# V41A-2750: GEOCHEMICAL AND MINERALOGICAL INVESTIGATION FOR CARBON CAPTURE AND STORAGE, WITHIN THE ARBUCKLE AQUIFER, KANSAS.

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## Introduction

- Geologic sequestration of $CO_2$ has been targeted as a way to mitigate future anthropogenic release of greenhouse gases. Deep saline aquifers are the most appealing geologic formations for sequestration because they are unfit for drinking and usually isolated from fresh water sources.
- **This work seeks to understand the long-term secure storage capacity of $CO_2$ within a supercritical state, which involves mineralization reactions in the presence of carbonates and constituent ionic species within the formation water, to effectively determine the sequestering potential of $CO_2$ within the Arbuckle aquifer near Wellington, Kansas.**
- The Arbuckle aquifer near Wellington, in SC Kansas, has been targeted for $CO_2$ sequestration. Cutter KGS#1 well, west of Wellington near Moscow in SW Kansas, will serve as a western calibration site. At Wellington, wells 1-28 & 1-32 have been drilled with 8 drill stem tests (DSTs), and 5 swabs taken, and at Cutter KGS#1, 11 swabs have been taken and have been analyzed for their hydrochemistry.
- Hydrochemical analyses have been done for stable isotopes, ionic species concentrations, and dissolved inorganic carbon ($d^{13}C$).
- Wellington 1-32 cored to basement with a total of 1,628' retrieved, and Cutter 1,042' of core was retrieved.
- Core samples for the south-central site, Wellington, have been analyzed with X-ray diffraction, thin section petrography, CT scans, and scanning electron microscopy.
- Hydrogeochemical and mineralogical data allow for comprehensive reservoir characterization to be utilized with a Geochemical Work Bench geochemical species model and CMG-GEM $CO_2$ injection simulation .

## Well Locations and Geology

Figure 1.

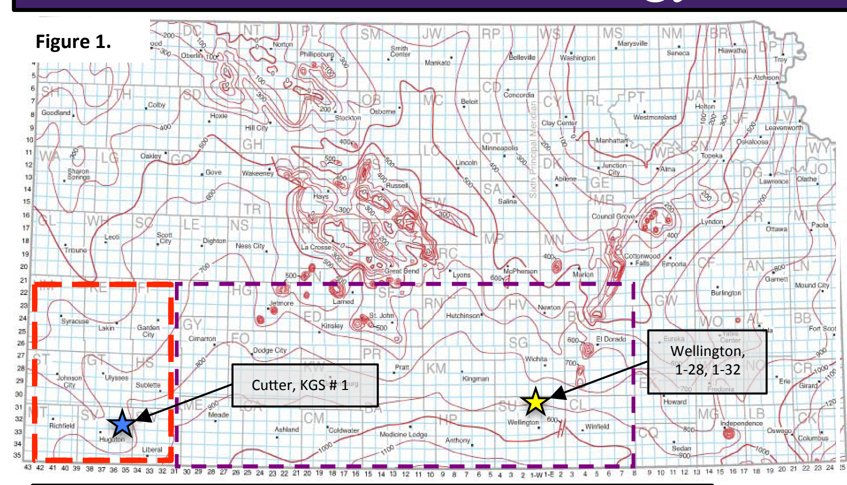



**Figure 1:** Contour and isopach map of the Arbuckle group in Kansas and regional study area (purple rectangle), and expanded study area (red rectangle). Experimental wells KGS 1-32 and 1-28 located in the Sedgwick Basin are 4 miles northwest of Wellington, KS (yellow star). Cutter KGS #1 located in Stevens County, 7 miles east of Moscow, KS (blue star). *Map courtesy of the Kansas Geologic Survey.*

**Figure 2:** Well log of the Arbuckle and Mississippian aquifers from KGS 1-32(**a**), and KGS Cutter #1(**b**) experimental wells, Sumner Co., and Stevens Co., Ks. DST (Yellow) and Swab (Red) sample depths are labeled.

- Arbuckle is the lower part of the Ozark Plateau Aquifer System(OPAS) which includes the freshwater Ogallala aquifer.
- Rocks are late Cambrian to early Ordovician in age consisting generally of porous dolomitic carbonates with interbedded shale-y aquitards. The wells extend through the entire Arbuckle formation and into the Precambrian granite bedrock below.
- The Arbuckle is overlain by the Simpson sandstone and the Chattanooga shale (absent in KGS 1-32, present in 1-28(not shown) and Cutter KGS #1).

