# Drilling operations, JAPEX/JNOC/GSC Mallik 2L-38 gas hydrate research well

T. Ohara[1], S.R. Dallimore[2], and E. Fercho[3]

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**Abstract:** The JAPEX/JNOC/GSC Mallik 2L-38 gas hydrate research well, located in the Mackenzie Delta, Northwest Territories, Canada, was completed to 1150 m on March 30, 1998, after 39 days. Operations were undertaken through a collaborative agreement between the Japan National Oil Corporation and the Geological Survey of Canada. Research goals included evaluation of engineering technologies used to drill and core gas-hydrate-bearing strata. Eight coring runs were conducted within the permafrost interval (0–640 m) in a surface hole drilled to 687 m. Subsequently, a 340 mm surface casing was installed and the main hole was advanced to a depth of 1150 m with 16 coring runs. A cooled (~2°C) KCl/polymer drilling mud and Drilltreat, a chemical mud additive, successfully stabilized gas hydrate within cores and formation sediments. No serious hole problems, accidents, or mishaps occurred; however, delays caused by adverse weather and mechanical problems caused cancellation of planned production testing. Coring in the main hole was successful, allowing the evaluation of four different core barrels. Gas-hydrate-bearing cores were collected in a variety of sediments between 896 and 952 m.

**Résumé :** Le puits de recherche sur les hydrates de gaz JAPEX/JNOC/GSC Mallik 2L-38 foré en 39 jours dans le delta du Mackenzie (Territoires du Nord-Ouest, Canada) jusqu'à une profondeur de 1 150 m, a été terminé le 30 mars 1998. Les travaux ont été réalisés dans le cadre d'un accord de collaboration conclu entre la Japan National Oil Corporation et la Commission géologique du Canada. Les objectifs de la recherche comprenaient l'évaluation des techniques d'ingénierie utilisées pour le forage et le carottage des strates renfermant des hydrates de gaz. Un trou en surface foré jusqu'à 687 m a permis d'effectuer huit opérations de carottage dans l'intervalle de pergélisol (de 0 à 640 m). Puis, un tubage de surface de 340 mm a été posé et le forage du trou principal a été poursuivi jusqu'à une profondeur de 1 150 m comprenant 16 opérations de carottage. On a réussi à stabiliser les hydrates de gaz contenus dans les carottes et les sédiments de la formation à l'aide d'une boue de forage à polymères et à chlorure de potassium refroidie (~2°C) et d'un additif de boue chimique, le Drilltreat. Aucun problème, accident ou contretemps grave n'a été relevé. Cependant, les essais de production prévus ont été annulés en raison d'un retard attribuable à des conditions climatiques défavorables et à des problèmes mécaniques. Le carottage dans le trou principal a été réussi, ce qui a permis de faire l'évaluation de quatre tubes carottiers différents. Des carottes renfermant des hydrates de gaz ont été extraites dans divers sédiments à une profondeur entre 896 et 952 m.

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## INTRODUCTION

The JAPEX/JNOC/GSC Mallik 2L-38 gas hydrate research well was drilled to a depth of 1150 m in February and March of 1998, at the northeast edge of the Mackenzie River delta, Northwest Territories, Canada (Fig. 1). In addition to the scientific goals outlined in a previous paper by Dallimore et al. (1999b), the well was undertaken as a research and development project to evaluate drilling, coring, and completion technologies for gas-hydrate-bearing strata. This collaborative project, between the Japan National Oil Corporation (JNOC) and the Geological Survey of Canada (GSC), formed part of a larger five-year program initiated by JNOC in 1995, with the participation of 10 Japanese companies. The objectives of this program are to evaluate and develop new technologies for exploration, drilling, and production, and to design tools required for safely and efficiently drilling gas hydrate layers offshore of Japan in 1999. Secondary objectives are to assess the possibility of natural gas production from offshore methane hydrate reservoirs and to develop technologies required to economically produce methane hydrate gas. Gas hydrate research interests in the Mallik well included 1) testing of coring technologies, including a newly developed Japanese pressure/temperature coring system; 2) core studies in association with the science program; 3) refining and assessing wireline logging methods; 4) testing and evaluating drilling mud, casing, and cementing technologies; and 5) undertaking primary production testing on a methane hydrate occurrence.

This paper provides an overview of drilling operations for the Mallik 2L-38 research well in addition to an evaluation of the various technologies employed for drilling and coring the gas-hydrate-bearing strata.

## BACKGROUND

Naturally occurring gas hydrate can exist in deep-water settings, at relatively shallow depths below the seafloor, or at terrestrial locations within and beneath deep permafrost. The most common natural form of gas hydrate, in these environments, is believed to be methane hydrate. At in situ formation temperatures and pressures, methane hydrate is often quite close to threshold stability conditions (Fig. 2). Historically, gas hydrate within sediments has been considered a hazard to hydrocarbon exploration drilling, similar to shallow gas, with the potential to cause a severe gas kick when the gas-hydrate-bearing layers are being penetrated, or if free gas is trapped below the gas hydrate zone (Yakushev and Collett, 1992). Most drilling problems have been attributed to rapid gas hydrate dissociation that may produce over 160 volumes of free gas for every volume of gas hydrate affected. Typically, this can occur if drilling operations or warm drilling mud alter the temperature or pressure regime of the gas hydrate within the formation sediments or within drill cuttings. Gas hydrate can occur at relatively shallow depth, above the surface casing point, and controlling the gas flow can be a problem as blowout-prevention equipment may not be installed. In situations where the temperature of the gas hydrate has been disrupted, conventional well-control methods, such as weighting up the drilling mud, may have little effect because the gas is being produced as a result of a thermal disequilibrium. In a worst-case scenario, gas hydrate dissociation is so vigorous that the drilling mud is displaced, thus reducing the hydrostatic head and creating the potential for an influx of free gas. Drilling problems in the Mackenzie Delta

