TECHNICAL REVIEWERS' RATING SUMMARY

G015-D

Geomechanical Study of Bakken Formation in the Nesson Anticline Area, Williams County, North Dakota

Submitted by University of North Dakota

Principal Investigator: Dr. Zhengwen Zeng

Request for $181,685; Total Project Costs $377,967

Rating Category	Weighting Factor	Technical Reviewer 15D-01 Rating	Technical Reviewer 15D-02 Rating	Average Weighted Score
Objective	9	3	3	27.0
Availability	9	2	2	18.0
Methodology	7	2	2	14.0
Contribution	7	2	2	14.0
Awareness	5	3	2	12.5
Background	5	4	4	20.0
Project Management	2	4	2	6.0
Equipment Purchase	2	2	3	5.0
Facilities	2	2	3	5.0
Budget	2	2	4	6.0
Average Weighted Score		128	127	**127.5**
Maximum Weighted Score				**250**

OVERALL RECOMMENDATION

FUND		
FUNDING TO BE CONSIDERED	**X**	**X**
DO NOT FUND		

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1. The objectives or goals of the proposed project with respect to clarity and consistency with North Dakota Industrial Commission/Oil and Gas Research Council goals are: 1 – very unclear; 2 – unclear; 3 – clear; 4 – very clear; or 5 – exceptionally clear.

Reviewer 015D-01 (Rating: 3)
If the project is successful the knowledge gained from it could improve the success rate of Bakken hydraulic fracture treatments. This would be consistent with Council Strategic Goals 1, 2, 3, and 4.

PI's Reply: Thank you for your appreciation on the importance of Geomechanics to the successful production of crude oil in the Bakken Formation. In addition, knowing the in-situ stress field will help us understand the possible orientation and distribution of the nature fracture systems, which is a key to the design of the trajectories of the horizontal wells.

Reviewer 015D-02 (Rating: 3)
The PI has enumerated a noteworthy goal, "investigate the in-situ stress field of the Bakken". However, it eventually becomes more clear that the PI 's efforts will be directed at one field along the Nesson anticline. A secondary goal also seems to be the creation of an in-state core testing laboratory at UND, which is admirable.

PI's Reply: Thanks for your appreciation on the importance of Geomechanics to the successful production of crude oil in the Bakken Formation and your support on our efforts for building an in-state petroleum engineering lab at UND.

In my opinion, there are two different approaches available for us to investigate the in-situ stress for the purpose of improving successful rate of producing oil by horizontal drilling and hydraulic fracturing in the Bakken Formation (Hudson, 1993). The first approach is basin-wide analysis for a general in-situ stress field map for the Bakken Formation in the whole Williston Basin. The second is reservoir- or field-wide analysis for a specific in-situ stress field map. We decided to choose the second approach due to the fact that the first approach needs much more efforts and much longer time for obtaining any practically meaningful results for our purpose.

The Beaver Lodge Field in William County, North Dakota was selected because of three reasons: (1) A petrophysical model of this field has been established in a previous research project supported by EERC's PCOR program (Belobraydic et al, 2007); (2) Many core samples and other data of adjacent formations have been accumulated and are available in this field due to its long time (53-year) production; and (3) One of the operators of the field has orally expressed their willingness of supporting our efforts on petroleum-related teaching and research activities, in addition to their current participation in the PCOR partnership.

Ref

- *Belobraydic, M.L., Zeng, Z., Patowiski, D., Ma, Y., Sorensen, J.A., Smith, S.A., and Dobroskok, A.A. 2007: Petrophysical Reservoir Model of the Beaver Lodge Oil Field, Williams County,*

North Dakota (paper abstract no. 22-9), presented at The Geological Society of America Annual Meeting, Denver, Colorado, USA. October 28-31.

- *Hudson, J.A. (1993). Comprehensive Rock Engineering: Principles, Practice and Projects (Ch 12-21: Stress, Stress Measurement Methods, and In-situ Stress). Pergamon Press, Ltd., New York, USA. pp. 297-552.*

2. With the approach suggested and time and budget available, the objectives are: 1 – not achievable; 2 – possibly achievable; 3 – likely achievable; 4 – most likely achievable; or 5 – certainly achievable.

