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

June 2003 Quarterly Technical Report
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ABSTRACT

Interim results are presented from the project designed to characterize, quantify, and determine the commercial feasibility of Alaska North Slope (ANS) gas-hydrate and associated free-gas resources in the Prudhoe Bay Unit (PBU), Kuparuk River Unit (KRU), and Milne Point Unit (MPU) areas. This collaborative research will provide practical input to reservoir and economic models, determine the technical feasibility of gas hydrate production, and influence future development, field extension, and exploration of this potential ANS resource.

The large magnitude of unconventional in-place gas (40 – 100 TCF) and conventional ANS gas commercialization evaluation creates industry-DOE alignment to assess this potential resource. This region uniquely combines known gas hydrate presence and existing production infrastructure. Many technical, economical, environmental, and safety issues require resolution before enabling gas hydrate commercial production.

Gas hydrate energy resource potential has been studied for nearly three decades. However, this knowledge has not been applied to practical ANS gas hydrate resource development. ANS gas hydrate and associated free gas reservoirs are being studied to determine reservoir extent, stratigraphy, structure, continuity, quality, variability, and geophysical and petrophysical property distribution. Phase 1 (October 2002 – October 2004) will characterize reservoirs, lead to recoverable reserve and commercial potential estimates, and define procedures for gas hydrate drilling, data acquisition, completion, and production. Phases 2 (October 2004 – October 2005) and 3 (October 2005 – October 2006) will integrate well, core, log, and production test data from additional wells, if justified by results from prior phases. The project could lead to future ANS gas hydrate pilot development.

This project will help solve technical and economic issues to enable government and industry to make informed decisions regarding future commercialization of unconventional gas-hydrate resources.

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2.0 INTRODUCTION

This project is helping to solve the technical and economic issues to enable government and industry to make informed decisions regarding potential future commercialization of unconventional gas-hydrate resources. The project is characterizing and quantifying in-place and recoverable gas-hydrate and associated free-gas resources initially in the Eileen trend area in the Prudhoe Bay Unit (PBU) – Kuparuk River Unit (KRU) – Milne Point Unit (MPU) areas on the Alaska North Slope (ANS).

Successful determination of the resource potential of gas hydrate and associated free gas resources could significantly increase current developable gas reserves available for reservoir energy support, secondary recovery, fuel gas, and commercial sales within and beyond current infrastructure on the North Slope of Alaska. Proving technical production feasibility and commerciality of this unconventional gas resource could lead to greater energy independence for the U.S., providing for future gas needs through an abundant, safe, secure, and stable domestic resource.

2.1 Project Open Items

Through June 30, 2003, DOE has obligated approximately 90% of Phase 1 research funds. BPXA currently accesses these project funds through the U.S. Treasury Department Automated Standard Application for Payments (ASAP) system in accordance with 10 CFR 600.122(b). As first indicated in the March 2003 Quarterly Report, full funding of Phase 1 research through October 2004 will require:

1. Obligation of the remaining 10% ($204,282) Phase 1 research funds into the U.S. Treasury account.
2. Obligation of additional funds ($237,480) used for pre-Phase 1 (October 2001 through October 2002) research and project administration before execution of the DOE – BPXA contract in October 2002. Despite the DOE-BP contract allowing retroactive funding of activities prior to October 2002, completion of Phase 1 research program will still require 2 years from date of contract execution (October 2002), since data could not be released for project work prior to contractual definition of data confidentiality. The pre-phase 1 funds requested will enable extension of the Phase 1 contract through October 2004 and will be requested no later than 60 days prior to the end of the current budget period (December 31, 2003) through a continuation application on the SF 424.

2.2 Project Status Assessment and Forecast

Project technical accomplishments from April 2003 through end-June 2003 are presented by associated project task. The attached milestone forms (Appendix A) present project tasks 1 through 13 with task duration and completion timelines.

2.3 Project Research Collaborations

Progress towards completing project objectives significantly benefits from continued DOE support and/or funding of the following associated projects and proposals. Section 5.4 provides additional detail on collaborative research accomplishments during the reporting period.

1. **LBNL Reservoir Modeling studies:** This research includes code calibration to data collected during 2002 Mallik gas hydrate test program as well as working with the BPXA project to evaluate potential development scenarios. DOE has currently obligated project funds to continue LBNL reservoir model research during the reporting period through approximately end 2003. UAF will second a graduate student to assist LBNL research in August 2003. BPXA and UAF will meet with LBNL on August 13-14, 2003.

2. **DE-FC26-01NT41248:** UAF/PNNL/BPXA studies to determine effectiveness of CO_2 as an Enhanced Recovery Mechanism for Gas Dissociation from Methane Hydrate. Recent project status presentation updates and funding indicate a strong level of DOE support for this associated project during the reporting period. UAF has seconded a graduate student to PNNL to assist with this research. BPXA and UAF will meet with PNNL to discuss project status and determine work progression on August 11-12, 2003.

3. **UAF/Argonne National Lab project:** This associated project was recently approved for funding by the Arctic Energy and Technology Development Lab (AETDL) and forwarded to NETL. The project is designed to determine the efficacy of Ceramicrete cold temperature cement to future gas hydrate drilling and completion operations. Evaluating the stability and use of a cold temperature cement will greatly enhance the ability to maintain the low temperatures of the gas hydrate stability field during drilling and completion operations, helping to ensure safe and cost-effective operations.

4. **UAF/McMillan-McGee/PNNL proposal:** This proposal was recently highly ranked during presentations to AETDL, but not forwarded to NETL for funding at this time. The proposal also received strong letters of support from BPXA and Conoco-Phillips viscous oil development teams. The project would investigate in-situ electromagnetic heating as an enhanced recovery method for both viscous oil and gas hydrate production. In addition to depressurization of an adjacent free gas, we are also considering the applicability of this technology to thermally enhance gas dissociation from gas hydrate-bearing reservoirs and also perhaps to counteract any cooling reaction (flow assurance) within the wellbore during gas production.

Progress toward completing the objectives of this project are aligned with a collaborative research agreement under evaluation between BPXA and Japan National Oil Corporation (JNOC). Execution of a BPXA – JNOC agreement would enable additional funding for technical studies and data acquisition. JNOC participation in Phase 1 research would also encourage JNOC participation in Phase 2 and/or 3 research should industry decide to progress into these operational phases of the research project. India's Institute of Oil and Gas Production Technology (IOGPT) has also indicated a continued interest in participating with our Phase 1 research program. At the present time, we have not replied to this unsolicited expression of research collaboration interest.

An additional collaborative research project under the Department of Interior (DOI) would also provide significant benefits to this project. The BLM, USGS, and the State of Alaska recognize that gas hydrates are potentially a large untapped onshore energy resource on the North Slope region of Alaska. To develop a complete regional understanding of this potential energy resource, the BLM, USGS and State of Alaska (DGGS) have entered into an Assistance Agreement to assess regional gas hydrate energy resource potential in northern Alaska. This agreement combines the resource assessment responsibilities of the USGS and the DGGS with the surface management and permitting responsibilities of the BLM. As interest in the resource potential of Alaska gas hydrates continue to grow, information generated from this agreement will help guide these agencies to promote responsible development of this potential arctic energy resource. The DOI project will work 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, both within and beyond current industry infrastructure.

2.4 Project Performance Variance

Contribution of shallow portions of PBU seismic data to the project under contractually specified confidentiality constraints is delayed, though discussion with industry partners continues. BPXA is working with industry partners to emphasize the importance of this data to our gas hydrate reservoir and fluid characterization studies. While the 100% BPXA MPU data is released (under confidentiality constraints) to the project, release of PBU data to the project is dependent upon industry partner approval.

A new PBU seismic survey ("S-cubed") is being planned for early 2004 and is specifically designed to enhance resolution of shallow oil resources. This seismic survey would also significantly enhance resolution of the shallow gas hydrate and associated free gas resources within PBU and the Eileen trend area of interest. Before consideration of this survey for the latter purposes, the survey would require addition to the limited rights data defined within the BPXA – DOE contract in an amendment to that contract.

3.0 EXECUTIVE SUMMARY

This Quarterly report encompasses project work from March 1, 2003, inclusive through June 30, 2003. Sections 4 and 5 provide a detailed project activities report.

- Loaded MPU, PBU, and KRU well data onto computing and mapping systems and continued reservoir/fluid characterization and seismic interpretation studies.
- Created Synthetic seismograms for well logs - seismic data tie, calculated initial attribute-cubes on original stacked data, and modeled fluid contact acoustic properties.
- Mapped shallow marker horizons and determined shallow fault offsets.
- Ran preliminary Neural Network classifications and visualized classification results.
- Started experiments with CP grade methane (99.9% pure) to determine phase behavior at different brine saturations.
- Completed experimental set-up for measurement of gas-water relative permeability.
- Wrote and submitted gas hydrate article for Marcel-Dekker encyclopedia review.
- Presented project informational briefings and results to UAF Energy Conference, GSA, BPXA, BP in D.C., regional AAPG, JNOC, U.S. Department of Interior, and USGS.
- Developed electromagnetic in-situ heating proposal with UAF and McMillan-McGee, presented proposal to AETDL, and considered proof-of-concept numerical modeling.
    - Research may apply to both viscous oil and gas hydrate enhanced recovery.

- Worked with AETDL and DOE to successfully fund separate UAF/ANL research proposal to study efficacy of Ceramicrete arctic conditions cold drilling cement.
  - Technology could enhance safety by maintaining gas hydrate stability field.
- Researched drilling muds and compared Kinetic Inhibitors with Anti-Agglomerates.
- Planned experimental apparatus to assess formation damage during operations.
- Inventoried available coring systems and reviewed related literature.
- Completed economic model template and ran 2 test simulations with positive results.

4.0 EXPERIMENTAL

During the time period from April through end-June 2003 encompassed by this report, primary experimental activities consisted of experiment apparatus design, setup, and execution.

4.1 TASK 6.0, Reservoir and Fluids Characterization

The University of Arizona (UA) loaded MPU, PBU, and KRU well data onto computing and mapping systems and continued data interpretation in association with seismic interpretation studies. Section 5.6 provides additional details, results, and recommendations.

4.1.1 Subtask 6.1: Reservoir and Fluid Characterization and Visualization

Continued seismic and well log interpretation for reservoir and fluid characterization studies.

4.1.2 Subtask 6.2: Seismic Attributes and Calibration

Created Synthetic seismograms for tying well logs to seismic data, calculated initial attribute-cubes on original stacked data, and modeled acoustic properties of gas/water and hydrate/gas contacts.

4.1.3 Subtask 6.3: Petrophysics and Artificial Neural Net

Ran preliminary Neural Network classifications and assessed various visualizations of classification results.

4.2 TASK 7.0: Laboratory Studies for Drilling, Completion, and Production Support

The University of Alaska Fairbanks (UAF) designed experiments and apparatus for gas hydrate equilibrium and relative permeability studies. Sections 5.7 through 5.12 provide additional details, results, and recommendations.

4.2.1 Subtask 7.1: Characterize Gas Hydrate Equilibrium

Started experiments using CP grade methane (99.9% pure) in brine solutions, generated curve for 2% brine solution, and began tests for 4% brine solution.

4.2.2 Subtask 7.2: Measure Gas-Water Relative Permeabilities

Completed experimental set-up for measurement of gas-water relative permeability.

5.0 RESULTS AND DISCUSSION

Project technical accomplishments from April 2003 through June 2003 are presented in chronological order by associated project task.

5.1 TASK 1.0: Research Management Plan – BP and Project Team

Task schedules are presented in the attached milestones forms (Appendix A). Expenditures by budget category and associated tasks are attached in Table 1.

- Coordinated, compiled, and fulfilled project reporting requirements
    - Resubmitted December Quarterly and yearly report
        - Corrected report to contractually defined formats
- Reviewed, processed, and ensured budget consistency of subcontractor invoices

5.2 TASK 2.0: Provide Technical Data and Expertise – BP, USGS

- Wrote and submitted gas hydrate article for Marcel-Dekker encyclopedia review
    - Incorporated input from USGS
- Provided well lists for UA of additional well logs through gas hydrate intervals of interest
    - Prepared for second release of publicly released well data to UA
- Solicited industry partner approval to release portion of NWEileen #2 core to project
    - Initial approval attempt unsuccessful
- Provided CAPEX assumptions development costs for UAF economic modeling studies
- Provided historical USGS ANS gas hydrate data to UA for incorporation and comparison

5.3 TASK 3.0: Wells of Opportunity, Data Acquisition – BP

- Worked with JNOC to Identify potential base and stretch well of opportunity operations activities to assist BP-DOE Phase 1-2 project activities if execute BPXA – JNOC collaborative research agreement
- Discussed well of opportunity separate fund setup with DOE and USGS

TABLE 1: Expenditures, DE-FC-26-01NT41332, June, 2003 Quarterly Report

BUDGET PERIOD 1 (2 year) COSTS SUMMARY

BP AFE #	Cost Category	% Obligated	NET COSTS	Budget Period 1	GROSS COSTS	SPENT COSTS	BALANCE FUNDS	REMAINING
GS2420H01	U. Arizona, Labor	90.168%	$779,125	$864,077	$779,125	$282,893	$496,232	64%
GS2420H02	U. Arizona, Travel	90.168%	$43,473	$48,213	$43,473	$7,515	$35,958	83%
GS2420H03	U. Arizona, Third Party	90.168%	$55,735	$61,812	$55,735	$39,047	$16,688	30%
GS2420H04	U. Arizona, Operations	90.168%	$155,311	$172,245	$155,311	$39,305	$116,006	75%
GS2420H05	U. AK Fairbanks, Labor	90.168%	$414,007	$459,148	$414,007	$0	$414,007	100%
GS2420H06	U. AK Fairbanks, Travel	90.168%	$26,528	$29,420	$26,528	$0	$26,528	100%
GS2420H07	U. AK Fairbanks, Third Party	90.168%	$39,791	$44,130	$39,791	$0	$39,791	100%
GS2420H08	U. AK Fairbanks, Operations	90.168%	$89,029	$98,736	$89,029	$0	$89,029	100%
GS2420H09	BPXA, Third Party Labor*	90.168%	$236,284	$262,047	$236,284	$146,900	$89,384	38%
GS2420H10	BPXA, Travel	90.168%	$25,247	$28,000	$25,247	$6,625	$18,622	74%
GS2420H11	BPXA, Operations	90.168%	$9,017	$10,000	$9,017	$2,858	$6,159	68%
	*TOTAL**	90.168%	$1,873,546	$2,077,828	$1,873,546	$525,143	$1,348,403	72%

* Only includes DOE funds (If include BP funds, add $84,063)

BP AFE #	Cost Category	Project Tasks**
GS2420H01	U. Arizona, Labor	Task 6.0, 6.1, 6.2, 6.3
GS2420H02	U. Arizona, Travel	Task 6.0, 6.1, 6.2, 6.3
GS2420H03	U. Arizona, Third Party	Task 6.0, 6.1, 6.2, 6.3
GS2420H04	U. Arizona, Operations	Task 6.0, 6.1, 6.2, 6.3
GS2420H05	U. AK Fairbanks, Labor	Tasks 7, 8, 9, 10, 11, 13
GS2420H06	U. AK Fairbanks, Travel	Tasks 7, 8, 9, 10, 11, 13
GS2420H07	U. AK Fairbanks, Third Party	Tasks 7, 8, 9, 10, 11, 13
GS2420H08	U. AK Fairbanks, Operations	Tasks 7, 8, 9, 10, 11, 13
GS2420H09	BPXA, Third Party Labor	Tasks 1, 2, 3, 4, 11, 12, 13
GS2420H10	BPXA, Travel	Tasks 1, 2, 3, 4, 11, 12, 13
GS2420H11	BPXA, Operations	Tasks 1, 2, 3, 4, 11, 12, 13

