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Field and laboratory characterization of intrapermafrost gas hydrates, Mackenzie Delta, NWT, Canada

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ABSTRACT:

Visible gas hydrate and possible pore space hydrate samples have been recovered from within ice bonded permafrost in a 451m deep corehole drilled in the Mackenzie Delta, Canada. A complementary laboratory program is described in which gas hydrates were grown in undisturbed and remoulded core samples. Preliminary results from these studies provide insights on the geologic controls on gas hydrate formation in ice bonded permafrost including the role of grain size, sediment fabric and water migration. The stability of field and laboratory specimens at atmospheric pressures is attributed to the self preservation phenomena where ice surrounding the hydrate may prevent dissociation. Field observations imply that self preservation of gas hydrates may occur in situ at depths substantially less than those predicted by conventional Pressure/Temperature analyses.

Gas hydrates have been identified in association with areas of thick permafrost in northern Canada, Alaska and Russia (1). In nearly all cases the presence of hydrates has been speculated from indirect evidence collected during the course of hydrocarbon exploration. Primary tools used to identify their presence include gas flows during drilling, steady build up of shut-in pressures, and geophysical well-log response (2). Because sediments with gas hydrate filling the pore space have similar geophysical properties to those with ice filling the pore space, with most indirect methods it is difficult to reliably identify hydrates within permafrost. As a result, most regional assessments of gas hydrates in polar areas, such as that by Smith and Judge (3) for northern Canada, provide few insights into the occurrences of hydrates within the ice-bonded permafrost interval.

The general lack of information about gas hydrates within ice-bonded permafrost is perplexing since for issues such as the assessment of the role of methane hydrate dissociation during climate warming, the permafrost interval is the most sensitive to change. Recently, a deep geotechnical corehole completed by the Geological Survey of Canada in the Mackenzie Delta (Figure 1) provided a unique opportunity to study in situ gas hydrates in a variety of ice-bonded sediments. This paper reviews the results of this study

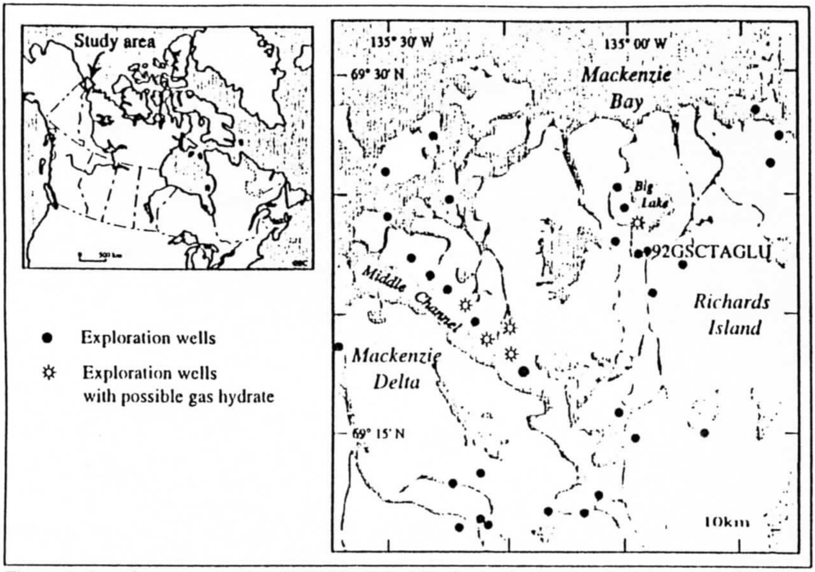

Figure 1: Location map showing 92GSCTAGLU drill site in the Mackenzie Delta and hydrocarbon exploration wells with possible gas hydrates as identified by Smith and Judge (3).

and preliminary results of a complementary laboratory investigation conducted on core samples associated with in situ hydrate occurrences.

II 92GSCTAGLU COREHOLE

The 92GSCTAGLU corehole site is located in the distal portion of the Mackenzie Delta in an area of active hydrocarbon exploration. Within a 20-km radius of the site (Figure 1), five hydrocarbon exploration wells have been identified as containing possible gas hydrates on the basis of well log analyses (3). However, each occurrence was beneath the base of ice bonded permafrost. The 92GSCTAGLU corehole used a geotechnical drilling rig designed to minimize physical and thermal drilling disturbance (4). Continuous core samples, 85mm in diameter, were collected in various unconsolidated sediments to a depth of 451m. In general, less than 1 °C warming of core samples was observed when compared to the in situ formation temperatures measured after drilling (Figure 2).

