Final Report

# GEOMECHANICAL STUDY OF BAKKEN FORMATION IN EASTERN WILLISTON BASIN, NORTH DAKOTA

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## Abstract

Bakken Formation in Williston Basin was recently reassessed to have 200-400 billion barrels of original oil in place (OOIP), and 3.65 billion barrels recoverable oil under present technical and economic conditions. Considering the fact that, excluding the Bakken oil, the total discovered OOIP in USA since 1850s is less than 600 billion barrels, of which less than 200 billion barrels has been produced, a recovery factor of about 30%, the reassessed Bakken oil represents a huge potential for improving US oil supply security through increasing domestic oil production. It also means a great opportunity to state and regional economy in attracting new investments, creating new jobs, and generating new revenues.

The recent reassessment indicated that the recovery factor in the Bakken Formation is less than 2%, much lower than the national average level of 30%. This is because the Bakken oil is stored in the middle intervals of Bakken Formation, which are naturally fractured, extremely thin and highly heterogeneous inter-bedded shale, shaly siltstone, shaly sandstone, and carbonates (limestone and dolomite). These geological features make activities of drilling in and oil production from the Bakken Formation at high risk, resulting in low success rate.

This project is designated to investigate the geomechanical properties of the Bakken Formation for improving the successful rate of drilling and production, and eventually increase the recovery factor.

The project has four objectives: (1) Determine the in-situ stress field of the targeted formation for better design of horizontal wells and hydraulic fracturing; (2) Measure the geomechanical properties, such as rock strength, to improve well stability during both drilling and production stages; (3) Develop local geomechanical laboratory capacities to serve the state and the regional demand; and (4) Establish lab facilities to teach lab classes for courses that include geomechanics components. Through the integrated efforts of the research and administration team at UND, with the support from state and industrial sponsors, most of these objectives have been achieved, as detailed in the executive summary and the attachments.

# Executive Summary

The project has four objectives: (1) Determine the in-situ stress field of the targeted formation for better design of horizontal wells and hydraulic fracturing; (2) Measure the geomechanical properties, such as rock strength, to improve well stability during both drilling and production stages; (3) Develop local geomechanical laboratory capacities to serve the state and the regional demand; and (4) Establish lab facilities to teach lab classes for courses that include geomechanics components. Through the integrated efforts of the research and administration team at UND, with the support from state and industrial sponsors, most of these objectives have been achieved, as detailed below.

(1) Determination of in-situ stresses

(a) Based on tectonic analysis, it is determined that Williston Basin is thought to be geo-mechanically stable. It has been tectonically quiescent for the past 500 million years and will likely continue over the significant future. As a typical intra-cratonic basin, the Williston Basin as a whole is in an overburden compressive stress regime. However, a local stress regime can be far more complicated than it appears to be due to possible shearing activities, burial and erosion history, diagenesis, salt dissolution features, and hydrocarbon generations. In general, the vertical stress has a gradient of 22.62MPa/km (1.0psi/ft) and the horizontal stress is a function of the vertical stress. It approaches the vertical stress with depth, and will lead to an isotropic stress condition at certain depth, as shown in Attachment 1.

(b) Due to the general conclusion on the in-situ stress regime in the Williston Basin, a method of using well logs to calculate over burden pressure (vertical stress) and horizontal stresses have been developed, and applied to the selected Bakken wells operated by the industrial sponsors of this project, as shown in Attachment 2.

(c) The method in (b) assumes that horizontal in-situ stresses are isotropic. This assumption is invalid in areas that have local structures, such as the Nesson Anticline area. In this case, a new method of using Kaiser Effect to estimate the in-situ stresses has been developed, as shown in Attachment 3.

(2) Measurement of formation rock geomechanical properties:

(a) Sample preparation capacity has been developed. This is especially important to the shale samples, such as Bakken. A portable core system has been designed, tested and improved, as shown in Attachment 4.

(b) Alternative tri-axial geomechancial testing system and method have been developed and tested, as shown in Attachment 5.

(c) Using the alternative tri-axial geomechancial testing system and method, geomechanical properties of Indian limestone and Pierre shale under representative reservoir conditions (in-situ stresses, pressure, temperatures and fluid flow) have been tested. In comparing to regular tri-axial testing device, this alternative system allows not only the detection of the change of geomechancial properties (strengths and elastic properties) due to fluid-rock reaction, but also the measurement of extremely low permeability at the nano-Darcy level, as shown in Attachments 6 and 7.

(3) Development of local geomechanical laboratory capacities:

(a) The alternative tri-axial testing system and methods have been applied to serve local research demands. It has been used to generate geomechanical and petrophysical properties for formation

rocks for CO2 sequestration in The University of North Dakota Energy and Environmental Research Center's (EERC) Plains CO2 Reduction (PCOR) Partnership Phase II PROJECT funded by US Department of Energy through contract DE-FC26-05NT42592, as shown in Attachment 8 (partial).
(b) Due to the growing activities in developing Bakken oil in Williston basin and the progresses in this research project, the PI and his collaborators were successful in obtaining two other major research projects: one from US DOE ($1M), the other from North Dakota Center of Excellence program ($3M). Using funds from these two projects, two advanced geomechanical and petrophysical testing systems (MTS 816 and AutoLab 1500C) have been purchased, as shown in Attachments 9 and 10 (partial).

