Oil and Natural Gas Technology

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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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National Energy Technology Laboratory (NETL)

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Office of Fossil Energy

PROJECT ABSTRACT

BP Exploration (Alaska), Inc. (BPXA) and the U.S. Department of Energy (DOE) co-sponsor this gas hydrate Cooperative Research Agreement (CRA) project in collaboration with the U.S. Geological Survey (USGS) to help determine whether or not gas hydrate can become a technically and commercially viable gas resource. Studies have included reservoir characterization, reservoir modeling, and associated research which indicated that up to 12 TCF gas may be technically recoverable from 33-44 TCF gas-in-place (GIP) within the Eileen gas hydrate 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 designs and sites are under evaluation which, if implemented, 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, including thermal, chemical, and mechanical. 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, USGS, and BPXA support of these studies is gratefully acknowledged.

DOE National Energy Technology Lab staff Brad Tomer, Ray Boswell, Richard Baker, Edith Allison, Tom Mroz, Kelly Rose, Eilis Rosenbaum, and others have enabled continuation of this and associated research projects. Scott Digert, Gordon Pospisil, and others at BPXA continue to promote the importance of this cooperative research within industry. BPXA staff Micaela Weeks, Larry Vendl, Dennis Urban, Dan Kara, Paul Hanson, and others supported stratigraphic test well plans and 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 experiments, and Dr. Mark White, reservoir modeling, at Pacific Northwest National Lab and Dr. George Moridis, reservoir modeling, and Dr. Jonny Rutqvist, geomechanics, at Lawrence Berkeley National Lab. Dr. Joe Wilder and Dr. Brian Anderson have led significant efforts of an International Reservoir Modeling Comparison team. The Colorado School of Mines under the leadership of Dr. Dendy Sloan and Dr. Carolyn Koh continue to progress laboratory and associated studies of gas hydrate. The significant efforts of international gas hydrate research projects such as those supported by the Directorate General of Hydrocarbons by the government of India and by the Japan Oil, Gas, and Metals National Corporation (JOGMEC) with the government of Japan and by others are 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 reservoir characterization, reservoir modeling, regional schematic modeling, and associated studies culminated in approval to proceed into a 2007 stratigraphic test to acquire data to help mitigate potential recoverable resource uncertainty. Future production testing is a key goal of the program, 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 arctic regions onshore 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 published in 1995 indicate that clathrate hydrate may contain a mean of 590 TCF in-place ANS gas volume (Figure 1). Recent USGS studies reveal up to 84 TCF undiscovered, technically recoverable gas hydrate resources beneath the North Slope of

Alaska (Figure 2). Over 33 TCF in-place potential gas hydrate resources are interpreted within shallow sand reservoirs beneath ANS production infrastructure within the Eileen trend (Figure 3). 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 also 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.

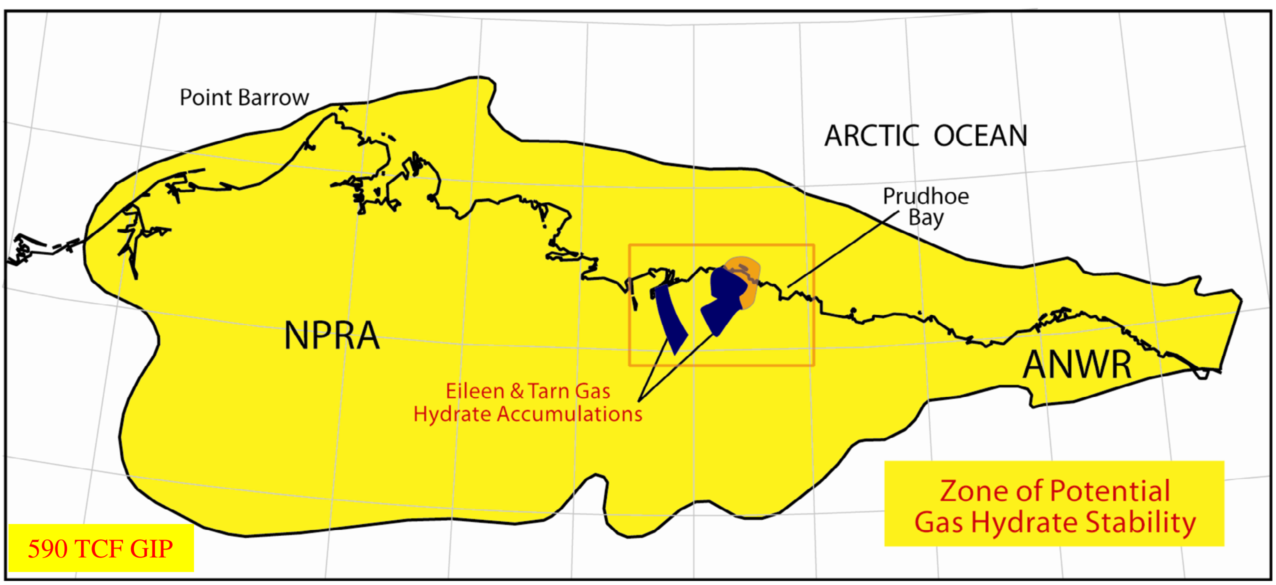


Figure 1: ANS gas hydrate stability zone with Eileen and Tarn gas hydrate trends (Collett, 1993).

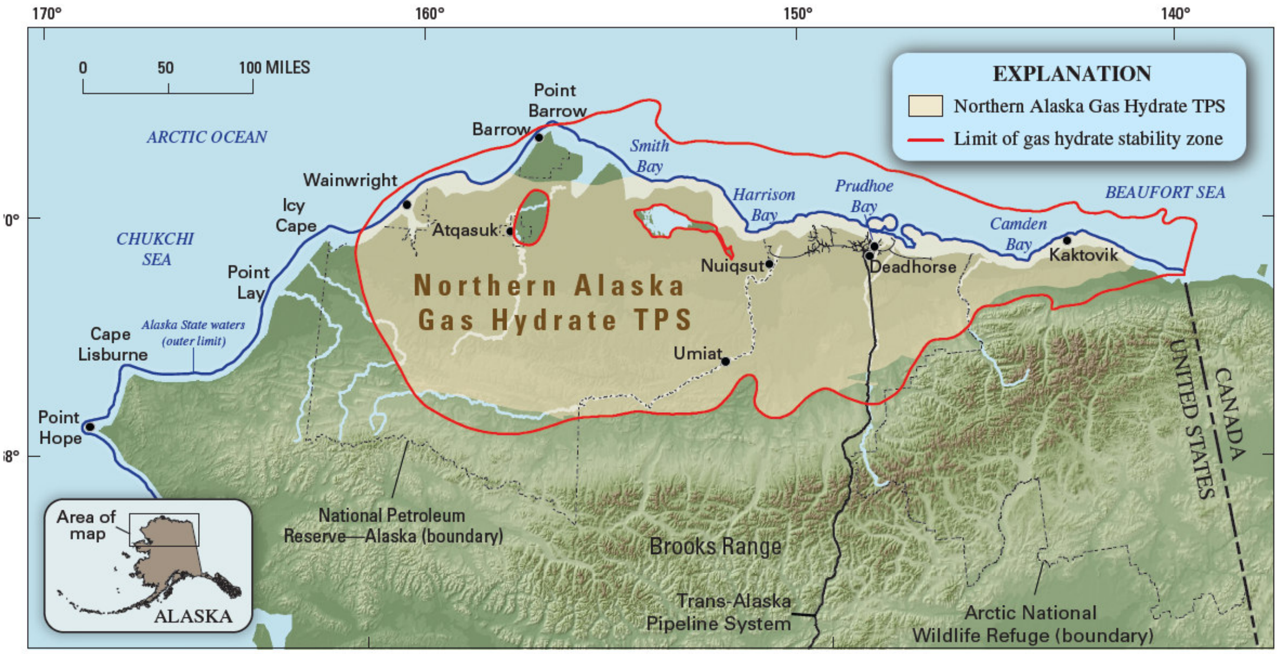


Figure 2: Northern Alaska Gas Hydrate Total Petroleum System (TPS) (shaded in tan), and the limit of gas hydrate stability zone in northern Alaska (red outline); USGS Fact Sheet 2008-3073.

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

Table 1: Alaska North Slope–Gas hydrate assessment results; USGS Fact Sheet 2008-3073. BCFG, billion cubic feet of gas. MMBNGL, million barrels of natural gas liquids. Results shown are fully risked estimates. F95 represents a 95-percent chance of at least the amount tabulated; other fractiles are defined similarly. Fractiles are additive, assuming perfect positive correlations. NGL, natural gas liquids; TPS, total petroleum system; AU, assessment unit. Sagavanirktok AU encompasses Eileen trend area within industry infrastructure (Figure 3).

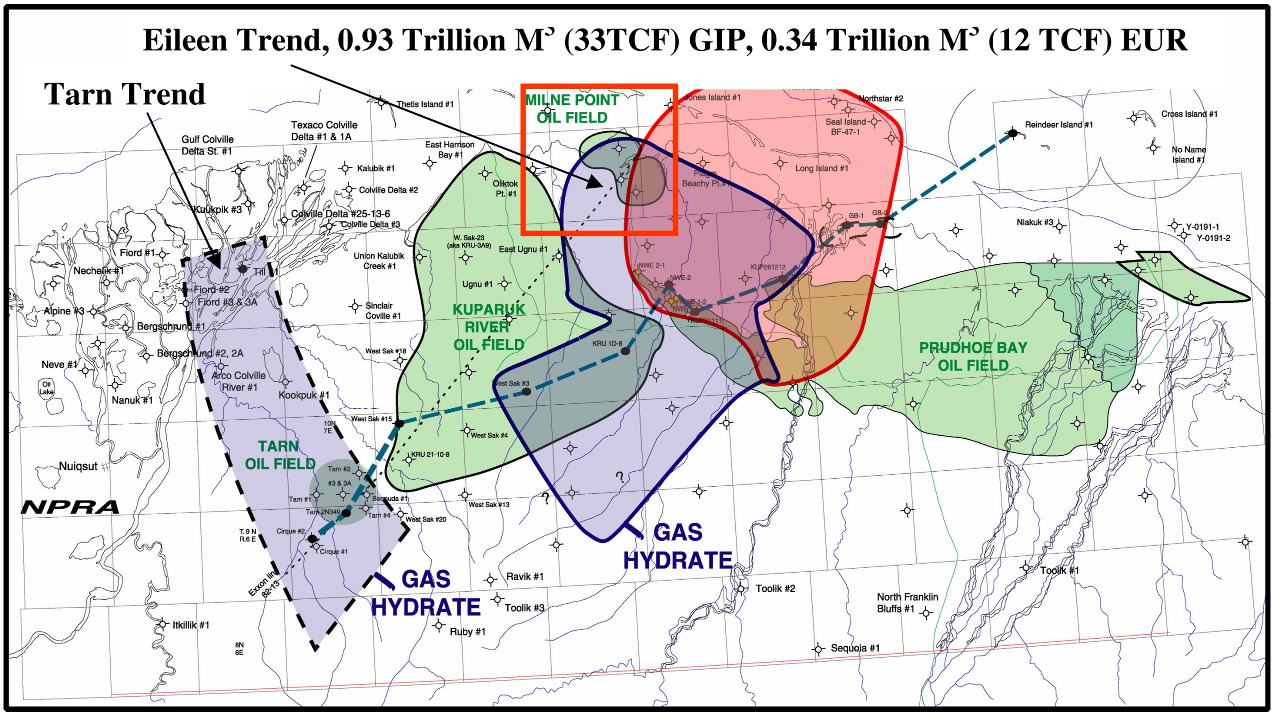


Figure 3: Eileen and Tarn Gas Hydrate Trends and ANS Field Infrastructure (modified after Collett, 1998) and including potential Eileen trend gas-in-place (GIP) and estimated ultimate recoverable (EUR) resource.

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 regional schematic model to quantify potential recoverable resource. Phase 3a stratigraphic test data interpretation further mitigated gas hydrate-bearing reservoir uncertainty and validated 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. These studies included rate forecasts and hypothetical well scheduling, methods typically employed to evaluate potential conventional large gas development projects.

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 4). 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 5). 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 data acquisition and future production testing could help determine the technical feasibility of depressurization-induced or stimulated dissociation of gas hydrate into producible gas.

Long-term production testing is not currently approved, although implementation of the designs at one of the sites under evaluation would provide a unique, valuable dataset that cannot be obtained from existing or planned desktop research or laboratory studies. Proximity to resource, industry technology, and infrastructure make the ANS an ideal site to evaluate gas hydrate resource potential through long-term production testing, which would initially evaluate depressurization technologies and if necessary, extend into a sequence of increasingly complex thermal, chemical, and mechanical stimulation procedures. Results might also help determine the resource potential of offshore gas hydrate resources in the GOM and in other continental shelf areas.

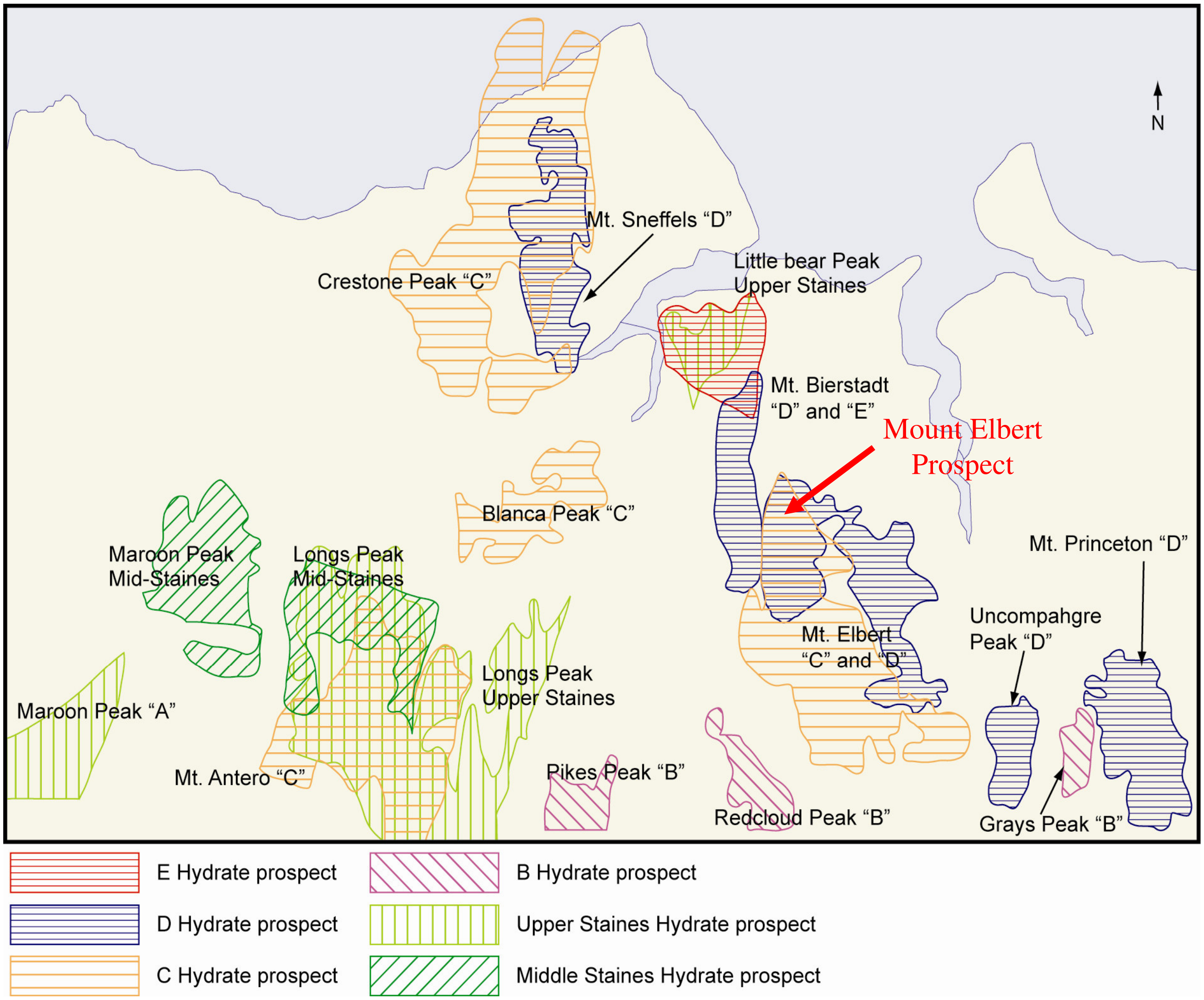


Figure 4: MPU gas hydrate prospects interpreted from Milne 3D seismic data, including Mount Elbert (Inks, T., Lee, M., Taylor, D., Agena, W., Collett, T. and Hunter, R., in press).

3.0 REPORT EXECUTIVE SUMMARY

This report documents Phase 3a accomplishments from October 2008 through end-March 2009. 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, 4Q08 and 1Q09

4.1 Project External Communications and Reporting

- Prepared and presented invited poster at Anchorage Northern Oil and Gas Conference
- Reviewed and provided input into National Research Council (NRC) meeting agenda
    - Prepared and delivered project summary and results presentation and discussion
- Provided PNNL CO_2 experiment final report to industry in support of research synergies
- Reviewed and edited AAPG gas hydrate abstracts on MountElbert-01 data analyses
    - Decided against project summary abstract / poster

- Reviewed, edited, and responded to questions regarding DOE Alaska gas hydrate projects presentation to Alaska Alliance meeting
- Coordinated and prepared 1/22 DOE NETL Alaska projects review presentation
    - Helped coordinate industry synergy and alignment preparations
- Edited project update for future DOE Fire/Ice newsletter article
- Prepared and presented project summary and plans to Alaska Department of Natural Resources (DNR) and to government and industry visitors
- Reviewed, provided input to, and solicited team input to external publication plans proposed for Journal of Marine and Petroleum Geology (Section 4.1.5)
- Prepared abstract, biographies, and poster to Northern Oil and Gas Conference, Anchorage

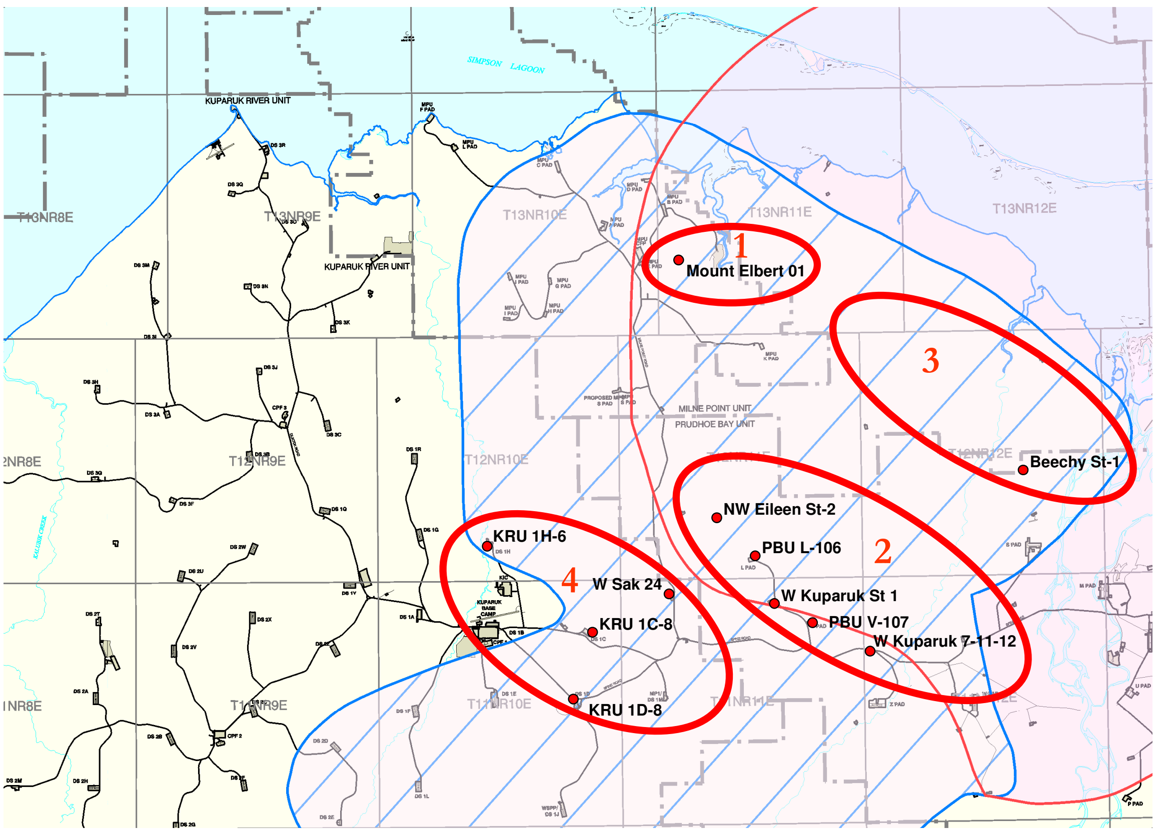


Figure 5: Eileen trend map of composite lateral extent of Sagavanirktok gas hydrate bearing zones A, B, C, D, E, and F (blue with stripes) with 4 areas-of-interest for a potential future production test site.

4.2 Project Internal Communications and Reporting

- Helped coordinate and participated in BP-internal gas hydrate workshop
    - Recognized future production test would enhance desktop and experiment studies
- Completed updated registration for Federal contracting (CCR and FedConnect)
    - Compiled and input financial and other documentation for registrations
- Reviewed, edited, and provided feedback to initial draft University of Arizona final report
    - Edited maps to full-page size to allow detailed QA/QC review

- Reviewed Messoyakha paper and case history and responded to correspondence
- Reported detailed vendor cost breakout report by project phase
- Reviewed, tracked, and categorized project invoices and accounting
    - Implemented accounting procedures for various project work and invoices
- Prepared and submitted project accrual, financial, and semi-annual technical reports
- Updated documents for project progression discussions and determination
    - Clarified preparations for continuation application
    - Executed contract amendments through end-1Q09
- Helped coordinate industry synergy and alignment; provided scope and budget input
- Participated in teleconferences with management and technical team leads

4.3 Stratigraphic Test Data Analyses

- Updated core sample tracking and analyses status with collaborating scientists/agencies
- Compared core scan to original core gamma and prepared for core gamma to log shift
    - Evaluated core scans, core gamma, and detailed core sedimentology description
    - Setup procedure, transferred files, and updated science team with shifted data
- Maintained core storage unit and coordinated industry and government core visits
- Provided input to Texas A&M Electromagnetic Propagation Tool (EPT) research
- Provided input to University of Oregon ANS formations salinity research and interpretation
- Downloaded OMNI core analyses; checked, distributed, and input to file system
- Helped coordinate MountElbert-01 analyses and interpretation for JMPG publication plans
    - Prepared detailed documentation of pressure/temperature core data in support of JMPG publication reports, including past correspondence and files
    - Reviewed, located, and distributed preserved core sample identifications
- Finalized, checked, tabulated, graphed, and distributed UAF minipermeameter study results
- Maintained project files, correspondence files, and electronic backup files

4.4 Production Test Preliminary Planning

- Coordinated update of well log database for reservoir characterization studies
- Evaluated gravel-based production test site location options within Eileen trend AOI
- Prepared draft continuation application and backup information including statement of work, milestones, budget for preliminary planning, scoping, and contractor consideration
- Coordinated additional core sample selection for future geomechanical analyses
- Evaluated gas hydrate-bearing zones clay content and grain size core analyses
    - Considered fluid contacts versus lithologic/reservoir zone boundaries
- Initiated project planning and prioritization for 1Q09; setup schedule and deliverables
- Evaluated potential production technology options and considerations
    - Considered completion, stimulation technology, sand control, and pump options
- Compared viscous oil evaluation synergies to hydrate-bearing reservoir characterization
- Held discussions with industry to discuss possible synergies and alignment

4.5 Journal of Marine and Petroleum Geology Thematic Volume

The 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 in in-progress for the *Journal of Marine and Petroleum Geology* (JMPG) to serve as a Scientific Results Volume to report on the February 2007 "Mount Elbert" gas hydrate stratigraphic test well data acquisition and interpretation conducted by the USDOE, BP, and 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 volume has four guest editors, who are helping ensure that the work is peer reviewed by 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 E&P Technology, BP Exploration (Alaska), Inc.

The Phase 3a 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 Thematic Volume provides 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

4.6 Mount Elbert-01 Status Reports

Detailed results are planned for publication within the JMPG thematic volume (Section 4.5). Relevant status updates are provided in this section.

4.6.1 Mount Elbert-01 CSM MDT Modeling Status Report

CSM experimental studies have modeled the predicted response encountered during Modular Dynamics Tool (MDT) wireline production testing of the gas hydrate-bearing reservoir intervals in the Mount Elbert-01 stratigraphic test. Preliminary results confirm that the configuration of the MDT coupled with the low-flow rates led to the abnormal pressure recovery profiles (Figure 6).

4.6.2 Mount Elbert-01 OMNI Petrography Report

This report documents the results of a detailed petrographic study of conventional core plugs taken from Mount Elbert-01 core. The mineralogy, pore systems, fabric, and texture of rocks from the sampled intervals were studied using standard thin section petrographic techniques. Included in this section are the results of ten (10) detailed thin section petrography (modal analysis) and ten (10) X-ray diffraction (XRD) analysis from the sampled interval. A summary list of the petrographic analyses by depth is provided in Table 2. The results of XRD analysis, thin section modal analysis data, and photographs with descriptive captions are also included.

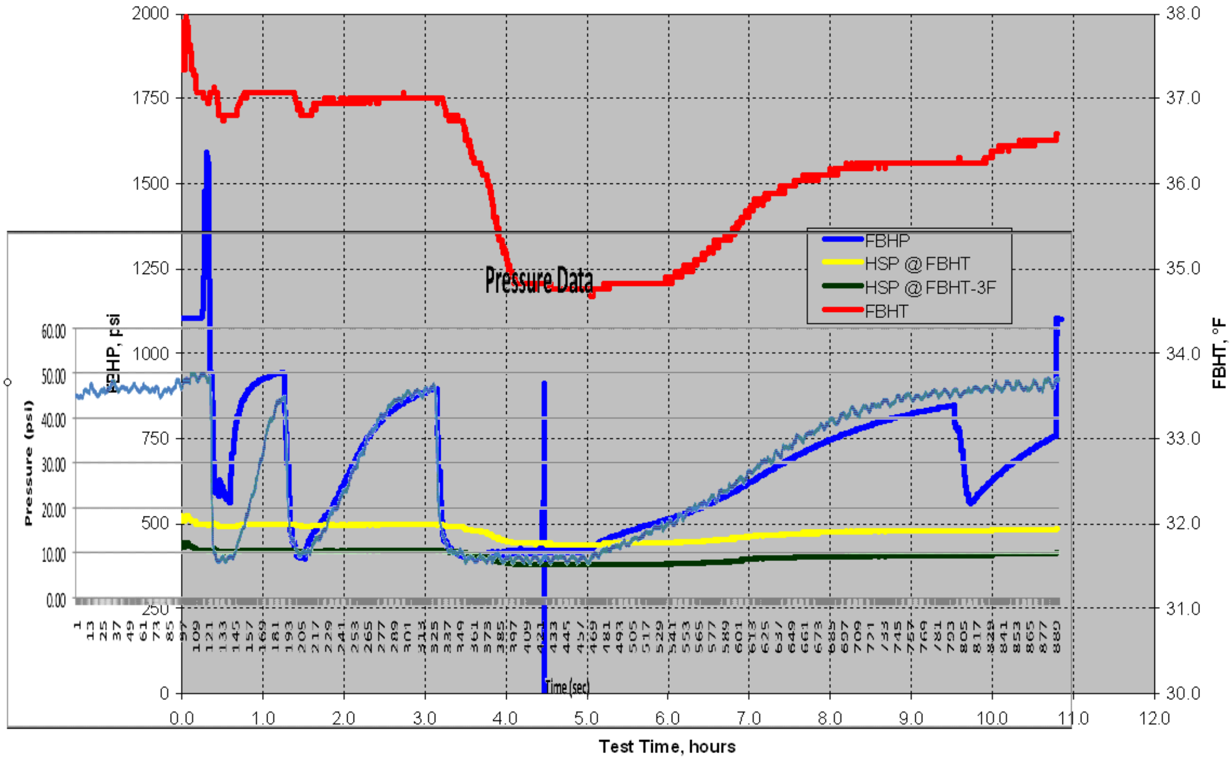


Figure 6: Preliminary pressure history match of CSM MDT tool experiment (jagged lighter blue line) to Mount Elbert-01 C2 MDT (blue line).

The samples include shales (5), a single coarse siltstone (1), and sandstones (4). Most samples show laminations ranging from distinct shale laminations to vague zoning by grain size differential. Grain sorting ranges from very poor to well, dependent mainly on the amount of detrital clay-rich matrix present.

Petrographic analyses of the samples indicate that they are poorly consolidated, and the sandstones show good to excellent reservoir quality. Porosity distribution is controlled primarily by sediment fabric, especially the distribution of shale laminations. Other factors include textural properties (grain size and sorting) and, to a lesser extent, by distribution of various cementing agents. Primary intergranular pores and microscopic pores are the dominant pore types. A minor amount of secondary dissolution porosity also contributes to the total pore volume. This secondary porosity is created by the partial to total dissolution of chemically unstable grains such as lithic fragments and feldspars.

Three (3) of the four (4) sandstones analyzed by thin section modal analysis are classified as feldspathic litharenites, and these sandstones are all considered very fine-grained. One (1) sandstone (2180.25 feet) is a fine-grained litharenite. All of these sandstones consist predominantly of quartz and lithic clasts, with minor feldspar (potassium and plagioclase varieties).

Sample Number	Sample Depth (feet)	Detailed Thin Section Analysis	X-Ray Diffraction Analysis
2-2-8-9	2017.10	X	X
2-2-21-27B	2018.35	X	X
2-7-16-17	2032.40	X	X
3-7-3	2045.90	X	X
5-8-1-6A	2106.60	X	X
6-5-30-36A	2124.75	X	X
8-3-10-11	2163.40	X	X
9-1-2-7A	2180.25	X	X
12-3-6-12A	2224.15	X	X
22-4-20-23B	2454.95	X	X

Table 2: Thin Section Petrographic Analyses Sample Number (2-2-8-9 corresponds to core 2, core section 2, and 8-9 inches) and Core Depth (depth in core-space would require shifting by -3 feet to approximate wireline log space).

4.6.2.1 Sedimentary Fabric, Mineralogy, and Texture

These samples are all fine-grained clastic rocks, and range from shales (5 samples) to coarse siltstone (1 sample) to sandstones (4 samples). The sandstones are classified as very fine-grained to fine-grained. The sandstone samples range from moderately well to well sorted, and most grains are subangular to subrounded. The fabrics observed range from massive to grain size-zoned. The coarse siltstone (2124.75 feet) is vaguely-laminated and moderately sorted. The shales are typically distinctly laminated and contain abundant detrital clay-rich matrix.

A brief description of the detrital and authigenic minerals from the sandstone samples only is provided. The shales and siltstone are not discussed here, but photos, descriptions, and tabulated data for all ten (10) samples are provided below. All percentages refer to point count modal analysis data. Thin section petrography and X-ray diffraction were used for mineral identification and description. Figures 7 through 17 provide thin section photographs representative of each thin section sample. In terms of composition, the sandstones are feldspathic litharenite to litharenite (Folk, 1980).

Quartz is the most abundant framework grain type in all of these sandstone samples. The grains are typically subangular to subrounded, with rounding increasing with greater grain size. Detrital quartz includes both monocrystalline quartz (individual crystals with non-undulose extinction; 22% to 40%, from point count modal analysis) and polycrystalline quartz (3% to 7%).

Typically, a moderate amount of feldspar grains are present in all of sandstone samples, with total feldspar amount ranging from 3% to 13%. Both potassium feldspar (microcline and orthoclase; 2%-6%) and plagioclase feldspar (1%-8%) exist in the samples, with the plagioclase variety slightly more common. Some feldspar grains were slightly altered from dissolution, with resultant secondary intragranular porosity and microporosity.

A variety of lithic fragments (16%-23% total) are encountered as detrital grains in the sandstone samples. The main grain types, subequal in abundance, are metamorphic, volcanic, and sedimentary chert fragments. The metamorphic fragments are typically low grade varieties such as phyllite and slate, ranging up to schist and occasional quartzite fragments. The volcanic rock fragments typically have a fine groundmass texture revealing thin feldspar laths. Sedimentary lithic fragments consist of chert, shale/mudstone, and rare siltstone/sandstone plus carbonate. Rarely, plutonic igneous grains are observed which are represented by polycrystalline fragments consisting of both feldspar and quartz.

Other accessory detrital grains include the mica minerals muscovite (trace-2%) and biotite (trace), carbonaceous (plant) fragments (1%-3%; often partially altered to pyrite), and glauconite (0%-trace). Glauconite pellets are indicative of marine depositional influence. Phosphatic grains are present in trace amounts in two samples. Minor amounts (trace to 2%) of heavy minerals are present, and include clinozoisite, epidote, hornblende, opaque minerals, garnet, epidote, pyroxene, rutile, and zircon.

The amount of matrix clay is highly variable, and is directly related to rock fabric. The total range is from 0% (in several sandstone samples) to 58% in the vaguely-laminated shale from 2106.60 feet.

Authigenic minerals in the coarse siltstone and shale samples ranges from 2% to 5%, and much of it is replacement pyrite, although siderite and clays are also observed. Only sandstone mineralogy will be discussed in the rest of this section. Based on point count modal analysis, the total amount of cement and authigenic replacements in these sandstones ranges from 1% to 5%.

These poorly cemented sandstones contain a wide variety of cements, albeit in very minor amounts. These include quartz overgrowths (trace), siderite (0%-2%), pyrite (trace-2%), Fe/Ti oxides (0%-1%), ankerite (0%-trace), and feldspar overgrowths (0%-trace). Siderite and pyrite act as both true cements and as replacement of labile components such as mudstone fragments and biotite mica. Pyrite is also associated with the alteration of carbonaceous debris. Authigenic clays are represented by pore-lining (trace-2%) and non-kaolin pore-filling (trace) varieties. Clay minerals are discussed in more detail in the following section.

Thin section observations have documented that the clay mineralogy of these samples is dominantly depositional (detrital) in origin, with only very rare chloritic and/or illitic clay rims of authigenic origin. X-ray diffraction analyses reveal that the main clay mineral types in these samples are subequal illite (avg. 10%, by weight) and chlorite (avg. 9%). Kaolinite and mixed-layer illite/smectite each comprise 2% (on avg.). Overall clay mineral content ranges from 5% (2180.25 feet) to 41% (2106.60 feet).

4.6.2.2 Pore Types and Reservoir Quality

The shales have total porosity ranging from 5% to 8%, and the coarse siltstone has a total porosity of 18% reflecting its well interconnected intergranular pore system in regions free of shale laminations. The four (4) sandstones are all considered to have good to excellent reservoir quality, with porosity determined from point count modal analysis ranging from 23% (2163.40 feet) to 31% (2032.40 feet). Primary intergranular pores are the most abundant porosity type in the sandstones (18% to 29%). This pore type represents the original voids between detrital grains, and these have been only very slightly reduced by compaction and cementation. As a general rule, the best preservation potential for intergranular pores are in sediments that have the best sorting in combination with the lowest amount of ductile grains and matrix clay.

Secondary intragranular and grain-moldic pores result from the diagenetic alteration and partial to complete dissolution of chemically unstable detrital grains. This type of porosity ranges from trace to 3%. Most commonly, these pores are associated with partially to fully dissolved feldspars and certain lithic fragments.

Microporosity in the sandstone samples ranges from 1% to 2%, based on point count modal analysis. Micropores are associated mainly with clay minerals, such as within detrital matrix clay, mudstone fragments, altered feldspars/lithics, and pore-lining or pore-filling authigenic clay.

The good to excellent reservoir quality exemplified by the sandstones is represented by well interconnected primary intergranular pores with slight augmentation by secondary dissolution. The factors affecting reservoir character in the depth interval represented by these sandstones are: 1) rock texture and fabric, 2) the degree of cementation and 3) the degree of compaction.

4.6.2.3 Mineralogic Influences on Log Response

The following section discusses the effects on log response of the mineralogy and associated porosity types found in these samples.

1. Resistivity Logs: The main factors that may suppress resistivity in these intervals are pore-lining and pore-filling authigenic clays and certain matrix clays. These clays have the potential to suppress resistivity by their associated bound water. This potential is considered highest in the coarse siltstone at 2124.75 feet. Microporous (leached) grains are also found within this interval. Caution is advised in this interval when evaluating well log resistivity, especially due to various clay types and amounts.

2. Density Logs: The sandstones analyzed from this well contain a variety of high-density minerals, including the carbonates siderite and ankerite, as well as pyrite, Fe/Ti oxides, and chlorite. These constituents are found as authigenic cements and replacements, and constitute a minor portion of these sandstones. Pyrite has a very high grain density of 5.01gm/cc. It is expected that the total effect of these components will be to result in a grain density slightly above the 2.65 gm/cc sandstone (quartz) standard.

