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Phase 1 Final Technical Report

Characterization and Quantification of the Methane Hydrate Resource Potential Associated with the Barrow Gas Fields

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CHARACTERIZATION AND QUANTIFICATION OF THE METHANE HYDRATE RESOURCE POTENTIAL ASSOCIATED WITH THE BARROW GAS FIELDS

DOE Project Number: DE-FC26-06NT42962

Awarded to

North Slope Borough, Alaska

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1.0 Project Overview

1.1 Statement of the Problem

The North Slope Borough relies on gas production from the Barrow Gas Fields (East Barrow, South Barrow and Walakpa Fields) for heating and electricity for Barrow, a community of approximately 3400 residents which also includes businesses and government services in this western North Slope city. Based on current estimates of remaining reserves and consumption rates, the borough's gas supply should last for over 150 years. However, demand for energy is expected to grow in Barrow, and the prospect of distributing gas to outlying villages in the borough will create increasing pressure on the public utility to grow gas supply to meet demand.

The North Slope Borough Department of Public Works Energy Management Group commissioned a study of the remaining reserves in the Walakpa Gas Field (Stokes et al., 2005), and is considering future studies to:

- Develop a depletion plan for the Barrow Gas Fields,
- Identify possible infrastructure and operations upgrades to expand gas production,
- Increase surveillance activities at the Walakpa, East Barrow, and North Barrow Fields,
- Update the geologic model for the Barrow Gas Fields to support the planning and drilling of additional development wells,
- Characterize, quantify and evaluate the impact of a postulated gas hydrate accumulation associated with the Barrow Gas Fields.

The depletion mechanism for the Barrow Gas Fields is thought to be primarily gas expansion, with potential contributions from edge water drive, and recharge from gas hydrate up dip of the free gas pool. Understanding the details of the drive mechanism is critical to field management, and will impact future development plans, particularly selection of new development well locations and future compression requirements.

The need to characterize and quantify a postulated methane hydrate accumulation in the Barrow area is closely aligned with the US Department of Energy (USDOE) objectives. If the presence of a significant methane hydrate accumulation is verified, the producing gas fields in Barrow provide an excellent opportunity to test the potential of production of methane hydrates through depressurization of the free gas zone at the free gas/hydrate interface.

1.2 Solution

This phased study builds on the results and recommendations of a prior research effort (Glenn & Allen, 1991), and is designed to determine if gas hydrates exist in association with the Barrow Gas Fields, and if so, to determine if hydrates contribute to the pressure support of one or more of the fields. The study builds on past and current methane hydrate studies, and will involve creation of a static reservoir model to characterize the reservoir extent, pore fluid properties, and pressure and temperature regime to determine the likelihood of gas hydrates. If the probability of methane gas hydrate presence is high, the next step will involve detailed geologic mapping to choose an optimum location for a dedicated Phase 2 gas hydrate well to intersect the gas hydrate/free gas surface. The objective of such a well would be to sample the hydrates, produce gas hydrates indirectly through production of free gas beneath the interface, and to monitor the hydrate/free gas interface and both zones as production occurs.

The proposed production method in a Barrow Area gas field test would be by depressurization, drilling horizontally through the up-dip methane hydrates zone and then horizontally down dip into the free gas zone. This plan is based on the current understanding of the Barrow Area gas fields' geology and will be confirmed by geologic models of the reservoir and the methane hydrate stability zone. A dedicated methane hydrate well drilled in Phase 2 could allow for initial testing in the hydrates zone and then later production from the free gas zone in the toe of the horizontal completion.

It has been suggested that a methane hydrate accumulation exists in the up dip extent of the Walakpa Gas Field (Glenn & Allen, 1991), and the interval was tested with the Walakpa #1 well. However, modeling of hydrate stability using Walakpa gas and formation water compositions, and accurate geothermal and pressure gradients needs to be completed to verify hydrate stability. This modeling effort should indicate whether or not hydrates are possible at the depths and temperatures of the reservoir with a fairly high degree of confidence.

Another issue which must be addressed is the presence of sufficient thickness and quality of reservoir up dip of the free gas accumulations. This requires an expansion of the geoscience work done prior to and since the development of the Walakpa Field, with particular emphasis on the characterization of the pinchout of the reservoir sands. This review will utilize the available 2-D seismic data and the 10 Walakpa wells, integrated with analysis of the production testing completed by Petrotechnical Resources Alaska (PRA) in 2005 to model the up dip terminus of the Walakpa sands. The South and East Fields have not been the focus of recent geoscience and reservoir analysis, and the study will include as detailed a review of those fields as the data will support.

Assuming the results of the hydrate stability modeling and reservoir limits review are positive, a detailed reservoir characterization to support simulation of hydrate production methodologies and planning of a dedicated hydrate well would be undertaken. Very sophisticated reservoir simulation tools and techniques have been developed to model the Mallik production tests, as well as to predict production rates and mechanisms in association with the BP-USDOE dedicated hydrate well that was planned and drilled at Milne Point.

Of particular interest in the reservoir simulation modeling will be to quantify the impact of hydrate dissociation on recharge of the producing gas fields. This work will aid in the understanding of secondary production effectiveness through depressurization of an associated free gas interval, and will potentially impact future field operations and development plans.

Based on the static and dynamic reservoir modeling, an optimum location to drill a dedicated hydrate well to sample and production test would be determined for subsequent drilling in Phase 2. The well would be designed to fit the geologic, reservoir, and operational specifics required in the Barrow Gas Fields, but would leverage and expand on the learnings of the Hot Ice, Mallik and Milne Point wells.

1.3 Study Objectives and Approach

The objectives of this study are to characterize and quantify the postulated methane hydrate resource in the Barrow area, and to sample and production test this resource to determine its impact on future free gas production and its viability as an energy source.

Phase 1 efforts focused on integrating prior research with the current knowledge base to determine if methane hydrates exist in association with the Barrow Gas Fields and if so, to characterize the hydrate accumulation in an integrated reservoir model. The work objectives for Phase 1 were:

- Develop a research management plan for the study,
- Perform a Technology Status Assessment,
- Determine that the methane hydrate stability zone exists up-dip of one or more of the Barrow Gas Fields,
- Determine probability that the reservoir is continuous up-dip into the methane hydrate stability zone through integrated geological/geophysical interpretation and mapping,
- Identify an optimum location for a dedicated methane hydrate well, based on geologic, infrastructure, and logistical considerations,
- Model the expected production (gas and liquids) from the optimized well.

Phase 1 represents the first step in better defining the local potential for methane hydrates. This included information gathering; gas sampling and geochemical analysis; methane hydrate stability modeling; seismic and well log analysis, including computer modeling; and documentation and dissemination of information to the DOE and other interested and affected entities. Phase 1 is comprised of a series of eight tasks, the first three tasks were completed as part of Phase 1A, The findings and conclusions from Phase 1A are fully described in the Final Phase 1A Technical Report (May 2008) found on the National Energy Technology Laboratory (NETL) website at www.net.doe.gov. A summary of the Phase 1A conclusions and recommendations are included in the following section. The remainder of this report addresses the findings of the Phase 1B effort, Tasks 5 through 8.

2.0 Phase 1A Conclusions and Recommendations

Extensive effort went into the search for existing data on the gas and formation water composition, and pressure and temperature gradient for the three Barrow Gas Fields. This data was supplemented by newly acquired information gathered specifically for this study. Considerable variability was revealed in the temperature gradient data between different fields, wells, and over time in a single well, and some decisions had to be made regarding data credibility. Where possible, temperature gradient information from wells which had not yet flowed, or which had been shut in for long (multi-year) periods before measurement were favored in the analysis to avoid effects of transient temperature behavior. The resulting dataset was supportive of the hydrate stability zone modeling.

Formation water sample information is sparse for the three fields, although the available samples indicate average salinities of 2-2.5%, with some samples as high as 4% salinity. Hydrate stability modeling incorporated several salinity values to measure sensitivity of the hydrate stability zone depth ranges to variation in salinity. Collection and analysis of produced water samples from the three fields was a proposed scope addition to Phase 1B.