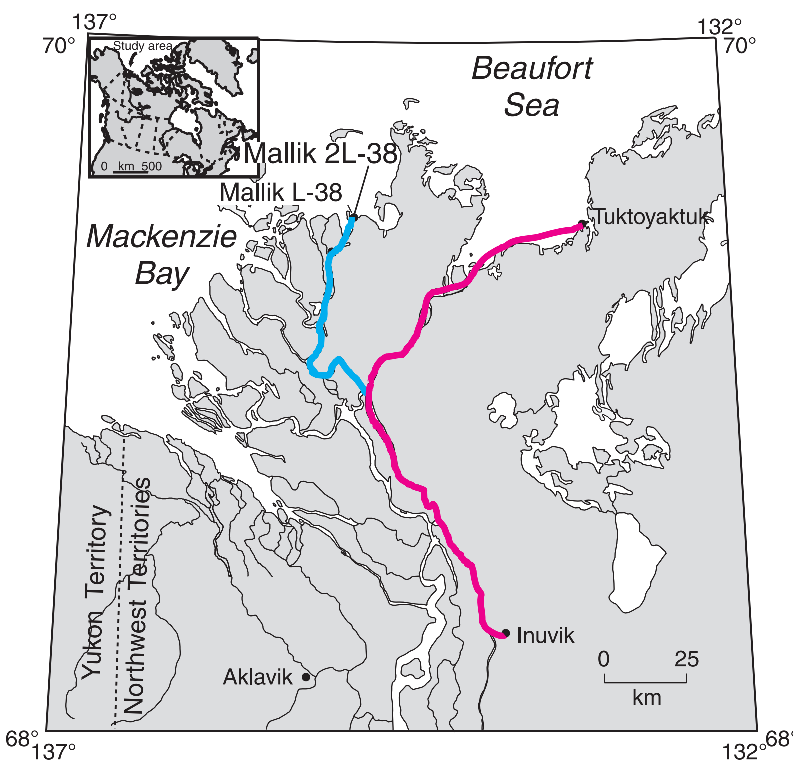


***Figure 1.***

*Location map showing Mallik 2L-38 gas hydrate research well drill site and the route of the ice road (pink–government road, blue–drill road) providing access to the town of Inuvik, Northwest Territories.*

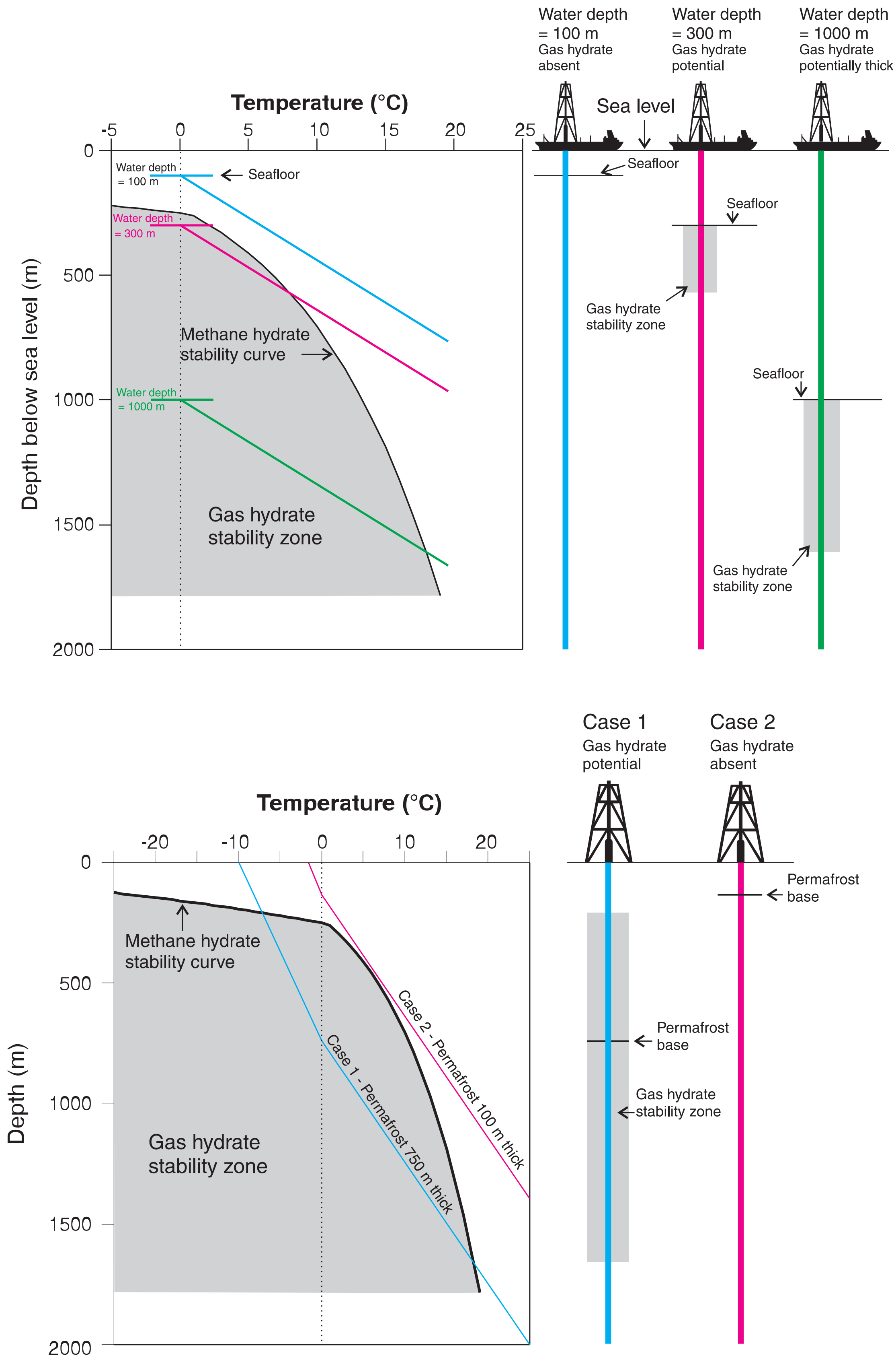


*Figure 2. Typical examples of the geothermal regime in a marine well and a permafrost well showing methane hydrate stability conditions for various ground-thermal scenarios.*

and northern Alaska have been attributed in part to this cause (Canada Oil and Gas Lands Administration, 1989; Schofield et al., 1997).

A number of secondary drilling and production problems have also been attributed to gas hydrate. Gas hydrate formation within the drill casing, during well shut-in periods, or within deep-water sub-sea well heads, can be a problem in some settings. This can occur when free gas, under optimal pressure and temperature conditions, forms gas hydrate, thus constricting flow paths. Similar problems are well known in gas pipelines. More recently, a variety of geotechnical problems have been attributed to gas hydrate dissociation weakening foundation conditions.

Due to the potential drilling hazards that gas hydrate presents, industry practice typically has been to drill through gas-hydrate-bearing strata as rapidly as possible in order to stabilize the interval and install surface casing. In arctic wells, chilled drilling muds have worked effectively to maintain gas hydrate stability conditions. The normal strategy employed when problems have been encountered is to slow the rate of penetration and circulate the gas hydrate cuttings out of the hole. More recently, chemical agents have been added to the drilling mud to stabilize the gas hydrate both in the formation and in the drill cuttings (Schofield et al., 1997). There is limited experience undertaking precision drilling and coring of gas-hydrate-bearing strata and it is mainly from scientific investigations conducted by the Ocean Drilling Program (e.g. Paull et al., 1996). Prior to this study, no documented core samples had been collected from beneath permafrost.