Figure 2a.

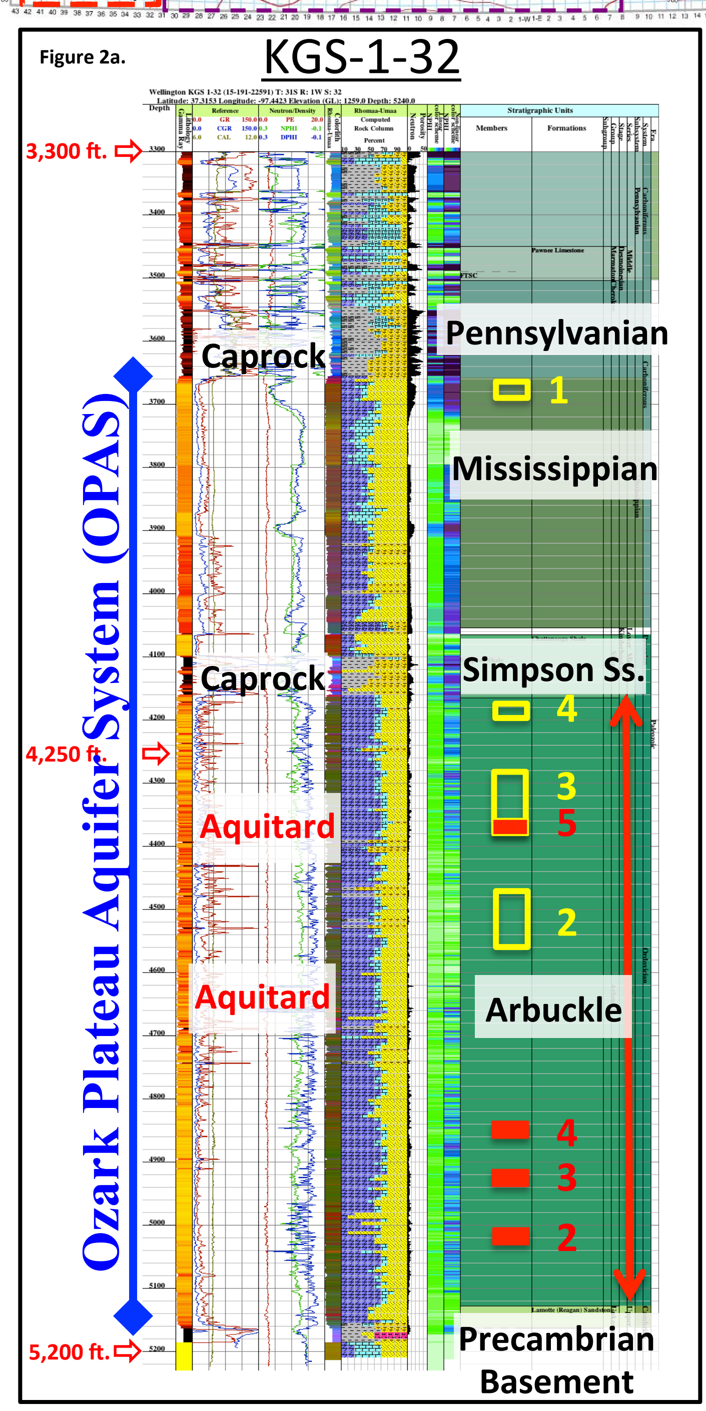
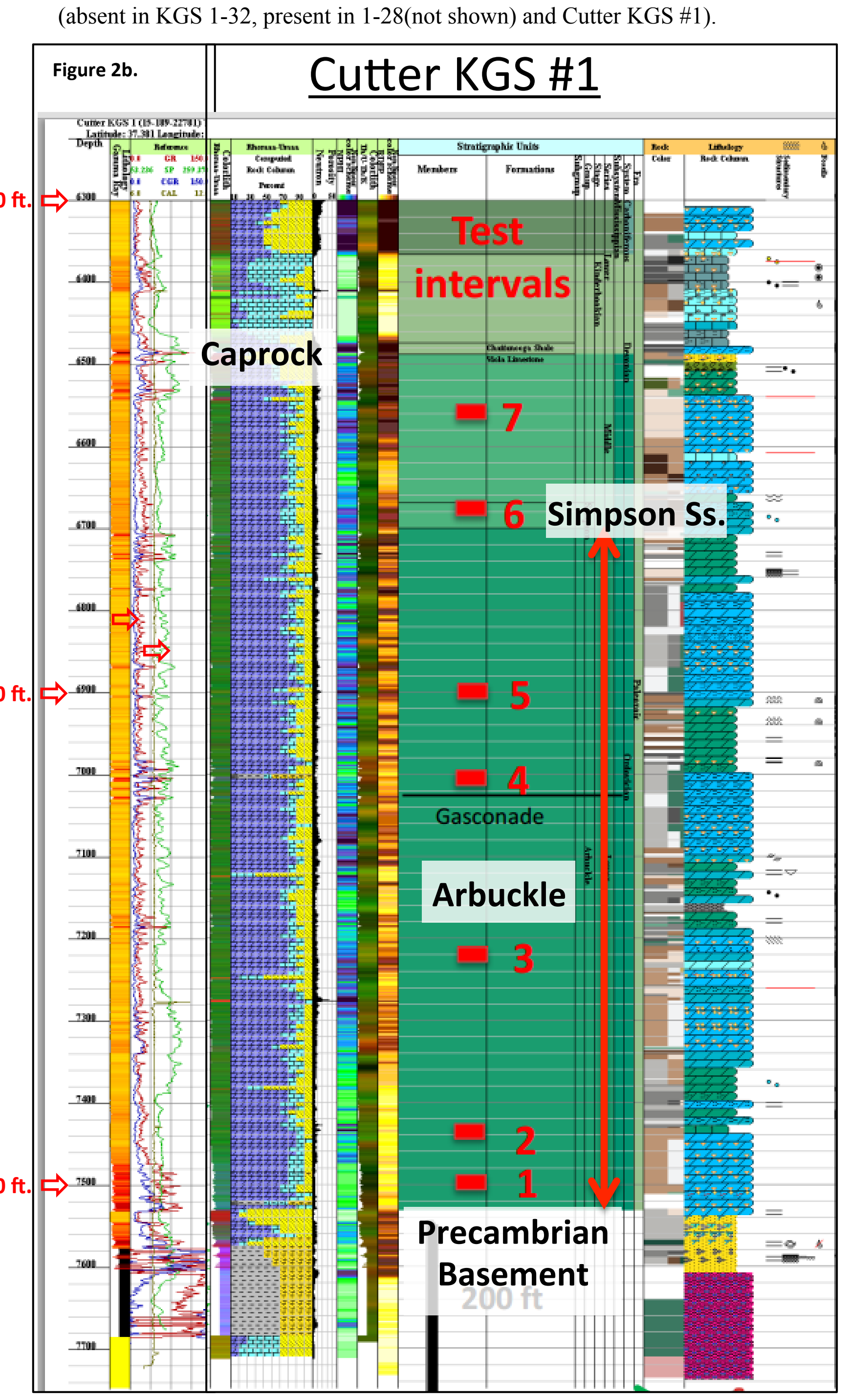



