

# Oil and Natural Gas Technology

Cooperative Research Agreement Award Number DE-FC-01NT41332

## 2Q2011 – 3Q2011 Semi-Annual Progress Report

Thirty-Fifth and Thirty-Sixth Quarterly Reports: April 2011 – September 2011

### 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

**Submitted by:**

BP Exploration (Alaska), Inc.  
Robert Hunter (ASRC Energy Services)  
with Stephen Lewis (Principal Investigator)  
P.O. Box 196612  
Anchorage, Alaska 99519-6612

**Prepared for:**

United States Department of Energy  
National Energy Technology Laboratory

October 31, 2011



Office of Fossil Energy



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### **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 continue to promote 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 of 2005 to 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<sub>2</sub> 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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## 2.0 EXECUTIVE SUMMARY

Accomplishments during the April 2011 through end-September 2011 reporting period were minimal due to reduced-scope activities pending Stakeholder agreement for project continuation. Phase 3a operations and associated studies are complete.

Project accomplishments during the reporting period include:

1. External communications, reporting, and contracts
2. Internal communications, filing, and reporting
3. Stratigraphic Test core transfer

Detailed accomplishments in these categories are summarized below in Section 4.

## 3.0 CURRENT STATUS REPORT

### 3.1 Continuation Application Status

Stakeholder consensus is needed before submission of a Continuation Application for a long-term production test project phase currently proposed within the PBU L-pad area.

The ConocoPhillips (CoP) Tract-operation for CO<sub>2</sub> gas hydrate completion and testing program is anticipated to occur during the ice-pad exploration season end-2011-early-2012. The PBU L-pad area test site has also been reviewed with area teams and remains under consideration to integrate operations and facilities into PBU activities supporting future CRA long-term gas hydrate production test plans.

BPXA continues project activities at a reduced scope following approved project extension through end-March 2014 (Amendment 31) and current budget period extension through end-September 2012 (Amendment 32) pending Stakeholder consensus for submission of a project Continuation Application necessary before proceeding into long-term testing operations.

### 3.2 Cost Status

Table 1 estimates project cost status through end-3Q11. Project cost-share remains to be updated with in-kind data, staff, and cash contributions for Phase 3a work.

Total Federal Share Estimate	<b>\$9,799,741.79</b>	Processed invoices and estimated accruals
Total Federal Funds input	<b>\$9,819,507.00</b>	Federal funds input to ASAP Account
Total Federal-share invoices	<b>\$9,629,796.30</b>	Through end-3Q2011
US Treasury Account Balance	<b>\$189,710.70</b>	Remaining funds in ASAP Account
Estimated Outstanding Invoices	<b>\$189,000.00</b>	Maximum Estimate Unprocessed invoices
Estimated Project Account Balance	<b>\$710.70</b>	Minimum Estimate

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

### 3.3 2Q11 – 3Q11 Reporting Period Significant Accomplishments

At request of DOE, all core (430 total feet) from the Mount Elbert-01 Stratigraphic Test well was removed from the frozen core storage facility in Anchorage and shipped (in frozen state) to a permanent DOE core storage facility in Corvallis, Oregon.

### 3.4 Actual or Anticipated Problems, Delays, and Resolution

Contract Amendment 31 authorized no-cost extension through end-September 2011 and project extension through end-March 2014. Contract Amendment 32 authorized no-cost extension through end-September 2012 pending Stakeholder approvals that could enable PBU long-term testing operations.

## 4.0 ACCOMPLISHMENTS SUMMARY, 2Q11 and 3Q11

### 4.1 External Communications, Reporting, and Contracts

- Write, review, and submit semi-annual 4Q10 through 1Q11 technical progress report
  - Document project accomplishments during reporting period
- Track financial status; calculate, review, and submit financial reports
- Participate in monthly progress report teleconference reviews with USGS and DOE
- Completed SBIR Phase 2 review
- Declined invitation to participate in November 2011 gas hydrate conference in Germany
- Accepted Amendment 31, no-cost extension through end-September 2011 and project extension through end-March 2014
  - Amendment 32 granted no-cost extension through end-September, 2012
  - Updated FedConnect and central contractor registration databases as needed

### 4.2 Internal Communications and Reporting

- Maintained contract recommendations, files, correspondence, and electronic backups
  - Transitioned contingent labor contract to electronic system
- Completed closeout of project accounting and all Phase 3a invoices
- Initiated updating of internal project accounting to project amendments
- Networked gas hydrate research within BP GOM, EPT, and R&D communities
  - Compiled past project accomplishments and related research
  - Identified potential gas hydrate R&D synergies to Alaska program
- Prioritized actions and accomplished selected reduced-scope minor project activities
- Reviewed ICGH papers
- Organized, catalogued, and returned technical files and data to file system

### 4.3 Mount Elbert Stratigraphic Test

- Transferred core from temporary storage in temperature-controlled Anchorage facility to permanent core storage facility in Corvallis, Oregon
  - Reviewed core storage and transport options and selected viable option
  - Designed and built prototype core storage box before selecting option of suitable coolers of adequate dimensions and capacity for safe air-freight transport while maintaining freezing conditions using combination of gel ice and dry ice
  - Decommissioned temporary core storage facility and prepared to surplus unit
  - Documented core transportation expenses
- Provided Mt Elbert-01 and vicinity temperature data to Petrotechnical Data Center (BP)

### 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 is a key goal of the program, but this remains 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, and 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, and 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, and 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) well, drilled in 1972 (Figures 4 and 5; Collett, 1993). NWEIL 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 within and associated with this CRA 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 Wilson, et al., 2010).



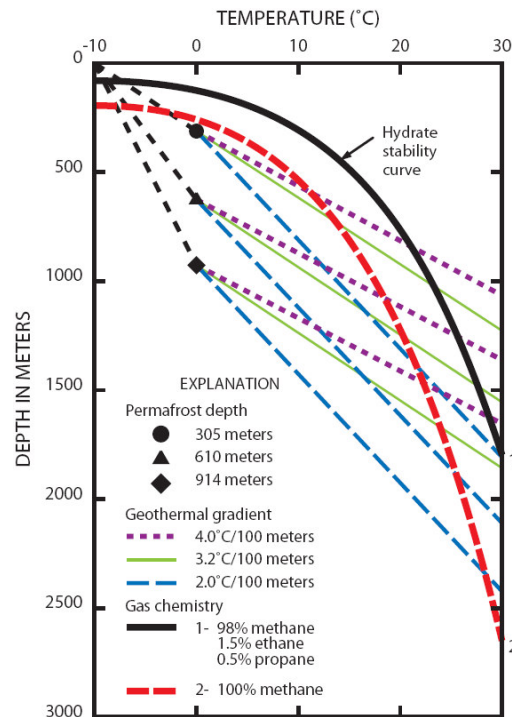


Figure 1: Gas Hydrate Stability Phase diagram (after Collett et al., 2010) shows effects of variable formation temperature, pore pressure, and gas composition on gas hydrate stability within depths between intersections of geothermal gradient and gas-hydrate stability curve.

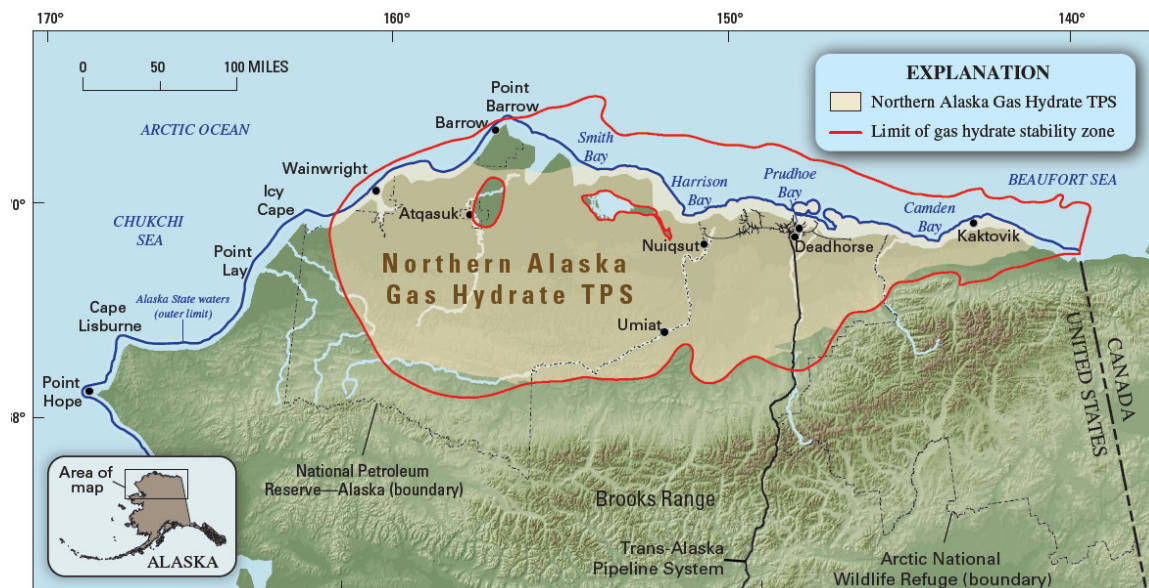


Figure 2: Northern Alaska Gas Hydrate Total Petroleum System (TPS) (shaded in tan), and the limit of gas hydrate stability zone in northern Alaska (red outline); USGS Fact Sheet 2008-3073.

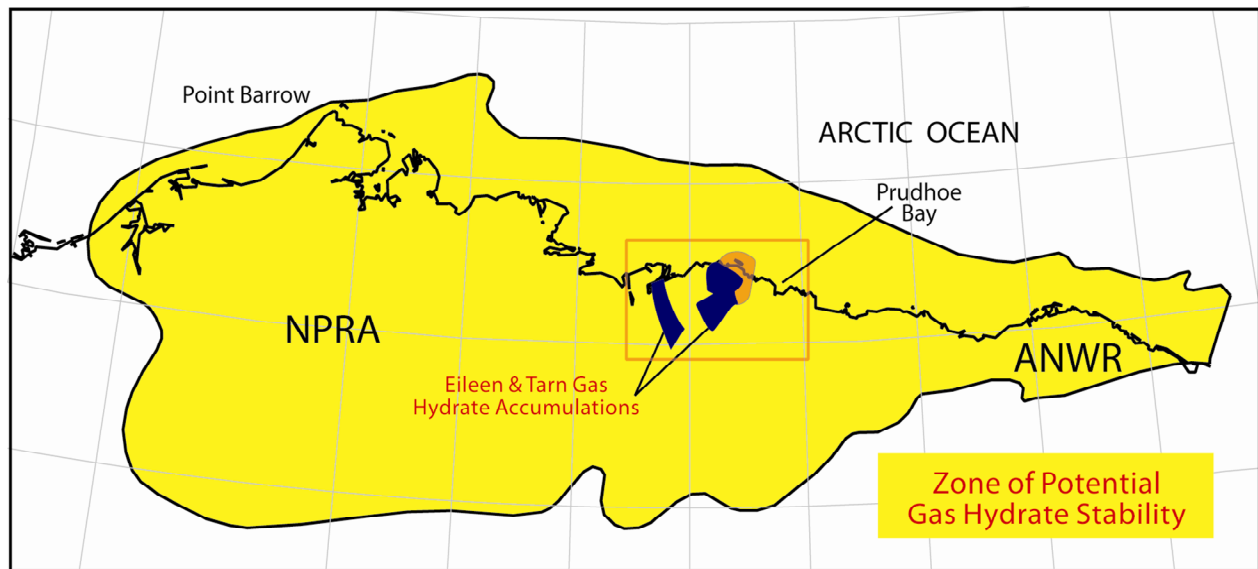


Figure 3: ANS gas hydrate stability zone (red outline of Figure 2) containing an estimated mean 590 TCF GIP showing Eileen and Tarn gas hydrate accumulations after Collett (1993 and 1995).

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, which indicated the technical feasibility of gas production from gas hydrate by conventional depressurization technology.

Although the technical recovery has been modeled for the ANS and proven possible in short-term production testing at the Mallik site, the economic viability of gas hydrate production will remain uncertain until sufficient field testing constrains 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.

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

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

<b>Prospect Name</b>	<b>Bulk Rock Volume (m<sup>3</sup>)</b>	<b>Acres</b>	<b>Porosity</b>	<b>Net to Gross</b>	<b>Gas Saturation</b>	<b>GIP (BCF)</b>
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	<b>34,891,823</b>	<b>332</b>	<b>39%</b>	<b>80%</b>	<b>66.9%</b>	<b>41.8</b>
D Combined	<b>172,167,556</b>	<b>1667</b>	<b>37%</b>	<b>80%</b>	<b>52.5%</b>	<b>179.9</b>
C Combined	<b>352,281,654</b>	<b>4117</b>	<b>38%</b>	<b>80%</b>	<b>57.7%</b>	<b>376.7</b>
B Combined	<b>33,613,297</b>	<b>577</b>	<b>38%</b>	<b>80%</b>	<b>58.03%</b>	<b>37</b>
A Combined	<b>26,261,864</b>	<b>375</b>	<b>38%</b>	<b>80%</b>	<b>81.2%</b>	<b>32.8</b>
<b>TOTAL</b>	<b>619,216,195</b>	<b>7068</b>	<b>38%</b>	<b>80%</b>	<b>63.3%</b>	<b>668.2</b>