Gas sample data and analysis was available for the Barrow Gas Fields from prior studies, and this data was supplemented with newly collected samples from three wells from each of the three fields. The analysis indicates that the gas is thermogenic in origin, Type I-II kerogen, and late mature to over mature, accounting for the very high proportion of methane in all gas samples. Using the Colorado School of Mines model, the Walakpa data and most of the Barrow data shows a structure II hydrate, or just on the edge between SI and SII. No consistent or convincing trends regarding methane hydrate dissociation are apparent in the compositional or isotope analysis, although there are a few indicators consistent with possible hydrate dissociation.

Material balance modeling for the Walakpa and East Barrow pools indicates a secondary depletion mechanism is in play in the two fields, beyond simple volumetric gas expansion. East Barrow, in particular, has a very flat, even negative decline curve, and the field was originally considered to be characteristic of a strong edge water drive. However, the wells have not watered-out as expected, and it is possible that hydrate dissociation is playing a role in pressure support in this field, which has exceeded original estimates of ultimate recovery by approximately 30% (Stokes & Walsh, 2007). Walakpa, which is a far larger field shows signs of additional pressure support (Stokes et al., 2005), but it is too early to characterize this effect with any confidence.

The methane hydrate stability modeling carried out at the University of Alaska, Fairbanks strongly supports the presence of hydrate stability zones above all three gas fields; however, only the East Barrow pool appears to demonstrate clear overlap between the base of the hydrate stability zone and the free gas reservoir. The hydrate stability zone over the Walakpa field appears to be slightly overlapping with the shallowest penetrated free gas reservoir, but slightly up dip of the Walakpa #1 well we would expect there to be a free gas-hydrate interface (Singh, 2007). It has been suggested that the Walakpa #1 well is actually within the hydrate stability zone, based on the results of production testing when the well was drilled (Glenn & Allen, 1991; Stokes et al., 2005). Based on the results of a four-point production test, the calculated absolute open flow rate for this well was 370MSCF/D, but the well shut in due to hydrate or ice formation in the wellbore. The South Barrow pool is somewhat more challenged, in that the modeled hydrate stability zone is significantly shallower than the known free gas reservoir (Singh, 2007).

The objectives of Phase 1A were met, with significant new data and previously recorded information integrated in a study indicating high probability of methane hydrate stability zones associated with the Barrow Gas Fields. Based on the findings of Phase 1A, it was the recommendation of the study team to continue to Phase 1B of the study, in order to characterize the reservoir, quantify the hydrate resource potential, and model the potential production from the hydrate resource. USDOE approved continuation to the next phase of the project and the results of each Phase 1B task are described in the following sections.

3.0 Phase 1B Technical Work Description

3.1 Task 5—Revise RMP, Map Barrow and Walakpa Gas Fields

3.1.1 Task 5a - Revise PMP

The Research Management Plan (RMP) was revised to incorporate input from the project’s Technical Advisory Group (TAG). Changes included: addition of a seismic reprocessing step to evaluate the use of AVO techniques to determine reservoir presence or absence; expansion of Task 5 to include produced water sampling and analysis from the East Barrow (E..B.) #14 well; and greater emphasis on the production history information to assess the importance of unusual material balance modeling results.

3.1.2 Task 5b - Map Barrow and Walakpa Gas Fields

Updated seismic mapping work was undertaken across the Barrow High area, including 1) the Barrow Gas Fields, in which the Jurassic Barrow sandstone is the primary reservoir unit, and 2) the Walakpa Gas Field, which produces from a Neocomian sandstone that was deposited on the Lower Cretaceous Unconformity (LCU) surface. A depth structure map on the LCU was produced for the entire region, and a sub-regional depth structure map on the top of the Barrow sandstone was produced covering the East

Barrow, South Barrow, and Sikulik field areas. In addition, individual field maps were produced for all four fields. Figure 1 shows there regional grid of 2D seismic data used in the interpretation.

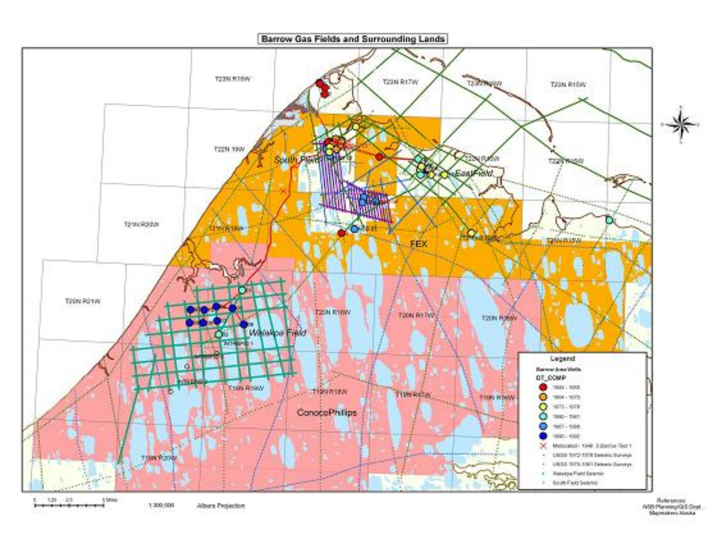

Figure 1. Seismic Data Interpreted in Barrow Area, North Slope Alaska.

All available well data files and reports were reviewed and incorporated into the interpretation, and an updated well pick data set was created from log correlation work. The well picks were used as control for the depth conversion of corresponding seismic horizons and for the generation of isochore maps. Structure and thickness grids, together with the well picks that resulted from this study, were used to build the framework for subsequent gas and methane hydrate reservoir modeling work within and near the field areas.

Careful tying of the seismic data with existing well control, incorporation of all available seismic lines, and phase and time matching of seismic data sets has resulted in improved structural maps for the region. Detailed stratigraphic interpretation of the key reservoir intervals through seismic modeling and attribute work has not been undertaken to date, due to the limited and inconsistent quality of available seismic data. Seismic isochore mapping of the HRZ (highly radioactive zone, or Pebble Shale) to LCU (late cretaceous unconformity) interval was undertaken and may provide some insight into the distribution of Walakpa sandstone to the north and east of the existing Walakpa Field area.

Extensive well log interpretation and correlation was integrated with the seismic interpretation to create depth and thickness maps for the Walakpa and Barrow Sandstone reservoirs. Figure 2 shows a SW-NE well cross-section through the Walakpa Gas Field, from the Walakpa #2 well to the updip Walakpa #1 well. Correlation of the Walakpa reservoir updip of the Walakpa #1 well indicates that the Walakpa reservoir extends tens of miles to the northeast, and well into the hydrate stability zone. Further information regarding the analysis supporting the mapping efforts can be found in the Topical Report *Seismic and Well Log Evaluation* (June 2008) on the NETL web site.