** Project Task 5.0 performed by USGS under separate funding

5.4 TASK 4.0: Research Collaboration Link – BP, USGS, Project team

- Updated project presentation for April 2003 UAF Energy Conference and workshop
  - Participated in expert panel workshop for UAF Energy Conference
  - Received distinguished service award from UAF School of Mineral Engineering
- Presented project and geophysical summary at Geophysical Society of Alaska meeting
- Designed, wrote, compiled, and completed three 4 by 8 foot panel posters for project review and presentation at May 2003 Regional AAPG meeting
  - Incorporated input from BPXA, UA, UAF, and USGS
- Justified approval for legal review of BPXA – JNOC draft agreement
  - Incorporated BP Chicago legal review to ensure Intellectual Property and Data Confidentiality language consistency with BPXA-DOE contract and subcontracts
  - Summarized and reviewed BPXA and JNOC contractual obligations
- Planned BPXA-JNOC Implementation Agreement potential base and stretch plan project activities with JNOC in meetings at BPXA
  - Identified additional desktop studies to assist BP-DOE Phase 1 project activities and better enable BPXA decision regarding phase 2 project progression
  - Identified potential base and stretch target operations activities to assist BPXA-DOE Phase 1-2 project activities and better enable BPXA decision regarding phase 2 project progression
- Submitted gas hydrate project for BP Helios Award programme
  - Submission recognizes innovative and progressive impacts of research project
- Presented project interim results to BPXA new and recent hires
- Provided review and input to Westport gas hydrate core procedures manual
- Researched electromagnetic thermal heating technology for potential application to gas hydrate (and viscous oil) enhanced recovery
  - Contacted lead researchers and technology providers to discuss EM technology
  - Developed related project research proposal with UAF and McMillan-McGee
    - Submitted proposal to AETDL; proposal not funded at present time
    - Developed plans for numerical modeling for proof-of-concept
    - Solicited/gave strong support letter for proposal from BP viscous oil group
- Worked with AETDL and DOE to fund separate UAF/ANL research proposal to study efficacy of Ceramicrete arctic conditions cold drilling cement
  - Proposal highly ranked and forwarded to NETL for funding
  - Technology could help maintain safety during drilling and completion operations by maintaining temperatures within gas hydrate stability field
- Assisted USGS and BLM in preparation for DOI Gas Hydrate informational briefings in Washington, D.C.
  - Developed regional Alaska North Slope gas hydrate research plans
  - Provided perspective on industry, BP, and Alaska as well as presented concise interim update of BPXA-DOE collaborative research.
  - Participated in discussions at BP, USGS, DOI, and U.S. Senate staff briefings
    - U.S. Senate staffers briefing included BP D.C. External Affairs staff
  - Represented broadly aligned research interests from USGS, BLM, DGGS (State of Alaska), and industry (GOM and Alaska).
    - Provided information to help enable both government and industry to make more informed decisions based upon interim research results.

5.5 TASK 5.0: Logging and Seismic Technology Advances – USGS, BP

- Reviewed application of Baker-Hughes INTEQ's 6 3/4" APX LWD tool, which could provide data acquisition through gas hydrate-bearing intervals during drilling.

5.6 TASK 6.0: Reservoir and Fluids Characterization – UA

- Literature research and group research on the stratigraphy and structural elements of the gas hydrate-bearing Sagavanirktok (Sag) formation and the regional geology of the central North Slope of Alaska.
- Compilation and preliminary evaluation of previous studies and local geology, focusing principally on a review of work done by Collett and others.
- Met with non-UA Research Team members Bob Hunter (BP), Tim Collett and Dave Taylor (USGS) on project status, update on geological background, future integration of efforts (March 13-14). Exchange of ideas, development of action items for follow-up and continuing work, and review of Collett’s and Taylor’s historical and current work on well logs and seismic attributes, respectively.
- UA Gas Hydrate Research Group Meetings and work sessions

5.6.1 Subtask 6.1: Reservoir and Fluid Characterization and Visualization – UA

5.6.1.1 Products, Preliminary Findings

- Successfully loaded BP Milne Point, KRU and PBU West End well log data
- Assessed available well log database for analysis and correlation work
- Produced a working base map of all wells showing presence/absence of the different log data within the Sagavanirktok (Sag) Formation. Approximately 67 out of 90 wells provided to UA contain suitable GR information for correlation and comprehensive petrophysical interpretation within the Sag Formation
- Developed independent UA stratigraphic naming scheme (strat. column) for the Sag
- Integrated USGS framework into stratigraphic column nomenclature
- Correlated wells, 65-70% complete, interpreted and defined over 20 independent parasequence units and genetically related succession of beds, bedsets and correlative marine-flooding surfaces within the Sag Formation.
- Determined from preliminary analysis that a significant degree of lateral and vertical variability in reservoir quality exists within the Sag.
- Compared USGS and UA regional parasequence interpretations within the Sag. Contrast between these independent stratigraphic frameworks appears negligible at this time.
- Confirmed preliminary seismic-to-well-log ties for gas-hydrate occurrences in MP18-01 and WSAK-25.
- Completed confirmation of correlative mid-Tertiary marker bed with seismic horizon for MPU B-01, MPU D-01, and MPU 18-01 wells.
- Identified preliminary faulted intervals from well logs within the Sag.
- Entered all available inferred USGS gas-hydrate picks into Stratwork database.
- Collaborated with GEOS team members to select areas with adequate seismic coverage and quality for neural network and well-log attribute-analysis techniques.

- Completed familiarization with Landmark software packages: StratWorks (Correlation, Cross-section, Map View, etc.), SeisWork, PetroWorks, Data Import/Export, Data Management modules.
- Completed familiarization of basic UNIX startup and data management commands.
- Tested third-party software that converts Landmark CGM output files into common graphic image formats (e.g. TIFF, PICT, JPEG).
- Held generalized discussions with BP geoscientists, Josef Chmielowski (Milne Point group) and Jason Lore (Houston), during UA GeoDaze Symposium on training students for petroleum industry work and on non-proprietary interpretations of North Slope geology (April 10-11).

5.6.1.2 Miscellaneous Project Activities

- Successfully loaded Landmark and Oracle software; all functions working in MGE.
- Fully installed and maintained all hardware.
- Installed and setup large format printer in the MGE Subsurface Characterization and Imaging Lab (SCIL).
- Completed new 100MB connectivity in MGE.
- Approved users authenticated in both GEOS and MGE labs.
- Ensured labs, dedicated project servers and databases are in secured rooms.
- Acquired and setup a 40/80 GB DLT in-lab backup system in MGE in addition to multiple server backups.
- Fully networked all computers and employed appropriate security switches.
- Applied latest software patches on weekly basis.
- Completed setup of all printers and secured printer network connectivity.
- Trained student researchers on the well and seismic data import, export, and the generation and displaying and formatting of professional graphics using lab software (e.g. Landmark, Petra, Adobe Illustrator, Photoshop, PowerPoint, etc.).
- Configured, generated, and printed cross-sections, posters and other products on all printers.
- Produced several posters for the 2003 UA GeoDaze Conference to gain experience and to serve as test runs for the gas hydrate research.
- Cross-trained students on GeoPlus Petra/PetraSeis 3D workstations (e.g. duplicating well log templates, cross section and map generation, etc.).
- Presented DOE Gas-Hydrate Project to UA Geoscience Dept. Colloquium.
- Reviewed gas hydrate article for Department of Geoscience Alumni Newsletter.
- Prepared project graphics for the May AAPG team poster in Salt Lake City.