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

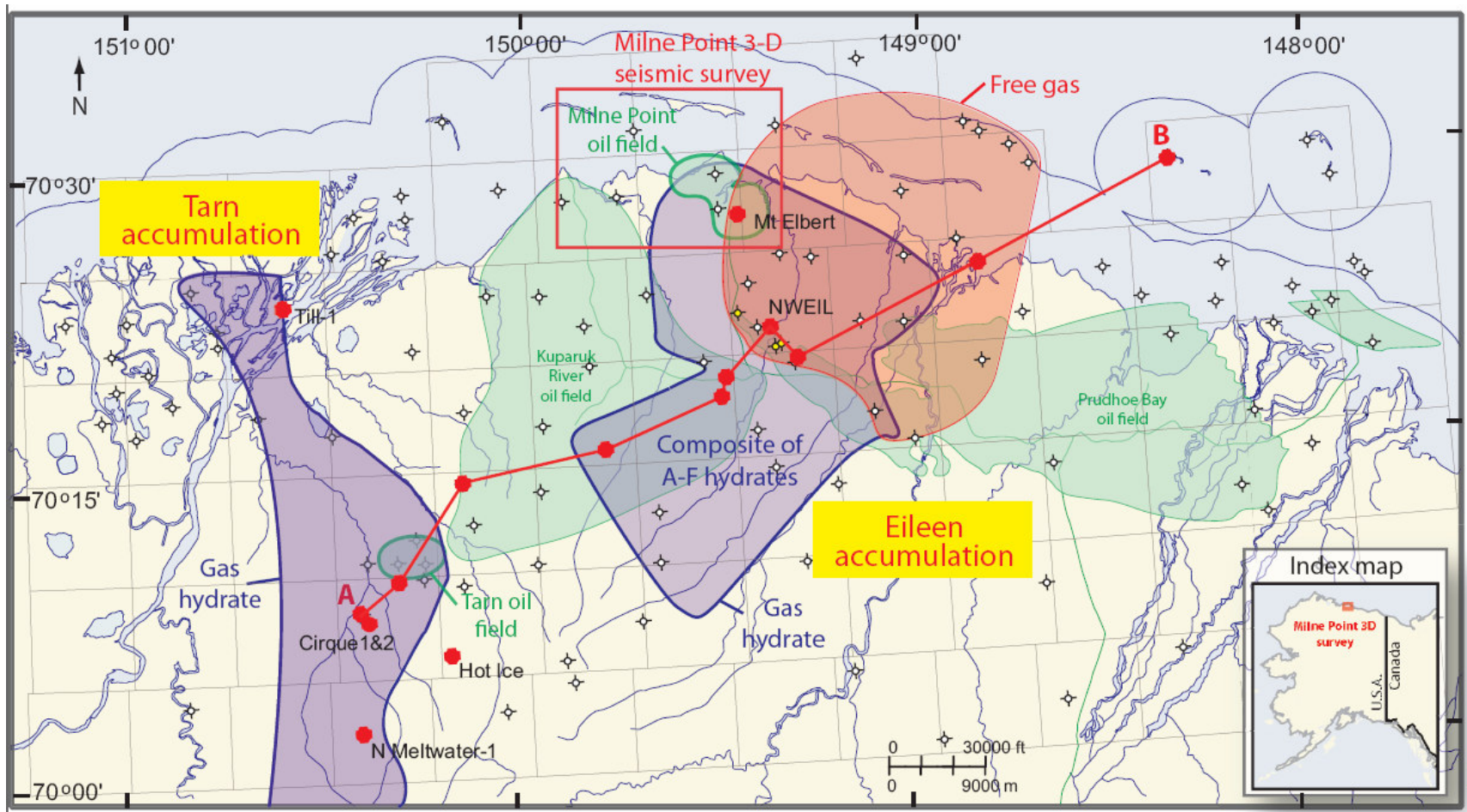


Figure 4: Eileen and Tarn Gas Hydrate Accumulations and ANS Field Infrastructure (modified after Collett et al, 2010). Estimated Eileen accumulation GIP = 33 TCF with EUR 2 - 12 TCF (Wilson et al, 2011).

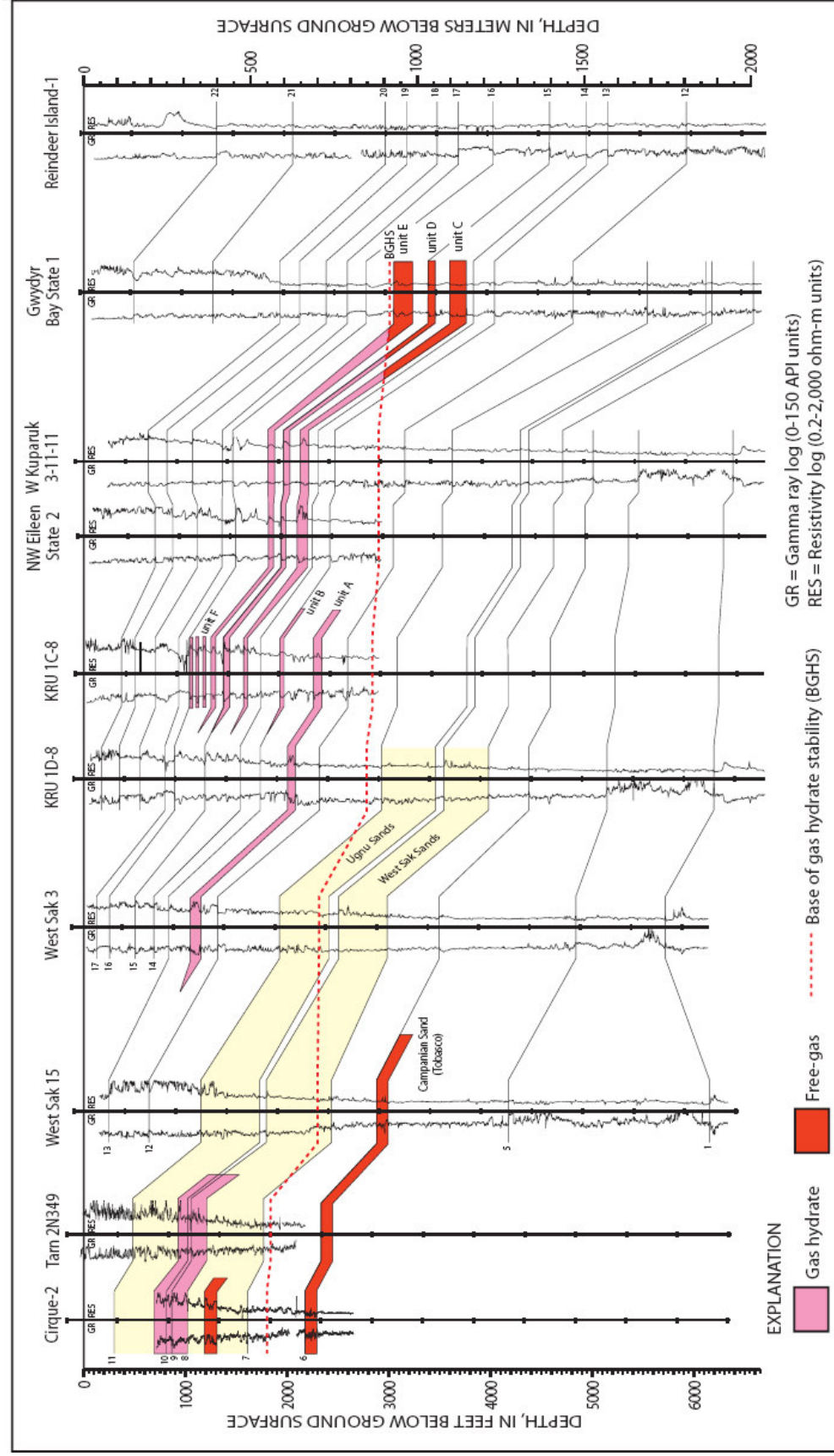


Figure 5: Well log cross-section (Red line of section A-B shown in Figure 4) illustrating gas hydrate-bearing formations within the Eileen and Tarn accumulations (Collett, et al, in-press). Informal Sagavanirktok Formation units A through F are shown within the Eileen accumulation. Log correlation markers,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

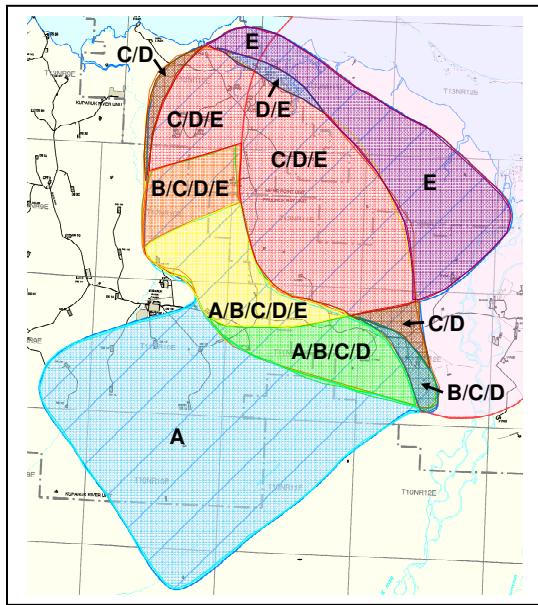


Figure 6: Interpreted gas hydrate-bearing Sagavanirktok units A through E in map of Eileen accumulation (modified from Collett, 1993) used to construct regional schematic model (Wilson, et al., 2011).

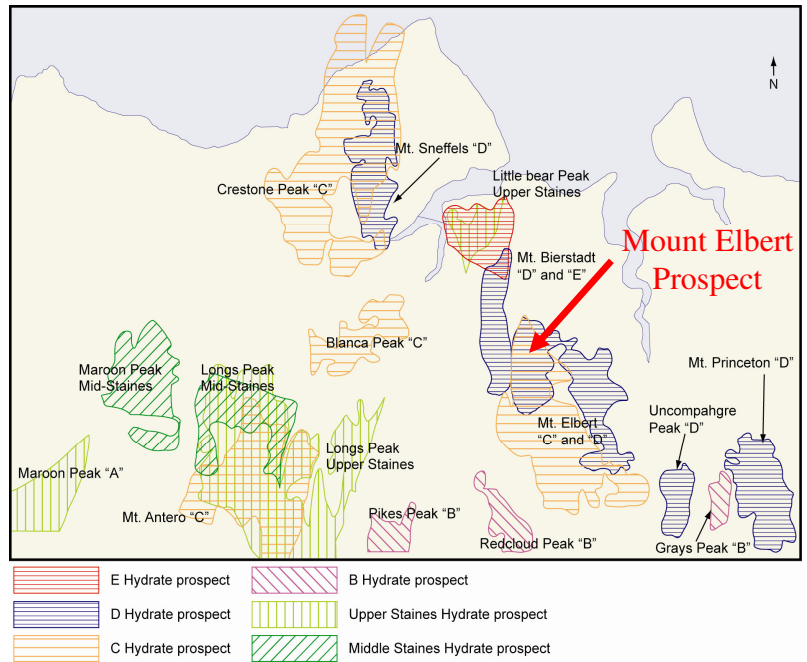


Figure 7: MPU gas hydrate prospects interpreted from 3D seismic, including Mount Elbert (Inks, T., Lee, M., Taylor, D., Agena, W., Collett, T. and Hunter, R., 2009).

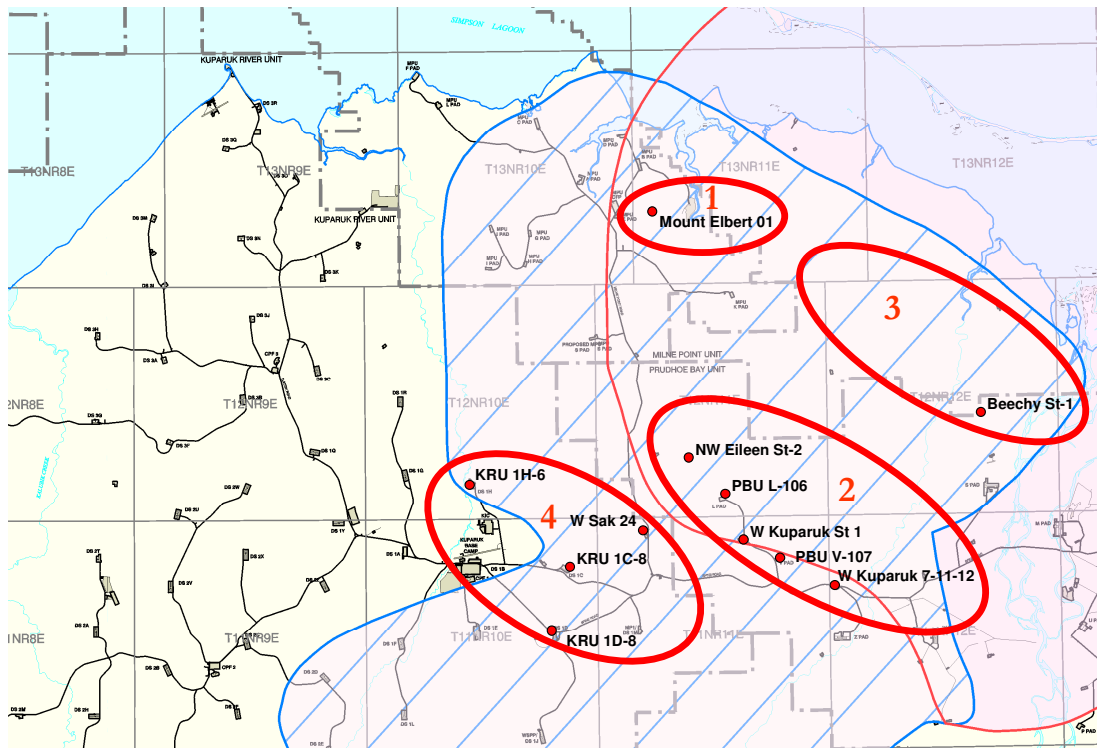


Figure 8: Eileen accumulation composite Sagavanirktok gas hydrate-bearing zones A, B, C, D, E (blue stripes; also Figure 6) with 4 areas-of-interest for a potential future production test site.

## 5.1 Project Task Schedules and Milestones

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

Note scope-of-work in contract amendments 1-8 for Phase 1.

**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
<b>Task 1.0</b>	Research Management Plan	12/02 – 12/04	12/02	Subcontracts Completed
<b>Task 2.0</b>	Provide Technical Data and Expertise	MPU: 12/02 PBU: * KRU: *	MPU: 12/02 PBU: * KRU: *	See Technical Progress Reports
<b>Task 3.0</b>	Wells of Opportunity Data Acquisition	Ongoing in Phase 2-3	Ongoing in Phase 2-3	See Technical Progress Reports
<b>Task 4.0</b>	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	
<b>Task 5.0</b>	Logging and Seismic Technology Advances	Ongoing in Phase 2-3	Ongoing in Phase 2-3	See Technical Progress Reports
<b>Task 6.0</b>	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
<b>Task 7.0</b>	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
<b>Task 8.0</b>	Evaluate Drilling Fluids	12/04		
Subtask 8.1	Design Mud System	11/03		
Subtask 8.2	Assess Formation Damage	9/05	Into Phase 2	
<b>Task 9.0</b>	Design Cement Program	12/04		
<b>Task 10.0</b>	Study Coring Technology	2/04	2/04	
<b>Task 11.0</b>	Reservoir Modeling	12/04	Ongoing in Phase 2-3	Interim Results presented, 2004 Hedberg Conference
<b>Task 12.0</b>	Select Drilling Location and Candidate	9/05	Ongoing in Phase 2-3	Topical Report submitted, June 2005
<b>Task 13.0</b>	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

Note scope-of-work in contract Amendment 9 for Phase 2.

