Prototyping and testing a new volumetric curvature tool for modeling reservoir compartments and leakage pathways in the Arbuckle saline aquifer: Reducing uncertainty in CO_2 storage and permanence

<u>Area of Interest 2 – Prototype Development and Test</u>

by

Kansas Geological Survey

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1. PROJECT OBJECTIVES

1.1. Project Overview—This proposed project will directly test seismically derived volumetric curvature[1] as a tool for predicting lateral and vertical reservoir boundaries[2] in the Arbuckle saline aquifer in southwestern, KS where formation pressure is greater than supercritical CO_2 pressure. Volumetric curvature (VC) defines how reflectors within a seismic volume are bent or flexed in three dimensions.[2] Curvature attributes have been used to infer fracture swarms, fracture sets, flexures, sags, and paleokarst[2]. However, to date no project has directly validated (1) what these attributes represent, (2) whether they accurately image a feature, or (3) whether they are acquisition or processing artifacts. Murfin Drilling Co. (Wichita, KS) is the industry partner of the Kansas Geological Survey (KGS) in this project and have agreed to donate at least 15 sq. miles of 3D seismic survey from southwestern KS for this proposed study (Figure 1). For this project, a vertical pilot hole will be drilled through the Arbuckle saline aquifer (to basement) and logged. The well will be sidetracked and a horizontal lateral (1500 ft) drilled at the top of the Arbuckle saline aquifer across VC-identified compartment boundaries. Logs, including image and sonic will be run. Sidewall cores, pressure, and fluid measurements acquired within and across compartment boundaries will help characterize the degree of transmissibility.

If the VC technique is validated, it will provide a cost-effective tool for addressing the following critical challenges identified in DOE Focus Area 2: (1) presence or absence of reservoir compartments at a site selected for CO_2 sequestration, (2) delineation of compartment size, (3) lateral and vertical extent of compart-

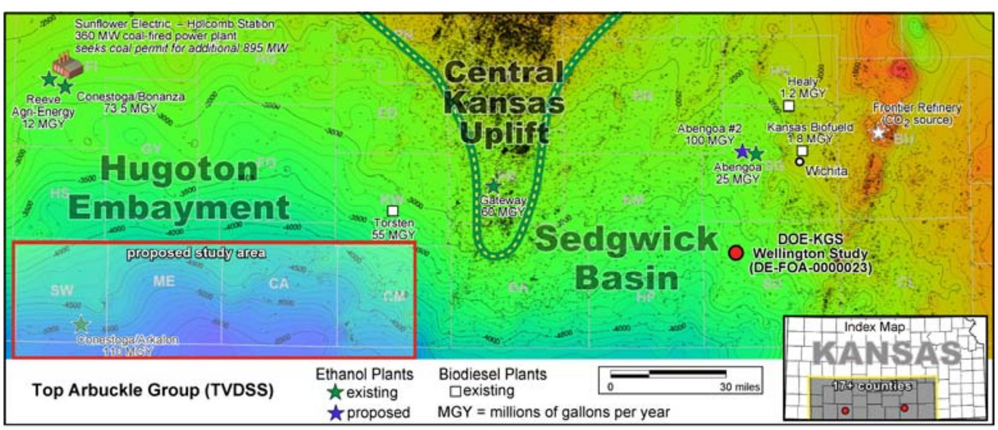

Figure 1. Structure map of top Arbuckle in relation to current DOE-funded project investigating 17+ counties in south-central Kansas. Red box shows general area of proposed project. The Arbuckle saline aquifer is thickest (>600 ft) and deepest (>4500 ft TVDSS) in the proposed study area and therefore has the greatest potential for CO_2 sequestration. Also, shown are nearby CO_2 point sources.

ments, (4) CO_2 transmissibility across compartment boundaries (5) CO_2 storage capacity of large compartments, (6) better estimation of plume containment/permanence (7) presence or absence of correlation between fracture/fault trends in basement and surface with those inferred from VC analysis. This project will leverage the regional geomodel of the Arbuckle Saline Aquifer system over 17+ surrounding counties being developed as part of another DOE funded study[3]. Results from the proposed project will also be used to develop better predictive models for CO_2 storage and permanence in the, DOE-supported project[3] underway in south-central Kansas.

1.2. Relevance of CO_2 Sequestration in Kansas—The Arbuckle saline aquifer in south-central KS is an attractive CO_2 sequestration target. Thickness ranges from 600 to 1000 ft thick and it resides at depths >4500 ft, which is sufficient to sequester supercritical CO_2. Numerous caprocks lie between the Arbuckle and the surface, including thick shales and evaporites. Estimates of CO_2 sequestration capacity in the Arbuckle vary between 1.1 to 3.8 billion metric tonnes[4], representing over a third of estimated capacity for KS[5]. These conservative estimates are based solely on static CO_2 solubility in brine. Dynamic models utilizing *in situ* convection result in greater CO_2 sequestration as heavier CO_2-saturated brine sinks and new unsaturated brine rises to come in contact with injected CO_2. Additionally, comparable volumes of CO_2 will be sequestered as residual gas[6-10] and by long-term mineralization.

1.3. Problem Statement—Arbuckle strata located a few hundred feet below the suprajacent pre-Simpson unconformity are usually fractured and brecciated[11-13]. This brecciation is thought to be a result from early compaction and collapse of paleocaverns below the Ordovician pre-Simpson or later pre-Pennsylvanian unconformities. Core, image logs, production and injection rates, and drilling records from thousands of vertical wells and 3D seismic images confirm that oil and gas production from the Arbuckle is controlled by paleokarst distribution. However, most of the production is from its upper 50 ft and only a few wells actually penetrate the entire Arbuckle. Moreover, no direct data exist for determining the dimensions of paleokarst features or their architecture. Characterization of the Arbuckle at off-structure locations is also limited. As such, a cost-effective seismic tool that can better image the entire Arbuckle is needed. Imaging lateral and vertical boundaries within karst-overprinted strata is especially critical to reduce uncertainty in CO_2 storage, movement, and permanence. Porosity development from deeper within the Arbuckle, also important in sequestration, will be investigated by performing stepwise VC with depth to compare and contrast patterns and relate them to internal unconformities and structure.

