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June 3, 2013

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
State Capitol – Fourteenth Floor
600 East Boulevard Avenue
Bismarck, ND 58505

Dear Ms. Fine:

Subject: Department of Petroleum Engineering proposal entitled "Williston Basin Advanced Core Analysis and Well Log Consortium"

Enclosed please find an original and copies of the subject proposal entitled "Williston Basin Advanced Core Analysis and Well Log Consortium." The results of the proposed work will advance reservoir modeling/characterization as well as production and exploration projects by providing key data and images that can be used by academia and industry. In addition, graduate and undergraduate students will gain valuable exposure to Williston Basin core and research projects that will better prepare them for oil and gas careers in the Williston Basin. Current co-sponsors of the project include Statoil, Hunt Oil, Murex Petroleum, UND Alumni Foundation (contribution from mineral owner), and Petroleum Research School of Norway. We currently have received verbal commitments from several organizations and the letters of support will be provided once we receive them. Also enclosed is the $100 application fee.

If you have any questions, please contact me by telephone at (701) 777- 4351 or by e-mail at scott.t.johnson@engr.und.edu.

Sincerely,

Scott T. Johnson
Principal Advisor
Institute for Energy Studies
Instructor
Petroleum Engineering Department

Oil and Gas Research Program

North Dakota

Industrial Commission

Application

Project Title: Williston Basin Advanced Core Analysis and Well Log Consortium

Applicant: University of North Dakota Petroleum Engineering Department

Principal Investigator: Scott T. Johnson

Date of Application: May 31, 2013

Amount of Request: $1,250,000

Total Amount of Proposed Project: $2,500,000

Duration of Project: 5 years

Point of Contact (POC): Scott Johnson.

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ABSTRACT

Objective:

Recently, the USGS increased the amount of recoverable oil in the Williston Basin from 3.65 billion bbl to 7.38 billion bbl largely due to increased drilling data from the Three Forks formation (USGS). While this is a significant increase from previous data, this is still based on the current 3-5% recovery of current production methods. In order to gain a better understanding of the basin and increase recoveries, a deeper understanding of the different formations and their unique properties is needed. The University of North Dakota (UND) Petroleum Engineering Department proposes a research consortium to further characterize the Bakken, including the Pronghorn member, and Three Forks formations in the Williston Basin. The objective is to use recent and pending purchased equipment (XRF, NMR, gamma ray, XRD, vitrinite reflectance, SEM, and advanced seismic analysis) to analyze core and cuttings samples, and tie the new data to high resolution core images and existing well logs (core calibrated). The goal of the project is obtain high quality analytical data linked with the high resolution core images and make the new database available on the NDGS website. In addition, industry directed projects will be conducted by teams of graduate students, faculty, and staff on specific areas.

Expected Results:

The results of the proposed work will advance reservoir modeling/characterization as well as production and exploration projects by providing key data and images that can be used by academia and industry. In addition graduate and undergraduate students will gain valuable exposure to Williston Basin core and research projects that will better prepare them for oil and gas careers in the Williston Basin.

Duration:

The duration of the project will be five years (October 1, 2013 to September 30, 2018) with a continuation application submitted to the ND OGRC at the end of each year for the next year of funding.

Total Project Cost:

The total cost of the project is $2,500,000. The amount being requested from the ND OGRC is $1,250,000 ($250,000 a year for five years). The remaining $1,250,000 ($250,000 a year for five years) is from a consortium of Williston Basin producers and the UND Alumni Foundation.

Participants:

Project participants include the UND Petroleum Engineering Department, the Harold Hamm School of Geology and Geological Engineering, NDGS, UND Alumni Foundation, Hunt Oil Company, Statoil, and Murex Petroleum Corporation. Collaborators will include the University of Bergen and the Petroleum Research School of Norway.

PROJECT DESCRIPTION

Objectives:

The primary goal of the project is to improve the understanding of the petrophysical properties of oil bearing formations in the Williston Basin using advanced analysis methods for core and drill cuttings. In order to meet the goal of the program the following specific objectives have been identified. These include:

- Identify strategic core and cutting samples for characterization
- Utilize newly acquired equipment and methodology to characterize core and cutting samples
- Compile information in an integrated database for access by project sponsors
- Develop and implement industry directed projects that utilize results of characterization that involve a combination of faculty, students (undergraduate and graduate), and staff
- Report the results of work in quarterly and annual reports, topical reports, and a final report for publication

Methodology:

In order to achieve the goals and objectives of the project, UND will work with the industry and the NDGS Core Library to identify key cores/cuttings within the Williston Basin for a detailed petrophysical analysis. The cores/cuttings selected will be from all areas of the basin in order to further characterize geographical differences within the basin. The suite of cores/cuttings analyzed will build upon existing datasets (Harju, 2011, Ramakrishna, 2010, Harju, 2013, Sarg, 2012, and Helms, 2006) and does not seek to duplicate existing data. References cited in this proposal are listed in Appendix B. In addition, very few to no datasets exist where the proposed suite of tests (XRF, NMR, gamma ray, vitrinite reflectance, XRD, SEM, and advanced seismic) have been systematically carried out on a group of cores for the Bakken, Including the Pronghorn member, and Three Forks formations. In addition, high resolution images of the core will be collected as a part of the analysis process. The project activities will be organized into the below tasks.

<u>Task Structure Summary</u>

The following task structure has been developed to meet the goal and objectives of the project. The tasks include:

Task 1. Project Management and Coordination

A key component of the success of this project is the management. The project manager will work closely with industry sponsors to ensure that all aspects of the project are completed on time and within budget. A project sponsors meeting will be held two times per year to review the project progress.

Task 2. Strategic Core and Cuttings Selection

UND, industry and the NDGS Core Library will assist UND in the selection of the core/cutting samples for detailed analysis.

Task 3. Core and Cuttings Characterization

Multiple methods of characterization of core and cuttings will be applied utilizing advanced methods of analysis to determine the porosity/permeability, mineralogy, and chemistry.

Task 4. Data Integration and Distribution

The data derived from the methods of analysis will be made available to be integrated with the high resolution core images and distributed to project sponsors and partners.

Task 5. Student Projects - Industry Directed

Industry directed projects will be conducted that utilize results of characterization that involve a combination of faculty, students (undergraduate and graduate), and staff. Each project will result in a detailed report that is only available to project sponsors.

Scope of Work

Task 1. Project Management and Coordination

The purpose of this task is coordination and planning of the Project with Project Participants. Once the notice of award is received from the ND Industrial commission, UND will negotiate contract terms with NDIC and other project participants. Subsequently, in this task we will address the following items throughout the project duration:

1. Monitoring and control of project scope
2. Monitoring and control of project cost
3. Monitoring and control of project schedule
4. Monitoring and control of project risk
5. Updating of the project scope plan after kick-off meeting with project sponsors at the start of the project
6. Updating the project plan periodically to reflect changes in scope/budget/schedule/risks
7. Using the project plan to report budget and schedule variances.
8. Coordinating reporting aspects of the project. The reporting will include: quarterly technical reports, annual, and topical student/faculty reports
9. Coordinating industry project review meetings. We anticipate having two project review meetings annually that will be used to report the progress of the project to project sponsors.

Task 2. Strategic Core and Cuttings Selection

UND, industry and NDGS Core Library will assist UND in the selection of the core samples for detailed analysis. The samples will incorporate the Bakken, Including the Pronghorn member, and Three Forks formations and will be spread out throughout the Williston Basin in order to allow for additional reservoir characterization and to look at geographical differences within the basin. Once the cores are selected, the core imaging and analysis schedule will be determined in order to minimize the amount of time that the cores are being analyzed.

Task 3. Core and Cuttings Characterization

The cores/cuttings selected in Task 2 will undergo multiple methods of characterization utilizing advanced methods of analysis to determine key petrophysical properties that can be used in reservoir characterization models and also to determine new areas of potential exploration. Table 1 displays the analysis techniques and petrophysical properties that will be determined for each of the core/cutting samples. Typical shale reservoir analysis techniques include: TOC, XRD, adsorbed/canister gas, vitrinite reflectance, detailed core and thin section descriptions, permeability, porosity, fluid saturation, and capture spectroscopy (Passey, 2010). The proposed work expands on typical petrophysical properties by including, XRF, total and spectral gamma ray, and NMR data. NMR is a newer petrophysical analysis technique and has only been used on a select number of Williston Basin cores (Ramakrishna, 2010).

Table 1. Core/Cutting Analysis Techniques and Petrophysical Properties

Analysis Technique	Petrophysical Properties Determined
X-Ray Fluorescence (XRF)	Major, minor, and trace elements
Nuclear Magnetic Resonance (NMR)	Pore size distributions, effective porosity, capillary pressure, free fluid index (FFI), bulk volume irreducible (BVI), clay bound water (CBW), hydrogen index permeability, 2-D data mapping (fluid typing)
Core Gamma Ray Logger	Total and spectral gamma
Vitrinite Reflectance	Kerogen age and maturity
X-Ray Diffraction (XRD)	Bulk mineralogy
Scanning Electron Microscopy (SEM)	Porosity and permeability
Triaxial Apparatus	Advanced sonic (Sonic Scanner) logs
Computed Tomography (CT) Scanner	Bulk density, porosity, lithology, and fractures mapping

In addition to the determination of petrophysical properties, high resolution core images will be collected for each of the selected cores. The data collected will add to the samples imaged as a part of the Continental Resources High Resolution Virtual Core Library (El-Rewini, 2012). Advanced scanning technology and software will be used to gain a better understanding of the macro- and micro-properties within the different facies and members of each formation.

In addition, existing well logs will be core calibrated so that the previously collected data will be able to be directly compared to the new data as well as to the core images. This will be accomplished through the use of Schlumberger's TechLog software. UND already has access to the TechLog software.

Task 4. Data Compilation/Analysis

The data from Task 3 will be reduced and compiled in order to look for correlations among cores and the different formations. The database that links the core images to the data collected in Task 3 will also be completed under this task. The data will be made available on the NDGS website and distributed to the project sponsors and partners.

Task 5. Student Projects - Industry Directed

Industry directed projects will be conducted that utilize the data collected in Tasks 3 & 4 and will involve a combination of faculty, students (undergraduate and graduate), and staff. Each project will result in a detailed report that is only available to project sponsors. The projects are anticipated to be smaller projects that will be identified by the project sponsors and by additional projects that develop as a part of the proposed project. It is anticipated that these projects will serve as cornerstone projects for the thesis documents of graduate students as well as be potential undergraduate senior design projects. Collaborative projects will be developed with the University of Bergen and the Petroleum Research School of Norway.

Anticipated Results:

Reservoir characterization is one of the most difficult tasks in the Williston Basin due to its complex formation properties. In order further advance and characterize the reservoir, advanced petrophysical characteristics are needed. The proposed project will provide a large petrophysical dataset along with the high resolution images that can be used to further characterize the Williston Basin. This will be one of the most complete datasets that looks at the Bakken, Including the Pronghorn member, and the Three Forks formations at the same time with the same analytical tools. The petrophysical data collected in Table 1 can be used for advanced reservoir characterization and analysis. The data will be used to further determine the amount of oil in place in each formation as well as provide information related to the most productive facies within each formation. The core calibrated well logs will also aid in the characterization of the different formations within the basin. In addition, the high resolution images can be used in order to identify new facies and potential areas of interest.

Another key result is that the data will be made available on the NDGS website and be made available to both academia and companies with an interest in the Williston Basin. This allows the dataset to be utilized by many different people and they can further characterize the basin.

Facilities:

Testing will be conducted within the Petroleum Engineering Department and the Harold Hamm School of Geology and Geological Engineering at UND. Some of the tests such as the gamma ray testing will be conducted in the NDGS Core Library building. The faculty and staff have diverse backgrounds in geology, geological engineering, chemistry and engineering disciplines. The Petroleum Engineering Department and the Harold Hamm School of Geology and Geological Engineering have or are acquiring the equipment required to conduct the analyses described in above tasks. Laboratories are located in Upson II and in Leonard Hall. No new equipment will be acquired under this project. Below are brief descriptions of the different buildings that will be utilized for the proposed work.

The College of Engineering and Mines is made up of seven units: Harold Hamm School of Geology and Geological Engineering, Department of Petroleum Engineering, Department of Chemical Engineering, Department of Civil Engineering, Department of Electrical Engineering, Department of Mechanical Engineering, and the Institute for Energy Studies. The College is currently located in a cluster of four buildings: Harrington Hall, Leonard Hall, Upson I, and Upson II. These buildings provide space for classrooms, laboratories, workshops, faculty and staff offices, conference rooms, and student and faculty gathering areas.

The Wilson M. Laird Core and Sample Library (North Dakota Geological Survey) is a climate-controlled facility, located directly across the street from Leonard Hall. The facility consists of 2000 square feet of office and laboratory space and 13,000 square feet of core storage. It currently houses approximately 80 miles of course and approximately 40,000 boxes of drill cuttings. The cores represent about 80% of the cores cut and about 95% of the samples collected in the North Dakota part of the oil-and coal-rich Williston Basin. The facility also houses a collection of water-well samples and cores. Over the past 50 years, students and faculty have been consistent users of the growing Laird Library, producing a significant number of theses and dissertations derived from cores, cuttings, and geophysical data. Many core thin sections were ground by students in pursuit of accurate mineral identification and porosity determinations. Upper level classes continue to use the Laird Library, and research projects continue to advance knowledge on North Dakota's petroleum and gas resources.

The Petroleum Research School of Norway (NFiP) is an interdisciplinary collaboration between six Norwegian, two European, and seven USA universities, including UND, focused on education of Petroleum related scientific disciplines. NFiP is sponsored by Statoil, Norwegian Ministry of Petroleum and Energy, and BP. Dr. Arne Graue, Chairman and Leader of NFiP, along with collaborator Dr. Pål Davidsen, University of Bergen (UiB), have committed their support to use the extensive research facilities and equipment (CT scanner) available through NFiP.

