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

Drilling and Data Acquisition Planning

Topical Report

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PROJECT ABSTRACT

This cooperative project between BP Exploration (Alaska), Inc. (BPXA) and the U.S. Department of Energy (DOE) facilitates collaboration between industry, government, and university researchers. Technical study results will help enable government and industry to make informed decisions regarding the energy resource potential of gas hydrate accumulations on the Alaska North Slope (ANS).

Gas hydrates are present in many arctic regions and offshore areas around the world. In the U.S., notable deposits of gas hydrate occur in the offshore Atlantic, Gulf of Mexico (GOM), offshore Pacific, offshore Alaska, and also onshore Alaska regions beneath and within permafrost. Collett (1998) estimates that up to 590 TCF of in-place ANS gas resources may be trapped in clathrate hydrates. Of that total, an estimated 33 to 100 TCF of in-place gas hydrate resources may occur beneath existing ANS production infrastructure within the Eileen and Tarn trends (Collett, 1993, 1998). Much like conventional oil and gas resources, potential gas hydrate resource accumulations require a unique combination of factors, including all required petroleum system components (e.g., source, migration, reservoir, trap, seal, and charge), adequate industry infrastructure, industry access to acreage, and feasible production technology. In addition, industry would need to estimate ultimate recovery potential, production rates, operating costs, and commercial feasibility within reasonable risk limits. Currently, the most likely areas for a favorable combination of these factors are the ANS and the GOM.

In this project, ANS gas hydrate and associated free gas-bearing reservoirs are being studied to determine reservoir extent, stratigraphy, structure, continuity, quality, variability, and geophysical and petrophysical property distribution. The objective of Phase 1 (October 2002 – December 2004) was the characterization of reservoirs and fluids, leading to estimates of recoverable reserve and commercial feasibility, and the study of procedures for gas hydrate drilling, data acquisition, completion, and production. If justified by prior phase results, an integrated future program would be planned to include recommendations to acquire specific well, core, log, and production test data at candidate site(s). Ultimately, the program could help determine whether or not gas hydrates might become a part of the overall ANS gas resource portfolio.

Potential gas hydrate and associated free-gas resources within the shallow reservoirs of the Prudhoe Bay – Kuparuk River – Milne Point Eileen trend area are interpreted to correlate with

gas hydrates that were originally cored and tested in the 1972 Northwest Eileen State #2 well and are penetrated by other wells targeting deeper reservoirs within the ANS development area. Correlation of geophysical attributes to gas hydrate occurrence are also under investigation. Seismic modeling of shallow (<950 ms) velocity fields suggests that both amplitude and waveform variations may help locate gas hydrate-bearing reservoirs. Permafrost can also complicate seismic identification of gas hydrates due to its similar acoustic properties. Identification of gas hydrate prospects within the Milne 3D seismic volume are based on seismic interpretation and modeling, gas hydrate-similar waveform classes, and fault-seal geometries integrated with well log-derived properties. Seismic and well data interpretation within the Milne Point Unit have revealed gas hydrate prospects within the shallow sands of the fluvial-deltaic Sagavanirktok Formation. However, these prospects remain largely unproven and require confirmation, delineation, and further data acquisition to mitigate uncertainties.

The shallow gas hydrate-bearing reservoirs of the Tertiary Sagavanirktok formation are part of a complex fluvial-deltaic system further complicated by structural compartmentalization within the Eileen trend. Stacked sequences of fluvial, deltaic, and nearshore marine sands are interbedded with both terrestrial and marine shales. Facies changes, intraformational unconformities, and high-angle normal faults disrupt reservoir continuity. Phase 1 work related to volumetric assessment includes detailed well-log analyses and description of reservoir facies and fluids as integrated with the 3D seismic data released to the project by BPXA. In conjunction with structural analyses, the identification and mapping of net pay in discrete sand bodies improves understanding of resource quality, quantity, distribution, and continuity. This work helps refine volume estimates, reservoir models, and recovery factors, and production forecasts. Gas may have migrated into conventional hydrocarbon traps before regional geothermal gradient depression, creation of gas hydrate stability conditions, and conversion of gas and water into gas hydrate. The structural and stratigraphic compartmentalization reduces lateral continuity of prospects and complicates the shallow velocity field. Velocity pull-ups associated with high-velocity gas hydrate prospects and velocity push-downs associated with low-velocity free gas prospects can also affect seismic interpretation of deeper, oil-bearing targets.

Preliminary production models of gas hydrate prospects help investigate whether or not the gas hydrates in northern Alaska might be technically recoverable. Production feasibility may be aided in areas where current or future local uses for gas exist. Potential production methods involve in-situ dissociation of solid, pore-filling gas hydrate into gas and water components through reservoir depressurization, thermal stimulation, and/or chemical stimulation. Production models indicate that depressurization of in-situ gas hydrate from producing adjacent free gas might more than double the expected ultimate recovery available from the associated free gas alone. Gas hydrate prospects without an adjacent free gas might also be depressurized by producing in-situ connate waters if sufficient mobile waters co-exist with gas hydrate. Thermal and/or chemical stimulation techniques are also under investigation as methods to enhance gas recovery from gas hydrate-bearing reservoirs. Major unresolved uncertainties include reservoir productivity, saturations, and absolute and relative permeabilities.

Studies completed in the July – December 2004 period included documentation of many Phase 1 research results. Many of these results were presented in September 2004 at the AAPG Hedberg Research Conference on Gas Hydrates. Phase 1 of the project was scheduled for completion by end-December 2004. Research has continued into 2005, and includes refining the scope-of-work to quantify the regional resource potential, evaluating multiple potential development scenarios, and recommending specific potential future data acquisition operations within suitable candidate site(s).

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1.2 Milne Point Unit Area Gas Hydrate Resource Characterization Studies

In September 2003, a collaborative study was initiated, using 3-D seismic in the Milne Point area of northern Alaska, to help answer questions about gas-hydrate reservoir characteristics and properties as input to possible production methods and commercial viability. Historical log correlation work and analysis of gas hydrates in the Milne Point area (Collett, et al., 1993, 2001) was used as a starting point for a seismic driven analysis of the Milne Point 3-D survey area. Modern seismic data were used to gain a better understanding of the geologic controls related to gas hydrate petroleum systems in the Milne Point area. The Landmark software suite was used to integrate and analyze detailed log correlations, specially processed log data, gas-hydrate composition information and specialized 3-D seismic volumes. Structural and stratigraphic interpretations encompassed the interval from the Base of Ice Bearing Permafrost (IBPF), into the Gas Hydrate Stability Zone (GHSZ), and into potential gas-bearing reservoirs immediately below the Base of the Gas Hydrate Stability Zone (BGHSZ).

The seismic data was also used to analyze reservoir fluid properties in comparison to theoretical modeling results by Lee (2005). The modeling showed that a relatively strong impedance contrast will occur when moderate to highly saturated gas hydrates exist within the GHSZ. Modeling shows that shallow gas hydrates and associated trapped sub-hydrate free gas may cause velocity anomalies that would effect the depth conversion of deeper, conventional hydrocarbon targets in the North Slope region. The primary result of the study has been the interpretation of "intra-hydrate" stability zone prospects and "sub-hydrate" free gas prospects. These prospects have been analyzed relative to the petrophysical parameters in analog wells, for comparable reservoir intervals. Monte Carlo style volumetrics were performed using Crystal Ball^{TM} software to calculate the potential range of in-place resources from the interpreted range of potential reservoir properties. Fourteen gas hydrate-bearing prospects were identified and calculated to contain a total of 620 BCF gas in hydrate in-place.

The study focused on the Milne Point 3-D seismic survey within the MPU (Figure 1), provided to the USGS and the University of Arizona by BP Exploration Alaska, Inc. (BPXA) as co-sponsor of this research. A small portion of the NW Eileen 3D survey just to the south of the Milne Point survey within the MPU was also provided. Regional 2-D seismic data, licensed by the USGS, supplemented the 3-D seismic data and was used along with well data to constrain and improve the quality of critical maps, such as time structure maps, fault maps and base hydrate stability zone maps within the MPU.

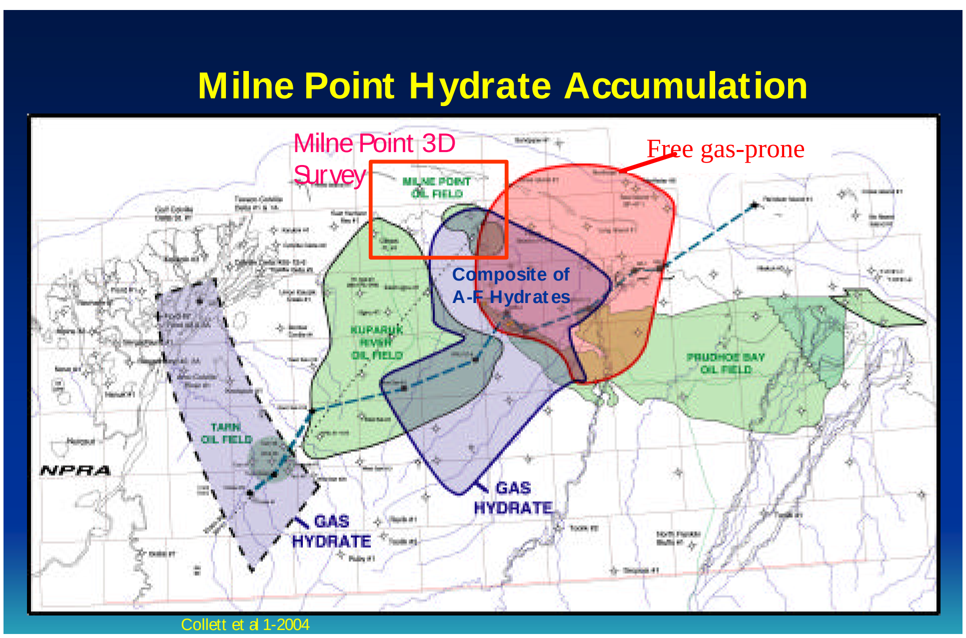


Figure 1: Map of the Milne Point 3D study area and regionally interpreted Tarn and Eileen trend gas hydrate accumulations. Gas hydrate and possible free gas-prone areas are shown within these trends.

The initial interpretation of the structural framework in the Milne Point 3-D seismic survey within the MPU shows that faulting may play a significant role in the migration and trapping of the gas associated with the gas hydrate-bearing reservoirs. North Slope gas hydrates are interpreted to be composed of mostly methane gas sourced from more deeply buried hydrocarbon-bearing formations, which likely accumulated as free gas in conventional traps prior to formation of the gas hydrate stability zone beneath permafrost with onset of arctic conditions. Therefore, a detailed fault interpretation is critical to understanding the relationship between faults, as the gas conduits, and shallow gas hydrate accumulations. The age relationship between various fault sets may play a significant role in determining migration pathways and the compartmentalization of these gas hydrate reservoirs. Fault analyses on a 3-D seismic volume enhanced by ESP (coherency) processing show that the fault orientation, above and below the Canning Formation, is distinctly different, and as such, the secondary and tertiary migration from deeper hydrocarbon reservoirs may be complex. Some faults may not be connected through the Canning Formation to deeper hydrocarbon-bearing reservoirs.

The interpretation of faulting on the ESP (coherency) volume greatly improved the overall understanding of fault compartmentalization at each mapped horizon. An example time structure map for the Top of the Staines Tongue horizon is shown in Figure 2. Figure 3 shows the same map in perspective view. Notice that some faults trend more North-South similar to the predominant younger fault trend. Some of the larger-offset faults within the Staines Tongue interval trend more NNE to SSW, similar to the older sub-Canning fault trend. These faults may be better connected to deeper hydrocarbon systems.