1.4. Prototype Development and Proposed Testing—As part of a previously funded DOE project,[14] the Kansas Geological Survey (KGS) developed and successively demonstrated application of a novel seismic tool (VC analysis) to indirectly image karst compartments in Mississippian reservoirs in Gove County, KS and Cheyenne County, CO. Using this technique, KGS scientists found that adjacent wells with significantly different production rates were likely draining different karst compartments. VC attributes also revealed that some wells very near paleokarst boundaries had low production rates. These observations were used to improve history matching and forecasting by simulation studies (Figure 2). These results indicate that VC may be a cost-effective tool for identifying reservoir compartmentalization in paleokarst and fractured reservoirs. It is difficult to infer from VC attributes if a compartment boundary represents subaerial erosion, paleocavern roof sags, flexure, or faulting. It is also difficult to determine boundary transmissibility without direct testing. However, better understanding of the petrophysical properties of these boundaries is critical for modeling CO_2 storage and plume dispersion. Therefore, the proposed project will test the efficacy of the VC mapping tool to image karst compartments in the Arbuckle saline aquifer by closely examining an inferred compartment by drilling, logging, coring, and testing a horizontal lateral well across that boundary. The major steps include: (1) pre-spud identification of Arbuckle paleokarst, fracture

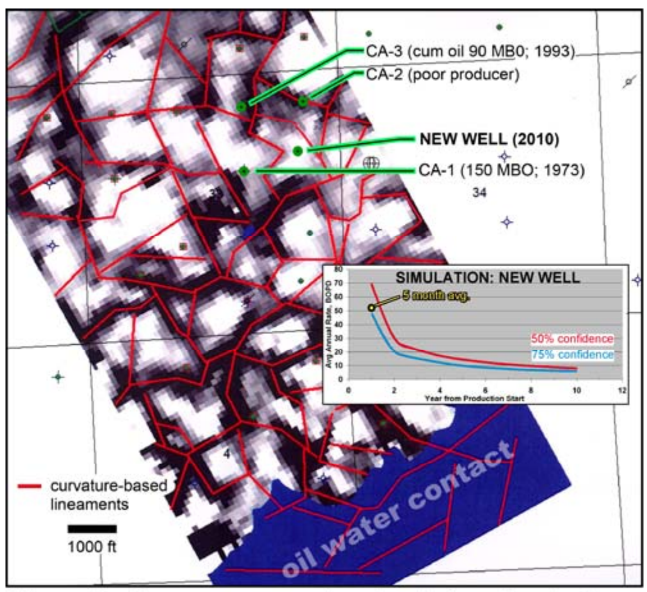

Figure 2. Curvature map showing inferred paleokarst compartment boundaries from field in Cheyenne County, Colorado. Recent well located using results from VC-constrained simulation.

sets, and fault-bounded compartments and their vertical extent using VC attributes derived from 3D seismic data, (2) test initial VC-identified compartment boundaries by history matching well performance of existing wells, (3) drill and log a pilot hole through Arbuckle (to basement) and then sidetrack and drill a 1500-ft horizontal lateral wellbore through paleokarst and fault zones interpreted from VC attributes, (4) run formation evaluation tools (image logs, pressure tools, fluid sampler, and rotary sidewall coring) to collect data on boundary architecture and petrophysics (5) compare pre-spud interpretation of compartmentalization with results of drilling and logging program to directly confirm or refute the presence of compartment boundaries, and if present, characterize their vertical and lateral extent, and flow properties, and (6) model and simulate CO_2 sequestration capacity and containment within and across boundaries.

2. MERIT REVIEW CRITERION

2.1. Scientific & Technical Merit (*subsections correspond to those listed in FOA on p. 31*) **(a)** The proposed project will address DOE objectives of seeking to cost-effectively and safely sequester and monitor CO_2 in geologic formations. This project fits within two focus areas under the DOE's Core R&D program: (1) Geologic Storage within deep saline aquifers, and (2) Simulation and Risk Assessment. This Area of Interest 2 project proposal will test and refine a new tool (VC) to better image compartments within a heterogeneous paleokarst saline aquifer. Successful testing and refinement of the VC tool will fill a technology gap related to i) selecting sufficiently large compartments in the Arbuckle saline aquifers that are amenable to large-scale CO_2 sequestration, and ii) reducing uncertainty of CO_2 movement and containment. **(b)** The VC technique was successfully applied within Mississippian paleokarst oil and gas reservoirs in KS and CO, where it was used to identify large undrained compartments within existing fields that were subsequently targeted for infill drilling.[14] This proposal will directly examine if the VC technique is capable of i) imaging paleokarst compartments, and ii) defining the lateral and vertical extent of the compartment boundaries. **(c)** The relation between structural curvature of geological surfaces and increased fracturing in reservoirs is recognized.[15] Several studies[16-17] have utilized curvature of interpreted 3-D seismic horizons to predict fracture trend and intensity, and more recently, the VC has been used to map lineations believed to represent faults and fractures.[2, 18-19] Several studies[20-21] have used comparisons with image data from horizontal wells to show that VC can successfully predict fracture intensity. The results of DOE project DE-FC26-04NT15504 suggest that VC can be used to delineate reservoir compartment boundaries that impact production. **(d)** VC is currently a relatively low-cost, commercially available product that has been used for several years by a number of petroleum companies for fracture detection, but its usefulness in delineating compartment boundaries has not been fully studied. If a methodology is developed for successfully using this tool to delineate compartment boundaries and leakage pathways, it will help to identify candidates for CO_2 storage. **(e)** The proposed study area would become the western anchor point for regional DOE Arbuckle sequestration assessment project[3]. Importantly, the study area will be near the coal-fired Sun-flower Electric power plant (360 MW; permit pending for additional 895 MW)[22] (Figure 1). Also, there are about 10 ethanol and biodiesel plants operating or planned in southwestern KS.[23] The VC tool can be used to cost-effectively, assess geomechanical processes and compartmentalization within the Arbuckle saline aquifer, thus enabling realistic simulation and risk assessments prior to large-scale super-critical CO_2 sequestration. Additionally, this proposed study will promote close interaction with major operators in the KS energy industry who will be active developing surface infrastructure for future sequestration operations. **(f)** Seismic data may not image all geologically significant boundaries and leakage pathways for it may have insufficient resolution to adequately define smaller reservoir compartments. **(g)** Anticipated benefits include: i) a cost-effective method to identify large compartments in the Arbuckle, ii) realistic determination of tonnage of CO_2 that can be sequestered in a compartment, iii) realistic determination of CO_2 plume migra-tion and permanency, iv) determination of leakage through faulted multi-storied karst deposits to identify high risk areas for CO_2 sequestration, and v) possible use of less expensive satellite imagery and gravity/magnetic data to identify leakage pathways.

