SDSM&T Shale Research Initiative

Letter of Intent

1.0 Introduction

The South Dakota School of Mines & Technology (SDSM&T) has a long-standing interest in shales and other fine-grained geologic media. For example, the team of SDSM&T and RESPEC, a Rapid City-based engineering firm, were funded in 2012 by the Department of Energy (DOE) Used Nuclear Fuel Disposition program to investigate generic, nonsite-specific issues associated with potential nuclear waste disposal in shale and other fine-grained geologic materials. Shale is a fine-grained, detrital sedimentary rock formed by the consolidation of clay, silt, or mud. This rock type is one of the most common geologic units at the surface of South Dakota and the surrounding region, both at the surface and in the subsurface. Although shale comprises much of the surficial cover in western South Dakota and often extends to depths of thousands of feet, these units are well-represented in the subsurface of eastern South Dakota as well.

2.0 Mission of the Initiative

The development of a shale research initiative at SDSM&T is intended to provide a mechanism for the university, along with its industrial and governmental partners, to lead research in the field of shale geosciences. With the recent funding provided by the state of South Dakota, the research team intends to contribute significantly to the state of knowledge and develop a foundation of research that includes investigating the properties, mineralogy, composition, and uses of various shale units. The research will be applicable for multiple industries where the understanding of the behavior of shale and other fine-grained geological units is critical.

3.0 Strategy for Development

The strategy for the early phases of the development of the initiative will be to advance a demonstration project. The demonstration project will include the acquisition of shale samples from a drilled borehole, whereby advanced material tests, constitutive model fitting, and geomechanical and hydrological computer simulations will be conducted. Depending upon the final location selected, insight into the potential for hydrocarbon production from the Pierre Shale could be evaluated. In situ experiments using downhole logging tools would also be conducted to correlate these measurements to material properties determined in the rock mechanics laboratory. This demonstration will lead to the development of a database of shale properties that are unique to the region and which have potential economic impacts. For example, the time-dependent properties of shale, also known as creep, are relatively unknown. Creep is the process wherein a material deforms over time when subjected to a sustained load. Understanding and quantifying this process has applications within the following areas:

- Oil and gas production from shale, including hydraulic fracturing
- Underground storage of hydrocarbons in mined shale caverns
- Used fuel disposition, waste disposal, and CO_2 sequestration in shale

The transferability of the research results within each of these areas is critical to the success of the research initiative. The demonstration project will identify some of the initial knowledge gaps within the field of shale geoscience, such as the effect of creep, and work to resolve these knowledge gaps while expanding expertise in regional shale properties. Furthermore, it is anticipated that the demonstration project will result in the assembly of a portfolio of knowledge gaps that warrant further study, ideally through funding provided by industry and government collaborators.

While many U.S. universities and private companies have initiated shale research institutes related to hydrocarbon production, this initiative is unique in its multi-industry approach to shale research. The sharing of information between industries is expected to advance the knowledge and understanding of shale behavior further than could be accomplished within the confines of a single industry. The research team is well-suited to realize this goal, having representatives from geology and geological engineering (which includes a petroleum engineering focus), mining engineering, and civil and environmental engineering, along with a long history associated with repository research, hydrocarbon storage, and deep underground waste disposal. In addition, the research team possesses many important industry connections in the areas identified above.

4.0 Ongoing Research Directions Dealing with Shale

The intent of the shale research initiative is to focus on the broad areas of storage technologies and energy development. The initial scope of work is therefore intended to address knowledge gaps that can ideally sustain long-term research interests. Examples of ongoing research directions within these areas are provided below.

4.1 STORAGE TECHNOLOGIES

Storage technology research is a topic of great interest in Europe and has led to the construction of three underground research laboratories (URL) in shale/clay media. These research facilities have been operating for over 15 years: (1) the high-activity disposal experimental site (HADES) in Mol, Belgium; (2) the Mont Terri Project in Switzerland; and (3) the Centre de Meuse/Haute Marne near Bure, France. The Mont Terri Rock Laboratory, for example, is located approximately 200 meters below the ground surface and is accessed via a motorway tunnel as shown in Figure 1. The construction of a URL within the Pierre Shale may be feasible in the future.