**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
<b>Task 1.0</b>	Research Management Plan	1/05 – 1/06	1/06	Subcontracts Completed
<b>Task 2.0</b>	Provide Technical Data and Expertise	MPU: 12/02 PBU: * KRU: *	MPU: 12/02 PBU: * KRU: *	See Technical Progress Reports
<b>Task 3.0</b>	Wells of Opportunity Data Acquisition	Ongoing	Ongoing	See Technical Progress Reports
<b>Task 4.0</b>	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	
<b>Task 5.0</b>	Logging and Seismic Technology Development and Advances	Ongoing in Phase 2-3	Ongoing in Phase 2-3	See Technical Progress/Topical Reports
<b>Task 6.0</b>	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	
<b>Task 7.0</b>	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	Phase 3a	No Samples Acquired; await Phase 3a acquisition
<b>Task 8.0</b>	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
<b>Task 9.0</b>	Field Operations and Data Acquisition Program Planning	4/06	Mt Elbert-01 stratigraphic test 2/07	Planning for Potential operations underway
<b>Task 10.0</b>	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

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### 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 32 through end-September 2012.

**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
<b>Task 1.0</b>	Research Management Plan	1/06 – 10/08	12/08	
<b>Task 2.0</b>	Provide Technical Data and Expertise	MPU: 12/02 PBU: * KRU: *	MPU: 12/02 PBU: * KRU: *	See Technical Progress Reports
<b>Task 3.0</b>	Wells of Opportunity Data Acquisition			See Technical Progress Reports
<b>Task 4.0</b>	Research Collaboration Link			See Technical Progress Reports
Subtask 4.1	Research Continuity			
<b>Task 5.0</b>	Logging and Seismic Technology Development and Advances			See Technical Progress/Topical Reports
<b>Task 6.0</b>	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	
<b>Task 7.0</b>	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	
<b>Task 8.0</b>	Implement completion/production Test for gas hydrate well	3/07	3/07	Stratigraphic Test Well Drilled February 3-19, 2007
<b>Task 9.0</b>	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

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### 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 3a (2007-2008)

Table with 9 main columns: 1. Program/Project Identification No., 2. Program/Project Title, 3. Performer (Name, Address), 4. Program/Project Start Date, 5. Program/Project Completion Date, 6. Identification Task Number, 7. Planning Category (Work Breakdown Structure Tasks), 8. Program/Project Duration (Phase 3a, 2007-2008), 9. Comments (Primary work Performer). Includes monthly progress indicators for tasks 1.0 through 9.0.

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.



## 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<sub>2</sub> as a potential enhanced recovery mechanism for gas dissociation from methane hydrate. DOE supported this associated project research which may help facilitate a possible future field test of this technology.
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. However, this project does not appear to have significantly progressed during 2006 through 2010.
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.
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<sub>2</sub> as a potential enhancement to recover gas from CH<sub>4</sub> hydrate-bearing reservoirs beneath ANS industry infrastructure. The goal of this project is 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 purpose is to evaluate the viability of this hydrate production technique and to understand the implications of the process at a field scale. If an initial field trial is successful, the program would 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.

### **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. 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), was drilled in 1972 within the Eileen accumulation (Figures 4 and 5). 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. 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 resource portfolio. Key data acquired included wireline 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.

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 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 interbedded 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). Although the technical recovery has been modeled for the ANS and proven possible in short-term production testing at the Mallik site, the economic viability of gas hydrate production remains unproven. Additional data acquisition and future 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.

<b>Field Area Parameter</b>	<b>MPU E-pad (area 1)</b>	<b>MPU B-Pad (area 1)</b>	<b>PBU L-pad (area 2)</b>	<b>PBU Kup St. 3-11-11 (area 2)</b>	<b>PBU Downdip L- pad (area 3)</b>	<b>KRU WSak-24 (area 4)</b>	<b>KRU 1H-Pad (area 4)</b>
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
<b>AVERAGE</b>	<b>L-M</b>	<b>L-M</b>	<b>L-M</b>	<b>M</b>	<b>M-H</b>	<b>M</b>	<b>M</b>

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).

## 7.0 PROJECT RESEARCH PUBLICATIONS

### 7.1 General Project References

Anderson, B.J., Wilder, J.W., Kurihara, M., White, M.D., Moridis, G.J., Wilson, S.J., Pooladi-Darvish, M., Masuda, Y., Collett, T.S., Hunter, R.B., Narita, H., Rose, K., and Boswell, R., 2008, Analysis of modular dynamic formation test results from the Mount Elbert 01 stratigraphic test well, Milne Point Unit, North Slope Alaska: Proceedings of the 6th International Conference

on Gas Hydrates (ICGH 2008), July 6–10, 2008, Vancouver, British Columbia, Canada, 13 p. (on CD-ROM).

Casavant, R.R. and others, 2003, Geology of the Sagavanirktok and Gubik Formations, Milne Point Unit, North Slope, Alaska: Implications for neotectonics and methane gas hydrate resource development, AAPG Bulletin.

Casavant, R.R. and Gross, E., 2002, Basement Fault Blocks and Subthrust Basins? A Morphotectonic Investigation in the Central Foothills and Brooks Range, Alaska, at the SPE-AAPG: Western Region-Pacific Section Conference, Anchorage, Alaska, May 18-23, 2002.

Casavant, R.R. and Miller, S.R., 2002, Tectonic Geomorphic Characterization of a Transcurrent Fault Zone, Western Brooks Range, Alaska, at the SPE-AAPG: Western Region-Pacific Section Conference, Anchorage, Alaska, May 18-23, 2002.

Collett, T.S., 1993, "Natural Gas Hydrates of the Prudhoe Bay and Kuparuk River Area, North Slope, Alaska", The American Association of Petroleum Geologist Bulletin, Vol. 77, No. 5, May 1993, p. 793-812.

Collett, T.S., 1995, Gas hydrate resources of the United States, in Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1995 National assessment of United States oil and gas resources—results, methodology, and supporting data: U.S. Geological Survey Digital Data Series 30 (on CD-ROM).

Collett, T.S., 2001, Natural-gas hydrates: resource of the twenty-first century? In M.W. Downey, J.C. Treet, and W.A. Morgan eds., Petroleum Provinces of the Twenty-First Century: American Association of Petroleum Geologist Memoir 74, p. 85-108.

Collett, T.S., 2001, MEMORANDUM: Preliminary analysis of the potential gas hydrate accumulations along the western margin of the Kuparuk River Unit, North Slope, Alaska (unpublished administrative report, December 6, 2001).

Collett et al., 2001, Modified version of a multi-well correlation section between the Cirque-2 and Reindeer Island-1 wells, depicting the occurrence of the Eileen and Tarn gas hydrate and associated free-gas accumulations (unpublished administrative report).

Collett et al., 2001, Modified version of a map that depicts the distribution of the Eileen and Tarn gas hydrate and associated free-gas accumulations (unpublished administrative report).

Collett, T.S., 2002, Methane hydrate issues – resource assessment, In the Proceedings of the Methane Hydrates Interagency R&D Conference, March 20-22, 2002, Washington, D.C., 30 p.

Collett, T.S., 2002, Energy resource potential of natural gas hydrates: Bulletin American Association of Petroleum Geologists, v. 86, no. 11, p. 1971-1992.

Collett, T.S., Johnson, A., Knapp, C., Boswell, R., 2009, Natural gas hydrates – a review, *in*

Collett, T., Johnson, A., Knapp, C., Boswell, R., eds, Natural Gas Hydrates -- Energy Resource Potential and Associated Geologic Hazards: American Association of Petroleum Geologists Memoir 89.

Collett, T.S., and Dallimore, S.R., 2002, Detailed analysis of gas hydrate induced drilling and production hazards, In the Proceedings of the Fourth International Conference on Gas Hydrates, April 19-23, 2002, Yokahama, Japan, 8 p.

Collett, T.S. and Ginsberg, G.D., 1998, Gas Hydrates in the Messoyakha Gas Field of the West Siberian Basin—A Re-examination of the Geologic Evidence, International Journal of Offshore and Polar Engineering 8 (1998): 22–29.

Digert, S. and Hunter, R.B., 2003, Schematic 2 by 3 mile square reservoir block model containing gas hydrate, associated free gas, and water (Figure 2 from December, 2002 Quarterly and Year-End Technical Report, First Quarterly Report: October, 2002 – December, 2002, Cooperative Agreement Award Number DE-FC-01NT41332.

Geauner, J.M., Manuel, J., and Casavant, R.R., 2003, Preliminary subsurface characterization and modeling of gas hydrate resources, North Slope, Alaska, , in: 2003 AAPG-SEG Student Expo Student Abstract Volume, Houston, Texas.

Howe, Steven J., 2004, Production modeling and economic evaluation of a potential gas hydrate pilot production program on the North Slope of Alaska, MS Thesis, University of Alaska Fairbanks, 141 p.

Hunter, R.B., Casavant, R. R. Johnson, R.A., Poulton , M., Moridis, G.J., Wilson, S.J., Geauner, S. Manuel, J., Hagbo, C., Glass, C.E., Mallon, K.M., Patil, S.L., Dandekar, A., And Collett, T.S., 2004, Reservoir-fluid characterization and reservoir modeling of potential gas hydrate resource, Alaska North Slope, 2004 AAPG Annual Convention Abstracts with Program.

Hunter, R.B., Digert, S.A., Casavant, R.R., Johnson, R., Poulton, M., Glass, C., Mallon, K., Patil, S.L., Dandekar, A.Y., and Collett, T.S., 2003, “Resource Characterization and Quantification of Natural Gas Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay-Kuparuk River Area, North Slope of Alaska”, Poster Session at the AAPG Annual Meeting, Salt Lake City, Utah, May 11-14, 2003. Poster received EMD, President’s Certificate for Excellence in Presentation.

Hunter, R.B., Pelka, G.J., Digert, S.A., Casavant, R.R., Johnson, R., Poulton, M., Glass, C., Mallon, K., Patil, S.L., Chukwu, G.A., Dandekar, A.Y., Khataniar, S., Ogbe, D.O., and Collett, T.S., 2002, “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”, presented at the Methane Hydrate Inter-Agency Conference of US Department of Energy, Washington DC, March 21-23, 2002.

Hunter, R.B., Pelka, G.J., Digert, S.A., Casavant, R.R., Johnson, R., Poulton, M., Glass, C., Mallon, K., Patil, S.L., Chukwu, G.A., Dandekar, A.Y., Khataniar, S., Ogbe, D.O., and Collett,

T.S., 2002, "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", at the SPE-AAPG: Western Region-Pacific Section Conference, Anchorage, Alaska, May 18-23, 2002.

Hunter, R.B., et. al., 2004, Characterization of Alaska North Slope Gas Hydrate Resource Potential, Spring 2004 Fire in the Ice Newsletter, National Energy Technology Laboratory.

Inks, T., Lee, M., Taylor, D., Agena, W., Collett, T. and Hunter, R., in press.

Jaiswal, Namit J., 2004, Measurement of gas-water relative permeabilities in hydrate systems, MS Thesis, University of Alaska Fairbanks, 100 p.

Lachenbruch, A.H., Galanis Jr., S.P., and Moses Jr., T.H., 1988 "A Thermal Cross Section for the Permafrost and Hydrate Stability Zones in the Kuparuk and Prudhoe Bay Oil Fields", Geologic Studies in Alaska by the U.S. Geological Survey during 1987, p. 48-51.

Lee, M.W., 2002, Joint inversion of acoustic and resistivity data for the estimation of gas hydrate concentration: U.S. Geological Survey Bulletin 2190, 11 p.

Lee, M.W., 2004, Elastic velocities of partially gas-saturated unconsolidated sediments, Marine and Petroleum Geology 21, p. 641-650.

Lee, M. W., 2005, Well-log analysis to assist the interpretation of 3-D seismic data at the Milne Point, North Slope of Alaska, U. S. Geological Survey Scientific Investigation Report SIR 2005-5048, 18 p.

Lewis, R.E., Collett, T.S., and Lee, M.W., 2001, Integrated well log montage for the Phillips Alaska Inc., Kuparuk River Unit (Tarn Pool) 2N-349 Well (unpublished administrative report).

Khataniar, S, Kamath, V.A., Omenihu, S.D., Patil, S.L., and Dandekar, A.Y., 2002, "Modeling and Economic Analysis of Gas Production from Hydrates by Depressurization Method", The Canadian Journal of Chemical Engineering, Volume 80, February 2002.

Singh, P. with Panda, M. and Stokes, P.J., 2008, Topical Report: Material Balance Study to Investigate Methane Hydrate Resource Potential in the East Pool of the Barrow Gas Field, in-press, prepared for USDOE NETL, DOE Project Number DE-FC26-06NT42962.

Sun, Y.F. and Goldberg, D., 2005, Analysis of electromagnetic propagation tool response in gas hydrate-bearing formations, IN Geological Survey of Canada Bulletin 585: Scientific Results from the Mallik 2002 Gas Hydrate Production Research Well Program, MacKenzie Delta, Northwest Territories, Canada, Editors S.R. Dallimore and T.S. Collett.

Werner, M.R., 1987, Tertiary and Upper Cretaceous heavy-oil sands, Kuparuk River Unit area, Alaska North Slope, in Meyer, R.F., ed., Exploration for heavy crude oil and natural bitumen: American Association of Petroleum Geologists Studies in Geology 25, p. 537-547.

Westervelt, Jason V., 2004, Determination of methane hydrate stability zones in the Prudhoe Bay, Kuparuk River, and Milne Point units on the North Slope of Alaska, MS Thesis, University of Alaska Fairbanks, 85 p.

Zhao, B., 2003, Classifying Seismic Attributes in the Milne Point Unit, North Slope of Alaska, MS Thesis, University of Arizona, 159 p.

## 7.2 Selected JMPG Publication References

Red Font denotes articles in JMPG publication

Anderson, B.J., Wilder, J.W., Kurihara, M., White, M.D., Moridis, G.J., Wilson, S.J., Pooladi-Darvish, M., Masuda, Y., Collett, T.S., Hunter, R.B., Narita, H., Rose, K., and Boswell, R., 2008, Analysis of modular dynamic formation test results from the Mount Elbert 01 stratigraphic test well, Milne Point Unit, North Slope, Alaska, Proceedings of the 6th International Conference on Gas Hydrates (ICGH 2008), July 6-10, 2008, Vancouver, British Columbia, Canada, 10 p.