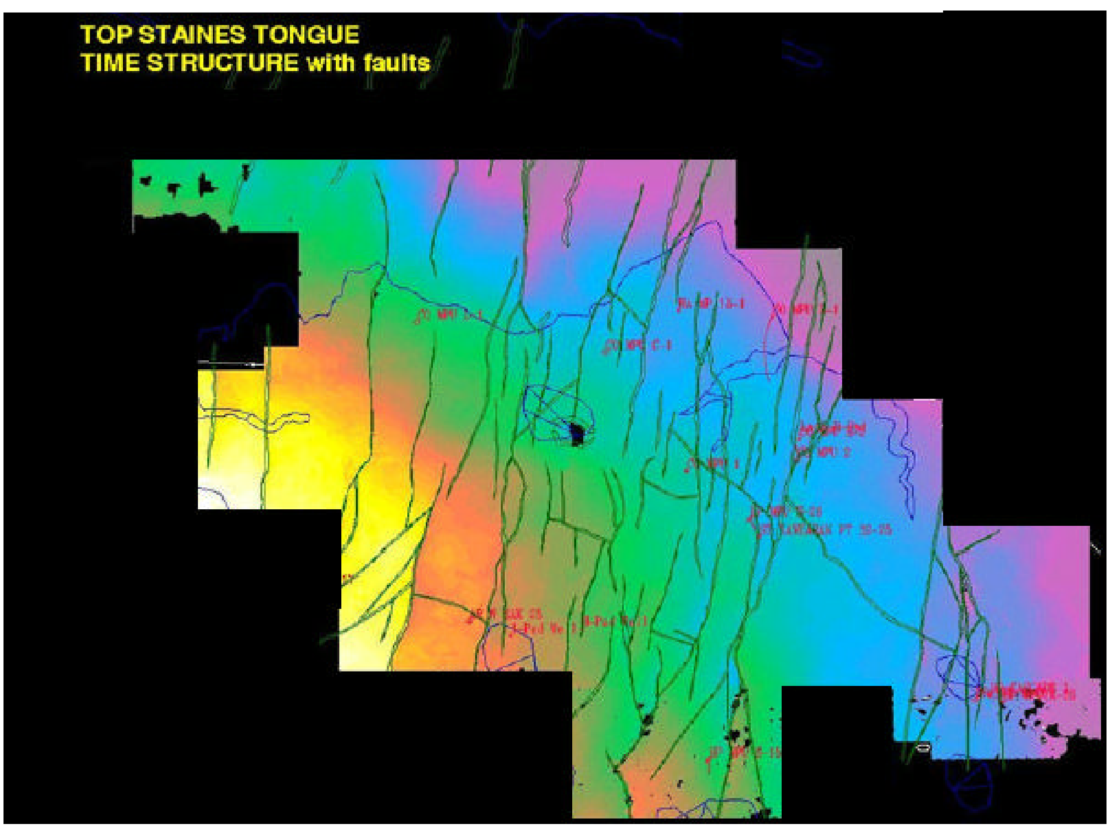


Figure 2: Top Staines Tongue time structure map with interpreted shallow faults

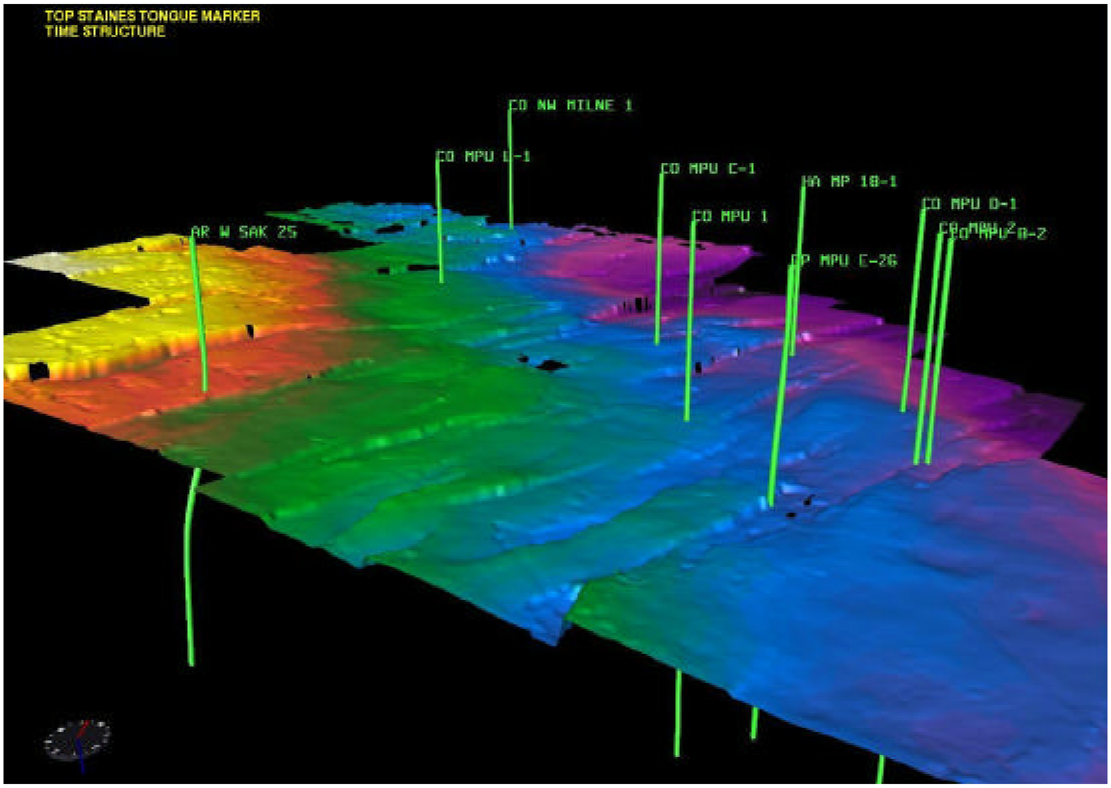


Figure 3: Top Staines Tongue time horizon in north-perspective view.

Theoretical seismic modeling of boundaries between ice-bearing permafrost to gas hydrate-bearing reservoirs, shale to gas hydrate-bearing reservoirs, and shale to free gas-bearing reservoirs as well as transitional gas hydrate to free gas reservoirs at the base of the gas hydrate stability zone have been used to understand the acoustic properties of these complex systems in the pre and post stack domain. The similarity in acoustic properties between ice and gas-hydrate makes it difficult to differentiate between ice- and gas hydrate-bearing sediments. That makes gas hydrates adjacent to permafrost, while prospective, both difficult to quantify and to produce. In the Milne Point 3-D area, some assumptions can be made to constrain modeled results describing the relationship of these boundaries in the stack and offset domains. First, if thermogenically-derived gas originally migrated into what are now fully saturated gas hydrate-bearing reservoirs, then a gas hydrate concentration within the pore system of a sandstone reservoir might also range between 80-85%, similar to saturations within conventional gas reservoirs. Thin bed seismic modeling shows that hydrate saturation is variable and that these gas hydrate-bearing reservoirs may be under-saturated with respect to gas hydrate, and may, therefore, possibly contain movable connate waters in some areas. Undersaturation could occur, possibly due to the gas volume reduction occurring when what was originally a free gas-bearing reservoir is transformed into gas hydrate in the presence of water within the GHSZ. Unconsolidated sandstone reservoirs within the Sagavanirktok Formation that contain the majority of gas hydrates within the MPU area typically have 30-40% porosity. Reservoir thickness is the main variable used in modeling acoustic attributes and in calculating volumetrics. However, thickness can be calculated using “thin-bed” modeling where these reservoirs are isolated and in a single pore-filling phase.

The base of the gas hydrate stability zone was computed using well log-interpreted ice-bearing permafrost (IBPF) depths and high resolution borehole temperature surveys. Figure 4 shows the "Eileen gas hydrate accumulation" correlations for interpreted regional gas hydrates. This study confirms the stratigraphic consistencies of this correlation into the Milne Point study area. Gas hydrate-bearing reservoir stratigraphy interpreted within wells within the MPU area have been correlated using both seismic and well log data. A pair of horizons representing the upper and lower limits of the base gas hydrate stability zone were mapped and displayed on the seismic data. The error range of the base gas hydrate stability zone was considered to be plus or minus 75 feet, or plus or minus 15 milliseconds.

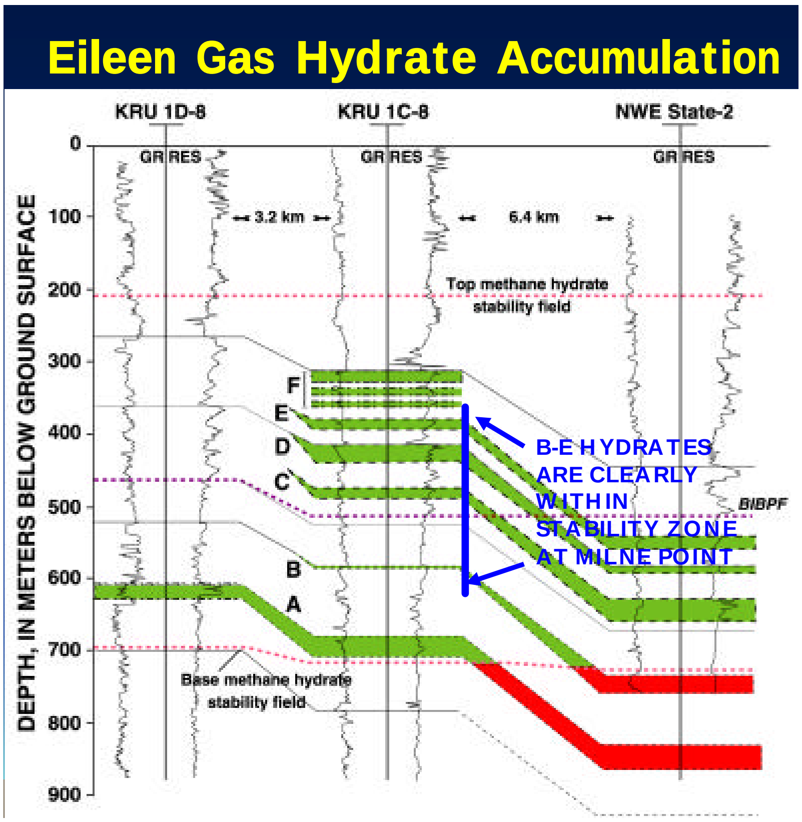


Figure 4: Eileen gas hydrate accumulation log correlations. In the Milne Point area, the base of the hydrate stability field is generally near the Top of the Staines Tongue, or approximately the A-zone hydrate of Collett, 1993.

Gas hydrate reservoirs below the IBPF and within the hydrate stability zone ("intra"-gas hydrate prospects) have acoustic properties allowing them to be interpreted by several simple seismic attributes. Several candidates for "Intra-Hydrate" prospects were found during reconnaissance mapping of this interval as shown in Figure 5.

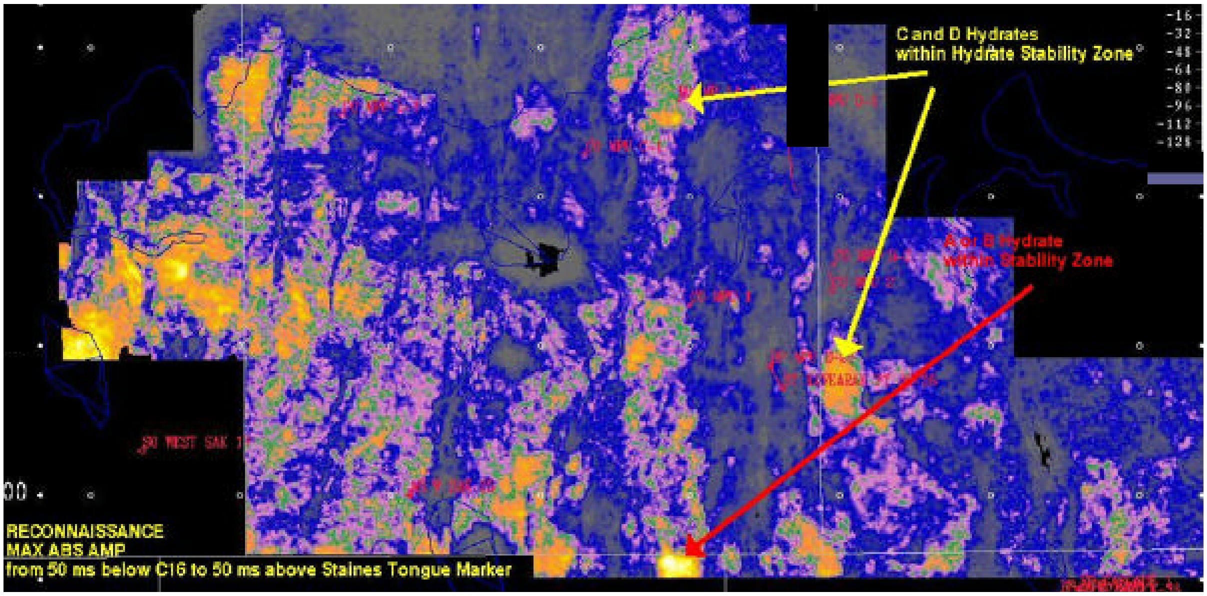


Figure 5: Reconnaissance mapping of 100 millisecond interval around Staines Tongue marker.

Free gas trapped below gas hydrates and/or below the gas hydrate stability zone can be identified by seismic attributes in this geologic setting. However, low saturation free gas can give nearly the same acoustic signature as higher saturation free gas reservoirs. The seismic amplitude anomalies are commonly associated with free gas near the base of the interpreted gas hydrate stability field and may be connected to up-dip gas hydrate-bearing reservoirs in some cases (Figure 6). In other cases, no distinct amplitude anomalies attributed to gas hydrates above the free-gas to gas-hydrate boundary have been identified, even though convention would indicate that gas-hydrates must be present to form a hydrate-seal trap. One hypothesis would be that there were changes in migration pathways and the rate of migration during the formation of the gas hydrate stability zone, or that the hydrates never reach the minimum values for thickness and/or saturation that would allow them to be imaged by the seismic data. The recent movement along younger faults in the post-Canning interval likely influenced migration pathways and may effect the location of sub-hydrate free gas accumulations. Another hypothesis would be that the charge is limited and/or the seal leaky for some of these systems.

From the analysis of the seismic data, several intra-gas-hydrate stability zone prospects have been identified in the Milne Point 3-D survey area. Interpreted intra-gas-hydrate prospects are typically conventional fault bounded traps and are identified primarily by their acoustic properties. As a rule, areas that are currently structurally high within prospective fault blocks can be shown to have acoustic properties that are interpreted to correspond to higher concentrations of gas-hydrate. This structural relationship is similar to conventional gas prospects, pointing back to the likely free-gas origin of these gas hydrates. Some of these fault blocks are interpreted as not “fully charged”, as there are down-dip limits to the mapped acoustic anomalies. Several of these intra-hydrate prospects might be candidates for gas-hydrate data acquisition and/or production testing, due to their proximity to existing roads and infrastructure.

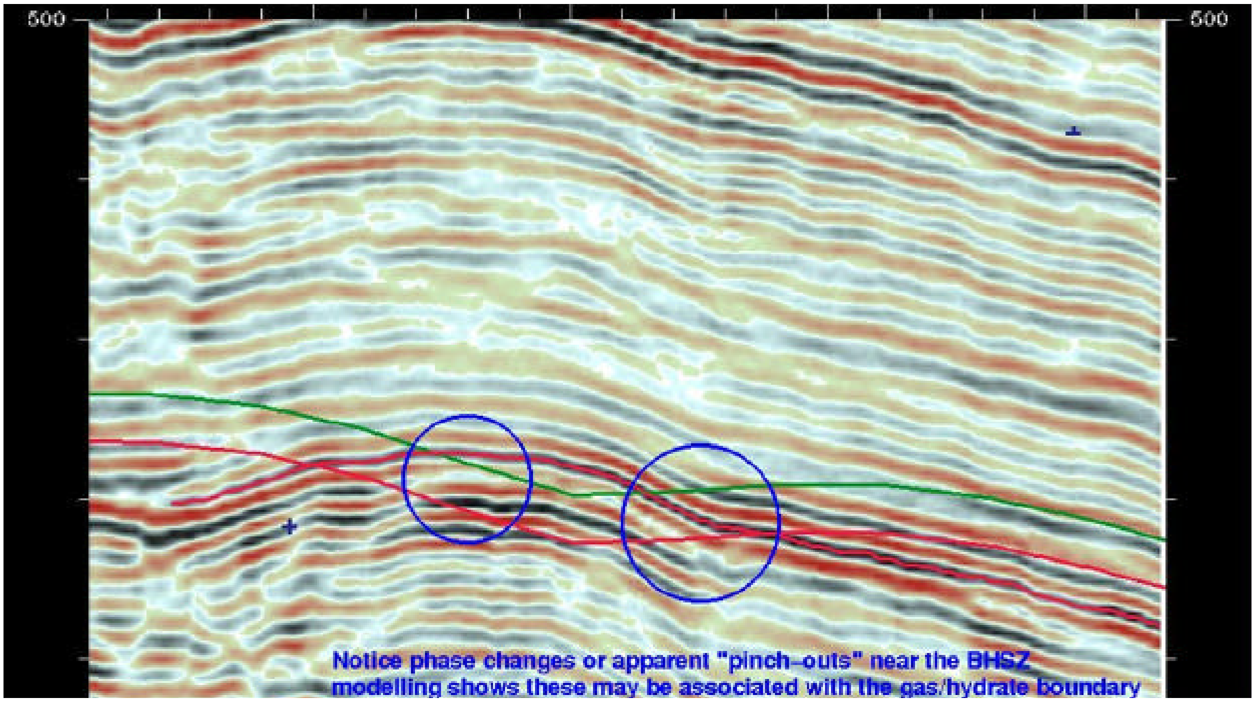


Figure 6: The minimum (green line) and maximum (red line) BHSZ relative to truncated high amplitude seismic reflections that are interpreted to be sub-hydrate gas accumulations. However, as shown in log data collected in this study from MPS-15i and MPI-16, saturations in the interpreted free gas may be lower than 10% in some cases.