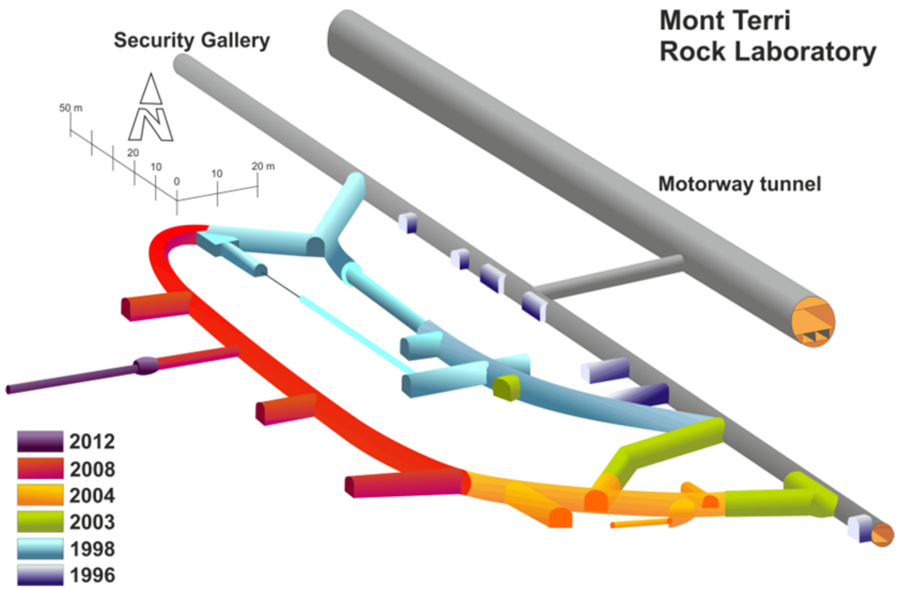


Figure 1. Generic Underground Research Laboratory at Mont Terri.

4.2 ENERGY DEVELOPMENT

Energy development in fine-grained materials is an exciting development that has affected the region in the past decade. Although hydraulic fracturing is extremely important to this energy production, it is important to be able to keep the fractures open after the fractures have been produced. This, then, is a function of the long-term deformational properties of the material. Creep characteristics of the shale and an understanding of the parameters that affect this creep behavior is important from an industrial and scientific aspect.

Therefore, the common denominator in these studies the "creep behavior" of the materials. To this end, the research directions for the initiative will be to determine the constitutive model for the deformational properties of the fine-grained materials that are used for a wide range of applications. This will require geomechanical testing, microscopic analysis of the materials using a range of techniques, analysis, and modeling.

5.0 Scope of Work for Research

At this time, the research effort is envisaged as a series of seven tasks. A general discussion of each task within the overall Scope of Work is provided below.