Figure 2b.




## Hydrogeochemistry of Swabs and Drill Stem Tests

Figure 3. Wellington

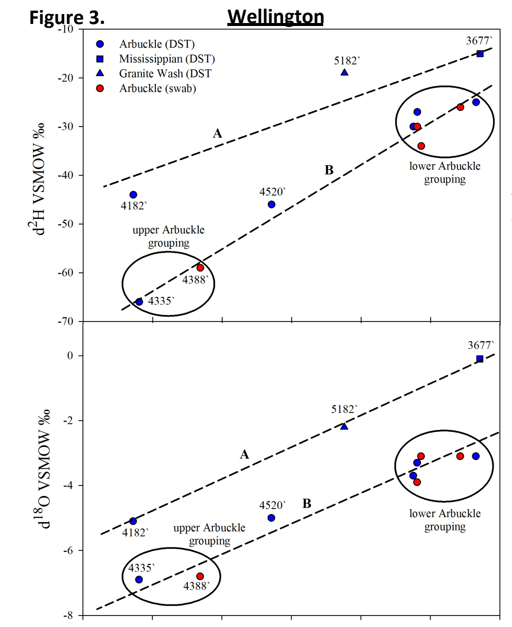



**Figure 3.** - Stable isotopes plotted with $Cl^-$ showing upper and lower Arbuckle groupings (circles) Hypothetical mixing lines between Mississippian aquifer and top of Arbuckle (A); and upper and lower Arbuckle zones (B).

