Methane Hydrate Production from Alaskan Permafrost

Technical Progress Report

October 1, 2004 to December 31, 2004

by

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February 2005

DE-FC26-01NT41331

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Disclaimer

Abstract

Natural-gas hydrates have been encountered beneath the permafrost and considered a nuisance by the oil and gas industry for years. Engineers working in Russia, Canada and the USA have documented numerous drilling problems, including kicks and uncontrolled gas releases, in arctic regions. Information has been generated in laboratory studies pertaining to the extent, volume, chemistry and phase behavior of gas hydrates. Scientists studying hydrate potential agree that the potential is great – on the North Slope of Alaska alone, it has been estimated at 590 TCF. However, little information has been obtained on physical samples taken from actual rock containing hydrates.

This gas-hydrate project is a cost-shared partnership between Maurer Technology, Anadarko Petroleum, Noble Corporation, and the U.S. Department of Energy's Methane Hydrate R&D program. The purpose of the project is to build on previous and ongoing R&D in the area of onshore hydrate deposition to help identify, quantify and predict production potential for hydrates located on the North Slope of Alaska.

As part of the project work scope, team members drilled and cored a well (the Hot Ice No. 1) on Anadarko leases beginning in January 2003 and completed in March 2004. Due to scheduling constraints imposed by the Arctic drilling season, operations at the site were suspended between April 21, 2003 and January 30, 2004. An on-site core analysis laboratory was constructed and used for determining physical characteristics of frozen core immediately after it was retrieved from the well. The well was drilled from a new and innovative Anadarko Arctic Platform that has a greatly reduced footprint and environmental impact. Final efforts of the project were to correlate geology, geophysics, logs, and drilling and production data and provide this information to scientists for future hydrate operations.

No gas hydrates were encountered in this well; however, a wealth of information was generated and is contained in the project reports. Documenting the results of this effort are key to extracting lessons learned and maximizing the industry's benefits for future hydrate exploitation. In addition to the Final Report (now being completed), several companion Topical Reports are being published.

Alaskan Hydrate Project Topical Reports

1. "Hydrate Core Drilling Tests"
2. "Drilling and Coring Operations"
3. "Logging Operations"
4. "Core and Fluid Analysis"
5. "3D Vertical Seismic Profile Survey"
6. "Hydrate Reservoir Characterization and Modeling"

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1. Introduction

The purpose of this project is to plan, design and implement a program that will safely and economically drill/core and produce natural gas from arctic hydrates. This project documents planning, operations and lessons learned to assist in future hydrate research and field operations to make an objective technical and economic assessment of this promising natural gas reservoir potential.

On February 7, 2004 the well reached the planned depth of 2300 ft, about 300 ft below the zone where temperature and pressure conditions would theoretically permit hydrates to exist. Although significant gas shows were encountered in highly porous sandstones, no methane hydrates were found. The continuous coring rig used in the project proved to be a safe and efficient drilling system, with 93% of the core recovered.

This project used a special purpose on-site laboratory to help analyze hydrate cores. Live data and images were transmitted from the rig over the internet, which reduced the number of engineers and scientists required to oversee the project. Additionally, the well was drilled from a special purpose-built arctic platform. A massive 3D VSP seismic survey was also conducted to investigate lateral variations of the potential hydrate reservoir.

2. Executive Summary

Objectives and Scope of Work

The objectives of this project were to analyze existing geological and geophysical data and obtain new field data required to predict occurrences of gas hydrates; to test the best methods and tools for drilling and recovering hydrates; and to plan, design, and implement a program to safely and economically drill and produce gas from hydrates in Alaska.

The overall Scope of Work was to:

1. Evaluate geological and geophysical data that aid in delineation of hydrate prospects
2. Evaluate existing best technology to drill, complete and produce gas hydrates
3. Develop a plan to drill, core, test and instrument hydrate wells in Northern Alaska
4. Characterize the resource through geophysics, logging, engineering and geological core and fluids analysis
5. Test and monitor gas production from hydrate wells for one year
6. Quantify models/simulators with data for estimating ultimate recovery potential
7. Learn how to identify favorable stratigraphic intervals that enhance methane production
8. Assess commercial viability of developing this resource and develop a long-term production plan
9. Provide real hydrate core samples for laboratory testing
10. Develop and test physical and chemical methods to stabilize hydrate wellbores and improve core recovery
11. Step outside the well-known Prudhoe Bay/Kuparuk River area to further delineate hydrate deposits in Alaska
12. Report results to the DOE and transfer technology and lessons learned to the Industry

Phase II Participants:

Maurer Technology Inc. – Performed project coordination, project management and testing of coring tools and techniques at the Drilling Research Center. Prime Contractor with the DOE.

Anadarko Petroleum Corporation – Served as project manager for the design, construction, and operation of the Arctic Drilling Platform, mobile core laboratory, and field coring operations. Secured well location and permitting.

Noble Engineering and Development – Provided personnel and real-time data collection and transmitted digital data and video to project participants located offsite and wellsite drilling personnel.

University of Alaska (Anchorage) – Provided support studies on geology, tundra, and disposal of produced water.

University of Oklahoma – Assisted with testing the core system and in development of purpose-built mobile core laboratory.

Lawrence Berkley National Laboratory (LBNL) – Performed reservoir modeling used for well test planning and onsite portable X-ray scanner with wellsite operator.

Sandia National Laboratories – Provided downhole mud pressure and temperature recording tool.

Pacific Northwest National Laboratory (PNL) – Provided portable infrared scanner.

United States Geological Survey (USGS) – Provided synthetic core for drilling tests, phase behavior model for hydrates, pressure vessels for hydrate core storage and technical advice. Modeled hydrate preservation and dissociation. Provided personnel for coal core and analysis.

Schlumberger Oilfield Services – Provided CMR equipment used in mobile core laboratory and two onsite analysts; and well-logging services.

Paulsson Geophysical Services – Performed vertical seismic profiling.

Advisory Board – Craig Woolard (University of Alaska, Anchorage); Steve Bartz (Schlumberger); Steve Kirby (USGS); Tim Collette (USGS); Theresa Imm (Arctic Slope Regional Commission); C. Sondergeld (University of Oklahoma); Richard Miller (University of Kansas); and David Young (Baker Hughes INTEQ)

Previous Accomplishments:

- Design and construction of Anadarko's Mobile Core Laboratory completed in August 2002. This highly capable laboratory permits cores to be maintained and analyzed at a reduced temperature and in close proximity to the drill site.

- Operational and logistics planning, geology and geophysics analysis, and site selection completed and environmental and operations permits obtained by the end of December 2002.

- Anadarko's Arctic Platform was installed on site in February 2003. Technology tested here could help achieve three goals independent of this project:
    - allow operators to work outside present operations season on the North Slope
    - provide access to remote areas where water to build ice roads is scarce and steep grades make it difficult to set or supply a drilling rig
    - reduce environmental impact of a well location on the tundra

- Arctic Platform topside facilities were set during March 2003.

- Hot Ice No. 1 Well was spudded on March 31, 2003.

- Well cored, logged and cased to the base of the permafrost during April 2003.

- The Arctic Platform fully met expectations for very low environmental impact as it remained in place through a summer season, and was successfully removed with no adverse impact to the surrounding site.

- Drilling operations resumed on January 30, 2004.

- Well successfully reactivated and cored to 2300 ft with 93% core recovery.

- Well was logged and a massive vertical seismic profile (VSP) survey conducted.

- Geological models were calibrated.

- Phase I Final Report and a Topical Report were completed to document the effort and transfer knowledge to the industry.

The Hot Ice No. 1 well is located approximately 20 miles south of the Kuparuk River oil field center and about 40 miles southwest of Prudhoe Bay. Based on evidence from nearby offsets in the Cirque and Tarn gas-hydrate accumulations, hydrates were expected to be found in sands near the base of the permafrost. The well was spudded on March 31, 2003, and was continuously cored from a depth of 107 feet to 2300 feet (RKB) with core recovery of 93%. The base of the permafrost was crossed at about 1250 ft.

Figure 1. Arctic Platform during Summer

Recent Activities:

Operations on the Hot Ice No. 1 well were suspended after the first drilling season on April 21, 2003 due to the end of the arctic drilling season (**Figure 1**). Drilling operations were resumed on January 30, 2004 at the opening of the conventional operations season. An ice road was constructed from an existing road to the west of the well location (**Figure 2**).

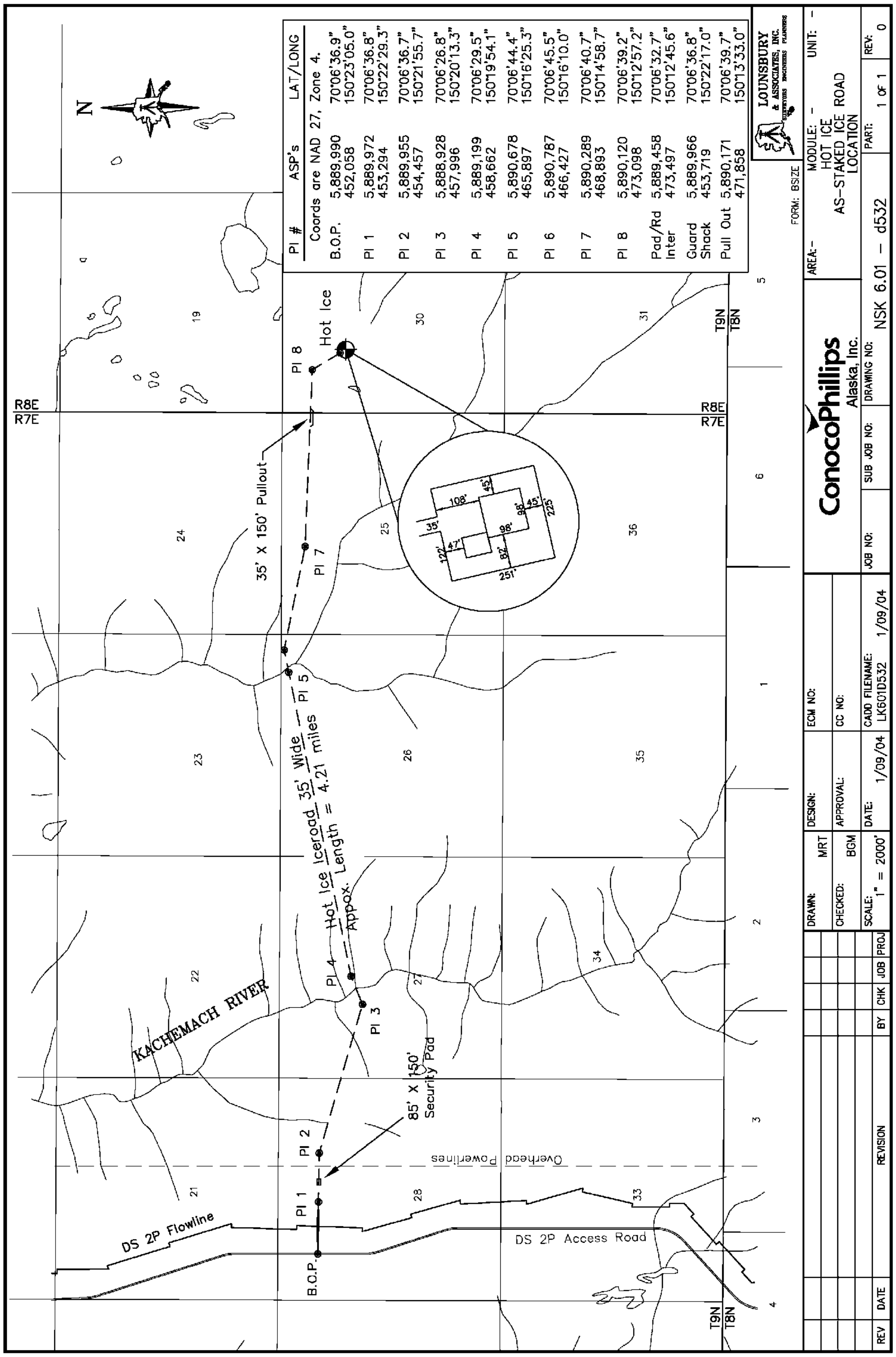

Figure 2. Map of Ice Road to Site

The Hot Ice No. 1 well was cored with a wireline-retrievable coring system using drilling mud that had been chilled to 23°F (-5°C) to preserve the 3.3-inch (8.5-cm) core and to prevent any hydrate from dissociating during core recovery. The mobile core laboratory was employed to immediately perform measurements on both whole core and 1-inch plugs taken from the whole core, while maintaining that temperature. Whole core measurements included: core gamma log, infrared temperature, velocity measurement, geologic description and white light photographs, high-resolution CT scan (using equipment from LBNL), and a nuclear magnetic resonance measurement (Schlumberger CMR tool) on a portion of each section of core. Plug measurements included: bulk volume, grain density, helium porosity and permeability at confining stress, P and S wave velocity, resistivity, and thermal conductivity. For hydrate samples, the NMR system (Schlumberger CMR tool) would have been used to determine the fluid volume in the sample at various steps in the dissociation process, while released gas volumes and composition are also recorded.

