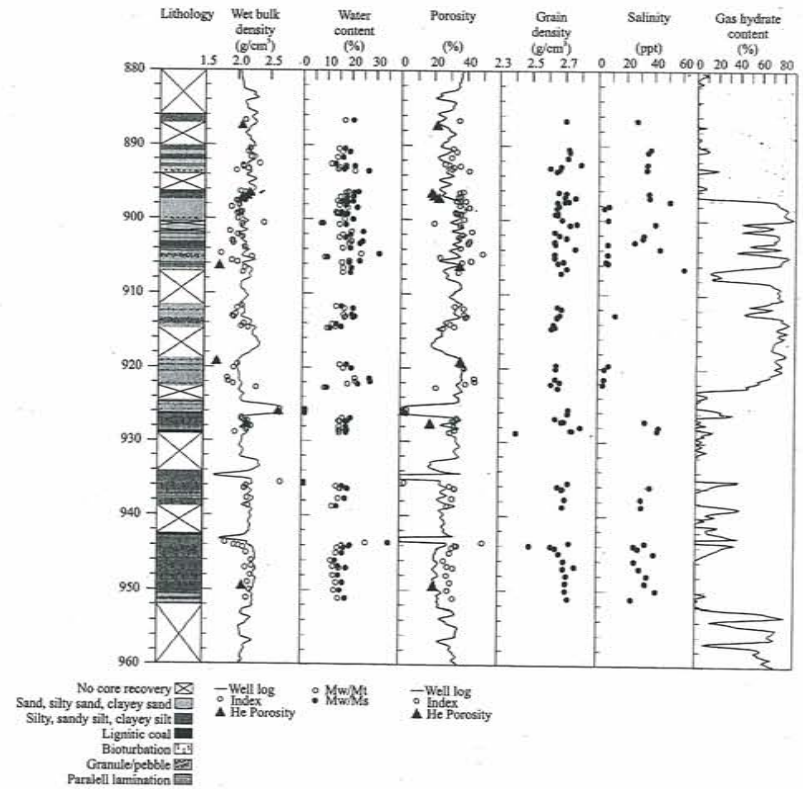

FIGURE 1. Core measurements of wet bulk density, water content, porosity, grain density, porewater salinity and gas hydrate concentration (percent occupancy of non-sediment grain void space). Water content (M_w/M_t represents mass water/mass total; M_w/M_s represents mass water/mass sediment grains), grain density, and pore-water salinity were measured from core subsamples and were used to calculate wet bulk density and porosity (assuming full water saturation and corrected for pore water salinity and presence of gas hydrate). Additional porosity and wet bulk density measurements by the helium porosimetry technique are also provided for petrophysical samples. Well log values are shown for wet bulk density, porosity, and hydrate saturation of pore voids from Collett *et al.*[7] A complete listing of physical properties is provided in Dallimore *et al.*[4]

FIGURE 2 shows grain size, core temperatures (measured immediately after sample extrusion from the core barrel), and visual qualitative estimates of gas hydrate content made by scientists at the drill site. The main gas hydrate interval from 897 to 922 m is dominated by sands, although some silty sands and low plastic silts are present in interbeds with lower gas hydrate concentrations. Sediments above this interval have similar grain size characteristics, however sediments below consist of low plastic silts with trace amounts of sand and clay.

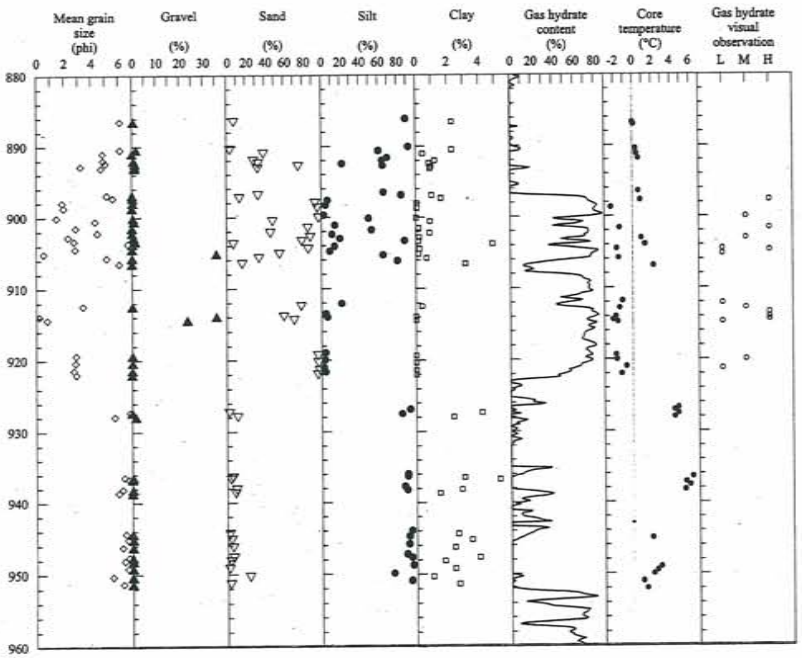

FIGURE 2. Grain size data, temperature measurements (made immediately after core extrusion), and qualitative estimates of gas hydrate concentration based on observations at the drill site. Well log gas-hydrate saturation values are from Collett *et al.*[7]