Figure 4. Wellington

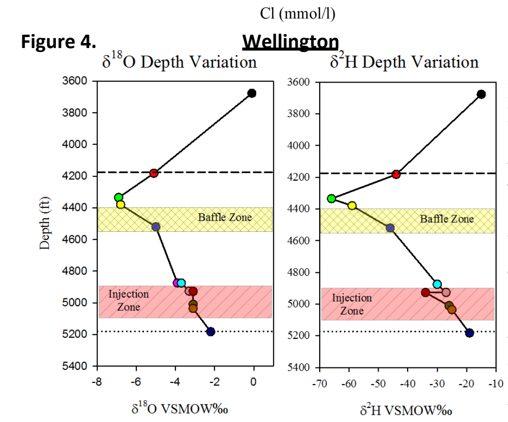



**Figure 4.** - Depth profile of δ18O and δ2H within Wellington. No continuous increase with depth. Upper depth, 4,182', enrichment could indicate communication between Mississippian and Arbuckle.

Figure 5. Wellington

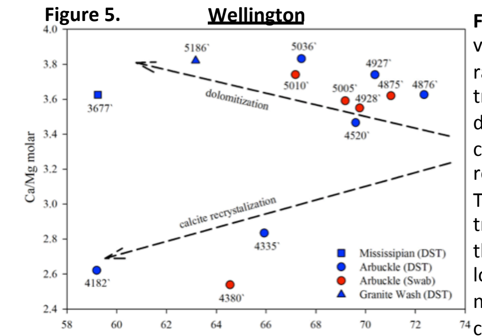



**Figure 5.** - Ca/Sr vs. Ca/Mg molar ratios showing trends of dolomitization and calcite recrystallization. The differing trends indicate that the upper and lower Arbuckle are not well connected.

Figure 7.

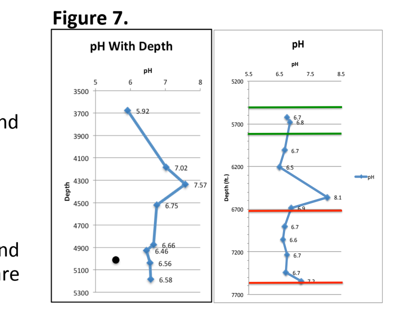



**Figure 7**- pH variation with depth. Shows similarities across the study area.

Figure 6a. Wellington Figure 6b. Cutter

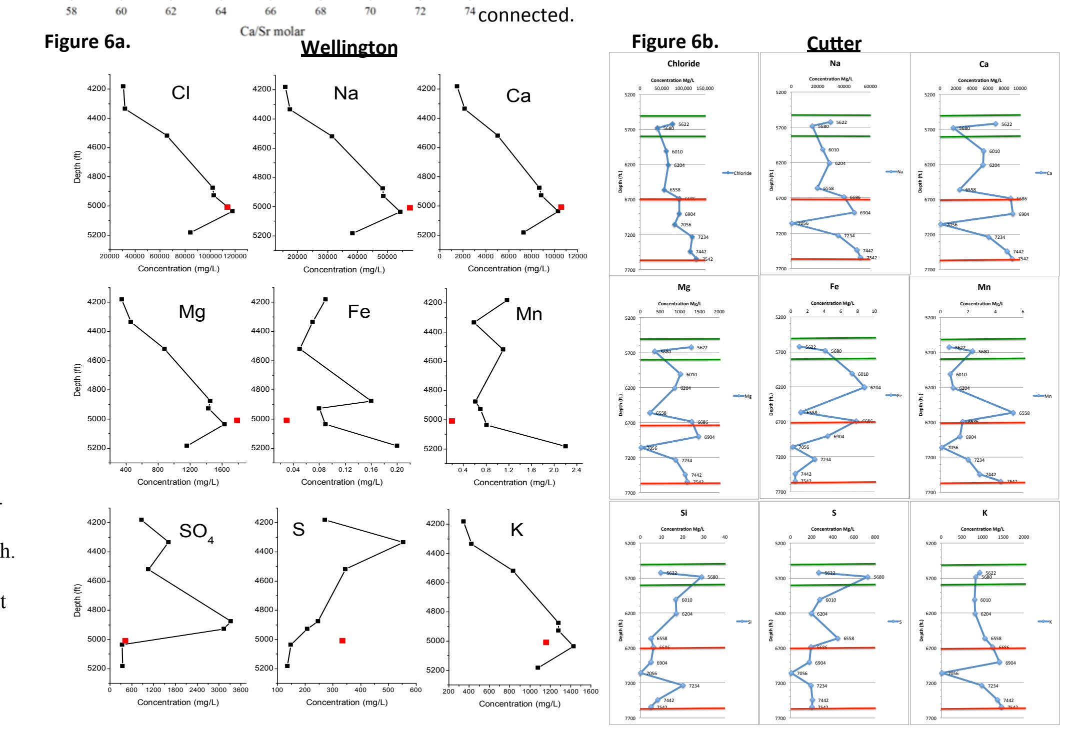



**Figure 6.** - Ionic species concentrations showing similarities and differences by depth. Figure **A** is Wellington (Red dot represents swab 1), and Figure **B** is Cutter (Green lines indicate Mississippian interval, Red lines indicate Arbuckle interval).