3. Gamma-Ray Log: Gamma-ray logs respond to radioactive isotopes. The clay minerals kaolinite (average 2% by weight from XRD) and chlorite (average 9% by weight from XRD) will not be detected by gamma-ray logs due to the absence of potassium in these minerals. Conversely, the mineral K-feldspar (average 1% by weight from XRD) will be detected as "clay" by gamma-ray logs due to the presence of potassium in this mineral. The total effect of these minor components is expected to result in an underestimation of rock shaliness by gamma-ray log response.

4.6.2.4 Formation Sensitivity related to Fines Migration

X-ray diffraction data, supplemented by thin section results indicate that the dominant clay types are illite (average 10%) and chlorite (average 9%). Minor clay types are kaolinite (average 2%)

and mixed-layer illite/smectite (average 2%). Authigenic Illite is found as a fibrous or filamentous grain coating whereas chlorite typically coats grains as well. However, these clays are dominantly detrital (depositional) in origin.

Fines migration is a slight concern because of the presence of both fibrous illite and dissolution debris. Some grain-coating illite is present as fibers that protrude into pores and pore throats. Secondary dissolution debris is also observed, mainly in secondary pores. This debris is loosely attached to nearby pore walls and is rather large in size, compared to nearby pore throats. When testing and/or producing this well, do not open the well on too large a choke. Begin with a low flow rate and gradually increase rate as desired. Be aware that every formation and pack has a critical velocity at which fines are mobilized and production actually drops. Many wells are damaged beyond repair by ill-advised well tests run to determine the maximum rate at which a well is capable of producing.

4.6.2.5 Petrographic Analytical Procedures

4.6.2.5.1 X-Ray Diffraction (XRD) Analyses

A representative portion of each sample was dried, extracted if necessary, and then ground in a Brinkman MM-2 Retsch Mill to a fine powder. This ground sample was next loaded into an aluminum sample holder. This “bulk” sample mount was scanned with a Bruker AXS D4 Endeavor X-ray diffractometer using copper K-alpha radiation at standard scanning parameters. Computer analyses of the diffractograms provide identification of mineral phases and semiquantitative analyses of the relative abundance (in weight percent) of the various mineral phases. It should also be noted that XRD does not allow the identification of non-crystalline (amorphous) material, such as organic material and volcanic glass.

An oriented clay fraction mount was also prepared for each sample from the ground powder. The samples were further size fractionated by centrifuge to separate the less than4 micron fraction. Ultrasonic treatment was used to suspend the material, then a dispersant was used to prevent flocculation when noted. The solution containing the clay fraction was then passed through a Fisher filter membrane apparatus allowing the solids to be collected on a cellulose membrane filter. These solids were then mounted on a glass slide, dried, and scanned with the Bruker AXS diffractometer. The oriented clay mount was then glycolated and another diffractogram prepared to identify the expandable, water sensitive minerals. The slide is heat-treated and scanned with the same parameters to aid in distinguishing kaolinite and chlorite.

4.6.2.5.2 Thin Section Petrographic Analyses

Samples selected for thin section analyses were prepared by first vacuum impregnating with blue-dyed epoxy. The samples were then mounted on an optical glass slide and cut and lapped in water to a thickness of 0.03 mm. The prepared sections were then covered with index oil and temporary cover slips, and then analyzed using standard petrographic techniques.

OMNI LABORATORIES, INC.
X-RAY DIFFRACTION
(WEIGHT %)

Client: BP Alaska
Well: MT. Elbert - 01
Area: AK, USA
Sample Type: Conventional Core

File No: HH-36510
Date: 03/07/08
Analyst: G. Walker

Sample	CLAYS				CARBONATES			OTHER MINERALS						TOTALS		
	Chlorite	Kaolinite	Illite	Mx I/S*	Calcite[1]	Dol/Ank	Siderite	Quartz	K-spar	Plag.	Pyrite	Zeolite	Barite	Clays	Carb.	Other
2-2-8-9	12	3	13	2	0	0	Tr	54	1	6	9	0	0	30	Tr	70
2-2-21-27B	14	3	17	3	0	0	Tr	47	1	7	8	0	0	37	Tr	63
2-7-16-17	3	2	3	2	0	0	Tr	83	1	4	2	0	0	10	Tr	90
3-7-3	3	2	3	2	0	0	Tr	81	1	7	1	0	0	10	Tr	90
5-8-1-6A	13	4	20	4	0	0	Tr	47	1	10	1	0	0	41	Tr	59
6-5-30-36A	7	2	9	1	0	0	Tr	67	1	12	1	0	0	19	Tr	81
8-3-10-11	6	1	7	1	0	0	Tr	73	1	10	1	0	0	15	Tr	85
9-1-2-7A	2	1	2	Tr	0	0	Tr	90	1	3	1	0	0	5	Tr	95
12-3-6-12A	11	2	12	2	0	0	Tr	61	1	10	1	0	0	27	Tr	73
22-4-20-23B	13	3	15	3	0	0	Tr	53	1	11	1	0	0	34	Tr	66
AVERAGE	9	2	10	2	0	0	Tr	65	1	8	3	0	0	23	Tr	77

* Randomly interstratified mixed-layer illite/smectite; Approximately 90-95% expandable layers
[1] May include the Fe-rich variety

Table 3: OMNI XRD analyses of core samples selected for thin sections.

THIN SECTION MODAL ANALYSIS

BP Alaska
Mount Elbert-01
North Slope Borough, Alaska
Job No.: HH-36510 Sample Type: Conventional Core Plug Analyst: C. Manske

DEPTH (ft):	**2017.10**	**2018.35**	**2032.40**	**2045.90**
SAMPLE NO.:	**2-2-8-9**	**2-2-21-27B**	**2-7-16-17**	**3-7-3**
Grain Size Avg. (mm):	**0.03**	**0.02**	**0.11**	**0.09**
Grain Size Range (mm):	**<0.01-0.38**	**<0.01-0.23**	**0.03-0.38**	**0.02-0.26**
Sorting:	**Moderately Poor**	**Moderately Poor**	**Moderately Well**	**Well**
Fabric:	**Laminated**	**Laminated**	**Vaguely G.S.-zoned**	**Massive**
Rock Name (Folk):	**Shale w/ Sd./Slt. Lams.**	**Shale w/ Sd./Slt. Lams.**	**Feldspathic Litharenite**	**Feldspathic Litharenite**
FRAMEWORK GRAINS				
Quartz	**33**	**34**	**27**	**28**
Monocrystalline	31	33	22	25
Polycrystalline	2	1	5	3
Feldspar	**8**	**5**	**13**	**13**
K-Feldspar	3	2	6	5
Plagioclase	5	3	7	8
Lithic Fragments	**6**	**3**	**23**	**21**
Plutonic	tr	tr	1	tr

Volcanic	3	2	7	7
Metamorphic	2	1	6	8
Chert	1	tr	7	5
Mudstone	tr	tr	2	1
Carbonate	0	0	tr	0
Sandstone/Siltstone	0	0	0	0
Accessory Grains	**5**	**4**	**1**	**3**
Muscovite	5	3	1	1
Biotite	tr	1	tr	tr
Heavy Minerals*	tr	tr	tr	2
ENVIRON. INDICATORS	**7**	**9**	**1**	**2**
Carbonaceous Material	7	9	1	2
Glauconite	tr	0	0	0
Calcareous Fossils	tr	0	0	0
Phosphatic Grains	tr	tr	0	tr
DETRITAL MATRIX	**29**	**33**	**0**	**0**
CEMENT/REPLACEMENT	**4**	**4**	**4**	**3**
Pore-lining Clay	tr	1	1	1
Kaolinite	tr	tr	0	0
Other Pore-filling Clay	1	tr	tr	tr
Quartz Overgrowths	tr	tr	tr	tr
Feldspar Overgrowths	0	tr	tr	tr
Calcite	0	0	0	0
Fe-Dolomite	0	0	0	0
Ankerite	0	0	tr	0
Siderite	tr	0	2	tr
Pyrite	2	3	1	2
Fe/Ti Oxides	1	tr	0	tr
Sulfate	0	0	0	0
Bitumen	0	0	0	0
POROSITY	**8**	**8**	**31**	**30**
Primary	5	3	29	28
Secondary	tr	tr	1	tr
Microscopic	3	5	1	2
TOTALS:	**100**	**100**	**100**	**100**

*Clinozoisite, Epidote, Garnet, Hornblende, Opaques, Pyroxene, Rutile

THIN SECTION MODAL ANALYSIS

BP Alaska
Mount Elbert-01
North Slope Borough, Alaska
Job No.: HH-36510 Sample Type: Conventional Core Plug Analyst: C. Manske

DEPTH (ft):	**2106.60**	**2124.75**	**2163.40**	**2180.25**
SAMPLE NO.:	**5-8-1-6A**	**6-5-30-36A**	**8-3-10-11**	**9-1-2-7A**
Grain Size Avg. (mm):	**0.02**	**0.05**	**0.08**	**0.21**
Grain Size Range (mm):	**<0.01-0.20**	**<0.01-0.14**	**0.03-0.25**	**<0.01-0.83**
Sorting:	**Poor**	**Moderate**	**Moderately Well**	**Moderate**
Fabric:	**Vaguely-Laminated**	**Vaguely-Laminated**	**Vaguely G.S.-zoned**	**Grain Size-zoned**
Rock Name (Folk):	**Shale w/ Sd. Lenses**	**Coarse Siltstone**	**Feldspathic Litharenite**	**Litharenite**
FRAMEWORK GRAINS				

Quartz	**18**	**38**	**45**	**46**
Monocrystalline	17	37	40	39
Polycrystalline	1	1	5	7
Feldspar	**4**	**10**	**6**	**3**
K-Feldspar	2	5	3	2
Plagioclase	2	5	3	1
Lithic Fragments	**4**	**9**	**16**	**20**
Plutonic	tr	tr	1	3
Volcanic	2	3	4	6
Metamorphic	1	2	7	3
Chert	1	1	3	7
Mudstone	tr	3	1	1
Carbonate	0	0	0	0
Sandstone/Siltstone	0	0	0	tr
Accessory Grains	**4**	**6**	**2**	**tr**
Muscovite	3	3	2	tr
Biotite	1	3	tr	tr
Heavy Minerals*	tr	0	tr	tr
ENVIRON. INDICATORS	**5**	**7**	**3**	**1**
Carbonaceous Material	5	6	3	1
Glauconite	tr	tr	0	tr
Calcareous Fossils	0	0	0	0
Phosphatic Grains	0	1	0	tr
DETRITAL MATRIX	**58**	**7**	**0**	**tr**
CEMENT/REPLACEMENT	**2**	**5**	**5**	**1**
Pore-lining Clay	tr	2	2	tr
Kaolinite	tr	0	0	0
Other Pore-filling Clay	1	1	tr	tr
Quartz Overgrowths	tr	tr	tr	tr
Feldspar Overgrowths	tr	0	tr	tr
Calcite	0	0	0	0
Fe-Dolomite	0	0	0	0
Ankerite	0	0	0	0
Siderite	tr	tr	1	0
Pyrite	1	2	2	tr
Fe/Ti Oxides	tr	tr	tr	1
Sulfate	0	0	0	0
Bitumen	0	0	0	0
POROSITY	**5**	**18**	**23**	**29**
Primary	2	12	18	27
Secondary	tr	1	3	1
Microscopic	3	5	2	1
TOTALS:	**100**	**100**	**100**	**100**

*Clinozoisite, Epidote, Hornblende, Opaques, Rutile, Zircon

THIN SECTION MODAL ANALYSIS

BP Alaska
Mount Elbert-01
North Slope Borough, Alaska
Job No.: HH-36510 Sample Type: Conventional Core Plug Analyst: C. Manske

DEPTH (ft): **SAMPLE NO.:**	**2224.15** **12-3-6-12A**	**2454.95** **22-4-20-23B**		

Grain Size Avg. (mm):	**0.05**	**0.03**		
Grain Size Range (mm):	**<0.01-0.28**	**<0.01-0.14**		
Sorting:	**Poor**	**Very Poor**		
Fabric:	**Vaguely-Laminated**	**Laminated**		
Rock Name (Folk):	**Sandy Shale**	**Shale w/ Sd. Lams.**		
FRAMEWORK GRAINS				
Quartz	**26**	**21**		
Monocrystalline	25	20		
Polycrystalline	1	1		
Feldspar	**5**	**5**		
K-Feldspar	2	2		
Plagioclase	3	3		
Lithic Fragments	**6**	**5**		
Plutonic	tr	tr		
Volcanic	3	3		
Metamorphic	1	1		
Chert	2	1		
Mudstone	tr	tr		
Carbonate	0	0		
Sandstone/Siltstone	0	0		
Accessory Grains	**6**	**5**		
Muscovite	5	3		
Biotite	1	2		
Heavy Minerals	0	0		
ENVIRON. INDICATORS	**5**	**6**		
Carbonaceous Material	5	6		
Glauconite	tr	0		
Calcareous Fossils	0	0		
Phosphatic Grains	0	0		
DETRITAL MATRIX	**41**	**45**		
CEMENT/REPLACEMENT	**3**	**5**		
Pore-lining Clay	tr	1		
Kaolinite	0	0		
Other Pore-filling Clay	tr	tr		
Quartz Overgrowths	tr	tr		
Feldspar Overgrowths	0	0		
Calcite	0	0		
Fe-Dolomite	0	0		
Ankerite	0	0		
Siderite	tr	1		
Pyrite	3	2		
Fe/Ti Oxides	0	1		
Sulfate	0	0		
Bitumen	0	0		
POROSITY	**8**	**8**		
Primary	5	3		
Secondary	tr	tr		
Microscopic	3	5		
TOTALS:	**100**	**100**		

Table 4: OMNI Thin Section Modal Analyses of core samples.

4.6.2.6 Petrographic Thin Section Photos and Description

4.6.2.6.1 Sample Depth: 2017.10 Feet, Sample Number: 2-2-8-9

Lithology: Shale
Fabric and Texture: Sand-/Silt-Laminated
Framework Grains: Mainly quartz (Plate 1B; C-D5); moderate potassium (Plate 1B; A-B7) and plagioclase (Plate 1B; K5.5) feldspar; minor lithics (Plate 1B; D-E15); elongate plant fragments (Plate 1B; B10)
Matrix: Clay-rich; organic-bearing; laminated (across Plate 1A from F-G)
Cements and Replacement Minerals: Pyrite (Plate 1B; A-B3.5); recrystallized clay matrix (Plate 1B)
Pore System and Reservoir Quality: Minor intergranular (Plate 1B; E-F12) and micropores (Plate 1B; area of H-J9)

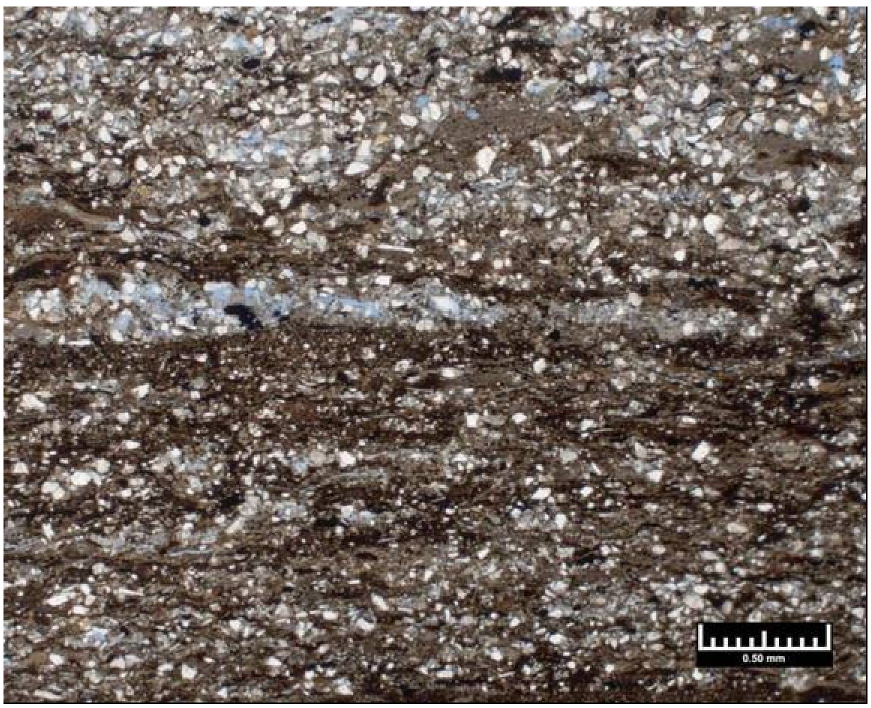


Figure 7: Photomicrograph of Sample Depth: 2017.10 Feet Sample Number: 2-2-8-9 Magnification: A: 40X

4.6.2.6.2 Sample Depth: 2018.35 Feet, Sample Number: 2-2-21-27B

Lithology: Shale
Fabric and Texture: Sand-/Silt-Laminated
Framework Grains: Mainly quartz (Plate 2A; G9); moderately potassium (Plate 2B; G11); minor lithics
Matrix: Clay rich; organic-bearing; laminated (across Plate 2A from G-H)
Cements and Replacement Minerals: Pyrite (Plate 2B; E-F4.5; recrystallized clay matrix (Plate 2B; G5)
Pore System and Reservoir Quality: Dominant micropores, minor intergranular porosity (Plate 2B; G-H5)

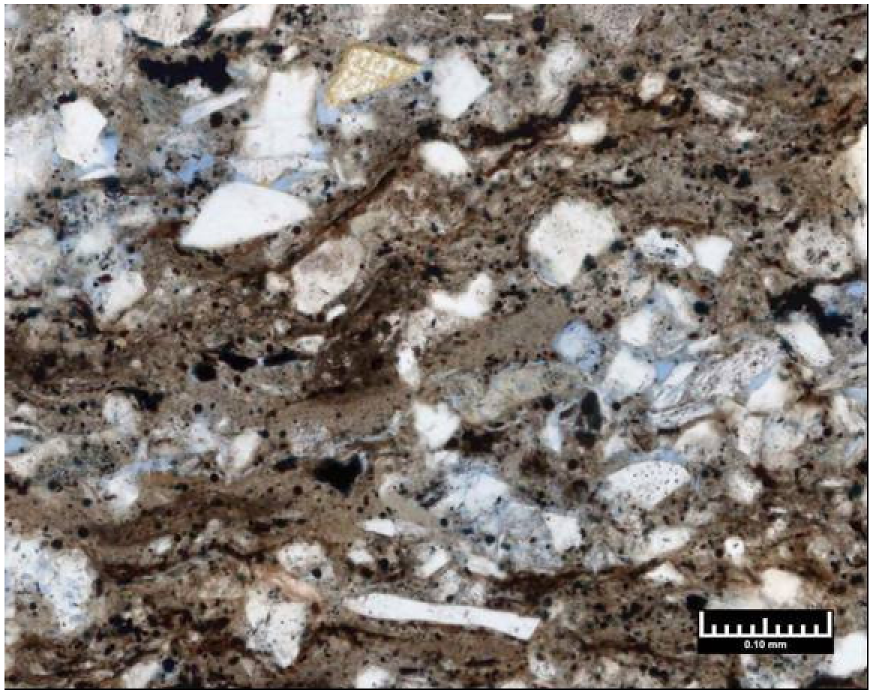


Figure 8: Photomicrograph of Sample Depth: 2017.10 Feet Sample Number: 2-2-8-9 Magnification: B: 200X

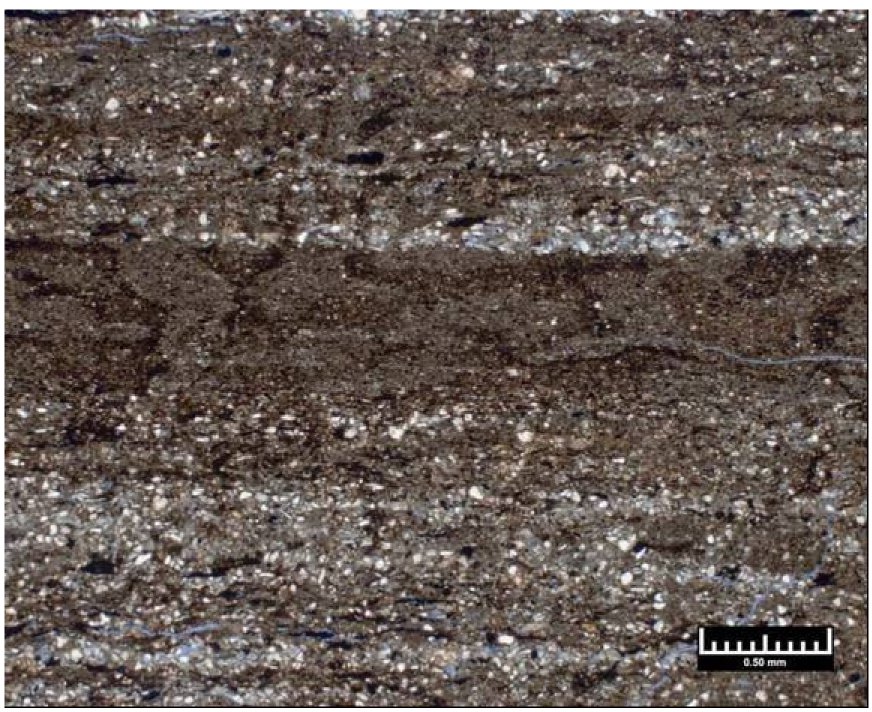


Figure 9: Photomicrograph of Sample Depth: 2018.35 Feet Sample Number: 2-2-21-27B Magnification: A: 40X

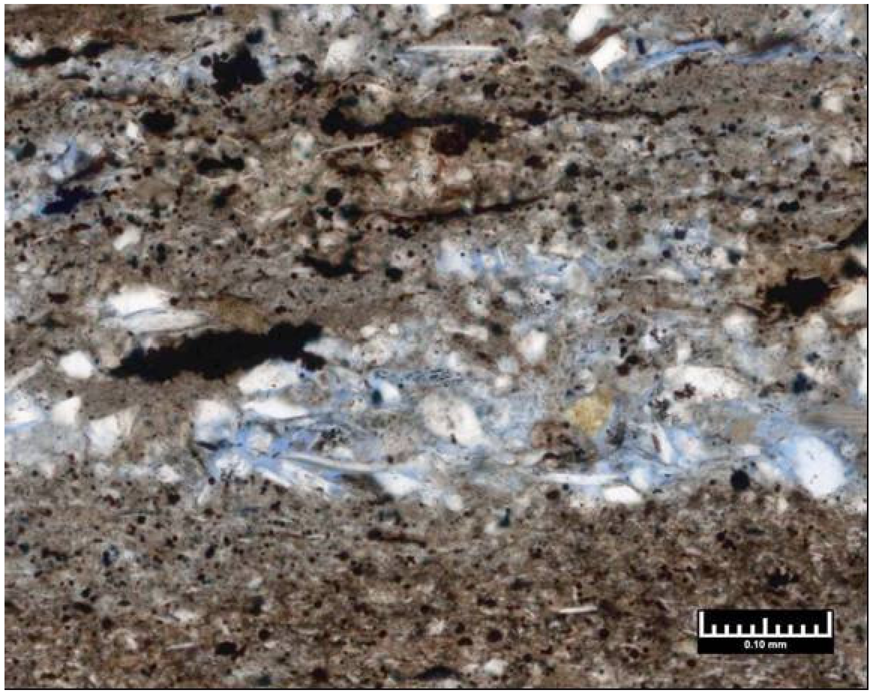


Figure 10: Photomicrograph of Sample Depth: 2018.35 Feet Sample Number: 2-2-21-27B Magnification: B: 200 X

4.6.2.6.3 Sample Depth: 2032.40 Feet, Sample Number: 2-7-16-17

Lithology: Sandstone
Fabric and Texture: Vaguely Grain size-zoned
Framework Grains: Mainly quartz (Plate 3A; B 5.5); sub-dominant lithics (Plate 3B; B-C11.5); moderate potassium (Plate 3B; H5)
Matrix: None
Cements and Replacement Minerals: Pyrite (Plate 3B; H7); pore-lining clay (Plate 3B; C1)
Pore System and Reservoir Quality: Dominant interporosity (Plate 3B; E9.5)

4.6.2.6.4 Sample Depth: 2045.90 Feet, Sample Number: 3-7-3

Lithology: Sandstone
Fabric and Texture: Massive, very fine-grained, well sorted
Framework Grains: Mainly quartz (Plate 4A; E11); moderate lithics (Plate 4B; E4.5); minor plagioclase (Plate 4A;G9) and potassium feldspars
Matrix: None
Cements and Replacement Minerals: Pyrite (Plate 4B; F12) ; pore-lining clay (Plate 4B; H5.5)
Pore System and Reservoir Quality: Dominant intergranular (Plate 4B; G9); minor microporosity (Plate 4B; within grain at D11)

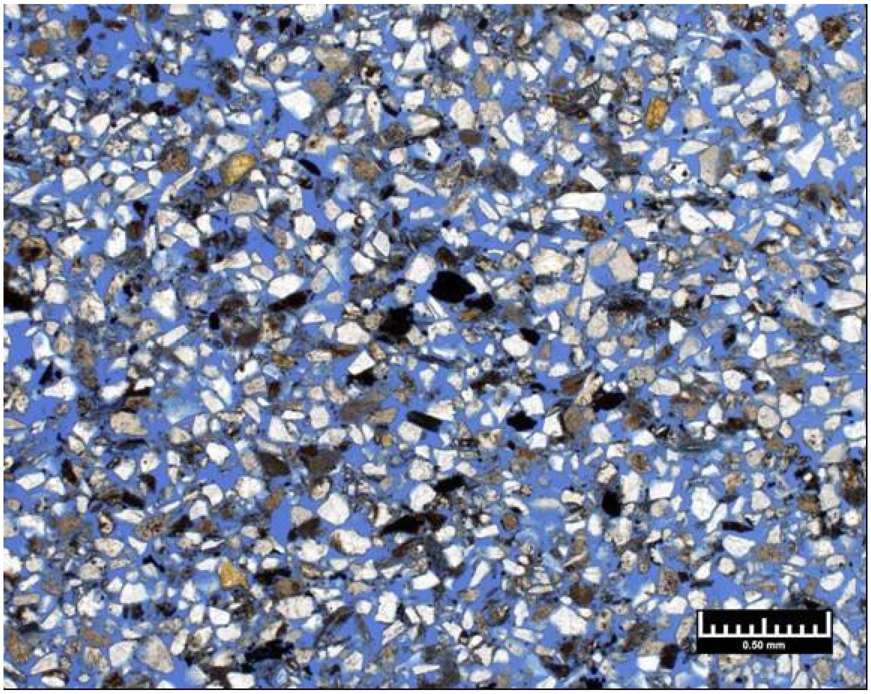


Figure 11: Photomicrograph of Sample Depth: 2032.40 Feet Sample Number: 2-7-16-17 Magnification: A: 40X

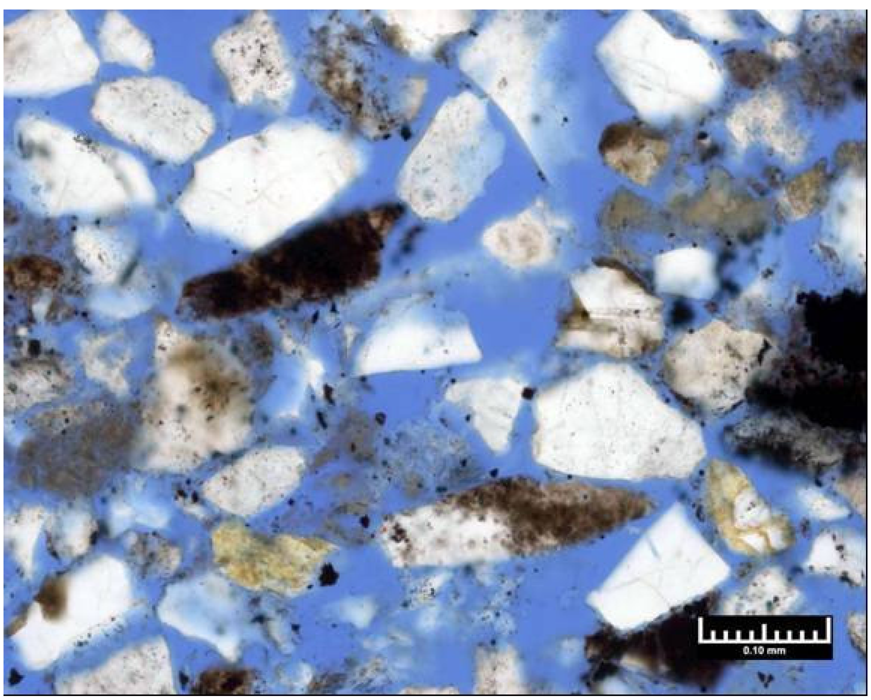


Figure 12: Photomicrograph of Sample Depth: 2032.40 Feet Sample Number: 2-7-16-17 Magnification: B: 200X

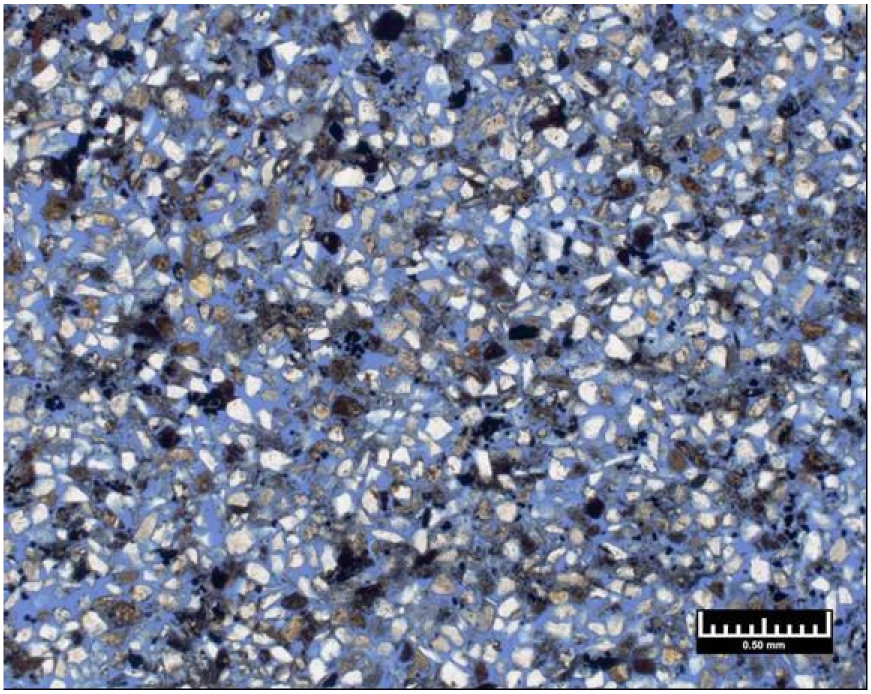


Figure 13: Photomicrograph of Sample Depth: 2045.90 Feet Sample Number: 3-7-3 Magnification: A: 40X

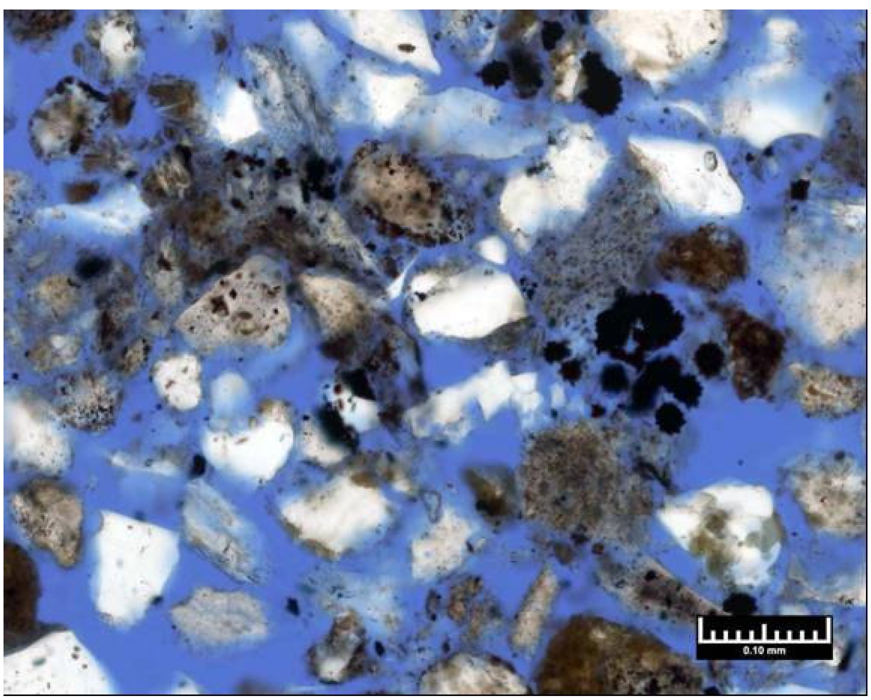


Figure 14: Photomicrograph of Sample Depth: 2045.90 Feet Sample Number: 3-7-3 Magnification: B: 200 X

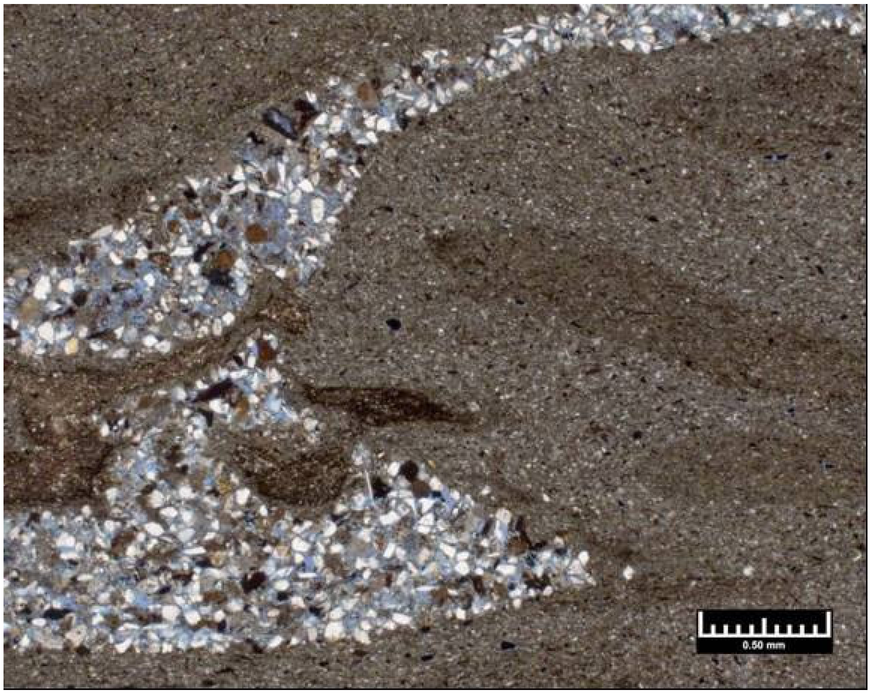


Figure 15: Photomicrograph of Sample Depth: 2106.60 Feet Sample Number: 5-8-1-6A Magnification: A: 40X

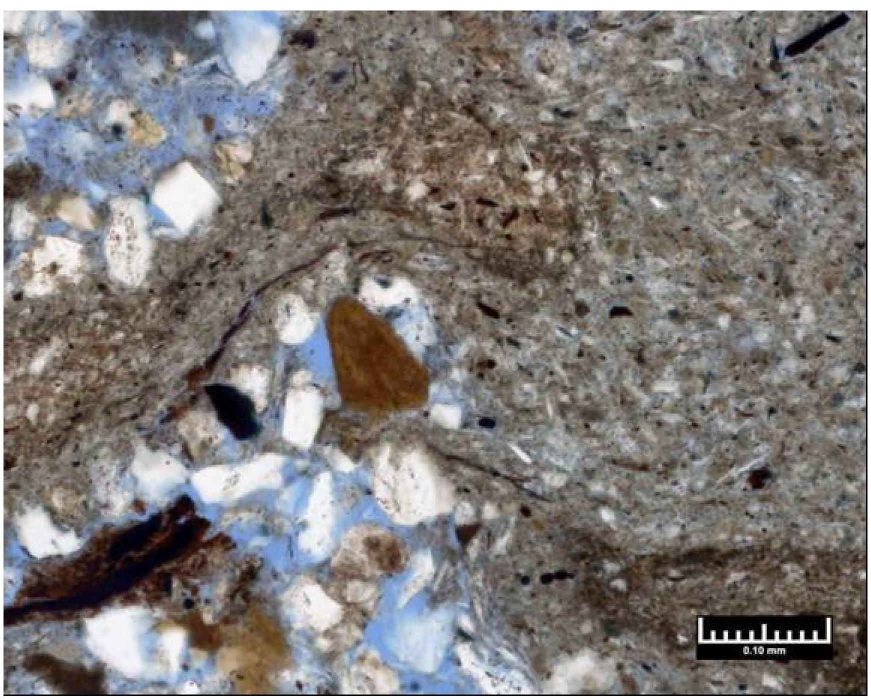


Figure 16: Photomicrograph of Sample Depth: 2106.60 Feet Sample Number: 5-8-1-6A Magnification: B: 200X

