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(5/09)
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**ATTACHMENT 3**
**U.S. Department of Energy**
**FEDERAL ASSISTANCE REPORTING CHECKLIST**
**AND INSTRUCTIONS**

| 1. Identification Number: **DE-FE0002056** | 2. Program/Project Title: **Modeling CO2 Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas** |
|---|---|
| 3. Recipient: University of Kansas Center for Research | |

| 4. Reporting Requirements: | Frequency | No. of Copies | Addresses |
|---|---|---|---|
| **A. MANAGEMENT REPORTING** | | | |
| ☒ Progress Report | Q | Electronic Version to NETL> | *FITS@NETL.DOE.GOV* |
| ☒ Special Status Report | A | | |
| **B. SCIENTIFIC/TECHNICAL REPORTING *** (Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at https://www.osti.gov/elink) | | | |
| Report/Product — Form | | | |
| ☒ Final Scientific/Technical Report — DOE F 241.3 | FG | Electronic Version to E-link> | *http://www.osti.gov/elink-2413* |
| ☒ Conference papers/proceedings/etc.* — DOE F 241.3 | A | | *http://www.osti.gov/elink-2413* |
| ☐ Software/Manual — DOE F 241.4 | | | *http://www.osti.gov/estsc/241-4pre.jsp* |
| ☒ Other (see special instructions) | | | |
| Topical — DOE F 241.3 | A | | |
| ** Scientific/technical conferences only* | | | |
| **C. FINANCIAL REPORTING** | | | |
| ☒ SF-425, Federal Financial Report | Q, FG | Electronic Version To NETL> | *FITS@NETL.DOE.GOV* |
| **D. CLOSEOUT REPORTING** | | | |
| ☐ Patent Certification | FC | Electronic Version To NETL> | *FITS@NETL.DOE.GOV* |
| ☐ Property Certificate | FC | | |
| ☐ Other | | | |
| **E. OTHER REPORTING** | | | |
| ☒ Annual Indirect Cost Proposal | A | Electronic Version To NETL> | *FITS@NETL.DOE.GOV* |
| ☒ Annual Inventory Report of Federally Owned Property, if any | A | | |
| ☐ Other | | | |
| **F. AMERICAN RECOVERY AND REINVESTMENT ACT REPORTING** | | | |
| ☐ Reporting and Registration Requirements | | | *http://www.federalreporting.gov* |

**FREQUENCY CODES AND DUE DATES:**

A - As required; see attached text for applicability.
FG - Final; within ninety (90) calendar days after the project period ends.
FC - Final - End of Effort.
Q - Quarterly; within thirty (30) calendar days after end of the calendar quarter or portion thereof.
S - Semiannually; within thirty (30) calendar days after end of project year and project half-year.
YF - Yearly; 90 calendar days after the end of project year.
YP - Yearly Property - due 15 days after period ending 9/30.

030648lw

**QUARTERY PROGRESS REPORT**

**Award Number: DE-FE0002056**

**Recipient: University of Kansas Center for Research &
Kansas Geological Survey
1930 Constant Avenue
Lawrence, KS 66047**

**"Modeling $CO_2$ Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional $CO_2$ Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas"**

**Project Director/Principal Investigator: W. Lynn Watney
Principal Investigator: Saibal Bhattacharya**

**Sixth Quarter Progress Report**

**Date of Report: 5-6-2011**

**Period Covered by the Report: January 1, 2011 through March 31, 2011**

**Contributors to this Report: Saibal Bhattacharya, Saugata Datta, John Doveton, Martin Dubois, David Fowle, Paul Gerlach, Robert Goldstein, Tom Hansen, Dennis Hedke, Larry Nicholson, Susan Nissen, Jason Rush, Aimee Scheffer, John Victorine, Lynn Watney, Dana Wreath, Randy Koudele**

## EXECUTIVE SUMMARY

The project "Modeling $CO_2$ Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional $CO_2$ Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas" is focused on the Paleozoic-age Ozark Plateau Aquifer System (OPAS) in southern Kansas. OPAS is comprised of the thick and deeply buried Arbuckle Group saline aquifer and the overlying Mississippian carbonates that contain large oil and gas reservoirs. The study is collaboration between the KGS, Geology Departments at Kansas State University and The University of Kansas, BEREXCO, INC., Bittersweet Energy, Inc. Hedke-Saenger Geoscience, Ltd., and Improved Hydrocarbon Recovery (IHR).

The project has three areas of focus, 1) a field-scale study at Wellington Field, Sumner County, Kansas, 2) 25,000 square mile regional study of a 33-county area in southern Kansas, and 3) selection and modeling of a depleting oil field in the Chester/Morrow sandstone play in southwest Kansas to evaluate feasibility for CO2-EOR and sequestration capacity in the underlying Arbuckle saline aquifer. Activities at Wellington Field are carried out through BEREXCO, a subcontractor on the project who is assisting in acquiring seismic, geologic, and engineering data for analysis. Evaluation of Wellington Field will assess miscible $CO_2$-EOR potential in the Mississippian tripolitic chert reservoir and $CO_2$ sequestration potential in the underlying Arbuckle Group saline aquifer. Activities in the regional study are carried out through Bittersweet Energy. They are characterizing the Arbuckle Group (saline) aquifer in southern Kansas to estimate regional $CO_2$ sequestration capacity. Supplemental funding has expanded the project area to all of southwest Kansas referred to as the Western Annex. IHR is managing the Chester/Morrow play for CO2-EOR in the western Annex while Bittersweet will use new core and log data from basement test and over 200 $mi^2$ of donated 3D seismic. IHR is managing the industrial partnership including Anadarko Petroleum Corporation, Cimarex Energy Company, Cisco Energy LLC, Glori Oil Ltd., and Merit Energy Company. Project is also supported by Sunflower Electric Power Corporation.

**Project Status:** Subtasks completed till date include: 1) 3D seismic survey at Wellington field (Sumner County, KS) processed and p-wave interpreted, 2) Wellington field seismic data merged with donated 3D seismic data from the adjacent Anson and Bates fields, 3) Wellington 3D seismic interpretation includes structure, time slices, volumetric coherency, curvature, and fault/flexure mapping, 4) two test boreholes drilled in Wellington Field, 5) gravity and magnetic surveys over 17+ county regional study area have been reprocessed and suggested basement faults/fracture trends mapped for validation, 6) remote sensing data over 17+ county regional study area analyzed and surface lineaments mapped, 7) multiple stratigraphic horizons have been mapped over regional study area, 8) multi-township areas selected within regional study area for detailed characterization and simulation studies to evaluate $CO_2$ sequestration potential in Arbuckle Group saline aquifer, 9) depth-constrained cluster analysis conducted on petrophysical properties to identify Arbuckle flow-units and analysis tool incorporated into Java petrophysical application, 10) initial simulation studies conducted to estimate $CO_2$ sequestration potential in selected area around Oxy-Chem #10 well, 11) available Arbuckle DST data collected, analyzed, and mapped showing hydraulic communication with northwestern Ozark uplift outcrop in Missouri, 12) website has been updated to include maps of latest subsurface geology, remote

sensing analysis, and reprocessed gravity and magnetic information., and 13) initial core description and sampling begun for special and routine core analysis.

## ACCOMPLISHMENTS

### Methods/Approach

### REGIONAL STUDY

**ONGOING AND COMPLETED ACTIVITIES concerning all or parts of 33 county study area** -- 1) Continue digitizing and correlating supertypes (deep Arbuckle and basement) wells; 2) establish licensing agreements for use of well, seismic, and related analyses in modeling Chester/Morrow sandstone reservoirs for CO2-EOR and underlying OPAS saline aquifer system for sequestration; 3) begin supplying data to NATCARB database.

Geoscientists in the Bittersweet subcontract continue to acquire well data, correlate logs within project area, identify and correct errors in database, assist in selecting internal correlations within Arbuckle formation, targeting and correlating stratigraphic divisions of the Arbuckle in prospective areas for simulating CO2 injection and generating maps (structure, isopach, and residual) as needed.

### TASK 2. CHARACTERIZE THE OPAS

#### Subtask 2.2. Acquire geologic, seismic and engineering data

Status of regional well database and formation top data collected to date:

| | |
|---|---|
| Total Wells | 95,120 wells |
| Pre-Cambrian Tests | 293 wells |
| Type Wells | 1417 wells |
| Super Type Wells | 91 wells |
| Download & depth register e-log images | 1337 wells |
| Import LAS files for Super Type wells | 124 wells |
| Convert wells with las to Profile Plot | 15 wells |

#### Subtask 2.3. Develop regional correlation framework and integrated geomodel

Continue to integrate existing Arbuckle insoluble residue correlations into well data in lieu of biostratigraphic information and compare with sample descriptions and lithologic solutions of well logs to help validate correlations to more recently drilled wells. Created west-to-east cross-section thru Arbuckle formation, correlating major zones. Correlate Arbuckle zonation thru all Super Type wells. Continue to map interval between top of Mississippian, Arbuckle, and Pre-Cambrian.

Eight (8) subregional areas have been selected for additional investigation based on structure, thickness of Arbuckle.

Within each subregion, provided maps and cross sections of flow units for modeling. Map multiple stratigraphic horizons. Continue to identify flow units, barriers to fluid migration and seals. Geotech continues to support team through acquisition of additional super type well logs, drill stem test information, and completion data. Continue to re-create well production histories for the wells in Wellington field. The largest leases are finished. Continue to compile data on the smaller leases along the edge of the field.

Regional cross sections are being updated and will be calibrated to the information that is being derived from the new wells, #1-28 and #1-32 (Figure 1). Arbuckle saline aquifer and overlying caprocks show some variation from the regional, but are representative and will provide a good calibration point for our regional study as the core, extensive log suite, and analyses are assimilated.

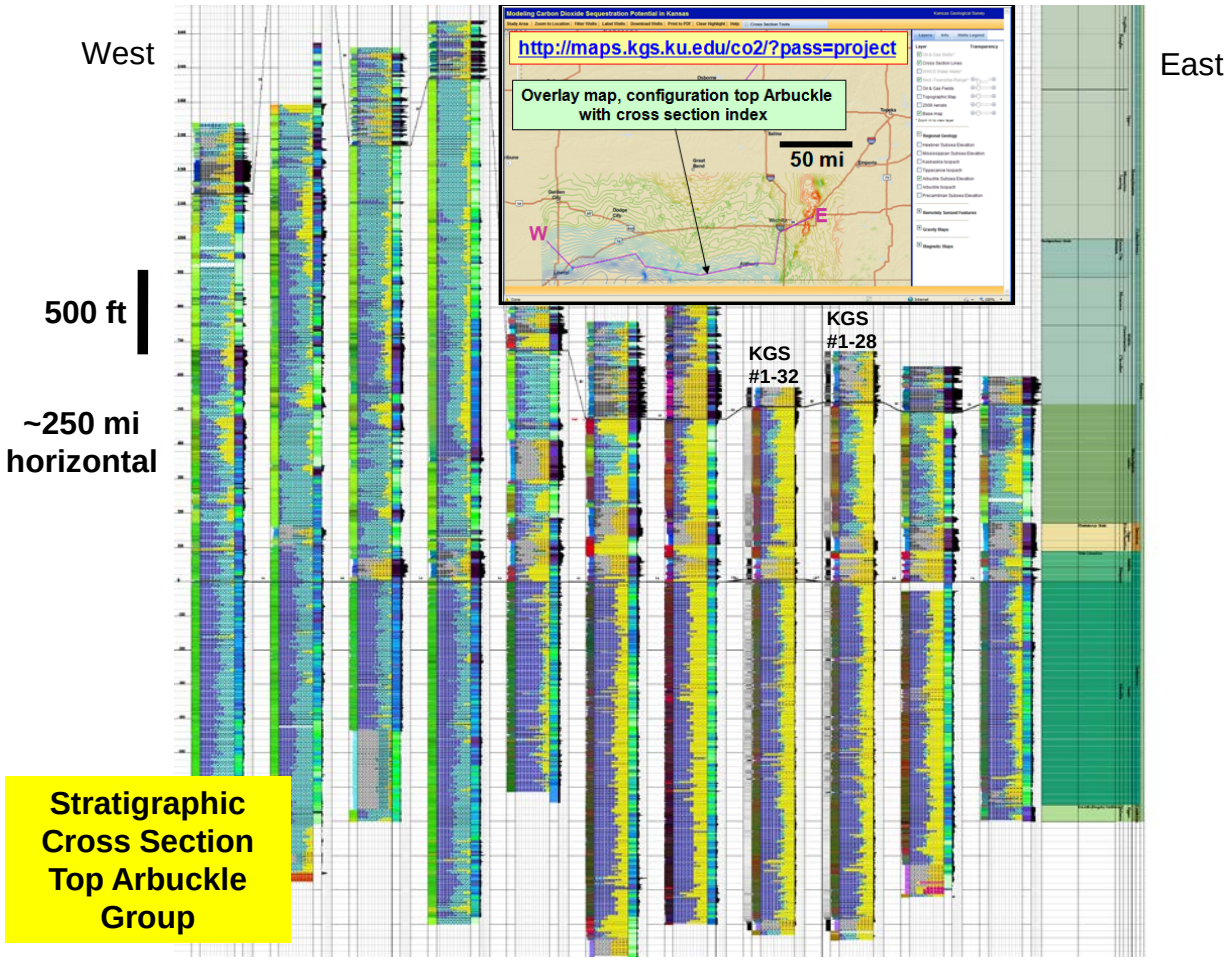



**Figure 1. Updated regional cross section built from interactive project mapper with index map in inset. Cross section datum is top of Arbuckle saline aquifer. Newly drilled wells KGS #1-32 and KGS #1-28 are identified. Color refers to the lithology with purple = dolomite, blue = limestone, yellow = silica, gray = shale.**

**Subtask 2.4. Subsurface fluid chemistry and flow regime analysis**

Compiling applicable literature available regarding Arbuckle geochemistry. Collect available resistivity and salinity data on Arbuckle. Prepared preliminary protocol for determination of regional flow system. Acquiring drill stem test data within Arbuckle formation.

## TASK 9. CHARACTERIZE LEAKAGE PATHWAYS - RISK ASSESSMENT AREA

**Subtask 9.1. Collect reservoir characterization data - external sources**

Identified 90 super type wells with modern day e-log suite. Uploaded tiff images on 36 wells for conversion to LAS. Identified 33 wells for image purchase. Selected additional well logs to be digitized & uploaded images for conversion to LAS.

**Subtask 9.2. Map fracture-fault network**

Continuing to compile published lineament maps to be used in identifying possible compartments created by faults. Convert published fault maps to tiff, geo-reference, and import into project. Add published (documented) faults to structure and isopach maps.