The Milne Point area study has identified both intra-gas hydrate and possible sub-gas hydrate free gas prospects that may become candidate areas for future data acquisition. The historical log analysis work conducted by the USGS in this area combined with interpretation of 3-D seismic attributes has promoted a better understanding the geologic setting for the unconventional gas hydrate-bearing reservoirs. Delineation of seismically-interpreted prospects through future data acquisition in this area would help verify assumptions used in the modeling used to evaluate the candidate prospects.

1.2.1 Calculation and Mapping of the Base Hydrate Stability Zone

In three of the wells within the study area, high resolution temperature logs were used to directly identify the base of the hydrate stability zone (BHSZ). Depths to the BHSZ in the MPU A-01, MPU C-01, and MPU D-01 were identified at 2,741, 2,688, and 2,836 feet below surface level, respectively. For wells without high-resolution temperature logs, resistivity and velocity logs were used to make picks identifying the base of the ice bearing permafrost (IBPF). Once the base of IBPF was identified, an algorithm developed at Colorado School of Mines was used to determine the BHSZ based on a predicted temperature gradient measured from the base of the IBPF (Table 1). Figure 7 shows the resulting time structure of the BHSZ using depths calculated or identified from wells within or near the survey area.

Table 1 – Depths to base of IBPF and BHSZ in wells within and nearby study area based on well log interpretation only.

Well	Ice-Bearing permafrost depth (MD, ft)	Temperature at the base of IBPF (deg F)	Depth to BHSZ (MD, ft)	Pressure at BHSZ (lbs/in2) (from CSM)	Temp. at base of BHSZ (deg F) (from CSM)	Sub-IBPF geothermal gradient (deg F/100 ft)
MPU E-26	1760	30.2	2820	1221.1	53	2.15
Kavearak Pt 32-25	1796	30.2	2856	1236.6	54	2.25
MPU A-1	1708	30.2	2741	1186.9	53	2.21
MPU D-1	1783	30.2	2836	1228.0	53	2.17
West Sak 25	1821	30.2	2899	1255.3	54	2.21
MPU C-1	1678	30.2	2688	1163.9	53	2.26
MPU B-1	1808	30.2	2853	1235.3	54	2.28
MPU B-2	1806	30.2	2852	1234.9	54	2.28
MPU S15i	1910	30.2	3051	1321.1	55	2.17
MPU L-1	1858	30.2	2918	1263.5	54	2.25
West Sak 17	1738	30.2	2788	1207.2	53	2.17
					AVG. Gradient	2.22
Cascade	1674	30.2	2711	1173.9	53	2.2

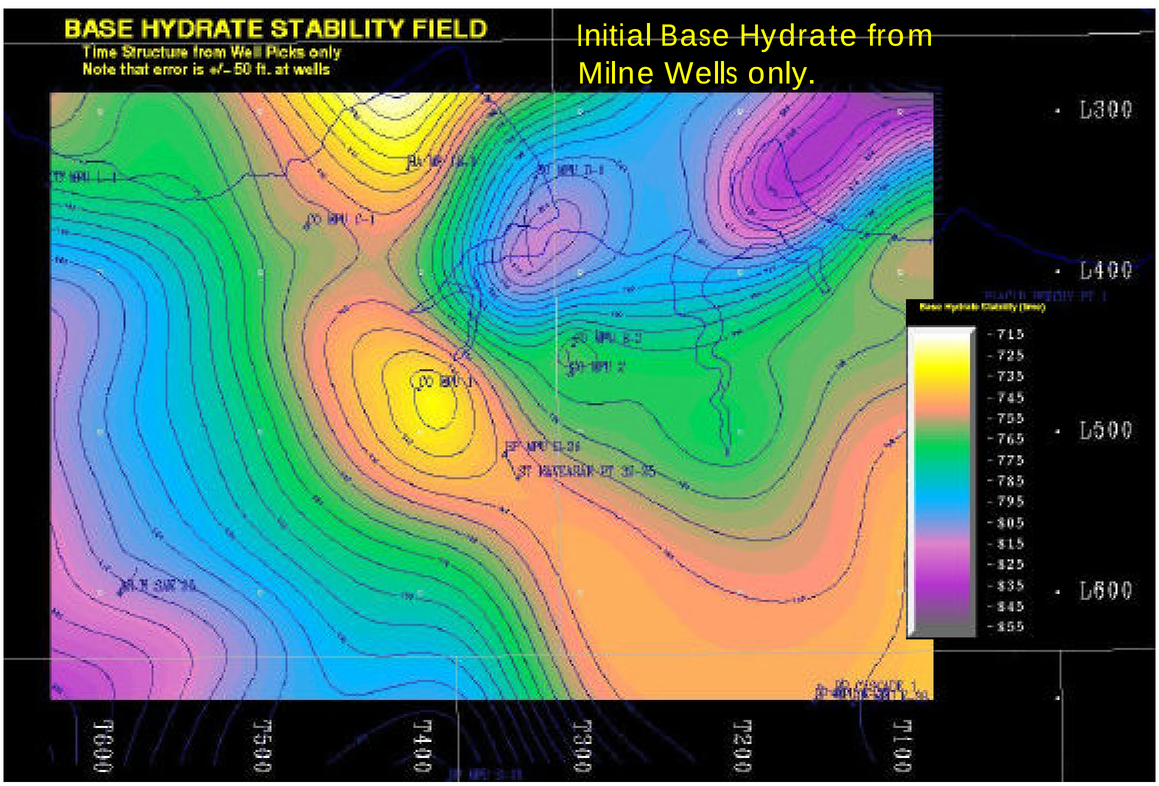
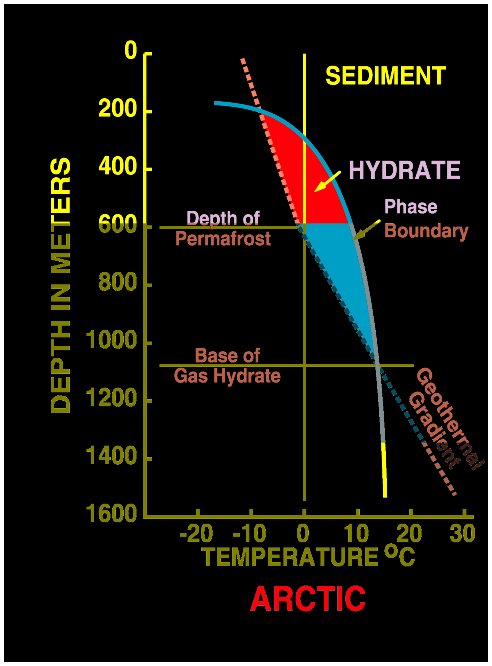


Figure 7: BHSZ time structure map generated using well picks only.

The West SAK 25 and the MPU S-15i wells were found to be problematic due to the fact that the base of IBPF was difficult to pick because hydrates were likely co-mingled with permafrost (Figure 8).



Hydrates co-exist with permafrost in the interval between 200 and 600 m (656-1968 ft)

Figure 8**:** Hydrate Stability Zone in Arctic Regions

The base of IBPF picks were then readjusted for these two wells based primarily on analyses of seismic amplitudes. From these readjusted picks, new BHSZ values were calculated and a new BHSZ horizon was generated. A pair of horizons was then generated representing the upper and lower limits of an error range of plus or minus 75 ft. (+/- 15 ms) as shown in Figure 6.

1.3 Intra-hydrate Prospecting, Volumetrics, Drilling Location and Candidate Selection

Plans for gas hydrate drilling and production testing operations are presented based on 2002-2005 research. The project is currently at a decision stage to determine whether or not to proceed into field operations and to determine maximum synergies with existing and planned field work at MPU. Therefore, the plans presented do not yet have resource owner or DOE approval and consensus is required prior to implementation.

“Intra-Hydrate” prospecting depends heavily on seismic character analysis. The results of rock physics modeling and trace modeling showed expected seismic attributes for various intra-hydrate stability zone scenarios. Seismic frequencies limited intra-hydrate stability zone prospects to those meeting a minimum criterion of 25 feet thickness and about 60% saturation with the attributes developed to-date. These prospects are defined within the standardized “Eileen” hydrate nomenclature as belonging to the A through E hydrate-bearing stratigraphic intervals. Current production modeling assigns those closest to the Base Hydrate Stability Zone, zones A, B, and C as those that would be the most likely to produce, with the D and E hydrates being more difficult to produce and complicated by their proximity to the permafrost in this area.

A series of 14 Intra-Hydrate prospects were identified that met the minimum thickness and saturation criterion. Additionally, three hydrate prospects within the Staines Tongue, that are associated with sub-hydrate gas prospects, have been defined. These prospects were further analyzed to compute volumetrics, using a Monte Carlo routine in Crystal Ball. Table 2 summarizes the 14 MPU-area intra-hydrate prospects. Figure 9 shows the location of intra-gas hydrate prospects within the MPU area.

Two prospects, the Mt. Elbert and the Crestone Peak prospects, stand-out due to their size and their potential for multiple pay zones. The Mt. Elbert prospect is the best defined and least complex of the "Intra-Hydrate" prospects, and is in close proximity to existing infrastructure at MPU B and E pads.

Table 2: 14 MPU-area Intra-Hydrate Prospects

Prospect Names	Zone	closure miles^2	closure acres
Hydrate Prospects			
Mt. Bierstadt "E" Hydrate Prospect	E	0.52	332
Elbert "D" Hydrate Prospect	D	0.42	267
Mt. Bierstadt "D" Hydrate Prospect	D	0.42	268
Mt. Sneffels "D" Hydrate Prospect	D	0.8	516
Uncompahgre Peak "D" Hydrate Prospect	D	0.26	167
Mt. Princeton "D" Prospect	D	0.7	449
Crestone Peak "C" Hydrate Prospect	C	2.7	1728
Mt. Antero "C" Hydrate Prospect	C	1.49	955
Mt. Elbert "C" Hydrate Prospect	C	1.69	1106
Blanca Peak "C" Hydrate Prospect	C	0.51	328
Pikes Peak "B" Hydrate Prospect	B	0.46	298
Redcloud Peak "B" Hydrate Prospect	B	0.3	194
Grays Peak "B" Hydrate Prospect	B	0.13	85
Maroon Peak "A" Hydrate Prospect	A	0.58	375

1.3.1 Volumetric Calculation Methodology

The estimation of parameters to be used for volumetric calculations are presented for intra-gas-hydrate stability zone prospects. Minimum, median and maximum values for porosity and net-to-gross were determined from log data in the Milne Point field area. The thin-bed model approach was used to estimate thickness and saturation for the relatively isolated intra-hydrate prospects. These maps were brought into Zmap+ for calculation of Bulk Rock Volume. Table 3 lists the variable inputs to the Crystal Ball volumetric calculations.

1.3.1.1 Variables for Gas-In-Place Calculations

When using Crystal Ball to calculate volumetrics, Zmap+ is used primarily to compute the Bulk Rock Volume. The Bulk Rock Volume variable then uses the computed value as the "median" value with a 10% standard deviation (1.5 standard deviations). Normally, calculation of net rock volume is based on the following:

- Structural grid for the top (and/or base) of the reservoir unit,

- Fault traces for the structural grid,
- The gas hydrate to water contact,
- The top of the gas hydrate as determined by pressure-temperature constraints,
- The gross interval isochore (vertical thickness) for the reservoir unit, and
- The net reservoir isochore versus the total gross isochore for the reservoir unit.

In the calculations from the "thin bed" modeling, used for generating thickness and saturation, the model assumes gas hydrate thicknesses that are less than 1.5 times the tuning frequency. For the Milne Point 3D survey (USGS wavelet processing) the 55 Hz. dominant frequency within the zone of interest allows calculation of gas hydrate-bearing reservoir thickness up to approximately 60 feet. The minimum thickness is also limited by frequency, where gas hydrate-bearing reservoirs less than 25 feet thick are acoustically transparent. The areal limits of the gas hydrate prospects are defined by amplitude rather than faulting or structure, and the thickness calculation naturally omits areas below any down-dip gas hydrate limits. The revised list of data needed for hydrate Bulk Rock Volume calculation is now the following:

- Time structure for the top of the gas hydrate (in this case, a trough) within the area meeting minimum amplitude criterion,
- Time structure for the event immediately below the gas hydrate (a peak),
- Amplitude difference between the trough and the peak,
- Calculated reservoir thickness from thin-bed modeling (by trace), and
- Calculated saturation from thin-bed modeling (by trace)

From these data, reservoir thickness is gridded in map view, and summed over the area that defines the reservoir limits within the geophysical amplitude cut-offs. Bulk Rock Volume is then reported and utilized in further Monte Carlo simulations. Similarly, saturation may be gridded, and grid to grid calculations may be performed to estimate volumetrics as a quality control to the Monte Carlo simulation results. Average saturation values from thin bed analysis were used as the median saturation value in the Monte Carlo simulations.

Assumptions for gas hydrate volumetric calculations are as follows:

- Bulk rock volume was calculated in Zmap+ by integrating the thickness grid for each prospect within the defined amplitude limits,
- Porosity varies for each gas hydrate interval (A-E) based on log value ranges,
- Saturations were estimated from seismic attributes for each prospect using model fitting, and
- Porosity values and Net-to-Gross values are similarly derived from Milne Point log data.

1.3.1.2 Crystal Ball™ Monte Carlo Calculations

Crystal Ball performs Monte Carlo simulations within Excel spreadsheets. In the case of the Milne Point simulation, 10,000 simulations of different distribution cases were run. Inputs and results of each calculation are saved as individual scenarios, such that the analysis of these scenarios shows the range of possible outcomes, their probability of each outcome, and which input has the most effect on the model (parametric analysis).

Monte Carlo simulation refers to an analytical method where values are randomly generated for multiple distributions of variables to simulate a model. For each uncertain variable a range of possible values are defined with a probability distribution (Figure 10). The program calculates multiple scenarios of a model by repeatedly sampling values from the probability distributions for the uncertain variables and using those values for the cell. Without the aid of simulation, a spreadsheet model will only reveal a single outcome, similar to the case where the calculated thickness map from thin-bed analysis is multiplied by the saturation map generated from the same thin-bed analysis to arrive at a single value for hydrocarbon volume. This "Base Case" is generally close to the P50 or median scenario. It is not exactly the same as a single valued calculation because the statistical combination of the component distributions does not result in a median value that is equal to the combination of the component medians. The type of distribution selected for variables in a simulation model is based on the conditions surrounding that variable. The resulting range of values resulting from a simulation model accounts for the uncertainty in every input variable to the gas-in-place calculation and provides a median value for hydrocarbon volume as well as a full distribution (P0-100), up-side (P10), and down-side (P90). Figure 11 summarizes the median value for gas-in-place for the 14 intra-gas hydrate prospects.

Table 3: Well log derived reservoir parameters for the MPU prospect volumetrics.