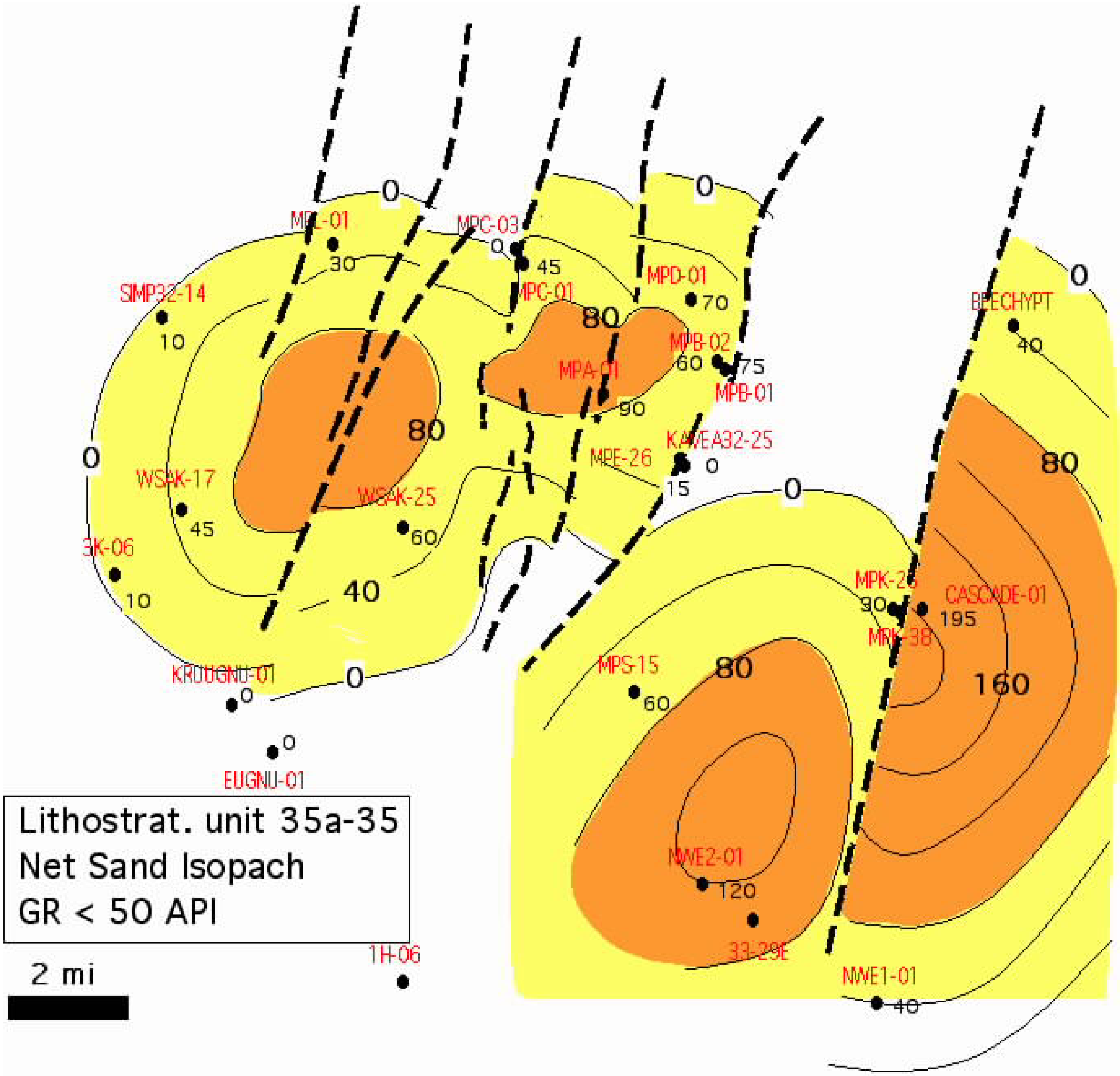

Figure 1: Net Sand Isopach Map, Lithostratigraphic unit 35a-35

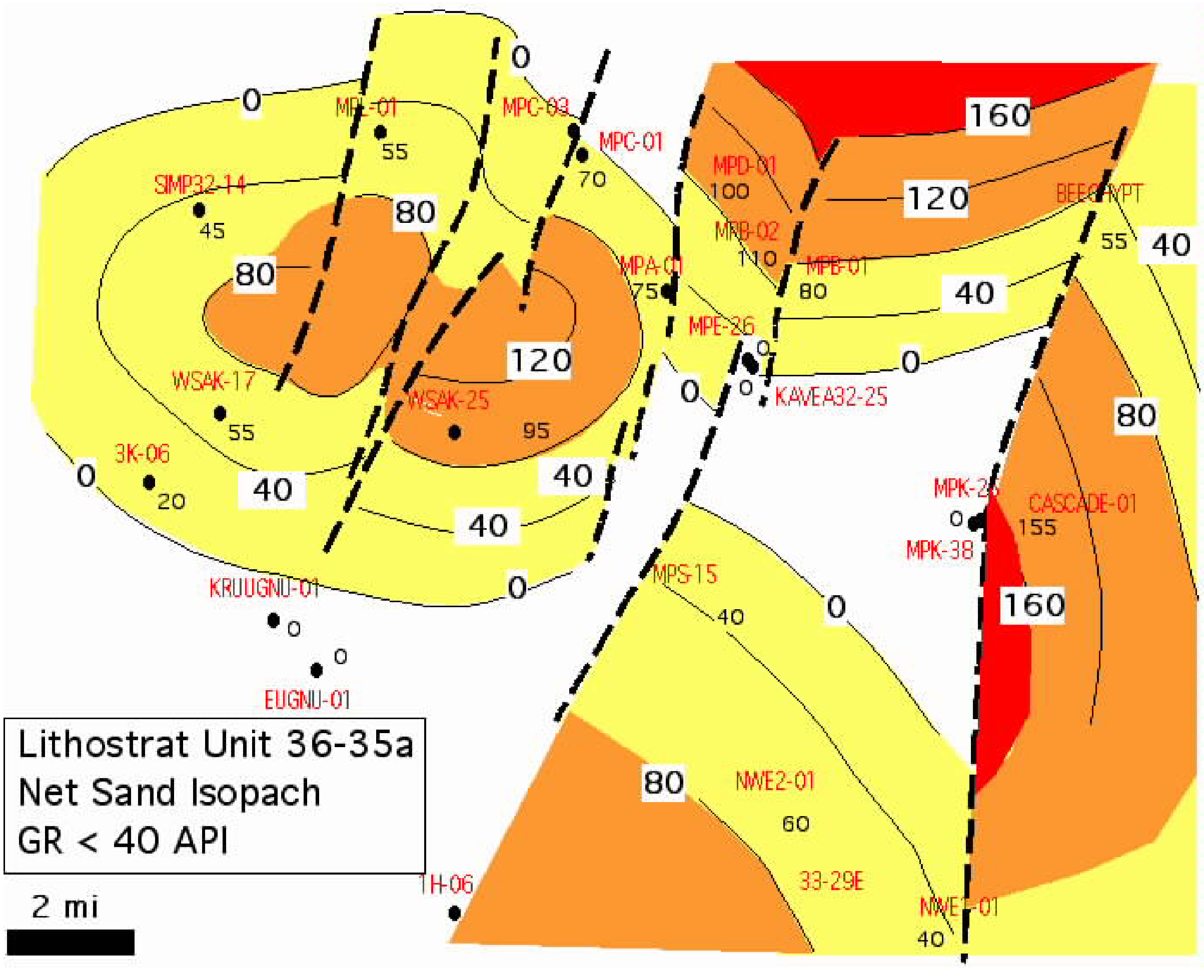

Figure 2: Net Sand Isopach Map, Lithostratigraphic unit 36-35a

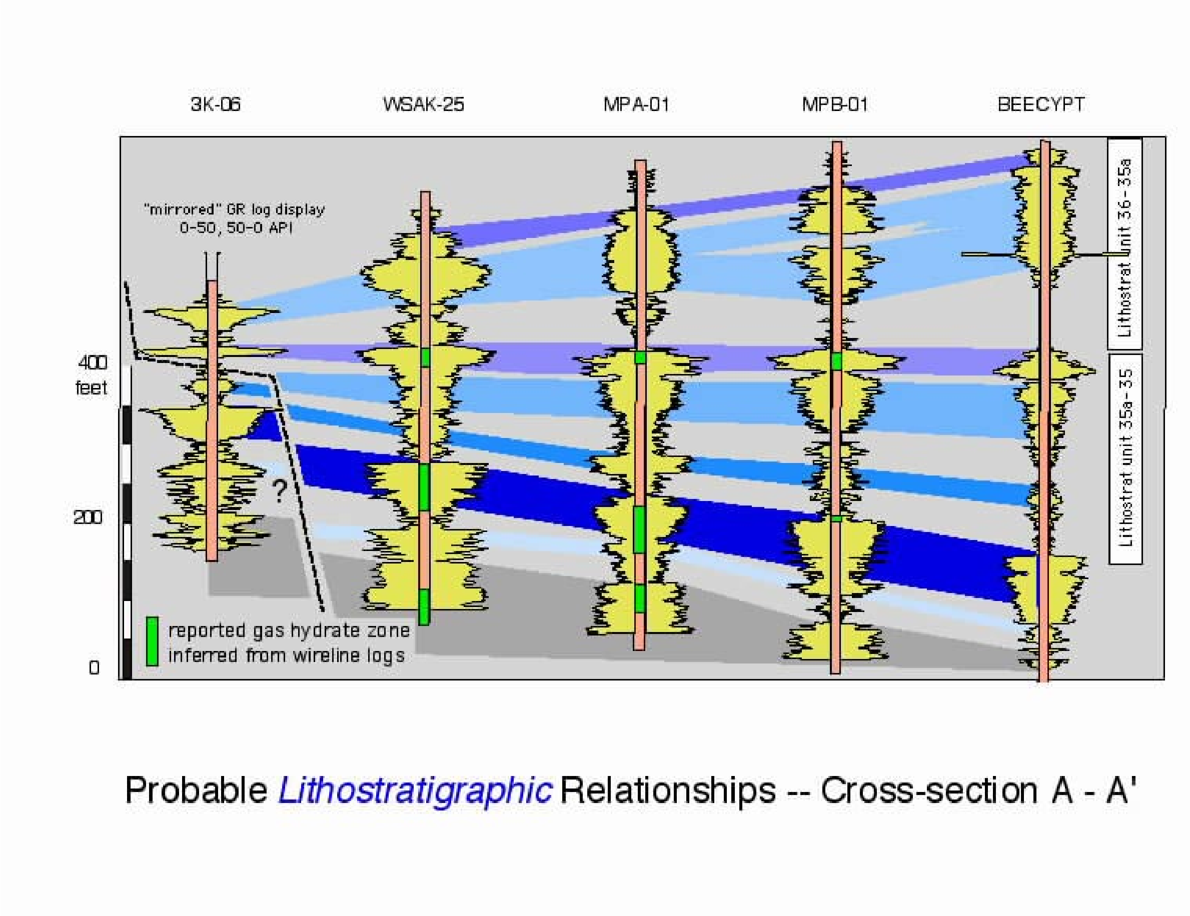

Figure 3: Regional Cross-section illustrating Probable Lithostratigraphic Correlations

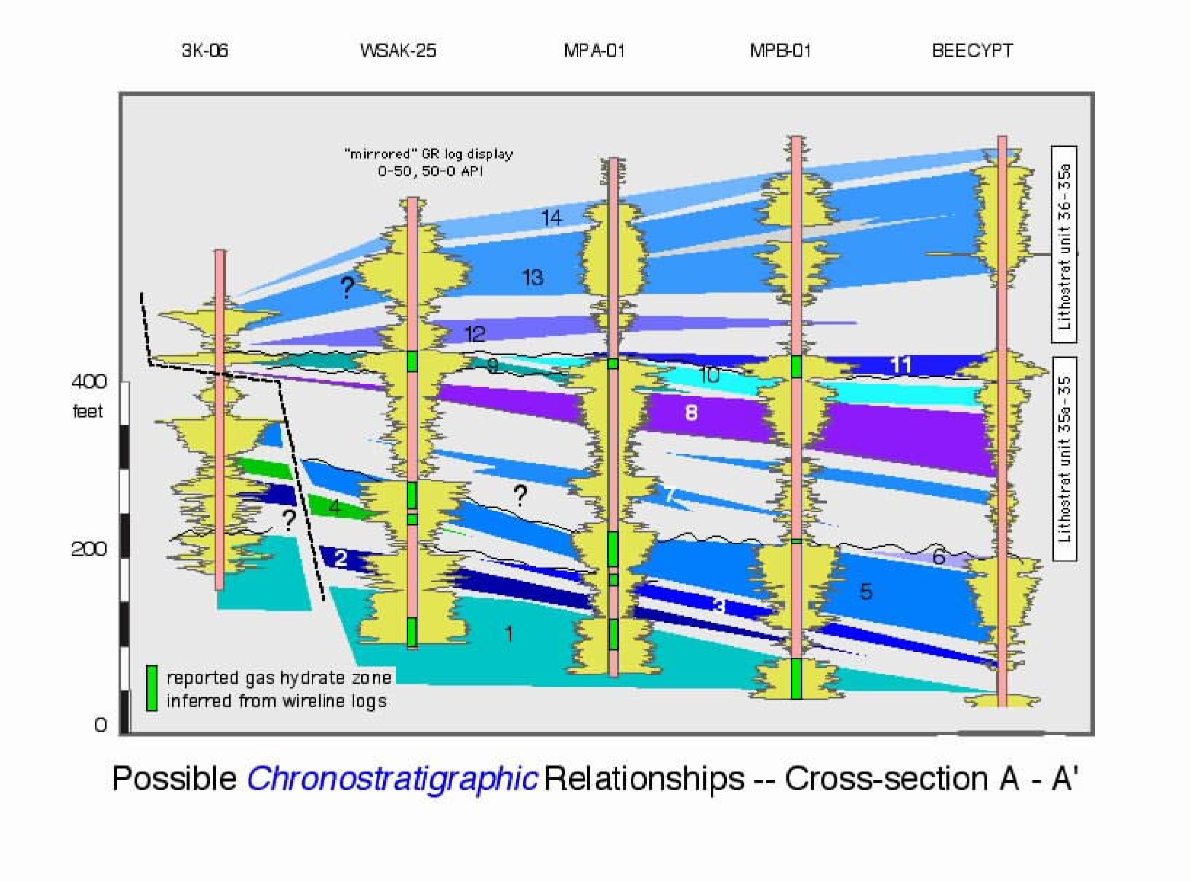

Figure 4: Regional Cross-section illustrating Possible Chronostratigraphic Correlations

5.6.1.3 Work in Progress

- Assessment of reservoir heterogeneity and interpretation of faulted intervals based on well log correlations.
- Correlation and regional tying of parasequence units and associated of beds, bedsets. and correlative marine flooding surfaces within the Sagavanirktok.
- Beginning integration and correlation of hydrate, permafrost and free-gas zones (inferred from log response; Collett, 1993) with new parasequences and well log character.
- Analysis of reported distribution of log-based inferred hydrate occurrences within UA stratigraphic framework.
- Training students in the classification of well log patterns and interpretation of sand body facies types and depositional environments from well logs.
- Training and production of a representative cross section for the AAPG poster illustrating correlation of sequences, parasequences, regional correlation markers within the Sag and vertical and lateral sandstone reservoir heterogeneity.
- Development of more detailed stratigraphic and structural geologic model based on findings from the geophysical and geological work
- Integration of the USGS log inferred hydrate picks within the UA stratigraphic framework. Will analyze their distribution in relationship to structure and facies changes.
- Development of an oral presentation on the role of non-conventional energy sources to be given at the UA Speakers Series in Green Valley, AZ

- Training on Landmark StratWorks and GeoPlus Petra in log correlation, cross-section and map generation.
- Security and nightly backup of database, project files and software system files.

5.6.1.4 Continuing needs and data

- Normalization of well log data for will be required at some point for accurate quantitative petrophysical analysis (e.g. net pay determinations and volumetric estimation) and a more accurate training and development of neural net classification,
- Obtain all the well log information that the USGS has used in their regional cross section analyses
- Obtain mud and drilling logs for aiding in the identification of coal-bearing zones within the highly variable Sag.
- Obtain all/any caliper, mudlog and drilling log information related to significant borehole washouts, gas shows, and penetration rate anomalies within the Sag.
- Within the study area obtain available cased-hole gamma ray logs from a list of wells as designated by the UA. The purpose is to confirm preliminary correlations and assess reservoir variability at a variety of scales.
- Continue our collaboration with UA geophysical group in an effort to link deep well log information with seismic data where seismic data is apparently of better quality.
- Obtain a full set of geological and other pertinent cartographic data for the general study area. This should include all thaw lake, river and shoreline features across and adjacent to the study area.
- Where possible, host general work/training sessions with Landmark representative for variety of software as needs arise.
- Obtain Fault maps at the Kuparuk formation level.

5.6.2 **Subtask 6.2: Seismic Attributes and Calibration – UA**

5.6.2.1 Products

- Created Synthetic seismograms for tying wells MP18-01, WSAK-25, MPS-15, MPA-01, MPB-01, MPC-01, and MPD-01 to seismic data.
- Calculated initial attribute-cube on original stacked data, including Instantaneous Phase, Instantaneous Frequency, Instantaneous Reflection Strength, Instantaneous Quality Factor, Instantaneous Amplitude Acceleration, Instantaneous Dominant Frequency, Event Similarity Prediction, Trace Balancing, and Image Enhancement.
- Modeled acoustic properties of gas/water and hydrate/gas contacts.
- Determined characteristic polarity reversal along reservoir horizon.
- Identified possible frequency response for gas contacts.
- Completed predictive deconvolution to eliminate peg-leg multiples.
- Completed preliminary seismic-to-well-log ties for gas-hydrate occurrences in MP18-01 and WSAK-25.
- Delineated possible free gas in the MPS-15 area.
- Created shallow horizon fault map for first 950 ms in Milne Point Survey and overlapping area of Northwest Eileen Survey.
- Mapped shallow marker horizons for determination of shallow fault offsets.

- Extracted amplitude along prominent reflections for possible correlation with gas hydrate and free gas occurrences.
- Generated Isochron maps for Milne Point area on marker horizons and unconformities.
- Created Gas-Hydrate Project poster for UA GeoDaze Student Symposium.
- Presented Gas-Hydrate Project for UA GeoDaze Student Symposium.
- Calculated initial volumes of free gas in fault-delimited reservoir using EarthCube.
- Developed digital physiographic and other maps from USGS Digital Elevation Models (DEM files) using GMT (Generalized Mapping Tools) software. Completed maps (so far) include various projections of regional topography (~1 km grid spacing) of Alaska with coastline/waterway information, which have been used in regional index maps for publication and poster and PowerPoint presentations.
- Wrote Department of Geoscience Alumni Newsletter article on Gas-Hydrate Project. This article, written for non-specialists in the geosciences, is distributed widely to former students, to administrators, and to other universities, and serves as a tool for outreach about the project.

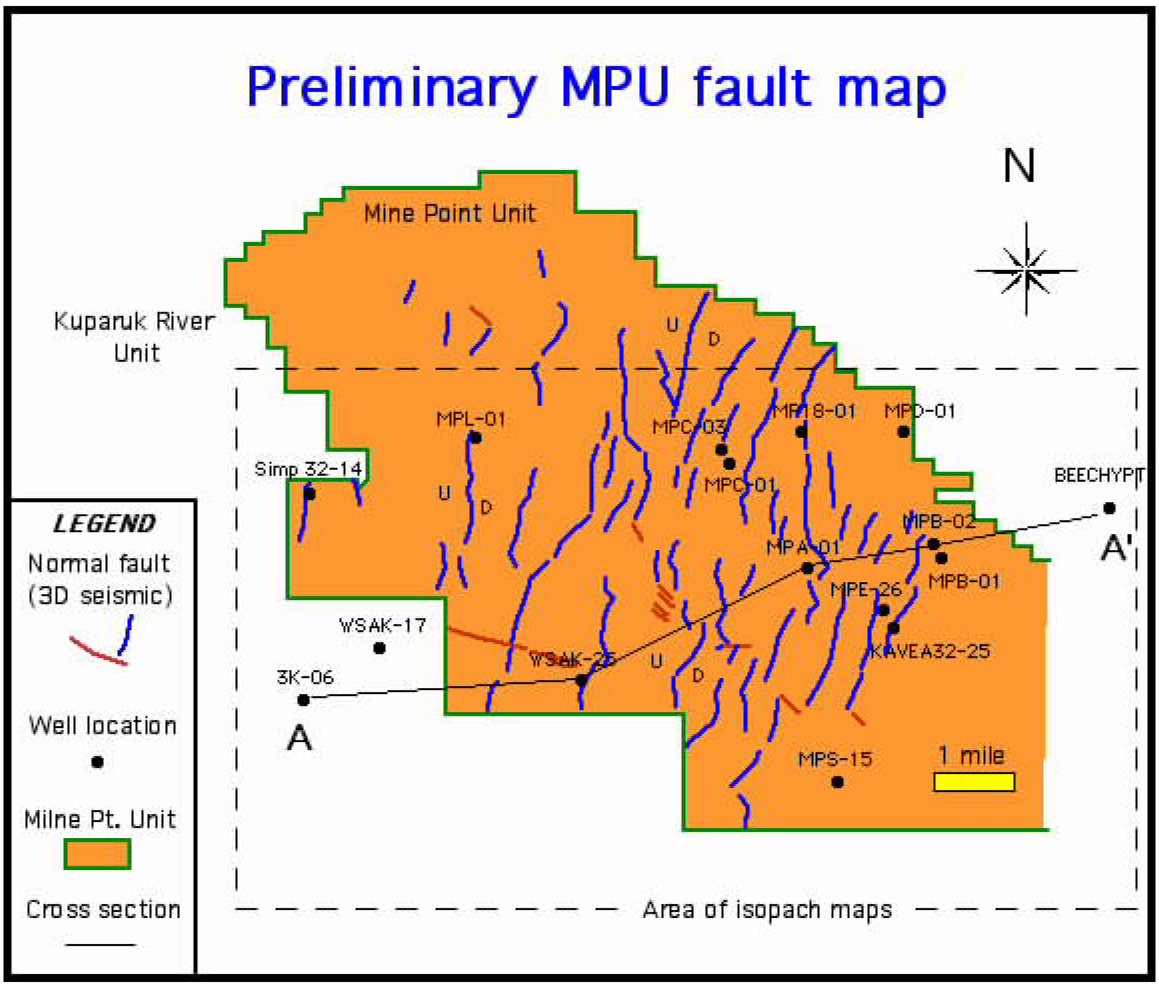

Figure 5: Preliminary fault map interpretation from shallow horizon well and seismic data.