4.6.2.6.5 Sample Depth: 2106.60 Feet, Sample Number: 5-8-1-6A

Lithology: Shale
Fabric and Texture: Vaguely-Laminated; Burrowed
Framework Grains: Dominant quartz (Plate 5A; C6); moderate lithics (Plate 5B; H7), minor potassium feldspar (Plate 5B; B3)
Matrix: Detrital (Plate 5A; brownish fine material)
Cements and Replacement Minerals: Pyrite (Plate 5B; J10)
Pore System and Reservoir Quality: Subequal microporosity (within matrix); and intergranular porosity (Plate 5B; E6)

4.6.2.6.6 Sample Depth: 2124.75 Feet, Sample Number: 6-5-30-36A

Lithology: Coarse Siltstone
Fabric and Texture: Vaguely-Laminated
Framework Grains: Mainly quartz (Plate 6A;F8); moderate plagioclase (Plate 6B;F5) and lesser potassium feldspar; minor lithics (Plate 6A; B-C12.5)
Matrix: Depositional; clay-rich; minor
Cements and Replacement Minerals: Pore-lining clay (Plate 6B; D8.5); pyrite (Plate 6B; K11.5)
Pore System and Reservoir Quality: Dominant intergranular (Plate 6B;B7.5); moderate microscopic (Plate 6B; G6)

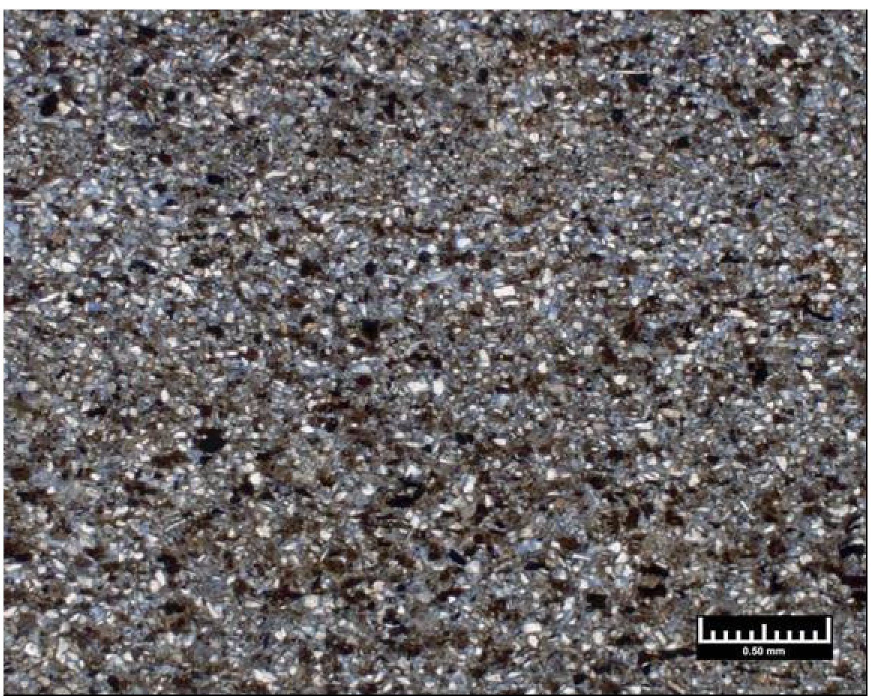


Figure 17: Photomicrograph of Sample Depth: 2124.75 Feet Sample Number: 6-5-30-36A Magnification: A: 40X

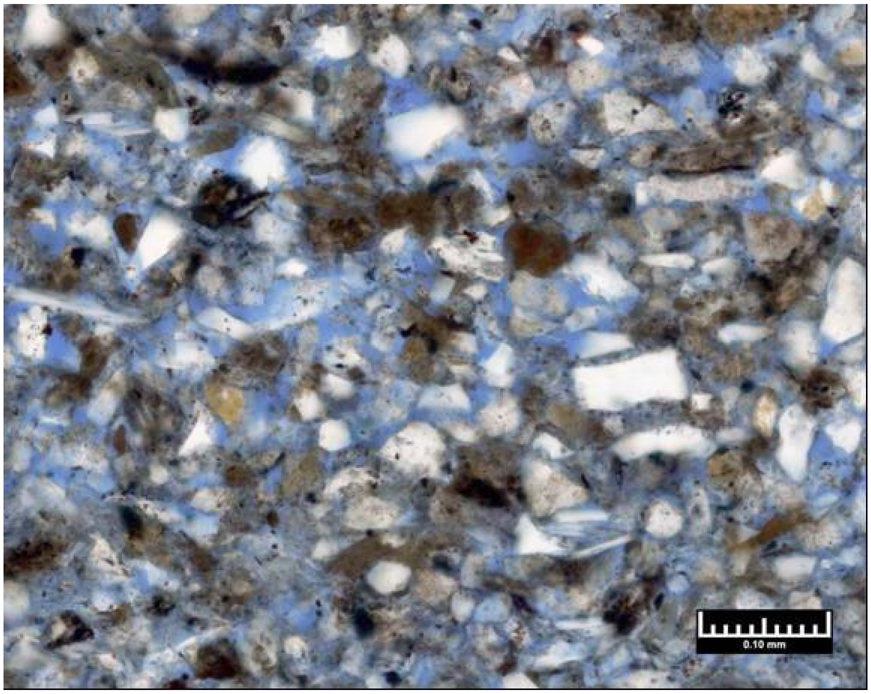


Figure 18: Photomicrograph of Sample Depth: 2124.75 Feet Sample Number: 6-5-30-36A Magnification: B: 200X

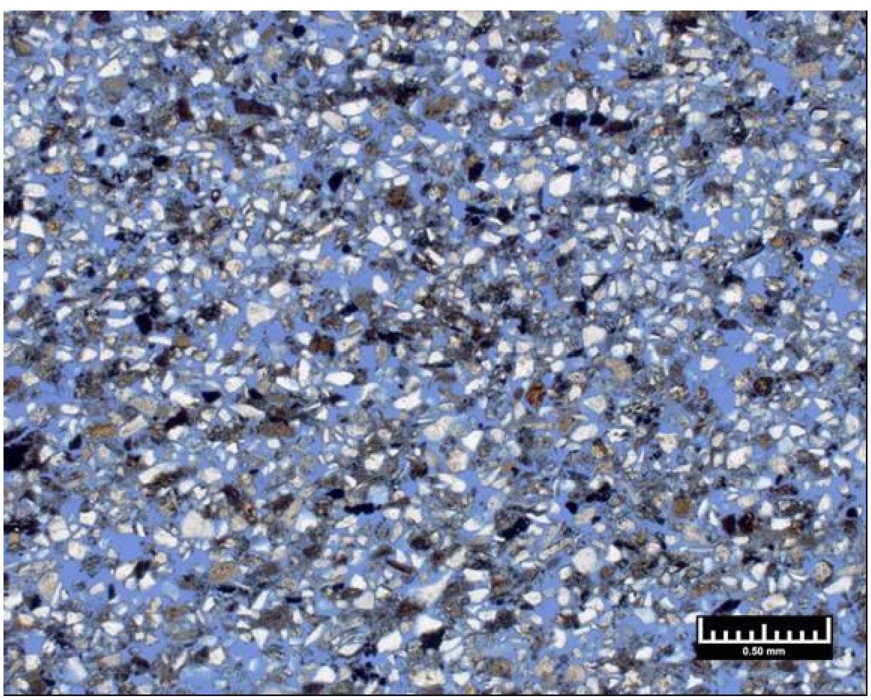


Figure 19: Photomicrograph of Sample Depth: 2163.40 Feet Sample Number: 8-3-10-11 Magnification: A: 40X

4.6.2.6.7 Sample Depth: 2163.40 Feet, Sample Number: 8-3-10-11

Lithology: Sandstone
Fabric and Texture: Vaguely Grain Size-zoned
Framework Grains: Mainly quartz (Plate 7A; C10); moderate lithics (Plate 7B; E5); minor potassium and plagioclase (Plate 7B; B6) feldspars
Matrix: Pyrite (Plate 7B; E9); pore-lining clay (Plate 7B; B10.5)
Cements and Replacement Minerals: Dominant intergranular (Plate 7B; D5); minor microscopic (within pore-lining clays)
Pore System and Reservoir Quality:

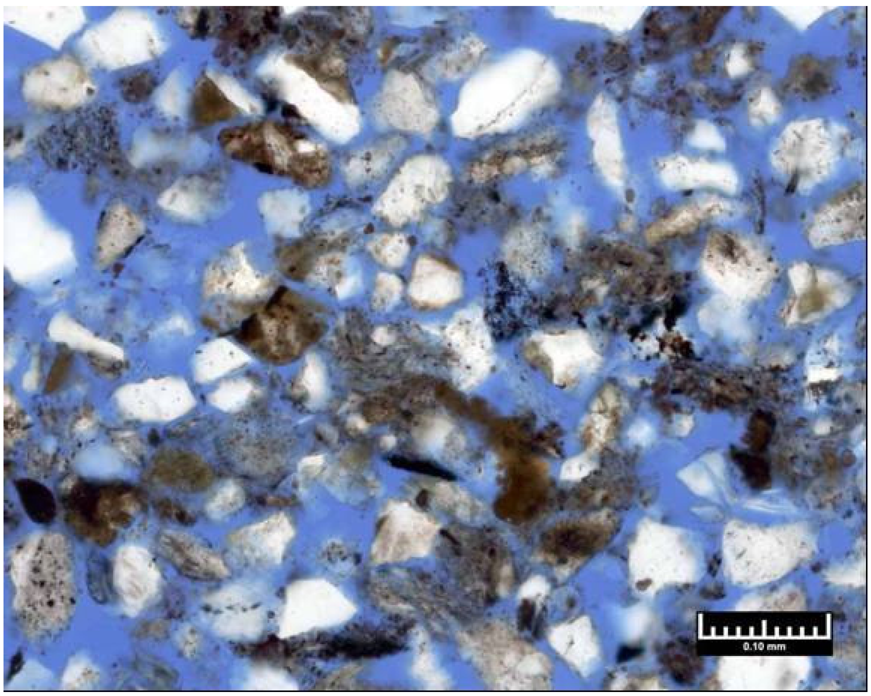


Figure 20: Photomicrograph of Sample Depth: 2163.40 Feet Sample Number: 8-3-10-11 Magnification: B: 200X

4.6.2.6.8 Sample Depth: 2180.25 Feet, Sample Number: 9-1-2-7A

Lithology: Sandstone
Fabric and Texture: Grain Size-zoned
Framework Grains: Mostly quartz (Plate 8A; H11); common lithics (Plate 8B; C11); minor plagioclase (Plate 8A; H-J3) feldspar
Matrix: None
Cements and Replacement Minerals: Minor pyrite (Plate 8B; F10)
Pore System and Reservoir Quality: Dominant primary intergranular (Plate 8B; E12); minor secondary intragranular porosity (Plate 8B; G-H6.5) and microscopic (associated with clays)

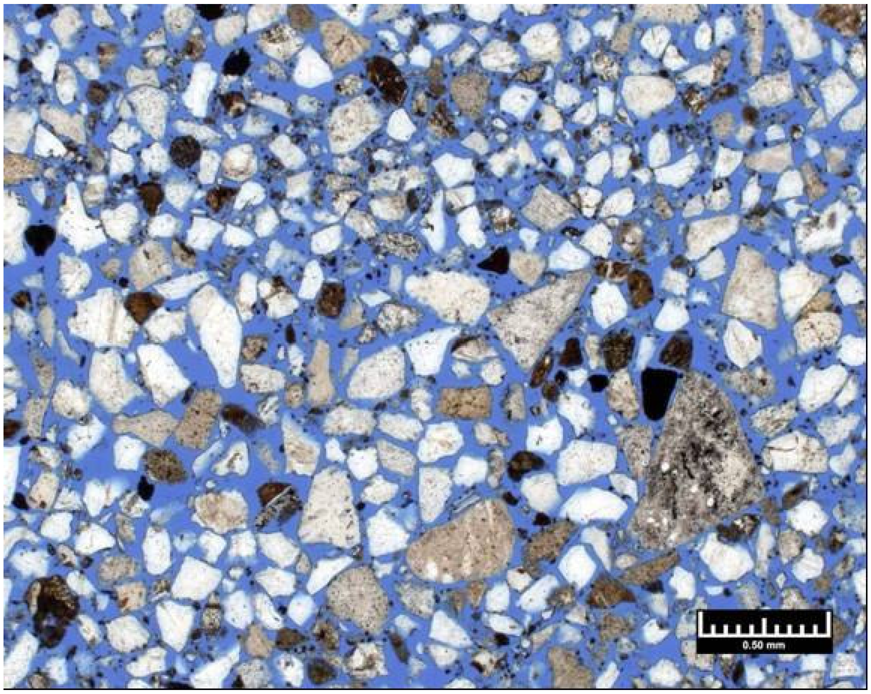


Figure 21: Photomicrograph of Sample Depth: 2180.25 Feet Sample Number: 9-1-2-7A Magnification: A: 40X

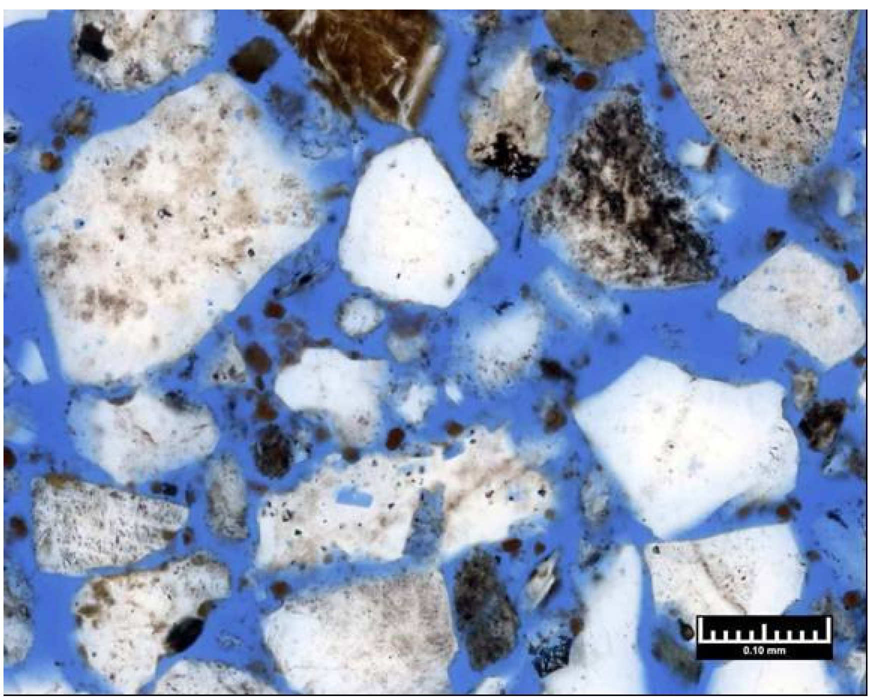


Figure 22: Photomicrograph of Sample Depth: 2180.25 Feet Sample Number: 9-1-2-7A Magnification: B: 200X

4.6.2.6.9 Sample Depth: 2224.15 Feet, Sample Number: 12-3-6-12A

Lithology: Shale
Fabric and Texture: Sandy; Vaguely-Laminated
Framework Grains: Mostly quartz (Plate 9A; E-F7); moderate lithics (Plate 9B: D9); minor plagioclase (D-E13) and potassium feldspars
Matrix: Detrital; brownish; clay-rich
Cements and Replacement Minerals: Pyrite (Plate 9B; E10)
Pore System and Reservoir Quality: Minor intergranular (elsewhere in thin section); moderate microscopic (Plate 9B: C-D8.5); rare secondary intragranular (Plate 9B; G10)

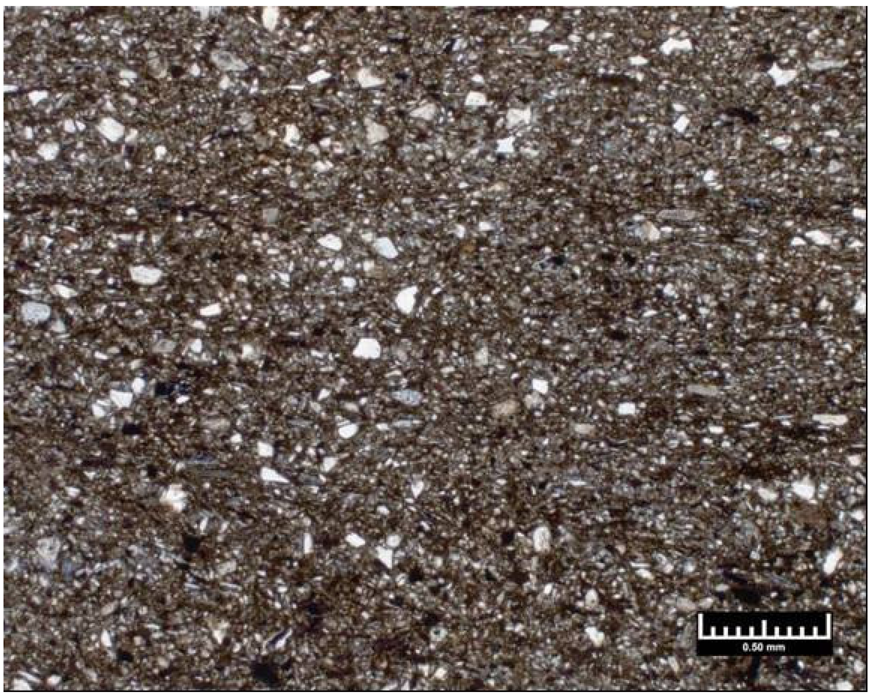


Figure 23: Photomicrograph of Sample Depth: 2224.15 Feet Sample Number: 12-3-6-12A Magnification: A: 40X

4.6.2.6.10 Sample Depth: 2454.95 Feet, Sample Number: 22-4-20-23B

Lithology: Shale
Fabric and Texture: Sand-Laminated
Framework Grains: Mostly quartz (Plate 10A; C13); moderate lithic fragments (Plate 10B; F4); minor muscovite mica (Plate 10B; F6); rare zircon (Plate 10B; E-F8)
Matrix: Detrital; clay-rich; organic-bearing
Cements and Replacement Minerals: Pyrite (Plate 10B; B14); minor siderite and Fe/Ti oxides
Pore System and Reservoir Quality: Dominate microporosity (Plate 10B; E9); moderate interporosity (Plate 10B; F10)

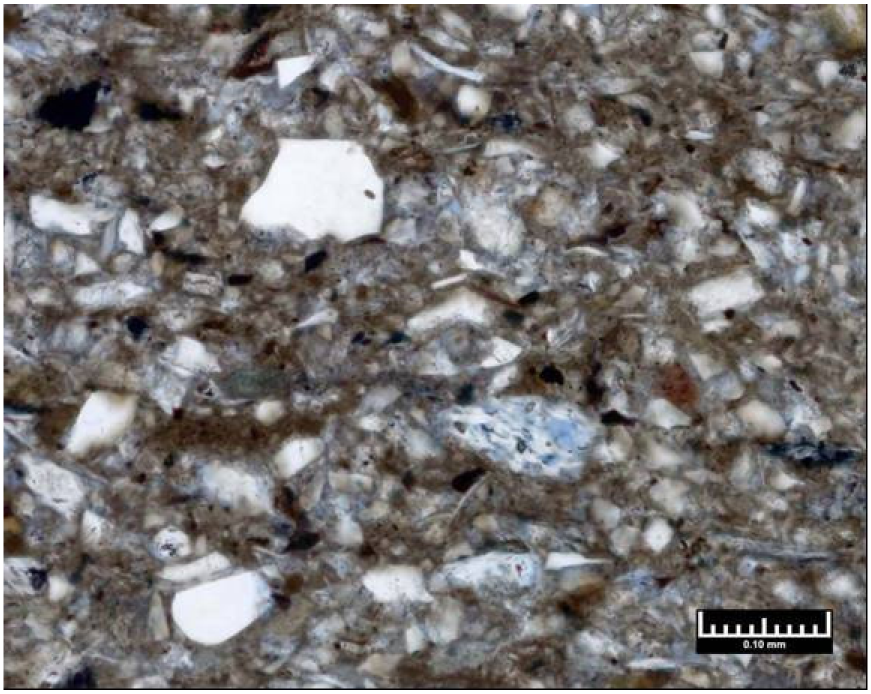


Figure 24: Photomicrograph of Sample Depth: 2224.15 Feet Sample Number: 12-3-6-12A Magnification: B: 400X

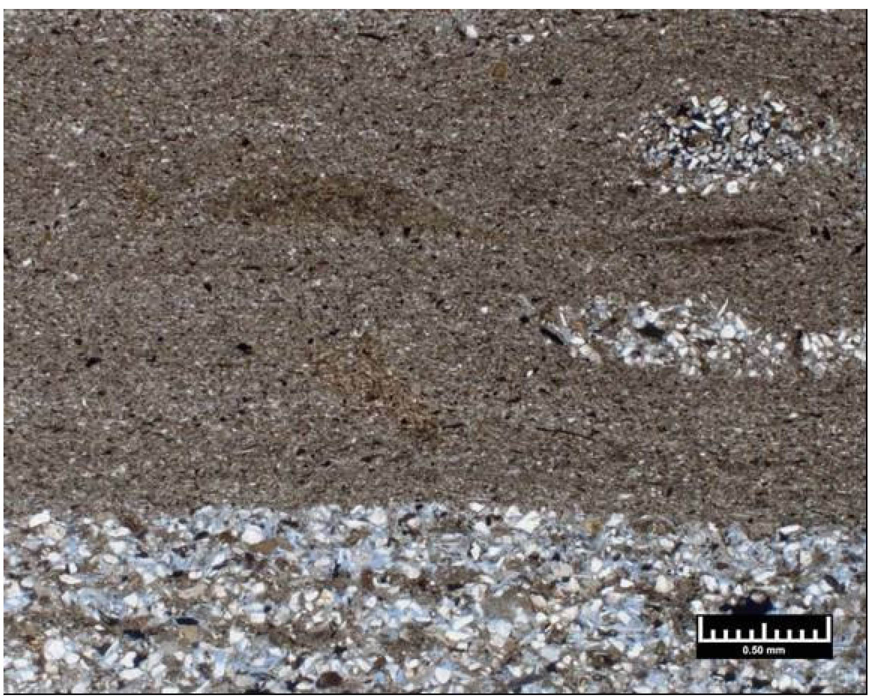


Figure 25: Photomicrograph of Sample Depth: 2454.95 Feet Sample Number: 22-4-20-23B Magnification: A: 40X

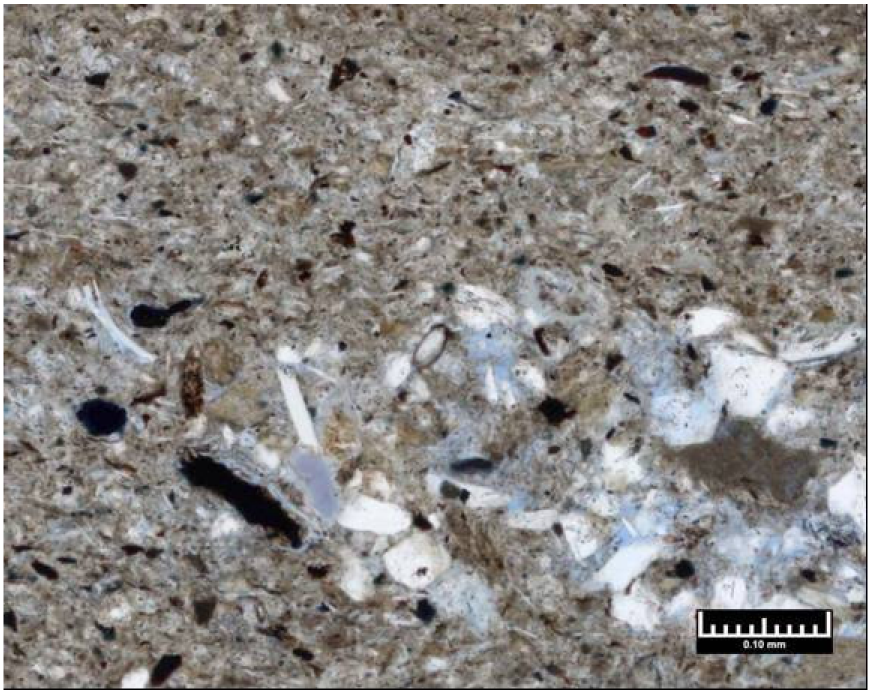


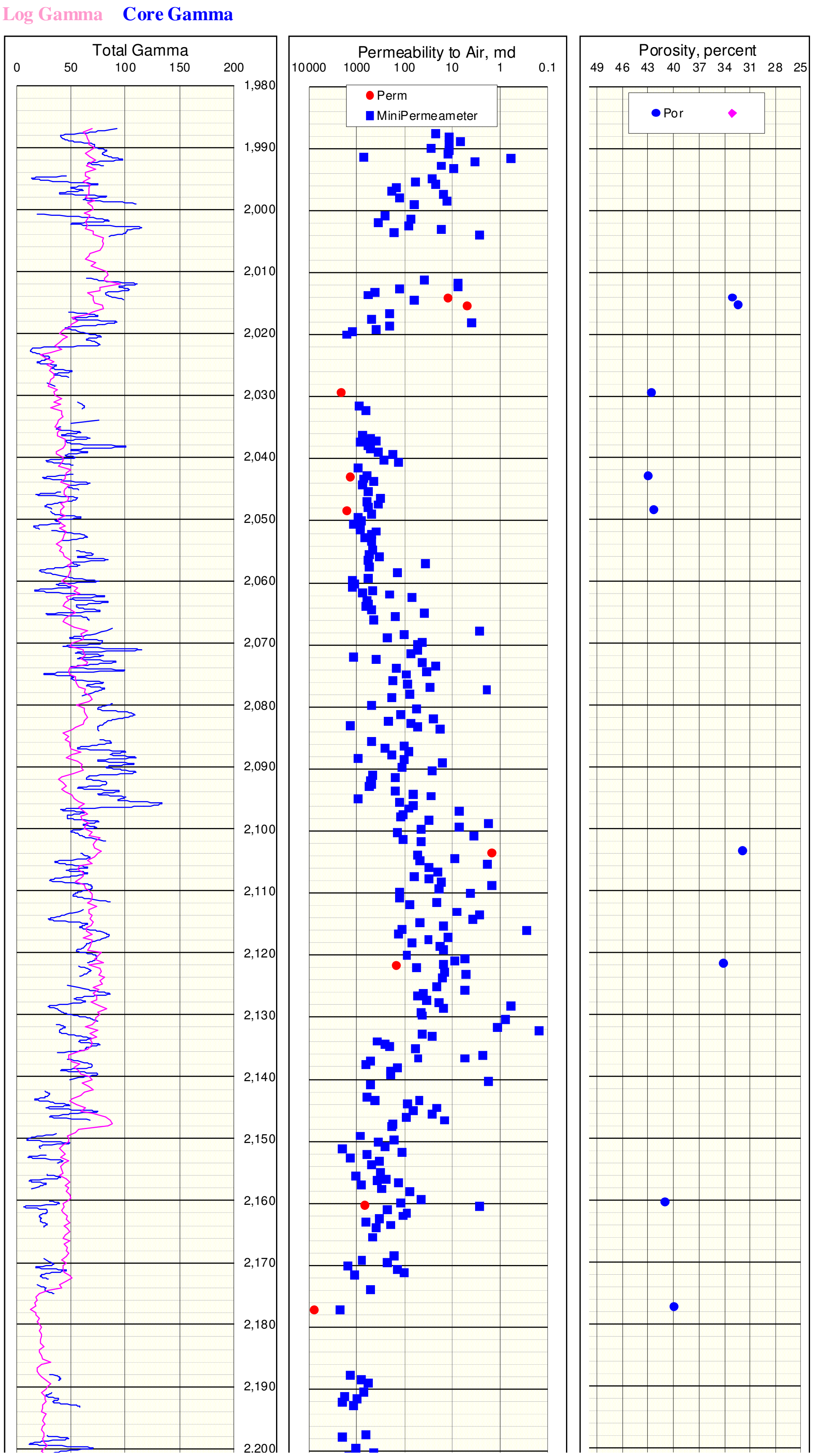
Figure 26: Photomicrograph of Sample Depth: 2454.95 Feet Sample Number: 22-4-20-23B Magnification: A: 200X

4.6.3 Mount Elbert-01 UAF Core Studies Status Report

UAF is analyzing five Mount Elbert-01 vertical plug core samples; studies in conjunction with CoP Bartlesville Lab were accomplished 4Q08-1Q09 in thesis work "Analysis of Permeabilities in Hydrate-Saturated Unconsolidated Core Samples" by UAF graduate student Andrew Johnson. Mr. Johnson is scheduled to defend his thesis in May 2009. Delicate core handling procedures were developed to help alleviate concerns that prior experiments were not performed on "native state" core samples.

Studies identified many difficulties hindering obtaining relative permeability data in gas hydrate-bearing porous media, including difficulties in handling unconsolidated cores during initial core preparation work, forming hydrates in the core to promote flow of both brine and methane, and obtaining simultaneous two phase flow of brine and methane necessary to quantify relative permeability using unsteady state displacement methods. Effective single phase permeabilities in unconsolidated hydrate samples were determined and results indicate that permeability reduction as a function of gas hydrate saturation follows a predictable trend. Relevant study results will be provided once the thesis has completed full committee review.

Over the course of this work, UAF students Aditya Deshpande and Praveen Singh applied a minipermeameter to study permeability variations on the half-slabbed Mount Elbert-01 core sample set. Figure 27 presents the results of the minipermeameter analyses and compares to OMNI Laboratory's conventional poro-perm data analyses.


Log Gamma
Core Gamma
Total Gamma
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50
100
150
200
1,980
1,990
2,000
2,010
2,020
2,030
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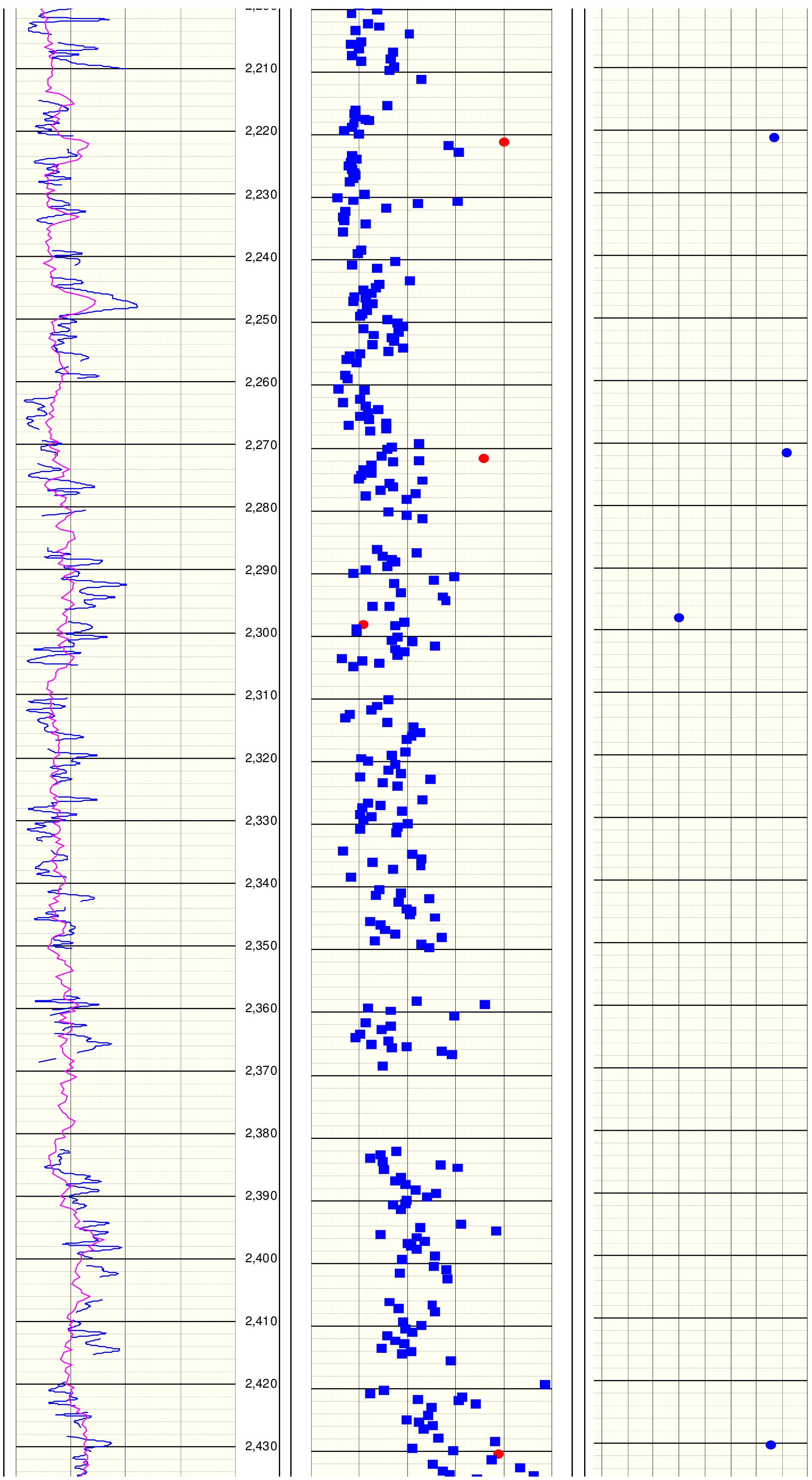
2,050
2,060
2,070
2,080
2,090
2,100
2,110
2,120
2,130
2,140
2,150
2,160
2,170
2,180
2,190
2,200
Permeability to Air, md
10000
1000
100
10
1
0.1
Perm
MiniPermeameter
Porosity, percent
49
46
43
40
37
34
31
28
25
Por


2,210
2,220
2,230
2,240
2,250
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2,270
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2,430

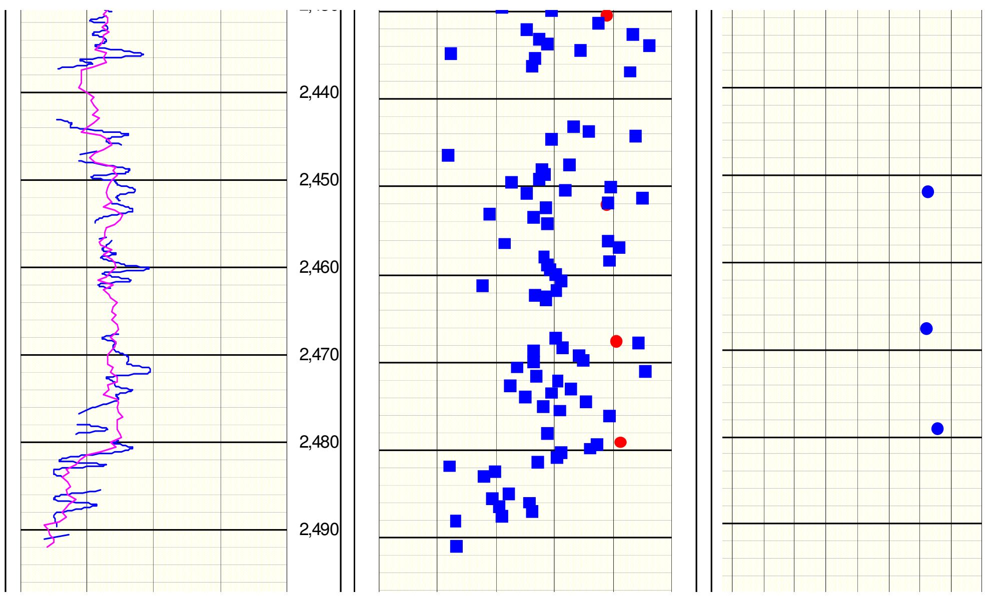


Figure 27: Minipermeameter data plotted with conventional poro-perm data in log-space (minus 3-foot shift applied to core data).

4.7 University of Arizona Draft Report Excerpts

Under the leadership of Principle Investigators Dr. Robert Casavant, Dr. Roy Johnson, and Dr. Mary Poulton, the University of Arizona (UA) submitted a draft final report during the reporting period. Certain sections of that draft report relevant to resource characterization are included here, although the final report remains in-preparation. An Interval-of-interest (IOI) was initially established between lithostratigraphic markers PS-36 and L-31A (Figure 28). However, due to time constraints and resource limitations, the IOI was later shortened to encompass primarily the USGS Zone C unit (Figure 28). Therefore, analyses and interpretation of USGS Zone D and Zone B horizons were limited. In addition, University of Arizona log pattern analyses and paleo-depositional environment interpretations within Zone C sand packages suggest more fluvial and less marine-influence than prior studies. Mount Elbert-01 core sedimentology and palynology descriptions were not available to the University of Arizona at the time of this work; lithostratigraphic interpretation of the Mount Elbert core indicates the B, C, and D Unit sands are shallow marine to shoreface sands interbedded with marine and nonmarine lithofacies. Importantly, however, the well log-based cross-sections, isopach maps, and net sand maps of the Eileen trend Zone C chronostratigraphic correlation intervals were used to interpret distribution and geometry of these gas hydrate-, associated free gas-, and water-bearing reservoir sands and to calculate volumetrics.