**Subtask 9.3. Verify seal continuity and integrity**

Continue to assemble available literature data and historic regulations regarding standard practices. Assembling and reviewing literature data regarding well integrity.

**Subtask 9.4. Inventory well status**

Continue to plan for well status database and creation of review protocol.

**Subtask 9.5. Gather expert advice on well integrity**

Continue to compile list of applicable literature regarding well integrity.

## WELLINGTON FIELD STUDY, SUMNER COUNTY, KS

**ONGOING & COMPLETED ACTIVITIES** concerning Wellington Field, Sumner County, KS -- - 1) Drilled and logged test boreholes #1-28 and #1-32 successfully coring of 1639 ft total interval of entire OPAS including upper Cherokee caprock (212 ft drilled in interval, 1427 ft recovered); 2) Conducted field trip to observe coring operation at #1-32 and program review for Program Manager (Jan. 20$^{th}$); 3) Performed initial analysis of wireline logs on new boreholes #1-32 and #1-28; 4) Ran drill stem tests of selected intervals of boreholes #1-28 and #1-32 in Mississippian and Arbuckle; 5) Initiated laboratory analysis of core from #1-32 with survey description of uncut core; 6) Conducted visual fracture characterization of undisturbed core and

began integration of fracture information with well logs, DST and seismic information; 7) Initiate geochemical analysis and microbial studies of water and rock samples obtained from #1-32 and #1-28; 8) Prepared initial geomodel and simulation of CO2 injection in the Arbuckle saline aquifer.

**Subtasks 4.3-4.6. Drill, core, DST, log Test Borehole #1 (BEREXCO Wellington KGS #1-32)**

| | |
|---|---|
| LEASE NAME: Wellington KGS #1-32 (1330001) | COUNTY: Sumner STATE: KS |
| WELL LOCATION: NE SW NE NE | SEC: 32-31S-1W |
| OPERATOR: Berexco LLC | API# 15-191-22591-00-00 |
| CONTRACTOR: Beredco LLC | ELEVATION: GL – 1259 ' KB – 1272 ' |
| RIG: 2 - 316-833-0380 | Toolpusher: Gilbert Davila, 316-833-0379 |
| Cc: Dana, Evan, Richard E-mail: G, Dana, Jim FINAL: AEB, WF | SPUD DATE: 12/29/10 |

12/29/10 7:00 am. Rigging up. Prep to spud.

12/30/10 7:00 am. 130' (130') Waiting on cement. Dry watch. Spudded well @9:00 am, 12/29/10. Drilled to 130' & set 13-3/8 conductor @130'. Cemented w/135 sx common cement, 3% calcium chloride, 1/4# 1 sx cello flake. Circulated cement to surface. Plug down @2:00 pm, 12/29/10. Drain up rig. Plan to resume drilling Jan 2, 2011.

12/31/10 7:00 am, Dry watch

01/01/11 7:00 am, Dry watch.

01/02/11 7:00 am, 130' (0') Pump water, mix mud & start all motors.

01/03/11 7:00 am, 613' (483'). Circulating prior to running Sonic log. Deviation 1/4° @130'.

01/04/11 7:00 am, 847' (234') Drilling. Set 14 jts 24#, 8-5/8" csg @607'. Cemented w/150 sx 60/40 POZ cement w/3% CC + 1/4# cello flake/sx and 150 sx common cement w/3% CC + 1/4# cello flake/sx. Had good circulation and circulated cement to surface. Ran one centralizer four joints off bottom and one up in conductor pipe. Bottom 3 jts 8-5/8" where strapped. Drilled out shoe after 8.5 hrs w/7-7/8" Smith F27J bit. Deviation 1 1/2° @613'.

01/05/11 7:00 am, 1745' (898') Drilling. Deviation 1° @1091'.

01/06/11 7:00 am, 2735' (990') Drilling.

01/07/11 7:00 am, 3423' (688') Drilling. Deviation 1 1/2° @2808'.

01/08/11 7:00 am, 3550' (127'). Coring. After reaching core point of 3540', circulated clean on bottom 1½ hrs, made short trip up to 600', back to bottom & circulated clean 1½ hrs. Tripped out & went in w/coring bottom hole assembly.

01/09/11 7:00 am, 3659' (109') Tripping out with core.

01/10/11 7:00 am, 3690' (31') Running DST #1 in Mississippi. Cored top 30' of Mississippi oil reservoir.

01/11/11 7:00 am, 3768' (78') Coring. Core from 3690'-3750' was full 60'.
DST #1, 3664-3690', Mississippian
Recovered 800' mud cut water (15% mud, 85% wtr overall)
68-240, 1048#
258-414, 1049#

01/12/11 7:00 am, 3870' (102'). Trip in w/coring tools to cut core #7. Core from 3768-3810' was full recovery.

01/13/11 7:00 am, 3962' (91') Coring.

01/14/11 7:00 am, 4038' (76') Coring. Loading out cores to send to Houston.

01/15/11 7:00 am, 4138' (100') Coming out to core.

01/16/11 7:00 am, 4226' (88') Coring.

01/17/11 7:00 am, 4267' (41') Reamed bottom of hole & return to coring.

01/18/11 7:00 am, 4303' (36') Coring.

01/19/11 7:00 am, 4414' (111') Tripping out w/core bbl. Recovered 2 full cores.

01/20/11 7:00 am, 4463' (49') Tripping w/core bbl.

01/21/11 7:00 am, 4523' (60') Coring. Started new core @4520'.

01/22/11 7:00 am, 4575' (52') Prep to log. Deviation 2 1/2° @4575'.

01/23/11 7:00 am, 4575' (0') Conditioning hole prior to running DST #3. In prior 24 hrs ran intermediate logs. Logger TD 4573' - good match w/drillers TD.
DST #2, 4465-4575', Arbuckle
Recovered: 3720' black sulfury water, 180' mud
1504-1867, 1867
1867-1867, 1867
NOTE: Permeability so high this test reached static reservoir pressure about ⅓ way through first 30 minutes open (1867#). All pressures after that remain at 1867# since well was at static reservoir pressure.

| | |
|---|---|
| LEASE NAME: Wellington KGS #1-32 (1330001) | COUNTY: Sumner STATE: KS |
| WELL LOCATION: NE SW NE NE | SEC: 32-31S-1W |
| OPERATOR: Berexco LLC | API# 15-191-22591-00-00 |
| CONTRACTOR: Beredco LLC | ELEVATION: GL – 1259 ' KB – 1272 ' |
| RIG: 2 - 316-833-0380 | Toolpusher: Gilbert Davila, 316-833-0379 |
| Cc: Dana, Evan, Richard E-mail: G, Dana, Jim FINAL: AEB, WF | SPUD DATE: 12/29/10 |

01/24/11 7:00 am, 4575' (0') Tripping in hole to condition prior to running DST #4.
DST #3, 4280-4390', Arbuckle
Recovered: 4006' sulfury water
1069-1782/1785
1781-1784/1783
NOTE: Like DST #2, this test reached static conditions during the first flow.

01/25/11 7:00 am, 4575' (0'). Tripping in hole to condition prior to resuming coring.
DST #4, 4175-4190', Arbuckle
Recovered: 450' sulfury mud cut water
18-90/1714
94-219/1718

01/26/11 7:00 am, 4587' (12') Prep to resume coring. Had 12' core recovery previous evening. Will circulate clean & resume coring.

01/27/11 7:00 am, 4605' (18') Prep to resume coring. Had 10' core recovery.

01/28/11 7:00 am, 4659' (54') Tripping out w/core - recovered 33'. Had partial lost circulation - lost 250 Bbls mud.

01/29/11 7:00 am, 4680' (21') Prep to resume coring. Drilled 4659-4680' w/conventional bit to try to get past heavily fractured interval.

01/30/11 7:00 am, 4727' (47') Prep to resume coring. Cored 4680-92' and jammed. Drilled 4692-4727' w/conventional bit.

01/31/11 7:00 am, 4764' (37') Coring. Cored from 4727-4750' and jammed. Cored from 4750-64' and coring OK at report time.

02/01/11 7:00 am, 4801' (37') Prep to resume coring. Core from 4750-4801'. Very cold conditions.

02/02/11 7:00 AM, 4801' (0') Cold weather, rig froze up.

02/03/11 7:00 am, 4891' (90') Cored from 4801-4821' & jammed. Went in w/conventional bit to drill from 4821' to 4900' & then will resume coring.

02/04/11 7:00 am, 4960' (69') Cored from 4900-4960' w/full recovery. Tripping in w/core Bbl to resume coring.

02/05/11 7:00 am, 4999' (39') Cored from 4960-4988' and jammed. Continued coring at 4988'.

02/06/11 7:00 am, 5050' (51') Cored from 4988-4999' and jammed. Ran conventional bit & drilled from 4999-5050' (51') w/conventional bit.

02/07/11 7:00 am, 5127' (77') Cored from 5050-5084' and jammed. Cored from 5084-5127' & coring OK at report time. Have not reached granite wash.

02/08/11 7:00 am, 5178' (51') Loading out coring equipment. Cored from 5084-5144' w/last foot in Regan Sand. Cored from 5144-5178' with last 4 feet in granite. Coring operations are complete.

02/09/11 7:00 am, 5240' (62') Logging. Reached TD at 11:00 pm, 2/8/11.

02/10/11 7:00 am, 5240' (0') Logging. Prep to run casing.

**Figure 2. Drilling report for KGS #1-32.**

Final drilling report is shown above that defines daily progress for Wellington KGS #1-32. The length of conventional core taken by this contractor (Devibliss Coring) in this well was a record for his 30+ years in business. Core was taken, DST tests and wireline logs were run, and borehole was cased from top to bottom.

Photomosaic in Figure 3 shows core barrel on rig floor with granite basement along with fracture in granite lined with epidote, and haze on rig floor from late night snowstorm in subzero conditions.

Figure 3. Last core run (#42) into granite basement.

The Arbuckle saline aquifer contains bed specific porosity types that were seen when core was described in Houston at Weatherford Labs. Pore types include between particle (BP), vugs, breccia pores, and zones of fracturing (Figure 4). Core was described in preliminary manner so that core analyses could be staged. More extensive description will follow.

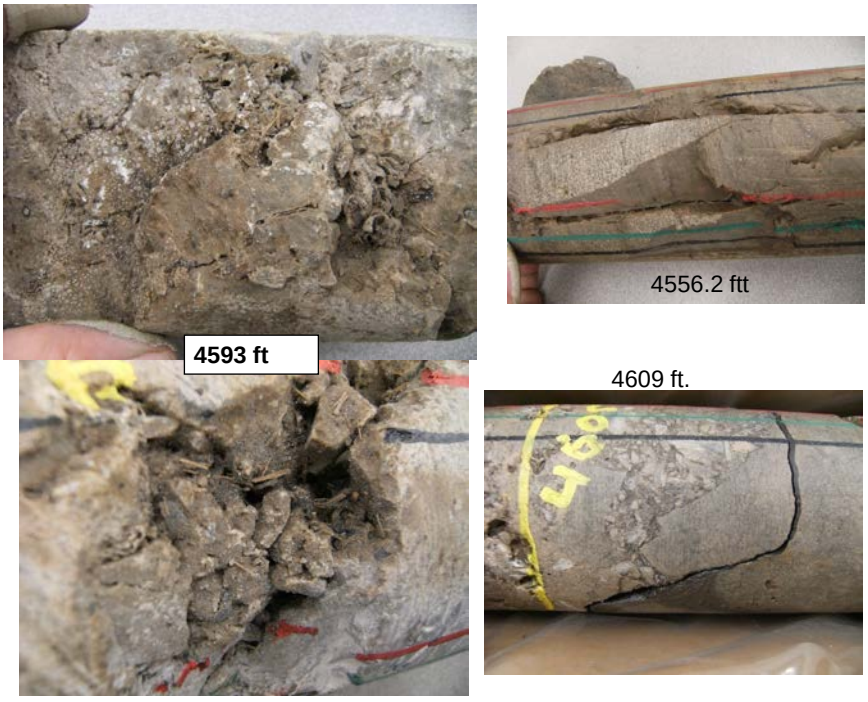



**Figure 4. Representative pore types observed in Arbuckle dolomite.**

The cored interval above the Arbuckle contains a thick section of shale dominated Lower Orodovican age Simpson Group overlain by lower Upper Devonian-Mississippian age shale and shaly carbonate that serve as the primary caprock. The secondary caprock is the Cherokee Group (Middle Pennsylvanian) shales shown at the top of Figure 5. The uppermost Mississippian is the underpressured oil reservoir that is the focus for enhance oil recovery using CO2 injection.