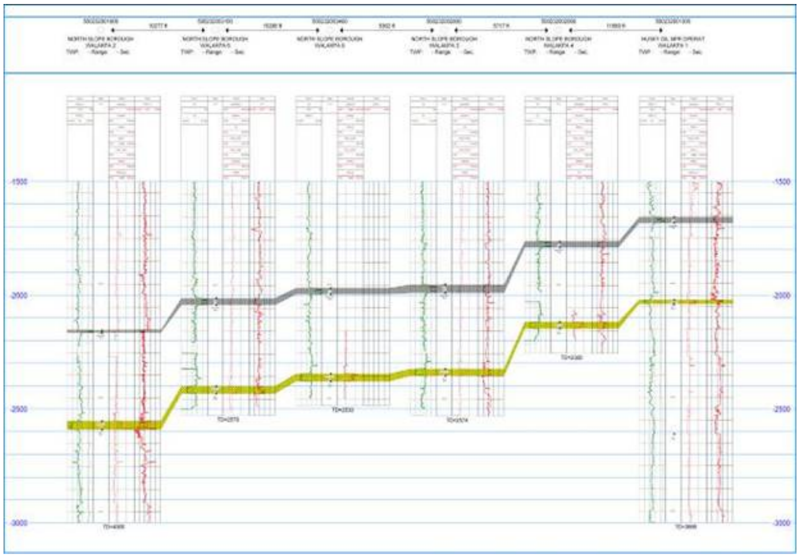

Figure 2. Structural Well Cross-Section, SW-NE Through Walakpa Gas Field

3.1.3 Task 5c – EB# 14 Water Sample Analyses

Comparative analysis of the recent EB#14 well produced water sample against earlier East Barrow well samples was completed, and samples will continue to be collected periodically from EB#14 to track any compositional changes over time. As there is very little water produced with the gas in the Barrow Gas Fields, and there is currently no means of separating any produced water at the wellhead, a bailing tool was acquired and utilized to "dip" formation water from the wellbore for analysis. Table 1 shows the recent EB#14 sample compared to historical water samples from the East Barrow Pool. The recent sample analysis reflects a general increase in total dissolved solids in the formation water from past samples, with the exception of the 1977 SB 14 contaminated sample, a result which is contrary to our expectations. We would like to have recorded a credible reduction in pore water salinity, indicating possible release of fresh water from hydrate dissociation.

Table 1. Well East Barrow #14 water sample analysis:

	TDS	Sodium	Calcium	Sulfate	Chloride	NaCl	Comment
SB 14 1977	111,662	5,108	35,600	790	67,000	107,809	Contaminated
SB 15 DST4 1980	24,475	8,907	550	1	14,400	24,300	
SB 15 DST4 1980	24,120	7,804	1,465	2	14,000	23,778	
SB 17 Prod test 1978	21,569	7,666	620	Tr	13,000	21,555	
SB 20 Prod test 1980	62,931	860	21,622	110	40,000	61,934	
SB 14 2007 Analytika	34,500	3,830	6,890	ND	20,400		

3.2 Task 6—Reservoir Characterization and Selection of Optimum Test Well Location

3.2.1 Task 6a – Reservoir Characterization

Geostatistical reservoir models were created in Roxar's RMS integrated modeling application for both the East Barrow and Walakpa Fields, incorporating all interpreted well, seismic and reservoir information.

These models allowed for interactive Q.C. of the interpretation results, and visualization of all reservoir parameters before loading to the Computer Modeling Group (CMG)-STARS reservoir modeling application for dynamic simulation. Reservoir depth-structure maps, isochores, N/G, porosity, permeability, and Sw calculated curves were all loaded to Roxar RMS to build the two geostatistical models of the East Barrow and Walakpa Fields. Selected realizations of the geostatistical models were then used for reservoir simulation modeling. The Topical Report *Integrated Reservoir Model* (June 2008), on the NETL web, describes the steps taken to develop the reservoir models for the East Barrow and Walakpa fields.

Figures 3 and 4 show the structure and reservoir temperature of the Upper Barrow Sandstone of the East Barrow Pool and Figures 5 and 6 show the structure and reservoir temperature of the Walakpa Sandstone for the Walakpa Field.