2.2. Technical Approach and Understanding (subsections correspond to those listed in FOA on p. 31)

(a) All PIs and Co-PIs are currently part of the DOE-supported CO_2 sequestration potential study.[3] The VC tool was developed and demonstrated successfully in a previously funded DOE project[14] to: i) image compartments in Mississippian karst reservoirs in KS and CO, and ii) identify undrained compartments for infill drilling. S. Bhattacharya (a PI in this proposal) was the PI in that project.[14] J. Rush (also a PI in this proposal) has extensive experience in geologic modeling, wellsite operations, and horizontal drilling. He has published on Permian paleokarst[24] and karst-modified fractures[25] and is currently conducting outcrop-based research on multi-storied Ordovician paleokarst in California. **(b)** The workplan, tasks, and subtasks are based on the PIs, Co-PIs, and subcontractors previous experiences with similar research programs. The workflow is typical of multi-disciplinary industry projects. **Year-one** objectives include data acquisition, processing, initial geologic modeling and seismic (VC) interpretation, and drilling and logging operations. **Year-two** objectives are formation evaluation, final seismic interpretations and VC analysis, and completing structural/geologic models. **Year-three** involves simulation studies to better estimate CO_2 sequestration capacity and permanence in select compartments, and technology transfer of lessons learned. **(c)** The logic and completeness of the proposed Statement of Project Objectives (SOPO) is outlined in detail under Section C of the SOPO. **(d)** The timeframe is based upon extensive KS drilling experience of Murfin. If awarded, the seismic data will immediately be made available for re-processing and analysis. Cost and time estimates for reprocessing have been obtained from professional vendors well known in KS. Over 292 wells have been drilled to basement in the 17+ county area including southwestern KS, and so substantial drilling problems are not anticipated. Murfin has confirmed the well design, drilling operations, and logging program. Contingencies for possible cost overruns have been included in the budget. Given KGS staff experience and commitments it is reasonable to expect timely completion of the proposed within budget. **(e)** All research methods are aimed at using the VC tool to reduce uncertainty in delineation of compartments in the faulted/fractured paleokarst Arbuckle saline aquifer. PIs, Co-PIs, and subcontractors are practicing professionals who are well-suited for their respective Tasks and Subtasks, and have a demonstrated track record of successfully managing and completing many DOE projects. The industry partner Murfin has extensive experience in drilling Arbuckle wells. The directional drilling and logging contractor is an industry leader in horizontal drilling technologies and tool-push formation evaluation. Subcontractors, D.

Hedke & S. Nissen, who will carry out seismic processing, interpretation, depth conversion, and VC algorithms and volumes, have a proven record of excellence and service. Geomechanical expertise will also be provided by J. Lorenz. Petrel geologic modeling, and CMG-GEM & WINPROP simulation software are licensed to KGS. **(f)** As a technology end-user, Murfin is encouraged with drilling results to date based on VC and would like to see tool validation and further testing.

2.3. Applicant/Team Capabilities (subsections correspond to those listed in FOA on p. 32)

(a) Details regarding credentials and experience of key personnel can be found in the biographical sketches. In short, the team consists of key personnel filling every required specialization: Murfin (drilling & logging operations), S. Bhattacharya (reservoir & simulation engineer), J. Doveton (log analyst), D. Hedke (geophysicist), J. Lorenz (structural geologist), D. Newell (geochemist), S. Nissen (geophysicist: VC specialist), J. Rush (carbonate geomodeler), and L. Watney (stratigrapher). **(b)** S. Bhattacharya has managed and successfully completed many DOE contracts. J. Rush joined KGS in 2009, with 8 years oil and gas industry experience modeling carbonate reservoirs and drilling horizontal wells. S. Nissen is an industry-experienced geophysicist with extensive publications in VC analysis[2]. The KU Center for Research (KUCR) is responsible for submitting all proposals for KU researchers seeking external funding. In addition, KUCR helps researchers by negotiating contracts, providing pre-proposal and post-award services, and administering compliance oversight. **(c)** The clarity, logic and effectiveness of the project organization, including subcontractors, are detailed under Project Organization and Structure in the PMP section, and summarized in above sections 2.3a and 2.3b. **(d)** The quality, availability, and appropriateness of the facilities and equipment to perform project tasks are detailed under Equipment Appendix to the SOPO section.

2.4 Project Management Plan (*subsections correspond to those listed in FOA on p. 32*) **(a)** The Gantt chart, under Section F (Resource Loaded Schedule) of the PMP section, details the time-frame of every task and subtask within the 3-year project. Milestone chart (Section D. Milestone Log of the PMP section), shows date of completion for major tasks and subtasks and relationship with subsequent tasks. The schedule of field activities is a conservative estimate developed through discussions and agreement with Murfin. **(b)** All quotes have been obtained from subcontractors. A 10% cost contingency for drilling and logging program is budgeted. **(c)** KUCR was established to manage externally funded projects at KU, and has the experience to monitor costs over the project life. PIs and Co-PIs have successfully worked with each other and KUCR on many DOE-funded projects. Monthly meetings will be held for the core team and subcontractors to review and monitor progress. Corrective action taken to ensure completion of major tasks within the stated timeframe. **(d)** **(1)** One contact person will be assigned for each subcontractor and will be held responsible for completion of respective tasks. Quarterly review meetings will review progress and enhance integration between KGS and its subcontractors, and to investigate new ideas and opportunities for analysis. Technical details and schedule, as stated in this proposal, have been agreed upon by KGS partners, Murfin, and associated subcontractors and vendors. **(2)** PIs will keep DOE project manager informed with technical reports, as required and will also travel to DOE-hosted meetings to present results. PIs will be available to DOE via telephone and e-mail. **(3)** External stakeholders include oil & gas producers, power companies, the public, regulatory bodies and state legislature. An outreach and technology transfer program will include presentations to stakeholders about project progress, lessons learned, and technical issues related to CO_2 sequestration. Detailed results will be shared through peer-reviewed publications. A website hosted by KGS will make reports and data available for public access, and will be linked to NATCARB database(s). **(e)** Evaluation of the Murfin's donated 3D seismic survey by D. Hedke and S. Nissen indicate it is adequate for VC analysis. Reservoir simulation studies will be carried-out to history-match well performance to determine how drain compartments. A successful history match will indirectly validate the VC tool for imaging compartments. Risks related to drilling vertical and horizontal wells are considered minimal, as 292 wells have been successfully drilled through Arbuckle to basement within the 17+ county area around southwestern KS. A leading oil services company will conduct directional drilling, tool-push logging, and lateral testing. Formation water geochemistry will be sub-contracted to Kansas State University, which has an extensive geochemical lab and an established record in performing such studies. **(f)** A completed environmental questionnaire submitted along with this proposal will detail the environmental impact of the drilling program. The proposed well is within an active drilling lease under the jurisdiction of the Kansas Corporation Commission. The operator will ensure that all laws and regulations are followed related to assessing, monitoring, and reporting potential impacts to air, land and water resources, and including waste disposal. **(g)** Regular reports will be submitted following DOE requirements detailing progress, field activities, data collected, and analysis carried out.

3. Relevance and Outcomes/Impacts - It is expected that successful prototyping of the VC tool will enable the following: a) refinement of the technique and determination of best practices to identify paleokarst compartments and fault/fracture sets, b) characterization of the vertical and lateral extent of compartment boundaries, c) better estimates of CO_2 sequestration capacity in compartments, d) better estimates of containment and leakage of CO_2 plume at compartment boundaries, and e) correlation of fault/fracture trends on surface (from satellite imagery) and basement (gravity/magnetic analysis) with karst compartment boundaries within Arbuckle aquifer to infer possible leakage pathways. VC algorithm fine tuning constrained by analysis of data from the lateral well is expected to optimize the process of imaging karst compartments and generating paleokarst distribution/probability maps, which can be used in simulation models to better assess risks in CO_2 sequestration. Interval-based VC analysis may reveal non-sealing fault/fracture corridors in vertically stacked paleokarst systems that probably result from upward fault/fracture propagation.

