Oil and Natural Gas Technology

Cooperative Research Agreement (CRA) Award Number DE-FC-01NT41332

2Q2008 – 3Q2008 Semi-Annual Progress Report

Twenty-Third and Twenty-fourth Quarterly Report: March 2008 – September 2008

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

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Prepared for:
United States Department of Energy (DOE)
National Energy Technology Laboratory (NETL)

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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 economically 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 trend 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). This research indicated sufficient potential for technical recovery and culminated in the drilling and acquisition of significant log, Modular Dynamics Testing (MDT), and core data in the Mount Elbert #1 Stratigraphic Test well within the MPU.

Demonstrated technical success and data interpretation improved understanding of uncertainties, validated reservoir production simulations, and led to a recommendation by the project technical team, DOE, and USGS to drill and complete a long-term production test within the ANS infrastructure area. If approved by stakeholders, this long-term 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.

Long-term production testing is not currently approved, although potential designs and sites are under evaluation which 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 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. Results might also 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 and maintain industry interest in the resource potential of shallow natural gas hydrate accumulations. DOE 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 execution for successful 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 Alaska 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 the MDT wireline testing program. 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). Steve Hancock and Scott Wilson also lead preliminary production test design planning. Dr. Shirish Patil and Dr. Abhijit Dandekar have maintained the University of Alaska (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 trend ANS Sagavanirktok formation gas hydrate-bearing reservoir sands.

Current related studies of gas hydrate resource potential are too numerous to mention here. National Labs studies include Dr. Pete McGrail, CO_2 Injection, 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 contributing significantly 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 PROJECT INTRODUCTION

The Cooperative Research Agreement (CRA) between BP Exploration (Alaska), Inc. (BPXA) and the U.S. Department of Energy (DOE) helps characterize and assess Alaska North Slope (ANS) methane hydrate resources and identify technical and commercial factors that could enable government and industry to understand the future development potential of this unconventional energy resource. Results of Phase 1-2 reservoir characterization, reservoir modeling, regional schematic modeling, and associated studies culminated in approval to proceed into a Phase 3a stratigraphic test to acquire data to help mitigate potential recoverable resource uncertainty. Future Phase 3b production testing is a key goal of the Federal Research and Development program and may follow, but this remains under evaluation and is not approved at this time.

Current research partners include the U.S. Geological Survey (USGS), ASRC Energy Services, Ryder Scott Co., RPS Engineering, University of Alaska Fairbanks (UAF), Oregon State University, Texas A&M University, Colorado School of Mines (CSM), and OMNI Laboratory. UAF participation is enabled through the DOE Arctic Energy Office. Additional collaborative research is not reported here, but includes Lamont-Dougherty Earth Observatory (LDEO), National Research Council Canada (NRCC), Lawrence Berkeley National Lab (LBNL), Pacific Northwest National Laboratory (PNNL), and others. A major effort to publish the Stratigraphic Test results and data analyses in the Journal of Marine and Petroleum Geology is in-progress.

Methane hydrate may contain a significant portion of world gas volumes within offshore and onshore arctic regions petroleum systems. In the United States, accumulations of gas hydrate occur within pressure-temperature stability regions in both offshore and also onshore near-permafrost regions. USGS probabilistic estimates indicate that clathrate hydrate may contain a mean of 590 TCF in-place ANS gas volume (Figure 1). Over 33 TCF in-place potential gas hydrate resources are interpreted within shallow sand reservoirs beneath ANS production infrastructure within the Eileen trend (Figure 2). Gas hydrate accumulations require the presence of all petroleum system components (source, migration, trap, seal, charge, and reservoir). 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 trend favorably combines these factors. The information and technology being developed in this onshore ANS program will be an important component to assessing the possible productivity of the potentially much larger marine hydrate resource. Although the technical recovery has been modeled for the ANS and proven possible in short-term production testing at the Mallik site in Canada in 2007-2008, the economic viability of gas hydrate production remains unproven.

Potential productivity of natural methane hydrate within ANS shallow sand reservoirs was confirmed by data acquired in the Northwest Eileen State-02 well, drilled in 1972. Although up to 100 TCF in-place gas may be trapped within the gas hydrate-bearing formations beneath existing ANS infrastructure, it has been primarily known as a shallow gas drilling hazard to the hundreds of well penetrations targeting deeper oil-bearing formations and has drawn little resource attention due to no ANS gas export infrastructure and unknown potential productivity. Characterization of ANS gas hydrate-bearing reservoirs and improved modeling of potential gas hydrate dissociation processes led to increasing interest to study gas hydrate resource and production feasibility.

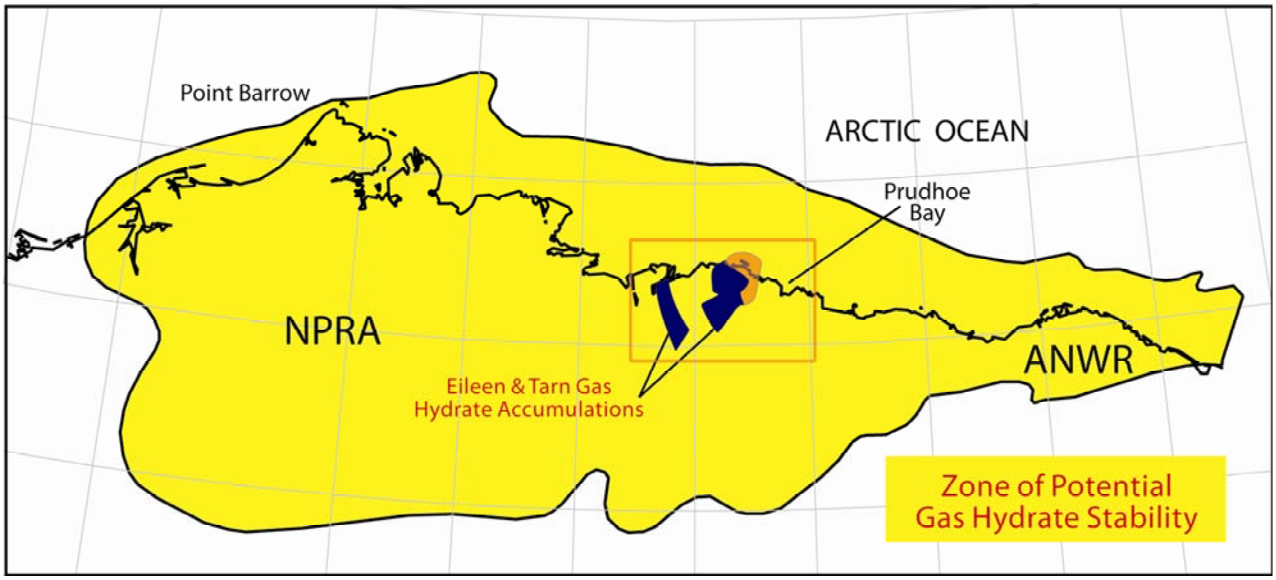

Figure 1: ANS gas hydrate stability zone with Eileen and Tarn gas hydrate trends (Collett, 1993).

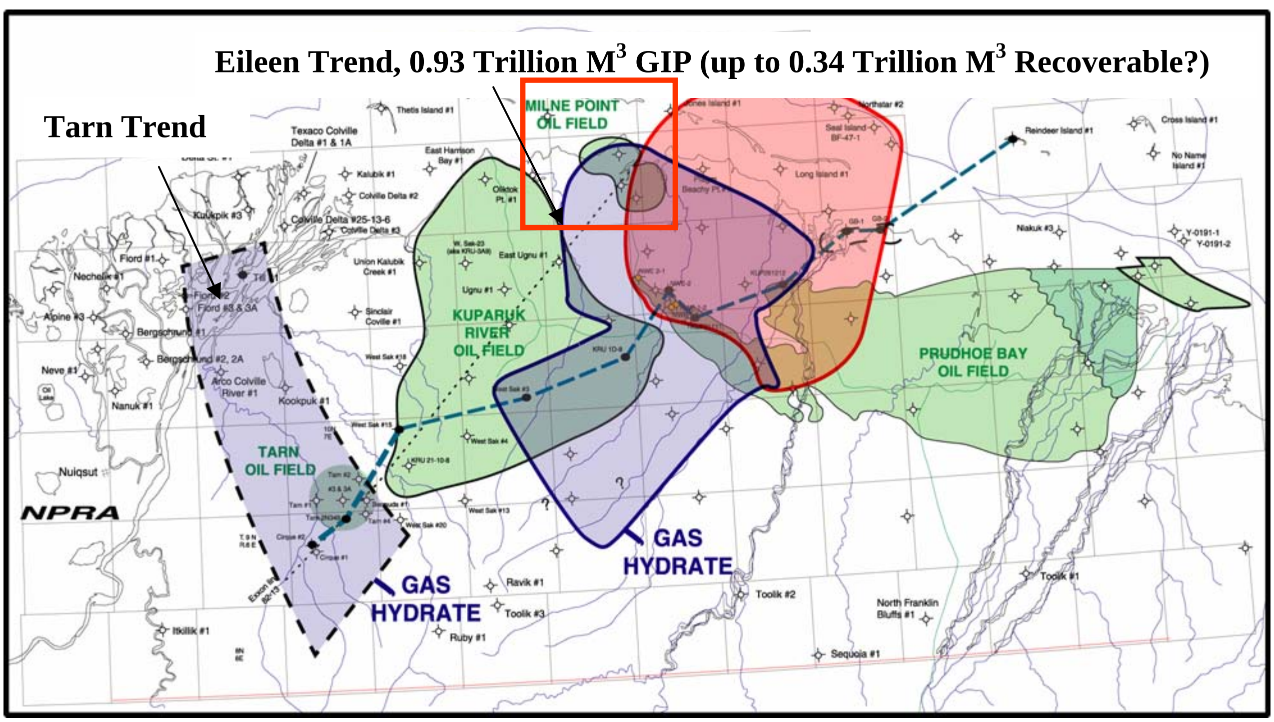

Figure 2: Eileen and Tarn Gas Hydrate Trends and ANS Field Infrastructure (modified after Collett, 1998) and including potential Eileen trend gas-in-place (GIP) and recoverable resource.

As part of a multi-year effort to encourage these feasibility studies, the DOE also supports significant laboratory and numerical modeling efforts focused on the small scale behaviors of gas hydrate. Concurrently, the USGS has assessed the potential in-place resource potential and participated in field operations with DOE and others to acquire data within many naturally occurring gas hydrate accumulations throughout the world. There remain significant challenges in quantifying the fraction of these in-place resources that might become a technically-feasible or possibly a commercial natural gas reserve. In an effort to estimate ANS gas hydrate resource potential within the Eileen trend, this study recommends and implements additional research, data acquisition, and field operations.

Past unconventional resource research and development has been commonly hindered by a lack of proven positive examples necessary before generating stand-alone interest from industry. This was true for tight gas resources in the 1950-1960's, Coal-Bed-Methane plays in the 1970-1980's and the 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, Phase 2 gas hydrate reservoir modeling efforts were coupled with a series of regional schematic models to quantify a suite of potential recoverable resource outcomes and Phase 3a stratigraphic test data acquisition helped mitigate gas hydrate-bearing reservoir uncertainty and validate numerical model results.

Phase 2 regional schematic modeling scenarios indicated that up to 12 TCF gas may be technically recoverable from 33 TCF in-place Eileen trend gas hydrate beneath ANS industry infrastructure within the Milne Point Unit (MPU), Prudhoe Bay Unit (PBU), and Kuparuk River Unit (KRU) areas. 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 (typical industry forecasts would not exceed 50 years). The downside case envisioned research pilot failure and economic or technical infeasibility. Upside cases identified additional potential recoverable resource. Phase 2 studies included rate forecasts and hypothetical well scheduling, methods typically employed to evaluate potential conventional large gas development projects. This work helped quantify: 1. Potential to technically produce gas from 33 TCF GIP Eileen trend gas hydrate resource using conventional petroleum technologies and 2. Up to 12 TCF possible recoverable resource based on potential future development schemes.

Phase 2 studies culminated in recommendations to acquire Phase 3a reservoir data including extensive core, wireline log, and MDT data within the Mount Elbert intra-hydrate MPU prospect interpreted from the Milne 3D seismic survey (Figure 3). Successful Phase 3a MountElbert-01 stratigraphic test drilling and data acquisition was completed between February 3-19, 2007. Significantly, this well effectively proved the ability to safely conduct drilling, completion, and testing operations within the hydrate-bearing formations. Demonstrated 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 4). 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 in Canada in 2007-2008, the economic viability of gas hydrate production remains unproven. Additional static data acquisition and possible future production testing could help validate whether or not these reference and upside model results might occur in a future potential development using depressurization-induced, thermally enhanced, and/or chemically stimulated dissociation of gas hydrate into producible gas. Modeled production methods involve subsurface depressurization and/or thermal stimulation of pore-filling gas hydrate into gas and water components.