## PROJECT MANAGEMENT AND LOGISTICS

The Mallik 2L-38 gas hydrate research well project was conducted under a collaborative agreement between JNOC and the GSC. A steering committee with equal representation from both organizations co-ordinated activities. The GSC led the scientific studies and the Japan Petroleum Exploration Company (JAPEX) acted as the designated operator for the well, leading drilling operations on behalf of JNOC. Project management for planning, engineering, procurement, permit approvals, and on-site supervision was provided by Canadian Petroleum Engineering Inc. Japan Petroleum Exploration Company provided the day-to-day program direction from a field office located in Inuvik, Northwest Territories, and maintained a drilling supervisor at the drill site throughout the program. Geological Survey of Canada and JAPEX scientists were present at the drill site and supervised core studies as well as the downhole and surface geophysical programs.

The Mallik 2L-38 well was offset approximately 100 m northeast from the abandoned Imperial Oil Mallik L-38 well drilled in 1972. This location was selected to intersect a thick sequence of gas-hydrate-bearing strata (Dallimore et al., 1999b). Site logistics were favourable, and considerable background data were available from the L-38 well (Bily and Dick, 1974). The same lease area used in 1972 was used for the Mallik 2L-38 well (Fig. 3). Operations were conducted during the winter season to allow access to the site with minimal disruption to the fragile environment of the Mackenzie Delta. An ice road, following the channels of the Mackenzie River, between the well site and the town of Inuvik was maintained throughout the operations period. Approximately half of the 180 km long ice road followed the Inuvik–Tuktoyaktuk winter road maintained by the government of the Northwest Territories while the remainder was constructed exclusively for the drilling project (Fig. 1). Due to the mild winter experienced in the Mackenzie Valley in 1998, freeze-up of the winter road occurred relatively late and the first heavy loads were transported to the drill site in late January. A short take-off and landing airstrip was also maintained at the drill site for emergencies. A 55 person trailer camp, with medical and communications facilities, served as the logistics and accommodation base at the drill site.

The Mallik 2L-38 gas hydrate research well project was conducted under Canadian regulations for hydrocarbon exploration wells, laid out by the National Energy Board. A complete record of engineering and scientific studies is therefore available for public inspection at their offices in Calgary. A digital version of the well history report is also available on a CD-ROM as GSC Open File Report 3726 (Dallimore et al., 1999a). A summary of the basic well data is given in Table 1.

## DRILL OPERATIONS

A conventional arctic exploration drill rig, owned and operated by Shehtah Drilling Ltd., (Fig. 4) was mobilized to the Mallik site in early February, 1998. The original drilling plan for the well, based on the collection of drilling, geological, and geophysical data from the Mallik L-38 well, called for a 31 day program with extensive coring, downhole geophysical logging, and production testing. A number of planning measures were taken to avoid drilling problems. A plate-type heat exchanger was utilized to chill the drilling mud in an attempt to minimize permafrost thawing and to depress the mud temperatures lower than the in situ formation temperatures when drilling the gas hydrate intervals. Based on research conducted in Japan, a KCl/polymer drilling mud was selected to maintain cold temperature, and rheological properties. Drill-treat, a chemical mud additive, was used in the main hole to stabilize gas hydrate cuttings carried in the drilling mud and within the formation. The drilling strategy employed included rigorous monitoring of mud-gas readings and return mud, with provisions to increase the mud weight if required to control free gas accumulations. During drilling of the gas hydrate interval, the degassing return mud was monitored visually for signs of gas hydrate.

The original drilling plan and actual drilling operations are shown in Figure 5. Critical drilling parameters are shown on the well-log schematic in Figure 6. Drilling of the well began on February 16 and reached the target depth of 1150 m on March 22, 1998 (all depths were measured from kelly bushing [8.31 m above sea level]). The drilling operations were completed on March 28, after 39 days, approximately 8 days longer than the original drilling plan (*see* Fig. 5). In addition to delays at the start of the program, during mobilization and rig up, the progress of drilling through the upper permafrost

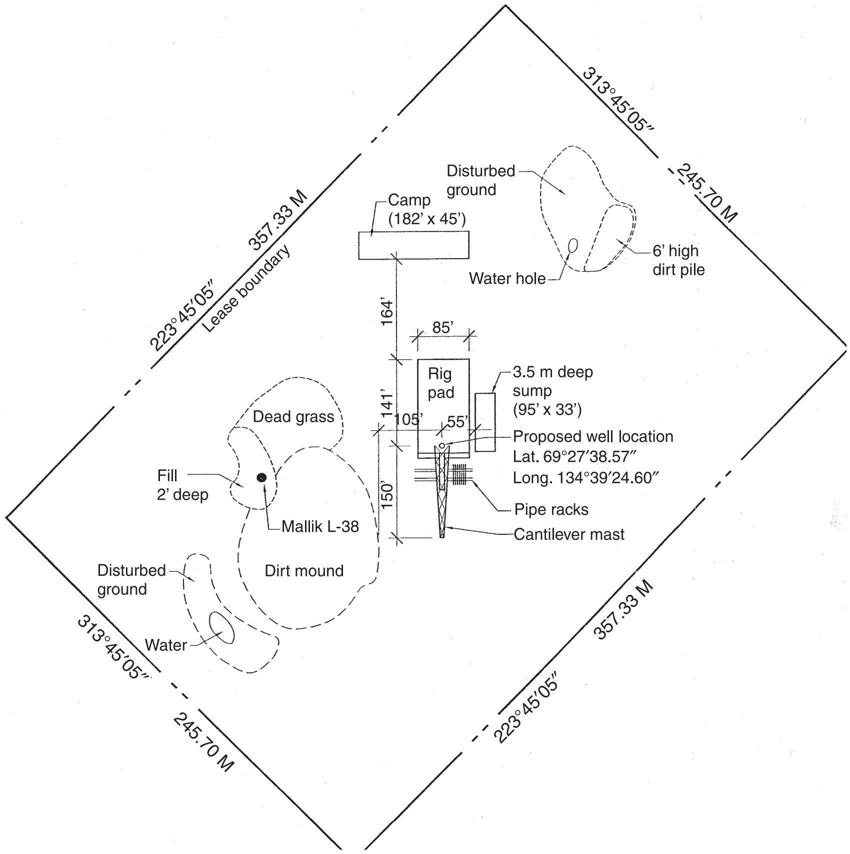


***Figure 3.*** *Survey plan showing detailed location of Mallik 2L-38 lease area and surface activities.*

**Table 1.** Well data summary.

| | |
|---|---|
| Well name: | JAPEX / JNOC / GSC MALLIK 2L-38 |
| Permitted: | JAPEX Canada Limited |
| Operator: | JAPEX Canada Limited, 2100 Hanover Bldg., 101 - 6th Ave S.W., Calgary, Alberta T2P 3P4 |
| Coordinates: | Latitude: 69°27'40.71" Longitude:134°39'30.37" |
| Location grid: | Unit L, Section 38, Area 69-30-134-30 |
| Universal well location reference: | Northing 7,705,661.19, Easting 513,374.39 |
| Exploration permit no.: | 1919 (Imperial Oil Ltd.) |
| Drilling contractor: | Shehtah Drilling |
| Drilling rig: | Rig 7E |
| Drilling authority no.: | File 9311-J31-1-1, WID 1827 |
| Classification: | Research project |
| Sea level to ground level: | +1.26 m |
| Sea level to kelly bushing: | +8.31 m |
| Total depth: | 1150 m KB |
| Objective: | Methane hydrate research well |
| Spud date: | February 16, 1998 |
| Last drilling date: | March 22, 1998 |
| Rig release date: | March 28, 1998 |
| Well status: | Plugged and abandoned |
| Participation: | JAPEX / JNOC / GSC |

