From Site to State: Design of an Integrated CCUS Operation in a Complex Geological Structure in Osage County, Oklahoma

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CUSP Annual Meeting-June 2022

Agenda

- Project Overview
- Preliminary Results
  - Geological Characterization
    - Data collection
    - Building 3D geological model
  - CO_2 Transport-TEA

Project Goal

Main goal: *Develop a two-step roadmap to help accelerate CCUS deployment in Oklahoma, focusing on a designing and permitting a novel stacked storage CCUS complex*:

Field site development: *Support Capture Point LLC to develop a plan to submit a Class VI well permit application for a stacked storage CCUS complex in Osage County, Oklahoma.*

Roadmap: *deliver a roadmap for industry, state government, and other stakeholders to jumpstart CCUS development in Oklahoma based on stacked storage.*

Project Tasks

- **Task 1:** A thorough formation evaluation of Arbuckle formation in Osage county
- **Task 2:** Determine the economic feasibility of a stacked storage site, combining CO_2-EOR and CO_2 sequestration operations using the same surface facility unit in Osage county.
- **Task 3:** Develop a representative geological model based on knowledge and understanding of the Arbuckle saline formation in Osage county as completed by prior tasks.
- **Task 4:** Develop a multi-pathway CCUS roadmap for Oklahoma centered on the stacked storage concept
- **Task 5:** Evaluation of Environmental and Social Justice parameters in Osage county

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Study Area and Data

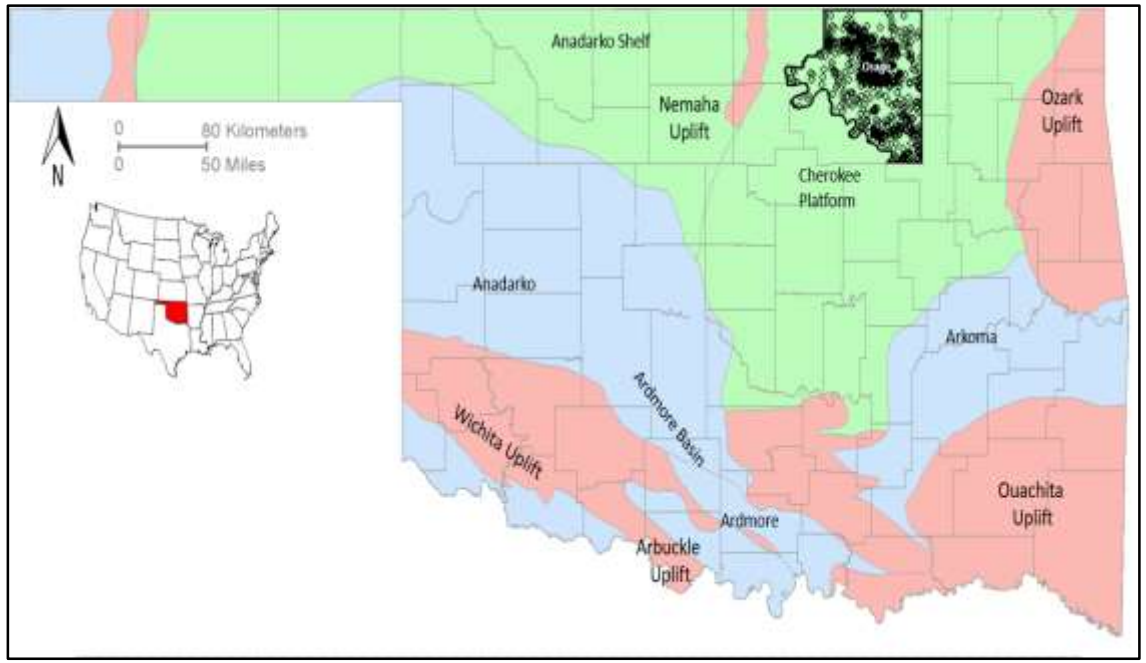
Highest Record:

Population: 45,772

Drilled wells: 35,700

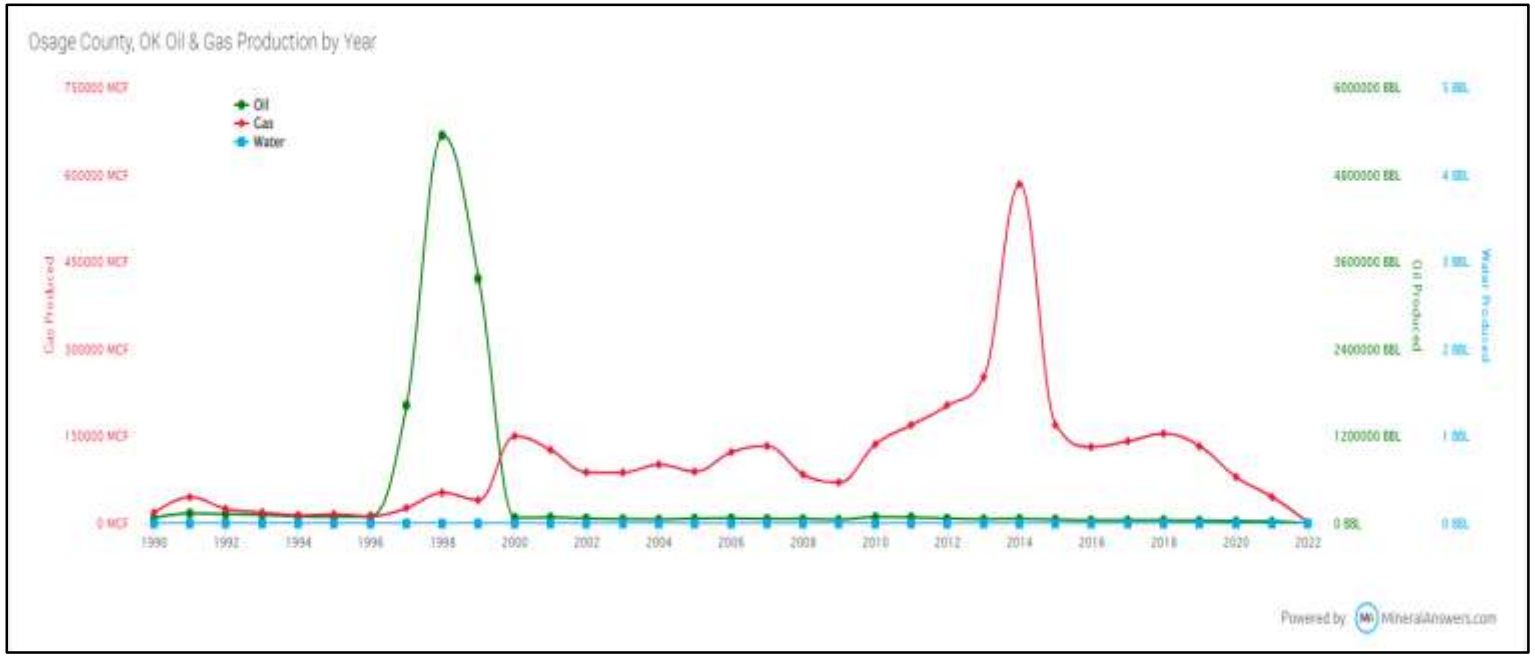
Oil, 4,800,000 Bbls, Year 1998, currently ranked # 62 in the State