## Arbuckle Injection Zone Mineralogy

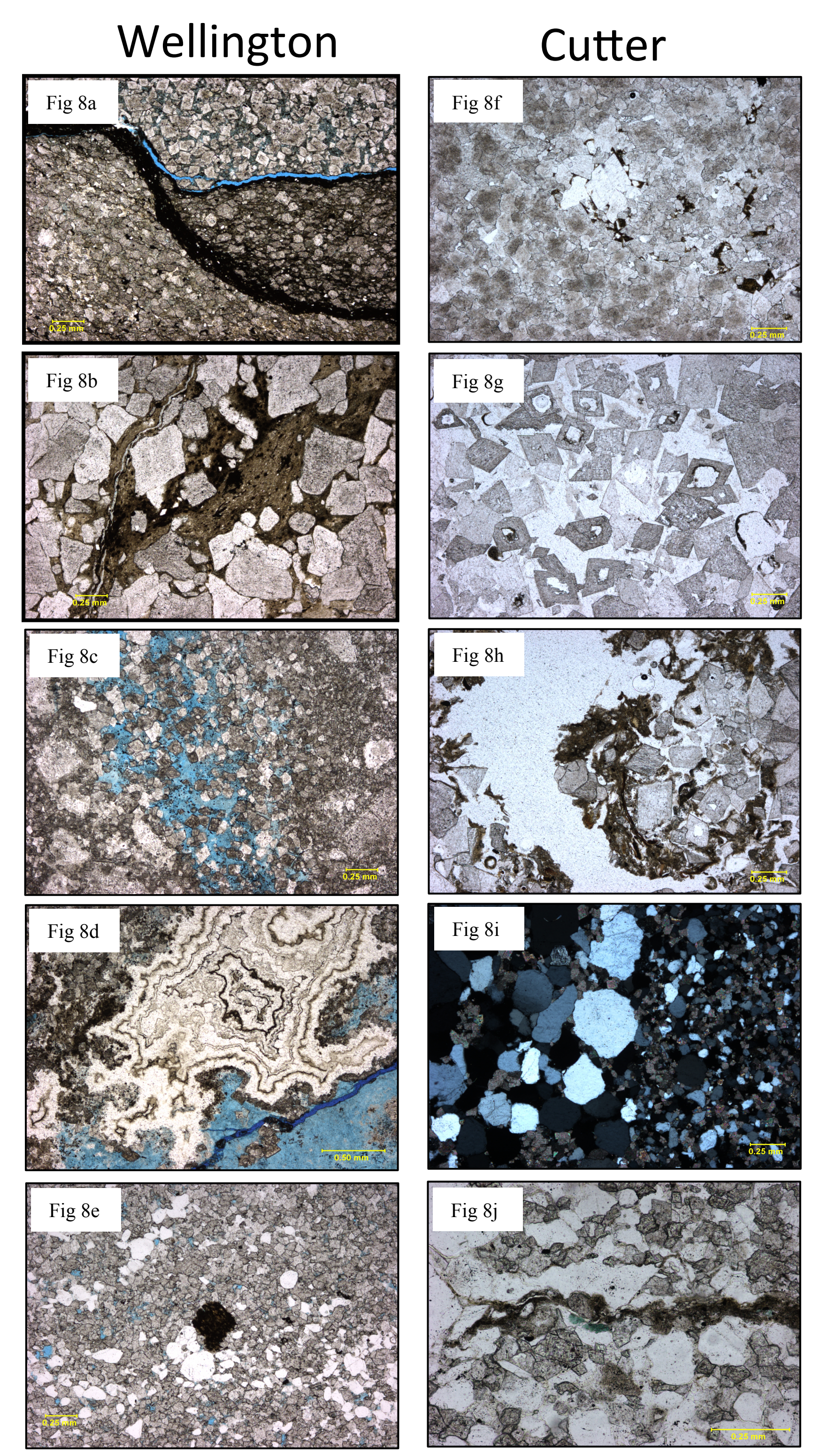



**Figure 8**: **a) (**4388.8') in pl; Fracture filled with sulfide/oxide minerals in brecciated zone. **b) (**4570.1') in pl; Fracture filled with argillaceous material and sulfide/oxide minerals. **c)** (4967.5') in pl; Porous zone filled with sub to euhedral dolomite rhombs within carbonate matrix. **d) (**4985.5') in pl; Radiating chalcedony along pore boundary. **e) (**5078') in pl; Dolomite mosaic with detrital quartz grains and large sulfide/oxide mineral. **f) (**6904.9') in pl; Large subhedral dolomite rhombs within pore spaces of finer grained anhedral matrix. **g) (**7225.7') in pl; Visible intracrystalline porosity via dedolomitization textures inside euhedral dolomite rhombs. **h) (**7225.7') in pl; Abundance of Fe-rich argillaceous materials along pore space boundaries inside subhedral dolomite matrix. **i) (**7536.5') in cpl; Dolomite-quartz boundary exhibiting sharply contrasting grain sizes. **j) (**7540.2') in pl; Chlorite growth near argillaceous filled fracture in dolomite-quartz matrix.