Resources:

The project team includes personnel from the UND Petroleum Engineering Department, the Harold Hamm School of Geology and Geological Engineering, graduate and undergraduate students, and the NDGS Core Library. The project team will work closely with the OGRC and other project partners through meetings, reports, and presentations in order to ensure overall project quality and that the project is completed on schedule. There is a very strong educational component to the research project. Undergraduate and graduate students will be actively working on each part of the project and will be key participants in the projects identified under Task 5. It is anticipated that presentations and publications at Society for Petroleum Engineers (SPE) conferences as well as other conferences will also lead to educational contributions.

Techniques to Be Used, Their Availability and Capability:

The proposed project will utilize numerous petrophysical techniques and types of instrumentation. UND currently owns or is in the process of acquiring all of the equipment required for the proposed work. No new equipment will be purchased from the proposed funding. The different techniques and petrophysical data obtained from each technique is described below.

XRF

The handheld XRF to be used for the project is a Bruker Tracer IV Geo equipped with a silicon drift detector. The instrument is also equipped with a vacuum system for better analysis of lighter elements. Since the system is portable, it can be taken over to the core library and be used on core and cuttings without taking the core out of the building. Major, minor, and trace elements will be determined on the core and cutting samples. Recently trace element analysis has been used as a way to estimate total organic carbon (TOC) and also can be used to identify different formations (Tonner, 2012, and Marsala, 2011). Samples will be collected every six inches along the core and each bag of selected cuttings will be analyzed by spreading the cuttings onto a piece of nitrocellulose filter paper. The filter paper has little to no XRF background so it is ideal to use in this case.

NMR

UND is in the process of acquiring an Oxford Instruments GeoSpec2 core NMR system complete with advance Green Imaging Technologies GIT-CAP™ software. The instrument is capable of analyzing cores from 1 to 6 inches in diameter and can provide the following petrophysical parameters: pore size distributions, effective porosity, capillary pressure, FFI, BVI, CBW, hydrogen index permeability, 2-D data mapping (fluid typing). The cores of interest will be analyzed over the entire formations of interest and existing NMR data, if available will be calibrated to the core data.

Gamma ray logger

UND will us an OFITE 740 gamma ray logger to collect both total and spectral gamma (uranium, thorium, and potassium) ray logs. The core for each well will place on the logger belt in order of depth. The belt pulls the core through the instrument and the total and spectral gamma ray logs are recorded. The existing down-hole well logs, if available, will be calibrated to the core gamma ray logs. The core gamma ray logs are able to be run at a much higher resolution and are able to better detect subtile changes within the different formations and facies.

Vitrinite reflectance

Vitrinite reflectance will be determined via ASTM D7708-11 "Standard Test Method for Microscopical Determination of the Reflectance of Vitrinite Dispersed in Sedimentary Rocks". Vitrinite reflectance is not widely determined on Williston Basin cores but recent research by Marathon Oil Corporation has developed a new petrophysical model for organic shales which is based on dividing the sample into kerogen and non kerogen domains with their unique properties (Alfred, 2012). Their research noted a correlation between the vitrinite reflectance signal and kerogen density. Core sample chips will be analyzed for areas of interest and the vitrinite reflectance (Ro) will be recorded.

XRD

XRD analysis will be performed on the core and cutting samples in order to obtain the bulk mineral composition as well as the relative abundance of the clay species present. Core and/or cutting samples will be ground into a fine powder onto an instrument specific slide. The Rigaku SmartLab instrument that plans on acquiring through previously awarded funding can also analyze larger samples and may not require samples to be ground into powders. Samples will be collected at 1 foot intervals along the selected cores or think films will be analyzed if available.

SEM

SEM images will be collected from core thin sections when available. The SEM images will provide porosity calculations and will also provide additional mineralogy information from the backscatter detector. The SEM images can provide the next level of imaging compared to the high resolution images and can provide additional detail related to the different formations and facies.

Triaxial apparatus (advanced seismic)

The triaxial apparatus is an AutoLab 1500 and is used to create geomechanical logs measured by advanced sonic logs through:

- Measuring dynamic and static elastic moduli (Young's modulus, Bulk modulus and Poisson's ratio) versus elevated confining pressure, pore pressure and temperature (true reservoir conditions)
- Measuring Biot's constant (for stress profile improvement)
- Measuring principal strains (for more accurate stress profiles)
- Thomsen anisotropy parameters (ε, γ and δ)
- Measuring transverse isotropic medium (VTI & HTI) stiffness tensor components (C_{11}, C_{12}, C_{13}, C_{33}, C_{44}, C_{55}, C_{66})

Micro computed tomography (CT) (Collaboration with Dr. Arne Graue)

CT images will be collected on select samples with the assistance of Dr. Arne Graue. The CT data will is typically used for rock characterization (bulk density, porosity), fluid distribution, reservoir characterization, formation damages, fractures mapping, and lithology analysis. CT scanning can be carried out on full diameter cores and is a nondestructive technique.

Environmental and Economic Impacts while Project is Underway:

No significant environmental or economic impacts are anticipated during and/or as a result of the proposed project activities.

Ultimate Technological and Economic Impacts:

The proposed project will provide a demonstration of how existing and new analysis technologies can be combined to advance industry knowledge and practices. New information in the form of an integrated data set of petrophysical properties for the Williston Basin will be produced and lead to improved reservoir characterization studies. As a result, sponsors will be better equipped to identify undeveloped resources and improve reservoir management practices that economically optimize existing resources. All stakeholders in the North Dakota oil and gas industry will benefit through the addition of new reserves, accelerated production, and reduced waste resulting from a higher drilling success rate.

Why the Project is Needed:

Even though there are a significant amount of reserves in the Williston Basin, the projected amount of recoverable oil is low due to currently low recovery rates of 3 to 5% and also due to the basin not being fully understood. The last estimate by the USGS significantly increased the amount of oil in place due to drilling in the upper part of the Three Forks formation. If the other members of the formation are also productive, it is likely that the amount of recoverable oil will significantly increase. This project is designed to provide a dataset linked to the high resolution core images that can be used by industry and academia to better characterize the Bakken, Including the Pronghorn member, and Three Forks formations. New industry, state, and educational standards will be developed utilizing the best available technologies to systematically analyze core and cuttings across the Williston Basin. A better understanding of the currently producing formations will lead to better estimates by the USGS as well as increased recovery rates by better well placement. The data can be entered into reservoir models to better characterize the reservoirs. The core images when used in combination with the data can be used to identify new formations of interest or to better identify the facies to target when drilling for increased production.

A key aspect as to why the project is needed is the education of graduate and undergraduate students. Currently, there is a significant demand for skilled and qualified geologists and petroleum engineers amongst the companies actively engaged in the Williston Basin. The proposed project will provide students the opportunity to conduct research directly related to the Williston Basin and they will also become more familiar with the Basin. The knowledge and experienced gained by working on this project will better prepare the students for a career with a company working in the Williston Basin and will also the students the ability to excel during their career.

STANDARDS OF SUCCESS

The success of the project will be measured through the completion of the project tasks and milestones on a timely manner. Success will also be measured through the development and progression of both graduate and undergraduate student research and reports such as graduate student thesis reports.

The project as a significant value to North Dakota by educating future geologists and petroleum engineers and by improving the amount of petrophysical data that is available for future research projects. The undergraduate and graduate students that will be working on the project will gain experience and knowledge on the Williston Basin formations. The experience will help them become valuable employees to the companies active in the Williston Basin. This will benefit ND by keeping young students educated within the state employed and living within the state.

The petrophysical data collected as a part of the project will benefit the state because it will enable advanced exploration and production opportunities within the state and additional reservoir modeling capabilities. These tools will allow for higher recoveries as well as increased production which will significantly benefit the state in terms of increased tax revenues. The state will also benefit because the NDGS will also have access to the data and high resolution core images.

BACKGROUND/QUALIFICIATIONS

Resumes of key personnel are provided in Appendix C. The graduate and undergraduate students that will be working on the project will be from Geology, Geological Engineering, Petroleum Engineering, or other engineering disciplines.

The UND Petroleum Engineering Department has already performed some initial XRF research on select core samples looking into major, minor, and trace element ratios at the lower Bakker/Three Forks contact area. Appendix D contains a manuscript in preparation for the XRF research.

The Williston Basin in the Northern Great Plains of North America and Canada contains significant resources of oil and gas. The ability to recover oil and gas resources from shales have improved through recent years as a result of horizontal drilling and fracturing. However, the recovery is still low. The challenges are associated with the low porosity shales. For example, the Bakken shale is generally low (< 5%) (Pitman, 2001). The low porosity translates to low permeability as well, typically 0.04 millidarcies. Improvements in horizontal well boring, and rock fracturing technology has made the Bakken shale a tight oil play, but the volume of recoverable oil makes the formation very attractive to investors.

The following equation relates the petrophysical properties to revenue from hydrocarbon bearing resources (Rafdal, 1991):

$$\text{Profit} = f\,(A * H * N/G * \text{Ø} * S_h * R)$$

Where:

$A * H$ = Gross rock volume
N / G = Net to gross ratio
Ø = Porosity
S_h = Hydrocarbon saturation
R = Recovery factor

Methods to characterize the formation begin initially at the well site during drilling and include among others, gamma ray, neutron, resistivity, and density measurements, mudlog and wireline logs (Crain, 2013). These logs can be calibrated to core data and be used for the prediction of mineralogy and estimates of porosity and permeability, although whole cores or sidewall core samples are considered the best source for quantitative data. Laboratory methods for the analysis of core samples include among others, measurements of porosity, permeability, total organic carbon (TOC), scanning electron microscopy (SEM) and other imaging techniques with mineral identification capabilities.

Porosity and permeability are related properties in geologic formations and crucial information for oil reservoir development. The porosity of a rock is a measure of its ability to hold a fluid. The porosity indicates the storage capacity of a reservoir and is used to calculate the hydrocarbon volume in place. Porosity is expressed as a percentage of open (fluid containing) space in a rock divided by the total rock volume. Several techniques are used to measure porosity including Archimedes Method of mass displacement of fluid, fluid displacement using a pycnometer, or by gas using Boyle's Law methods. Other methods use volume of whole rock divided by the volume of pulverized rock to assess porosity (Pitman, 2001, Rafdal, 1991, Crain, 2013, Curtis, 2011, Knackstedt, 2010, Honarpour, 2012, and Jabbari, 2013).

Digital imaging analysis of the rock can provide accurate estimates of porosity by calculating the pixel areas of the pores divided by the total pixels contained in the image. This is possibly the easiest technique to assess porosity, although two dimensional imaging may not provide information on the actual interconnectivity of the pores.

Permeability of a rock is a measure of the ease in which the rock will permit the passage of fluids. Permeability is measured in the laboratory by flowing a liquid of known viscosity through a core sample of known dimensions at a set rate, measuring the pressure drop across the core, or by setting the fluid to flow at a set pressure difference, and measuring the flow rate produced (Pitman, 2001 and Rafdal, 1991).

Analysis of core samples to determine mineralogy of the formation may lead to a better understanding of the formation on a whole. The information gained regarding the geology of the formation may be correlated to stress, strain, strength, and compressibility of the formation. This information may be useful in fracturing technology. Analysis of core samples show major and minor mineral species present, the grain size, distribution, and density of the minerals, as well as other information that may prove useful as technology advances. Current methods for characterizing the geology of core samples include among others, X-ray diffraction analysis, X-Ray CT, NMR, and multiple SEM methods that offer both two dimensional and three dimensional analysis.

Advanced 3D modeling (Curtis, 2011 and Knackstedt, 2010) can be achieved with both X-Ray CT and SEM, however SEM techniques offer a higher magnification to tight oil plays such as the Bakken where pore sizes exist in nanometer scale. Several techniques offer 3D imaging including focused ion beam scanning electron microscopy (FIB-SEM) which originated in the electronics development field. The technique uses a beam of focused gallium ions which slice away a 3-5 nanometer section from the sample, coupled with a SEM which images each section and also collects EDS spectra of the sample surface. Commercial software is available that can reconstruct in three dimensions the pore space and interconnectivity of the pores. With this information, permeability can also be estimated. A drawback to this method is the sample is destroyed during the analysis and the small scale of the analysis.

To increase the permeability of shales, hydraulic rock fracturing techniques have been developed. The walls of the well bore are hydraulically fractured, creating additional paths for the oil to flow into the well. To determine the required pressures necessary to "frac" a well, two basic rock mechanical properties are used to the determine the compressive strength of the reservoir, Young's Modulus and Poisson's ratio (Honarpour, 2012). Several laboratory methods are available to measure the compressibility and strength of the reservoir rock surrounding the well bore. Recently, research at UND has involved integrating geomechanical properties of the Bakken Formation, Williston Basin with reservoir and hydraulic fracture simulations. The simulations were used to evaluate several combinations of fracturing materials (i.e. fluids and proppants) and well/fracture parameters (i.e. lateral length, fracture spacing, and fracture half-length) to find the best candidate(s) for well stimulation planning (Jabbari, 2013). Another recent study at UND has involved developing a better understanding of the Bakken formation elastic properties (Young's Modulus and Poisson's Ratio), geomechanical behavior and stresses around the borehole. The interpretation of these data is used to estimate rock strength, pore pressure, and in situ stresses of the reservoir (Ostadhassan, 2013).

MANAGEMENT

The UND Petroleum Engineering Department in partnership with the UND Institute for Energy Studies has performed work on project of similar and larger scales. Meetings and/or webinars/conference calls will be held twice a year to keep the ND OGRC and the project sponsors up to date regarding the progress of the project. The deliverables of the proposal will also be incorporated into the contractual agreement to ensure that the deliverables are achieved in a timely manner consistent with what is being proposed. Each year, the project will also submit a continuation application to be evaluated by project sponsors and the ND OGRC for the next year of funding. This ensures that adequate project progress is occurring and that the project is moving forward in a manner consistent with the expectations of the OGRC and industry sponsors. In addition, progress reports will be prepared on a quarterly basis and will serve as the way to evaluate the project with regards to schedule, budget, and technical/milestone achievement. The decision points are identified in the below timetable.