4. Roles of Participants – Contact PI, J. Rush has considerable academic and industry experience in carbonate reservoir characterization, geomodeling, horizontal drilling, and wellsite operations and management. S. Bhattacharya, with 12 years petroleum experience in Kansas fields, will be the 2nd principal investigator, and has considerable experience in reservoir simulation. Other KGS co-investigators include: Watney, structural geology and regional stratigraphy; D. Newell, diagenesis and cap rock integrity; J. Doveton, log petrophysics and core-log modeling; and J. Xia, gravity-magnetic modeling and interpretation. From The Kansas State University Geology Department, S. Datta will conduct aquifer geochemistry. S. Nissen will produce VC attributes. J. Lorenz will work with J. Rush, L. Watney, and D. Newell to characterize fractures. Murfin engineers and geologists will supervise drilling and logging. Hedke-Saenger Geosciences will reprocess and depth convert seismic data.

5. Multiple Principal Investigators - J. Rush, the contact PI, will oversee data integration, well planning and logging operations, geological analysis, geomodel construction, and data integration and synthesis. S. Bhattacharya, the 2nd PI, will oversee engineering studies, well testing, simulation, and geochemical analysis. ***A. Coordination and Management Plan:*** Rush and Bhattacharya will work closely together at the KGS and communicate with team members to assess progress using emails, biweekly conference calls, and meetings. Publications will be encouraged with authorship-order based on contribution. KU's intellectual property policy will be followed and conflicts resolved promptly and professionally.

STATEMENT OF PROJECT OBJECTIVES (SOPO)

Prototyping and testing a new volumetric curvature tool for modeling reservoir compartments and leakage pathways in the Arbuckle saline aquifer: Reducing uncertainty in CO_2 storage and permanence

A. PROJECT OBJECTIVES - This project will directly test seismically derived volumetric curvature (VC) as a tool for detecting vertical and lateral reservoir boundaries in the Arbuckle saline aquifer in southwestern KS. A vertical pilot well will be drilled and logged through Arbuckle followed by a sidetracked horizontal lateral entering the top part of the Arbuckle and penetrating a compartment boundary, as imaged by the VC analysis. **Phase 1** (Year 1) objectives are to collect geologic and engineering data, reprocess seismic, conduct VC analysis, initiate Petrel geologic modeling, simulate and history match performance of existing wells to verify VC-identified compartments. Field activities include drilling, logging, and testing the vertical well and sidetracked horizontal lateral. **Phase 2** (Year 2) objectives are to complete formation evaluation, re-interpret seismic, optimize VC, model seismic attributes, followed by integration of seismic, VC analysis, and well data into a comprehensive geomodel. **Phase 3** (Year 3) objectives include simulation studies to model CO_2 storage and plume movement (dispersal, leakage at compartment boundary, and attenuation over time), and thereby determine the effectiveness of VC as a tool to better estimate CO_2 sequestration capacity and permanence in karst-compartmentalized saline aquifers.

B. SCOPE OF WORK - Phase 1: Rush, Bhattacharya, and Watney will collect well and seismic data. Hedke will reprocess and depth convert seismic data. Nissen will interpret seismic and conduct pre-spud VC analysis. Rush will build the geomodel. Bhattacharya will begin simulation studies of compartments identified by VC analysis. The KGS team and Murfin (operator) will decide on well location. A vertical pilot well will be drilled through Arbuckle and logged, and then sidetracked to drill horizontal lateral. **Phase 2:** Log analysis will be performed by Doveton. Image processing and interpretation will be provided by service company and verified by Rush, Doveton, and Lorenz. Bhattacharya will analyze pressure data and oversee routine and special core analysis. Kansas State University will perform water geochemistry, while Newell will perform XRD on clays and diagenetic studies. Nissen will optimize VC curvature and provide final seismic interpretations. Rush will construct the comprehensive geomodel. **Phase 3:** Bhattacharya will simulate CO_2 sequestration and model plume dynamics to evaluate permanence of injected CO_2. Team members will present results to DOE, public, industry/technical conferences, and prepare manuscripts for peer-reviewed journals.

C. TASKS TO BE PERFORMED - Task 1. Program Management and Planning (PMP): This task shall include all work elements required to maintain and revise the PMP, and to manage and report on activities in accordance with the plan. It shall also include the necessary activities to ensure coordination and planning of the project with DOE/NETL and other project participants. **Task 2. Initiate Geomodel development:** Data from existing wells in the study area be interpreted to build a geomodel of the Arbuckle saline aquifer. **Subtask 2.1. Collect seismic, geologic, and engineering data**: Wireline log, production, core, DST, geo-reports, water analyses, and well test data will be collected from wells in study area. **Subtask 2.2. Petrel data import and modeling:** A preliminary geomodel will be built with Petrel software. Process will include data import and analysis, well correlation, layering, and log upscaling. **Subtask 2.3. Analysis of gravity and magnetic data:** Gravity-magnetic data from KGS's database will be analyzed to map basement structure and identify faults/fractures. **Subtask 2.4. Remote sensing analysis:** Available remote sensing data shall be interpreted to map surface lineaments and faults. **Task 3. Pre-spud seismic**