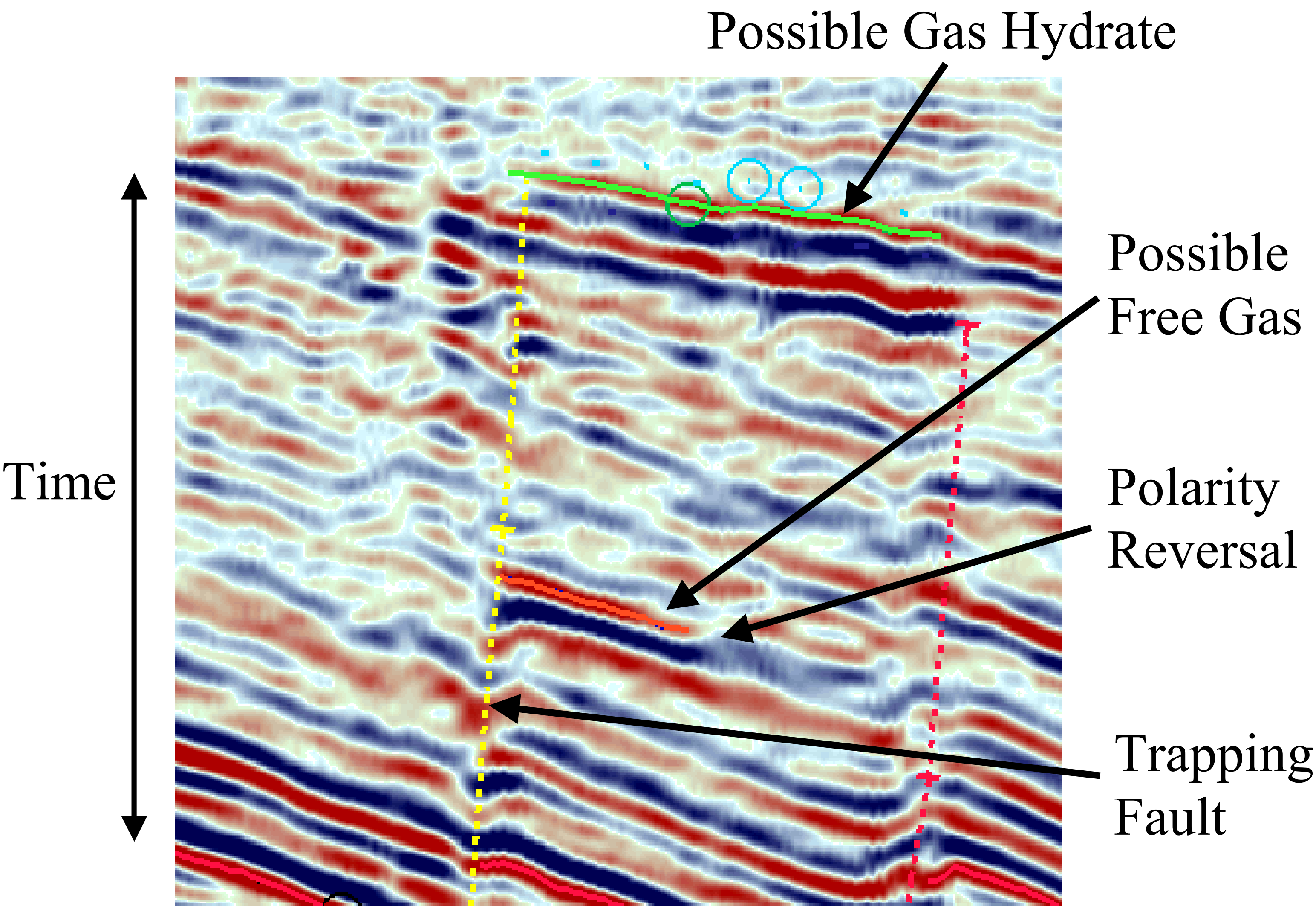

Figure 6: Preliminary seismic data interpretation illustrating potential fluid characterization.

5.6.2.2 Miscellaneous Project Activities

- Evaluated availability and applicability of high-resolution borehole temperature data from North Slope.
- Entered all available USGS gas-hydrate, hydrate-stability-field and permafrost picks into Landmark database system.
- Helped Department of Mining and Geological Engineering with initial OpenWorks use.
- Worked with team members from MGE to identify key areas with project seismic data for application of neural network and other attribute-analysis techniques.
- Familiarized with Landmark software packages: EarthCube, OpenVision, PostStack/Pal, StratWorks, TDQ, SynTool, PetroWorks, ZAP!, Data Import/Export, Data Management modules, Promax Wavelet Processing and others.

- Met with BP representatives Josef Chmielowski (Milne Point group) and Jason Lore (Houston) during UA GeoDaze Symposium for project-related discussions (April 10-11).
- Created seismic-derived graphics for the May AAPG team poster in Salt Lake City.

5.6.2.3 Work in Progress

- Horizon and fault interpretations for Milne 3D and NW Eileen 3D within MPU.
- Wavelet deconvolution of Predictive Deconvolution data for increased resolution of seismic data and more accurate depiction of subsurface geology.
- Advanced wave-equation modeling of gas hydrate and gas occurrences. Beginning of calibration of seismic response from hydrate, permafrost and free-gas zones.
- Development of more robust geologic models for elastic modeling.
- Further attribute investigation for potential direct gas hydrate and free gas fluid indicators and fluid characterization.
- Tying USGS hydrate picks to seismic data.
- Evaluation of track lines for data request to facilitate AVO analyses.

5.6.2.4 Continuing Needs

- Normalization of well log data for quantitative petrophysical analysis and more accurate neural net modeling and volumetric estimations
- 3D stacking velocity model for shallow section (above 950 ms) for more accurate depth conversions.
- 3D migration velocity model for shallow section (above 950 ms) for more accurate migrations and depth conversions.
- Near-, intermediate- and far-offset stack volumes for AVO analyses for fluid characterization and hydrate identification.
- Ties from well logs to seismic data based on deeper correlations where data quality is better, and so that sufficient signal length for accurate correlations is available.
- Detailed processing history for assembled data sets.
- GIS geological data for region; other pertinent geological and cartographic data.

5.6.3 Subtask 6.3: Petrophysics and Artificial Neural Net – UA

- Learned and coded Matlab and Artificial Neural Network (ANN) Toolbox software for transfer of seismic data into Matlab.
- Established a Self-Organizing Map (SOM) network
- Assessed various visualizations of the ANN classification results in progress.
- Ran preliminary ANN classification for several seismic attributes completed in the vicinity of well West Sak 25. The latter include amplitude, instantaneous frequency, dominant frequency, and amplitude acceleration.
- Supervised training of ANN algorithms (in progress).
- Ran preliminary ANN classifications using instantaneous frequency, dominant frequency, and amplitude acceleration
    - Results suggest a potential linkage to gas hydrate zones as inferred from log responses published by the USGS.

- Commenced investigation of a new model that can predict gas hydrate concentrations using sonic and bulk density logs in conjunction with seismic attributes such as compressional wave velocity (Glass).

5.7 TASK 7.0: Lab Studies for Drilling, Completion, and Production Support – UAF

5.7.1 Subtask 7.1: Characterize Gas Hydrate Equilibrium

- Designed and executed Gas Hydrate Phase Equilibrium experiments.
- Trained student for summer employment.
- Set up equipment for using Canon digital camera on an automated system.
- Programmed the Watlow process controller to evenly control temperature changes. (Previous temperature changes were accomplished manually.)
- Acquired laboratory grade NaCl for mixing brine solutions.
- Started tests using CP grade methane (99.9% pure) in brine solutions
  - Generated curve for 2% brine (Table 2)
  - Began tests for 4% brine solution

Future Work

- Continue experiments using CP grade methane and different brine solutions.
- Develop methods to improve experiment repeatability.

Table 2: 2% Brine Data Results, Gas Hydrate Phase Behavior Experiments

Temperature (°F)	Temperature (°K)	Pressure (psia)	Equivalent Depth (ft)	Equivalent Depth (m)
29.9	272	300	727	221.5255
42.7	279	600	1420	432.7034
49	282	892	2094	638.2498
51	284	1195	2794	851.5394
54.4	285	1497	3491	1064.125

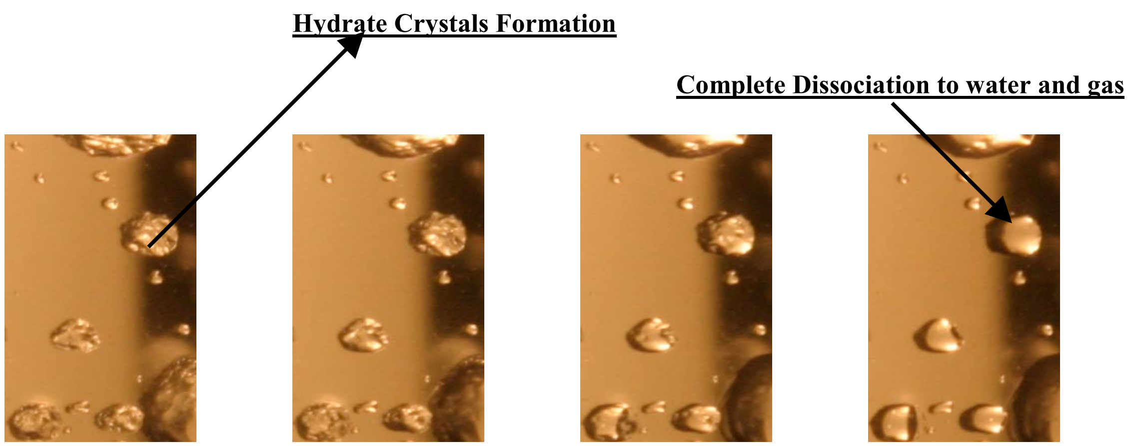

Figure 7: Visual Observations of Methane Hydrate Dissociation in 2% Brine at 1500 psi

Table 3: Gas Dissociation Data, Gas Hydrate Phase Behavior Experiments

psia	Predicted (°F)	Experimental (°F)
1500	54.95	54.4
1200	51.49	51.0
900	46.78	49.0
600	39.77	42.7
300	27.26	29.9

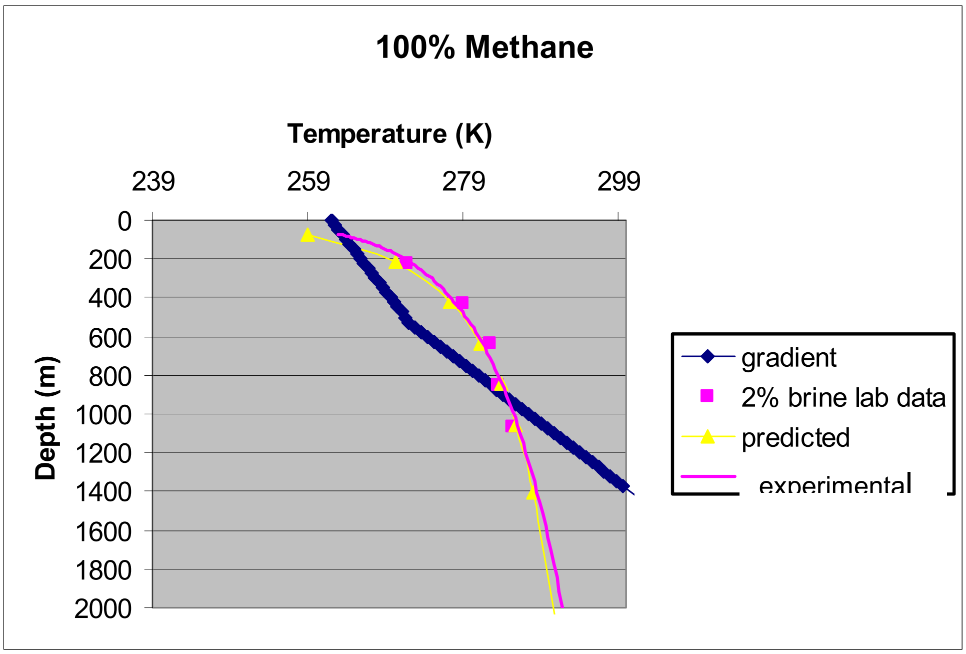

Figure 8: Comparison of Predicted and Experimental Data for CP Grade Methane and 2% Brine with Geothermal Gradients at NW Eileen State-2

55.1°F 10:15pm

55.8°F 10:50pm

56.4°F 11:25pm

57.1°F 12:00am

Figure 9: Visual observations of methane hydrate dissociation in 4% brine at 1800 psi.

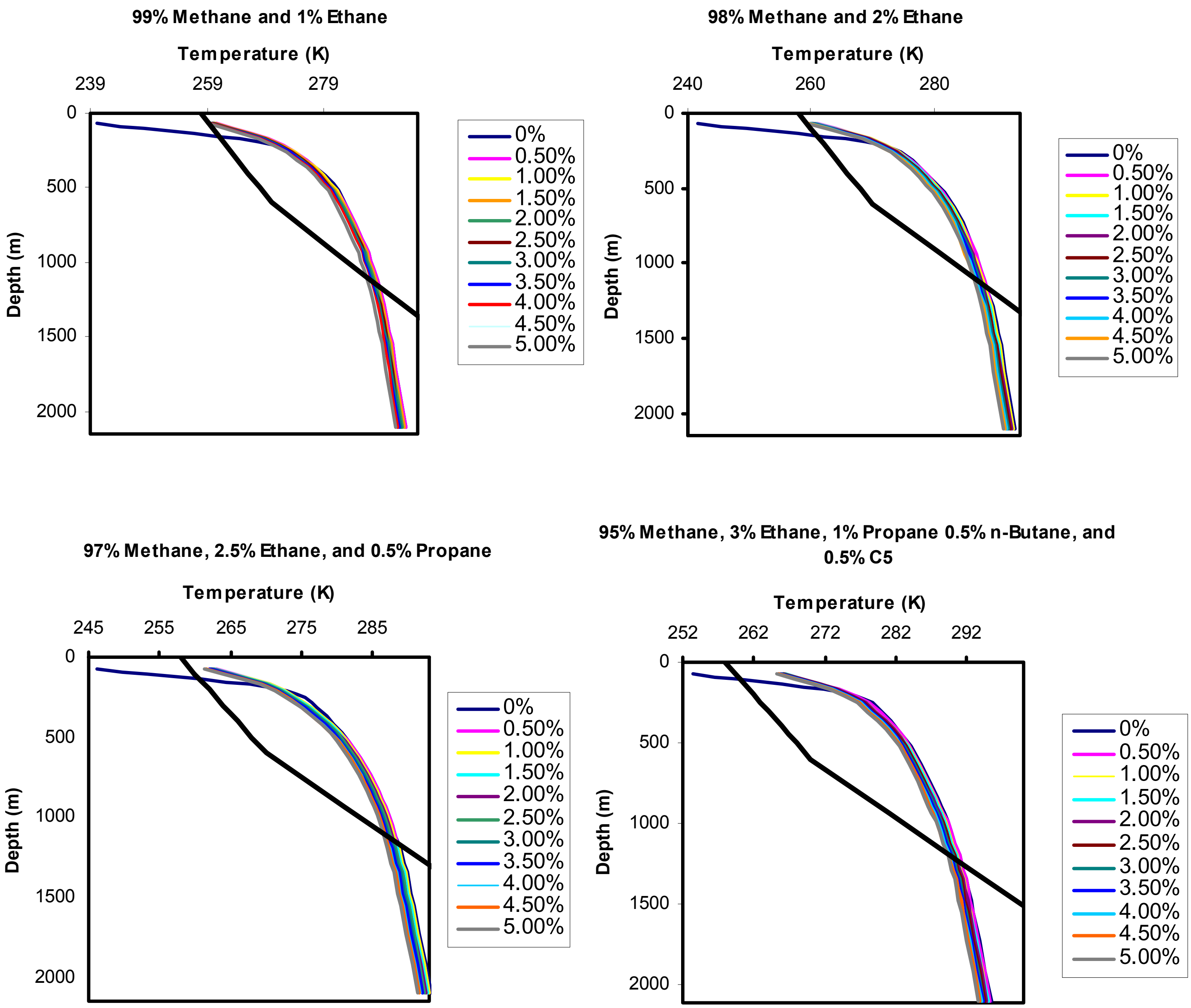

Figure 10: Predicted Methane Hydrate Stability Zones for NW Eileen and Effect of Gas Composition and Salinity

5.7.2 Subtask 7.2: Measure Gas-Water Relative Permeabilities

5.7.2.1 Subtask 7.2 Objective

The objective of the project is to measure the relative permeability function relationships by conducting two phase relative permeability experiments and assess gas productivity from gas hydrate bearing porous media. The current research plays important role in the simulation studies for the hydrate zone drilling. The simulation study is one of the important tasks to be carried out in second phase of ongoing research.

