Oil and Natural Gas Technology

Cooperative Research Agreement Award Number DE-FC-01NT41332

4Q2012 – 1Q2013 Semi-Annual Progress Report

Forty-First and Forty-Second Quarterly Reports: October 2012 – March 2013

Resource Characterization and Quantification of Natural Gas Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay – Kuparuk River Area on the North Slope of Alaska

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United States Department of Energy
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Office of Fossil Energy

DISCLAIMER

PROJECT ABSTRACT

BP Exploration (Alaska), Inc. (BPXA) and the U.S. Department of Energy (DOE) co-sponsor this gas hydrate Cooperative Research Agreement (CRA) project in collaboration with the U.S. Geological Survey (USGS) to help determine whether or not gas hydrate can become a technically and commercially viable gas resource. Studies have included reservoir characterization, reservoir modeling, and associated research which indicated that up to 12 TCF gas may be technically recoverable from 33-44 TCF gas-in-place (GIP) within the Eileen gas hydrate accumulation beneath industry infrastructure within the Milne Point Unit (MPU), Prudhoe Bay Unit (PBU), and Kuparuk River Unit (KRU) areas on the Alaska North Slope (ANS). To further constrain these estimates and to enable the selection of a test site for further data acquisition, the USGS reprocessed and interpreted MPU 3D seismic data provided by BPXA to delineate 14 MPU prospects interpreted to contain significant highly saturated gas hydrate-bearing sand reservoirs. The “Mount Elbert” site was selected to drill a stratigraphic test well to acquire a full suite of wireline log, core, and formation pressure test data. Drilling results and data interpretation confirmed pre-drill predictions and thus increased confidence in both the prospect interpretation methods and in the wider ANS gas hydrate resource estimates. The interpreted data from the Mount Elbert well provide insight into and reduce uncertainty of key gas hydrate-bearing reservoir properties, enable further refinement and validation of the numerical simulation of production potential of both MPU and broader ANS gas hydrate resources, and help determine viability of potential field sites for future extended term production testing. Drilling and data acquisition operations demonstrated that gas hydrate scientific research programs can be safely, effectively, and efficiently conducted within ANS infrastructure. The program success resulted in a recommendation to Stakeholders to drill and complete a long term production test within ANS infrastructure. If approved, this long term test would build on prior arctic research efforts to better constrain the potential gas rates and volumes that could be produced from gas hydrate bearing sand reservoirs and would provide a unique, valuable dataset that cannot be obtained from existing or planned desktop research or laboratory studies. Proximity to resource, industry technology, and infrastructure combine to make the ANS an ideal site to evaluate gas hydrate resource potential through long-term production testing. Designs under consideration would initially evaluate depressurization technologies and if necessary, extend into a sequence of increasingly complex stimulation procedures, possibly including thermal, chemical, and/or mechanical. Results might also be applied to help determine the resource potential of offshore gas hydrate resources in the GOM and in other continental shelf areas.

ACKNOWLEDGEMENTS

The DOE-BPXA CRA helps facilitate industry interest in the resource potential of shallow natural gas hydrate accumulations. DOE, USGS, and BPXA support of these studies is gratefully acknowledged. DOE National Energy Technology Lab staff Brad Tomer, Ray Boswell, Richard Baker, Edith Allison, Tom Mroz, Kelly Rose, Eilis Rosenbaum, and others have enabled continuation of this and associated research projects. Scott Digert, Gordon Pospisil, and others at BPXA have promoted the importance of this cooperative research within industry. BPXA staff Micaela Weeks, Larry Vendl, Dennis Urban, Dan Kara, Paul Hanson, and others supported stratigraphic test well plans and successfully implemented Phase 3a well operations and data acquisition. The State of Alaska Department of Natural Resources through the efforts and leadership of Dr. Mark Myers, Bob Swenson, Paul Decker, and others has consistently recognized the contribution of this research toward identifying a possible additional unconventional gas resource and actively supported the Methane Hydrate Act to help enable continued funding of these studies.

The USGS has led ANS gas hydrate research for three decades. Dr. Timothy Collett coordinates USGS partnership in the BPXA-DOE CRA. Seismic and associated reservoir characterization studies accomplished by Tanya Inks (Interpretation Services) and by USGS scientists Tim Collett, Myung Lee, Warren Agena, and David Taylor identified multiple MPU gas hydrate prospects. Support by USGS staff Bill Winters, Bill Waite, and Tom Lorenson and Oregon State University staff Marta Torres and Rick Colwell is gratefully acknowledged. Steve Hancock (RPS Energy) and Peter Weinheber (Schlumberger) helped design and implement MDT wireline testing. Scott Wilson at Ryder Scott Co. has progressed reservoir models from studies by the University of Calgary (Dr. Pooladi-Darvish) and the University of Alaska Fairbanks (UAF). Dr. Shirish Patil and Dr. Abhijit Dandekar have maintained the UAF School of Mining and Engineering as an arctic region gas hydrate research center. University of Arizona reservoir characterization studies led by Dr. Bob Casavant with Dr. Karl Glass, Ken Mallon, Dr. Roy Johnson, and Dr. Mary Poulton also described the structural and stratigraphic architecture of Eileen accumulation ANS Sagavanirktok formation gas hydrate-bearing reservoirs.

Related studies of gas hydrate resource potential are too numerous to mention here. National Labs studies include Dr. Pete McGrail, CO_2 injection experiments, and Dr. Mark White, reservoir modeling, at Pacific Northwest National Lab and Dr. George Moridis, reservoir modeling, and Dr. Jonny Rutqvist, geomechanics, at Lawrence Berkeley National Lab. Dr. Joe Wilder and Dr. Brian Anderson have led significant efforts of an International Reservoir Modeling Comparison team. The Colorado School of Mines under the leadership of Dr. Dendy Sloan and Dr. Carolyn Koh continue to progress laboratory and associated studies of gas hydrate. The significant efforts of international gas hydrate research projects such as those supported by the Directorate General of Hydrocarbons by the government of India and by the Japan Oil, Gas, and Metals National Corporation (JOGMEC) with the government of Japan and by others are significantly contributing to a better understanding of the resource potential of natural methane hydrate. JOGMEC and the government of Canada support of the 2002 and 2007-2008 Mallik project gas hydrate studies in Northwest Territories, Canada are gratefully acknowledged. This DOE-BPXA cooperative research project builds upon the accomplishments of many prior government, academic, and industry studies.

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1.0 LIST OF TABLES AND FIGURES

2.0 EXECUTIVE SUMMARY

Accomplishments during the October 2012 through end-March 2013 reporting period were minimal due to reduced-scope activities pending Stakeholder agreement for project continuation. Phase 3a operations and associated studies are complete.

3.0 CURRENT STATUS REPORT

3.1 Continuation Application Status

Stakeholder consensus is required before submitting a Continuation Application for a long-term production test (Phase 3b). The Milne Point Unit (MPU) area is under consideration for testing.

Project activities remain at a reduced scope; contract Amendment 31 extended the project period through end-March 2014 and contract Amendment 33 extended the current budget period through end-September 2013.

3.2 Cost Status

Table 1 estimates project cost status through end-1Q13. Project cost-share remains to be updated with in-kind data, staff, and cash contributions for Phase 3a work.

Total Federal Share Estimate	**$9,799,741.79**	Processed invoices and estimated accruals
Total Federal Funds input	**$9,819,507.00**	Federal funds input to ASAP Account
Total Federal-share invoices	**$9,629,796.30**	Through end-1Q2013
US Treasury Account Balance	**$189,710.70**	Remaining funds in ASAP Account
Estimated Outstanding Invoices	**$189,000.00**	Estimated Unprocessed invoices
Estimated Project Account Balance	**$710.70**	Minimum Estimate Balance

Table 1: Estimated project cost status and remaining Phase 3a project funds, including accruals

3.3 4Q12 – 1Q13 Reporting Period Significant Accomplishments

No significant accomplishments occurred during the reporting period.

3.4 Actual or Anticipated Problems, Delays, and Resolution

Contract Amendment 31 authorized project extension through end-March 2014. Contract Amendment 33 authorized no-cost extension through end-September 2013.

4.0 ACCOMPLISHMENTS SUMMARY, 4Q12 and 1Q13

4.1 External Communications, Reporting, and Contracts

- Submitted semi-annual 2Q12 through 3Q12 technical progress report
    - Documented minimal reduced scope during reporting period
- Tracked financial status; calculated, reviewed, and submitted quarterly financial reports
- Participated in project teleconferences with USGS and DOE
- Updated FedConnect database; transferred from Central Contractor Registration (CCR) to System for Award Management (SAM) database

4.2 Internal Communications and Reporting

- Maintained contracts, recommendations, files, correspondence, and electronic backups
- Attended March 2013 ConocoPhillips workshop on results of Ignik Sikumi test well
- Networked gas hydrate research within BP GOM, EPT, and R&D communities
    - Compiled past project accomplishments and related research
    - Tracked gas hydrate Research and Development synergies to Alaska operations
        - Considering MPU testing option with synergy to future facility fuel gas

5.0 PROJECT INTRODUCTION

This Cooperative Research Agreement (CRA) between BP Exploration (Alaska), Inc. (BPXA) and the U.S. Department of Energy (DOE) in collaboration with the U.S. Geological Survey (USGS) helps characterize and assess Alaska North Slope (ANS) methane hydrate resources and identify technical and commercial factors to enable a better understanding of the future development potential of this unconventional energy resource. Results of reservoir characterization, reservoir modeling, regional schematic modeling, and associated studies culminated in the 2007 Mount Elbert Stratigraphic Test, which acquired extensive core, wireline log, and formation pressure data to help mitigate potential recoverable resource uncertainty. The stratigraphic test results and data analyses in the Journal of Marine and Petroleum Geology (JMPG) were published in Boswell, et al., 2011). Future production testing remains a key goal of the program, but this is still under evaluation by Stakeholders at this time.

Gas and water combine under appropriate pressure-temperature conditions within both subsea and onshore arctic region sediments to form gas hydrate, a solid that may contain a significant portion of worldwide natural gas resources (Collett, 2002). Natural gas hydrate accumulations require the presence of all petroleum system components (source, migration, trap, seal, charge, and reservoir) within the gas hydrate stability conditions depicted in Figure 1. For example, in Figure 1, the temperature profile projected to an assumed permafrost base of 610 m intersects the 100% methane-hydrate stability curve at about 200 m, thus marking the upper boundary of the methane-hydrate stability zone. A geothermal gradient of 4.0°C/100 m projected from the base of permafrost at 610 m intersects the 100% methane-hydrate stability curve at about 1,100 m; thus, the methane hydrate stability zone in this example is approximately 900 m thick.