4.7.1 Regional Geologic Framework

A robust petroleum system is in place for the generation and emplacement of shallow gas hydrate and associated free-gas resources (Collett et al., 1988) on the central North Slope of Alaska. Current interpretations place these resources within the eastern portions of the Kuparuk River and the Milne Point Units (KRU, MPU), and the western edge the Prudhoe Bay Unit (PBU) (Collett et al., 1988). The majority of reservoirs are contained within a thick interval of Late Cretaceous to Late Tertiary stacked sequences of fluvial-deltaic and nearshore marine gravels, sands, and shales.

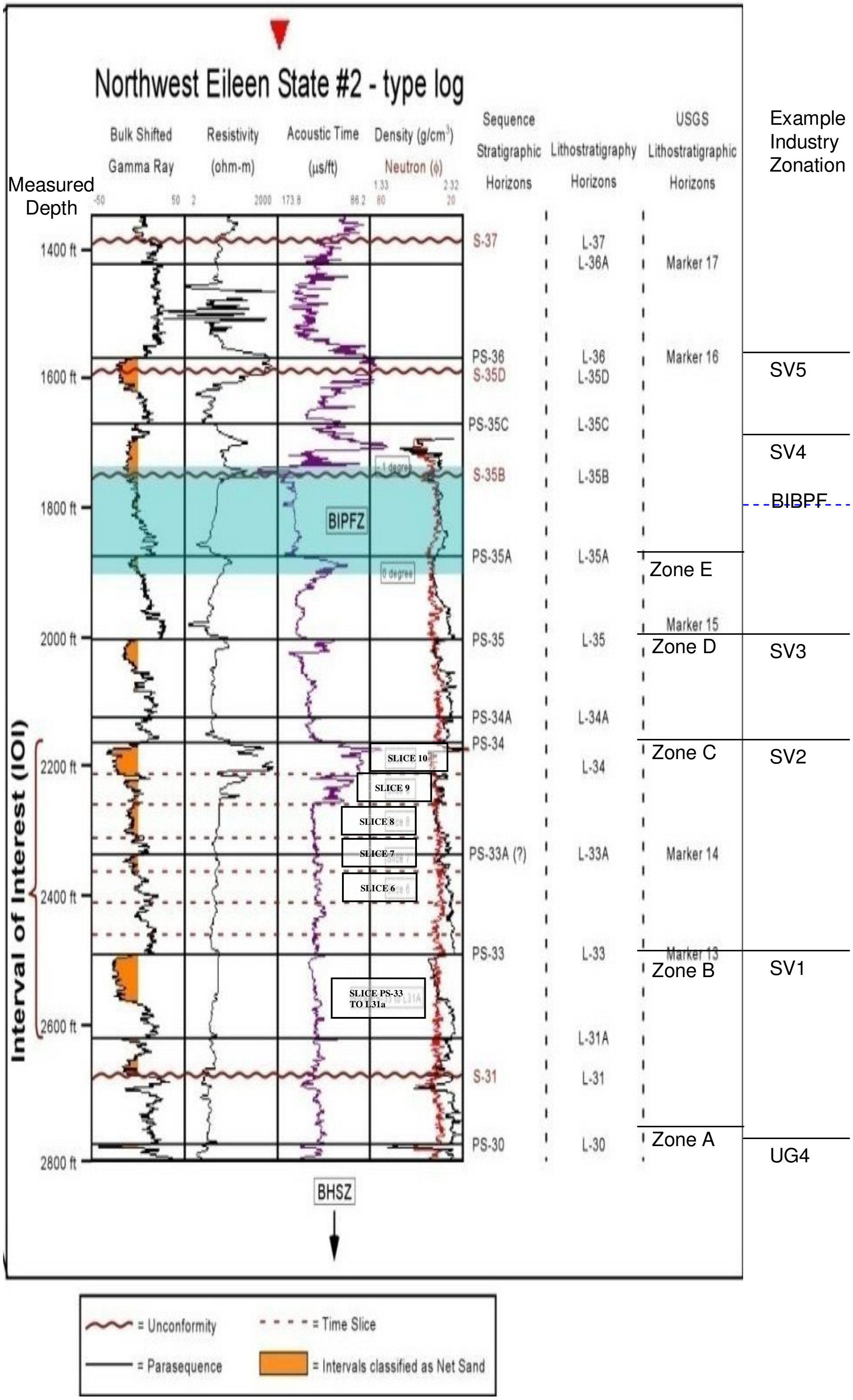


Figure 28: Type Log Northwest Eileen State #2, Eileen Trend showing UA, USGS, and industry zonation for the Sagavanirktok formation. UA chronostratigraphic slices 6-10 occur within Zone C as shown in the small boxes between PS-33 and PS-34.

Regional structural mapping in the MPU and KRU indicates that gas hydrates and free-gas occur along the highly faulted, northeast-dipping flank of a large anticlinal structure (Casavant, 2001; Hennes, Johnson, and Casavant, 2004) This southeast-plunging antiform lies along a regional east-west trending basement antiform, known as the Barrow Arch, which coincides with the northern rifted margin of the Arctic Alaska terrane (AAT) that rifted and docked into its present position during the mid-late Mesozoic. Fault reactivation and structural inversion along weakened and long-lived basement fault blocks beneath MPU and KRU have been linked to basinal fluid migration and variations in permafrost thickness. Periodic crustal shortening along the southern margin of the terrane continues to reactivate basement deformation across the major structural provinces (Casavant, 2001), which included continued segmentation and rotation of the Barrow Arch. Figure 29 illustrates the geologic setting of the study area.

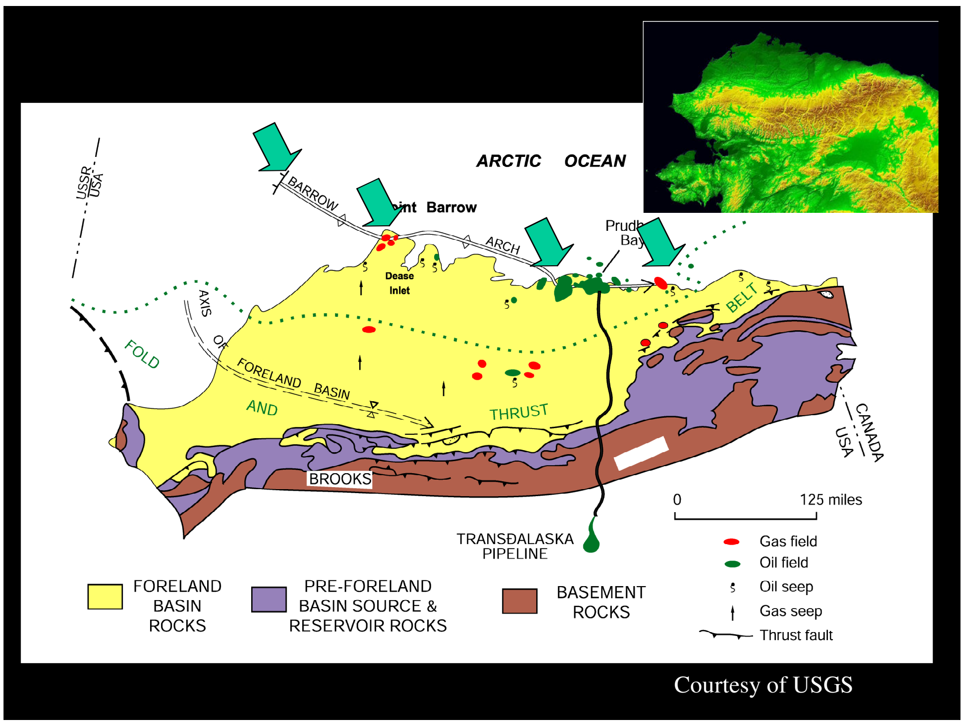


Figure 29: Generalized geologic setting of Arctic Alaska. The Barrow Arch approximates the northern margin of the rifted Arctic Alaska Terrane. Note that the majority of major gas and oil fields occur along the flank of the arch and/or in locations where major bends or offset occur along its axial trend.

Interpretations of 3-D seismic data in the MPU (Hennes, Johnson, and Casavant, 2004 and KRU (Casavant, 2001) reveal that the shallow package of gas hydrate-bearing rocks in the area is extensively deformed by north- and north-northeast trending syn- and post-depositional faults. The presence of diffuse and segmented northwest-trending structural hingeline can be identified on seismic maps as well, by (1) the alignment of termini of north- and north-northeast-trending faults, (2) alignment of inflections, jogs or offset of those sets, (3) the offset/termination of some graben structures, and (4) first-order changes in the structural attitude of stratigraphic units downflank, although no NW-trending offset is resolvable in the vertical seismic sections. These hingelines have been linked to deeper fault zones that segment oil reservoirs and define important oil/water contacts in deeper Cretaceous-age reservoirs (Werner, 1987).

Shallow fault displacements, vertical morphologies, and plan-view distribution suggest that MPU is dominated by down-to-the-east northeast-trending and down-to-the-north northwest-trending systems of normal faulting. A similar conjugate set has been illustrated in numerous studies.

Regional stratigraphic and geophysical studies show that periodic reactivation along basement block boundaries resulted in localized sagging and structural inversion along zones of weakened crust that were constrained to the margins of basement blocks. In numerous locales across the AAT, a morphotectonic analysis suggests that basement faulting has long influenced the morphology, location of both modern and ancient fluvial-deltaic, nearshore marine systems, and upward migration of fluids and heatflow (Casavant, 2001; Rawlinson, 1993; Casavant and Miller, 1999a). Our structure mapping of shallow seismic sequences in MPU revealed a certain degree of spatial correlation between subsurface structure and geomorphic features at the surface as was proposed in earlier studies (Casavant, 2001; Rawlinson, 1993). Such spatial associations suggest the influence of shallow basement control on the morphology of coastal and fluvial elements across the Arctic coastal plains.

Seismic attribute analysis and geologic mapping confirm that in addition to fault compartmentalization, reservoir continuity is also related to changes in facies type and geometry. Regional lithostratigraphic and chronostratigraphic correlations address the stratigraphic framework and implications for reservoir rock continuity. Lithostratigraphic correlation across the study area confirmed the presence of at least six distinct and correlative hydrate-bearing rock units, defined in earlier studies (Collett et al., 1988). Our sequence stratigraphic framework implies, however, a higher degree of reservoir heterogeneity than previously mapped. The distribution and quality of reservoir sands relates not only to rapid changes in depositional environments and facies, but also to the preservation and scouring of reservoir units that can be linked to numerous intraformational unconformities and other structural features (Casavant et al, 2004; Manuel, 2008). A study of facies, sand body dimensions, and related seismic facies mapping was employed to develop a more accurate model of reservoir description needed for estimating volumetric and recovery factors (Manuel, 2008).

We conclude that for the most part, hydrates appear to be influenced by a combination of structural-stratigraphic trapping on the upper flanks and axes of structural highs, where the presence and thickness of porous and permeable reservoir facies is adequate. This is not unlike constraints required for production from deeper, oil-prone marine and fluvial sandstone and conglomerate deposits encountered in the area. Hydrates must be in the pressure-temperature window defined by thermal modeling. We find that the base of the ice bearing permafrost undulates as a function of lithology and thermal gradients. The expert systems and neural networks did not find evidence of gas hydrates in wells outside the likely geologic areas we identified and did find hydrate in areas with favorable geology.

4.7.2 Lithostratigraphic correlations

A lithostratigraphic framework was initially employed in this project. During our initial lithostratigraphic correlation phase, identifying several regionally distinguishable geologic horizons was completed based principally on similar petrophysical log patterns and their vertical relationship among each other. Comparing our early defined lithostratigraphic horizons against previous lithostratigraphic work, (Collett et al., 1988) most of the horizons compared well (Figure 28). Only a few horizons displayed some discrepancies.

During this phase, changes in log character were observed as we moved across the AOI below and above major horizons. These changes were later identified in our facies characterization phase as different depositional environments ranging from onshore fluvial point bars to offshore marine mouthbars and prodelta shales (Figure 30). Variations in depositional settings were not obvious in the early stages, but as our work progressed into mapping lateral changes in sand quality, quantity and connecting potential reservoir bodies, these discrepancies did warrant a re-evaluation of our framework. Initial net sand and facies characterization maps connected thin interbedded and abundantly rich sand bodies together over large areas. Both fluvial and marine sand bodies displayed an unrealistic amount of connectivity in a fashion that is not demonstrated in modern depositional environments (Casavant et al., 2004). Realizing the shortcomings of our early lithostratigraphic framework, a chronostratigraphic (sequence stratigraphic) framework (Van Wagoner et al., 1990) was adopted.

4.7.3 Chronostratigraphic (Sequence Stratigraphic) Correlation

In a chronostratigraphic framework, correlating time significant units is established by identifying major sequence and parasequence units. A diagram emphasizing this point is provided in Figure 31. In our Interval of Interest (IOI – Figure 28) there were several sequence and parasequence units identified, which are displayed in cross-section form in Figures 30, 32, and 33.

4.7.3.1 Sequences

Identifying major sequence units was one key element in creating our chronostratigraphic framework. A sequence by definition is a relatively conformable succession of genetically related strata bounded at its top and base by unconformities and/or their correlative conformities (Van Wagoner et al., 1990). An unconformity is a surface separating younger from older strata, along which there is evidence of subaerial erosional truncation or non-deposition, and, in some areas, correlative submarine erosion, or subaerial exposure, with a significant hiatus indicated (Van Wagoner et al., 1990).

In our initial effort to identify regional sequence units, identification of unconformable surfaces was completed by conducting a pattern analysis of the natural gamma ray log. For this analysis seventeen cross-sections were generated over the AOI. These cross-sections were orientated parallel and perpendicular to the regional strike and dip of the area (Figures 34 and 35). For each cross-section generated, a large transparent paper was overlain and grouping of the natural gamma ray log response took place. Four separate groups of patterns were decided upon to classify the gamma ray log response. These four groups were referred to as, coarsening up, fining up, sandy and shale rich intervals. This gross classification approach was initially performed to see if any major patterns obviously revealed themselves. An example of this procedure is given in Figure 36 with corresponding colors to emphasis classified intervals.

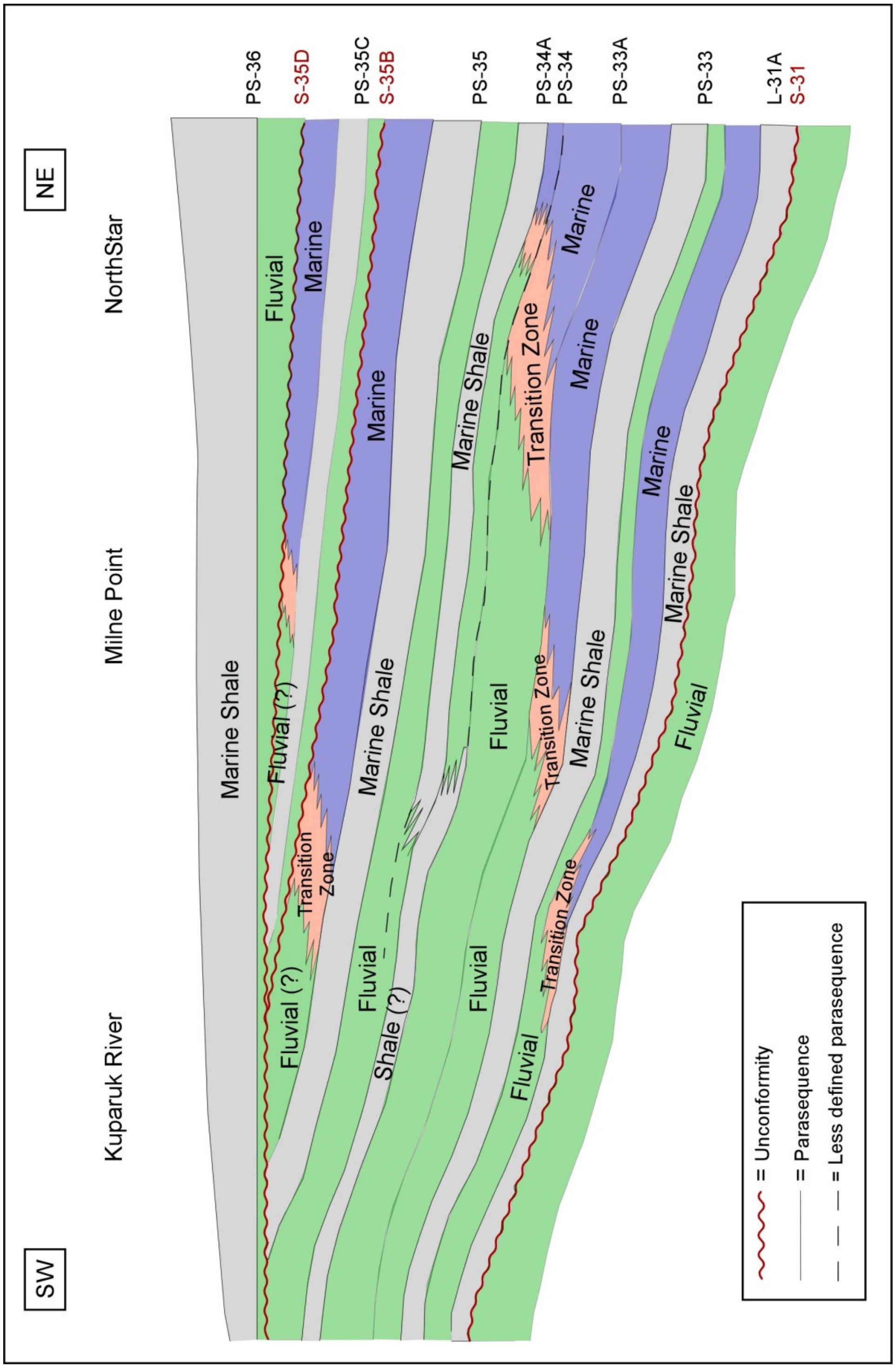


Figure 30: A diagrammatic stratigraphic cross-section representing the interpreted depositional environments that exist throughout the AOI. This cross-section was interpreted from the stratigraphic cross-section in Figure 33.

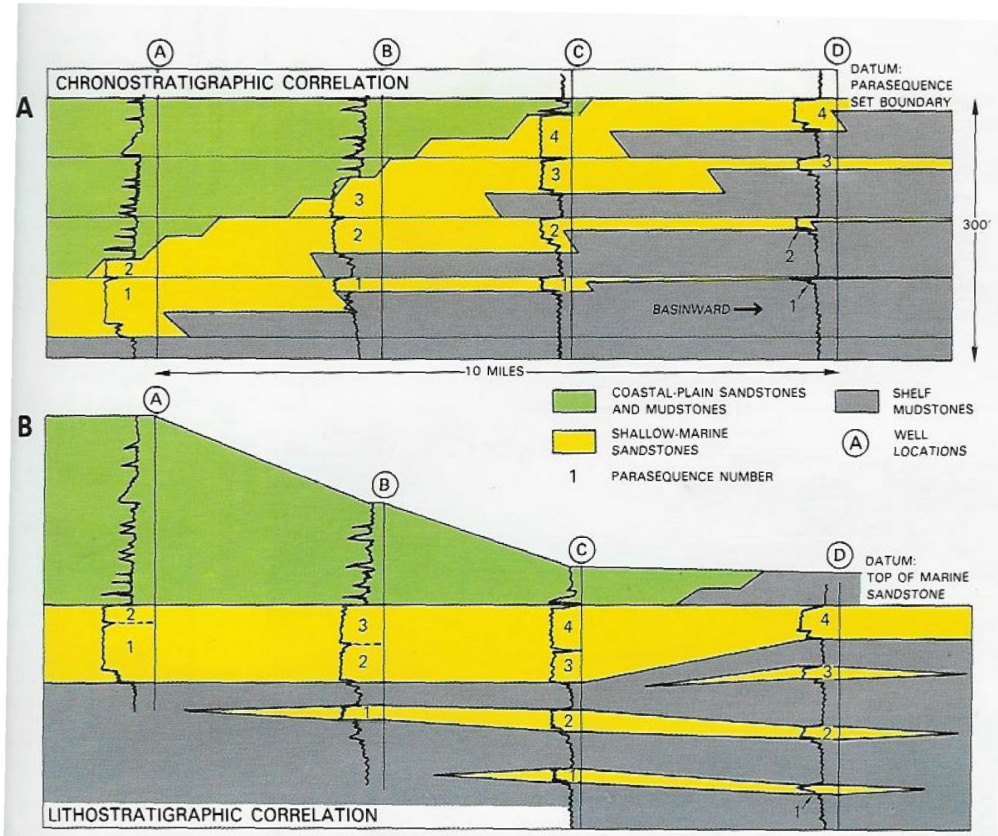


Figure 31: A diagrammatic sketch cross-section representing the drastic differences between a lithostratigraphic and chronostratigraphic framework system (Van Wagoner 1990).

Initial interval grouping was carried out on similar gamma ray log responses greater than 60 feet. This data corresponds to the black arrows in Figure 36. After reviewing the initial results, much detail was felt to be left out and in many intervals general under classification of units was observed. Acknowledging this fact, a second and more refined pattern analysis was conducted, which is shown by the red arrows in Figure 36. This analysis appeared to reveal more of the rapidly changing nature displayed in the gamma ray log. Blocky shades of color were added to this pattern analysis to enhance changing behaviors.

From this initial work, interpretation of intraformational unconformities commenced. The criteria for classifying an unconformity was to identify an interval that displayed interpreted pattern characteristics of a fluvial unit, usually classified as a fining up or sandy rich interval, lying directly above and truncating a marine unit, usually classified as coarsening up, sandy or shale rich interval. This approach was adopted in this work because of the abrupt behavior observed as sea level rapidly drops during the transition period from a high to low stand system track, as described by Van Wagoner in his Siliciclastic Sequence Stratigraphy book (Van Wagoner et al., 1990).

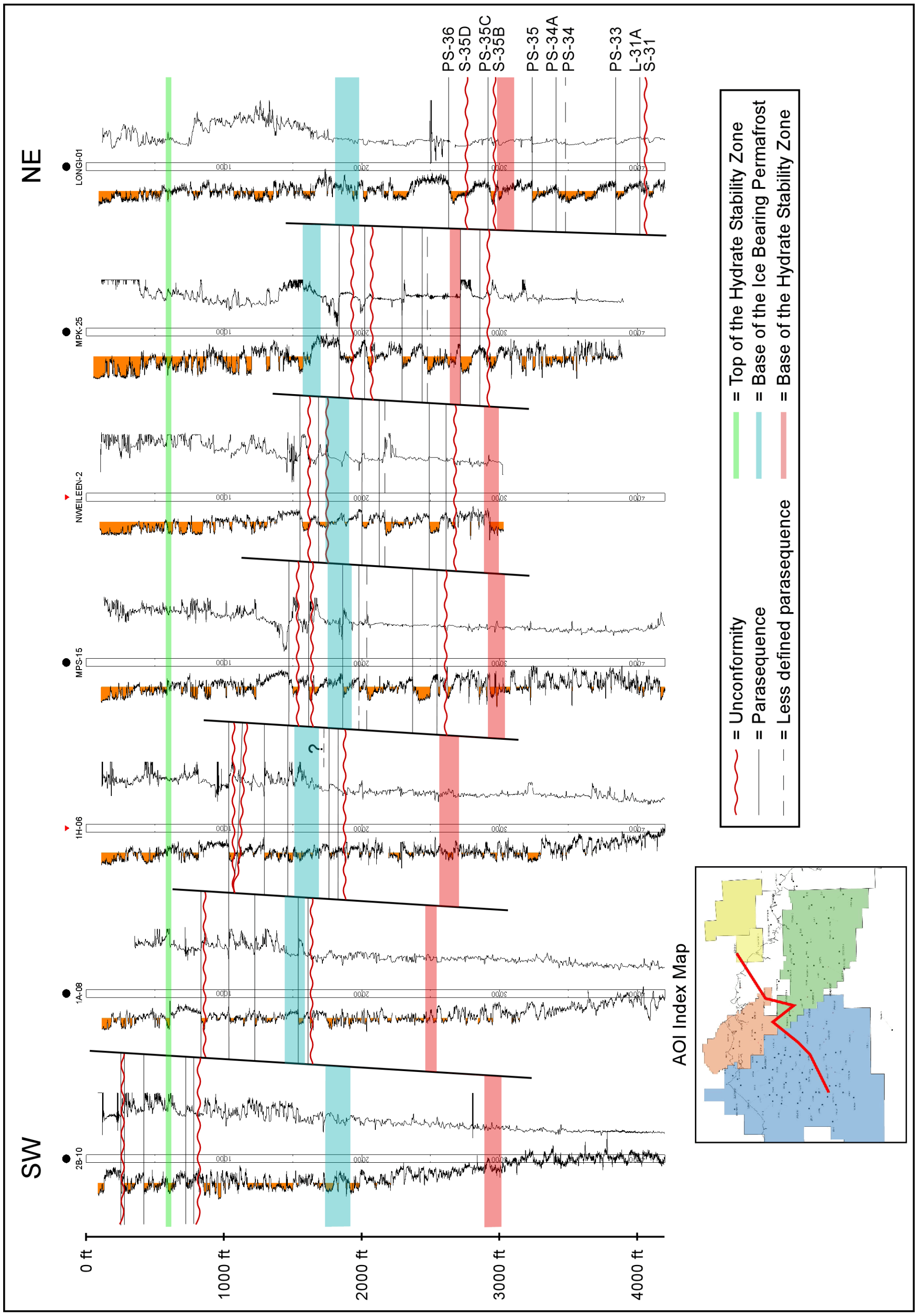


Figure 32: A northeast oriented structural cross-section, using PS-36 marker as the stratigraphic datum, illustrates identified sequence and parasequence horizons in their present day position.

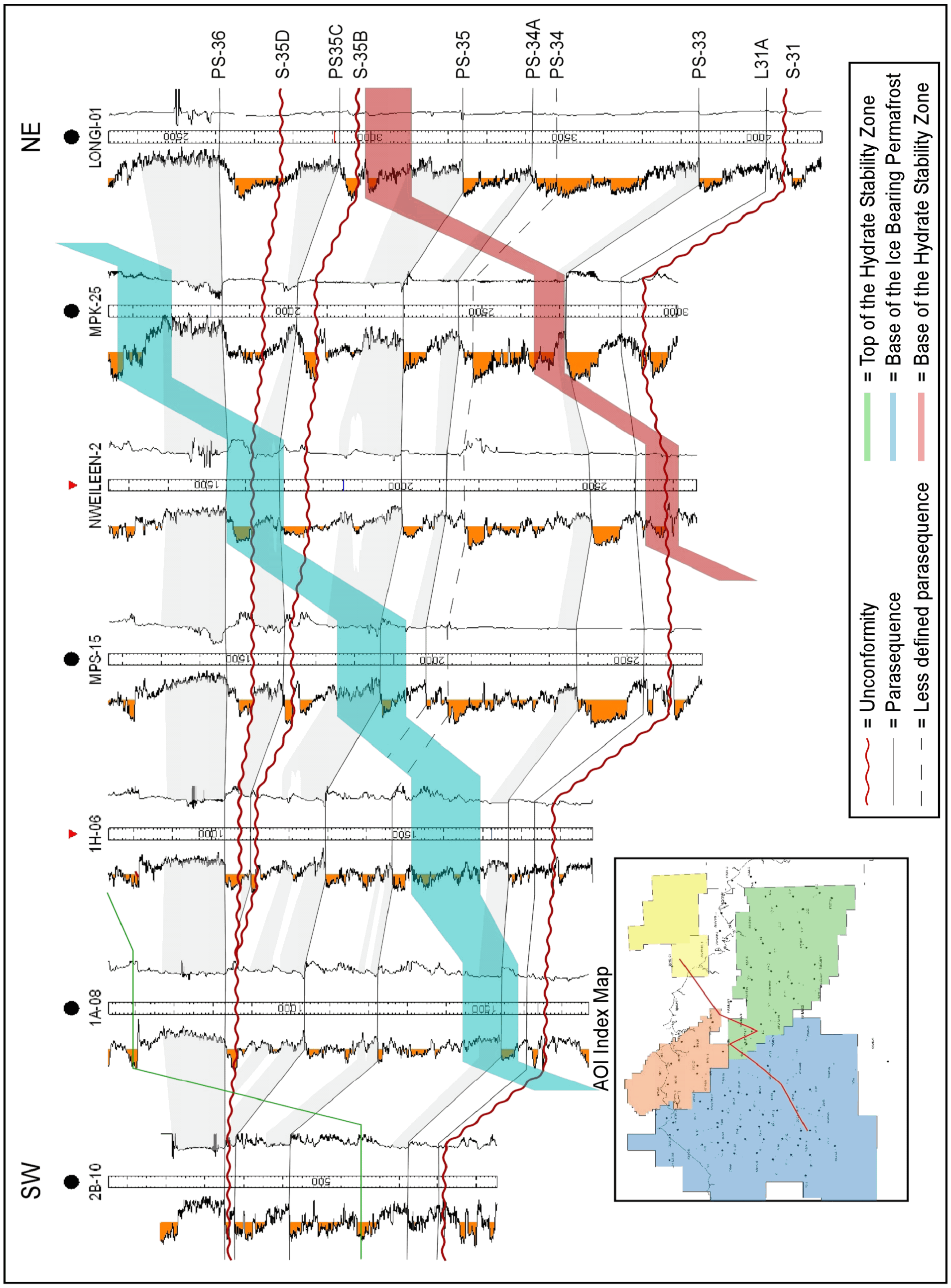


Figure 33: A northeast oriented stratigraphic cross-section, using PS-36 marker as the stratigraphic datum, illustrates sequence and parasequence horizons in our AOI. This cross-section provides a good example of the complexity encountered during the correlation phase of our study. Note the number of lower parasequence units terminating into the upper unconformities. The green, blue and red areas represent the intersection of the Top Hydrate Stability Zone (THSZ), Base Ice-bearing Permafrost Zone (BIPFZ) and Base Hydrate Stability Zone (BHSZ) in this cross-section respectively.

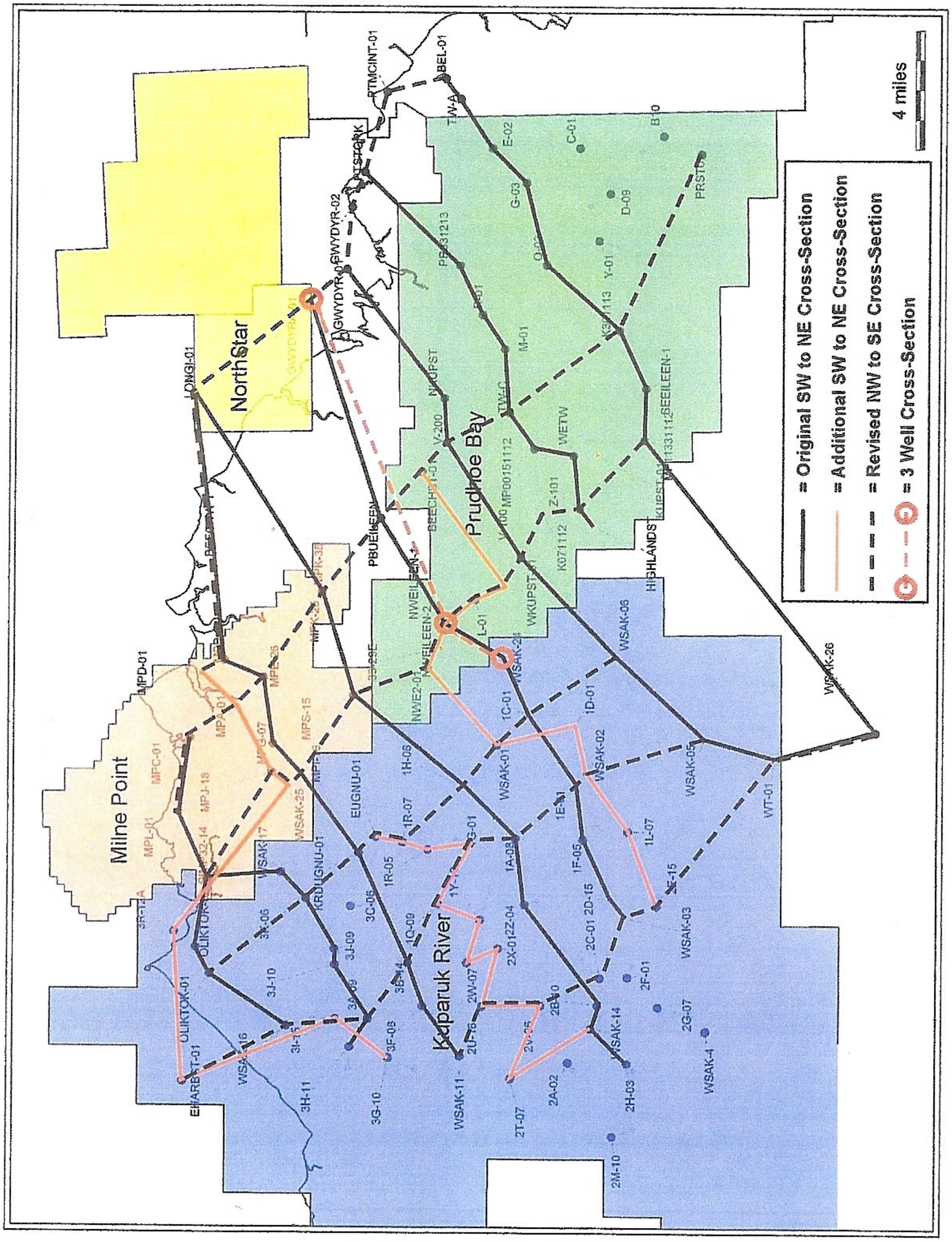


Figure 34: A cross-section base map displaying the location of all cross-sections generated in this study. The three well cross-section displays the location of the wells used in Figure 36.

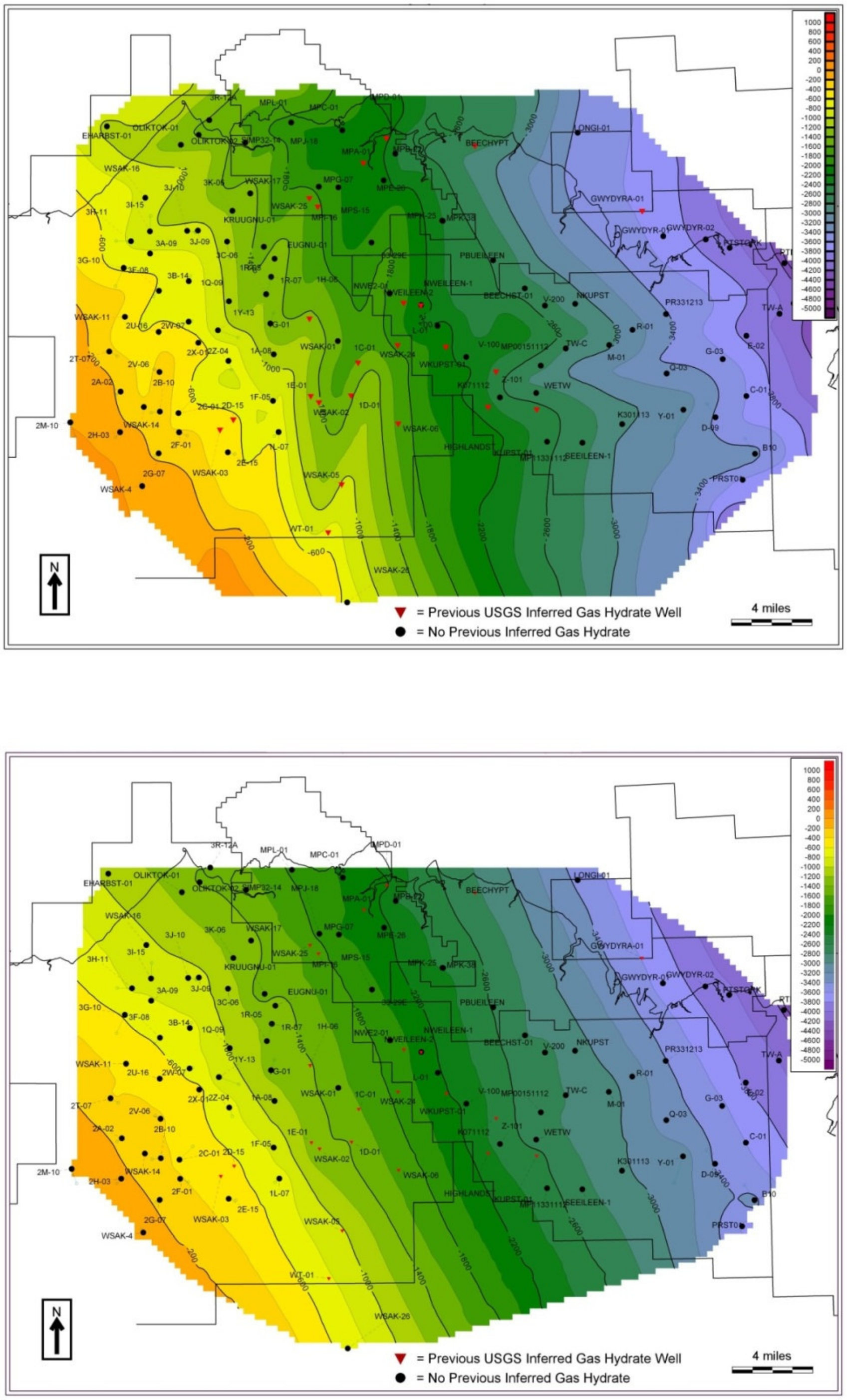


Figure 35: Two structural contour maps on parasequence 34 horizon are displayed. The upper map represents Casavant hand contoured map of this horizon. The lower map was generated using GeoPlus Corporation – PETRA computer program. Notice the difference in contour interval location between both maps.

