

Characterization of Recoverable Resources from Methane Hydrate Deposits

Progress Report

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NOTE: *In past years, LBNL staff completed all tasks and exhausted the corresponding budget by the end of the fiscal year (September 30) regardless of the time when full funding became available. In light of the realities of Continuing Resolution (CR) in the last few years, and following instructions from DOE Headquarters (Edith Allison), work on the various tasks in this project is (by design) not scheduled to be completed at the end of the 2009 Fiscal Year, but at a later date (December 31, 2009). This project end date is expected to provide sufficient time for Fiscal Year 2010 CR funds to reach LBNL before the FY2009 funds are exhausted, thus preventing disruptions, and allowing seamless project operation and continuation into the next fiscal year.*

Task Progress

Task 1: Code Maintenance, Update and Support

Subtask 1.1: Updates, corrections and improvements of the forward hydrate simulation codes

This subtask has been completed. Significant improvements have been implemented into (a) the serial TOUGH+HYDRATE (T+H) code, (b) the parallel TOUGH+HYDRATE (pT+H) code, (c) the coupled T+H/FLAC3D code, which allows the concurrent study of geomechanical processes, fluid and heat flow and thermodynamic states in a hydrate system undergoing changes, and (d) the coupled T+H/G code, for the concurrent study of changes in a hydrate accumulation (usually associated with dissociation-supported gas production) and the corresponding geophysical signature. The T+H Version 1.1 and the corresponding User's Manual were released in August 2009. Several licenses of T+H V1.1 have been granted to various international research organizations. The T+H V.1 has now been fully incorporated into the most recent versions (V1.1) of the coupled T+H/FLAC3D and T+H/G codes, which are being used in several investigations.

Similarly, the pT+H V1.1 code was released in February 2009, and is now the main version of the code used on any multi-processor platform. The code was shared with NETL (2 cost-free licenses), and was purchased by two major international oil and gas companies.

Additionally, several new web-based applications have been developed to significantly improve (a) the creation and modification of input files, (b) the design and development of complex grids for T+H and pT+H applications, and (c) the ability to

predict the properties of hydrate-forming real gas properties. These applications are operational (although additional work is needed to provide the widest possible range of options), and can be found on the web at the following address: <http://esdtools.lbl.gov>

Subtask 1.2: Improvement of the history-matching parallel I-pT+H code

This task was originally scheduled for completion by 8/31/2009. Given the lack of laboratory or field data that would make the early completion of this task a priority, the availability of the operational (though not yet optimized) earlier version of the code, and the need to respond to other priorities (earlier commitments, in addition to acceptance of invitations to conduct studies and prepare publications related to various aspects of gas production from hydrates), work on this task is continuing. The revised completion date is December 31, 2009.

Task 2: Support of DOE's Field Activities and Collaborations

Subtask 2.1: Evaluation of production potential and design support for a field test at the Mount Elbert site, North Slope, Alaska

This task describes LBNL's participation in a DOE-supported field test under consideration. The test will involve long-term gas production from a Class 3 permafrost hydrate deposit. Under consideration are (a) the Unit D deposit at the Mount Elbert site and (b) the Unit C deposit at the site of the PBU-L106 well, both in North Slope, Alaska. Most of the numerical studies in this task have been completed, and several papers have either been completed or are being prepared.

LBNL staff have completed an analysis of the gas production potential from the Unit D hydrate deposit (a Class 3 system) at the Mount Elbert site, and the following paper on this subject was submitted to the *Journal of Marine and Petroleum Geology*:

- (1) ***Gas Production From a Cold, Stratigraphically Bounded Hydrate Deposit at the Mount Elbert Site, North Slope, Alaska***, by G.J. Moridis, S. Silpngarmlet, M.T. Reagan, T. Collett, and K. Zhang (currently in review)

A second related study has been completed, and its results will be reported in the following paper under preparation:

- (2) ***Effect of Heterogeneity on Gas Production From the Unit D Class 3 Hydrate Deposit at the Mount Elbert Site, North Slope, Alaska***, by M.T. Reagan, G.J. Moridis, and K. Zhang, to be submitted for publication to either *Transport in Porous Media* or to *Journal of Petroleum Science and Engineering*

Additionally, a study of gas production from the warmer Unit C at the site PBU L106 has been completed. This investigation involves very high-definition grids (involving up to 250,000 cells), and seeks to determine not only the gas production potential, but also potential interference with other wells in the vicinity. The results of the study are being included in the following paper under preparation:

- (3) ***Design of a potential long-term test of gas production from a hydrate deposit at the PBU-L106 site in North Slope, Alaska: Production predictions and sensitivity***

analysis, by G.J. Moridis, M.T. Reagan, T. Collett, K. Boyle and K. Zhang, to be submitted for publication to the *Journal of Petroleum Science and Engineering*

A paper/abstract under the same title has been submitted and is currently under review for presentation during the 2009 Fall Meeting of the American Geophysical Union (to be held in December 2009).