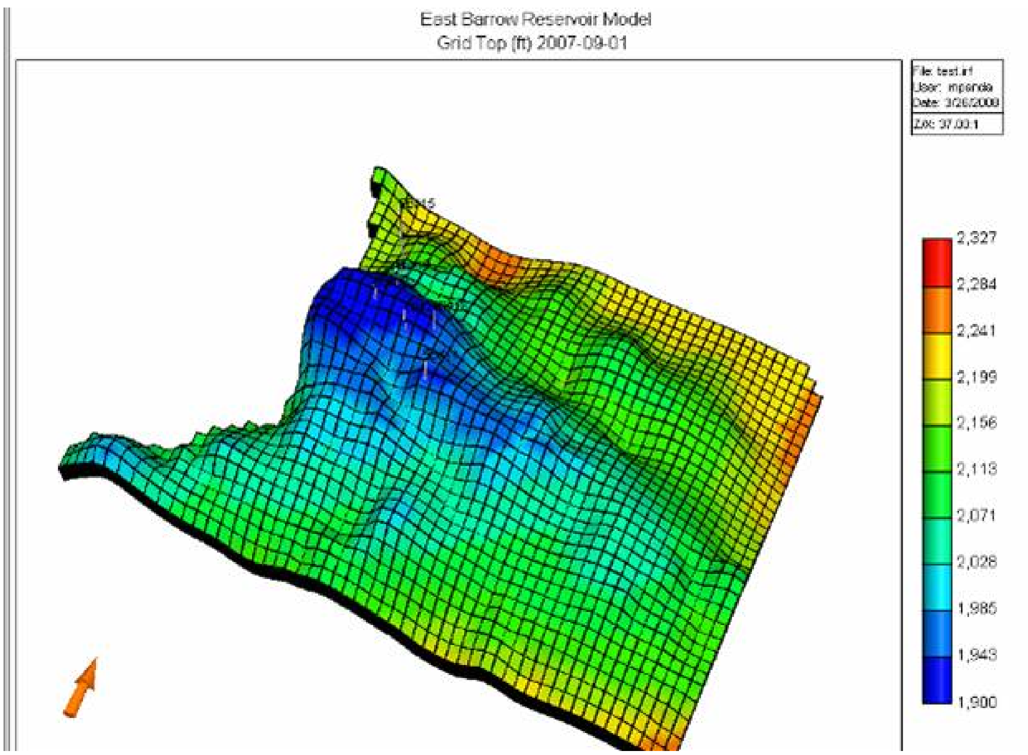

Figure 3. Depth grid on Top Upper Barrow Sandstone, E Barrow Field

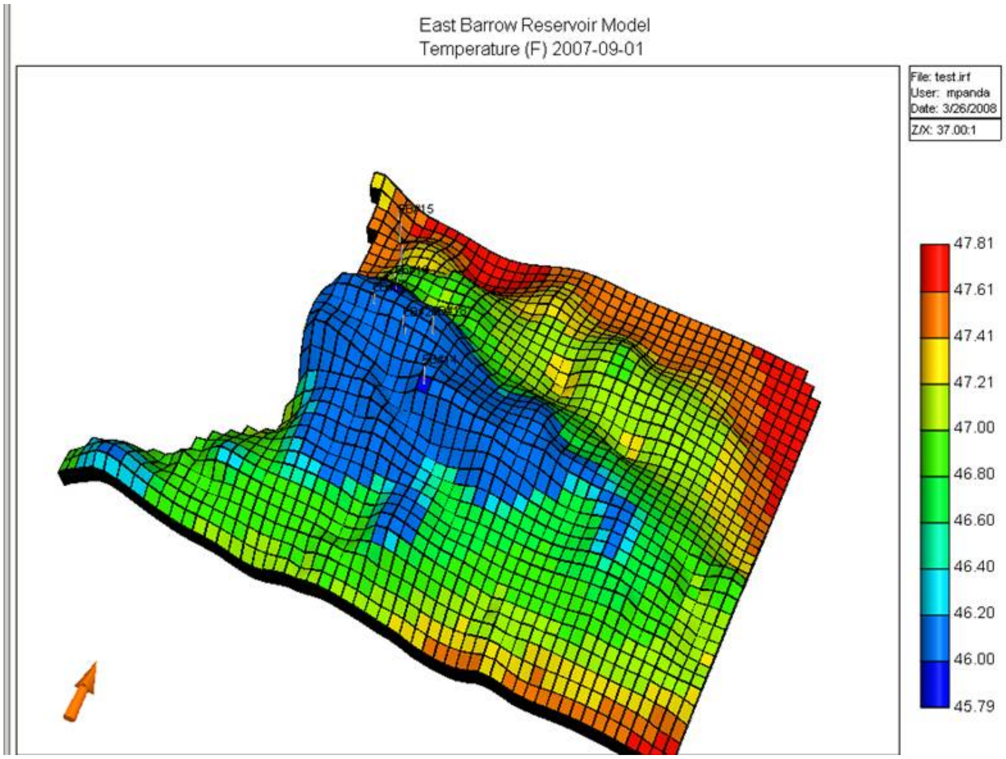

Figure 4. Reservoir Temperature for E Barrow Field

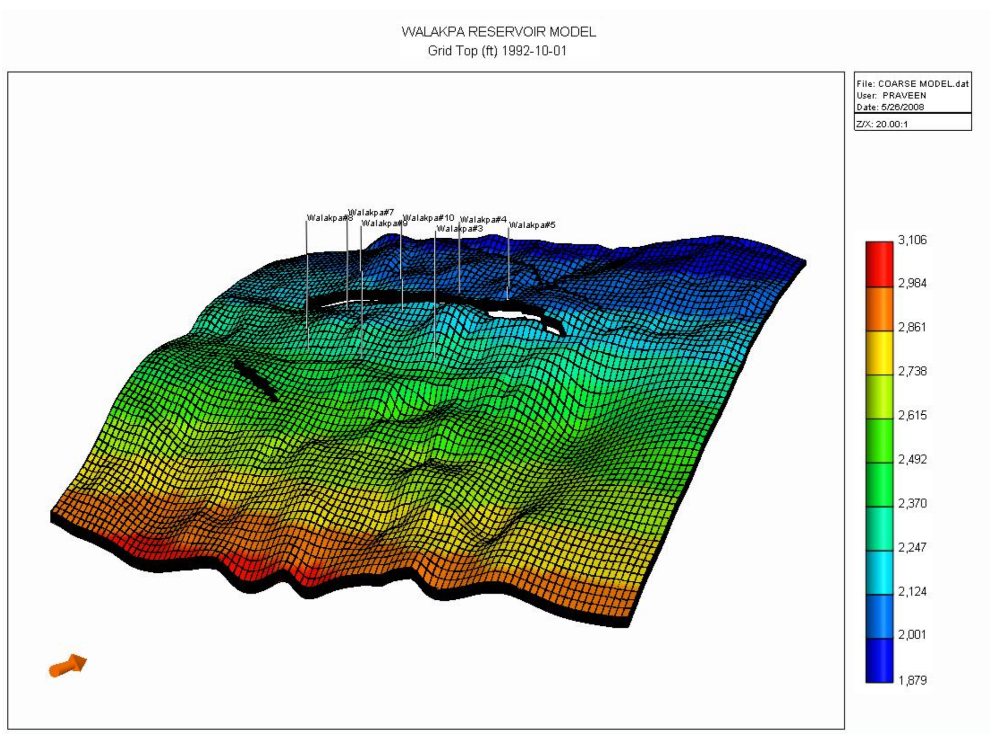

Figure 5. Depth Grid on Top Walakpa Sandstone, Walakpa Gas Field

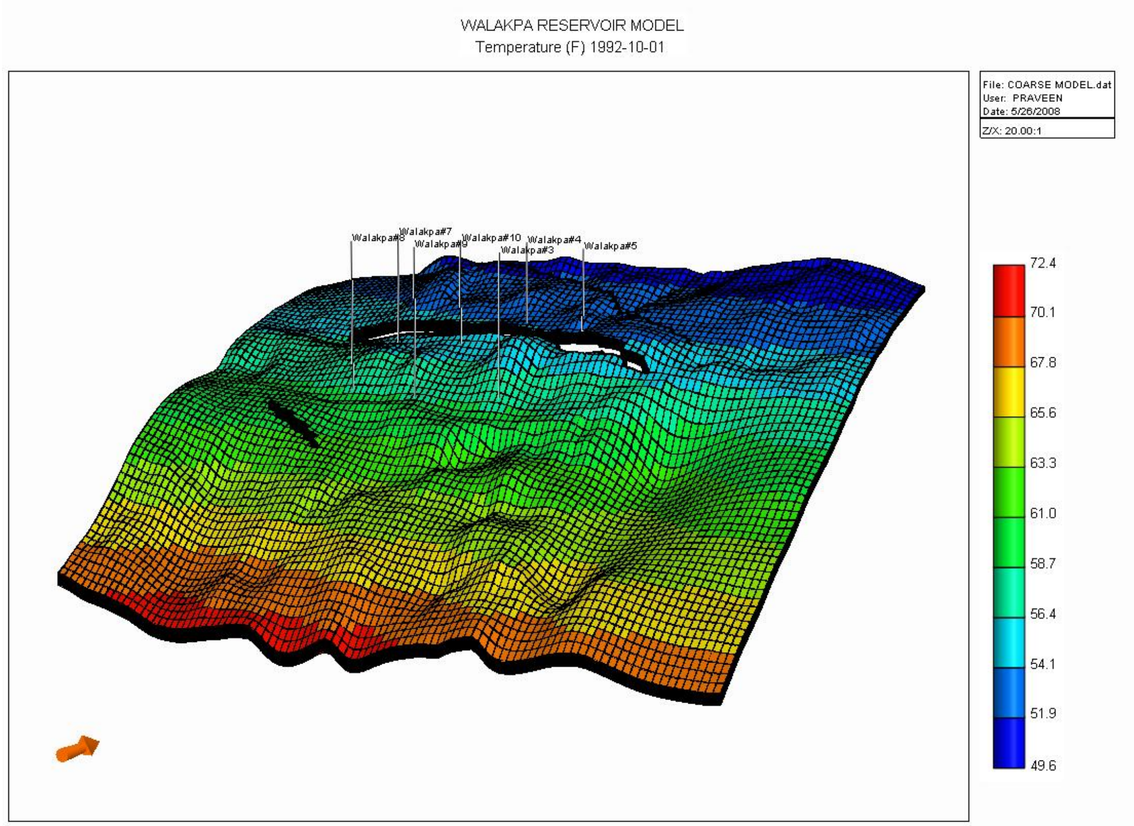

Figure 6. Reservoir Temperature for Walakpa Field

3.2.2 Task 6b – Selection of Optimum Test Well Location

Two potential locations were selected as optimal hydrate test well sites, based on geoscience, reservoir and logistical considerations. The wells are situated near the modeled base of hydrate stability zone, ideally intersecting the hydrate/free-gas interface, and they are both located on seismic lines. The primary candidate is in the updip extent of the East Barrow Gas Field, and is favored due to proximity to road access. The second location is updip of the main Walakpa Gas Field, and while more difficult logistically, it benefits from better seismic and well coverage, and therefore more accurate reservoir characterization. Figure 7 shows the proposed location of a hydrate production and test well at the top of the structure in the East Barrow Pool. Figure 8 shows the proposed well location in a seismic section.