Unit	POR Low	POR Best	POR High	POR Source	Sh Low	Sh Best	Sh High	Sh Source	Thick Low	Thick Best	Thick High	Thick Source
	%	%	%		%	%	%		ft	ft	ft	ft
E	37	39	40	NWEIL 2	40	50	60	NWEIL2	15	25	55	ALL Wells
D	36	37	38	NWEIL 2	40	50	60	NWEIL2	25	50	65	ALL Wells
									10 in MPUB?			
C	34	38	40	NWEIL 2	75	85	90	NWEIL2	20	50	70	ALL Wells
B	34	38	40	NWEIL 2	30	40	50	MPUS15	45	50	55	ALL Wells
					70	80	85	KRU				
A "Staines" MPU ONLY CASE 1	34	36	38	MPU wells	10	25	40	MPU S-15; MPU I-16	15 upper SS; 20 middle SS	25 upper SS; 25 middle SS	40 upper SS; 35 middle SS	MPU wells; Little Bear thin bed analysis
A "Staines" MPU ONLY CASE 2	34	36	38	MPU wells	60	70	80	KRU	15 upper SS; 20 middle SS	25 upper SS; 25 middle SS	30 upper SS; 35 middle SS	MPU wells

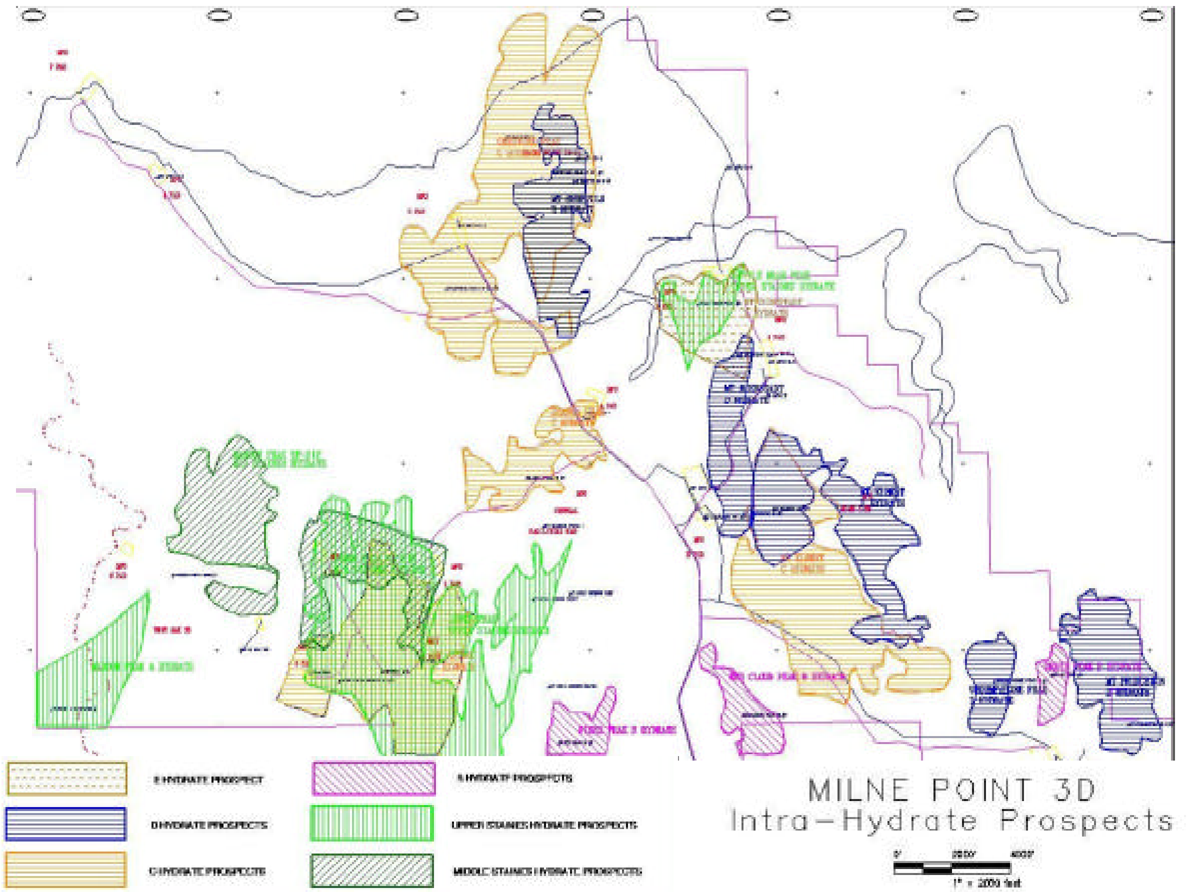


Figure 9: Location of MPU-area Intra-hydrate prospects

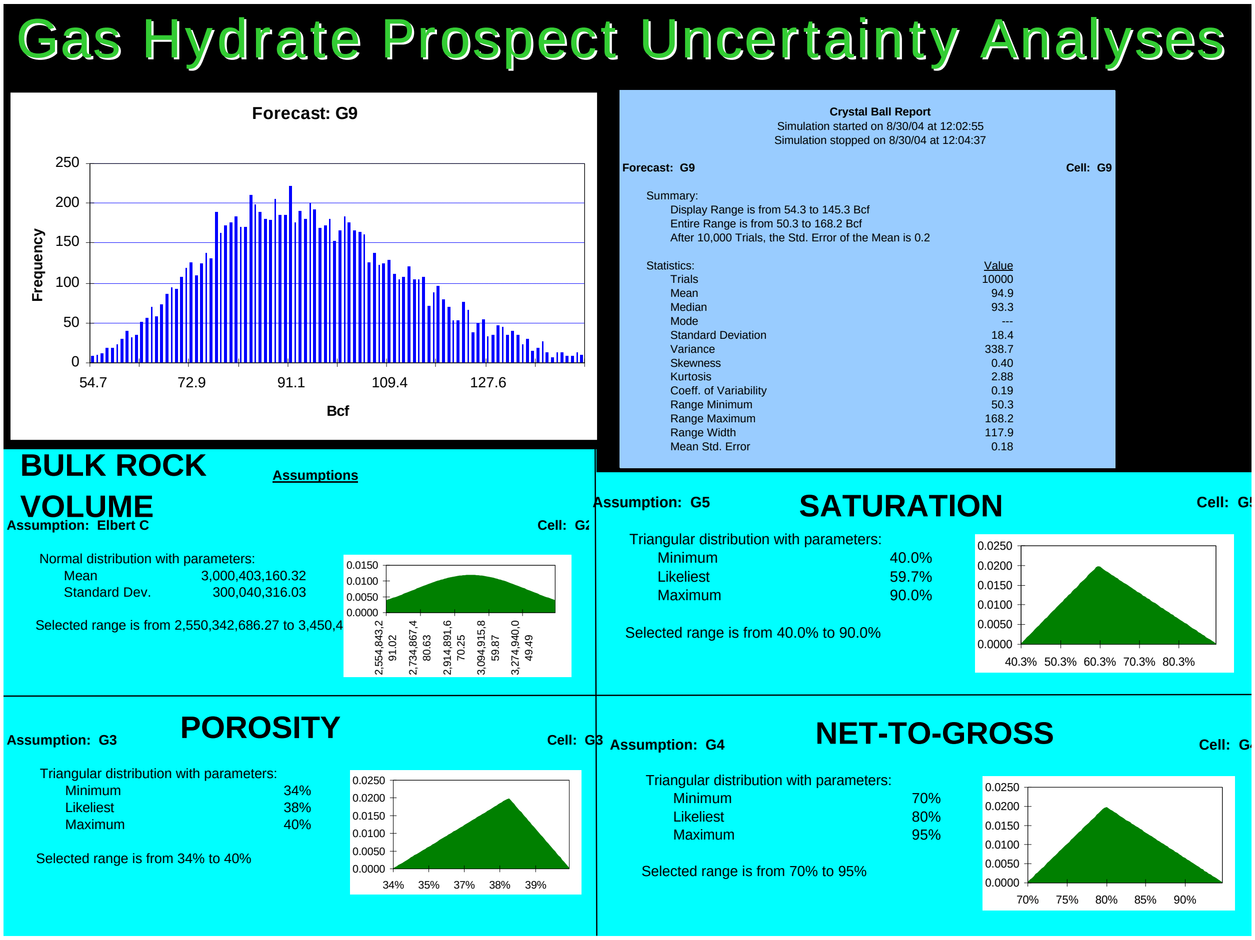


Figure 10: Example distributions of variables used for gas-in-place Monte-Carlo calculations

MPU HYDRATE PROSPECTS VOLUMETRICS

	Antero C	Bierstadt D	Bierstadt E	Blanca C	Crestone C	Elbert C	Elbert D	Grays Peak B
GRV (cu ft)	2350045580	1119622596	1232193097	740796681	6349463797	3000403160	1761367545	203815727
Porosity	38%	38%	38%	38%	38%	38%	38%	38%
Net-to-Gross	80%	80%	80%	80%	80%	80%	80%	80%
Gas Saturation	66.1%	49.8%	66.9%	55.1%	49.8%	59.7%	52.6%	47.2%
1/Bg	164	164	164	164	164	164	164	164
Volume in Place cu ft)	77.4	27.8	41.1	20.4	157.6	89.3	46.2	4.8

Maroon Peak A	Mt Princeton D	Pikes Peak B	Red Cloud B	Sneffels D	Uncompaghre Peak D
927428988.1	1291844038	397708421.7	585518227.8	1516746825	390458860.9
38%	38%	38%	38%	38%	38%
80%	80%	80%	80%	80%	80%
81.2%	53.2%	68.8%	58.1%	57.6%	49.3%
164	164	164	164	164	164
37.5	34.3	13.6	17.0	43.6	9.6

14 "Intra-Hydrate" Prospects

620 BCF Median Estimated Gas in Place

A Volumes (Bcf)	37.5
B Volumes (Bcf)	35.4
C Volumes (Bcf)	344.7
D Volumes (Bcf)	161.4
E Volumes (Bcf)	41.1
Volume	620.2

Figure 11: Volumetric calculations for 14 MPU-area Intra-hydrate prospects

Reservoir and fluid characterization studies, investigation of seismic technologies in tasks 5.0 and 6.0, and reservoir and economic modeling studies completed in tasks 11.0 and 13.0 helped to identify prospective areas within MPU for possible future gas hydrate data acquisition and/or production testing operations. The associated project study by USGS identified seismic attribute anomalies potentially associated with changes in pore fluid types (water, free gas, and gas hydrate) within reservoir (sand-prone) intervals. Multiple gas hydrate-bearing prospects from these studies were evaluated and comparatively ranked. Table 4 summarizes the MPU prospect ranking for the top 7 MPU-area intra-gas-hydrate prospects.

Table 4: MPU Gas Hydrate Prospect Ranking

Mt Elbert C and D --> E-Pad

Estimated Rank - #1

POSITIVE QUALITY (PQ)	NEGATIVE QUALITY (NQ)
135 BCF Gas Hydrate In-Place	Requires Delineation
Stacked Prospects (C and D horizons)	No Staines Tongue gas hydrate or free gas
Conventional, Fault-bounded structural trap	
	No well penetration, fault-separated from correlative wells
Well organized and consistent amplitude anomaly	
MPB-02 and MPE-26 confirm gas hydrates in C and D	
Both MPB-02 and MPE-26 have excellent synthetic ties	
Gas hydrate in C/D causes velocity pull-up in Staines T.	

Interpreted 45 feet C-hydrate thickness	Requires Delineation
Interpreted 45 feet D-hydrate thickness	Requires Delineation
Interpreted high-saturation in gas hydrate at crest	Requires Delineation
Potential movable connate waters downdip position	Requires Delineation
Facilities	
E-pad gas compression and injection available	
Good distance from E-pad for horizontal well	Need delineation well and data before production testing
3000 feet from E-pad, 3500 feet from B-pad	Possible limitations for wireline & core acquisition?
Reservoir Model	
Import Structure, thickness, saturation grids	
Test water saturation and connate water mobility	
Horizontal well test	
Depressurization test (connate water mobility)	
Test hot gas injection/circulation	
Test hot water injection/circulation	

Blanca --> A-Pad

Estimated Rank - #2

PQ	NQ
23 BCF Gas Hydrate In-Place (C-horizon only)	
Stacked Prospects (C and D horizons)	
Penetrated/delineated by MPA-01	
35+ feet D; 30+ feet C	
Thicknesses nearer seismic resolution limits	Less well-organized amplitudes
Possible destructive interference affecting amplitudes	Less well-organized amplitudes
Possibly more stratigraphically controlled	Flat structure, less 4-way-type closure
Possibly more lateral extent upside	
Possibly more thickness upside	
Facilities	
On A-pad; readily accessible from A-pad	No facility infrastructure other than gravel

Crestone C and Sneffels D -- C-pad

Estimated Rank - #3

PQ	NQ
186 BCF Gas Hydrate In-Place (Crestone C-horizon)	Gas Chimney in updip position to SW may be leaky seal
46 BCF Gas Hydrate In-Place (Sneffels D-horizon to SE)	
4.8+ upside free gas in Shavano Mid-Staines w/ Crestone	
MPC-01 has good gas shows in Mid-Staines	
Fault-bounded and 4-way closure traps	Structurally compartmentalized into 6 fault blocks
MP18-01 delineated good C and D gas shows in NE	
Best amplitudes in North and Northeast Crestone	Not as well-organized amplitudes in South and Southwest
Interpret ~40 feet Crestone C hydrate reservoir thickness	

Interpret ~45 feet Sneffels D hydrate reservoir thickness
Interpret 60-70% Saturation gas hydrate in C and D

Facilities
SW corner directly beneath C-pad (Crestone C)

Actions
Potential for C-pad WOO - Review drilling schedule

Princeton D -- K-pad
Estimated Rank - #4

PQ	NQ
38 BCF Gas Hydrate In-Place in D-horizon	Very structurally complex and likely compartmentalized
Good K-pad delineation in MPK-38 and MPK-25	
K-pad area very active gas-prone area	Very structurally complex and likely compartmentalized
200 feet free gas in C and D zones delineated in wells	
Stacked prospect potential in Staines Tongue	
Staines Tongue Yale prospect with 3.6-10 BCF	Possible low-saturation Staines tongue

Facilities
K-pad area not very active; Minimal disruption/distraction

Antero C -- H-pad
Estimated Rank - #5

PQ	NQ
68 BCF Gas Hydrate In-Place in C-horizon	No confirmation wells; seismic-only anomaly
Interpreted 45 feet C-horizon reservoir thickness	Structurally compartmentalized, may require delineation
	Patchy saturation interpretation
Stacked with Staines Tongue Prospect	Staines Tongue likely low-saturation as tested at MPI-16
May provide potential fresh water source	Possible coal-associated gas versus free gas?
Gas Hydrate in upper Staines	Closely associated with updip-edge gas chimney
Free gas potential in middle Staines	Gas Chimney may indicate leaky seal
	Free gas requires delineation

Facilities

Prospect very near road access - 100 feet from road	
Prospect near H-pad - 1,600 feet from pad	
Possible option to inject produced gas into Staines Tongue	Question whether hi-pressure gas injection option available

Actions
Check for new well data over shallow intervals

Pikes Peak B -- S-pad
Estimated Rank - #6

PQ	NQ
13-26 BCF Gas Hydrate In-Place in B-horizon	Low-Saturation B-horizon directly below S-pad
Upside as off 3D survey edge on NW Eileen Structure	
B-zone is clean marine sandstone	
Additional upsides in C, D, E, F horizons	