Gas, 600,000 MCF, Year 2014, currently ranked # 59 in the state



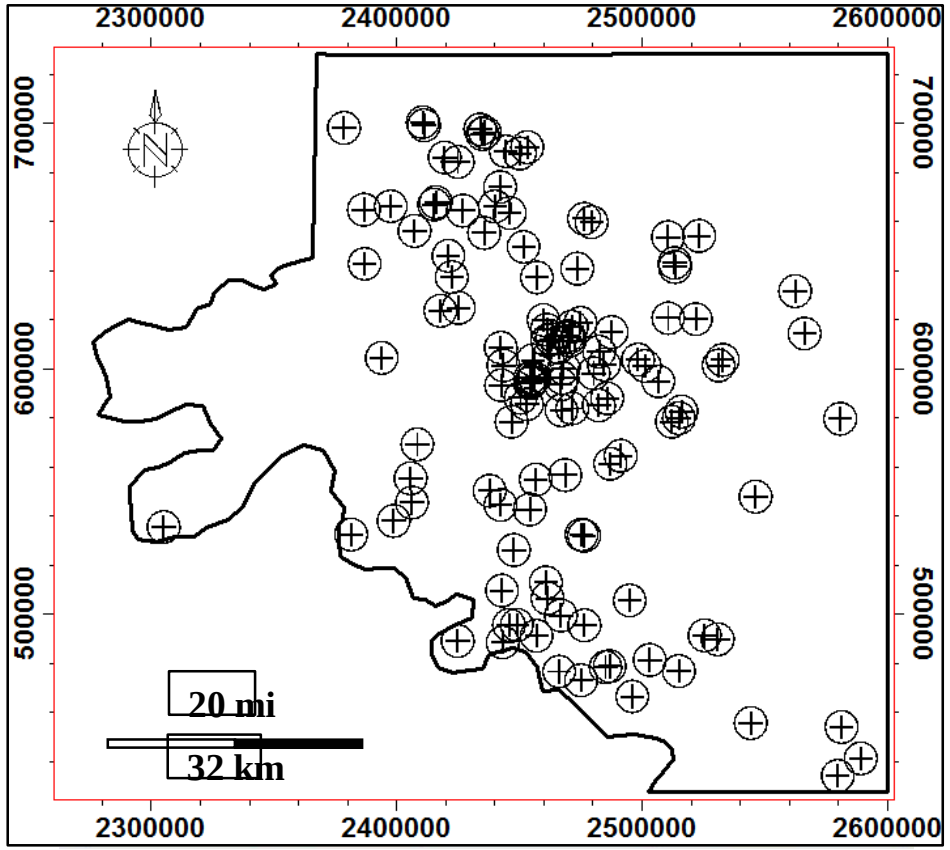
Focused Project-OSAGE County

SIMCCS Analysis, Geological Model

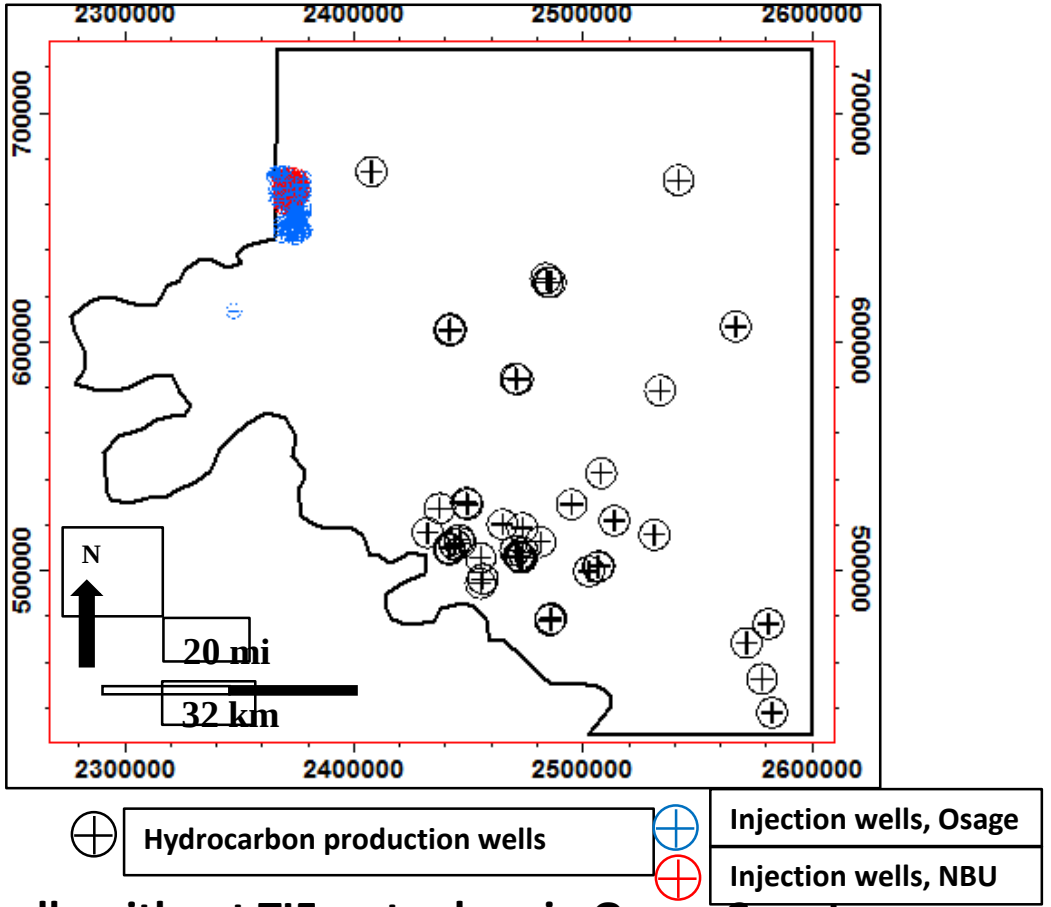


Data available: Core, Log, Production and Injection Data

Core and Log wells in Osage



Injection and hydrocarbon production wells in Osage



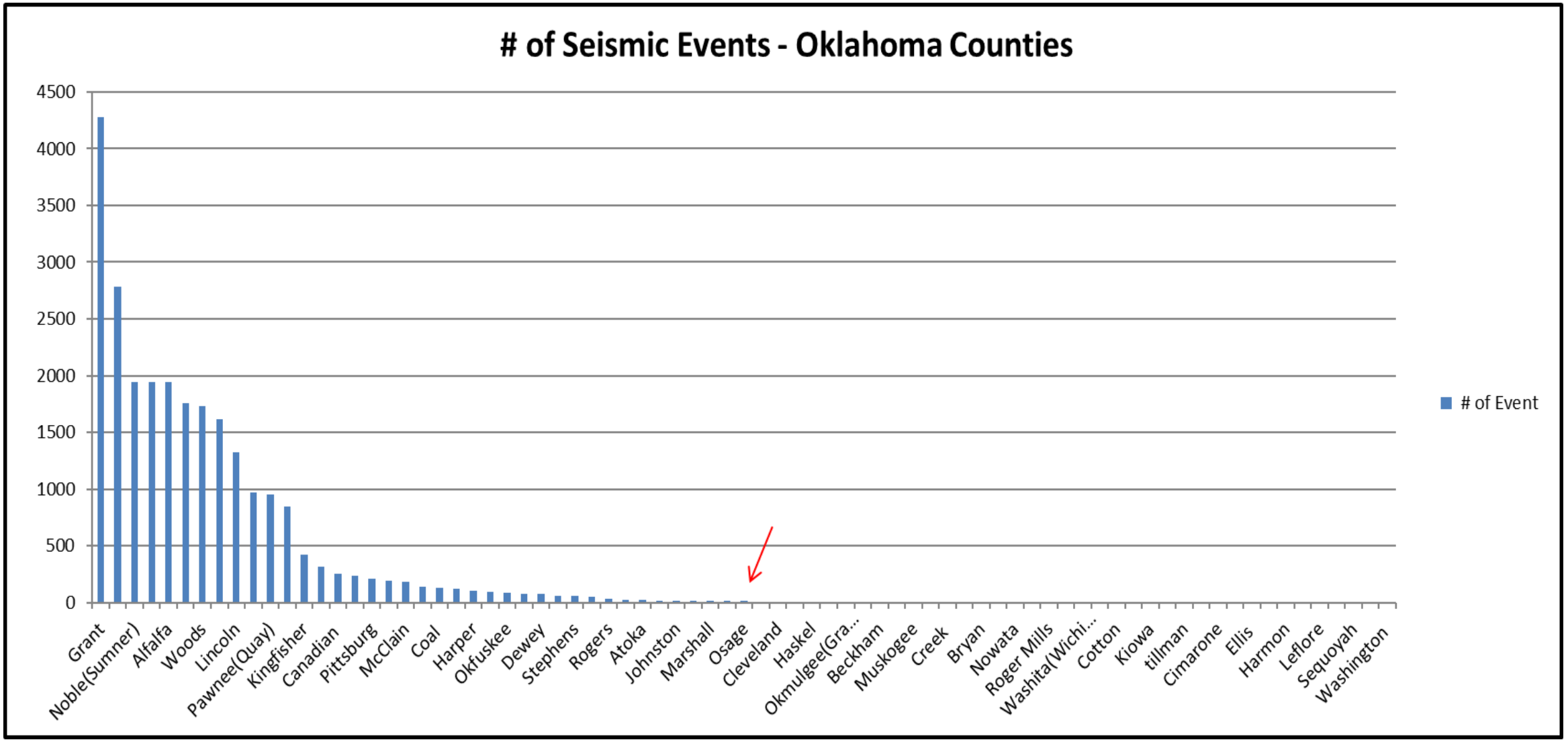
- Wells with 1000 TIF raster logs in Osage County
  - 124 wells consisted of 665 logs had been digitized
- 5 Cored well in Osage County
- 161 injector wells without TIF raster logs in Osage County
  - 66 injector wells with monthly and cumulative water volume and 109 wells with injection intervals
- 80 produced wells with their production data in Osage County