Anderson, B.J., Hancock, S., Wilson, S.J., Collett, T.S., Boswell, R.M., Hunter, R.B., 2011 (a), Modular Formation Dynamics Testing at the Mount Elbert-01 Stratigraphic Test Well, Milne Point Unit, North Slope Alaska: Operational Summary, History Matching, and Interpretations *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Anderson, B.J., Kurihara, M., Wilson, S.J., Pooladi-Darvish, M., Moridis, G., White, M., 2011 (b), Regional Forward Production Modeling from Single Well Test *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Boswell, R., Collett, T.S., Hunter, R.B., and Anderson, B.J., Editors, 2011, **Thematic Set on Scientific Results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope**, Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Boswell, R., Rose, K., Collett, T.S., Lee, M.W., Winters, W.F., Lewis, K., and Agena, W.F., 2011, Geologic controls on gas hydrate occurrence in the Mount Elbert prospect: Milne Point Unit, Alaska North Slope *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Bujak, J.P., 2008, Palynological Biostratigraphy of the Interval 1990-2484 feet, Mount Elbert-01 Well, Northern Alaska, July 2008 project report, 22pp, 2 plates. *Also published as Appendix to CRA DE-FC-01NT41332 2Q2008-3Q2008 Semi-Annual Project Report.*

Collett, T.S., 1993, Natural gas hydrates of the Prudhoe Bay and Kuparuk River area, North Slope, Alaska: American Association of Petroleum Geologists Bulletin, v. 77, no. 5, p. 793-812.



Collett, T.S., 1995, Gas hydrate resources of the United States, *in* Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1995 National assessment of United States oil and gas resources on CD-ROM: U.S. Geological Survey Digital Data Series 30.

Collett, T., 2002, Energy resource potential of natural gas hydrates: American Association of Petroleum Geologists Bulletin, v. 86, no. 11, p. 1971-1992.

Collett T.S., Agena, W.F., Lee, M.W., Zyrianova, M.V., Bird, K.J., Charpentier, R.R., Cook, T., Houseknecht, D.W., Klett, T.R., Pollastro, R.M., and Schenk, C.J., 2008, Assessment of Gas Hydrate Resources on the North Slope, Alaska, U.S. Geological Survey, U.S. Department of the Interior, Fact Sheet 2008-3073, October 2008.

Collett, T.S. and Boswell, R.M., 2009, The Identification of Sites for Extended-term Gas Hydrate Reservoir Testing on the Alaska North Slope, USDOE NETL Fire-in-the-Ice Newsletter, Summer 2009, p.12-16.

Collett, T.S., Johnson, A., Knapp, C., Boswell, R., 2009, Natural gas hydrates – a review, *in* Collett, T., Johnson, A., Knapp, C., Boswell, R., eds, Natural Gas Hydrates -- Energy Resource Potential and Associated Geologic Hazards: American Association of Petroleum Geologists Memoir 89.

Collett, T.S., Lee, M.W., Agena, W.F., Miller, J.J., Lewis, K.A., Zyrianova, M.V., Boswell, R.M., Inks, T.L., 2011 (a), Permafrost Associated Natural Gas Hydrate Occurrences on the Alaska North Slope *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Collett, T.S., Lewis, R.E., Winters, W.J., Lee, M.W., Rose, K.K., and Boswell, R.M., 2011, Downhole well log and core montages from the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Collett, T.S., Lewis, R.E., Winters, W.F., Lee, M.W., Rose, R., and Boswell, R., 2009, Downhole well log and core montages from the Mount Elbert Gas Hydrate Stratigraphic Test Well, North Slope, Alaska.

Colwell, F., Briggs, B., Schwartz, 2011, Microbial Community Distribution in Sediments from the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Dai, S., Lee, C., and Santamarina, A., 2011, Formation history and physical properties of sediments from the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, *in*

Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., *Journal of Marine and Petroleum Geology*, Vol. 28, Issue 2, Feb. 2011.

Collett, T.S., and Dallimore, S.R., 2002, Detailed analysis of gas hydrate induced drilling and production hazards, In the Proceedings of the Fourth International Conference on Gas Hydrates, April 19-23, 2002, Yokohama, Japan, 8 p.

Dallimore, S.R., and Collett, T.S., Eds., 2005. Scientific Results from the Mallik 2002 Gas Hydrate Production Research Well Program, Mackenzie Delta, Northwest Territories, Canada, *Geological Survey of Canada Bulletin* **585**, two CD-ROM set.

Dallimore, S., Wright, J.F., Nixon, F.M., Kurhiara, M., Yamamoto, K., Fugjii, T., Fujii, K., Numasawa, M., Yasuda, M., and Imasato, Y., 2008a, Geologic and Porous Media Factors Affecting the 2007 Production Response Characteristics of the JOGMEC/ NRCAN/ Aurora Mallik Gas Hydrate Production Research Well: Proceedings of the 6th International Conference on Gas Hydrates (ICGH 2008), July 6-10, 2008, Vancouver, British Columbia, Canada, 10 p.

Dallimore, S. R., J. F. Wright, and K. Yamamoto, 2008b, Appendix D: Update on Mallik, *in* Energy from gas hydrates: Assessing the opportunities and challenges for Canada: Ottawa, Canada, Council of Canadian Academies, p. 196-200.

[http://www.scienceadvice.ca/documents/\(2008-11-05\)%20Report%20on%20GH.pdf](http://www.scienceadvice.ca/documents/(2008-11-05)%20Report%20on%20GH.pdf)

Hancock, S.H., Collett, T.S., S.R. Dallimore, T. Satoh, T. Inoue, E. Huenges, J. Henniges, and B. Weatherill: 2004, Overview of thermal-stimulation production-test results for the JAPEX/JNOC/GSC et al. Mallik 5L-38 gas hydrate production research well, IN Scientific Results from the Mallik 2002 Gas Hydrate Production Research Well Program, Mackenzie Delta, Northwest Territories, Canada, Dallimore, S.R., and Collett, T.S., Eds., *Geological Survey of Canada Bulletin* **585**.

Howe, S., Nanchar, N., Patil, S., Ogbe, D., Chukwu, G., Hunter, R., Wilson, S.J., 2004, Economic Analysis and Feasibility Study of Gas Production from Alaska North Slope Gas Hydrate Resources. Presented at AAPG Hedberg Conference, Vancouver, BC.

Hunter, R.B., Collett, T.S., Boswell, R., Anderson, B.J., Digert, S.A., Pospisil, G., Baker, R., and Weeks, M., 2011, Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope: Overview of Scientific and Technical Program, *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., *Journal of Marine and Petroleum Geology*, Vol. 28, Issue 2, Feb. 2011.

Inks, T., Lee, M., Agena, W., Taylor, D., Collett, T., Hunter, R., Zyrianova, M., 2010, Seismic prospecting for gas hydrate and associated free-gas prospects in the Milne Point Area of Northern Alaska; in Collett, T., Johnson, A., Knapp, C., and Boswell, R., eds, *Natural Gas Hydrates: Energy Resource and Associated Geologic Hazards*; American Association of Petroleum Geologists Memoir 89.

Johnson, A., Patil, S., and Dandekar, A., 2011, Experimental Investigation of Gas-Water Relative Permeability for Gas Hydrate-Bearing Sediments from the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., *Journal of Marine and Petroleum Geology*, Vol. 28, Issue 2, Feb. 2011.

Kneafsey, T., Lu, H., Winters, W.J., Boswell, R., Hunter, R.B., Collett, T.S., 2011, Examination of core samples from the Mount Elbert gas hydrate stratigraphic test well, Alaska North Slope, effects of retrieval and preservation, *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., *Journal of Marine and Petroleum Geology*, Vol. 28, Issue 2, Feb. 2011.

Kurihara, M., Junihiro, F., Hisanao, O., Masuda, Y., Yasuda, M., Yamamoto, K., Numasawa, M., Fuji, T., Nariat, H., Dallimore, S., and Wright, F., 2008, Analyses of the JOGMEC/NRCAN/Aurora Mallik Gas Hydrate Production Test Through Numerical Simulation: Proceedings of the 6th International Conference on Gas Hydrates (ICGH 2008), July 6-10, 2008, Vancouver, British Columbia, Canada, 13 p.

Kurihara, M., Funatsu, K., Ouchi, H., Masuda, Y., Yamamoto, K., Narita, H., Dallimore, S., Collett, T., Hancock, S., 2008, Analyses of Production Tests and MDT Tests Conducted in Mallik and Alaska Methane Hydrate Reservoirs: What can We Learn from These Well Tests?, *IN Proceedings of the 6th International Conference on Gas Hydrates (ICGH 2008), Vancouver, British Columbia, CANADA, July 6-10, 2008.*

Kurihara, M., Sato, A., Funatsu, K., Ouchi, H., Masuda, Y., Narita, H., and Collett, T.S., 2011, Analysis of Formation Pressure Test Results in the Mount Elbert Methane Hydrate Reservoir through Numerical Simulation *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., *Journal of Marine and Petroleum Geology*, Vol. 28, Issue 2, Feb. 2011.

Lee, M.W., Collett, T.S., and Agena, W.F., 2008, Assessing gas-hydrate prospects on the North Slope of Alaska – Theoretical considerations: U.S. Geological Survey, Scientific Investigations Report 2008 – 5175, 28pp.

Lee, M.W., Collett, T.S., and Inks, T.L., 2010, Seismic attribute analysis for gas-hydrate and free-gas prospects on the North Slope of Alaska, *in* Collett, T., Johnson, A., Knapp, C., Boswell, R., eds, *Natural Gas Hydrates -- Energy Resource Potential and Associated Geologic Hazards: American Association of Petroleum Geologists Memoir 89.*

Lee, M.W., Agena, W.F., Collett, T.S., and Inks, T.L., 2011 (a), Pre- and post-drill comparison of the Mount Elbert gas hydrate prospect, Alaska North Slope *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., *Journal of Marine and Petroleum Geology*, Vol. 28, Issue 2, Feb. 2011.

Lee, M.W. and Collett, T.S., 2011 (b), In-situ gas hydrate saturations estimated from various well logs at the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Lorenson, T.D., Collett, T.S., and Hunter, R.B., 2011, Gas geochemistry of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope: Implications for gas hydrate exploration in the Arctic *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Lu, H., Lorenson, T.D., Moudrakovski, I.L., Ripmeester, J.A., Collett, T.S., Hunter, R.B., and Ratcliffe, C.I., 2011, The Characteristics of Gas Hydrates Recovered from the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Moridis, G.J, Silpngarmlet, S, Reagan, M.T., Collett, T.S., and Zhang, K., 2011, Gas Production from a Cold, Stratigraphically Bounded Gas Hydrate Deposit at the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Moridis, G.J., Collett, T.S., Boswell, R., Kurihara, M., Reagan, M.T., Sloan, E.D., and Koh, C., 2008, Toward production from gas hydrates: assessment of resources and technology and the role of numerical simulation: Proceedings of the 2008 SPE Unconventional Reservoirs Conference, Keystone, Colorado, February, 10–12, 2008, SPE 114163, 45 p.

Pooladi-Darvish, M. and Hong, H., 2011, Use of Formation Pressure Test Results over a Hydrate Interval for Long Term Production Forecasting at the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope: Implications of Uncertainties *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Rose, K., Boswell, R., and Collett, T.S., 2011, Mount Elbert gas hydrate stratigraphic test well, Alaska North Slope: coring operations, core sedimentology, and lithostratigraphy *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Sigal, R.F., Rai, C., Sondergeld, C., Spears, B., Ebanks, W.J., Zogg, W.D., Emery, N., McCardle, G., Schweizer, R., McLeod, W., Van Eerde, J., 2008, Characterization of a Sediment

Core from Potential Gas Hydrate Bearing Reservoirs in the Sagavanirktok, Prince Creek, and Schrader Bluff Formations of Alaska's North Slope, Part 1. Project Summary and Geological Description of Core IN American Association of Petroleum Geologists Memoir 89, Natural Gas Hydrates -- Energy Resource Potential and Associated Geologic Hazards.

Stern, L.A., Lorenson, T.D., and Pinkston, J.C., 2011, Gas hydrate characterization and grain-scale imaging of recovered cores from the Mount Elbert gas hydrate stratigraphic test well, Alaska North Slope *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Sun, Y., Goldberg, D., Collett, T.S., and Hunter, R.B., 2011, High-resolution well-log derived dielectric properties of gas-hydrate-bearing sediments, Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Torres, M.E., Collett, T.S., Rose, K., Sample, J.C., Agena, W., Rosenbaum, E., 2011, Pore Fluid Geochemistry from the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

White, M., Wurstner, S., and McGrail, P., 2011, Numerical studies of methane production from Class 1 gas hydrate accumulations enhanced with carbon dioxide injection *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Wilson, S.J., Hunter, R.B., Collett, T.S., Hancock, S., Boswell, R., Anderson, B.J., 2011, Alaska North Slope Regional Gas Hydrate Production Modeling Forecasts *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Winters, W.J., Walker, M., Kwon, O., Waite, B., Torres, M., Collett, T.S., and Rose, K., 2011, Physical Properties of Sediment from the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope *in* Scientific results of the Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska North Slope, Ed. by Boswell, R., Collett, T., Anderson, B., and Hunter, R., Journal of Marine and Petroleum Geology, Vol. 28, Issue 2, Feb. 2011.

Yamamoto, K., and Dallimore, S., 2008, Aurora-JOGMEC-NRCan Mallik 2006-2008 Gas Hydrate Research Project progress, *in* DOE-NETL Fire In the Ice Methane Hydrate Newsletter, Summer 2008, p. 1-5.

<http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/Newsletter/HMNewsSummer08.pdf#Page=1>

### **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.
- 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 Reservoirs 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. 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.
- f. 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. Suppl., Abstract OS42B-06.
- g. 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.
- h. 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.
- i. 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.
- j. Hagbo, C. and R. Johnson, 2003, Delineation of gas hydrates, North Slope, Alaska, 2003 Univ. of Arizona Dept. Geosciences Annual GeoDaze Symposium.
- k. 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.
- 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.

### 7.3.4 Sponsored Thesis Publications

- 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. Zhao, 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.

### 7.3.5 Artificial Neural Network References

Bishop, C., 1995, Neural Networks for Pattern Recognition: Oxford Press.

Broomhead, D., and Lowe, D., 1988, Multivariable functional interpolation and adaptive networks: Complex Systems, 2, 321-355.

Casavant, R. R., 2001, Morphotectonic Investigation of the Arctic Alaska Terrane: Implications to Basement Architecture, Basin Evolution, Neotectonics and Natural Resource Management: Ph.D thesis, University of Arizona, 457 p.

Casavant, R., Hennes, A., Johnson, R., and Collett, T., 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.