5.7.2.2 Experimental Setup

The experimental set-up for measurement of gas-water relative permeability is now complete. Additional components of the apparatus such as high-precision weighing balance (for logging water production data), and data collection modules for system pressure and gas production were ordered. A schematic of the modified experimental set-up for measurement of relative permeability is shown in Figure 11. A drill bit for cutting the core samples to desired diameter (1.5 inch) was also ordered. Preliminary gas-water displacement tests were conducted in the apparatus on a sandstone core sample. Additionally, one of the core samples obtained from Anadarko Hot Ice #1 core was also tested in the apparatus. The initial experience with some of these tests is described in the section on 'Equipment Specification and Procedures'. A computer program (MS Excel based spreadsheet) was obtained from Colorado School of Mines for calculation of gas-water relative permeability values based on the two-phase production data. The program has already been tested.

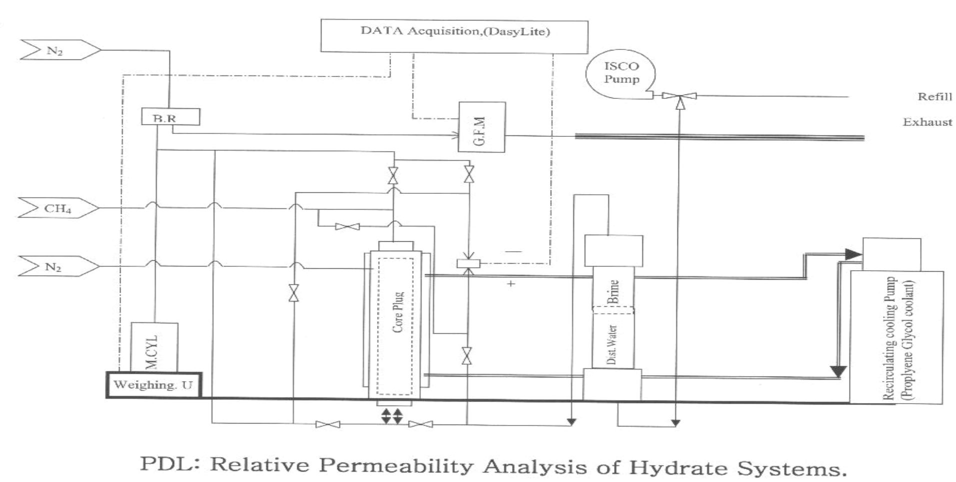

Figure 11: The modified experimental set-up for measurement of gas-water relative permeability.

5.7.2.3 Measuring Relative Permeability

Due to the friable and the heterogeneous nature of permafrost hydrate core specimen, laboratory techniques of measuring relative permeability are difficult. Laboratory analyses of gas hydrate specimens are further complicated by the difficulty in accurately measuring the pore volume of gas hydrate samples. The present work focus on performing the necessary theoretical and experimental research required to adequately characterizing the two-phase fluid flow in gas hydrate samples. Conventional analytical techniques have been studied and modified to more accurately to measure these parameters in the laboratory.

5.7.2.4 Equipment Specification and Procedures

Standard laboratory techniques for measurement of rock properties (porosity, permeability and gas-water relative permeability) are modified for current work. As per our earlier planned schedule for this quarter, we developed a robust model for permeability measurement of gas hydrate samples. Trial tests were performed at high-pressure up to 600-psi overburden.

Heat transfer calculations done for nitrogen for overburden shows that it takes more then day to achieve equilibrium temperature for completely insulated system. The experimental results confirmed the calculation. Trial tests showed that nitrogen replaced with the liquid at the top (with nitrogen for pressure maintenance) is a good alternative. Currently we are trying to see the optimum height of liquid in the overburden jacket that could give some favorable results.

The initial experiments were carried out on rock samples available in lab to gain the confidence on the measurements. 1) Samples of pure water ice, without sediment present, formed in the test chamber. 2) Frozen sediment formed in the laboratory. 3) Frozen sediment containing laboratory formed gas hydrate. 4) Sediment containing just gas hydrate formed in the lab. 5) Field samples containing natural water ice and gas hydrate (samples collected from field) are planned for testing in the future work.

As per the first step frost core is used for measurements. Frost was prepared by heating a container filled with distilled water and transferring the container to freezer, the resulting steam formed ice (frost of approximately 400 micron size), was then shaved off the freezer walls and crushed. The frost was then compacted in the core holder using a compactor built specifically for this purpose. The core holder is maintained at low temperature around $-15^{o}C$. Care is taken not to melt the frost during the process. Since this test was done to check the robustness and effectiveness of the setup no data was recorded.

Permafrost core samples (ϕ= 3”) obtained from Anadarko Hot Ice #1 well for testing are presently used in developing desired core sizes (ϕ= 1.5”). Conventional coring equipment has been tried, but high heat generation (without water cooling) leads to dissociation of cores. Intermediate coring is one of the identified alternatives for core preparation of desired size.

5.7.2.5 Unsteady State Methods

At the present time there are no generally accepted methods in the industry for the laboratory measurement of porosity, permeability, and relative permeability for a gas hydrate system, nor are there any published laboratory measurements of permafrost gas hydrate properties, which are accepted standards for comparison.

As per literature survey it is clear that porosity and permeability in gas hydrate is very low. Automated data collection using mass flow meters to monitor total effluent (gas plus water) production after gas breakthrough and a gas water separator placed on a electronic balance to monitor water production are used (Figure 11) to achieve the accuracy required for unsteady state relative permeability measurements in a gas hydrate system. The porosity of gas hydrate systems is quite low; therefore, the dead volume (inlet, outlet lines, and the ring channel distribution system) of the set-up plays an important role in the displacement tests. The magnitude of the effect of inaccuracies in determining dead volume on gas-water unsteady state relative permeability measurements for low porosity is documented well in literature [Gash, 1991]. For our calculation dead volume is assumed to be water filled at the start of gas injection. The displacement of the water in the dead volume was assumed to be piston-like so that the dead volume was subtracted from the water produced. The Johnson, Bossler, and Neumann (JBN) [Johnson, 1959] is being used to calculate relative permeability curves.

5.7.2.6 Mathematical Model Development

The flow through porous media is dominated by the continuous flow channel with the largest minimum cross-sectional dimension. The permeability of a porous medium partially saturated with gas hydrate depends critically on where gas hydrate forms in the pore space. Following are some of the models identified in literature for a gas hydrate system.

1. Gas Hydrate coats capillary walls. [Scheidegger, 1960]

Gas Hydrate uniformly coats the walls of each capillary, the radius of the water-filled pore space will be reduced to a_r.

$$q = n\pi a_r^4 \frac{\Delta p}{8\mu L}$$

Since the number of capillaries per unit cross-section remains

$$n = \frac{\phi}{\pi a^2}$$

The permeability of water is reduced to

$$K(S_h) = \frac{\phi a_r^4}{8a^2}$$

S_h is gas hydrate saturation (the volume fraction of pore space occupied by gas hydrate),

And $a_r^2 = a^2(1-S_h)$

So, $K(S_h) = \dfrac{\phi a^2(1-S_h)^2}{8}$

The relative permeability of water is defined by

$$k_{rw} = \frac{K(S_h)}{k_o}$$

k_0 is permeability without any gas hydrates.

$$k_{rw} = (1-S_h)^2$$

2. Gas Hydrate formed in center of capillary. [Lamb 1945 modified]

$$k_{rw} = 1 - S_h^2 + \frac{2(1-S_h)^2}{\log(S_h)}$$

3. Permeability prediction for granular media [Hearst et al, 2000 with Spangenberg, 2001]

$$krw = (1 - S_h)^{n+2} \left(\frac{A_0}{A((S_h)} \right)^2$$

A is internal surface area of the pore space.

4. Permeability prediction when gas hydrate coats the grain surface. (Spangenberg, 2001)

$$Krw = (1 - S_h)^{n+1}$$

Saturation exponent n equals 1.5 for $0<S_h<0.8$. Above 0.8 saturation exponent diverges.

5. Gas Hydrate occupies pore centers.

$$k_{rw} = \left(\frac{(1 - S_h)^{n+2}}{(1 + S_h^{0.5})^2} \right)$$

n=0.4 at S_h=0.1 (ref literature)

6. University of Tokyo Model. [Masuda, 1997]

$$krw = (1 - S_h)^N$$

$$N = 10..or..15$$

7. LBNL Model [Parker et al]

$$Krw = S_w^{1/2} \left[1 - (1 - S_w^{1/m})^m\right]^2$$

$$S_w = \left(\frac{S_w - S_r}{1 - S_r} \right)$$ S_r is irreducible water saturation, m is soil dependent.

Figure 12 shows the gas permeability measurement [Nadem, 1989] performed at UAF, which can be useful for absolute gas permeability comparison of a gas hydrate system.

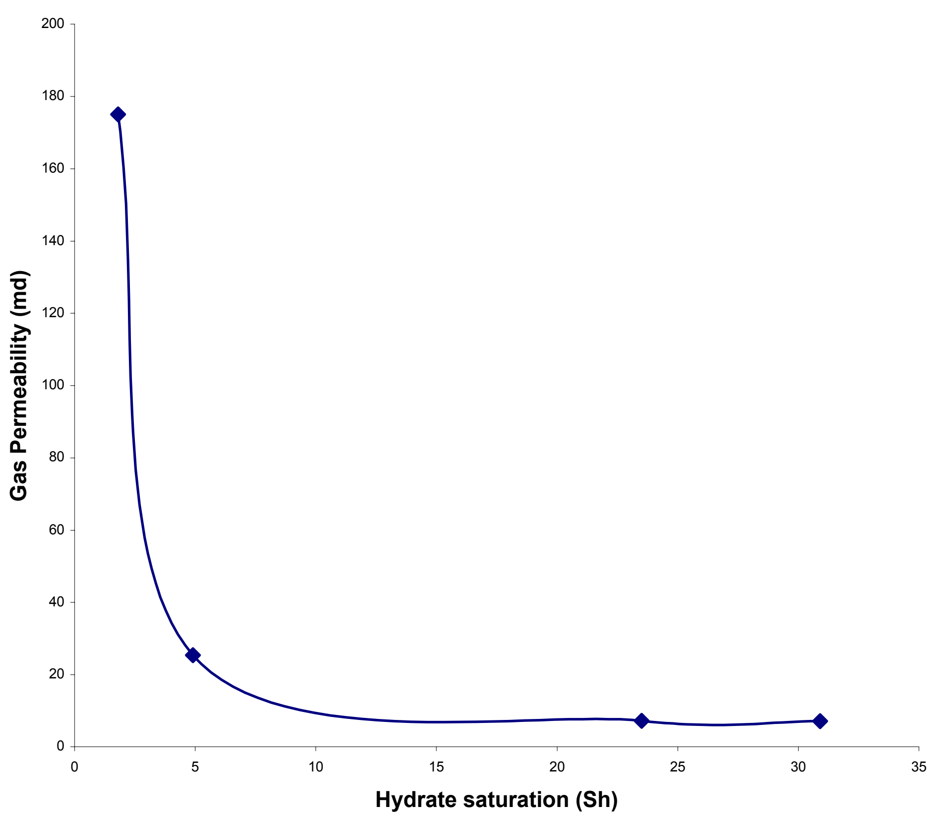

Figure 12: Gas Permeability [Nadem, 1989]

Development of a mathematical model is an important future aspect of our studies. A mathematical model of the experiment can be performed in two stages. The first stage involves the determination of equilibrium gas production using dissociation production model. In the second stage, a 1D, two phase numerical simulator based on the initial and boundary conditions of the experimental constraints is presently being studied to obtain representative capillary pressure and relative permeability characteristics.

Stage 1: Non-Linear Gas Hydrate Gas Production Model
Still under study for selection.

Stage 2: Formulation simulation equations
To obtain capillary pressure and relative permeability characteristics by the system response analysis, a finite difference formulation is used. The simulator can be based on the solution of set of partial differential equation, initial and boundary conditions that accurately model the behavior of our experimental set up.

5.7.2.7 Future Work

Along with improving the measurement technique developed plans are underway to develop:

1. Mathematical model of flow equation for anisotropic gas hydrate systems.
2. Functional relationship between permeability, porosity, structure discontinuities, tortuosity and fluid parameters such as viscosity.

5.8 TASK 8.0: Evaluate Drilling Fluids – UAF

5.8.1 Subtask 8.1: Design Integrated Mud System for Effective Drilling, Completion and Production Operations

5.8.1.1 Literature Review Emphasis

- Gas Hydrate inhibitors (thermodynamic, kinetic and low dosage hydrate inhibitors)
- Application of Anti-agglomerates Gas Hydrate Inhibitors
- Scale formation and Prevention in the presence of Gas Hydrate Inhibitors
- Thermal and Rheological Drilling Fluid Properties as a tool to design mud chiller
- Formation damage characterization techniques

5.8.1.2 Thermodynamic Inhibitors

- Loss of the inhibitor to the oil or gas phase
- Pollution of hydrocarbon fractions
- Recovery costs from the wastewater
- Large tanks and injection facilities

5.8.1.3 Kinetic hydrate Inhibitors (KIs)

- Water-soluble or water-dispersible polymers, which bind to the surface of gas hydrate particles in the early stages of nucleation and growth preventing the particle from reaching the critical size (size at which particle growth becomes thermodynamically favorable), or slowing down the growth of particles that have reached the critical size.

- KIs are effective at concentration typically ten to one hundred times less the effective concentration of ethylene glycol or methanol. With thermodynamic inhibitors increasing in price, kinetic inhibitors are becoming economically favorable.

5.8.1.4 Anti-Agglomerates (AA)

- Polymers and surfactants that only work in the presence of both water and hydrocarbon phases to prevent gas hydrates from agglomerating or depositing in the pipeline. The emulsification of the oil and water phases prior to hydrate formation may be critical part of the process for some classes of AA.
- Effect depends on the mixing process at the injection point and the turbulence in the pipe. Also, a water-in-oil emulsion to be required as an oil-in-water emulsion to be required as an oil-in-water emulsion has a water-continuous phase
- Separation of water as droplets in an oil phase seems a likely way to avoid agglomeration.

5.8.1.5 Kinetic Inhibitor and Anti-Agglomerates Comparison

- KIs are affected by interaction in the bulk water phase or water interfaces and water cut increases as a field is produced. Therefore, if all other conditions remain the same (e.g. pressure, temperature, production water composition), an increased dosage of KI according to the water cut will maintain the same inhibitor effect.
- An important drawback of KIs is their limited activity below 6-7^{o}C. However, AAs do not depend upon sub cooling temperature.
- AAs work only in the presence of a hydrocarbon phase and their effectiveness is determined by the type of oil/condensate, the salinity of the water, and the water saturation.