Digitized wells: Summary

	Name	UWI	WSN	DEPT	BULK_DENSITY	CALIPER	DEEP_RESISTIVITY	DENSITY_POROSITY	GR	MEDIUM_RESISTIVITY
89	CORPS OF ENGINEERS 1	35113286210000	1758	Yes	Yes	Yes	Yes	Yes	Yes	Yes
90	STUART DOUGLAS 1-8	35113287240000	1760	Yes	Yes	Yes	Yes	Yes	Yes	Yes
91	WINSELL 2	35113287750000	1762	Yes	Yes	Yes	Yes	Yes	Yes	Yes
92	CONNIE 2BW	35113290070000	1773	Yes	No	No	No	No	Yes	No
93	BETTS UNIT 7-8	35113290380000	1775	Yes	No	Yes	Yes	Yes	Yes	Yes
94	OXLEY 9-18	35113292070000	1782	Yes	Yes	Yes	Yes	Yes	Yes	Yes
95	DRUMMOND 8-A	35113293700000	1790	Yes	Yes	Yes	No	Yes	Yes	No
96	BARTON JAY 1	35113294190000	1793	Yes	Yes	Yes	Yes	No	Yes	Yes
97	OSAGE WS-1	35113305610000	1812	Yes	No	Yes	No	No	No	No
98	OSAGE 227	35113313130000	1822	Yes	No	No	No	No	No	No
99	JANE 2	35113401340000	1863	Yes	Yes	Yes	Yes	Yes	Yes	Yes
100	DRUMMOND 9	35113402400000	1867	Yes	Yes	No	Yes	Yes	Yes	Yes
101	COLD SPRINGS 6	35113403000000	1869	Yes	Yes	Yes	Yes	Yes	Yes	Yes
102	COLD SPRINGS 7	35113403010000	1870	Yes	No	Yes	Yes	Yes	Yes	Yes
103	COLD SPRINGS 3-7	35113403980000	1874	Yes	Yes	Yes	Yes	Yes	Yes	Yes
104	COLD SPRINGS 3-8	35113404140000	1875	Yes	Yes	Yes	Yes	Yes	Yes	Yes
105	NATURE CONSERVANCY 2	35113406230000	1887	Yes	Yes	Yes	No	Yes	Yes	No
106	U S GOVERNMENT 13	35113407860000	1902	Yes	No	No	Yes	No	Yes	Yes
107	PEARSONIA UNIT 60	35113410520000	1918	Yes	No	No	No	No	Yes	No
108	DRUMMOND TRUST 86-9	35113410680001	1920	Yes	Yes	Yes	Yes	Yes	Yes	Yes
109	BUREAU OF INDIAN AFF	35113411590000	1921	No	No	No	No	No	No	No
110	OSAGE 23A	35113412590000	1923	Yes	Yes	Yes	Yes	Yes	Yes	Yes
111	MILLSAP CLAUDE G JR	35113413270000	1927	Yes	Yes	Yes	Yes	Yes	Yes	No
112	HULL 33-1	35113415220000	1951	Yes	Yes	No	Yes	Yes	Yes	No
113	OSAGE 14-2	35113415460000	1960	Yes	Yes	Yes	Yes	Yes	Yes	No
114	KERR 32-1	35113415580000	1966	Yes	No	No	No	No	Yes	No
115	SOONER CATTLE CO 1	35113421270000	1976	Yes	No	Yes	No	Yes	Yes	No
116	STUART 1A-13	35113436870000	1983	Yes	No	Yes	Yes	Yes	Yes	Yes
117	OSAGE 2A-15 SWD	35113440520000	1986	Yes	Yes	Yes	Yes	No	Yes	Yes
118	STROHM NORTHWEST 2A-	35113440630000	1988	Yes	Yes	Yes	Yes	No	Yes	Yes
119	TO-OP-PE 2A-4	35113443910000	1991	Yes	Yes	Yes	Yes	No	Yes	Yes
120	SUNSET C-1	35113449670000	1994	Yes	Yes	No	Yes	Yes	Yes	No
121	CASSELMAN 3	35113453530000	1996	Yes	No	No	Yes	Yes	Yes	No
122	JOHMAN 8	35113453550000	1997	Yes	Yes	No	Yes	Yes	Yes	Yes
123	SUNSET 7-2	35113453620000	1998	Yes	Yes	No	Yes	Yes	Yes	Yes
124	MILLSAP 1-B	35113018880000	1118	Yes	No	No	No	No	Yes	No

List of Digitized wells/logs in Osage County	
Number of wells	**124**
BULK_DENSITY	80
CALIPER	70
DEEP_RESISTIVITY	66
DENSITY_POROSITY	79
GR	105
MEDIUM_RESISTIVITY	57
NEUTRON_POROSITY	46
PE	8
SHALLOW_RESISTIVITY	62
SP	81
DELTA_TIME	8
SONIC_POROSITY	3
All digitized logs	**665**
Complete section of Arbuckle	**41**

