Methodology for Constructing Reservoir Maximum Pore Pressure Maps to Meet Class VI Constraints and Prevent Earthquakes

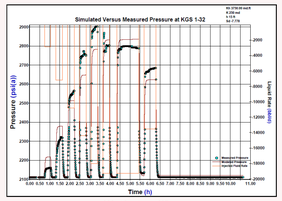
Tiraz Birdie, Eugene Holubnyak, Lynn Watney, and Jennifer Hollenbach

EPA Class VI Based Pressure Limits

The CO_2 sequestration capacity of saline aquifers in the U.S. has been estimated based on pore space considerations. Injection of CO_2 however is regulated by the EPA via the Class VI injection permit, which restricts the maximum pressure in the injection zone to 90% of the formation Fracture Gradient. This limitation will govern how much CO_2 can be economically injected and stored in the coming decades as we transition to non-fossil fuel sources of energy. A methodology is presented to construct regional maps of the allowable increase in pore pressure which can assist in identifying suitable locations for sequestration. The approach is demonstrated for the Cambro-Ordovician Arbuckle aquifer in Kansas.

As per Class VI Rule, the maximum allowable pore pressure in the Injection Zone, $P_{max} = 0.9 * Fracture\ Gardient$ → $\nabla P_{max} = 0.9 * Fracture\ Gardient - Existing\ Pressure$

Step 1: Determine Fracture Gradient by Conducting Step Rate Test



Wellington, KS

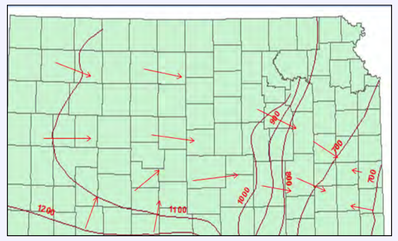
Formation fractured at 2,900 psi at ~ 5,000 ft

Fracture Gradient ~ 0.60 psi/ft

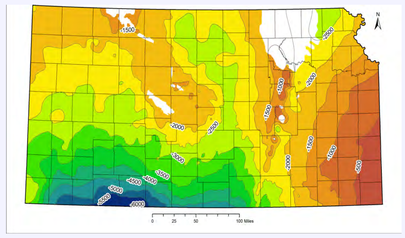
Step 2: Determination of Existing Pressure in Middle of Arbuckle Aquifer

$Existing\ Pressure\ in\ midArbuckle = (Equivalent\ Freshwater\ Head\ Elevation - Elevation\ of\ midArbuckle) * Density\ of\ Freshwater$

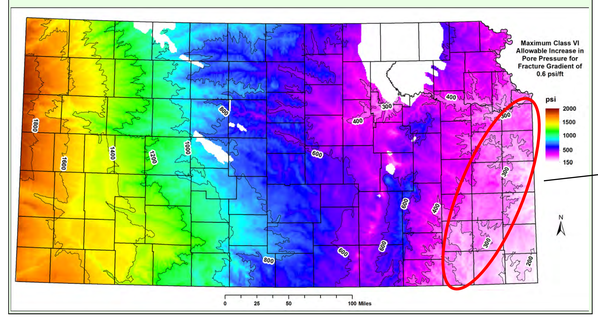
Equivalent Freshwater Head in Kansas (ft, amsl)

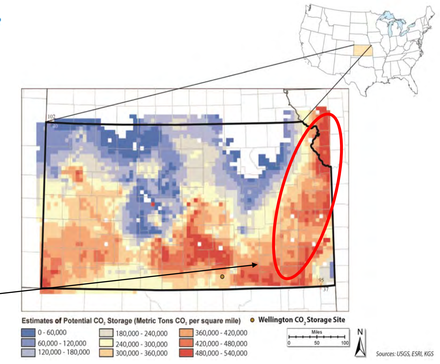


Elevation of Mid-Arbuckle (ft, amsl)



Step 3: Maximum Allowable Increase In Pore Pressure in mid-Arbuckle (psi)