After the well was suspended after the first season due to unseasonably warm conditions that prevented transport of heavy loads over the tundra, the mobile core laboratory and collected core were moved to Deadhorse, Alaska, where core analysis was continued. The laboratory was then shipped to Tulsa, Oklahoma where repairs and upgrades were made by the University of Oklahoma. The laboratory was shipped back to the location in January 2004. After the well was completed and equipment demobilized, the core was provided to the University of Alaska and the mobile laboratory was sent to the University of Oklahoma, where it is now available for other research projects.

As mentioned, drilling operations were resumed during January 2004, and the well was successfully cored to 2300 ft with 93% core recovery on February 7, 2004. The well was then logged and a massive VSP survey conducted. Casing was set directly above the West Sak formation. Gas-bearing sands were encountered in highly porous sandstones that were situated within the hydrate stability zone. The sands were areally extensive and stratigraphically equivalent to sand units in offset wells. Total depth was reached at 2300 ft, which was approximately 300 ft below the gas-hydrate stability zone. A localized temperature model was developed for predicting the base of the hydrate stability zone. This model was verified by the well results and used to determine the TD of the well. The well was logged, VSP was run and, because no hydrates were encountered, the planned completion and testing programs (see **Appendix B and C**) were not implemented.

A complete set of core, well log, production and downhole pressure and temperature data has been provided for use in evaluating the hydrate reservoir's quality and to determine potential for production from arctic hydrate intervals. These data are now available for incorporating into hydrate reservoir models to test possible scenarios for producing methane from hydrates in similar settings.

Drilling operations at the Hot Ice No. 1 well marked the first test of Anadarko's Arctic Platform. The primary platform consists of 16 lightweight aluminum modules fitted together and mounted on steel legs 12 ft above ground. The platform is large enough to contain a coring rig, auxiliary equipment, mud tanks, and the mobile core analysis laboratory. Another five modules form an adjacent platform with living quarters for up to 40 people. An IADC/SPE paper (Kadaster and Millheim, 2004) was presented to the industry on March 2, 2004 by Ali Kadaster of Anadarko.

Several companion **Topical Reports** were compiled for detailed documentation of project activities in various areas. These include:

1. "Hydrate Core Drilling Tests"

2. "Drilling and Coring Operations"

3. “Logging Operations”
4. “Core and Fluid Analysis”
5. “3D Vertical Seismic Profile Survey”
6. “Hydrate Reservoir Characterization and Modeling”

Information on operations, geology, and geophysics was presented to the industry at the AAPG Hedberg Research Conference, “Natural Gas Hydrates: Energy Resource Potential and Associated Geologic Hazards,” on September 12-16, 2004 in Vancouver, BC, Canada. These presentations are:

1. “Integration of VSP Seismic Data with Core and Well Log Data to Investigate Lateral Variations of Potential Hydrate-Bearing Sands, Alaska North Slope,” by Donn McGuire, Steve Runyon, Tom Williams, and Richard Sigal.
2. “Characterization of Potential Hydrate Bearing Reservoirs in the Ugnu and West Sak Formations of Alaska’s North Slope,” by Richard Sigal, C. Rai, Carl H. Sondergeld, William J. Ebanks, William D. Zogg, and Robert L. Kleinberg.
3. “HOT ICE Well No. 1 – Well Planning, Operations and Results of the First Dedicated Gas Hydrate Well in the Alaskan Arctic,” by Tom Williams, Bill Liddell, Ali Kadaster, and Tom Thompson.

The project Final Report is now being completed for submission to DOE.

3. Experimental

3.1 Background

Natural-gas hydrates (**Figure 3**) beneath the permafrost have been encountered by the oil and gas industry for years. Numerous drilling problems, including gas kicks and uncontrolled gas releases, have been well documented in the arctic regions by Russian, USA and Canadian engineers. There has been a significant volume of scientific information generated in laboratory studies over the past decade as to the extent, volume, chemistry and phase behavior of gas hydrates. However, virtually all of this information was obtained on hydrate samples created in the laboratory, not samples from the field.

Figure 3.
Methane Hydrate

Discovery of large accumulations around the world (**Figure 4**) has confirmed that gas hydrates may represent a significant energy source. Publications (Makogon and others) on the Messoyakhi gas-hydrate production in Siberia (which has produced since 1965), clearly document that the potential for gas-hydrate production exists. Several studies have also addressed the potential for gas hydrates in the permafrost regions of North America. Results from the Mallik Hydrate, Mackenzie Delta Northwest Territories, Canada wells drilled by JAPEX, JNOC and GSC, provide a significant amount of useful background information. The USGS made sizeable contributions to the Mallik project, as well as many other investigations on gas hydrates in the USA (especially Alaska), and has much information on the presence and behavior of hydrates.

This knowledge is being applied around the world for environmentally sound development of this resource. The present project work represents the first attempt to drill, core and monitor hydrate wells in the USA. Specific objectives of this effort were to obtain field data required to verify geological, geophysical and geochemical models of hydrates and to plan, design and implement a program to safely and economically drill and produce gas from arctic hydrates.

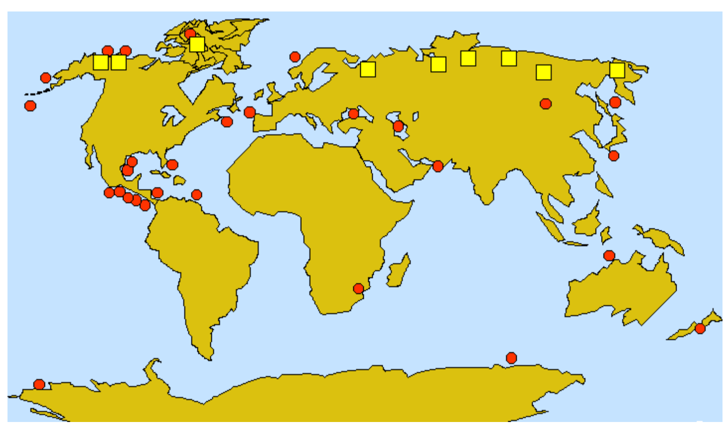

Figure 4. Methane Hydrate Deposits (USGS)

North America's emphasis on utilizing clean-burning natural gas for power generation has increased demand for gas and resulted in higher gas prices. A number of forecasts, including the NPC Study on Natural Gas (2000), indicate higher demand with prices in the range of \$4 to \$8/mcf. This is sufficiently high to allow investments in sources previously deemed uneconomic. The projected US demand for natural gas may grow to nearly 30 TCF by the end of the decade. This demand, particularly on the West Coast of the US, strongly suggests that a proposed Alaska Natural Gas Pipeline may now be economically feasible. This pending pipeline should provide a commercial market for natural gas, thereby allowing necessary investments in new technology to develop and market the hydrate resource.

Team member Anadarko Petroleum is one of the largest independent oil and gas exploration and production companies in the world, with proved reserves of 7.7 TCF of gas and 1.2 BBO of crude oil, condensate and NGL's (approximately 2.5 BBOE). Domestically, it has operations in Texas, Louisiana, the Mid-Continent and Rocky Mountains, Alaska and the Gulf of Mexico. Anadarko is also one of the most active drillers in North America, and is balancing its current exploration and production programs by investing in developing new gas resources in North America, including areas where the risks and potential rewards are high with the application of advanced technology. It is now one of the largest leaseholders in Alaska, with an ongoing program of exploratory drilling and seismic studies. Anadarko's Alaska holdings number about 2 million net acres; some of which may hold potential for commercial production from hydrates. Anadarko also has extensive holdings in the Mackenzie Delta region of the Northwest Territories of Canada, which also may have potential for hydrates. Thus, Anadarko is very interested in seeing this resource become commercially viable.

With the amount of information on hydrates now available and the potential of developing this huge resource, this project was clearly scientifically and economically viable at this time. The best resources and ideas from around the world were used to implement the technology in the field. Thorough planning of the project hydrate well allowed avoiding some of the problems encountered in previous gas-hydrate drilling projects.

This project has provided valuable information to the DOE, industry, and research community to identify key barriers and problems related to gas-hydrate exploration and production. This information will be useful in developing innovative, cost-effective methods to overcome these barriers. An Advisory Board was formed for planning well operations. It included Teresa Imm (Arctic Slope Regional Corp.), Craig Woolard (University of Alaska Anchorage), Steve Kirby (USGS), Steve Bartz (Schlumberger), Timothy Colette (USGS), David Young (Baker Hughes INTEQ), Rick Miller (Kansas Geological Survey) and Carl Sondergeld (University of Oklahoma).

3.2 Objectives

Objectives of this gas-hydrate project were to:

1. Analyze existing geological and geophysical data and obtain new field data required to predict hydrate occurrences
2. Test the best methods and tools for drilling and recovering hydrates
3. Plan, design, and implement a program to safely and economically drill and produce gas from hydrates

3.3 Scope of Work

The overall scope of the work for this project was to:

1. Evaluate geological and geophysical data that aid in delineation of hydrate prospects
2. Evaluate existing best technology to drill, complete and produce gas hydrates
3. Develop a plan to drill, core, test and instrument a gas-hydrate well in Northern Alaska
4. Characterize the resource through geophysics, logging, engineering and geological core and fluids analysis
5. Test and then monitor gas production from the hydrate wells for an extended period of time
6. Quantify models/simulators with data for estimating ultimate recovery potential
7. Learn how to identify favorable stratigraphic intervals that enhance methane production
8. Assess commercial viability of developing this resource and ultimately develop a long-term production plan
9. Provide real hydrate core samples for laboratory testing
10. Develop and test physical and chemical methods to stabilize hydrate wellbores and improve core recovery
11. Step outside the well-known Prudhoe Bay/Kuparuk River area to further delineate hydrate deposits in Alaska
12. Report results to the DOE and transfer technology to the Industry

4. Results and Discussion

4.1 Deliverables

During **Phase I**, an effective plan was developed for drilling new hydrate wells in Alaska. This included geological and geophysical assessment, site selection, and developing well plans.

In separate reports, the project team provided DOE with the following Phase I Deliverables:

- Digital map of well locations
- Well log correlation sections
- Seismic maps and sections showing stratigraphic and lithologic units within gas hydrate stability zone
- Reservoir modeling report
- Well data for control wells used for site selection
- Site selection plan
- Testing and analytical procedures (Topical Report)
- Well plan
- Permit application
- NEPA requirements

Additional Phase I achievements beyond the original contract obligations were also delivered. These include:

- Topical reports from University of Oklahoma and the Drilling Research Center on hydrate core apparatus and testing (see Topical Report – “Hydrate Core Drilling Tests”)
- Support of other DOE hydrate projects including the Westport Core Handling Manual
- Three reports from the University of Alaska Anchorage:
    1. Geological Research of Well Records
    2. Fundamental and Applied Research on Water Generated during Production of Gas Hydrates
    3. Permafrost Foundations and Their Suitability as Tundra Platform Legs (see Topical Report – “Drilling and Coring Operations”)
- USGS report on dissociation of hydrates at elevated pressures (see Topical Report – “Core and Fluid Analysis”)
- LBNL report on hydrate preservation in cores (see Topical Report – “Core and Fluid Analysis”)
- Arctic platform video
- National Press Release and Conference in Washington, DC

- First-ever North Slope coal cores provided to the USGS for coalbed methane study (see Topical Report – “Core and Fluid Analysis”)
- New equipment for measuring hydrates

Phase II achievements encompassed drilling/coring a new hydrate well.

- The well was cored to 2300 ft with 93% of core recovered successfully.
- A geologic model was developed and quantified to predict the potential hydrate-bearing strata.
- A continuous coring rig proved to be a safe and efficient drilling system.
- The ability to characterize whole core on site was demonstrated using a mobile core laboratory. Tools developed for making hydrate-specific measurements were tested on gas-bearing sands and permafrost.
- Petrophysical measurements were quickly performed on site.
- A state-of-the-sate CT scanner from Lawrence Berkley was used to analyze whole cores on site.
- The USGS collected and analyzed coal cores in real time.
- A massive 3D VSP was designed and conducted. The data were processed and are presented in the Topical Report – “3D Vertical Seismic Profile Survey.”
- Viability of the concept of extending the drilling season on the North Slope of Alaska by using a low impact platform was demonstrated.
- Live data feed from the North Slope to Houston and other areas was demonstrated during the project.

Specific **Phase II Deliverables** (as listed in the Statement of Work) include:

1. Drilling and Coring Operations (Topical Report) (Task 9.2)
2. Logging Operations (Topical Report) (Task 10.0)
3. Core and Fluid Analysis (Topical Report) (Task 11.0)
4. 3D Vertical Seismic Profile Survey (Topical Report) (Task 12.0)
5. Proposed Well Completion Report (**Appendix B**) (Task 13.0)
6. Proposed Well Testing Report (**Appendix C**) (Task 15.0)
7. Hydrate Reservoir Characterization and Modeling (Topical Report) (Tasks 17, 18, &19)
8. Economic Projections and a Production Options Report (see Section 4.3) (Task 20.0)
9. Plan for Future Hydrate Well on the North Slope (see Section 4.3) (Task 21.0)
10. Technical Publications Summarizing Project Findings (see Section 6) (All Tasks)

11. Final Report Summarizing Project Findings (All Tasks)

4.2 Team Organization

Team organization is shown in **Figure 5**.