Seismicity Concern



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Geological Setting—Type Log

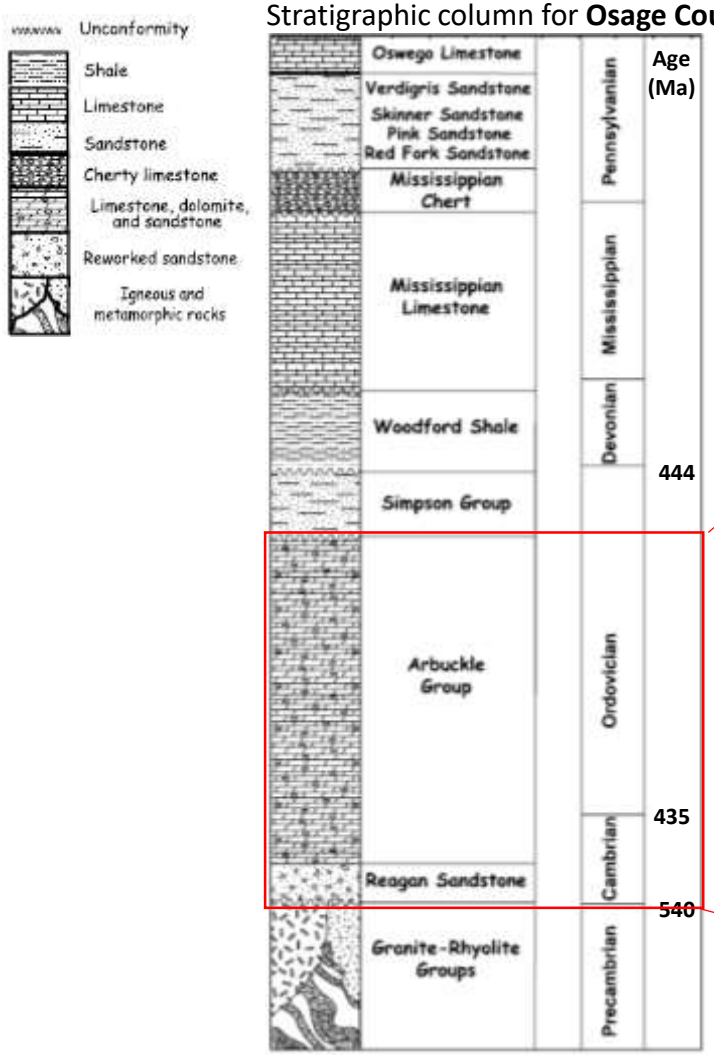
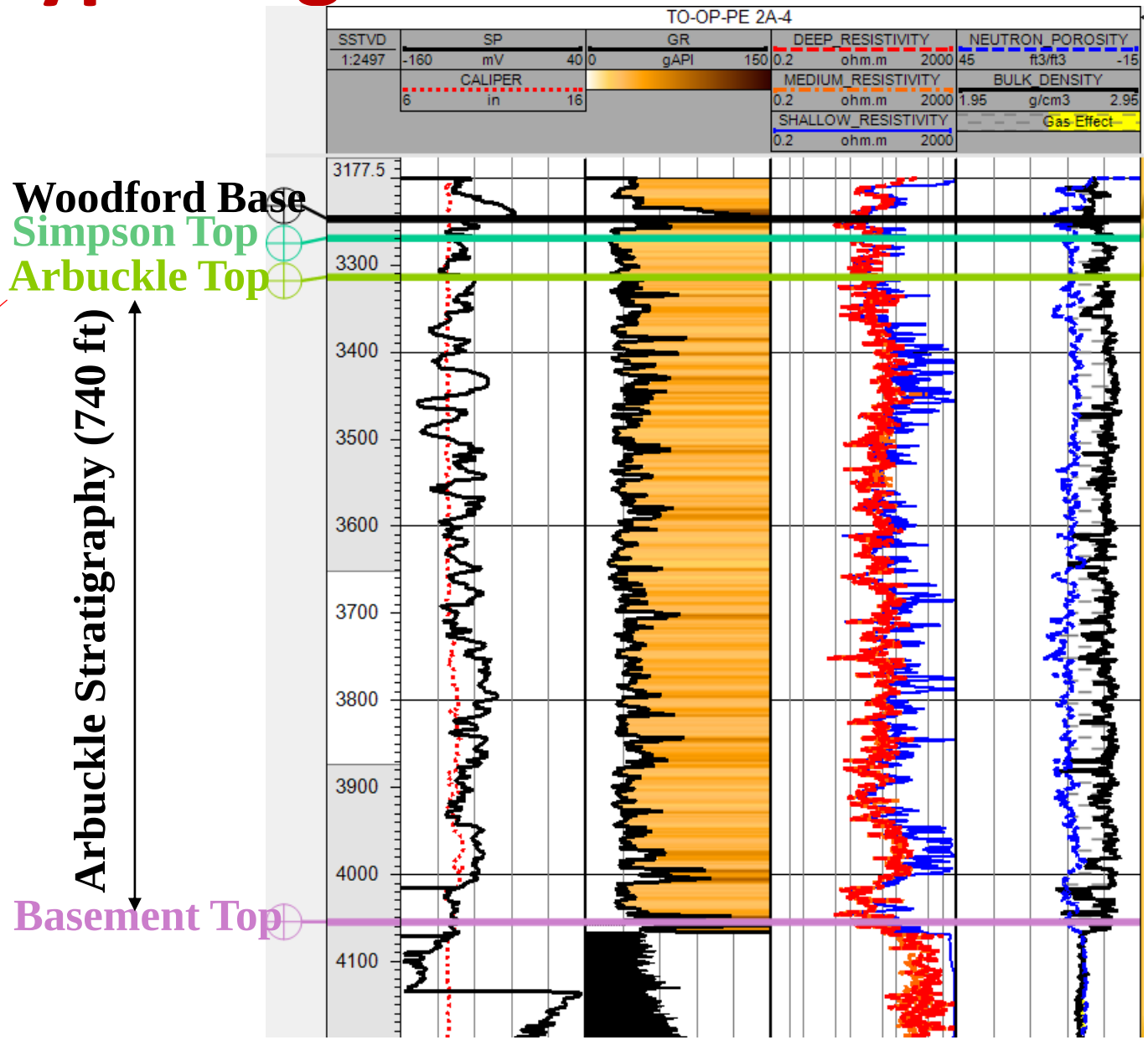