The project management structure is illustrated in Figure 1. The overall project management will be the responsibility of Mr. Scott T Johnson. Mr. Johnson will coordinate work with project sponsors, project advisors, and project collaborators to coordinate the project and review progress. Key collaborations with the University of Bergen and Petroleum Research School of Norway are aimed to enhance modeling and advanced characterization of core. Dr. Nicholas Lentz will be responsible for the coordination and direction of the selection and characterization of the core samples. Dr. Lance Yarbrough will be responsible for the coordination of the database and making it available for integration with the core library and high resolution core imaging being conducted by the Harold Hamm School of Geology and Geological Engineering. Dr. Yarbrough will also work with project sponsors and advisor to develop and manage key projects identified by industry that are conducted by teams of graduate students, staff, and faculty.

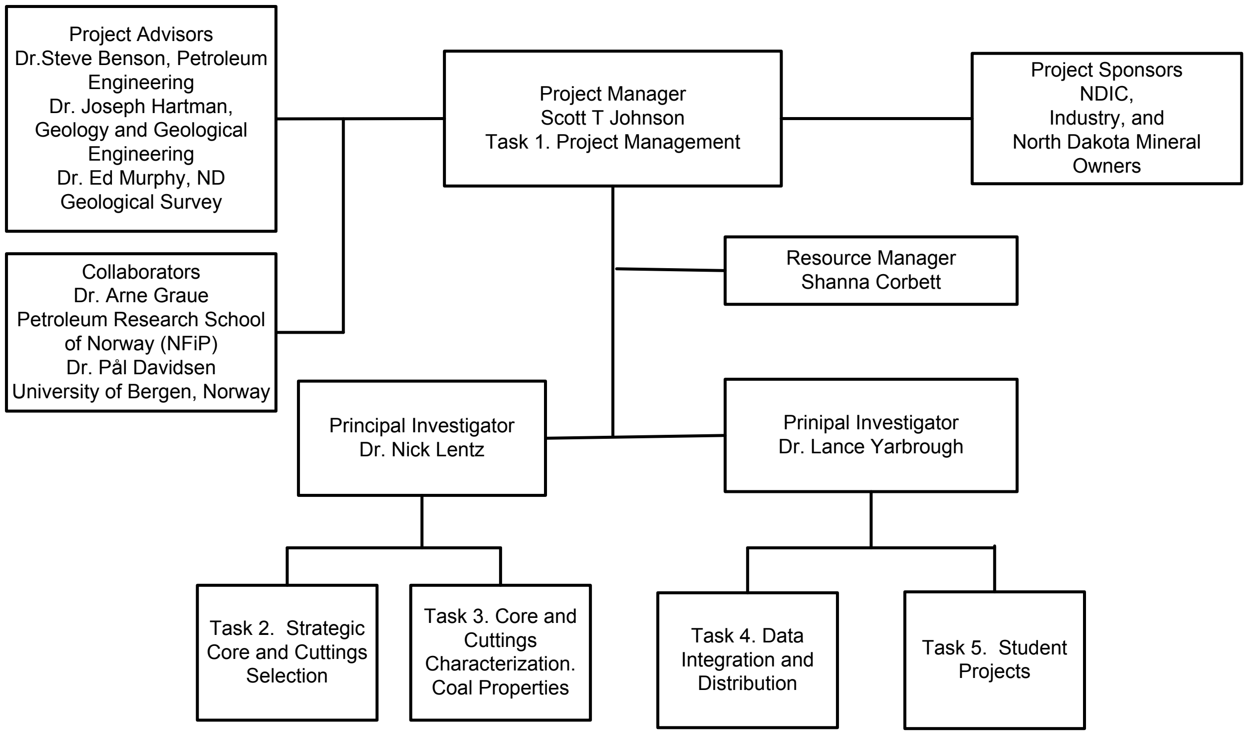

Figure 1. Overall project management structure.

TIMETABLE

Table2 displays the Gantt chart for the five year project. A continuation application will be submitted at the end of each year for the next year of funding. Decision points 1-4 (D1-D4) indicate the submission and approval of the continuation application to the ND OGRC as well as cost share commitments for the subsequent year(s) of funding for the project. Milestones denoted with the letter "M" are described in Table 3 along with the anticipated completion dates.

Table 2. Proposed Project Timeline

	Year 1				Year 2				Year 3				Year 4				Year 5			
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Task 1				D1				D2				D3				D4				M13
Task 2	M1																			
Task 3						M3	M4	M5		M6	M7		M8		M9		M10			
Task 4																		M11	M12	
Task 5			M2																	

Table 3. Proposed Project Milestones and Completion Dates

Milestone	Planned Completion Date
M1: Finalize core and cuttings selection	12/31/2013
M2: Identify first student project	5/31/2014
M3: Complete gamma ray data collection	3/31/2014
M4: Complete XRF data collection	6/30/2015
M5: Complete XRD data collection	9/30/2015
M6: Complete vitrinite reflectance data collection	3/31/2016
M7: Complete NMR data collection	6/30/2016
M8: Complete SEM data collection	12/31/2016
M9: Complete seismic data collection	6/30/2017
M10: Complete high resolution imaging	12/31/2017
M11: Develop draft database	3/31/2018
M12: Final database and integration with NDGS website	6/30/2018
M13: Issue final report	9/30/2018

BUDGET

*Please use the table below to provide an **itemized list** of the project's capital costs; direct operating costs, including salaries; and indirect costs; and an explanation of which of these costs will be supported by the grant and in what amount. The budget should identify all other committed and prospective funding sources and the amount of funding from each source, differentiating between cash, indirect costs, and in-kind services. Justification must be provided for operating costs not directly associated to the costs of the project. Higher priority will be given to those projects that have matching private industry investment equal to at least 50% or more of total cost. (Note ineligible activities or uses are listed under OGRP 2.02) **Please feel free to add columns and rows as needed.***

Project Associated Expense	NDIC's Share	Applicant's Share (Cash)	Applicant's Share (In-Kind)	Other Project Sponsor's Share
Personnel	874,170			211,689
Operating	31,626			694,109
Total Direct	905,796			905,798
F&A	344,202			344,203
Total Cost	$1,249,998			$1,250,001

Please use the space below to justify project associated expenses, and discuss if less funding is available that that requested, whether the project's objectives will be unattainable or delayed.

The total project cost is $2,500,000. $1,250,000 is being requested from the ND OGRC ($250,000 a year for five years), and $1,250,000 is being requested from industry ($250,000 a year for five years). We currently have sufficient sponsors with letters of commitment totaling half of the cost share for the proposed effort. We have several verbal commitments waiting on letters. We will continue to seek additional sponsorship for the program and will adjust the scope of work to match funding level. At the end of each year, a continuing application will be filed to the ND OGRC for the next year of funding. This also allows industry sponsors to commit to the project in 1-year intervals. A further budget justification can be found in Appendix E.

CONFIDENTIAL INFORMATION

There is no confidential information.

PATENTS/RIGHTS TO TECHNICAL DATA

Patents and rights to technical data do not apply to this proposal.

STATUS OF ONGOING PROJECTS (IF ANY)

The UND Petroleum Engineering Department and the Harold Hamm School of Geology and Geological Engineering have previously been awarded ND OGRC funding for one project entitled "Public-Private Partnership to Support Geology and Geological Engineering Education and Research at UND's College and Engineering and Mines". The project is currently in the contract approval process with the ND OGRC.

Appendix A: Letters of Support

MUREX® PETROLEUM CORPORATION

www.murexpetroleum.com

Donald A. Kessel
Vice President
Email: dkessel@murexpetroleum.com
(281) 590-3313

515 N. Sam Houston Pkwy. E.
Suite 485
Houston, TX 77060
(281) 590-3381 - Fax

May 28, 2013

Dr. Steven A Benson
Director Institute for Energy Studies
Professor & Chair, Petroleum Engineering Department
University of North Dakota
366V Upson II
243 Centennial Drive, Stop 8153
Grand Forks, ND 58202-8153

Dear Steve:

Murex Petroleum Corporation is pleased to enumerate its intent to provide $25,000 per year in cash funding to support the UND Petroleum Engineering Department's proposed effort entitled "Williston Basin Advanced Core Analysis and Well Log Consortium." Murex Petroleum Corporation understands that UND is seeking the support of the North Dakota Oil and Gas Research Council (ND OGRC), and additional industry sponsors.

We strongly feel that the proposed work is in line with the goals set forth by the ND OGRC and feel that the proposed work will significantly contribute to the understanding and development of the Bakken, Pronghorn, and Three Forks Formations in ND. Murex Petroleum Corporation's commitment is contingent on UND's allocation of the necessary funding from the ND OGRC and the additional industry sponsors followed by the negotiation of contractual agreements that are mutually agreed upon by all key entities involved in the proposed work.

The annual funding is also contingent on approval of the continuing application submitted to the ND OGRC and industry sponsor support. Please do not hesitate to contact me if you need further clarification or would like to further discuss the proposed work.

Donald A. Kessel

Hunt

HUNT OIL COMPANY
1900 North Akard Street
Dallas, Texas 75201-2300
214-978-8000
Fax: 214-978-8888

May 31, 2013

Dr. Steven A Benson
Director Institute for Energy Studies
Professor & Chair, Petroleum Engineering Department
University of North Dakota
366V Upson II
243 Centennial Drive, Stop 8153
Grand Forks, ND 58202-8153

Re: Support for proposal entitled "Williston Basin Advanced Core Analysis and Well Log Consortium" submitted to the North Dakota Oil and Gas Research Council.

Dear Steve:

Hunt Oil is pleased to support the UND Petroleum Engineering Department's proposed effort entitled "Williston Basin Advanced Core Analysis and Well Log Consortium." Hunt Oil agrees to provide $25,000 per year for up to 5 years. Hunt Oil understands that UND is seeking the support of the North Dakota Oil and Gas Research Council (ND OGRC), and additional industry sponsors. We understand that the project will be renewed on an annual basis. We strongly feel that the proposed work is in line with the goals set forth by the ND OGRC and feel that the proposed work will significantly contribute to the understanding and development of the Bakken, Pronghorn, and Three Forks Formations in ND.

Hunt Oil's commitment is contingent on UND's allocation of the necessary funding from the ND OGRC and the additional industry sponsors followed by the negotiation of contractual agreements that are mutually agreed upon by all key entities involved in the proposed work. The annual funding is also contingent on approval of the continuing application submitted to the ND OGRC and industry sponsor support. Please do not hesitate to contact me if you need further clarification or would like to further discuss the proposed work.

Sincerely,

Amos Sanders

Amos Sanders
Sr. Staff Geologist

Statoil Gulf Services.
Shale Oil and Gas Research
2103 Citywest Blvd #800
Houston, TX 77042

May 31, 2013

Dr. Steven A Benson
Director Institute for Energy Studies
Professor & Chair, Petroleum Engineering Department
University of North Dakota
366V Upson II
243 Centennial Drive, Stop 8153
Grand Forks, ND 58202-8153
Office: (701)-777-5177

Dear Steve:

Statoil is pleased to enumerate its intent to provide $25,000 per year in cash funding to express its interest in supporting the UND Petroleum Engineering Department's proposed research project entitled "Williston Basin Advanced Core Analysis and Well Log Consortium." Statoil understands that UND is seeking the support of the North Dakota Oil and Gas Research Council (ND OGRC), and additional industry sponsors. Statoil strongly feels that the proposed work is in line with the goals set forth by the ND OGRC and feel that the proposed work will significantly contribute to the understanding and development of the Bakken, Pronghorn, and Three Forks Formations in North Dakota.

Statoil commitment is contingent on UND's allocation of the necessary funding from the ND OGRC and the additional industry sponsors followed by the negotiation of contractual agreements that are mutually agreed upon by all key entities involved in the proposed work. The annual funding is also contingent on approval of the continuing application submitted to the ND OGRC and industry sponsor support. Please do not hesitate to contact me if you need further clarification or would like to further discuss the proposed work.

Sincerely,

Simon Leary
Head of Reservoir Management
RDI Shale Oil and Gas
Statoil ASA

Petroleum Research School of Norway (NFiP)

May 30, 2013

Dr. Steven A Benson
Director Institute for Energy Studies
Professor & Chair, Petroleum Engineering Department
University of North Dakota
366V Upson II
243 Centennial Drive, Stop 8153
Grand Forks, ND 58202-8153

Re: Support for proposal entitled "Williston Basin Advanced Core Analysis and Well Log Consortium" submitted to the North Dakota Oil and Gas Research Council.

Dear Steve:

The Petroleum Research School of Norway (NFiP) and The University of Bergen (UiB) are pleased to work with the UND Petroleum Engineering Department's proposed effort entitled "Williston Basin Advanced Core Analysis and Well Log Consortium." The Dr. Arne Graue, Chairman and Leader of NFiP and Head of Petroleum and Process Technology Research at UiB, along with Dr. Pål Davidsen, UiB, Norway, agree to:

- act as collaborators with the project,
- work to secure access to the extensive research facilities and imaging equipment available through the 15 Norwegian, European, and USA NFiP universities,
- work to provide a number of exchange students and faculty,
- provide experience on fluid flow in SCAL and related techniques.

The NFiP understands that UND is seeking the support of the North Dakota Oil and Gas Research Council (ND OGRC), and additional industry and North Dakota mineral owner sponsors. We strongly feel that the proposed work is in line with the goals set forth by the ND OGRC and feel that the proposed work will significantly contribute to the understanding and development of the Bakken, Pronghorn, and Three Forks Formations in North Dakota.

Please do not hesitate to contact me if you need further clarification or would like to further discuss the proposed work.