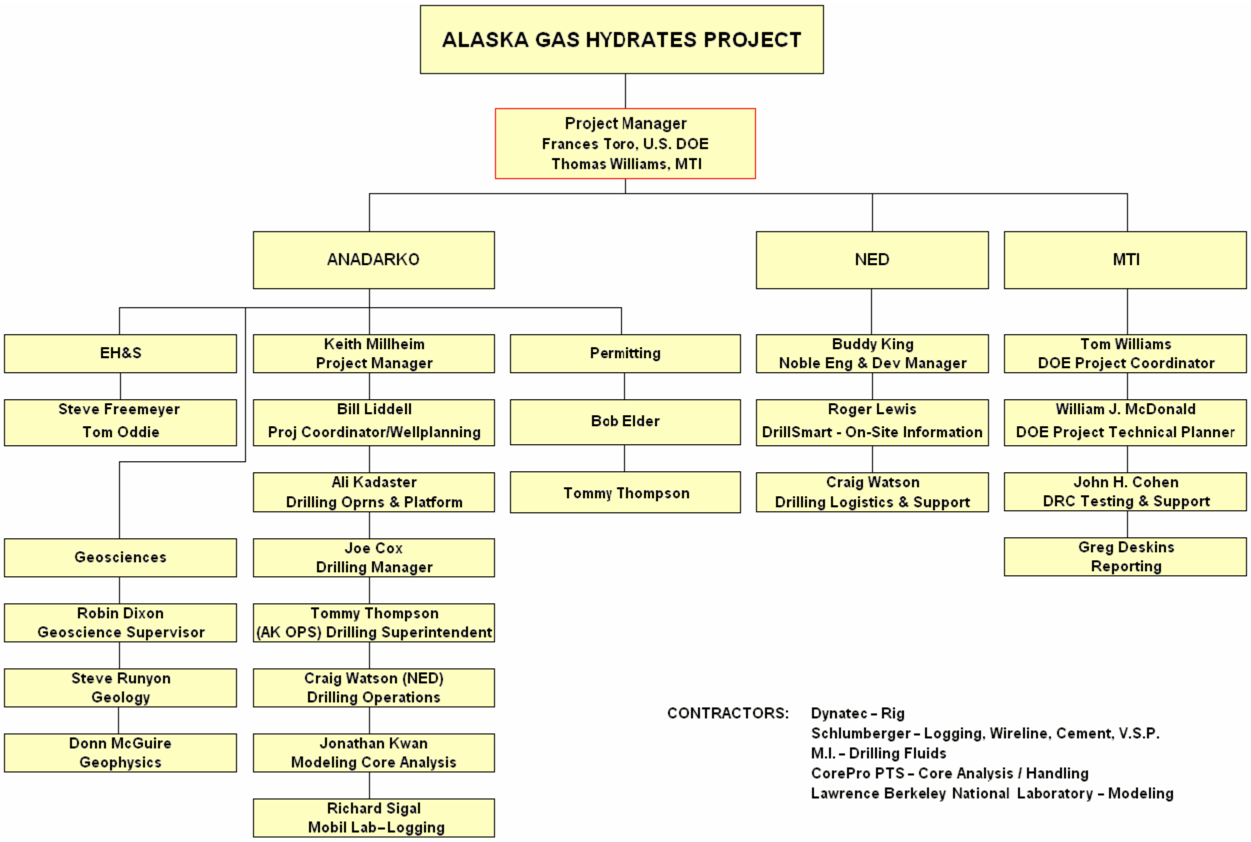

Figure 5. Project Team Structure

4.3 Accomplishments

PHASE I

Phase I (Tasks 1-7) was completed.

Phase I Task Activities that Continued into Phase II

A "lessons learned" workshop was held at Anadarko's office in the Woodlands on June 12-17, 2003. Each activity and task were reviewed and a budget revision was completed. Cost of the unanticipated demobilization and stand-by fees significantly increased the cost of the project.

Subtask 4.2 – Permitting

Permitting was completed; however, revisions for re-mobilization prior to the normal drilling season (due to freezing of the permafrost) were required. The platform did not move due to thawing during the summer of 2003. Three wells were initially permitted, named Hot Ice No. 1, 2 and 3 (HOT ICE = High Output Technology Innovatively Chasing Energy). Following the Anadarko Geological and Geophysical assessment and the Site Selection task, the best location was selected in November and final permitting activity focused on the location for Hot Ice #1. With the addition of the Arctic Platform, new permitting activities and costs have been required. Meetings with and inspections by State and Federal regulators continued. Results included a number of positive reports complimentary of the operation.

The permit application was provided to the DOE.

A map showing the location of the site is presented in **Figure 6**.

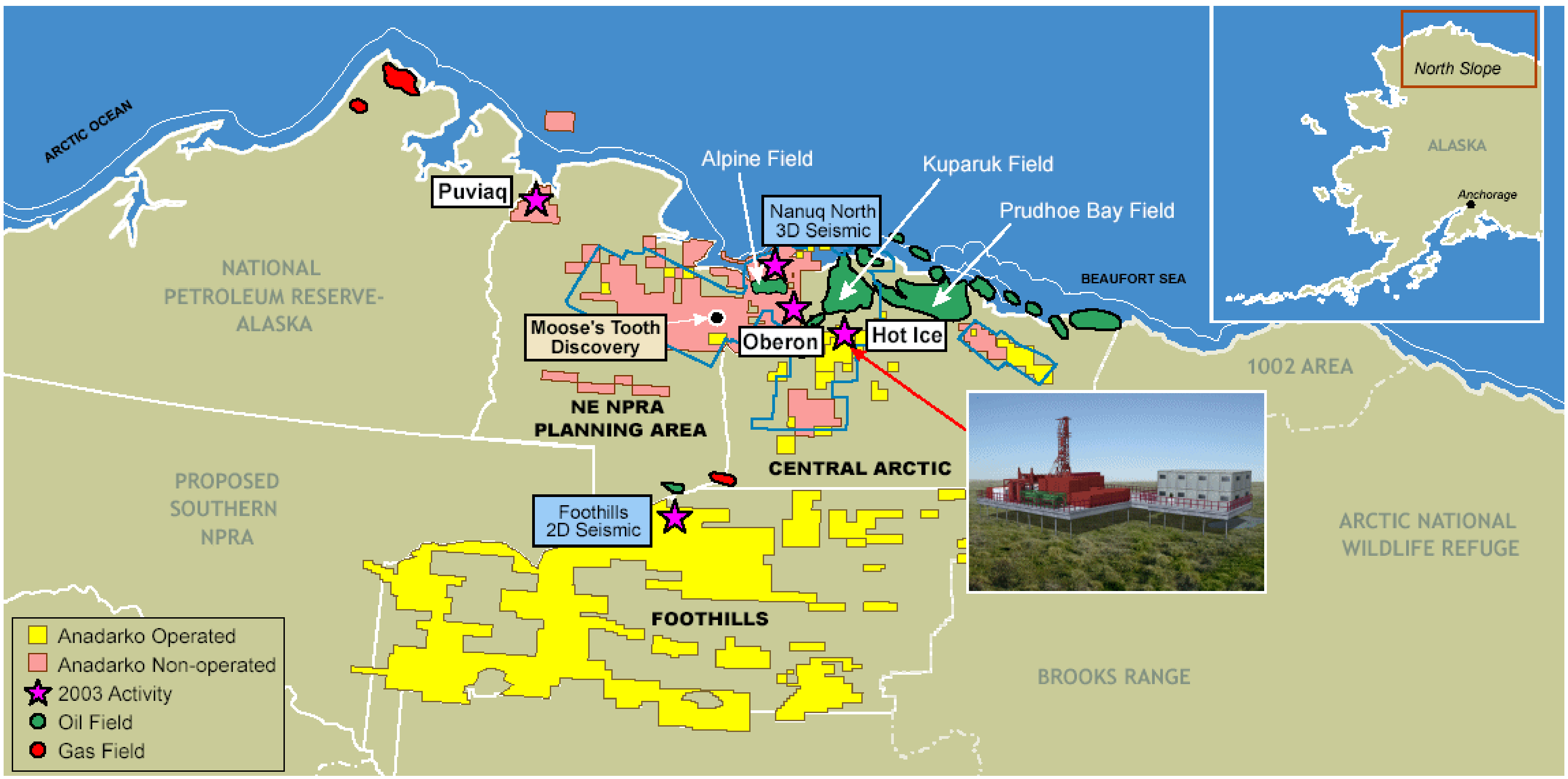

Figure 6. Map of North Slope Showing Location of Hot Ice No. 1

Task 7.0 – Posting Data on Existing Web Sites

Maurer Technology constructed an Internet web site for hydrate project updates:

http://www.maurertechnology.com/Engr/RDprojects/HydratesHome.asp

It is also linked to the NETL hydrate web site and displayed presentations, progress highlights and photos. This site was updated regularly during the project to make results available to the R&D community. Information about our project is being exchanged with other hydrate research organizations and meetings. Press releases were issued, and the energy press contacted Maurer and Anadarko for progress updates and information about the project. A number articles and papers have appeared in Pe*troleum New Alaska, Hart's E&P, World Oil, IADC/SPE* and others. These articles and publications are listed in the project bibliography in Section 6.

PHASE II

Phase II is complete including Tasks 8-22. The overall objective of Phase II was to test exploitation techniques developed in Phase I by drilling/coring and completing the well, and then performing a battery of well tests and logs. Because no gas hydrates were encountered, the completing and testing tasks of the well were not conducted. Draft procedures for completing and testing were prepared, however (**Appendices B and C**). Tasks to accomplish these objectives are described below.

The schedule for Phase II is shown in **Figure 7** and **Table 1**.