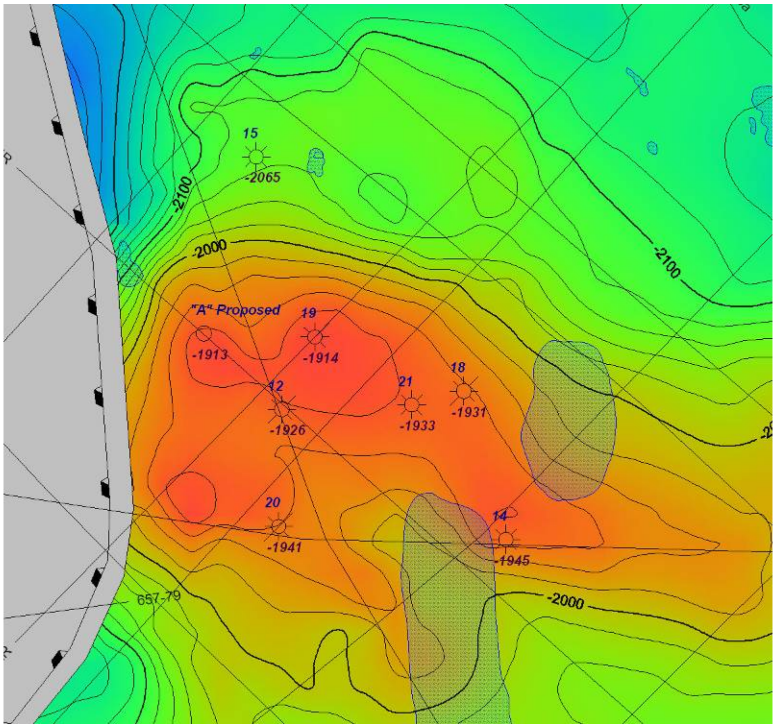

Figure 7. Map of East Barrow Gas Field with Proposed Hydrate Test Well Location

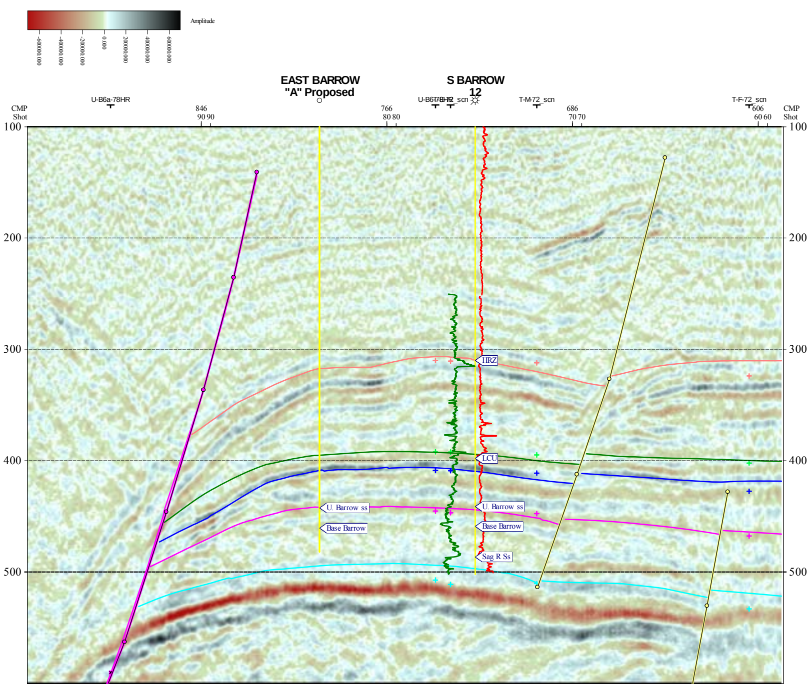

Figure 8. Seismic Line through Proposed East Barrow Hydrate Test Well Location

Figure 9 shows the location of a proposed methane hydrate test well in the Walakpa Field. Figure 10 shows the location on seismic section.

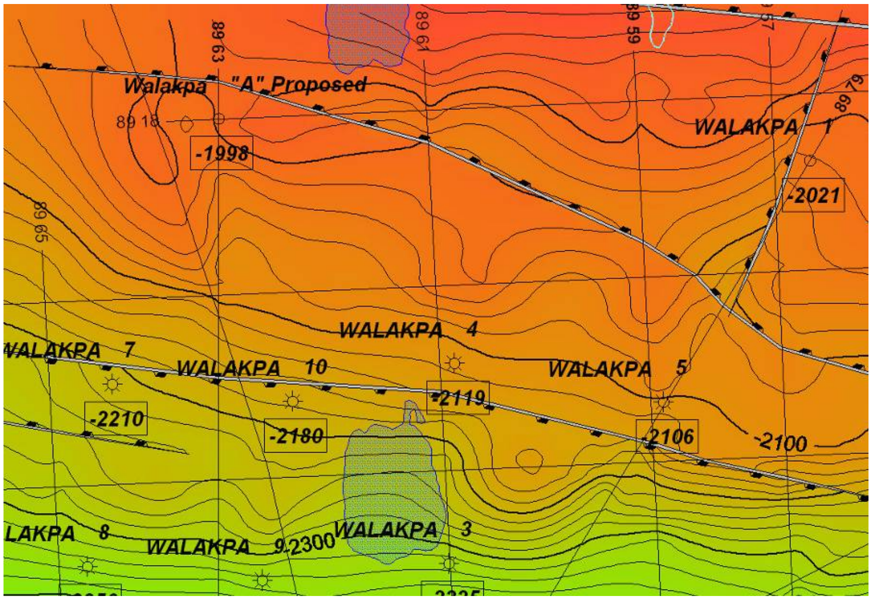

Figure 9. Map of Walakpa Gas Field with Proposed Hydrate Test Well Location

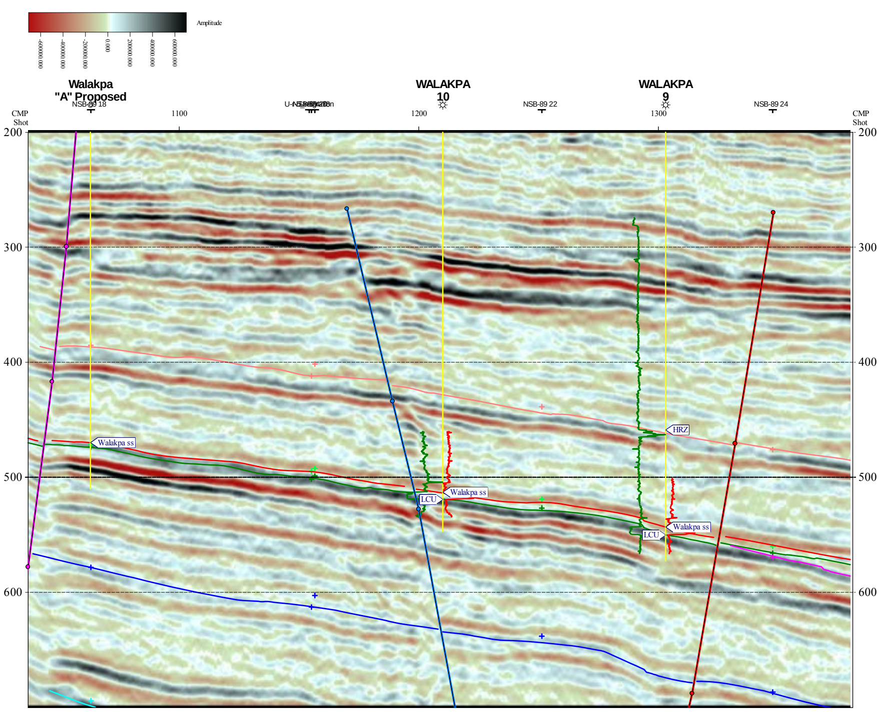

Figure 10. Seismic Line through Proposed Walakpa Hydrate Test Well Location

3.3 Task 7—Build methane hydrate reservoir simulator to model methane hydrate test well production

3.3.1 Task 7a – Material Balance "Tank" Modeling of East Barrow Field

Material balance modeling was carried out as a screening-level study to compare relative impacts of volumetric expansion, aquifer support, and hydrate dissociation as potential drive mechanisms for gas production in the East Barrow Gas Field. The detailed results of this modeling effort can be found in the Topical Report *Material Balance Study* (March 2008) on the NETL web page. This simple "tank" modeling was undertaken prior to building a full-field reservoir simulation model to indicate whether or not there was enough evidence in the production history to support further investigation of the hydrate dissociation drive mechanism.

Reservoir performance history matching using material balance models was done progressively as follows:

- a volumetric reservoir with an iterative technique that was developed for tight shallow gas reservoirs by West & Cochrane, 1994 called Extended Material Balance (EMB).
- a volumetric reservoir with aquifer support with an analysis technique developed by Pletcher, 2001 and Ahmed & McKinney, 2005.
- a volumetric reservoir with methane hydrate dissociation model used was developed by Gerami & Darvish, 2006.