Sincerely,

Arne Graue
Professor

Dr. Arne Graue, Chairman and Leader, Petroleum Research School of Norway (NFiP)
University of Bergen (UiB), Norway
http://nfipweb.org/home.html
Arne.Graue@ift.uib.no
Cellphone: +47 900 22 855

UND ALUMNI ASSOCIATION FOUNDATION
3501 University Ave. Stop 8157 | 800.543.8764 / 701.777.2611
Grand Forks, ND 58202-8157 | fax: 701.777.4054

May 31, 2013

Dr. Steven A Benson
Director Institute for Energy Studies
Professor & Chair, Petroleum Engineering Department
University of North Dakota
366V Upson II
243 Centennial Drive, Stop 8153
Grand Forks, ND 58202-8153
Office: (701)-777-5177

Dear Steve:

The University of North Dakota Alumni Association and Foundation (UND Alumni Foundation) is pleased to support and enumerate its intent to provide $108,000 in cash funding to support student scholarships for student research in the UND Petroleum Engineering Department's proposed effort entitled "Williston Basin Advanced core Analysis and Well Log Consortium." This funding support is made possible with research gifts from alumni and companies who acknowledge the pressing need and the importance of student experiential learning that will accompany the important work. We support this effort with great enthusiasm. Our association with the College of Engineering has deep roots, and the recent successes of this College to form successful public private partnerships is nothing short of outstanding. The UND Alumni Foundation understands that the UND Petroleum Engineering Department is seeking the support of the North Dakota Oil and Gas Research Council (ND OGRC), and additional industry sponsors. The UND Alumni Foundation strongly feels that the proposed work will contribute significantly to student research and education as well as goals set forth by the ND OGRC. In addition, the proposed work will significantly contribute to the understanding and development of the Bakken, Pronghorn, and Three Forks Formations in ND.

The UND Alumni Foundation is nearing completion of a highly successful eight year $300 Million campaign themed, "North Dakota Spirit". We have exceeded our goal and have experienced North Dakota "spirit" in a variety of meaningful and impactful ways. In expressing our support of this project we are once again associated with another example of innovative and strategic spirit.

The UND Alumni Foundation's commitment is contingent on UND's allocation of the necessary funding from the ND OGRC and the additional industry sponsors followed by the negotiation of contractual agreements that are mutually agreed upon by all key entities involved in the proposed work. The subsequent annual funding is also contingent on approval of the continuing application submitted to the ND OGRC and industry sponsor support. Please do not hesitate to contact me if you need further clarification or would like to further discuss the proposed work.

Sincerely,

CFO

UND Alumni Foundation

Appendix B: References

Alfred, D., Vernik, L., 2012, A new petrophysical model for organic shales: Paper presented at SPWLA 53rd Annual Logging Symposium, Cartagena, Colombia, June 16-20, 2012, 15 pp.

Crain, E.R., 2013, Crain's Petrophysical Handbook, http://www.spec2000.net/15-permbasics.htm. (accessed May 2013).

Curtis, M.E., Ambrose, R.J., Sondergeld, C.H., Rai, C.S., 2011, Investigating the Microstructure of Gas Shales by FIB/SEM Tomography & STEM Imaging, SPE144391.

El-Rewini, H., 2012, Public-private partnership to support geology and geological engineering education and research at UND's College of Engineering and Mines. Proposal G-028-01 submitted to the North Dakota Oil and Gas Research Council.

Harju, J., 2011, CO2 – Enhanced Bakken recovery research program. Proposal G-026-056 submitted to the North Dakota Oil and Gas Research Council.

Harju, J., 2013, Program to determine the uniqueness of Three Forks bench reserved, determine optimal well density in the Bakken pool, and optimize Bakken production. Proposal G-030-06 submitted to the North Dakota Oil and Gas Research Council.

Helms, L. and Murphy, E., 2006, Digital Thin Section and Core Photo Project Final Report. Proposal G-002-006 submitted to the North Dakota Oil and Gas Research Council.

Honarpour, M.M., Nagarajan, N.R., Orangi, A., Arasteh, F., Yao, Z., 2012, Characterization of Critical Fluid, and Rock-Fluid Properties-Impact on Reservoir Performance of Liquid-rich Shales, SPE 158042.

Jabbari, H., 2013, Hydraulic Fracturing Design for Horizontal Wells in the Bakken Formation, Williston Basin, PhD Dissertation, University of North Dakota.

Knackstedt, M., Jaime, P., Butcher, A.R., Botha, P., and Sok,R., 2010, Integrating Reservoir Characterization: 3D Dynamic, Petrochemical and Geological Description of Reservoir Facies, SPE133981.

LeFever, J. and Helms, L., 2008, Bakken Formation reserve estimates: White paper presented at 2009 Williston Basin Petroleum Conference, Minot, North Dakota, North Dakota Department of Mineral Resources – Oil and Gas Division Web site, www.dmr.nd.gov/ndgs/bakken/newpostings/07272006_BakkenReserveEstimates.pdf. (accessed May 2013).

Marsala, A.F., Loermans, T. Shen, S. Scheibe, C. Zereik, R., 2011, Real-time mineraloge, lithology, and chemostratigraphy while drilling using portable energy-dispersive x-ray fluorescence: SPE 143468.

Ostadhassan, M. and Benson, S.A., 2013, Stress Analysis and Wellbore Stability in Anisotropic Formations, ARMA 13-150.

Passey, Q.R., Bogacs, K.M., Esch, W.L., Klimentidis, R., and Sinha, S., 2010, From oil-prone source rock to gas-producing shale reservoir – geologic and petrophysical characterixation of unconventional shale-gas reservoirs: SPE 131350.

Pitman, J.K., Price, L.C., and LeFever, J.A., 2001, Diagenesis and Fracture Development in the Bakken Formation, Williston Basin: Implications for Reservoir Quality in the Middle Member, USGS Professional Paper 1653.

Ramakrishna, S., Balliet, R., Miller, D., Sarvotham, S., Merkel, D., 2010, Formation Evaluation in the Bakken complex using laboratory core data and advanced logging technologies: Paper presented at SPWLA 51st Annual Logging Symposium, Perth, Australia, June 19-23, 2010.

Sarg, J.F., 2012, The Bakken – an unconventional petroleum and reservoir system: Final Report for U.S. Department of Energy National Energy Technology Laboratory DE-NT-0005672.

Sorenson, J.A., Schmidt, D.D., Smith, S.A., Bailey, T.P., Mibeck, B.A.F., and Harju, J.A., 2010, Subtask 1.2– evaluation of key factors affecting successful oil production in the Bakken Formation, North Dakota: Final Report for U.S. Department of Energy National Energy Technology Laboratory DE-FC26-08NT43291.

Tonner, D. Hughes, S. Dix, M., 2012, Wellsite geochemistry – new analytical tools used to evaluate unconventional reservoirs to assist in well construction and smart completions: Paper presented at SPWLA 53rd Annual Logging Symposium, Cartagena, Colombia, June 16-20, 2012, 11 pp.

Scott T. Johnson

Education and Training

South Dakota School of Mines	Mechanical Engineering	B.S.	1980
Amoco E&P Training	Petroleum Engineering		1988
University of Bergen	Master of System Dynamics		ABT

Research and Professional Experience

2012 – present Principal Advisor/Instructor, Institute for Energy Studies/Petroleum Engineering – assist in the coordination energy related education and research activities that involve faculty, research staff, and students.

2009 – present President of SYSDYNX, LLC -- uses System Dynamics skills to help organizations improve decisions and more effectively learn in dynamically complex environments.

2001 – 2009 Senior Business Dynamics Engineer at British Petroleum (BP) -- applied System Dynamics, petroleum / facilities engineering, and project management expertise to improve major project and business unit operations performance.

1999 – 2001 Integration Manager at Cap Gemini Ernst & Young -- applied system dynamics and program/ project management expertise to Information Technology (IT) / Management consulting engagements: Developed high-level business start up and sales processes to enable a wireless company to quickly establish global business operations in the highly competitive mobile portal industry.

1997 -- 1999 System Dynamics Specialist at Storage Technology -- applied system dynamics conceptualization and computer simulation methodologies to help teams improve business performance.

1996 – 1997 Manager at Arthur Andersen Business Consulting -- provided System Dynamics and petroleum / facilities engineering expertise to worldwide business consulting engagements

1981 – 1996 Senior Staff Petroleum Engineer at Amoco E&P -- applied petroleum / facilities engineering, system dynamics, and program / project management skills to improve business results. Managed the technical, economic, and safety evaluation of an acid gas re-injection project. Managed multinational engineering operations teams in Egypt responsible for well surveillance and workover recommendations to maintain production in fields producing 50,000 to 200,000 BOPD. Provided petroleum engineering expertise to cross-functional exploration teams responsible for identifying new plays in the Africa Middle East Region. Provided leadership, petroleum engineering, and economic analysis expertise to cross- functional teams responsible for optimizing and protecting competitive position of producing acreage through development and extension drilling recommendations. Achieved a 60% drilling and economic success rate over a fiveyear period with expenditures averaging $15M per year.

Publications

1. David N. Ford, Ivan Damnjanovic, and Scott T. Johnson, Public-Private Partnerships: A Study of Risk Allocation Design Envelopes , Chapter 8, Policy Informatics Handbook, MIT Press. Q1, 2013
2. Scott T. Johnson, David W. Peterson, Greg R. Swank, Project of the Future Vision: Using System Dynamics to Achieve 'Model-in-Loop' Project Planning & Execution, International System Dynamics Conference, Nijmegan, The Netherlands. July 23-27, 2006.

3. Johnson, S., Taylor, T., and Ford, D.N., Using System Dynamics to Extend Real Options Use: Insights from the Oil & Gas Industry, 2006 International System Dynamics Conference, Nijmegan, The Netherlands. July 23-27, 2006.
4. Scott T Johnson, Bob Eberlein, Alternative Modeling Approaches: A Case Study in the Oil & Gas Industry, 2002 International System Dynamics Conference, Palermo, Italy, July 28 – August 1, 2002.
5. George Backus, Michael T. Schwein, Scott T. Johnson, Robert J. Walker Comparing expectations to actual events: the post mortem of a Y2K analysis, Special Issue: Special Issue on Consulting and Practice, Volume 17, Issue 3, pages 217–235, Autumn (Fall) 2001 System Dynamics Review.

DR. NICHOLAS B. LENTZ

Associate Director for Energy Technology Applications
Institute for Energy Studies (IES), and Assistant Professor, Department of Petroleum Engineering, The University of North Dakota (UND)
243 Centennial Drive, Stop 8153, Grand Forks, North Dakota 58202-8153 USA
Phone: (701) 777-2684, E-Mail: nicholas.lentz@engr.und.edu

Principal Areas of Expertise

Dr. Lentz's principal areas of expertise are the identification and development of new analytical methods for the advancement of elemental and small molecule analysis in a wide range of matrices including coal and coal by-products, CO_2 capture solutions, oil and gas fuels; analysis for combustion flue gas, syngas, fuel oil, and biowaste; and experimental design and analysis related to control technologies to remove mercury and other elements from combustion and gasification systems. Dr. Lentz is also proficient in planning, managing, reporting, and day-to-day activities associated with pilot- and full-scale test programs.

Qualifications

Ph.D., Analytical Chemistry, Iowa State University, Ames, Iowa.
B.S., Chemistry, Bemidji State University, Bemidji, Minnesota.

Proficient in the use of Word, Excel, PowerPoint, Origin, and instrumentation software.

Professional Experience

2012-Present: Associate Director for Energy Technology Applications, IES, and Assistant Professor, Department of Petroleum Engineering, UND. Dr. Lentz's responsibilities include developing research projects and research teams to conduct energy related research as well as advising and instructing Petroleum Engineering students.

2009-2012: Center for Air Toxic Metals (CATM®) Program Area Manager, EERC, UND. Dr. Lentz's responsibilities included managing a portfolio of measurement based research projects in the Analytical Measurement Area of CATM as well as experimental design and analysis related control technologies to remove mercury, trace metals, and halogens from combustion and gasification systems.

2007–2012: Research Scientist, EERC, UND. Dr. Lentz's responsibilities included identification and development of new analytical methods required for the advancement of elemental analysis in biological tissues and nonbiological samples including coal and coal by-products, as well as analysis for combustion flue gas, fuel oil, and biowaste. His work also involves experimental design and analysis related to control technologies to remove mercury and other elements from combustion systems.

2002–2007: Research Assistant, Iowa State University, Ames, Iowa. Dr. Lentz's responsibilities included performing analytical research in pursuit of a graduate degree.

2005–2006: Teaching Assistant, Iowa State University. Dr. Lentz's responsibilities included teaching three physical chemistry laboratory sections, grading laboratory reports and problem sets, recording scores and helping to prepare final examinations, and maintaining three lab instruments.

2002–2003: Teaching Assistant, Iowa State University. Dr. Lentz's responsibilities included teaching general chemistry recitations and laboratory sections, proctoring exams and recording scores, grading of homework and examinations, and conducting weekly office hours at the chemistry help center.

2001–2002: Lab Assistant, Bemidji State University. Dr. Lentz's responsibilities included preparing samples and standards for general chemistry labs, performing quality control checks on undergraduate laboratories, collecting hazardous waste from laboratories and filling out necessary manifest forms, and organizing and taking inventory of all chemicals used in the stockroom.

2001–2001: Undergraduate Researcher, Bemidji State University. Dr. Lentz's responsibilities included collecting water samples from Lake Bemidji and the Mississippi River for ion chromatograph analysis as well as analyzing fuel samples for the Petroleum Products Research Laboratory.

Professional Memberships
Society of Petroleum Engineers

Publications and Presentations
Has coauthored several professional publications.