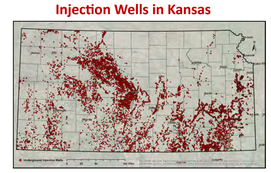


Pore space based CO_2 storage potential may not be economically realizable due to Class VI pressure constraints

Protection of Drinking Water Aquifers

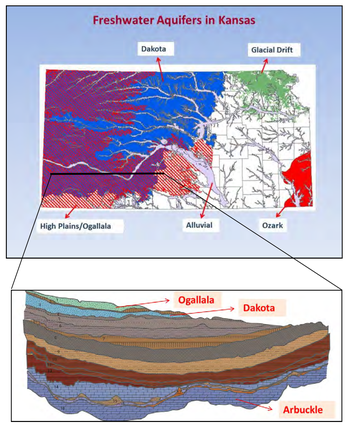
Commercial scale injection of CO2 is expected to cause large increases in pore pressure in saline aquifers. These aquifers are currently used to dispose liquid waste. There are a large number of waste disposal wells in Kansas through which brines in the injection zone can migrate into overlying freshwater aquifers. Therefore, it is beneficial to limit the increase in injection zone pressures so that brines cannot migrate into freshwater aquifers. A methodology is presented to develop regional maps of the maximum increase in pore pressures to prevent bine migration, and the approach demonstrated for freshwater aquifers in Kansas.

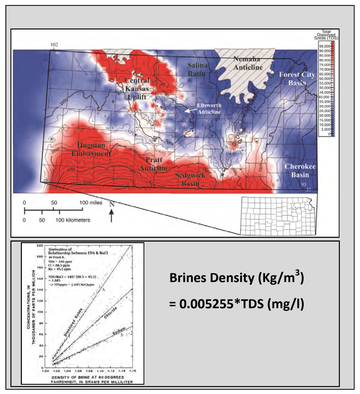
Injection Wells in Kansas



Required Pressure For Migration of Brines in Drinking Water Aquifers = (Elevation of Base of Drinking Water Aquifer—Elevation of Arbuckle Insitu Heads) * Density of Arbuckle Brine

Step 1: Determination of Brine Density



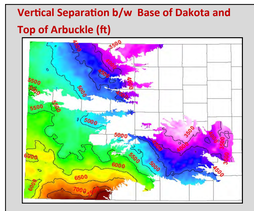


Brines Density (Kg/m^3)

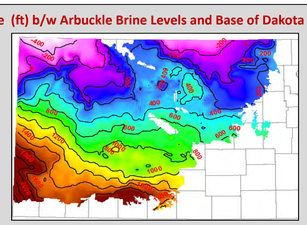
= 0.005255*TDS (mg/l)

Step 2: Determination of In-situ Heads and Distance to Base of Freshwater Aquifers

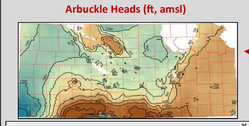
Vertical Separation b/w Base of Dakota and Top of Arbuckle (ft)



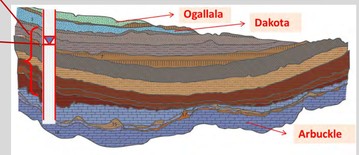
Distance (ft) b/w Arbuckle Brine Levels and Base of Dakota Aquifer



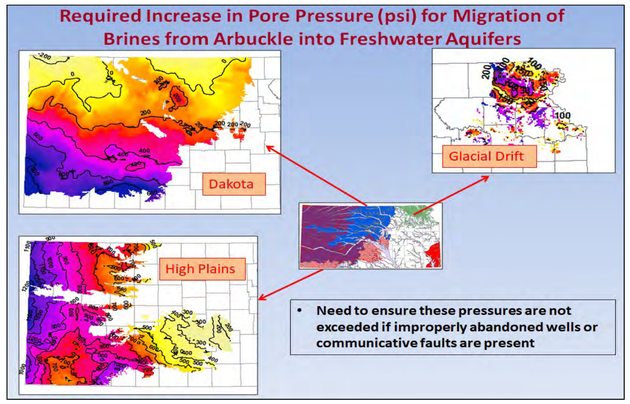
Arbuckle Heads (ft, amsl)