TASK 1: COORDINATION WITH FEDERAL, STATE, AND LOCAL AGENCIES

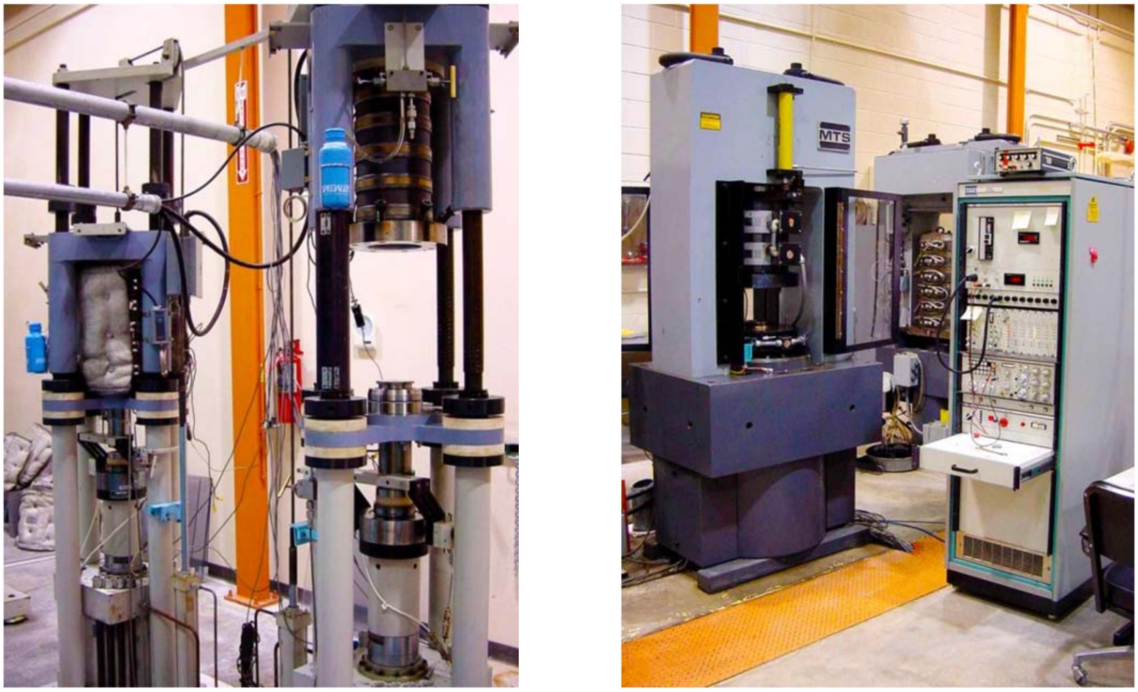
This task will involve coordination between the research team and the South Dakota Geological Survey (SDGS), the South Dakota Department of Environment & Natural Resources (SD DENR), and potentially the U.S. Geological Survey (USGS) to obtain the necessary permits and approvals for the drilling, coring, and sampling activities and to establish mutual areas of research interest among multiple agencies. Coordination with local stakeholders within both counties and townships will also occur as needed. At this time, it is anticipated that drilling will occur on private land that overlies the shale units of interest.

TASK 2 – SAMPLE ACQUISITION

This task will involve drilling, coring, logging, and sampling of the Pierre Shale to a depth of approximately 200 meters. During this task, the weathering profile will be identified through logging exercises and core will be retrieved for advanced material testing. It is also proposed to perform the typical suite of downhole logging including gamma ray, density, neutron porosity, resistivity, delta T sonic, and dipole sonic.

TASK 3 – ADVANCED LABORATORY TESTING

This task will provide the desired material properties for the Pierre Shale to begin the development of a database. Assuming that intact core samples are successfully retrieved during the acquisition activities, the research team will conduct several types of advanced material tests: (1) static triaxial compression and extension with ultrasonic measurements, (2) Brazilian indirect tension strength, (3) static triaxial creep (i.e., constant stress creep), (4) x-ray diffraction (XRD) analyses, (5) water content (i.e., degree of saturation), and (5) permeability/porosity testing. At this time, it is desired that the strength and creep testing be conducted at several different testing temperatures (up to 100°C) and that the creep tests be conducted for a minimum of 30 days (or until samples achieve steady-state); however, the final test matrix will be developed after sample acquisition. This task will especially focus on the constant stress creep testing since time-dependent behavior of shale and mechanisms of creep under confined and long-term conditions are generally unknown. Fundamental research that includes defining the processes by which creep is obtained in shale need to be incorporated within the research related to repository science, energy production, and hydrocarbon storage. The constant stress creep and static triaxial testing apparatuses that will be used in this research are shown in Figures 2a and 2b, respectively.



(A) (B)

Figure 2. (A) Constant Stress Creep and (B) Static Triaxial Testing Apparatuses.

The effects of confining stress and pore pressure on the hydrologic properties of the shale will also be examined in this task by measuring hydraulic conductivity of intact samples. A controlled longitudinal fracture will then be created within the sample and the hydraulic conductivity measurements will be repeated at the same test conditions. Hydraulic conductivity measurements will be made at various magnitudes of confining stress and water pressure. These tests will determine conditions under which sealing of fractures becomes effective and would further evaluate differences between highly-indurated shale specimens and samples from the Pierre Shale. Variations in the hydraulic conductivity as a function of water pressure will also allow assessment of the effect of water pressure on sealing efficiency and will investigate non-Darcian flow under a range of conditions. These tests will be performed in the same testing apparatus as the constant stress creep tests.