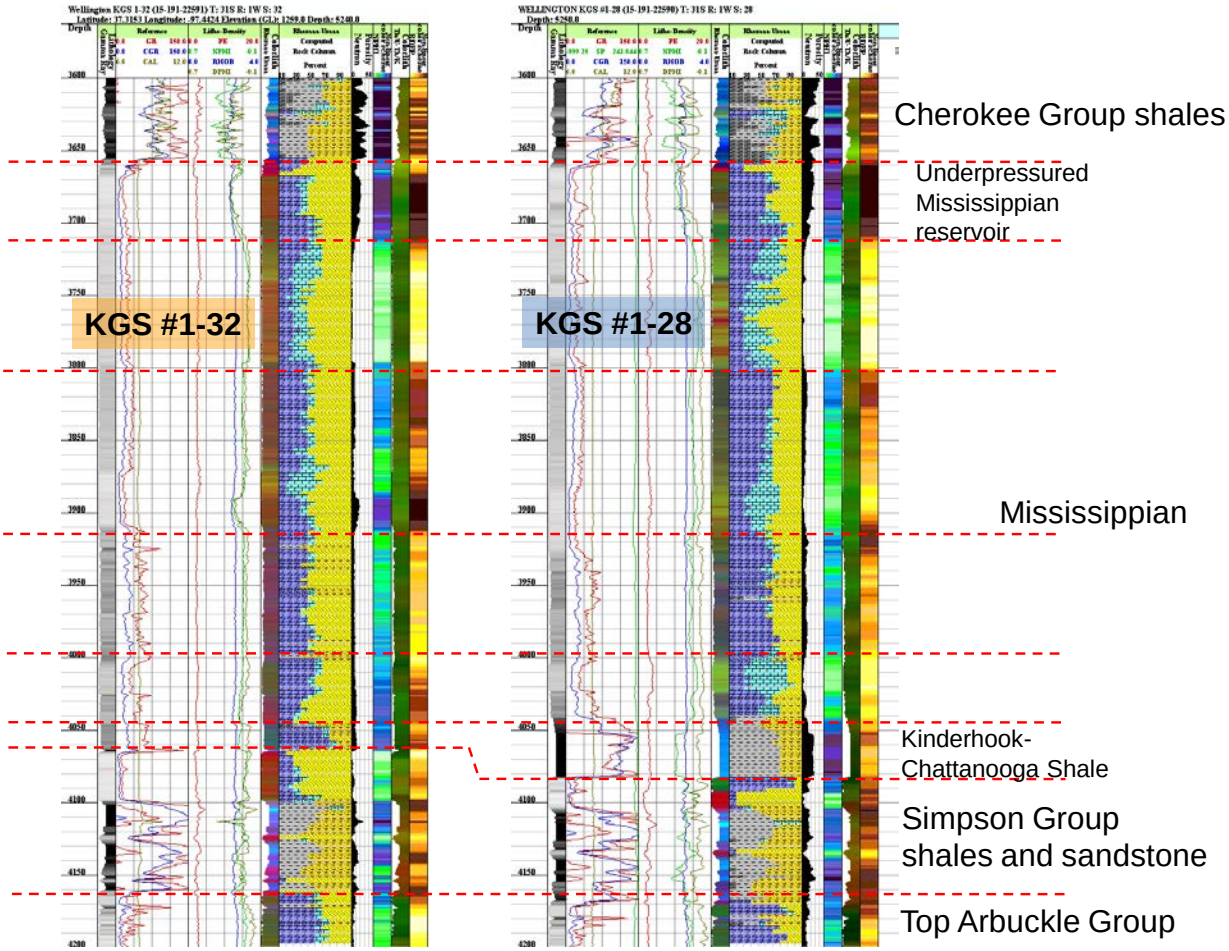



**Figure 5. Color image log of the lowermost Pennsylvanian, Mississippian and Upper Devonian, and the Lower Ordovician Simpson Group for the two newly drilled wells, KGS #1-32 and #1-28. Note that the Kinderhook and Chattanooga Shale interval thins in the KGS #1-32 while the lower Mississippian shaly carbonate strata are thick and continuous. Local thickening of underlying sandstone in the Simpson Group appears to have led to thinning of the overlying Kinderhook-Chattanooga Shale.**

The Arbuckle saline aquifer in the cored well, #1-32, is 1000 ft thick consisting of a complex succession of meter-thick beds of clean (less argillaceous) porous dolomite (grainstone, packstone, breccia) interbedded with shaly dolomudstones. The lower third of the Arbuckle is cleaner and more porous while the mid section of the Arbuckle is shalier and less porous (Figure 6). It appears individual shale beds in this mid section correlate between wells #1-32 and #1-28. This stratigraphic succession has been observed on well logs in the Arbuckle in surrounding

areas, thus the core is quite representative of the area. Moreover, this succession supports the preliminary concept of injecting CO2 near the base of the Arbuckle to take advantage potential baffling effects of possible aquicludes.

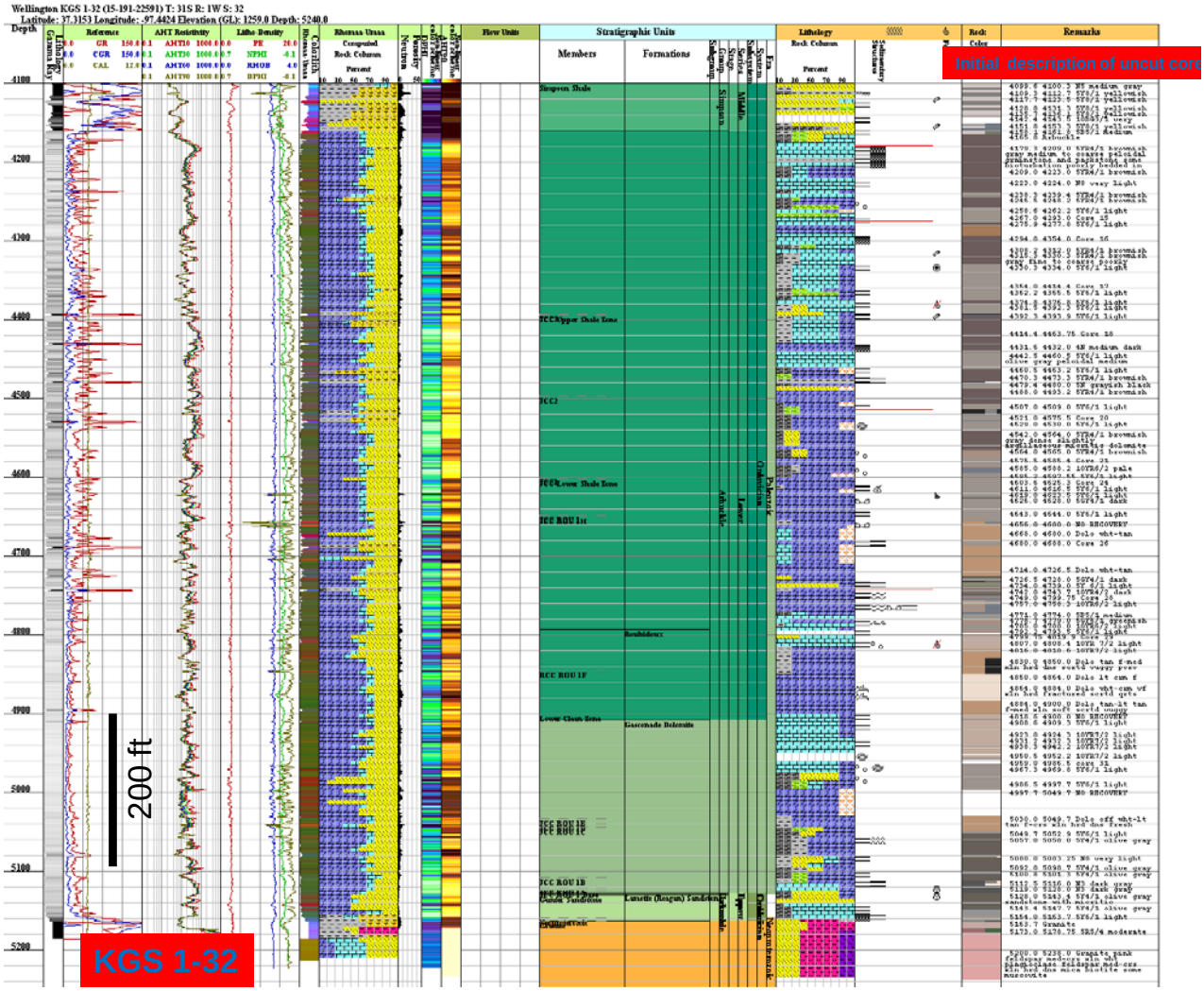



**Figure 6. The complete section of Arbuckle saline aquifer from the Precambrian basement into the overlying Simpson Group. The diagram includes wireline logs on left with color imaging corresponding to lithology, a central column with stratigraphic nomenclature, and on right a stratigraphic column and preliminary description of the unslabbed core.**

The wireline ran in KGS #1-32 and#1-28 were comprehensive ranging from formation microimaging, nuclear magnetic resonance (NMR), dipole sonic (spectral sonic), array induction, spectral gamma ray and geochemical log. The NMR log was used to obtain profiles of the total effective porosity and permeability estimate in both wells (Figure 7). The whole core analyses of much of the Arbuckle (every other foot selected by lithofacies and beds) will be used to further calibrate the NMR log. Also the sonic log will be used to add the contribution of fractures.

## Role of Matrix Contribution to Porosity & Permeability in the Arbuckle Aquifer

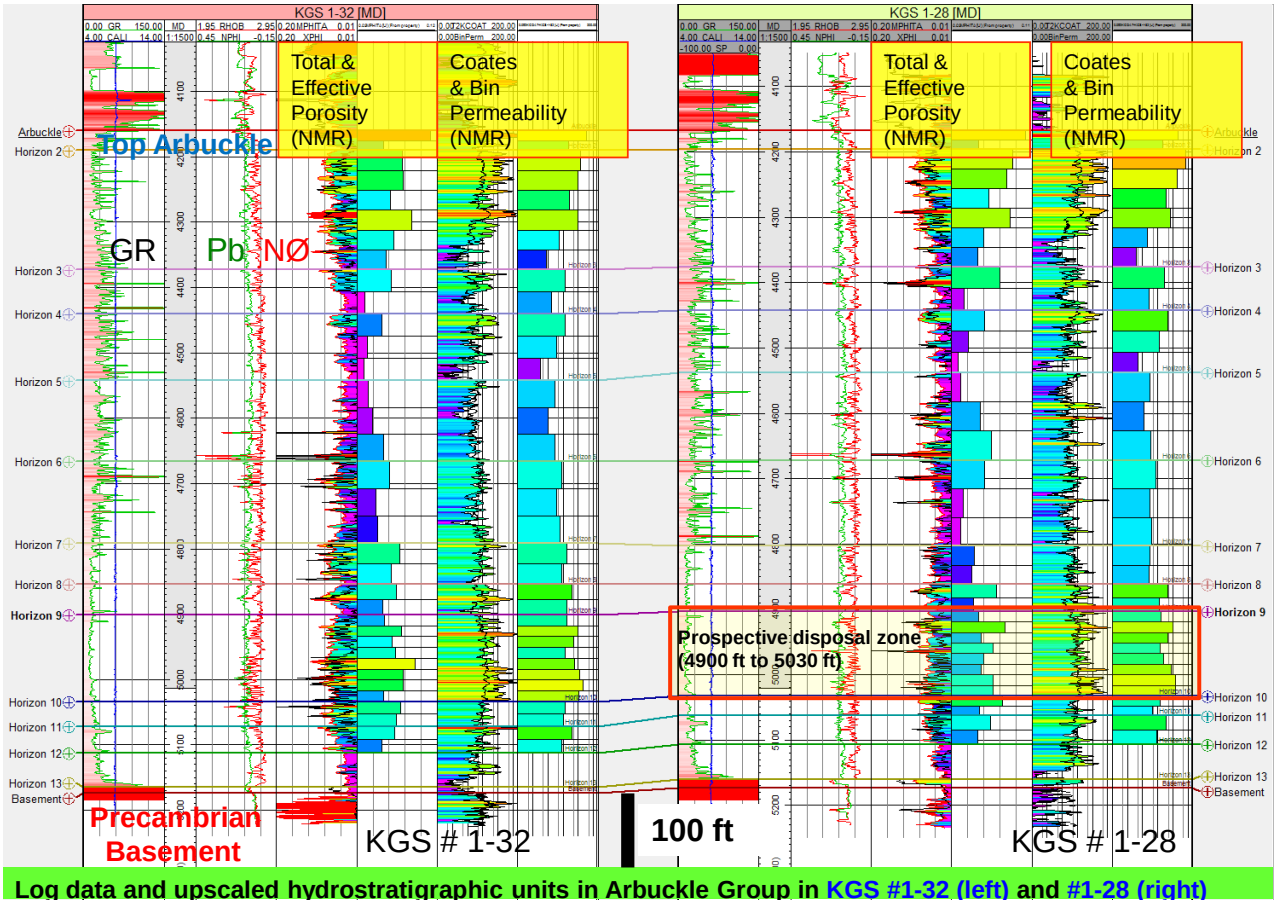
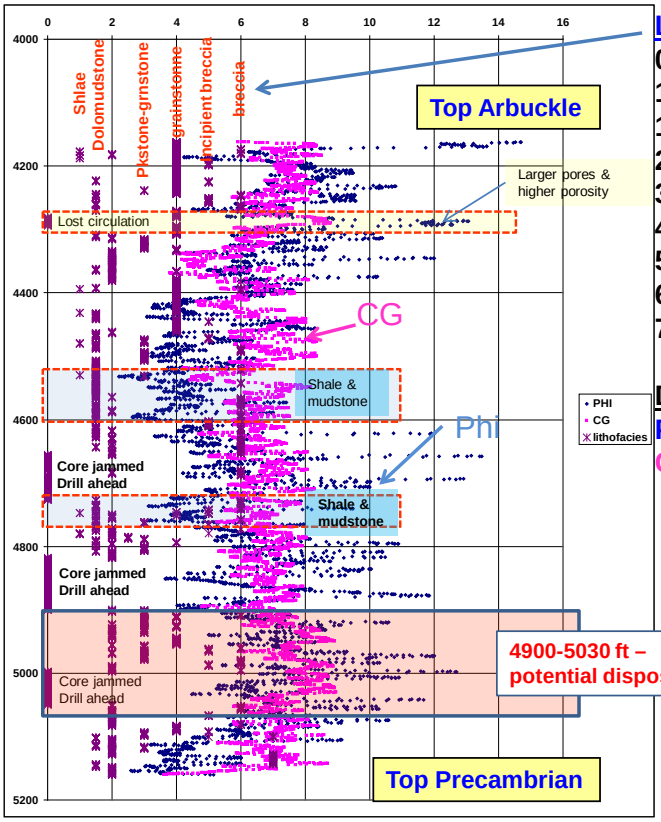



**Figure 7 shows the gamma ray, bulk density, and neutron porosity with the NMR permeability that have been upscaled in Petrel to form horizons (correlatable units between #1-32 and#1-28) and layers within the horizons. A prospective injection zone in the lower Arbuckle is shown that will likely be used in the initial simulations.**

The preliminary core description consisted of distinguishing basic flow units (hydrostratigraphic units) and shalier tight zones by delimiting the tight mudstones, packstone-grainstones with interparticle porosity, and the breccias with varying amounts of interclast porosity. Locally, quartz sandstone is present. These lithofacies and distinct beds that they comprise also contain fractures of varying abundances, but fractures are less significant in tight, argillaceous intervals. More discussion will come later as the fracture analysis proceeds.

The lithofacies were compared to the NMR T2 (relaxation time) and the sum of porosity derived from the NMR log. T2 is proportional to the size of pores. Figure 8 strongly suggests that the particle- and breccia-dominated lithofacies correlate to higher porosity and larger pores, the largest being associated with the interformational breccias.

## Preliminary analysis of nuclear magnetic resonance imaging log in Arbuckle Group compared with core in Wellington #1-32




**Lithofacies from core (vertical colums) (x)**
**0 = no core recovered**
**1 = shale**
**1.5 = argillaceous dolomudstone**
**2 = mudstone-wackestone**
**3 = packstone-grainstone**
**4 = grainstone**
**5 = incipient autoclastic brecca**
**6 = autoclastic brecca**
**7 = quartz sandstone**

**Derived from relaxation time of NMR log:**
**PHI (+) = sum of porosity in T2 channels**
**CG (Δ) = center of gravity of T2 spectrum**
**units are powered relaxation times**
**e.g. $T2 = CG^2$**
**=>larger number, larger the size of pores**

**Figure 8. NMR log values of porosity and pore size (T2) compared to lithofacies from preliminary core description.**

Figure 9 shows the relationship between porosity and pore size and T, relaxation time in milliseconds.