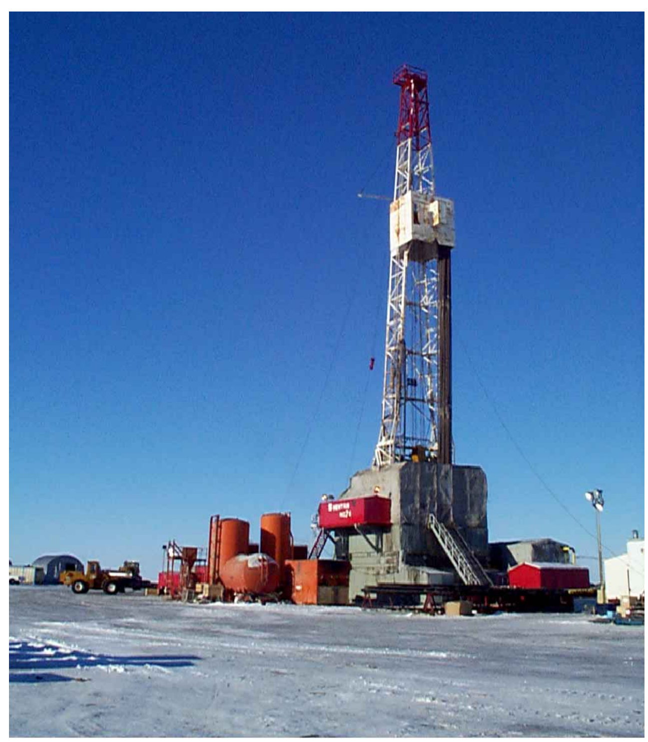

***Figure 4.*** *Photograph of Shehtah Drilling Ltd. Rig 7E at Mallik 2L-38 drill site, February 1999. Photograph by S.R. Dallimore. GSC 1999-010*

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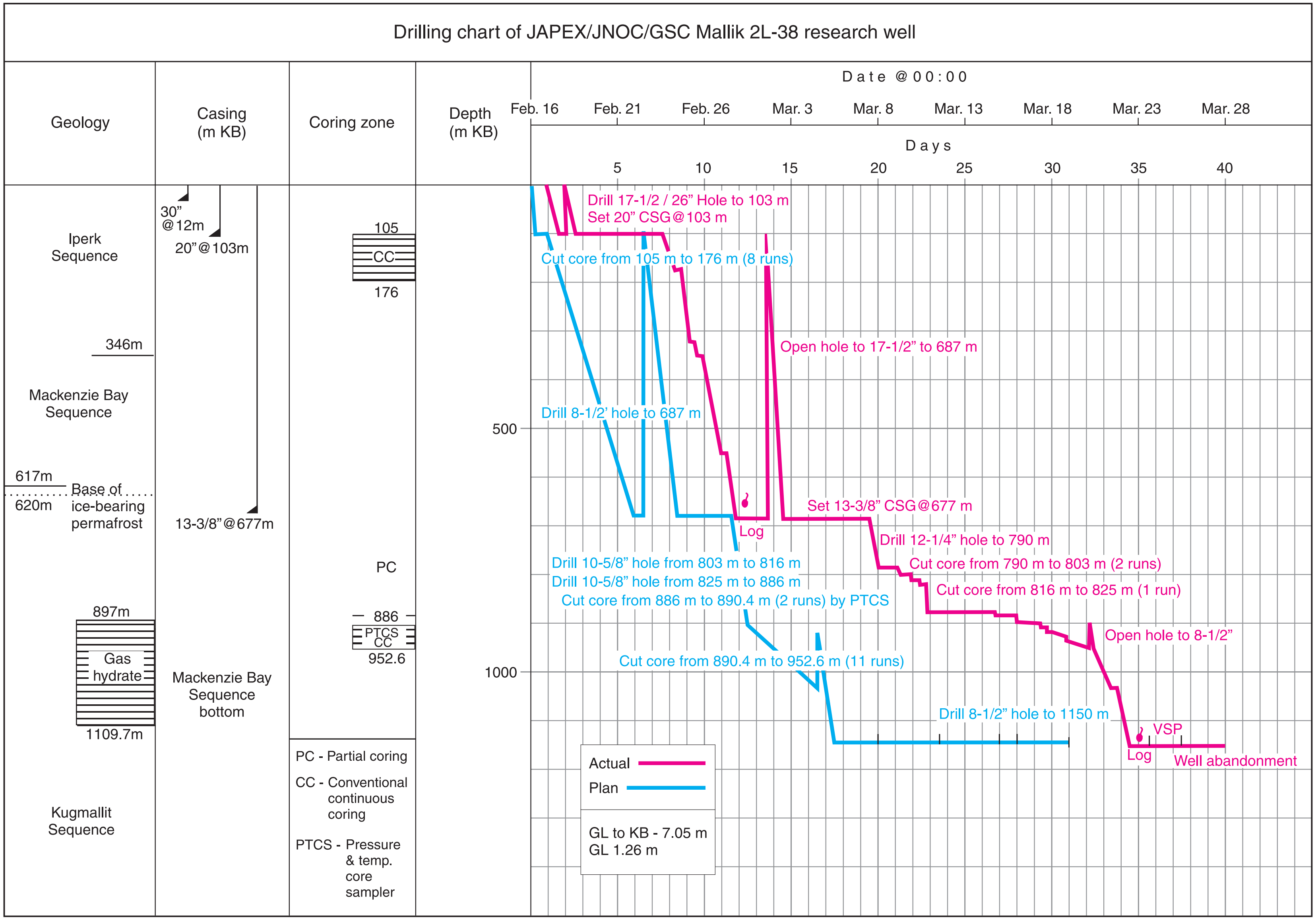


*Figure 5.* *Flow chart schematic showing planned and actual drilling operations. GL – ground level, KB – kelly bushing.*

section was very slow. As a result, running and cementing of the 219 mm (8-5/8") production casing and subsequent production test (DST), which were included in the original plan, were canceled to concentrate on gas hydrate coring objectives and geophysical studies.