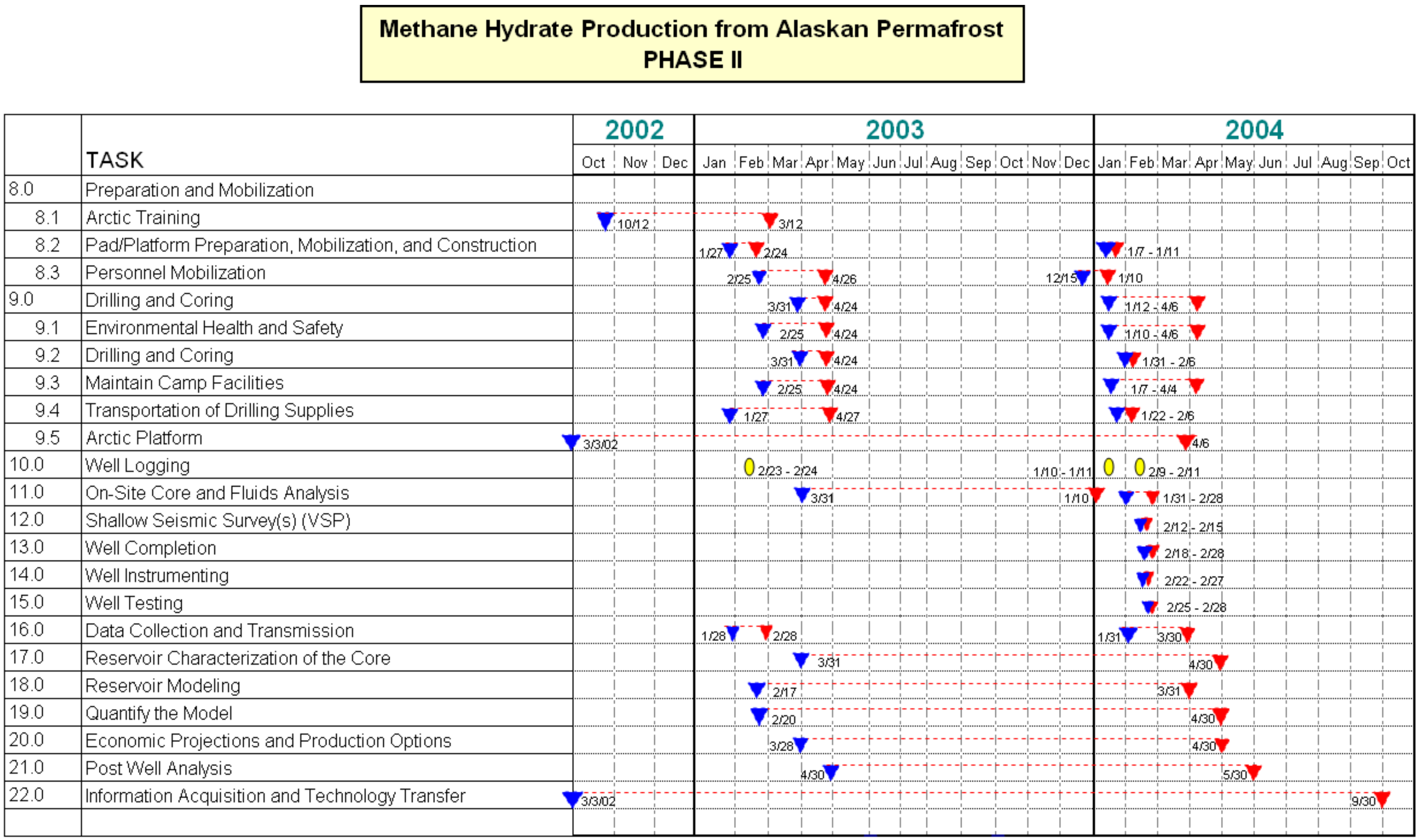

Figure 7. Phase II Project Schedule

Table 1. Hot Ice No. 1 – Time Line

ID	Task Name	Duration	Start	Finish	Predecessors
1	Tundra Opening (Actual)	0 days	1/9/2004	1/9/2004	
2	Open Deadhorse w/ key Personnel	4 days	1/7/2004	1/11/2004	
3	Hot Ice Project Resumption	67 days	1/12/2004	3/19/2004	
4	**Mobilization**	**10 days**	**1/12/2004**	**1/22/2004**	
5	Build 4-mile Ice Road From Meltwater	10 days	1/12/2004	1/22/2004	
6	Deadhorse Office Officially Open	0 days	1/12/2004	1/12/2004	
7	Prep Hot Ice No. 1 Camp	4 days	1/18/2004	1/22/2004	
8	MOB Crews to Deadhorse	0 day	1/20/2004	1/20/2004	
9	Training & Pre-Spud Mtg in Deadhorse	3 days	1/18/2004	1/21/2004	
10	**Rig Up & Preparation for Spud**	**12 days**	**1/18/2004**	**1/30/2004**	
11	RU Electrical	6 days	1/18/2004	1/24/2004	
12	RU Plumbing	2 days	1/19/2004	1/21/2004	
13	RU Communications	1 day	1/22/2004	1/23/2004	
14	Haul Fuel and Fluids	5 days	1/21/2004	1/26/2004	
15	RU Rig and Support Equipment	5 days	1/21/2004	1/26/2004	
16	Set up & RU Lab	3 days	1/23/2004	1/26/2004	
17	RU Instrumentation	6 days	1/24/2004	1/30/2004	
18	Test BOP	1 day	1/28/2004	1/29/2004	
19	**Drilling & Coring Operations**	**17 days**	**1/29/2004**	**2/15/2004**	
20	RIH w/BHA, DO Ice Plugs & Displace Hole	1 day	1/29/2004	1/30/2004	
21	Test Casing, DO Shoe & 20', FIT/LOT	1 day	1/30/2004	1/31/2004	
22	Core 1425' to 2300'	7 days	1/31/2004	2/7/2004	
23	TOH, Test BOP, TIH, C&C	1 days	2/6/2004	2/7/2004	
24	C&C, TOH & RU Loggers	1 day	2/7/2004	2/8/2004	
25	OH Log	1 day	2/8/2004	2/9/2004	
26	Wiper Trip	1 day	2/9/2004	2/10/2004	
27	VSP	5 days	2/10/2004	2/15/2004	
28	**Abandonment & Demobilization**	**25 days**	**2/15/2004**	**3/11/2004**	
29	Test BOP	1 day	2/15/2004	2/16/2004	
30	P&A/ L/D CHD 134 & Set Packer & Plugs	1 day	2/16/2004	2/17/2004	
31	Rig Down & Demob. Rig Topside	10 days	2/17/2004	2/27/2004	
32	Rig Down & Demob. Rig Platform	2 days	2/27/2004	2/29/2004	
33	Remove Rig Platform Legs	3 days	2/29/2004	3/3/2004	
34	Rig Down Camp	2 days	3/3/2004	3/5/2004	
35	Remove Camp Platform & Legs	2 days	3/5/2004	3/7/2004	
36	Remediate Site	4 days	3/7/2004	3/11/2004	
37	Wrap up at Deadhorse	19 days	2/29/2004	3/19/2004	
38	Wash Bay Operations	12 days	2/29/2004	3/12/2004	
39	Long-term Storage	7 days	3/7/2004	3/14/2004	
40	Inventory	17 days	3/2/2004	3/19/2004	
41	**Hot Ice Project Complete**	**0 days**	**3/19/2004**	**3/19/2004**	

Task 8.0 – Preparation and Mobilization

Subtask 8.1 Arctic Training

The required training was conducted for personnel who were to work on the North Slope overnight in support of this project. Training courses included: First Aid, Respiratory, FIT Test, H_2S Training, NSTC Training, Hazcom/Hazwoper, PPE, Alaska Safety Handbook, Arctic Survival, Bear Awareness, NPRA Training, and Fire Extinguisher Training. Refresher training and updated certifications were provided for the 2004 drilling season.

Subtask 8.2 Pad/Platform Preparation, Mobilization, and Construction

Permits were issued, and the arctic platform was installed at the well location in February 2003. The project team mobilized the drill platform equipment to the well location, using an existing gravel road and a staging area at the end of the road. The permits allowed the platform to remain during the summer months. An ice road was permitted and utilized for access during operations in 2004.

Phase 2 of the drilling operation incorporated an ice road (**Table 2** and **Figure 2**) instead of making use of Rolligons.

Table 2. Hot Ice Location Winter 2004 Access

Point Name	Lat (WGS 84)	Long (WGS 84)	Comments
001	70.10992	150.38774	Road Alignment
002	70.11032	150.38779	Road Alignment
003	70.10943	150.38774	Road Alignment
HI Start	70.10991	150.38741	Beginning of Ice Road Alignment off road
PL-X-1	70.10997	150.38255	Pipeline crossing
004	70.10959	150.37146	
005	70.11026	150.37123	Power line alignment
HI PI-03-1	70.10712	150.34009	Point of Intercept
HI X-03-1	70.10763	150.33920	Steam Crossing 1
HI X-03-2	70.11195	150.27660	Stream Crossing 2
HI-1	70.10836	150.21756	Hot Ice No. 1 Platform location (West Side)

The three pipelines at the single pipeline crossing are protected by casings and 7 ft of coarse gravel. The gravel ramp on each side is shown in **Figure 8**.

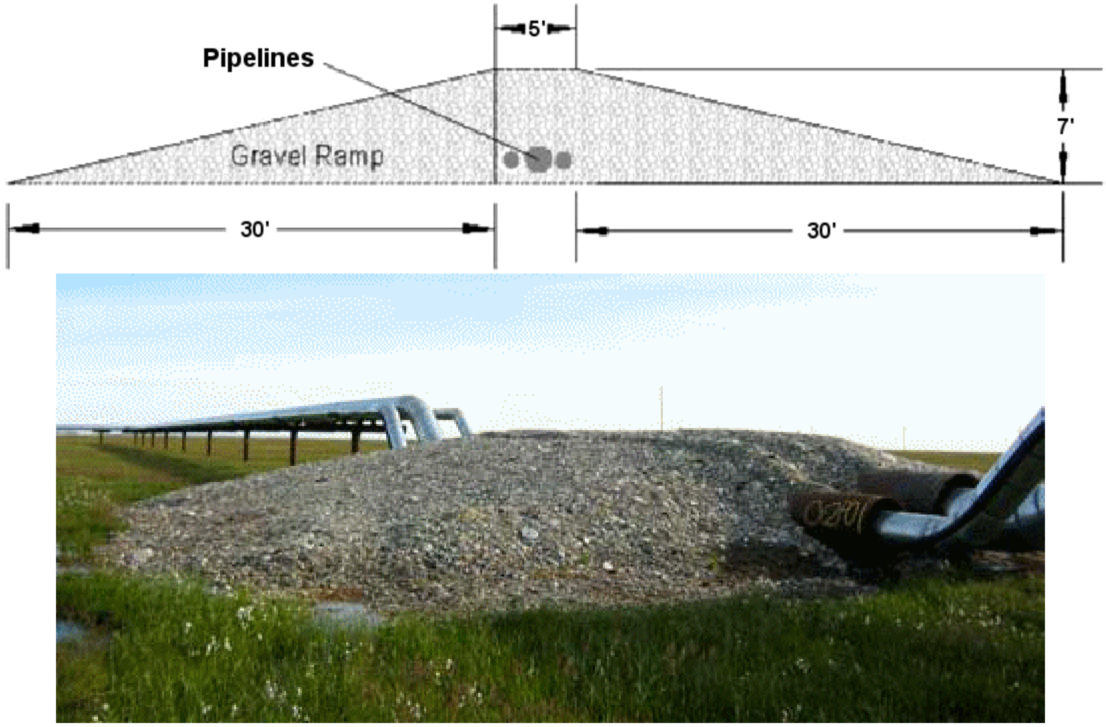

Figure 8. Gravel Ramp for Pipeline Crossing

The site for one of the stream crossings is shown in **Figure 9**.

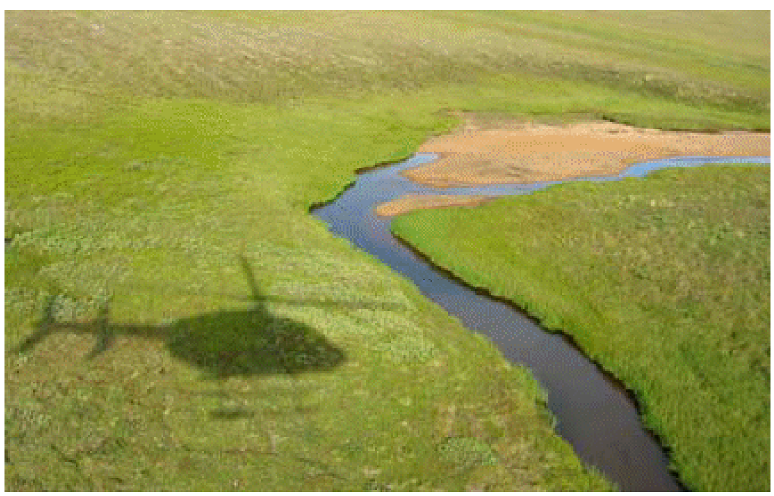
Figure 9. Stream Crossing 1 for Ice Road

Subtask 8.3 Personnel Mobilization

The team made provision to transport all project personnel to and from the well site. This included transport of camp crew, catering staff, maintenance crew, rig crew, laboratory crew, logging crew, cementing crew, mud crew, and supervisory personnel.

Task 9.0 – Drilling and Coring

The team winterized the drill rig and mobilized it to Deadhorse and then to the well location. We drilled and cored the Hot Ice No. 1 well from the arctic platform.

Subtask 9.1 Environmental Health and Safety

The recipient monitored and responded to environmental health and safety concerns, including monitoring and manifesting waste, in order to ensure compliance with regulations specified in permits.

Subtask 9.2 Drilling and Coring

The recipient drilled the Hot Ice No. 1 well from the arctic platform constructed in Subtask 8.2. We used chilled drilling fluids and monitored the downhole temperature and inclination using a tool provided by Sandia National Laboratories. Noble Engineering and Development's Drill Smart System was used to allow engineers to monitor and view drilling operations live from Houston. Owing to unseasonably warm weather, the team was unable to complete the drilling program as originally scheduled during the Spring of 2003. We resumed and completed drilling operations during the Winter 2004 drilling season.

A detailed summary of Task 9.2 activities is provided in the Topical Report – "Drilling and Coring Operations."

Subtask 9.3 Maintain Camp Facilities

The team provided camp facilities to house and feed the crews rotating on a 12/12 shift schedule.

Subtask 9.4 Transportation of Drilling Supplies

During the 2003 season, no ice road was used. Transportation of personnel, equipment, and supplies was via Rolligons and helicopter. By contrast, the team constructed an ice road during the Winter 2004 season to facilitate the mobilization of equipment, supplies, and personnel to the Hot Ice No. 1 Site to complete the drilling and coring operations. Equipment was also removed by ice road after operations were complete.

Subtask 9.5 Arctic Platform

The Anadarko Arctic Platform was constructed and tested in Houston, Texas. Tests of platform leg strength are described in the Topical Report – "Drilling and Coring Operations." The structure is made of lightweight aluminum. It was mobilized to the base camp in January 2003, and inspected prior to mobilization to the well location in February (**Figure 10**). The legs were tested and put on location as soon as the freeze period began in January. A video of the transportation and construction was provided to the DOE. Legs were installed into the tundra permafrost and frozen into place. The platform can be mobilized by either helicopter and/or Rolligon from the base camp and assembled at the well location. Environmental monitoring equipment was also installed.


Figure 10. Arctic Platform at Hot Ice No. 1

The platform drilling area is 100 x 100 ft, and the base camp is 62.5 x 50 ft on an adjacent platform. The rig, equipment and base camp were installed on the platform by Rolligon and two cranes. After completion of drilling and completion operations, the equipment was demobilized. There was no adverse environmental impact at the drill site (**Figure 11**). The entire platform was demobilized to Dead Horse. The platform was thoroughly inspected by a third party and a post-analysis study was conducted with recommendations on future operations.


Figure 11. Final Stage of Platform Removal and Site Remediation

Task 10.0 – Well Logging

The team ran a suite of logs in the well to characterize gas hydrate-bearing intervals, including the following: 1) electrical resistivity (dual induction), 2) spontaneous potential, 3) caliper, 4) acoustic transit-time, 5) neutron porosity, 6) density, and 7) nuclear magnetic resonance. Logging operations are described in the Topical Report – "Logging Operations."

Core data were used to calibrate and quantify log information. A report on NMR log measurements of core taken during the 2003 drilling season is presented in the Topical Report– "Core and Fluid Analysis."