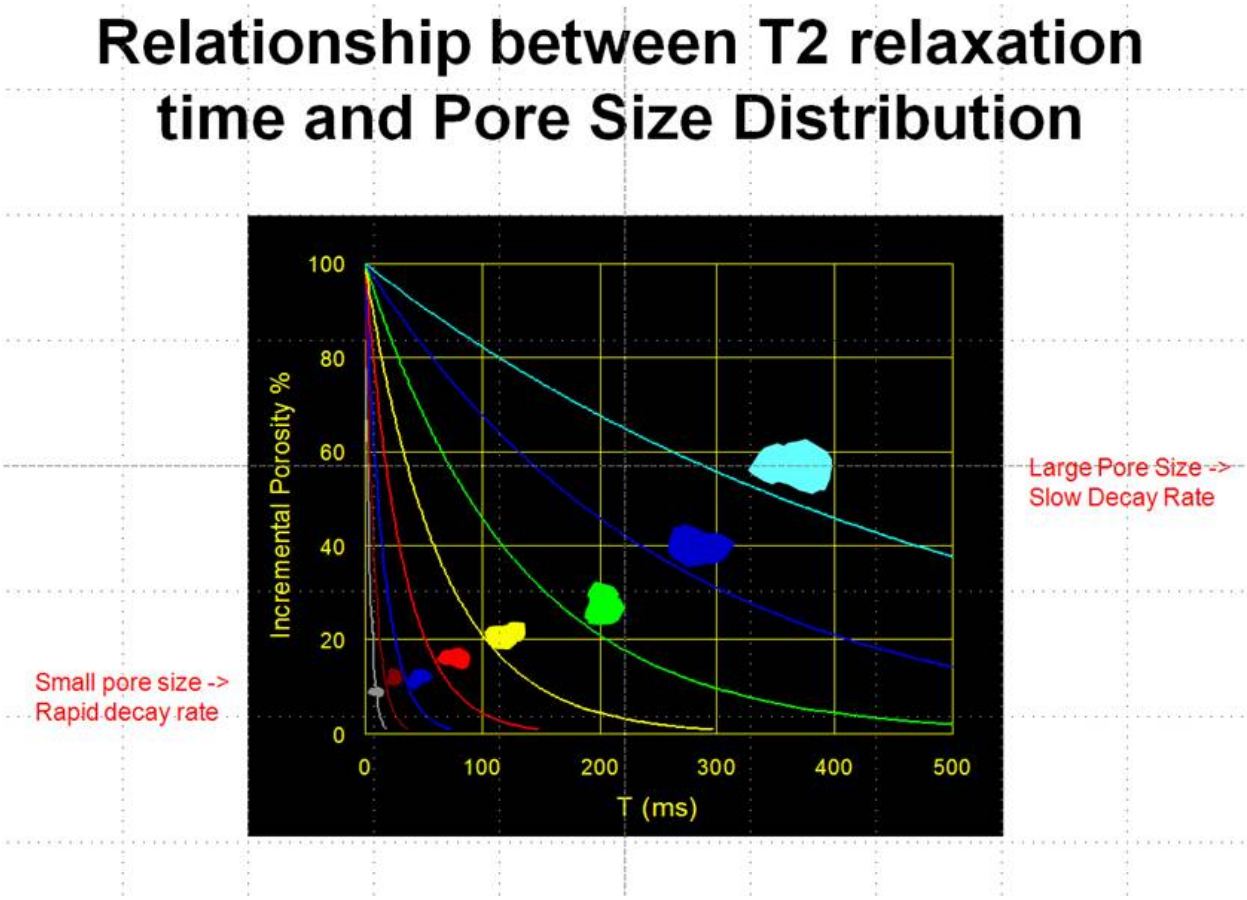



**Figure 9. Incremental porosity vs. relaxation time (T) and pore size.**

**Subtask 4.1l. Geochemical analysis of water samples**

Kansas State University
Department of Geology
Geochemistry Team
DST Water Analysis Report 5/01/2011
Robinson Barker and Dr. Saugata Datta

**Introduction**

This report presents the water analyses by the K-State Geochemistry team from drill stem tests on wells KGS-1-32 and KGS-1-28. During the drilling of the two study wells a total of 8 drill stem test (DST) waters were collected. Each of the DSTs was sampled at various depths (Table 1) and represents a depth profile of the Arbuckle aquifer including the overlying and underlying strata. From each DST three samples were collected. DST 1 and 5 did not have much recovery and only two and one samples were collected, respectively. DST 1 was taken from the Mississippian aquifer that overlies the Arbuckle. DST 5 tested the Reagan sandstone which underlies the Arbuckle formation. DST 1- 4 were collected from KGS_1-32 and DST 5-8 were

collected from KGS_1-28. Sample collection and preparation methods are explained for the water that was collected. The results are demonstrated into graphs that show the relationships between key elements and depth profiles of the elements of the greatest concentrations.

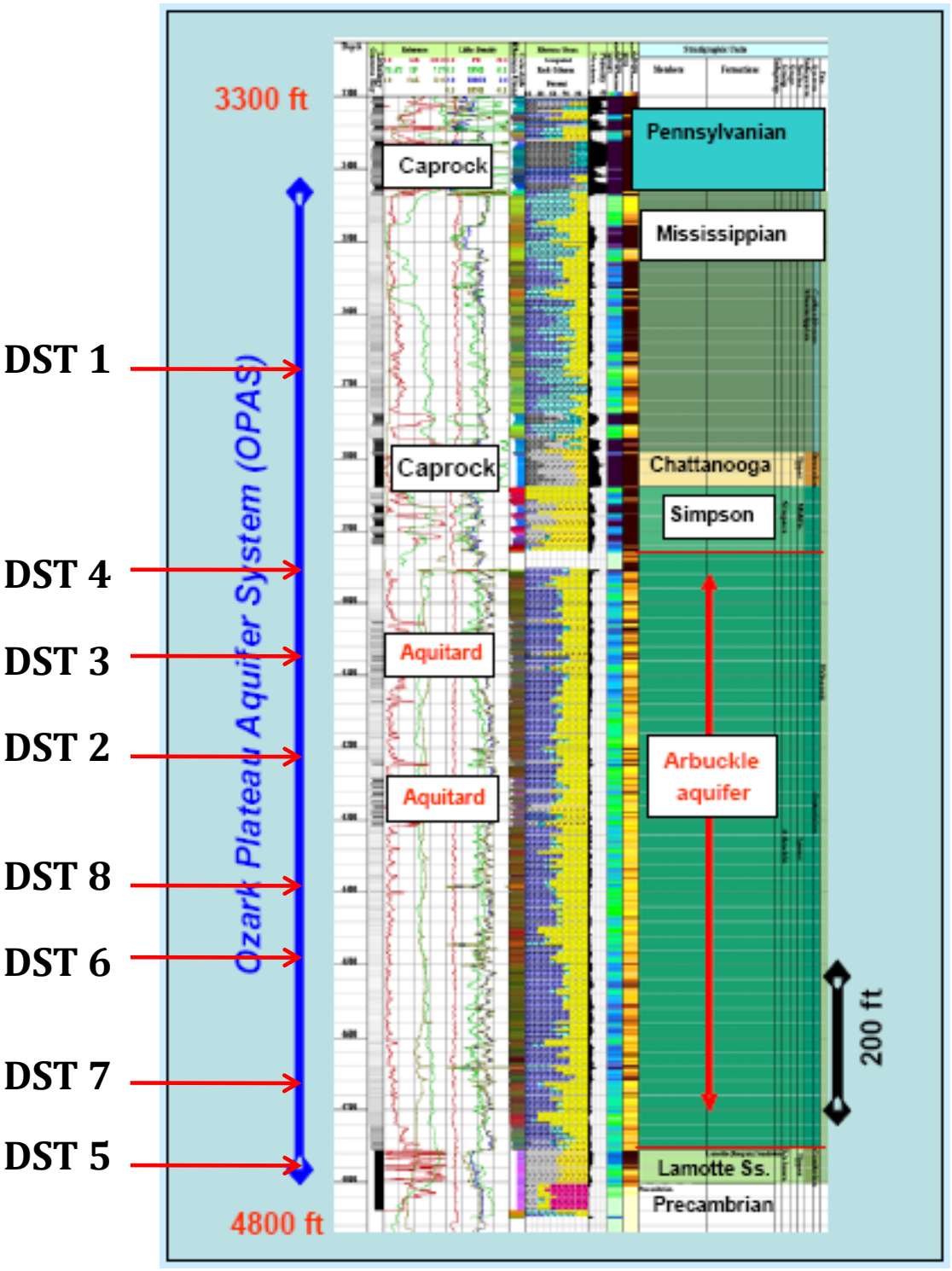
**Methods**

Samples were chosen from the end (bottom) of the pipe, usually in the last few stands of drill collar to ensure minimal contamination with drilling mud. The water was caught in 5 gallon buckets and quickly transferred to various sampling containers, including one 2 gallon HDPE jug, two 50mL centrifuge tubes, two 125mL amber HDPE bottles, two 500mL clear HDPE bottles, one 125mL glass bottle and one 60mL glass bottle, which pertains to various analyses. The samples were stored cold and transferred to the Geochemistry lab where they underwent centrifugation in 50 mL centrifuge tubes for 15 minutes to separate the residual mud/oil that was in the samples. The water samples were then filtered through a 0.45 μm filter. The samples that were analyzed for major and trace elements and cations by inductively coupled plasma optical emission spectroscopy (ICP-OES) were acidified to <2 pH using Optima Grade nitric acid according to the analytical protocol. Ion Chromatographic (IC) analysis were done on unacidified samples, hence two analytical samples from each DST were prepared for ICP-OES and IC.

**Results**

The following graphs display the results from one sample from each DST. Other samples were also analyzed, and will be reported if needed. The sample that was collected closest to the DST tool was selected for these graphs to portray the 'cleanest' sample. The depth values that represent the 8 DST samples are the median of the interval tested.

Figure 10. Approximate depths of the eight drill stem tests taken from KGS-1-32 and KGS-1-28. Log column adapted from KGS.



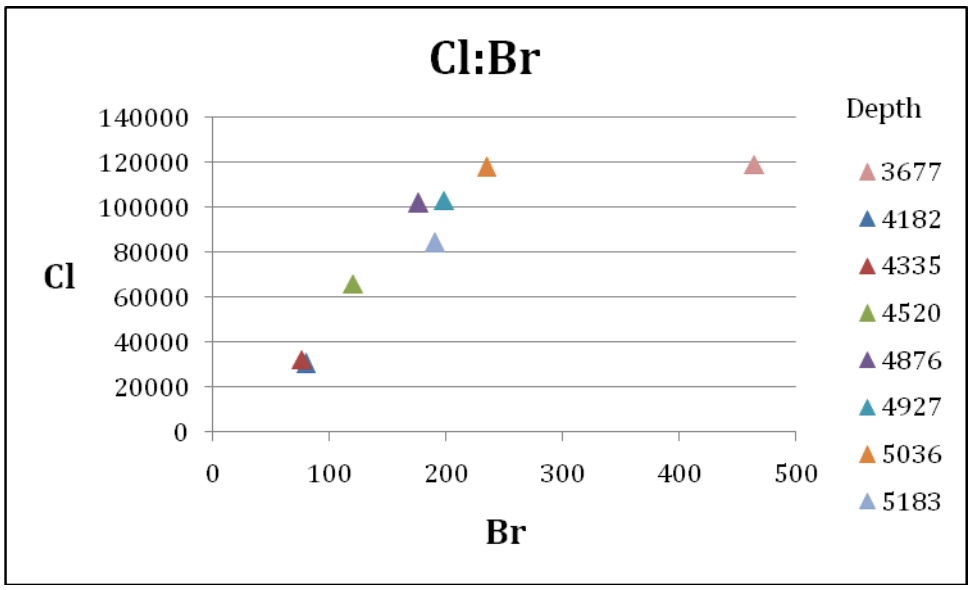



Figure 11. Chloride to Bromide ratio with depth, concentrations in mg/L. A 1:1 ratio is observed with an exception in the 3677 foot data point taken from the Mississippian aquifer overlying the Arbuckle. See fig. 4 for trend line and $R^2$ value.