and volumetric curvature: Subtask 3.1. Reprocess 3D seismic data: Prestack time migration and depth conversion will be carried out on 3D seismic data donated by Murfin. **Subtask 3.2. Compute volumetric curvature attributes:** Long- and short-wavelength curvature volumes will be generated from the reprocessed 3D seismic data. Short-wavelength curvature can delineate localized fracture systems, while long-wavelength curvature can enhance subtle flexures related to fracture zones below seismic resolution.[26] **Subtask 3.3. Generate synthetic seismograms:** Available sonic and density logs will be used to generate synthetic seismograms for tying seismic horizons to stratal units. **Subtask 3.4. Interpret reprocessed 3D seismic volume:** Faults and key horizons on the top and within the Arbuckle will be mapped using the reprocessed 3D seismic data. Karst features (compartments) will be identified. **Subtask 3.5. Impedance inversion of seismic volume:** Inversion will be constrained to borehole information. **Subtask 3.6. Generate, extract, and integrate single-trace attributes with petrophysics:** Single-trace attributes (e.g., instantaneous amplitude, frequency, phase) and spectral decomposition will be extracted for key strata. Statistical methods and/or neural networks will identify ties between seismic attributes and petrophysical properties. **Subtask 3.7. Interpret VC:** Curvature will be extracted along key horizons and lineaments representing potential fault/fractures and compartment boundaries will be identified. Interpretations along multiple horizons will show vertical variations in the features. **Subtask 3.8. Import seismic interpretations into Petrel:** Seismic horizons, faults, and compartment boundaries and their attributes will be loaded into Petrel. **Subtask 3.9. Complete initial Petrel geomodel:** Seismic horizons will be depth converted to rebuild a structural model. Facies and properties within compartments will be inferred using VC and production data. **Task 4. Validate reservoir compartmentalization using history matching by simulation: Subtask 4.1. Develop Petrel geomodel for reservoir simulation:** Petrel software will be used to build a fine-scale geomodel for the Arbuckle by integrating data from wireline logs, cores, geo-reports, and production and pressure tests from existing wells. The model will be upscaled to a flow-unit based multi-layered model for simulation studies. **Subtask 4.2. History match well performance – productive/non-productive wells:** Reservoir simulation studies will history match performance of wells. Log analysis, VC mapping, and simulation will determine if non-productive wells result from absence of pay and/or small compartment sizes. **Subtask 4.3. Indirect validation of reservoir compartments and fluid flux across its boundaries:** Simulation studies of productive wells will determine any effects of compartment size on their performance (i.e., initial rate, decline rate, pressure change, etc.). Simulations will offer indirect validation of reservoir compartments as imaged from VC mapping, in absence of direct physical tests. **Task 5: Locate and plan for drilling - Well #1: Subtask 5.1. Locate Well #1:** The well will be located so that a lateral of 1500 ft will intersect paleokarst/fault zones as imaged from VC analysis. The compartment boundary will be cored and tested to evaluate its transmissibility and petrophysical properties **Subtask 5.2. Permitting for Well #1:** After site selection, necessary permits will be obtained. **Subtask 5.3. Finalize, drilling, mud, and logging program:** Mud program will be optimized for potential lost-circulation zones and logging program. The logging program is designed to obtain petrophysical data (i.e., porosity, saturation, well bore imagery, pore size distribution, lithology, and sonic velocity). **Task 6. Drilling & Testing: Subtask 6.1. Drill vertical pilot to basement**: The vertical pilot will be drilled through the Arbuckle using conventional rotary methods. **Subtask 6.2. Wireline Logging:** A "triple combo" and full-wave sonic will be run in the pilot well. **Subtask 6.3. Test select Arbuckle zones:** DSTs will be run on zones within the Arbuckle to test for pressure and collect fluid samples. **Subtask 6.4. Set cement plug above Arbuckle:** A cement plug will be set in the vertical pilot well to aid open-hole sidetrack operations. **Subtask 6.5. Open-hole sidetrack and drill lateral well (< 1500 ft):** Drill a directional hole from plug and TD ~25 ft vertically below top Arbuckle. Run and cement casing, test cement, and perform leak-off test to determine the fracture gradient. Drill horizontal lateral to intersect nearby compartment boundaries. **Subtask 6.6. Tool push logging through open hole lateral:** The wellbore will be conditioned for tool-push logging operations including "triple combo" (GR, neutron-density, and resistivity), image logging. **Subtask 6.7. Test for pressure and fluids and rotary side wall coring:** Using image logs, intervals within and bounding paleokarst, fractures, fault damage zones will sampled for pressure and fluids to ascertain the extent of compartmentalization. Rotary sidewall cores will be recovered from host strata, fault damage zones, paleokarst, and clays. Samples will provide petrophysical and geomechanical properties, as well as information on diagenesis and fault seal. **Task 7. Formation evaluation: Subtask 7.1. Log Analysis:** Analysis of wireline logs will: i) calibrate with core measurements to predict porosity and permeability; ii) integrate compression, shear velocity, and anisotropy parameters determined from dipole sonic logs and seismic data; iii) estimate rock mechanical properties from dipole sonic waveforms; iv) image analysis to determine location and orientation of natural fractures; and v) evaluate formation invasion to identify flow-units. Other analysis shall include facies-specific permeability and porosity predictions using numerical models and stratigraphic correlations to other wells with wireline logs. **Subtask 7.2. Geochemical analysis of formation water:** Geochemical analysis (cations, anions, TDS etc.) on water samples collected from different Arbuckle zones within and on either side of the compartment boundary will be conducted to determine if the boundaries are barriers or conductive to flow. **Subtask 7.3. Routine and special core analysis:** Sidewall cores from the horizontal lateral will be analyzed for induced and natural fractures. Petrophysical properties of compartment boundaries will be generated from laboratory analysis (porosity-permeability trends, relative permeability, hysteresis end point saturations, capillary pressure, and rock mechanical properties). **Subtask 7.4. Pressure analysis:** Pressure analysis along horizontal lateral will be conducted to determine if the boundaries are conductive to fluid flow. **Subtask 7.5. XRD on cuttings/core for fault/seal analysis:** Sidewall cores from the Arbuckle cap rock and saline aquifer will be analyzed for occluding cements. Isotopic, petrographic, and fluid-inclusion analysis shall be carried out to understand if diagenesis can prevent CO_2 leakage. **Subtask 7.6. Background aquifer velocity modeling:** Core, log analysis, and water analysis from Well #1 will be compared to similar data from nearby wells nearby to determine hydraulic gradient, and understand the continuity and competence of aquitards. **Task 8.0. Validate and optimize VC. Subtask 8.1. Confirm pre-spud VC interpretations via interpretation of faults, fractures, karst sinks, & differential compaction.** Compare sizes and types of features identified on image log with lineaments and other features interpreted from VC analysis. **Subtask 8.2. Optimize VC wavelength selection:** Curvature will be generated at a suite of wavelengths to identify the best wavelengths for imaging features identified from the image log. **Subtask**