Core samples containing visible gas hydrate were recovered at 336m in ice-bonded silts and at 354m from ice-bonded silty clay (Figure 2). As described by Dallimore and Collett (5), the visible hydrate occurred as thin icelike lenses and veins which released methane gas initially upon core retrieval, but then stabilized for up to 4 hours at atmospheric pressure conditions and negative temperatures. In addition to the visible gas hydrate, gas venting was observed from ice bonded core samples at many horizons and high headspace gas concentrations were measured in canned samples (Table 1).

Given that the unfrozen water content in ice bonded permafrost is generally very low,

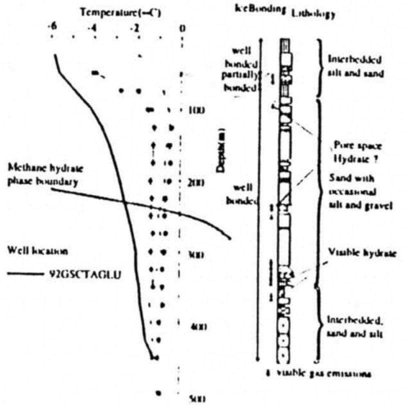

Figure 2: Stratigraphy, gas hydrate observations and ground temperatures from 92GSCTAGLU borehole.

Table 1: Geochemical analyses of 92GSCTAGLU corehole samples

DEPTH (m)	METHANE (ppb)	ETHANE (ppb)	PROPANE (ppb)	N BUTANE (ppb)	$C_1/C_2+C_3+C_4$
2.30	2 287 003	6 071	2 260	600	254
3.80	128 047	6 186	2 265	731	14
6.10	1 935 890	5 650	1 826	607	240
29.96	466 134	371	256	131	630
56.98	44 041 525	1 421	1 067	190	15 669
88.49	15 718 841	3 157	962	137	4 264
119.45	30 085 714	4 134	1 321	278	5 2484
136.26	5 229 528	2 214	376	229	1 855
167.52	18 400 838	2 718	617	190	4 901
195.87	18 912 000	6 131	3 365	1 405	1 712
225.77	9 200 920	5 346	1 700	1 222	1 102
262.41	11 186 784	2 792	1 270	792	2 834
296.78	17 710 448	4 916	972	728	2 677
326.96	34 001 509	3 875	1 896	1 206	4 943
354.32	*95 000 000*	23 900	1 997	189	>3 0002
386.34	59 445 405	10 585	1 419	909	4 654
413.82	14 832 915	4 074	483	179	3 136

(C_1,C_2,C_3,C_4 determinations by Direct Geochemical Surveys, Colorado. Isotopic determinations by Global Geochemistry, California. *indicates value exceeded detection limit of instrument)

these high values strongly suggest that pore space hydrate was present throughout much of sequence with the shallowest occurrence being at 119m.

Observations of the stabilization of the visible hydrate in core samples at atmospheric pressures and negative temperatures are similar to the behavior of visible methane hydrate samples grown in various porous media in the laboratory experiments in Russia (6,7,8,9). These authors refer to the phenomena as gas hydrate self preservation and attribute the behavior to the formation of a coating of ice around the gas hydrate allowing maintenance of hydrate structure outside the normal Pressure/Temperature stability field. The results from Taglu corehole are significant since they provide the first confirmation of the self preservation behavior on natural samples of visible hydrate within ice bonded sediments. The presence of pore space hydrate at 119m, a depth considerably shallower than the 200m depth predicted with the formation pressures observed in the Taglu well, suggests that the self preservation of pore space hydrate may also in situ.