The operational problems encountered during preparation and drilling operations, particularly in the early stages of the well, are listed below:

- late start due to warm weather and heavy snow on ice road, slowing ice growth

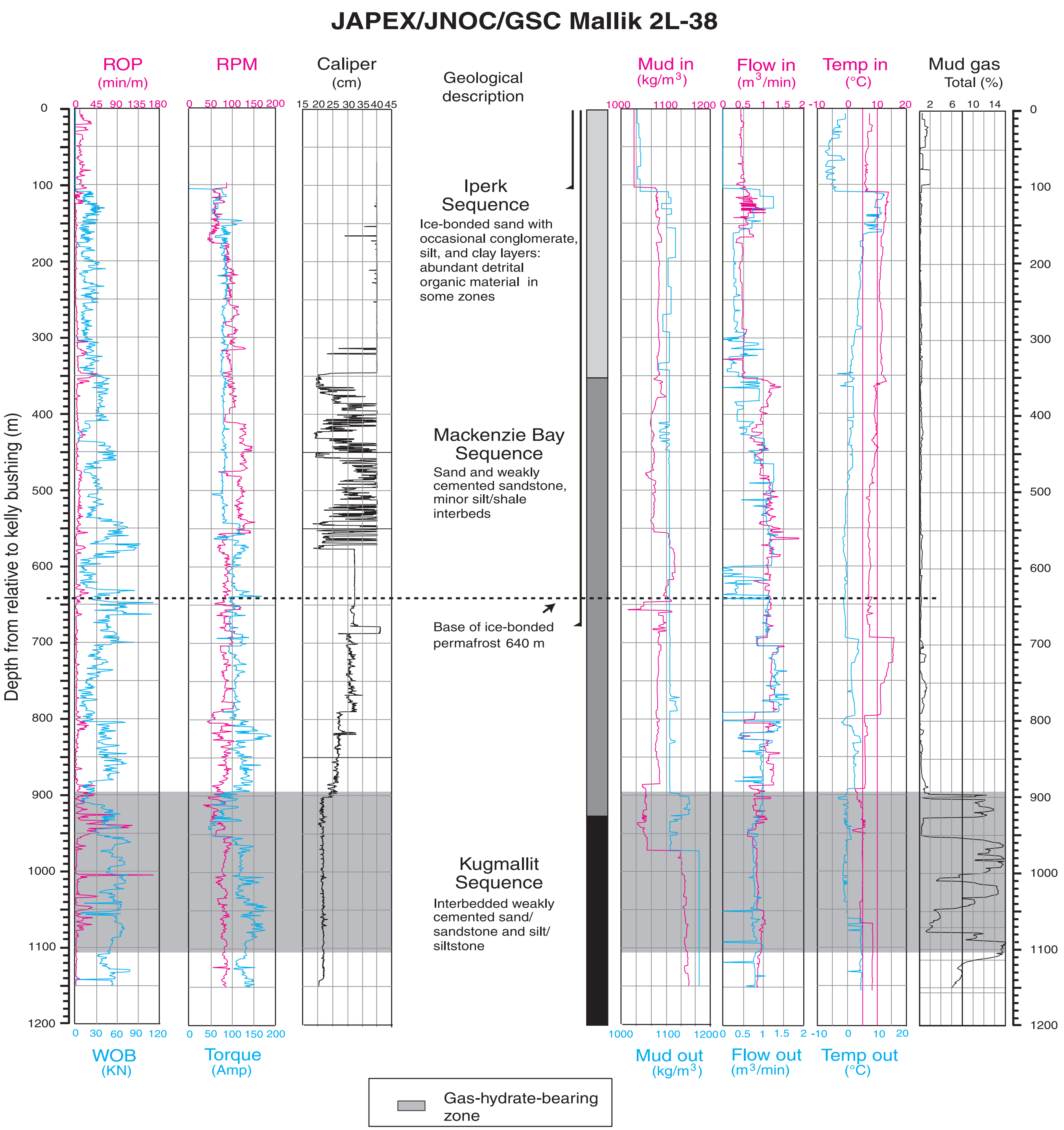


***Figure 6.** Well-log montage showing drilling parameters during drilling of Mallik 2L-38 research well. ROP – rate of penetration, RPM – revolutions per minute, WOB – weight on bit.*

- problems encountered with a crane required for rigging up, causing 3 days of delays in rigging up in a very remote location
- rig-up difficulties and slow rigging up due to crew's lack of detailed experience with the rig
- many problems with electrical systems due to an extended shut down period this rig had experienced
- drilling-mud control system not functioning properly due to system being built in early 1980s with no major upgrades, namely poor shakers, no desander, no degasser, no desilter, no jet hopper mix and poor winterization
- extended time periods required to assemble and test the blowout preventer (BOP) stack, caused by rig not having been running for an extended period and the crew's lack of familiarity with all of the hook-up assemblies. A lot of high-pressure-rated welding was also required to properly fit the BOP, manifold, and flare line system.

Details of the various components of the drilling and coring program are outlined in the following sections.

## DRILLING FLUIDS PROGRAM

A conventional KCl/polymer drilling mud was used for drilling the surface hole. Unfortunately, the mud cooler was not operating effectively during initial operations and problems with hole erosion were encountered within the permafrost interval (*see* section titled 'Coring Operations'). The main problem stopping effective cooler operation was the plugging of the mud-cooler strainer screen by unsheared polymer products and organic material (i.e. twigs, rootlets) from formation cuttings. Under normal circumstances, the mud entering the suction tank is clean; however, during drilling of the surface hole, the volume of solids and organic debris being returned to the surface in the cuttings blocked the shale shaker screens. In several instances this necessitated bypassing the screens to prevent high losses of drilling mud and maintain circulation. Additional problems were also encountered due to the mud freezing in the heat exchanger immediately after it stopped circulating. This apparently resulted because the glycol used to chill the mud became too cold (i.e. -15 to -20°C). In order to clean and reconfigure the cooler circulation lines, the cooler was shut down during most of the drilling operations for the surface hole. The net result was that mud inlet and outlet temperatures during drilling of the surface hole averaged 6 to 10°C. Subsequent caliper logging revealed considerable hole enlargement, as has been widely observed when drilling with warm drilling mud at other permafrost sites (Kutasov and Caruthers, 1988). In the Iperk Sequence (0–346 m), the hole was enlarged to over 800 mm in diameter. The more competent Mackenzie Bay Sequence sediments, beneath the Iperk Sequence, were less prone to severe hole erosion.