Stacked with Mt Holy Cross Staines Tongue Prospect	
Upper Staines Tongue Free Gas - 3.5 BCF w/ upside	Low Saturations calculated in Staines Tongue (25%)
Downdip Staines in Longs Peak gas hydrate prospect	MPI-16 was low-saturation in Staines Tongue
(23 BCF w/ upside potential if greater saturations)	
Mid-Staines Tongue free gas potential 9+ BCF	Likely low saturation in Staines Tongue
Facilities	
	Long Stepout, 6,840 feet from S-pad may be prohibitive

Beirstadt E -- B-Pad and D-Pad
Estimated Rank - #7

PQ	**NQ**
42 BCF Gas Hydrate In-Place in E-horizon	Very cold & near Permafrost
Opportunity for E-horizon evaluation	Possible Ice formation on production testing
Interpreted to 50 feet E-horizon reservoir thickness	
Excellent geophysically-constrained prospect	
Very organized amplitude anomaly	Not an obvious velocity pull-up in Staines Tongue below
Fault closure with downdip amplitude dimming	
Saturation may have significant upside	Surface statics (inlet) may decrease amplitude anomaly
Stacked with Little Bear Staines Tongue Prospect	Amplitude anomaly is limited in Staines Tongue
Well-constrained prospect	Low Saturations are likely (10-40%)
Gas hydrate/free gas/water contacts follow contours	MPD-01 well is only 20 ohm*m resistivity
	Small volumes in Staines Tongue
Facilities	
B-pad on location	Horizontal well option may be limited from B-pad
Consider horizontal well design turn up into gas hydrate	E-horizon penetration may not allow Staines penetration
This design could help mitigate water production	(may be possible to mitigate with well design)
D-pad near location & may provide better horizontal well	

1.4 Mt Elbert Prospect Characterization and Data Acquisition Planning

The gas hydrate-bearing zones of the Mt. Elbert prospect are fault separated from the E-pad and the B-pad well penetrations that contain only thin gas hydrate-bearing zones C and D. The highest amplitude and interpreted highest saturation are in the most up-dip portion of the prospect. Both the Zone C and D hydrate anomalies may be drilled from the same surface location from either MPU B or E pad (Figure 12). This prospect is one of the most promising "intra-hydrate" prospects. It's proximity to the existing infrastructure and processing facilities near E-pad make it one of the most convenient opportunities in the Milne Point field area (figures 9 and 12). From the proposed Mt. Elbert prospect location, which is optimized for both C and D hydrate targets, the road is 2,370 feet, the Kavearak pad is 2,740 feet, and the E-pad area Central Production Facility and Drillsite is 3,020 feet away. The C and D hydrates are found in wells adjacent to the prospect in the MPU B-02 and MPU E-26 wells, although these hydrates are thought to be thinner and of lower saturation than that expected in the up-dip portion of the prospect. Good synthetics in both of these wells give a high confidence level in the interpretation of the C and D zone hydrates in the prospect. The prospect is fault separated from the E-pad, on the west side, by a large regional normal fault.

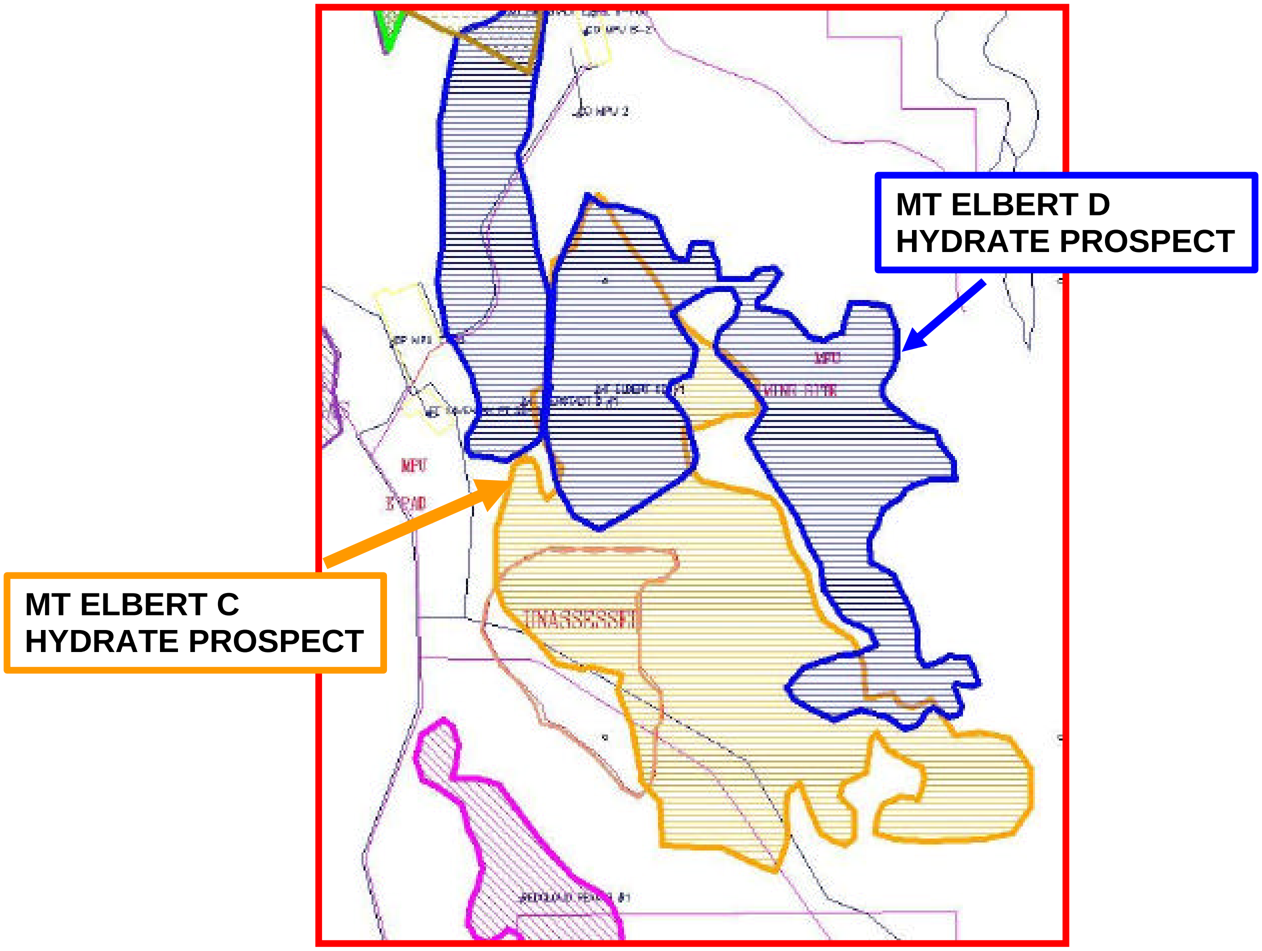


Figure 12: Location of Mt. Elbert Zone C and D prospects, Milne Point area

1.4.1 Mt Elbert Zone D Prospect Characterization

The Zone D hydrate horizon correlates to the D hydrate found in the MPB-02 well, on the down-dip side of a large regional fault. A single well or 2 wells (updip and downdip) could delineate both the D and C hydrates at the Mt. Elbert Prospect. Figure 13 illustrates the seismic amplitude attribute defining this Zone D hydrate accumulation. Figure 14 shows the west to east seismic cross-section E-A to E-A' from Figure 13. Figure 15 shows the south to north seismic cross-section E-B to E-B' from Figure 13. Figure 16 shows the Zone D reservoir thickness in the Mt. Elbert prospect as interpreted from seismic attribute analyses. Figure 17 shows the Zone D reservoir gas hydrate saturation in the Mt. Elbert prospect as interpreted from seismic attribute analyses.

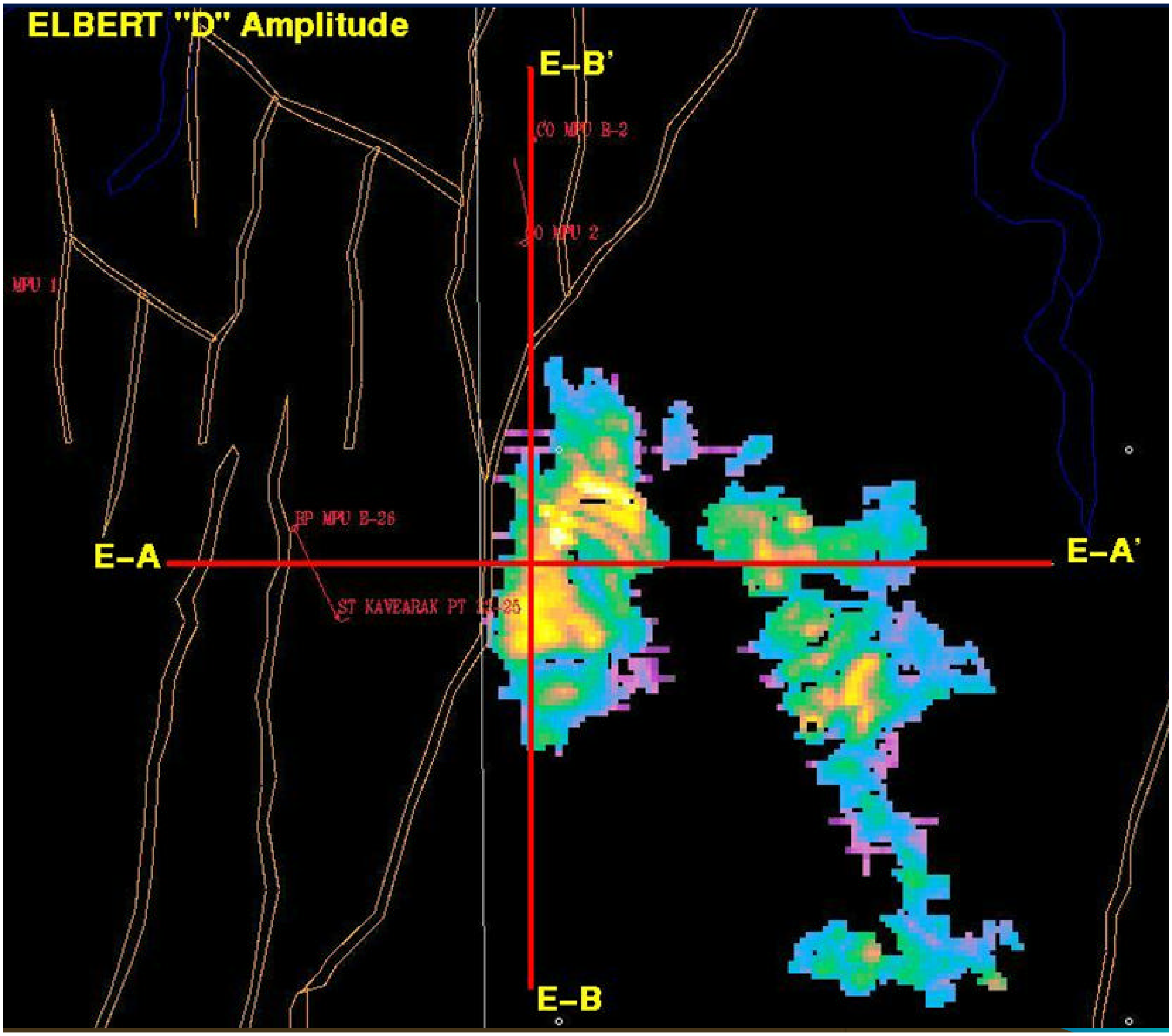


Figure 13: Seismic Amplitude of Zone D horizon, Mt. Elbert Prospect

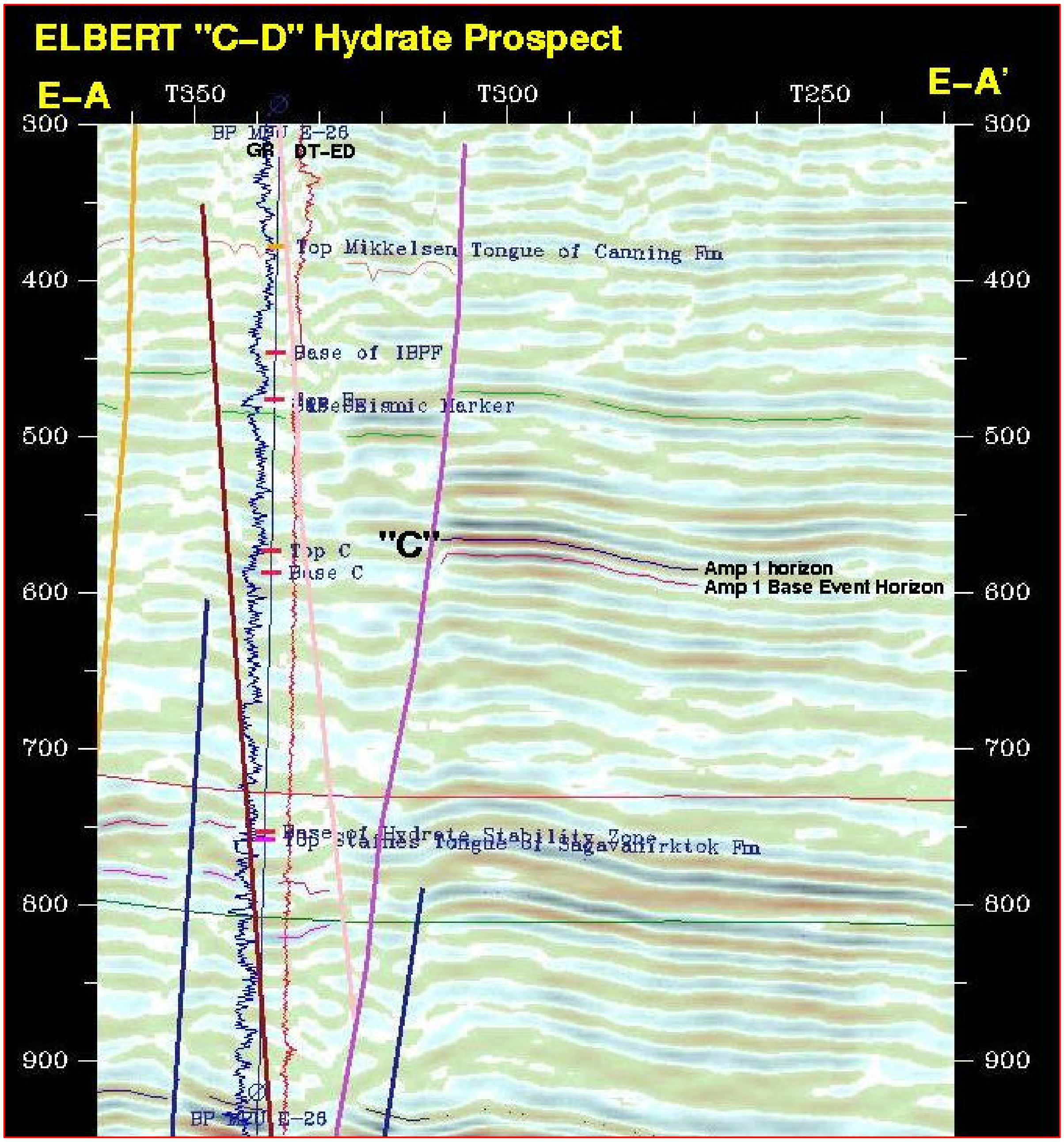


Figure 14: Seismic cross-section E-A to E-A', showing Zone C, Mt. Elbert Prospect