Task 11.0 – On-Site Core and Fluids Analysis

The project team analyzed core and fluids using a specially constructed mobile core laboratory, staffed by trained laboratory technicians. Core was received in the cold module, where it was photographed and assessed for the presence of hydrate. One-inch plugs were removed from the core, and these plugs were measured for porosity, permeability, compressional and shear wave velocity, resistivity, thermal conductivity, and NMR with specialized equipment specifically designed for making these hydrate core measurements, including a Schlumberger CMR tool. All of these measurements were made under controlled pressure and temperature. Core measurements are summarized in the Topical Report – "Core and Fluid Analysis."

Because no hydrates were encountered, no hydrate dissociation testing was conducted, although the procedures and equipment are described in project reports. Laboratory technicians assisted in preparing core for additional testing at other locations. Results of core and fluids handling procedures were provided for the DOE-funded Westport Hydrate Core Handling Manual. The results of the analysis were incorporated in Tasks 17, 18, 19 and 20.

Subtask 11.1 Mobile Laboratory Repair and Upgrade

During both the 2003 and 2004 coring seasons, a special mobile core laboratory (**Figure 12**) was employed to immediately perform measurements on both whole core and 1-inch plugs taken from the whole core, while maintaining temperature. Anadarko, in cooperation with Rock Properties Resources, designed the mobile core laboratory which was operated on the drilling site. Rock Properties Resources constructed the laboratory as well as provided critical support throughout the project. Resulting from the effort was a state-of-the-art, winterized, mobile core characterization laboratory capable of measuring large volume of core in a cost-effective manner in arctic conditions. This effort represents the first comprehensive on-site gas hydrate analytical laboratory of its kind to be deployed in the Arctic.

Figure 12. Mobile Core Laboratory at Hot Ice No. 1 Site

The team repaired and upgraded the mobile core laboratory in Tulsa during the summer and fall of 2003 specifically to: 1) redesign the pressure and cooling system for the NMR spectrometer, in order to achieve significantly lower temperature capability required for analysis of hydrate samples; 2) improve insulation for the velocity-thermal conductivity-resistivity measurement system; 3) configure the NMR and VCR systems with capability to allow positive pore pressures of methane for hydrate stability; and 4) develop a central database for managing and storing all data measured in the mobile core laboratory.

Regarding the use of the LBNL CT on site:

1. We partitioned one end of a 20-ft Conex with a separate door to the outside for the X-ray room.
2. There was a heater located in the room or an electrical outlet to add a portable heater.
3. The x-ray room is adjacent to the station where the core will be cut to 3-ft lengths.
4. Core sections were taken outside and then into the x-ray room.
5. The x-ray machine can be started in a temperature-controlled environment.
6. During shipment, the machine can be subjected to ambient temperatures of as low as -40°F (unless special measures are taken).

The x-ray scanner is certified to be "cabinet safe." This means that any personnel can be near it for normal operation, and the user does not need to be fitted with a dosimeter. Only a certified "system maintainer" can use tools to perform maintenance and has the ability to modify or override interlock safety features. This authority is granted from our EH&S department, and Victor was the system maintainer.

Regarding operation – the machine needs to be "tuned" to the samples that are collected. This means that adjustments must be made to both x-ray voltage and current depending on the density and composition of the samples. There may also be adjustments to the camera behind the image intensifier. It is hard to predict how often and when this task should be performed. Since dual-energy scanning was performed, both hard and soft x-ray energies needed to be periodically readjusted depending on the collected core density and composition.

LBNL modified the machine so that it will hold a 3-ft piece of core. Four-ft long core holders were constructed since the extra space at the top of the core holder will be empty, preventing concern about core length. The quick scan will be performed in about 2 to 3 minutes from the time the sample in the sample holder is placed in the x-ray unit, to when it can be removed from the x-ray unit. A more detailed full 3-D CT characterization will take about 12 minutes for the entire 3-ft length. A shorter interval (i.e., 4 inches) can be scanned in full 3-D mode in about 2 minutes. Three to five core holders were provided so that one can be loaded, while another one is being cleaned or prepped and a third can be in the scanner.

Results of the CT measurements are described in detail in the Topical Report – "Core and Fluid Analysis."

At the conclusion of the Hot Ice field operations, Anadarko donated the mobile core laboratory to the University of Oklahoma (**Figure 13**). Shown in the photo (left to right) are Susan Howes (APC), Doug Hazlet (APC), Bill Liddell (APC), Julie Struble (APC), Tom Williams (MTI), Richard Sigal (OU), Carl Sondergeld (OU), Dean Oliver (OU), Chandra Rai (OU), Brad Johnson (APC).

Figure 13. Members of Project Team after Donation of Mobile Core Laboratory to University of Oklahoma

Task 12.0 – Shallow Seismic Survey(s)

After the well was logged, a 3D vertical seismic profile (VSP) was conducted to calibrate the shallow geologic section with seismic data and to investigate techniques to better resolve lateral subsurface variations of hydrate-bearing strata. Paulsson Geophysical Services, Inc. deployed their 80 level 3C clamped borehole seismic receiver array in the wellbore to record samples every 25 ft. The surface vibrators successively occupied 800 different offset positions arranged around the wellbore. This technique generated a 3D image of the subsurface. Correlations of these seismic data with cores, logging, and other well data were generated. This task included additional fabrication of receiver cables, rental of field vibrators and recording equipment and associated personnel.

This work is described in detail in the Topical Report – "3D Vertical Seismic Profile Survey."

Task 13.0 – Well Completion

Because no gas hydrates were encountered, the project team did not complete the well. Completion procedures were developed based on experiences in similar wells. Draft Completion Procedures are presented in **Appendix B**.

The completion for this well was designed to try to address all issues that were identified with producing hydrates at this location. Based on rig capacity, the largest production casing that can be used below the permafrost is 4½ inch. The location would not be accessible by ice roads during production testing. All equipment would need to be transported by rolligon or helicopter. As a result, size and weight of the equipment needs to be minimized. Completion and testing equipment need to be simple and require minimum support. With environmental regulations and cost constraints, the base plan will conclude testing before tundra closure occurs. There was also potential for formation sand production. Freeze protection also has to be incorporated into the completion design, since potential for forming hydrates or ice will exist.

Task 14.0 – Well Instrumenting

Because no hydrates were encountered, the pressure and temperature gauge and a surface sensor to provide monitoring capabilities were acquired and tested, but not installed.

Task 15.0 – Well Testing

There was no well testing, although a comprehensive (draft) well testing plan was developed by the recipient and is presented in **Appendix C**. Water and gas samples were collected to determine their composition. The well was plugged and abandoned according to State regulations.

Task 16.0 – Data Collection and Transmission

The project team performed laboratory work on fluids captured during operations. Results were transmitted daily via email.

Task 17.0 – Reservoir Characterization of the Core

The team characterized the reservoir, based on analyses of fluids, geology, engineering, logs, geophysics, and rock physics. All these data were analyzed and the results presented in the Topical Report – "Hydrate Reservoir Characterization and Modeling." These data were provided to Lawrence Berkeley National Laboratory for incorporation into their well simulator.

Task 18.0 – Reservoir Modeling

The team provided information developed in reservoir characterization efforts to Lawrence Berkeley National Laboratory to be used to quantify their hydrate simulator. LBNL's advanced simulator system is based on EOSHYDR2, a new module for the TOUGH2 general-purpose simulator for multi-component, multiphase fluid and heat flow and transport in the subsurface environment. Reservoir simulation during this phase of the project was focused on considering production schemes, both short and long term, for hydrate production on the North Slope based on all the reservoir characterization data obtained. Depressurization, injection and thermal methods are some of the production processes considered with the simulation.

Results of LBNL's simulation studies are summarized in the Topical Report – "Hydrate Reservoir Characterization & Modeling."

Task 19.0 – Quantify the Model

This task was to be conducted in parallel with Tasks 17 and 18. The reservoir model used would need to be continuously refined as well test data were acquired. This effort is required for making projections. Models were enhanced iteratively to incorporate dynamic production data during the well test period. (See Topical Report "Hydrate Reservoir Characterization and Modeling," Appendix B – "Numerical Simulation Studies Related to the Hot Ice No. 1 Well," George J. Moridis, 2004.)

Task 20.0 – Economic Projections and Production Options

The project team prepared economic projections and production options (see below). The team will present the results of the program to the DOE. Information from other gas-hydrate projects was reviewed and included in our recommendations. Model-based estimates and production options were developed. If it was determined that a significant volume of gas production from hydrates is technically possible, an economic analysis was to be conducted.

Prior to beginning the project, the team developed an estimate of potential reserves. Below are estimates used to calculate a distribution of the potential reserves of the free gas portion and hydrate-bearing rock for the entire area that was being assessed:

Stochastic Reserve Determination
August 2,2002

	Min	**Most Likely**	**Max**
Gross Area Sand Package	100	150	200

Hydrate Portion

	Min	**Most Likely**	**Max**
Number of sections Hydrate	90	140	195
Hydrate Thickness (ft)	50	75	100
Vol (ft3)			
Porosity (%)	20%	30%	35%
Hydrate Saturation (%)	50%	75%	85%
Pore Volume of Hydrates (ft3)			
Hydrate FVF	142	165	187

Free Gas Portion

	Min	**Most Likely**	**Max**
Number of sections free gas	40	145	330
Sand Thickness			
Vol (ft3)			
Porosity (%)	20%	30%	35%
Gas Saturation (%)	70%	75%	80%
Pore Volume of Gas			
Bg	80	100	120

Distribution of the potential gas accumulation is shown in **Figure 14**. Mean gas volume for ~140 sections of leases was 17.1 TCF gas in place. This estimate does not imply that this gas would be commercial and has no bearing on productivity of the accumulation.

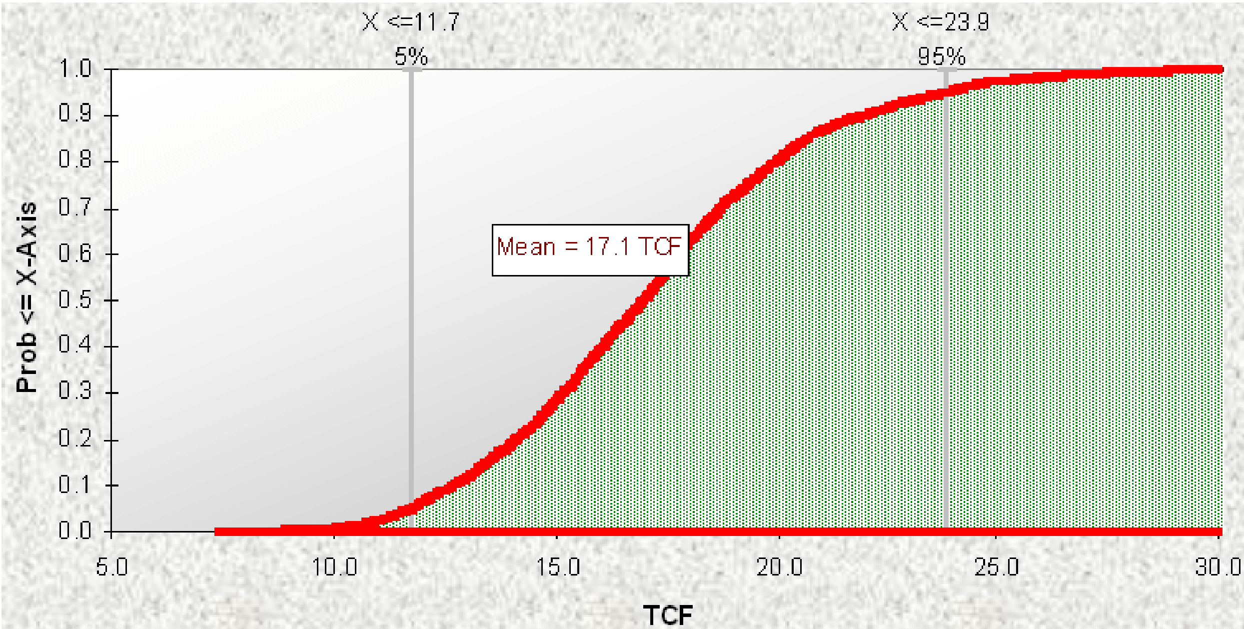

Figure 14. Distribution for Total Free Gas and Hydrate Reserves in Cirque/Tarn Area

Production options considered depended on the location of the free gas relative to the hydrate accumulation. To effectively produce hydrates, the consensus was that a free gas leg needed to be located adjacent to the hydrate interval. To the extent that this occurred, we believed that the free gas could be produced similar to a coalbed methane accumulation by drilling several wells in an area in "pods" and producing them until pressure and/or rate began to drop below a pre-determined level. This pod would then be shut in and another pod produced, thereby allowing the hydrates to dissociate into the free gas leg. After pod production dropped below the threshold, production would be returned to the first pod of wells.

Task 21.0 – Post Well Analysis

This task was to include a lessons-learned report based on past operations, and was designed to help planning operations on other areas of the North Slope of Alaska. The report was to include a budget for an additional well and an extended well test based on the information generated from the Phase II activities. The production test plan would help determine the producibility of hydrate deposits. These plans will be valuable for future hydrate operations, even if this project is not extended into Phase III. The Post-Well Analysis report is being prepared and will be included as part of the Final Report.