III LABORATORY TESTING PROGRAM

In order to characterize the geological controls on gas hydrate formation in the Mackenzie Delta environment, and to substantiate the self preservation behavior, an extensive laboratory testing program was conducted at the University of Moscow. A key goal of the program was to utilize actual sediments from hydrate intervals observed in the Taglu corehole and to replicate aspects such as moisture content and bulk density as close as possible to the field situation. Methane hydrate was grown within a test cell (Figure 3) using both undisturbed and remoulded core samples. For each experiment the test cell was saturated with methane gas and pressurized to about 8MPa. The system was then closed and the temperature was dropped in two time steps, from room temperature

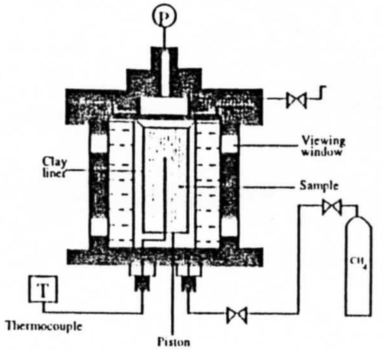

Figure 3: Gas hydrate test cell used for experimental work.

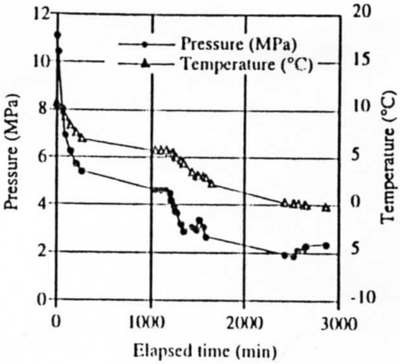

Figure 4: Experimental data from undisturbed silt sample showing temperature (solid dots) and pressure (open triangles) response with time.

to about 2 °C and then from 2 °C to -5 °C. Pressure and temperature response during hydrate formation (Figure 4) was monitored and after the test the sample was extracted from the cell in a cold room.

In total, 10 experiments were undertaken to investigate the effects of soil type, soil structure and moisture content on hydrate formation. In each case after completion of the test, the methane hydrates were observed (both physically on specimens and with X-ray analyses) to be stable at atmospheric pressure and negative temperatures confirming the self preservation behavior. The self preservation behavior was in fact used to further the investigations since samples could be sectioned for study without dissociating the hydrates. This allowed detailed observations of the form and volume of visible gas hydrates and determinations of the bulk density, moisture content and gas content of soil specimens (Figure 5). X-ray and Scanning Electron Microscope studies were also conducted on some samples to assess the hydrate/sediment microstructure.

IV RESULTS

Indications of pore space methane hydrate occurred in each sample after testing and in most samples visible hydrates were observed. An indication of the general Pressure/Temperature response for each of the three soils is given on Figure 6 which shows the consumption of methane gas to form gas hydrate for representative Sand, Silt and Clay samples. A summary of the physical observations on each sample after completion of the testing is given on Table 2. The sand samples, on a volume basis, were the most conducive to hydrate growth with abrupt and substantial pressure drops during the test. In contrast the clay samples were much less conducive to hydrate growth with only rare visible hydrate forms and less pressure drop during the test. Hydrate growth in the silt sample was found to be strongly affected by soil structure with the form of the visible hydrate and the pressure response varying substantially between an undisturbed core

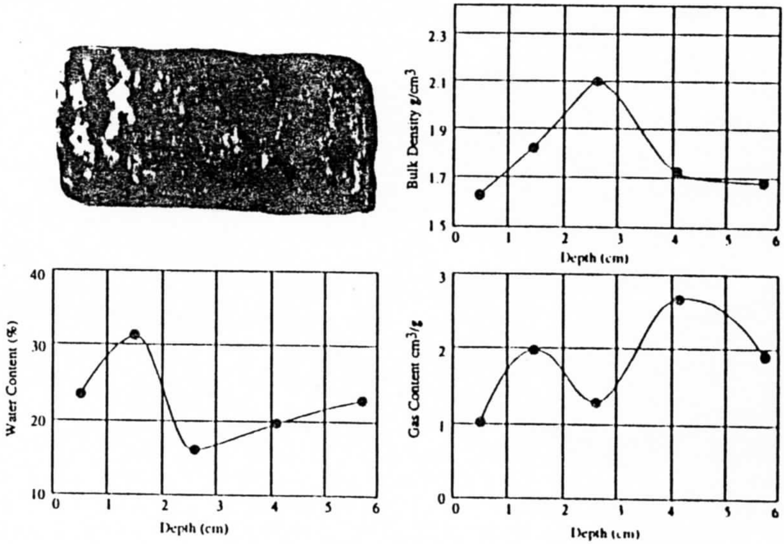

Figure 5: Photograph and laboratory data from undisturbed silt sample after completion of test. White areas on sample correspond to visible gas hydrate.

sample and a remoulded samples.