Collett, T., Bird, K., Kvenvolden, K., and Magoon, L., 1988, Geologic interrelations relative to gas hydrates within the North Slope of Alaska: USGS Open File Report, 88-389.

Darken, C., and Moody, J., 1990, Fast adaptive K-means clustering: Some empirical results: IEEE INNS International Joint Conference on Neural Networks, 233-238.

Gandler, G., Casavant, R., Glass, C., Hennes, A., Hagbo, C., and Johnson, R., 2004, Preliminary Spatial Analysis of Faulting and Gas Hydrate 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.

Geauner, S., Manuel, J., Casavant, R., Glass, C., and Mallon, K., 2004, Well Log Normalization and Comparative Volumetric Analyses 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.

Girosi, F. and Poggio, T., 1990, Networks and the best approximation property: *Biological Cybernetics*, 63, 169-176.

Glass, C. E. 2003, Estimating pore fluid concentrations using acoustic and electrical log attributes, Interim Report, UA Gas Hydrate Project.

Hagbo, C., 2003, Characterization of gas hydrate occurrences using 3D seismic data and seismic attributes, Milne Point, North Slope, Alaska: MS Thesis, University of Arizona, Tucson, Arizona.

Hashin, Z and S. Shtrikman, 1963, A variational approach to the theory of the elastic behavior of multiphase materials, *Journal of the Mechanics and Physics of Solids*, Vol. 11, p. 127-140.

Haykin, S., 1994, *Neural Networks. A Comprehensive Foundation*: Macmillan.

Light, W., 1992, Some aspects of radial basis function approximation, in Singh, S., Ed., *Approximation Theory, Spline Functions and Applications: NATO ASI series*, 256, Kluwer Academic Publishers, 163-190.

Mavco, G., T. Mukerji and J. Dvorkin, 1988, *The rock physics handbook*, Cambridge University Press.

Moody, J., and Darken, C., 1989, Fast learning in networks of locally-tuned processing units: *Neural Computation*, 1, 281-294.

Musavi, M., Ahmed, W., Chan, K., Faris, K., and Hummels, D., 1992, On the training of radial basis function classifiers: *Neural Networks*, 5, 595-603.

Poggio, T. and Girosi, F., 1989, A theory of networks for approximation and learning: A.I. Memo No. 1140 (C.B.I.P. Paper No. 31), Massachusetts Institute of Technology, Artificial Intelligence Laboratory.

Poulton, M., 2002, Neural networks as an intelligence amplification tool: A review of applications: *Geophysics*, vol. 67, no. 3, pp. 979-993.

Poulton, M., (Ed.), 2001, *Computational Neural Networks for Geophysical Data Processing*: Pergamon, Amsterdam, 335p.

Powell, M., 1987, Radial basis functions for multivariable interpolation: A review, in Mason, J. and Cox, M., Eds., *Algorithms for Approximation*: Clarendon Press.

Zell, A., 1994, *Simulation Neuronaler Netze*: AddisonWesley.

Zhao, B., 2003, Classifying Seismic Attributes In The Milne Point Unit, North Slope of Alaska: MS Thesis, University of Arizona, Tucson, Arizona.

### **7.3.6 University of Arizona Final Report References**

Abu-Hamdeh, N. H., and R. C. Reeder, 2000, Soil thermal conductivity--effects of density, moisture, salt concentration, and organic matter: *Soil Science Society of America Journal*, v. 64, p. 1285-1290.

Alaska, O. G. C. C., 1981, Mud Log Baroid Logging Systems, Sohio Alaska West Sak No. 16 and West Sak No. 17, Anchorage, AK.

Archie, G. E., 1942, The electrical resistivity log as an aid in determining some reservoir characteristics: *Journal of Petroleum Technology*, v. 5, p. 1-8.

Bishop, C., 1995, *Neural Networks for Pattern Recognition*: Oxford Press.

Bird, K. J., 1985, The framework geology of the North Slope of Alaska as related to oil-source rock correlations, in L. B. Magoon and G. E. Claypool, eds., *Alaska North Slope oil-rock correlation study; analysis of North Slope Crude: AAPG Studies in Geology*, v. 20, p. 3-29.

Bird, K. J. and L. B. Magoon (1987). *Petroleum geology of the northern part of the Arctic National Wildlife Refuge, northeastern Alaska Bulletin*. Washington, D.C., U.S. Geological Survey.

Bond, L. O., R. P. Alger, and A. W. Schmidt, 1972, Well log applications in coal mining and rock mechanics: *Transactions of the American Institute of Mining, Metallurgical and Petroleum Engineers*, v. 250, p. 355-362.

Bouvier, J. D., C. H. Kaars-Sijpesteijn, D. F. Kluesner, C. C. Onyejekwe, and R. C. Van Der Pal, 1989, Three-Dimensional Seismic Interpretation and Fault Sealing Investigations, Nun River Field, Nigeria: *AAPG Bulletin*, v. 73, n. 11, p. 1397-1414.

Broomhead, D., and Lowe, D., 1988, Multivariable functional interpolation and adaptive networks: *Complex Systems*, 2, 321-355.

Carman, G. J., and P. Hardwick, 1983, *Geology and Regional Setting of Kuparuk Oil Field, Alaska: AAPG Bulletin*, v. 67, n. 6, p. 1014-1031.

Casavant, R.R., 2001, *Morphotectonic Investigation of the Arctic Alaska Terrane: Implications to Basement Architecture, Basin Evolution, Neotectonics and Natural Resource Management*: Ph.D. thesis, University of Arizona, 457 p.

Casavant, R., 2004, *Reservoir-Fluid Characterization and Reservoir Modeling of Potential Gas Hydrate Resources, Alaska North Slope*, Calgary, AB, Canada, Canadian Society of Petroleum Geologists Technical Conference, June 1.

Casavant, R.R. and Gross, E., 2002, Basement Fault Blocks and Subthrust Basins? A Morphotectonic Investigation in the Central Foothills and Brooks Range, Alaska: Western Region-Pacific Section Conference, Anchorage, Alaska, May 18-23, 2002.

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.

Casavant, R.R., and Miller, S.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.

Casavant, R. R. and K. M. Mallon, 1999, Facies and reservoir characterization of the Morrow Sandstones (Lower Pennsylvanian), White City Penn Gas Pool, Eddy County, southeastern New Mexico. Symposium of the Oil and Gas fields of southeastern New Mexico, 1999 Supplement "Pennsylvanian Gas Field", Roswell, NM, Roswell Geological Society.

Casavant, R. R., and S. R. Miller, 1999a, "Is the Western Brooks Range on the move?", Abstracts with Program, Geological Society of America, 1999 Annual meeting, Denver, CO, v. 31, n. 7, p. 474.

Casavant, R.R. and others, in preparation, Geology of the Sagavanirktok and Gubik Formations, Milne Point Unit, North Slope, Alaska: Implications for neotectonics and methane gas hydrate resource development.

Collett, T. S., 1983, Detection and evaluation of natural gas hydrates from well logs, Prudhoe Bay, Alaska: Masters thesis, University of Alaska, Fairbanks, 77 p.

Collett, T. S., 1993, Natural Gas Hydrates of the Prudhoe Bay and Kuparuk River Area, North Slope, Alaska: AAPG Bulletin, v. 77, n. 5, p. 793-812.

Collett, T. S., 1997, Gas hydrate resources of northern Alaska: Bulletin of Canadian Petroleum Geology, v. 45, p. 317-338.

Collett, T. S., 1998, Gas hydrates of northern Alaska – a potential energy resource or just a nuisance?: Alaska Geology, v. 28, p. 1-5.

Collett, T. S., and K. A. Kvenvolden, 1987, Evidence of naturally occurring gas hydrates on the North Slope of Alaska: U.S. Geological Survey Open-File Report, v. 87-255, p. 8 pp.

Collett, T. S., K. J. Bird, K. A. Kvenvolden, and L. B. Magoon, 1988, Geologic interrelations relative to gas hydrates within the North Slope of Alaska: U.S. Geological Survey Open-File Report, v. 88-389, p. 150 p.

Collett, T. S., K. J. Bird, and L. B. Magoon, 1993, Subsurface temperatures and geothermal gradients on the North Slope of Alaska: Cold Regions Science and Technology, v. 21, p. 275-293.

Collett, T. S., R. E. Lewis, S. R. Dallimore, M. W. Lee, T. H. Mroz, and T. Uchida, 1999, Detailed evaluation of gas hydrate reservoir properties using JAPEX/JNOC/GSC Mallik 2L-38 gas hydrate research well downhole well-log displays: Scientific Results from JAPEX/JNOC/GSC Mallik 2L-38 Gas Hydrate Research Well, Mackenzie Delta, Northwest Territories, Canada, p. 295-311.

Dallimore, S. R., 1992, Borehole logs from joint GSC-industry Mackenzie Delta geology/permafrost transect, Geological Survey of Canada Open File Report, p. 3 Sheets.

Dallimore, S. R. and T. S. Collett, 1995, Intrapermafrost gas hydrates from a deep core hole in the Mackenzie Delta, Northwest Territories, Canada: Geology, v. 23, n. 6, p. 527-530.

Dallimore, S. R., T. Uchida, and T. S. Collett, 1999, Scientific results from JAPEX/JNOC/GSC Mallik 2L-38 Gas Hydrate Research Well, Mackenzie Delta, Northwest Territories, Canada, v. 544, Geological Survey of Canada Bulletin, 403 pp.

Darken, C., and Moody, J., 1990, Fast adaptive K-means clustering: Some empirical results: IEEE INNS International Joint Conference on Neural Networks, 233-238.

Davidson, D. W., M. K. El-Defrawy, et al. (1978). Natural gas hydrates in northern Canada. Proceedings of the 3rd International Conference on Permafrost, National Research Council of Canada.

Deming, D., J. H. Sass, A. H. Lachenbruch, and R. F. De Rito, 1992, Heat flow and subsurface temperature as evidence for basin-scale ground-water flow, North Slope of Alaska: Geological Society of America Bulletin, v. 104, p. 528-542.

Dennis, J., Gay, D., and Welsch, R., 1981, An adaptive nonlinear least-squares algorithm: ACM Transactions on Mathematical Software, 7, 3, 348-368.

Doughty, P., 2003, Clay smear seals and fault sealing potential of an exhumed growth fault, Rio Grande Rift, New Mexico: AAPG Bulletin, 87(3), p. 427-444.

Dooley, T., and K. McClay, 1997, Analog modeling of pull-apart basins: American Association of Petroleum Geologists, v. 81, n. 11, p. 1804-1826.

Galate, J. W., and M. A. Goodman, 1982, Review and evaluation of evidence of in-situ gas hydrates in the National Petroleum Reserve in Alaska: U.S. Geological Survey unpublished report, Contract No. 14-08-000119148, p. 102.

Gandler, G.L., Casavant, R.R., Johnson, R.A., Glass, K., and Collett, T.S., 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.

Geauner, S., Manuel, J., and Casavant, R.R., 2003, Preliminary subsurface characterization and modeling of gas hydrate resources, North Slope, Alaska, , in: 2003 AAPG-SEG Student Expo Student Abstract Volume, Houston, Texas.

Geauner, S., Manuel, J., Casavant, R.R., Glass, C.E., and Mallon, K., 2004, Well Log Normalization and Comparative Volumetric Analyses 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.

Geauner, S., 2009, Fault analysis, seismic facies modeling and volumetric reassessment of gas hydrates in the Milne Point Unit, North Slope, Alaska: Master of Science thesis, University of Arizona, Tucson, in progress.

Geman, S., Bienenstock, E. and Doursat, R., 1992, Neural networks and the bias/variance dilemma: *Neural Computation*, 4, 1-58.

Girosi, F. and Poggio, T., 1990, Networks and the best approximation property: *Biological Cybernetics*, 63, 169-176.

Glass, C. E. 2003, Estimating pore fluid concentrations using acoustic and electrical log attributes, Interim Report, UA Gas Hydrate Project.

Glass, C.E., and Casavant, R.R., 2007, Using thermal conductivity modeling and wireline petrophysical logs to identify intrapermafrost gas hydrate: manuscript submitted to *Journal of Geophysical Research*.

Glass, C.E., and Casavant, R.R., in progress (2009), Estimating permafrost thinning on the central North Slope of Alaska using well bore temperature and petrophysical wireline logs: manuscript in preparation for submittal.

Glass, C.E., and Casavant, R.R., in progress (2009), Expert system for estimating gas hydrate concentrations using petrophysical wireline logs on the central Alaskan North Slope: manuscript in preparation for submittal.

Glass, C.E., and Casavant, R.R., in progress (2009), Estimating the base of the permafrost and base of the hydrate stability field using simulated well bore temperature logs: manuscript in preparation for submittal.

Grantz, A., S. Eittreim, and D. A. Dinter, 1979, *Geology and Tectonic Development of the Continental Margin of North Alaska: Tectonophysics*, v.59, p. 263-291.

Grantz, A., S. D. May, and D. A. Dinter, 1988a, Geologic framework, petroleum potential, and environmental geology of the United States Beaufort and northeasternmost Chukchi Seas, in G. Gyr, ed., *Geology and Exploration of the National Petroleum Reserve in Alaska, 1974 to 1982*, Washington, D.C., U.S. Geological Survey Professional Paper, p. 231-256.

Grantz, A., S. May, and P. Hart, 1994, Geology of the Arctic continental margin of Alaska, in G. Plafker and H.C. Berg, eds., *The Geology of Alaska: Boulder, Colorado, Geological Society of America, The Geology of North America*, v. G-1, p. 17-48.

Grollmund, B., and M. D. Zoback, 2003, Impact of glacially induced stress changes on fault-seal integrity offshore Norway: *AAPG Bulletin*, v. 87, n. 3, p. 493-506.

Gyr, G., Ed. (1988). *Geology and Exploration of the National Petroleum Reserve in Alaska, 1974 to 1982*. Washington D.C., U.S. Geological Survey Professional Paper.

Hagbo, C.L., 2003, Characterization of Gas hydrate Occurrences using 3D Seismic Data and Seismic Attributes, Milne Point, North Slope, Alaska, M.S. Thesis, Department of Geosciences, University of Arizona, Tucson, 127 pp.

Hagbo, C. and R. A. Johnson, 2003, Use of Seismic Attributes in Identifying and Interpreting Onshore Gas hydrate Occurrences, North Slope, Alaska (abs.): *Eos Transaction American Geophysical Union* 84 (46), Fall Meet. Suppl., Abstract OS42B-06, 2003

Hagbo, C. and Johnson, R., 2003, Delineation of gas hydrates, North Slope, Alaska, 2003 University of Arizona Department of Geosciences Annual GeoDaze Symposium presentation.