Currently, the project team does not have plans to continue an assessment of the hydrate potential on the North Slope of Alaska until gas can be commercialized. A gas pipeline from the North Slope to existing pipeline infrastructure (as well as space in the line) is required for gas exploration and production. Additionally, the economics of this type of endeavor must be considered. It is apparent that high-GOR oil wells that are currently producing in known areas of the region will be the first ones to sell gas and can absorb a much higher tariff than new wells.

Because development costs must be competitive, realistically, it might be several years to be competitive with existing producers.

A thorough assessment of gas hydrate potential will be an important requirement before any operating company will consider developing exploration plans for this resource.

Task 22.0 – Information Acquisition and Technology Transfer

The project team gave high priority to communicating and exchanging information with experts in the field of hydrate well drilling, coring, and testing, including Advisory Board members, to stay abreast of the latest technology and preferred methodologies. Results of the field tests were well documented and transferred to the industry via several Topical Reports, the project's web page, technical papers and presentations.

Subtask 22.1 Information Acquisition

The team identified and networked with other experts in the field of hydrate well drilling, coring, testing, and analysis to gain insights into the latest methodologies and technologies. The team followed the latest developments related to hydrate wells by meeting with experts in the scientific and drilling communities.

Subtask 22.2 Technology Transfer

The hydrate project team documented project results and transferred the new information and technology to the industry via web site postings, meetings, workshops, and several technical papers. Several presentations and poster sessions were presented at the AAPG Hedberg Conference in September 2004. The team also used the NED Drill Smart system to allow well activities to be viewed by scientists, engineers, and DOE project managers who were not present at the well site during drilling/coring operations.

DELIVERABLES

Periodic, topical, and final reports were submitted in accordance with the DOE's Reporting Requirements Checklist. In addition, the project team submitted the following:

Phase I

1. Digital Map of all well locations in and adjacent to project area (Task 2.1)

2. Well log correlation sections showing lithologic and stratigraphic units that fall within the gas hydrate stability zone in and adjacent to the project area (Task 2.1)

3. Seismic maps and sections showing extent of stratigraphic and lithologic units that fall within the gas hydrate stability zone in and adjacent to the project lease area (Task 2.2)

4. Reservoir modeling report for proposed site (Task 3.0)

5. Well Data for individual control wells used for site selection (Tasks 2.1 & 4.1)

6. Site Selection Plan (Task 4.1)

7. Testing and analytical procedures report (Task 5.0)

8. Well plan(s) (Task 6.0)

9. Permit application (Task 4.2)

Phase II

1. Drilling and Coring Operations (Topical Report) (Task 9.2)

2. Logging Operations (Topical Report) (Task 10.0)

3. Core and Fluid Analysis (Topical Report) (Task 11.0)

4. Bibliography of Publications by Project Personnel (see Section 6)

5. 3D Vertical Seismic Profile Survey (Topical Report) (Task 12.0)

6. Well Completion Report (see **Appendix B**) (Task 13.0)

7. Well Testing Report (see **Appendix C**) (Task 15.0)

8. Hydrate Reservoir Characterization and Modeling (Topical Report) (Tasks 17, 18, &19)

9. Economic Projections and a Production Options Report (above under Task 20)

10. Plans for Future Hydrate Well on the North Slope (above under Task 21)

11. Technical Publications Summarizing Project Findings (see Section 6) (All Tasks)

12. Final Report Summarizing Project Findings (All Tasks)

In addition to the required reports, the team submitted informal status reports directly to the COR. These included short descriptions of successes, problems, advances or other general project status information.

A four-day internal workshop was conducted prior to the project review meeting with the DOE, where a briefing of the program results was presented at the Anadarko facility in the Woodlands, Texas on May 13, 2004.

5. Conclusions

5.1 Project Accomplishments

A number of significant accomplishments were achieved during this project:

1. The geologic model used to predict potential hydrate-bearing strata was proven correct.
    - Gas-bearing sands were encountered in highly porous sandstones that were situated within the hydrate stability zone (HSZ). These sands are areally extensive and are stratigraphically equivalent (by correlation) to sand units present in offset wells.
    - A localized temperature model was developed for predicting the base of the HSZ. This model was verified by well results and used to determine the total depth of the well.
2. The continuous coring rig proved to be a safe and efficient drilling system.
    - The team demonstrated the ability to recover frozen core (permafrost).
    - 93% of attempted continuous core was recovered.
3. The project team demonstrated the ability to characterize whole core on site using a mobile core laboratory uniquely equipped for hydrate evaluation.
    - Tools were developed for hydrate-specific measurements to analyze dissociation of water and methane.
    - Petrophysical measurements were performed quickly on site.
    - A state-of-the-art CAT scan tool supplied by Lawrence Berkeley National Laboratory was used to analyze whole core.
    - The USGS collected and analyzed in real time coal cores taken on the North Slope.
4. The project team designed and recorded a massive 3D vertical seismic profile (VSP).
    - The VSP recorded shallow seismic data with 3D perspective using dense spacing of receivers and vibrators.
    - Processed data allow investigation of lateral variations of potential hydrate reservoirs.
5. The project team demonstrated the concept of extending the drilling season on the North Slope of Alaska by using a low-impact platform design.
    - The modular platform remained in place during the summer and appears to have had no adverse impact on wildlife.

- At the conclusion of drilling and completion operations, the equipment was demobilized as designed. After clean-up, there was no adverse environmental impact at the drill site.

6. The project team transmitted live data from the North Slope to Houston and Washington D.C. during the project.
    - The ability to transmit live data from the well site reduced the number of on-site scientists required to oversee the project.

5.2 Occurrence of Hydrates at Hot Ice No. 1

The primary objective of this project was to determine how to successfully explore and produce gas hydrates on the North Slope of Alaska. The Hot Ice No. 1 well was continuously cored to a depth of 2300 ft. The well reached its planned total depth on February 7, 2004, approximately 300 feet below the theoretical base of the hydrate stability zone (HSZ). No gas hydrates were encountered. This was a surprise and disappointment to the Anadarko/Maurer/Noble team since the geological model successfully predicted porous sands containing natural gas within the HSZ.

The Hot Ice well encountered several relatively thin zones with the characteristics of hydrates (high velocity and resistivity indicated on well logs, coupled with gas shows on the mud logs) that were determined to be highly cemented sands. The existence of similar zones in offset wells examined during the planning phase now raise questions about the presence of hydrates in this area.

In larger sand packages structurally up-dip from the Hot Ice location, offset wells have been documented to contain hydrates. Also, several wells located structurally down-dip have exhibited mud log gas shows in these same sand zones. Rather than hydrates, the Hot Ice well encountered free gas and water in the HSZ. This raises questions about what other variables are involved in the formation of methane hydrates in porous sand.

An assessment to address these issues will continue in developing possible recommendations to enhance future exploration efforts. Steps taken to assist in that effort included:

1. Processing and interpreting the high-resolution 3D VSP
2. Performing reservoir characterization to correlate the VSP/core/well log data
3. Providing available data to engineers and scientists for use in hydrate modeling and for future hydrate reservoir evaluation activities

Continuous core was recovered throughout the HSZ. It had been predicted before drilling began that the location would have significant sands in the HSZ and gas in the system. As no shallow seismic data were available, and the cost of acquiring such data was too expensive, it was not known if any traditional hydrocarbon traps existed. Hydrates were established as existing in wells to the northwest in sands that would be cut by Hot Ice. Core showed in the HSZ (as predicted) good high-porosity, high-permeability reservoir sands, and gas shows on the mud log. Despite this, no hydrates were recovered in this well.

Modeling of hydrate dissociation indicates that, if significant hydrates were cored, they would not completely dissociate before reaching the surface. There was no evidence on well logs for hydrates existing *in-situ*. Information on formation brine extracted from samples and resistivity measurements showed it to be somewhat less saline than seawater; therefore, there is no reason to believe that the HSZ had been incorrectly calculated. Experience at Hot Ice No. 1 further establishes what was already clear from earlier studies: **even in very good reservoir rocks, more is required beyond correct thermodynamic conditions and gas in the system to produce a hydrate reservoir.**

Numerous wells drilled on the North Slope of Alaska have reported drilling through hydrates. Hydrates were definitely recovered at the Northwest Eileen Well 2. Thus, there is no question that hydrates exist at some locations on the North Slope. It is also clear that they are not everywhere. The question then becomes: *What is the nature of the geographic distribution?* The most optimistic model is that they exist as continuous sheet-like deposits. For this case, detection of hydrates in isolated wells can be used to contour the existence of hydrates between the wells. At the other extreme, the most conservative model states that hydrates only exist where there were shallow gas reservoirs before temperatures cooled a few million years ago. The first model makes hydrates a very large potential resource, the second at best a marginal one. Wells in which hydrates have been detected or inferred from well logs were generally drilled based on the expected existence of a deeper trap containing oil. Such traps often imply the existence of traps in shallower formations. For such a scenario, drilled wells form a biased set, not a random sampling of shallow formations.

It is well known that hydrate plugs can form in pipelines. In addition, ocean floor hydrates seem to form without the presence of traditional hydrocarbon traps. These observations show that, given a sufficient methane flux and proper temperature/pressure conditions, hydrates are a self-trapping system. It would follow that, if no trapped gas already exists, the size of the gas flux through the system is probably a critical parameter. Lack of hydrates at Hot Ice No. 1 implies that this critical flux was not achieved there. One question then arises: *Does or did a large enough gas flux exist in some areas on the North Slope?* If so, sheet-like accumulations should exist.

If gas fluxes everywhere on the Slope are below the critical value, a traditional trapping mechanism seems to be necessary. Under these conditions, fields could still be larger than the gas volume the trap can hold. This is because after trapped gas is converted to hydrate it could act as a seed reservoir that grows by converting gas passing by into hydrate. It is therefore essential to obtain quantitative bounds on the gas flux passing through North Slope reservoirs in the last few million years.

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7. Acknowledgements

The project team acknowledges the many important contributors to this project:

- University of Oklahoma
- Craig Woodard and the University of Alaska, Anchorage
- Steve Kirby and Tim Collett with the United States Geological Survey
- Robert Kleinberg and Doug Griffin with Schlumberger
- Berry Freifeld and George Moridis with Lawrence Berkeley National Laboratory
- Pacific Northwest National Laboratory
- Sandia National Laboratories
- Ocean Drilling Program, JOI – Frank Rack
- Anadarko Petroleum Corp. Team – Tommy Thompson, Ali Kadaster, Donn McGuire, Steve Runyon, Richard Sigal, Bill Liddell and Jonathon Kwan
- Paulsson Geophysical Services, PGS Onshore
- Frances Toro and John Rogers with DOE NETL

Appendix A – Hot Ice No. 1 Site/Rig Photos

Figure A-1. Hot Ice Well #2 Site

Figure A-2. Base Camp

Figure A-3. Setting the First Platform Module

Figure A-4. Assembling the Platform

Figure A-5. Complete Camp Ready for Drilling

Figure A-6. Team Members on the Rig Floor


Figure A-7. Site at First Season Shutdown


Figure A-8. Site during Summer 2003


Figure A-9. Beginning of Second Season


Figure A-10. Deploying VSP Array into Well


Figure A-11. VSP Thumper Truck


Figure A-12. Disassembling the Platform

Figure A-13. Vacuuming Platform Leg Holes

Figure A-14. Site after Demob & Remediation

Appendix B: Draft Completion Procedures

HOT ICE No. 1 Well

Completion Challenges

The completion for this well was designed to try to address all issues that have been identified with producing hydrates at this location. Based on rig capacity, the largest production casing that can be used below the permafrost has an OD of 4½ inches. This will have a drift diameter of approximately 4 inches. The location will not be accessible by ice roads during production testing. All equipment will be transported by Rolligon or helicopter. As a result, size and weight of the equipment needs to be minimized. Completion and testing equipment need to be simple and require minimum support. With environmental regulations and cost constraints, the base plan will conclude testing before tundra closure occurs. The original plan was to not incorporate artificial lift in the base plan. There was also potential for formation sand production. Freeze protection has to be incorporated into the completion design. The fact that the well produces fresh water and predominately methane creates the possibility of forming hydrates or ice in both the tubing and tubing/casing annulus. Potential for having hydrate or freezing problems is greatest during shut-in periods.

Completion Base Plan

There will be a number of uncertainties until we pull core from the well. We plan to perforate one hydrate interval after cementing 4½ inch casing. The base case is to produce one well completed in a single hydrate interval using a tubing string, packer and permanent downhole pressure/temperature gauges. Water and gas will be produced into the tubing string. We will have the capability to swab the well to reduce bottomhole producing pressure. The well will be set up so that it can be shut in downhole by setting a plug in a profile to reduce wellbore storage volume. The well will be equipped with two electronic bottomhole pressure gauges and one temperature gauge near the perforations. A heat strip will be attached to the tubing string to prevent fresh produced water from refreezing across from permafrost when the well is shut in.

The base completion plan is to perforate one interval that is located at a depth with a reservoir temperature greater than 32°F. After the completion is run, production facilities consisting of a two-phase vertical separator with gas and water measurement in winterized enclosures will be hooked up.