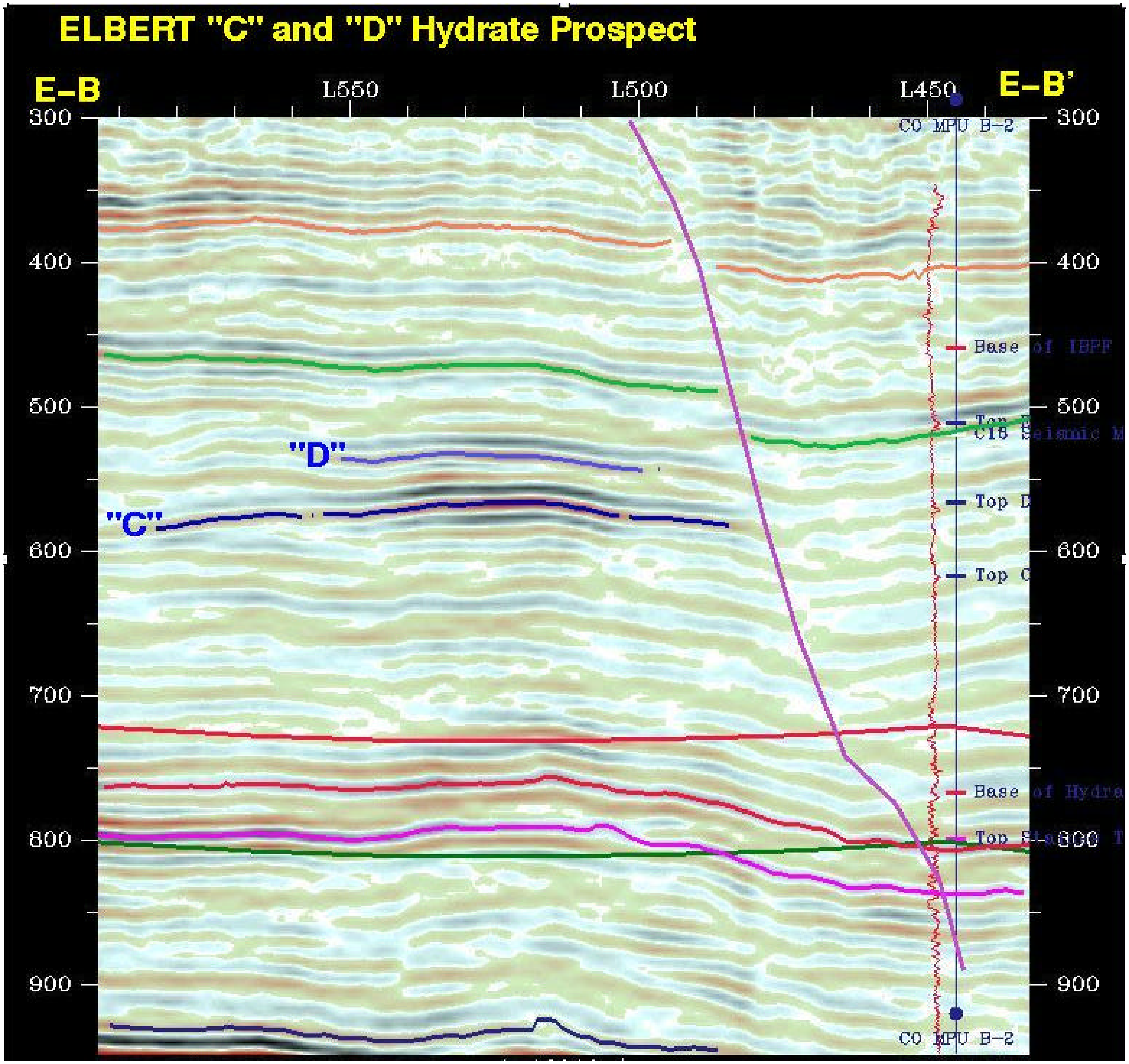


Figure 15: Seismic cross-section E-B to E-B', showing Zones C and D, Mt. Elbert Prospect

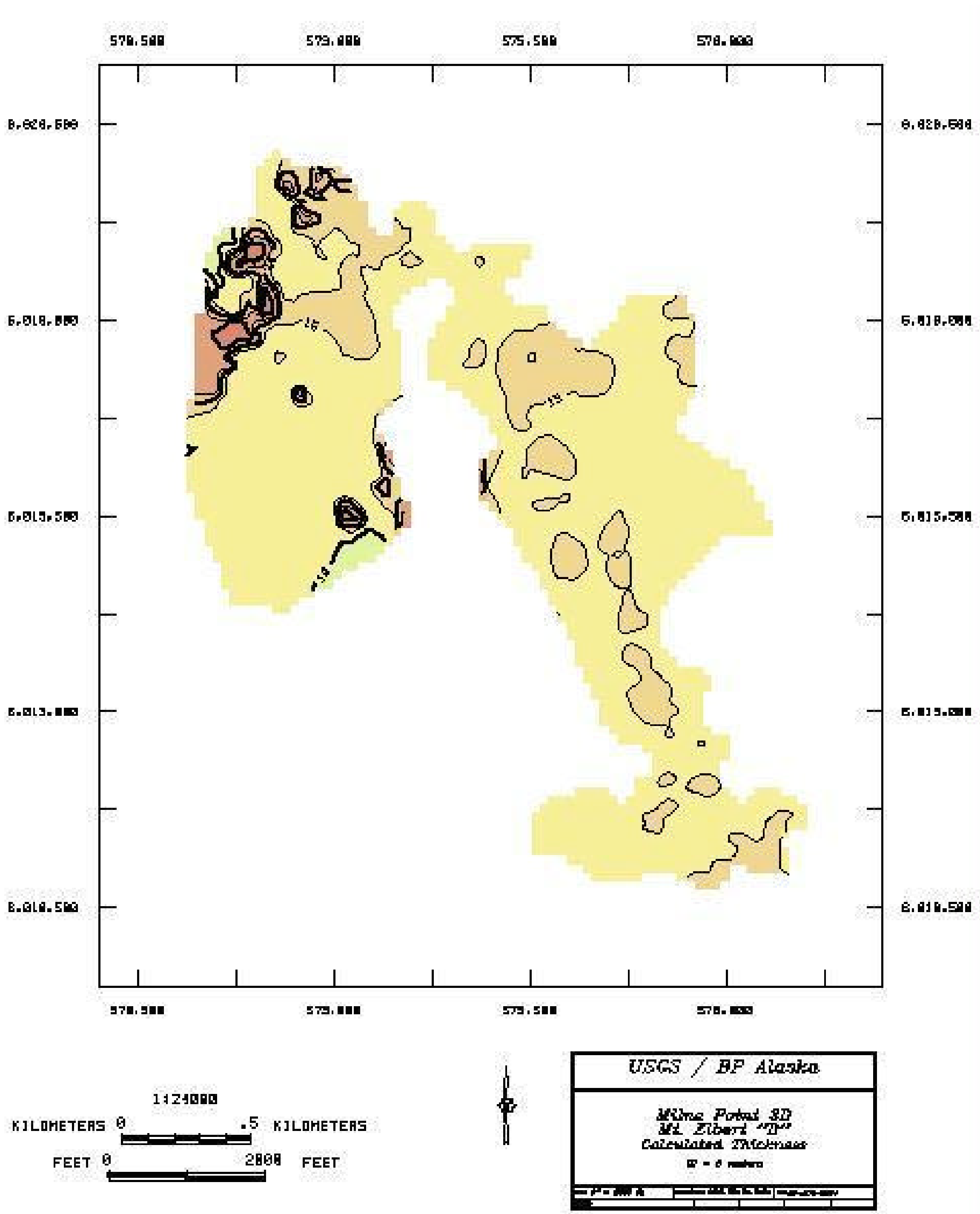


Figure 16: Zone D reservoir thickness (in meters) as interpreted from seismic attribute analyses, Mt. Elbert prospect.

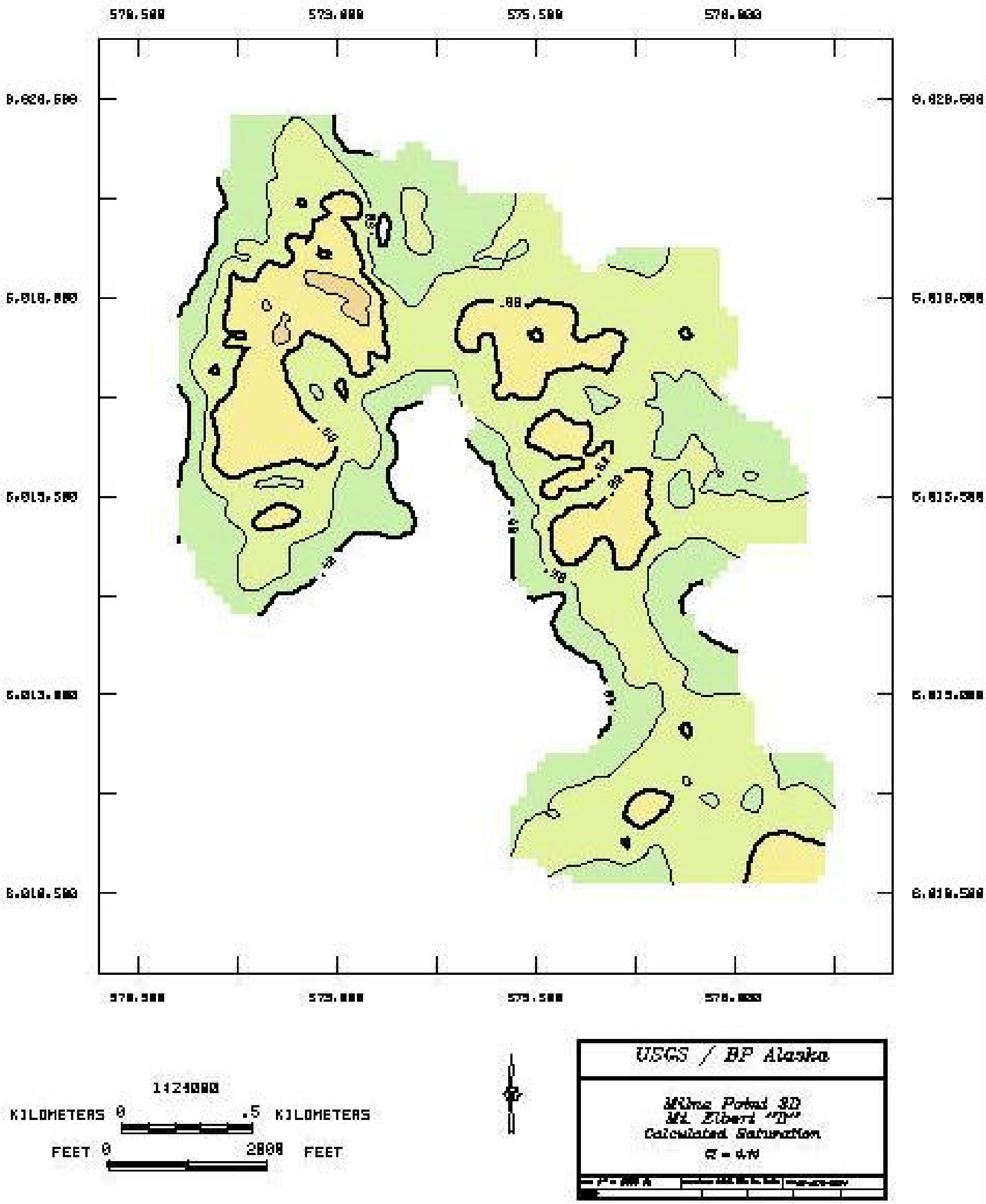


Figure 17: Zone D reservoir gas hydrate saturation as interpreted from seismic attribute analyses, Mt. Elbert prospect.

1.4.2 Mt Elbert Zone C Prospect Characterization

The Mt. Elbert C Hydrate prospect is, in part, coincident with the Mt. Elbert D Hydrate prospect, but is interpreted to be more laterally extensive, thicker, and of higher saturation than the D Hydrate at this location. Figures 18-19 illustrate the seismic amplitude attribute defining this Zone D hydrate accumulation. Figure 14 shows the west to east seismic cross-section E-A to E-A' from Figure 19. Figure 15 shows the south to north seismic cross-section E-B to E-B' from Figure 19. Figure 20 shows the Zone C reservoir thickness in the Mt. Elbert prospect as interpreted from seismic attribute analyses. Figure 21 shows the Zone C reservoir gas hydrate saturation in the Mt. Elbert prospect as interpreted from seismic attribute analyses.

The "C" hydrate amplitude is shown in figures 14 and 15. Notice that the highest amplitude portion of the Mt. Elbert Prospect anomaly is on the highest up-dip portion of the prospect to the Northwest (Figure 18). The same is true for the less dramatic "D" hydrate mapped amplitude shown in Figure 13. These higher amplitudes have been shown to correspond to the highest saturation portions of the prospect based on the thin bed analysis previously discussed. The location of these higher amplitudes, in the most up-dip portion of the prospect, point to the likelihood that these hydrates were originally emplaced as gas and later passed into the hydrate stability zone.

Figure 14 shows seismic cross section E-A to E-A' through the BP MPU E-26 well and across the Mt. Elbert Prospect anomaly. The prospect is separated by the large down-to-the-west normal fault shown in purple. Notice that the higher amplitude "C" hydrate zone in the prospect correlates to the thin "C" hydrate in the E-26 well. Figure 15 shows seismic cross section E-B to E-B', through the Mt. Elbert Prospect. The "C" and "D" hydrates which appear in the prospect, on the left of the purple fault, can be correlated to thin "C" and "D" hydrate intervals in the MPU B-02 well. The reduction in amplitude to the south and east shown in Figure 15 is probably largely due to a decrease in hydrate saturation. Figure 22 shows a three dimensional display of the prospect with the bounding faults and adjacent key wells.