8.3. Recompute VC, generate new impedance inversion, integrate petrophysical analysis from new well: VC will be recomputed for the entire seismic volume at wavelengths optimal to identify fault, fracture, and compartment boundaries. Full-wave sonic logs will be used to improve impedance inversion. Information from the new well will be used to update the tie between seismic attributes and petrophysical properties. **Subtask 8.4. Revise 3D seismic interpretation and update lateral and vertical extent of seismically defined reservoir compartments.** Interpretations of karst features and compartment for multiple vertical horizons will be refined using the new VC volumes and data from the new well. **Task 9. Revise Petrel geomodel: Subtask 9.1. Build structural model incorporating new well data and intermediate 3D seismic interpretation:** The depth-converted 3D seismic volume will be imported into Petrel. Seismically-mapped faults will be correlated to image log features. **Subtask 9.2. Fault seal analysis: shale offset & shale gouge ratio analysis:** Investigate top seal offsets across faults. Identify mineralogy of clay types using x-ray diffraction. Create shale gouge ratio curves from well logs.[27] Create formation pressure curves to identify depths where capillary pressure may exceed sealing capacity. **Subtask 9.3. Import seismic attribute volumes/maps: paleokarst probability & porosity:** Use seismic attribute volumes/maps to condition porosity and discrete fracture network models. Use paleokarst probability derived from VC to determine vug pore types/permeability. **Subtask 9.4. Build lithofacies model and paleokarst model:** Build a stratigraphic facies model lacking paleokarst overprint using variography, vertical proportion curves, histograms, trend maps, internal cycle-scale based correlations, and probability maps. Build paleokarst model based upon VC interpretation, paleokarst probability, and rock fabrics derived from image logs and core data.[28-29] **Subtask 9.5. Combine facies model with paleokarst overprint:** Create filtering routine and functions whereby non-null cell values from paleokarst model replace "host rock" lithofacies cells. **Subtask 9.6. Build property models:** Rock fabrics with unique porosity, permeability, and capillary pressure functions will be determined for both host strata and paleokarst lithofacies. Touching-vug pore types will likely be modeled for paleokarst facies. Property models will be conditioned to facies and co-kriged to other attributes. **Subtask 9.7. Build discrete fracture network (DFN) model:** A DFN model will be built using the Petrel DFN module. **Subtask 9.8. Complete Petrel Geomodel** Final comprehensive model will be reviewed by KGS team members, Nissen, and Murfin. **Subtask 9.9. Correlate surface and basement fracture/fault trends with VC mapping:** Surface lineaments will be overlaid on compartment boundaries delineated from VC analysis and gravity/magnetic analysis of basement to identify any CO_2 leakage pathways. **Task 10. Simulate CO_2 sequestration capacity in Arbuckle Saline Aquifer:** A multi-layer aquifer geomodel (using CMG-GEM and WINPROP) will be constructed to include aquifers/aquitards and cap rock of the Arbuckle. Simulator input shall include data such as reservoir compartment size, petrophysically defined compartment boundaries, relative permeability and hysteresis curves, porosity-permeability trends, and aquifer/aquitard-specific water chemistry and pressures. **Subtask 10.1. Estimate CO_2 sequestration potential of aquifer:** Simulation studies will determine: CO_2 storage capacity in Arbuckle compartments, optimal injection rates and best injection intervals, storage capacity of various trapping mechanisms (residual gas saturation, brine solution, and mineralization), size and fate of CO_2 plume, plume interaction with the compartment boundary, and time frame over which CO_2 flux becomes negligible. **Subtask 10.2. Evaluate long-term effectiveness of cap rock:** Free-phase CO_2 accumulation and pressure increase under the cap rock and at compartment boundaries shall be quantified upon CO_2 injection. Interactions between CO_2 and aquifer cap rock and compartment boundaries will be modeled to evaluate location and changes in porosity. **Subtask 10.3. Quantify CO_2 sequestered in brine solution:** Simulation studies will be used to estimate CO_2 tonnage sequestered in brine under aquifer salinity, pressure, and temperature in presence of *in situ* convection currents and background aquifer flow. **Subtask 10.4 Quantify CO_2 sequestered as residual gas saturation:** Simulation studies will be used to estimate CO_2 tonnage sequestered as residual gas saturation including effects of absolute and relative permeability, buoyancy, dip, background flow gradient, and alternating layers of aquifers and aquitards. **Subtask 10.5. Quantify tonnage of CO_2 sequestrated by mineralization:** Simulation studies carried out over varying time scales (1000 to 10,000 yrs) will help quantify potential CO_2 tonnage locked permanently as minerals. **Subtask 10.6. Outline field management plans to maximize CO_2 entrapment:** Scenarios, such as simultaneous and sequential injection of CO_2 and brine and use of horizontal injectors, will be simulated to model plume development and incremental CO_2 sequestration, and estimate maximum injection rates that do not compromise cap rock and compartment boundaries. **Subtask 10.7. Monte Carlo simulation estimate total CO_2 sequestration capacity:** Monte Carlo simulations will be used to stochastically model uncertainty in CO_2 storage using probability distributions of petrophysical data. **Task 11. Simulate permanence of CO_2 sequestration in Arbuckle:** Near- and long-term leakage scenarios across cap rock and the compartment boundaries will be simulated. **Subtask 11.1. Model CO_2 plume leakage/containment at compartment boundary:** Simulation studies for plume leakage and containment will be carried out for different compartments. **Subtask 11.2. Model CO_2 plume for 100, 1000, and 5000 yrs after end of injection:** Simulation studies will be undertaken to model free-phase CO_2 plume development, migration, and attenuation for up to 5000 years to verify containment within the reservoir. Studies will be conducted to understand how free CO_2 behaves upon encountering sealing or conductive faults. **Subtask 11.3. Plume attenuation during and after injection:** Simulations will quantify free phase CO_2 accumulation (and its pressure) under the cap rock and at compartment boundaries with CO_2 being injected to force the free phase CO_2 to travel through a succession of aquitards and aquifers before reaching the cap rock. **Subtask 11.4. Model effects of natural aquifer flow on CO_2 plume:** Scenarios will be simulated to study the sensitivity of plume dispersion to background aquifer velocity and direction. **Subtask 11.5. Time frame for negligible free phase CO_2:** Coarse-grid simulations for 10,000+ years shall be run to determine the time necessary to sequester all injected CO_2 into solution, residual gas saturation, and minerals. **Task 12. Technology Transfer:** Data and results shall be conveyed to stakeholders at meetings and with publications, and with a web-site. **Subtask 12.1. Build and maintain project website with interactive access to data and analyses via graphic display and analytical web tools:** The project website will be hosted at the KGS and will be regularly updated with project results and progress. **Subtask 12.2. Link project web-site to relevant DOE databases:** The KGS online GIS map viewer shall interface with DOE's NatCarb and Southwest Regional Carbon Sequestration Partnership. **Subtask 12.3. Submit**

project results to peer reviewed journals for publication: Project results will be published in peer-reviewed technical journals.

D. Deliverables: Periodic, topical, and final reports will be submitted in accordance with the Federal Assistance Reporting Checklist. In addition the following products will be submitted: **(1)** Task 7: petro-physical properties of compartment boundaries to better model CO_2 plume leakage at compartment boundaries; **(2)** Task 8: a refined and validated workflow using VC analysis to identify karst compartments in the Arbuckle saline aquifer; **(3)** Task 9: characterization of lateral and vertical extent of compartment boundaries by using vertically segregated interval windows during VC analysis; and **(4)** Tasks 10 & 11: estimates for CO_2 sequestration capacity in select Arbuckle compartments within the 3D seismic survey area.

E. Briefings and Technical Presentations: The recipient shall prepare detailed briefings for presentation to the Project Officer at the Project Officer's facility located in Pittsburg, PA or Morgantown, WV. The recipient shall make presentation to the NETL Project Officer/Manager at a project kick-off meeting held within 90 days of project start date. At minimum, annual briefing shall also be given by the recipient to explain the plans, progress, and results of the technical effort. A final project briefing at the close of the project shall also be given. The recipient shall also complete a minimum of 1 presentation at a National Conference.