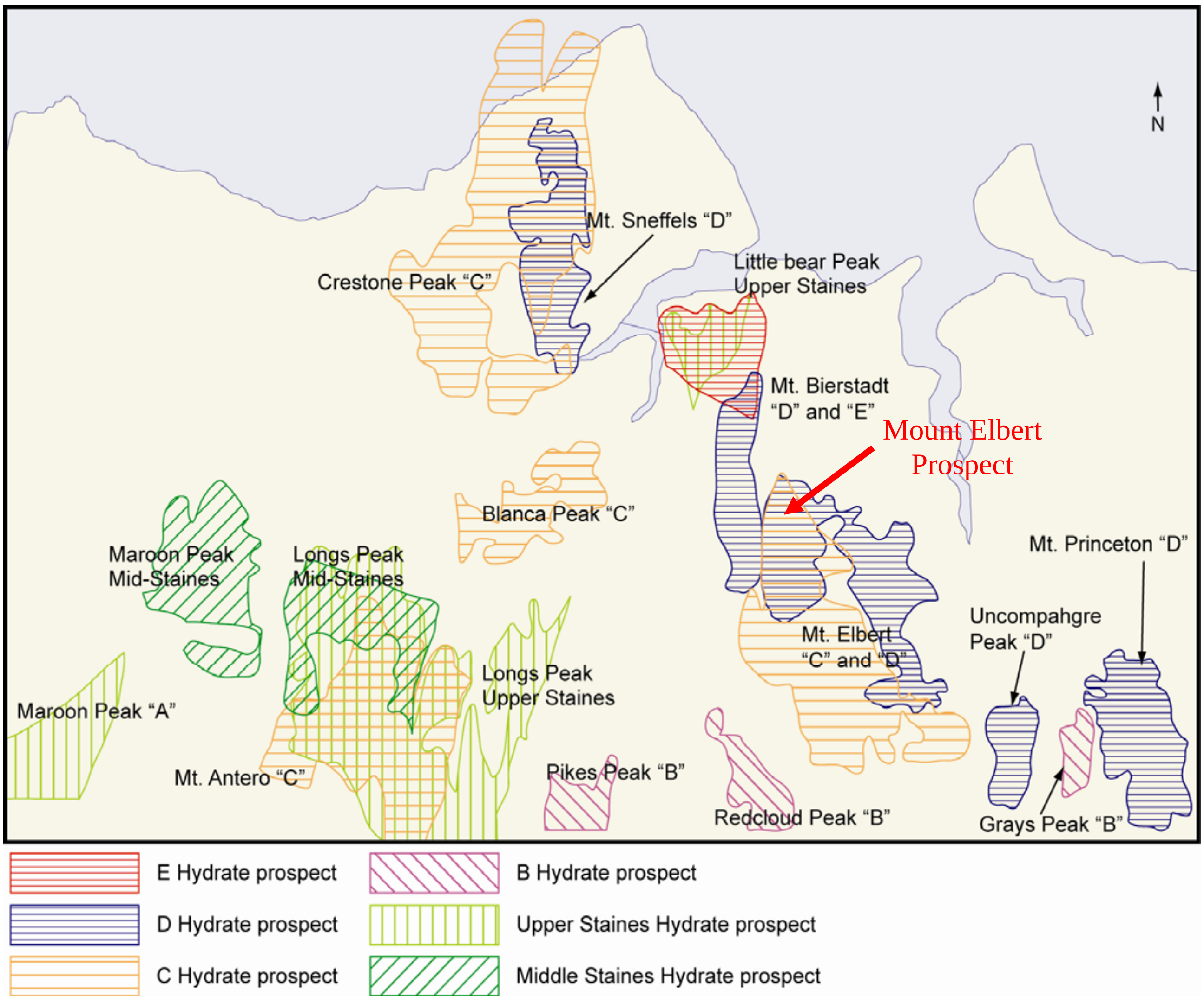

Figure 3: MPU gas hydrate prospects interpreted from Milne 3D seismic data, including Mount Elbert (Inks, T., Lee, M., Taylor, D., Agena, W., Collett, T. and Hunter, R., in press).

Long-term production testing is not currently approved, although implementation of the potential 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 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. Results might also help determine the resource potential of offshore gas hydrate resources in the GOM and in other continental shelf areas.

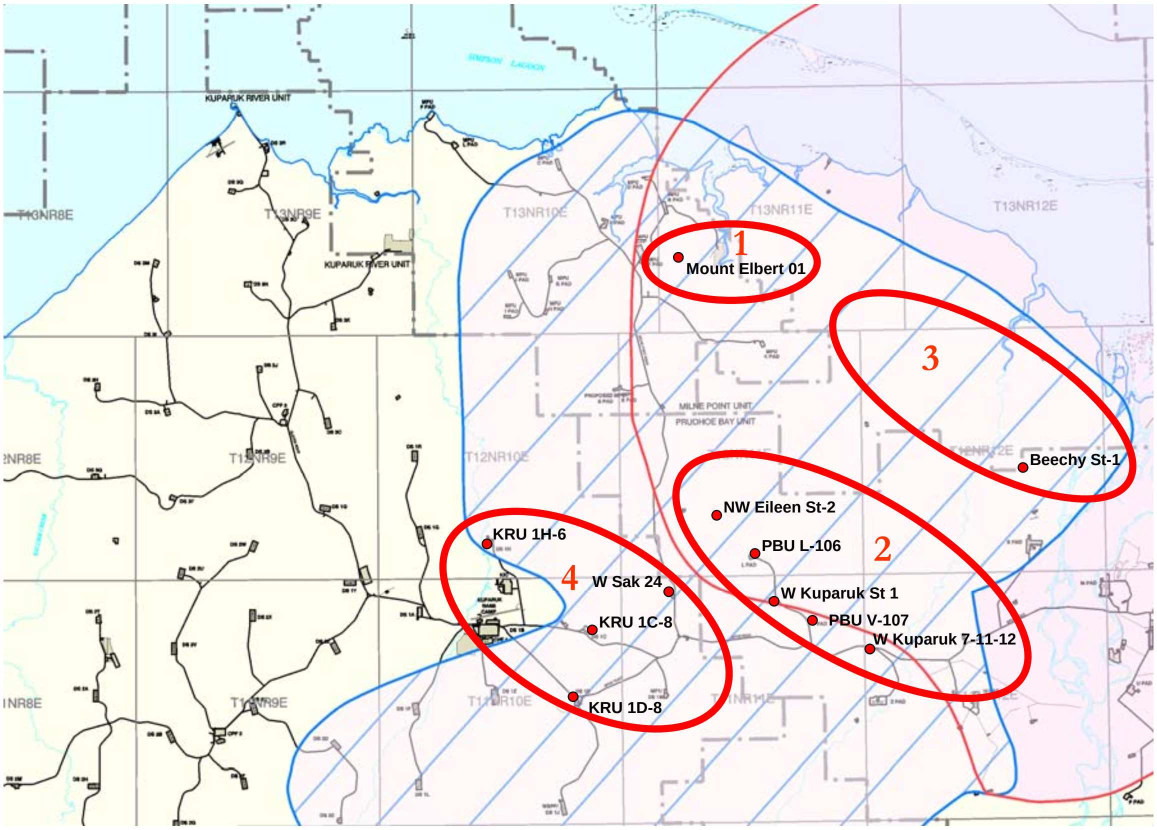

Figure 4: Eileen trend map of composite lateral extent of Sagavanirktok gas hydrate bearing zones A, B, C, D, E, and F (blue with stripes) with 4 areas-of-interest for a potential future production test site.

3.0 REPORT EXECUTIVE SUMMARY

This report documents Phase 3a accomplishments from April 1, 2008 through end-October 2008. Research objectives completed during the reporting period include project communications, Stratigraphic Test data analyses/interpretation, and initial production test design/site evaluation.

4.0 QUARTERLY RESULTS, 2Q08 and 3Q08

4.1 Project Management Summary, 2Q08 and 3Q08

4.1.1 Project External Presentations, Publications, Reporting, and Associated Research

- Prepared and presented project summary and accomplishments to AAPG in San Antonio

- Attended Research Partnership to Secure Energy for America (RPSEA) conference in Anchorage and discussed issues pertaining to gas hydrate
- Reviewed and edited CSM manuscript proposed for Elsevier Journal of Energy Economics
- Reviewed and edited Canadian preprint "Energy from Gas Hydrates, Assessing the Opportunities and Challenges for Canada"
- Reviewed contributions and attended 6th International Conference on Gas Hydrate (ICGH)
    - Attended conference presentations, poster sessions, and events
    - Discussed research perspectives and resource potential with attendees
    - Summarized studies, actions, and potential impacts to ANS research (Section 4.1.5)
- Responded to media inquiries from Environmental Science and Technology and others
- Reviewed, provided input to, and solicited team input to external publication plans proposed for Journal of Marine and Petroleum Geology (Section 4.1.6)
    - Edited regional development scenario reservoir modeling studies from 2006 report
    - Reviewed and edited reservoir modeling publication drafts
    - Prepared draft introductory materials
- Prepared abstract, bios, and poster for Northern Oil and Gas Conference, Anchorage

4.1.2 Project Internal Communications and Reporting

- Maintained, updated, and checked consistency of financial reports 2Q05 through present
- Reviewed, tracked, and categorized project invoices and accounting
- Prepared and submitted project accrual, financial, and semi-annual technical reports
- Prepared DOE Advisory Committee materials for BP representative (Digert) presentation
- Updated documents for project progression discussions and determination
    - Clarified project internal expectations in preparation for Continuation Application
    - Executed contract amendments and extensions through end-2008
- Helped coordinate ANS Joint Industry Participating (JIP) study preparations within CRA
    - Reviewed draft JIP documents and provided scope and project background input
- Participated in progress teleconferences with management and technical team leads
    - Summarized teleconferences and provided notes and actions to team as-needed
- Recommended objectives, participants, and disciplines for BP gas hydrate workshop

4.1.3 Stratigraphic Test Data Analyses

- Reviewed 2007-2008 Mallik production test documents and impact to Alaska project plans
- Setup UAF minipermeameter study for Mount Elbert core study
    - Tabulated and checked validity of UAF minipermeameter feasibility study
    - Developed minipermeameter apparatus and procedure to minimize core disturbance
- Maintained project files, correspondence files, and computer backup files
- Edited and finalized March workshop notes summarizing Phase 3a data analyses
    - Forwarded notes to workshop participants for information and action
    - Reviewed, resolved, and scheduled completion of identified workshop actions
- Reviewed ORNL images of Mount Elbert-01 core samples and provided recommendations
- Reviewed and forwarded Mount Elbert-01 USGS Palynology report (Section 4.2)
- Provide drilling mud properties to Dr. Sun for EPT analyses (Section 4.3)
- Prepared for Mount Elbert core sedimentology and core placement review (K. Rose lead)
- Updated core sample tracking and analyses status with collaborating scientists/agencies

4.1.4 Production Test Preliminary Planning

- Reviewed gas hydrate production test DOE solicitation and discussed with stakeholders
- Reviewed synergies with Cold Heavy-Oil Production with Sand (CHOPS) technologies
- Edited and finalized March workshop notes summarizing Phase 3b preliminary test design
- Reviewed gas hydrate geomechanical studies and recommended inclusion for Phase 3b
- Setup procedures for Isotech Laboratory analyses of additional PBU hydrate gas analyses

4.1.5 ICGH Synergies, Actions, and Applications

4.1.5.1 Potential Research Synergies and Actions Identified from ICGH

1. Review Canada Commission report and issues in-common with Alaska
2. Complete detailed review of 2007-2008 Mallik reports (and 2007 report). Recognize lessons-learned such as sand control, downhole equipment placement, downhole induction heater, downhole pump, and other technologies
3. Evaluate horizontal production modeling options and recognize potential benefits
4. Consider contacting Virginia Walker to determine if any Antifreeze Proteins (AFP) tests exist for porous media
5. Consider contacting Professor Jayasinghe, University of Calgary, for geomechanics investigations (referenced by Dr. Pooladi-Darvish)
6. Ensure NRCC has Mount Elbert-01 XRD and clay data for studies on CH_4 and Cl-
7. Determine availability of detailed plots presented for 2007 and 2008 Mallik gas and water production and data. These data and plots would be useful for calculation of potential gas/water rates for design of fluid handling requirements for potential production testing operations in Alaska. Any indications on amounts of solids handled would also be useful.
8. Evaluate Poster 243, Fluid flow through heterogeneous gas hydrate-bearing sand, observations using X-Ray CTscanning, Y. Seol, Tim Kneafsey
9. Ask Laura Stern to post USGS SEM photos on Alaska project ftp site showing pore-filling, small veins, and “pods” in Mount Elbert samples.
10. Evaluate Poster 302 for theory of potential microfracture likely initiated with dissociation of gas hydrate which might create and sustain flow conduits to enhance gas flow during production. Discuss this further with team; JOGMEC-authored poster. Note history match of 2007-08 Mallik tests required creating such a high-permeability conduit.
11. Evaluate Poster 262 where graduate student lab study noted CO_2 hydrate significantly more stable with small amounts of SO_2 impurities. Solutions with 1% SO_2 and 1% NO_2 were evaluated in this study (resource assessment or field-scale injection beyond study scope).
12. Consider contacting Richard Birchwood, Schlumberger Houston, for possible further discussion of geomechanical aspects of hydrate, Poster 264
13. Evaluate Poster 266, Heriot Watt University, Yang, et al. Clays promote gas hydrate growth in sediments. This research may be applicable to Mount Elbert sediment/clay analyses. Smectite versus Kaolinite strains react very differently. Stronger deformation with smectite-associated hydrate.
14. Evaluate Poster 233, LBNL, horizontal well application and followup with George Moridis to evaluate progress in horizontal well simulations and assessment of Alaska application.

4.1.5.2 Selected ICGH quotes applicable to production test research and design

These quotes were compiled by R. Hunter from personal notes taken during public ICGH presentations. Any errors or omissions are the sole responsibility of R. Hunter.

1. **Colette Reynolds**: "… solution that is sustainable, environmentally responsible, safe, and commercial. Rates must be competitive. Production technology … issues of water production and sand control. Stress need investments from governments."
2. **Roy Hyndman**: "Rough estimate that $2Bbn spent in last 10 years on worldwide gas hydrate R&D. This is ripe time to determine if gas hydrate can become a part of the global energy resource portfolio. Real world petroleum systems are very complex; gas hydrate petroleum systems are very complex."
3. **John Grace**: "Industry must be engaged if gas hydrate is to be developed (Canada experience in Alberta oil-sands). Seek government-industry partnerships; if wait on industry, nothing is going to happen."
4. **Scott Dallimore, Mallik 2007-2008 programs**: "gas hydrate occurrence is lithologically controlled, in sand reservoirs bounded by non-gas hydrate-bearing silts and clays. 2007 Mallik test employed an inverted ESP pump with shroud beneath perforations (sand control issue here with poor pump placement). Sand production was problematic. Chose too-complicated completion scheme. 2008 program changed to ESP pump above perforations, using some sand screens and a bottom hole induction heater. 2008 rates complex with instantaneous rate calculations of 1800-2100 m^3 per day (0.063 – 0.074 MMCF/d). Cumulative production 12,000 – 13,000 cubic meters gas (0.423 – 0.459 MMCF). Water production was much less than predicted: 25-75 cubic meters/day. Temperature change mimicked flow response. Sand control worked in 2008 with robust rates over 6-day testing. Proof of concept achieved a continuous, even 'boring' reservoir response that validated production models. We are closer to showing gas hydrate can become an energy reserve. Completions: elegance is simplicity."
5. **Tim Collett, India program:** Next steps following the initial 2006-07 exploration program is government-industry integrated R&D with goal to establish development testing program as a necessary precursor to demonstrate commercial production potential. Key is gas hydrate petroleum system concept. Exploration aspect leading to production testing leading to pilot program. Long-term testing is key goal, likely in arctic regions first. Cost of India program: $23MM including mobilization; $36MM including all demobilization costs.