Lance D. Yarbrough
Harold Hamm School of Geology and Geological Engineering
The University of North Dakota
Grand Forks, ND 58202

Professional Preparation

Institution	Degree	Year	Field
University of Mississippi	Ph.D.	2006	Geological Engineering
University of Mississippi	M.S.	2000	Geological Engineering
University of Missouri-Rolla	B.S.	1995	Geological Engineering

Appointments

- Assistant Professor, Department of Geology and Geological Engineering, The University of North Dakota (August 2008–Present)
- Drilling Engineering Fellow, Hess Corporation, Houston, Texas (Summer 2013)
- Summer Engineering Faculty for Field Instruction, South Dakota School of Mines and Technology (2009–Present)
- Visiting Assistant Professor, Department of Geology and Geological Engineering, The University of Mississippi (July 2005–August 2008)
- Graduate Research Assistant/Graduate Instructor, Department of Geology and Geological Engineering, The University of Mississippi (January 1998–June 2005)
- Hydrologic Technician (GS-04), United States Department of Agriculture, National Sedimentation Laboratory, Oxford, Mississippi (February 1998–April 1999)
- Project Manager/Project Engineer, Environmental Monitor Systems Corp.-Environmental Construction Division, Indianapolis, Indiana, (March 1997–January 1998)
- Geological Engineer/Site Superintendent, Sverdrup Environmental, Inc., St. Louis, Missouri (May 1995–February 1997)

Four most relevant publications (as of May 2013)

- Lance D. Yarbrough, G. Easson, and J.S. Kuszmaul (2012) Proposed workflow for improved Kauth–Thomas transform derivations, Remote Sensing of Environment, 124, pp. 810–818.doi: 10.1016/j.rse.2012.05.003.
- Ries, Adam, and L.D. Yarbrough, 2011. Characterization of Banks and Slope Failures along the Shoreline of Lake Sakakawea, North Dakota, USA. 2011 Geologic Society of America Annual Meeting in Minneapolis, MN (9–12 October 2011). GSA Abstracts with Programs, 43 (5), Paper #196389.
- Crowell, Anna, W. Gosnold, and L.D. Yarbrough, 2010. Identifying Potential Geothermal Resources from Co-Producing Fluids Using Existing Data From Drilling Logs: Williston Basin, North Dakota. GSA Abstracts with Programs, 42 (5), Geological Society of America Annual Meeting & Exposition, 31 October–3 November 2010. Colorado Convention Center, Denver, Colorado.
- Yarbrough, Lance D., 2009. Use of Synthetic Aperture Radar in Cold Climate Flood Response. EOS, Transactions, American Geophysical Union, 90 (52), Fall Meeting Supplement, Abstract NH43C-1342.

Steven A. Benson, PhD

Education and Training

Minnesota State University	Chemistry	B.S. 1977
Pennsylvania State University	Fuel Science	Ph.D. 1987

Research and Professional Experience

2010 – present Director, Institute for Energy Studies – coordinate energy related education and research
activities that involve faculty, research staff, and students.

2008 – present Professor, University of North Dakota -- Dr. Benson is responsible for teaching courses on energy production and associated environmental issues. Dr. Benson conducts research, development, and demonstration projects aimed at solving environmental, efficiency, and reliability problems associated with the utilization of fuel resources in combustion/gasification systems that include: transformations of fuel impurities; carbon dioxide separation and capture technologies, advanced analytical techniques, and computer based models.

1999 – 2008 Senior Research Manager/Advisor, Energy & Environmental Research Center, University of North Dakota (EERC, UND) -- Dr. Benson is responsible for leading a group of about 30 highly specialized group of chemical, mechanical and civil engineers along with scientists whose aim is to develop and conduct projects and programs on combustion and gasification system performance, environmental control systems, the fate of pollutants, computer modeling, and health issues for clients worldwide.

1994 – 1999 Associate Director for Research, EERC, UND -- Dr. Benson was responsible for the direction and management of programs related to integrated energy and environmental systems development. Dr. Benson led a team of over 45 scientists, engineers, and technicians.

1991 – Present President, Microbeam Technologies Incorporated (MTI) -- Dr. Benson is the founders of MTI whose mission is to conduct service analysis of materials using automated methods. MTI began operations in 1992 and has conducted over 1400 projects for industry, government, and research organizations.

1989 – 1991 Assistant Professor of Geological Engineering, Department of Geology and Geological Engineering, UND -- Dr. Benson was responsible for teaching courses on coal geochemistry, coal ash behavior in combustion and gasification systems, and analytical methods of materials analysis.

1986 – 1994 Senior Research Manager, Fuels and Materials Science, EERC, UND -- Dr. Benson was responsible for management and supervision of research on the behavior of inorganic constituents in fuels in combustion and gasification.

1984 – 1986 Graduate Research Assistant, Fuel Science Program, Department of Materials Science and Engineering, The Pennsylvania State University, Mr. Benson took course work in fuel science, chemical engineering (at UND), and ceramic science and performed independent research leading to a Ph.D. in Fuel Science.

1983 – 1984 Research Supervisor, Distribution of Inorganics and Geochemistry, Coal Science Division, UND Energy Research Center -- He was responsible for management and supervision of research on coal geochemistry and ash chemistry related to inorganic constituents and mineral interactions and transformations during coal combustion and environmental control systems.

1977 – 1983 Research Chemist, U.S. Department of Energy Grand Forks Energy Technology Center, Grand Forks, North Dakota -- He performed research on methods development for the characterization of coal and coal derived materials

Publications

1. Benson, S.A., Gasification of Lignites of North America, North Dakota Industrial Commission, 2010.
2. Pavlish, J.H., Laumb, J.D., and Benson S.A., Eds, Air Quality VI: Mercury, Trace Elements, SO_3, Particulate Matter, & Greenhouse Gases, Special Issue of Fuel Process. Technol.; Elsevier Science Publishers: Amsterdam, 2009, Vol. 90, No. 11, 1327-1434.
3. Van Dyk, J.C., Benson, S.A., Laumb, M.L., and Waanders, B., Coal and coal ash characteristics to understand mineral transformations and slag formation, Fuel, Volume 88, Issue 6, 2009, Pages 1057-1063.
4. Benson, S.A., Pavlish, J.H., Holmes, M.J., Crocker, C.R., Galbreath, K.C., and Zhaung, Y., Mercury control testing in a pulverized lignite-fired system, Fuel Processing Technology, Volume 90, Issue 11, 2009, Pages 1378-1387.
5. Jones, M.L., Pavlish, B.M., Laumb, J.D., Lentz, N.B, and Benson, S.A., Fuel derived impurities impacts on CO_2 separation and capture technologies, *Prepr. Pap.—Am. Chem. Soc., Div. Fuel Chem.* 2008, *53* (2), 812-813.
6. Stanislowski, J.J., Laumb, J.D., Swanson, M.L., and Benson, S.A., Impact on lignite impurities on gasification and gas clean up, *Prepr. Pap.—Am. Chem. Soc., Div. Fuel Chem.* 2008, *53* (2), 810-812.
7. Benson, S.A.; Holmes, M.J. Coproducing Electricity, Hydrogen, and Synthetic Fuels from Lignite with Carbon Dioxide Capture and Utilization. Presented at the Energy Generation Conference, Bismarck, ND, Jan 31 – Feb 1, 2007.
8. Jones, M.L.; Stanislowski, J.J.; Benson, S.A.; and Laumb, J.D. Gasification of Lignites to Produce Liquid Fuels, Hydrogen, and Power, Twenty-Fourth International Pittsburgh Coal Conference, Johannesburg, South Africa, Sep 10-14, 2007.
9. Ma, Z.; Iman, F.; Lu, P.; Sears, R.; Vasquez, E.; Yan, L.; Kong, L.; Rokanuzzaman, A.S.; McCollor, D.P.; Benson, S.A. A comprehensive slagging and fouling prediction tool for coal-fired boilers and its validation/application, *Fuel Process. Technol*, 2007, 88, 1035–1043.
10. Steadman, E.; Benson, S. Gasification, CO_2 Capture, and Sequestration. In *Proceedings of the Symposium on Western Fuels: 20th International Conference on Lignite, Brown, and Subbituminous Coals Workshops*; Denver, CO, Oct 23, 2006.
11. Olson, E.S.; Crocker, C.R.; Benson, S.A.; Pavlish, J.H.; Holmes, M.J. Surface Compositions of Carbon Sorbents Exposed to Simulated Low-Rank Coal Flue Gases. *J. Air Waste Manage.* **2005**, *55* (6), 747–754.

Patents – 3 patents issued and several applications pending

7,574,968 **-** Method and apparatus for capturing gas phase pollutants such as sulfur trioxide.
7,628,969 - Multifunctional abatement of air pollutants in flue gas.
7,981,835 -System and method for coproduction of activated carbon and steam/electricity.

Synergistic Activities

- Lignite Energy Council, Distinguished Service Award, Research & Development, 1997; College of Earth and Mineral Science Alumni Achievement Award, Pennsylvania State University, 2002; Lignite Energy Council, Distinguished Service Award, Research & Development, 2003; Lignite Energy Council, Distinguished Service Award, Government Action Program (Regulatory), 2005; Lignite Energy Council, Distinguished Service Award, Research & Development, 2008.
- Provided testimony to the United States Senate Committee on the Environment and Public Works – Mercury emissions control at coal fired power plants - 2008 and 2005

Institute of Energy Studies

UND PETROLEUM ENGINEERING
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Elemental Characterization of the Bakken and Three Forks Formations in the Williston Basin of North Dakota Using X-Ray Fluorescence

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Abstract

The ability to characterize subsurface lithology is critical for hydrocarbon identification and subsequent production. Well-logging methods currently used in industry practices consist of gamma ray, spontaneous potential (SP), resistivity and mud logging principles. Relatively little focus has been placed on using X-Ray Fluorescence (XRF) to identify the geochemical signatures of hydrocarbon bearing strata. Because the exploitation of unconventional resources will demand greater stratigraphic resolution, future drilling may involve a XRF device incorporated into a MWD package for additional trace element recording and mud logging.

This study analyzes the elemental composition of the Lower Bakken and Three Forks Formations of the Williston Basin in North Dakota using X-Ray Fluorescence. Nine core sections from industry wells in multiple oil fields were exposed to X-Ray at 15-keV and 45-keV excitation voltages to provide XRF spectra. Count rate values were obtained from each sample and elemental ratios were calculated to assess the geochemical composition of the Bakken-Three Forks contact. The results of the analyses were used to create XRF well-logs representing the subsurface lithology of the Williston Basin. Diagenetic processes are then assessed based on elemental ratios.

Understanding the presence of lightweight, mid-range, and trace metal elements in the Bakken hydrocarbon system will lead to a better comprehension of what is affecting the accuracy and precision of typical industry well-logs. The ability to precisely and accurately measure the elemental composition of core samples will allow for further insight into how elemental composition changes can be correlated with diagenetic changes of the petroleum system.

INTRODUCTION

The Mississippian-Devonian Bakken Formation has been a source of continual research since being declared a 'tremendous source of oil production' in the early 1970's (Dow, 1974). Although many publications have addressed the hydrogeologic regime, resource potential, lithologic characterization, and chemical composition of the Bakken, few publications have addressed the elemental differences between Bakken and Three Forks source rocks and whether chemical composition controls petroleum recovery. This paper will attempt to assess the potential use and validity of X-Ray Fluorescence as a well-logging method. Count rate elemental ratios are created as a means of correlating subsurface wire line logs for the purpose of determining diagenetic processes between major geologic formations.

In 2010 the North Dakota Department of Mineral Resources estimated that, "Almost 20 billion barrels of oil appear to be in place within the Three Forks portion of the Bakken oil pool." However, only two billion barrels appear to be recoverable (Nordeng, 2010). In 2008 The Department of Mineral Resources calculated that, "The Bakken Pool contains 169 billion barrels of oil in place, which about four billion barrels will likely be produced (Nordeng, 2008). As of February 2013 1,186 horizontal wells and well segments have been completed into the Three Forks; 98.8 million barrels of oil have been produced from Three Forks horizontal wells. As of February 2013, 69 horizontal wells and well segments have been completed into the Lower Bakken; 6.8 million barrels of oil have been produced from Lower Bakken horizontal wells. Combined, horizontal Bakken and Three Forks wells have produced 105.6 million barrels of oil (Nordeng, 2013).

Understanding the elemental lithofacies changes between the Bakken and Three Forks Formations has never been assessed as a well-logging method. With technological advances in unconventional resource production, the ability to produce hydrocarbons will likely be a function of being able to identify where Bakken oil has migrated into Three Forks host rock. Gamma-ray, resistivity, spontaneous potential (SP), and neutron-density logs are commonly coupled with field mud logging to assess subsurface lithology during petroleum exploration. These wire line logs are industry standard, yet each log has potential drawbacks that could affect the accuracy of lithologic identification.

Gamma-ray wireline logs measure the natural emission of gamma ray electromagnetic radiation of geologic units from the decay of potassium, uranium, and thorium. Shales will typically emit a higher count rate of gamma compared to sandstones and carbonates, which will emit lower count rate. The presence of mica or potassium feldspar in sandstone will cause a high gamma-ray reading, which would subsequently be interpreted as shale. Due to the heterogeneity of geologic formation environments, variability will occur and precision will be limited in a subsurface geologic environment.

Resistivity logs measure shallow and deep induction resistance to electrical current flow. Deionized water electrical resistance is roughly $1.8 \times 10^5\ \Omega \bullet m$ whereas sea water conducts far more electrical current with a resistance of $2.0 \times 10^{-1}\ \Omega \bullet m$. The invaded zone resistivity of a production borehole would display a resistivity value representative of the drilling mud; the uninvaded deep induction resistivity value would be representative of the formation fluid. For both situations, resistivity will identify the fluid in the pore spaces of the geologic unit rather than the lithology. If oil becomes saturated with formation brines or drilling muds, the resistivity value will drop and hydrocarbons may not be interpreted from the log.

