Modeling CO₂ Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO₂ Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas

Funding Opportunity Number: DE-FOA-0000033
CFDA Number: 81.089 Fossil Energy Research and Development
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National Energy Technology Laboratory
Outline - I

- Project Description
- Local industry cooperation & competitive bidding
- How will project results improve current estimates of CO$_2$ sequestration in OPAS (Ozark Plateau Aquifer System)?
- Work in progress (time permitting)

Oil and Gas Industry Partner –
BEREXCO – largest oil producer in Kansas (~1000 wells)
Outline - II

- Project Description *(official start date – December 8, 2009; completion 12/7/12)*
  - Geologic Sequestration of CO₂
  - Project Study Area – Wellington field & 17+ counties
  - Project Objectives
  - OPAS – Target for CO₂ sequestration
  - Project Suitability
    - Arbuckle Aquifer System – 17+ counties
    - Arbuckle Saline Aquifer underlying Wellington field & Wellington depleted oil reservoir
  - Data Collection & Analysis
  - Approach to Characterization – Wellington field
  - Approach to Characterization – Regional (17+ counties in south-central KS)
    - Limitations
  - Risk Analysis
  - Technology Transfer
  - Project Timeline
  - Budget
  - Relevance & Impacts
  - Participants
Geologic Sequestration of CO$_2$

Global annual CO$_2$ emissions $\approx$ 8 gigatons

**Earth Policy Institute**

US emissions $\approx$ 3.8 gigatons

Carr 2010

<table>
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<th>Formation Type</th>
<th>$10^9$ Metric Tons</th>
<th>%</th>
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<td>Saline Aquifers</td>
<td>3,297 – 12,618</td>
<td>91.8 – 97.5</td>
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<td>Unmineable Coal Seams</td>
<td>157 – 178</td>
<td>4.4 – 1.4</td>
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<td>Mature Oil &amp; Gas Reservoirs</td>
<td>138</td>
<td>3.8 – 1.1</td>
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<td>Total Capacity</td>
<td>3,592 – 12,934</td>
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**Residual Gas**

**Free gas**

**Solution**

**Minerals**

Ozah, 2005 – after 50 years of injection

Bachu, 2003
Project Study Area
Wellington Field (Sumner County) + 17 Counties

Central Kansas Uplift
Sedgwick Basin
Arbuckle Core - Front Refinery (El Dorado field)
50 miles

Wellington Field (BEREXCO, INC.)

Sunflower Electric
Holcomb (Garden City)
Arbuckle Core - TX World Op (disposal well)

Mississippian Chat Fields
Westar Jeffrey Energy Center, Saint Marys

Arbuckle Core, deep well field Occidental Chemical (brine injection)

Arbuckle Core - TX World Op (disposal well)

20,000 sq mi. regional study area

http://maps.kgs.ku.edu/oilgas/
Project Objectives

• Build 3 geocellular models
  - 1. Mississippian oil reservoir at Wellington field (Sumner County) - depleted
  - 2. Arbuckle saline aquifer underlying Wellington field
  - 3. Regional Arbuckle saline aquifer system over 17+ counties

• Simulation studies to estimate CO₂ sequestration potential in
  - 1. Arbuckle saline aquifer underlying Wellington field
    – 2. Miscible CO₂ flood in Wellington field (along with incremental oil recovery)

• Identify potential sites for CO₂ sequestration in Arbuckle saline aquifer - 17+ county area

• Simulation studies to estimate CO₂ sequestration potential of Arbuckle saline aquifer – 17+ county area

• Risk analysis related to CO₂ sequestration

• Technology transfer

No CO₂ will be injected in this project
OPAS - Arbuckle Aquifer System
Target for CO₂ Sequestration

• OPAS
  – Arbuckle Saline Aquifer System
    • Thick, deep saline aquifer
    • Interbedded shaly aquitards
    • Estimated sequestration capacity – 1.1 to 3.8 gigatons
    • Propose detailed reservoir characterization & simulation
      – Better estimate sequestration capacity (tonnage) – solution, residual, free phase, minerals & risk analysis
      – Identify prospective sequestration sites in 17+ county study area
  – Mississippian Chat fields - overlies
    • Miscible CO₂-EOR
      – Incremental oil recovery
      – CO₂ tonnage sequestered
CO₂ Sequestration Target
Arbuckle Saline Aquifer