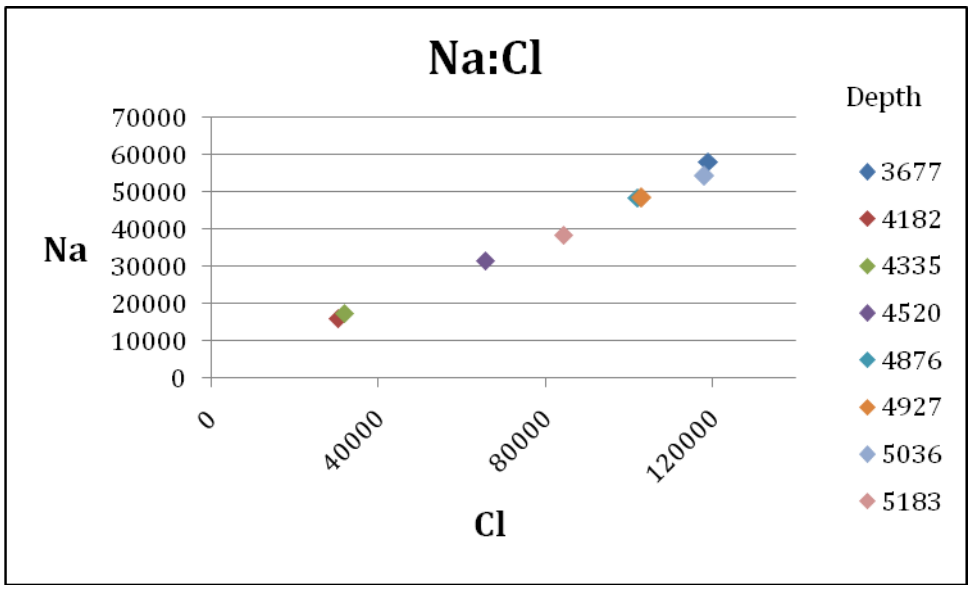
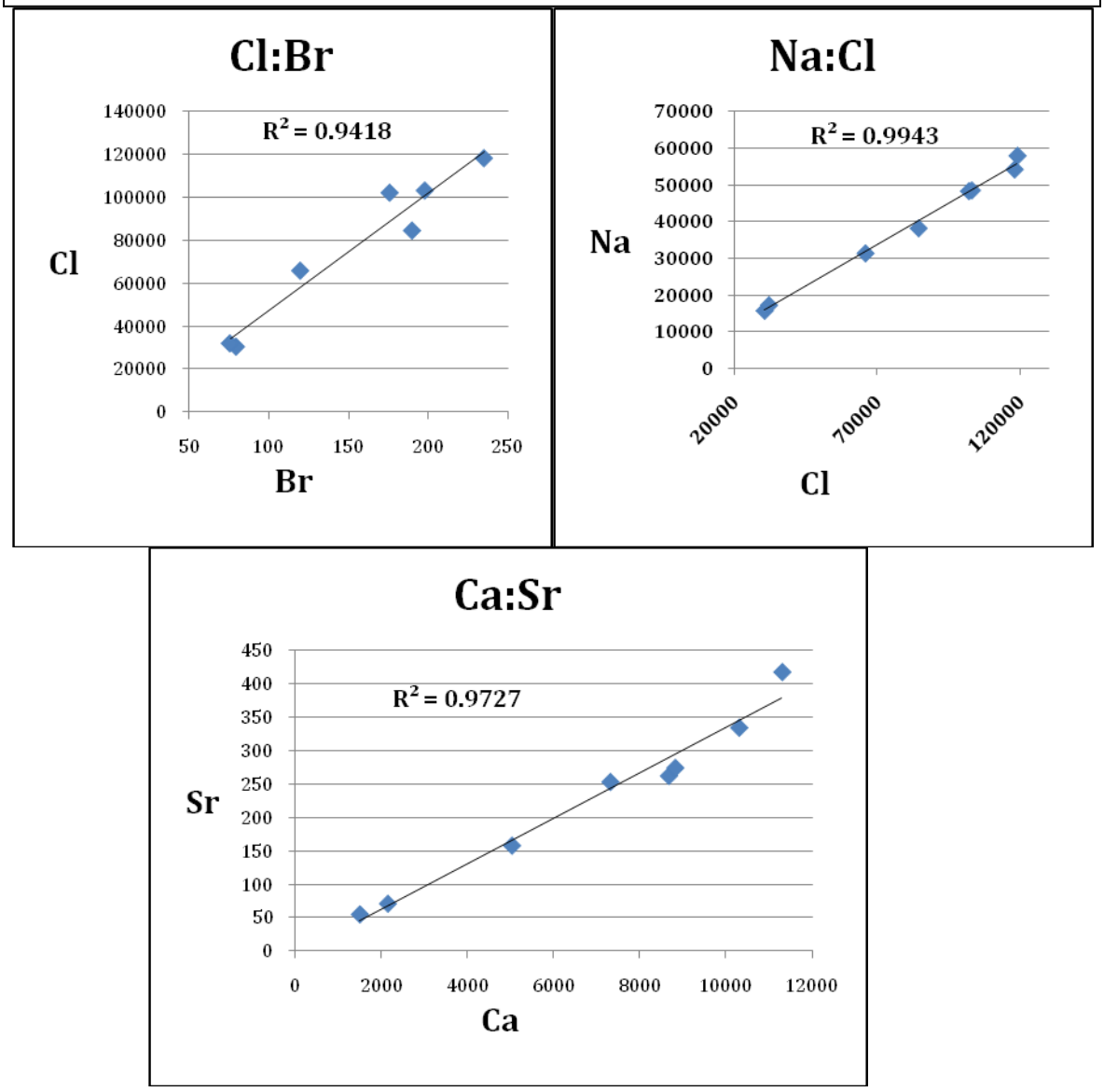



Figure 12. Sodium to Chloride ratio, concentrations in mg/L. A 1:1 trend is observed in this data. This follows the trend common to saline aquifers. See fig 4 for trend line and $R^2$ value.

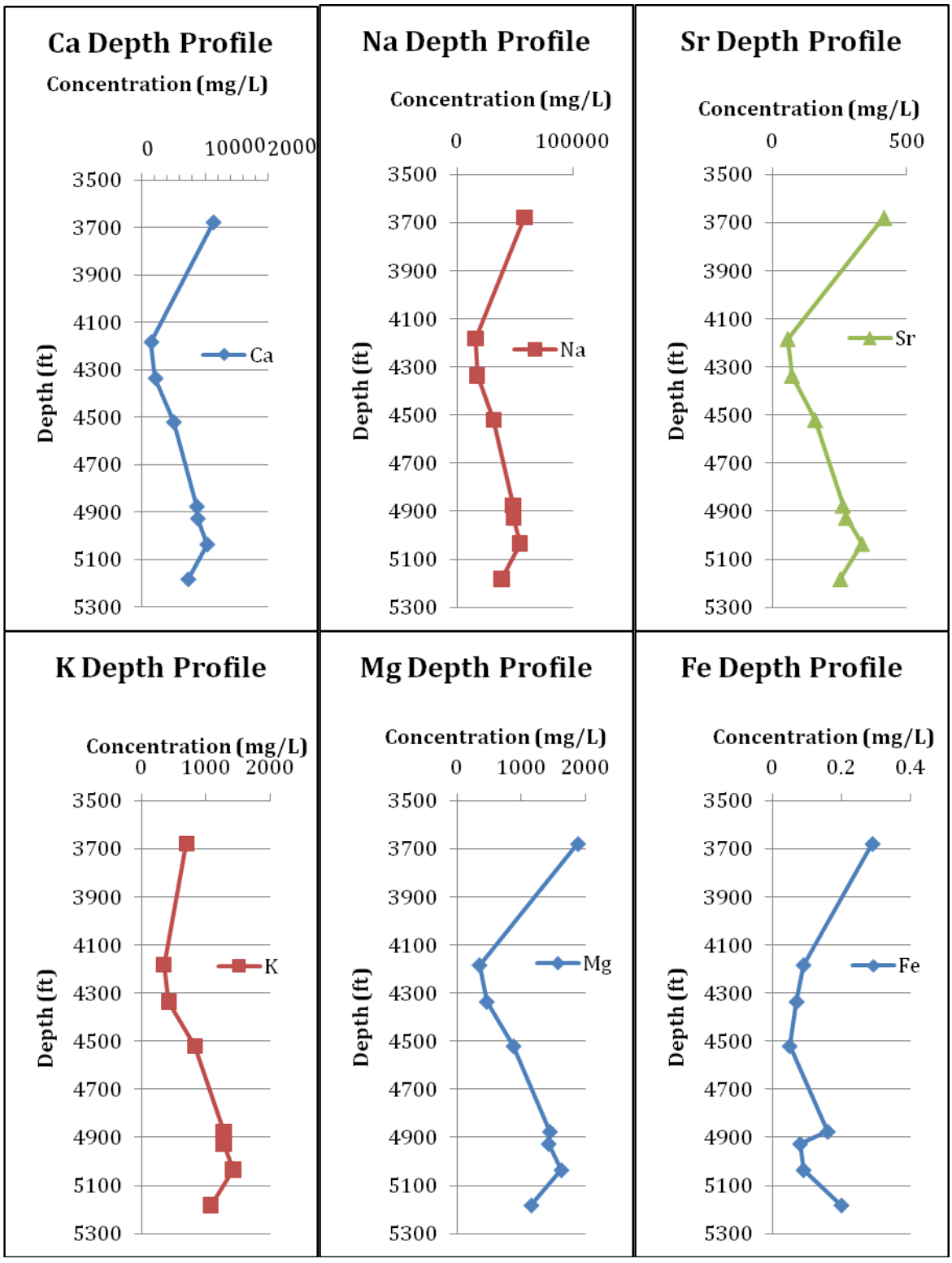
Figure 13. Elemental graphs showing correlations and possible trend lines and respective $R^2$ values. Ca:Sr graph was added to show correlation. The anomalous data point (3677 ft) on the Cl:Br graph was omitted to show the trend within the Arbuckle. Concentrations are in mg/L.

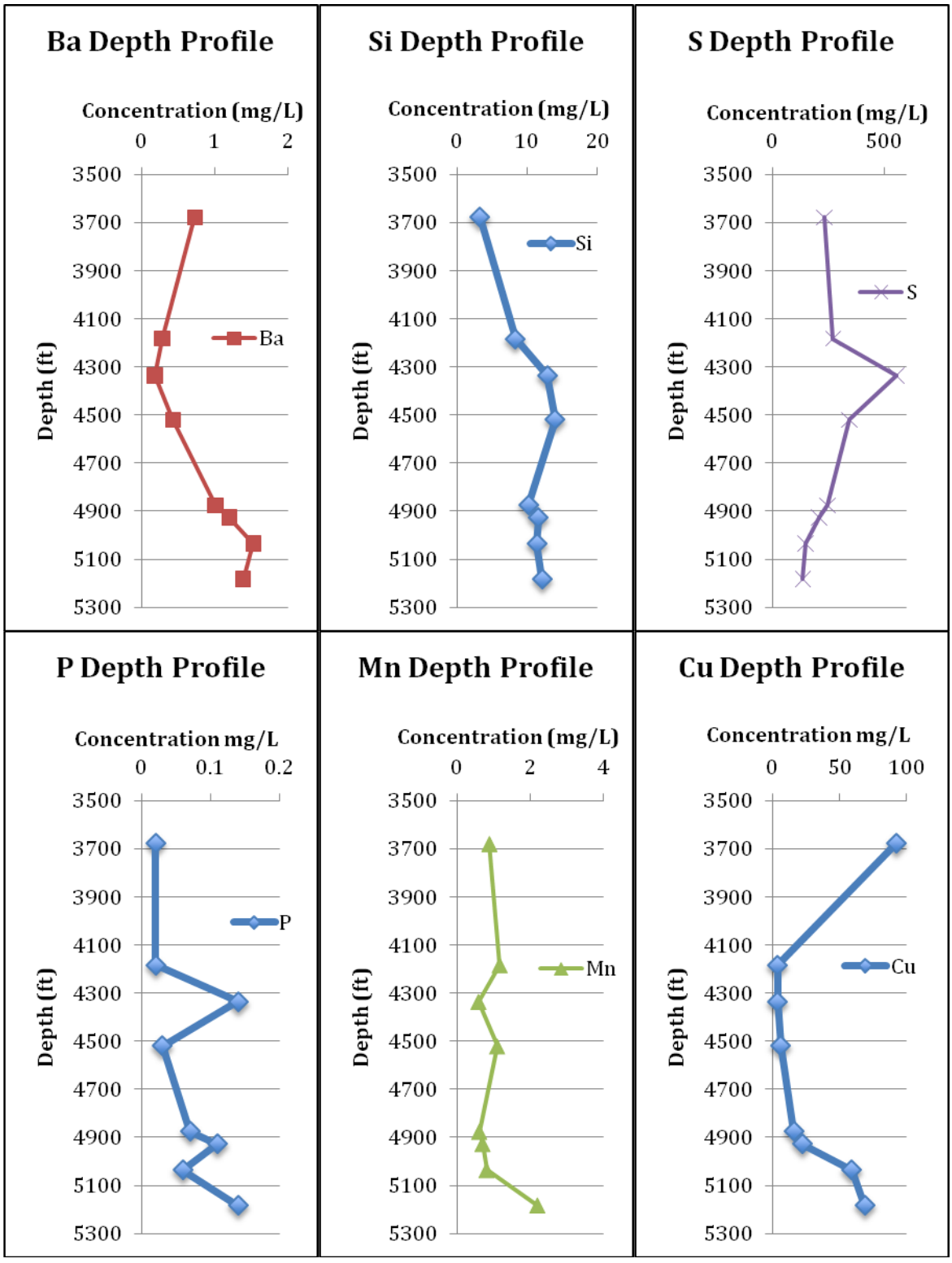


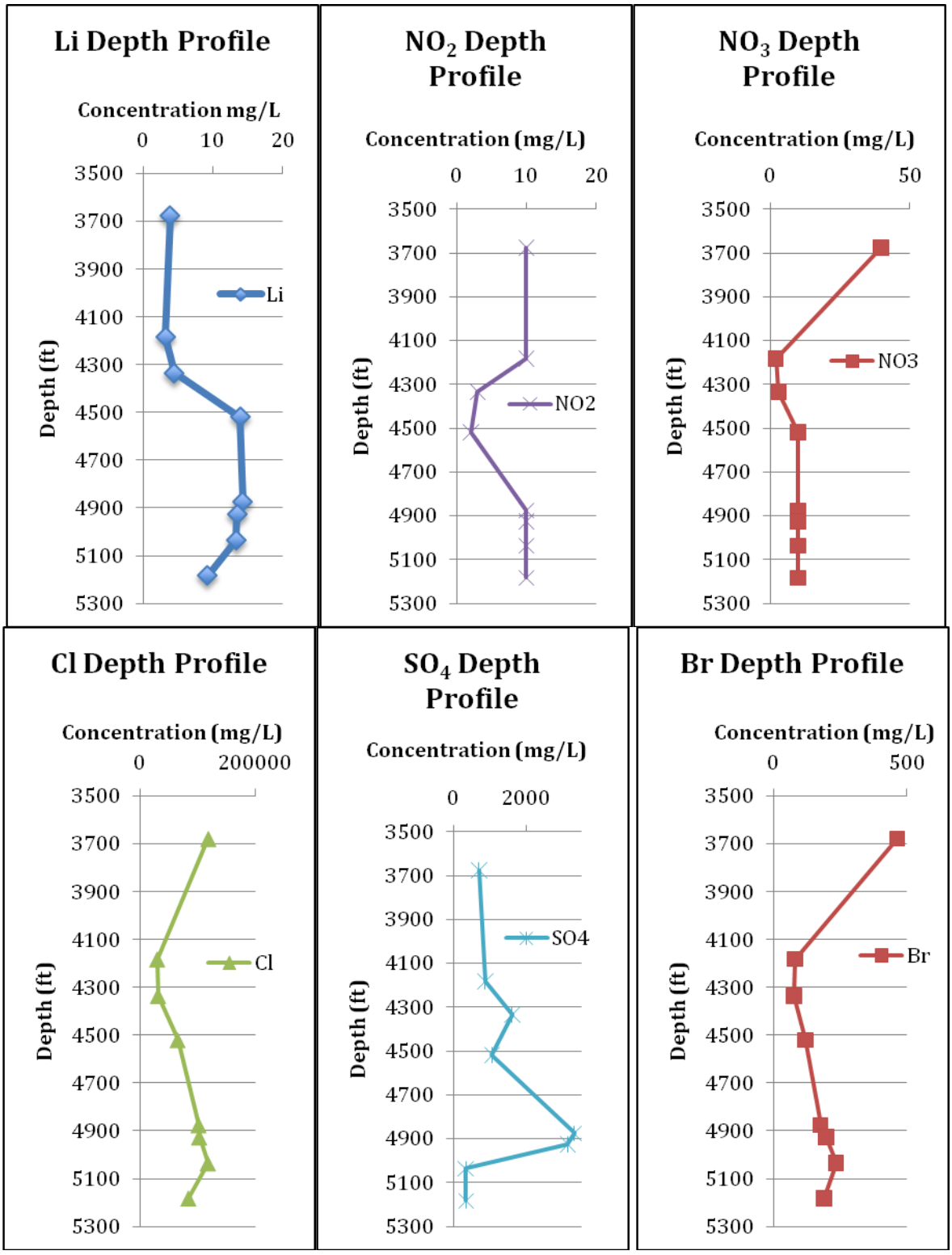
| DST | KGS-1-32 | DST | KGS-1-28 |
|---|---|---|---|
| 1 | 3664-3690 | 5 | 5133-5233 |
| 2 | 4465-4575 | 6 | 5026-5047 |
| 3 | 4280-4390 | 7 | 4917-4937 |
| 4 | 4175-4190 | 8 | 4866-4885 |

Table 1. Depth intervals tested for the 8 DSTs in KGS-1-32 and KGS1-28. The median value was selected for plotting on graphs.