4.1.5.3 Selected ICGH notes applicable to production test research and design

These notes were compiled by R. Hunter from personal notes taken during public ICGH presentations. Any errors or omissions are the sole responsibility of R. Hunter.

1. **Virginia Walker, inhibitor molecules**. Antifreeze proteins (AFP) used as hydrate inhibitor. Question if cost and availability of AFP in large enough volumes to potentially be considered for application to a stimulation or hydraulic fracture program, which might help induce and maintain hydrate dissociation. However, there seemed to be an effect causing bounding of AFP to grain surfaces, which might reduce relative permeability in porous media; lab testing would be needed to see if this effect might adversely impact fluid mobility. Much uncertainty exists when transfer technology from lab to field operations and into porous media.

2. **Kasumi Fujii, Japan assessments and plans.** Plan for offshore Japan production testing in 2009-11 timeframe. Plans call for 2012-16 definition of commercialization. Mallik 2007 rates 830 m^3 (0.03 MMCF/d), 0.5 days, 8000m^3/d (0.28 MMCF/d) maximum, 1600m^3/d (0.056 MMCF/d) average. Mallik 2008 average rate 2000-4000m^3 (>13,000m^3 cumulative production over 6-day testing (similar to Dallimore numbers above). Project manager Koji Yamamoto available if need further details. Downhole fiber-optics-based Distributed Temperature Sensor (DTS) very valuable tool for operations, feedback to production testing and analyses.
3. **Kurihara-san, reservoir modeling of 2007-2008 Mallik.** 2007 results noted significant pump temperature increases, likely associated with partial plugging of pump with sand; therefore, pump rates are unreliable. Noted no sand protection in 2007 program and forced to stop pump 3 times during short production testing. Noted 6,500-8,000 m^3/d gas with 10-200 m^3/d water. Note that a high-permeability conduit had to be created for model to match observed production rates (this might be natural wormhole stimulation with depressurization and sand production?). Consider designing an ANS simulation with a permeability conduit of this nature; however, note that Mallik temperatures in producing interval were near base gas hydrate stability zone at 10-12^o C; also note that cannot lift much sand with just gas and water, unlike viscous oil CHOPS process. During 2007 testing, noted that radius of gas hydrate dissociation was 7-10 meters out and 1 meter above and below perforated interval. This points to need for geomechanics studies and what expected radius might be with a longer-term production test.
4. **J. Rutqvist, LBNL Geomechanical Modeling and G. Moridis, reservoir simulation**. Combined LBNL's TOUGH+HYDRATE model with FLAC3D geomechanical model for arctic region modeling (also poster 149). Mallik simulation shows depressurization affects first 10 meters of formation in radius from borehole within only 2-days production. After 3 years, model shows 300 meters propagation of pressure front from borehole region. Mount Elbert simulation shows much less dissociation due to the lower (2-4^{o}C) temperatures; however, investigations of up to 800 meter horizontal well show that this may compensate for colder temperatures. For vertical well, Mallik was 7 times rate of Mount Elbert area after 5 years production simulation. Stress evaluation studies show stress response within 3 days for Mallik. However, Mount Elbert stress response was 9 times smaller than Mallik. Strength evaluation studies for Mallik show weakening within 10 days; strength studies for Mount Elbert weakens within 2 months. After 1-year, no discernable difference in strength noted between the 2 arctic sites. Rapid shear failure noted; this would lead to reservoir compaction as function of (initial stress, Poissons ratio, geomechanical properties of gas hydrate-bearing sediments). Shear failure would likely yield sand production; unknown if these LBNL models account for creation of high-permeability conduit (as noted by Kurihara-san above) in order to history-match 2007 Mallik. Shear failure might also enhance production, which might cause the "high-permeability conduit".
5. **Korea gas hydrate program,** KIGAM and KOGAS from 2005-07 acquired 7 km 2D seismic and 400 km^2 3D seismic. Cruise for data in 2007 was based on BSR; 14 sites obtained LWD and 346m core, with 20m pressure core. Plan 2008 3D seismic survey and 2010 second cruise/data acquisition.
6. **Graham Westbrook** reported on British studies of high-resolution 3D seismic of hydrate-bearing fluid escape chimneys in offshore Norway. Increased seismic velocities were noted with velocity pull-ups nearer chimneys. Some carbonate ridges were also noted.

7. **N. Kundu, India program.** Studies suggest role of paleo-gas hydrate as exploration model for free gas. Interesting application of hydrate theory to present day petroleum system offshore India. May see some paleo-indicators such as pore-water freshening, authigenic siderite (working isotopic analyses).
8. **T. Fujii, JOGMEC Japan Nankai Trough Resource Assessment.** 1996 assessment GIP = 164 TCF hydrate + 95 TCF free gas (100 years Japan gas consumption). METI program started in 2001 as 16-year research program. Excellent technical approach presented, probabilistic approach using Monte Carlo and Crystal Ball software with normalized distributions of all inputs to GIP equation. However, method still appears to retain linkage to identification of hydrate-bearing sands above BSR's; the BSR's were mapped and only these areas were used for GRV calculations, so this assessment may be conservative? End result: P90: 10 TCF, P50: 40 TCF, P10: 82 TCF. But this is only for BSR-area of 4,600 km^2 versus whole offshore Japan at 52,000 km^2. They are currently using a 50% recovery factor to calculate "reserves" based on simulations.
9. **Saeki-san, JOGMEC.** High-density/velocity analyses technique developed by JGI partner to JOGMEC. Used 4 indicators: BSR for gas hydrate, turbidite sequence identification from seismic above BSR for reservoir, strong seismic reflections indicate gas hydrate saturation, relatively higher interval velocity indicate gas hydrate. Some exceptions were questioned, such as no BSR at 1 well with gas hydrate.

4.1.6 Thematic Volume Proposal, Journal of Marine and Petroleum Geology

The proposed volume title is "SCIENTIFIC RESULTS OF 2007 USDOE-BP-USGS "MOUNT ELBERT" GAS HYDRATE STRATIGRAPHIC TEST WELL, MILNE POINT, ALASKA NORTH SLOPE"

A special volume has been proposed for *Journal of Marine and Petroleum Geology* (JMPG) to serve as a Scientific Results Volume to report on the February 2007 "Mount Elbert" gas hydrates stratigraphic test well data acquisition and analyses conducted by the USDOE, BP, and the USGS. A webpage for the field program can be found at http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/rd-program/ANSWell/ANSWell_main.html.

The proposed volume will have four guest editors, who will ensure that the work is peer reviewed by project external subject matter experts and otherwise meets the standards of JMPG:

1. Dr. Ray Boswell, U.S. DOE, National Energy Technology Laboratory
2. Dr. Tim Collett, U.S. Geological Survey
3. Dr. Brian Anderson, West Virginia University/NETL-IAES
4. Robert Hunter, ASRC Energy Services, BP Exploration (Alaska), Inc.

The field program at the Mount Elbert site (Milne Point, Alaska North Slope) provided a unique opportunity for the collection and integration of numerous datasets related to the prediction and description of naturally-occurring gas hydrate reservoirs. The field program included a science team drawn primarily from the USGS, BP, DOE-NETL, and Oregon State University, which has been augmented by the collaboration with leading groups worldwide in the post-field-program analyses of data and samples.

The proposed Thematic Volume will provide an opportunity for all the critical science conducted within the project to be presented in one coherent and integrated form. The volume will include approximately 20-30 original scientific research papers (covering the results of the seismic data analysis used to site the well, advanced well log interpretation, the geological, geochemical and petrophysical analysis of sediment core samples, the results of pressure testing of reservoir response, and numerical simulations of potential reservoir productivity) that will be complimented by approximately 5 introductory project review and data synthesis articles that will fully integrate findings across the multiple disciplines.

The final volume length will conform to JMPG guidelines. The publication would also pursue the opportunity for including within the project the capacity to offload project data and tables, both in the form of a data CD to accompany the hard copy volume, and as special web-based data files that can be linked to the web publications.

The proposed time schedule is as follows:

- First submission deadline to guest editors: March 1, 2009
- Completion of initial reviews: May 1, 2009
- Completion of review-revision process: July 1, 2009.
- Appearance on the web: August 15, 2009
- Hardcopy: Jan-Feb, 2010

The proposed outline for articles would be presented in 5 broad categories as follows:

Introductory Materials (Hunter, ed.)

1. R. Hunter (ASRC/BP): Research overview and Stratigraphic Test
2. M. Lee (USGS): 3D seismic analysis of Mount Elbert prospect
3. T. Collett (USGS): Prudhoe Bay regional geologic framework
4. R. Boswell (DOE): Geologic controls of gas hydrate, Milne Point
5. S. Wilson (RyderScott Co.) Regional production modeling

Coring Program (Boswell, ed.)

6. K. Rose (DOE): Core operations and sedimentology
7. B. Winters (USGS): Physical and grain-size properties
8. B. Winters (USGS): Geotechnical behavior
9. T. Lorenson (USGS): Gas geochemistry
10. M. Torres (Oregon St. U.): Pore water geochemistry
11. F. Colwell (Oregon St. U.): Microbial community diversity
12. T. Kneafsey (LBNL): Core disturbance and handling
13. L. Stern (USGS): SEM and XRD imaging and characterization
14. H. Lu (Natural Resources Canada): Characteristics of gas hydrate
15. A. Johnson (UAF): Gas-Water Relative Permeability and other Experiments

Well Logging Program (Collett, ed.)

16. T. Collett (USGS): Operations and core/log data
17. M. Lee (USGS): Data analysis
18. Y. Sun (Texas A&M): High-resolution dielectric properties

19-21: TBD: Advanced log analyses

MDT Program (Anderson, ed.)

22. B. Anderson (West Va. U.): Operations summary and interpretation

23. M. Pooladi-Darvish (U. Calgary): MDT data - implications
24. M. Kurihara (Japan Oil Eng.: MDT/Mallik data findings

Production Modeling (Anderson, ed.)

26. B. Anderson (West Va. U.): Production modeling overview
27. J. Rutqvist (LBNL): Geomechanical system during production testing
28. G. Moridis (LBNL): Evaluation of gas production testing
29. M. White (PNNL): Production of Gas Hydrate using CO_2 Injection

4.2 Mount Elbert-01 Palynology report

The USGS (David Houseknect) sampled Mount Elbert-01 core for palynology study. A report was issued by *Bujak Research International* in July 2008 to document the palynological assemblages and is reproduced with permission of the authors in the Appendix.

4.3 Mount Elbert-01 Status Reports

4.3.1 Mount Elbert-01 EPT Log Status Report

Dr. Yuefeng Sun, Texas A & M University, is completing the EPT and associated log analyses with Dr. David Goldberg. A report is expected 1Q09. A status update abstract is provided and is planned to be presented in poster form at the 2009 Denver AAPG.

4.3.1.1 EPT Study Abstract

High-resolution Dielectric Estimation of Gas Hydrate Amount in the Mount Elbert-01 Gas Hydrate Stratigraphic Test Well, North Slope, Alaska

Sun, Y.[1]; Goldberg D.[2]; Collett, T.[3]; Hunter, R.[4]
(1) Department of Geology and Geophysics, Texas A&M University, College Station, TX.
(2) Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY.
(3) US Geological Survey, Denver, CO.
(4) ASRC Energy Services, BP Exploration (Alaska), Inc., Anchorage, AK.

An electromagnetic propagation tool (EPT), was deployed to measure the dielectric properties, which when combined with density log measurements result in high-resolution (cm-scale) estimates of gas hydrate saturation. In the two massive hydrate zones of more than 20m thick, Zone D (upper) and Zone C (lower), the average in-situ hydrate saturation based on the EPT and density logs is about 65%, ranging from 45% to 90%. In the hydrate Zone D and the upper part of the Zone C, which mostly consist of silty sands and are relatively homogeneous and thick, the dielectric measurements are in good agreement with lower resolution estimates from the combinable magnetic resonance log (CMR). In the lower part of the Zone C, a 1.2-m-thick layer of gas hydrates in clean sands has a hydrate saturation over 75%. This thin hydrate layer is sandwiched above and below by alternating layers of clay and thin hydrate beds with hydrate saturation over 90%. These thin-bedded hydrate layers are usually less than 15-cm thick, whereas the clay layers are about 5-cm thick. In these zones, CMR log underestimates hydrate saturation by three to five times because of the spatial averaging effect of the magnetic resonance tool.

The dielectric measurement interpretations reveal many thin-bedded layers of hydrates at various depths above and below the massive pore-filling hydrate within zones C and D. These layers

range from 30-cm to about 1-m thick and indicate hydrate saturations of 50% to 90%. Comparison of these thin hydrate layers identified using dielectric logs to borehole images from the oil-base microimager (OBMI) allow many of them to be observed. However, thin layer hydrates are not currently interpreted in other logs or from the onsite visual observation of core.

Numerous questions remain regarding the occurrence of high hydrate saturation within thin layers, their variation and interbedding with clays, the associated processes of hydrodynamic formation, and future strategies for assessment of potential reserves. In order to address these questions, as well as assess any influence on future production strategies, the deployment of high-resolution logs such as dielectric, density and imaging tools is strongly recommended for other future gas hydrate wells.

4.3.2 Mount Elbert-01 Microbiology Status Report

Dr. Rick Colwell, Oregon State University, is completing the microbiological analyses. A status progress report update for this work follows.