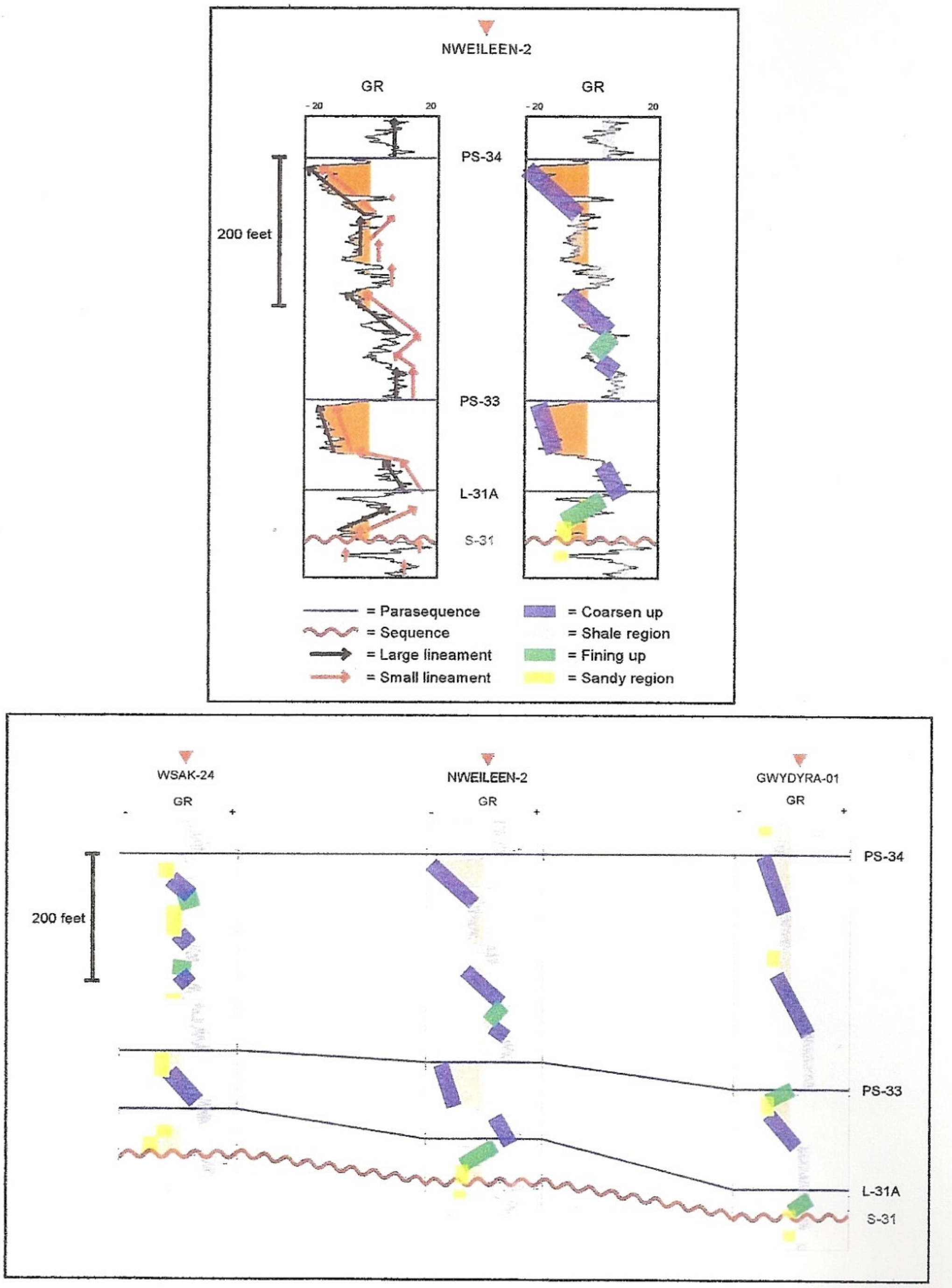


Figure 36: An illustration presenting the log pattern analysis conducted in this study. Northwest Eileen State #2 type log was used to provide a detailed example of the pattern analysis and a three well cross-section with corresponding colors are exhibited to provide a visual example of this research method.

A number of intraformational unconformities were inferred and attempts to correlate all of them across the AOI proceeded. Some of the interpreted unconformities could only be locally correlated. Other unconformity horizons were difficult and sometimes impossible to correlate, particularly in dominate fluvial regions. This phase of the research was iterative and all unconformity horizons underwent a number of circular well log “ties” throughout the AOI. From this research, three well-defined regional intraformational unconformities were identified and labeled as S-31, S-35B and S-35D (Figures 30, 32, and 33). Besides having fluvial units deposited over marine deposits, some of these unconformity horizons truncate into underlying lower parasequence units. This is especially evident in the stratigraphic cross-sections provided in figures 30, 32, and 33. More unconformable surfaces maybe present within the AOI, but evidence for strong regional extents from the well log patterns was not noted. It is recommended that future confirmation of the well log-based sequence boundaries be obtained through high-resolution seismic interpretation and core descriptions wherever possible.

4.7.3.2 Parasequences

Identifying parasequence boundaries began after the major sequence boundaries were identified. By definition a parasequence is a relatively conformable succession of genetically related beds or bedsets bounded by marine-flooding surfaces or their correlative surfaces (Van Wagoner et al., 1990).

In the IOI, several marine-flooding surfaces were observed (Figure 33). A marine-flooding surface on the natural gamma ray well logs exhibits a more radioactive (higher gamma ray) reading relative to the shale unit it usually resided within. Difficulties emerged in correlating maximum flooding surfaces throughout the AOI. Most were due to the rapidly changing gamma ray log character from well to well. Some of this behavior could be attributed to inconsistencies from using different well log tools to acquire the data and others may be due to wells being surveyed after metal casing was installed, which “muted” the log response. Moreover, a larger part was dependent on the lateral position the well resided in relative to the paleodepositional environment the unit was deposited in, which became more evident during the facies characterization mapping phase of this project.

Instead of correlating the maximum marine-flooding surface, correlation of the base of the marine shale that contained the maximum marine-flooding surface was completed. This action was warranted because many of the maximum flooding surfaces were complicated to identify, due to the reasons previously given and some did not appear to extend into the up-dip fluvial-dominated regions. In many instances the maximum marine-flooding surfaces were approximately in the same position as the base of the marine shale unit that encased them. A detailed figure using parasequence 36 marker as a stratigraphic datum shows multiple parasequence units extending across the AOI (Figure 33).

Several major parasequence boundaries are identified in the AOI. Out of the parasequence boundaries identified, one boundary presented an anomalous shale-like surface that was also correlated well throughout most of the AOI, which is labeled PS-34. This surface is interpreted as a coastal plain mudstone or tidal flat mud based on its lateral occurrence, abrupt truncation and pinch out behavior. Correlating this horizon in the northwest portion of the AOI was difficult because of the sandy nature this horizon rapidly changes to the further northwest you travel. This horizon is the only parasequence marker that displays this behavior. In finalizing the boundaries of each parasequence unit, numerous circular well "ties" were completed to verify the accuracy of the lateral correlations for each boundary.

More parasequence boundaries were identified in the AOI than discussed above. Many were locally present and not regional in extent. One notable parasequence boundary labeled PS-33A, presented difficulties in the correlation phase, especially in the Kuparuk River Unit due to the overwhelming fluvial deposits that surrounded it. The importance of this boundary did not manifest itself at this point in the study, but during the net sand mapping phase the importance of this boundary became apparent (Net Sand – Time Slice 8, Section 4.7.7.4).

4.7.4 Interval of Interest (IOI)

Extending from parasequence marker 34 (PS-34) down to lithostratigraphic marker 31A (L-31A), our research team decided to define the IOI over this region because it contained the most prominent and thickest gas hydrate bearing sand unit that was cored on the North Slope at the time of this study. The core was obtained from the Northwest Eileen State #2 well (Figure 28). Although some minor sand-rich intervals above and below the IOI also contain gas hydrate, these were not evaluated in this study due to time and program resource limitations.

4.7.5 Correlation Discussion

Following the correlation phase most lithostratigraphic boundaries turned out to coincide with chronostratigraphic boundaries. For the seventeen regional cross-sections created (Figure 34), all sections generated used the PS-36 marker as their stratigraphic datum (e.g. Figure 33).

On examination of various cross-sections throughout the AOI, some general trends were noted. An increase in interval thickness is present as progressing from southwest to northeast over the AOI. Spatial relationships, such as the termination of parasequence units into unconformities exist and changes in log character, are interpreted to relate to structurally-controlled depositional changes that are predominately oriented in the same direction. This spatial relationship suggests there is an underlying connection between the timing of structural and stratigraphic events.

4.7.6 Structural and Stratigraphic Characterization

4.7.6.1 Faults

Three separate fault maps over the AIO were complied and sutured together to create one regional composite fault map for the University of Arizona studies (Figure 37).

The first fault map was obtained using Hagbo thesis work (Hagbo, 2003). This map covers the MPU area (orange color). The location of the faults mapped in this unit was completed by using Hagbo's fault trace maps created on lithostratigraphic 34 and 33 horizons. These fault trace maps were chosen because this interval is equivalent to our IOI. The average distance between each fault location on both horizon maps was used in the final placement for all faults displayed in the MPU. Throughout the MPU, the majority of faults appear nearly vertical in all seismic sections (Geauner, personal communication) and many of the fault traces for both horizons reside on top of one another.

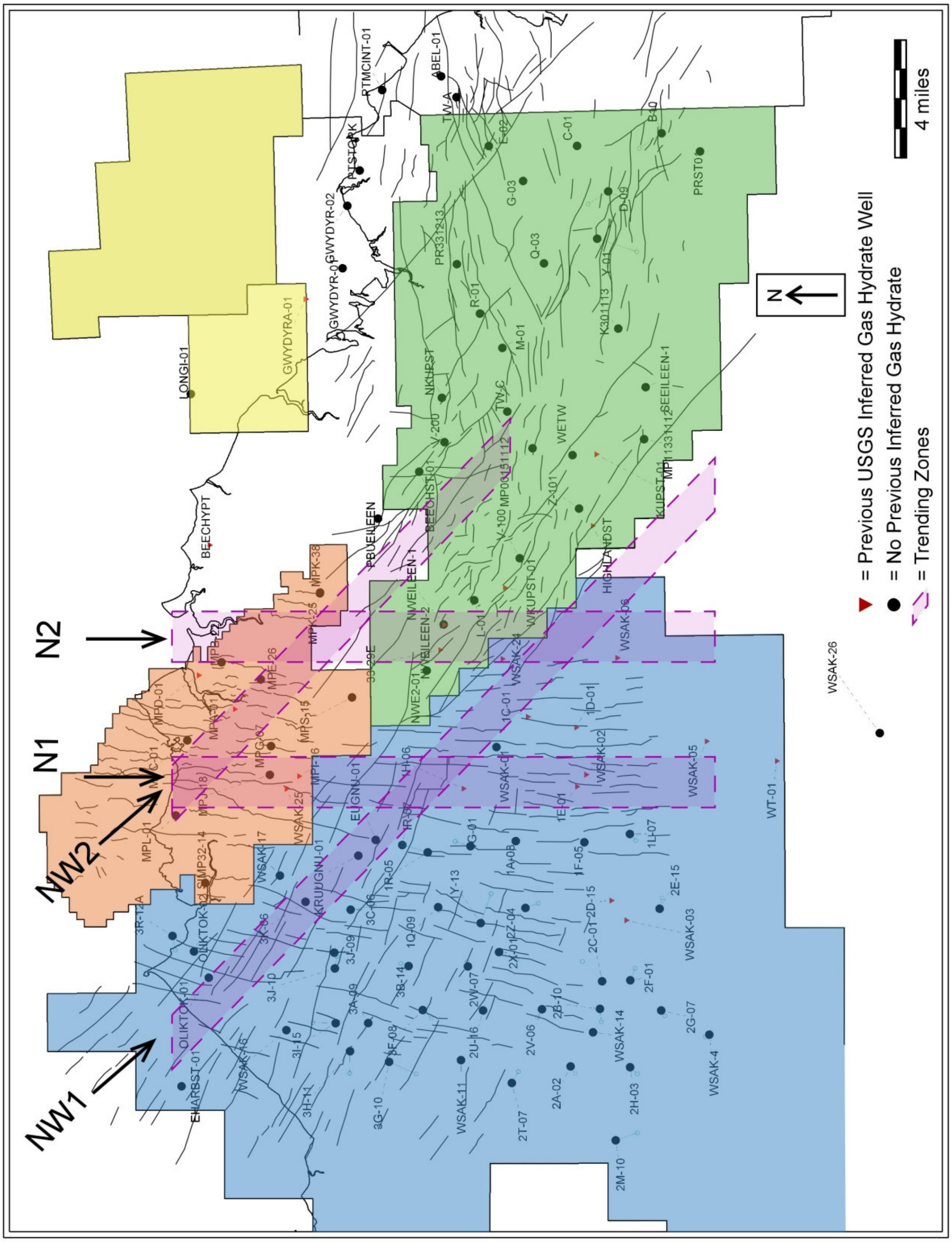


Figure 37: A composite fault map across the AOI. This fault map was created by combining three separate data sets together. The faults in the MPU were taken from Hagbo (2003). Faults for the KRU are taken from Casavant (2001). Faults from the PBU were provided to this study from previous work.

The second fault map, which cover the majority of the Kuparuk River Unit (shown in blue), was compiled from Casavant's previous research (Casavant, 2001). These faults were interpreted from a black and white artificially-illuminated IHS (intensity, hue, saturation) image of the fault structure at the top of the Kuparuk River Formation at depths ranging from 5,800-6,200 feet below mean sea level. The third fault map was a compilation of faults taken from Carman and Hardwick 1983 study (Carman et al., 1983). These faults were imaged at depths ranging from 8,500-9,200 feet below mean sea level in the Prudhoe Bay Field Unit. Selected fault traces were digitized by the gas hydrate team for this study.

During the compilation phase, the KRU and PBU fault maps had to be geographically registered with one another. This manual manipulation of the data does inherently bring some errors into the map. In addition, although shallow seismic data shows that most faults are near vertical, no adjustment of each data set to a common datum was made.

In evaluating the strength of this regional composite fault map, some observations were noted. The north-south fault trends that exist in the MPU, when extended south, align well with deeper faults present in the KRU fault map. The northwest trending zone (labeled in many figures as NW2) in the MPU is a dominant trend in the PBU fault map. In Hennes's thesis, he observed that fault throw decreases and termination of faults are noted in this region (Hennes, 2004). Projecting the PBU faults into the MPU, the location of major faults are approximately in the same location as the northwest trending zone. This spatial relationship suggests that deep seated faults extend from both the KRU and PBU areas into the MPU and issues such as fault frequency and termination of faults are connected with deeper structure (Casavant, 2001; Casavant et al., 2004).

4.7.6.2 Structural Mapping

One regional structural map was created for our IOI at the top of the parasequence 34 marker. This map was produced using GeoPlus Corporation - PETRA mapping software modular. A highly connected least squares algorithm was employed in creating this contour map. Analyzing the map reveals a structural northwest-trending strike with a regional dip down to the northeast (Figure 35 – lower figure). Besides the pronounced first-order northwest-striking fabric expressed in the map, no other obvious trends are noted.

This is in contrast to a variety of second-order features that are interpreted to exist when a detailed hand-contoured map was generated with the same data (Figure 35 – upper figure). A structural hand-contoured map, provided by Dr. Casavant, was digitally recreated in PETRA using guided contour lines and control points. Visual examination of this map reveals an oval shaped north oriented basin interpreted to exist in the south central part of the MPU. This area is proposed to contain a pull-apart basin (Figure 38) that may be underrepresented by the computer generated structural map (Casavant et al., 2004). Mapping also inferred the continuation of the MPU basin complex southward into the KRU area, where additional gas hydrate bearing sands are likely to be constrained. This area in which Casavant and others (2004) proposed potential gas hydrate bearing sand to be related to another pull-apart basin, is further investigated in the net sand and net pay sections of this report.

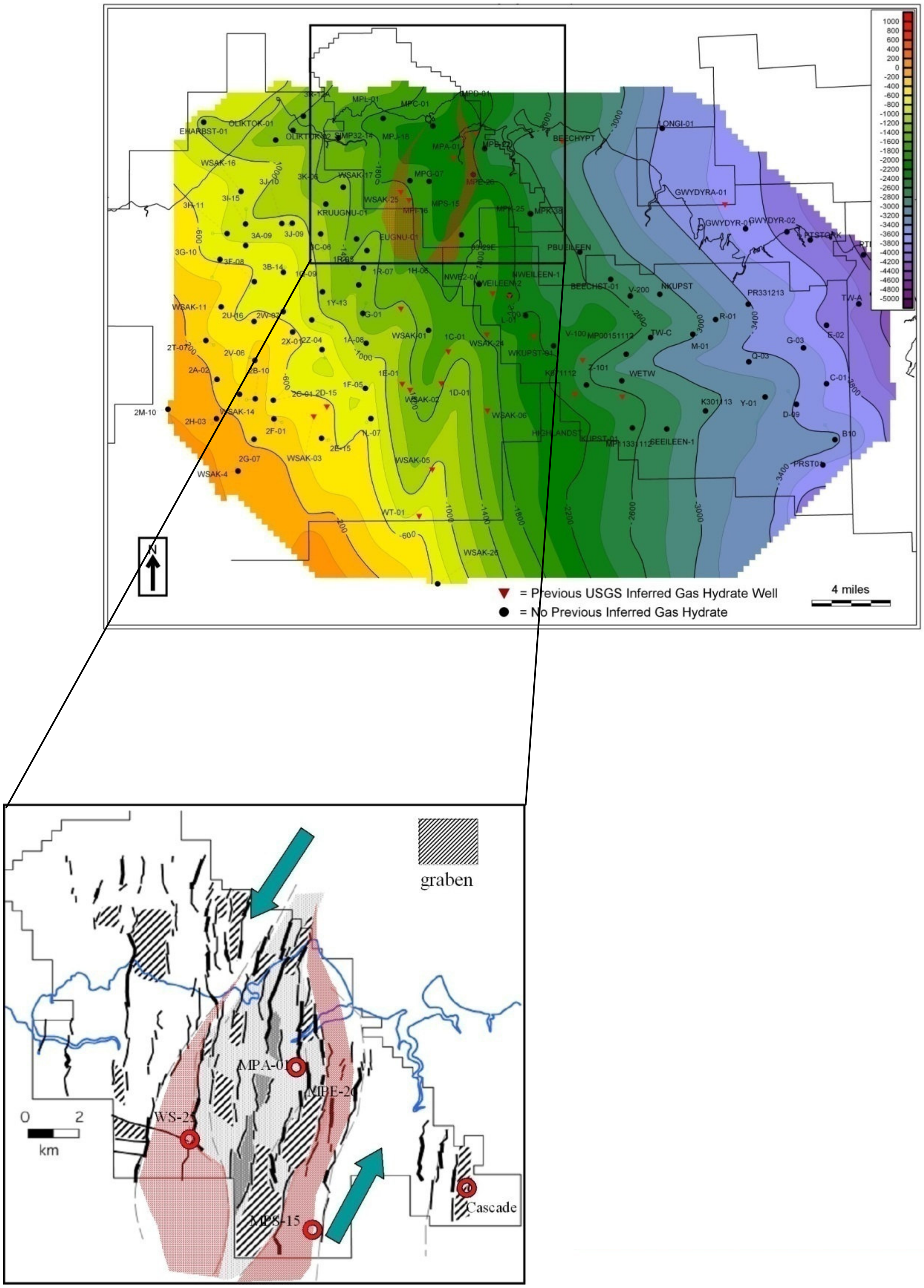


Figure 38: A diagram relating Casavant structure map to his proposed pull-apart basin that is inferred to exist in the MPU.

4.7.7 Chronostratigraphic Slice, Net Sand, and Facies Mapping

4.7.7.1 Net Sand

All wells in the AOI were analyzed to determine a net sand cutoff value on an individual well basis. For each well, all gamma ray (GR) logs present were printed out between PS-36 and L-31A markers. Data between these horizons was chosen to determine a net sand cutoff since our original IOI extended up to the parasequence 36 horizon boundary. Due to time constraints and resources available, the thickness of the IOI was later shortened.

4.7.7.2 Facies Characterization

Facies characterization is a method of identifying specific log response patterns from downhole geophysical tools that correspond to specific depositional environments that are relevant to the geologic setting being investigated (Figure 39). In our study, the geologic setting in the AOI was in many ways similar to other fluvio-deltaic, nearshore marine siliciclastic systems described by other researches (Saxena, 1979; Van Wagoner et al., 1990) Using all the available log data for each well, eight general classification categories were generated and listed as followed; coastal plain mud/siltstone, point bar, fluvial channel, interbedded fringe, distributary mouth bar channel, distributary mouth bar, prodelta shale and marine shale. Along with the above classifications categories, many intervals also expressed an additional fringy character on the logs. This fringy expression correlated with wells located near or within a transition zone between fluvial to marine environments (Figure 40). When this behavior was identified, an additional fringy description was added to the end of an initial characterization category (e.g. "distributary mouth bar fringe"). Examples of the facies characterization procedure are shown throughout Figures 39 and 40 with a corresponding net sand and paleodeposition map in Figure 40. This classification method is later combined and interpreted with all the net sand and paleodeposition maps to determine lateral continuity of potential reservoirs.

4.7.7.3 Time Slice Horizons

Time slice mapping is a simplified method of breaking down a complex three-dimensional data set into interpretable two-dimensional map products (Casavant et al., 1999). In creating a time slice map, time slice horizons must be defined. Once all sequence and parasequence boundaries were identified, all boundary markers were imported into PETRA from working cross-sections. Once imported, 50-foot true vertical depth time slice horizons were computed between each parasequence set in the IOI. A time slice horizon is a marker that is calculated below a parasequence boundary in our chronostratigraphic framework system. This horizon is intended to "slice" the interval incrementally into smaller genetically related sections to help reveal lateral and vertical variations within the reservoir (Figure 31). An example of these time slice horizons are shown in Figure 28.

Grouping of parasequence and time slice horizons commenced, defining time slice intervals for mapping purposes. These intervals are labeled as followed from deep to shallow: Slice L-31A to PS-33, Slice 6, 7, 8, 9, 10 and PS-34. Slices 6 through PS-34 incrementally divide the top 250 feet below PS-34 horizon. The lower time slice horizons (Slice 5, 4, 3, 2, and 1) in the parasequence bounded by PS-34 to PS-33 markers are not displayed in this study since the majority of the maps generated show large areas rich in shale content. The stratigraphic position of the time slices are shown as small boxes on the type log in Figure 28. These slices correspond to reservoir sand intervals B and C, according to the USGS's naming scheme (Collett et al., 1988)

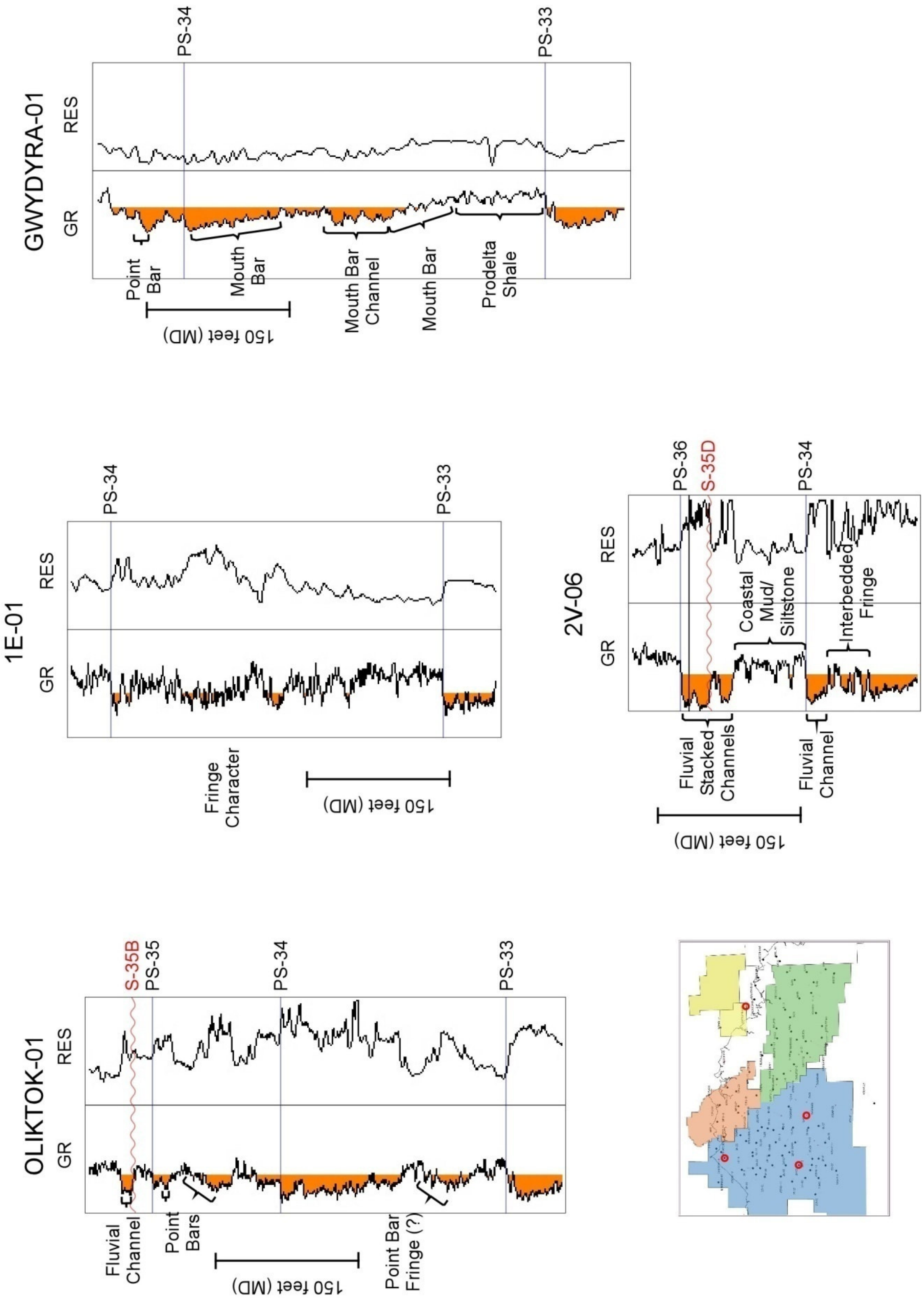


Figure 39: A facies characterization map providing well log based examples of the classification categories used during the facies characterization phase of this study.

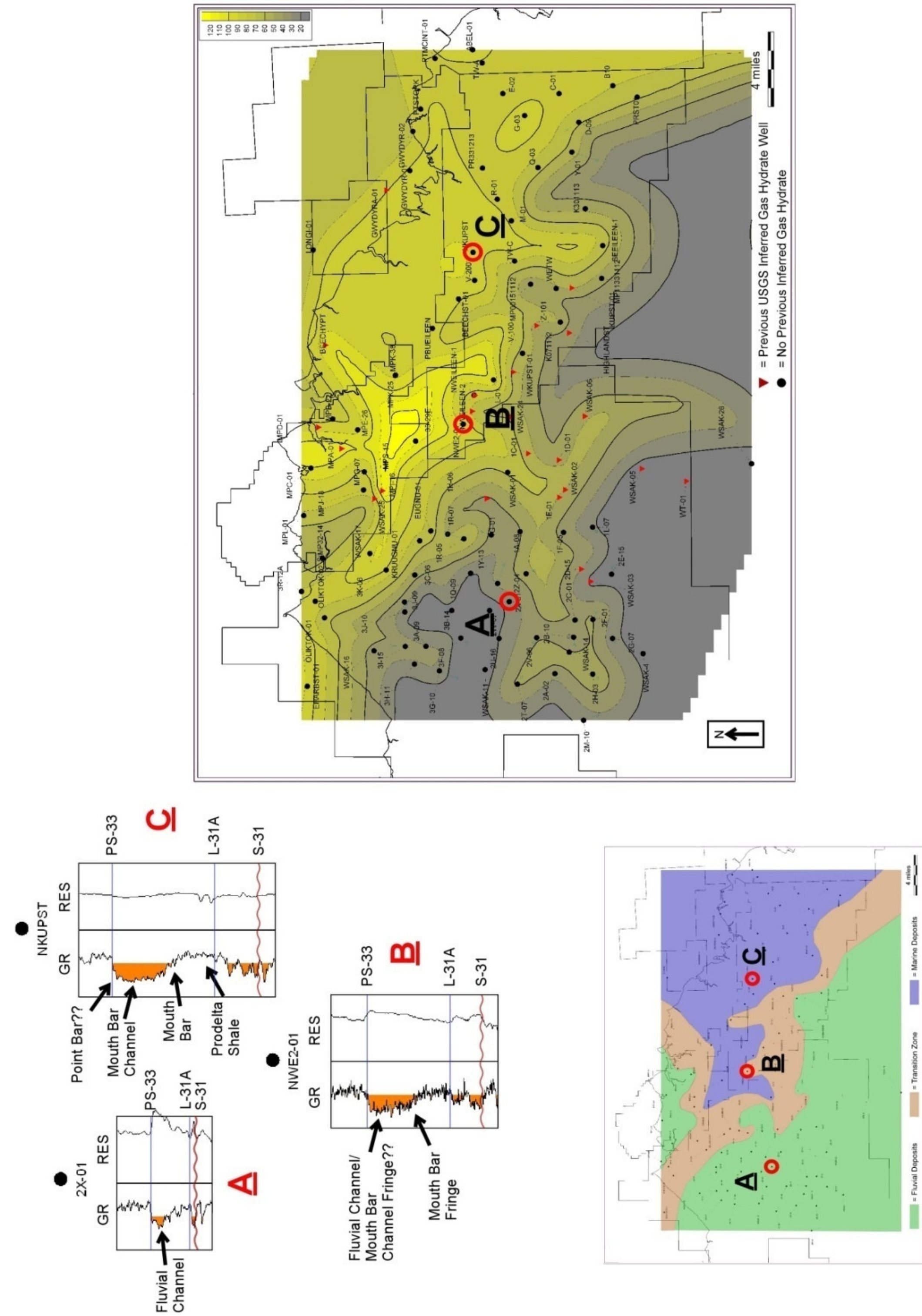


Figure 40: Diagram relating facies characterization to sand content and paleo-deposition.

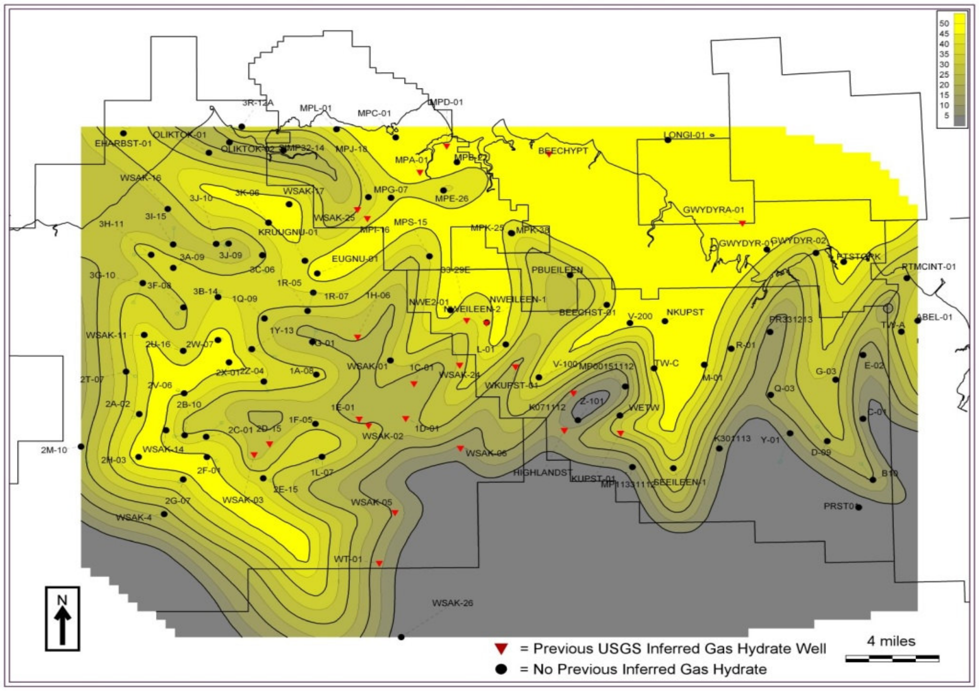
4.7.7.4 Net Sand and Facies Characterization Mapping

In evaluating lateral and vertical distributions of potential reservoir sands over the AOI, net sand and facies characterization maps were generated through the IOI. Using the time slice horizons described above along with the GR_SAND_SHALE curve and PETRA's computing capabilities, net sand totals for each time slice interval were calculated. For all depths that registered GR readings beneath the 0 API GR cutoff value, these interval lengths were classified as net sand regions and consequently their thicknesses were summed up to provide the total net sand footage for that interval. After all the net sand footages were calculated for every interval, initial net sand contour maps were generated using PETRA. In these initial maps, a highly connected – least squares algorithm was employed. The intention of creating these maps was to quickly gain a sense of the sand distribution, but these maps were not used as final net sand maps since their appearance was directly a function of a mathematical algorithm and does not incorporate geologic information that influence sand distribution (e.g. faulting, facies type - Figure 41).

Quality control standards were addressed next based on the appearance of the initial contour maps. Areas with closely spaced wells that displayed drastic differences in net sand totals were first re-evaluated to verify the accuracy of the totals. In most cases abrupt changes in sand thickness reflected changes in structure and stratigraphy, so totals were left unchanged. In only a few wells net sand cutoff values were either over- or underestimated. In these situations, adjustment of the net sand cutoff value was necessary and sand totals for all intervals were recalculated. In other circumstances, such as two or more wells originating from the same well pad (e.g. MPU K-25 and MPU K-38), the average net sand totals between these wells was used to represent the net sand content for the area. Since producing a regional analysis of sand distribution was our objective, using the average values in closely-spaced wells was deemed acceptable. If more localized mapping of net sand distribution is ever required, contouring both values independent of each other is recommended to reflect local structure and stratigraphic changes. Other cases that warranted quality control measures occurred when two GR logging runs had been merged together within one of our time slice intervals. The interval totals above and below the GR log merge used different cutoff values and were evaluated separately. In these cases, net sand totals for that interval were not used.

Once all quality control checks were complete, interpretation of facies types were performed for each interval. For many time slice map intervals, more than one facies type was present, which suggested that two or more depositional episodes occurred within the map intervals. In attempting to slice the intervals into smaller units (less than 50 feet) to have only one depositional episode represented proved to be impractical since variations at this scale could not be tracked over large distances. In many cases more than one facies type existed. To simplify this situation, the dominant facies type was labeled on all maps. A strong correlation between facies type and net sand was discovered and hand contouring of net sand totals followed (Figure 40).