Figure 14. Depth profiles for major and trace metals in the Arbuckle. Profiles for Fe, Ba, Mn, $SO_4$, K, S, Mg, Sr, Ca, Cl, Na, Br, Si, $NO_2$, $NO_3$, Cu, Li and P are plotted below. Note the top data point (3677) is from the Mississippian aquifer and the deepest data point (5183) represents the Reagan sandstone.


Ca Depth Profile
Concentration (mg/L)
0
10000
2000
Depth (ft)
3500
3700
3900
4100
4300
4500
4700
4900
5100
5300
Ca
Na Depth Profile
Concentration (mg/L)
0
100000
Na
Sr Depth Profile
Concentration (mg/L)
0
500
Sr
K Depth Profile
Concentration (mg/L)
0
1000
2000
K
Mg Depth Profile
Concentration (mg/L)
Mg
Fe Depth Profile
Concentration (mg/L)
0
0.2
0.4
Fe


Ba Depth Profile
Concentration (mg/L)
0
1
2
3500
3700
3900
4100
4300
4500
4700
4900
5100
5300
Depth (ft)
Ba
Si Depth Profile
Concentration (mg/L)
0
10
20
Depth (ft)
Si
S Depth Profile
Concentration (mg/L)
0
500
Depth (ft)
S
P Depth Profile
Concentration mg/L
0
0.1
0.2
Depth (ft)
P
Mn Depth Profile
Concentration (mg/L)
0
2
4
Depth (ft)
Mn
Cu Depth Profile
Concentration mg/L
0
50
100
Depth (ft)
Cu


Li Depth Profile
Concentration mg/L
0
10
20
3500
3700
3900
4100
4300
4500
4700
4900
5100
5300
Depth (ft)
Li
NO2 Depth Profile
Concentration (mg/L)
0
10
20
3500
3700
3900
4100
4300
4500
4700
4900
5100
5300
Depth (ft)
NO2
NO3 Depth Profile
Concentration (mg/L)
0
50
3500
3700
3900
4100
4300
4500
4700
4900
5100
5300
Depth (ft)
NO3
Cl Depth Profile
Concentration (mg/L)
0
200000
3500
3700
3900
4100
4300
4500
4700
4900
5100
5300
Depth (ft)
Cl
SO4 Depth Profile
Concentration (mg/L)
0
2000
3500
3700
3900
4100
4300
4500
4700
4900
5100
5300
Depth (ft)
SO4
Br Depth Profile
Concentration (mg/L)
0
500
3500
3700
3900
4100
4300
4500
4700
4900
5100
5300
Depth (ft)
Br

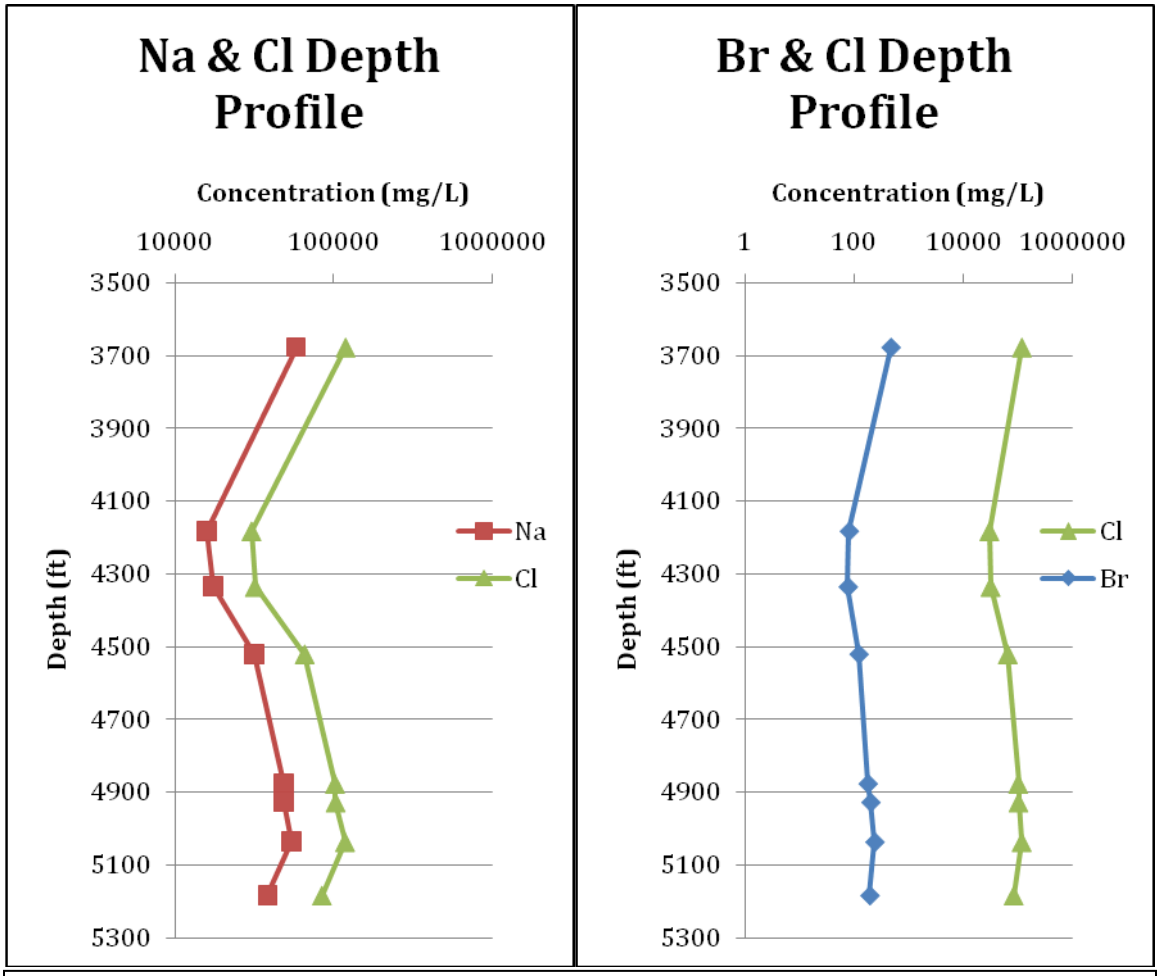



Figure 15. Depth profiles for sodium/chloride and bromide/chloride. The concentrations of these ions increase with similar trends. Na and Cl are the dominant components of the Arbuckle water. Note the concentrations are displayed as log scale due to high concentrations

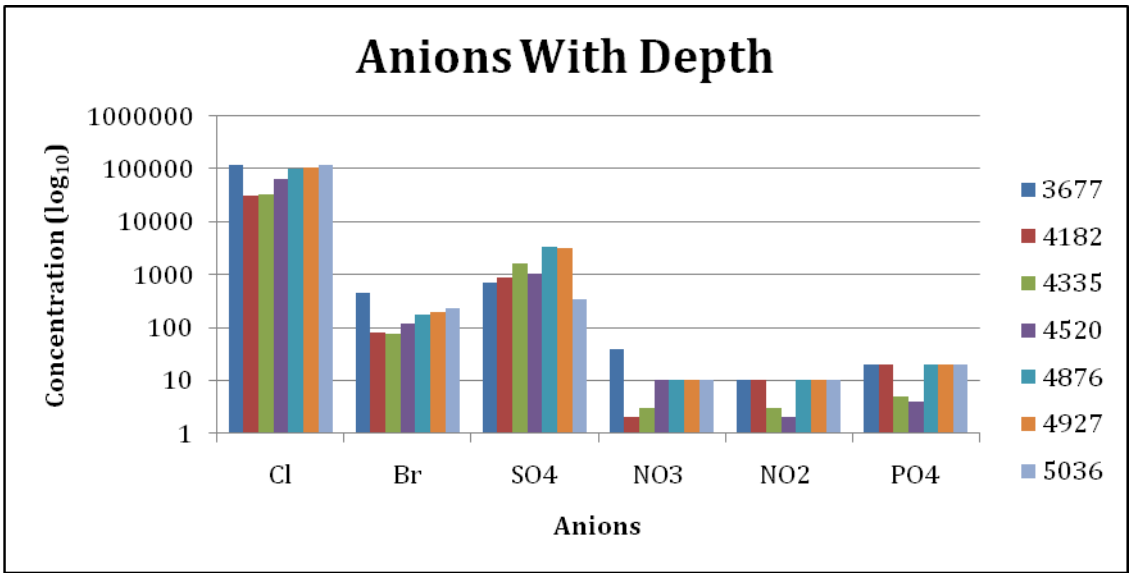



Figure16. Histogram showing the major anions and their variation with depth. Depth increases from left to right. Note the log scale used on the y axis.

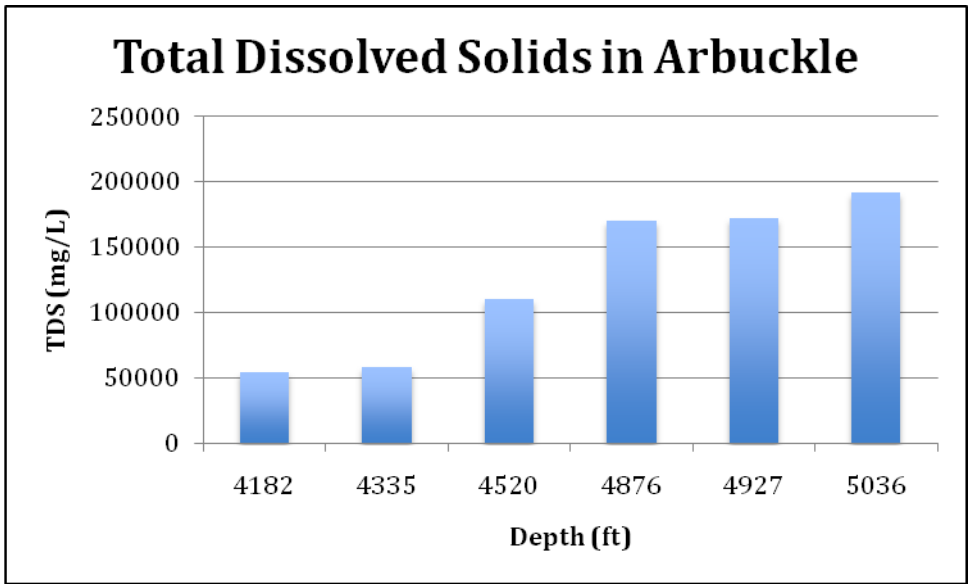



Figure 17. Total dissolved solid within the Arbuckle formation. A clear increase follows the trend of increasing salinity with depth.

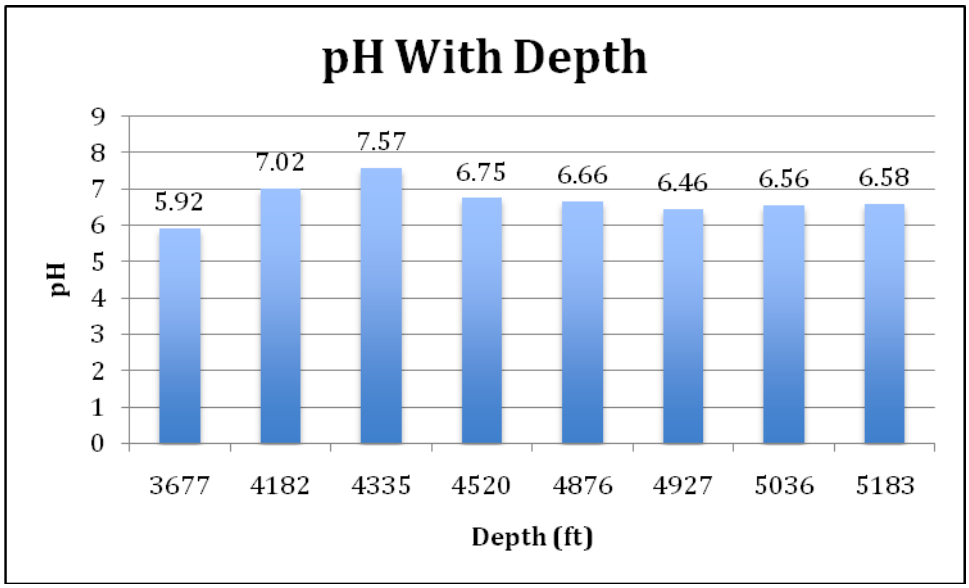



Figure 18. Bar graph showing pH variation with depth. This graph includes the Mississippian aquifer and the Reagan sandstone. pH shows a slight decrease with depth but the variation is minimal.