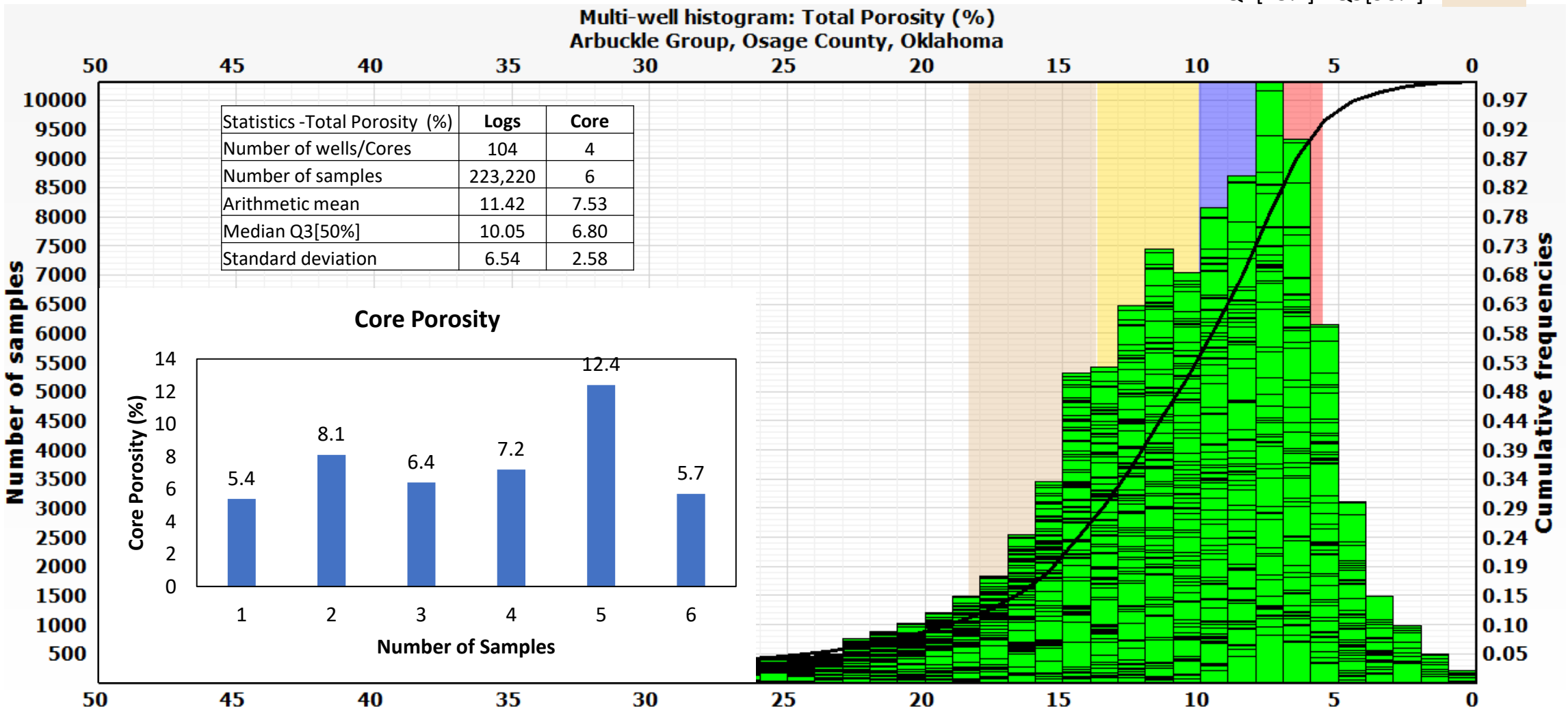


Figure. Stratigraphic column for Osage County. Olubunmi O. Elebiju et al., 2010, Extracted from Zeller (1968), Thorman and Hibpshman (1979), and Franseen et al., 2004