<u>Reviewer 015D-01 (Rating: 2)</u>
The methodology utilized in determining the in-situ stress field is proven and the budget for that portion of the project adequate. However, the chosen location for the work is quite unique and may have limited applicability to other areas of North Dakota.

Successfully measuring geomechanical properties with an ISCO pump and triaxial core holder as an alternative to the conventional triaxial loading machine is uncertain.

<u>PI's Reply:</u> Thanks for the positive comments on the methodology about the in-situ stress determination and on the plan of time and budget.

For the selection of the specific oil field, please refer to PI's Reply to Reviewer 015D-02 in Category 1.

For the uncertainty of how to measure the Geomechanical parameters using the alternative method, there is a misunderstanding here. The original statement in the proposal was "Adding an ISCO pump and a triaxial core holder to exiting system will allow the realization of measuring the Geomechanical parameters proposed in this project." UND Petroleum Engineering Lab currently has two ISCO pumps and other equipment, as detailed below:

(1) ISCO Pump 260D (260 ml, 7500 psig, volumetric resolution 16 nl (nano-liter));
(2) ISCO Pump 500D (500 ml, 3750 psig, volumetric resolution 31.71nl);
(3) HP/HT Acoustic Core Flooding System (5000 psig, 250°F, P-/S-wave);
(4) Back Pressure Regulators: (5000 psig);
(5) Positive Displacement Pump (1000 ml, 10,000 psig);
(6) High Pressure Generator (20 ml, 15,000 psig);
(7) Temperature controlling system (750°F, ±1°F);
(8) Automatic control-acquisition-processing system; and
(9) Airbath (25" x 19" x 16", 750°F).

Adding another ISCO pump and a triaxial core holder will allow us to apply, control and measure axial stress, radial stress (i.e. confining pressure), and pore pressure (i.e. reservoir pressure) onto the core sample independently. By setting up the radial stress and pore pressure at pre-scheduled levels, triaxial strength of the core sample can be determined by increasing the axial stress until failure. Repeating the test under different radial stresses and pore pressures will generate triaxial strengths of the formation rock under different radial stresses (confining pressures corresponding to different depths) and pore pressures (corresponding to different reservoir pressures). Using triaxial strengths under different radial stresses and pore pressures, Mohr's circles and failure envelop can be generated; from which cohesion and angle of internal friction can be defined.

The Young's modulus, bulk modulus, compressibility and Poison's ratio will be determined by measuring the axial and radial volumetric changes of the core sample while the axial stress is being increased (Jaeger and Cook, 1979). The volumetric changes are measured using the extremely high volumetric resolution of the ISCO pumps (16 ~ 31.71 nl), from which the linear axial and radial strains, and thus the requested parameters, can be calculated.

The uniaxial compressive and tensile strengths will be measured using a Point Load tester (Zeng, 2002), which is available in the Mining Engineering Lab in our department.

The P- and S-wave seismic velocities and dynamic Young's modulus and Poison's ratio can be measured using the currently existing HP/HT Acoustic Core Flooding System (Jakupi, 2007).

Ref:

- *Jaeger, J.C. and Cook, N.G.W. 1979. Fundamentals of Rock Mechanics (3rd ed), Chapman and Hall, New York, USA. pp 77-194.*
- *Jakupi, A. 2007. Seismic Waveform Based Criteria for Phase Transition of CO_2 in Sample Rocks, MS Thesis, University of North Dakota, Grand Forks, ND, USA.*
- *Zeng, Z. 2002. Laboratory Imaging of Hydraulic Fractures Using Microseismicity, Ph.D. Dissertation, University of Oklahoma, Norman, Oklahoma, USA.*

Reviewer 015D-02 (Rating: 2)

It is unclear how the approach outlined by the PI is going to result in the achievement of meaningful objectives. There is no clear indication of an oil & gas industry interface, which would be essential to this effort.

PI's Reply: Please refer to PI's Reply to Reviewer 015D-01 in Category 2 on the approach/methodology, above.