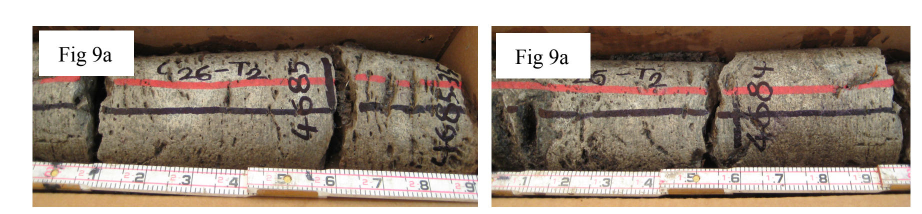



**Figure 9:** Whole core section (4684-4686`) from KGS 1-32. Notice large vugs and heterogeneity throughout the core (photos taken on-site during February 2011).

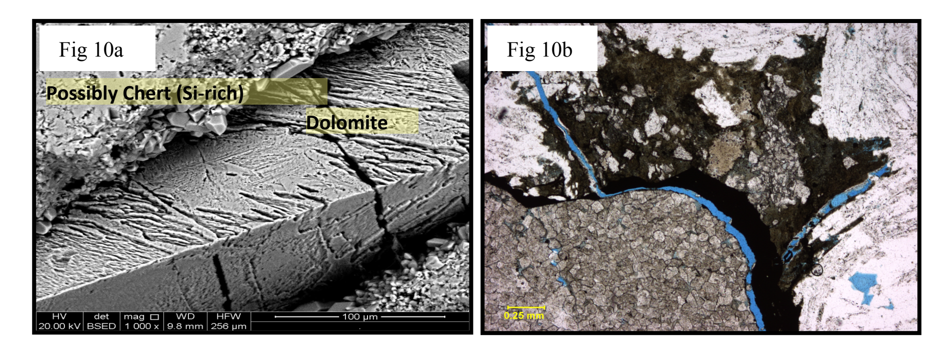



**Figure 10: a)** SEM, (4977`), from Wellington. Dolomite-chert contact could be a potential reaction site with preferential dissolution of dolomite and formation of fractures along reaction fronts. **b)** Thin section (4504`) showing complexity of chert/carbonate boundary.

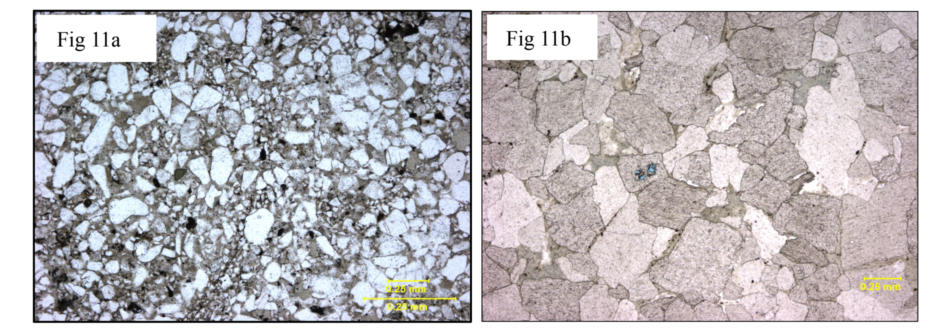



**Figure 11- a) Cutter** Mississippian interval **(**5564.3') in pl; Angular to subangular quartz grains with interspersed argillaceous materials throughout. **b) Wellington** potential baffle zone (4570.1') Coarse grained dolomite mosaic with some clay/carbonate matrix support.