Carr, Bartley, Merriam (2005)

17+ county Study Area (230 mi x 85 mi)

Interpreted flow pattern

Fresh water boundary

Wellington field

Red Areas – Sequestration capacity - at least 480,000 metric tons/mi²
CO₂ Sequestration Target
Depleted Mississippian Chat Reservoirs - EOR

• 6-counties in the regional study area
  – Contain six of top 13 Kansas fields (Mississippian chat reservoirs) – candidates for CO₂ EOR
  – Multiple fields – produced ≈ 0.47 billion bbls & 3 tcf gas
  – Reservoirs characteristics for CO₂-EOR
    • Depth – miscible CO₂-EOR
    • Lack strong water drive
    • Many near depletion
    • Some underwent successful waterfloods – Wellington field

• CO₂ sequestration potential of CO₂-EOR – minor compared to deep saline aquifers
  – Viable CO₂-EOR will encourage KS oil and gas industry to participate in infrastructure development suitable also for CO₂ sequestration in underlying saline aquifers
• 4.6 billion barrels crude oil produced – Mississippian, LKC, & Arbuckle

• CO₂-EOR could recover substantial incremental oil
  • 10% of primary and secondary recovery (technically feasible) ~ 400 MMBO
  • Recovery depends on field readiness, infrastructure, and access to CO₂

• Independent Oil and Gas companies are a primary stakeholder for CCS in Kansas
Suitability of Project
Arbuckle Aquifer System

• Arbuckle Aquifer System
  – “Excellent opportunity of large-scale CO₂ sequestration with hydrodynamic trapping, long isolation (>1000 yr) from the atmosphere, and protection of underground sources of drinking water supplies” ……
  
  Carr et al. (2005)
  – Extensive brine geochemical database – NatCarb (3700 samples)
  – Other factors
    • Depth > 3500 ft, thickness > 800 ft
    • Remoteness from freshwater > 150 mi to east
    • Vertically isolated from shallow freshwater – aquitards & evaporites (salt)
    • Arbuckle Group – Class I & II disposal zone since 1950s
**Suitability of Project**

**Evaporite seal** overlying Arbuckle Saline Aquifer

**Depth to top of Hutchinson Salt**

Data from Watney and Paul (1981); Watney et al. (1989)

Preliminary isopach map of evaporite interval - Top of Hutchinson Salt to Top of Chase

*Depositional edge of salt, underlying anhydrite beds are present + shallower evaporite beds*

Regional study area: 230 mi x 85 mi
Suitability of Project
Wellington field, Sumner County

- Wellington field
  - Discovered 1922 (134+ wells)
  - 44 active wells, 20.5 MM BO
  - Unitized and owned by BEREXCO
  - Excellent waterflood – ideal for CO$_2$-EOR
  - Arbuckle aquifer (1050 ft thick, top 4150 ft)
  - Considered for CO$_2$-EOR (Coffeyville refinery)

- Anson & Bates fields
  - Mississippian chat reservoir
  - 6 MM BO
  - 3D donated by Noble Energy

- 3 fields could sequester $\approx$ 30 MM tons CO$_2$ (MidCarb Sequestration Vol. calculator)
Data Collection & Analysis

- Geophysical surveys at Wellington field
  - Gravity & magnetics begin Feb. 4th
  - 3D multicomponent (converted wave) seismic (~10 mi²) begins Feb. 10th
  - 2-2D shearwave surveys (8 linear miles)
- Well #1 - Drill, core (1600 ft from base of Pennsylvanian), log, case, perforate, and test to basement (~5100 ft)
- Well #2 - Drill, log, case, perforate, and test to basement
- Core Analysis (Mississippian and Arbuckle core - Well #1) & PVT
- Geochemical studies on Arbuckle water – KSU Geology Dept.
  - Major reactive pathways and reaction kinetics
- 17 county regional study – OPAS
  - Regional geomodel – Arbuckle Aquifer
  - Flow-unit mapping (aquitards, caprock, & overlying salt bodies)
- Cap rock integrity and micro-biological studies – KU Geology Dept.
- Reservoir simulation
  - Wellington field – Arbuckle Aquifer & Mississippian Chat depleted field
  - Compartments in 17+ county study area
Approach to Characterization
Wellington - Arbuckle Saline Aquifer & Mississippian Chat Reservoir - I