Currently, the only work in progress within this task is a joint study with NETL (Eugene Myshakin) that aims to investigate the effect of heterogeneity on production from the Unit C deposit at the PBU-L106 site in North Slope, Alaska. It is expected that the simulations will be completed by the end of November 2009, and a joint LBNL-NETL paper will be prepared and submitted for publication to an appropriate peer-reviewed journal.

Subtask 2.2: *Geomechanical system response and stability analysis during the proposed production test from the Mount Elbert deposit*

This task describes LBNL's participation in the DOE-supported field test under consideration that has been discussed previously. Work on this task is ahead of schedule. Two studies that proceed in tandem with the activities in Subtask 2.1 are currently active. In the first, LBNL staff have completed an analysis of the expected geomechanical response during production from the Unit D hydrate deposit (a Class 3 system) at the Mount Elbert site, and the following paper is in the final stages of preparation:

- (4) ***Geomechanical Response and Stability Analysis During Production From a Cold, Stratigraphically Bounded Hydrate Deposit at the Mount Elbert Site, North Slope, Alaska***, by L. Chiaramonte, J. Rutqvist, G.J. Moridis, and T. Collett, to be submitted for publication to the *Journal of Petroleum Science and Engineering*.

In the second study, the simulations of the geomechanical system response during gas production from the Unit C deposit at the site PBU L106 have been completed. The results of the study are being analyzed, and the following paper is in preparation:

- (5) ***Design of a potential long-term test of gas production from a hydrate deposit at the PBU-L106 site in North Slope, Alaska: Geomechanical response and stability analysis***, by L. Chiaramonte, J. Rutqvist, G.J. Moridis, and T. Collett, to be submitted for publication to an appropriate peer-reviewed journal.

Subtask 2.3: *Feasibility of using geophysical surveys to monitor the proposed production test from the Mount Elbert deposit*

This task describes LBNL's participation in the DOE-supported field test under consideration that has been discussed previously. Work on this task is on schedule. Two studies that are analogous to those in Subtask 2.2 (with which they proceed in tandem) are in progress. In these studies, LBNL staff are analyzing the feasibility of monitoring hydrate dissociation during potential long-term production tests at two sites: a) the Unit D deposit at the Mount Elbert site and (b) the Unit C deposit at the site of the PBU-L106 well. Simulations are nearing completion, and the following two papers are in preparation:

- (6) *Geophysical Monitoring of Gas Production From a Cold, Stratigraphically Bounded Hydrate Deposit at the Mount Elbert Site, North Slope, Alaska*, by M. Kowalsky, S. Nakagawa, and G.J. Moridis, to be submitted for publication to an appropriate peer-reviewed journal.
- (7) *Design of a potential long-term test of gas production from a hydrate deposit at the PBU-L106 site in North Slope, Alaska: Feasibility of seismic monitoring*, by M. Kowalsky, L. Chiaramonte, and G.J. Moridis, to be submitted for publication to an appropriate peer-reviewed journal.

The following paper on a related study evaluating the feasibility of using geophysical methods to monitor on gas production from hydrate deposits in the Gulf of Mexico has been accepted for publication, and is currently in press:

- (8) *Feasibility of Monitoring Gas Hydrate Production with Time-Lapse VSP*, by M. Kowalsky, S. Nakagawa and G.J. Moridis, in press, *SPE Journal*.

The following paper/abstract (a combination of the studies in papers 5 and 8) has been submitted and is currently under review for presentation during the 2009 Fall Meeting of the American Geophysical Union (to be held in December 2009):

- (i) *Design of a potential long-term test of gas production from a hydrate deposit at the PBU-L106 site in North Slope, Alaska: Geomechanical system response and seismic monitoring*, by L. Chiaramonte, M.B. Kowalsky, J. Rutqvist and G. Moridis.

Subtask 2.4: Support to other DOE national and international projects

The LBNL hydrate research team continued to provide support to the various DOE national and international projects, interacting with US scientists working for DOE-supported national laboratories and foreign scientists involved in DOE-related international activities. As part of this task, the LBNL team organized and hosted the US-Korea Gas Hydrate Workshop at the LBNL campus in Berkeley on April 27-29, 2009. The Workshop was attended by over 30 US and Korean scientists, and developed a pathway for the development of joint research programs in support of Korean activities focusing on gas production from marine hydrates in the Ulleung Basin in the Korean East Sea.