Spontaneous potential (SP) logs rely on a fixed electrode at the surface of the well casing and a moving electrode down bore. As the electrode is moved with depth, the Direct Current potential differences are measured. For this technique to work, the formation fluids have to be able to conduct electricity. Similar to the drawbacks of resistivity wire-line logging, oils saturated with brine or formation fluids could display higher conductivities and be mistaken for brine. Both resistivity and SP well-logging methods assess the electrical properties of the pore fluids rather than the lithologic properties of the host rock. Due to the highly variable nature of formation fluids and fluid saturation, host units bearing hydrocarbons could remain unseen in the subsurface.

This study attempts to determine whether elemental changes produce reliable signatures that distinguish lithologic units more accurately than current wire line logs. Lithologic changes are controlled by sediment influx, sea level transgression and regression, and paleoenvironment. As sediment source changes throughout geologic time, elemental composition change occurs accordingly. Continental crust is commonly composed of quartz silica and feldspar; by volume silica, potassium, sodium, and calcium are the most common minerals. Trace element presence, especially metals such as palladium, tin, zirconium, strontium, and rubidium, could more adequately distinguish lithologic divisions in the subsurface. Three main questions will be discussed to further the understanding of the relationship between elemental composition and hydrocarbon production: Does the Lower Bakken Formation have a distinctly different elemental composition than the underlying Three Forks Formation, does the Lower Bakken Formation have a distinctly different gamma ray signature than the underlying Three Forks Formation, and finally, does the mineral composition affect the precision of current wireline logs.

GEOLOGY

The Williston Basin:

The Williston Basin is an intracratonic sedimentary basin with the deepest basement located near Williston, North Dakota (Webster, 1984). Major structural features in the Williston Basin include the Nesson Anticline, the Billings Anticline, the Cedar Creek Anticline, the Welson Fault, and the Brockton-Froid Fault Zone. The lateral extent of the Williston Basin is widely considered to be contained within North Dakota, Montana, South Dakota, and South-Central Canada (Gerhard, 1982). The majority of Williston Basin subduction occurred before the onset of the Phanerozoic eon. This distortion is largely related to the movement of Precambrian cratonic rocks under lithostatic stress. The spatial extent of the Nesson Anticline is of particular importance to the petroleum industry due to numerous traps of Bakken oil in the Upper Three Forks Formation. Hydrodynamic oil entrapment models have been widely assessed to determine where oil pools accumulate. Three distinct oil families have been identified from thermally mature units in the Red River, Bakken, and Madison Formations (Price, 1994). Vertical hydrodynamic communication between strata allows hydrocarbons to flow from generation units to host units (Bachu and Hitchon, 1996).

Oils generated from the thermally mature Bakken Formation have pooled in Bakken shale reservoirs and the underlying Three Forks Formation. The relative buoyancy of oil controls the migration of Bakken sourced oils; hydrodynamic flow has less control over migration due to the low permeability of the bituminous shale (Martiniuk, 1994). Lower Bakken oils penetrated the more permeable Three Forks; hydrodynamic flow of formation waters in the northeastward direction creates traps throughout the Williston Basin and allows hydrocarbon deposition along structural traps such as the Nesson Anticline.

Lithology:

The Mississippian age Bakken and Devonian age Three Forks Formations of the Williston Basin in North Dakota are distinct stratigraphic intervals in the geologic record. The Bakken Formation has distinctly low levels of clastic sedimentation, high organic content, and the development of anaerobic conditions. The Three Forks Formation underlies the Bakken Formation and contained a higher degree of clastic sedimentation, low organic content, and oxygenated conditions. The Three Forks deposition in the Williston Basin occurred in the Late Devonian; the Bakken deposition occurred in the Late Devonian-Early Mississippian. Because of the abrupt sea-level transgression that occurred at the beginning of the Mississippian, the Three Forks and Bakken Formations are autonomous in the geologic record.

Both the Bakken Formation and the Three Forks Formations are part of the Kaskaskia Sequence. The Kaskaskia sequence contains the Elk Point Group, the Manitoba Group, the Jefferson Group, the Madison Group, and the Big Snowy Group. In the North Dakota Stratigraphic column, the Bakken and Three Forks Formations are located above the Jefferson Group and below the Madison Group. The Lodgepole formation overlies the Bakken Formation; the Three Forks Formation overlies the Birdbear Formation. The Bakken and Three Forks deposition occurred during the “mid-Kaskaskia interval,” which was a reorientation of seaways. Mississippian sedimentation in the Williston Basin was open to the west through central Montana (Bjorlie, 1979). The Upper Three Forks formation was deposited in a shallow marine environment. At the end of the Devonian, a large transgressive event took place creating high standing sea levels that deposited the organic rich black shales common in the Lower Bakken.

The Bakken Formation consists of three members. The upper member consists of black and organic rich shale, the middle member consists of calcareous siltstone, and the lower member consists of black organic rich shale with a higher concentration of trace metals. For the purpose of this paper, the lower member of the Bakken will be focused on. The sedimentary column in the Williston Basin is more than 15,000 feet thick, and the Lower Bakken shale will only attain a maximum thickness of 50 feet (Webster, 1984). The Lower Bakken can be considered hard, siliceous, pyritic, fissile, and nocalcareous. The environment needed to create a shale with such high organic content can best be described as an offshore, marine, anoxic environment where anoxic conditions may have been caused by a stratified water column and restricted circulation. Organic matter deposited in the black shales was derived mostly from planktonic algae. (Webster, 1984). Although oil is collected from stratigraphic intervals above and below the Bakken Formation, the upper and lower shales are considered to be the only soure-rock within several thousand feet of vertical stratigraphic section (Meissner, 1991).

The Upper Three Forks Formation is composed of thinly interbedded greenish-gray and reddish-brown shales, light brown dolostone, gray to brown siltstone, and minor occurances of anhydrite (Kume, 1963). The Three Forks Formation will appear greenish-gray in conditions that were anoxic, and reddish-brown in oxygen-rich environments. The contact between the Lower Bakken Formation and the Three Forks Formation appears to be conformable in the deepest portions of the Williston Basin. The Upper Three Forks Formation will often contain thin beds of fine grained quartz arenite, and hence is often referred to as the "Sanish Sand." The depositional environment of the Upper Three Forks Formation is considered to be a near shore marine environment. During the transition from the Upper Devonian into the Lower Mississippian, a large transgressive sequence occurred throughout the Williston Basin.

METHODOLOGY

Nine core samples were collected from the Wilson M. Laird Core and Sample Library at the University of North Dakota. The Core and Sample Library contains approximately 70 miles of cores and 34,000 boxes of drill cuttings. The cores represent roughly 75 percent of the cores cut in the North Dakota portion of the Williston Basin. Core samples for this study were selected based on the spatial extent of the Bakken and Three Forks Formations in the Williston Basin. Figure 1 from the North Dakota Department of Mineral Resources shows the extent of the Bakken and Three Forks Formations; intact cores representing both formations were chosen for the study.

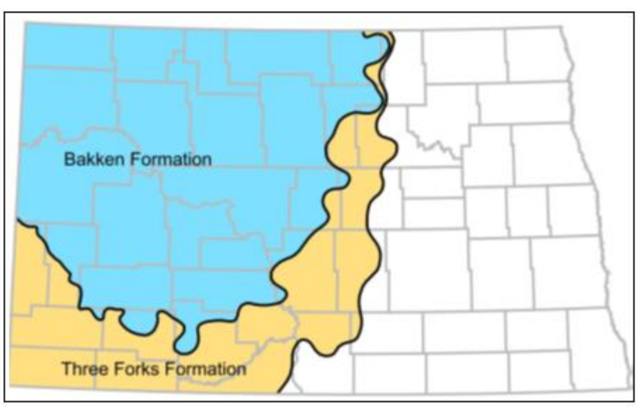

Figure 1: Spatial extent of the Bakken-Three Forks system in the Williston Basin of North Dakota (Nordeng, 2010).

X-Ray counts were collected using a Bruker Tracer IV-SD Handheld XRF instrument. This technology uses Silicon Drift Detection (SDD) for dramatically improved speed and sensitivity. The advent of the SDD technology allows for accurate light element analysis; previous XRF analysis relied on vacuum and helium flushing. The technology is based on energy dispersive X-ray fluorescence and uses an X-ray tube as its excitation source. Operation acceleration voltages range from 10 to 45 kilovolts (kV) and anode currents range from 0.05 to 60 micro amps (µA).

The Bruker Tracer IV-SD Handheld XRF is fully field portable and can be used in combination with S1PXRF software for bench-top analysis. For the purpose of this study, the Bruker Tracer IV-SD was configured into a vertical stand and core sections were placed on top of the instrument. Each core section was exposed to ionizing X-rays at excitations of 15 and 45 kilovolts for thirty seconds. Backscatter X-ray energies were detected and quantified by the Tracer IV-SD to create an elemental spectrum. Count-rate data was collected for each element detected during the analysis.

Core sections were chosen based on the presence of a Lower Bakken and Three Forks contact. Well study locations were selected based on the spatial extent of the Bakken-Three Forks system in figure one. Figure two shows the locations of all nine study wells in Divide, Williams, Mountrial, McKenzie, and Dunn Counties, North Dakota.

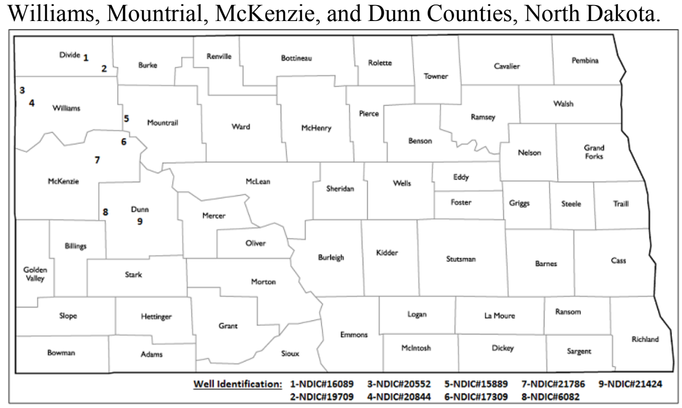

Figure 2: Core sections were analyzed from nine wells in North Dakota.

Once the contact was identified, X-Ray scans were completed at seven locations using 15 and 45 kilovolt excitation voltages. Scans were completed at the contact, one foot above and below the contact, two feet above and below the contact, and seven feet above and below the contact. For quality control, a core section representing the Upper Bakken and Middle Bakken contact was included in the study.

After backscatter energies were collected, S1PXRF software was utilized to graph the elemental spectra. This software allowed for the identification and quantification of elemental count-rates. Count-rates were collected for 27 elements: fluorine, sodium, magnesium, aluminum, silica, phosphorus, sulfur, chlorine, argon, potassium, calcium, titanium, vanadium, chromium, manganese, iron, nickel, copper, zinc, arsenic, bromine, rubidium, strontium, zirconium, molybdenum, palladium, and tin. Elemental count rates were plotted in two-dimensional space as a function of count-rate versus core depth (Figures 3, 4, 5, 6, and 7). Overall, 243 count-rate versus core depth graphs were created representing all 27 elements in nine study wells.

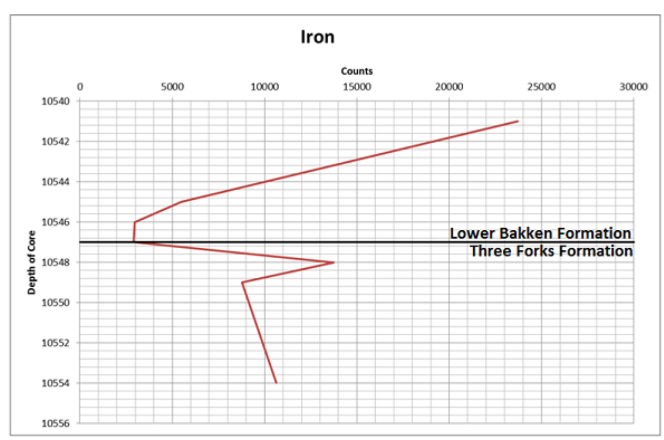

Figure 3: North Dakota Industrial Commission (NDIC) well number 21424 iron count-rate transition between the Bakken and Three Forks Formation in North Dakota.

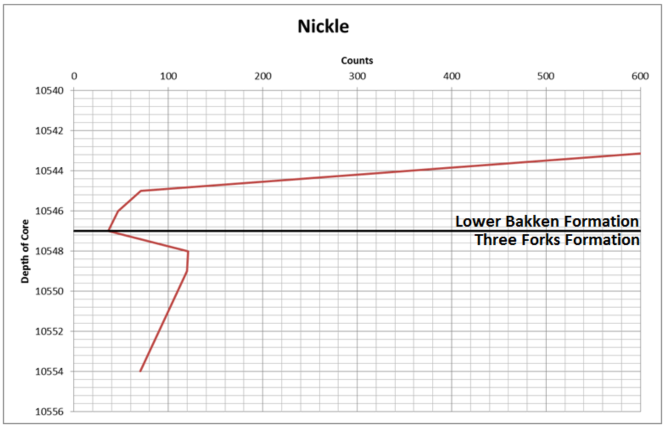

Figure 4: North Dakota Industrial Commission (NDIC) well number 21424 nickle count-rate transition between the Bakken and Three Forks Formation in North Dakota.

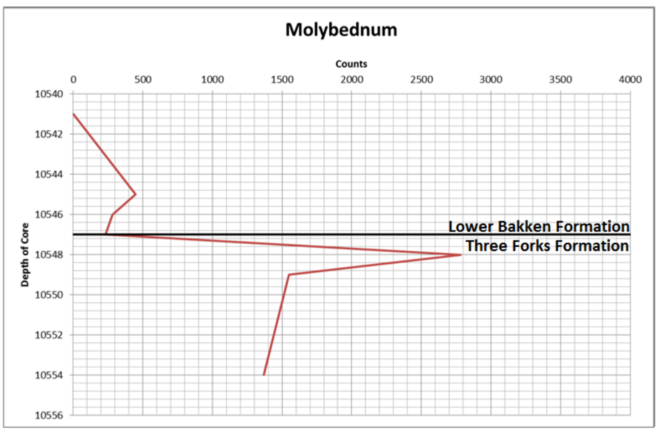

Figure 5: North Dakota Industrial Commission (NDIC) well number 21424 molybdenum count-rate transition between the Bakken and Three Forks Formation in North Dakota.