The USGS conducted the first systematic assessment of the in-place natural gas hydrate resources of the United States (Collett, 1995) and estimated that ANS gas hydrates within and beneath permafrost contain a mean 590 trillion cubic feet (TCF) gas-in-place (GIP) (Figures 2 and 3). Of this total, 100 TCF estimated GIP may be trapped within the gas hydrate-bearing formations of the "Eileen" and "Tarn" gas hydrate accumulations (Collett, 1993) in close proximity to established ANS oil and gas production infrastructure within the Prudhoe Bay Unit (PBU), Kuparuk River Unit (KRU), and Milne Point Unit (MPU) field areas (Figures 3, 4, 5). Over 33 TCF GIP hydrate resources are interpreted within gas hydrate-bearing Sagavanirktok reservoir units E, D, C, B, and A within the Eileen accumulation in this area (Figures 4, 5, 6). The probabilistic volumetric assessment (Collett, 1995) did not identify or characterize the nature of individual gas hydrate accumulations or assess estimated ultimate recovery (EUR). Significant challenges remain in quantifying the fraction of these in-place resources that might become a technically-feasible or possibly a commercial natural gas reserve. Additional USGS studies estimate a mean 85.4 TCF undiscovered, technically recoverable gas hydrate resources beneath the North Slope of Alaska (Table 2; Collett et al., 2008).

The USGS interpreted a MPU 3D seismic volume provided by BPXA to characterize gas hydrate resource potential. The study identified 14 sub-permafrost gas hydrate prospects containing an estimated mean 668 BCF GIP within the MPU portion of the Eileen accumulation (Figures 4, 5, 6, 7; Table 3; Lee et al., 2009; Lee et al., 2010; Inks et al., 2009). The Mount Elbert prospect was selected after comparative review of these prospects as interpretation indicated a greater probability of achieving stratigraphic test program data acquisition objectives at this site.

Historically, ANS gas hydrates were considered a shallow drilling hazard to the hundreds of well penetrations targeting deeper oil-bearing formations rather than a potential gas resource. Interpreted occurrence of gas hydrate within Eocene Sagavanirktok Formation shallow sand reservoirs was originally confirmed by log, core, and Drillstem Test (DST) data acquired in the first ANS dedicated gas hydrate test within the Northwest Eileen State-02 (NWEIL-02) well, drilled in 1972 (Figures 4, 5; Collett, 1993). NWEIL-02 DST data indicate limited gas production at a calculated maximum rate of only 3,960 cubic feet/day (CF/d). Since that time, active investigation of gas hydrate recoverable resource potential has been limited due to no ANS gas export infrastructure, assumed low-rate production potential, unknown production methods, and lack of real-world, field-scale data to validate laboratory experiments and reservoir models. However, studies supported by this CRA and other studies have improved characterization of ANS gas hydrate-bearing reservoirs, provided reservoir simulations to help better understand gas hydrate dissociation processes, and recognized significant gas hydrate energy resource potential.

Past unconventional resource research and development was commonly hindered by a lack of proven positive examples necessary before generating stand-alone interest from industry. This pre-development condition held true for tight gas resources in the 1950-1960's, coal-bed-methane plays in the 1970-1980's and shale gas/oil resources in the 1990-2000's. In each case, the resource was thought to be technically infeasible and uneconomic until the combination of market, technology (new or newly applied), and positive field experience helped motivate widespread adoption of unconventional recovery techniques in an effort to prove whether or not the resource could be technically and commercially produced.

In an attempt to bridge this gap, gas hydrate reservoir modeling efforts were coupled with a regional schematic model to quantify potential recoverable resource within the Eileen accumulation (Figure 6; Wilson, et al., 2010). Production forecast and regional schematic modeling studies included downside, reference, and upside cases. Reference case forecasts with type-well depressurization-induced production rates of 0.4-2.0 MMSCF/D predicted that 2.5 TCF of gas might be produced in 20 years, with 10 TCF ultimate recovery after 100 years from the 33 TCF GIP. The downside case envisioned research pilot failure and economic or technical infeasibility. Upside cases identified additional potential recoverable resource. These studies included rate forecasts and hypothetical well scheduling, methods typically employed to evaluate potential conventional large gas development projects (additional detail available from June 2006 Quarterly Technical Report Fifteenth Technical Quarterly Report, July 31, 2006 and also from Wilson, et al., 2010).

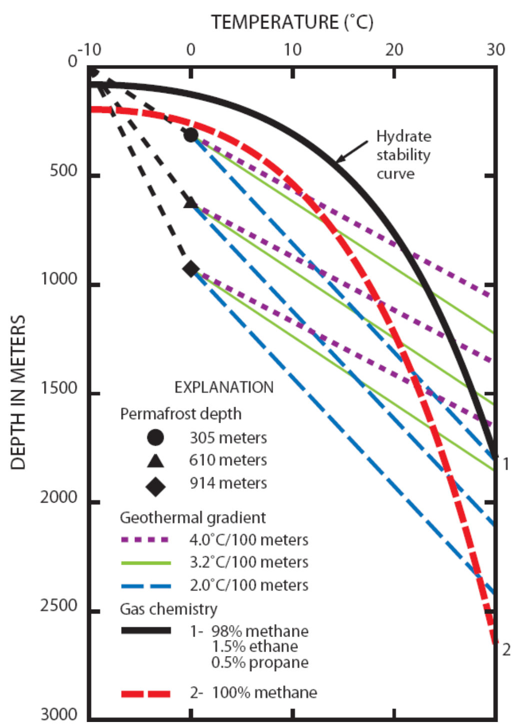

Figure 1: Gas Hydrate Stability Phase diagram (after Collett et al., 2010) shows effects of variable formation temperature, pore pressure, and gas composition on gas hydrate stability within depths between intersections of geothermal gradient and gas-hydrate stability curve.

These reservoir simulation and regional schematic studies culminated in recommendations to drill the Mount Elbert Stratigraphic Test (Figure 7, Table 3), which acquired reservoir data including extensive core, wireline log, and formation pressure data between February 3-19, 2007. Significantly, this well effectively proved the ability to safely conduct drilling and extended data acquisition and pressure testing operations within the hydrate-bearing formations. Demonstrated Stratigraphic Test technical success and data interpretation improved understanding of uncertainties, validated reservoir production simulations, and led to an evaluation of potential long-term production test sites in one of four general areas within ANS infrastructure (Figure 8). If approved by Stakeholders, a future long-term ANS test would build on the successful short-term production test conducted in March 2008 at the Mallik site in the MacKenzie Delta by the governments of Japan and Canada, and on the successful 2012 ANS Ignik Sikumi medium-term production test, both of which indicated the technical feasibility of gas production from gas hydrate by conventional depressurization and by CO_2-replacement technology, respectively.

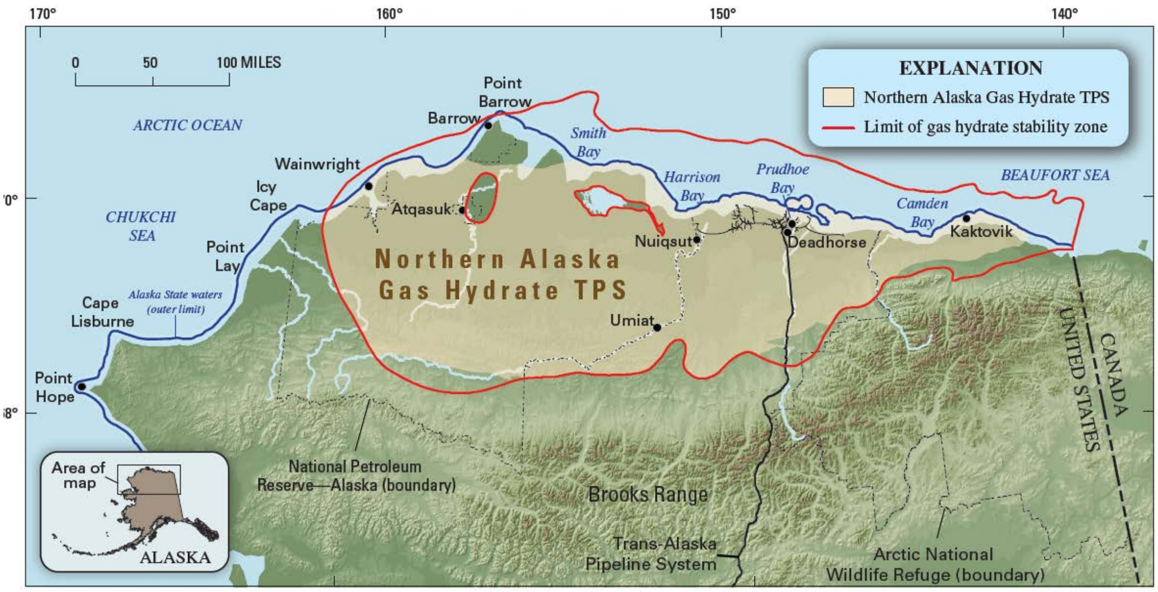

Figure 2: Northern Alaska Gas Hydrate Total Petroleum System (TPS) (shaded in tan), and the limit of gas hydrate stability zone in northern Alaska (red outline); USGS Fact Sheet 2008-3073.

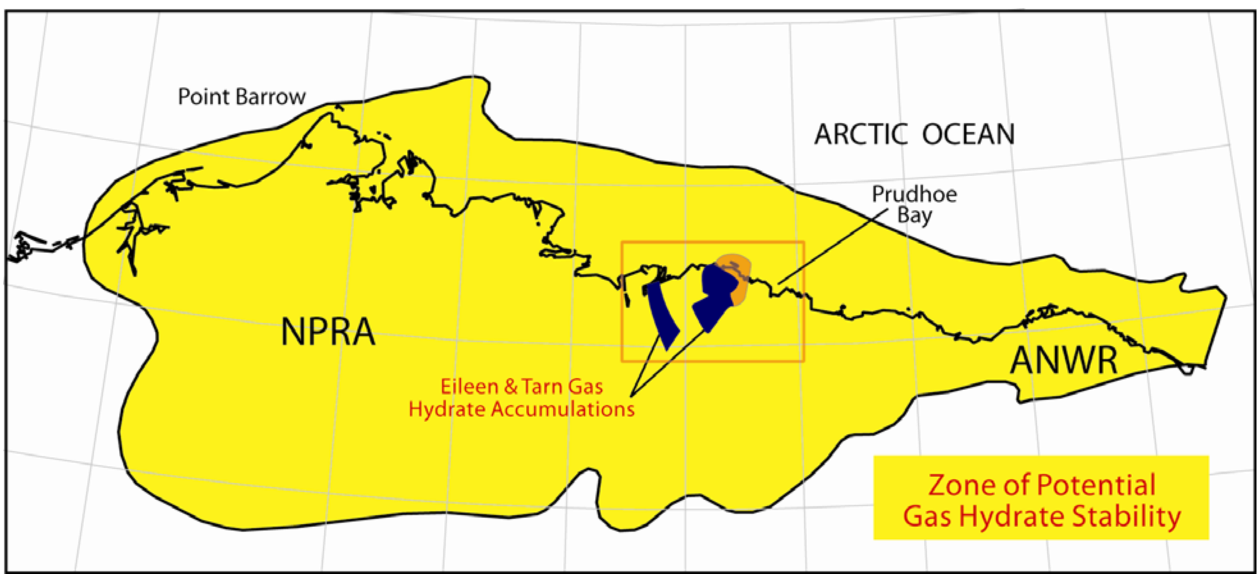

Figure 3: ANS gas hydrate stability zone (red outline of Figure 2) containing an estimated mean 590 TCF GIP showing Eileen and Tarn gas hydrate accumulations after Collett (1993 and 1995).