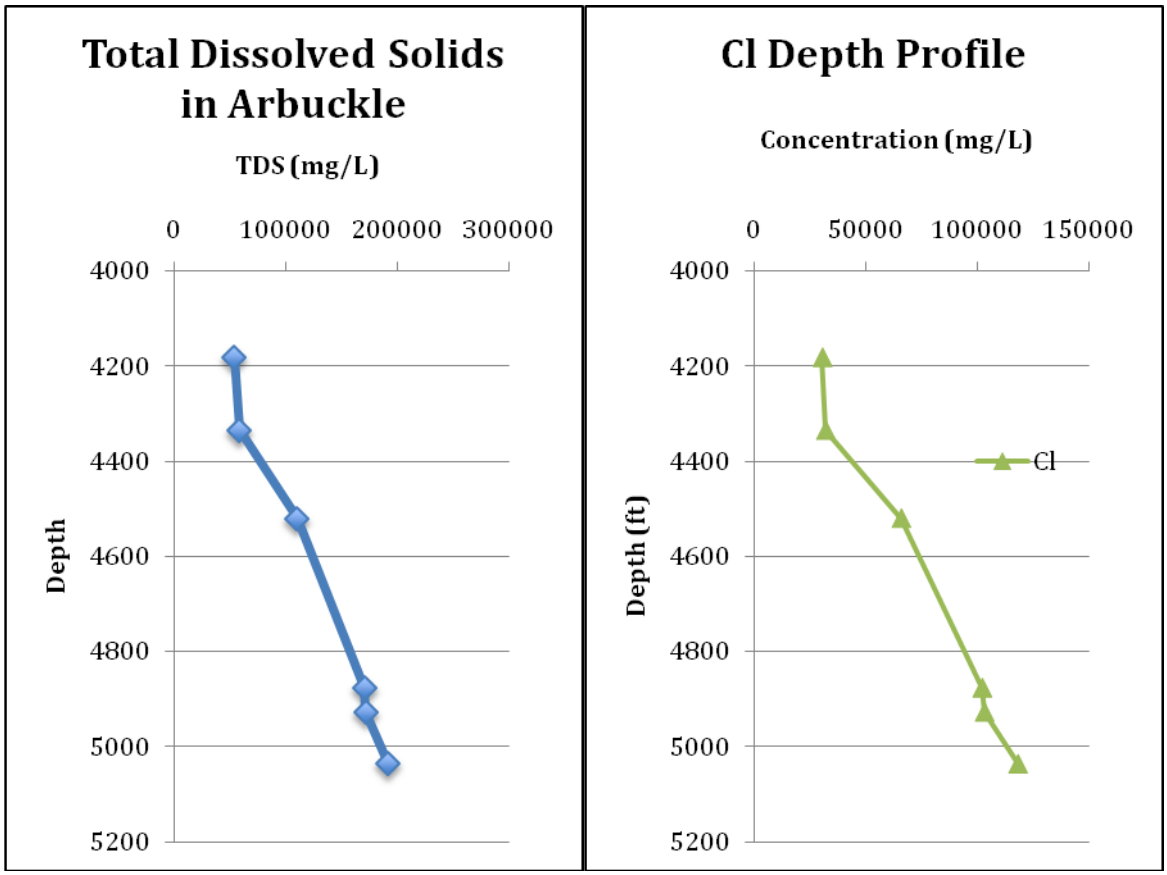
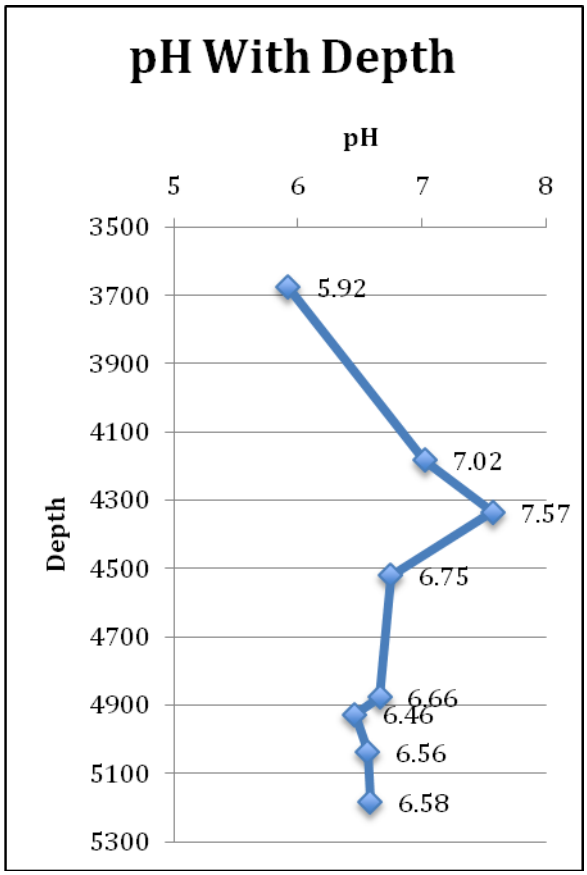



Figure 19. Total dissolved solid depth curve with chloride for comparison. pH depth profile shows variation with depth.


pH With Depth
pH
5
6
7
8
Depth
3500
3700
3900
4100
4300
4500
4700
4900
5100
5300
5.92
7.02
7.57
6.75
6.66
6.46
6.56
6.58

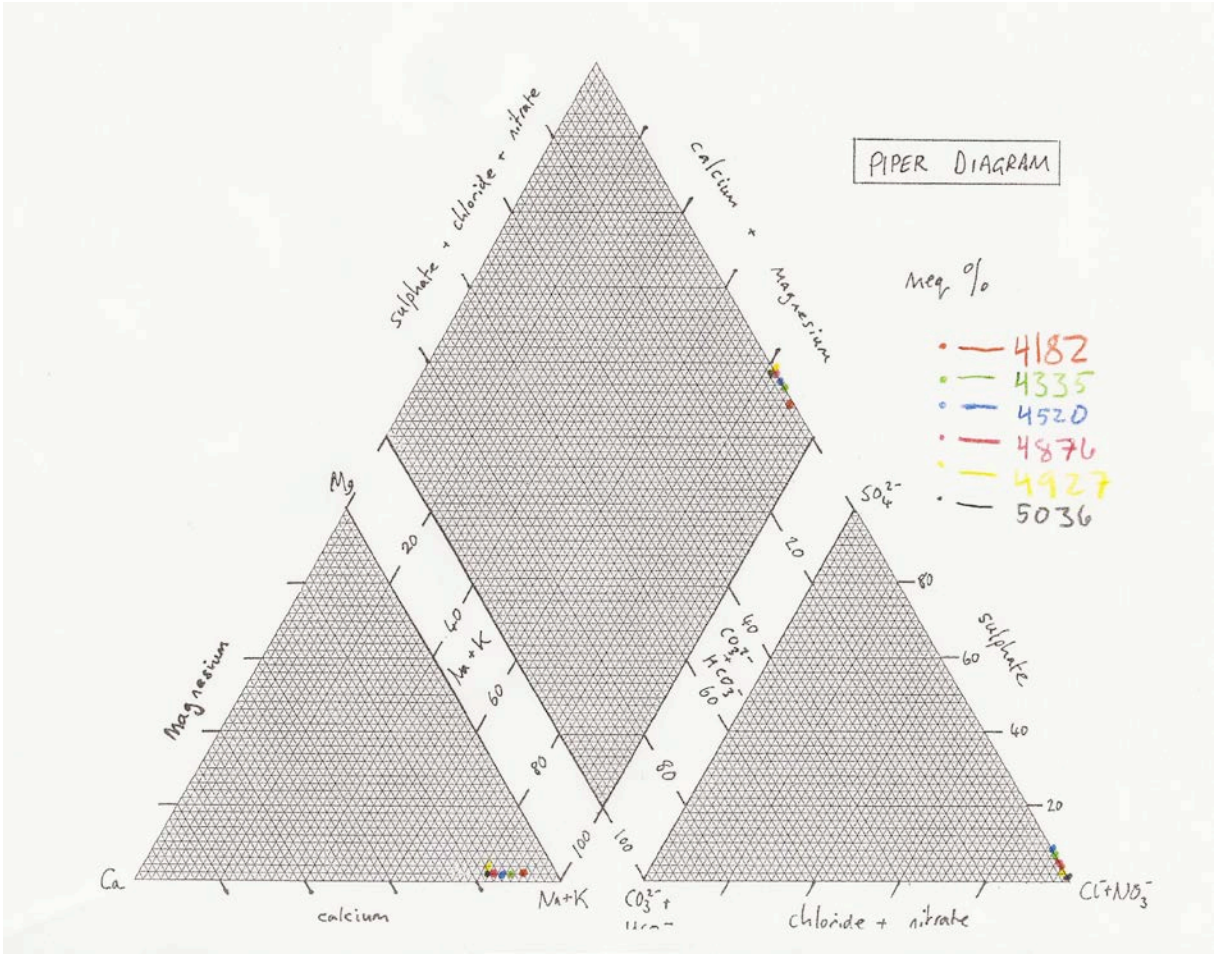



Figure 20. Piper diagram showing the relationships between the main cations and anions in the Arbuckle.

**Discussion**

Figure 11 shows the ratio of chloride to bromide. Cl and Br associate together in saline aquifer systems and the 1:1 ratio observed is typical of this type of aquifer. The water sample from 3677 ft represents the sample collected from the Mississippian aquifer overlying the Arbuckle. This data point does not fit the trend found in the Arbuckle and could point to much different chemistry in that aquifer. Hence this particular data point was omitted from Figure 13 to show the trend and correlation within the Arbuckle. Figure 12 shows the sodium to chloride ratio and here also a 1:1 ratio is observed (see Figure 11 for trend line and $R^2$). This ratio is typical for a saline aquifer and shows that the chemistry is dominated by Na and Cl. Figure 4 also shows the relationship between Ca and Sr. These elements usually associate together because they have similar properties and commonly substitute for one another. The $R^2$ value for these two elements is very high, showing a strong correlation. These ratios demonstrate that this aquifer displays trends that are common to other known saline aquifers.

Figure 14 contains depth profiles for the elements that had the highest concentration upon analysis. Figure 6 shows Na and Cl together because they are the dominant species in water. It

is clear from all the depth profiles that the chemistry of the water changes with depth, with either increasing or decreasing trends. Some profiles show no clear trend and have specific spikes at certain depths that could mean changing mineralogy. It is important to keep in mind that the shallowest (3677) and the deepest (5183) depths are from the Mississippian aquifer and the Reagan sandstone, respectively. These data points do not follow the trends found within the Arbuckle and demonstrate different water chemistries. The Mississippian generally has higher salinity values than the Arbuckle while the Reagan has lower values. The Ca, Na and Cl profiles all show increase with depth, which is expected in a saline aquifer. Sr, K, Ba and Mg also show strong increase with depth in the Arbuckle. Fe concentrations were low and showed a slight increase with depth. Because Fe is not present in high concentrations it is not anticipated to play a greater role in geochemical reactions as Ca or Mg. At about 4900 feet there is a spike in Fe concentrations. This spike is observed in several of the depth profiles of different elements. SO4, Fe and P show a strong spike at this depth. The cause of this spike is unknown but could be due to changing mineralogy of the formation at this depth and its variable reactions with the water. This is a point that will be investigated in the analysis of the formation mineralogy and during the swab testing.

Figure 16 shows the major anions with depth. This, in general, exhibits increasing trend with depth in all of these anions. The trends observed in the nitrate, nitrite and phosphate represent the detection limit achieved by the ICP-OES. Figure 17 shows the calculated total dissolved solids (TDS) for the Arbuckle formation. An increase in TDS with depth is clear and follows the trend of increasing salinity with depth. Figure 18 shows the pH variation between the 8 DST samples. The lowest pH is observed in the Mississippian aquifer. Within the Arbuckle the pH shows no strong correlation, but slightly decreases with depth. The exception is the 4335 ft depth sample. Several of the ions show spikes at this depth, most notably sulfur. It is unclear at this point why the pH show a spike at 4335 feet, but this 'spike' is still small and is not anomalous. Figure 19 shows the depth profiles of TDS and pH. The chloride profile is included to show its correlation to TDS.

Figure 20 is a piper diagram of the DST water analysis. The water sample plots show the salinity is dominated by Na and Cl with Ca and Mg playing minor roles. The alkalinity values used were taken 2 weeks after the samples were collected and are lower than expected in the aquifer. Alkalinity data will be taken from the swab tested water the same day to ensure accurate results. It will be tested on site using a titration kit and within 48 hours in the K-State geochemistry lab using a Spectrophotometer. Because normalized percentages are used for the cation and anion ternary diagrams, and the Cl values are so high, even the historical Arbuckle values do not change the diagram significantly. So this diagram is a semi-accurate depiction of the Arbuckle water which shows Na-Ca-Mg-Cl-HCO3 source and directly reflects the mineralogy of the Arbuckle along a stratigraphic column; Arbuckle is pretty homogenous in broad mineralogy but fine scale heterogeneities are the ones here to be closely looked at and will be confirmed with results from the swab testing. Behavior of same elements in saline environment vs. a non-saline fresh water aquifer is completely different and it is clearly shown among most of the major elements tested for these waters.

It is unclear how much influence drilling fluid contamination had on these samples. Values for chloride and sodium along with some trace elements and bicarbonate are most likely to have

been influenced by the drill mud to some extent. By analyzing the water pumped from the well during a swab test we will be able to validate these finding to see what the level of contamination is, if at all.

### Quality Control

To ensure the validity of the ICP-OES analysis two standard were run. A NIST 1643e standard and a SLRS-5 standard were run along with a blank and a duplicate sample to ensure accuracy. The standard deviation values are in general low and attest to the accuracy of the machine. The standard deviations for selected major elements are listed with the NIST 1643e first and SLRS-5 second. Ca (2.404, 0.212), Mg (0.733, 0.099), Na (1.0889, 0.0141), Sr (16.334, 4.525), Ba (24.18, 4.24), Fe (0.0057, 0.0062). An IC Reference Standard was also run in the IC analysis of anions. The standard deviation values for Cl (0.141), Br (0.028) and $SO_4$ (0.07) were found to be low.