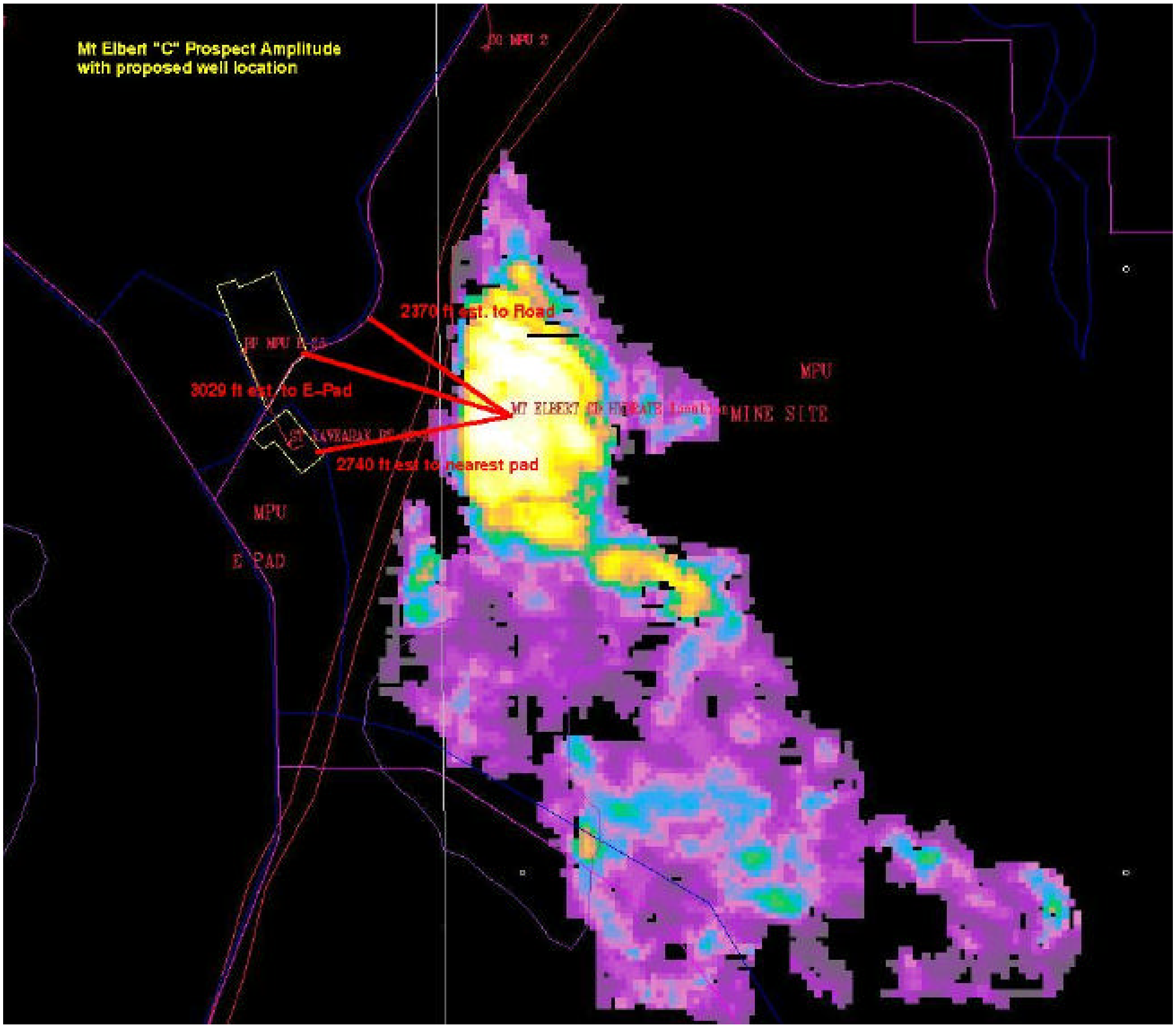


Figure 18: Zone C seismic amplitude, Mt. Elbert prospect, showing proposed potential well location.

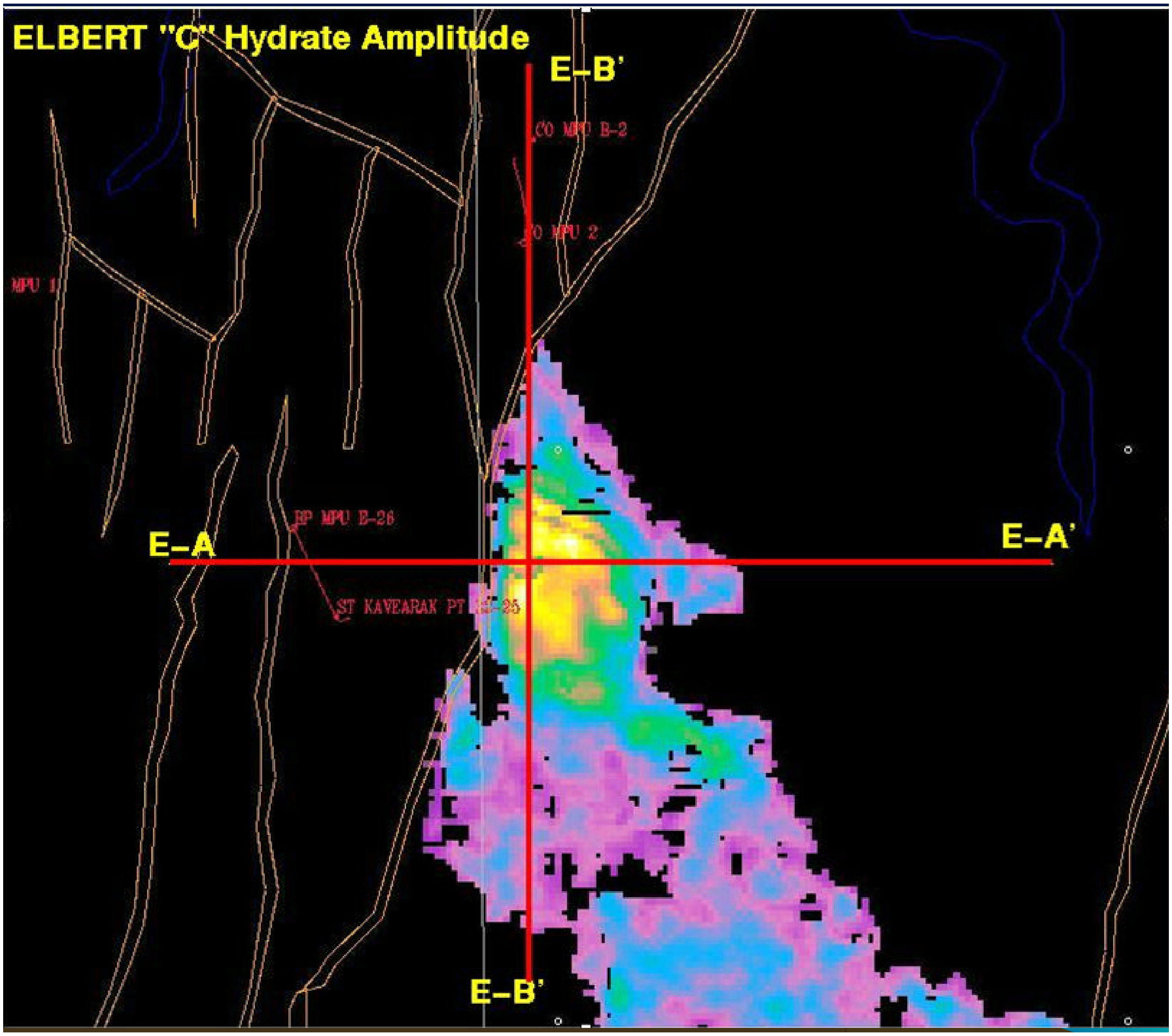


Figure 19: Zone C seismic amplitude, Mt. Elbert prospect, showing location of cross-sections in figures 14-15.

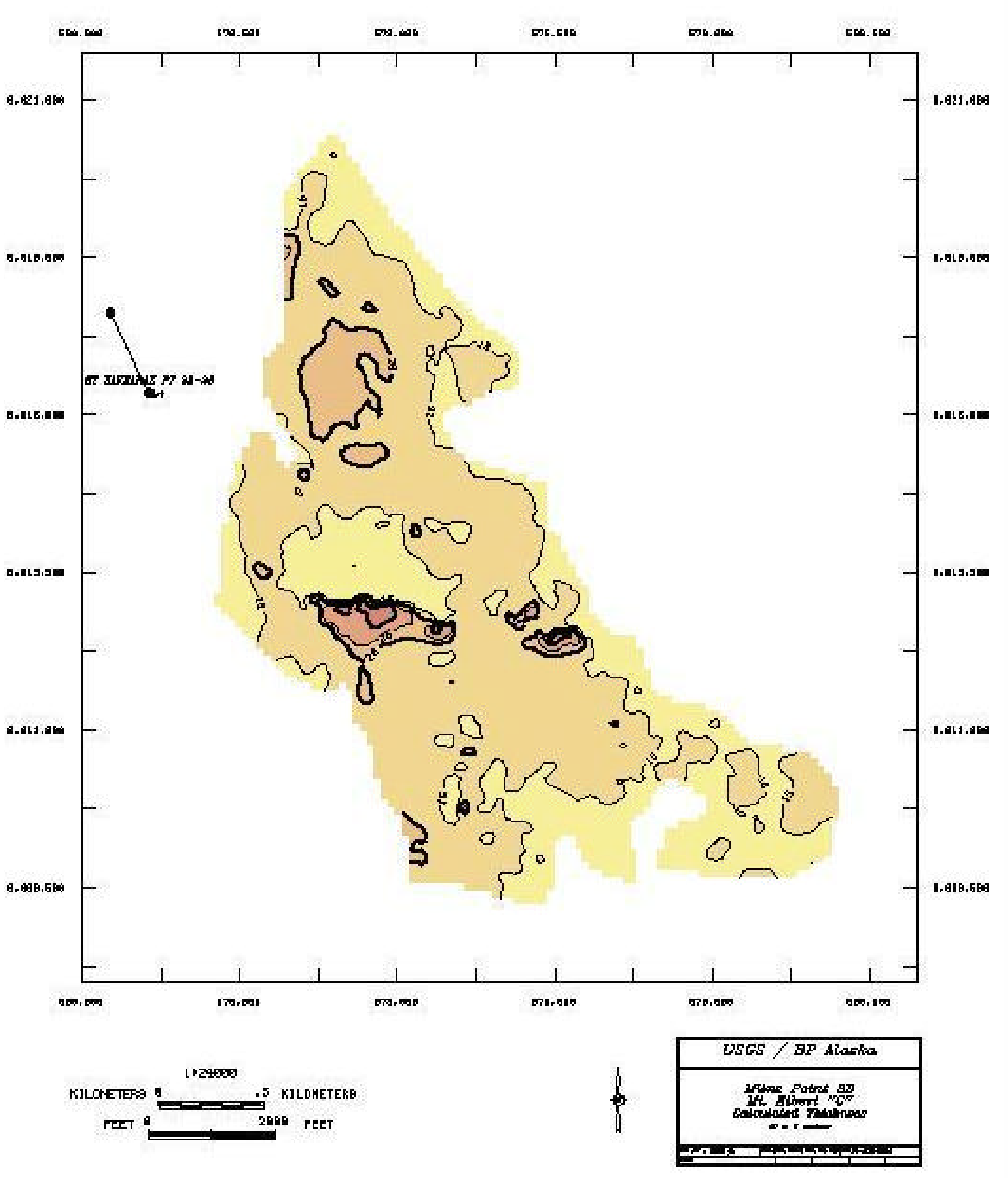


Figure 20: Zone C reservoir thickness (in meters) as interpreted from seismic attribute analyses, Mt. Elbert prospect.

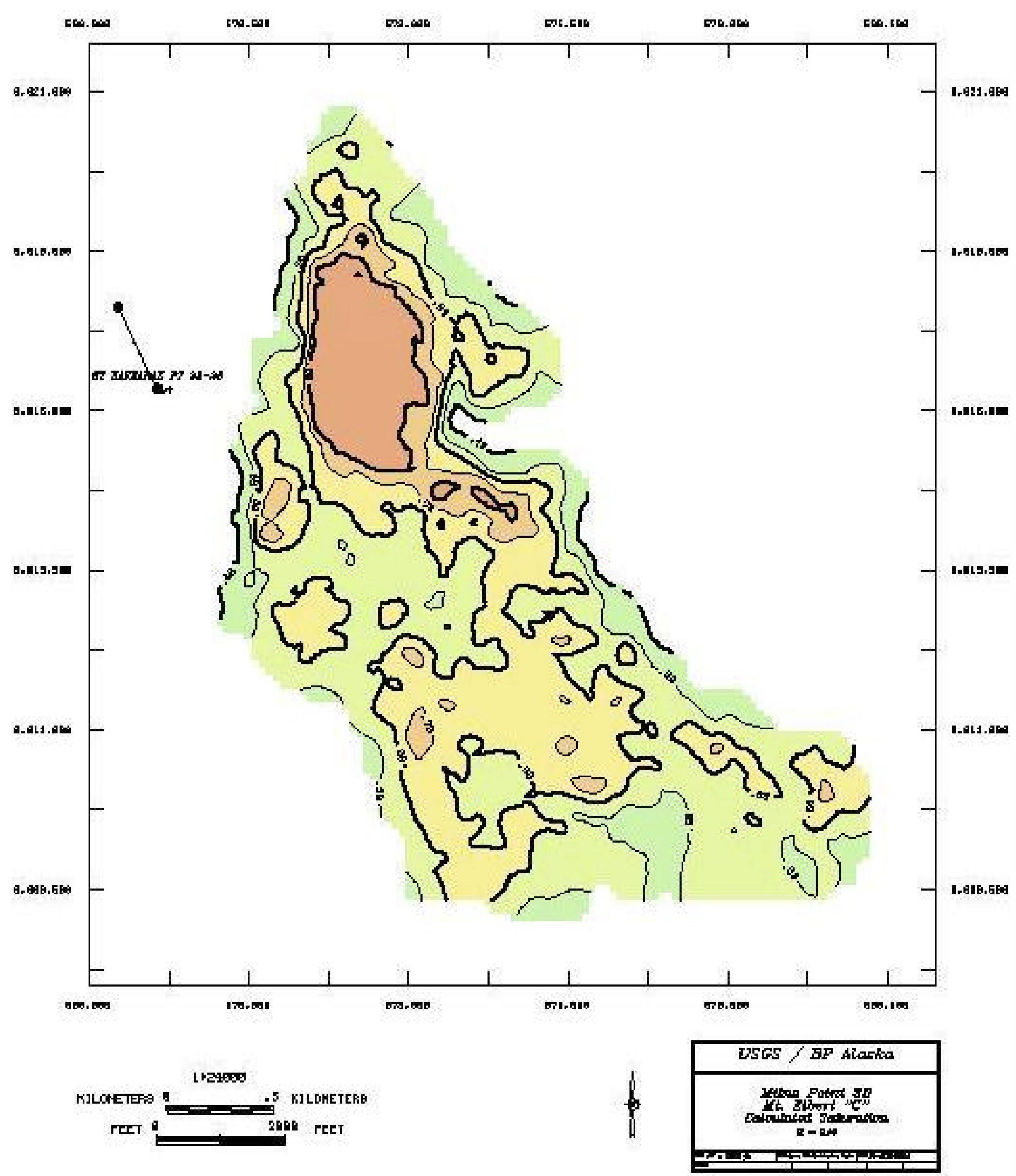


Figure 21: Zone C reservoir gas hydrate saturation as interpreted from seismic attribute analyses, Mt. Elbert prospect.