Although the technical recovery has been modeled for the ANS and proven possible in short-term production testing at the Mallik site and medium-term production testing at the Ignik Sikumi site, the economic viability of gas hydrate production will remain uncertain until sufficient field testing constrains long-term production rates, predicts EUR volume, and defines and implements applicable production technologies. Additional data acquisition and future production testing would help determine the technical feasibility of depressurization-induced or stimulated dissociation of gas hydrate into producible gas. Long-term production testing is not currently approved, although implementation of the designs at one of the sites under evaluation would provide a unique, valuable dataset that cannot be obtained from existing or planned desktop research or laboratory studies. Proximity to resource, industry technology, and infrastructure combine to make the ANS an ideal site to evaluate gas hydrate resource potential. Future exploitation of gas hydrate would require developing feasible, safe, and environmentally-benign production technology, initially within areas of industry infrastructure. The ANS onshore area within the Eileen accumulation area favorably combines a well-characterized gas hydrate petroleum system with accessible infrastructure and technology. Long-term production testing, if approved, would initially evaluate depressurization technologies and if necessary, extend into a sequence of increasingly complex thermal, chemical, and mechanical stimulation procedures. The information and technology being developed in this onshore ANS program might also help determine the resource potential of the potentially much larger marine gas hydrate resources in the GOM and in other continental shelf areas. If gas can be technically produced from gas hydrate and if studies help prove production capability at economically viable rates, then methane dissociated from ANS gas hydrate could possibly help supplement field operations fuel-gas, provide additional lean-gas for reservoir energy pressure support, sustain long-term production of portions of the geographically-coincident 20-25 billion barrels viscous oil resource, and/or supplement conventional export-gas in the longer term.

Total Petroleum System and Assessment Unit	Field Type	Total Undiscovered Resources							
		Gas (BCFG)				NGL (MMBNGL)			
		F95	F50	F5	Mean	F95	F50	F5	Mean
Northern Alaska Gas Hydrate TPS									
Sagavanirktok Formation Gas Hydrate AU	Gas	6,285	19,490	37,791	20,567	0	0	0	0
Tuluvak-Schrader Bluff-Prince Creek Formations Gas Hydrate AU	Gas	8,173	26,532	51,814	28,003	0	0	0	0
Nanushuk Formation Gas Hydrate AU	Gas	10,775	35,008	68,226	36,857	0	0	0	0
Total Undiscovered Resources		**25,233**	**81,030**	**157,831**	**85,427**	**0**	**0**	**0**	**0**

Table 2: ANS EUR gas hydrate resource (USGS Fact Sheet 2008-3073). Sagavanirktok Assessment Unit (AU) includes Eileen accumulation infrastructure area (Figure 4).

Prospect Name	**Bulk Rock Volume (m^3)**	**Acres**	**Porosity**	**Net to Gross**	**Gas Saturation**	**GIP (BCF)**
Mt. Antero C	66,545,880	955	38%	80%	66.1%	75.2
Mt. Bierstadt "D"	31,704,181	268	37%	80%	49.8%	32.3
Mt. Bierstadt "E"	34,891,823	332	39%	80%	66.9%	41.8
Blanca Peak "C"	20,977,026	328	38%	80%	55.1%	22.4
Crestone Peak C	179,796,792	1728	38%	80	49.8	185.8
Mt. Elbert "C"	84,961,956	1106	38%	80%	59.7%	93.3
Mt. Elbert "D"	49,876,375	267	37%	80%	52.6%	52
Grays Peak "B"	5,771,419	85	38%	80%	47.2%	5.8
Maroon Peak "A"	26,261,864	375	38%	80%	81.2%	32.8
Mt. Princeton "D"	36,580,949	449	37%	80%	53.2%	38.2
Pikes Peak "B"	11,261,848	298	38%	80%	68.8%	13.2
Redcloud Peak "B"	16,580,030	194	38%	80%	58.1%	18
Mt. Sneffels "D"	42,949,487	516	37%	80%	57.6%	46.2
Uncompahgre Peak "D"	11,056,564	167	37%	80%	49.3%	11.2
E Combined	**34,891,823**	**332**	**39%**	**80%**	**66.9%**	**41.8**
D Combined	**172,167,556**	**1667**	**37%**	**80%**	**52.5%**	**179.9**
C Combined	**352,281,654**	**4117**	**38%**	**80%**	**57.7%**	**376.7**
B Combined	**33,613,297**	**577**	**38%**	**80%**	**58.03%**	**37**
A Combined	**26,261,864**	**375**	**38%**	**80%**	**81.2%**	**32.8**
TOTAL	**619,216,195**	**7068**	**38%**	**80%**	**63.3%**	**668.2**

Table 3: ANS MPU gas hydrate prospect reservoir properties (after Inks et al, 2010).

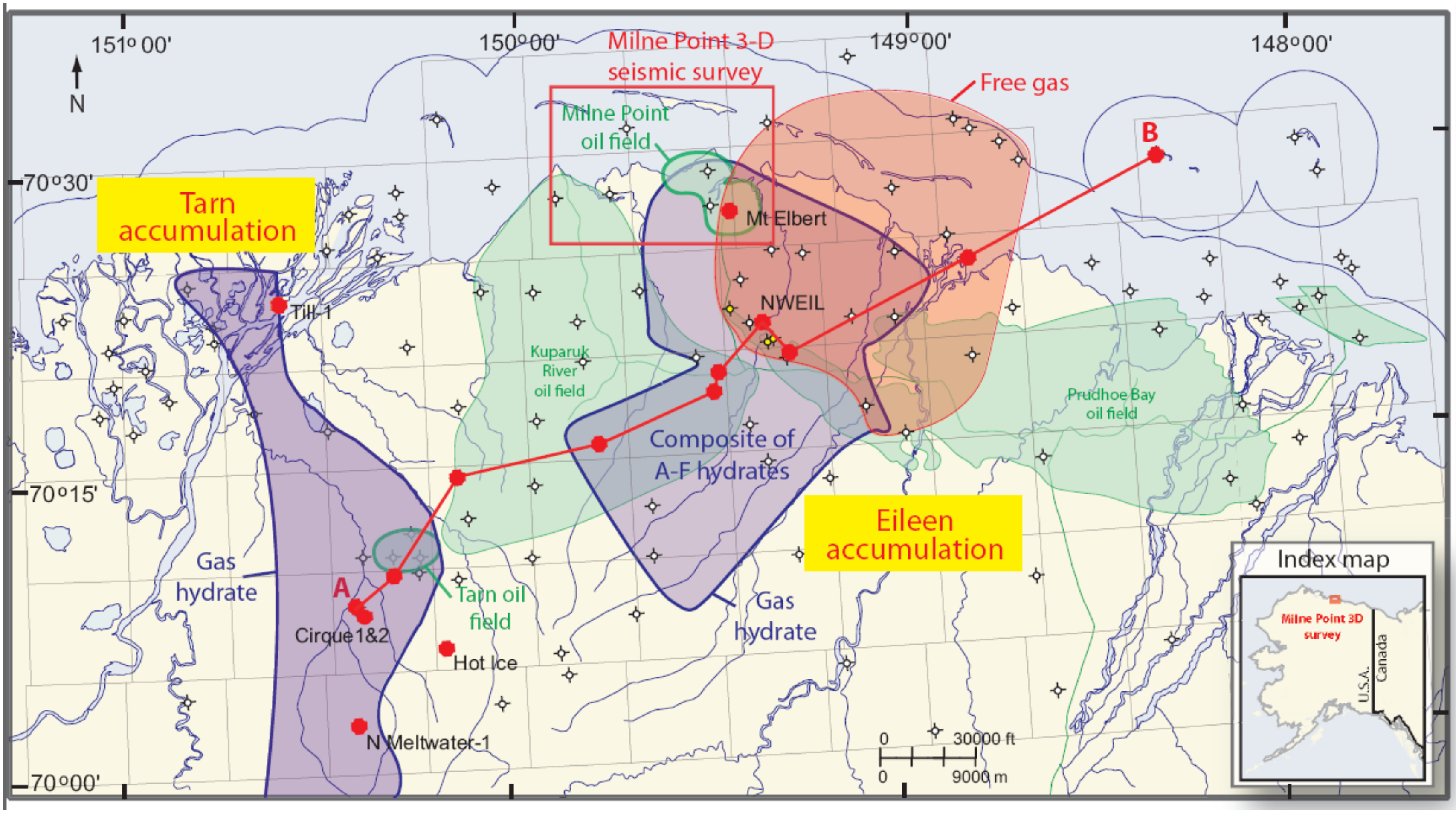

Figure 4: Eileen and Tarn Gas Hydrate Accumulations and ANS Field Infrastructure (modified after Collett et al, 2010). Estimated Eileen accumulation GIP = 33 TCF with EUR 2 - 12 TCF (Wilson et al, 2011).

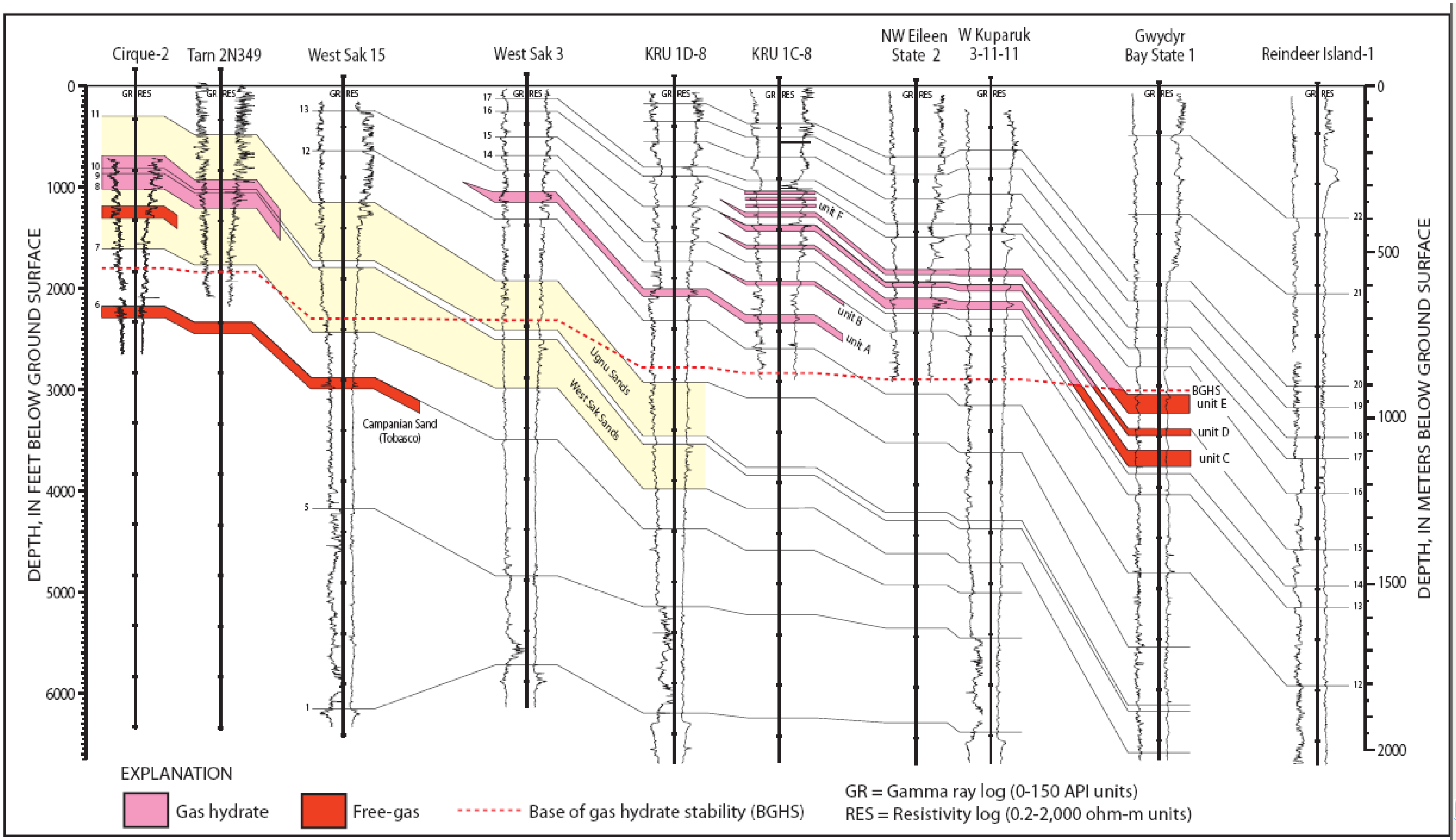

Figure 5: Well log cross-section (Red line of section A-B shown in Figure 4) illustrating gas hydrate-bearing formations within the Eileen and Tarn accumulations (Collett, et al, in-press). Informal Sagavanirktok Formation units A through F are shown within the Eileen accumulation. Log correlation markers, shown by numbered solid lines, are used to construct a regional stratigraphic framework (modified from Collett, 1993, Collett, et al, 2011).