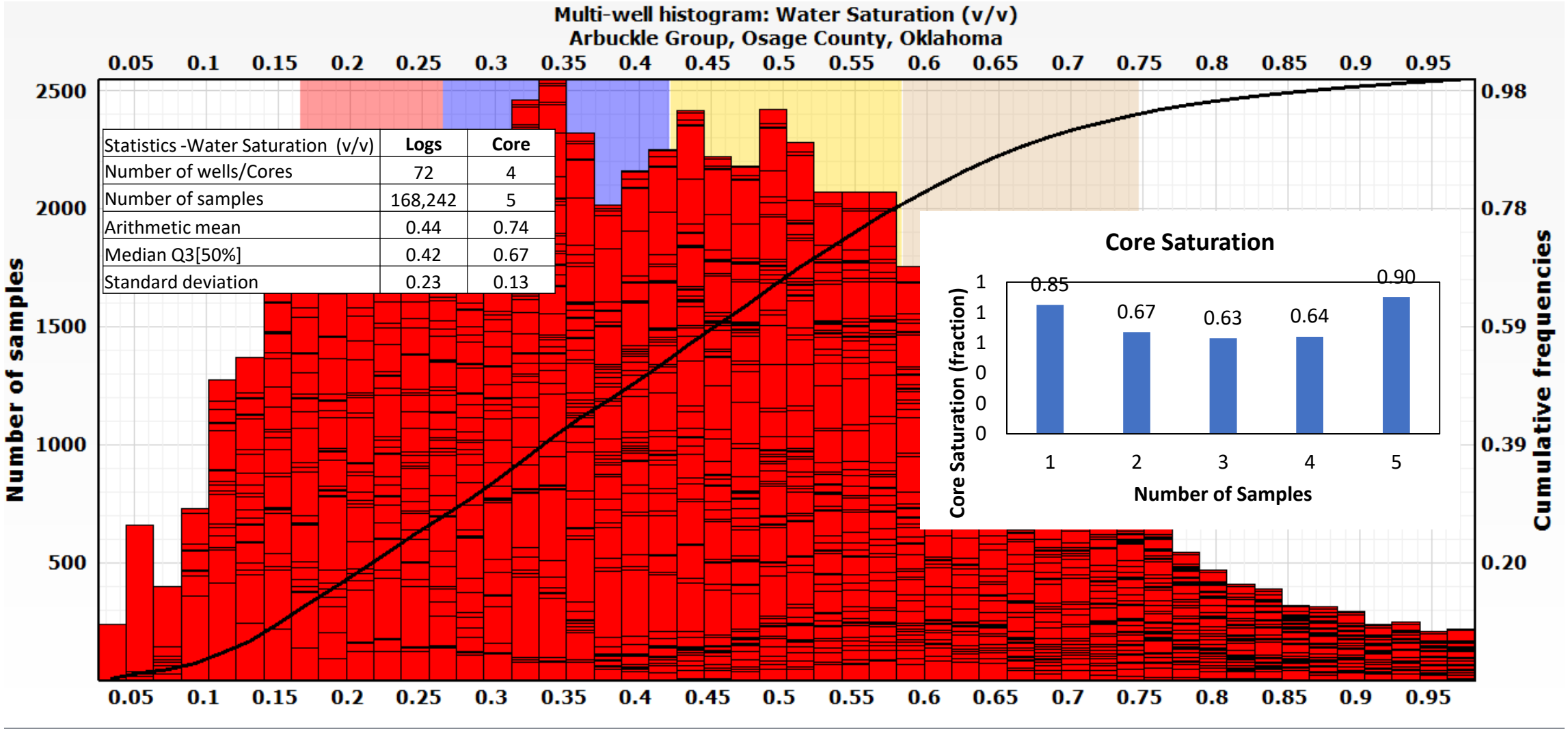


Total Porosity: Log VS. Core

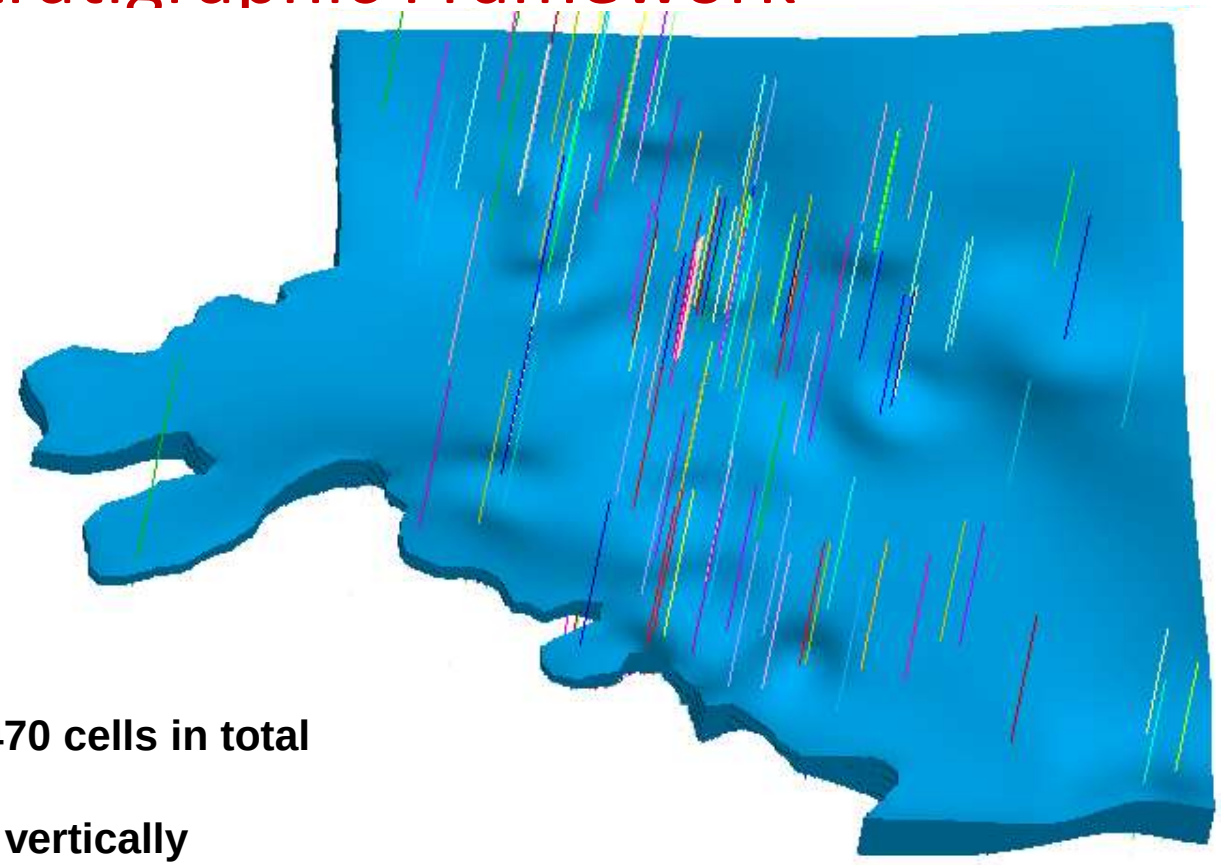


Statistics -Total Porosity (%)	Logs	Core
Number of wells/Cores	104	4
Number of samples	223,220	6
Arithmetic mean	11.42	7.53
Median Q3[50%]	10.05	6.80
Standard deviation	6.54	2.58