5.8.1.6 Mud Cooler (Plate type Heat exchanger)

- The gas hydrates within sediments are hazard to hydrocarbon exploration drilling, similar to shallow gas, with the potential to cause a severe gas kick when the gas hydrate bearing sections are penetrated, or if free gas is trapped below the gas hydrate zone especially in the presence of warm drilling mud.
- The commercially available unit is currently configured for both Arctic winter operation and all season high temperature mud cooling.
- The fan coil can dissipate up to 1,800,000 BTU/hr of heat operating at +/- 0^{0}C at an ambient air temperature of -30^{0}C.
- Capacity increases by two or three times if the LMTD is allowed to increase (i.e., increase the temperature difference between the cooling medium and the drilling fluid).
- The Mud Cooling System consists of an Alfa Laval "plate type" heat exchanger designed for cooling drilling fluid. The system was originally designed for drilling in permafrost and gas hydrates in the Beaufort Sea and Mackenzie Delta.
- Heat induced by drilling operations affect not only surface operations but will be transferred directly into the bitumen formation and it can result in unstable wellbore conditions at greater depths.

- Cooled casing not only results in a more stable wellbore, but also ensures the stability of the drilling rig and conductor. Cooler stabilizes the permafrost and gas hydrates, allowing drilling to continue into solids formations while minimizing wellbore instability.

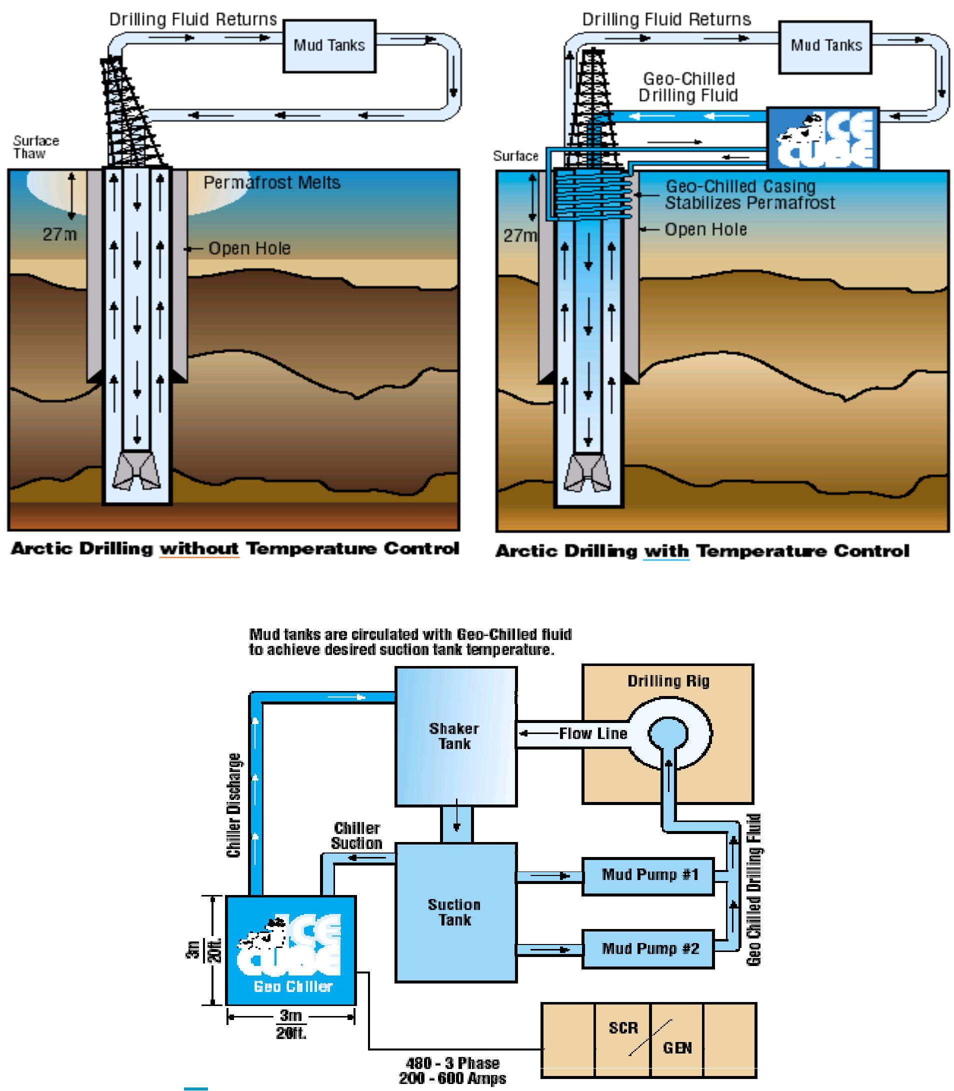

Figure 13: Mud Temperature Control, Arctic Environment (Drill Cool Systems Canada, Inc.)

5.8.1.7 Future Plans

Future work will assess incompatibility between brine and injection water in the drilling mud simulator. The basic idea for the design was conceived from a similar experimental setup used to study the effects of gas-cut mud on cuttings removal, annular flow parameter and cutting transport ratio. The schematic of prototype apparatus is shown below and we plan to build similar equipment up to a height of 15 feet to better observe the incompatibility between fluids and to measure transport ratio for the drilling fluid that is used in Mackenzie Delta Research Well.

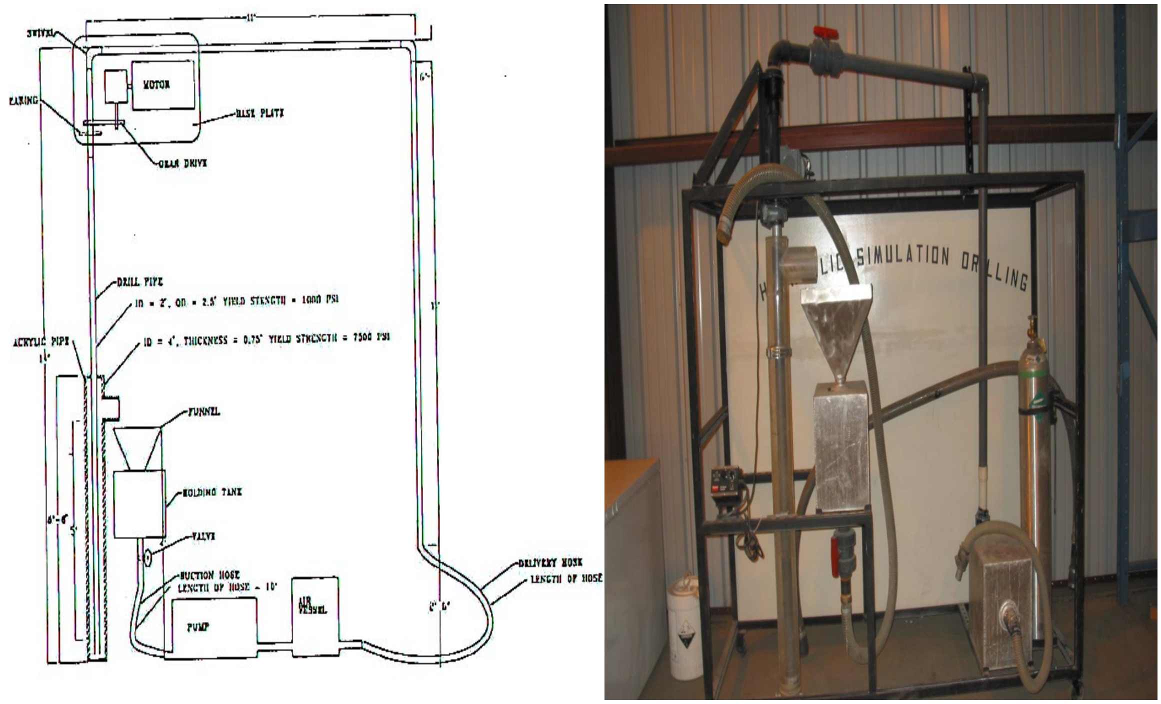

Figure 14: Schematic and photograph of Prototype Drilling Mud Simulator (Belavadi, 1994)

5.8.2 Subtask 8.2: Assess formation damage: Testing, Analysis and Interpretation

- Frequently the formation damage potentials are investigated by subjecting the reservoir core samples to flow at near-in situ conditions in the laboratory.
- For meaningful formation damage characterization, laboratory core flow tests should be tested under certain conditions, namely: samples of actual fluids and formation cores, temperature and pressure similar to that in field operations.
- Since the underbalanced drilling has been touted recently as a solution to many problems associated with invasive formation damage. We plan to build the underbalanced drilling apparatus is designed so that a dynamic underbalanced conditions can be maintained while flowing either gas or oil while the drilling fluid of interest, be it either a hydrocarbon or water-based system, can be turbulently circulated across the core face while continuous permeability measurements are conducted.
- We plan to build an experimental setup to assess the formation damage.

5.9 TASK 9.0: Design Cement Program – UAF

5.9.1 Task 9 Future Work

- Continue literature survey; assess current permafrost cements
- Work with AETDL and DOE to fund cooperative research program with Argonne National Lab (ANL) to study efficacy of Ceramicrete as arctic conditions and chilled mud system drilling cement
    - Proposal presented to AETDL review panel in July
    - Proposal ranked second and to be forwarded to NETL for funding by AETDL

- Project co-funding and participation commitments by Bindan Corporation (Ceramicrete manufacturer) and BJ Drilling (mud company)
- Design experiments to assess cements
- Conduct preliminary experiments at ANL

5.10 TASK 10.0: Study Coring Technology – UAF

5.10.1 Task 10 Overview and Objectives

Methane hydrates are ice-like crystalline solids, formed from a mixture of water and natural gas. Discovered roughly a century ago, these compressed lattices of natural gas have been found extensively in arctic and marine sediment and are believed to contain the majority of the world's natural gas [1]. Around the United States, large deposits have been identified and studied in Alaska, the west coast from California to Washington, the east coast, including the Blake Ridge offshore of the Carolinas, and in the Gulf of Mexico [2]. Despite their prevalence, however, hydrates have been considered for most of the past century little more than a nuisance. The trapped methane was considered unrecoverable, and the formation of hydrates within gas pipelines would often create undesirable plugs. Little practical assessment of gas hydrate as a potential resource was devoted to this unique phenomenon.

Yet as the nation moves towards energy independence, the natural gas trapped within methane hydrates takes on new importance. Natural gas is expected to take on a greater role in power generation, largely because of increasing pressure for clean fuels and the relatively low capital costs of building new natural gas-fired power equipment. Demand for natural gas is expected to grow at a rate of at least 2% per year over the next twenty years, outstripping the predicted growth for coal, petroleum, electricity, and renewable energy sources [2]. Given the growing demand for natural gas, the development of new, cost-effective supplies can play a major role in moderating price increases and assuring consumer confidence in the long-term availability of reliable, affordable fuel.

Methane hydrates could provide this new source for natural gas production. If only 1 percent of hydrate resources could be made technically and economically recoverable, the United States could more than double its domestic natural gas resource base. Under current estimates, the natural gas potential of methane hydrates approach 400 million trillion cubic feet worldwide, or nearly five orders of magnitude more natural gas than current makes up the world's reserves [3]. For this reason, research in the field of gas hydrates has taken on a new importance. Issues with recovery, transportation, and processing of methane hydrates will all need to be addressed in the near future to determine whether or not gas hydrates are an economically feasible source of energy. To begin such research, it is necessary to recover an undisturbed pressurized core of methane hydrate, as well as determine means for the transport of these cores to a laboratory setting, and tools for their analysis and long-term preservation.

The objective of this subsection is to summarize the various methods for recovering gas hydrate cores at in-situ conditions, as well as provide a rough methodology for core preservation and transport. This is accomplished by investigating the current academic and corporate literature available on methane hydrate recovery and analyses.

5.10.2 Available Coring Systems

While numerous systems are currently available, conventional coring is less appropriate for use in recovering gas hydrates. Coring for preserved hydrate samples is unlike conventional coring. First, temperatures are much lower than normal oilfield conditions, with operating temperatures down to -40^o F [4]. Secondly, conventional retrieval times are insufficient to prevent gas hydrate disassociation. Gas hydrate stability depends strongly on the pressure-temperature conditions to which a core is exposed. As conventional coring systems do not maintain the high in-situ pressure of gas hydrate, recovered samples will warm sufficiently in the retrievable process to disassociate, releasing the methane previously trapped in the gas hydrate lattice structure. Conventional coring, with the drill string retrieval process, will in most cases lead to the destruction of the gas hydrates within the core sample, thus negating the value of the operation. Therefore, wireline-coring tools are recommended, as this alternative has a significantly higher retrieval time [4].

Regardless, the lack of means to preserve in-situ pressures makes conventional coring less desirable for the purposes of this research project. Special pressurized coring systems must be considered for hydrate recovery. These systems are designed for low temperature use, and have the capability to maintain natural gas hydrate pressures and/or temperatures. The four most prominent systems are outlined below.

5.10.2.1 Pressure Core Sampler (PCS)

Developed by the Ocean Drilling Program, the Pressure Core Sampler (PCS) is a first generation wireline coring device. The PCS is also the first significant effort by the research community to acquire pressurized gas hydrate cores, designed to make use of APC or XCB assemblies common to conventional coring systems. This backwards compatibility, as well as the ability to retrieve cores at pressures up to 10,000 psi (690 bar), has won significant favor for the PCS in research applications [5]. The PCS system has seen more use in recovering pressurized cores than any other system to date.

Despite its widespread use, however, the PCS system has a number of trade-offs that make it a less than ideal choice for research purposes. A common complaint with the PCS design is directly linked to the ball valve seal that allows for pressurized recovery. The use of a ball valve allows for a high pressure to be retained during the coring process, but also severely restricts the diameter of recoverable cores to a mere 42 millimeters [4].

Table 4: Overview of PCS System

Advantages	Limitations
▪ Makes use of existing infrastructure (APB and XCB Assemblies)	▪ Recovered cores have severely restricted diameter
▪ Capable of retrieving cores at very high pressure (10,000 psi)	▪ Makes use of a top drive system
▪ Has seen the most extensive real-world testing	▪ Not possible to recover cores under pressure

The PCS system has also been recently suspected of diluting methane concentrations in recovered gas hydrate samples. This criticism arises from a design feature of the PCS assembly in which an inner chamber, containing sediment core, is open to mixing with contents of an enclosing outer chamber, containing predominantly borewater. The borewater of the outer chamber contains negligible amounts of CH_4, and has nearly twice the volume of the inner chamber. When allowed to mix, the recovered core sample is suspected to equilibrate with the methane-containing borewater, diluting the in-situ conditions of the sample [6].

Other limitations to the PCS include a lack of temperature control, the use of a top drive for drilling, and an inability to store gas hydrate cores under pressure [7]. The addition of temperature sensors to the system would add functionality to the PCS, providing more information as to the conditions under which gas hydrates form. Furthermore, temperature information would significantly aid in attempts to preserve and transport core samples without generating and/or disassociating hydrate. The top drive system used by the PCS, while common

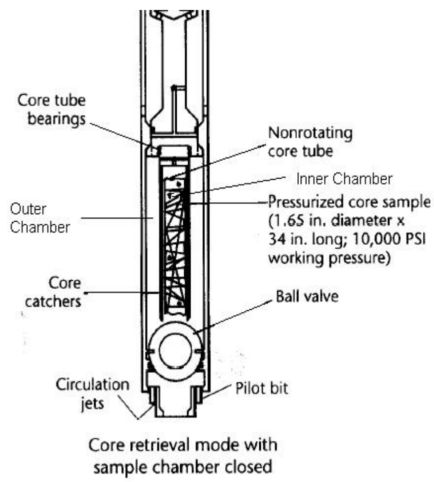

Figure 15: Illustration of PCS Design

to conventional coring systems, also generates lateral oscillations within the downhole assembly. This movement has the negative effects of breaking core samples during recovery, reducing the overall core recovery rate. Finally, the PCS system has no means of transferring pressurized cores from the assembly under pressure. The only way in which gas hydrate may be studied is to reduce the pressure within the sampler and bleed off the generated gas, limiting the usefulness of the PCS system in extensive gas hydrate study.