Hashin, Z., and S. Shtrikman, 1963, A variational approach to the theory of the elastic behavior of multiphase materials: *Journal of the Mechanics and Physics of Solids*, v. 11, p. 127-140.

Haykin, S., 1994, *Neural Networks. A Comprehensive Foundation*: Macmillan.

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), Department of Geosciences, University of Arizona, Tucson, 76 pp.

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 University of Arizona Department of Geosciences Annual GeoDaze Symposium.

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, University of Arizona Department of Geosciences Annual GeoDaze Symposium presentation.

Hennes, A.M., Johnson, R.A., and Casavant, R.R., 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.

Hertz, J., Krogh, A. and Palmer, R.G., 1991, Introduction to the Theory of Neural Computation: Addison Wesley.

Holder, G. D., R. D. Malone, et al. (1987). "Effects of gas composition and geothermal properties on the thickness and depth of natural gas hydrate zone." *Journal of Petroleum Technology* 39(9): 1147-1152.

Hubbard, R. J., S. P. Edrich, and R. P. Rattey, 1987, Geologic evolution and hydrocarbon habitat of the Arctic Alaska microplate, in I. Tailleux, and P. Weimer, eds., *Alaskan North Slope Geology*, Bakersfield, CA, Society of Economic Paleontologists and Mineralogists, Pacific Section, and Alaska Geological Society, p. 797-830.

Hunter, R.B., Pelka, G.J., Digert, S.A., Casavant, R.R., Johnson, R., Poulton, M.M, Glass, C., Mallon, K., Patil, S.L., Chukwu, G.A., Dandekar, A.Y., Khataniar, S., Ogbe, D.O., and Collett, T.S., 2002, "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", presented at the Methane Hydrate Inter-Agency Conference of US Department of Energy, Washington DC, March 21-23, 2002.

Hunter, R.B., Pelka, G.J., Digert, S.A., Casavant, R.R., Johnson, R., Poulton, M., Glass, C., Mallon, K., Patil, S.L., Chukwu, G.A., Dandekar, A.Y., Khataniar, S., Ogbe, D.O., and Collett, T.S., 2002, "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", at the SPE-AAPG: Western Region-Pacific Section Conference, Anchorage, Alaska, May 18-23, 2002, p. 81-82.

Hunter, R.B., Digert, S.A., Casavant, R.R., Johnson, R., Poulton, M., Glass, C., Mallon, K., Patil, S.L., Dandekar, A.Y., and Collett, T.S., 2003, "Resource Characterization and Quantification of Natural Gas Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay-Kuparuk River Area, North Slope of Alaska", Poster Session at the AAPG Annual Meeting, Salt Lake City, Utah, May 11-14, 2003. Poster received EMD, President's Certificate for Excellence in Presentation.

Hunter, R.B., Casavant, R.R. Johnson, R.A., Poulton, M., Moridis, G.J., Wilson, S.J., Geauner, S. Manuel, J., Hagbo, C., Glass, C.E., Mallon, K.M., Patil, S.L., Dandekar, A., and Collett, T.S., 2004, Reservoir-fluid characterization and reservoir modeling of potential gas hydrate resource, Alaska North Slope, 2004 AAPG Annual Convention Abstracts with Program.

Hunter, R., T. Collett, S. Patil, R. Casavant, and T. Mroz, 2004, Characterization, Appraisal and Economic Viability of Alaska North Slope Gas Hydrate Accumulations, Vancouver, BC, Canada, The American Association of Petroleum Geologists Hedberg Research Conference, September 12-16.

Hunter, R., T. Collett, S. Wilson, T. Inks, R. Casavant, R. Johnson, M. Poulton, K. Mallon, S. Patil, and A. Dandekar, 2005, Gas Hydrate Prospect Development and Production Modeling, Alaska North Slope, Calgary, AB, Canada, The American Association of Petroleum Geologists Annual Meeting, June 19-22.

Hyndman, R. D., and G. D. Spence, 1992, A Seismic Study of Methane Hydrate Marine Bottom Simulating Reflectors: *Journal of Geophysical Research*, v. 97, n. B5, p. 6683-6698.

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.

Jones, H. P. and R. G. Speers (1976). "Permo-Triassic reservoirs of Prudhoe Bay Field, North slope, Alaska." *Memoir - AAPG(24)*: 23-50.

Khairkhah, D., M. Pooladi-Darvish, P. R. Bishnoi, T. S. Collett, and S. R. Dallimore, 1999, Production potential of the Mallik field reservoir in S. R. Dallimore, T. Uchida, and T. S. Collett, eds., *Scientific Results from JAPEX/JNOC/GSC Mallik 2L-38 Gas Hydrate Research Well, Mackenzie River Delta, Northwest Territories, Canada: Geological Survey of Canada Bulletin 544*, p. 377-390

Knipe, R. J., 1997, Juxtaposition and Seal Diagrams to Help Analyze Fault Seals in Hydrocarbon Reservoirs: *AAPG Bulletin*, v. 81, n. 2, p. 187-195.

Koleodye, B. A., A. Aydin, and E. May, 2003, A new process-based methodology for analysis of shale smear along normal faults in the Niger Delta: *AAPG Bulletin*, v. 87, n. 3, p. 445-463.

Krantz, R. W., 1995, The transpressional strain model applied to strike-slip, oblique-convergent and oblique-divergent deformation: *Journal of Structural Geology*, v. 17, n. 8, p. 1125-1137.

Kvenvolden, K. A., 1993, A Primer on Gas Hydrates in D. G. Howell, eds., *The Future of Energy Gases: U.S. Geological Survey Professional Paper 1570*, p. 279-291.



Kvenholden, K. A., and M. A. McMennamin, 1980, Hydrates of natural gas—a review of their geologic occurrence: US. Geological Survey Circular, v. 825, p. 11p.

Lachenbruch, A. H., P. S. Galanis Jr., and T. H. Moses Jr., 1987, A Thermal Cross Section for the Permafrost and Hydrate Stability Zones in the Kuparuk and Prudhoe Bay Oil Fields, in J. P. Galloway, and T. D. Hamilton, eds., Geologic Studies in Alaska by the U.S. Geological Survey during 1987: USGS Geological Survey Circular 1016, p. 48-51.

Lachenbruch, A. H., J. H. Sass, et al. (1982). "Permafrost heat flow, and the geothermal regime at Prudhoe Bay, Alaska." *Journal of Geophysical Research* 87(B11): 9310-9316.

Lachenbruch, A. H., J. H. Sass, et al. (1987). "Temperature and depth of permafrost on the Alaskan Arctic Slope." *Alaska North Slope Geology* 2: 545-558.

Lachenbruch, A. H., J. H. Sass, B. V. Marshall, and T. H. Moses, 1982, Permafrost heat flow, and the geothermal regime at Prudhoe Bay, Alaska: *Journal of Geophysical Research*, v. 87, p. 9310-9316.

Lachenbruch, A. H., J. H. Sass, L. A. Lawver, M. C. Brewer, B. V. Marshall, R. J. Munroe, J. P. J. Kennelly, S. P. J. Galanis, and T. H. J. Moses, 1987, Temperature and depth of permafrost on the Alaskan Arctic Slope, in I. Tailleux, and P. Weimer, eds., *Alaska North Slope Geology*, v. 2, Bakersfield California Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 545-558.

Lamorey, G., 2003, West Arctic Ice Sheet Antarctic Glaciological Data Center Catalog.

Lee, M. W., 1999, Methods of generating synthetic acoustic logs from resistivity logs for gas hydrate-bearing sediments, in U. S. G. Survey, ed., *U.S. Geological Survey Bulletin*, U.S. Geological Survey, p. 11p.13.

Lee, M. W., Hutchinson, D. R., Collett, T. S., and Dillon, W. P., 1996, Seismic velocities for hydrate-bearing sediments using weighted equation: *Journal of Geophysical Research*, v. 101, n. B9, p. 20,347-20,358.

Lee, M. W., and T. S. Collett, 1999, Amount of gas hydrate estimated from compressional and shear-wave velocities at the JAPEx/JNOC/GSC Mallik 2L-38 gas hydrate research well, in S. R. Dallimore, T. Uchida, and T. S. Collett, eds., *Scientific results from JAPEx/JNOC/GSC Mallik 2L-38 gas hydrate research well, Mackenzie Delta, Northwest Territories*, v. 544, Canada Geological Survey of Canada Bulletin p. 313-322.

Light, W., 1992, Some aspects of radial basis function approximation, in Singh, S., Ed., *Approximation Theory, Spline Functions and Applications: NATO ASI series*, 256, Kluwer Academic Publishers, 163-190.

Makogon, Y. F., 1981, *Hydrates of natural gas*: Tulsa, OK, Penn Well Publishing

Company, 237 p.

Manuel, J., 2008, A chronostratigraphic framework of the Sagavanirktok Formation, North Slope Alaska: Incorporating facies characterization, reservoir continuity and dimensions in relation to gas hydrate and associated free-gas resources, M.Eng. Report, Department of Mining and Geologic Engineering, University of Arizona.

Mavco, G., T. Mukerji and J. Dvorkin, 1988, The rock physics handbook, Cambridge University Press.

Mendes, N., C. P. Fernandes, P. C. Philippi, and R. Lamberts, 2001, Moisture content influence on thermal conductivities of porous building materials: Seventh International IBPSA Conference, p. 957-963.

Meyer V., A. Nicol, C. Childs, J. J. Walsh, and J. Watterson, 2002, Progressive localization of strain during the evolution of a normal fault population: *Journal of Structural Geology*, v. 24, p. 1215-1231.

Mitchell, K., Casavant, R., and Manuel, J., 2003, Regional characterization of the Cretaceous Nanushuk Group: Preliminary assessment for coal-bed methane potential in arctic Alaska, The American Association of Petroleum Geologists-SEG Student Expo, Houston, TX, October 5-6.

Michelli, C., 1986. Interpolation of scattered data: distance matrices and conditionally positive definite functions: *Constructive Approximations*, 2, 11-22.

Moody, J., and Darken, C., 1989, Fast learning in networks of locally-tuned processing units: *Neural Computation*, 1, 281-294.

Moore T., W. Wallace, K. Bird, S. Karl, C. Mull, and J. Dillon, 1994, Geology of Northern Alaska, in G. Plafker, and H. C. Berg., eds., *The Geology of Alaska: Boulder, Colorado, Geological Society of America, The Geology of North America*, v. G-1, p. 49-140.

Morgridge, D. L. and W. B. Smith (1972). "Geology and discovery of Prudhoe Bay field, eastern Arctic Slope, Alaska." *AAPG Memoir* 16: 489-501.

Musavi, M., Ahmed, W., Chan, K., Faris, K., and Hummels, D., 1992, On the training of radial basis function classifiers: *Neural Networks*, 5, 595-603.

Ohara, T., S. R. Dallimore, and E. Fercho, 1999, Drilling operations, JAPEX/JNOC/GSC Mallik 2L-38 gas hydrate research well, in S. R. Dallimore, T. Uchida, and T. S. Collett, eds., *Scientific results from JAPEX/JNOC/GSC Mallik 2L-38 Gas Hydrate Research Well, Mackenzie Delta, Northwest Territories, Canada*, v. 544, *Geological Survey of Canada Bulletin*, p. 19-30.

Osterkamp, T. E., and M. W. Payne, 1981, Estimates of permafrost thickness from well logs in northern Alaska: *Cold Regions Science and Technology*, v. 5, p. 13-17.

Poggio, T. and Girosi, F., 1989, A theory of networks for approximation and learning: A.I. Memo No. 1140 (C.B.I.P. Paper No. 31), Massachusetts Institute of Technology, Artificial Intelligence Laboratory.

Poggio, T. and Girosi, F., 1990a, Regularization algorithms for learning that are equivalent to multilayer networks. *Science*, 247, 978-982.

Poggio, T. and Girosi, F., 1990b, Networks for approximation and learning. *Proceedings of the IEEE*, 78, 1481-1497.

Poulton, M., (Ed.), 2001, *Computational Neural Networks for Geophysical Data Processing*: Pergamon, Amsterdam, 335p.

Poulton, M., 2002, Neural networks as an intelligence amplification tool: A review of applications: *Geophysics*, vol. 67, no. 3, pp. 979-993.

Poulton, M.M., Casavant, R.R., Glass, C.E., and Zhao, B., 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.

Poulton, M.M. and Meisberger, D., in progress (2009), Artificial neural network analysis and gas hydrate characterization, Milne Point Unit, Alaskan North Slope.

Powell, M., 1987, Radial basis functions for multivariable interpolation: A review, in Mason, J. and Cox, M., Eds., *Algorithms for Approximation*: Clarendon Press.

Rawlinson, S. E., 1993, Surficial geology and morphology of the Alaskan central Arctic Coastal Plain: Alaska Division of Geological and Geophysical Surveys Report of Investigations, v. 93-1, n. 172.

Reister, D. B., 2003, Using measured velocity to estimate gas hydrates concentration: *Geophysics*, v. 68, p. 884-891.

Roberts, S. B., 1991, Subsurface cross section showing coal beds in the Sagavanirktok Formation, vicinity of Prudhoe Bay, East-Central North Slope, Alaska, U.S. Geological Survey.

Saxena, R. S. (1979). *Facies Models and Subsurface Exploration Methods for the Analysis of Deltaic and other Associated Sandstone Reservoirs*: 233.

Slack, G. A., 1980, Thermal conductivity: *Physic Review*, v. B, p. 3065.

Sloan, E. D., 1990, Clathrate hydrates of natural gases: New York, Marcel Drekker, 641 p.

Spath, H., 1980, Cluster Analysis Algorithms for Data Reduction and Classification of Objects: Elis Horwood Publishers.

Stein, J.A., Johnson, R.A., Casavant, R.R., and Warren, M.B., 2007, Calibration and analysis of methane hydrate beneath Alaska's North Slope using spectral decomposition of 3-D seismic reflection data: manuscript submitted to American Geophysical Union.

Tikhonov, A. and Arsenin, V., 1977, Solutions of Ill-Posed Problems: W.H.Winston.

Tye, R. S. (2004). "Geomorphology: An approach to determining subsurface reservoir dimensions." AAPG Bulletin 88(8): 1123-1147.

U.S. Geological Survey, 1989, U.S. Geological Survey's Borehole Temperature Logs from Arctic Alaska, pre-1989, U.S. Geological Survey.