$Head_{insitu} = Elev_{mid-Arbuckle} + EFWH_{mid-Arbuckle} * \left(\frac{\gamma_{fw}}{\gamma_{br}}\right)$



Step 3: Determination of Maximum Allowable Pore Pressure in Arbuckle Aquifer to Prevent Migration of Brine into Freshwater Aquifers

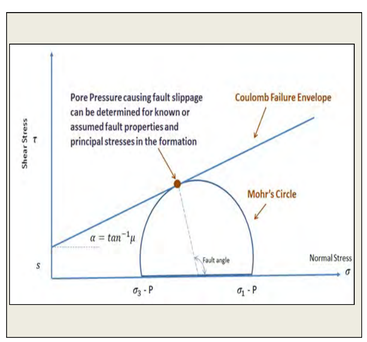


- Need to ensure these pressures are not exceeded if improperly abandoned wells or communicative faults are present

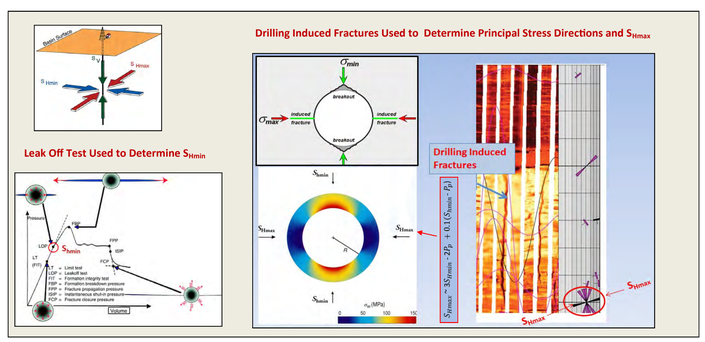
Seismic Based Pressure Limits

Injection of liquid waste in the Arbuckle is associated with earthquakes in Kansas. A methodology is developed to construct regional maps of the maximum increase in pore pressure that can be induced without causing earthquakes for assumed fault properties and stress field. The approach is demonstrated for faults in the Arbuckle aquifer in Kansas.

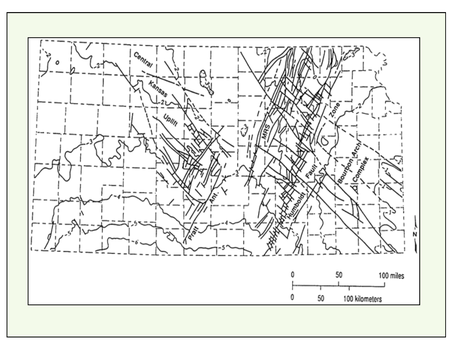
Conceptualization of Failure Condition



Determination of Stress Field Magnitudes and Directions

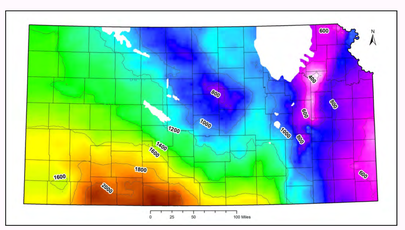


Orientation of Primary and Conjugate Faults in Kansas

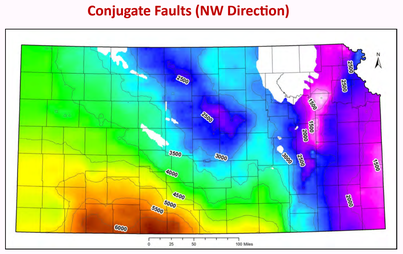


Maximum Allowable Increase in mid-Arbuckle Pore Pressures (psi) to Prevent Fault Slippage

Primary Faults (NE Direction)



Conjugate Faults (NW Direction)



- Primary faults more susceptible to failure due to critical orientation with respect to the present-day stress field