Sectioning of the sediment samples after testing revealed details of moisture content, gas content and density changes induced by hydrate growth (Table 2). In all cases, sediment containing visible hydrate had higher moisture contents and lower bulk densities than surrounding areas. The most visible hydrate and the largest fluctuations in physical properties were associated with the undisturbed silt sample. In this case the moisture content was greater than 30% near visible sub-horizontal hydrate lenses and veins and less than 15% in surrounding sediment (Figure 4). Remolded samples of silt formed less visible hydrate with more abundant horizontal hydrate lenses and fewer veins. The sand samples only had rare visible hydrate however, they had the highest overall gas

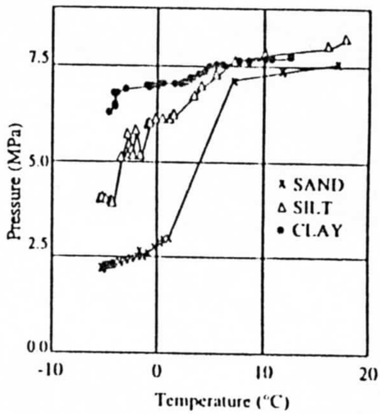

Figure 6: Summary plot of Pressure/ Temperature response for typical samples. Note two phase response to drop in temperature from 15 °C to 2 °C and from 2 °C to -5 °C.

Table 2: Summary of observations from laboratory program conducted on Sand, Silt and Clay samples from 92GSCTAGLU corehole.

Sediment	P/T response	Hydrate forms	Remarks
Sand	Abrupt 2-stage response (7.5-2MPa)	Cap, pore space, rare lens and vein (<1mm), rare inclusions	Moisture and bulk density changes associated with water migration and volumetric expansion during hydrate growth. Visible hydrate forms generally thinner than for silt but gas contents higher
Silt	Abrupt 2-stage response (8.5-4MPa)	Cap,pore space, lens and vein (1-4mm), some inclusions	Moisture and bulk density changes associated with water migration and volumetric expansion during hydrate growth. Growth controlled by soil structure and moisture content with. Abundant visible hydrate but gas contents overall lower than for sand
Clay	Gradual 2-stage response (8-6MPa)	Cap and pore space hydrate, rare visible hydrate as inclusions	Moisture and bulk density changes associated with water migration and volumetric expansion during hydrate growth. Hydrate growth controlled by initial water content with high water

content and the greatest pressure drop during testing. This suggests the presence of considerable amounts of pore space hydrate.

Initial moisture content was a critical factor for clay samples with visible hydrate only forming in samples with low initial moisture contents. Samples with moisture contents close to saturation only had pore space hydrate.

Additional studies are ongoing to investigate the mineralogy, pore size distribution, compressibility of the soil matrix and the permeability (gas and water) of each test specimen to provide further insights into the geologic constraints on hydrate formation.

V CONCLUSIONS

In Polar areas gas hydrates within the ice bonded permafrost interval are critical for hazard evaluation and global change studies. However, on a worldwide basis almost no data are available to assess hydrate abundance or the geologic controls affecting hydrate accumulation. The investigations reported here represent a first attempt to provide a link between corehole observations from the Mackenzie Delta of visible and pore space methane hydrate and laboratory experiments to grow hydrate under controlled environmental conditions.

Preliminary conclusions include:

1)Under favorable geologic conditions gas hydrate accumulations both as visible and pore space hydrates may be significant within ice bonded permafrost.

2)Self preservation of visible and pore space hydrate has been confirmed both in the laboratory and in situ. Thus occurrences of gas hydrates at shallower depths than predicted from conventional pressure/temperature relationships should be considered during the course of regional gas hydrate evaluations in permafrost areas.

3)Under similar conditions of gas saturation and temperature regime, gas hydrate formation is strongly influenced by sediment characteristics including; grain size, initial moisture content and sediment fabric.

4)Moisture content and bulk density changes observed in laboratory samples suggest that substantial migration of unfrozen water can occur within ice bonded permafrost in response to hydrate formation. Variations in similar properties in field samples suggest that these processes may also be important in nature.

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