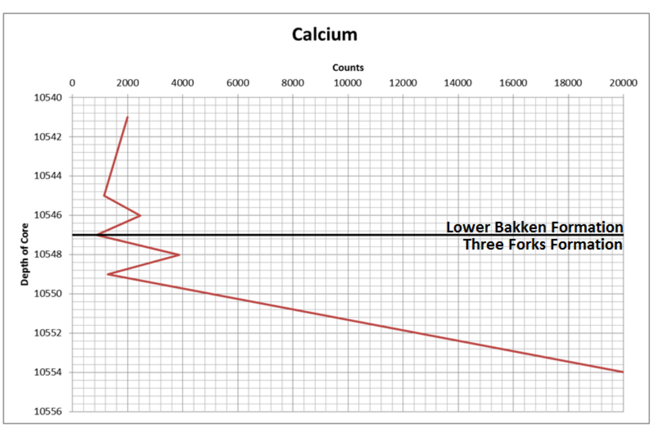

Figure 6: North Dakota Industrial Commission (NDIC) well number 21424 calcium count-rate transition between the Bakken and Three Forks Formation in North Dakota.

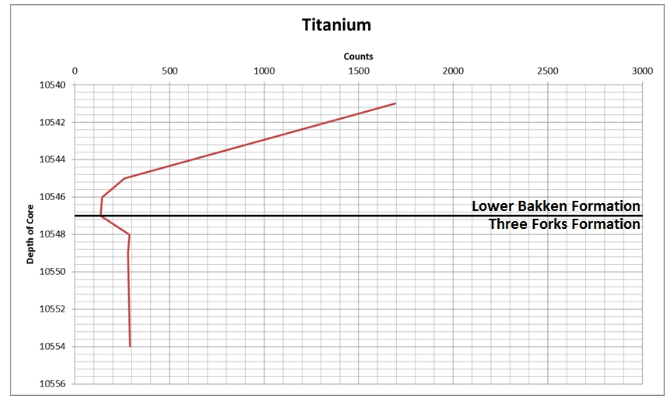

Figure 7: North Dakota Industrial Commission (NDIC) well number 21424 titanium count-rate transition between the Bakken and Three Forks Formation in North Dakota.

After all 243 count-rate versus core depth graphs were completed, no visible trend was identifiable between all nine well-logs. Figures four through seven represent Well Number 21424 in Dunn County, North Dakota. These graphs do show a definitive transition between the count-rate composition of the Bakken and Three Forks Formations, but when comparing all nine study wells no correlation is noticeable. Due to surface roughness geometry, backscatter count-rate radiation will be highly variable (Ge et al., 1997). Due to the highly variable surfaces seen in geologic core, a simple count-rate versus depth log will not be adequate for identifying lithological variations in the subsurface.

ELEMENTAL RATIOS

The potential use of X-Ray Fluoresence (XRF) as a logging will depend on an effective data processing method. The Bruker Tracer IV-SD Handheld XRF measures backscatter Kα counts and the accompanying S1PXRF software displays channel-count and energy values in the elemental spectra. The Bruker IV-SD output X-rays emit at a 143 degree angle from the horizontal, producing a two-dimensional vector of -.799i+.602j. As the output vector X-ray excite the core sample, secondary Kα x-rays are emitted and return to the detector. Due to surface roughness, it is impossible for the detector to return consistent Kα counts on homogenous samples. Numerous methods have been proposed to alleviate secondary emission dispersion for more accurate concentration determinations. (Ge et al., 1997) proposed a physical correction method using a least-squares iterative fitting for the area under count peak curves. (Loermans et al., 2011) suggest the most adequate way to alleviate surface roughness dispersion is to physically grind the sample into a fine powder with a grain size of 100µm; then the system must be flushed with helium. Both the Ge and the Loerman method fail to suggest an in-situ remedy for corrections downbore during hydrocarbon exploration.

For the sake of this analysis two possible corrections will be investigated: elemental ratios and count-percentages. Despite the difference in vector direction between the emission and secondary x-ray, the ratio between the two should stay consistent in all samples. To investigate this theory, calcium-magnesium, sodium-chloride, iron-calcium, potassium-rubidium, zirconium-rubidium, titanium-rubidium, iron-rubidium, copper-rubidium, copper-titanium, manganese-titanium, bromine-chloride, and iron-manganese ratios will be compared across all nine wells. Count-percentages will be analyzed for calcium, magnesium, sodium, chloride, iron, and manganese throughout the study site.

Unit	Depth	Ca:Mg	S:Cl	Fe:Ca	K:Rb	Zr:Rb	Ti:Rb
Bk	+7	3.47	1.36	31.08	2.16	1.58	0.73
Bk	+2	3.16	0.85	24.81	0.68	1.83	0.31
Bk	+1	2.82	1.06	23.29	0.77	2.74	0.35
Contact	0	5.56	0.69	8.01	0.70	2.81	0.37
Tf	-1	11.27	0.49	3.53	0.64	2.27	0.30

Tf	-2	15.28	0.65	3.20	0.88	2.94	0.41
Tf	-7	17.00	0.68	2.16	1.03	3.41	0.48

Table 1: Count-Ratios averaged from all nine study wells were computed for the Bakken-Three Forks petroleum system.

Unit	Depth	Fe:Rb	Ca:Rb	Ca:Ti	Mn:Ti	Br:Cl	Fe:Mn
Bk	+7	36.63	8.54	4.17	0.54	1.54	103.69
Bk	+2	10.32	1.59	3.59	0.44	1.12	91.68
Bk	+1	12.53	1.31	3.01	0.49	1.17	86.83
Contact	0	7.62	2.14	5.55	0.54	0.75	48.49
Tf	-1	7.44	2.94	9.99	0.76	0.94	37.41
Tf	-2	13.89	5.78	16.71	0.94	0.75	37.49
Tf	-7	7.20	7.45	18.10	0.78	0.80	27.89

Table 2: Count-Ratios averaged from all nine study wells were computed for the Bakken-Three Forks petroleum system.

Count ratios were calculated by dividing the Kα elemental counts on each well and dividing them by the Kα counts from another element of interest. For the sake of this study the ratios investigated included calcium-magnesium, sodium-chloride, iron-calcium, potassium-rubidium, zirconium-rubidium, titanium-rubidium, iron-rubidium, copper-rubidium, copper-titanium, manganese-titanium, bromine-chloride and iron-manganese.

Based on the count ratios seen between various elements in all nine study wells, we begin to notice strong trends. The ratio of calcium to magnesium begins to strongly increase in all nine study wells from the Bakken into the Three Forks. The ratio between sodium and chloride does not appear to dramatically differ between the two formations, and the fluorescence count values could be more representative of the drilling fluid rather than the actual mineralogical composition. The ratio between iron and manganese drops significantly between the Bakken Formation and the Three Forks. This means that the Bakken is far more Iron rich than the underlying Three Forks Unit. The ratio of iron to calcium is high in the Bakken and dramatically decreases in the Three Forks. Overall, the two most important ratios observed in this analysis include the ratio of calcium to magnesium and iron to calcium. At the well site a field geologist equipped with a Bruker Tracer IV-SD handheld XRF would be able to analyze drill cuttings and determine that if the ratio of calcium to magnesium was low, the corresponding lithologic unit in the subsurface would be the Bakken Formation. Once that ratio increased above 10, the geologist would immediately recognize that the bore was entering into the Three Forks. The ratio of Iron to Calcium could be used in the same manner but would follow an inverse relationship; a high Iron to Calcium ratio would represent the Bakken whereas a low Iron to Calcium ratio would represent the Three Forks Formation.

The count-percentage was calculated by dividing the sum of the autonomous elemental Kα counts and dividing by the total Kα counts collected. This process was completed for the counts collected on Calcium, Magnesium, Sodium, Chloride, Iron, and Manganese. The sample means and standard deviations were collected; the coefficient of variation was calculated by dividing the standard deviation by the average. Table 3 shows that between the nine wells, the percentage of calcium in the sample increased remarkably from the Bakken into the Three Forks Formation. The percentage of Iron followed an inverse relationship, the percentage decreased dramatically from the Bakken into the Three Forks Formation. The coefficient of variation did not show any significant trending between the formation contacts. Another interesting point to note is that as the average percentage of Iron decreased, the average percentage of Manganese increased. This observation could be related to the electron acceptor sequence noted by (Korom et al., 1992) describing the interaction between Iron and Manganese in a hydrogeological environment.

		Calcium (%)		Magnesium (%)		Sodium (%)	
Unit	Depth	Average	σ	Average	σ	Average	σ
Bk	+7	1.42	0.72	0.52	0.15	0.48	0.28
Bk	+2	1.38	0.25	0.62	0.04	0.62	0.05
Bk	+1	1.54	0.26	0.47	0.13	0.49	0.12
Contact	0	3.27	1.90	1.03	0.58	1.11	0.70
Tf	-1	8.38	4.03	0.87	0.06	0.89	0.08
Tf	-2	14.16	4.89	1.18	0.62	1.15	0.56
Tf	-7	21.30	22.14	0.74	0.10	0.81	0.11

Table 3a: Elemental percentages averaged from all nine study wells were computed for the Bakken-Three Forks petroleum system.

		Chlorine (%)		Iron (%)		Manganese (%)	
Unit	Depth	Average	σ	Average	σ	Average	σ
Bk	+7	0.35	0.17	63.41	22.49	0.39	0.07
Bk	+2	0.50	0.06	51.38	4.57	0.40	0.04
Bk	+1	0.39	0.07	60.89	6.59	0.35	0.06
Contact	0	1.10	0.90	36.60	13.53	0.43	0.13
Tf	-1	3.42	2.26	33.96	4.70	0.57	0.20
Tf	-2	1.88	1.19	27.29	7.72	0.62	0.25
Tf	-7	1.01	0.58	27.47	14.61	0.72	0.36

Table 3b: Elemental percentages averaged from all nine study wells were computed for the Bakken-Three Forks petroleum system.

PRELIMINARY RESULTS

Elemental Ratios:

The analysis of elemental ratios for the study provided intriguing results for future well-logging applications. Mapping trends between elemental ratios while drilling could have the potential to replace mud-logging applications if a wire-line X-Ray fluorescence device was patented and applied in the field. Strong trends could distinguish the autonomous Lower Bakken and Three Forks Formations.

The ratios that displayed a strong trending up sequence included: calcium to magnesium (Figure 8), zirconium to rubidium (Figure 9), and calcium to titanium (Figure 10). In all instances the Lower Bakken displayed a noticeably lower ratio than the underlying Three Forks Formation. The ratio of Calcium to Magnesium was 3.47 in the Bakken Formation seven feet above the contact, and the ratio dramatically increased to 17.00 in the Three Forks Formation seven feet below the contact. A wire-line X-Ray fluorescence device would be able to detect this change without the use of mud-logging principles. The same principle would apply to the ratios of zirconium-rubidium (1.58 in the Bakken, 3.41 in the Three Forks), and calcium to titanium (4.17 in the Bakken, 18.10 in the Three Forks).

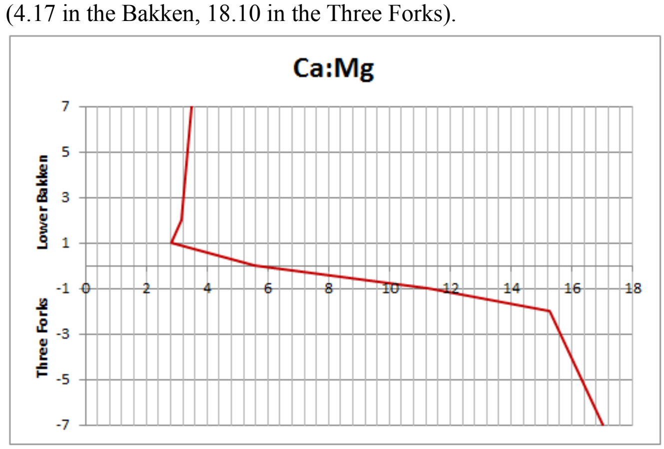

Figure 8: Nine well average of calcium to magnesium ratios. The ratio of calcium to magnesium increased into the Three Forks Formation.

The ratios that displayed a strong trending down sequence included: iron to calcium (Figure 11), iron to rubidium (Figure 12), and iron to manganese (Figure 13). In all instances the Lower Bakken displayed a noticeably higher ratio than the underlying Three Forks Formation. The ratio of iron to calcium was 31.08 in the Bakken Formation seven feet above the contact, and the ratio dramatically decreased to 2.16 in the Three Forks Formation seven feet below the contact. The same principle applies to the ratios of iron to rubidium (36.63 in the Bakken, 7.20 in the Three Forks), and iron to manganese (103.69 in the Bakken, 27.89 in the Three Forks).

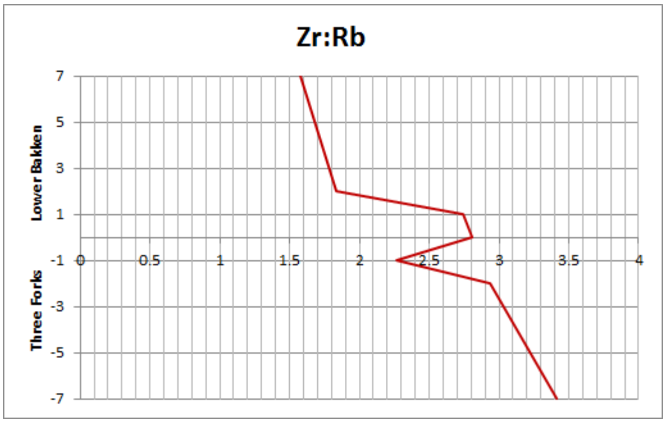

Figure 9: Nine well average of zirconium to rubidium ratios. The ratio of zirconium to rubidium increased into the Three Forks Formation.