• Integrated Reservoir modeling – geocellular Petrel© models
  – Multicomponent 3D seismic survey
  – Routine and special core analysis
  – Water chemistry analysis – flow-unit specific
  – Cap rock competency analysis
  – Hydrogeologic studies
    • Lateral continuity of aquifer & aquitards
    • Aquifer velocity, direction, and gradient

• Reservoir simulation – CMG - GEM©, WINPROP©, & CMOST©
  – Simulator
    • Multiphase multicomponent
    • Phase and chemical equilibrium
    • Rate dependent mineral dissolution/precipitation modules
Approach to Characterization
Wellington - Arbuckle Group Saline Aquifer & Mississippian Chat Reservoir - II

• Reservoir simulation
  – Inputs
    • Integrated reservoir geomodel – fracture/fault trends
    • Facies-specific - relative-permeability, hysteresis curves, K - Phi trends
    • Aquifer/aquitard specific – water chemistry and pressure
  – Anticipated results - Arbuckle Group Saline Aquifer
    • Plume movement and spread
    • Tonnage of CO₂ sequestered (25 & 50 yrs)
    • Optimum injection pressure
    • Pressure of free-phase CO₂ under cap rock
    • Sequestration enhancement - simultaneous brine injection from upper horizons
    • Porosity changes due to mineralization - location of maximum porosity change
Approach to Characterization
Wellington - Arbuckle Group Saline Aquifer & Mississippian Chat Reservoir - III

• Anticipated results (cont.) - Mississippian Chat reservoir
  – Identify areas with significant residual oil saturation
    • Model 5-spot patterns
      – Incremental oil recovery
      – Tonnage CO₂ sequestered - solution, residual gas saturation, minerals
      – Tonnage CO₂ injected for recovery of 1 incremental barrel oil
      – Tonnage CO₂ recycled
    • Other injection patterns – optimize oil recovery
    • Field-scale EOR model – maximum oil recovery with minimum up-front investment
      – Identify areas viable for multiple pattern EOR implementation
      – Total incremental oil recovery
      – Tonnage of CO₂ sequestered - solution, residual gas saturation, minerals
      – Tonnage CO₂ recycled
Approach to Characterization
Arbuckle Saline Aquifer (17+ county area)

• Detailed saline aquifer characterization
  – Storage, flow, and composition changes due to CO₂ injection

• Proposed studies for regional Arbuckle Saline Aquifer
  – Inventory all available data – select key deep wells
    • Database of 95,000+ wells, 1413 deep wells, 147 wells to basement
  – Integrated data analysis – identify reservoir compartments
    • Structural and derivative mapping
    • Petrophysical catalog (4 Arbuckle cores) – facies-specific rock catalog
    • Water chemistry database – aquifer/aquitard specific database
  – Simulation of select large compartments
    • Use stratigraphic & facies-specific data
      – Water chemistry
      – Petrophysical data
    • Tonnage of CO₂ that can be sequestered before plume reaches boundaries
  – Estimate total tonnage of CO₂ that can be sequestered
Magnetic – reduced to pole, overlain with configuration of Precambrian surface

Wellington Field

Bouguer Gravity -- with Midcontinent rift and sub elements, terrain boundary (Kruger, 1999)

New algorithm will be developed to interpret gravity and magnetic data in the 17+county study area to delineate depth to basement, basement faults and fractures

High resolution satellite imagery maps will be interpreted to map surface faults and lineaments

Kansas – 200 mi x 400 mi
Approach to Characterization - Limitations

Arbuckle Saline Aquifer (17+ county area)

- Uneven distribution of wells penetrating Arbuckle – per section
- **Current** assessment
  - 1413 wells > 100 ft penetration in Arbuckle
  - 276 wells – full Arbuckle penetration (basement test)
- Cores – 4 Arbuckle cores available
  - Ideally – more cores would help better characterize flow-units
- Wellington field area – data rich
  - Facies specific – petrophysical and water chemistry catalog
- Regional geomodeling
  - Use all available Arbuckle well data – identify pore-types, facies/flow-units
  - Quantify petrophysical properties of flow units using data from Wellington area catalog
  - Access subsurface information collected from USGS’s Anadarko Basin Resources Assessment Project
- Ongoing efforts to encourage operators to donate additional 3D data
  - Noble Energy donated 3D data for Anson-Bates field
  - Palomino Petroleum donated 3D data for Wellington West field
Risk Analysis
Wellington Field