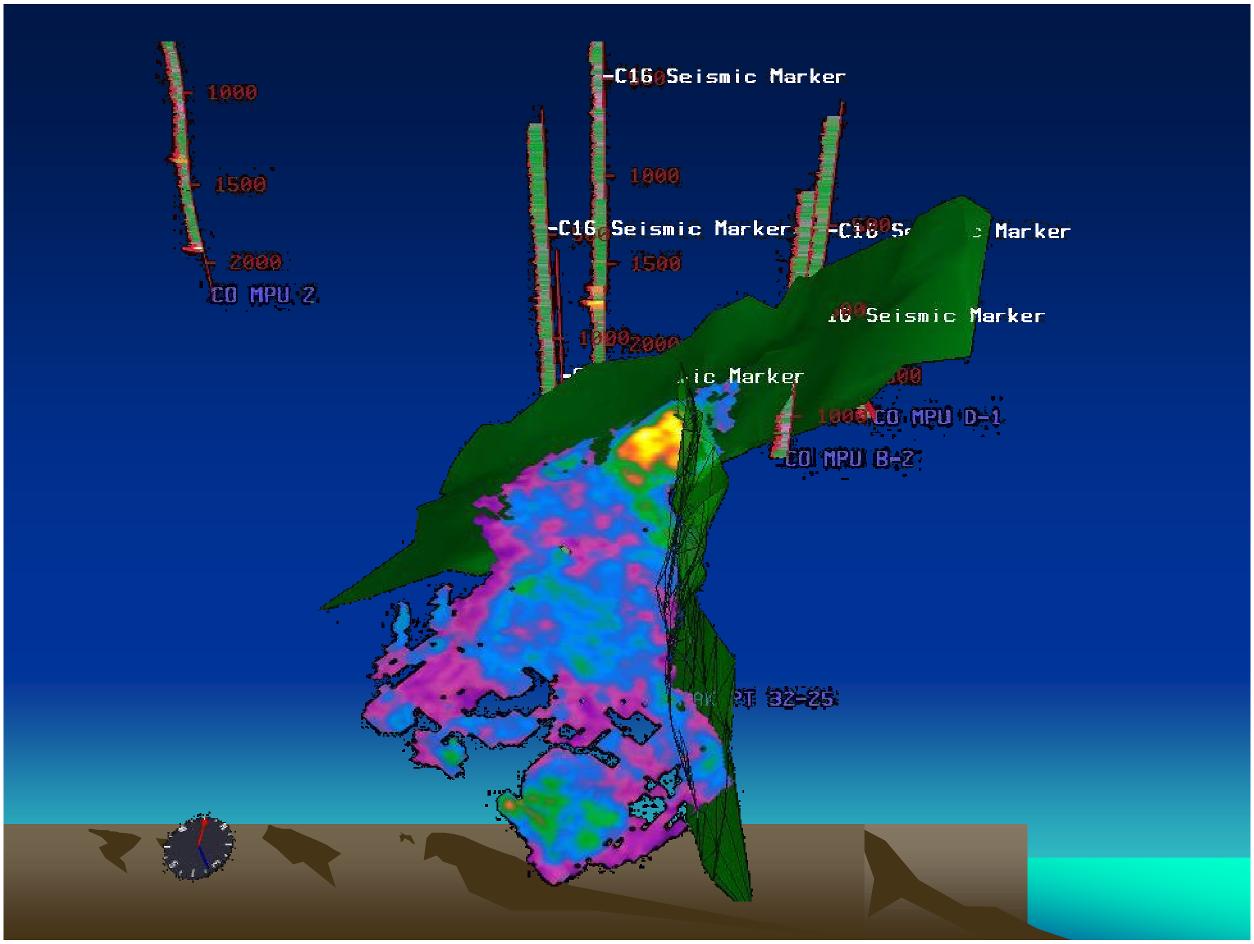


Figure 22: Three dimensional display of the Mt. Elbert prospect with the bounding faults and adjacent key wells.

1.4.3 Mt Elbert Prospect Data Acquisition Planning

If approved by the resource owner and DOE, plans for additional static data acquisition would delineate the seismically-defined Mt. Elbert prospect. Since the prospect lies 3,000 to 4,000 feet from MPU E and B pads, data could be better acquired from vertical well(s) drilled from an ice pad directly over the prospect during the winter drilling season (Figure 23). If acquired data confirmed the geophysical interpretation, then the delineation well(s) could be followed by a horizontal production test well drilled from MPU E or B pads. The B-pad location may offer the best orientation with respect to the interpreted faults which define the western and eastern boundaries of the prospect. Table 5 illustrates the type of data that could be acquired from the delineation well(s) and from the potential production test.

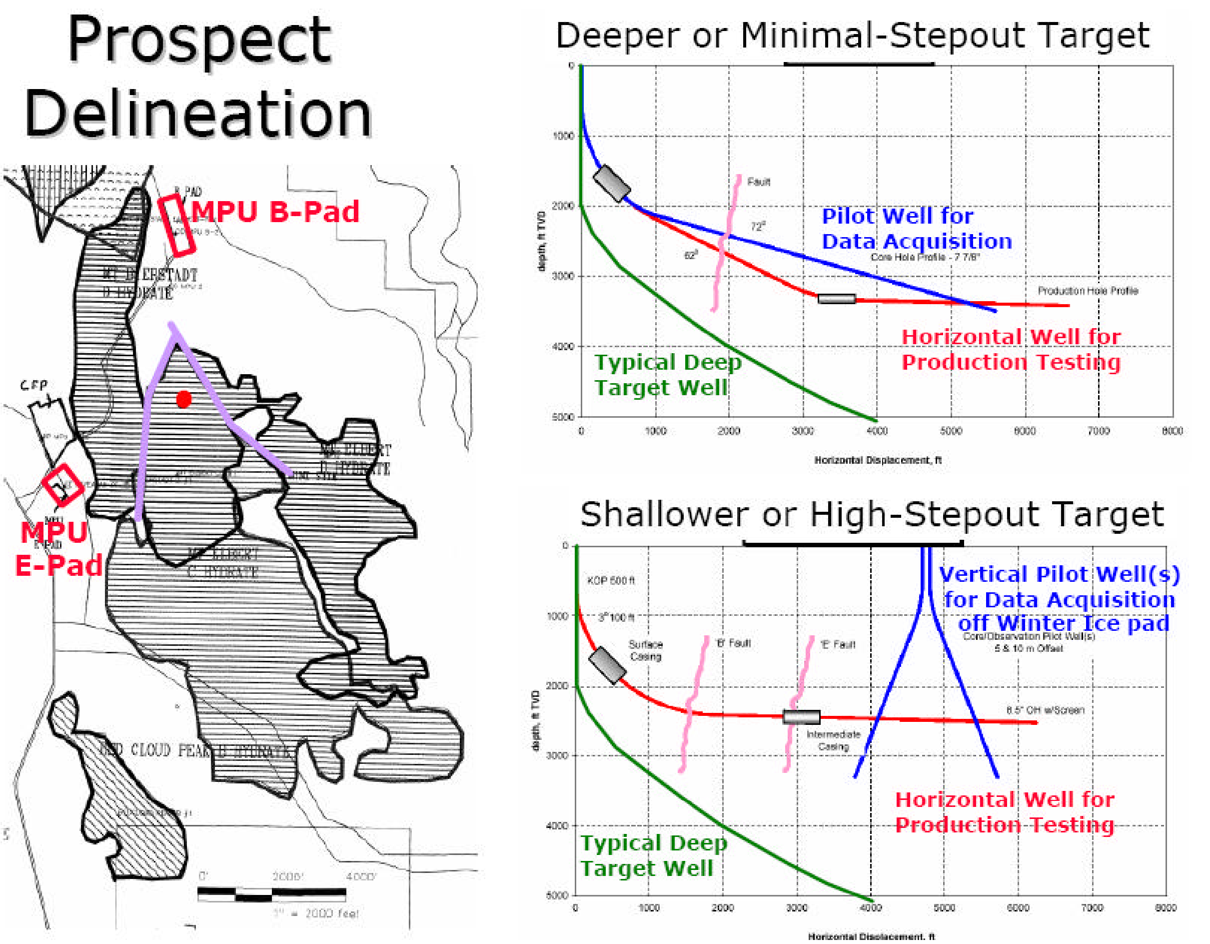


Figure 23: Mt. Elbert Prospect Delineation (vertical) and Production Testing (horizontal) well plan schematics. Lower well diagram schematic illustrates potential vertical data acquisition wells drilled off ice pad.

Table 5: Example Data Acquisition Program, Mt. Elbert Prospect

Gas Hydrate-only prospect	**Recommended Data Acquisition**	**Data Issues**
	Core	Requires nearly vertical well
	Wireline &/or MWD/LWD logs	Requires nearly vertical well
	MDT testing and samples	Requires nearly vertical well
		Dedicated sidetrack an option
Possible Testing Sequence:	1. Vertical Well for data and observations	
	2. Horizontal sidetrack for testing	
	3. Fracturing and Huff-Puff testing	
	4. Chemical treatment testing?	
	Method of Production Test Temperature	**Production Testing Issues**
		Hot Water Injection
		Hot Gas Injection
		Chemical Injection
		In-situ Combustion?

		Near-wellbore electro-magnetics
	Pressure	In-situ water production (?Sw?) Horizontal well setup options circulation with gas lift mandrel fracture with Huff/Puff
	Chemical	CO2 injection? Salt additives Methanol
	Other	Possible motor at/near surface Rod in-hole to 45 degrees Water & Sand Production Handling SSRDPCP (surface sucker-rod driven progressive cavity pump)
Gas Hydrate/Free Gas prospect	**Recommended Data Acquisition**	**Data Issues**
	Core	Requires nearly vertical well
	Wireline &/or MWD/LWD logs	Requires nearly vertical well
	MDT testing and samples	Requires nearly vertical well Dedicated sidetrack an option Depressurization Case Test
	Method of Production Test	**Production Testing Issues**
	Pressure	Produce well-constrained Free Gas Gas disposal/facilities issue
	Temperature	Combat near-wellbore drawdown Could reform hydrate &/or ice gas/water cycling/hot gas/water
	Chemical	CO2 injection? Salt additives Methanol
	Other	Possible motor at/near surface Rod in-hole to 45 degrees Water & Sand Production Handling SSRDPCP (surface sucker-rod driven progressive cavity pump)

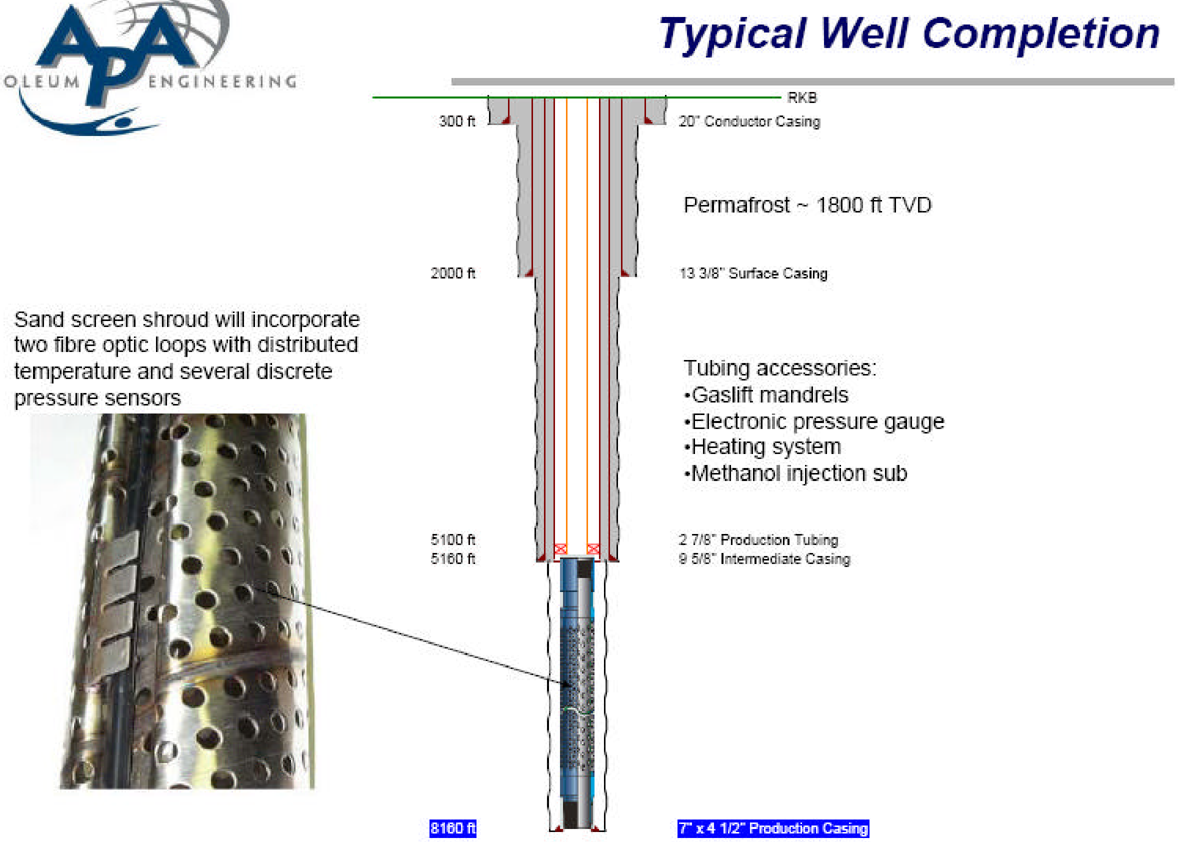


Figure 24: Example Well Design, Mt. Elbert Prospect

1.4.3.1 Mt Elbert Prospect Area Facility Infrastructure

Several options exist to help facilitate potential production testing operations from MPU B-pad. There is only one production line not in use out to B-pad and it is an 8" water line (ANSI 600) that at one time was used to bring source water from B-pad to the Central Production Facility (CFP). However, the 14" 3-phase pipeline could be used as it is currently bringing produced fluids from B-pad to the CFP at E-pad, but is nowhere near its hydraulic limit with current B-pad production rates. Also, there is active gas-lift at B-pad with room to add additional wells. Current gas-lift supply pressure at B-pad is about 1325 psi. The 3-phase header pressure at E-pad is about 205 psi and the header pressure at B-pad is about 160 psi.

1.5 Conclusions

Reservoir characterization, reservoir modeling, prospect ranking, and facilities infrastructure indicate that the MPU Mt. Elbert prospect is a good candidate for additional data acquisition. If data acquired during prospect delineation confirms the seismic interpretation and reservoir modeling, then the site is also a good candidate for production testing operations conducted from the nearby MPU B-pad facilities. If the resource owner, in collaboration with DOE, determines to proceed into field operations, the Mt. Elbert site would provide a suitable candidate for data acquisition and production testing operations to help narrow the uncertainties regarding gas hydrate-bearing reservoir productivity, saturations, and absolute and relative permeabilities.