The technical specifications of the PCS system are as follows: the PCS is capable of recovering a core that is 42 mm in diameter and up to 86 cm in length. The PCS is not internally instrumented, but is capable of maintaining pressure of up to 10,000 psi (690 bar). There is no capability to transfer samples at in-situ pressures [5].

5.10.2.2 Hydrate Autoclave Coring Equipment (HYACE)

Following the initial use of the PCS system, the Technische Universität Berlin began work on a competing pressurized coring system. The HYdrate Autoclave Coring Equipment system (HYACE) was the final product of their work, a prototype system targeted at recovering cores from the gas hydrate bearing sediments of the continental slopes [7]. The HYACE system differs from the PCS system in two significant respects: first, the wireline coring tools are bottom-driven rather than top driven and secondly, the HYACE system allows for the transfer of core under pressure into a Laboratory Transfer Chamber (LTC), allowing gas hydrate to be preserved and studied under pressure. In the eyes of the designer, the HYACE project was “more than about designing coring tools, it was about designing a system which will allow a series of studies to be made on core which has never been de-pressurized” [8].

Table 5: Overview of HYACE Core System

Advantages	Limitations
▪ Makes use of existing infrastructure (APB and XCB Assemblies)	▪ Transfer system is hindering and poorly set up.
▪ Has transfer system allowing for core recovery and storage at in-situ pressures	▪ Flapper valve used to maintain core pressure is of questionable strength
▪ Bottom driven, allowing for better core recovery.	▪ No pressure or temperature monitoring.

The addition of bottom-driven coring to the HYACE system allows for increased core recovery. As stated before, the use of a top-driven coring system results in lateral oscillations being transmitted down to the bottomhole assembly. These oscillations can break core samples and reduce the chances of recovery. HYACE solves this simple problem with a bottom-driven system, which allows the assembly to hang stationary on the drill string and removes any lateral oscillation. This lack of movement allows for cores to be recovered more easily and in one segment [7]. A second design advantage of the HYACE system was the addition of a coring toolset, allowing for drilling in different lithologies. Three different drill bits are available, a push corer for soft sediments; a rotary corer for hard sediment; and a percussion core for sandy sediments [4]. This drilling toolset allows for greater versatility in where the HYACE system can be applied.

The most significant addition to HYACE, however, is the implementation of a core transfer system, allowing for recovered cores to be placed into a storage chamber for preservation and future study. The integrated laboratory transfer chamber allows for cores to be stored under in-situ pressures, using a vessel constructed from a fiber-reinforced epoxy pressure tube with steel end caps. The LTC, while fully functional in the laboratory, has seen problems when used in actual research applications. However, the reinforced pressure tubes themselves have proven effective for the storage of hydrate cores, and are rated to pressures up to 3,625 psi (250 bar) [5].

To address the limited core size available in the PCS system, the HYACE system makes use of a flapper valve instead of a ball valve. This alternative valve design creates a lower pressure maximum for the HYACE system, and some concern has been raised as to the strength and reliability of this flapper valve [4].

The technical specifications of the HYACE system are as follows: the HYACE system is capable of retrieving samples cores at a diameter of 50 mm and a length up to 1 meter. Pressure and temperature monitoring are not a part of this system, but a laboratory transfer chamber is, allowing for storage of samples at pressures up to 3,625 psi (250 bar) [5].

5.10.2.3 HYACE tools In New Tests on Hydrates (HYACINTH)

The HYACINTH is a second-generation wireline coring system, building upon the functionality and design of the HYACE system. Whereas HYACE was primarily an engineering development project, the primary objective of HYACINTH was to bring the tools developed in HYACE to operational use. As such, HYACINTH has all the advantages that previously existed in the HYACE system, namely the bottom driven coring device and the LTC. However, as a second-generation device, many of the perceived design flaws had been corrected. Issues with core transfer within the LTC were addressed, and the previous flapper valve was made more robust to improve performance.

Furthermore, the capabilities of the HYACE system were expanded. Equipment for sub-sampling the pressurized cores to obtain samples for chemical, microbiological and petrophysical study were added to the coring system, and the LTC chambers were redesigned to be multichambered.

Technical specifications for the HYACINTH system are as follows: the HYACINTH system is capable of retrieving samples cores at a diameter of 50 mm and a length up to 1 meter. Pressure monitoring is a part of this system, as is a laboratory transfer chamber, allowing for storage of samples at pressures up to 3,625 psi (250 bar) [5].

Table 6: Overview of HYACINTH Core System

Advantages	Limitations
▪ Makes use of existing infrastructure (APB and XCB Assemblies)	▪ Recovered cores have limited length (up to one meter)
▪ Uses improved HYACE transfer system	
▪ Has improved flapper valve strength	

5.10.2.4 OMEGA Multiple Autoclave Corer (OMEGA MAC)

Most recently, the German OMEGA Project has developed a Multiple Autoclave Corer (MAC) to sample gas hydrate bearing surface sediments down to 1400 m water depth. It provides up to four cores simultaneously under in-situ conditions (e.g. pressure, temperature), for subsequent geoscientific and microbiological laboratory investigation [9].

Little is currently known about this particular instrument, though the results of its initial trials will soon be published. Like the HYACE/HYACINTH systems, the OMEGA MAC has a laboratory transfer chamber (LTC) for long-term core storage under in-situ conditions. While the frame, damping system and corers are made of stainless steel, the pressure chambers consist of an inner glass-fiber reinforced plastic (GRP) tube and an outer aluminum mantle for axial forces [10]. Thus, after in-situ retraction of the cores into the LTC, non-destructive analytical methods such as X-Ray Computed Tomography (CT) can be applied before core sub sampling. The latter is enabled by a ball valve port at the top of each LTC, also suitable for axial gauging of the core. Each LTC is equipped with a pressure-preserving system designed to keep the in-situ pressure constant over several months. In addition, it is enclosed in a transparent plastic mantle filled with ambient seawater for cooling the pressure cores on board [10].

Unlike the HYACINTH system, which shares many of the same features, the OMEGA MAC makes use of a ball valve system to maintain samples at in-situ pressures, rather than the flap valve. Furthermore, the OMEGA MAC system does not share compatibility with the APC or XCB assemblies.

The technical specifications of the OMEGA MAC are as follows: the OMEGA MAC system is capable of retrieving four samples cores simultaneously at a diameter of 0.1 meters and a length up to 0.6 meter. Cores can be stored under pressure comparable to that of the HYACINTH system.

Table 7: OMEGA MAC Core System Overview

Advantages	Limitations
▪ Acquires four cores simultaneously	▪ Has not seen adequate real world testing
▪ Has transfer system allowing for core recovery and storage at in-situ pressures	▪ Does not share compatibility with existing assemblies (APC or XCB assemblies
▪ Bottom driven, allowing for better core recovery.	

5.10.2.5 Pressure-Temperature Core Sampler (PTCS)

The PTCS is a pressure coring system developed in Japan to potentially sample the country's significant offshore methane hydrate accumulation. A developmental system, the PTCS has seen extensive testing in the Mackenzie Delta of arctic Canada, as well as in the marine setting of the Nankai Trough [5]. Despite an extensive drilling toolset, the PTCS is limited in the lithologies that are appropriate for its use; as a prototype system, it was designed for the specific test region's sediment, rather than for general use.

However, the PTCS has a strong advantage of being the only pressurize coring system with an active temperature controller [11]. In addition to measuring the temperature at which a core is recovered, the PTCS has numerous cooling rods built into the core chamber to maintain in-situ temperatures. Like all other pressurized coring devices, the PTCS also has extensive pressure sensors, and is capable of maintaining pressures up to 3,500 psi (241 bar). However, the PTCS lacks the capability to transfer cores under pressure, making it unsuitable for gas hydrate study that does not occur in the field. Furthermore, the diameter of core recovered makes it incompatible with existing APC or XCB assemblies [12].

The technical specifications of the PTCS are as follows: the PTCS recovers cores with a diameter of 67 mm and a length of 3.0 meters. It is capable of storing cores at pressures up to 3,500 psi (2.4 bar), but has no current system to transfer cores under pressure to long-term storage chambers [12].

Table 8: Overview of PTCS System

Advantages	Limitations
▪ Has active temperature controller, capable of maintaining in-situ pressures	▪ No transfer system available for pressurized cores
▪ Tested in limited lithologies	▪ Does not share compatibility with existing assemblies (APC or XCB assemblies

5.10.3 Core Storage and Transport

Once a sediment core has been recovered, appropriate measures must be taken to ensure that the core can be transported to a laboratory setting and can be maintained for long-term storage. In many cases, a good coring operation can be ruined by poor core handling procedures at the surface. The final objectives of the core analyses must be incorporated into the procedure for proper handling at the well site. Most laboratory tests are sensitive to sample conditions, with poor initial handling significantly changing the in-situ conditions of the core sample.

Pressure concerns are easily considered in the majority of systems. With the exception of the PCS, all the examined systems have transfer mechanisms in place to maintain cores in pressurized chambers. These systems serve more than adequately to maintain in-situ pressure, with these pressures having been shown to be sustainable over a period of many months. Beyond the specialized core vessels, no further steps are necessary to maintain cores under pressure.

The second in-situ condition that needs to be maintained is temperature. Temperature is the variable that generates the greatest concern, as the range of appropriate temperature is very small for core storage. Too great a temperature, and any gas hydrate within a sample core may risk disassociation, destroying the natural conditions of the sample. Too cool a temperature, and the sample runs the risk of generating additional gas hydrate that did not exist initially. Unfortunately, it is not currently feasible to store recovered cores under individual temperature conditions; otherwise their in-situ temperature could be maintained regardless of variation. Instead, the recommended procedure for maintaining temperature for pressurized cores is to place the cores in a bath of seawater (in the case of marine sampling) or to place the cores in dry ice (in the case of arctic sampling). These cores should be transferred under refrigeration to a laboratory setting, where they can be stored at ideally at temperatures of 2-3° C. Freezing of the samples should be avoided, and should not be necessary so long as natural pressures are maintained.

Transportation of the cores is a straightforward matter. Pallets of cores can be transported, under refrigeration, by trunk, plane, or boat. No special concerns need to taken with the samples as they pose no significant safety hazard so long as the samples do not disassociate. However, as a safety precaution against disassociated samples, open flames/sparks should be kept away from transported samples.

5.10.4 Task 10 Future Work

- Continue literature survey
- Assess coring technologies and recommend best core methods for ANS application

5.11 TASKS 11.0 and 13.0: Reservoir Modeling and Project Commerciality and Progression Assessment – UAF, BP (+LBNL)

5.11.1 Reservoir and Economic Modeling Progress

Upon completion of the economic model, test runs were carried out to check robustness and accuracy. During this exercise, several small errors were identified and corrected. In addition, a facility was added to allow for the easy running of sensitivities in key economic inputs such as gas price, tariffs, etc.

While waiting for access to the methane hydrate reservoir simulator, an opportunity was taken to examine the feasibility of a methane hydrate pilot production development, using existing models as a base for production profiles. Two simulation approaches were taken.

5.11.1.1 Simulation One

Simulation One used a production profile (Figure 16) generated by an earlier version of the LBNL – BPXA scoping evaluation model run in October 2002. This scenario encompasses a five-well development on the edge of the Milne Point Field. The gas hydrates overlie a zone of free gas within a fault block, and it is in the free gas that the wells are perforated. As the free gas zone depressurizes during production, the reduction in pressure causes the gas hydrate at the free gas-hydrate boundary to dissociate, thus providing additional gas and pressure to the reservoir.

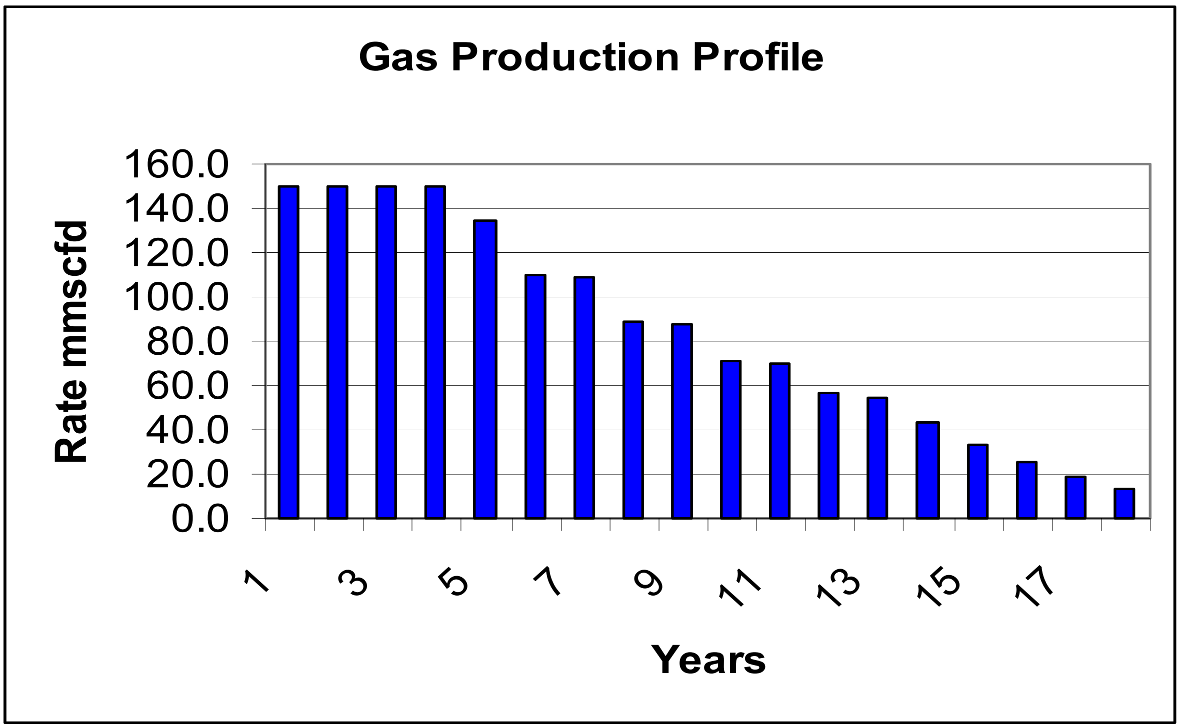

Figure 16: Gas Production Profile from October 2002 Scoping Evaluation

Economics were run using the following economic parameters:

- Gas Price $4 mmbtu
- Alaska Gas Line tariff $2.80 mscf
- Opex – for the gas $0.25/scf, which is based on an upper quartile benchmark of $2.50 boe, for Milne fixed costs of $2mm
- Capex - $500k per well, plus tie in costs, plus a stab in the dark for additional facilities.
- Gas processing – no gas processing fee, as the partners would process equity amounts through the existing facilities
- State Royalty Rate of 20%

At a gas price of $4.0 mbtu, the project has a positive return of NPV9 $29 million. The break-even price gas price is $3.78, all other things remaining equal. As may be anticipated, the project is highly sensitive to gas price, as can be seen from the sensitivity analysis (Figure 17).