• Arbuckle saline aquifer underlying Wellington field
  – Free-phase CO₂ plume growth and attenuation over time
    • How close will the plume be to the nearest fault/fracture trend? (time frame)
    • Will the plume migrate outside the risk-assessment area (10-mile radius around Wellington field)? (time frame)
    • Effects of sealing or transmitting faults on plume migration and attenuation
    • How long will it take for free-phase CO₂ to become negligible?
  • Plume growth and pressure under cap-rock
    – CO₂ injected deep and rising plume travels through multiple aquitards

• Wellington Mississippian Chat CO₂-EOR
  – Given the age of wells and quality of cement
    • How many wells in Wellington likely to fail?
    • Upon failure – amount of CO₂ (% injection) leaking to shallow horizons (surface)
Technology Transfer

• KGS has a successful history of technology transfer
• Huge amount of data will be collected, analyzed, and generated
  – Project website - hosted by KGS
    • Repository of all data, analyses, and reports
    • Linked to NatCarb databases – NatCarb hosted at the KGS
  – Easy access & download from project website
    • Interactive GIS-based online mapping system, developed at the KGS, will be modified to display, filter, and query cross-sections and maps from the study areas
• Best-practices manual for site selection and characterization for CO₂ sequestration will be developed
• Disseminate lessons learned
  – Core workshops
  – Presentations at industry conferences
  – Peer-reviewed journal articles
Project Time Line

Regional geomodel development of Arbuckle saline aquifer
Collect, process, interpret 3D seismic data - Wellington field
Collect, process, interpret gravity and magnetic data - Wellington field
Drill, core, log, and test - Well #1
Collect, process, and interpret 2D shear wave survey - Well #1
Analyze Mississippian and Arbuckle core
PVT - oil and water
Geochemical analysis of Arbuckle water
Cap rock diagenesis and microbiology
Drill, log, and test - Well #2
Complete Wellington geomodels - Arbuckle and Mississippian reservoirs
Evaluate CO2 sequestration potential in Arbuckle underlying Wellington
Evaluate CO2 sequestration potential in CO2-EOR in Wellington field
Risk assessment - in and around Wellington field
Regional CO2 sequestration potential in Arbuckle aquifer - 17+ counties
Technology transfer
# Budget

![Budget](image)

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* Geophysical acquisition & processing by Paragon (3D), Lockhart (2D and gravity/mag), Fairfield & Echo (seis. Processing) Geophysical post processing and analysis by Hedke-Saenger Geosciences, Geo-Textures, Nissan, Miller, Raef, Xia

** Logging by Halliburton
Relevance & Impact

- **Proposed Project**
  - “Shovel ready” – BEREXCO INC (sole owner and operator of Wellington field) is very interested in evaluating the viability of CO$_2$-EOR and follow-up with field implementation if viable
    - Wellington field along with nearby Anson-Bates field – potential of sequestering 30 million tons of CO$_2$
    - Nearby CO$_2$ sources – refineries at El Dorado (50 miles), Coffeyville (120 miles)
  - **Will create and retain jobs in Kansas and elsewhere in the US**
    - Seismic surveys
    - Drilling 2 wells
    - Logging 2 wells and coring 1 well
    - Routine and special core analysis
    - Geologic consultants – regional study
    - Reservoir simulation consultants
  - **Viability of CO$_2$ sequestration in deep, thick, Arbuckle saline aquifer in KS**
    - Has potential of developing into a major industry in Kansas
  - **Viability of CO$_2$-EOR in depleted Mississippian chat reservoirs**
    - Encourage KS O&G operators to develop CO$_2$-EOR infrastructure – beneficial to CO$_2$ sequestration in Arbuckle saline aquifer
  - **Share best practices in characterization, modeling, and forecasting fate of injected CO$_2$ in aquifers and depleted oil fields**
    - Southwestern Regional Sequestration Partnership, NatCarb, & industry
    - Develop regional expertise in CO$_2$ sequestration
Participants

Kansas Geological Survey, Univ. of KS, & KS. State Univ.