After running and cementing the 340 mm (13-3/8") surface casing to 677 m depth, the cement plug was drilled out and the drilling mud was displaced with new mud. In drilling the main hole, including the gas hydrate layers, a KC1/polymer/lecithin mud system was utilized. The basic composition of the mud used in the main hole intervals consisted of 50 kg/m$^3$ of KC1 (antifreeze agent and shale inhibitor), 1–3 kg/m$^3$ of Xanvis (viscosifier), 0.5 kg/m$^3$ of KOH (pH control), 6 L/m$^3$ of lecithin (62% Drilltreat; gas hydrate promoter), 10 kg/m$^3$ of Dextrid LT (filtration control), 5 kg/m$^3$ of Drispac (filtration control), 0.3 kg/m$^3$ of $Na_2SO_3$, and barite (weighting material). Prior to coring in the main hole, 6 L/m$^3$ of lecithin were added. Mixing of the Drilltreat caused some foaming to occur and required some extra time to effectively condition the mud. The mud weight was gradually increased from 1070 kg/m$^3$ to 1190 kg/m$^3$ as a precautionary measure. With improvements to the mud-cooler system, the mud temperatures during drilling of the main hole were effectively held between 1 and 3°C, while formation temperatures increased from 0°C at 670m to approximately 14°C at 1150 m.

Mud-gas readings during drilling of the gas hydrate intervals increased periodically to values from 12 to 16%, as each individual layer was penetrated, indicating that a certain amount of gas hydrate was dissociated within the mud column and creating free gas. While rare, in some instances 1–3 mm grains of white gas hydrate were visible. The rates of penetration and mud circulation were carefully controlled when mud-gas readings increased. Between coring runs circulation times were controlled to ensure that drill cuttings were brought to the surface (bottoms up). Although relatively minor, some mud-volume gain in the mud tanks was observed several times during drilling and coring of gas hydrate layers.

## CORING OPERATIONS

Twenty-four coring runs were conducted using the Baker Hughes Inteq (BHI) CoreDrill system, a specially designed pressure-temperature coring system (PTCS), and two different sizes of BHI conventional core-barrel systems. The record of coring, showing specifications of each core run, is shown in Table 2. Eight runs were conducted in the surface hole, within the permafrost interval, with 20.6% average core recovery. The remaining 16 runs were conducted in the main hole, below the permafrost, mainly in the hydrate interval with 42.1% average core recovery. Details of the coring operations for the surface hole and the main hole are discussed below.

### *Surface hole*

An attempt was made to core the upper section, from 105 m to 176 m, with the BHI CoreDrill system. This system is similar to continuous wireline coring systems used in the mining industry, with modifications for use on oil and gas drilling rigs. An unique design feature allowed replacement of the inner core barrel with a drilling bit insert to enable the system to be used in a conventional drilling mode. This avoids the necessity to raise and lower the conventional drilling assembly to advance the hole between core points.

The first two coring runs from 105–123 m recovered 50% of the cored interval. Unfortunately, the subsequent five coring runs, over the interval from 123–165 m (no. 3–no. 7),

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**Table 2.** Record of coring.

| Coring no. | Core bit | | | | | | Coring system | Depth | | Metre-range (m) | Average ROP (m/hr) | WOB (1000daN) | Rotary speed (rpm) | Flow rate (L/min) | Recovery | | Catcher type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Run no. | Size (in) | Type | Serial no. | TFA (in$^2$) | Core size (in) | | In (m) | Out (m) | | | | | | Meterage (m) | Rate (%) | |
| 1 | 3 | 8-1/2 | AUC435 | 0321943 | 0.810 | 2 | CoreDrill | 105.0 | 114.0 | 9 | 12.00 | 2 | 60 | 0.669 | 4.50 | 50 | Conventional & flapper |
| 2 | 3 | 8-1/2 | AUC435 | 0321943 | 0.810 | 2 | CoreDrill | 114.0 | 123.0 | 9 | | 2 | 65 | 0.780 | 0.00 | 50 | Conventional & flapper |
| 3 | 3 | 8-1/2 | AUC435 | 0321943 | 0.810 | 2 | CoreDrill | 123.0 | 132.0 | 9 | 20.77 | 3 | 60 | 0.930 | 0.00 | 0 | Conventional & flapper |
| 4 | 3 | 8-1/2 | AUC435 | 0321943 | 0.810 | 2 | CoreDrill | 132.0 | 141.0 | 9 | | 3 | 60 | 0.780 | 0.00 | 0 | Basket & flapper |
| 5 | 3 | 8-1/2 | AUC435 | 0321943 | 0.810 | 2 | CoreDrill | 142.0 | 151.0 | 9 | 31.76 | 3 | 60 | 0.665 | 0.00 | 0 | Conventional & flapper |
| 6 | 3 | 8-1/2 | AUC435 | 0321943 | 0.810 | 2 | CoreDrill | 151.0 | 156.0 | 5 | | 3 | 60 | 0.445 | 0.00 | 0 | Conventional & flapper |
| 7 | RR3 | 8-1/2 | AUC435 | 0321943 | 0.810 | 2 | CoreDrill | 156.0 | 165.0 | 9 | 30.00 | | 50 | 0.660 | 0.00 | 0 | Conventional & flapper |
| 8 | RR3 | 8-1/2 | AUC435 | 0321943 | 0.810 | 2 | CoreDrill | 167.0 | 176.0 | 9 | | 2 | 50 | 0.357 | 5.00 | 56 | Conventional & flapper |
| | | | | | | | | | | 68.0 | | | | | 14.00 | 20.6 | |
| 9 | RR3a | 8-1/2 | AUC435 | 0321943 | 0.810 | 2 | CoreDrill | 790.0 | 799.0 | 9 | 7.30 | 2 | 60 | 0.820 | 0.00 | 0 | Conventional &flapper |
| 10 | RR3a | 8-1/2 | AUC435 | 0321943 | 0.810 | 2 | CoreDrill | 799.0 | 803.0 | 4 | | 3 | 60 | 0.554 | 0.00 | 0 | Conventional & flapper |
| 11 | 11 | 7-7/8 | C22B | 061570 | 0.500 | 3-1/2 | Conventional | 816.0 | 825.0 | 9 | 12.00 | 5 | 65 | 0.512 | 0.00 | 0 | Conventional & flapper |
| 12 | 12 | 10-5/8 | ARC412 | 1901941 | 1.200 | 2-5/8 | PTCS | 886.0 | 889.0 | 3 | | 2 ~ 5 | 70 | 0.800 | 1.05 | 35 | Conventional |
| 13 | 12 | 10-5/8 | ARC412 | 1901941 | 1.200 | 2-5/8 | PTCS | 889.0 | 890.4 | 1.4 | | 2 ~ 4 | 70 | 0.800 | 0.10 | 7 | Conventional |
| | | | | | | | | | | 4.4 | | | | | 1.15 | 26.1 | |
| 14 | 13 | 9-7/8 | ARC412 | 0119932 | 1.000 | 5-1/4 | Conventional | 890.4 | 896.4 | 6 | 10.59 | 3 ~ 8 | 60 ~ 70 | 0.923 | 3.80 | 63 | Basket |
| 15 | RR13 | 9-7/8 | ARC412 | 0119932 | 1.000 | 5-1/4 | Conventional | 896.4 | 901.2 | 4.8 | | 2 ~ 8 | 60 ~ 75 | 0.820 | 4.30 | 90 | Basket |
| 16 | RR13a | 9-7/8 | ARC412 | 0119932 | 1.000 | 5-1/4 | Conventional | 901.2 | 902.0 | 0.8 | 0.43 | 2 ~ 8 | 50 ~ 70 | 0.820 | 0.45 | 56 | Basket |
| 17 | RR13b | 9-7/8 | ARC412 | 0119932 | 1.000 | 5-1/4 | Conventional | 902.0 | 902.6 | 0.6 | | 2 ~ 8 | 50 ~ 120 | 1.025 | 0.30 | 50 | Basket |
| | | | | | | | | | | 12.2 | | | | | 8.85 | 72.5 | |
| 18 | 14 | 7-7/8 | ARC412 | 0119610 | 0.500 | 3-1/2 | Conventional | 902.6 | 911.6 | 9 | 7.20 | 2 ~ 5 | 60 | 0.820 | 4.65 | 52 | Basket |
| 19 | RR14 | 7-7/8 | ARC412 | 0119610 | 0.500 | 3-1/2 | Conventional | 911.6 | 919.0 | 7.4 | | 2 ~ 5 | 50 ~ 80 | 1.025 | 3.30 | 45 | Basket |
| 20 | RR14a | 7-7/8 | ARC412 | 0119610 | 0.500 | 3-1/2 | Conventional | 919.0 | 925.4 | 6.4 | 6.40 | 2 ~ 5 | 60 ~ 80 | 0.820 | 3.80 | 59 | Basket |
| 21 | RR14b | 7-7/8 | ARC412 | 0119610 | 0.500 | 3-1/2 | Conventional | 925.4 | 926.7 | 1.3 | | 2 ~ 5 | 50 | 0.820 | 1.20 | 92 | Basket |
| 22 | 15 | 7-7/8 | C201 | 0601942 | 0.500 | 3-1/2 | Conventional | 926.7 | 935.7 | 9 | 3.00 | 2 ~ 5 | 60 ~ 70 | 1.025 | 2.60 | 29 | Basket |
| 23 | RR15 | 7-7/8 | C201 | 0601942 | 0.500 | 3-1/2 | Conventional | 935.7 | 943.6 | 7.9 | | 2 ~ 5 | 75 | 0.800 | 3.20 | 41 | Basket |
| 24 | RR14c | 7-7/8 | ARC412 | 0119610 | 0.500 | 3-1/2 | Conventional | 943.6 | 952.6 | 9 | 2.40 | 2 ~ 5 | 60 | 0.615 | 8.55 | 95 | Basket |
| | | | | | | | | | | 50.0 | | | | | 27.30 | 54.6 | |