Volumetric Reservoir Analysis

The EMB methodology was applied to East Barrow gas reservoir. Several iterations were carried out to obtain a constant deliverability coefficient (C). Z-factor and gas viscosity calculations were also undertaken to provide accurate gas property. The best case (constant C) was obtained by assuming an initial gas in place, *G* of 90 std bcf. The initial reserve obtained using this model is exceptionally high compared to volumetric estimates of 15 std bcf (Gruy, 1978).

P/Z vs. Gp relationship obtained for the best case and the actual production data is compared in Figure 11. As it is clearly evident from the plot, the profile obtained from EMB model follows a typical volumetric reservoir profile. The model incorporates the deliverability equation in the material balance equation by considering the fact that for a shallow gas reservoir, like East Barrow, the pressure decline is primarily under the influence of pseudo steady state condition.

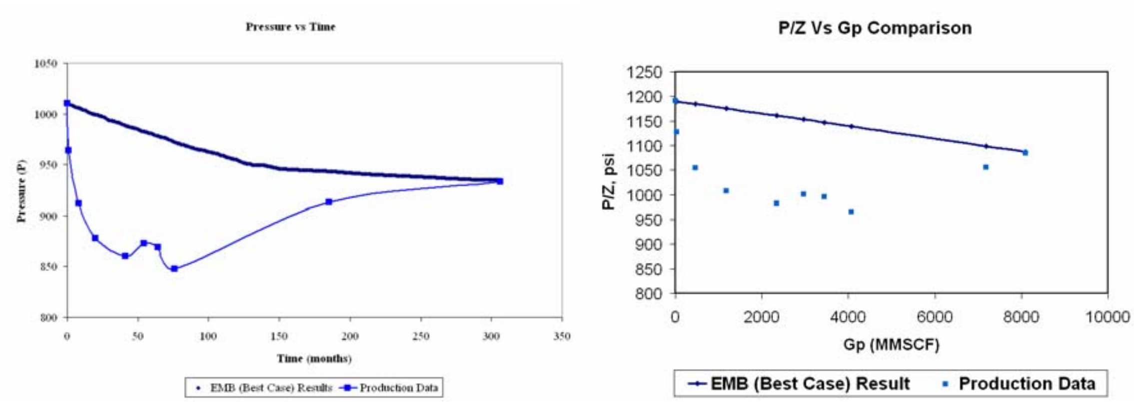

Figure 11. EMB Model – Pressure (P) vs. Time plot and P/Z vs. Gp plot for East Barrow gas reservoir

P/Z vs. *Gp* relationship obtained for the base case is used to obtain reservoir pressure *P* vs. monthly Time (t) (refer Figure 11). The plot is compared with the production profile. Extremely low production rates keeps the bottom hole pressure essentially equal to the reservoir pressure and hence the EMB model matches the production history data in later times, but cannot simulate early pressure draw down.

A maximum error of 20% was observed between the EMB model results and production data. Figure 11 clearly shows that the production history data taken from East Barrow gas reservoir never followed the EMB results. This marked deviation confirms that the East Barrow gas reservoir is not volumetric.

The actual reservoir performance for East Barrow pool was not even close to the prediction for a volumetric reservoir drive. This can be seen in Figure 11. The flattening of the P/Z vs. Cum curve is the classic sign of water influx or other replacement of voidage as gas is produced.

<u>Water Influx Analysis</u>
East Barrow production data is utilized to develop material balance model considering a waterdrive mechanism. Figure 12 shows a plot between (*GpBg* + *WpBw*) / (*Bg* − *Bgi*) and cumulative gas production Gp. A slope is constructed passing through points lying in early production times.

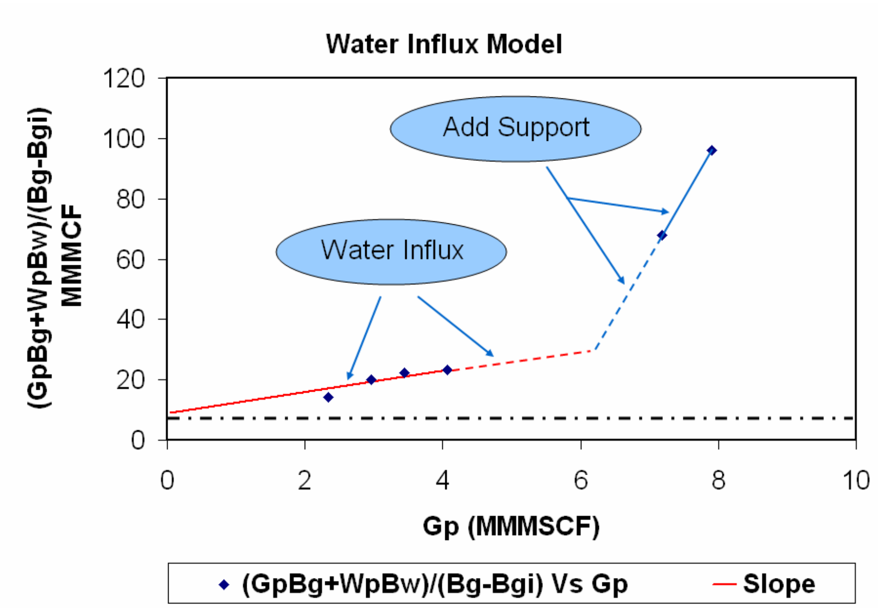

Figure 12. Water in Influx Model - (*GpBg* + *WpBw*) / (*Bg* − *Bgi*) vs. *Gp* plot

Following are the observations and inferences drawn from the plot.

1. The data points clearly show a positive buildup of slope thereby confirming the hypothesis that the reservoir is not volumetric.

2. The steep slope observed in early production time confirms the fact that the reservoir was dominated by gas expansion accompanied with considerable water influx.

3. However during later stages of production, the data points shows a vertical jump. Such behavior cannot be explained with water influx model.

4. Hence, due to the limitation with water influx model, the study is now limited to early time periods only. The slope developed through the data points results into an OGIP (original gas in place) estimate of 9 Std BCF. Based on this information, cumulative water influx calculations were also performed. At the end of 76 month about 6.83 MMBBLS of water influx has taken place.

5. Interestingly, while estimating aquifer size, it was observed that the aquifer size tends to increase with time and never remained constant as expected. This observation confirms that the size of associated aquifer may not be large enough to support observed reservoir pressures. Nevertheless, after 76^{th} month of production, the size of the aquifer was estimated in the range of 6 MMMBBLS. In other words one will require 6 MMMBBLS of aquifer size to supply water to the gas reservoir in order to achieve the observed reservoir pressure after 76 months of gas production.

To summarize, water influx study confirmed the existence of an aquifer in contact with the gas reservoir. During early production time, the reservoir was producing under moderate to active water drive. However, the model failed to explain the observed shift/jump in the slope (Figure 12) in later time periods.

Methane Hydrate Material Balance Analysis

The Darvish hydrate model and modified version constructed during this study provides a powerful tool to compare the performance of the East Barrow reservoir in presence of hydrate zone.

1. Modifications to Darvish model were made to handle gas reservoir (with no associated hydrates). The result obtained from modified Darvish model was validated by comparing the performance of a volumetric reservoir (no hydrates). The P/Z vs. Gp and P vs. Time plots were constructed and responses were compared. The results show a close agreement between the results obtained using two different models. The exercise validates the effectiveness of modified Darvish model in representing no hydrate condition in a gas reservoir.

2. The modified Darvish model is now applied to East Barrow type reservoir. The reservoir is produced at a constant production rate of 1600 MSCF/Day. The reservoir is considered to be of volumetric type (no associated hydrates). Actual production data is compared with the performance of modified Darvish model. As expected the production data and modified Darvish results never matched during the entire production life of the reservoir. Thus, we conclude that the reservoir is under constant pressure support from either water influx and/or associated hydrates.

3. To study the impact of hydrate layer on reservoir performance, original Darvish model is used and performance of East Barrow type reservoir model is evaluated. The reservoir performance is then compared for several hydrate thicknesses as shown in Figure 13. The plot shows that as the thickness of hydrate zone is increased, the reservoir pressure stabilizes.