### Subtasks 5.3-5.6. Drill, DST, log Test Borehole #2 (BEREXCO Wellington KGS #1-28)

The daily drilling report for well #1-21 are shown in Figure 21 summarizing the activities in drilling, DST and logging, and casing this borehole from top to bottom.

| | |
|---|---|
| LEASE NAME: **Wellington KGS #1-28 (1330002)** | COUNTY: **Sumner** STATE: **KS** |
| WELL LOCATION: **NE SW SE SW** | SEC: **28-31S-1W** |
| OPERATOR: **Berexco LLC** | API# **15-191-22590-00-00** |
| CONTRACTOR: **Beredco LLC** | ELEVATION: GL – **1257** ' KB – **1270** ' |
| RIG: **2 - 316-833-0380** | Toolpusher: **Gilbert Davila, 316-833-0379** |
| Cc: **Dana, Evan, Richard, OKC** E-mail: **G, Dana, Jim** FINAL: **AEB, WF** | SPUD DATE: **2/19/11, 12:00 pm** |

| | |
|---|---|
| 02/14/11 | 7:00 am. Moving in rig. |
| 02/15/11 | 7:00 am, Rig up. Secure rig. Go to dry watch. |
| 02/16-<br>02/19/11 | Dry watch |
| 02/20/11 | 7:00 am, 196' (196') Drilling. Spud well at 12:00 pm on 2/19/11. Set 48#, 13-3/8" conductor pipe @125'. Cement w/135 sx cement, 3% CC. Circulated cement to surface. |
| 02/21/11 | 7:00 am, 651' (455') Wait on cement. Set 24#, 8-5/8" surface casing @647'. Cemented w/325 sx cement, 3% CC. Circulated cement to surface. Deviation 1¼° @651'. |
| 02/22/11 | 7:00 am, 1160' (509') Drilling. Drilled out of surface @7:30 pm, 2/21/11. |
| 02/23/11 | 7:00 am, 2110' (950') Drilling. Deviation 1° @1247' and 3/4° @1995'. |
| 02/24/11 | 7:00 am, 2815' (705') Drilling. Deviation 1/2° @2776'. Displaced mud @2776'. |
| 02/25/11 | 7:00 am, 3160' (345') Drilling. Made bit trip @3048'. |
| 02/26/11 | 7:00 am, 3700' (540') Drilling. |
| 02/28/11 | 7:00 am, 4000' (300') Drilling. |
| 02/28/11 | 7:00 am, 4233' (233') Drilling. Made bit trip @4118'. Deviation 1¼° @4118'. |
| 03/01/11 | 7:00 am, 4570' (337') Drilling. |
| 03/02/11 | 7:00 am, 4845' (275') Drilling. |
| 03/03/11 | 7:00 am, 5153' (308') Drilling. |
| 03/04/11 | 7:00 am, 5250' (97') Logging. Reached TD @4:00 pm on 3/3/11. Deviation 1° @5250'. Loggers TD 5250'. Drillers TD 5250'. TD is in granite. |

**Figure 21. Daily drilling report for borehole #1-21.**

## Subtask 6.2. Revise 3D seismic interpretation

A synthetic seismogram was developed using the new log data from borehole #1-32 (Figure 22). The fit of the original stratigraphic horizons with their seismic reflectors is very good. This new information will significantly aid the tasks to create a full volume post-stack depth migration of the 3D seismic so the data can be imported into Petrel.

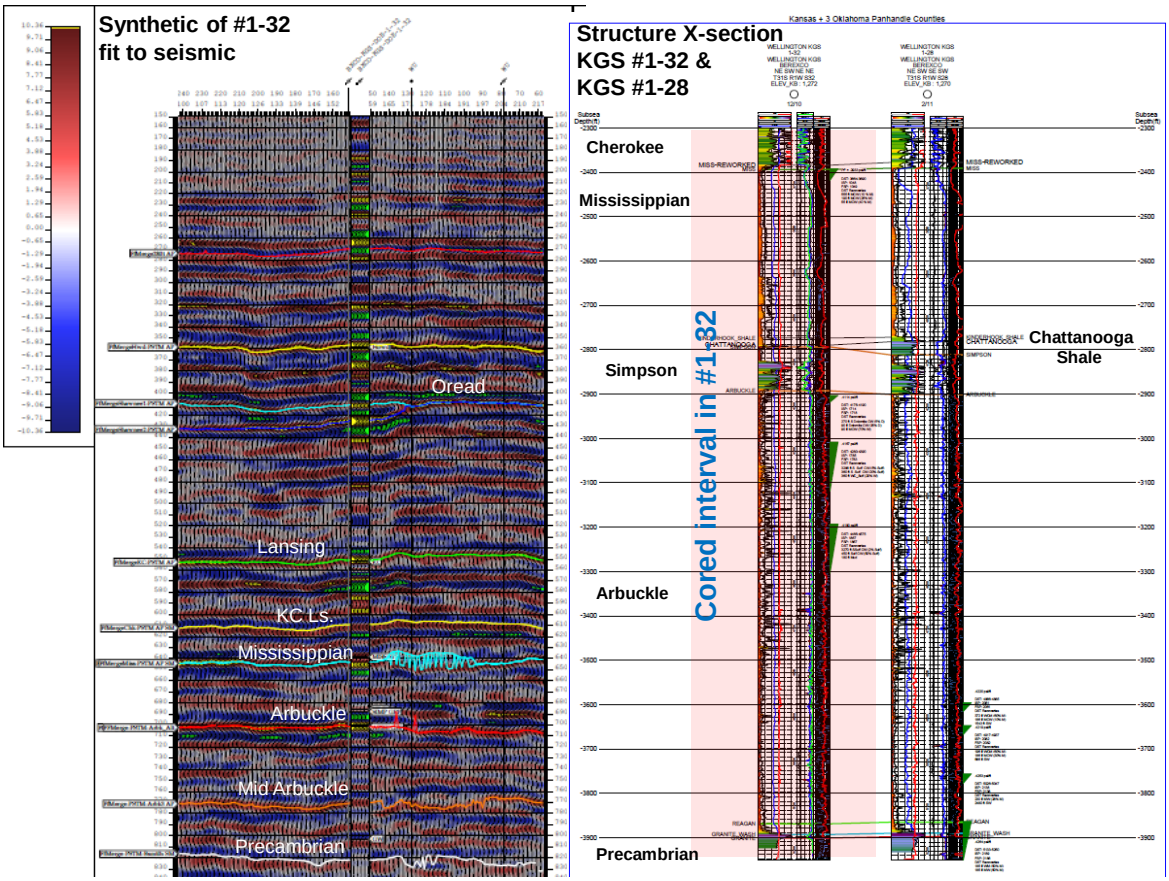
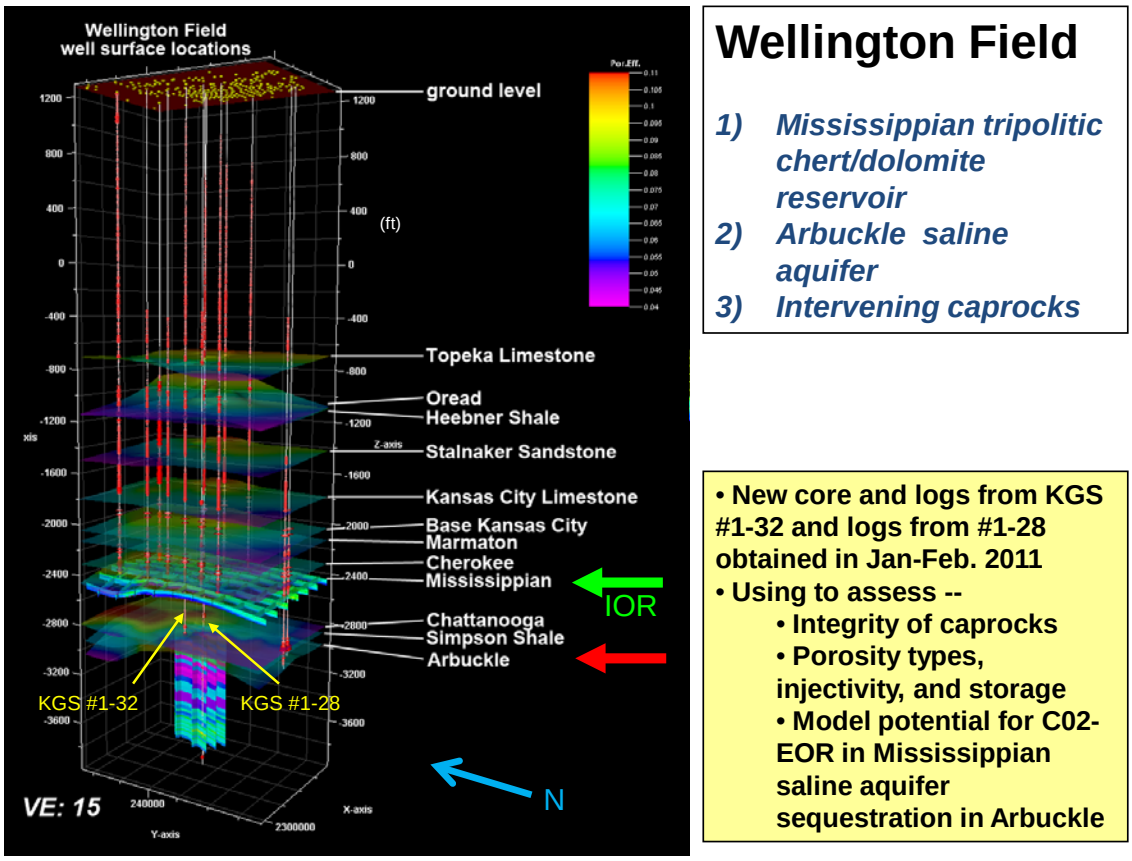



**Figure 22. Synthetic seismogram integrated with a seismic profile from the 3D seismic survey in Wellington that passes through new borehole, #1-32. To the right are the log profiles of the two new wells showing major correlations.**

## Subtask 6.3. Update geomodel – Arbuckle and Mississippian

The geomodels were updated for both the Arbuckle saline aquifer and the Mississippian oil reservoir with the log data derived from drilling #1-28 and #1-32 (Figure 23). We will wait until whole core analysis is incorporated to fully update and finalize geomodels that would be used in simulation.




# Wellington Field

1) *Mississippian tripolitic chert/dolomite reservoir*
2) *Arbuckle saline aquifer*
3) *Intervening caprocks*

- **New core and logs from KGS #1-32 and logs from #1-28 obtained in Jan-Feb. 2011**
- **Using to assess --**
  - **Integrity of caprocks**
  - **Porosity types, injectivity, and storage**
  - **Model potential for C02-EOR in Mississippian saline aquifer sequestration in Arbuckle**

**Figure 23. 3D view of Wellington Field from grassroots to Precambrian basement showing mapped horizons to date including Mississippian oil reservoir (porous interval shown) and the Arbuckle saline aquifer showing porosity based on two new boreholes, #1-32 and #1-28.**

## TASK 14. TECHNOLOGY TRANSFER

Field trip and project review meeting were held in January 2011.

**Agenda of Talks - Jan 20, 2011**
**Review of DOE Projects at KGS by DOE Project Manager: Brian Dresssel**

| | | |
|---|---|---|
| **Introduction** | **8:00 - 8:15 AM** | **Watney** |
| **Welcome** | 8:15 - 8:30 AM | Buchanan |
| **REVIEW OF VALIDATION OF VOLUMETRIC CURVATURE TOOL PROJECT - DE-FE004566** | | |
| **Project Goals – Geology** | 8:30 - 9:00 AM | Rush |
| **Project Goals – Engineering** | 9:00 - 9:30 AM | Bhattacharya |
| **Project Status** | | |
| Contracts & Data collection | 9:30 - 9:45 AM | Rush/Bhattacharya |
| **Geophysical Techniques** | | |
| Reprocessing Donated Data | 9:45 – 10:00 AM | Hedke |
| Volumetric Curvature Analysis Tool | 10:00 – 10:15 AM | Nissen |
| **Break – Coffee & Snacks** | **10:15 – 10:30 AM** | |

**Key Findings**

1. Boreholes #1-32 and #1-28 were drilled, logged, tested, and cemented. Borehole #1-32 as cored over 1600 ft interval with nearly complete recovery.
2. Initial interpretation of well logs, description of core, and sampling of core for routine and special core analyses has begun.
3. The Arbuckle hydrologic system and overlying caprocks are much more clearly defined with this new data which will continue to unfold as the analyses are completed and integrated.
4. Brine geochemistry conducted on DST water samples show consistent patterns of increasing salinity with depth in the Arbuckle and waters in the Mississippian and Reagan (Lamotte) Sandstone and basement suggest different kind of water chemistry, i.e., the brine systems are not freely exchanging. The abrupt changes in water chemistry at 4900 ft interestingly correspond with the top of the more porosity and permeable interval being considered as a prospective injection zone.

**Plans**

1. Core and wireline log analyses have gotten underway. Core analyses could continue into the summer 2011.
2. 2D shear wave surveys at Wellington and process the multicomponent 3D seismic survey for the converted shear wave will commence in next quarter.
3. Swab testing of borehole #1-32 will commence in next quarter to obtain cleaner water samples.
4. Geomodels of the Arbuckle and Mississippian will be updated and finalized for simulations when core and log analyses are complete and integrated.
5. Regional work will begin go focus on refining correlations of hydrostratigraphic units as the digitizing of well logs is completed.
6. The Western Annex portion of the project will begin in earnest as part of budget period 2.

## Cost Plan/Status

Costs in the 6th quarter were incurred in Tasks.

**COST PLAN/STATUS**

| Baseline Reporting Quarter | Year 1 Starts: 12/8/09 Q1 | Q2 | Ends: 2/7/11 Q3 | Q4 | 10/1 - 12/31/10 Q5 | 1/1/11 - 3/31/11 Q6 |
|---|---|---|---|---|---|---|
| **Baseline Cost Plan (from SF-424A)** | (from 424A, Sec. D) | | | | | |
| Federal Share | $1,007,625.00 | $1,007,622.00 | $1,007,625.00 | $1,007,625.00 | $0.00 | $0.00 |
| Non-Federal Share | $277,263.00 | $277,263.00 | $277,263.00 | $277,263.00 | $0.00 | $0.00 |
| Total Planned (Federal and Non-Federal) | $1,284,888.00 | $1,284,885.00 | $1,284,888.00 | $1,284,888.00 | $0.00 | $0.00 |
| Cumulative Baseline Cost | $1,284,888.00 | $2,569,773.00 | $3,854,661.00 | $5,139,549.00 | $5,139,549.00 | $5,139,549.00 |
| **Actual Incurred Costs** | | | | | | |
| Federal Share | $4,019.93 | $84,603.97 | $494,428.37 | $111,405.52 | $238,675.97 | $1,902,936.55 |
| Non-Federal Share | $0.00 | $0.00 | $0.00 | $84,564.82 | $251,354.30 | $20,887.31 |
| Total Incurred Costs-Quarterly (Federal and Non-Federal) | $4,019.93 | $84,603.97 | $494,428.37 | $195,970.34 | $490,030.27 | $1,923,823.86 |
| Cumulative Incurred Costs | $4,019.93 | $88,623.90 | $583,052.27 | $779,022.61 | $1,269,052.88 | $3,192,876.74 |
| **Variance** | | | | | | |
| Federal Share | $1,003,605.07 | $923,018.03 | $513,196.63 | $896,219.48 | -$238,675.97 | -$1,902,936.55 |
| Non-Federal Share | $277,263.00 | $277,263.00 | $277,263.00 | $192,698.18 | -$251,354.30 | -$20,887.31 |
| Total Variance-Quarterly Federal and Non-Federal) | $1,280,868.07 | $1,200,281.03 | $790,459.63 | $1,088,917.66 | -$490,030.27 | -$1,923,823.86 |
| Cumulative Variance | **$1,280,868.07** | **$2,481,149.10** | **$3,271,608.73** | $4,360,526.39 | $3,870,496.12 | $1,946,672.26 |