TFA – total flow area, ROP – rate of penetration, WOB – weight on bit.

recovered no core. The last run, from 167–176 m (no. 8), had 56% recovery. A major factor contributing to the poor recovery overall was almost certainly the failure of the mud-cooling system described previously. Perennially frozen sands and conglomerate of the Iperk Sequence (0–346 m) that occur in this interval are uncemented, and consolidated only by the bonding of pore ice. When thawed by warm drilling mud, the sediments are extremely difficult to retain within the core barrel. Core samples retrieved in this interval were either thawed, or only marginally ice bonded, and showed considerable disturbance. Under these difficult coring conditions, the lower bearing assembly of the CoreDrill system was observed to be packed with drill cuttings. This caused the bearing to seize and allowed the inner core barrel to rotate with the outer barrel, further hampering core recovery. Below 176 m, the hole was advanced with conventional drilling to the casing point at 687 m.

### *Main hole section*

The main hole section of Mallik 2L-38 was begun after running and cementing the 340 mm (13-3/8") surface casing to 677 m depth. Strata in this section were more competent than in the surface hole, consisting of weakly lithified sandstones and siltstones of the Mackenzie Bay and Kugmallit sequences. A final attempt was made with the BHI CoreDrill system, with two coring runs, from 790–803 m (no. 9 and no. 10). No core was recovered; however, there were indications of gravel scoring on the core barrel. A decision was made to switch to 159 mm (6-1/4") BHI conventional core-barrel system (250P Series core barrel) in the hopes that the larger sample diameter would increase the chances of core recovery. Coring from 816–825 m (no. 11) again yielded no recovery; however, there was abundant evidence of the presence of loose gravel, with damage having occurred on the drill bit, core catchers, and outer barrel. It was concluded that the gravel, either occurring within the formation, or chased down from the surface hole, had rolled under the bit, preventing core collection. Mud temperatures were likely not a factor, as the mud cooler was operating efficiently and keeping mud temperatures at approximately 2°C, which was thought to be significantly colder than the formation temperatures.

The hole was advanced to 886 m and great effort was taken to clean the hole and remove any traces of gravel which might have been at the bottom of the hole. A newly developed coring system, referred to as the pressure-temperature coring system (PTCS), was attempted. The PTCS is a prototype, wireline-retrievable coring system designed to recover methane hydrate core at in situ pressure and temperature conditions. The design principles include a pressure-retaining, wireline-retrievable, inner-barrel system, and an inner tube designed to cut core samples as large as possible. The PTCS system also includes a temperature-control system and a surface transport container to transfer core samples under pressure immediately after coring. The equipment uses a 270 mm (10-5/8") core bit and the 146 mm (5-3/4") inner barrel is designed to run in 168 mm (6-5/8") custom drill pipes and 219 mm (8-5/8") drill collars. The system had only recently been fabricated and this was the first time it had been run in an actual well. The 270 mm (10-5/8") core bit and 219 mm (8-5/8") PTCS outer barrel were run on 6-5/8" drill pipes and 8-5/8" drill collars to 886 m. The inner barrel was run in the drill pipe with a Schlumberger wireline. On the first PTCS run, 3 m of core were cut, from 886–889m (no. 12), with 1.05 m recovery. On the second run, 1.4 m of core were cut from 889 m to 890.4 m (no. 13), and 0.1 m of core was recovered. The circulating-mud temperature was maintained at an average of 2°C throughout PTCS runs. On both runs the ball valve failed to close and the core recovered was not pressurized. The bit nozzles were also plugged on the second run. No methane hydrate cores were recovered.