Water Saturation: Log VS. Core

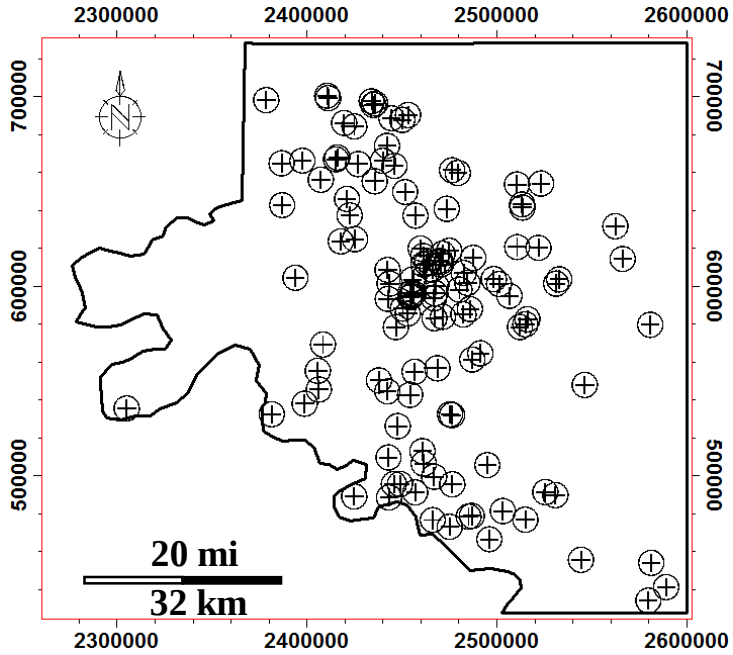


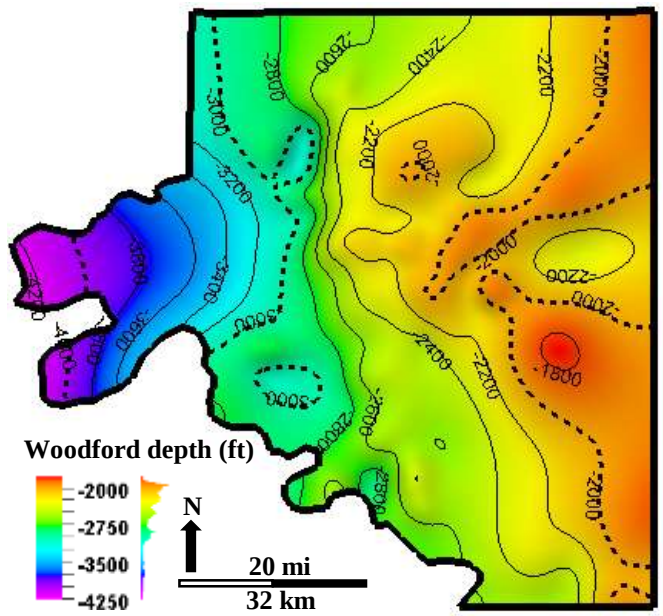
3D Geological Modeling: Stratigraphic Framework

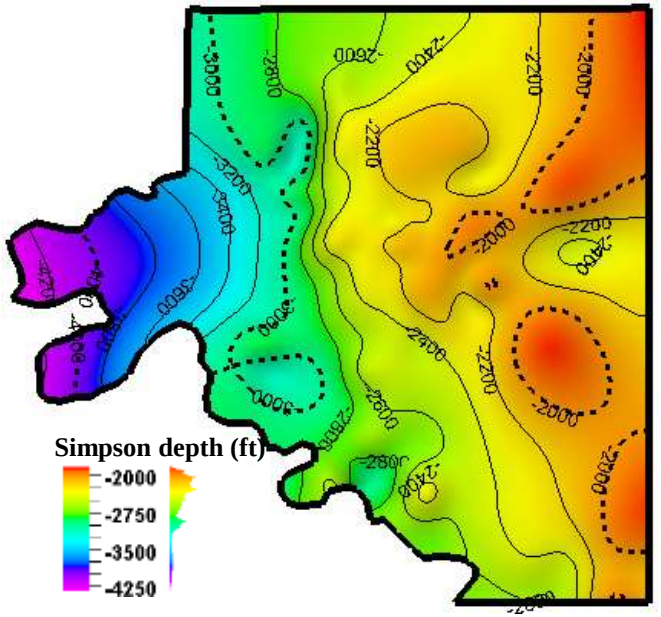


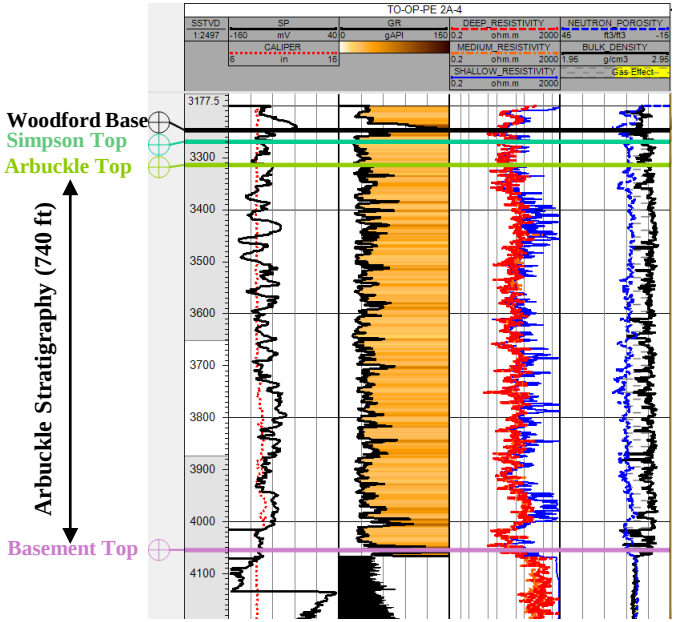
- **Constrained to well-logs only**
- **The model area covers entire Osage County 2,304 mi^2**
- **The 3-D grid has 647 x 601 x 10 cells (I x J x K) and 3,888,470 cells in total**
- **Each cell is 200 x 200 ft aerially and 64 ft thick on average vertically**
- **Number of geological layers in Arbuckle are 10**