Several versions of hand-contoured net sand maps were created. Each map reflected different sand thickness trends and displayed various ways of contouring the same data. Certain trends imposed consisted of, favoring regions where either sand or shale was interpreted to exist, based on previous and concurrent structural-stratigraphic research (Collett et al., 1988; Hagbo, 2003; Hennes, 2004; Casavant et al., 2004). Other factors taken into account in net sand mapping included, adjustments based on structural and stratigraphic changes that occurred consistently over



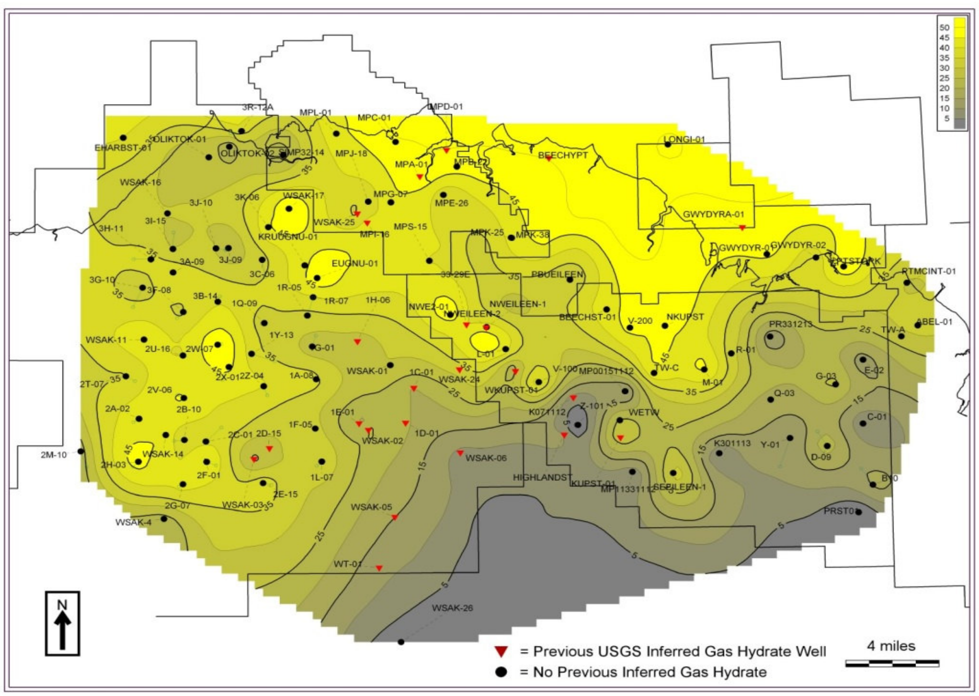


Figure 41: Two Slice 8 contour maps displaying major difference in of net sand. Both maps use the same data but the hand contoured map contains numerous control line and points to display its character.

multiple time slice maps. These areas are later referred to as "trending zone" in this report and in all map figures. Contouring in areas with little well control was influenced by all factors mentioned above along with the facies characterization displayed in certain regions. An example of using the facies characterization to help contour net sand maps was especially relevant in fluvial areas where sand rich intervals were, in reality, not connected over large distance as models of modern depositional environments dictate. Evenly spaced contour lines were drawn to display gradational changes. This was done since the low well density and regional-scale facies characterization analysis could not define these areas more precisely. Thus, the tightening or spreading apart of contour lines was not warranted. Final maps were created incorporating geologic interpretations and major trends that existed in multiple map versions. When digitizing the final net sand maps, control lines and points were used when creating the map grids to replicate the final hand-contoured maps. Although a highly connected – least square algorithm was used for gridding, its influence on the final outcome was minimal.

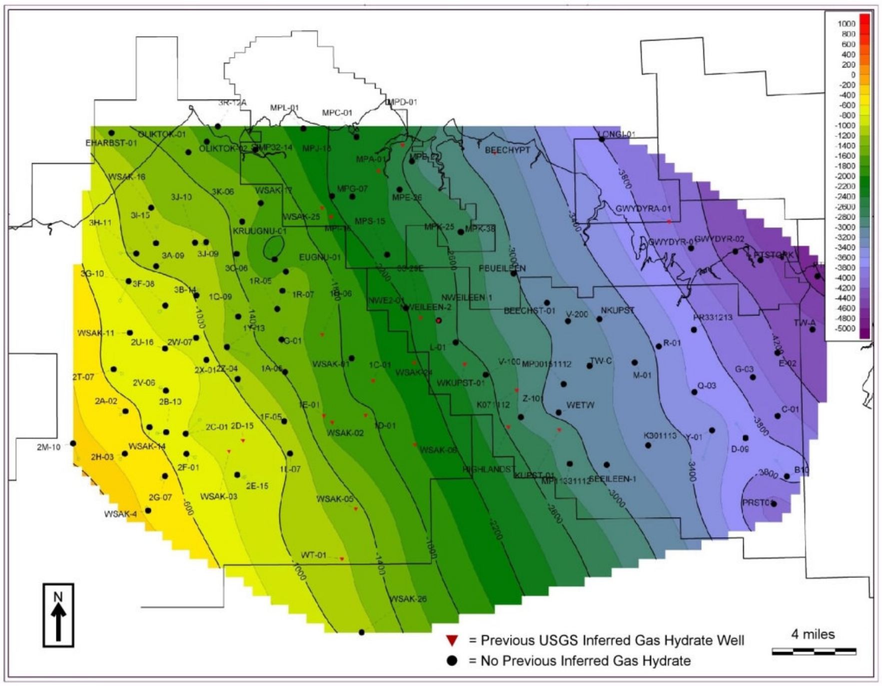
4.7.7.5 Time Slice Mapping

The intention of this section is to dissect each series of maps for all time slice horizons generated. Starting from the lowest section and moving upward, this discussion will reveal our results in chronological order.

4.7.7.5.1 Time Slice between PS-33 to S-31A

The PS-33 to S-31A maps are located in Figures 42 and 43. Figure 28 shows the stratigraphic position of this interval. The color scales for these maps differ from the rest of the time slice horizon maps because this is the only series of maps generated that includes multiple parasequence horizons. All the other map slices were at higher resolution and subject to the 50 foot interval condition imposed on them. Caution must be used if this slice map is compared to the other thinner time slice maps above it (slices 6-10, Figure 28).

A general trend noted in slice PS-33 to L-31A was, a regional increase in net sand from southwest to northeast over the AOI (Figure 43). This increase correlates well with an increase of thickness in the gross isopach map and the regional strike and dip displayed in the structure map (Figure 42). In the KRU, the east-west higher sand content trend (marked as C – Figure 43) is also present as a thicker region in the gross isopach map (Figure 42). Facies characterization for this sand body classified this area as containing fluvial channel deposits (marked as A - Figure 40 and marked as C - Figure 43). The areas north and south of this sandy region in the KRU are higher in shale content and facies characterization analysis classified for these regions as shales and interbedded sands that were different in character from thicker marine units to the northeast and east. Multiple channels are interpreted to exist in this area, stacked on top of each other. The connectivity of the sand-rich area is most likely not as broad as the net sand map displays due to the nature of fluvial channel migration, incising channels, meandering orientations and lateral width displayed in modern fluvial environments. Also present in these maps are a northwest-oriented sand body connecting with the previously east-west trending body described in the KRU. This area displays the same fluvial characteristics and is interpreted to be physically connected with the east-west sand-rich body. Moving to the boundary between KRU and MPU, a large regional change occurs in the northwest-trending zone 1, labeled as NW1. An increase in sand content (Figure 43) and isopach thickness (Figure 42) characterizes this zone.



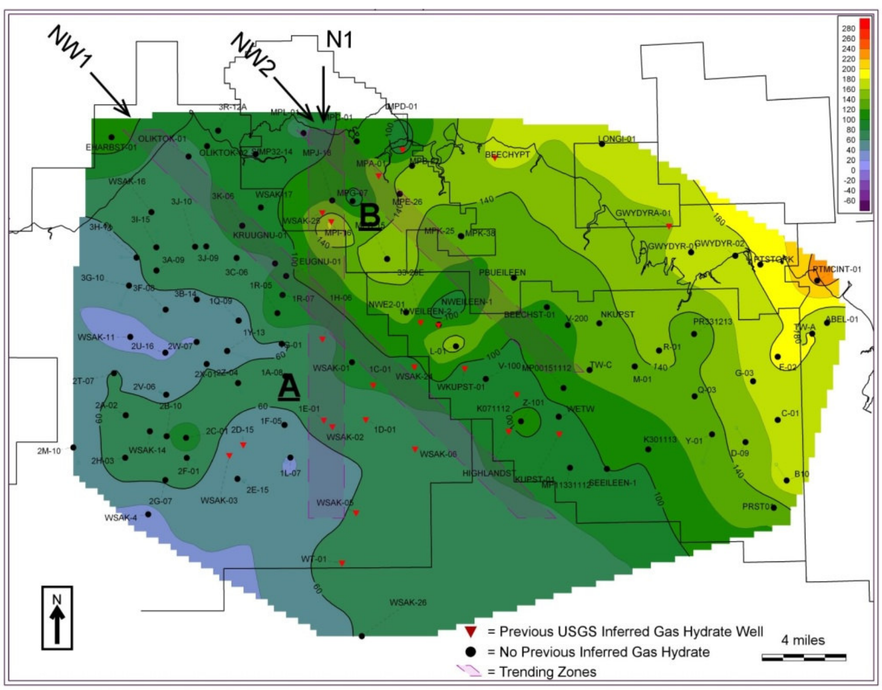
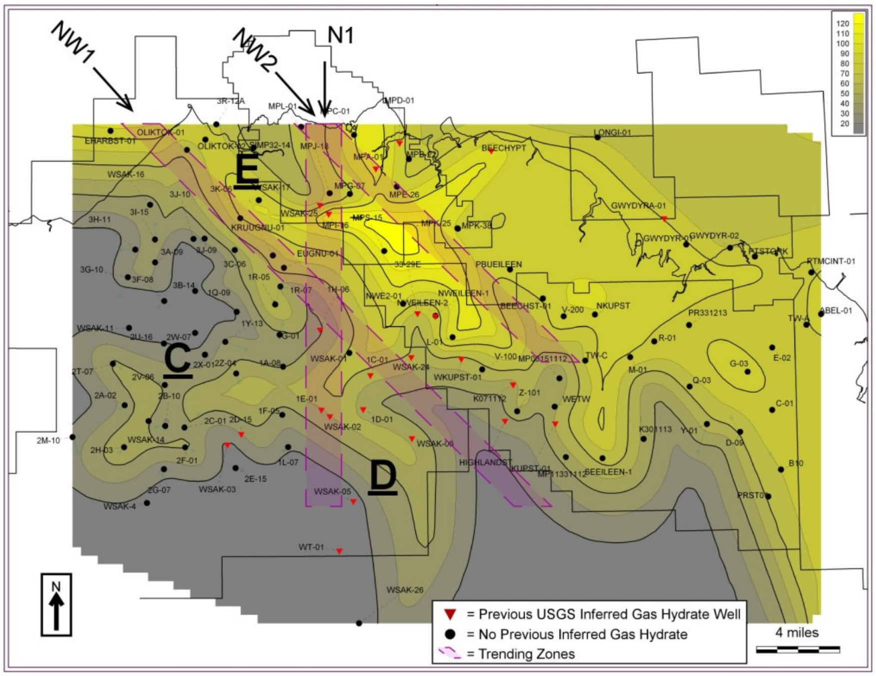


Figure 42: The upper map is a structure map using parasequence 33 marker. The lower map is a computer generated gross isopach map between parasequence 33 and lithostratigraphic 31A (S-31) markers.



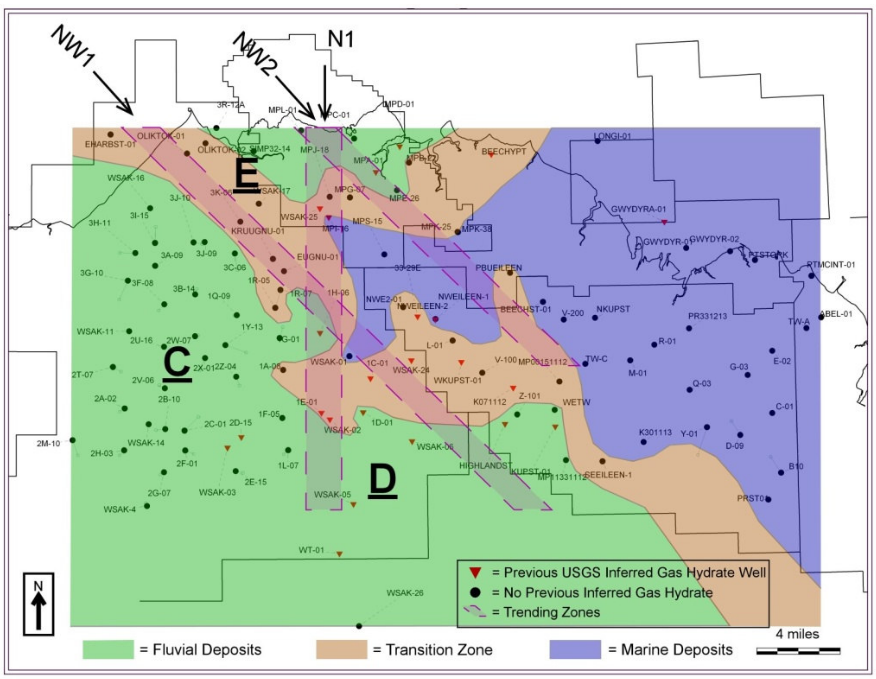
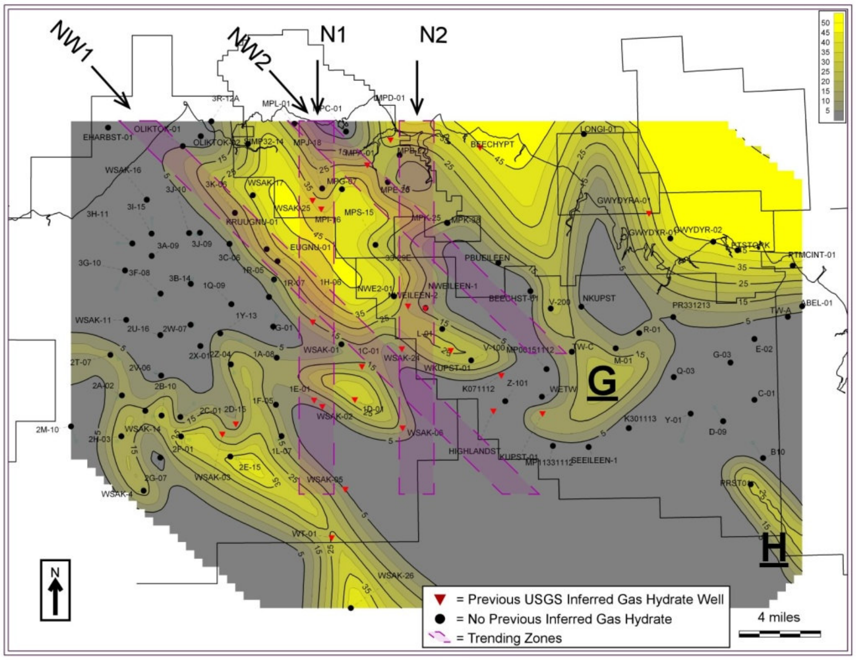


Figure 43: The upper map is a hand contoured net sand map between parasequence 33 and lithostratigraphic 31A marker generated during the net sand phase of this study. The lower map is an interpreted paleo-reconstruction map for this same interval. The interpretations displayed in this map are from the facies characterization study.

Coupling this behavior with the orientation of major deep seated faults that exist in the PBU (Figure 37) and extending their orientation northwestward supports the notion that structural faulting was influencing deposition. Within the NW1, both fluvial and marine facies deposits are interpreted to exist from our facies characterization study, which suggest this was a transitional zone between both environments during the time of deposition (Figure 43). The NW1 zone exhibits much stratigraphic changes in many of the maps created for this interval. Another northwest-trending zone, labeled as NW2 in figure 43, also influences the distribution of facies on many maps. Contours lines reflect, increases in isopach thickness and sand content within this zone. The trend and stratigraphic character of NW2 also implies that structural faulting influenced deposition in this area. Comparing the magnitude of changes displayed between NW1 and NW2 reveals that NW1 was more influenced by structural control than NW2. For the north-south trending zone, labeled N1, structural and stratigraphic changes and contour deflections occur within this region, but are less pronounced than the northwest-trending zones. In the marine section of the facies map, sand bodies were more correlative and connected, and their facies patterns (Figure 40) reflected that of modern distributary mouth bar deposits (Saxena, 1979; Tye, 2004). The south boundary for all net sand maps shows a laterally extensive shale region. This interpretation also reflects a decrease of the data that was available to the study. The data available to us, suggest that one or two north-trending sand-rich corridors may also be present in this area, but due to the lack of data, interpreting the location of these probable corridors was not completed. This statement holds true for all corresponding stratigraphic maps.

4.7.7.5.2 Time Slice 6

Time slice 6 is the lowest of the time slice intervals between the PS-33 to PS-34 markers (Figure 28). This slice shown in figure 44 represents the lower 250 to 200 foot interval beneath PS-34 marker. This interval is interpreted to reside completely below PS-33A marker, which displayed variations in the regional correlation over the AOI. In the northwest and southeast portions of the interval, shale-rich regions exist and cover large areas of the KRU and PBU, respectively (Figure 44). This marine shale contains the maximum flooding surface that lies on top of the PS-33 marker. Many sand-rich areas in the KRU have wells in which previous USGS studies inferred gas hydrate to be present in sands at lower intervals below PS-33 and Slice 6 (Collett, 1993). These wells are represented by a red triangle. Note how all of these wells reside in the sand rich regions within the KRU that were mapped in time slice 6 (Figure 44). NW1 and NW2 zones are also strongly expressed in the map and bound the largest sand-rich region in the KRU and MPU areas. A large part of this sand rich region coincides with the location of a pull apart basin previously mentioned (Casavant et al., 2004). For NW1, an increase in net sand content is still apparently dominant as you move from the southwest to northeast along the zone. Recall that this same behavior was displayed in the lower PS-33 to L-31A time slice maps. In time slice 6, facies characterization places the transitional zone between marine and fluvial deposits further northeastward compared to the previous map (compare figures 43 and 44). The migration of the transition zone to the east, suggests that the river systems and the paleo-shoreline are prograding oceanward during the deposition of time slice 6. In the KRU, fluvial channel facies characterization still correlated well with an increase in sand content, and dominate the southwest portion of the AOI. The meandering-like nature of this sand body is interpreted to be strongly controlled by a northwest trending fault fabric, which correspond to deeper basement structure as previously mentioned. The higher east-west sand content trend displayed in the KRU from the prior maps (Figure 43) is still present, but has less of an influence in this slice (Figure 44). The more dominant trend in the KRU is the northwest-trending sand-rich zones made up of fluvial channels.



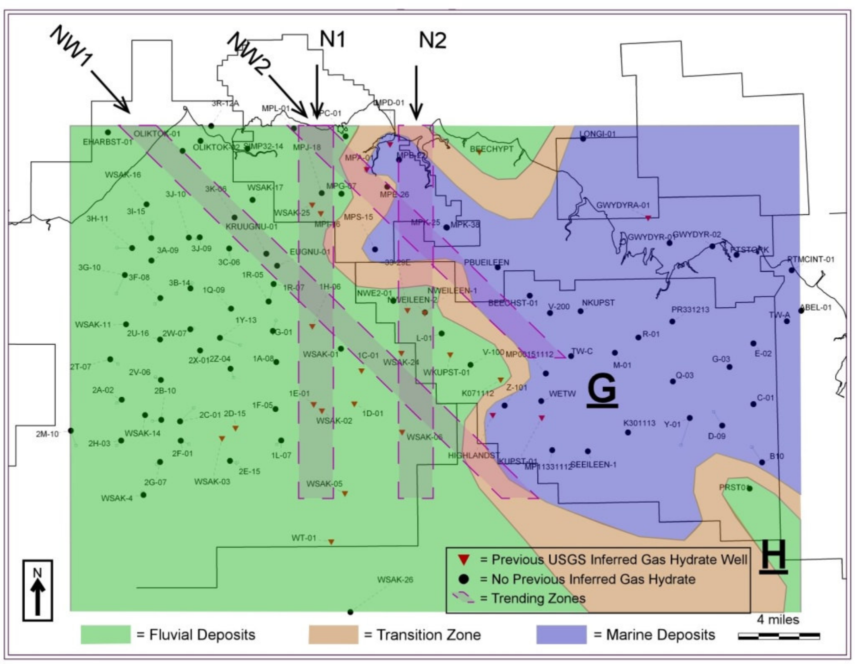


Figure 44: The upper map is a hand contoured net sand map of time slice 6 generated during the net sand phase of this study. The lower map is an interpreted paleo-reconstruction map for this same interval. The interpretation displayed in this map is from the facies characterization study.

In the southern part of KRU, WSAK-26 displayed a large pronounced sand interval for this time slice. During the cross-section phase of this study, this sand body in WSAK-26 was originally placed below the PS-33 horizon marker, but a more detailed investigation disagreed with this interpretation. This sand body seemed to be anomalous to the AOI, and occurred only in a few southern wells. Development of this sand southward is possible, but connectivity within the AOI is questionable and the southern part of the net sand map should be viewed with caution.

In the northern part of the AOI, east of the MPU another interpreted fluvial channel is shown on the net sand map (Figure 44 - BEECHYPT). This sand body is anomalous because this is the only well that contained interpreted fluvial deposits, unlike the marine facies that dominate this region. The sand in the PBU (labeled G in Figure 44), classified as marine deposits, is interpreted to be sourced from a fluvial channel to the west or northwest in this area. Deposit G resembles a modern distributary mouth bar.

In the southwestern part of the PBU, an interpreted fluvial sand deposit is present in PRST01 (labeled H in Figure 44). Wells close to this area are shale-rich and do not exhibit any sand development. This isolated fluvial sand was hypothesized to exist near the paleo-coastline with its channel oriented along the coastline entering the ocean at another location away from the area. This could explain why no distributary mouth bar sands are interpreted in nearby wells. The two north-south trending zones N1 and N2 are substantially less pronounced compared to the northwest trending zones NW1 and NW2. NW2 only slightly expresses itself in a linear fashion in the northwest part of the PBU, where the boundary between sand and shale rich sands are located. In the MPU, net sand total for the WSAK-25 well was omitted due to difficulties in contouring a very small shale-prone region inside a prevailing sandy area. This area should be viewed with caution since WSAK-25 is still a valid data point.

4.7.7.5.3 Time Slice 7

Time slice 7 resides 200 to 150 feet below PS-34 marker. This interval is interpreted to reside completely below PS-33A marker, which as mentioned earlier, was difficult to correlate regionally. Sand development improved in time slice interval 7 compared to time slice 6 (compare Figure 44 and 45). The predominant sand/shale relationship in NW1 zone is still evident in this slice, with multiple wells displaying lower sand content to the southwest side of this zone. No obvious sand channel development is noted between the large sand body (to 40 feet thick) in the middle of the KRU (labeled I) and the other northwest-trending sand body northeast of NW1. In the reservoir characterization analysis, fluvial channel deposits are present on both sides of this minor northwest-trending shale zone, but no obvious connection was determined to exist with the data available. The link between both sand bodies is uncertain, but contours do encroach into the thinner shale region across which potential channel connections could exist. The NW2 zone has less of a signature compared to NW1 zone, but deflections in contour lines do occur in the net sand map in the southeast part of the AOI. In the facies characterization analysis for time slice 7, the transition zone has again moved eastward compared to the intervals below. This suggests that the river systems and paleo-shoreline are prograding oceanward during the deposition of time slice 7. The KRU east-west thicker sand feature (area I) is once again evident with good channel development present in the logs as was also seen in PS-33 to L-31A time slice maps (compare Figure 43 area C and 45 area I).

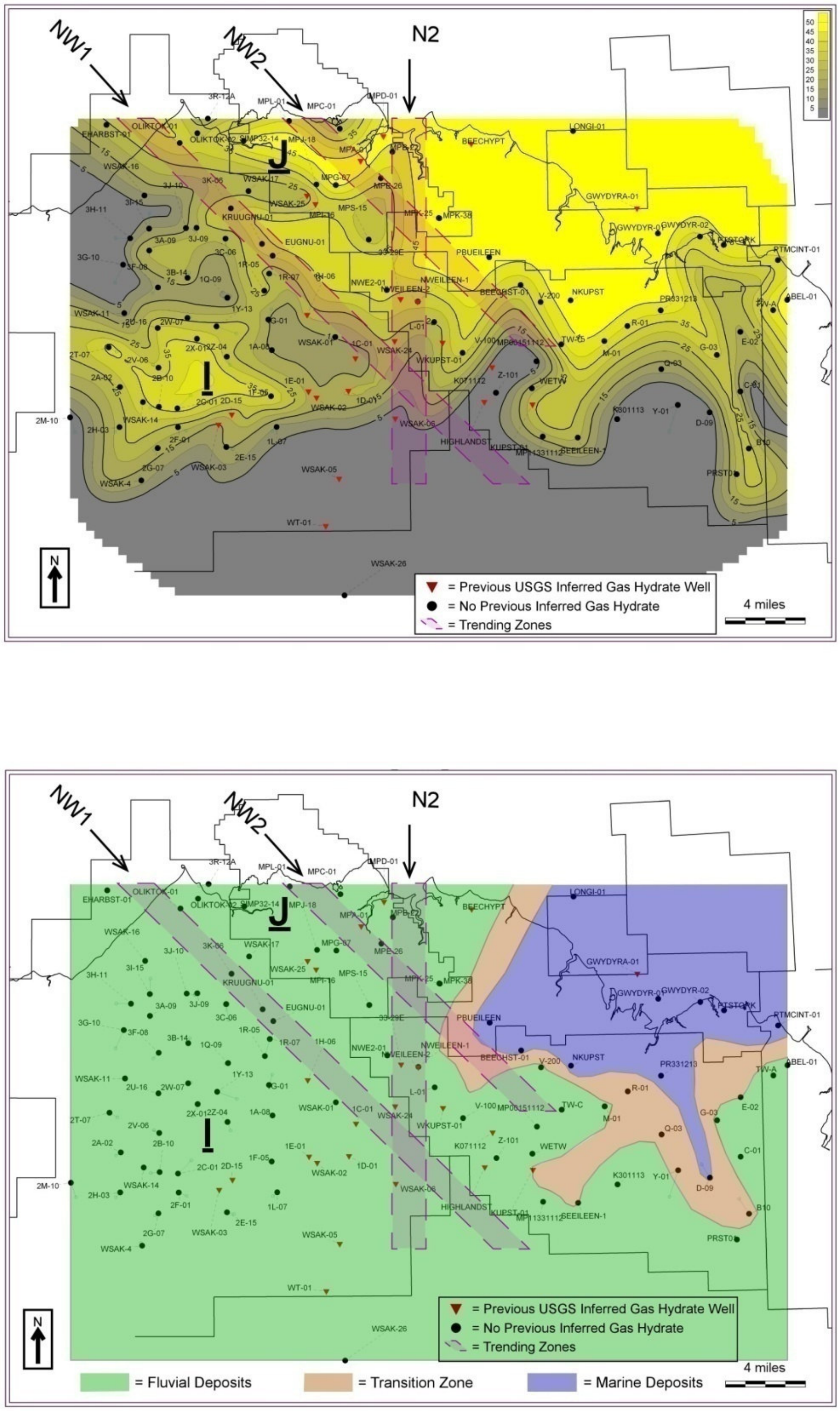


Figure 45: The upper map is a hand contoured net sand map of time slice 7 generated during the net sand phase of this study. The lower map is an interpreted paleo-reconstruction map for this same interval. The interpretation displayed in this map is from the facies characterization study.

4.7.7.5.4 Time Slice 8

Time slice 8 resides 150 to 100 feet below PS-34 marker (Figure 28). This interval is interpreted to reside in both an upper and lower parasequence set that is not easily correlated across the field. The majority of this interval is believed to be captured in upper parasequence set between PS-33A to PS-34 markers, based on the vertical location this interval resides in for the majority of wells that were evaluated. An important point to remember is that interpretations generated from this time slice are a combination of two parasequence sets and results may be misleading.

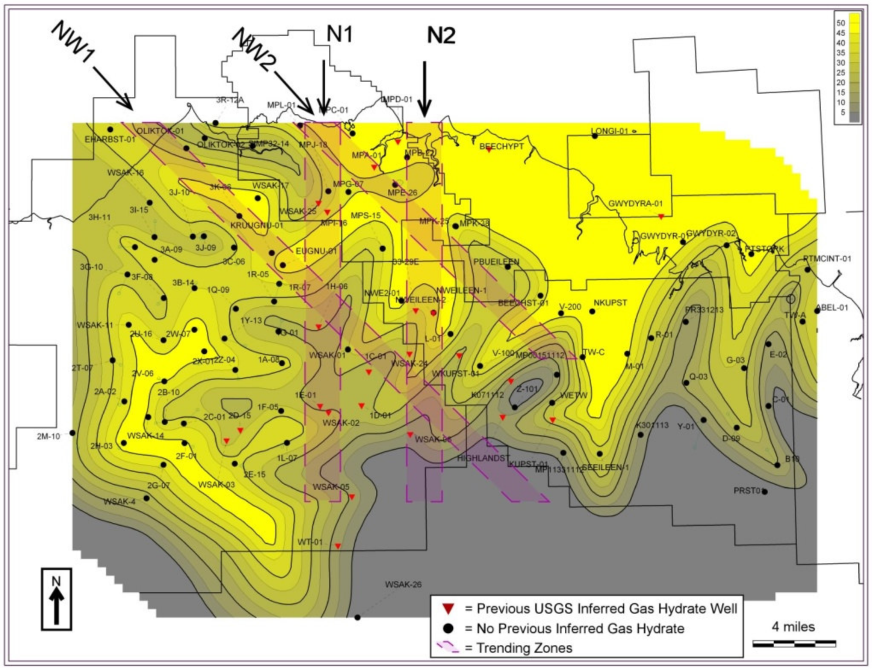
Overall sand development and distribution increases again relative to lower intervals (Figure 46). The predominant shale region south of NW1 is only slightly apparent in the net sand map. Multiple fluvial channels are interpreted throughout the AOI in this time slice. Their frequency is probably related to the combination effect displayed by joining two parasequence data sets together. From the abundance of channels that are noted, the net sand map displays a jagged contour nature. The N1 zone, appears to mildly influence net sand contour lines in both the KRU and MPU areas. In the PBU, multiple fluvial channels are orientated fairly north-south. A small area in the northeastern most part of the AOI still contains marine distributary mouth bar facies (Figure 46). From the facies characterization across most of the AOI, it is still apparent the river systems are prograding northeastward as the transition zone and paleo-shoreline move further to the northeast, compared to previous lower intervals (Figure 46).

4.7.7.5.5 Time Slice 9

Time slice 9 resides 100 to 50 feet below PS-34 marker (Figure 28). This interval is hosted entirely between the PS-33A to PS-34 correlation markers, which is in the upper parasequence set that is not easily correlated across the field. An overall increase in sand content is noted (Figure 47). The shale-prone region southwest of NW1 zone is not a major feature anymore. Large sand developments are now located throughout in the north KRU area where once a strong northwest shale region existed in lower net sand maps. The NW2 zone exhibits a minor influence on net sand contour map in the PBU area (Figure 47). The interpreted jagged multiple channel contour behavior displayed in time slice 8 is still present, but it is not as pronounced in this net sand map. In the PBU multiple potential channel areas are interpreted and are oriented northeastward, pointing towards the marine sand facies region. Log-based facies analysis reveals no significant change from the previous paleodeposition map in terms of the fluvial, transition and marine deposit distributions (compare Figure 46 and 47). Fluvial deposits still reside over much of the AOI with a small marine area identified in the northeastern part of the AOI. Since the transition zone did not move laterally, progradation either slowed or stopped completely. More adequate well density in the northeastern portion of the AOI would address this issue better.

4.7.7.5.6 Time Slice 10

Time slice 10 resides 50 feet below the PS-34 correlation marker up to the marker (Figure 28). The most pronounced sand content for the IOI is displayed in this time slice (Figure 48). The shale-prone region southwest of NW1 zone is represented as a minor shale region appearing in the KRU. Good sand development is displayed in many northern areas throughout the AOI. The north-south N1 and N2 structural zones slightly manifest themselves in the KRU and PBU by deflecting net sand map contours in these areas (Figure 48). Facies characterization analysis reveals no vital location changes from the previous paleodeposition map. The large sand rich areas on time slice 10 are interpreted as fluvial deposits (Figure 48). Spatial connectivity between individual sand bodies associated with this fluvial dominated time slice is considerably less than what is illustrated.



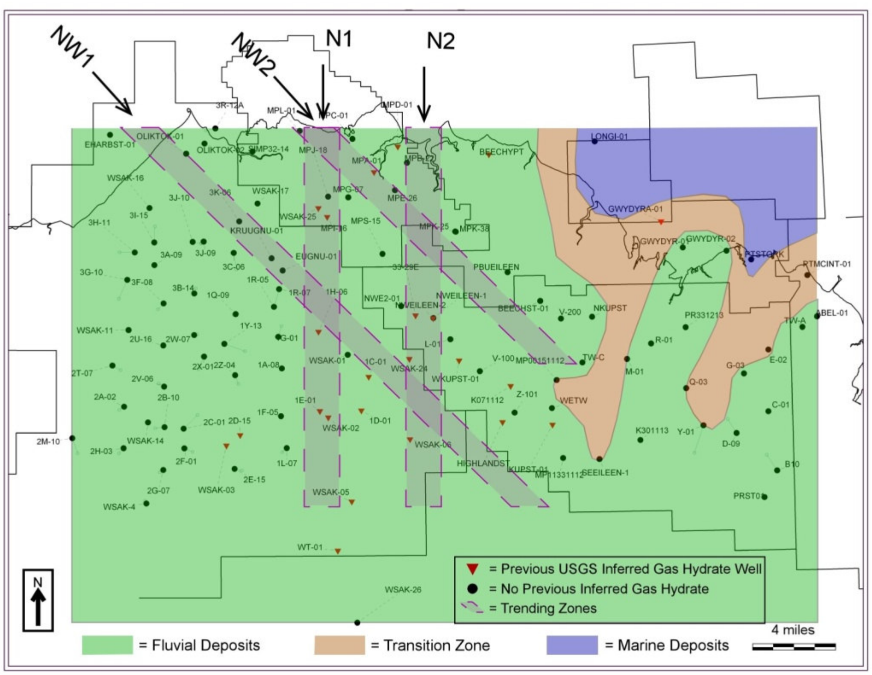
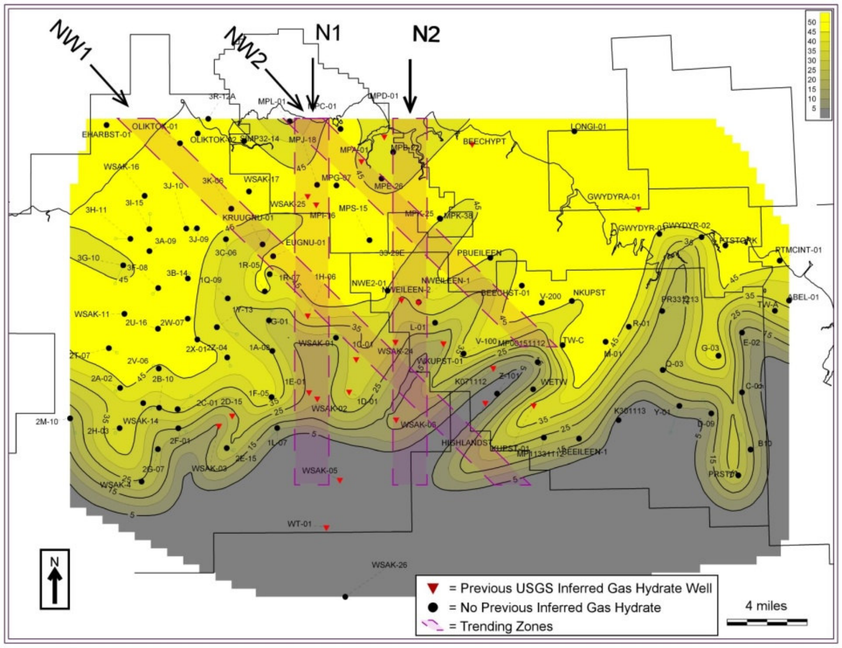


Figure 46: The upper map is a hand contoured net sand map of time slice 8 generated during the net sand phase of this study. The lower map is an interpreted paleo-reconstruction map for this same interval. The interpretation displayed in this map is from the facies characterization study.