Microbial communities collected from hydrate-bearing sediments on the ANS were studied to determine how abiotic variables (e.g., grain size, hydrate presence, original depositional environment) may control the type and distribution of microbes in the sediments. The cores were acquired from sub-permafrost, Eocene (35-36 million years ago (MYA)) sediments laid down as a marine transgressive series within which hydrates are believed to have formed 1.5 MYA. Forty samples, eight of which originally contained hydrates, were acquired from 606–666 meter depths. Five samples from drilling fluids acquired from the same depth range were included in the analysis as a control for contamination during the drilling and handling of cores. DNA was extracted from the samples (typically <1 ng DNA/g sediment was recovered) and then amplified using polymerase chain reaction with primers specific for bacterial and archaeal 16S rDNA. Only bacterial DNA amplicons were detected. Terminal-restriction fragment length polymorphism (t-RFLP) was used to measure bacterial diversity in the respective samples. Non-metric multidimensional scaling (NMDS) was then used to determine the abiotic variables that may have influenced bacterial diversity. NMDS analysis revealed that sediment samples were distinct from those obtained from drilling fluids suggesting that the samples were not contaminated by the drilling fluids. All samples had evidence of microbial communities and sample depth, temperature, and hydrate presence appeared to have some influence on community diversity. Samples sharing these environmental parameters often shared common t-RFLP profiles. Further examination of selected samples using clone libraries should help to identify the key taxa present in these unique sediments and yield a better understanding of the biogeochemistry of these gas-bearing systems.

4.3.3 Mount Elbert-01 Pore Water Status Report

Dr. Marta Torres, Oregon State University, is completing the pore water analyses. A status progress report update for this work follows.

The analyses of the pore water samples recovered during the Mount Elbert Stratigraphic Test has been completed. These include major and minor cations (Ba, Fe, Li, Mn, Sr, Ca, K, and Mg); anions (sulfate and chloride); water isotopes (oxygen and hydrogen) and carbon in dissolved inorganic carbon. In addition solid subsamples were sent to W. Winters (USGS) for a complete analyses of the grain size and selected samples were analyzed for carbon (inorganic and organic) and nitrogen. Only sediment samples that were deemed free of oil contamination from the drilling mud were analyzed.

Pore fluid data from Mount Elbert document the importance of acquiring a complete pore water data set in concert with logging data to generate robust estimates of gas hydrate content of permafrost sequences. Both dissolved chloride and the isotopic composition of the water co-vary in gas-hydrate bearing zones, consistent with gas hydrate dissociation during recovery. In this well, gas hydrate saturation values estimated from dissolved chloride agree with estimates of based on logging data when the gas hydrate saturation is higher than 20% of the pore space; however, the correlation is less clear at lower saturation values. Reasons for this discrepancy are still unclear, but may reflect the effect of host sediment on parametization of the gas saturation estimates from logs. The highest gas hydrate saturation in these permafrost regions is clearly associated with reservoir sequences, as expected from theoretical and field observations in marine sediment cores. Gas hydrate, however, also occur in finer-grained lithologies.

4.3.4 Mount Elbert-01 CSM Core Studies Status Report

CSM received 2 core samples with no visually detectable hydrate. CSM performed powder XRD on both cores and found no hydrate peaks; only ice and alumina standard peaks were observed.

With respect to natural hydrates, CSM lab is, as least currently, focused on characterizing the hydrates from within the cores (as accomplished with the NGHP 01 cores) rather than the properties of the sediment comprising the actual core.

CSM has retained the remaining sections of the cores received for possible geologic or petrophysical measurements in the future.

4.3.5 Mount Elbert-01 OMNI Laboratory Core Studies Status Report

OMNI Laboratory is completing conventional and special core analyses as summarized in prior reports. A brief status update follows. The NMR part of the program has been completed and data should be uploaded to the OMNI project website in 4Q08. OMNI is preparing to run the USS gas-water relative permeability measurements on these same 4 plugs and plan to have those results reported by the middle of January 2009.

Once the relative permeability measurements are completed, the samples will have electrical properties determined followed by HgPc at stress. Both the ERP and HgPc work should be completed and reported by May of 2009. There are no current issues with any of the testing; just managing these last 4 plugs with the remainder of the program. Some additional rock mechanics sampling and subsequent geomechanics analysis work may be undertaken as well (W. Winters lead).

4.3.6 Mount Elbert-01 UAF Core Studies Status Report

UAF is working on five core samples; studies in conjunction with CoP Bartlesville Lab are also planned for 4Q08-1Q09. Two of the five samples have been used in UAF experimental work; one of these samples was consumed and remaining core consists of unconsolidated sand. Very delicate core handling procedures were developed to help alleviate concerns that prior experiments were not performed on "native state" core samples. These procedures may help retain the grain structure, permeability, and porosity attributes of the reservoir.

5.0 PROJECT PHASE 3A RESULTS SUMMARY, 1Q07 – 1Q09

A major project milestone was achieved with drilling, data acquisition, and interpretation of the Mount Elbert-01 gas hydrate Stratigraphic Test well. Analyses of well data is expected to be fully completed by end-1Q09 and a summary of Phase 3a results will be provided in the next Semi-annual Progress Report 25-26. The JMPG thematic volume (Section 4.1.6) is planned to formally publicize these results. Prior quarterly progress reports 18-22 provide additional detail.

6.0 STATUS REPORT

6.1 Cost Status

Project cost auditing of the Mount Elbert-01 gas hydrate Stratigraphic Test was completed and documented in the 3Q07 Progress Report 20 and used to prepare contract Amendment 18. Outstanding invoices for Mount Elbert-01 well operations and data acquisition are completed.

Table 1 summarizes project cost status through end-3Q08. Table 2 augments this information and estimates remaining project funds. Project cost-share remains to be updated with in-kind data, staff, and cash contributions for Phase 3a work.

Total Federal Share 2001 to end-3Q08	$9,199,918	Total processed invoices reimbursed
US Treasury Account Balance	**$619,680**	Remaining funds in ASAP Account

Table 1: Project cost status summary through end 3Q-08

Estimated Outstanding Invoices	**$216,838.00**	October – December 2008
Additional Anticipated Invoices	**$231,500.00**	January – March, 2009
US Treasury Account Balance	**$619,680**	(Table 1)
Estimated Remaining Funds end-1Q09	**$171,251.00**	Funds obligated in amendments 18-20

Table 2: Remaining project funds estimate

6.2 Project Task Schedules and Milestones

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

Note that 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
Task 1.0	Research Management Plan	12/02 – 12/04	12/02 and Ongoing	Subcontracts Completed
Task 2.0	Provide Technical Data and Expertise	MPU: 12/02 PBU: * KRU: *	MPU: 12/02 PBU: * KRU: *	See Technical Progress Reports
Task 3.0	Wells of Opportunity Data Acquisition	Ongoing	Ongoing	See Technical Progress Reports
Task 4.0	Research Collaboration Link	Ongoing	Ongoing	See Technical Progress Reports
Subtask 4.1	Research Continuity	Ongoing	Ongoing	
Task 5.0	Logging and Seismic Technology Advances	Ongoing		See Technical Progress Reports
Task 6.0	Reservoir and Fluids Characterization Study	12/04	1/08; awaiting final report	Interim Results presented, 2004 Hedberg Conference
Subtask 6.1	Characterization and Visualization	12/04	1/08; awaiting final report	Interim Results presented, 2004 Hedberg Conference
Subtask 6.2	Seismic Attributes and Calibration	12/04	1/08; awaiting final report	Interim Results presented, 2004 Hedberg Conference
Subtask 6.3	Petrophysics and Artificial Neural Net	12/04	1/08; awaiting final report	Interim Results presented, 2004 Hedberg Conference
Task 7.0	Laboratory Studies for Drilling, Completion, Production Support	6/04	6/04	
Subtask 7.1	Characterize Gas Hydrate Equilibrium	6/04	6/04	Results presented, 2004 Hedberg Conference
Subtask 7.2	Measure Gas-Water Relative Permeabilities	6/04	6/04	Results presented, 2004 Hedberg Conference
Task 8.0	Evaluate Drilling Fluids	12/04		
Subtask 8.1	Design Mud System	11/03		
Subtask 8.2	Assess Formation Damage	9/05	Into Phase 2	
Task 9.0	Design Cement Program	12/04		
Task 10.0	Study Coring Technology	2/04	2/04	
Task 11.0	Reservoir Modeling	12/04	Ongoing task	Interim Results presented, 2004 Hedberg Conference
Task 12.0	Select Drilling Location and Candidate	9/05		Topical Report submitted, June 2005
Task 13.0	Project Commerciality & Phase 2 Progression Assessment	9/05	Redesigned 2005 Phase 2	BPXA and DOE decision

* Date dependent upon industry partner agreement for seismic data release

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

Note that 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
Task 1.0	Research Management Plan	1/05 – 1/06	Ongoing	Subcontracts Completed
Task 2.0	Provide Technical Data and Expertise	MPU: 12/02 PBU: * KRU: *	MPU: 12/02 PBU: * KRU: *	See Technical Progress Reports
Task 3.0	Wells of Opportunity Data Acquisition	Ongoing	Ongoing	See Technical Progress Reports
Task 4.0	Research Collaboration Link	Ongoing	Ongoing	See Technical Progress Reports
Subtask 4.1	Research Continuity	Ongoing	Ongoing	
Task 5.0	Logging and Seismic Technology Development and Advances	Ongoing		See Technical Progress/Topical Reports
Task 6.0	Reservoir and Fluids Characterization Study	12/06	1/08; awaiting final report	
Subtask 6.1	Structural Characterization	12/06	1/08; awaiting final report	
Subtask 6.2	Resource Visualization	12/06	1/08; awaiting final report	
Subtask 6.3	Stratigraphic Reservoir Model	12/06	1/08; awaiting final report	
Task 7.0	Laboratory Studies for Drilling, Completion, Production Support	12/06		Some Hiatus; Phase 2-3a design, studies, & decision
Subtask 7.1	Design Mud System	12/05		
Subtask 7.2	Assess Formation Damage	1/06		
Subtask 7.3	Measure Petrophysical and Other Physical Properties	9/06	Phase 3a	No Samples Acquired; await Phase 3a acquisition
Task 8.0	Design Completion / Production Test for Gas Hydrate Well	4/06	Mt Elbert-01 stratigraphic test	Design of Phase 3a Strat Test operation Complete
Task 9.0	Field Operations and Data Acquisition Program Planning	4/06	Mt Elbert-01 stratigraphic test	Planning for Potential operations underway
Task 10.0	Reservoir Modeling and Project Commercial Evaluation	1/06		Regional Resource Review & Development Planning
Subtask 10.1	Task 5-6 Reservoir models	Ongoing		
Subtask 10.2	Hydrate Production Feasibility	1/06		
Subtask 10.3	Project Commerciality & Phase 3a Progression Assessment	1/06		January 2006 approval for Phase 3a Stratigraphic Test

* Date dependent upon industry partner agreement for seismic data release

6.2.3 U.S. Department of Energy Milestone Log, Phase 3a, 2006-2008

Phase 3a scope-of-work from contract Amendment 11 with additional detail provided in support of Amendments 18 and 20.

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

Identification Number	Description	Planned Completion Date	Actual Completion Date	Comments
Task 1.0	Research Management Plan	1/06 – 10/08	12/08	
Task 2.0	Provide Technical Data and Expertise	MPU: 12/02 PBU: * KRU: *	MPU: 12/02 PBU: * KRU: *	See Technical Progress Reports
Task 3.0	Wells of Opportunity Data Acquisition	Ongoing	As-identified	See Technical Progress Reports
Task 4.0	Research Collaboration Link	Ongoing	Ongoing	See Technical Progress Reports
Subtask 4.1	Research Continuity	Ongoing	Ongoing	
Task 5.0	Logging and Seismic Technology Development and Advances	Ongoing	As-needed	See Technical Progress/Topical Reports
Task 6.0	Reservoir and Fluids Characterization Study	12/07	final report in preparation	University of Arizona contract terminated 12/07
Subtask 6.1	Structural Characterization	12/07	As above	Contract terminated
Subtask 6.2	Resource Visualization	12/07	As above	Contract terminated
Subtask 6.3	Stratigraphic Reservoir Model	12/07	As above	Contract terminated
Task 7.0	Laboratory Studies for Drilling, Completion, Production Support	9/08		UAF contract to 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	Expect 1Q09	
AEO Task 1	Relative Permeability Studies	9/08	Expect 1Q09	
AEO Task 2	Minipermeameter Studies	6/08	Completed	
Task 8.0	Implement completion/production Test for gas hydrate well	3/07	3/07	Stratigraphic Test Well Drilled February 3-19, 2007
Task 9.0	Reservoir Modeling and Project Commercial Evaluation	9/08	Completed	Regional Resource Review & Development Planning
Subtask 9.1	Task 5-6 Reservoir models	9/08	As-needed	
Subtask 9.2	Project Commerciality & Phase 3b Production Test Decision	9/08	In-preparation	Phase 3a analyses and Phase 3b planning/design

* Date dependent upon industry partner agreement for seismic data release

6.2.4 U.S. Department of Energy Milestone Plans

(DOE F4600.3)

DOE F 4600.3#

U.S. DEPARTMENT OF ENERGY FEDERAL ASSISTANCE MILESTONE PLAN: PHASE 1

1. Program/Project Identification No. DE-FC26-01NT41332	2. Program/Project Title Resource Characterization and Quantification of Natural Gas-Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay - Kuparuk River Area on the North Slope of Alaska
3. Performer (Name, Address) BP Exploration (Alaska), Inc., 900 East Benson Blvd, P.O. Box 196612, Anchorage, Alaska 99519-6612	4. Program/Project Start Date 10/22/02* 5. Program/Project Completion Date 12/31/08 (through Phase 3a)

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

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

DOE F 4600.3#

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

1. Program/Project Identification No. DE-FC26-01NT41332	2. Program/Project Title Resource Characterization and Quantification of Natural Gas-Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay - Kuparuk River Area on the North Slope of Alaska
3. Performer (Name, Address) BP Exploration (Alaska), Inc., 900 East Benson Blvd, P.O. Box 196612, Anchorage, Alaska 99519-6612	4. Program/Project Start Date 10/22/02* 5. Program/Project Completion Date 12/31/08 (through Phase 3a)