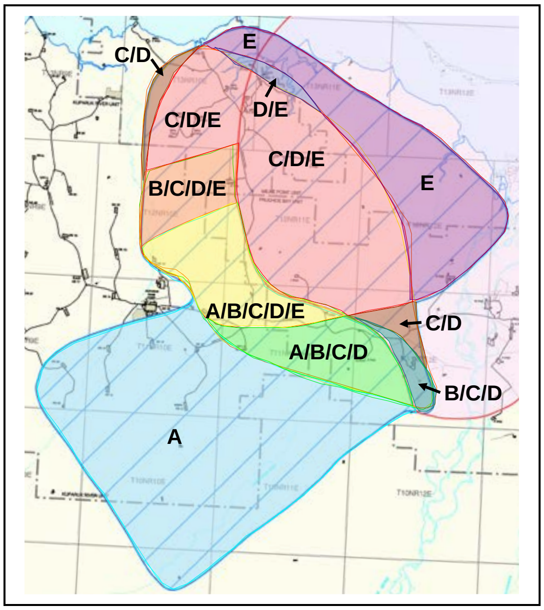

Figure 6: Interpreted gas hydrate-bearing Sagavanirktok units A through E in map of Eileen accumulation (modified from Collett, 1993) used to construct regional schematic model (Wilson, et al., 2011).

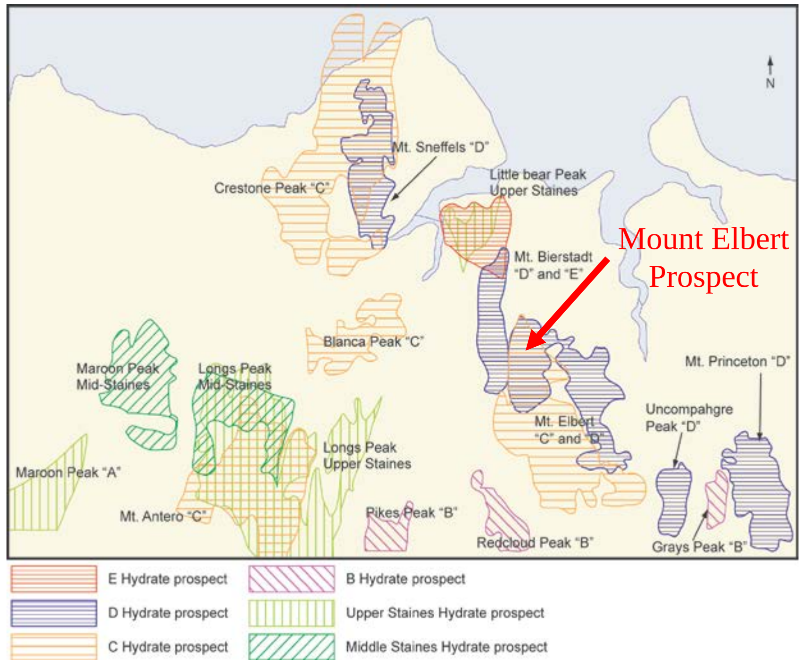

Figure 7: MPU gas hydrate prospects interpreted from 3D seismic, including Mount Elbert (Inks, T., Lee, M., Taylor, D., Agena, W., Collett, T. and Hunter, R., 2009).

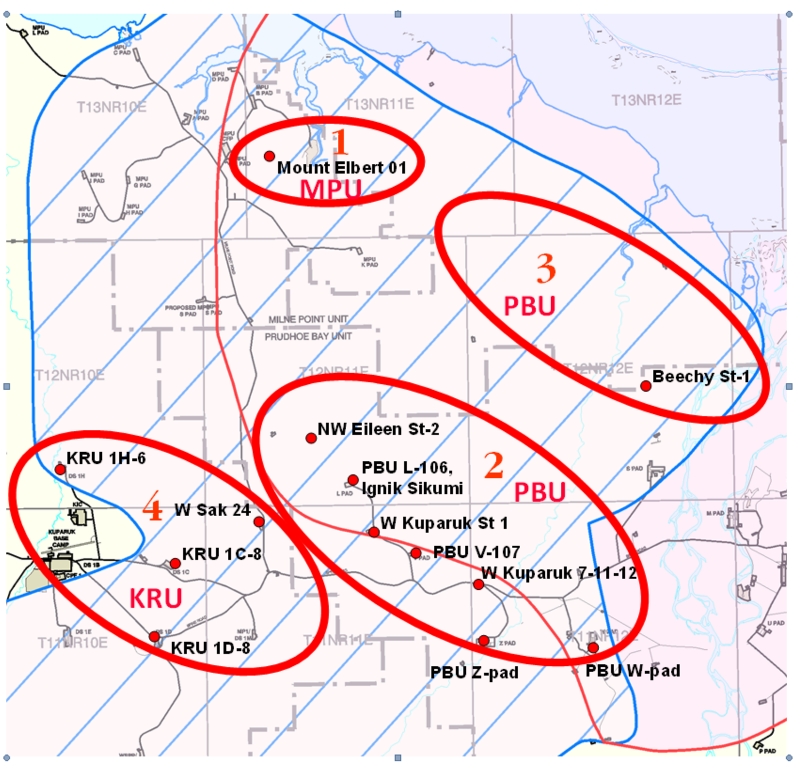

Figure 8: Eileen gas hydrate accumulation composite Sagavanirktok zones A, B, C, D, E (blue striped area; also Figure 6) with 4 areas-of-interest for a potential future long-term production test site.

5.1 Project Task Schedules and Milestones

5.1.1 U.S. Department of Energy Milestone Log, Phase 1, 2002-2004

Program/Project Title: DE-FC26-01NT41332: Resource Characterization and Quantification of Natural Gas Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay - Kuparuk River Area on the North Slope of Alaska. (Phase 1 scope-of-work in contract amendments 1-8).

Identification Number	Description	Planned Completion Date	Actual Completion Date	Comments
Task 1.0	Research Management Plan	12/02 – 12/04	12/02	Subcontracts Completed
Task 2.0	Provide Technical Data and Expertise	MPU: 12/02 PBU: * KRU: *	MPU: 12/02 PBU: * KRU: *	See Technical Progress Reports
Task 3.0	Wells of Opportunity Data Acquisition	Ongoing in Phase 2-3	Ongoing in Phase 2-3	See Technical Progress Reports
Task 4.0	Research Collaboration Link	Ongoing in Phase 2-3	Ongoing in Phase 2-3	See Technical Progress Reports
Subtask 4.1	Research Continuity	Ongoing in Phase 2-3	Ongoing in Phase 2-3	
Task 5.0	Logging and Seismic Technology Advances	Ongoing in Phase 2-3	Ongoing in Phase 2-3	See Technical Progress Reports
Task 6.0	Reservoir and Fluids Characterization Study	12/04	final report received 9/09	Interim Results presented, 2004 Hedberg Conference
Subtask 6.1	Characterization and Visualization	12/04	final report received 9/09	Interim Results presented, 2004 Hedberg Conference
Subtask 6.2	Seismic Attributes and Calibration	12/04	final report received 9/09	Interim Results presented, 2004 Hedberg Conference
Subtask 6.3	Petrophysics and Artificial Neural Net	12/04	final report received 9/09	Interim Results presented, 2004 Hedberg Conference
Task 7.0	Laboratory Studies for Drilling, Completion, Production Support	6/04	6/04	
Subtask 7.1	Characterize Gas Hydrate Equilibrium	6/04	6/04	Results presented, 2004 Hedberg Conference
Subtask 7.2	Measure Gas-Water Relative Permeabilities	6/04	6/04	Results presented, 2004 Hedberg Conference
Task 8.0	Evaluate Drilling Fluids	12/04		
Subtask 8.1	Design Mud System	11/03		
Subtask 8.2	Assess Formation Damage	9/05	Into Phase 2	
Task 9.0	Design Cement Program	12/04		
Task 10.0	Study Coring Technology	2/04	2/04	
Task 11.0	Reservoir Modeling	12/04	Ongoing in Phase 2-3	Interim Results presented, 2004 Hedberg Conference
Task 12.0	Select Drilling Location and Candidate	9/05	Ongoing in Phase 2-3	Topical Report submitted, June 2005
Task 13.0	Project Commerciality & Phase 2 Progression Assessment	9/05	Redesigned 2005 Phase 2	BPXA and DOE decision

* Release as limited-rights data would be dependent on industry partner agreement

5.1.2 U.S. Department of Energy Milestone Log, Phase 2, 2005-2006

Program/Project Title: DE-FC26-01NT41332: Resource Characterization and Quantification of Natural Gas Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay - Kuparuk River Area on the North Slope of Alaska. (Phase 2 scope-of-work in contract Amendment 9).