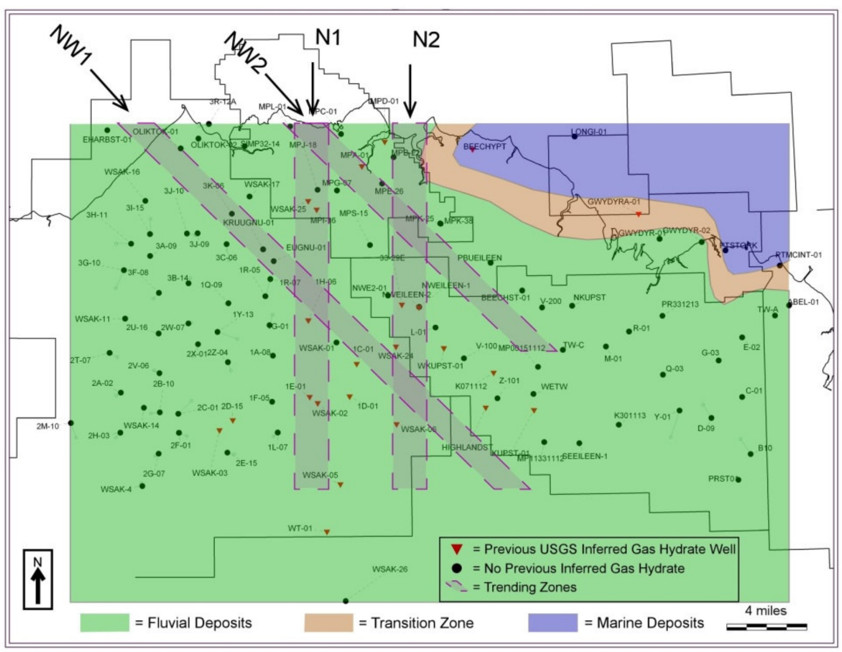
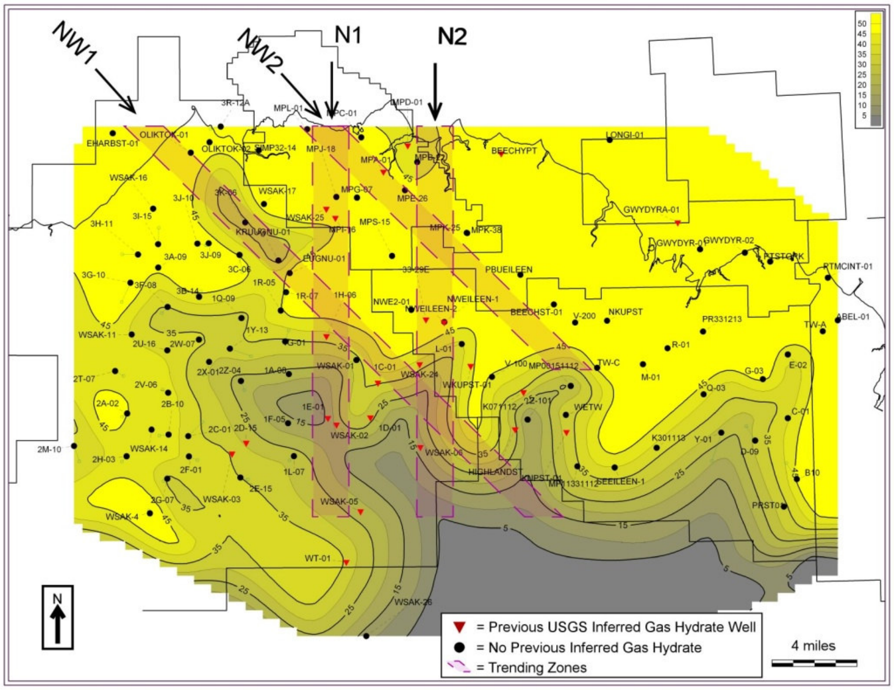


Figure 47: The upper map is a hand contoured net sand map of time slice 9 generated during the net sand phase of this study. The lower map is an interpreted paleo-reconstruction map for this same interval. The interpretation displayed in this map is from the facies characterization study.



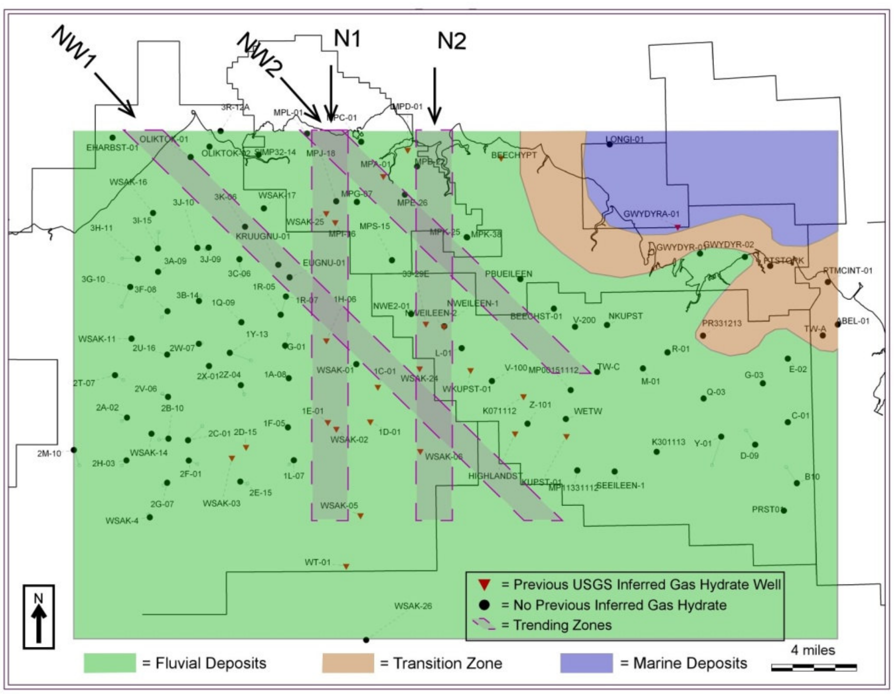


Figure 48: The upper map is a hand contoured net sand map of time slice 10 generated during the net sand phase of this study. The lower map is an interpreted paleo-reconstruction map for this same interval. The interpretation displayed in this map is from the facies characterization study.

4.7.7.5.7 Interval above Time Slice 10

Between PS-34 to PS-34A correlation markers, a retrogradation sequence is interpreted to exist in the northeast part of the AOI. Evidence of this transition is displayed in the cross-section shown in Figure 33. Examining the increasing gamma ray readings and the step back nature of the smaller distributary mouth bars in LONGI-01 well above PS-34 correlation marker, these qualities are indicative to be associated with a retrograde or transgressive phase of deposition. However, strong evidence of this sequence is not always expressed in other wells throughout the AOI. Facies characterization analysis of this unit does not support this hypothesis because no major paleodeposition movements occur within this interval. In the next higher parasequence set between PS-34A to PS-35, all sand-rich areas were interpreted to be fluvial deposits (Figure 33 and 30), which really contradicts our retrogradation interpretation. This parasequence behavior is debatable.

Also present above PS-34 marker is an anomalous shale-rich area located in the southwest part of the AOI, mainly in KRU (Figure 30). Based on the opposite lateral location and the pinching out behavior displayed towards the northeast (Figures 33 and 30), this shale unit was hypothesized to be a coastal plain mud or siltstone. No well developed sand intervals are displayed throughout this shale unit in the KRU region. This may suggest that a major change in the river system locations occurred during this time. This is one proposed explanation of why no sand-rich fluvial deposits are associated with this interval over the KRU area. Combining this observation with the retrogradation hypothesis observed in LONGI-01, dramatic changes in sediment deposition orientation must have been present during this time. No consensus was agreed upon to describe the data results observed in this parasequence set.

One important point to mention, for a few wells mainly in the MPU, gas hydrate is interpreted to exist between PS-34 to PS-34A correlation markers. Since gas hydrate bearing sands in slice 10 and above the parasequence set are laterally connected, for intervals that were identified to contain gas hydrate between the PS-34 and PS-34A markers, these net pay values were added to slice 10.

4.7.7.6 Paleosol Horizon Alternative Interpretation

Well log-based stratigraphic interpretation within the MPU reveals the presence of potential single and stacked paleosol units that may be alternatively interpreted as potential gas hydrate-bearing reservoir zones in previous studies. A lack of available core data and cuttings for analysis keeps this alternate paleosol interpretation speculative. The interpreted paleosols appear as one and/or several relatively thin resistive zones that are characterized by low GR readings and are immediately overlain by above-normal velocity and bulk density responses. Thicknesses of individual resistive units (possibly ankerite or calcite cemented beds) range from 1-4 meters. These units can be interleaved with shale zones comprising what is commonly referred to as a paleosol stack, which commonly produce intermittent, but relatively strong impedance contrasts along sequence boundaries in seismic data. These vary in thickness within the MPU and appear to reach thickness of 5 meters or more (e.g. ~ 1930 feet MD in MPB-02). The paleosol interpretation might explain the notable lack of increase in background or “total” gas seen on mud logs across these previously interpreted “gas hydrate-bearing” zones within the MPU. Similar intervals have been correlated and noted in many other wells in the KRU and PBU areas and are the subject of on-going research. Reviews of any available core and/or sample descriptions, drilling exponents, and porosity log litho-identification and MSFL analysis would prove most useful in validating this preliminary interpretation. Although this data had been requested early in the project, little was available for study.

Table 5 lists the MPU wells that are thought to contain potential paleosol intervals based on well log interpretation. Paleosol horizons are based on petrophysical calculations where relevant logs available and correlative horizons where logs for complete petrophysical analysis are not available.

Well	**USGS-zone**	**UA-zone**	**Comment**
MPU B-02	E	L_35a - 35	
MPU E-26	E	L_35a – 35	
MPU A-01	E	L_35a – 35	Possible thicker paleosol stack interbeds
MPU K-38	E	L_35a - 35	Possible thicker paleosol stack interbeds
MPU B-02	C	L_34 – 33	2 meter interval may correlate to 3-4 meter interval interpreted above gas hydrate in NWEileen-02
MPU B-01	E	L_35a - 35	Logs for complete petrophysical analysis not available
Kavea32-25	E	L_35a - 35	Logs for complete petrophysical analysis not available
MPU D-01	E	L_35a - 35	Logs for complete petrophysical analysis not available
MPU A-01	E	L_35a - 35	Logs for complete petrophysical analysis not available
MPU K-25	E	L_35a - 35	Logs for complete petrophysical analysis not available
Cascade-01	E	L_35a - 35	Logs for complete petrophysical analysis not available
WSak-25	E	L_35a - 35	Logs for complete petrophysical analysis not available
MPU B-01	D	L_35 – 34	Logs for complete petrophysical analysis not available
MPU B-01	C	L_34 – 33	Logs for complete petrophysical analysis not available

Table 5: Interpreted Possible Paleosol Intervals within MPU Wells.

UA chronostratigraphic or sequence stratigraphic analysis shows that these interpreted paleosol units are commonly linked to the upper beds of incised channel deposits or upper units of point bar parasequences that overlie intraformational unconformities. This spatial relationship and their regional correlativity also makes these units ideal indicators for detailed sequence boundary interpretation. The latter are critical to accurate chronostratigraphic correlations that ultimately lead to more accurate characterization of reservoir connectivity, potential production modeling, refinement of volumetric assessments, and paleodepositional reconstructions. Studies were planned to assess the relations between potential paleosol horizons within the MPU area and the adjacent Eileen trend area (within KRU and PBU) and their potential linkage to underlying northwest-trending fault zones and, in some locations, syndepositional north-northeast-trending faulting. Both are expressed as reactivated structural areas that could well have been associated with subaerial exposure, erosion and subsequent formation of paleosol units that currently occur within the gas hydrate stability zone within the MPU area. Their role in the constraining of gas hydrate and free gas occurrences are not fully understood.

4.7.7.7 Net Pay Estimations

Due to the common overestimation of net pay totals observed using the expert system, manual interpretation of net pay commenced. In determining final net pay totals for each well, all net pay intervals must meet the following standard log conditions:

Gamma Ray: Net pay must reside in an interval that is classified as net sand according to our net sand study.

Caliper: Net pay that resides in intervals with sudden caliper increases “washouts” will be evaluated on an individual well basis. All other areas are considered valid data points.

Resistivity: An increase in resistivity not related to changes in lithology, but related to pore fluid changes is required for net pay to exist.

Acoustic time: For gas hydrate, an increase in acoustic time from background responses must be present for net pay to exist. For associated free gas, a decrease in acoustic time from background responses must be present for net pay to exist.

Density: For gas hydrate, a density response is not one of the primary logs used in determining net pay, but any response with the combination of the previous log responses may be classified as net pay depending on the circumstances. For associated free gas, a decrease in the density log creating a cross-over affect with the neutron log will be classified as net pay.

Neutron: For gas hydrate, a neutron response is not one of the primary logs used in determining net pay, but any response with the combination of the previous log responses maybe classified as net pay depending on the circumstances. For associated free gas, an increase in the neutron log creating a cross-over affect with the density log will be classified as net pay.

Using the above primary log responses outlined, the Expert System (ES) and the location of the wells relative to the Top Hydrate Stability Zone (THSZ), Base Ice-bearing Permafrost Zone (BIPFZ), and Base Hydrate Stability Zone (BHSZ), manual interpretations of net pay for each time slice was visually determined. During the manual interpretation phase, a transitional trend of net pay was discovered to exist. This trend evolved in lateral space from areas with well-developed net pay “shows” to moderate net pay “shows” then onto slight “shows” and finally to no “shows” intervals. These trends later became classification categories for all net pay intervals. Every identified net pay interval that contained gas hydrate/associated free gas on a slice map demonstrated this lateral trend. This lateral observation was mapped for all interval slices and net pay strength categories were assigned to each location in an attempt to emphasis the strength of the net pay shows. Along with the classification of net pay based on the strength of the shows, when a well contained an incomplete set of petrophysical logs, an additional asterisk was placed on the map disclosing this condition. For areas that contained well-developed to moderate shows, net pay interval footages were determined and were recorded on the slice maps. Defining net pay for an interval classified as slight shows were difficult since no sharp petrophysical log responses were present. Only gradational and subtle changes were available in the data. Due to this affect, no net pay values were calculated for these intervals.

Once all net pay totals were recorded, correcting the measure depth to true vertical depth for all net pay intervals, using the directional survey data was initiated. Since all petrophysical log data is displayed in measured depth, the true vertical and measure depth values for each time slice horizon were exported from PETRA into a Microsoft Excel spreadsheet. In Excel, a ratio between measure depth and true vertical depth was calculated for each interval containing net pay. Using these ratios calculated as a multiplier, net pay footages from measured depth to true vertical depth were calculated by multiplying these numbers together. For the vast majority of cases, no change occurred between measured and true vertical depth for net pay values. Only in a few intervals, minor changes were required.

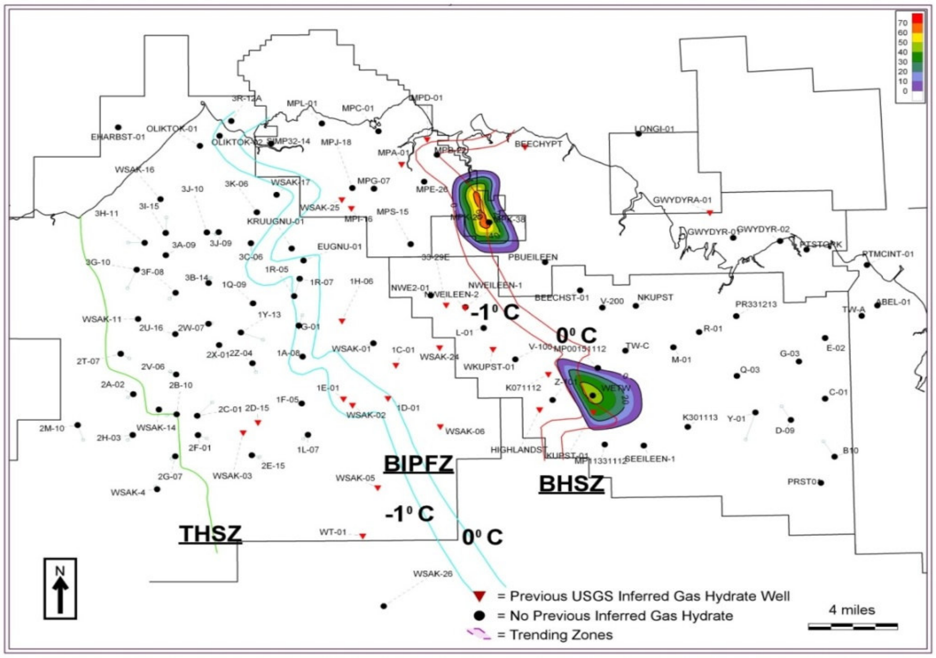
4.7.7.8 Net Pay Mapping

After determining final net pay footages for all slice map intervals, contouring of net pay maps began. Incorporating all geologic trends discussed earlier, net pay maps for each interval were highly constrained. During the creation of all net pay maps, the corresponding net sand map was used, as a transparent background, in defining the shape and lateral limits of these maps. During the contouring process, no net pay contour was allowed to be greater than corresponding net sand contour for each interval evaluated. This condition eliminated the possibility of having areas display larger net pay values then their corresponding net sand values. Below are a review of all net pay maps created and a short discussion of why certain contour shapes, orientations and lateral extent of contour lines were chosen beginning with the oldest (deepest) interval.

4.7.7.8.1 Net Pay Map between PS-33 to L31A

Two separate potential associated free-gas and gas hydrate reservoirs exist in this interval. The first resides in the eastern MPU and the second in the south central part of the PBU (Figure 49). For the MPU, well-developed gas shows are identified in MPU K-25 and MPU K-38 wells. In the MPU K-38 well, a near complete set of petrophysical logs were available. In this well the gas crossover affect is present and covers almost the entire sand interval. In the MPU K-25 well an incomplete set of petrophysical logs were available. A strong resistivity response was displayed and is similar in nature to the response seen in the MPU K-38 well, which contained an obvious gas crossover response on the neutron porosity log. Leaning towards a conservative estimate of net pay totals, the net pay for this area was determined to be 60 feet. This number was estimated by examining net pay totals from both wells and using the more conservative number. Other nearby wells did not demonstrate any well-developed to moderate associated free gas or gas hydrate shows for this region. Since these wells are the only conclusive evidence of net pay for this extensively sand-rich area, the shape of this reservoir was guided by our net sand maps and the BHSZ. The Mount Elbert prospect lies in a structurally higher area than the MPU K-pad and is fault bounded (Figure 4). The gas show displayed in the MPU K-pad could be the down-dip associated free gas source providing methane to the structurally higher gas hydrate reservoir. This occurrence is supported by early gas hydrate/associated free gas models (Collett, 1988). With the BHSZ between this prospect and the MPU K-pad, a decrease in the amount of gas is interpreted as one moves up-dip into the BHSZ. Within and on the opposite sides of this zone, the amount of gas hydrate increases in the same fashion as the associated free gas decreases (Figure 49). This contour effect was done to illustrate that gas is continuously present throughout this area but just changing its physical state from associated free gas to gas hydrate. Sand rich areas east of the MPU K-pad could potentially contain associated free gas, but net pay contours do not extend far into this region with no well data available. The south end of this prospect is not extended much further past the MPU boundaries due to the lack of petrophysical well log data. Associated free-gas and gas hydrate reservoirs could exist in these areas based on the net sand map and facies characterization results, but these regions will not be connected with the MPU K-pad shows, using a more conservative approach.

For the PBU, associated free gas/gas hydrate reservoir, three wells contained well-developed to moderate shows. In WETW and KUPST-01, well-developed gas shows were illustrated with density and neutron logs displaying the gas crossover affect. In K071112, a moderate increase in resistivity is present. The acoustic log for this interval is invalid due to the straight line nature that was displayed, so interpretation of gas hydrate was made based on its location relative to the BHSZ. Other wells in the area had either slight to no shows.



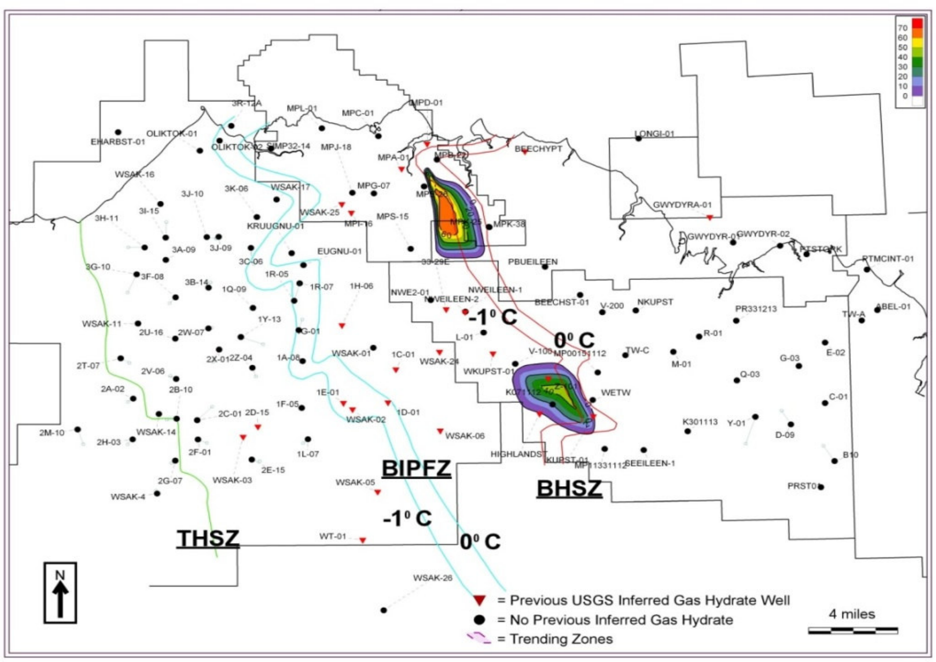


Figure 49: The upper map is a hand contoured net pay map is located between PS-33 to L-31A. This map represents the associated free gas that is inferred to exist in this interval. The lower map

is a hand contoured net pay map for gas hydrate reservoirs that are inferred to exist within this interval.

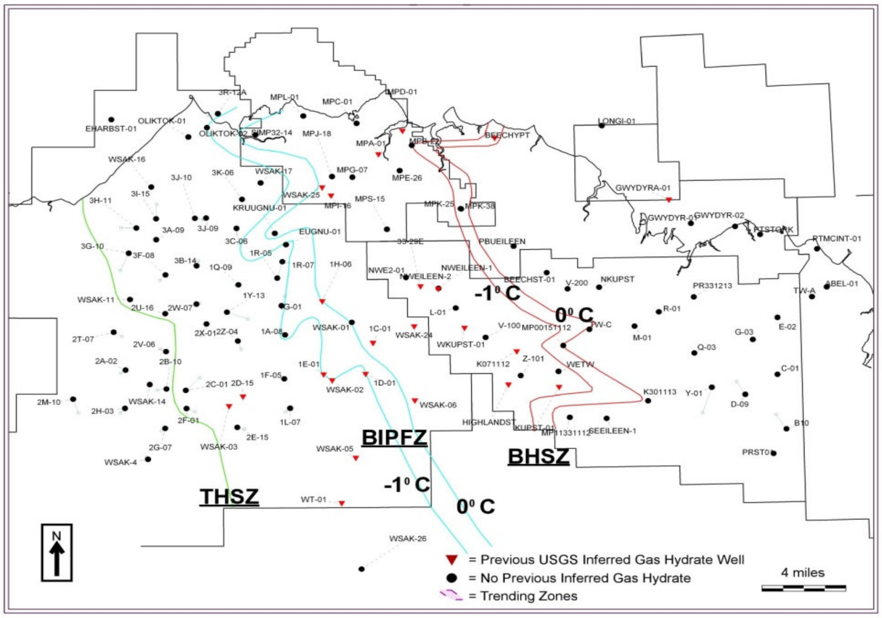
The lateral extent of this reservoir is controlled with nearby wells that contained no shows. Net sand contours for this region between the associated free gas and gas hydrate areas are divided by a shale prone region (Figure 43). Examining a three well cross-section revealed this shale appears to be a function of less sand development and does not imply there is a physical boundary between these wells. Connectivity between the three wells is probable and gas hydrate located structurally above a down dip associated gas-reservoir is inferred. Due to the lack of seismic data, net pay contours were constrained by well density and net sand map trends.

4.7.7.8.2 Net Pay Map Within Time Slice 6

One potential gas hydrate-bearing reservoir exists near the intersection of the MPU, KRU and PBU. Three wells define the amount of net pay for this reservoir with strengths ranging from moderately to slightly developed (Figure 50). In WSAK-24, a minor resistivity response coupled with a sudden drop in acoustic time defined a moderate show of gas hydrate for this interval. Slight shows from 1C-01 and NWE2-01 were documented. Analyzing the well locations against the net sand map shows primarily under-developed sand areas (Figure 44). Facies analysis displays fluvial channels with interbedded shales as the predominant rock type in the net pay intervals. Northwest structurally up-dip from all well positions sand development improves according to our study. A relationship relating increases in sand quality to increases in net pay was assumed. Using the given relationship, areas structurally up-dip in more developed sand regions had contours representing more net pay without well data support. This more aggressive approach was taken since all wells in this interval with net pay shows were in structurally down-dip locations in less sand rich areas. Using the surrounding well data, net sand contour patterns, BIPFZ and all trending zone boundaries, the reservoir lateral extent was defined and a final net pay contour map was generated (Figure 50). No associated free gas was identified for this interval.

4.7.7.8.3 Net Pay Map within Time Slice 7

One potential gas hydrate reservoir is interpreted to reside in time slice 7 map (Figure 51) approximately in the same location as the gas hydrate reservoir displayed in time slice 6 map (Figure 50). Four wells are used in determining net pay values for this interval. All wells display a moderate to slight strength response. Well 1H-06 is the only well with questionable data since Time Slice 7 resides above the BIPFZ. This questionable response could be related to the formation of ice, but this interval was interpreted to contain gas hydrate due to the similar log responses compared to the other wells. WSAK-24 is the only well that possessed an acoustic log, which shows a slight decrease coupled with an increase in resistivity in the potential reservoir interval. This behavior suggests the presence of gas hydrate. For the NWE2-01 and 33-29E wells, only gamma ray and resistivity logs were available. Comparing the resistivity character for both wells to WSAK-24 response, similar resistivity patterns emerged. In the facies characterization analysis, fluvial channels and point bars were identified throughout the net pay interval. According to the trends displayed in the net sand map, these intervals are most likely connected based on their lateral extent and similar facies patterns. The NW1 zone, bounded net pay contours on the south portion of this reservoir (Figure 51). On the west and east boundaries lie the N1 and N2 zones, respectively. For the north boundary a more shale-rich region is present with no gas hydrate shows in those wells. On the southwest portion of the net pay area, migration of contours southward is drawn to integrate the potential higher sand rich areas interpreted from our net sand study (Figure 45). Reservoir volumes from this map are considered to be upper limit estimates since no pronounced gas hydrate shows were present. No associated free gas shows were seen in this time slice.



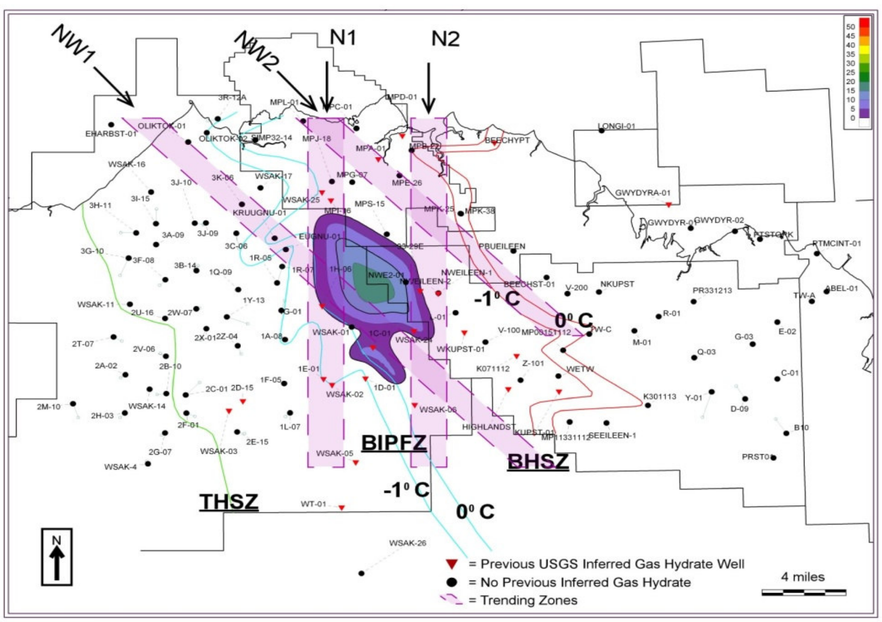
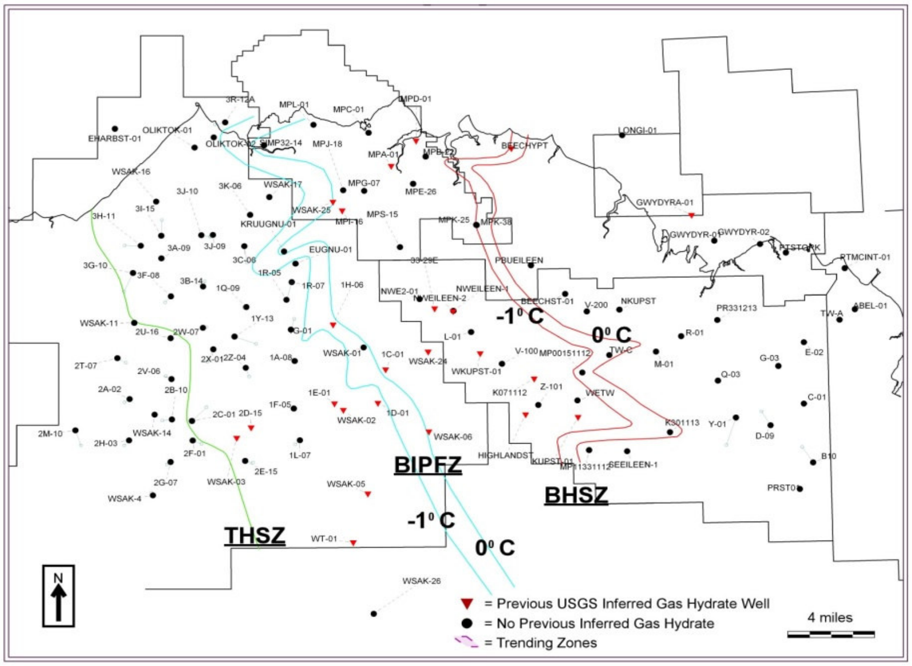


Figure 50: The upper map represents the associated free gas that is inferred to exist in this Time-slice 6 interval. The lower map is a hand contoured net pay map for gas hydrate-bearing reservoirs that are inferred to exist within this interval. On both maps the three major transition zones are present.



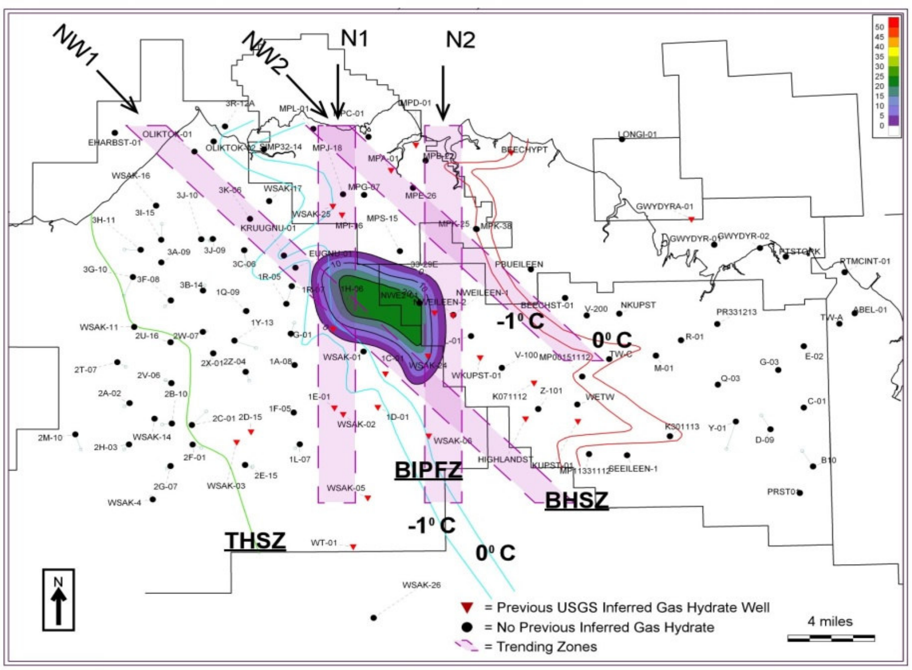


Figure 51: The upper map is a hand contoured net pay map of time slice 7. This map shows no associated free gas is inferred to exist in this interval. The lower map is a hand contoured net pay map for gas hydrate reservoirs that are inferred to exist within this interval. On both maps the three major transition zones are present.

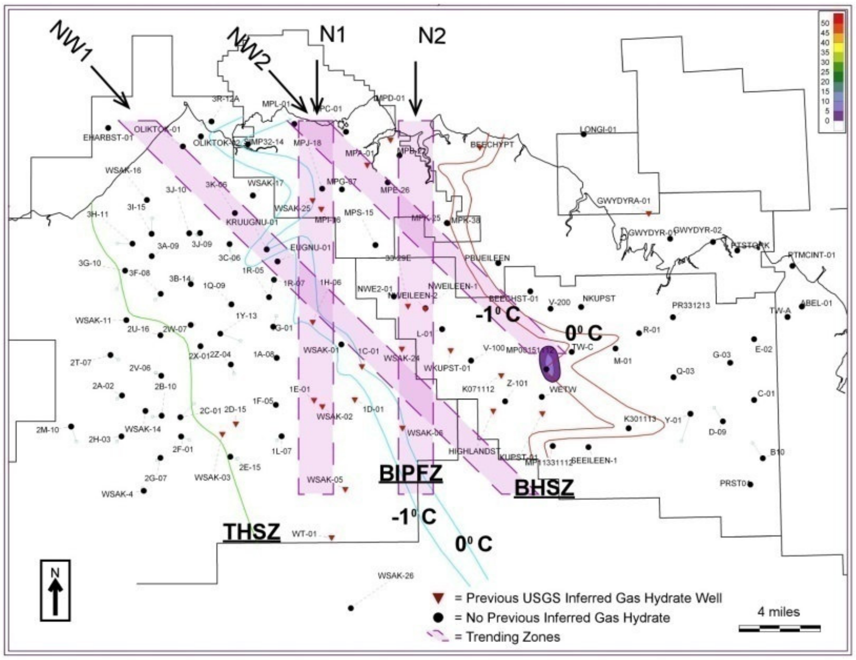
4.7.7.8.4 Net Pay Map Within Time Slice 8

One potential gas hydrate and one associated free gas reservoir are present in time slice 8 map (Figure 52). The gas hydrate reservoir located in the northwest part of the PBU is defined by two wells. The L-01 well was not evaluated for net pay in this study because the gamma ray log was the only petrophysical log available in this well. Instead an additional well (L-106) was obtained near the end of this project and was used to determine net pay for this interval. Visual comparison of the gamma ray character for both wells display an almost identical pattern and correlation horizons between the two wells was straightforward. The distance between the two wells is relatively close and acknowledging the fact that the gamma ray responses are similar, net pay identified in L-106 was assumed to be present in L-01. L-106 contained a full suite of petrophysical logs. A moderate resistivity response displayed in this interval suggested the presence of gas hydrate. In NWE2-01, an incomplete set of petrophysical logs was available. Only the gamma ray and resistivity surveys were present. Similar resistivity surveys behavior was illustrated and compared well with responses seen in the L-106 well. Though this response was not as strong, compared to the L-106 data, defining net pay for the NWE2-01 was detectable. The horseshoe-shaped reservoir geometry is strongly influenced by the net sand contour map and no shows present in 33-29E and Northwest Eileen State #2 well. This volume should be considered the upper limit of gas hydrate for this interval. No associated free gas reservoir co-existed with this gas hydrate reservoir.

In the central part of the PBU the MP00151112 and the K091112 wells were used to identify a small gas show. On the net pay map, only the MP00151112 well is displayed. The K091112 well is available and is located relatively in the same location as the MP00151112, but was not chosen to be displayed because of complications that arose from wells being spaced too closely together. Using an incomplete petrophysical log sets from both wells that included the gamma ray, resistivity, acoustic and density curves, this interval was evaluated. A slight to moderate resistivity response is illustrated with an increase in acoustic time and decrease in the density log for the K091112 well. Since the MP00151112 well was chosen to represent the area, projecting the net pay identified from the K091112 well was completed by visually verifying that both the gamma ray and resistivity responses over this interval were similar. No other nearby well contained any net pay shows so the radial extent of this reservoir is assumed to be limited as demonstrated in the map (Figure 52).

4.7.7.8.5 Net Pay Map Within Time Slice 9

Two small associated free gas and one fairly large gas hydrate reservoirs are interpreted to be present in time slice 9 map (Figure 53). The large associated free gas/gas hydrate reservoir, located in the northwest portion of the PBU, is defined by four wells. Two well developed gas hydrate shows are from the Northwest Eileen State #1 and #2 wells. In Northwest Eileen State #2 well, gas hydrate was previously cored at this interval. This interval (Figure 28) is within USGS C Unit (Collett et al., 1988). While resistivity increases, acoustic time decreases in this interval. This behavior represents a classic example of gas hydrate petrophysical log response. Density and neutron logs do not display dramatic changes in this interval. In Northwest Eileen State #1, similar resistivity increases are observed but poor quality is present in the acoustic, density and neutron logs. Considering the short distance between these wells and similar gamma ray and resistivity log



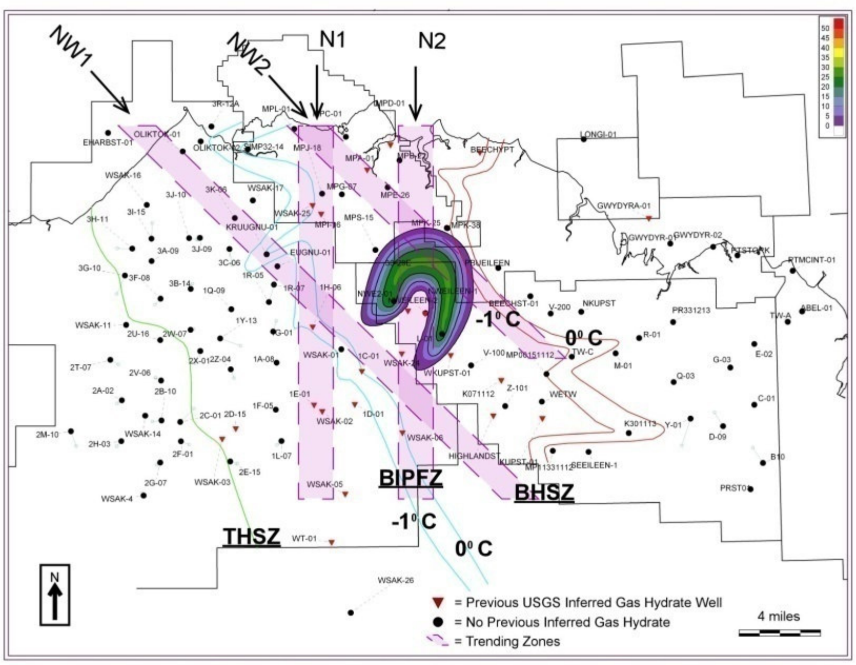


Figure 52: The upper map is a hand contoured net pay map of time slice 8. This map represents the associated free gas that is inferred to exist in this interval. The lower map is a hand contoured net pay map for gas hydrate reservoirs that are inferred to exist within this interval. On both maps the three major transition zones are present.