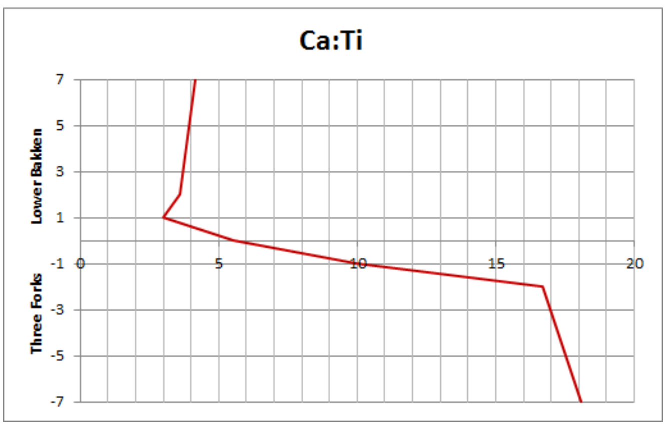

Figure 10: Nine well average of calcium to titanium ratios. The ratio of calcium to titanium increased into the Three Forks Formation.

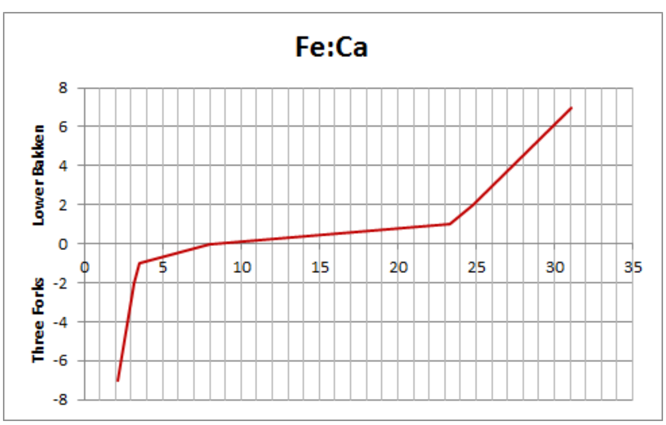

Figure 11: Nine well average of iron to calcium ratios. The ratio of iron to calcium decreased into the Three Forks Formation.

Two ratios were particularly interesting in this study and were indicative of the Bakken-Three Forks contact rather than the separate geologic units. The ratio of calcium to rubidium and the ratio of potassium to rubidium displayed high values in the Bakken and Three Forks and dropped at the contact. The ratio of calcium to rubidium was 8.54 in the Bakken, dramatically dropped to 2.14 at the contact, and then increased back to 7.45 in the Three Forks. The ratio of potassium to rubidium was 2.16 in the Bakken, dropped to 0.70 at the contact, and then increased back to 1.03 in the Three Forks. These ratios could be used in industry to truly determine lithologic contacts.

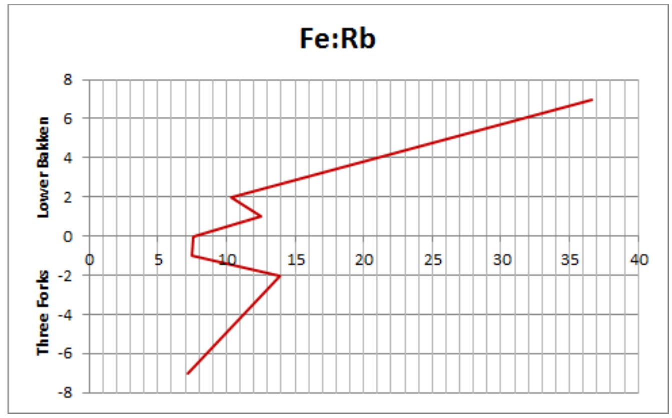

Figure 12: Nine well average of iron to rubidium ratios. The ratio of iron to rubidium decreased into the Three Forks Formation.

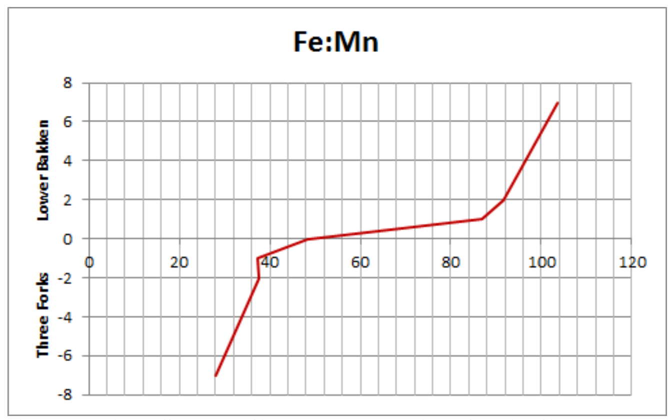

Figure 13: Nine well average of iron to manganese ratios. The ratio of iron to manganese decreased into the Three Forks Formation.

Overall, the trending up and trending down sequences seen during elemental ratio analysis should be investigated further. The averages between all nine study wells show strong sequences of geochemical composition. Elemental ratios between lithologic units could be used in both academia and industry; both fields could expand research to map subsurface geology using elemental ratios rather than other common principles. As discussed earlier in the introduction section of this paper, other well-logging methods have numerous drawbacks. Resistivity, neutron density, and spontaneous potential logs all are indicative of formation fluids rather than lithology. The only true lithologic log used in industry is the gamma-ray log. X-Ray fluorescence down bore has the potential to map lithology once standards are created for an oil field.

Elemental Ratios and Diagenetic Association:

Elemental ratios have been used by several authors as a means of calibrating X-Ray fluorescence count-rates (Croudace, 2006; Richter, 2006; Rothwell, 2006; Calvert and Pederson, 2007). One author that contributed a particular wealthy amount of diagenetic elemental ratio knowledge to the geologic lexicon was (Croudace, 2006). Using an ITRAX X-Ray fluorescence device, elemental ratios were computed and diagenetic processes were discussed. Based on the diagenetic processes described by Croudace, several important results regarding the Bakken and Three Forks system can be assessed.

The ratio of calcium to iron is indicative of biogenic carbonate, can show strong correlation to sedimentary units, and can distinguish shell rich layers (Croudace, 2006). Based on the calcium to iron ratios completed in this study, these interpretations are validated. The ratio of calcium to iron was low in the Lower Bakken, which traditionally has low carbonate content. The ratio dramatically increased into the Three Forks which is considered carbonate rich.
The ratio of potassium to rubidium is considered to be indicative of detrital clay deposited in turbidite muds (Croudace, 2006). Higher ratios generally indicate the absence of turbidite muds whereas lower ratios represent the presence of turbidite muds. The study location with the lowest ratio of potassium to rubidium was the contact between the Bakken and Three Forks. This value appears to be valid; the contact between the Bakken and Three Forks would represent a period of sea-level regression between deep-ocean sequences. The ratio of zirconium to rubidium is considered to be indicative of heavy minerals and can be enhanced in turbidite muds (Croudace, 2006). In our study, the ratios of zirconium to rubidium were fairly consistent but gradually increased from the Lower Bakken into the Three Forks.

The ratio of iron to titanium can be indicative of redox-related diagenesis seen in oxic, or formerly oxic parts of sediment (Croudace, 2006). Furthermore, the ratio of manganese to titanium is an indicator of redox-related diagenesis. The ratio of manganese to titanium was low in the Bakken and then increased into the Three Forks. If this elemental ratio is truly indicative of redox-related diagenesis, our values support the claim. The Bakken Formation is widely regarded to have been deposited in a deep-water marine environment with reduced conditions. Organic carbon needs reduced and sulfate-free environments to develop into Kerogen. The Bakken is a tremendous generation unit because it formed in redox conditions. Based on this manganese to titanium ratio found in this study and the literature published by (Croudace, 2006), the Bakken formed in redox conditions.

Elemental Percentages:

Once again, to avoid confusion, elemental percentages in this study refer to the percentage of total counts rather than the concentration. Elemental percentages should also be considered as a method for evaluating the lithological changes in the subsurface. Percentages that trended up included calcium (1.42% Bakken, 21.30% Three Forks), chlorine (0.35% Bakken, 1.01% Three Forks), and manganese (0.39% Bakken, 0.72% Three Forks). The only elemental percentage that trended definitively down was iron (63.41% Bakken, 27.47% Three Forks).

Elemental percentages should be considered as a potential well-logging method; surface roughness may hinder this technique. This application would not provide cross-well correlation. The elemental ratio technique would have more potential for wide-scale geologic environments.

CONCLUSIONS

Based on the count ratios seen between various elements in all nine study wells, we begin to notice strong trends. The ratio of calcium to magnesium begins to strongly increase in all nine study wells from the Bakken into the Three Forks. The ratio between sodium and chloride does not appear to dramatically differ between the two formations, and the fluorescence count values could be more representative of the drilling fluid rather than the actual mineralogical composition. The ratio between iron and manganese drops significantly between the Bakken Formation and the Three Forks. This means that the Bakken is far more Iron rich than the underlying Three Forks Unit. The ratio of iron to calcium is high in the Bakken and dramatically decreases in the Three Forks. Overall, the two most important ratios observed in this analysis include the ratio of calcium to magnesium and iron to calcium. At the well site a field geologist equipped with a Bruker Tracer IV-SD handheld XRF would be able to analyze drill cuttings and determine that if the ratio of calcium to magnesium was low, the corresponding lithologic unit in the subsurface would be the Bakken Formation. Once that ratio increased above 10, the geologist would immediately recognize that the bore was entering into the Three Forks. The ratio of Iron to Calcium could be used in the same manner but would follow an inverse relationship; a high Iron to Calcium ratio would represent the Bakken whereas a low Iron to Calcium ratio would represent the Three Forks Formation.

This research could be useful for both the industrial and academic sectors. Elemental ratios can clearly distinguish the Bakken and Three Forks Formations and could potentially be used down-bore to determine where the drill bit is located. Elemental ratios can then be used in the academic sector to determine the diagenetic processes associated with the Bakken and Three Forks Formations.

Further work needed for this study includes quality assurance, quality control, and gamma-log interpretation. Obtaining gamma ray logs for all study wells will help determine if elemental ratio mapping can be more accurate for mapping lithological changes in the subsurface.

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Appendix E: Budget Justification

NDIC Oil and Gas Research Council
Williston Basin Advaced Core Analysis and Well Log Consortium

BUDGET OUTLINE

F&A (INDIRECT COST) RATE FOR PROPOSAL = 38.00%

DESCRIPTION	NDIC-OGRC YR 1	Industry Cost Share	NDIC-OGRC YR 2	Industry Cost Share	NDIC-OGRC YR 3	Industry Cost Share	NDIC-OGRC YR 4	Industry Cost Share	NDIC-OGRC YR 5	Industry Cost Share	TOTAL
SALARIES - REGULAR	22,095	15,303	23,620	20,474	20,873	23,852	20,811	25,703	0	53,569	226,300
SALARIES - OTHER	33,078		34,401		35,777		37,208		33,562	5,134	179,159
SALARIES - FACULTY	79,032		82,193		85,481		84,600		103,120	18,525	452,951
FRINGE BENEFITS	34,751	5,356	36,365	7,166	36,527	8,348	36,385	8,996	34,292	19,263	227,449
TOTAL PERSONNEL	168,955	20,659	176,579	27,640	178,658	32,200	179,004	34,699	170,974	96,491	1,085,858
TRAVEL	8,020		0	8,020	0	5,960	0	5,960	0	16,344	44,304
COMMUNICATIONS-PHONE	500		500		500		500		500	500	3,000
COMMUNICATIONS-POSTAGE	500		500		500		500		888	542	3,430
INSURANCE	0		0		0		0		0		0
RENTS/LEASES-EQUIPMENT & OTHER	0		0		0		0		0		0
RENTS/LEASES-BUILDING/LAND	0		0		0		0		0		0
OFFICE SUPPLIES	200		580		501		451		580		2,312
PRINTING-COPIES, DUPLICATING	500		500		500		400		2,000		3,900
REPAIRS	0		0		0		0		0		0
UTILITIES	0		0		0		0		0		0
SUPPLIES-IT SOFTWARE	0	20,000	0	10,000	0	7,500	0	5,000	5,000		47,500
SUPPLY/MATERIALS-PROFESSIONAL	0		0		0		0		0		0
SUPPLIES-MISCELLANEOUS	0	10,000	0	5,000	0	5,000	0	5,000	717	1,283	27,000
IT EQUIPMENT <$5,000	0		0		0		0		0		0
OTHER EQUIPMENT <$5,000	0		0		0		0		0		0
FEES-OPERATING FEES & SERVICES	0	130,500	0	130,500	0	130,500	0	130,500	0	66,000	588,000
FEES-PROFESSIONAL FEES & SERVICES	0		0		0		0		0		0
FEES-SUBCONTRACTS (see Note 1 below)	0		0		0		0		0		0
PROFESSIONAL DEVELOPMENT	2,000		2,000		0		0		0		4,000
FOOD AND CLOTHING	484		500		500		305		500		2,289
WAIVERS/SCHOLARSHPS/FELLOWSHPS	0		0		0		0		0		0
TOTAL OPERATING	12,204	160,500	4,580	153,520	2,501	148,960	2,156	146,460	10,185	84,669	725,735
EQUIPMENT >$5,000	0		0		0		0		0		0
IT EQUIPMENT >$5,000	0		0		0		0		0		0
TOTAL EQUIPMENT	0		0		0		0		0		0
TOTAL DIRECT COST	181,159	181,159	181,158	181,160	181,159	181,160	181,160	181,159	181,159	181,160	1,811,593
F&A (INDIRECT COST) *	68,840	68,840	68,840	68,841	68,840	68,841	68,841	68,840	68,840	68,841	688,405
TOTAL COST	249,999	249,999	249,998	250,001	249,999	250,001	250,000	249,999	250,000	250,000	2,499,998