Identification Number	Description	Planned Completion Date	Actual Completion Date	Comments
Task 1.0	Research Management Plan	1/05 – 1/06	1/06	Subcontracts Completed
Task 2.0	Provide Technical Data and Expertise	MPU: 12/02 PBU: * KRU: *	MPU: 12/02 PBU: * KRU: *	See Technical Progress Reports
Task 3.0	Wells of Opportunity Data Acquisition	Ongoing	Ongoing	See Technical Progress Reports
Task 4.0	Research Collaboration Link	Ongoing in Phase 2-3	Ongoing in Phase 2-3	See Technical Progress Reports
Subtask 4.1	Research Continuity	Ongoing in Phase 2-3	Ongoing in Phase 2-3	
Task 5.0	Logging and Seismic Technology Development and Advances	Ongoing in Phase 2-3	Ongoing in Phase 2-3	See Technical Progress/Topical Reports
Task 6.0	Reservoir and Fluids Characterization Study	12/06	final report received 9/09	
Subtask 6.1	Structural Characterization	12/06	final report received 9/09	
Subtask 6.2	Resource Visualization	12/06	final report received 9/09	
Subtask 6.3	Stratigraphic Reservoir Model	12/06	final report received 9/09	
Task 7.0	Laboratory Studies for Drilling, Completion, Production Support	12/06		Some Hiatus; Phase 2-3a design, studies, & decision
Subtask 7.1	Design Mud System	12/05	Completed	
Subtask 7.2	Assess Formation Damage	1/06	Completed	
Subtask 7.3	Measure Petrophysical and Other Physical Properties	9/06	To Phase 3a	No Samples Acquired; await Phase 3a acquisition
Task 8.0	Design Completion / Production Test for Gas Hydrate Well	4/06	Mt Elbert-01 stratigraphic test 2/07	Design of Phase 3a Strat Test operation Complete
Task 9.0	Field Operations and Data Acquisition Program Planning	4/06	Mt Elbert-01 stratigraphic test 2/07	Planning for Potential operations underway
Task 10.0	Reservoir Modeling and Project Commercial Evaluation	1/06	Ongoing in Phase 2-3	Regional Resource Review & Development Planning
Subtask 10.1	Task 5-6 Reservoir models	Ongoing in Phase 2-3	Ongoing in Phase 2-3	
Subtask 10.2	Hydrate Production Feasibility	1/06	Phase 2-3	
Subtask 10.3	Project Commerciality & Phase 3a Progression Assessment	1/06	Phase 2-3	January 2006 approval for Phase 3a Stratigraphic Test

* Release as limited-rights data would be dependent on industry partner agreement

5.1.3 U.S. Department of Energy Milestone Log, Phase 3a, 2006-2012

Phase 3a scope-of-work in contract Amendment 11 with additional detail provided in support of Amendments 18 and 20. Current no-cost extension Amendment 33 through end-September 2013.

Program/Project Title: DE-FC26-01NT41332: Resource Characterization and Quantification of Natural Gas Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay - Kuparuk River Area on the North Slope of Alaska

Identification Number	Description	Planned Completion Date	Actual Completion Date	Comments
Task 1.0	Research Management Plan	1/06 – 10/08	12/08	
Task 2.0	Provide Technical Data and Expertise	MPU: 12/02 PBU: * KRU: *	MPU: 12/02 PBU: * KRU: *	See Technical Progress Reports
Task 3.0	Wells of Opportunity Data Acquisition			See Technical Progress Reports
Task 4.0	Research Collaboration Link			See Technical Progress Reports
Subtask 4.1	Research Continuity			
Task 5.0	Logging and Seismic Technology Development and Advances			See Technical Progress/Topical Reports
Task 6.0	Reservoir and Fluids Characterization Study	12/07	9/09	University of Arizona contract completed
Subtask 6.1	Structural Characterization	12/07	9/09	
Subtask 6.2	Resource Visualization	12/07	9/09	
Subtask 6.3	Stratigraphic Reservoir Model	12/07	9/09	
Task 7.0	Laboratory Studies for Drilling, Completion, Production Support	9/08	Completed	Current UAF contract with DOE Arctic Energy Office
Subtask 7.1	Design Mud System	9/07	Completed	
Subtask 7.2	Assess Formation Damage	9/07	Completed	
Subtask 7.3	Measure Petrophysical and Other Physical Properties	9/07	Completed	
AEO Task 1	Relative Permeability Studies	9/08	Completed	
AEO Task 2	Minipermeameter Studies	6/08	Completed	
Task 8.0	Implement completion/production Test for gas hydrate well	3/07	3/07	Stratigraphic Test Well Drilled February 3-19, 2007
Task 9.0	Reservoir Modeling and Project Commercial Evaluation	9/08	Completed	Regional Resource Review & Development Planning
Subtask 9.1	Task 5-6 Reservoir models	9/08	As-needed	
Subtask 9.2	Project Commerciality & Phase 3b Production Test Decision	9/08	Pending	Phase 3b planning/design

* Release as limited-rights data would be dependent on industry partner agreement

5.1.4 U.S. Department of Energy Milestone Plans

(DOE F4600.3)

DOE F 4600.3# U.S. DEPARTMENT OF ENERGY FEDERAL ASSISTANCE MILESTONE PLAN: PHASE 1 (2002-2004)

1. Program/Project Identification No. DE-FC26-01NT41332	2. Program/Project Title Resource Characterization and Quantification of Natural Gas Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay - Kuparuk River Area on the North Slope of Alaska
3. Performer (Name, Address) BP Exploration (Alaska), Inc., 900 East Benson Blvd, P.O. Box 196612, Anchorage, Alaska 99519-6612	4. Program/Project Start Date 10/22/02* 5. Program/Project Completion Date 3/31/11 (through Phase 3a)

6. Identification Number	7. Planning Category (Work Breakdown Structure Tasks)	8. Program/Project Duration (Phase 1, 2002-2004) O N D J F M A M J J A S O N D J F M A M J J A S-D	9. Comments (Primary work Performer)
Task 1.0	Research Management Plan	>>!>	BPXA
Task 2.0	Technical Data and Expertise	>>>>>>----->>>>------>>>>>>>>------------>>>>>>>>-------->>>>>>>>-->>>>>>>>--!-	BPXA
Task 3.0	Wells of Opportunity - Data	------>>>>>-------------->>>>>---------->>>>>>>>>>>>>>>---------->>>>>>>>>>>>>>>!-	BPXA
Task 4.0	Research Collaboration Link	>>>!>	BPXA, USGS, UAF, UA
Task 5.0	Logging/Seismic Technology	>>!	USGS, BPXA
Task 6.0	Characterize Reservoir/Fluid	------->>!>>	UA
Task 7.0	Lab Studies: Ph Behav, Rel k	-- ----->>>!----------	UAF
Task 8.0	Evaluate Drilling Fluids	------->>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>--->>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>	UAF
Task 9.0	Design Cementing Program	------->>>>>>>>>>>>>>>>>>>>>>>>>>>>>>	UAF
Task 10.0	Study Coring Techniques	-------->>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>- --	UAF
Task 11.0	Reservoir Modeling	>>>>------------------------>>>>>>>>>------------------>>>>>>>>>>>>>>>>>>>>>>!>>>	UAF, RyderScott
Task 12.0	Drilling Candidate Selection	>>>------ ----->>>>>>------>>>>>>>>>>>>---->>>>>>>>>>>>>!	BPXA, UA, USGS, RyderScott
Task 13.0	Commerciality Assessment	>>>>>>-------------------------------->>>>>>>>-------------->>>>>>>----->>>>>>>>>	BPXA, UAF, Ryder Scott

10. Remarks * Official Contract Date 10/22/02; Funded reduced-cost pre-Phase 1 from 10/01-10/02. Phase 1 project from 10/02 through 12/04.
Explanation of Symbols: (> = Major Task Work); (- = Minor Task Work); (! = Milestones).
Additional significant milestones presented in Quarterly Technical Progress Reports.

DOE F 4600.3# U.S. DEPARTMENT OF ENERGY FEDERAL ASSISTANCE MILESTONE PLAN: PHASE 2-3a (2005-2006)

1. Program/Project Identification No. DE-FC26-01NT41332	2. Program/Project Title Resource Characterization and Quantification of Natural Gas Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay - Kuparuk River Area on the North Slope of Alaska
3. Performer (Name, Address) BP Exploration (Alaska), Inc., 900 East Benson Blvd, P.O. Box 196612, Anchorage, Alaska 99519-6612	4. Program/Project Start Date 10/22/02* 5. Program/Project Completion Date 3/31/11 (through Phase 3a)

6. Identification Task Number	7. Planning Category (Work Breakdown Structure Tasks)	8. Program/Project Duration (Phases 2-3, 2005 - 2006) ← Planning/Analysis → ← DECISION---→ ←Planning--------→← IMPLEMENTATION deferred to 2007→ J F M A M J J A S O N D J F M A M J J A S O N D	9. Comments (Primary work Performer)
Task 1.0	Contracts and Research Management Planning	>>>>>>>!>>>--->>>>>!-->>>>>>>>>>>>>>>>>>!---------------------->>---->>-->>>>>>>	BPXA, AES
Task 2.0	Technical Data and Expertise	-->>>>>>----->>>>--!---->>>>>>>>>-------!--->>>>>>>>-------->>>>>>>>-->>>>>>>>--	BPXA, AES
Task 3.0	Wells of Opportunity - Data	------------->>>>>-!------------>>>>>---!---->>>>>>>>>>>>>>>------------>>>>>>>>	BPXA, AES
Task 4.0	Research Collaboration Link	---------->>>>>>>>>!---------->>>>>>>>>>!>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>	BPXA, USGS, AES, UAF,UA
Task 5.0	Logging/Seismic Technology	>>>>>>>>>>>>>>>>>>>!>>>>>>>>>>>>>>>>>>>>!>>>>>>>>>---------------------------->>	USGS, BPXA
Task 6.0	Characterize Reservoir/Fluid	------->>>>>>>>>>>>!---------->>>>>>>>>>!>>>>>>>>>>>>>>>>---------->>>>>>>>>>>>>	UA, USGS
Task 7.0**	Lab Studies: Drilling, Completion, Production	------------>>>>>>>!---------->>>>>>>>>>!>>>>>>>----------------->----->>>>>>>>>	UAF
Task 8.0**	Stratigraphic Test Decision, Design, and Implementation	-->>>>>>>>>>>!>>>----->>>>>>>>>>>>!>>>>>>>--------------------->>>>>>>>>>>	APA, BPXA, AES, UAF
Task 9.0**	Field Operations Planning and Implementation	---->>>>>>>>>!>>>------->>>>>>>>>>!>>>>>>>--------------------->>>>>>>>>>>	APA, BPXA, AES, UAF
Task 10.0**	Reservoir Modeling and Commercial Evaluation	----->>>>>>>>>>>>>>!>>>>>>>>>>>>>>>>>---!---------------------------------------	RS, AES, BPXA, UAF

10. Remarks * Schedule shows Phases 2-3a from 2005 through end-2006. Phase 2 project from 1/05 through 12/05. Phase 3a stratigraphic test initiated 6/05 and included 9/05 Continuation Application culminating in 1/06 decision to Drill. Explanation of Symbols: >> Major Task Work; -- Minor Task Work; ! Milestone. Significant technical work and milestones presented in Technical Progress and Topical Reports. **Note new (Phase 2-3a) Task numbers.