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Facilities & Other Resources Appendix:Kansas Geological Survey

KGS Computer and Support Systems

The Kansas Geological Survey (KGS) has major programs in data management and distribution, public information, and education. It is a leader in the field of web-based dissemination of geological and resource information and it operates under contract with the Kansas Data Access and Support Center (http://www.kansasgis.org/), a repository and distribution facility for GIS databases for the state of Kansas. Although its primary focus is the state of Kansas, KGS and its research staff are internationally recognized, and contribute to earth science research and information in many arenas.Including DASC, there is a staff of 12 full-time professional computer and data support personnel, 7 positions in the relevant public information areas, and numerous part-time and temporary employees. KGS research projects have access to central design, development, and support services for databases and internet-based systems. This provides operational standardization and documentation and permits routine upgrades and maintenance. These development and management support services are part of an institutional commitment to the longevity and accessibility of data and information facilities.

KGS maintains a suite of Unix (Solaris), Linux, and Windows web servers as well as extensive computer and production facilities for data management and computerized cartography and geospatial data management. KGS supports critical facilities (e.g., for the State Department of Emergency Management), and therefore devotes major efforts to ensuring consistent and reliable service. Redundant servers are located in a professionally managed computer facility featuring dual air conditioning systems and power conditioning equipment. Our Oracle database server is automatically replicated at two off-site locations. Regular backups are stored both on- and off-site, and arrangements with partner institutions outside the region permit mutual transfer of data service in the event of large-scale disruptions. All backups are performed “hot,” allowing for 24x7 operations.

All KGS investigators, staff and student employees are provided with access to networked computer hardware and software appropriate for their responsibilities. The institution provides publication, graphics, and communication support in addition to office and laboratory space.

Rock and Fluid Analyses

The Survey is equipped with complete instrumentation for inorganic water quality analyses, including low-level phosphate analysis. These facilities are available for use on a cooperative basis with researchers at the KGS. Clean and dirty saw-rooms are available for core preparation, as are grinding wheels for cutting and polishing core slabs, and thin-section billets. A thin-section preparation laboratory for hot (using heated epoxy) and cold (i.e., adhesives activated using UV light) thin-section cutting and polishing is present in house. Petrographic microscopes with reflection fluorescence cathode luminescence, and fluid-inclusion attachments are on site for thin-section analysis of rocks. Other relevant analytical equipment available at the University of Kansas (Lawrence) include the scanning electron microscope facilities.

Mapping and Modeling Software

The Kansas Geological Survey is licensed for running CMG (Computer Modeling Group, Calgary) reservoir simulator suite including CGM GEM with its GHG (Green House Gas) simulator, WINPROP (PVT simulator). Saibal Bhattacharya has worked extensively with CMG simulators for the last 10 years and has attended numerous training courses in its operations at CMG headquarters. Petrel 2009 (licensed to the Kansas Geological Survey from Schlumberger) will be used for constructing the static geologic models.

Well Log Analysis Software

Well-log analysis (aside from processing necessary for image analysis and magnetic resonance imaging) can be performed in-house on software developed by the Kansas Geological Survey. The software includes:

- PfEFFER Pro (Petrofacies Evaluation of Formations for Engineering Reservoirs). This software was developed in collaboration with 14 companies and U.S. Department of Energy, BDM-Oklahoma, Inc., and Kansas Technology Enterprise Corporation. PfEFFER Pro is a cost-effective and practical tool for real-time, interactive log analysis.

- Excel spreadsheet packages in the on-line “Yellow-Book Series” for well log analysis, developed in-house.
- Web-based Java analytical tools -- **The LAS File Viewer** presently allows the user to plot LAS, core analyses, and stratigraphic tops that are stored on the Kansas Geological Survey (KGS). Plots are Standard LAS File Curve, Measured Core Data and Log Image Tracks, e.g., lithology along with Formation Tops Picks on one plot. **The Cross Section Web Tool** allows the user to view a standard well profile presentation of multiple wells datum by elevation or by horizons with standard selected horizons stored on the KGS database.

KU Department of Geology

Laboratory space and equipment

The University of Kansas W. M. Keck Foundation Paleoenvironmental and Environmental Laboratory has been funded by the University of Kansas and grants from NSF and the W. M. Keck Foundation. After its completion, the laboratory will provide capabilities for the analysis of a broad range of inorganic and organic samples including carbonates, silicates, bulk organic matter (TOC), specific compounds, gases, and water and dissolved gases. All instrumentation is optimized to handle the smallest sample sizes at the highest precision. The laboratory currently houses a Finnigan Mat 253 Gas Source Isotope Ratio Mass Spectrometer and includes a KIEL III Carbonate Reaction Device and GasBench II sample processing system. In addition, mechanical micro-samplers and a variety of liquid-handling (micro-volumes) systems are available. A general gas extraction line is available for the preparation and purification of gas samples. A second mass spectrometer, a Finnigan DeltaPlus XP, a Costech Elemental Analyzer, a GC (Agilent GC) with a GC-C/TC III interface, and a TC/EA are currently in place. A laser ablations system and a laser fluorination line will be added in the next six months. The laboratory is under the direction of Dr. Luis A González and daily laboratory operations are overseen by full time laboratory manager and staffed by graduate and undergraduate research assistants.

The Geology Department at the University of Kansas has a geochemistry laboratory equipped with a Hewlett Packard 1100 HPLC with diode array detector and supporting Chemstation software, and a Hewlett Packard gas chromatograph 6890 with photoionizaiton and flame ionization detectors, autosampler and Chemstation software, a BET surface area analyzer, ion chromatograph (Dionex), a laser ablation spectrometer and an inductively coupled plasma mass spectrometer (ICPMS) and inductively coupled plasma atomic emission spectrometry (ICPAES) which are available to support this project. The Department also houses a thermal ionization mass spectrometer and a fluid inclusion laboratory.

Microscopy and Electronic Imaging Laboratory

The Microscopy and Electronic Imaging Laboratory at KU is equipped with a LEO field emission scanning electron microscope, equipped with externally controllable scan generator and computer-controlled motor driven stage and back scattered electron dectector, EDAX electron backscattering spectroscopy, energy dispersive system and Gatan color cathodoluminescence detector. The lab also includes a Nikon inverted fluorescence microscope equipped with a BioRad MRC 1000 confocal unit and filters to detect a variety of fluorescent probes. A conventional fluorescence unit for detection of rhodamine and fluorescein fluorescence is provided for rapid analysis of fluorescence. Both microscopes are equipped with digital imaging capability.