TASK 4 – ENERGY DEVELOPMENT TESTING

A program of microscopic analysis involving a range of techniques will be applied to the materials derived from the drilling. This will include scanning electron microscope (SEM) analysis, petrographic analysis, and micro-CT imaging (density computer tomography). The current plan will be to image the pore distribution in the shales including both the macroscopic and nanoporosity. Of special interest will be a study that images the pores using micro-CT before and after the geomechanical testing to examine the effect of the deformation on the porosity. This will allow the effects of the porosity distribution to be incorporated into the model if it proves to be significant.

If cored materials are recovered from portions of the shale section in appropriate locations, the hydrocarbon potential and analysis of possible reservoirs will be evaluated. The lower portion of the Pierre Shale is especially interesting from this standpoint, and this study may be useful in gaining a better understanding of the potential for hydrocarbon production.

TASK 5 – TRANSFERABILITY OF CONSTITUTIVE MODELS

The results of laboratory testing will be used to assess the applicability of the existing strength (i.e., Mohr-Coulomb, Barcelona basic [Alonso et al., 1990], and damage-elastoplastic [Vaunat and Gens, 2003]) and time-dependent (i.e., Norton power law and Salzar et al. [1998]) constitutive models. A combination of analytical solutions and numerical modeling will be used to complete this assessment. It is possible that through the assessment, adjustments will need to be made to the existing models or new models will need to be developed, especially with respect to the creep behavior. For this research, various constitutive models will be incorporated into either finite element or finite difference software codes to determine the basic design concepts for underground openings in shale.

TASK 6 – FUTURE RESEARCH PLAN

The creation of a shale research initiative is intended to provide a mechanism for SDSM&T and its partners to lead the research in shale geoscience. Based on the results from the site investigation and drilling, laboratory testing, and constitutive modeling, the research team will develop a plan for advancing the research. Since the length of this project will only be one year, it is anticipated that the next stage of research would include additional drilling and characterization activities, laboratory testing, advanced modeling of specific applications (i.e., hydraulic fractures, underground storage caverns, and waste repositories), along with additional in situ field experiments.

TASK 7 – FINAL REPORT

The research team will develop a final report that provides the results of the research. This report will be in a format acceptable to the Board of Regents.

6.0 Justification and Benefits

Economic uses of shale vary greatly depending upon its composition and mechanical behavior. In the northern portions of the mid-continent, altered volcanic ash has created thick beds of bentonite that are mined for additives for drilling muds, absorbent applications, and geo-lining materials for pits and reservoirs. The impact of improving the efficiency of energy production for within shale units that possess deposits of hydrocarbons would be significant and would lead to increased energy independence for the U.S. The impermeable nature of shale has long been recognized as a tremendous benefit for potential storage of hydrocarbons, produced water and other wastes from oil and gas production operations, and other types of wastes that require isolation from the surface ecosphere. The university is also equidistant from the Bakken, Mowry, and Niobrara shale plays in the upper Midwest, possesses significant geoscience technical capabilities in several of its departments, and is well-positioned to lead the research effort. To that end, the development of a shale research initiative at SDSM&T has the potential to advance the state-of-the-art in shale research and contribute to an investment in national security, national surety, and energy policy.

The economic development opportunities for the state of South Dakota could be quite significant because research in shale would advance the STEM (Science, Technology, Engineering, and Mathematics) fields and create a considerable number of high- paying jobs, provide for substantial research funding to several of the state universities, and stimulate new development in a number of support industries that require specialized labor of trades. In the end, the funding of a shale research initiative is both timely and beneficial for the state of South Dakota.

7.0 Budget

The total funding available from the state of South Dakota for the research project is $464,000. The project will be completed by June 30, 2015, and the budget is shown in Table 1 with the budget justification provided after Table 1.