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

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

DOE F 4600.3#

U.S. DEPARTMENT OF ENERGY FEDERAL ASSISTANCE MILESTONE PLAN: PHASE 3a

1. Program/Project Identification No. DE-FC26-01NT41332	2. Program/Project Title Resource Characterization and Quantification of Natural Gas-Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay - Kuparuk River Area on the North Slope of Alaska
3. Performer (Name, Address) BP Exploration (Alaska), Inc., 900 East Benson Blvd, P.O. Box 196612, Anchorage, Alaska 99519-6612	4. Program/Project Start Date 10/22/02* 5. Program/Project Completion Date 12/31/08 (through Phase 3a)

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

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

DOE F 4600.3# U.S. DEPARTMENT OF ENERGY FEDERAL ASSISTANCE MILESTONE PLAN: DRAFT PHASE 3b (not approved)

1. Program/Project Identification No. DE-FC26-01NT41332	2. Program/Project Title Resource Characterization and Quantification of Natural Gas-Hydrate and Associated Free-Gas Accumulations in the Prudhoe Bay - Kuparuk River Area on the North Slope of Alaska
3. Performer (Name, Address) BP Exploration (Alaska), Inc., 900 East Benson Blvd, P.O. Box 196612, Anchorage, Alaska 99519-6612	4. Program/Project Start Date 10/22/02* 5. Program/Project Completion Date 12/31/10 (through Phase 3b)

6. Identification Task Number	7. Planning Category (Work Breakdown Structure Tasks)	8. Program/Project Duration (Phase 3b, 2009-2010) ←Phase 3a→←Phase 3b Planning→ 3bPlanning→← Phase 3b Implementation → J F M A M J J A S O N D J F M A M J J A S O N D	9. Comments (Primary work Performer)
Task 1.0	Contracts and Research Management Planning	!>>>>>>>>!>--->>>>>--->>>>>>>>>>>>>>>>>>!------------------!--------->>!>>>>>>>>	BP, AES
Task 2.0	Technical Data and Expertise	!->>>>>>>!--->>>>------->>>>>>>>>-------!--->>>>>>>>-------!>>>>>>>-->!>>>>>>--	BP, AES
Task 3.0	Recommend Data Acquisition	!------------>>>>>--------------->>>>---	BP, AES
Task 4.0	Stakeholder Communications	!>>>>>>>>!>>>>>>>>>----------->>>>>>>>>>!>>>>>>>>>>>>>>>>>>!>>>>>>>>>>>!>>>>>>>>	BP, USGS, AES
Task 5.0	Logging/Seismic Technology	!>>>>>>>>!>>--	USGS, BP
Task 6.0	Long-term Production Test Drill, Complete, Test Plan	!------->!>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>!>>>>>>>>>>>>>>>---!------>>>>>!>>>>>>>>	BP, AES
Subtask 6.1	Finalize Test Site Location	!>>>>>>>>!>>>>>>>>>!--	BP, USGS, DOE
Subtask 6.2	Production Test Plan	!------->!>>>>>>>>>->>>----->>>>>>>>>>>>!>>>>>>>>>>>>>>>>>>!>>>>>>>>>>>!>>>>>>>>	RPS, RS, BP, AES
Subtask 6.3	Implement Production Test	!--->>>>>>>!>>>>>>>!>>>>>>>>>>>!>>>>>>>>	RS, RPS, BP, AES
Task 7.0	Reservoir Modeling	!--->>>>>>>!>>>>>>>!>>>>>>>>>>>!>>>>>>>>	RS

10. Remarks * Schedule shows DRAFT Phase 3b in red (not currently approved) with primary objective to complete a detailed design and implement a long-term gas hydrate production test. Explanation of Symbols: >> Major Task Work; -- Minor Task Work; ! Milestone. Note that 2009 Drilling Schedule apparently fully dedicated; 2010 Implementation possible, but not currently approved.

6.3 2Q08 – 3Q08 Reporting Period Significant Accomplishments

Continued analyses of Stratigraphic Test data and actions identified in March project workshop. Continued evaluation, planning, and design of production test site and operations.

6.4 Actual or Anticipated problems, delays, and resolution

Contract Amendment 21 authorized a no-cost extension to complete Phase 3a data analyses and continue Phase 3b planning activities through end-December 2008. A Continuation Application was in-preparation 4Q08, but was delayed to address third-party relations. Another no-cost extension amendment through end-March 2009 will be requested to provide additional time to resolve these issues.

6.5 Project Research Products, Collaborations, and Technology Transfer

6.5.1 Project Research Collaborations and Networks

Project objectives significantly benefit from DOE awareness, support, and/or funding of the following associated collaborations, projects, and proposals:

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 continued into simulation of field-scale gas hydrate bearing reservoirs, to history matching of the Mount Elbert-01 stratigraphic test MDT data, and to evaluation of ANS potential production test options. These studies have facilitated an 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), Pete McGrail (Pacific Northwest National Laboratory), 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, consultant to BP-DOE project), Mehran Pooladi-Darvish and Huifang Hong (University of Calgary and Fekete), Timothy Collett (U.S. Geological Survey), and Robert Hunter (ASRC Energy Services; BP Exploration (Alaska), Inc.).
2. **DE-FC26-01NT41248:** This UAF/PNNL/BPXA study investigated the effectiveness of CO_2 as a potential enhanced recovery mechanism for gas dissociation from methane hydrate. DOE supported this associated project research which may help facilitate a possible future field test of this technology.
3. **UAF/Argonne National Lab project:** This associated project was approved for funding by the Arctic Energy and Technology Development Lab (AETDL) / Arctic Energy Office (AEO), forwarded to NETL for review, and was funded in mid-2004. The project is 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 the ability to maintain the low temperatures of 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 (primary contact Lee Dillenbeck). Although Ceramicrete was not yet 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 2008.

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 indicate possible synergies, particularly regarding potential in-situ reservoir heating. Successful modeling and lab work could potentially proceed into field applications in future gas hydrate 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. If the BP/DOE project proceeds into Phase 3b operations, a thermal component of production testing may be recommended and a 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 have continued from 2004 through present; potential adaptation of this downhole technology for an Alaska North Slope production test is 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 this project 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) indicates a continued interest in the BPXA – DOE research. Dr. Tim Collett, partner in the BPXA-DOE research team, and Ray Boswell, DOE gas hydrate program, led and participated in, respectively, certain aspects of the data acquisition at multiple offshore India field sites. India sent a technical observer to view ANS Phase 3a operations and data acquisition.
8. **Korea gas hydrate research:** Korea is developing a gas hydrate research program. Korea has discussed Alaska gas hydrate research with DOE and USGS. BPXA has not initiated direct contact with Korea, but referred 2007 correspondence to DOE and USGS. Korea gas hydrate program representatives visited UAF in fall 2007.
9. **China gas hydrate research:** China is also developing a significant gas hydrate research program. BPXA has not initiated contact with China, but DOE is collaborating in certain gas hydrate research studies in China.
10. **U.S. Department of Interior, USGS, BLM, State of Alaska DGGS:** An additional collaborative research project under the Department of Interior (DOI) may provide

significant benefits to this project. The BLM, USGS, and the State of Alaska recognize that gas hydrate is potentially a large untapped ANS onshore energy resource. 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) have 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. Information generated from this agreement will help guide these agencies to promote responsible development if this potential arctic energy resource becomes proven. 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 was issued in November 2008 indicating 84 TCF potential recoverable resource.

11. **DE-NT0006553**: ConocoPhillips and DOE initiated a cooperative research agreement in October 2008 to design and field test CO_2 as a potential enhancement to recover gas from CH_4 hydrate-bearing reservoirs beneath ANS industry infrastructure. The goal of this project 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 this initial field trial is successful, the program would help advance the larger-scale, longer-term tests needed to test viable 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 adverse environmental impacts such as water production and subsidence while simultaneously providing a synergistic opportunity to sequester carbon dioxide.

6.5.2 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 and/or chemical 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.

6.5.3 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.

6.5.4 Project Research Publications

6.5.4.1 General Project References

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6.5.4.2 University of Arizona Research Publications and Presentations

6.5.4.2.1 Professional Presentations

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6.5.4.8 Short Courses

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6.5.4.9 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.

7.0 CONCLUSIONS

The first ANS dedicated gas hydrate coring and production testing well, NW Eileen State-02, was drilled in 1972 within the Eileen trend. Since that time, ANS gas hydrates have been known primarily as shallow a drilling hazard to deeper well targets. 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 helped create industry - government alignment necessary to investigate the resource potential of the potentially large (33 to 100 TCF in-place) unconventional ANS methane hydrate accumulations beneath or near existing production infrastructure. Studies show this in-place resource is compartmentalized both stratigraphically and structurally within the petroleum system.

The BPXA – DOE cooperative research agreement enables a better understanding of the resource potential of this ANS methane hydrate petroleum system through comprehensive regional shallow reservoir and fluid characterization utilizing well and 3D seismic data, implementation of methane hydrate experiments, and design of techniques to support methane 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 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 which validates reservoir modeling efforts. 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., in-press). Reservoir modeling also demonstrates this potential as documented in the March 2003 Quarterly report, in the December 2003 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 an intra-hydrate accumulation emphasizes the importance of saturation and permeability as key variables which, when better understood, could help mitigate productivity uncertainty. A schematic potential development screening study was undertaken to set ranges on potential recoverable resources given various possible production scenarios of the ANS Eileen gas hydrate trend, which may contain up to 33 TCF gas-in-place. 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 would 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 development 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.

ANS Phase 3a stratigraphic test field operations enabled acquisition and analyses of critical gas hydrate-bearing reservoir data. Key data acquired included wireline cores, logs, and wireline production (MDT) testing of gas hydrate-bearing reservoir sands and associated sediments. Analyses of the core, log, and MDT results is helping to reduce the uncertainty regarding gas hydrate-bearing reservoir productivity and improve planning of Phase 3b gas hydrate production test studies, although Phase 3b operations are not currently approved.

8.0 LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Denotation
2D	Two Dimensional (seismic or reservoir data)
3D	Three Dimensional (seismic or reservoir data)
AAPG	American Association of Petroleum Geologists
AAT	Alaska Arctic Terrane (plate tectonics)
AGS	Alaska Geological Society
AEO	Arctic Energy Office (DOE AETDL)
AETDL	Alaska Energy Technology Development Laboratory (DOE AEO)
ADEC	Alaska Department of Environmental Conservation
ANL	Argonne National Laboratory
ANN	Artificial Neural Network

ANS	Alaska North Slope
AOGCC	Alaska Oil and Gas Conservation Commission
AOI	Area of Interest
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)
CP	ConocoPhillips (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
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

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)
NETL	National Energy Technology Laboratory
NMR	Natural Magnetic Resonance (wireline or LDD tool – see also CMR)
NRC	National Research Council of Canada
OBM	Oil Based Mud, drilling fluid
ONGC	Oil and Natural Gas Corporation Limited (India)
PBU	Prudhoe Bay Unit
PNNL	Pacific Northwest National Laboratory
POOH	Pull out of Hole; pulling drillpipe or wireline from borehole during operations
POS	Pump-out Sub (pertaining to MDT tool)
SCAL	Special Core Analyses, references analyses beyond basic porosity/permeability
SPE	Society of Petroleum Engineers
TCF	Trillion Cubic Feet of Gas at Standard Conditions
TCM	Trillion Cubic Meters of Gas at Standard Conditions
T-D	Time-Depth (referencing time to depth conversion of seismic data)
UA	University of Arizona (or Arizona Board of Regents)
UAF	University of Alaska, Fairbanks
USGS	United States Geological Survey
USDOE	United States Department of Energy
Vp	Velocity of primary seismic wave component
Vs	Velocity of shear seismic wave component (commonly useful to identify GH)
VSP	Vertical Seismic Profile
WOO	Well-of-Opportunity

9.0 APPENDIX: PALYNOLOGY REPORT

The palynology report, "PALYNOLOGICAL BIOSTRATIGRAPHY OF THE INTERVAL 1990-2484 FT, MOUNT ELBERT 01 WELL, NORTHERN ALASKA" was issued during the reporting period. This report is reproduced here with permission of the author (Bujak Research International (BRI) Limited) and collaborating scientist, David Houseknect (USGS). Due to size constraints, the palynological range charts and correlation diagrams are not reproduced here. Special acknowledgement to David Houseknect for core subsampling, May 2008.

PALYNOLOGICAL BIOSTRATIGRAPHY OF THE INTERVAL 1990-2484 FT, MOUNT ELBERT 01 WELL, NORTHERN ALASKA

FIGURES

PALYNOLOGICAL RANGE CHART IN EXCEL FORMAT
Taxa arranged alphabetically within major palynomorph groups (not reproduced here due to size limitations).

PALYNOLOGICAL RANGE CHART IN STRATABUGS FORMAT
Taxa arranged by highest occurrences (tops) within major palynomorph groups, including gamma and sonic logs, and sequences inferred from the gamma logs and observed palynological zones (see text for details) (not reproduced here due to size limitations).

CORRELATION DIAGRAMS
Correlations are from the Bujak Research 2006 *Azolla* study, plus the Mount Elbert 01 well (see Figure 5 for locations) (not reproduced here due to size limitations).