Thanks for reminding us the importance on the application of the results to the practical petroleum engineering practice. Results from this research can be used in many different ways (Fjaer, et al., 1992; Aadnoy, 1997; Economides and Nolte, 2000), such as:

(1) Predict the fracture orientation;
(2) Design the best well trajectories (vertical, horizontal or multi-lateral);
(3) Make decisions on hydraulic fracturing;
(4) Calculate mud weight for safe drilling; and
(5) Simulate reservoir compaction and reduction of productivity.

Ref:

- *Aadnoy, B.S. 1997. Modern Well Design. Gulf Publishing Company, Houston, TX, USA.*
- *Economides, M. and Nolte, K.G. 2000. Reservoir Stimulation. John Wiley and Sons Ltd., Chichester, England, UK.*
- *Fjaer, E., Holt, R.M., Horsrud, P. Raaen, A.M, and Risnes, R. 1992. Petroleum Related Rock Mechanics. Elsevier, New York, USA.*

3. The quality of the methodology displayed in the proposal is: 1 – well below average; 2 – below average; 3 – average; 4 – above average; or 5 – well above average.

Reviewer 015D-01 (Rating: 2)

The standard approach to measuring the proposed rock properties is a triaxial loading machine. The proposed method is an alternative using equipment designed for core flooding analysis.

PI's Reply: Please refer to PI's Reply to Reviewer 015D-01 in Category 2 on the approach/methodology, above.

Reviewer 015D-02 (Rating: 2)
The methodology section of this proposal, while populated with all of the appropriate technical terms, is unclear and poorly constructed.

PI's Reply: Please refer to PI's Reply to Reviewer 015D-01 in Category 2 on the approach/methodology, above.

4. The scientific and/or technical contribution of the proposed work to specifically address North Dakota Industrial Commission/Oil and Gas Research Council goals will likely be: 1 – extremely small; 2 – small; 3 – significant; 4 – very significant; or 5 – extremely significant.

Reviewer 015D-01 (Rating: 2)
The project is designed to investigate the geomechanical properties of the Bakken formation in Beaver Lodge Field. Drilling and production information indicate that the Bakken formation on the Nesson Anticline is not representative of the major Bakken producing areas in North Dakota. For example the orientation of the Beaver Lodge Field structural high indicates a unique in-situ stress orientation and magnitude that would yield results that likely could not be applied to other potential producing areas in the state.

PI's Reply: For the reason of the selection of the specific oil field, please refer to PI's Reply to Reviewer 015D-02 in Category 1.

Thank you for your comments and information about the fact that the Bakken Formation on the Nesson Anticline is not representative. We are willing to work on another more representative area. A request for another reservoir/field for this research has been emailed out.

Reviewer 015D-02 (Rating: 2)
The potential of this effort to contribute to the fulfillment of NDIC/OGRC goals is not very high. Perhaps seamless integration with companies operating in the Williston Basin would increase this potential.

PI's Reply: Thank you for your comments and suggestions.

The PI was motivated by an NDIC expert's recent presentation which revealed the complexity of the Bakken Formation in the North Dakota side. While the production was very successful in the Montana part, the story on the North Dakota part was much different. The PI was astonished by the fact that one company drilled and hydraulically fractured 13 horizontal wells, each costing 3~7 million dollars, with only one successful. The expert's conclusion of the presentation was that the company needed to improve their understanding on the rock mechanics, especially the in-situ stress field in the Bakken Formation. The PI felt obliged to tackle this problem with his expertise in rock mechanics and petroleum engineering.

The main purpose of this research project is to obtain the in-situ stress and geomechanical properties of the Bakken Formation so as to improve the rate of success in drilling horizontal wells and in hydraulically fracturing the targeted formation. With improved rate of success, more oil companies will be attracted to North Dakota for more activities of exploration and

development, resulting in more jobs and more oil production, thus fulfilling some of the NDIC/OGRC goals.

The PI appreciates the suggestion of seamless integration with the industry, and will continue our ongoing efforts to network the companies. The PI considers this proposal as the first step to get involved into the North Dakota's petroleum E&D activities.

5. The principal investigator's awareness of current research activity and published literature as evidenced by literature referenced and its interpretation and by the reference to unpublished research related to the proposal is: 1 – very limited; 2 – limited; 3 – adequate; 4 – better than average; or 5 – exceptional.

Reviewer 015D-01 (Rating: 3)
All references to published work related to the proposed project are somewhat dated. There are no references to work more recent than 2004. Most of the Bakken and shale gas drilling and hydraulic fracturing work has been done since then.