Table 1. Proposed Research Project Budget

	Funds	
Salaries		
Senior Personnel (Faculty)	$ 66,672.00	
Student Support	$ 102,823.00	
	Subtotal	**$ 169,495.00**
Equipment and fees		
Equipment	$ 50,000.00	
Equipment usage fees	$ 7,000.00	
	Subtotal	**$ 57,000.00**
Travel	$ 12,505.00	**$ 12,505.00**
External Services		
Geotechnical Contractor	$ 150,000.00	
Drilling Subcontractor	$ 50,000.00	
Logging Subcontractor	$ 25,000.00	
	Subtotal	**$ 225,000.00**
	Total	**$ 464,000.00**

7.1 PERSONNEL

The senior personnel consist entirely of faculty who will be participating in the project. In general, it is anticipated that each of the participating faculty will be funded for one month on the project with the exception of the Principal Investigator, who has committed at least two months to the project work. Eligible personnel earn vacation at the rate of 10 hours per month if they have 15 years or less of service and 13.33 hours per month if their period of service exceeds 15 years. This vacation is handled in the budget by including the appropriate accrual adjustment in the salary rate. This procedure is used for all sponsored research to ensure that each project pays only its prorata share of the vacation authorized. Fringe benefits have been budgeted at 22.95 percent of salaries for some faculty (co-PI and senior researchers) and 7.90 percent of salaries and wages for the PI and for the students. The benefits consist of contributions to social security, the unemployment insurance program, the workmen's compensation program, the flexible benefit fee program, a group insurance program, and matching contributions to the state employee retirement program. Only the actual costs of the fringe benefit programs are charged to the project.

7.2 TRAVEL

Travel funds will be used by the research team to travel back and forth between Rapid City and the proposed field site (assumed to be located near Ft. Pierre, South Dakota). Travel dates are not known at this time; however, the approximate distance from Rapid City to the proposed field site is 150 miles one-way. Out-of-State travel will be required to enlist participation of industrial and governmental partners. The exact number of trips is not currently available. The travel will be conducted in accordance with the State of South Dakota Travel Regulations.

7.3 EQUIPMENT AND EQUIPMENT USAGE

Funds will be expended to purchase a rapid triaxial rock testing system to support the research effort. The amount of funds that will be used for this purchase of this equipment will be approximately $50,000. The microscopic analysis will require equipment usage fees for the scanning electron microscope, X-ray diffraction used for compositional analysis, and the micro-CT imaging.

7.4 DIRECT COSTS

External Consultant Services

Geotechnical Contractor – A total of $150,000 is requested for the geotechnical consultant to perform rock mechanics testing, constitutive model fitting, and finite element modeling during the course of the research project. The rock mechanics tests are per-test costs, while personnel labor is charged at fully burdened rates based on allowable overhead and fringe rates. Travel costs are also included and are in accordance with the state of South Dakota travel regulations.

Drilling Contractor – A total of $50,000 is requested for the drilling contractor to perform the drilling, coring, and sampling of the shale. Depth of drilling is anticipated to be up to approximately 200 meters. The costs include mobilization and setup, drilling and coring at cost per foot, and cleanup and demobilization.

Downhole Logging Contractor – A total of $25,000 is requested for the logging contractor to perform the logging activities as described herein during the drilling. The costs include mobilization and setup, drilling and coring at cost per foot, and cleanup and demobilization.

8.0 References

Alonso, E. E., A. Gens, and A. Josa, 1990. "A Constitutive Model for Partially Saturated Soils," *Géotechnique*, Vol. 40, pp. 405–430.

Salzar, K., K. Konietzky, and R.-M. Gunther, 1998. "A New Creep Law to Describe the Transient and Secondary Creep Phase," *Proceedings of the 4th European Conference on Numerical Methods in Geotechnical Engineering–NUMGE98,* Udine, Italy, A. Cividini (ed.), Wein: Springer-Verlag.

Vaunat, J. and A. Gens, 2003. "Bond Degradation and Irreversible Strains in Soft Argillaceous Rock," *Proceedings of the 12th Panamerican Conference on Soil Mechanics and Geotechnical Engineering,* Boston, Pub. VGE, Vol. 1, pp. 479–484.