• Project Manager & PI – Dr. Lynn Watney
  – Geologist - 33 yrs experience in KS geology
• 2nd PI – Saibal Bhattacharya
  – Reservoir Engineer – 12 yrs reservoir simulation experience in KS fields
• Other KGS Co-PIs
  – Dr. D. Newell – Structure & diagenesis
  – J. Rush – Petrel geomodeling and data integration
  – Dr. R. Miller – Seismic interpretation
  – Dr. J. Doveton – Log petrophysics and core modeling
  – Dr. J. Xia – Gravity-magnetic modeling and interpretation
  – Dr. M. Sophocleous – Aquifer modeling and well testing
  – Others
    • J. Victorine – Java web application
    • D. Laflen – core curation
    • M. Killion – ESRI GIS
    • K. Look, G. Gagnon, D. Suchy, D. Stewart – manage data
• Department of Geology – University of KS
  – Dr. E. Franseen – Stratigraphy & diagenesis
  – Dr. R. Goldstein – Cap rock integrity (Fluid inclusions and diagenesis)
  – Drs. Roberts & Fowle – experiments in microbial-CO₂ interactions
• Department of Geology – Kansas State University
  – Dr. S. Datta – Aquifer geochemistry
  – Dr. A. Raef – Seismic analysis and modeling
Participants

Industry & Consulting Partners

- **BEREXCO INC.** – owner/operator of Wellington field
  - Dana Wreath – Divisional Engr – Supervise all field operations
  - Randy Koudele – Reservoir Engr
  - Bill Lamb – Petra database management and data transfer
  - Evan Mayhew – Operations Engr – drilling, completion, and well testing
  - Robert Hefner – Geophysicist – 3D acquisition, processing, and interpretation
  - Phyllis Shahin – Landman – landowner negotiations and contracts
  - Charles Spradlin – VP and Land Manager
  - Adam Beren – President

- **Hedke-Saenger Geosciences Ltd.** – Seismic acquisition & initial interpretation
  - Paragon Geophysical, Lockhart Geophysical, Fairfield, Echo, Geotextures & Susan Nissen

- **Bittersweet Energy Inc.** – Geologic Consultants (17+ county regional geomodel)
  - Tom Hansen – Arbuckle aquifer geomodeling
  - Ken Cooper – Arbuckle aquifer simulation and coring
  - John Lorenz – Fracture characterization
  - Paul Gerlach - Arbuckle aquifer geomodeling
  - Larry Nicholson - Arbuckle aquifer geomodeling

- **Weatherford Laboratories** - Routine & Special core, Rock Mechanics, PVT

- **Computer Modeling Group**
  - Bob Brugman – Simulation Engineer – CMG WINPROP & GEM-IMEX simulation

- **David Koger** – Satellite imagery analysis – surface lineaments and fractures

- **Noble Energy** – 3D seismic donation (Anson Bates field), David DesAutels, contact

- **LogDigi** – Log digitization

- **Halliburton** – Well logging
Co-operation with Local Industry & Competitive Bidding

• Long history of KGS’s close interaction with KS O&G industry
  – 2009 calendar
    • Organized RPSEA Small Producer meeting
    • KGS forum to identify research problems
    • Presentations at industry meetings – KIOGA
    • Helped identify research subjects relevant to KS O&G industry
      – Regional Arbuckle characterization
    • Contentious issues – risk, liability, global warming

• BEREXCO INC. – largest KS O&G company
  – Helped negotiate best quotes
    • Logging – Reduced costs by half, helped circumvent restrictions imposed on KGS by another vendor regarding software use
    • Seismic – best quotes with significant cost-match
    • Coring – competitive coring, supervision of coring, core storage
    • Used leverage on other sub-contractors
  – Independent KS O&G industry – prefers to use local companies
    • Knowledge base, relationships, comfort level, & cost-effectiveness

• Data donation from industry – Hugoton Project
  – Data confidentiality respected – results available for publication
Existing CO₂ storage methodology
2008 DOE Carbon Sequestration Atlas

• Volumetric Method
  – Porosity, area, and thickness
  – Efficiency terms – heterogeneity, fraction PV contacted by CO₂
    • Net to total area \( A_{ntg} \)
    • Net to gross thickness \( H_{ntg} \)
    • Effective to total porosity \( \Phi_{ntg} \)