4. The Darvish model is proposed for a volumetric gas reservoir system with a layer of hydrates. It has no provision to include the effect of water influx into the overall material balance and therefore the two external pressure support mechanisms (water influx and hydrate supports) cannot be modeled together with simple material balance method.

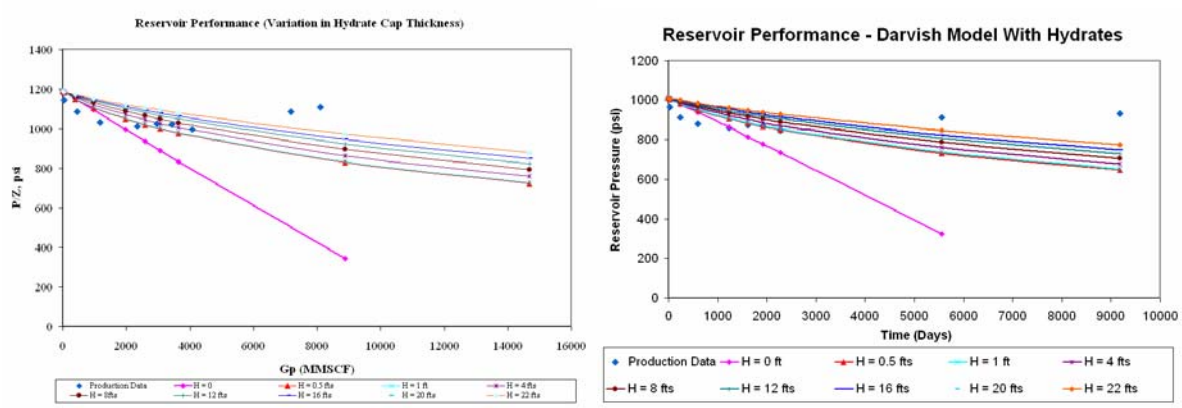

Figure 13. Hydrate Model: P/Z vs. Gp and Pressure vs. Time comparison for Darvish model

<u>Material Balance Modeling Conclusions</u>

The reservoir performance is not volumetric and therefore has external pressure support either from an aquifer, methane hydrate dissociation or a combination of both.

The water influx model did not match the reservoir performance, as matching the pressure history required an increasing size of aquifer.

The hydrate model came close to matching the reservoir performance with thicknesses of 22' of hydrates, but it still did not fully explain the pressure history.

Based on the material balance investigation with the volumetric model, the water influx model and the methane hydrate model, the pressure history can be explained by a combination of water influx and methane hydrate dissociation. The material balance modeling justifies the next step in modeling this reservoir using a three dimensional reservoir and thermodynamic model. This will also allow varying the strength of the aquifer and the thickness of the hydrate zone to better match the reservoir performance.

3.3.2 Task 7b – Build methane hydrate reservoir simulator to model methane hydrate test well production – East Barrow Field

Based on the results of the material balance modeling, a full-field reservoir simulation model was run using CMG-STARS to extend the history match work and to facilitate planning for potential drilling and production of the methane hydrate reservoir. A summary of the of the CMG-STARS model simulations for the East Barrow Field is provided in the following paragraphs. For more detailed information pertaining to model development and reservoir simulations for both the East Barrow and Walakpa fields, the reader is directed to the Topical Report *Full Scale Reservoir Simulation Studies* (June 2008) found on the NETL website.

<u>Full-Field History Match and Forecast Modeling</u>

Porosity and permeability grids were imported from the geostatistical characterizations generated in Roxar RMS for the East Barrow and Walakpa gas reservoirs, along with all other interpreted and modeled reservoir parameters, and CMG-STARS data decks were generated. Individual well gas and water historical production data were used for all wells as input to the history matching process. An interpreted gas-water contact (GWC) was derived from the well log interpretation (EB#17 well) for East Barrow Field, and a range of GWC was used for the Walakpa Field, as no GWC has been encountered in a well in that field. Base of the hydrate stability zone was derived from the regional temperature and pressure regimes, as described above. Average reservoir pressure of the fields and the cumulative water production were used as the history matching parameters.

Several sensitivity runs were also made to test the variation in the gas-water-contact and the hydrate stability zone: 1. free gas only, 2. free gas and aquifer only. A number of variations of case 2 were also studied. The sensitivity analysis (Figure 16) shows that the free gas volumetric expansion case cannot match the dip in pressure at the outset of production, but does a fair job of matching pressure at later stages of field life, with low production rates. The free gas expansion with aquifer support does a better job matching the dip in pressure in the early stages of production, but shows only minor correction to pressure response at later stage of production, indicating that the aquifer response cannot account for the pressure recovery measured at East Barrow Gas Field. Finally, the combination of volumetric gas expansion, aquifer support and hydrate dissociation represent a very good match to historic pressure response with gas offtake. A fairly exhaustive set of simulations were run for each of the three depletion mechanisms described, and the best matches for each are shown in Figure 14.

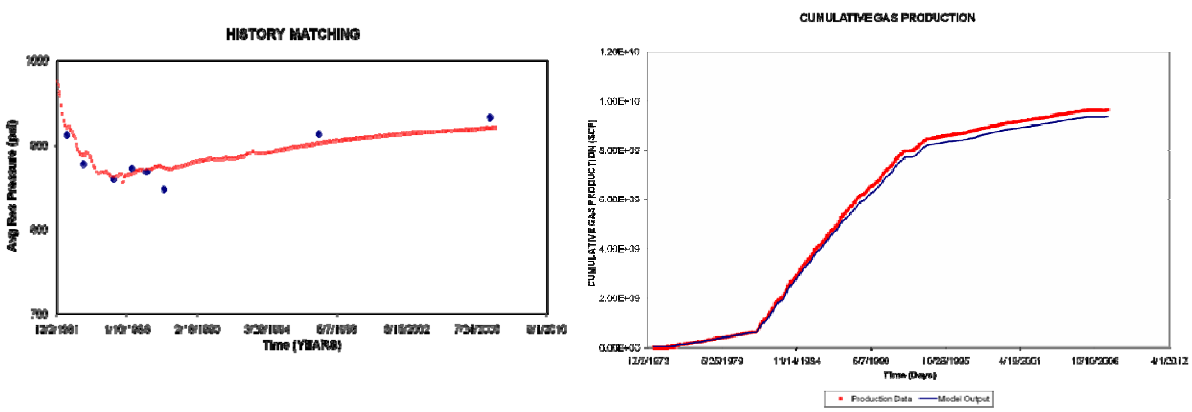

Figure 14. East Barrow Field Average Reservoir Pressure and Cumulative Production History Match

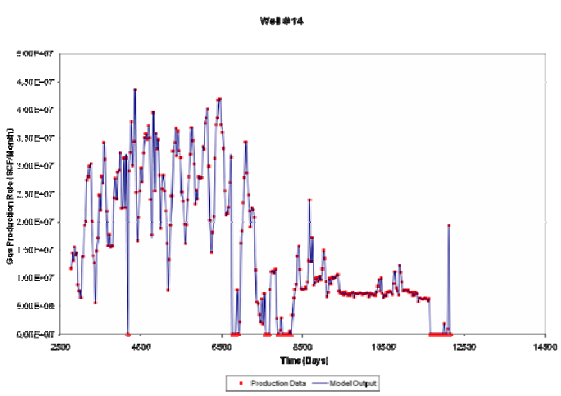

Figure 15. History match EB# 14 well

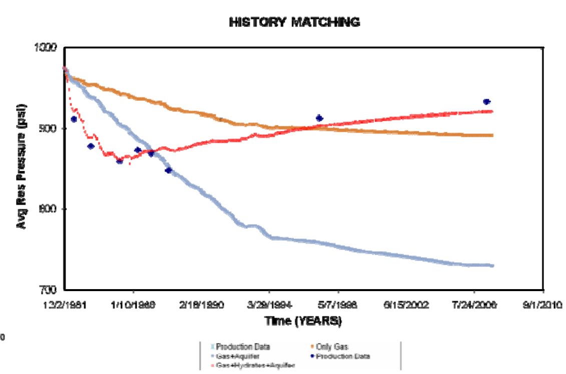

Figure 16. Fieldwide Average Pressure History Match

Based on the history match two forecast runs were made using EB#14 well as the producer. In the first forecast run EB#14 was used as a vertical producer and in the second run it is used as a horizontal producer. The forecast runs show that the horizontal well is more prolific as a gas producer, both in terms of rate and cumulative gas production (Figure 17).