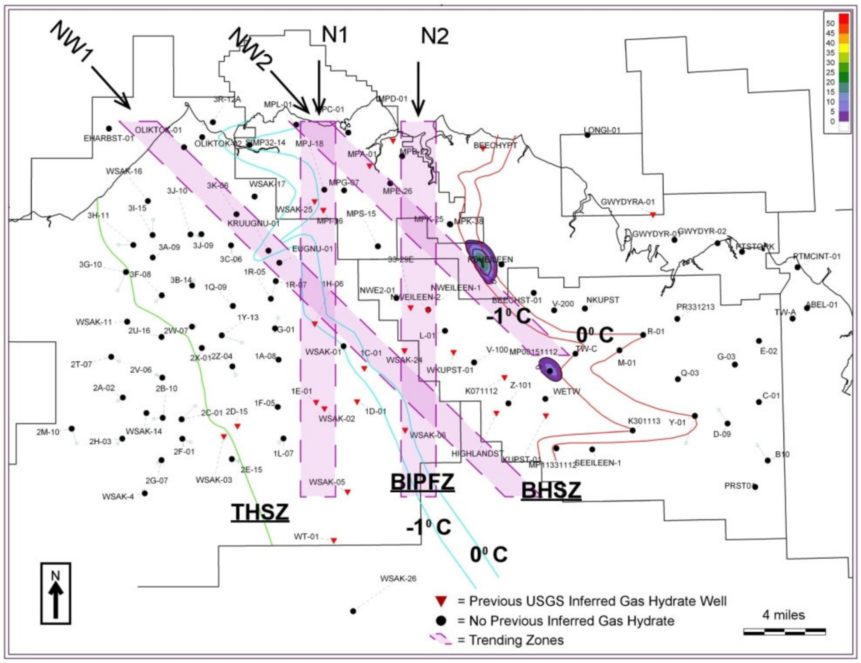
behavior, assuming gas hydrate is also present in Northwest Eileen State #1 was deemed acceptable. In the NWE2-01 and 33-29E wells, only gamma ray and resistivity logs were available. A moderate resistivity increase was displayed in both wells. These intervals were classified to have moderate shows and net pay footages were recorded. The structural up-dip location relative to the Northwest Eileen State wells provides a plausible pathway for migration of gas to occur into the NWE2-01 and 33-29E wells before the formation of gas hydrate. All four wells in this region were inferred to contain gas hydrate. Facies characterization analysis reveals this region to be sand-rich with fringe channel and point bar deposits. Connectivity between these areas is likely to occur due to the sand-rich nature of this interval, but the lateral extent may not be as widely spread as drawn considering the limited dimensions of sands bodies typically associated with fluvial deposits. No dense well control is available in this area. Based on the strong log responses indicated, the net pay area interpretation was extended beyond well control. The north and south boundaries of the net pay region were constrained by wells with no gas hydrate shows. The west and east boundaries were controlled by the BIPFZ and BHSZ respectively. In the southern part of the net pay map, a contour inflection is displayed to show the influence of the net sand map on this interval. Towards the east, the associated free gas corresponding with the gas hydrate reservoir is displayed. This associated free gas contains no well control. Assuming that the lateral extent of this reservoir may potentially cross the BHSZ boundary, this smaller area would be the down dip gas associated with this reservoir as predicted in early gas hydrate models (Collett, 1988), similar to the inferred reservoir behavior between PS-33 to L-31A markers. The location of the BHSZ below the MPU K-pad is estimated and does not contain good well density for constraining purposes. This zone may lie further westward than drawn but its exact location is uncertain. Depending on the true location of this zone, the amount of associated free gas inferred in this region can significantly change.

In the central part of the PBU a small gas show is again present in the MP00151112 and K091112 wells. Associated free gas was first determined in K091112, then projected into the MP00151112 with similar log behavior as seen in time slice 8 (Figure 52). The radial extent of this reservoir is limited since no surrounding wells demonstrate any net pay shows. The limited and small gas show is expressed as a small oval-shaped area in the map.

4.7.7.8.6 Net Pay Map Within Time Slice 10

One each intra-permafrost, gas hydrate and associated free gas reservoir exist on the time slice 10 map (Figure 54 and 55). This slice contains the best defined net pay shows and laterally covers the largest area of potential reservoir in the AOI.

Beginning with the associated free gas reservoir, two wells contain gas shows. Evaluating the well developed to moderate gas shows in PBUEILEEN and BEECHST-01, resistivity and acoustic time log measurements increase along with density logs decreasing throughout this interval. PBUEILEEN was the only well with a neutron log. The typical density and neutron crossover gas effect was present in this well. Well density in this area is minimal. Using the limited well control available, the BHSZ and the up-dip structural trend toward the southwest, a radial decreasing contour map was drawn that corresponding with the gas hydrate contour map (Figure 54).



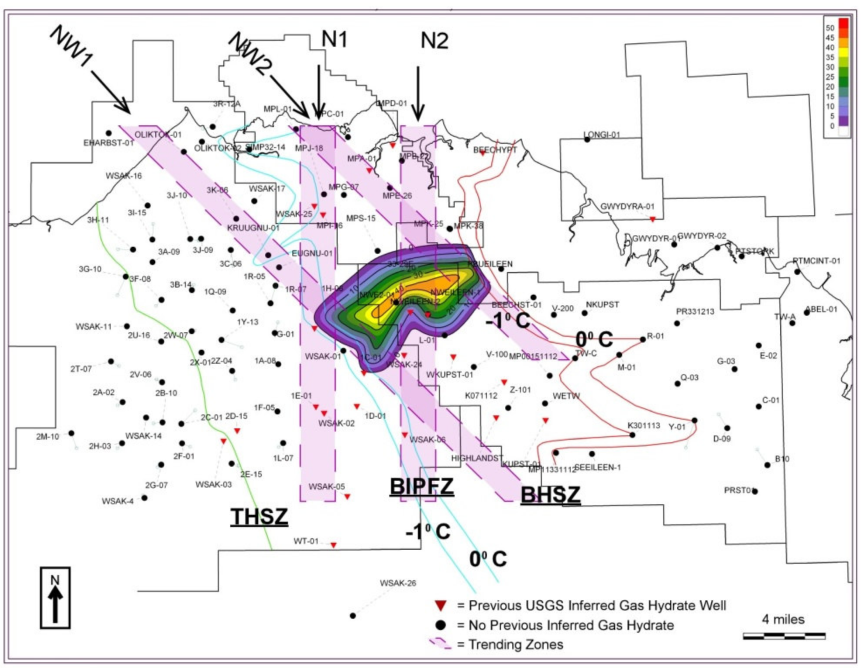
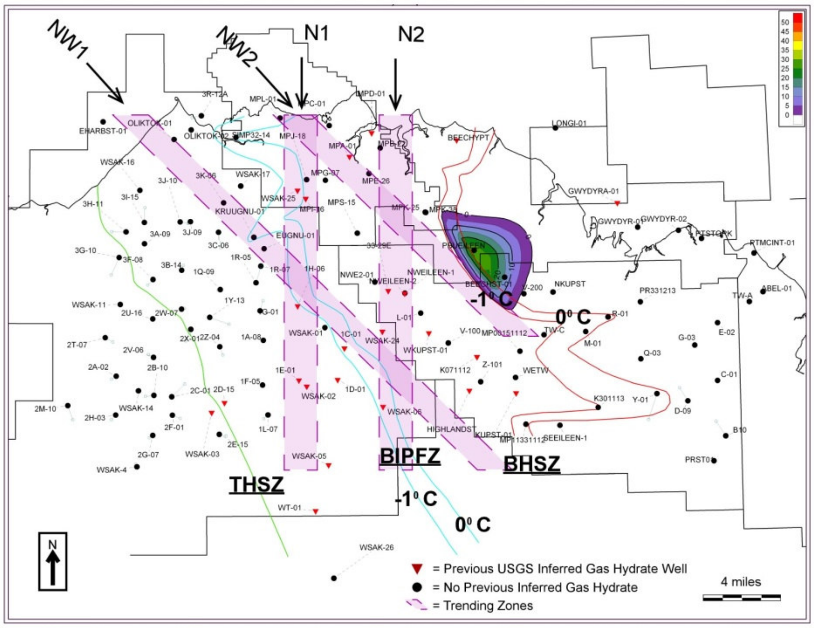


Figure 53: The upper map is a hand contoured net pay map of time slice 9. This map represents the associated free gas that is inferred to exist in this interval. The lower map is a hand contoured net pay map for gas hydrate reservoirs that are inferred to exist within this interval. On both maps the three major transition zones are present.

In the gas hydrate reservoir, fifteen wells were identified with shows ranging in strength from well developed to slight. The well-developed shows reside in the northwest portion of the PBU and are derived from the Northwest Eileen State #1 and #2, 33-29E, L-106 and WKUPST-01 wells. In this slice gas hydrate cores were recovered from Northwest Eileen State #2. Another well-developed to moderate show is interpreted to exist in the MPA-01 well. This well has the only strong show in the MPU. Net pay contours were controlled by well density in many areas. In the southern part of the map, an abrupt termination of contours exist which was highly influenced by the V-107 well. The nearby WKUPST-01 and HIGHLANDST wells did contain sufficient amounts of net pay. Based on their location and the magnitude of net pay, a fault interpretation between these wells is presumed. The inferred fault at this location is oriented northwest, based on our net pay contour map and fault trends displayed. This direction appeared to align semi-parallel with the trending zones present in this study. A consistent contour thickness was still maintained for the area despite this condition. The lower extension of net pay beyond HIGHLANDST was projected from net sand trends situated in this area. Along the east part of the net pay map, no well control was present and contour thickness limited the lateral extent of the pay for this region. Since no data is present between the BIPFZ and net pay contour map, this area could contain additional gas hydrate resources. Recognizing this area is structurally up-dip to proven gas hydrate zones and stratigraphically connected, migration of gas up-dip into these locations is conceivable. Along the west part of the map, the BHSZ controls contour behavior for this region. The phase transition occurring within the BHSZ correlates with the associated free gas contour map to illustrate the presence of gas throughout this zone. Physical connection of both reservoirs is assumed for this area. On the north end in the MPU, well control and contour thickness dictates net pay contour behavior. A thicker net pay regions is presently extended southward with no supporting well data. Contours were drawn in this manner to reflect the pull-apart basin inferred by Casavant (2004). For the entire reservoir in the MPU, five wells contain net pay values that reside above PS-34 horizon. These wells are MPB-01, MPA-01, MPJ-18, NWE2-01 and WSAK-24.

The intra-permafrost net pay map is a direct function of the net sand map for this interval. Identical resistivity well log responses from all wells are observed between the THSZ and BIPFZ. Attempting to identify net pay in this area using only a well log based analysis is unfeasible since ice and gas hydrate cannot be distinguished from each other. Recognizing from Lachenbruch study that intra-permafrost gas hydrate does exist (1988), assuming gas hydrate prospects in this region is probable. Making a second assumption that net pay is a function of sand quality, net pay contours for this area were generated. Acknowledging the fact that this area is located structurally up-dip and is stratigraphically connected to the largest and most well developed reservoir in the IOI and that inferred gas hydrate reservoirs exist at greater depths according to the previous USGS studies (Collett et al., 1988 - red triangles), the source providing methane to this region is plausible. The parameters constraining the limits of this reservoir are the THSZ, BIPFZ, trends in the net sand map and the location of USGS inferred lower gas hydrate reservoir wells. No net pay contour extended past these boundaries. Gas volumes from this area are to be viewed with extreme caution since these assumptions only imply its existence.



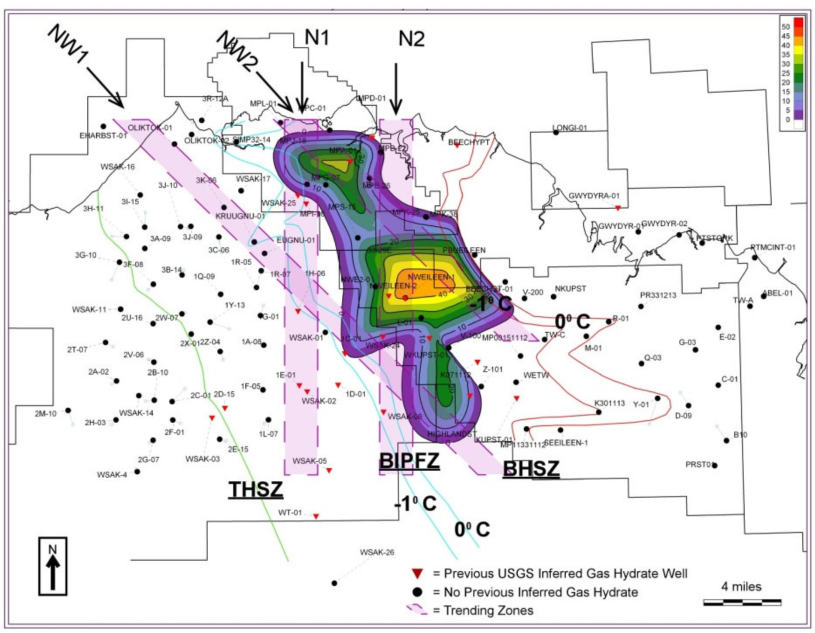


Figure 54: The upper map is a hand contoured net pay map of time slice 10. This map represents the associated free gas that is inferred to exist in this interval. The lower map is a hand contoured net pay map for gas hydrate reservoirs that are inferred to exist within this interval. On both maps the three major transition zones are present.

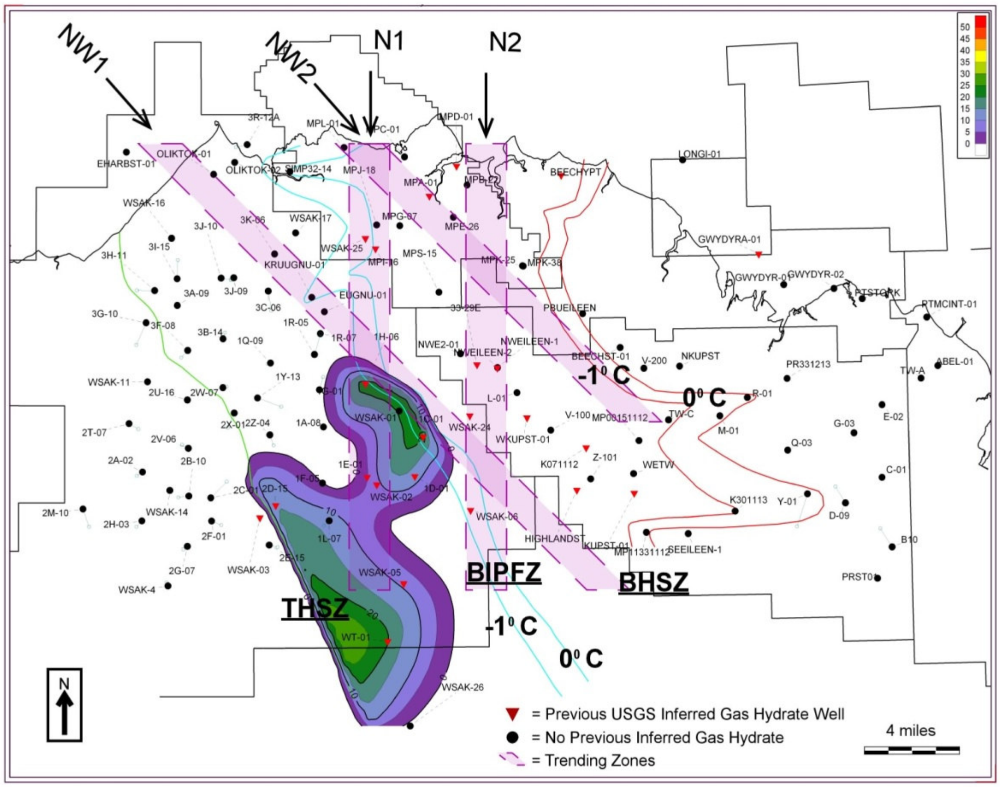


Figure 55: This map display the hand contoured regions that are inferred to contain intra-permafrost gas hydrate for time slice 10. Since identification of gas hydrate solely using petrophysical well logs is impractical in this area, the results displayed in this map should be viewed with extreme caution.

4.7.8 Volumetric Assessment for the Area and Intervals of Interest

The following volumetric analysis is from the work of Manuel (2008) from well log and other geologic data. After all net pay maps were created, total rock volumes from all maps were calculated. Using the net pay contour maps and PETRA's volumetric capabilities, volume totals for areas that contained positive contour values were computed. Each volume total was generated using a grid refinement of three and average porosity, gas saturation, gas expansion factors and other volumetric parameters. Raw volumes in cubic square feet were generated from PETRA and were exported into a Microsoft Excel spreadsheet. These volumes are recorded in Tables 6 and 7, documented by interval. Both associated free gas (Table 6) and gas hydrate (Table 7) volumetrics were generated. The equations used to quantify the amount of original-gas-in-place (OGIP) for gas hydrate and associated free gas reservoirs are listed below.

Volumetrics for Chronostratigraphy Framework in AOI area
Justin's Associated Free Gas Volumetrics

1 Interval Unit	2 Data Area (ft^2)	3 Volume (ft^3)	4 Reservoir Volume (ft^3)	5 Original Gas-In-Place (tcf)
Slice 10	418,989,139.49	4,455,513,544.17	1,603,984,875.90	0.121
Slice 9	83,812,607.24	546,777,721.94	196,839,979.90	0.015
Slice 8	39,775,400.79	122,256,197.84	44,012,231.22	0.003
Slice 7	0.00	0.00	0.00	0.000
Slice 6	0.00	0.00	0.00	0.000
Slice M4 to L31A	476,313,708.72	11,109,044,594.64	3,999,256,054.07	0.302

Static Variables	
Porosity =	**36%**
B_G =	**108**
Gas Saturation =	**70%**

Total Reservoir Volume (bcf) = 5.84

Total Gas Volume (tcf) = 0.44

Total Gas Volume (x 10^{12} m^3) = 0.01252

(1) Interval unit defined by gas hydrate team
(2) Data area of net pay for each unit calculated in GeoPlus - PETRA volumetric program
(3) Volume of reservoir rock computed in GeoPlus-PETRA volumetric program
(4) Reservoir Rock Volume = Volume * Porosity
(5) OGIP volume calculated assuming a gas saturation of 70 % and a B_G expansion factor of 108.

Note: Porosity, B_G and Gas Saturation values were taken from USGS Milne Point seismic volumetric study to produce comparable volumetric numbers

Assumed 35.3 ft^3 = 1 m^3

Table 6: Free Gas-in-place Volumetrics calculations total 0.44 TCF for chronostratigraphic framework in IOI within AOI (Figure 28) from Manuel (2008).

Volumetrics for Chronostratigraphy Framework in AOI
Justin's Gas Hydrate Volumetrics

1 Interval Unit	2 Data Area (ft^2)	3 Volume (ft^3)	4 Reservoir Volume (ft^3)	5 Original Gas-In-Place (tcf):
Slice 10	2,488,199,686.68	40,724,439,557.19	15,475,287,031.73	2.157
Slice 9	899,687,933.01	16,646,464,963.44	6,325,656,686.11	0.882
Slice 8	648,523,815.31	8,391,902,527.30	3,188,922,960.37	0.445
Slice 7	743,768,460.56	9,289,901,619.59	3,530,162,615.44	0.492
Slice 6	857,382,533.33	6,049,729,635.31	2,298,897,261.42	0.320
Slice M4 to L31A	441,641,750.83	11,399,232,628.77	4,331,708,398.93	0.604
Permafrost Slice 10	2,092,833,531.56	23,243,667,664.36	8,832,593,712.46	1.231
		Total Reservoir Volume (bcf) =	43.98	
		Total Gas Volume (tcf) =	6.131	4.900
		Total Gas Volume (x 10^{12} m^3) =	0.174	

Static Variables	
Porosity =	**38%**
B_{GH} =	**164**
Gas Saturation =	**85%**

(1) Interval unit defined by gas hydrate team
(2) Data area of net pay for each unit calculated in GeoPlus - PETRA volumetric program
(3) Volume of reservoir rock computed in GeoPlus-PETRA volumetric program
(4) Reservoir Rock Volume = Volume * Porosity
(5) OGIP volume calculated assuming a gas saturation of 85% and a B_{GH} expansion factor of 164 as suggested by Collett (1993) and Sloan (1990)

Note: Porosity and B_{GH} values were taken from USGS Milne Point seismic volumetric study to produce comparable volumetric numbers

Assumed 35.3 ft^3 = 1 m^3

Table 7: Gas Hydrate Gas-in-place Volumetrics calculations total 6.1 TCF for chronostratigraphic framework in IOI within AOI (Figure 28) from Manuel (2008). This compares to 8.9 TCF risked gas-in-place from the Eileen trend regional schematic modeling documented in Quarterly Report 15. The 4.9 TCF is gas hydrate volume gas-in-place below ice-bearing permafrost (IBPF).

4.7.8.1 Gas Hydrate Volumetrics

$OGIP_{GH}$ = Volume total * ϕ * B_{gh} * S_{gh}

Volume total = Computed utilizing net pay contour maps and PETRA computing capabilities

ϕ = Average porosity, taken from USGS MPU seismic volumetric study (38%)

B_{gh} = Gas hydrate expansion factor, taken from USGS MPU seismic volumetric analysis (164), (originally proven by Sloan, 1990)

S_{gh} = Gas saturation, assumed to be 85% taken from Collett's 1988 and 1993 studies

4.7.8.2 Associated Free Gas Volumetrics

$OGIP_{G}$ = Volume total * ϕ * B_g * S_g

Volume total = Computed utilizing net pay contour maps and PETRA computing capabilities

ϕ = Average porosity, taken from USGS MPU seismic volumetric study (36%)

B_g = Associated free gas expansion factor, taken from USGS MPU seismic volumetric study (108)

S_g = Gas saturation, taken from USGS MPU seismic volumetric study (70%)

In an attempt to provide comparable volumetric results against the USGS MPU study, porosity, expansion and saturation values for gas hydrate and associated free gas were used from Collett's previous work (1988 and 1993). The only parameter not directly used from the USGS volumetric study was the gas expansion factor for gas hydrate. This parameter was taken from the work of Sloan (1990).

The original gas-in-place (OGIP) for all gas hydrate reservoirs studied within the IOI is 6.131 trillion cubic feet (tcf). Subtracting out the intra-permafrost interval due to the uncertainty related to this prospect, the modified OGIP is 4.900 tcf. The greatest volumes of gas reside in slice 10 (uppermost Zone C). This interval overall contained the best development of net pay and covers a large vast area. The second largest gas volumes originate from the inferred intra-permafrost reservoir. This reservoir is based on assumptions of gas migration pathways and the presence of intra-permafrost gas hydrate. No unambiguous shows can be proven with the data provided, but if this phenomenon does exist, gas volumes in this area could be immense. Slice 9 contains the third largest gas volumes. This reservoir is physically connected with Slice 10 and provides a favorable area for future production. In slices 8, 7 and 6, less pronounced reservoirs exist and are located beneath the reservoirs identified in Slices 10 and 9. Between PS-33 to L-31A markers, an inferred reservoir exists in the southeast section of the MPU from USGS seismic analysis. This strong response is a combination of seismic interpreted gas hydrate and a large associated free gas interval identified in the MPU K-pad. Also, in this slice at the western boundary of the PBU resides another reservoir.

The OGIP for all associated free gas reservoirs studied within the IOI is 0.44 trillion cubic feet (tcf). The largest volumes of gas reside between the PS-33 to L-31A markers. The MPU reservoir is defined by two closely spaced wells in the MPU K-pad with the Mount Elbert prospect at its northwest boundary. Another less pronounced reservoir in the PBU exists in this interval. Combining both reservoirs, approximately 68% of the gas volume is contained in this slice. Since three wells, two from the same well pad, define majority of the net pay for the IOI, assuming the largest gas volumes reside in this interval should be done with caution due to the lack of data available. The second largest gas reservoir is present in slice 10. This associated free gas is inferred to be the down-dip gas source related to the pronounced gas hydrate reservoir in this interval. The other two gas reservoirs in Slice 9 and 8 are minor gas contributors and should not be viewed as primary targets.

Combining all OGIP totals, the GIP in the IOI is 6.131 tcf. Acknowledging that only well-defined and moderate shows contributed to the final gas total, shale prone, interbedded sand and marginal reservoirs could add significant gas amounts to the final gas totals during production, but were not quantified in the study.

4.7.9 University of Arizona Workforce

One of the goals of this research contract was to increase the professional workforce for the energy, engineering, and natural resources sectors. Exposure to the DOE-BP funded gas hydrate research and access to technology, training and mentoring associated with related laboratory facilities (e.g. GEOS Seismic Laboratory, MGE's Computational and Visual Interpretation Lab-CVIL, Subsurface-surface Characterization Laboratory-SSCIL) contributed to (1) increased exposure to the energy, mineral and water-resource exploration and management industries, (2) increased student participation in professional organizations (e.g. SPE, AAPG, AEG, AGU, SEG, AZGS, HGS, etc.), and (3) development of professional writing and presentation skills as students prepared and delivered a number of their research topics and findings to professional audiences in a variety of academic- and industry-conference settings. A summary of the students employed on this project during the contract period is contained in this section.

Codes used in the student descriptions:

Student demographic information: *Male (M); Female (F); White non-Hispanic (W); Hispanic (H); African-American (B); American Indian (I); Veteran (V); Foreign student (N)*
Principal research director(s): Drs. Roy Johnson (RJ); Bob Casavant (RC); M. Poulton (MP); Karl Glass (KG)
Departments involved in the hydrate program: Geosciences (GEOS), Mining and Geological Engineering (MGE)

4.7.9.1 Mining and Geological Engineering Students

Bo Zhao (M, N, MP)

- B.S. Degree, Geology, China,
- M.S. Degree, Univ. AZ., Aug. 2003
    - M.S. Thesis: *Classifying Seismic Attributes in the Milne Point Unit, North Slope of Alaska*
- Summer internship; GIS project w/ UA Facilities Planning Dept.
- Bo is completing a Ph.D program in Petroleum Engineering at University of Houston, expected completion 2007;
    - Dissertation: *Fizz and gas separation with SVM classification*
    - employed by ExxonMobil

Shanda Wagner (F, I, RC)

- B.S. Degree, Geological Engineering, Univ. AZ., May 2004
    - Undergraduate research project(s): *Preliminary kinematic study of the "Kartchner Block, Southeastern Arizona*
- Shanda is currently an environmental scientist with AMEC Earth and Environmental in Phoenix, AZ

Gwyn Smith (F, W, RC)

- B.S. Degree, Geological Engineering, Univ. AZ., expected completion Dec. 2006
    Undergraduate research assistance: Helped Dr. Casavant digitize, georegister and synthesize a regional fault map across the AOI for the gas hydrate project (phase 2) and produced graphics used by MP and RC in AAPG Hedberg conference presentations
- 2 summer internships with a mining and petroleum company
- Multiple job offers from energy and mining companies
- Summer internship (limnology research project) in Africa with Dept. Geosciences faculty A. Cohen
- Peace Corps in Surinam, graduate school at Michigan Tech

Greg Gandler (M, W, RC)

- B.S. degree, Geological Engineering, Univ. AZ, May. 2004
    - *Sr. Undergraduate Research Thesis:* Preliminary spatial analysis of hydrate occurrence with respect to faulting Milne Point Unit, Northern Alaska.
- *Multiple internships with mining and petroleum companies*
- *M.S. Degree, Petroleum Engineering, May 2006, University of Texan, Austin*
- *Will begin employment with Anadarko Petroleum as a Production Engineer*

Keith Mitchell (M, B, RC)

- B.S. Degree, Geological Engineering, minors in Geosciences and Mining Engineering, Univ. AZ, May 2005
    - Sr. Undergraduate Thesis: *Preliminary Investigation of Structural Control on Deposition of the Nanushuk Formation; Implications to CBM (Coal Bed Methane) Exploration in the NPRA (National Petroleum Reserve, Alaska)*
- Job offers: Dowl Engineering
- Summer internships with AK-based Dowl Engineering (Tucson office), research project for Evergreen Gas (Denver)
- Keith is currently Sr. Vice President of Business/Technology, My Types, Inc.

Justin Manuel (M, I, RC, KG)

- B.S. degree, Geological Engineering, Dec. 2004
- Sr. Undergraduate Research
    - *Well Log Normalization and Comparative Volumetric Analysis of Gas Hydrate and Free-Gas Resources, Central North Slope, Alaska*

  - *Geophysical and GIS investigation of the Black Mesa Basin area (Navajo Nation), Northeastern Arizona: Implications to natural resource management*
- M.S. Degree, Geological Engineering, May 2006
  - *MS Thesis*: A chronostratigraphic framework of the Sagavanirktok Formation, North Slope Alaska: Incorporating facies characterization, reservoir continuity and dimensions in relation to gas hydrate and associated free-gas resources
- *Summer internships: USGS (geophysics), Phelps Dodge Corp (subsurface geohydrologic characterization, mining), 2 internships with ExxonMobil (production engineering, reservoir engineering)*
- *Considering employment offers from Phelps Dodge, Vector Engineering, ExxonMobil, Chevron*
- *Employed with Freeport McMoRan Copper and Gold*
- *Completed Master of Engineering in December 2008*

Scott Geauner (M, V, RC)
- B.S. Degree, Astrophysics, Univ. AZ
- M.S. Degree, Geological Engineering, May 2006
  - MS Thesis: *Fault analysis, seismic facies modeling and volumetric reassessment of gas hydrates in the Milne Point Unit, North Slope, Alaska*
- *Summer internships: Zonge Engineering (Alaska near-surface geophysical projects)*
- Employed with Kerr McGee as a development geoscientist

Dustin Meisburger(M,W, MP)
- BS Degree, Mining Engineering, Univ. AZ
- Applying to Medical School
- Employed by Mintec, Inc., Tucson, AZ

4.7.9.2 GEOS Students

Casey Hagbo (M, W, RJ)
- B.S. Degree, Applied Geophysics, Michigan Technical University, Houghton, MI, May 2001
- M.S. Degree, Geosciences, University of Arizona, Dec. 2003
  - MS Thesis: *Characterization of gas hydrate occurrences using 3D seismic data and seismic attributes, Milne point, North Slope, Alaska*
- *Summer internships: BP, ChevronTexaco*
- Employed as production geophysicist with ChevronTexaco, Bakersfield, CA

Andy Hennes (M, W, RJ)
- B.S. Degree, Geology, May 2002, University of Montana, Missoula, MT
- M.S. Degree, Geosciences, University of Arizona, May 2004
  - MS Thesis: *Structural constraints on gas hydrate formation and distribution in the Milne Point Unit, North Slope of Alaska*
- *Summer internship: ChevronTexaco*
- Employed as production geophysicist with ChevronTexaco, Bakersfield, CA

Lynn Peyton (F, W, N, RJ)

- B.S. Degree, Geology and Geophysics, University of Durham, Durham, UK, June, 1988
- M.S. Degree, Geophysics, University of Utah, Salt Lake City, UT, Dec. 1991
- Ph.D. Degree, Geosciences, University of Arizona, Expected 2007
    - As part of RA, worked on seismic and synthetic seismogram analysis, well-log to seismic correlation, Milne Point Unit
- Professional experience with Amoco Production Company, Texaco.
- Principle and Geophysicist, Coal Creek Resources, Inc., Lakewood, CO, 2001-present.

M. Serkan Arca (M, N, RJ)

- M.S. Degree, Geology, Middle Eastern Technical University, Ankara, Turkey, June 2004.
- Ph.D. Degree, Geosciences, University of Arizona, Expected 2008
    - As part of RA, worked on seismic data analysis, Milne Point Unit

Margaret Barker (F, W, RJ)

- B.S. Degree, Astronomy and Physics, University of Arizona, Tucson, AZ.
- B.S. Degree, Geosciences, University of Arizona, Tucson, AZ, in progress.
    - Worked on interpretation and spectral analysis of seismic data, Milne Point Unit

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 and interpretation of well data is expected to be fully completed and reported in the peer-reviewed JMPG thematic volume (Section 4.5). Prior quarterly progress reports 18-24 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 8 summarizes project cost status through end-1Q09 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-1Q09	**$9,307,652**	Total processed invoices reimbursed
US Treasury Account Balance	**$511,855.35**	Remaining funds in ASAP Account
Estimated Outstanding Invoices	**$340,832.55**	1Q09 – 2Q09
Estimated US Treasury Account Balance	**$171,022.80**	
Estimated Remaining Funds end-2Q09	**$171,251.00**	Funds obligated in amendments 18-20

Table 8: Project cost status summary through end 1Q-09 and 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, 2006-2009

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 6/30/09 (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 6/30/09 (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 6/30/09 (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 (into Phase 3b)

6. Identification Task Number	7. Planning Category (Work Breakdown Structure Tasks)	8. Program/Project Duration (Phase 3b, 2009-2010) ← Phase 3a →← Phase 3bPlanning →← Implement Phase 3b 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 4Q08 – 1Q09 Reporting Period Significant Accomplishments

Continued Stratigraphic Test data analyses and interpretation. Continued evaluation, planning, and design of production test site and operations.

6.4 Actual or Anticipated Problems, Delays, and Resolution

Contract Amendment 25 authorized a no-cost extension to complete Phase 3a data analyses and continue Phase 3b planning activities through end-June 2009. Industry synergies and alignment are in-progress.

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 also simulated field-scale gas hydrate bearing reservoirs, history matched the Mount Elbert-01 stratigraphic test MDT data, and evaluated ANS potential production test options (Figure 5). These studies have improved understanding of how these different gas hydrate reservoir models handle the basic physics of gas hydrate dissociation processes within gas hydrate-bearing formations. Significant contributors to this effort include: Masanori Kurihara (Japan Oil Engineering Co., Ltd.), Yoshihiro Masuda (The University of Tokyo), George Moridis (Lawrence Berkeley National Laboratory, University of California), Hideo Narita (National Institute of Advanced Industrial Science and Technology), Mark White (Pacific Northwest National Laboratory), Joseph W. Wilder (University of Akron), Brian Anderson (West Virginia University), Scott Wilson (Ryder Scott Company, consultant to BP-DOE CRA), 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 2009.

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 lead to application in future gas hydrate field operations. BPXA provided a letter in April 2004 in support of progression of PCI's project into their phase 2: prototype tool design and possible surface testing. 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 correspondence to DOE and USGS.
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:** A gas hydrate resource assessment research project under the Department of Interior (DOI) has provided 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) entered into an Assistance Agreement in 2002 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 research proves technical and/or commercial feasibility of this potential arctic energy resource. The DOI project has worked with the BPXA – DOE project to assess the regional recoverable resource potential of onshore natural gas hydrate and associated free-gas accumulations in northern Alaska, initially within current industry infrastructure. A report, Assessment of Gas Hydrate Resources on the North Slope, Alaska, 2008, was issued in October 2008 indicating 84 TCF recoverable resources (Figure 2, Table 1).

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 an 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

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6.5.4.7 Regional Schematic Modeling Scenario Study References

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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. Consideration of the resource potential of conventional ANS gas helped create industry - government alignment necessary to investigate the unconventional resource potential of the potentially large (33 to 100 TCF in-place) 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. However, long-term production testing could resolve many remaining uncertainties.

The potential to induce gas hydrate dissociation across a broad regional contact from adjacent free gas depressurization may have been observed at Messoyakha field production in Russia (Collett and Ginsberg, 1998) and possibly at East Barrow gas field in Alaska (Singh, et al., 2008). Reservoir modeling also demonstrates this potential as documented in the March 2003 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 regional 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 could exhibit a long production character with flat declines, potentially analogous to Coalbed Methane production.

Results from the various scenarios show a wide range of potential outcomes. None of these forecasts would qualify for Proved, Probable, or even Possible reserve categories using the SPE/WPC definitions since there has yet to be a fully documented case of long-term economic production from hydrate-derived gas. Each of these categories would, by definition, require a positive economic prediction, supported by historical analogies, prudent engineering judgment, and rigorous geological characterization of the potential resource before a decision on an actual development could proceed.

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 designs, 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

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