A heater cable will be used to keep water in the production tubing from freezing. It is anticipated that produced water will have a low salinity. Undisturbed surface temperature is approximately 12°F. As a result, there is a high probability that there will be a problem with water freezing or hydrate formation inside the tubing, if heat is not added. The heater cable is basically a flat ESP cable that is shorted above the packer. Electrical current flowing through the cable results in the generation of heat. The majority of the heat generated is transferred to the production tubing. Modeling results predicted that the heater cable would keep temperature of fluid inside the tubing above 50°F.

A heater cable should eliminate problems with water freezing, but adds other completion challenges. Using a heater cable requires use of wellhead penetration. There is not enough room in a standard wellhead for 4½ inch casing to have a high amperage penetration. To solve this problem, two additional casing spools will be used to allow the electrical penetrator. The top two joints of casing will be 5½ inch so that there is enough room for the splices and the pigtail connection. With the heater cable and standard 2-3/8 inch EUE tubing, there is very little clearance inside of 4½ inch casing. The weight of 4½ inch was reduced to 9.5 pounds per foot to give the largest possible internal diameter. This results in a clearance of slightly more than 0.25 in. between the heater cable over the coupling and drift of the 4½ inch casing. This is especially tight since Range 1 tubulars (15-24 ft/joint) will be utilized for this project since a continuous coring rig is being used to run the completion equipment. 2-3/8 inch NU (10rd) tubing will be used in place of 2-3/8 inch EUE (8rd) tubing to increase the clearance by approximately 0.20 inch at each connection.

The well will be set up so that bottomhole pressure and temperature measurements can be made from surface. Because of the large cost to come back and plug the well in an isolated Arctic environment, it is planned to plug the well at the end of the production test. This will also minimize the need to mobilize equipment at a later time to the well and reduce environmental impact.

Completion Procedure

NOTE: The completion procedure will not be finalized until the completion interval is selected after the well has been logged.

NOTE: All connections below the packer will be 2-3/8" EUE 8rd special clearance couplings, except for the sand screen. All connections above the packer will be 2-3/8" NU 10rd special clearance couplings, unless noted otherwise. All tubulars are 4.6-4.7#/ft, L-80 unless noted otherwise.

Cement plug was bumped with 9.3 ppg KCl completion fluid + X bbl of diesel and 4½" casing was landed with mandrel hanger.

1. ND BOP Stack and install the tubing head per FMC procedure *2.XX*. This will involve installation of reducer bushing and 11" 5k x 7-1/16" 5k tubing head.

2. Install a 7-1/16" 5K x 11" 5K DSA on top of the tubing head. NU 11" 5K Double Ram preventor (blind rams and 2-3/8" rams) + 11" 5K Annular preventer. Test BOP stack to 5000 psi per FMC procedure 2.12. **Note**: APC will need to provide one joint of 3½" IF drillpipe.or a 3½" crossover to our drillpipe. Install short bowl protector per FMC procedure 2.13, if we are anticipating drilling out cement.

3. Move in 2-3/8" NUE production tubing. Remove thread protectors and visually inspect boxes and pins. Have TIW valve made up to appropriate crossovers and available on rig floor. RIH with 3-7/8" mill + casing scraper + bit sub on 2-3/8" NUE production tubing with special clearance couplings. Dope entire pin of connection lightly and evenly; do not dope boxes. Tubing should be made up using MU torque values on Tubular Data Sheet. RIH so that bit is 50 ft below bottom perforation. Circulate hole with 9.3 ppg KCl completion fluid until clean returns are seen. POOH with mill and scraper. Install thread protectors and lay down tubing. Remove short bowl protector if installed in step 2.

4. RU Schlumberger Wireline Unit on rolligon. RU on 11" 5K flange on top of annular preventer. No pack-off will be used for this step. RIH w/ Gamma ray, CCL and 3.85" Gauge Ring to 50 ft below bottom perforation. Log from 50 ft below bottom perforation up to 50 ft above the top of the permafrost. Correlate to openhole logs. POOH.

5. TCP gun assembly will be run with a pack-off on top of annular preventer. Radio silence is not required with this perforating system. MU TCP assembly on wireline setting tool (assembly may need to be modified by adding an additional 4-ft pump joint to make sure that the packer is not set in a collar). Rabbit all joints while lifting joints to rig floor. Verify that TIW valve is made up to appropriate crossovers and available on the rig floor.
   a) Bull plug
   b) 2-7/8" tubing conveyed perforating guns with 6 JSPF, 60° phasing (HSD-WL-DP 2906 PJ, HMX charges, perforated interval to be determined)
   c) 10 ft 2-7/8" blank gun (spacer assembly)
   d) Firing head with dual hydraulic firing heads (firing pressure will be approximately 2500 psi over hydrostatic pressure) and 2-3/8" SXAR gun drop assembly
   e) Solid collar
   f) 4 ft x 2-3/8" SC EUE pup joint
   g) 4 ft x 2-3/8" SC EUE pup joint
   h) X-over 2-3/8" seal-lock HT box x 2-3/8" EUE SC pin
   i) Baker 2-3/8" Excluder 2000 sand screen 2-3/8" seal-lock HT box x pin
   j) X-over 2-3/8" EUE SC box x 2-3/8" seal-lock HT pin
   k) SLB type "D" NO-GO style profile nipple with 1.562" polished bore made out of 9CR-1MO with 2-3/8" 4.7#/ft EUE SC box x pin
   l) 4 ft x 2-3/8" SC EUE pup joint
   m) 4 ft x 2-3/8" SC EUE pup joint
   n) Baker 24-23 F-1 Permanent production packer, 10 ft seal bore extension, bottom cross over to 2-3/8" EUE 8rd pin
   o) Schlumberger wireline setting tool with slow burn charge

   Note components d, e, f (SLB) g, h, i, j, k, l (Baker) and m, n (Baker) will be made up in the shop by the indicated company prior to bringing out to the platform.

6. Correlate to CCL run in step 4, set packer on wireline with perf guns across hydrate interval. POOH. RD Schlumberger wireline unit. Move Schlumberger wireline unit against container. RU Bell nipple.

7. Pick up Baker 21-23 "GBH" locator seal assy with 70 durometer seals and 6 ft 2-3/8" NU 10 RD pup joint. Run one joint of 2-3/8" NU 10RD tubing with special clearance (SC) couplings.

8. Make up Promore gauges. Gauge sub will have 6 ft 2-3/8" NU 10RD handling subs on top and bottom. Prep to run the electric cable for the Promore gauges and #8 heater cable. Attach gauge cable to Promore gauge and verify electrical connection. Run one joint of 2-3/8" NU 10RD tubing. Termination block should be installed on the heater cable prior to arriving on location. Termination block at end of heater cable should be approximately 25 ft above Promore gauge. Guides will be placed on top of heater cable and banded every 3 ft (±). Promore gauge cable should be banded to outside of heater cable guide per attached drawing. Be careful with slips to make sure that heater cable and gauge cable are not damaged when setting the slips.

9. MU SLB 2-3/8" DS NO-GO 9Cr-1MO nipple with 1.875" ID with 6 ft 2-3/8" NU handling subs top and bottom (made up by Baker). Note the profile will have 2-3/8" NU coupling instead of 2-3/8" NU special clearance coupling. This will still have a clearance of more than 0.4". Run remaining 2-3/8" NU 10RD SC production tubing banding heater cable and Promore cable every 3 ft (±) per procedure.

10. Note when weight indicator shows seal assembly locator bottoms out on packer. Do not set down more than 10,000 lb on seal assembly. Pick up on tubing so that seals are 5 ft below the top of packer. Pressure up on tubing to 100 psi (using BOP test pump). Note: the perforating guns have dual hydraulic firing heads that are set at an absolute pressure of x psi (2000 psi over hydrostatic @ pay depth). Be extremely careful not to put more than 100 psi on the tubing. PU on tubing and note when seals come out of seal bore by monitoring the tubing and annulus pressure.

11. PU and space out so that seals will be x ft into the seal bore extension when hanger is landed. Pick up tubing hanger and landing joint (see FMC running procedure 2.14). Hanger will have 15 ft tubing subs made up on top and bottom before being taken to platform. Connect lower pigtail assembly to penetrator. Splice heater cable to lower pig tail assembly. Splice Promore gauge cable to ¼" line that will go through tubing hanger. Test continuity of heat trace line and Promore gauge line. Lower tubing assy until seals are 2 ft above packer. Align hanger so that gauge line, heater cable and wing from the tree will have proper orientation.

12. Install TIW valve on top of landing joint. Connect line from rig pump to top of TIW valve. Pump tubing capacity + 3.0 bbl of diesel down tubing at a maximum rate of 1 bpm. Tubing pressure should be approximately x psi at the end of displacement (300 psi at 2500 ft). Shut tubing valve.

13. Sting seals into packer, land tubing and lock down hanger.

14. Test annulus to 1000 psig, confirm that tubing is open so that pressure inside tubing will not build up if there is communication between tubing and casing. Remove landing joint.

15. Install 2" ISA 100 BPV in tubing hanger.

16. ND BOP's. Note: Use caution when nippling down the BOP to prevent damaging penetrator or gauge line. NU tubing head assembly. Install surface pigtail to wellhead penetrator for downhole heat trace. Connect surface TECH wire to Promore HPHT surface pack-off. Test continuity of heat trace line and Promore gauge line. Install tree consisting of two 2-1/16" 5000 # master valves, cross with one blind flange, 2-1/16" swab valve and 3-1/8" wing valve and blind flange. Hook up downhole gauge to Provision surface unit. Start recording pressure and temperature every minute. Remove 2" ISA 100 BPV. Install 2" ISA 100 tree testing plug. Remove blind flange from 3-1/8" wing valve.

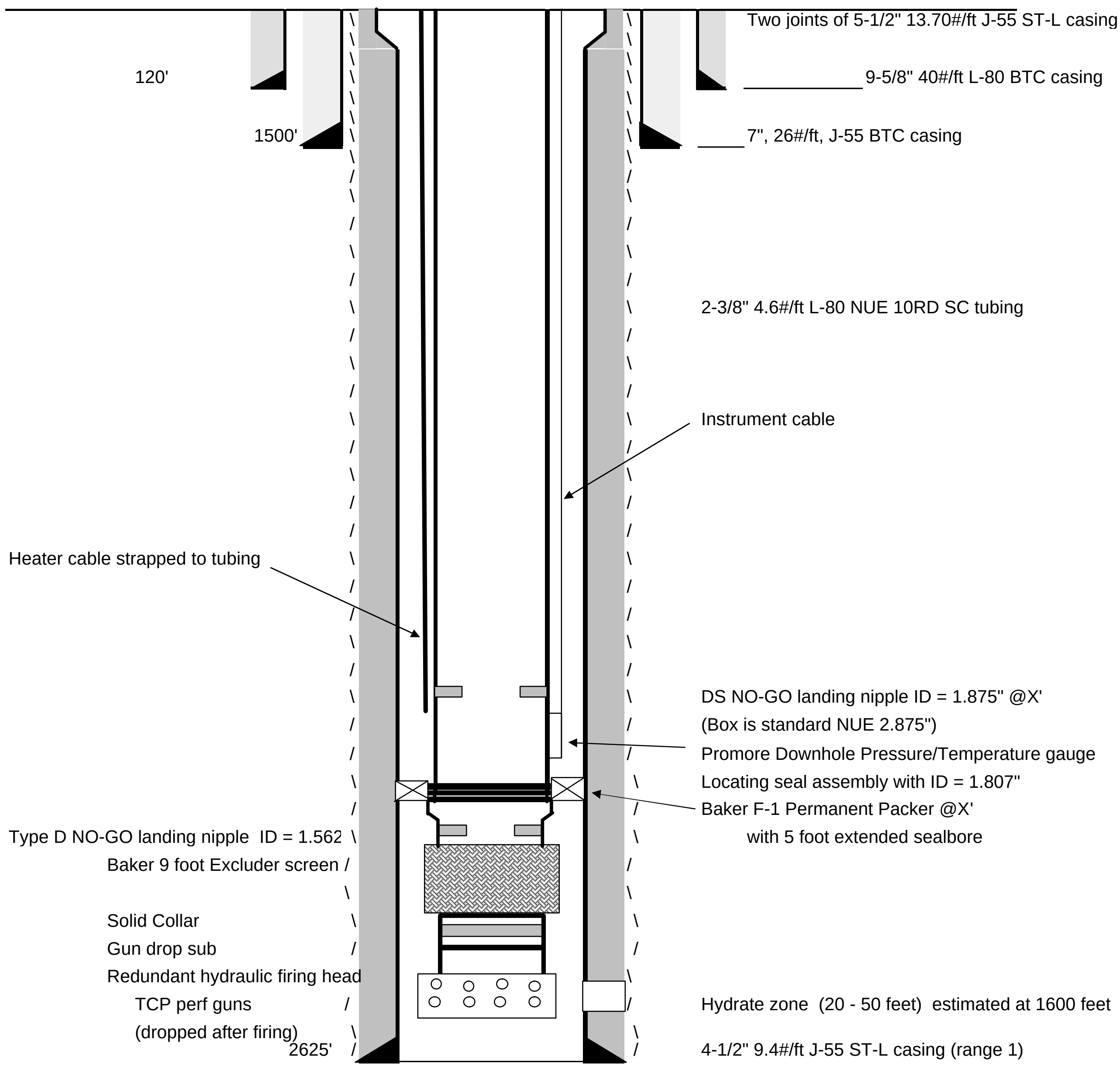
17. Make sure that wing valve is closed. RU on 2-3/8" EUE threads on inside of tree cap. Pressure test wellhead to wing valve to 200 psi, verify that the tree test plug is holding by checking the BHP gauge reading. Increase test pressure to 4000 psi and observe pressure for 15 minutes. Remove 2" ISA 100 tree test plug. Install Halliburton 3-1/8" surface safety valve + 3-1/8" choke downstream of 3-1/8" wing valve.