Van Wagoner, J. C., R. M. Mitchum, et al. (1990). Siliciclastic Sequence Stratigraphy in Well Logs, Cores, and Outcrops: Concepts for High-Resolution Correlation of Time and Facies. Tulsa, OK, The American Association of Petroleum Geologists.

Waite, W. F., L. Y. Gilbert, W. J. Winters, and D. H. Mason, 2004, Thermal property measurements in tetrahydrofuran (THF) hydrate between -25 and +4°C and their application to methane: EOS Transactions, American Geophysical Union, p. abstract # OS41C-0489.

Weimer, P. (1987). Northern Alaska Exploration - the past dozen years. Alaskan North Slope Geology. I. Tailleir and P. Weimer. Bakersfield, CA, The Pacific Section, Society of Economic Paleontologists and Mineralogists. 1: 31-39.

Werner, M. R., 1987, West Sak and Ugnu Sands: Low-gravity oil zones of the Kuparuk River area, Alaskan North Slope, in I. Tailleir, and P. Weimer, eds., Alaskan North Slope Geology, Bakersfield, CA, The Pacific Section, Society of Economic Paleontologists and Mineralogists.

Wright, J. F., S. R. Dallimore, and M. F. Nixon, 1999, Influences of grain size and salinity on pressure-temperature thresholds for methane hydrate stability in JAPEX/JNOC/GSC Mallik 2L-38 gas hydrate research-well sediments: Scientific Results from JAPEX/JNOC/GSC Mallik 2L-38 Gas Hydrate Research Well, Mackenzie Delta, Northwest Territories, Canada, p. 229-240.

Wyllie, M. R. J., A. R. Gregory, and G. H. F. Gardner, 1958, An experimental investigation of factors affecting elastic wave velocities in porous media: Geophysics, v. 23, p. 459-493.

Yakushev, V. S., and T. S. Collett, 1992, Gas hydrates in arctic regions: Risk to drilling and production: 2nd International Offshore and Polar Engineering Conference, p. 669-673.

Yielding, G., B. Freeman, and D. T. Heedham, 1997, Quantitative Fault Seal Prediction: AAPG Bulletin, v. 81, n. 6, p. 897-917.

Yielding, G., J. A. Overland, and G. Byberg, 1999, Characterization of Fault Zones for Reservoir Modeling: An Example from the Gullfaks Field, Northern North Sea: AAPG Bulletin, v. 83, n. 6, p. 925-951.

Zell, A., 1994, Simulation Neuronaler Netze: Addison Wesley.

Zhao, B., 2003, Classifying Seismic Attributes in the Milne Point Unit, North Slope of Alaska, MS Thesis, University of Arizona, 159 p.

## **7.4 University of Alaska Fairbanks Research References**

### **7.4.1 Gas Hydrate Phase Behavior and Relative Permeability References**

ASTM, 2000, "Standard Test Method for Permeability of Granular Soils (constant head) D 2434-68", American Society for Testing and Materials, Annual Book of ASTM Standards, West Conshohocken, PA, 202-206.

Dvorkin, J., Helgerud, M.B., Waite, W.F., Kirby, S.H. and Nur, A., 2000, "Introduction to Physical Properties and Elasticity Models", in Natural Gas Hydrate in Oceanic and Permafrost Environments, edited by M.D. Max, pp 245-260, Kluwer, Dordrecht.

Gash, B.W., 1991, "Measurement of Rock Properties in Coal for Coalbed Methane Production", Paper 22909 presented at the 1991 SPE annual Technical conference and Exhibition, Dallas, October 6-9.

Johnson, E.F., Bossler, D.P., and Neumann, V.O., 1959, "Calculation of Relative Permeability from Displacement Experiments", Trans. AIME, 216, 370- 372.

Jones, S.C. and Roszelle, W.O., 1978, "Graphical Techniques for Determining Relative Permeability from Displacement Experiments", JPT, (May 1978), 807-817.

Joseph W. W. and Duane H.S., 2002, "Upper Limits on the Rates of Dissociation of Clathrate Hydrates to Ice and Free Gas", J. Phys. Chem. B., (May 2002), 106, 6298-6302.

Makogon, Y.F., Makogon, T.Y. and Holditch, S.A., 1998, "Several Aspects of the Kinetics and Morphology of Gas Hydrates", Proceedings of the International Symposium on Methane Hydrates: Resources in the Near Future?, Chiba City, Japan, 20-22, October 1998.

Masuda, Y., Ando, S., Ysukui, H., and Sato, K., 1997, "Effect of Permeability on Hydrate Decomposition in Porous Media", International Workshop on Gas Hydrate Studies, Tsukuba, Japan, Mar 4-6, 1997.

Mehrad, N., 1989, "Measurement of gas permeability in hydrate saturated unconsolidated cores", M.S thesis, University of Alaska Fairbanks.

Owens, W.W., Parrish, D.R., and Lamoreaux, W.E., 1956, "An Evaluation of Gas Drive Method for Determining Relative Permeability Relationships", *Trans., AIME* 207, 275-280.

Scheidegger, A.E., 1998, *The Physics of Flow Through Porous Media*, Macmillan, New York.

Sloan, E.D., 1998, *Clathrate Hydrates of Natural Gases*, Marcel Dekker, New York.

Spangenberg, W., 2001, "Modeling of the influence of gas hydrate content on the electrical properties of porous sediments", *J of Geophys. Res B.*, 106, 6535-6549.

Stern, L.A., Kirby, S.H., Durham, W.B., Circone, S. and Waite, W.F., 2000, "Laboratory synthesis of pure methane hydrate suitable for measurement of physical properties and decomposition behavior" in *Natural Gas Hydrate in Oceanic and Permafrost Environments*, edited by M.D. Max, pp 323-348, Kluwer, Dordrecht.

Tooth, J., Bodi, T., et al., 2000, "Analytical Techniques for Determination of Relative Permeability from Displacement Experiments", *Progress in Mining and Oilfield Chemistry*, Vol-2, 91-100.

Westervelt, J.V., 2004. "Determination of methane hydrate stability zones in the Prudhoe Bay, Kuparuk River, and Milne Point units on the North Slope of Alaska". MS Thesis, University of Alaska Fairbanks, Fairbanks, AK.

Wilder, J.W., Seshadri, K. and Smith, D.H., 2001, "Modeling Hydrate Formation in Media With Broad Pore Size Distributions", *Langmuir* 17, 6729-6735.

Winters, W.J., Dillon, W.P., Pecher, I.A. and Mason, D.H., 2000, "GHASTLI-Determining physical properties of sediment containing natural and laboratory formed gas hydrate" in *Natural Gas Hydrate in Oceanic and Permafrost Environments*, edited by M.D. Max, pp 311-322, Kluwer, Dordrecht.

#### **7.4.2 Drilling Fluid Evaluation and Formation Damage References**

Collett, T.S.: "Well Log Characterization of Sediments in Gas hydrate-Bearing Reservoirs", SPE 49298, presented at SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, September 27-30, 1998.

Collett, T.S., Bird, K.J., Magoon, L.B.: "Subsurface Temperatures and Geothermal Gradients on the North Slope of Alaska", SPE 19024, Society of Petroleum Engineers, 1988.

Collett, T.S.: "Natural Gas Hydrates of the Prudhoe Bay and Kuparuk River Area North Slope, Alaska", *The American Association of Petroleum Geologists Bulletin*, Vol. 77, No. 5, pp. 793-812, May 1993.

Dallimore, S.R., Uchida, T., Collett, T.S.: "Scientific Results from JAPEX/JNOC/GSC Mallik 2L-38 Gas Hydrate Research Well, Mackenzie Delta, Northwest Territories, Canada", *Geological Survey of Canada Bulletin* 544, February 1999.

Dvorkin, J., Helgerud, M.B., Waite, W.F., Kirby, S.H., Nur, A., "Introduction to Physical Properties and Elasticity Models, in Natural Gas Hydrate in Oceanic and Permafrost Environments, edited by M.D. Max, pp. 245-260, Kluwer, Dordrecht, 2000.

Ginsburg, G., Soloviev, V., Matveeva, T., Andreeva, I.: "Sediment Grain Size Control on Gas Hydrate Presence, Sites 994, 995, and 997", Proceedings of the Ocean Drilling Program, Scientific Results, Leg 164, edited by C.K. Paul et al., chap. 24, Ocean Drilling Program, College Station, Texas, 2000.

Kamath, V.A., Patil, S.L.: "Description of Alaskan Gas Hydrate Resources and Current Technology", studies by University of Alaska Fairbanks, January 1994.

Kerkar, P.B.: "Assessment of Formation Damage from Drilling Fluids Dynamic Filtration in Gas Hydrate Reservoirs of the North Slope of Alaska", M.S. Thesis, University of Alaska Fairbanks, August 2005.

Marshall, D.S., Gray, R., Byrne, M.: "Development of a Recommended Practice for Formation Damage Testing", SPE 38154, presented at the SPE European Formation Damage Conference, Hague, Netherlands, June 2-3, 1997.

Matsumoto, R., "Comparison of Marine and Permafrost Gas Hydrates: Examples from Nankai Trough and Mackenzie Delta, Proceedings of the Fourth International Conference on Gas Hydrates, Yokohama, 19-23 May 2002a.

Murlidharan, V., Putra, E., Schechter, D.S.: "Investigating the Changes in Matrix and Fracture Properties and Fluid Flow under Different Stress-state Conditions", M.S. Thesis, Texas A & M University, 2002.

Shipboard Scientific Party: "Leg 204 Preliminary Report, Drilling Gas Hydrates on Hydrate Ridge, Cascadia Continental Margin", ODP Texas A & M University, December 2002, Available from World Wide Web:  
[http://www-odp.tamu.edu/publications/prelim/204\\_prel/204PREL.PDF](http://www-odp.tamu.edu/publications/prelim/204_prel/204PREL.PDF).

Winters, W.J., Dallimore, S.R., et al.: "Physical properties of sediments from the JAPEX/JNOC/GSC Mallik 2L-38 Gas Hydrate Research Well", in Geological Survey of Canada Bulletin 544: Scientific Results from JAPEX/JNOC/GSC Mallik 2L-38 Gas Hydrate Research Well, Mackenzie Delta, Northwest Territories, Canada, edited by Dallimore, S.R. et al. Geological Survey of Canada, Ottawa, 1999.

Yousif, M.H., Abass, H.H., Selim, M.S., Sloan, E.D.: "Experimental and Theoretical Investigation of Methane-Gas hydrate Dissociation in Porous Media"; SPE 18320, SPE Reservoir Engineering, February 1991.

### **7.4.3 Supplemental Formation Damage Prevention References**

Anselme, M.J., Reijnhout, M.J., Muijs, H.M., Klomp, 1993, U.C.; World Pat. WO 93/25798.

Belavadi, M.N., 1994, "Experimental Study of the Parameters Affecting Cutting Transportation in a Vertical Wellbore Annulus"; M.S.Thesis, UAF; Sept., 1994.

Bennion D.B., Thomas F.B., Bietz R.F., 1996, "Low permeability Gas Reservoirs: Problems, Opportunities and Solution for Drilling, Completion, Simulation and Production"; SPE 35577; May 1996.

Bennion D.B., Thomas F.B., Bietz R.F., 1996 "Formation Damage and Horizontal Wells- A Productivity Killer?" SPE 37138; International Conference on Horizontal Well Technology, Calgary; Nov. 1996.

Bennion D.B., Thomas F.B., Bietz R.F., 1995, "Underbalanced Drilling and Formation Damage- Is it a Total Solution?"; The Journal of Canadian Petroleum Tech.; Vol. 34 (9); Nov. 1995.

Bennion D.B., Thomas F.B., et al., 1995, "Advances in Laboratory Core Flow Evaluation to minimize Formation Damage Concerns with Vertical/Horizontal Drilling Application"; CAODC; Vol. 95 (105).

Bennion D.B., Thomas F.B., Jamaluddin, K.M., Ma T.; "Using Underbalanced Drilling to Reduce Invasive Formation Damage and Improve Well Productivity- An Update"; Petroleum Society of CIM; PTS 98-58.

Chadwick J., 1995, "Exploration in permafrost"; Mining Magazine; February, 1995.

Chen, W., Patil S.L., Kamath, V.A., Chukwu, G.A., 1998, "Role of Lecithin in Hydrate Formation/Stabilization in Drilling Fluids"; JNOC; October 20, 1998.

Chilingarian G.V., Vorabutr P., 1983, "Drilling and drilling fluids"; Elsevier; NY.

Cohen J.H., Williams T.E., 2002, "Hydrate Core Drilling Tests: Topical Report"; Maurer Technology Inc., Houston, Texas; November 2002.

Crowell, E.C., Bennion, D.B., Thomas, F.B., Bennion, D.W., 1992, "The Design and Use of Laboratory Tests to Reduce Formation Damage in Oil and Gas Reservoirs"; 13<sup>th</sup> Annual Conference of the Ontario Petroleum Institute.

Dallimore, S.R., Uchida, T., Collett, T.S., 1999, "Scientific Results from JAPEX/JNOC/GSC Mallik 2L-38 Gas Hydrate Research Well, Mackenzie Delta, Northwest Territories, Canada"; Geological Survey of Canada Bulletin 544; February, 1999.

Drill Cool Systems Canada Inc., [www.drillcool.com](http://www.drillcool.com).

Duncum, S.N., Edwards, A.R., Osborne, C.G., 1993, Eur. Pat. 536,950.



Francis P.A., Eigner M.R.P., et. al., 1995, "Visualization of Drilling-Induced Formation Damage Mechanisms using Reservoir Conditions Core Flood Testing"; paper SPE 30088 presented at the 1995 European Formation Damage Conference, The Hague, May 15-16.

Fu, S.B., Cenegy, L.M., Neff C.S., 2001, "A Summary of Successful Field Application of A Kinetic Hydrate Inhibitor"; SPE 65022.

Hammerschmidt E.G., 1934, *Ind.Eng.Chem.*; 26, 851.

Howard S.K., 1995, "Formate Brines for Drilling and Completion: State of the Art"; SPE 30498.

I.F.P. patents: Fr.Pats. 2,625,527; 2,625,547; 2,625,548; 2,694,213; 2,697,264; Eur. Pats. 594,579; 582,507323,775; 323307; US Pat. 5,244,878. Can.Pat. 2,036,084.

Jamaluddin A.K.M., Bennion D.B., et. al.; "Application of Heat Treatment to Enhance Permeability in Tight Gas Reservoirs"; Petroleum Society of CIM; Paper No. 98-01.

Kalogerakis N., Jamaluddin, et. al., 1993, "Effect of Surfactants on Hydrate Formation Kinetics"; SPE 25188.