• Efficiencies
  – Areal displacement \( E_A \)
  – Vertical displacement \( E_I \)
  – Gravity – density difference (CO₂ & water) – \( E_g \)
  – Microscopic displacement - \( E_d \)

\[ E_{saline} = A_{ntg} \times H_{ntg} \times \Phi_{ntg} \times E_A \times E_I \times E_g \times E_d \]

Assume injection wells placed regularly throughout basin – “maximum storage”
Existing CO₂ storage methodology
2008 Carbon Sequestration Atlas

- **Compressibility method - Monte Carlo**
  - Applicable for single phase (constant compressibility)
    - Ex: single phase oil reservoir, confined saline formations
  - CO₂ injection into saline aquifer – 2 phases
    - Approximation – apply formula to water phase only
    - Original water volume \( (V_{wo}) \) compressed by pressure increase \( (P - P_0) \)
      - \( P \) - maximum capillary pressure to breach seal or pressure to activate fault
      - \( P \) - average water pressure over entire \( V_{wo} \)
    - Compressed water volume \( (\Delta V_w \text{ or } G_{CO₂}) \) – occupied by CO₂
      - \( \Delta V_w \text{ or } G_{CO₂} = V_{wo} \times c_t \times (P-P_0) \)
      - \( V_{wo} = A \times H \times \phi \)
      - \( c_t = c_f + c_w \) (sum of formation and water compressibility)
  - Closed system – \( V_{wo} \) can be defined (water contained by compartment)
    - How many aquifers are closed systems?
  - Open system – \( V_{wo} \) is infinite and can not be defined

- Neither method provides plume description or spread, CO₂ entrapment by residual saturation, solution, and mineralization
  - Free phase CO₂ plume – highest risk
Proposed Project
Improve Current Sequestration Estimates

• Geocellular model – incorporates variation in
  – Layering – flow-units/facies
    • Porosity
    • Thickness
    • Permeability
    • Seal continuity
  – Fracture and fault boundaries
• 3D reservoir model includes
  – Facies specific petrophysical properties
  – Aquifer/aquitard specific water geochemistry
• Compositional reservoir simulation
  – Dynamic modeling of \textit{in situ} CO$_2$ flow and entrapment
  – Model CO$_2$ entrapment by different mechanisms
    • Solution, residual gas, free phase, and minerals
    • Convective current due to CO$_2$ dissolution in brine
  – Model plume shape, migration with time – compartment boundaries
    • Include aquifer velocity and direction
  – Model if free phase pressure under cap/seal has potential to breach
    • Time frame when free phase CO$_2$ becomes negligible
Work in Progress
Modifying Web-based Well Profile & Cross Section Java Codes

Three well stratigraphic cross section with datum on top of the Mississippian carbonates showing color images of gamma ray (gray scale), lithology track (multicolor image column), and color lithology percentage.

Index map, South-Central KS & North-Central OK

All well data saved in LAS 3.0 format
Work in Progress

Adapting Oil and Gas Map Viewer for Project

- Google-type map interface to pan and zoom
- Display **ALL** wells, access well data, launch well profile and cross section web tools
- Display georeferenced maps and simulations
Work in Progress

PfEFFER – Java-based log analysis program

Saline aquifer analysis –
- Total and secondary porosity
- Rwa – apparent water resistivity
- Ma – apparent cementation exponent – estimate of pore type (size & tortuosity; compare to secondary porosity)
- Secondary porosity
  - Permeability estimate via pore type
Work in Progress

Status of identifying key wells in regional study area

YELLOW SQUARE = Potential TYPE WELLS
MAGENTA CIRCLE = Well with elog (raster) downloaded and depth registered in Geographix

As of 2-1-10:
Total wells available ~95,000
KEY WELLS to date = 1413
Pre-Camb Tests = 276
Wells Penetrating Basement (2/1/10), **regional study area**, Bittersweet Energy subcontractor

Depth-registered raster well logs (magenta) loaded (2/1/10)
Top Arbuckle subsea (2/1/10) – **regional study area**, Bittersweet Energy subcontractor

Work in Progress

Wellington Field

Precambrian subsea (2/1/10)

20 mi
Work in Progress

Arbuckle Isopach based on key wells (small magenta dots)
Insoluble Residue Wells (large red dots) with index for cross section (2/1/10)
Bittersweet Energy subcontractor

20 mi
North-South stratigraphic cross section showing insoluble residue profiles -- data from KGS Bulletin 72 (Kroher and Kirby, 1948) index on previous map.