After the second run, the PTCS system was laid down and the 203 mm (8") BHI conventional core barrel was run to cut 13.3 mm (5 ¼") diameter core with a 251 mm (9-7/8") core bit. With this system, four cores from 890.4 m to 902.6 m (no. 14–no. 17), were retrieved with 72.5% average core recovery. Although the quality of the core was excellent, extraction of the core from the barrel was difficult and much of the core was broken into 10 cm long sections. The 203 mm barrel was replaced with a 159 mm (6 ¼") BHI conventional core barrel utilizing a 200 mm (7-7/8") bit. This system collected 89 mm (3 ½") diameter core retained within a plastic liner, improving the overall quality of the core retrieved. A total of seven more cores were cut with this configuration, from 902.6–952.6 m (no. 18–no. 24), with recoveries ranging from 29–95%.

Naturally occurring gas hydrate was observed in core samples recovered from cores no. 15 through no. 20, primarily within medium-grained sands and gravelly sand. For the most part, the gas hydrate occurred within the sediment pore spaces and was not visible; however, in some instances, particles of gas hydrate up to 10 mm in diameter were observed (Uchida et al., 1999). Core samples, when retrieved at the surface, were typically ice bonded, with temperatures between -1 and -3°C. These were substantially below the formation temperatures which were thought to be between 12 and 14°C. Because of the engineering data collected during the course of the gas hydrate coring, it was possible to recreate the temperature history of the samples. Thermal modelling described by Wright et al. (1999) attributed this cooling to sensible heat transfer from the core to the cold drilling mud during transit to the surface and to cooling resulting from dissociation of gas hydrate. When the samples were stored at negative temperatures, they were found to be very stable; however, when samples were warmed or immersed in water, the gas hydrate would dissociate quickly and could be ignited. Further information on the core samples and their properties are provided in various papers in this volume.

## WELL COMPLETION

The drill rig was released from the Mallik site on March 28, 1998, after successful completion of the research well program. With the elimination of the production casing, two casing strings were left in place: a 508 mm conductor casing to 103 m, and a 340 mm surface casing to 677 m. During the cementing job, for the surface casing, severe hole enlargement in some sections resulted in a 150% increase in the cement volume requirement. The cement job was, however, considered successful. The main hole beneath the surface casing was abandoned with a 300 m cement plug at the bottom. Two additional abandonment plugs were placed from 607 m to 677 m at the bottom of the surface casing.

## DISCUSSION

Drilling operations penetrating gas hydrate layers have been successfully conducted in permafrost areas of North America and Siberia, as well as at a number of offshore sites where the exploration targets were conventional oil and gas reservoirs existing in deeper formations. For the most part, these wells collected little detailed drilling information about the gas hydrate intervals themselves or their engineering behaviour. More recently, as part of the Deep Sea Drilling Project and the Ocean Drilling Program, scientific research wells have been drilled at various offshore sites with successful retrieval of gas hydrate core samples. However, these wells employed riserless drilling and thus it was not possible to monitor certain drilling parameters. The Mallik 2L-38 well represents the first scientific investigation of a permafrost-associated gas hydrate occurrence utilizing conventional exploration drilling methods. Thus it provided an unique opportunity to evaluate drilling-mud-system technologies, drilling behaviour, and coring technologies in gas-hydrate-bearing strata.

While problems were experienced with the mud system during drilling of the surface hole for Mallik 2L-38, the drilling mud and mud cooler performed very well in the main hole. The combination of the chilled mud and the Drilltreat additive worked effectively within the gas hydrate intervals. Mud-gas levels observed during penetration of the gas hydrate layers were between 10 and 12%, which while significant, were not severe. This was despite the fact that the concentration of the gas hydrate in most intervals was over 60% of the pore space volume (*see* Miyairi et al., 1999). Visible evidence of gas hydrate observed in the mud returns at the surface also confirmed that the drilling mud worked to retard dissociation of gas hydrate present in the drill cuttings. Overall, the drilling and coring also seem to have caused relatively little disturbance of the gas-hydrate-bearing formation. Caliper logs and other geophysical logs revealed a gauge hole with very minor side-wall disruptions. The Formation Micro Imager log, for instance, allowed the discrimination of detailed fractures and faults as well as gas-hydrate-saturated intervals (see Collett et al., 1999). In keeping with these observations there was almost no sloughing of wall material observed in the hole, and the geophysical logs were able to be run to bottom confirming very efficient hole cleaning.

As outlined previously, coring success in the surface hole was limited by problems with the mud system and gravel in the hole. However, our impression is that the BHI CoreDrill system is only marginally effective for coring soft and/or unconsolidated formations. In part, the problems were due to difficulties with the bottom bearing which became clogged with drill cuttings on several core runs. Valuable operational experience was gained with the previously untried PTCS coring system. Based on a number of mechanical and operational problems, the PTCS system will undergo an extensive review within the Japanese research and development program. Areas for further design modifications are expected to include design dimensional tolerances, mud-port clearances, latch-mechanism operation, and ball-valve actuation mechanics. As the PTCS system is mainly for coring partially consolidated to consolidated formations, the test on Mallik 2L-38 suggests that the current design of the PTCS would also be unlikely to be effective in very soft formations. The BHI conventional coring system did recover hydrate cores at Mallik 2L-38 in unconsolidated sediments where both wireline systems failed. The main differences between the conventional system and the CoreDrill system, other than the wireline retrieval capabilities, are the core size, bearing configuration, and core catchers used. The conventional barrel cut a larger diameter core and has no bottom bearing, the fluid ports were larger than the CoreDrill or the PTCS, and a basket core catcher was used. All of these factors are believed to have contributed to success in recovering core samples.

## CONCLUSIONS

The drilling operations for the Mallik 2L-38 well were completed without any serious hole problems, accidents, or mishaps. In this regard, management and logistics arrangements were successful in efficiently directing operations and the development of tools and procedures for remote operations with minimum lost time due to waiting on orders of equipment and supplies. Most problems, including those with the mud cooler, were attributed to either weather, or mechanical problems that were particularly evident because the drill rig had not been used for some years. Certainly as the well progressed, operations proceeded more smoothly.

With the exception of the production casing and testing, which was cancelled due to time and budget constraints, the main research and development objectives of the well were achieved. Overall, the drilling mud system, including the plate-type heat exchanger for chilling the drilling mud and the KCl/polymer/Drilltreat mud, performed well. The mud had good cold-temperature rheology and filtration properties which effectively retarded decomposition of gas hydrate in drill cuttings, core samples, and within the formation. Considerable experience was gained with four different coring systems. The BHI CoreDrill system was only marginally effective for coring soft and/or unconsolidated formations. The prototype PTCS system, designed by the Japanese research and development consortium, also was found to be marginally effective and was not successful in retrieving samples under in situ pressure and temperature conditions. Based on these trials numerous design changes will be implemented. Conventional coring with BHI 203 mm (8") and 159 mm (6-1/4") core barrels proved to be most effective with retrieval of all of the gas hydrate core samples with these systems.

The experiences gained in the Mallik 2L-38 gas hydrate research well project will be applied in the various phases of planning, drilling operations, and postoperation scientific studies for the 1999 exploration well planned for offshore Japan.

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