Kamath V.A., Mutalik P.N., et. al., 1991, "Experimental Study of Brine Injection and Depressurization Methods for Dissociation of Gas Hydrate"; SPE Formation Evaluation; December 1991.

Kastube T.J., Dallimore S.R., et. al., 1999, "Gas Hydrate Investigation in Northern Canada"; JAPEX; Vol. 8; No. 5.

Kelland, M.A., Svartaas, T.M., Dybvik, L.A., 1994, "Control of Hydrate Formation by Surfactants and Polymers"; SPE 28506; p. 431-438.

Kotkoskie T.S., AL-Ubaidi B., et. al., 1990, "Inhibition of Gas Hydrates in Water-Based Drilling Mud"; SPE 20437.

Kutasov I.M., 1995, "Salted drilling mud helps prevent casing collapse in permafrost"; Oil and Gas Journal; July 31, 1995.

Marshal, D.S., Gray, R., Byrne, M.; 1997, "Development of a Recommended Practice for Formation Damage Testing"; SPE 38154; Presented at the 1997 SPE European Formation Damage Conference; Netherlands, 2-3 June 1997.

Maury V., Guenot A., 1995, "Practical Advantages of Mud Cooling Systems for Drilling"; SPE Drilling and Completion, March 1995.

Max M.D., 2000, "Natural Gas Hydrate in Oceanic and Permafrost Environments"; Kluwer Academic Publishers; Boston; 2000.

Muijs, H.M., Beers, N.C., et al., 1990, Can. Pat. 2,036,084.

Oort E.V., Friedheim J.M., Toups B., 1999, "Drilling faster with Water-Base Mud"; American Association of Drilling Engineers – Annual Technical Forum; Texas; March 30-31, 1999.

Paez, J.E., Blok, R., Vaziri, H., Islam M.R., 2001, "Problems in Hydrates: Mechanisms and Elimination Methods"; SPE 67322.

Pooladi-Darvish M., Hong, H., 2003, "A Numerical Study on Gas Production From Formations Containing Gas Hydrates"; Canadian International Petroleum Conference, Calgary, June 10-12, 2003.

Reijnhout, M.J., Kind, C.E., Klomp, 1993, U.C.; Eur. Pat. 526,929.

Robinson L.; 1977, "Mud equipment manual, Handbook 1: Introduction to drilling mud system"; Gulf Publishing Company; Houston.

Sasaki K., Akibayashi S., Konno S., 1998, "Thermal and Rheological properties of Drilling Fluids and an Estimation of Heat Transfer Rate at Casing pipe"; JNOC-TRC, Japan; October 20-22, 1998.

Schofield T.R., Judis A., Yousif M., 1997, "Stabilization of In-Situ Hydrates Enhances Drilling Performance and Rig Safety"; SPE 32568 ; Drilling and Completion.

Sira J.H., Patil S.L., Kamath V.A., 1990, "Study of Hydrate Dissociation by Methanol and Glycol Injection"; SPE 20770.

Sloan, E.D., 1994, World Pat. WO 94/12761.

Spence G.D., Hyndman R.D., 2001, "The challenge of Deep ocean Drilling for Natural Gas Hydrate"; Geoscience Canada; Vol.28 (4); December, 2001.

Sumrow Mike, 2002, "Synthetic-based muds reduce pollution discharge, improve drilling"; Oil and Gas Journal; Dec. 23, 2002.

Szczepanski R., Edmonds B., et. al., 1998, "Research provides clues to hydrate formation and drilling-hazard solutions"; Oil and Gas Journal; Vol. 96(10); Mar 9, 1998.

Toshiharu O., Yuriko M., et. al., 1998, "Kinetic Control of Methane Hydrates in Drilling Fluids"; JNOC-TRC; October 20-22, 1998.

Urdahl, O., Lund, A., Moerk, P., Nilsen, T-N, 1995 "Inhibition of Gas Hydrate Formation by means of Chemical Additives: Development of an Experimental Set-up for Characterization of Gas Hydrate Inhibitor Efficiency with respect to Flow Properties and Deposition"; Chem. Eng. Sci.; 50(5), 863.

Vincent M., Guenot Alain, 1995, "Practical Advantages of Mud Cooling System for Drilling"; SPE Drilling and Completion; March 1995.

Weidong C., Patil S.L., Kamath V.A., Chukwu G.A., 1998, "Role of Lecithin in Hydrate Formation/Stabilization in Drilling Fluids"; JNOC-TRC; October 20-22, 1998.

Yuliev, A.M.; Gazov, Delo, 1972, 10, 17-19, Russ.

Zakharov A.P., 1992, "Silicon-based additives improve mud Rheology"; Oil and Gas Journal; Aug. 10, 1992.

#### **7.4.4 Coring Technology References**

Amann, H. et al., 2002, "First Successful Deep-Sea Operations of OMEGA-MAC, the Multiple Auto Corer, during the OTEGA-I campaign on Hydrate Ridge". Fachgebiet Maritime Technik. August 2002.

Carroll, John, 2002, "Natural Gas Hydrates: A Guide for Engineers". Gulf Professional Publishing. October 30, 2002.

Dickens, Gerald R. et al., 2000, "Detection of Methane Gas Hydrate in the Pressure Core Sampler (PCS): Volume-Pressure-Time Relations During Controlled Degassing Experiments". *Proc. of the Ocean Drilling Program*, Vol. 164.

Francis, T.J.G., 2001, "The HYACINTH project and pressure coring in the Ocean Drilling Program". Internal Document: Geotek, Ltd. July 2001.

Hohnberg, H.J. et al., 2003, "Pressurized Coring of Near-Surface Gas Hydrate Sediment on Hydrate Ridge: The Multiple Autoclave Corer, and First Results from Pressure Core X-Ray CT Scans". Geophysical Research Abstracts, Vol. 5. European Geophysical Society.

"HYACE", 2003, [www] <http://www.tu-berlin.de/fb10/MAT/hyace/description/describe.htm>. Accessed June 15th, 2003.

"Methane Hydrate Recovery", JNOC Website. [www] <http://www.mh21japan.gr.jp/english/mh/05kussaku.html#e>.

"Methane Hydrates: A US Department of Energy Website". [www.fossil.energy.gov](http://www.fossil.energy.gov).

"Natural Gas Demand". [www] [www.naturalgas.org/business/demand.asp](http://www.naturalgas.org/business/demand.asp).

"Patent No. 6,214,804: The Pressure-Temperature Coring System". U.S. Patent Office. [www]<http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=/netahtml/srchnum.htm&r=1&f=G&l=50&s1=6,216,804.WKU.&OS=PN/6,216,804&RS=PN/6,216,804>. Viewed July 14, 2003.

Rack, Frank R, "In-Situ Sampling and Characterization of Naturally Occurring Marine Hydrate Using the D/V JOIDES Resolution". Joint Oceanographic Institute, Cooperative Agreement DE-FC26-01NT41329.

Shukla, K., et al., 2002, "Overview on Hydrate Coring/Handling/Analysis". Westport Technology Center International. Prepared for DOE on December 12, 2002 under award No. DE-PS26-NT40869-1.

### **7.5 Reservoir and Economic Modeling References**

Brown, G., Storer, D., and McAllister, K., 2003, Monitoring Horizontal Producers and Injectors during Cleanup and Production Using Fiber-Optic-Distributed Temperature Measurements, SPE 84379.

Chuang Ji, Goodarz Ahmadi, Duane H. Smith. 2003; "Constant rate natural gas production from a well in a hydrate reservoir"; Energy Conversion and Management 44, 2403-2423.

Chuang Ji, Goodarz Ahmadi, Duane H. Smith, 2001, "Natural gas production from hydrate decomposition by depressurization"; Chemical eng. science 56, 5801-5814.

Stephen J Howe, 2004, Production modeling and economic evaluation of a potential gas hydrate pilot production program on the north slope of Alaska", MS Thesis, University of Alaska Fairbanks, Fairbanks, AK.

Howe, S.J., Nanchary, N.R., Patil S.L., Ogbe D.O., Chukwu G.A., Hunter R.B and Wilson S.J., "Production Modeling and Economic Evaluation of a Potential Gas Hydrate Pilot Production Program on the North Slope of Alaska".

Howe, S.J., Nanchary, N.R., Patil S.L., Ogbe D.O., Chukwu G.A., Hunter R.B and Wilson S.J., "Economic Analysis and Feasibility study of Gas Production from Alaska North Slope Gas Hydrate Resources", Presentation at the AAPG Hedberg Conference in Vancouver in September 2004.

Jaiswal N.J presented on "Measurement of Relative Permeabilities for Gas hydrate Systems" and received third prize in International Thermal Operations and Heavy-Oil Symposium and SPE Regional Meeting Bakersfield, California, USA.

Jaiswal, N.J., Dandekar, A.Y., Patil, S.L. and Chukwu, G.C., "Measurement of Relative Permeability for Gas hydrate System", at 54th Arctic Science Conference, 23<sup>rd</sup> Sept-2003.

Jaiswal N.J., Westervelt J.V., Patil S.L., Dandekar A.Y., Nanchary, N.R., Tsunemori P and Hunter R.B., "Phase Behavior and Relative Permeability of Gas-Water-Hydrate System", Submitted for Presentation at the AAPG Hedberg Conference in Vancouver in September 2004.

McGuire, P.L., 1982, "Recovery of gas from hydrate deposits using conventional technology," SPE/DOE 10832, *Proc. Unconventional Natural Gas Recovery Symposium Pittsburgh PA*, pp. 373-387, Society of Petroleum Engineers, Richardson Texas.

McGuire, Patrick L., 1982, "Methane hydrate gas production by thermal stimulation"; proceedings of the 4th Canadian Permafrost Conference, pp.356-362.

Moridis, G. J., 2002, "Numerical Studies of Gas Production from Methane Hydrates". Paper SPE 75691, presented at the SPE Gas Technology Symposium, Calgary, Alberta, Canada, 30 April – 2 May 2002b.

Moridis, G.J. and Collett, T.S., 2004, "Gas Production from Class 1 Hydrate Accumulations".

Moridis, G., Collett, T.S., Dallimore, S.R., Satoh, T., Hancock, S. and Weatherill, B., 2003, "Numerical simulation studies of gas production scenarios from hydrate accumulations at the Mallik site, Mackenzie Delta, Canada". In, Mori, Y.S., Ed. Proceedings of the Fourth International Conference on Gas Hydrates, May 19-23, Yokohama, Japan, pp 239-244.

Nanchary, N.R., Patil S.L., Dandekar A.Y., "Numerical Simulation of Gas Production from Hydrate Reservoirs by Depressurization", Journal of Petroleum Science and Engineering (Elsevier publication), *Under Review*.

Nanchary, N.R., Patil S.L., Dandekar A.Y and Hunter, R.B., "Numerical Modeling of Gas Hydrate Dissociation in Porous Media", Submitted for Presentation at the AAPG Hedberg Conference in Vancouver in September 2004.

Swinkles, W.J.A.M. and Drenth, R.J.J., 1999, "Thermal Reservoir Stimulation Model of Prediction from Naturally Occurring Gas Hydrate Accumulations", Society of Petroleum Engineers, SPE 56550, 13 p.

Tsunemori, Phillip, 2003, presented "Phase Behavior of Natural Gas from Gas Hydrates" and received first in International Thermal Operations and Heavy-Oil Symposium and SPE Regional Meeting Bakersfield, California, USA.

Tsyarkin, G.G. 1992, Appearance of two moving phase transition boundaries in the dissociation of gas hydrates in strata. Dokl. Ross. Akad. Nauk. 323. 52-57 (in Russian).

Yousif, M., H., Abass H., H., Selim, M., S., Sloan E.D., 1991, Experimental and Theoretical Investigation of Methane-Gas hydrate Dissociation in Porous Media, SPE Res. Eng. 18320, pages 69-76.

Tsyarkin, G.G. 1991, Effect of liquid phase mobility on gas hydrate dissociation in reservoirs. Izvestiya Akad. Nauk SSSR. Mekh. Zhidkosti i Gaza. 4: 105-114 (in Russian).

Westervelt J.V: MS Thesis: "Determination of methane hydrate stability zones in the Prudhoe Bay, Kuparuk River, and Milne Point units on the North Slope of Alaska".

## 7.6 Regional Schematic Modeling Scenario Study References

Collett, Timothy S.: "Natural Gas Hydrates of the Prudhoe Bay and Kuparuk River Area, North Slope, Alaska," AAPG Bulletin, Vol. 77, No. 5, May, 1993, p 793-812.

S. J. Howe, N. R. Nanchary, S. L. Patil, D. O. Ogbe, and G. A. Chukwu, R. B. Hunter, S. J. Wilson. "Economic Analysis and Feasibility Study of Gas Production from Alaska North Slope Gas Hydrate Resources," AAPG Hedberg Conference, September, 2004.

S.H. Hancock, T.S. Collett, S.R. Dallimore, T. Satoh, T. Inoue, E. Huenges, J. Henniges, and B. Weatherill: "Overview of thermal-stimulation production-test results for the JAPEX/JNOC/GSC et al. Mallik 5L-38 gas hydrate production research well" 2004.

Richard Sturgeon-Berg, "Permeability Reduction Effects Due to Methane and Natural Gas Flow through Wet Porous Media," Colorado School of Mines, MS thesis T- 4920, 9/30/96.

Stephen John Howe, "Production Modeling and Economic Evaluation of a Methane Hydrate Pilot Production Program on the North Slope of Alaska," University of Alaska, Fairbanks MS Thesis, May, 2004.

Hong H., Pooladi-Darvish, M., and Bishnoi, P. R.: Analytical Modeling of Gas Production from Hydrates in Porous Media," *Journal of Canadian Petroleum Technology (JCPT)* November 2003, Vol. 42 (11) p. 45-56.

## 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

<u>Acronym</u>	<u>Denotation</u>
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
V <sub>p</sub>	Velocity of primary seismic wave component
V <sub>s</sub>	Velocity of shear seismic wave component (commonly useful to identify GH)
VSP	Vertical Seismic Profile
WOO	Well-of-Opportunity



## **National Energy Technology Laboratory**

626 Cochrans Mill Road  
P.O. Box 10940  
Pittsburgh, PA 15236-0940

3610 Collins Ferry Road  
P.O. Box 880  
Morgantown, WV 26507-0880

One West Third Street, Suite 1400  
Tulsa, OK 74103-3519

1450 Queen Avenue SW  
Albany, OR 97321-2198

539 Duckering Bldg./UAF Campus  
P.O. Box 750172  
Fairbanks, AK 99775-0172

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