Correlation 1: Northwest Milne Point 1 / Mount Elbert 01 / Beechey Point State 1 / Abel State 1 / Prudhoe Bay 1 / Foggy Island 1 / West Mikkelsen Bay 1 / Mikkelsen 13-9-19 / East Mikkelsen Bay 1

Correlation 2: Crackerjack 1 OCS-Y-1320 / Popcorn 1 (OCS-Y-1275) / Northwest Milne Point 1 / Mount Elbert 01 / Sandpiper 1 / North Star 1 / Seal Island 2 / Beaufort Block 54 / No Name Island 1 / Salmon 2 / Jeanette Island 1

Correlation 3: Northwest Milne Point 1 / Mount Elbert 01 / Long Island 1 / Sandpiper 1 / North Star 1 / Abel State 1 / Salmon 2 / Duck Island 1 / West Mikkelsen 1

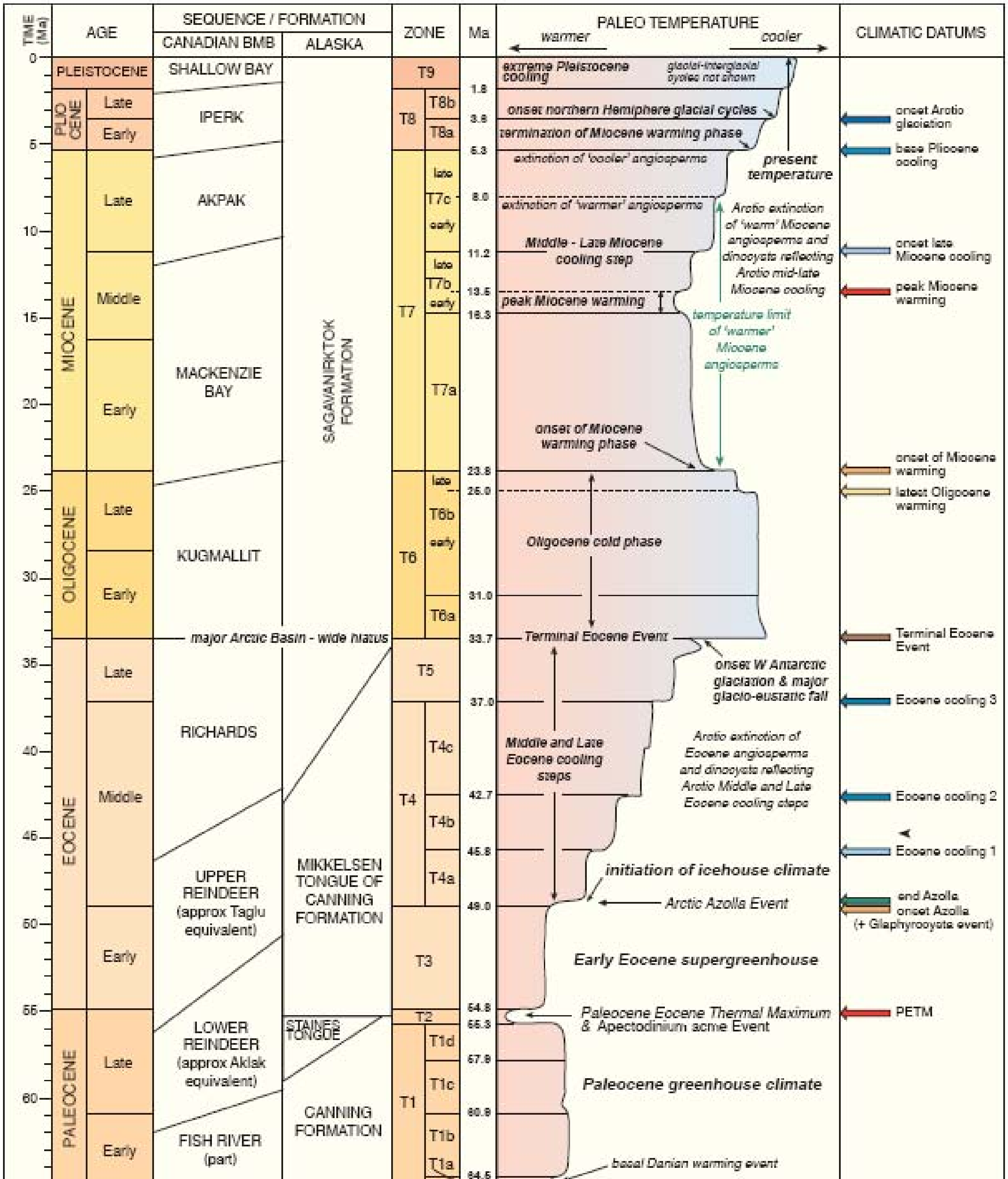

Figure 1. Bujak Research integrated Arctic Cenozoic palynological zones and temperature changes plotted against the northen Alaskan and Beaufort Mackenzie Basin (BMB) lithostratigraphy, regional Arctic sea-surface temperature and climatic datums.

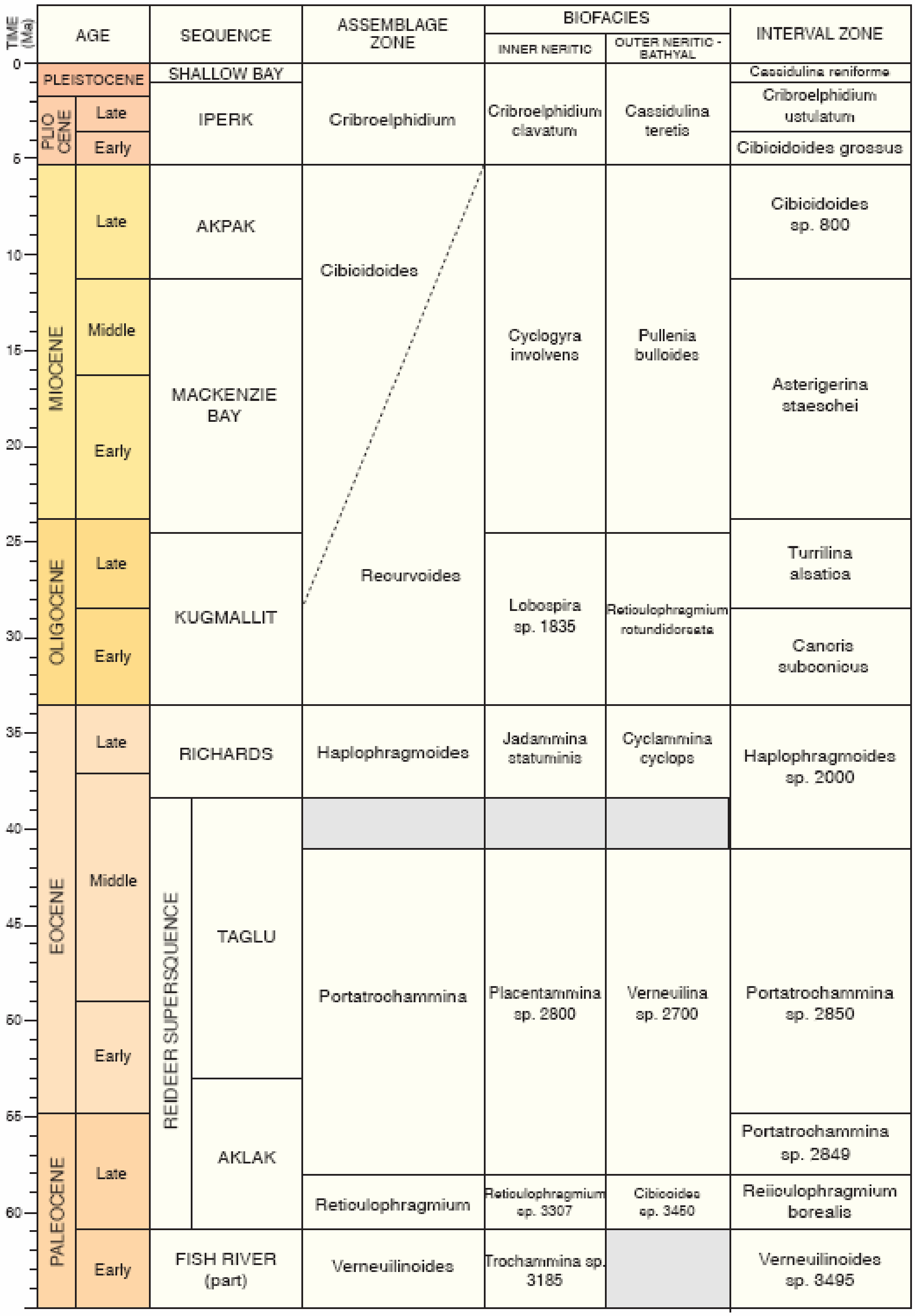

Figure 2. Beaufort Mackenzie Basin Cenozoic sequences and foraminiferal biostratigraphic scheme. From McNeil (1989) and McNeil *et al.* (1990). Absolute ages modified to the time scale of Gradstein *et al.* (1995).

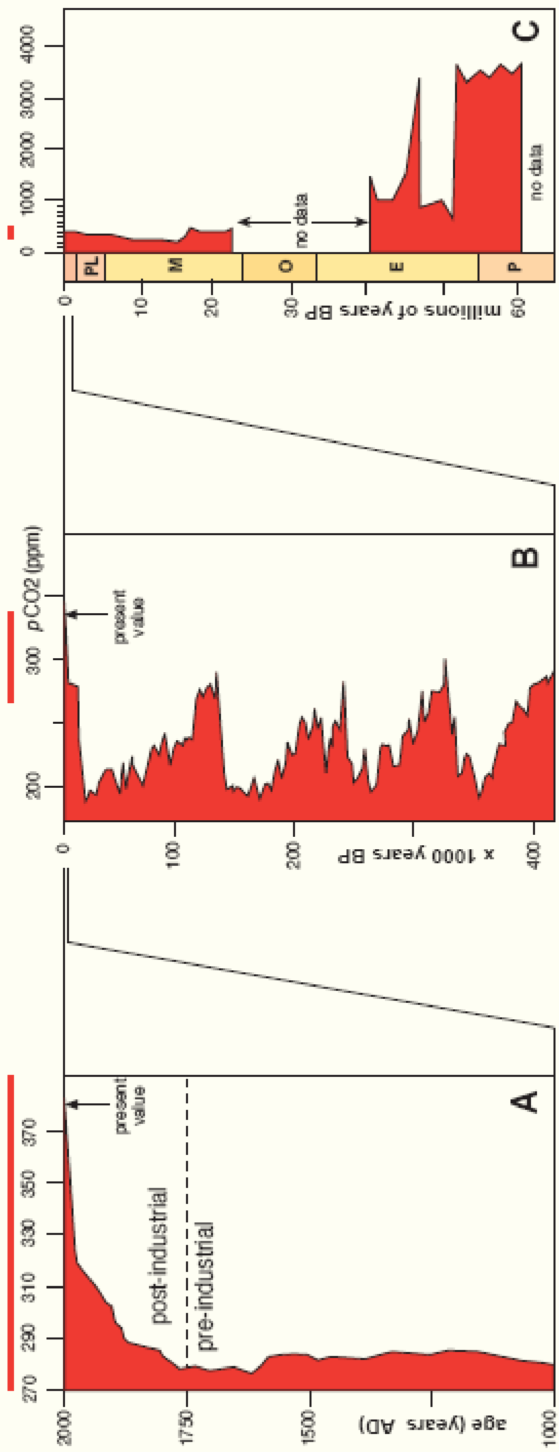

Figure 3. Cenozoic variation in atmospheric CO_2 (after Bujak 2007).

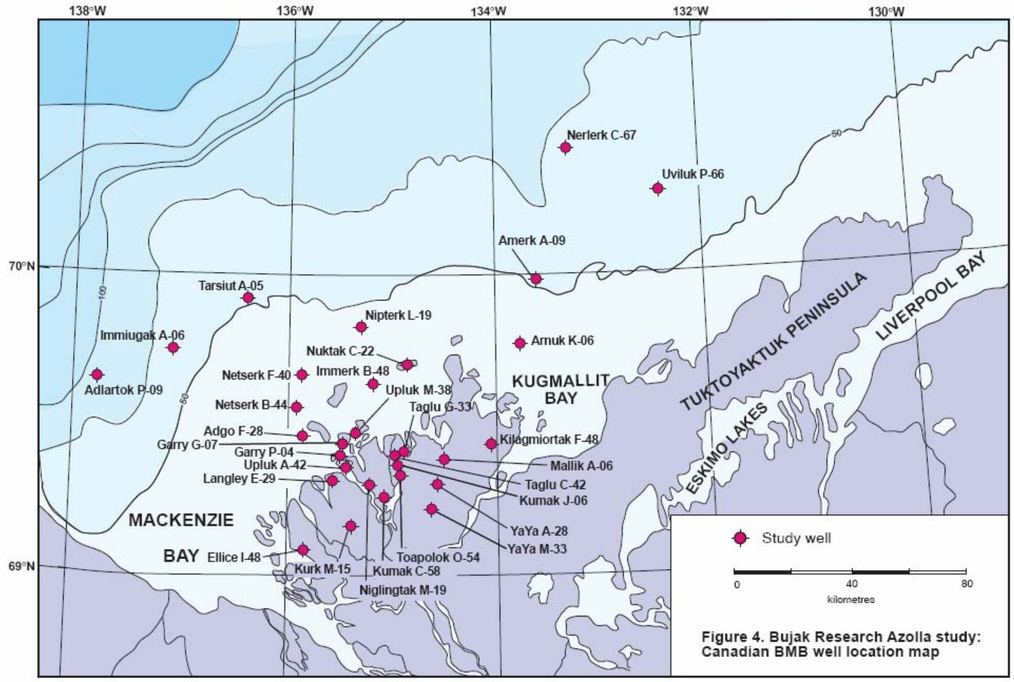

Figure 4. Bujak Research Azolla study: Canadian BMB well location map

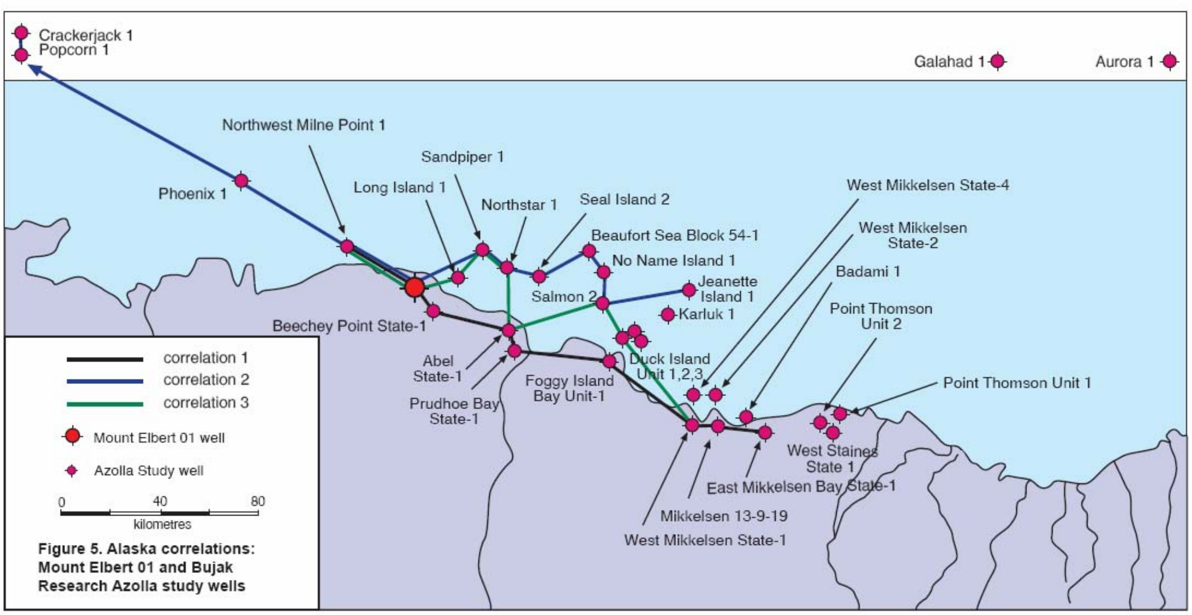

Figure 5. Alaska correlations: Mount Elbert 01 and Bujak Research Azolla study wells