PI's Reply: Thanks for the comments. This is an ongoing effort (Zhou, et al, 2008). A literature/critical review will be conducted later. With the research moving on forward, more understanding on the rock mechanics of the Bakken Formation can be expected.

Reviewer 015D-02 (Rating: 2)
The PI only references his own publications in this regard.

PI's Reply: Thanks for the comments. We should have cited more papers by others related to the Bakken Formation E & D activities in Williston Basin (Besler et al, 2007; Phillips et al, 2007). This problem will be solved with the ongoing effort and an upcoming literature/critical review.

Ref

- *Besler, M.R., Steele, J.W., Egan, T., and Wagner, J. 2007. Improving Well Productivity and Profitability in the Bakken--A Summary of Our Experiences Drilling, Stimulating, and Operating Horizontal Wells, paper SPE110679 presented at SPE Annual Technical Conference and Exhibition, 11-14 November, Anaheim, California, U.S.A.*
- *Phillips, Z.D., Halverson, R.J., Strauss, S.R., Layman J.M. II, and Green, T.W. 2007. A Case Study in the Bakken Formation: Changes to Hydraulic Fracture Stimulation Treatments Result in Improved Oil Production and Reduced Treatment Costs, paper SPE 108045 presented at Rocky Mountain Oil & Gas Technology Symposium, 16-18 April, Denver, Colorado, U.S.A.*
- *Zhou, X., Zeng, Z., Smith, S.A. and Sorensen, J.A. 2008. Geomechanical Stability Assessment of Eastern Williston Basin Formations for CO_2 Sequestration, accepted for presentation at the 42nd US Rock Mechanics Symposium and 2nd U.S.-Canada Rock Mechanics Symposium, to be held in San Francisco, June 29-July 2.*

6. The background of the investigator(s) as related to the proposed work is: 1 – very limited; 2 – limited; 3 – adequate; 4 – better than average; or 5 – exceptional.

Reviewer 015D-01 (Rating: 4)
The list of published references clearly shows that the PI has extensive research and publication experience in the area of the proposed project.

PI's Reply: Thanks.

Reviewer 015D-02 (Rating: 4)
The PI is well qualified "trained and practiced…for more than 20 years"

PI's Reply: Thanks.

7. The project management plan, including a well-defined milestone chart, schedule, financial plan, and plan for communications among the investigators and subcontractors, if any, is: 1 – very inadequate; 2 – inadequate; 3 – adequate; 4 – very good; or 5 – exceptionally good.

Reviewer 015D-01 (Rating: 4)
The timetable, budget plan, and responsibility assignments are well defined.

PI's Reply: Thanks.

Reviewer 015D-02 (Rating: 2)
The project management plan, milestone chart, and financial plan provided are inadequate. There is no substantive communication plan. A communications plan and substantive effort therein would likely positively influence the outcome of this effort.

PI's Reply: Thanks for the comments and suggestions.

The communication was included in the Technology Transfer section. More efforts will be made to improve this portion.

8. The proposed purchase of equipment is: 1 – extremely poorly justified; 2 – poorly justified; 3 – justified; 4 – well justified; or 5 – extremely well justified. (Circle 5 if no equipment is to be purchased.)

Reviewer 015D-01 (Rating: 2)
The equipment to be utilized is listed but how it will be used and how the proposed alternative testing methods will work is not explained.

PI's Reply: Thanks for the comments. Please refer to PI's Reply to Reviewer 015D-01 in Category 2 on the approach/methodology on how the equipment will be utilized.

Reviewer 015D-02 (Rating: 3)
The equipment to be purchased is justifiable and seems to be cost effective.

PI's Reply: Thanks for the comments.

9. The facilities and equipment available and to be purchased for the proposed research are: 1 – very inadequate; 2 – inadequate; 3 – adequate; 4 – notably good; or 5 – exceptionally good.

Reviewer 015D-01 (Rating: 2)
The existing PE lab that the proposed equipment will be incorporated into is mentioned only briefly as a work in progress. The long term application beyond the time frame of this project is not mentioned at all. The adequacy of the alternative equipment and testing methods to yield useable data is not supported.