DOE F 4600.3# U.S. DEPARTMENT OF ENERGY FEDERAL ASSISTANCE MILESTONE PLAN: PHASE 3a (2007-2008)

1. Program/Project Identification No. DE-FC26-01NT41332	2. Program/Project Title Resource Characterization and Quantification of Natural Gas Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay - Kuparuk River Area on the North Slope of Alaska
3. Performer (Name, Address) BP Exploration (Alaska), Inc., 900 East Benson Blvd, P.O. Box 196612, Anchorage, Alaska 99519-6612	4. Program/Project Start Date 10/22/02* 5. Program/Project Completion Date 3/31/14(through Phase 3a)

6. Identification Task Number	7. Planning Category (Work Breakdown Structure Tasks)	8. Program/Project Duration (Phase 3a, 2007-2008) ←Phase 3a Strat Test→←3a Analyses/Audit → 3bPlanning→←3a Analyses, 3b Decisioning & 3b Planning→ J F M A M J J A S O N D J F M A M J J A S O N D	9. Comments (Primary work Performer)
Task 1.0	Contracts and Research Management Planning	!>>>>>>!>>>--->>>>>--->>>>>>>>>>>>>>>>>!-----------------!--------->>!>>>>>>>>	BPXA, AES
Task 2.0	Technical Data and Expertise	!->>>>>>----->>>>------->>>>>>>>>-------!--->>>>>>>>------!>>>>>>>>-->!>>>>>>>--	BPXA, AES
Task 3.0	Wells of Opportunity - Data	!----------->>>>>--------------->>>>---!----->>>>>>>>>>>>!>----------!>>>>>>>>	BPXA, AES
Task 4.0	Research Collaboration Link	!>>>>>>>>>>>>>>>>>>---------->>>>>>>>>>!>>>>>>>>>>>>>>>>>!>>>>>>>>>>>!>>>>>>>>	BPXA, USGS, AES, UAF
Task 5.0	Logging/Seismic Technology	!>>>>>>>>>>>>>>>>>>->>>>>>>>>>>>>>>>>>>!>>>>>>>>>>>>>>>>>!>>>>>>>>>>>!>>>>>>>>	USGS, BPXA
Task 6.0	Characterize Reservoir/Fluid	!------>>>>>>>>>>>>---------->>>>>>>>>>!>>>>>>>>>>>>>>---!------>>>>>!>>>>>>>>	UA, USGS
Task 7.0	Lab Studies: Drilling, Completion, Production	!----------->>>>>>>---------->>>>>>>>>>!>>>>>>>>>>>>>>>>>!>>>>>>>>>>>!>>>>>>>>	UAF
Task 8.0	Drill/Analyze Strat Test Evaluate/Design Production Test & Phase 3b progression	! -->>>>>>>>>>>->>>----->>>>>>>>>>>>!>>>>>>>>>>>>>>>>>!>>>>>>>>>>>!>>>>>>>>	APA, BPXA, AES, UAF
Task 9.0	Reservoir Modeling and Commercial Evaluation	!---->>>>>>>>>>>>>>->>>>>>>>>>>>>>>>>>>>>!>>>>>>>>>>>>>>>>>!>>>>>>>>>>>!>>>>>>>>	RS, AES, BPXA, UAF

10. Remarks * Schedule shows Phases 3a from 2007 through end-2008. Phase 3a stratigraphic test deferred until early 2007 by 3rd party rig delay. Explanation of Symbols: >> Major Task Work; -- Minor Task Work; ! Milestone. Significant technical work and milestones presented in Technical Progress and Topical Reports.

DOE F 4600.3# U.S. DEPARTMENT OF ENERGY FEDERAL ASSISTANCE MILESTONE PLAN: Phase 3a (2009-2013)

1. Program/Project Identification No. DE-FC26-01NT41332

2. Program/Project Title Resource Characterization and Quantification of Natural Gas Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay - Kuparuk River Area on the North Slope of Alaska

3. Performer (Name, Address)
BP Exploration (Alaska), Inc., 900 East Benson Blvd, P.O. Box 196612, Anchorage, Alaska 99519-6612

4. Program/Project Start Date 10/22/02*

5. Current Program/Project Completion Date 3/31/14 (through Phase 3b)

6. Identification Task Number	7. Planning Category (Work Breakdown Structure Tasks)	8. Program/Project Duration (continuing Phase 3a, 2009-2012) ← Phase 3a and Phase 3b Stakeholder alignment →+ J F M A M J J A S O N D J F M A M J J A S O N 2013	9. Comments (Primary work Performer)
Task 1.0	Contracts and Research Management Planning	!>>>>>>>>!>--->>>>>!-->>>>>>>>>>>>>>>>>>----------------------------------->>>	BP
Task 2.0	Technical Data and Expertise	!->>>>>>>!--->>>>--!---->>>>>>>>>>---------->>>>>>>>-------------------------->>>	BP
Task 3.0	Recommend Data Acquisition	!------------>>>>>-!------------->>>>--->>>	BP
Task 4.0	Stakeholder Communications	!>>>>>>>>!>>>>>>>>>!---------->>>>>>>>>>>>>>>>>>>>>>>>>>>>>------------------>>>	BP
Task 5.0	Logging/Seismic Technology	!>>>>>>>>!>>-------!---	USGS, BP
Task 6.0	Long-term Production Test Drill, Complete, Test Plan	!------->!>>>>>>>>>!>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>--------------------->>>	BP
Subtask 6.1	Finalize Test Site Location	!>>>>>>>>!>>>>>>>>>!-------->>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>-------------------	BP, USGS, DOE
Subtask 6.2	Production Test Plan	!--------!---------!-------------->>>>>>>>>>>>>>>>>>>>>>>>-------------------->>>	RPS, RS, BP
Subtask 6.3	Implement Production Test	!-----------------!-->>>	RS, RPS, BP
Task 7.0	Reservoir Modeling	!-----------------!--	RS

10. Remarks * Schedule shows DRAFT Phase 3b in red (not currently approved, currently deferred in 2013) with primary objective to complete a detailed design and implement a long-term gas hydrate production test. Explanation of Symbols: >> Major Task Work; -- Minor Task Work; ! Milestone.

5.2 Project Research Products, Collaborations, and Technology Transfer

5.2.1 Project Research Collaborations and Networks

A detailed bibliography is provided in Section 7. Project objectives have benefited from DOE support and recognition of the following associated studies:

1. **Reservoir Model Comparison studies:** DOE NETL and West Virginia University (Dr. Brian Anderson) coordination of reservoir modeling significantly increased collaborative reservoir modeling efforts with Japan, Lawrence Berkeley National Lab (LBNL), Pacific Northwest National Lab (PNNL), and University of Calgary and Fekete. This important work has simulated field-scale gas hydrate bearing reservoirs, history matched the Mount Elbert-01 stratigraphic test MDT data, and evaluated ANS potential production test options (Figure 8, Table 4). These studies improved understanding of how these different gas hydrate reservoir models handle the basic physics of gas hydrate dissociation processes within gas hydrate-bearing formations. Significant contributors to this effort include: Masanori Kurihara (Japan Oil Engineering Co., Ltd.), Yoshihiro Masuda (The University of Tokyo), George Moridis (Lawrence Berkeley National Laboratory, University of California), Hideo Narita (National Institute of Advanced Industrial Science and Technology), Mark White (Pacific Northwest National Laboratory), Joseph W. Wilder (University of Akron), Brian Anderson (West Virginia University), Scott Wilson (Ryder Scott Company), Mehran Pooladi-Darvish and Huifang Hong (University of Calgary and Fekete), Timothy Collett (USGS), and Robert Hunter (AES, BPXA).
2. **DE-FC26-01NT41248:** This UAF/PNNL/BPXA study investigated the effectiveness of CO_2 as a potential enhanced recovery mechanism for gas dissociation from methane hydrate. DOE supported this associated project research.
3. **UAF/Argonne National Lab project:** This project was funded by the Arctic Energy and Technology Development Lab (AETDL) / Arctic Energy Office (AEO) in mid-2004. The project was designed to determine the efficacy of Ceramicrete cold temperature cement for possible future gas hydrate drilling and completion operations. Evaluating the stability and use of an alternative cold temperature cement may enhance ability to maintain lower temperatures within the gas hydrate stability field during drilling and completion operations and help ensure safer and more cost-effective operations. In early 2006, the Ceramicrete material was approved for field testing at the BJ Services yard in Texas. Although Ceramicrete was not field tested in time to be evaluated for use in 2007 Alaska operations, successful future yard testing of the material may enable limited testing in Alaska project operations.
4. **Precision Combustion, Inc. (PCI) – DOE collaborative research project:** Potential synergies from this DOE-supported research project with the BPXA – DOE gas hydrate research program were recognized in December 2003 by Edie Allison (DOE). Communications with Precision Combustion researchers continue to indicate possible synergies, particularly regarding potential in-situ reservoir heating. Successful modeling and lab work could potentially lead to application in future gas hydrate field operations. BPXA provided a letter in April 2004 in support of progression of PCI's project into their phase 2: prototype tool design and possible surface testing. A thermal component of Phase 3b production testing may be recommended and a viable delivery mechanism could potentially incorporate this technology.

5. **McGee-McMillan, Inc.:** Dr. Bruce McGee leads application of downhole thermal electromagnetic production stimulation for a pilot viscous oil project at Fort McMurray, Canada. Discussions with Dr. McGee continued from 2004 through 2009; potential adaptation of this downhole thermal technology for an Alaska North Slope production test remains under consideration.
6. **Japan gas hydrate research:** Progress toward completing the objectives of this project remain aligned with gas hydrate research by Japan Oil, Gas, and Metals National Corporation (JOGMEC), formerly Japan National Oil Corporation (JNOC). JOGMEC remains interested in research collaboration, particularly if the BPXA-DOE CRA proceeds into production testing operations. JOGMEC successfully accomplished short-term gas hydrate production test operations in 2007-2008 at the Mallik field site in Canada's MacKenzie Delta and continues activities in the Nankai Trough offshore Japan.
7. **India gas hydrate research:** India's Institute of Oil and Gas Production Technology (IOGPT) maintains interest in the BPXA – DOE CRA. Dr. Tim Collett, USGS partner in the BPXA-DOE CRA team, and Ray Boswell, DOE NETL gas hydrate program lead, led and participated in, respectively, certain aspects of the data acquisition at multiple offshore India field sites. BPXA sponsored a technical observer from the India project to view ANS Phase 3a operations and data acquisition during the 2007 Mount Elbert Stratigraphic Test. Detailed results of the 2007 India offshore program are available at: http://energy.usgs.gov/other/gashydrates/india.html. A full program summary, data, and analyses are available in Dvd format.
8. **Korea gas hydrate research:** Korea is developing a gas hydrate research program, have discussed Alaska gas hydrate research with DOE and USGS, and maintain an active interest in Alaska program R&D. BPXA has not initiated direct contact with Korea.
9. **China gas hydrate research:** China is also developing a significant gas hydrate research program. BPXA has not initiated contact with China.
10. **U.S. Department of Interior, USGS, BLM, State of Alaska DGGS:** A gas hydrate resource assessment research project under the Department of Interior (DOI) has provided significant benefits to this project. To develop a more complete regional understanding of this potential energy resource, the BLM, USGS and State of Alaska Division of Geological and Geophysical Surveys (DGGS) entered into an Assistance Agreement in 2002 to assess regional gas hydrate energy resource potential in northern Alaska. This agreement combined the resource assessment responsibilities of the USGS and the DGGS with the surface management and permitting responsibilities of the BLM. Information generated from this agreement has helped guide these agencies to promote responsible development if research proves technical and/or commercial feasibility of this potential arctic energy resource. The DOI project has worked with the BPXA – DOE project to assess the regional recoverable resource potential of onshore natural gas hydrate and associated free-gas accumulations in northern Alaska, initially within current industry infrastructure. A report, Assessment of Gas Hydrate Resources on the North Slope, Alaska, 2008, was issued in October 2008 estimating 85.4 TCF mean technically recoverable undiscovered resources (Figure 2, Table 2).