## Supercritical Flow Experiments

- Experiments conducted in National Energy Technology Laboratory, Pittsburgh, PA Core Flow Laboratory on Wellington Core.
- Core Flow System 839z instrument was used to flow brine and $CO_2$ through injection zone core.
- Confining pressure 2100 psi; Temperature 40°C.
- Brine only was flowed at 0.2 ml/min for 13 hours to saturate core (hour zero).
- $CO_2$ was introduced with brine at 1 ml/min (hour 1).
- Effluent collected hourly for analyses ('hour 14' is an average of over night brine + $CO_2$ flow).

Figure 14 Wellington

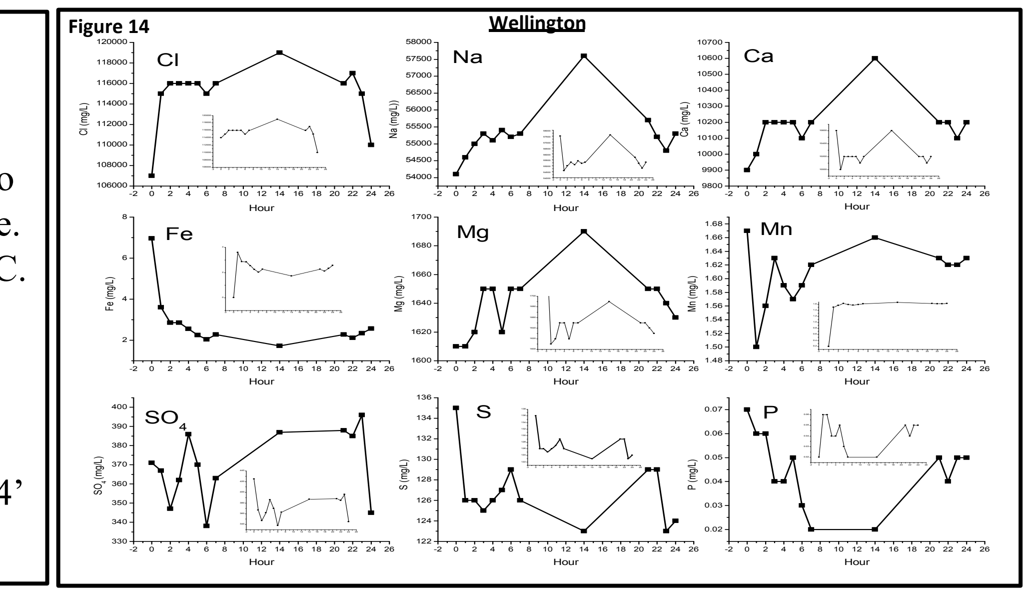



Figure 12a

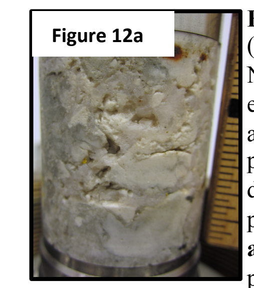
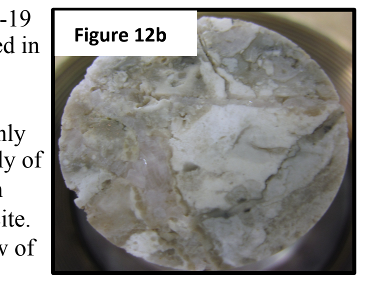


**Figure 1:** Core plug 31-19 (4977', Kmax 4.59) used in NETL flow through experiment. Core is autoclastic breccia, highly porous consisting mainly of dolomite and chert with possible secondary calcite. **a)** side view **b)** top view of plug.

Figure 12b



- **Figure 14:** Time series (24 hour) analysis for $CO_2$-brine flow-through experiment using formation water collected from swab test 1 from KGS 1-28 (5000-5020') and using core plug number 31-19 (4977 ft).
- $CO_2$ injection began at hour 1; flow rate of 1 mL/min for $CO_2$ and brine.
- Pre-flow analysis of swab 1 show different brine composition.
- Inset graphs show the 'hour zero' data replaced with the pre-flow swab 1 data.
- The values for pre flow brine were either higher ($SO_4$, S, Mg, Ca, Na) or lower (Cl, Fe, Mn, P). The difference in brine compositions could be due to contamination or chemical changes prior to $CO_2$ introduction.