(4) Establishment of lab facilities to teach lab classes for courses that include geomechanics components:
(a) Since the establishment of this alternative tri-axial geomechanical testing system and the start of this project, undergraduate students have been trained using this facility for course work (Attachment 11 & 12, partial), and graduate students have been using it for degree thesis research (Attachment 13, partial).
(b) Due to the success in research, the petroleum engineering group has now got more graduate student applicants than it can handle. More than that, to respond to the call from petroleum industry for more petroleum engineers, UND has started its process of building a BS in Petroleum Engineering program with in its School of Engineering and Mines (Attachment 14).

# Publication list

In addition to accomplishing the objectives, the following papers are published with full or partial supported from this project:


1. Fa, L., Zeng, Z. and Liu, H. 2010. A New Device for Measuring In-situ Stresses by Using Acoustic Emissions in Rocks, paper ARMA10-160, Proc. 44th US Rock Mechanics Symp. and 5th U.S.-Canada Rock Mechanics Symp, Salt Lake City, UT, USA. June 27–30. p.p. 1-7.
2. Pei, P., Zeng, Z. and He, J. 2010. Feasibility Study of Underground Coal Gasification Combined with CO2 Capture and Sequestration in Williston Basin, North Dakota, paper ARMA10-240, Proc. 44th US Rock Mechanics Symp. and 5th U.S.-Canada Rock Mechanics Symp, Salt Lake City, UT, USA. June 27–30. p.p. 1-8.
3. Wang, C. and Zeng, Z. 2010. Methodology of in-situ stress analysis and its application to a pumped-storage hydro-power station in China, ARMA 10-238, Proc. 44th US Rock Mechanics Symp. and 5th U.S.-Canada Rock Mechanics Symp, Salt Lake City, UT, USA. June 27–30. p.p. 1-9.
4. Zhou, X, Zeng, Z. and Liu, H. 2010. Laboratory Testing on Pierre Shale for CO2 Sequestration under Clayey Caprocks, ARMA 10-107, Proc. 44th US Rock Mechanics Symp. and 5th U.S.-Canada Rock Mechanics Symp, Salt Lake City, UT, USA. June 27–30. p.p. 1-12.
5. Jabbari, H. Kharrat, R., Zeng, Z., Mostafavi, V. R., and Emamzadeh, A. 2010. Modeling the Toe-to-Heel Air Injection Process by Introducing a New Method of Type-Curve Match, SPE 132515, Proc. Western North America Regional Meeting, Anaheim, CA, USA, 26–30 May. p.p. 1-14.
6. Fa, L. Castagna, J.P., Zeng, Z., Brown, R.L., and Zhao, M. 2010. Effects of anisotropy on time-depth relation in transversely isotropic medium with a vertical axis of symmetry. Chinese Science Bulletin (accepted after revision, in press).
7. Fa, L. Zeng, Z., Deng, C. and Zhao, M. 2010. Effects of geometrical-size of cylindrical-shell transducer on acoustic-beam steering efficiency for a slim-hole acoustic-logging tool. The Open Acoustics J. (accepted after revision, in press).
8. Fa, L. Lu, X., Zeng, Z., Liu, Y. and Li G. 2010. Transmission network model for seismic reflection signals in elastic layered media. Chinese Petroleum Instrumentation, No.1. p.p.1-15.
9. Jiang, A., Zeng, Z., Zhou, X. and Han, Y. 2009. A strain-softening model for drilling-induced damage on boreholes in Williston Basin, paper ARMA09-026, Proc. 43rd U.S. and 4th U.S.-Canada Rock Mech. Symp., Ashville, NC, USA. June 28-July 1. p.p.1-8.
10. Zhou, X., Zeng, Z., Liu, H. and Boock, A. 2009. Laboratory testing on geomechanical properties of carbonate rocks for CO2 sequestration, paper ARMA09-011, Proc. 43rd U.S. and 4th U.S.-Canada Rock Mech. Symp., Ashville, NC, USA. June 28-July 1. p.p. 1-9.
11. Zeng, Z. and Jiang, A. 2009. Geomechanical Study of Bakken Formation for Improved Oil Recovery, SINOROCK2009 paper No. 341, Proc. ISRM Int. Symp. Rock Mech., Hong Kong, China. May 19-22. p.p. 1-5.
12. Zhou, X., Zeng, Z., Belobraydic, M., and Han, Y. 2008. Geomechanical stability assessment of Williston Basin formations for petroleum production and CO2 sequestration. Paper ARMA08-211, Proc. 42nd US Rock Mech. Symp & 2nd U.S.-Canada Rock Mech Symp, San Francisco, CA, USA June 29-July 2. p.p. 1-9.

## Attachments

1. ***Geomechanical Stability Assessment of Williston***
2. ***Estimation of In-situ Stresses of the Bakken Formation in Eastern Williston Basin, North Dakota***
3. ***A New Device for Measuring In-situ Stresses***
4. ***A Portable Bakken Shale Core Sampling System***
5. ***An Alternative Methodology for Triaxial Geomechanical Testing***
6. ***Laboratory testing on geomechanical properties***
7. ***Laboratory Testing on Pierre Shale***
8. ***Experimental Study of Formation Rock Properties for CO2 Sequestration (Partial)***
9. ***816 Rock Test System by MTS (Partial)***
10. ***AutoLab 1500C by NER (Partial)***
11. ***GeoE 455 HW#5 RQD Measurement (Cover)***
12. ***GeoE 455 HW#7 Lab Testing (Partial)***
13. ***MS Thesis (Boock, partial)***
14. ***UND BS in Petroleum Engineering Cover Letter***