PI's Reply: Thanks for the comments.

The existing PE Lab has been finished and tested, from which a MS student and two BS students finished their theses. A paper based on part of the experimental results has been accepted for presentation in this year's US Rock mechanics Symposium (Zeng et al, 2008).

After finishing this project, we plan to apply this method to Bakken Formations in other fields in North Dakota. The lab system will be used in those future projects. Our expectation is to apply DOE/RPSEA funds with match from the industry for those future projects.

In addition, the lab system will be used for teaching purpose and to serve the needs on geomechanical testing in the state and the region.

Ref

- *Zeng, Z., Jakupi, A., Bigelow, T.A. and Grigg, R.B. 2008. Laboratory Observation of CO_2 Phase Transition Induced Seismic Velocity Change, accepted for presentation at the 42nd US Rock Mechanics Symposium and 2nd U.S.-Canada Rock Mechanics Symposium, to be held in San Francisco, June 29-July 2.*

Reviewer 015D-02 (Rating: 3)
There is little discussion in these regards, but one can probably assume so, given that the PI has "spent all his new faculty startup fund in the past two years on building up the Petroleum Engineering Lab at UND".

PI's Reply: Thanks for your supportive comments.

Yes, this lab was designed and built to meet the experimental and numerical simulation demands in activities related to petroleum and environmental research, teaching and service.

10. The proposed budget "value"[1] relative to the outlined work and the financial commitment from other sources is of: 1 – very low value; 2 – low value; 3 – average value; 4 – high value; or 5 – very high value. (See below)

Reviewer 015D-01 (Rating: 2)
The proposed work will yield geomechanical information on one producing formation in a unique in-situ stress orientation.

The budget contains $12,000 in travel expenses to attend annual conferences, and the matching funds are soft money tuition waivers and salaries. There is no industry involvement, cost share, or financial contribution.

PI's Reply: Thanks for comments.

Industrial involvement and support is under contact. Interest or willingness of support has been expressed orally by several companies. Because the current share from UND alone already met the 50% matching requirement, no industry cost share and financial contribution has been included in the budget plan. But their involvement and support is very valuable.

Reviewer 015D-02 (Rating: 4)
However, the only additional financial commitment is from UND. Again, with involvement from industrial stakeholders, better value could be derived.

PI's Reply: Thanks for comments.

Please refer to PI's Reply to Reviewer 015D-01 in Category 10 (immediate above).

Section C. Overall Comments and Recommendations:
Please comment in a general way about the merits and flaws of the proposed project and make a recommendation whether or not to fund.

Reviewer 015D-01 (Fund May Be Considered)
The proposed project will enhance the PE lab capabilities at UND, but how that will benefit North Dakota's oil and gas industry is not explained.

The project will provide an excellent learning opportunity for PhD, undergraduate, and Laboratory Technicians at UND.

The project will test an alternative less expensive method of measuring geomechanical rock properties.

The PI has a great deal of knowledge and experience in this field of study.

The rock property and in-situ stress data developed will likely have very limited applicability.

There is no involvement or financial contribution from industry.

The PI should be asked to resubmit the project after seeking out an industry partner to provide financial support, and project guidance so the project can yield broadly applicable results with long term benefit to North Dakota oil and gas operators.

PI's Reply:
Thanks for the review, comments and suggestions.

Hope the above reply and explanations would help answer your questions and concerns about this proposal.

The PI strongly believes that the earlier the project is approved and conducted, the earlier the results would benefit the state in producing more oil from the Bakken Formation in North Dakota.

Reviewer 015D-02 (Funding may be considered)
There are admirable goals in the proposed effort. In particular, those related to defining key Bakken rock properties, developing in-state capabilities for critical core testing, and providing key hands on training to students. Unfortunately, they have been packaged in a poorly written proposal that is not compelling. Perhaps the investigator could rewrite his proposal, provide an indication of appropriate industrial involvement (an advisory committee?) and funding could be considered.

PI's Reply: Thanks for the review, comments and suggestions.

Hope the reply and explanations would help answer your questions and concerns.

The PI strongly believes that the earlier the project is approved and conducted, the earlier the results would benefit the state in producing more oil from the Bakken Formation in North Dakota.