SUMMARY OF RESULTS

- Palynological assemblages in the Mount Elbert 01 core vary strongly due to paleo-environmental shifts. Most of the core was deposited in environments that were not fully marine, including [1] wet lowlands, [2] brackish and freshwater lakes and lagoons, and [3] intertidal *Taxodium* swamps similar to today's mangrove swamps.
- Marine dinocysts are absent or very sparse in most of the examined core, but the highest samples examined from 1990.0-2002.0 ft were deposited in a marine setting and contain dinocysts that comprise 10-26% of the palynomorph assemblage. These indicate assignment to the Early Eocene *Glaphyrocysta ordinata* T3 Zone based on the presence of common *Areoligera* and *Glaphyrocysta*.
- The three highest samples examined from the core, from 1990.0-1998.0 ft, contain rare specimens of *Azolla*, which comprises less that 3% of the total assemblage. These provide evidence that the Arctic *Azolla* event began in the latest part of the Early Eocene. This is significant because no data for this are presently available from the 2004 ACEX Lomonosov location due to lack of core recovery. Data are also not presently available from BRI's 2006 *Azolla* study of northern Alaskan and Canadian BMB wells due to the absence of conventional or sidewall core samples.
- Early Eocene Zone T3 is indicated down to 2429.0 ft where relatively common *Apectodinium* indicate assignment to the *Apectodinium* acme Zone, corresponding to the PETM. Marine dinocysts are absent or very rare in this zone, which extends from 2429.0-2478.0 ft, reflecting predominantly nonmarine / brackish environments, similar to other wells near this location documented in BRI's 2006 *Azolla* study.
- The lowest two sample examined from the core, from 2482.0-2484.0 ft, are assigned to the lower part of Zone T2, representing the pre-PETM section, based on the highest occurrence of the pollen *Paraalnipollenites* cf. *confusus*.
- The zonal and age assignments are supported by gamma logs, which comprise a succession of cycles that correlate with the same palynological zones in all of the onshore and northern Alaskan wells documented in the BRI 2006 *Azolla* study and the BRI Alaskan well database.

9.1 INTRODUCTION

9.1.1 Material and methods

The following report is based on palynological analysis of 39 conventional core samples from the interval 1990-2484 ft in the Mount Elbert 01 well, northern Alaska. Samples were analysed for palynology by J Bujak using quantitative analysis of the palynological assemblage in all samples with the exception of bisaccate pollen, which are potentially blown to the depositional site from distances of up to thousands of miles. The samples were processed at the Laboratory of Palaeobotany and Palynology at Utrecht University in order to ensure consistency with samples from the IODP Leg 302 Arctic Coring Expedition (ACEX) which were processed at the same location.

9.1.2 Biostratigraphic zonation

The Arctic Cenozoic scheme of Bujak is plotted in Figures 1 and 2 against the generalised lithostratigraphy for northern Alaska and the Canadian Beaufort Mackenzie Basin (BMB). The scheme is an integrated biostratigraphic/climatic scheme to be published in 2009 (Bujak *et al.*, in prep.), reflecting the close relationship between the succession of Arctic marine and nonmarine palynomorphs to sea-surface and air temperature changes accompanying the greenhouse to icehouse change.

Paleoceanographic reconstructions predict that this scheme is applicable to the entire Arctic Basin which was centred on the North Pole during the entire Cenozoic and this has been substantiated by data from areas as widespread as northern Alaska, the Canadian BMB, the Chukchi Sea, the Sverdrup Basin and the Barents Sea. Little data is presently available from the Siberian shelves, but the model predicts that the scheme will also apply to those areas.

Paleocene greenhouse conditions were inherited from the Cretaceous, with no appreciable change across the Cretaceous-Tertiary boundary other than the relatively short lived K/T boundary event. As today, the Arctic Basin lay north of the Arctic Circle, with 24 hour summer daylight and 24 winter darkness due seasonality north of the Arctic Circle, but with SST's probably averaged about 10-12^{o}C, resulting in environments totally unknown today. The Basin was fringed by angiosperms, gymnosperms and fern plant communities, with the former comprising the common ancestors of modern angiosperm trees such as alder, beech, birch, hickory, linden and oak. The fossil pollen record indicates that the seasonal winter darkness probably resulted in the evolution of deciduous character typical of most temperate angiosperm trees, and their subsequent southward migration.

The Arctic Basin was largely enclosed and had limited marine connection via gateways into the Norwegian-Greenland Sea and Turgay Strait. High temperatures led to high evaporation, rainfall and runoff into the basin from major river systems, leading to locally and occasional widespread lowered salinity and partial basin stratification. Brackish water conditions are reflected by the presence of the local abundances of the low-salinity dinocyst *Subtilisphaera*, plus a general paucity of marine dinocysts across most of the basin.

The Paleocene Eocene Thermal Maximum (PETM) is strongly defined in the Arctic Basin by an influx of the subtropical dinocyst *Apectodinium*, reflecting mean SST values that may have reached about 16^{o}C. This provides a strong chronostratigraphic datum for the inception and end of the event, which lasted for less that half a million years. The event is also characterized by a high gamma peak in onshore and offshore northern Alaskan wells, which can be tied to a distinctive seismic event (D. Houseknecht, pers. comm.). In the MacKenzie Delta depocenter, the high gamma peak is often masked by local deltaic events.

An extensive discussion of the PETM / *Apectodinium* acme event is given in Sluijs *et al.* (2008). The PETM was succeeded by the Early Eocene supergreenhouse world which, apart from the PETM, represents the warmest phase of the Cenozoic. The Early Eocene is characterized by the dinocyst genera *Areoligera* and *Glaphyocysta*, which define Zone T3. This interval represents most of the examined section from the Mount Elbert core based on both its distinctive dinocyst assemblages and its gamma log character.

The base Middle Eocene *Azolla* event has received considerable attention since it was recovered from ACEX cores on the Lomonosov Ridge. The model proposed by ACEX scientists indicates a highly enclosed basin characterized by episodic surface freshwater layers that were repeatedly colonized by the floating freshwater fern *Azolla* for about 800,000 years. Briefly stated, the model proposes that sequestration of atmospheric carbon by *Azolla* lowered atmospheric CO_2 levels from above 2500 ppm to less that 1000 ppm, shifting the world toward the modern icehouse state.

The *Azolla* interval was succeeded in the Arctic Basin by the first cooling step seen in the Cenozoic, coeval with minor cooling in Nordic Seas, as well as the North Sea Basin and North Atlantic Basin systems (Bujak Mudge 1998, 1999), plus the onset of Antarctic glaciation. A succession of cooling steps are indicated by dinocyst extinctions during the succeeding Middle and Late Eocene, with the magnitude and effect of these steps increasing northwards in the Northern Hemisphere towards the pole. Within the Arctic Basin, each of these steps resulted in the extinction of 20% to 30% of the dinocyst and pollen assemblages, defining individual subzonal boundaries within Zone T4 as well as the boundary between Zones T4 and T5.
The top of Zone T5 corresponds to the Eocene-Oligocene boundary and the Terminal Eocene Event (TEE). This was probably caused by:

- Plate tectonic separation of Australasia and South America leading to widening and deepening of the Drake Passage.
- Intensification of the Antarctic Circumpolar Current (ACC) which in turn initiated the modern system of deep cold-water oxygen rich circulation that extended into the North Atlantic (causing widespread seismically-reflected scouring by contorites.
- Sequestration of atmospheric CO_2 by this new deep-water circulation to below 1000 ppm, which in tern led to global temperature fall.
- Thermal isolation of Antarctica leading to widespread permanent Eastern Antarctic glaciation.
- Global eustatic sea-level fall. Moran *et al.* (2006) have also suggested the development of minor Arctic glaciation at this time based on the presence of ice-rafted material, but this remains to be confirmed by bother studies.

The Eocene-Oligocene boundary is often characterized by a hiatus in northern Alaskan and Canadian BMB wells, at the top of the Mikkelsen Tongue in the former. This may reflect global sea-level fall, or local tectonism, or a combination of both.

The succeeding Oligocene cold phase is characterized by an absence of marine dinocysts in northern Alaska, the Canadian BMB and probably in many other Arctic areas with the exception of the Barents region, where well data indicate marine dinocyst assemblages similar to those in the Norwegian-Greenland Sea. This indicates that some surface water flowed into the Arctic and warmed the Barents region sufficiently for dinocysts to grow and, at the same time, opening between Greenland and Spitsbergen allowed benthic foraminifera, including the Oligocene marker *Turrilina,* to migrate into the Arctic.

In contrast, the Oligocene of northern Alaska and the Canadian BMB (Kugmallit Formation) is difficult to subdivide biostratigraphically due to the cold phase which resulted in impoverished palynological assemblages mostly comprising long-ranging spores. The uppermost part of Zone 6 is characterized by the presence of an undescribed species of dinocyst, *'Caritasphaeridium* *pseudopoculum'*, which may reflect latest Oligocene warming, just prior to strong Early Miocene warming.

The Early Miocene is characterized by the migration into the Arctic Basin by both pollen and dinocysts, reflecting marked increases in both air and sea-surface temperatures. It is probable that the Early Miocene warming shown in Figures 1 and 2 occurred as a series of steps, providing increased resolution in this part of the section. These would be based on earliest occurrence events reflecting the migration of successive species as the Arctic warmed above their minimum temperature thresholds. Documentation of these therefore depends on the availability of suitable outcrop or well core samples because their earliest occurrences would be masked by downhole cavings in cuttings samples.

Renewed cooling during the Middle and Late Miocene resulted in a succession of pollen and dinocyst Arctic extinction events, similar to those in the Middle and Late Eocene. This progressive depletion of both marine and terrestrial palynomorphs increased during the Plio-Pleistocene, leading to the highly impoverished assemblages that characterize the modern Arctic. The detailed succession was more complex than is shown in Figure 1, including a slightly warmer Early Pliocene phase, plus a series of middle Pliocene to Recent glacial-interglacial cycles, but the resolution provided by well samples is generally insufficient in most Arctic wells to make further refinement uncertain.

9.1.3 Bujak Research International (2006) Azolla study

Bujak Research International (2006) documented the *Azolla* and PETM intervals in 24 northern Alaskan wells, two Chukchi Sea wells and 27 Canadian Beaufort Mackenzie Basin (BMB) wells (Figures 4, 5). All samples were cuttings, with no sidewall or conventional core samples being available from sections containing the acme events. The top of the intervals are therefore well constrained in these wells by highest occurrence and abundance palynomorph events, including species of *Azolla* and *Apectodinium* that characterize the two intervals. However, the base of the intervals were not well constrained due to downhole cavings that obscure lowest (earliest) bioevents.

The base of the *Azolla* interval was also not defined in the 2006 ACEX cores due to lack of core recovery across the lower boundary of the *Azolla* interval. The character of this interval is crucial for understanding the age and nature of its base, and for understanding the conditions that triggered the event in the Arctic Basin. The Mount Elbert 01 core is therefore important because the present study indicates that the highest samples examined from the core were deposited during the inception of the *Azolla* interval.

The Bujak Research study also demonstrated that the both the *Azolla* and PETM intervals are associated with a distinctive high-gamma curves in northern Alaska and the Chukchi Sea areas, away from the Mackenzie Delta. However, in the Canadian BMB neither of these intervals are associated with the high-gamma curves seen in northern Alaskan wells. BRI attributed this to masking of the gamma due to local sedimentation within the proto MacKenzie Delta.

The BRI *Azolla* study included four correlation diagrams for the Alaskan wells to illustrate the age and log character of the sections at various locations, shown in Figure 5. These clearly show the association of the *Azolla* and PETM intervals with high gamma peaks, but, as noted above, the precise relationship between the base of the intervals and the gamma curve is uncertain and therefore indicated by a dashed line.

9.1.4 Data files

Computer files of the report are provided with this report and are also available from Bujak Research International at jonathan@bujakresearch.com.

9.2 BIOSTRATIGRAPHIC RESULTS

9.2.1 SPECIES OCCURRENCE CHARTS

This section of the report discusses the biostratigraphic succession interpreted from the palynological data shown on the range charts in Appendices 1 and 2 *(not reprinted here due to size restriction):*

- Appendix 1: chart in Excel format lists all taxa arranged alphabetically within major palynomorph groups
- Appendix 2: chart in Stratabugs format lists all taxa arranged alphabetically within major palynomorph groups, plotted against age, zones, lithostratigraphy and the gamma well log.