Task 3: Assessment of Resource Recoverability From Natural Hydrate Deposits

Subtask 3.1: Gas Production From Oceanic Hydrate Deposits

Work on this subtask is ahead of schedule. Several investigations that began the previous year were completed in this period, and the results are presented in the following papers:

- (9) *Evaluation of the Gas Production Potential of Marine Hydrate Deposits in the Ulleung Basin of the Korean East Sea*, by G. Moridis, M. Reagan, S.-J. Kim, Y.

Seol, and K.Zhang, in press, *SPE Reservoir Evaluation and Engineering* (doi: 10.2118/110859-PA).

- (10) ***Toward Production From Gas Hydrates: Current Status, Assessment of Resources, and Simulation-Based Evaluation of Technology and Potential***, by G.J. Moridis, T. S. Collett, R. Boswell, M. Kurihara, M.T. Reagan, C. Koh, and E.D. Sloan, in press, *SPE Reservoir Evaluation and Engineering* (doi: 10.2118/114163-PA).

A new study analyzing the production potential of three new hydrate deposits discovered in the Gulf of Mexico in 2009 is in progress, and preliminary scoping calculations are being conducted. The following abstract/paper proposal has been submitted to the 2010 Offshore Technology Conference (to be held in May 2010), and is currently under review:

- (ii) ***Preliminary Evaluation of the Production Potential of Recently Discovered Hydrate Deposits in the Gulf of Mexico***, by G. Moridis, M. Reagan, R. Boswell, T. Collett, K. Boyle and K. Zhang – to be later submitted for publication in one of the journals of the Society of Petroleum Engineers.

Another area of study currently in progress aims to determine the production potential of oceanic hydrate deposits that are characterized by the absence of confining boundaries, low hydrate saturation, and low-permeability sediments. Using data corresponding to the Tigershark formation, LBNL staff have completed an analysis of production from such deposits, including an evaluation of new well designs and configurations. The results of this study are reported in the following paper that was recently presented to the 2009 TOUGH Symposium (Berkeley, California, September 14-16, 2009):

- (11) ***Evaluation of the gas production of challenging oceanic hydrate deposits***, by G.J. Moridis, M.T Reagan, K.L. Boyle and K. Zhang (submitted to *Transport in Porous Media* for review).

Within the same framework of the study of challenging hydrates, using data provided by Chinese colleagues from their 2007 expedition in the South China Sea, LBNL staff are in the process of analyzing and evaluating alternative methods (including new well designs and configurations) that may yield gas at commercially viable rates. This effort requires very large 3D grids of fine discretization (about 300,000 gridblocks), and the results will first be reported in the following papers (under preparation):

- (iii) ***Evaluation of Gas Production Potential from Marine Gas Hydrate Deposits in the Shenhu Area of the South China Sea: Depressurization and Thermal Stimulation Methods***, by G. Li, G. Moridis, G.J. Moridis, K. Zhang, and X. Li, abstract/paper proposal submitted to the 2010 Offshore Technology Conference (to be held in Houston in May 2010) – to be later submitted for publication in one of the journals of the Society of Petroleum Engineers.
- (iv) ***Numerical Investigation of Gas Production Strategies for the Hydrate Deposits in the Shenhu Area***, by Z. Su, G.J. Moridis, K. Zhang and N. Wu, abstract/paper

proposal submitted to the 2010 Offshore Technology Conference (to be held in Houston in May 2010) – to be later submitted for publication in one of the journals of the Society of Petroleum Engineers.

- (v) ***Production Potential of Oceanic Hydrates in the South China Sea***, by K. Zhang, G. Moridis and N. Wu, abstract/paper proposal submitted to the 9th International Oil and Gas Conference and Exhibition in China (to be held in Beijing in June 2010) – to be later submitted for publication in one of the journals of the Society of Petroleum Engineers.

Subtask 3.2: Gas Production From Permafrost-Associated Hydrate Deposits

Work on this subtask is in progress and ahead of schedule. Several investigations that began the previous year continued, were completed, and the results are presented in the following papers:

- (12) ***Estimating the Upper Limit of Gas Production From Class 2 Hydrate Accumulations in the Permafrost***, by G. Moridis and M. Reagan, in review for publication in the *Journal of Petroleum Science and Engineering*
- (13) ***The Use of Horizontal Wells in Gas Production From Hydrate Accumulations***, by G.J. Moridis, M.T. Reagan, and K. Zhang, in review for publication in the *Journal of Petroleum Science and Engineering*

Investigations are in progress to determine the production potential of challenging hydrate deposits that are characterized by high stability, proximity to deep water zones, and extremely low effective permeabilities (which preclude reasonable flow). Using data from several permafrost locations, LBNL staff are in the process of analyzing and evaluating various production strategies that will result in economically sustainable gas production rates, while minimizing water production. This effort requires very large 3D grids of fine discretization, and the results will first be reported in the following paper under preparation:

- (14) ***Evaluation of gas production from challenging hydrate deposits in the permafrost***, by G. Moridis, M. Reagan and K. Zhang – to be submitted for publication in *Transport in Porous Media*.