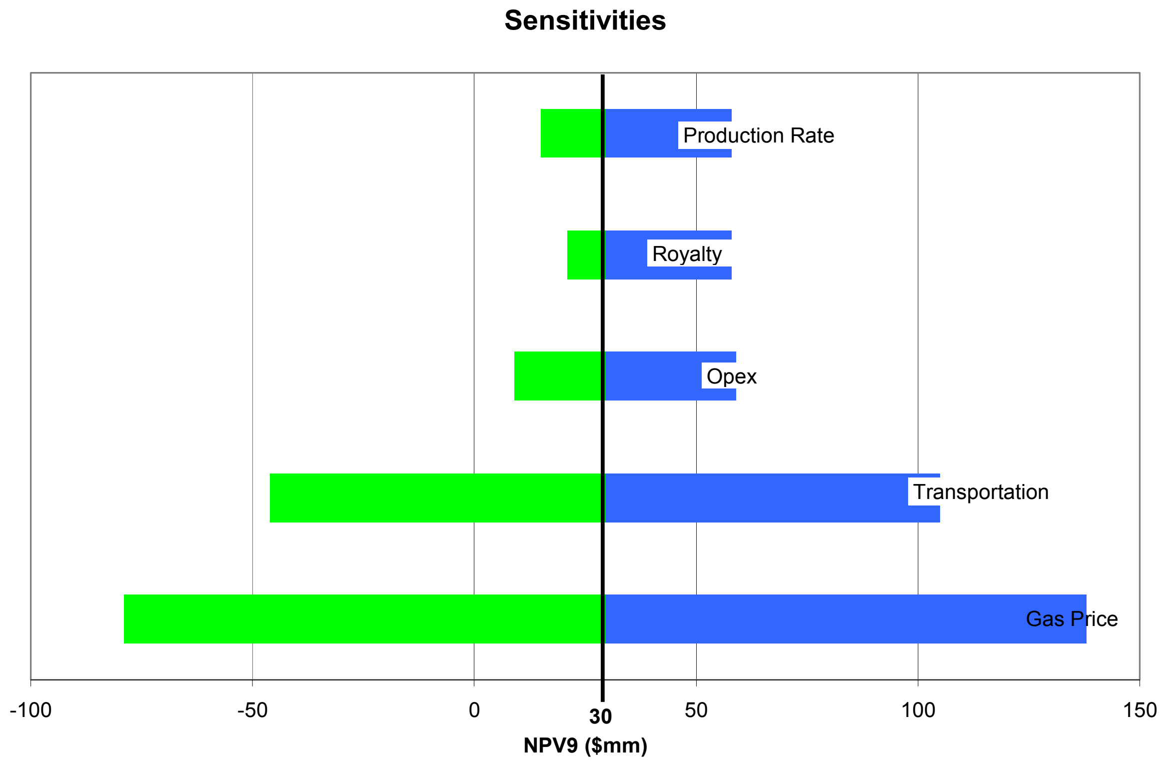

Figure 17: Economic Sensitivities for Simulation One

5.11.1.2 Simulation Two

Simulation Two involved the theoretical development of a large, field-wide methane hydrate accumulation, such as those within the Eileen trend on the North Slope. In this case, the producing wells would be in the hundreds. To develop a gas hydrate production profile, the model developed by Omenihu (1995) was utilized (Figure 18). This numerical simulator uses gas hydrate kinetics combined with gas inflow performance and material balance equations. As in the LBNL model, a layer of gas hydrate is assumed to overlie a free gas zone (however, free gas distribution within the Eileen trend is unknown and expected to be highly compartmentalized).

The economic parameters used were the same as for the pilot project, apart from the fixed opex costs, which in this case were assumed to be $100 million.

At a gas price of $4.00/mbtu the project NPV9 is $1.47 billion. The breakeven gas price is $3.68/mbtu. Once again the project is highly sensitive to gas price (Figure 19).

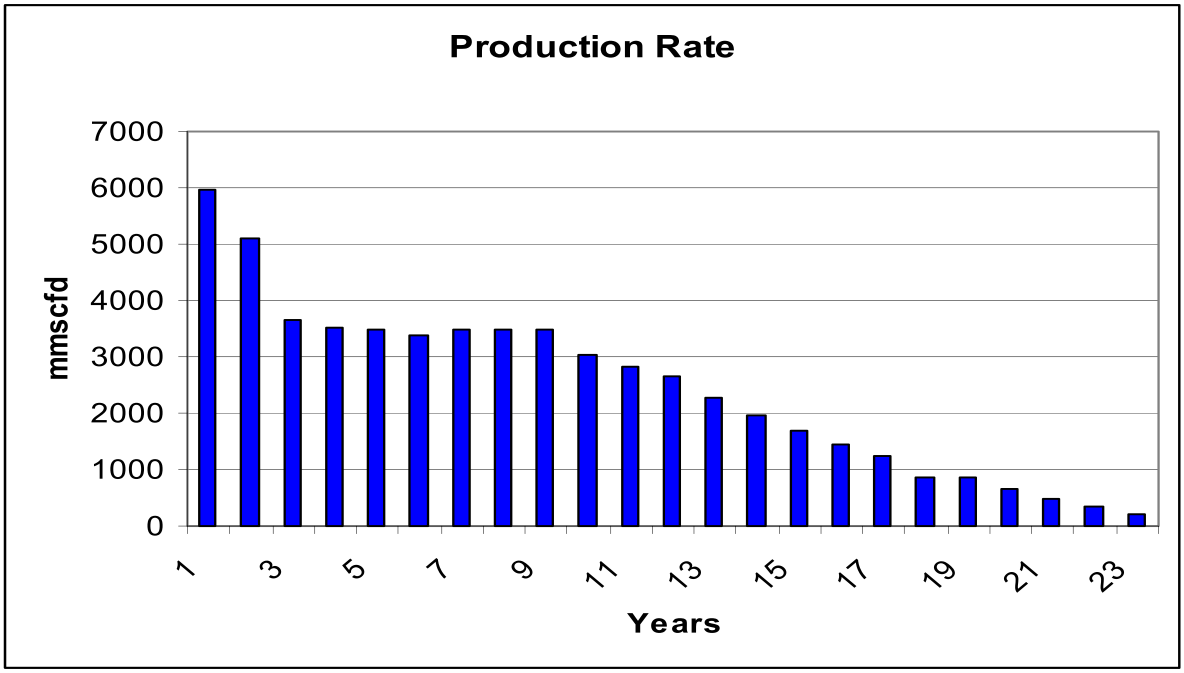

Figure 18: Theoretical Gas Hydrate Production Profile for Simulation Two

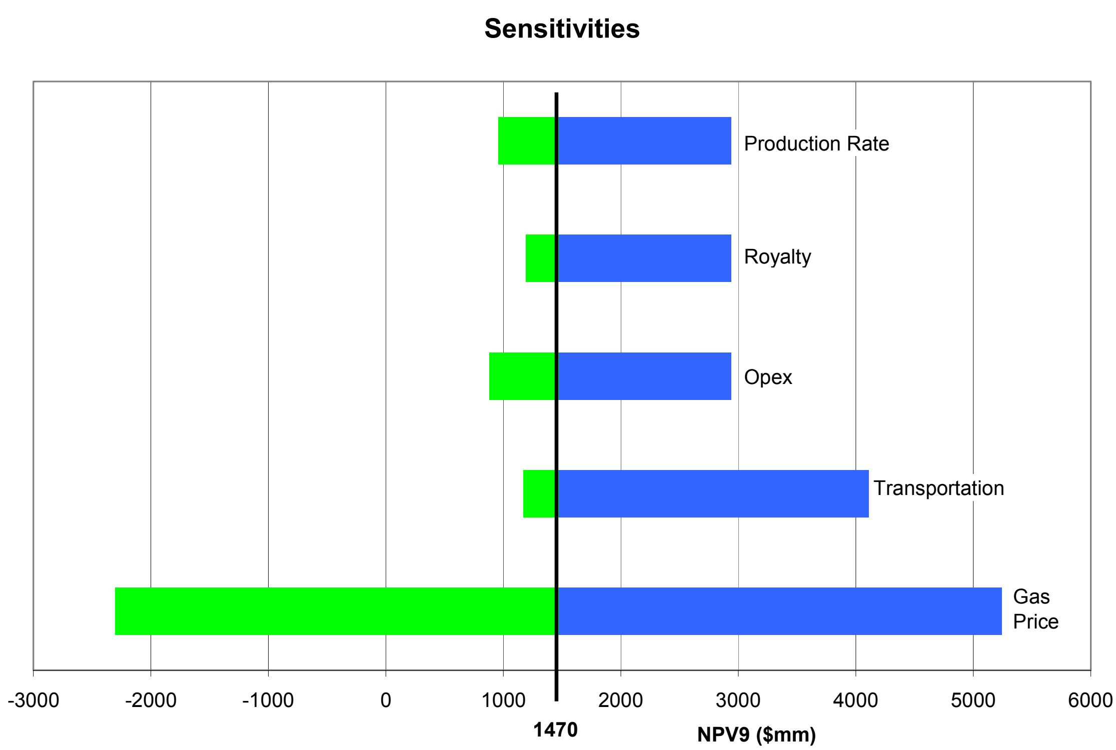

Figure 19: Economic Sensitivities for Simulation Two

5.11.2 Tasks 11 and 13 Future Work

In mid-August, UAF will second one graduate student to Lawrence Berkeley National Laboratory to train in the use of and to help further develop the EORHYD-TOUGH2 numerical simulator. Following this and the receipt of geologic characterization data from University of Arizona, the more specific reservoir and economic modeling for the project can begin.

5.12 TASK 12.0: Select Drilling Location and Candidate – BP, UA

No significant progress was made in this task during the report period.

6.0 CONCLUSION

Interim conclusions only are presented at this stage in the research program. Establishing this collaborative research agreement culminates nearly three decades of hundreds of well penetrations of methane hydrate during oil production operations on ANS following the first dedicated gas hydrate coring and production testing in NW Eileen State – 02, drilled in 1972 within the Eileen gas hydrate trend by Arco and Exxon. During this time, methane hydrates were known primarily as a drilling hazard. Industry has only recently considered the resource potential of conventional ANS gas during industry and government efforts in working toward an ANS gas pipeline. Consideration of the resource potential of conventional ANS gas created the industry – government alignment necessary to also consider the resource potential of the potentially huge (40 – 100 TCF in-place) unconventional ANS methane hydrate accumulations beneath existing production infrastructure. The BPXA – DOE collaborative research project is designed to enable industry and government to make informed decisions regarding the resource potential of this ANS methane hydrate through the first-ever regional shallow reservoir and fluid characterization utilizing 3D seismic data, implementation of methane hydrate experiments, and design of techniques to support potential methane hydrate drilling, completion, and production operations.

The results of the collaborative BPXA-LBNL pre-Phase 1 scoping reservoir model and economics study (presented in the March 2003 Quarterly report) demonstrate first-ever potential commerciality of gas production from gas hydrate across a broad regional contact from adjacent free gas depressurization. This collaborative research project will verify the size of the potential resource, determine the extent of reservoir/fluid compartmentalization, and validate potential production techniques.

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7.5 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.

8.0 LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Denotation
2D	Two Dimensional (seismic or reservoir data)
3D	Three Dimensional (seismic or reservoir data)
AAPG	American Association of Petroleum Geologists
AETDL	Alaska Energy Technology Development Laboratory
ANL	Argonne National Laboratory
ANN	Artificial Neural Network
ANS	Alaska North Slope
AOGCC	Alaska Oil and Gas Conservation Commission
AVO	Amplitude versus Offset (seismic data analysis technique)
ASTM	American Society for Testing and Materials
BLM	U.S. Bureau of Land Management
BP	British Petroleum (commonly BP Exploration (Alaska), Inc.)
BPXA	BP Exploration (Alaska), Inc.
DOI	U.S. Department of Interior
DGGS	Alaska Division of Geological and Geophysical Surveys
DNR	Alaska Department of Natural Resources
EM	Electromagnetic (referencing potential in-situ thermal stimulation technology)
GEOS	UA Department of Geology and Geophysics
GOM	Gulf of Mexico (typically referring to Chevron Gas Hydrate project JIP)
GR	Gamma Ray (well log)
GSA	Geophysical Society of Alaska
HP	Hewlett Packard
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
KRU	Kuparuk River Unit
LBNL	Lawrence Berkeley National Laboratory
MGE	UA Department of Mining and Geological Engineering
MPU	Milne Point Unit
NETL	National Energy Technology Laboratory
ONGC	Oil and Natural Gas Corporation Limited (India)
PBU	Prudhoe Bay Unit
PNNL	Pacific Northwest National Laboratory
Sag	Sagavanirktok formation
SPE	Society of Petroleum Engineers
TCF	Trillion Cubic Feet of Gas at Standard Conditions
TCM	Trillion Cubic Meters of Gas at Standard Conditions
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
VSP	Vertical Seismic Profile

9.0 APPENDICES

9.1 APPENDIX A: Project Task Schedules and Milestones

9.1.1 U.S. Department of Energy Milestone Log

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

Identification Number	Description	Planned Completion Date	Actual Completion Date	Comments
Task 1.0	Research Management Plan	12/02	12/02	Subcontracts Completed
Task 2.0	Provide Technical Data and Expertise	MPU: 12/02 PBU: 6/03* KRU: unk*	MPU: 12/02 PBU: * KRU: *	Ongoing, See Technical Progress Report Description
Task 3.0	Wells of Opportunity Data Acquisition	Ongoing to 12/03-10/04**	Ongoing	Ongoing, See Technical Progress Report Description
Task 4.0	Research Collaboration Link	Ongoing to 12/03-10/04**	Ongoing	Ongoing, See Technical Progress Report Description
Subtask 4.1	Research Continuity	Ongoing	Ongoing	
Task 5.0	Logging and Seismic Technology Advances	Ongoing to 12/03-10/04**		Ongoing, See Technical Progress Report Description
Task 6.0	Reservoir and Fluids Characterization Study	10/04**		Interim Results to also be presented
Subtask 6.1	Characterization and Visualization	10/04**		Interim Results to also be presented
Subtask 6.2	Seismic Attributes and Calibration	10/04**		Interim Results to also be presented
Subtask 6.3	Petrophysics and Artificial Neural Net	10/04**		Interim Results to also be presented
Task 7.0	Laboratory Studies for Drilling, Completion, Production Support	6/04**		
Subtask 7.1	Characterize Gas Hydrate Equilibrium	6/04**		
Subtask 7.2	Measure Gas-Water Relative Permeabilities	6/04**		
Task 8.0	Evaluate Drilling Fluids	6/04**		
Subtask 8.1	Design Mud System	11/03		
Subtask 8.2	Assess Formation Damage	5/04**		

Task 9.0	Design Cement Program	10/04**		
Task 10.0	Study Coring Technology	2/04**		
Task 11.0	Reservoir Modeling	10/04**		Interim Results to also be presented
Task 12.0	Select Drilling Location and Candidate	10/04**		
Task 13.0	Project Commerciality & Progression Assessment	10/04**		Interim Results to also be presented

* Date estimate dependent upon industry partner agreement for seismic data release

** Anticipated completion dates beyond 12/31/03 will require no-cost (and possibly some-cost) time-extension to complete 2-year Phase 1 program

9.1.2 U.S. Department of Energy Milestone Plan

(DOE F4600.3)