11. **ConocoPhillips-DOE CRA DE-NT0006553**: ConocoPhillips and DOE initiated a cooperative research agreement in October 2008 to design and field test CO_2 as a

potential enhancement to recover gas from CH_4 hydrate-bearing reservoirs beneath ANS industry infrastructure. The goal of this project was to define, plan and conduct a field trial of a methane hydrate production methodology whereby carbon dioxide molecules are exchanged in situ for the methane molecules within a methane hydrate structure, releasing the methane for production. The project evaluated the viability of this hydrate production technique and helped to understand the implications of the process at a field scale. The success of this field trial will help advance the larger-scale, longer-term tests needed to test viability of production technologies for methane hydrates. The exchange technology could prove to be a critical tool for unlocking the methane hydrate resource potential in a manner that minimizes potential adverse environmental impacts such as water production and/or subsidence while simultaneously providing a synergistic opportunity to sequester carbon dioxide. Final project results are available at: http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/rd-program/ANSWell/co2_ch4exchange.html

5.2.2 Project Research Technologies/Techniques/Other Products

Multiple technologies are under evaluation in association with this project. With research progression into Phase 3 operations, technologies under evaluation include gas hydrate production techniques such as thermal, chemical, and mechanical stimulation to enhance gas dissociation during future Phase 3b production testing, if approved by Stakeholders. Recent advances in electromagnetic thermal stimulation techniques may benefit potential future production test operations. Coiled-tubing unit-supported completions may offer sufficient flexibility to support various completion options during potential future production test operations.

5.2.3 Project Research Inventions/Patent Applications

DOE granted an advance patent waiver to the project in 2003. No patents are currently recorded in association with the project.

6.0 PROJECT CONCLUSIONS

The first ANS dedicated gas hydrate production test, NW Eileen State-02 (NWEIL-02), was drilled in 1972 within the Eileen accumulation (Figures 4, 5, and 8). Since that time, ANS gas hydrates have been primarily considered a shallow drilling hazard to wells targeting deeper horizons due to a combination of factors: no ANS gas export infrastructure, assumed low-rate production potential, unknown production methods, and overall lack of production test data to validate gas hydrate resource experiments and models. Consideration of conventional ANS gas resource potential helped create industry – government alignment necessary to investigate the unconventional resource potential of the potentially large (33 to 100 TCF GIP) ANS gas hydrate accumulations beneath or near existing production infrastructure. Studies show this resource is compartmentalized both stratigraphically and structurally within the petroleum system.

The BPXA – DOE CRA enables a better understanding of the resource potential of this ANS gas hydrate petroleum system through comprehensive regional shallow reservoir and fluid characterization utilizing well and 3D seismic data, implementation of gas hydrate experiments, and technology design in support of gas hydrate drilling, completion, and production operations.

Following discovery of natural gas hydrate in the 1960-1970's, significant time and resources have been devoted over the past 40-50 years to study and quantify natural gas hydrate occurrence. However, only in the past decade have there been serious attempts to understand the potential production of methane from hydrate. Although significant in-place natural gas hydrate deposits have been identified and inferred, estimation of potential recoverable gas from these deposits is difficult due to the lack of empirical or even anecdotal evidence. This evidence was improved by the short-term Mallik production testing accomplished by JOGMEC in 2007-2008 and by the CoP ANS production testing in 2012. However, long-term production testing could resolve many remaining uncertainties.

The potential to induce gas hydrate dissociation across a broad regional contact from adjacent free gas depressurization may have been observed at Messoyakha field production in Russia (Collett and Ginsberg, 1998) and possibly at East Barrow gas field in Alaska (Singh, et al., 2008). Reservoir modeling also demonstrates this potential as documented in the March 2003 CRA Quarterly report, in the December 2003 CRA Quarterly report, in the June 2006 CRA Quarterly report, and others.

The possibility to induce in-situ gas hydrate dissociation through producing mobile connate waters from within an under-saturated gas hydrate-bearing reservoir was postulated by Howe, Wilson, and Hunter et. al. (2004). This potential to induce a depressurization drive within a gas hydrate accumulation emphasizes the importance of saturation and permeability as key variables which, when better understood, could help mitigate productivity uncertainty. A schematic regional screening study was undertaken in 2005 (Wilson et al., 2011) to evaluate ranges of potential recoverable resources given various possible production scenarios of the ANS Eileen gas hydrate accumulation, which may contain up to 33 TCF GIP. Type-well production rates modeled at 0.4-2 MMSCF/d yield potential future peak field-wide development forecast rates of up to 350-450 MMSCF/d and cumulative production up to 12 TCF gas. Individual wells could exhibit a long production character with flat declines, potentially analogous to Coalbed Methane production. Results from the various scenarios show a wide range of potential outcomes. None of these forecasts would qualify for Proved, Probable, or even Possible reserve categories using the SPE/WPC definitions, since there has yet to be a fully documented case of long-term economic production from hydrate-derived gas. Each of these categories would, by definition, require a positive economic prediction, supported by historical analogies, prudent engineering judgment, and rigorous geological characterization of the potential resource before a decision on an actual development could proceed.

BPXA conducted a comprehensive logging, coring, and well pressure testing program in collaboration with the DOE and USGS at the ANS MPU Mount Elbert location in February, 2007. Operational and data acquisition priorities for this Stratigraphic Test field program were designed to better constrain critical uncertainties of gas hydrate-bearing reservoir properties used in initial reservoir simulations (Howe et al., 2004) and regional schematic development modeling (Wilson et al., 2011) and to help assess whether or not gas produced from gas hydrate might someday become part of the broader ANS gas resource portfolio. Key data acquired included cores, logs, and wireline pressure tests (MDT) within gas hydrate-bearing reservoir sands. Analyses of the core, log, and MDT results has helped reduce the uncertainty regarding gas hydrate-bearing reservoir productivity and improved planning of Phase 3b gas hydrate production test designs, although Phase 3b operations are not currently approved by Stakeholders.

The Stratigraphic Test location was selected based on detailed geologic-geophysical reservoir and fluid characterization and prospecting studies conducted primarily by the USGS (Inks et al., 2009; Lee et al., 2009; Lee et al., 2010) in collaboration with the BPXA-DOE CRA utilizing MPU 3D seismic data provided by BPXA. The field program adhered to BPXA ANS operations standards and proved the ability to safely conduct drilling and data acquisition operations within ANS gas hydrate-bearing reservoirs. A key element enabling drilling program success was using chilled Mineral-Oil-Based-Mud (MOBM) drilling fluid, which with proper borehole maintenance and conditioning, helped provide stable and in-gauge hole conditions for data acquisition of continuous wireline core, full wireline log suite, and extended open hole MDT within interlayered gas hydrate-bearing and water-bearing intervals. The acquired data helped calibrate reservoir models, improve recoverable resource estimates, and characterize gas hydrate-bearing porous media reservoir quality, fluid saturations, mobile versus irreducible water content, water chemistry, and microbiology. Operations proceeded safely, smoothly, on-time, and without incident.

The Stratigraphic Test field operations program acquired the first significant Sagavanirktok formation core data within ANS gas hydrate-bearing reservoirs. Studies of acquired data reveal a combined 30.5 meters (100 feet) thickness of gas hydrate-bearing sediment (Lee et al., 2011, a) within a complex stratigraphic-structural trap within two distinct stratigraphic units C and D (Rose et al., 2011, Boswell et al., 2011). These results conform well to the pre-drill prediction (Lee et al., 2011, a). The MDT results significantly improved understanding of the in-situ petrophysics of the reservoir and provided insight into reservoir response to local depressurization through free water withdrawal and associated gas production from hydrate dissociation (Anderson et al., 2011, a; Pooladi-Darvish et al., 2011; Kurihara et al., 2011). Reservoir modeling indicates that the ability of the gas hydrate-bearing porous media to transmit a pressure front could be a key parameter to enable pressure-depletion drive during production testing (Wilson et al, 2011), provided temperatures do not fall below freezing, which would effectively transform the small remaining mobile fluid phase into an immobile ice phase. Reservoir simulations based on an idealized Mount Elbert-01 unit D geologic model have better constrained the range of possible production responses across variable gas hydrate occurrences within the Eileen accumulation and indicate these gas hydrate-bearing reservoirs may be capable of gas production through sustained dissociation by depressurization (Wilson et al., 2011; Anderson et al., 2011 a, b; Moridis et al., 2011). These reservoir characterization and modeling techniques have also been applied to identify, compare, and select prospective future production test sites (Collett and Boswell, 2009; Table 4 and Figure 8).

The results at Mount Elbert confirm that long-term production testing within the Eileen accumulation infrastructure area (Figure 8) would better constrain what portion of gas hydrate in-place resources might become a technically-feasible or possibly even a commercial natural gas resource. If approved by Stakeholders, a future long-term ANS gas hydrate production test would be designed to build on the successful short-term production test conducted in March 2008 at the Mallik site in the MacKenzie Delta by the governments of Japan and Canada, which indicated the technical feasibility of gas production from gas hydrate by conventional depressurization technology (Dallimore et al., 2008; Kurihara et al., 2008) and on the successful CO_2-injection gas hydrate production test conducted on the ANS by CoP in 2012. Although the technical recovery has been modeled for the ANS and proven possible in short-term production testing at the Mallik and ANS sites, the economic viability of gas hydrate production remains unproven. Additional data acquisition and future long-term production testing could help determine the technical feasibility of depressurization-induced or thermal-, chemical-, and/or mechanical-stimulated dissociation of gas hydrate into producible gas.

Long-term production testing would provide a valuable dataset that cannot be obtained from existing or planned desktop research or laboratory studies. The PBU L-pad site (area 2, Figure 8) may offer the unique combination of low geologic risk, maximal operational flexibility (multiple zones), low operational risk (near-vertical wells adjacent to infrastructure) and near-term meaningful reservoir response (Table 4; Collett and Boswell, 2009). Test designs under consideration would initially evaluate depressurization technologies and if necessary, extend into a sequence of increasingly complex thermal, chemical, and/or mechanical stimulation procedures. Test results might also apply to helping determine the resource potential of offshore gas hydrate accumulations in the Gulf of Mexico (GOM) and in other continental shelf areas.

Field Area **Parameter**	**MPU E-pad (area 1)**	**MPU B-Pad (area 1)**	**PBU L-pad (area 2)**	**PBU Kup St. 3-11-11 (area 2)**	**PBU Downdip L-pad (area 3)**	**KRU WSak-24 (area 4)**	**KRU 1H-Pad (area 4)**
Temperature	H	H	M	M	L	H	H
Ownership	L	L	H	H	H	M-L	M-L
Gravel Access	M	M	L	L	H	L	L
Geologic	L	L	L	L	H	M	M
Data Constraints	L	L	L	M	H	M	M
Well / Drilling	L-M	L-M	M	M	H	M	M
Facilities	L	L	L	M	H	M	L
Gas Handling	H	H	H	H	H	H	H
Water Handling	L	L	L	M	H	M	L
Simultaneous Operations	L	M	H?	L	L	L	H?
Operations Linkage	L?	L?	M	M	M	L	L?
Multi-zone Options	M-H	M-H	L	L	M-H	H	H
AVERAGE	**L-M**	**L-M**	**L-M**	**M**	**M-H**	**M**	**M**

Table 4: Review of risk factors for potential long-term production test sites with area corresponding to Figure 8. H = high risk associated with this parameter (unfavorable); M = medium risk; L = low risk (after Collett and Boswell, 2009).