Fluid Inclusion Laboratory

Laboratory space includes a state-of-the-art fluid inclusion microthermometry facility. This system consists of a Fluid Inc. heating and freezing stage and a Leitz Ortholux II transmitted light and UV fluorescence microscope equipped with a video camera, monitor and high resolution VCR. The second system consists of an Olympus BX60 microscope and Linkam heating and freezing stage. The system is equipped with a special 100X objective setup to work on small fluid inclusions and is outfitted with a real time video measurement system. Both microscope systems are outfitted with UV epi-illumination used to evaluate growth zoning in crystals and included organic components. These fluid inclusion systems are capable of determining eutectic and intermediate melting temperatures in aqueous fluid inclusions as an aid in determining major ion compositions. Freezing point depressions can be determined to analyze bulk salinity of aqueous fluid inclusions. Homogenization temperatures can also be determined. The microscope system serves the needs of UV epifluorescence microscopic identification of organic inclusions and allows for petrography of UV-luminescent phases. A third research grade microscope, an Olympus BH-2, is used for petrography and photomicroscopy of samples containing fluid inclusions.

Cold cathode microscope

Petrographic analysis is aided by a cold cathode luminescence microscopic system. The system is equipped with an automatically stabilized C.I.T.L. cold cathodoluminescence stage mounted on a Leitz SM-Lux Pol microscope. The system uses a Q-imaging electronically cooled digital camera system.

Thin section and rock preparation lab

The Department of Geology is well equipped for preparation of doubly polished thin sections for fluid inclusion work. We are equipped with low-temperature vacuum impregnation facilities for impregnation of temperature sensitive travertine samples. A Buehler low-speed cutoff saw is used for all temperature-sensitive samples to avoid alteration of low-temperature fluid inclusions. Mounting is accomplished with a UV curing mounting system to avoid heating of samples. A wide suite of standard rock saws and trim saws are also available. Standard cutoff, grinding and polishing equipment are in place. A full-time technician services the lab for the Department and KGS.

Microsampling Device

Geochemical sampling will be carried out with a Merchantek computer controlled microsampling device.

Sr isotope lab

Strontium isotope analyses will be carried out at the University of Kansas lab which is equipped with clean room and all elemental separation facilities, and a VG Sector multi-collector Mass Spectrometer.

SEM-CL-BSE lab

The proposal will take advantage of the LEO 1550 field emission SEM, which is equipped with extra BSE detector, and Oxford instruments pana-CL color CL detector, digital lithography capabilities, EDS, and EBSD detectors. This state of the art instrument, acquired in 2001, will provide the best capability of high resolution of paragenesis and fracturing history.

Research Microscope lab

The laboratory is equipped with an Olympus BX60 microscope equipped with digital imaging capabilities and UV epi-illumination as well as an Olympus BH-2 equipped with digital photomicroscopy capabilities.

Kansas State University – Department of Geology

Geochemistry lab (details enclosed)

FACILITIES, EQUIPMENT, AND OTHER RESOURCES-Kansas State University

Geochemistry and Hydrogeology Laboratory (Dept. of Geology, KSU)-*Approx Lab size: 21.25ft * 11.70 ft-Room 14A-Thompson Hall, KSU + FULL Access to General Geochemistry Lab (Room 14D)*

Datta's lab inherits a state-of-the-art water cation-anion analyser (Dionex RFIC Ion Chromatography-ICS 3000), hence water samples will be analysed first for cations and anions, before sending for precise ICP-MS analysis at Tulane lab for trace element analysis + ICP-MS at KSU-VET MED. Datta also acquired through his other grants the following field kits: (a) Multi350i-(WTW) meter along with MPP 350-25 pH/DO/COND electrode, sensolyte MPP-A and Electrode for MPP + HYDROLab. (b) AMS Environmental soil auger-full set with split spoon sampler (c) 3001 Solinst Gold LT Levellogger Gold (4 pieces); (d) Water level Meters-Solinst with 300, 50' with the Direct Read Comm Pkg with USB; (e) Model 410 Solinst Peristaltic Pump with 3.5L/min to 40mL/min. A whole gamet of modeling softwares and plotting programs are owned by Datta., (a) Groundwater Models (b) GMS/SMS/WMS Software pkg, (c) Geochemists' Workbench Std 6.0 (d) Origin (e) AqQa and EnviroInsite and Surfer and Kaleidagraph. Datta also has acquired through his startup a laminar flow hood, N2 glove box, two high precision analytical balances (Cahn C33 microbalance + Denver Instrument A-160 analytical balance), and three variable speed centrifuges. In addition, Datta also has 2 Oakton* pH 510 Benchtop Meters, Fisher Traceable* Bench Conductivity Meter, and 3 high end computers with ArcView GIS package for use. Datta has a modern 450 ft^2 laboratory, with one specific fumehood. Datta also has numerous different field kits like Hach 2800 Portable Spectrophotometer, Hach Arsenic Single test kits, CHEMets Kits for measuring a whole range of DO, Hondex Digital Depth Sound, different pippettors. Also the Department hosts a state-of the-art GC-MS which ready for Datta to use. Also Datta has access to Inductively Coupled Plasma-Optical Spectrometry at Department of Agronomy-KSU for water and sediment digest analysis. Datta has his own office so has his three students with high end APPLE computing facilities. Datta has a newly (Dec 09) installation of Millipore Element + Elix nanopure water system. Datta has also access to a Central Facility of Stable Isotope lab under Dr Jessie Nippert-Biology, KSU. KSU also has support services such as machine shop, and electronics shop, and can be used to make the needle samplers and coring devices and they will be available for the project. Datta has contractual arrangement with Kansas Geological Survey for other analytical work.

General Sample Preparation and Petrography (Dept. of Geology, KSU)-*Approx "clean" Lab size: 26.5ft*13ft and crushing/pulverizing facility: 24ft*11ft.*

Brueseke: Preparation facilities include rock saws; rock crushing facilities and sample layout space; a deionized water system; a Franz magnetic barrier magnetic separator for mineral/glass separation; and a clean work area with a binocular and a petrographic microscope with an attached digital camera. Additional petrographic equipment includes 13 student binocular petrographic microscopes. A clean work area with analytical balances for rock powder weighing and a work area containing drying ovens exist in PI Brueseke's laboratory. A SEM-EDX is available in the Department of Entomology @ KSU is available for Datta/Brueseke and their students will use for micromorphological analysis.

Optically Stimulated Luminescence (OSL) Facilities (Department of Geology, KSU)
The OSL laboratories at KSU are comprised of a suite of three interconnecting rooms accessed via a common entranceway. The constituent minerals in sediment samples analyzed are sensitive to normal daylight and therefore the laboratories are illuminated with a low-intensity red or yellow light, similar to photographic darkrooms. The principle minerals analyzed in the laboratories are quartz and feldspar; red light is used when preparing and measuring quartz and yellow light for feldspars. This lab has state-of-the-art fully automated luminescence dating system model no. Risø TL-DA-20C/D.

Computing Facilities (Dept. of Geology, KSU)

The Department of Geology houses two computer laboratories (all with wireless internet access) that house computers and/or workstations, scanners, printers, and plotters. Additionally, a computer in the laboratory is dedicated to petrographic imaging, GIS/remote sensing, computer-based geologic mapping, and petrologic modeling applications. A few modeling softwares and plotting programs are owned by Datta and are will be installed on a computer in his laboratory.