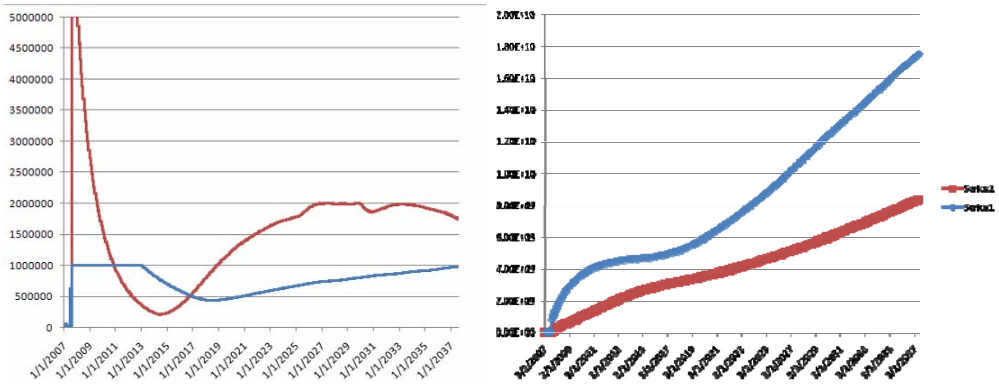

Figure 17. Horizontal vs. Vertical Producer, Rate and Cumulative Gas Production, East Barrow (EB #14 Well)

3.4 Task 8—Phase 1 Final Report

This report represents the deliverable for Task 8.

4.0 Phase 1B Conclusions

The work completed to date in support of the Barrow Gas Field Hydrate Study does not conclusively show that hydrates are present in any of the Barrow Gas Fields, nor is there proof that hydrates are currently interacting with the free gas fields. However, it is difficult to explain the preponderance of circumstantial evidence in favor of hydrate dissociation as a depletion mechanism, at least in the East Barrow Gas Field. Hydrate stability zone predictions, material balance and numerical simulation show that dissociation of methane hydrates all support methane hydrates being present.

The next step proposed is to collect a sample of in-situ hydrate via drilling and coring, and to design a "smart" well completion which will allow for real-time surveillance of reservoir temperature, pressure, production rate, water cut, and produced gas and water composition and isotope geochemistry. As part of this effort it is also recommended that the pressure transient analysis on the East Barrow and Walakpa Gas Fields be significantly expanded to start to fill in the gaps in data points for material balance modeling.

5.0 Recommendations for Phase 2

The North Slope Borough has proposed an extension beyond Phase 1 of the Barrow Gas Field Hydrate Study, which will build on the body of global hydrate research, and expand the scope of the Barrow study into the field to test the concept that hydrates are interacting with free gas pools at East Barrow and Walakpa Gas Fields, and that hydrates represent an economically viable resource to the North Slope Borough.

Phase 2 will again be a phased effort, with the initial phase comprised of designing an optimal well plan for a dedicated hydrate test well in Barrow. This well design phase will expand on the findings of prior hydrate research, particularly at Mallik and Mt. Elbert, and will incorporate the latest arctic drilling technological advances. Phase 2A, the initial phase of the project being proposed, will include technical and design work up through the generation of an Authority For Expenditure (AFE) for the drilling of a dedicated hydrate test well, which will represent a decision point for the project. If AFE costs exceed available funds for the project, the program will need to be revised, or curtailed, based on the level of cost differential.

Phase 2B, the second phase of the project will include drilling a pilot well to sample the gas hydrate, and then drilling a sidetrack production hole as a high-angle or horizontal hole, ideally starting in the hydrate zone, and sidetracking for completion into the free gas pool (Figure 18). The well would be completed as a producer in the free gas interval, and instrumented appropriately for long-term real-time surveillance. Specifically, the well surveillance would monitor the free gas/gas hydrate interface and both zones as production occurs.

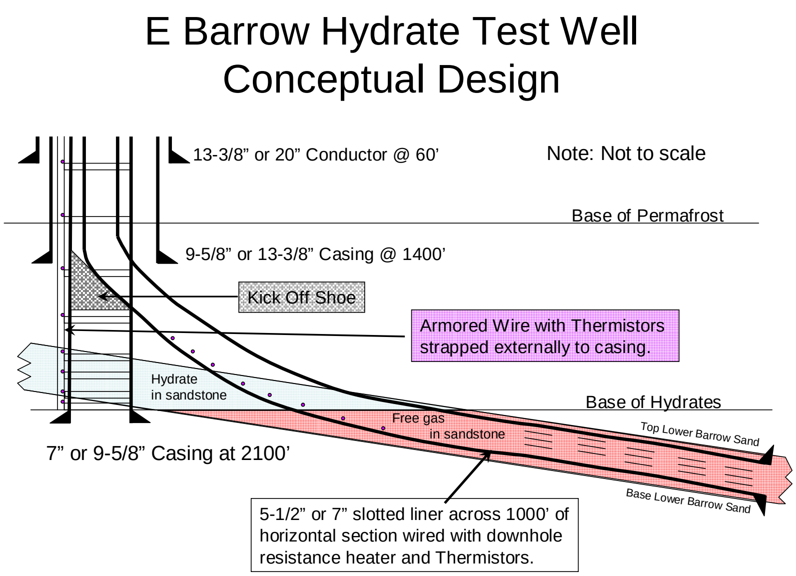

Figure 18. Conceptual Hydrate Test Well Design

The proposed hydrate production method represented in the Barrow Gas Fields test would be by depressurization, drilling a test well near the free gas/hydrate interface and drawing down the pressure via production of the free gas. The East Barrow Gas Field is ideal for monitoring the dissociation process, as it is a relatively small container, and the gas needed for local consumption is well-aligned with the level of production needed to draw down the reservoir enough to detect hydrate dissociation, without freezing the near wellbore reservoir.

Aside from the decision point prior to well sanction, another possible decision point under consideration is at the point of completing the drilling of the pilot hole at East Barrow. A contingency is being considered in which a negative result on convincing evidence of in situ hydrate in this pilot hole would trigger abandonment or suspension of this well, and a move to an updip Walakpa Gas Field location.

The proposed Phase 2 project is aligned with the USDOE objectives to characterize and evaluate the production rates obtainable from gas hydrate deposits as well as determine the most appropriate methodologies for maximization of production. With a clear need for a long-term hydrate production test, the Barrow Gas Fields provide an extremely attractive opportunity to do just that. The East Barrow Gas Field, and the Walakpa Gas Field each show strong evidence of influence of gas hydrates on production, and based on the results of Phase 1 of the Barrow Gas Fields Hydrate Study, it does not seem unlikely that commercial production of gas hydrates is occurring in the East Barrow Gas Field today. This research effort will endeavor to prove that to be the case by drilling a gas hydrate production/surveillance well, which will prove the presence of hydrate up-structure of the free gas, and will monitor reservoir properties and performance on a real-time basis to detect changes in the hydrate zone, directly and indirectly.

In addition, the study could significantly advance the understanding of Class 1 hydrates, and the effectiveness of producing gas from gas hydrate via depressurization dissociation. Beyond adding benefit to global research efforts in gas hydrate resource assessment, the proposed project has the potential to greatly benefit the local community of Barrow and communities across the North Slope by expanding the energy resources available for heating and electricity.

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