As discussed by Dallimore *et al.*,[1] core temperature measurements can provide a proxy to the presence of gas hydrate. Given that *in situ* temperatures are almost certainly above 8°C and mud temperatures were above 2°C, measurements of core temperatures below 2°C are interpreted to result from the endothermic cooling effect occurring because of gas hydrate dissociation. Furthermore, sediment cemented by gas hydrate and ice was observed at depths where temperatures below 0°C were measured. Quantitative visual estimates of gas hydrate concentration were typically made by immersing representative subsamples in water and estimating the intensity and volume of gas hydrate dissociation. Good correlation is observed between visual observations and negative core temperatures.

Gas hydrate was typically recovered in sandy material with a porosity of 32 to 45% and in gravel with a lower porosity of 23 to 29% (corrected for the presence of gas hydrate).[4] Silts and silty sands that are present above, within, and below the different gas hydrate layers (but do not contain gas hydrates) have similar or slightly lower porosities (26–41%) compared to the sands. This suggests that porosity alone is not a primary control on the distribution of gas hydrate and that gas hydrate may

preferentially form in the larger void spaces of sand and gravels, whereas formation is inhibited within the smaller voids of the finer-grained sediment. Also, the lower permeability of the finer silts and sandstone could influence gas migration and hydrate formation. Localized elevated pore water salinity, which may have resulted from salt exclusion caused by initial gas hydrate formation in surrounding sediments, may also inhibit hydrate formation.[11]

CONCLUSIONS

Gas hydrate was typically recovered in sandy sediments and in layers with a high gravel content. Silts and silty sands that are present above, within, and below the gas hydrate layers, but contain lesser amounts of hydrate, have similar porosities to the sands but they exhibit higher pore-water salinities. This suggests that porosity may not be a primary control on the distribution of gas hydrate and that gas hydrate may preferentially form in the larger void spaces of sand and gravels, whereas formation may be somewhat inhibited within the smaller voids of the finer-grained and more saline sediments. Perhaps the lower permeability of the finer silts and sandstone also influences gas migration and hydrate formation. Other considerations such as the supply of gas may also be a factor.

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Gas Hydrates of Siberia

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ABSTRACT: Natural gas hydrates were first observed on 21 July 1961 (the discovery was officially registered on 24 December 1969).[1] It soon became clear that these compounds are not just chemical curiosities, or a nuisance for gas transportation in pipe lines, but rather that they are related significant natural phenomena. It is possible that in the past natural gas hydrates have manifested themselves in marine and land incidents. In future gas hydrates may offer an inexhaustible source of energy and chemical raw material. However, if not accessed with sufficient knowledge, gas hydrates may be destabilized to create many local problems and possibly global problems as well. In the USSR and more recently in Russia, a number of groups are traditionally involved in investigation of different aspects of gas hydrates problems. These groups have made significant contributions to present knowledge about the nature and properties of the gas hydrates. The Siberian branch of the Russian Academy of Sciences recently started an interdisciplinary program to comprehensively investigate all major aspects of gas hydrates, with special emphasis on natural gas hydrates and gas hydrates deposits in Siberia and its adjacent regions. The program consists of three components: (1) Geology of gas hydrates in the cryolito-zone of Siberia and in the bottom deposits of the Arctic and East seas, and of Lake Baikal. (2) Physicochemical study of hydrates of different gases. (3) Ecological monitoring. In this paper we offer a short summary of the main results of these three components of the program. We emphasize the second component, since it is close to the scientific interests of the author.

GEOLOGY OF GAS HYDRATES IN CRYOLITO-ZONE OF SIBERIA, IN BOTTOM DEPOSITS OF ARCTIC SEAS AND OF LAKE BAIKAL

Gas-hydrate stability zones have been outlined (see FIGURE 1) based on analysis of data collected to date. The data include geothermal conditions, pressure, mineralization of underground waters, and presence of gas (required for formation of hydrates). The scheme outlines the most favorable areas for the search for gas hydrate accumulations that formed from free gas that existed in these areas prior to rock and sediment freezing, or from gas that migrated to the hydrate-formation zone from lower layers. The analysis shows that early conclusions need to be reconsidered.

More detailed mapping of the gas-hydrate stability zones (GHSZ) in Northern Siberian regions was performed with use of computer technology. The aim was to determine the upper and lower boundaries of the zone. FIGURE 2 shows the results

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