18. Connect surface pigtail connector to junction box and set step-down voltage on transformer so that it will not exceed 160 Amps during a cold start. Voltage setting will be determined by the length of heater cable installed and cannot be determined until completion interval is selected. Downhole heater cable needs to be turned on initial voltage for at least 30 minutes. This will heat up cable and cause resistance to increase. Using higher voltage initially could result in exceeding amperage rating of penetrator. Supply power to downhole heat trace. After 2 hours it may be necessary to increase voltage after heater cable has heated up to maximize the temperature in the annulus.

19. Monitor casing pressure every 6 hours.

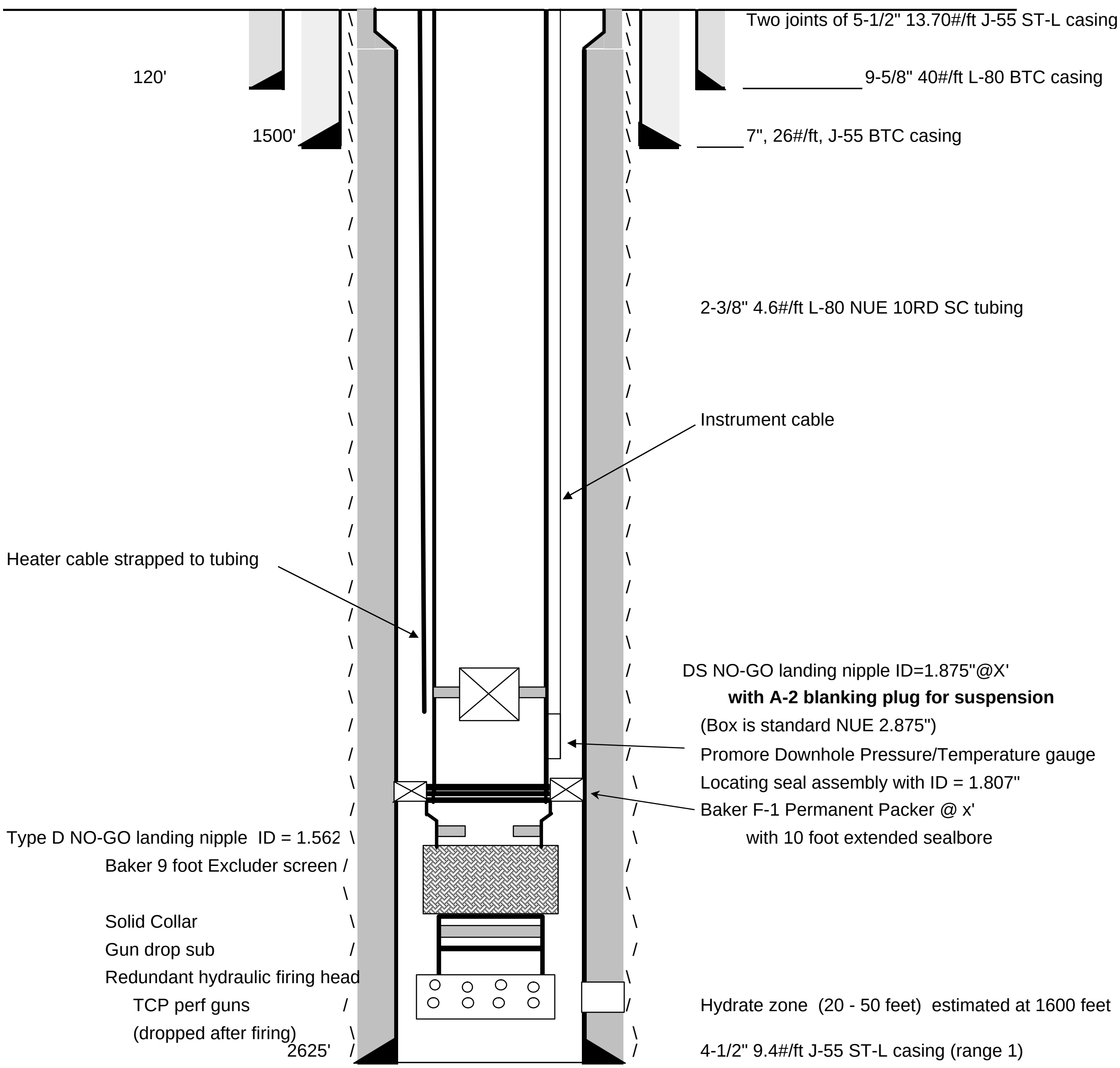
Proposed Completion

Well Name: Hot Ice #1 — 18-Feb-03
Field: Wildcat
Legals: Anadarko-Maurer Hydrate project with DOE
Status: Proposed Completion - Short term test with permanent gauges



Proposed Suspension

Well Name:	Hot Ice #1	16-Jan-03
Field:	Wildcat	
Legals:	Anadarko-Maurer Hydrate project with DOE	
Status:	Proposed Suspension - Short term test with permanent gauges	



Petroleum Corporation

Hot Ice # 1 Tubular Data Sheet

Hydrate Project 2003

Tube	WT (lb/ft)	Grade	Conn	OD (in)	Couplg or TJ OD (in)	ID (in)	Drift ID (in)	Rec MU TQ (ft-lb)	Burst @ 100% (psig)	Collapse @ 100% (psig)	Tensile Yield @ 100% (M lb)	Open End Disp (bbl/ft)
Surface Casing	40.00	L-80	Buttress	9.625	10.625	8.835	8.679		3950	2570		0.01455
Intermediate Casing	26.00	J-55	Buttress	7.000	7.656	6.276	6.151		4980	4320		0.00946
Production Casing	13.70	J-55	STL	5.500	5.500	4.941	4.887	1400-1800	4270	3120	118	0.00509
Production Casing	9.40	J-55	STL	4.500	4.500	4.010	3.965	900-1100	4380	3310	74	0.00346
Production Tubing	4.70	L-80	EUE SC 8rd	2.375	2.910	1.995	1.901	1800	11200	11780	104	0.00171
Production Tubing	4.60	L-80	NUE SC 10rd	2.375	2.710	1.995	1.901	960	11200	11780	72	0.00167
Heater cable	1.01	--	--	0.360	0.885	--	--	--	--	--	--	0.00039
Heater Cable Guide		--	--	0.426	1.22	--	--	--	--	--	--	0.00064
Promore cable		--	--	0.426	--	--	--	--	--	--	18300	0.00018

Annular Capacities	bbl/ft		2500 ft	80 ft
4-1/2" CSG x 2-3/8" EUE TBG	0.01071		26.78 bbl	
4-1/2" CSG x 2-3/8" NUE TBG	0.00998	w/cable + guides	24.95 bbl	
4-1/2" CSG x 2-3/8" NUE TBG	0.01080		27 bbl	
5-1/2" CSG x 2-3/8" NUE TBG	0.01889			1.5112 bbl

Tubular Capacities	Wt	bbl/ft
9 5/8" Surface Casing	40.00	0.07583
7" Intermediate Casing	26.00	0.03826
5 1/2" Production Casing	13.70	0.02440
4 1/2" Production Casing	9.40	0.01630
2 3/8" Production Tubing	4.60	0.00387

Appendix C:
Draft Test Procedures

HOT ICE No. 1 Well

Well Name:	Hot Ice No. 1
AOGCC Permit No.:	
BLM Lease No.:	
API No.:	
AFE:	26495

Red text indicates estimated values

Unless specified, all depths are measured (RKB) referenced to GR/CCL

Corr Logs:	Tie-in log will be the GR/CCL
Depth Control:	Correlation log
RKB Elev:	?’ = ?’ + ?’
Top of Platform Elev:	?’ MSL
Ground Level Elev:	?’ MSL
Perforations:	*1600’ – 1620’* (TBD) TCP Charges 6 spf 60 deg phase
Packer Top:	*1550’* (TBD)
Reservoir Pressure:	Estimated *700 psi* (TBD)
Well Status:	Completion has been run as shown on attached well schematic. No perforating has been done. Note Promore Gauge at *1500’* (TBD) 2-3/8” x 4-1/2” annulus freeze protected to 200’ with diesel
Objectives:	1) Perform operations without any accidents or spills 2) Test Hydrate interval for flow rate potential, gas composition, and reservoir pressure 3) Obtain quality pressure data during flow and shut-in periods 4) Obtain quality fluid samples for laboratory analysis 5) Suspend the well by setting a plug in production tubing

Test Procedure

Complete Rig Up of Test Equipment

1. Confirm that a copy of Anadarko Hot Ice No. 1 Air Permit is on location.

2. Conduct pre-job safety meeting.

3. Confirm that power to downhole heat trace has been turned on.

4. Rig up secondary containment around separator. RU surface test equipment according to attached equipment layout. Pressure test lines to flare and liquid lines downstream of separator to heated fluid tank to 100 psia with air for 15 minutes.

5. Rig up a line from the mud pump into a tee on the flowline with an isolation valve. (This will allow the well to be killed if required during the well test without changing the lines.) Ensure master valves are closed. Wing valve, surface safety valve and choke should be open. Fill surface lines with heated diesel. Test from wellhead to separator outlet valves to 200 psi. Check bottomhole pressure gauge and make sure that the master valves are holding. Increase test pressure to 400 psi. Check BHP to verify that master valves are holding prior to increasing test pressure above 400 psi. Shut valve upstream of the separator, and pressure test from wellhead to separator inlet to 1500 psi with heated diesel for 15 minutes. Shut Halliburton 3-1/8" surface safety valve. Bleed off pressure downstream of the SSV and observe pressure on wellhead to verify that the SSV will hold pressure. Note: tree should have been tested after installation to 4000 psi up through the wing valve.

6. Complete heat trace and insulation of all surface test lines.

7. Purge lines with nitrogen.

Perforate: TCP Guns

NOTE: Promore surface readout gauges will be run in place with the completion.

8. Obtain a hot work permit for flaring/venting prior to conducting safety meeting.

9. Conduct pre-job safety meeting.

10. Check annular pressure. Rig up steel line on top of crown valve. Verify that wing valve, surface safety valve and choke are closed. Separator bypass valve should be open to tank to relieve any pressure if the wing and SSV leak. Shut crown valve and pressure test line to 4000 psi using diesel.

11. Increase data-acquisition rate on Promore ProVision data-acquisition unit. Open crown valve. Pressure up on tubing to 2700 psi and hold the pressure for 1 minute. Open wing valve and SSV. Bleed off pressure to tank through separator bypass line by slowly opening choke. Leave separator bypass valve open. Monitor wellhead and bottom-hole pressure gauge to ensure that guns fired. If guns do not fire, close wing valve and pressure up to 4000 psi wellhead pressure, hold pressure for 1 minute then bleed off

pressure. Shut in separator bypass valve and monitor data header to determine if the surface pressure is increasing.

12. Close the crown valve. RD lines used to pressure up tubing. Determine if there is any pressure on the well. If BHP has not increased, rig-up swabbing equipment per attached swabbing procedure. If BHP is building, install tree cap, pressure gauge and attempt to flow well.

13. Verify that surface safety valve and wing valve are open and then close the choke. Light pilot light on flare. Determine if well will flow to separator by gradually opening the choke. Monitor annulus pressure. If well stops flowing, consult with onsite Anadarko Engineer about rigging up swab equipment. A decision on flaring or venting will be made based on the production rate, wind and other considerations.

14. It is anticipated that the well will be flow/swab tested for 5 days. Length of flowing time will be dependent on how the well responds.

15. At the end of the flow period, use Schlumberger slickline to set a plug to suspend the well. Shut crown valve, remove tree cap or swab equipment. RU slickline lubricator. Pressure-test lubricator to 1000 psi with diesel. Set A-2 plug with CS lock in Schlumberger DS NO-GO landing nipple with 1.875" bore @ 1500' to suspend well.

16. Leave well shut in for twice the flow period. If well will be suspended and not plugged, production tubing should be freeze protected. Swab produced fluid from production tubing down below the permafrost. Fill tubing with diesel to prevent formation of hydrates and ice. Install 2" ISA 100 back-pressure valve in tubing hanger. The downhole heat trace can be turned off after production tubing has been freeze protected.

Plug and abandonment procedures to be outlined separately as appropriate.

Prepared by:	______________________ D. L. Copeland	________ Date
Approvals:	______________________ T. Thompson	________ Date
	______________________ J. Cox	________ Date
	______________________ Keith Millheim	________ Date