Figure 13a Before flow

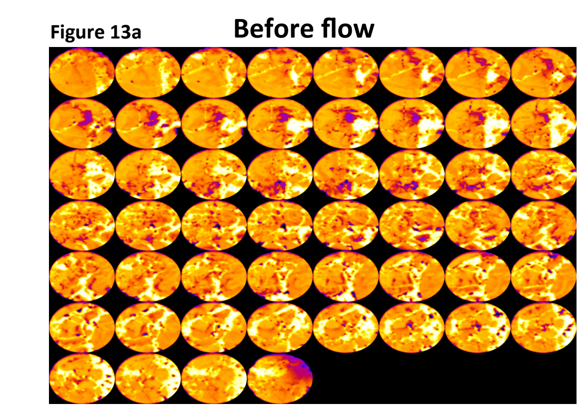


Figure 13b After flow

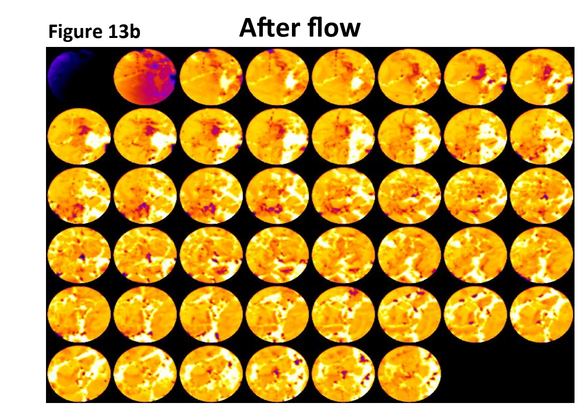


**Figure 13**. CT scans (250μm resolution) of core plug 31-19 used in supercritical flow experiment at NETL. White areas are dense material, orange is more porous and darker areas are open vugs. Apparent changes in the after image include an increase in dense material, potentially due to mineral precipitation. Supporting evidence can be found in flow effluent analyses where 15-24 hours showed decrease in Ca, Mg, Na and $SO_4$ which could be due to mineral precipitation.

## Conclusions

- The hydrogeochemical facies in the Arbuckle at both locations is majorly Na-Ca-Cl type. Average salinity of the injection zone formation water at Wellington is 116,000 ppm Cl, and at Cutter it is 83,636 ppm Cl.
- Average pH for Wellington and Cutter are 6.7 & 6.9 respectively. Differing Ca/Sr and Ca/Mg concentrations at Wellington indicate limited vertical connectivity, and δ18O and δ2H variations confirm this.
- Iron is the only major cation species that shows variation with depth between the sites hydrochemistry, which entitles further investigation in the role of iron in enhancing or depressing the carbonate dissolution with the injection of $CO_2$.
- Mineralogy of the cores from KGS 1-32 and Cutter KGS#1 show extensive small and large scale heterogeneity with major mineralogy being dominated by dolomitic limestone with frequent cherty nodules and infillings. Microfractures and discontinuous argillaceous zones where marked all through the 1,600 and 1,000 ft. cores.
- Cutter mineralogy is dominated by dolomite, with Fe-rich argillaceous material, vuggy porosity, and opaque minerals commonly lining pore boundaries. Lower silicification and heterogeneity found in Cutter as compared to Wellington.
- Heterogeneity of the core and proportion of chert increases with depth through the proposed injection zone. Visible porosity increases with depth in cores from both sites. SEM micrographs of the core plugs in Wellington show clear interface between chert and dolomite where fractures could develop with accentuated dissolution reactions.
- Flow-through experiments of the Wellington core plug showed variable responses for major species involved over a 24 hour period. From 0-5 hours Ca, Cl, Mg, Na, $SO_4$ and K increased while Fe, S and K decreased. From 5-15 hours Ca, Cl, Mg, Na, $SO_4$, K and Mn increased while Fe and S decreased. From 15-23 hours $SO_4$, Fe and S increased while Ca, Cl, Na, Mg, K and Mn decreased. Further time series results might indicate effect of high $SO_4$ and Cl in the system make a difference in dissolution kinetics and extent of carbonate mineralization in the injection zone.
- Apparent increase in dense material in the core plugs after supercritical flow experiments seen in CT scans could imply mineral precipitation; This conclusion is also supported by decreases in Ca, Mg, Na, Cl, and $SO_4$ measured in the last 10 hours of the experiment.

## References

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