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7.3 University of Arizona Research Publications and Presentations

7.3.1 Professional Presentations

a. Casavant, R.R., Hennes, A.M., Johnson, R., and T.S. Collett, 2004, Structural analysis of a proposed pull-apart basin: Implications for gas hydrate and associated free-gas emplacement, Milne Point Unit, Arctic Alaska, AAPG Hedberg Conference, Gas Hydrates: Energy Resource Potential and Associated Geologic Hazards, September 12-16, 2004, Vancouver, BC, Canada, 5 pp.
b. Hagbo, C. and R. Johnson, 2003, Delineation of gas hydrates, North Slope, Alaska, 2003 Univ. of Arizona Dept. Geosciences Annual GeoDaze Symposium
c. Hagbo, C., and Johnson, R. A., 2003, Use of seismic attributes in identifying and interpreting onshore gas hydrate occurrences, North Slope, Alaska, Eos Trans. AGU, 84, Fall Meet.
d. Hennes, A., and R. Johnson, 2004, Structural character and constraints on a shallow, gas hydrate-bearing reservoir as determined from 3-D seismic data, North Slope, Alaska, 2004 Univ. of Arizona Dept. Geosciences Annual GeoDaze Symposium.

7.3.2 Professional Posters

a. Poulton, M.M., Casavant, R.R., Glass, C.E., and B. Zhao, 2004, Model Testing of Methane Hydrate Formation on the North Slope of Alaska With Artificial Neural Networks, AAPG Hedberg Conference, Gas Hydrates: Energy Resource Potential and Associated Geologic Hazards, September 12-16, 2004, Vancouver, BC, Canada, 2 pp.
b. Geauner, S., Manuel, J., and R.R. Casavant, 2004, Well Log Normalization and Comparative Volumetric Analysis of Gas Hydrate and Free-Gas Resources, Central North Slope, Alaska, AAPG Hedberg Conference, Gas Hydrates: Energy Resource Potential and Associated Geologic Hazards, September 12-16, 2004, Vancouver, BC, Canada, 4 pp.
c. Gandler, G.L., Casavant, R.R., Johnson, R.A., Glass, K, and T.S. Collett, 2004, Preliminary Spatial Analysis of Faulting and Gas Hydrates-Free Gas Occurrence, Milne Point Unit, Arctic Alaska, AAPG Hedberg Conference, Gas Hydrates: Energy Resource Potential and Associated Geologic Hazards, September 12-16, 2004, Vancouver, BC, Canada, 3 pp.
d. Hennes, M., Johnson, R.A., and R.R. Casavant, 2004, Seismic Characterization of a Shallow Gas Hydrate-Bearing Reservoir on the North Slope of Alaska, AAPG Hedberg Conference, Gas Hydrates: Energy Resource Potential and Associated Geologic Hazards, September 12-16, 2004, Vancouver, BC, Canada, 4 pp.
e. Hennes, A., and R. Johnson, 2004, Pushing the envelope of seismic data resolution: Characterizing a shallow gas hydrate reservoir on the North Slope of Alaska, 2004 Univ. of Arizona Dept. Geosciences Annual GeoDaze Symposium.

f. Geauner, J.M., Manuel, J., And Casavant, R.R., 2003, Preliminary Subsurface Characterization And Modeling Of Gas Hydrate Resources, North Slope, Alaska, in: Student Abstract Volume, 2003 AAPG-SEG Student Expo, Houston, Texas.

7.3.3 Professional Publications

a. Poulton, M.M., Casavant, R.R., Glass, C.E., and B. Zhao, 2004, Model Testing of Methane Hydrate Formation on the North Slope of Alaska With Artificial Neural Networks, AAPG Hedberg Conference, Gas Hydrates: Energy Resource Potential and Associated Geologic Hazards, September 12-16, 2004, Vancouver, BC, Canada, 2 pp.
b. Geauner, S., Manuel, J., and R.R. Casavant, 2004, Well Log Normalization and Comparative Volumetric Analysis of Gas Hydrate and Free-Gas Resources, Central North Slope, Alaska, AAPG Hedberg Conference, Gas Hydrates: Energy Resource Potential and Associated Geologic Hazards, September 12-16, 2004, Vancouver, BC, Canada, 4 pp.
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e. Johnson, R. A., 2003, Shallow Natural-Gas Hydrates Beneath Permafrost: A Geophysical Challenge To Understand An Unconventional Energy Resource, News From Geosciences, Department Of Geosciences Newsletter, V. 8, No. 2, p. 4-6.
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l. Casavant, R. R., 2002, Tectonic geomorphic characterization of a transcurrent fault zone, Western Brooks Range, Alaska (linkage of shallow hydrocarbons with basement deformation), SPE-AAPG: Western Region-Pacific Section Joint Technical Conference Proceedings, Anchorage, Alaska, May 18-23, 2002, p. 68.

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a. Hennes, A.M., 2004, Structural Constraints on Gas hydrate Formation and Distribution in the Milne Point, North Slope of Alaska, M.S. Thesis (Prepublication Manuscript), Dept. of Geosciences, University of Arizona, Tucson, 76 pp.
b. Hagbo, C.L., 2003, Characterization of Gas hydrate Occurrences using 3D Seismic Data and Seismic Attributes, Milne Point, North Slope, Alaska, M.S. Thesis, Dept. of Geosciences, University of Alaska, Tucson, 127 pp.
c. Zhoa, Bo, 2003, Classifying Seismic Attributes in the Milne Point Unit, North Slope of Alaska, M.S. Thesis, Dept. of Mining and Geological Engineering, University of Arizona, Tucson, 159 pp.

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7.7 Short Courses

"Natural Gas Hydrates", By Tim Collett (USGS) and Shirish Patil (UAF), A Short Course at the SPE-AAPG: Western Region-Pacific Section Conference, Anchorage, Alaska, May 18-23, 2002, Sponsored by Alaska Division of Geological and Geophysical Surveys and West Coast Petroleum Technology Transfer Council, Anchorage, Alaska.

7.8 Websites

There are currently no external project-sponsored websites. Project information is available on the DOE website: http://www.fossil.energy.gov/programs/oilgas/hydrates/index.html. A project internal website has been developed for storage, transfer, and organization of project-related files, results, and studies. This website is available to project participants and collaborators; information contained on this working website will be finalized and released at project final reporting.

8.0 LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Denotation
2D	Two Dimensional (seismic or reservoir data)
3D	Three Dimensional (seismic or reservoir data)
AAPG	American Association of Petroleum Geologists
AAT	Alaska Arctic Terrane (plate tectonics)
AGS	Alaska Geological Society
AEO	Arctic Energy Office (DOE AETDL)
AETDL	Alaska Energy Technology Development Laboratory (DOE AEO)
ADEC	Alaska Department of Environmental Conservation
AES	ASRC Energy Services, E&P Technology

ANL	Argonne National Laboratory
ANN	Artificial Neural Network
ANS	Alaska North Slope
AOGCC	Alaska Oil and Gas Conservation Commission
AOI	Area of Interest
ASRC	Arctic Slope Regional Corporation
AVO	Amplitude versus Offset (seismic data analysis technique)
ASTM	American Society for Testing and Materials
BGHSZ	Base of Gas Hydrate Stability Zone
BHA	Bottom Hole Assembly; equipment at bottom hole during drilling operations
BIBPF	Base of Ice-Bearing Permafrost
BLM	U.S. Bureau of Land Management
BMSL	Base Mean Sea Level
BP	BP or BPXA
BPXA	BP Exploration (Alaska), Inc.
CMR	Combinable Magnetic Resonance log (wireline logging tool – see also NMR)
CPAI	ConocoPhillips Alaska, Inc. (or CoP)
CRA	Cooperative Research Agreement (commonly in reference to BP/DOE project)
CSM	Colorado School of Mines
DOE	U.S. Department of Energy
DOI	U.S. Department of Interior
DGGS	Alaska Division of Geological and Geophysical Surveys
DNR	Alaska Department of Natural Resources
DTS	Distributed Temperature Survey (used to monitor hydrate dissociation)
EM	Electromagnetic (referencing potential in-situ thermal stimulation technology)
EPT	Electromagnetic Propagation Tool for geophysical wireline logging
ERD	Extended Reach Drilling (commonly horizontal and/or multilateral drilling)
FBHP	Flowing Bottom-Hole Pressure (during MDT wireline production testing)
FEL	Front-End Loading, reference to effective pre-project operations planning
FG	Free Gas (commonly referenced in association with and below gas hydrate)
GEOS	UA Department of Geology and Geophysics
GH	Gas Hydrate
GIP	Gas-in-Place
GMC	Geological Materials Center, State of Alaska in Eagle River, Alaska
GOM	Gulf of Mexico (typically referring to Chevron Gas Hydrate project JIP)
GR	Gamma Ray (well log)
GSC	Geological Survey of Canada
GTL	Gas to Liquid
GSA	Geophysical Society of Alaska
HP	Hewlett Packard
HSE	Health, Safety, and Environment (typically pertaining to field operations)
JBN	Johnson-Bossler-Naumann method (of gas-water relative permeabilities)
JIP	Joint Industry Participating (group/agreement), ex. Chevron GOM project
JNOC	Japan National Oil Corporation
JOGMEC	Japan Oil, Gas, and Metals National Corporation (reorganized from JNOC 1/04)
JSA/JRA	Job Safety Assessment/Job Risk Assessment; part of BP HSE operations protocol

KRU	Kuparuk River Unit
LBNL	Lawrence Berkeley National Laboratory
LDD	Generic term referencing Logging During Drilling (also LWD and MWD)
LDEO	Lamont-Dougherty Earth Observatory
LN	Liquid Nitrogen
LNG	Liquefied Natural Gas
MDT	Modular Dynamics Testing wireline tool for downhole production testing data
MGE	UA Department of Mining and Geological Engineering
MOBM	Mineral Oil-Based Mud drilling fluid used to improve safety and data acquisition
MPU	Milne Point Unit
MSFL	Micro-spherically focused log (wireline log indication of formation permeability)
NAS	National Academy of Sciences (National Research Council of the National Academies)
NETL	National Energy Technology Laboratory
NMR	Natural Magnetic Resonance (wireline or LDD tool – see also CMR)
NRC	National Research Council of Canada
OBM	Oil Based Mud, drilling fluid
ONGC	Oil and Natural Gas Corporation Limited (India)
PBU	Prudhoe Bay Unit
PNNL	Pacific Northwest National Laboratory
POOH	Pull out of Hole; pulling drillpipe or wireline from borehole during operations
POS	Pump-out Sub (pertaining to MDT tool)
SCAL	Special Core Analyses, references analyses beyond basic porosity/permeability
SPE	Society of Petroleum Engineers
TCF	Trillion Cubic Feet of Gas at Standard Conditions
TCM	Trillion Cubic Meters of Gas at Standard Conditions
T-D	Time-Depth (referencing time to depth conversion of seismic data)
UA	University of Arizona (or Arizona Board of Regents)
UAF	University of Alaska, Fairbanks
USGS	United States Geological Survey
USDOE	United States Department of Energy
Vp	Velocity of primary seismic wave component
Vs	Velocity of shear seismic wave component (commonly useful to identify GH)
VSP	Vertical Seismic Profile
WOO	Well-of-Opportunity

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