Task 4: Predictive Studies of the Geomechanical Behavior in Hydrate-Bearing Systems

Work on this task is in progress and on schedule. The current effort focuses on the analysis of the effect of hydrate dissociation on oceanic slope stability under three conditions: (a) increasing ocean floor temperatures because of warming marine waters, (b) thermal loading of hydrate-bearing sediments by heat losses of ascending conventional reservoir fluids through non-insulated wells, and (c) gas production from hydrate deposits, during which the mechanical integrity of the deposit is adversely

affected as the media-cementing hydrates dissociate. The first results of this study are included in the following publication (in preparation):

- (vi) ***Geomechanical Response of Sloping Oceanic Hydrate Deposits to Thermal Loading and Production Activities***, by J. Rutqvist, G.J. Moridis and L. Chiaramonte, abstract/paper proposal submitted to the 2010 Offshore Technology Conference (to be held in Houston in May 2010) – to be later submitted for publication in one of the journals of the Society of Petroleum Engineers.

An additional study incorporates the results and conclusions gleaned from the geomechanical stability analysis of hydrate deposits that undergo dissociation in the course production in the design of wells. The results of this study are included in the following publication (in preparation):

- (vii) ***Well Design Requirements For Deepwater And Arctic Onshore Gas Hydrate Production Wells***, by S. Hancock, G. Moridis, S. Wilson and A. Robertson, abstract/paper proposal submitted to the 2010 Offshore Technology Conference (to be held in Houston in May 2010) – to be later submitted for publication in one of the journals of the Society of Petroleum Engineers.

The following study on the geomechanical system response and stability analysis during production from oceanic hydrates (focusing on the Tigershark deposit) was completed and published in this period:

- (15) ***Numerical studies on the geomechanical stability of hydrate-bearing sediments***, by J. Rutqvist and G. Moridis, *SPE Journal*, **14**(2): 267-282, 2009 (June 2009 issue, doi:10.2118/126129-PA).

The following study on the comparative geomechanical behavior of two permafrost-associated deposits (the Mallik deposit in Northwest Territories, Canada, and the Unit C deposit at the Mount Elbert site, Alaska) was also completed and published in this period:

- (16) ***Geomechanical response of permafrost-associated hydrate deposits to depressurization-induced gas production***, by J. Rutqvist, G.J. Moridis, T. Grover and T. Collett, *Journal of Petroleum Science and Engineering*, **67**:1-12, 2009 (July 2009 issue, doi: 10.1016/j.petrol.2009.02.013).

Task 5: Communications and Technology Transfer

Activities in this task are ahead of schedule. All the papers numbered with Arab numerals that are discussed in this progress report have already been accepted or are to be published in peer-reviewed journals, and have already been presented, or will be presented, to scientific meetings; the papers numbered with Latin numerals are in the process of review for possible acceptance for presentation at future scientific meetings.

G. Moridis has been invited to be the organizer of two sessions on gas production from hydrates during the 2010 Offshore Technology Session (to be held in Houston,

Texas, in May 2010). Additionally, G. Moridis has been invited to join the Technical Program Committee of (a) the OTC Arctic Technology Conference (to be held in Houston in November 2009) and (b) the SPE 9th International Oil and Gas Conference and Exhibition in China (to be held in Beijing in June 2010), in both of which he will be a session chair in charge of unconventional resources and responsible for inclusion of representative studies of gas production from hydrates, in addition to being a keynote speaker presenting his DOE-supported work. G. Moridis is beginning his tour as a SPE Distinguished Lecturer (lecturing on hydrate-related subjects that are based on DOE-supported studies) in October 2009.

Additional General Publications

The following hydrate-related papers in which LBNL staff had significant contributions were published in this period:

- (17) *Preliminary report on the commercial viability of gas production from natural gas hydrates*, by M.R. Walsh, S.H. Hancock, S.J. Wilson, S.L. Patil, G.J. Moridis, R. Boswell, T.S. Collett, C.A. Koh and E.D. Sloan, *Energy Economics*, **31**(5): 815-823, 2009 (September 2009 issue, 10.1016/j.eneco.2009.03.006).
- (18) *Occurrence of gas hydrate in Oligocene Frio sand: Alaminos Canyon Block 818: Northern Gulf of Mexico*, by R.D. Boswell, D. Shelander, M. Lee, T. Latham, T. Collett, G. Guerin, G. Moridis, M. Reagan and D. Goldberg, *Journal of Marine and Petroleum Geology*, **26**(8): 1499-1512, 2009 (September 2009 issue, doi:10.1016/j.marpetgeo.2009.03.005).