9.2.2 GAMMA LOGS

BRI's 2006 *Azolla* study demonstrated the northern Alaskan wells exhibit a succession of distinctive gamma log signatures within the upper Paleocene to Eocene interval, shown in the three correlation diagrams included with this report together with the Mt Elbert 01 well. The section corresponds to the Mikkelsen Tongue of the Sagavanirktok Formation and to the Bujak Research palynological zones as follows:

T6 SEQUENCE [corresponds to the lower part of Zone T6]

--------------- *TOP MIKKELSEN TONGUE (TERMINAL EOCENE EVENT)* ---------------

T5 SEQUENCE [corresponds to Zone T5]

T4c SEQUENCE [corresponds to Zone T4c]
T4b SEQUENCE [corresponds to Zone T4b]
T4a SEQUENCE [corresponds to Zone T4a]
High gamma at the base of T4a sequence corresponds in part to the *Azolla* interval

T3 (iii) SEQUENCE [T3 (i-iii) sequences correspond to Zone T3 which has no subzones]
T3 (ii) SEQUENCE
T3 (i) SEQUENCE

T2 (PETM) (corresponds to the *Apectodinium* acme interval)
T2 (i) SEQUENCE (corresponds to Zone T2 older than the *Apectodinium* acme interval)

--------------------------------- *BASE MIKKELSEN TONGUE* -----------------------------------

T1 SEQUENCE (corresponds to the upper part of Zone T1)

9.2.3 INTEGRATION OF GAMMA LOGS AND BIOSTRATIGRAPIC RESULTS

The correlation of gamma cycles with palynomorph zones suggests a relationship to either (1) depositional cycles, (2) shifts in surface (SST) and bottom water temperature that affected the planktonic and benthic biotas, plus the amount of organic material being deposited, or (3) a combination of depositional cycles and shifts in water temperature.

9.2.3.1 Middle and Upper Eocene Section

The BRI northern Alaskan well database and 2006 Azolla study has demonstrated that the succession of gamma cycles corresponds closely to palynological zones and subzones T4a, T4b, T4c and T5 within the Middle and Upper Eocene section. This is confirmed by the present study for the Mt Elbert 01 well where precisely the same relationship occurs as in other northern Alaskan wells, as shown in the three correlations included with this report.

At the base of the Middle Eocene, the Azolla interval is also characterized by a high gamma peak in onshore and offshore northern Alaskan wells, and this can be tied to a distinctive seismic event (D. Houseknecht, pers. comm.). However, data are not available for base of the Azolla interval from either the 2004 ACEX cores or northern Alaskan and Canadian BMB wells due to a core gap in the ACEX cores, and the absence of conventional or sidewall core samples in the wells. It was therefore not possible to characterize the gamma log signature at the base of the Azolla interval, but the Mount Elbert 01 core provides some information, although the highest samples provided for the present study do not include an abundance of Azolla. This may be due to either [1] Azolla abundance not being developed at the Mt Elbert 01 well location, or [2] the highest examined sample being older that the Azolla abundance, which would then occur higher in the Mt Elbert 01 section.

9.2.3.2 Lower Eocene Section

The Lower Eocene section, corresponding to Zone T3 was not subdivided into subzones because no bioevents have been observed to date within this interval. Three distinctive gamma log cycles occur within this interval – listed above as sequences T3(i), T3(ii) and T3(iii) - and these can be correlated in all of the northern Alaskan wells, plus the Mt Elbert 01 section. Their uniform character across the northern Alaskan well is shown on the correlation diagrams included with this report, suggesting that they reflect shifts in depositional environment and (tectonically induced) relative sea-level change across the region.

9.2.3.3 Apectodinium acme interval (PETM)

As noted above, the *Apectodinium* acme interval is characterized by a high gamma peak with a distinctively sharp base in both marine and nonmarine to marginal marine settings. In marine settings, the interval is characterized by an acme of the low-latitude marine dinocyst genus *Apectodinium* which migrated into mid and high latitudes during the PETM as originally proposed by Bujak & Brinkhuis (1998). In marginal to nonmarine settings *Apectodinium* are reduced in relative abundance or absent, as in Mt Elbert 01, but the characteristic gamma signature is still developed.

The lower part of Zone T2, representing the pre-PETM section, is designated T2(i) and is defined palynologically by the section below the base of the *Apectodinium* acme and also by the highest occurrence of the pollen *Paraalnipollenites* cf. *confusus*. T2(i) has a characteristic bow-shaped gamma curve which can be seen in the correlation diagrams, but only the uppermost part of this interval occurs in the cored section from Mt Elbert 01.

The top of underlying Zone T1 is defined by the pollen marker *Paraalnipollenites confusus sensu* strict and by a strong shift in the character of the gamma log at the base of the Mikkelsen Tongue.

9.2.4 DOCUMENTATION OF BIOSTRATIGRAPHIC EVENTS

1990.0 – 2429.0: *Glaphyrocysta ordinata* Zone T3 (Early Eocene)

The following zonal markers occur in this interval and have their highest observed occurrences in the listed samples. The taxa have their highest occurrences in the subzones indicated in brackets and all range down into Early Eocene Zone T3, providing strong evidence for assignment of the interval to the Early Eocene due to common specimens of *Areoligera* and *Glaphyrocysta* in the highest samples. All taxa are dinocysts, except for the fungal spore genus *Pesavis*.

1990.0 ft	*Areoligera medusettiformis* (T3)
	Areoligera senonensis (T3)
	Charlesdowniea coleothrypta (T4b)
	Glaphyrocysta exuberans (T3)
	Glaphyrocysta ordinata (T3)
	rare *Hystrichosphaeridium tubiferum* (top rare occurrence is in Zone T3; top consistent / common occurrence occurs in Zone T2)
	Lentinia wetzelii (T4a)
	Operculodinium tiara var. A (T4c)
	Wetzeliella meckelfeldensis (T4b)
	Thalassiphora delicata (T4c)
	Thalassiphora pelagica (T4a)
	Wetzeliella articulata (T4c)
1993.5 ft	*Cordosphaeridium gracile* (T4c)
	Polysphaeridium subtile (T3)
	Systematophora placacantha (T4c)
2002.0 ft	*Wetzeliella hampdenensis* (T4b)
	rare *Apectodinium homomorphum* (top rare occurrence is in Zone T3; top consistent / common occurrence occurs in Zone T2)
	Charlesdowniea tenuivirgula (T4b)
2123.5 ft	*Apectodinium parvum* (top rare occurrence in is Zone T3; top consistent / common occurrence occurs in Zone T2)
2367.0 ft	*Pesavis* sp. A, Ioannides & McIntyre 1980 (T4c)
	Pesavis tagluensis (T4a)

2429.0-2478.0 ft: *Apectodinium homomorphum* Acme Zone T2 (late Paleocene)
Marine dinocysts are absent or rare throughout this interval, reflecting nonmarine to low-salinity environments. *Cyclopsiella* predominates between 2429.0-2439.0 ft, indicating deposition in brackish to freshwater lake or lagoon close to intertidal *Taxodium* swamps. Minor marine influence is also indicated by the presence of rare dinocysts, including 5-8% *Apectodinium*. This is similar to the upper part of the *Apectodinium* acme interval (= PETM) observed in several other northern Alaskan wells in BRI's 2006 *Azolla* study.

This freshwater lake or lagoon phase also corresponds to the upper (decreasing) part of a high gamma curve that characterizes the *Apectodinium* acme interval in the 2006 study wells.

The lower part of Zone T2 occurs from 2451.0-2478.0 ft in the Mt Elbert 01 core. This is dominated by miospores that reflect wet lowland plant communities close to intertidal *Taxodium* swamps. *Apectodinium* is present in very low numbers in this interval, consistent with the lower part of the *Apectodinium* acme interval in several other northern Alaskan wells (BRI 2006 *Azolla* study). This corresponds to the lower part of a high gamma curve that characterizes the *Apectodinium* acme interval in the 2006 study wells.

NOTE: The age of the PETM (and hence the *Apectodinium* acme interval) is currently under revision due to re-definition of the Paleocene-Eocene boundary at the inception of the PETM. Its previous definition at the top of the PETM assigned the *Apectodinium* acme interval to the latest Paleocene, whereas the revised PETM age definition will re-assign the *Apectodinium* acme interval to the earliest Eocene.

9.3 PALAEOENVIRONMENTAL INTEPRETATIONS

9.3.1 MICROFOSSIL TYPES
The following palynological groups were observed in the well and are distinguished on the range charts:

Palynomorphs

Dinoflagellate cysts (dinocysts): These comprising the cysts of planktonic dinoflagellates. These are all marine species, with the exception of *Subtilisphaera* species which inhabited brackish and freshwater environments.

Miscellaneous algae: mostly comprising *Cyclopsiella / Paralecaniella* species that inhabited brackish and freshwater lakes and lagoons.

Miospores: (the spores and pollen of plants), primarily comprising:

[1] *Taxodium* pollen (*T. hiatus*) from mangrove-like trees, which lived in intertidal swamps and were mostly, transported by water.

[2] Angiosperm pollen of flowering plants. These characterised a variety of lowland environments and were transported by wind, water and insects.

[3] Fern spores, which characterised wet lowland environments and were mostly transported by water.

Fungal remains: mostly comprising fungal spores, which probably characterised moist, non-marine environments.

9.3.2 PALEOENVIRONMENTAL INTREPRETATIONS: MT ELBERT 01 CORE

The palynological succession present in the Mount Elbert 01 core shows major fluctuations in the assemblage composition that reflecting shifts in the depositional environment.

1990.0 ft: NEARSHORE MARINE WITH EPISODIC FRESHWATER SURFACE LAYERS

Palynological assemblage: Marine dinocysts 13%; *Subtilisphaera* 17%; *Cyclopsiella* 4%; Miospores 64% including 11% *Taxodium*, fungi 1%, reworking <1%

1993.5 ft: FULLY MARINE: PROBABLY MIDDLE NERITIC

Palynological assemblage: Marine dinocysts 20%; *Subtilisphaera* 19%; *Cyclopsiella* 4%; Miospores 56% including 8% *Taxodium*, fungi <1%, reworking <1%

1998.0 ft: NEARSHORE MARINE WITH EPISODIC FRESHWATER SURFACE LAYERS

Palynological assemblage: Marine dinocysts 10%; *Subtilisphaera* 34%; *Cyclopsiella* 6%; Miospores 49% including 25% *Taxodium*, fungi 1%, reworking 1%

2002.0 ft: FULLY MARINE: PROBABLY MIDDLE NERITIC

Palynological assemblage: Marine dinocysts 26%; *Subtilisphaera* 8%; *Cyclopsiella* 2%; Miospores 64% including 22% *Taxodium*, fungi <1%, reworking 0%

2007.0-2014.5 ft: INTERTIDAL TAXODIUM SWAMP CLOSE TO WETLOWLAND HABITATS

Palynological assemblage: Marine dinocysts 3-4%; *Subtilisphaera* 11-19%; *Cyclopsiella* <1-1%; Miospores 76-85% including 31-44% *Taxodium*, fungi <1-1%, reworking 0%

2017.0-2020.0 ft: FULLY MARINE: PROBABLY MIDDLE NERITIC

Palynological assemblage: Marine dinocysts 43-45%; *Subtilisphaera* 10-16%; *Cyclopsiella* 1-<1%; Miospores 39-43% including 6-8% *Taxodium*, fungi 1%, reworking 0%

2065.0 ft: NONMARINE WETLOWLAND CLOSE TO BRACKISH / FRESHWATER LAKE OR LAGOON AND INTERTIDAL TAXODIUM SWAMP

Palynological assemblage: Marine dinocysts 0%; *Subtilisphaera* 0%; *Cyclopsiella* 13%; Miospores 75% including 13% *Taxodium*, fungi 13%, reworking 0%

2082.7 ft: BRACKISH / FRESHWATER LAKE OR LAGOON CLOSE TO INTERTIDAL TAXODIUM SWAMP AND WETLOWLAND:

Palynological assemblage: Marine dinocysts <1%; *Subtilisphaera* 2%; *Cyclopsiella* 66%; Miospores 31% including 16% *Taxodium*, fungi 0%, reworking 0%

2086.0-2115.0 ft: NONMARINE WETLOWLAND CLOSE TO BRACKISH / FRESHWATER LAKE AT 2115.0 FT

Palynological assemblage: Marine dinocysts 2-3%; *Subtilisphaera* 0-5%; *Cyclopsiella* 1-6% (13% at 2115.0 ft); Miospores 80-95% including 5-18% *Taxodium*, fungi 1-3%, reworking 0-4%

2123.5 ft: FULLY MARINE: PROBABLY INNER NERITIC TO POSSIBLE MIDDLE NERITIC
Palynological assemblage: Marine dinocysts 11%; *Subtilisphaera* 2%; *Cyclopsiella* 2%; Miospores 83% including 11% *Taxodium*, fungi 2%, reworking 1%

2134.0-2405.0 ft: NONMARINE WETLOWLAND CLOSE INTERTIDAL TAXODIUM SWAMP AT 2293.5- 2304.0 FT AND 2367.0- 2394.0 FT. POSSIBLY NEARSHORE MARINE AT 2134.0 FT
Palynological assemblage: Marine dinocysts 0-3% (5% at 2134.0 ft); *Subtilisphaera* 0-4%; *Cyclopsiella* 0-6%; Miospores 88-99% including 11-30% *Taxodium*, fungi 1-4% (11% at 2367.0 ft), reworking 0-3%

2429.0-2439.0 ft: BRACKISH / FRESHWATER LAKE OR LAGOON CLOSE TO INTERTIDAL TAXODIUM SWAMP:
Palynological assemblage: Marine dinocysts <1%; *Subtilisphaera* ,1%; *Cyclopsiella* 22-39%; Miospores 53-76% including 21-40% *Taxodium*, fungi ,1%, reworking 0%

2451.0-2484.0 ft: NONMARINE WETLOWLAND CLOSE INTERTIDAL TAXODIUM SWAMP AT 2451.0 FT AND 2478.0- 2482.0 FT.
Palynological assemblage: Marine dinocysts <1; *Subtilisphaera* <1%; *Cyclopsiella* <1-1%; Miospores 97-99% including 11-30% *Taxodium* 1% at 2460.0 ft, elsewhere 16-50% fungi <1-2%, reworking 0-2%

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