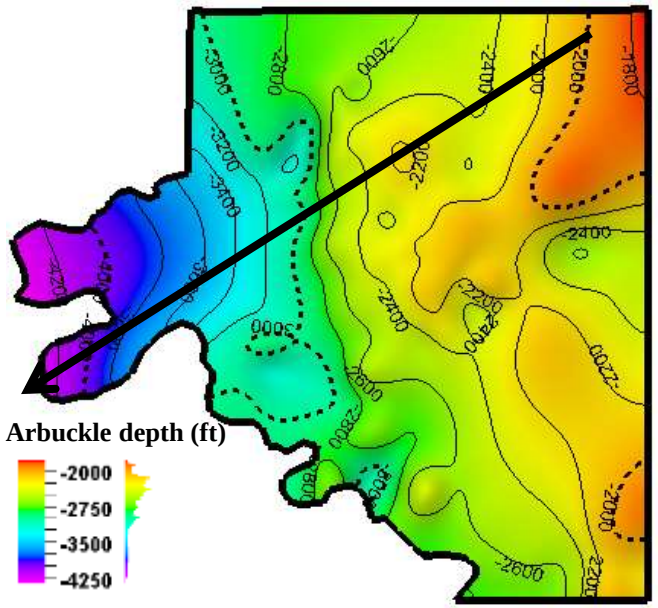
Structure maps: Woodford, Simpson, Arbuckle and the Granite Basemen

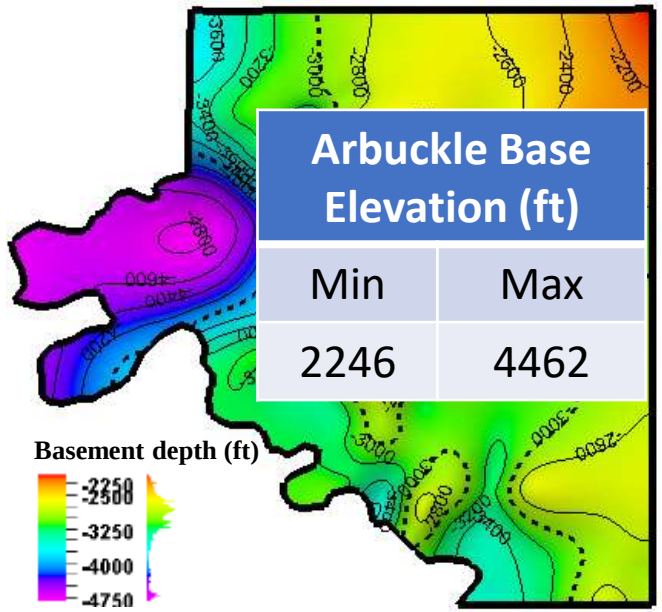








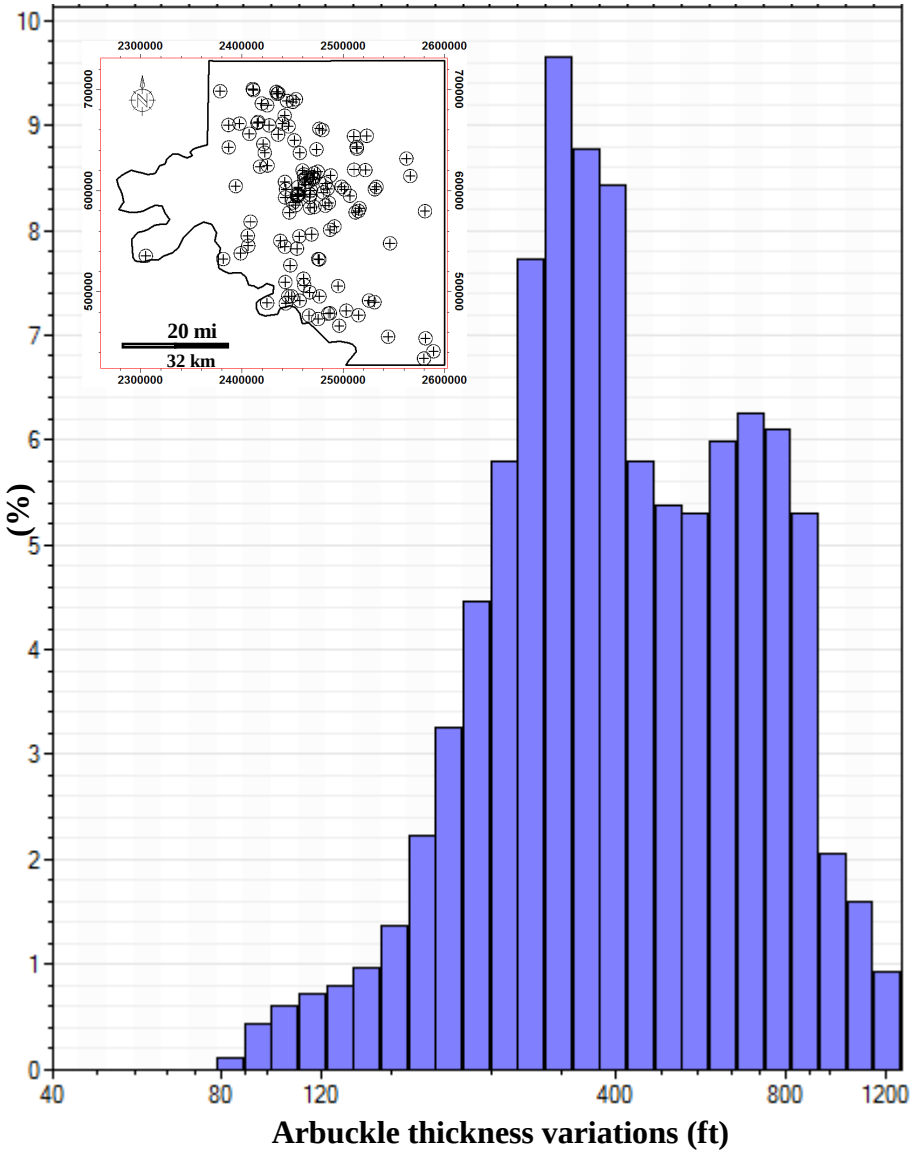




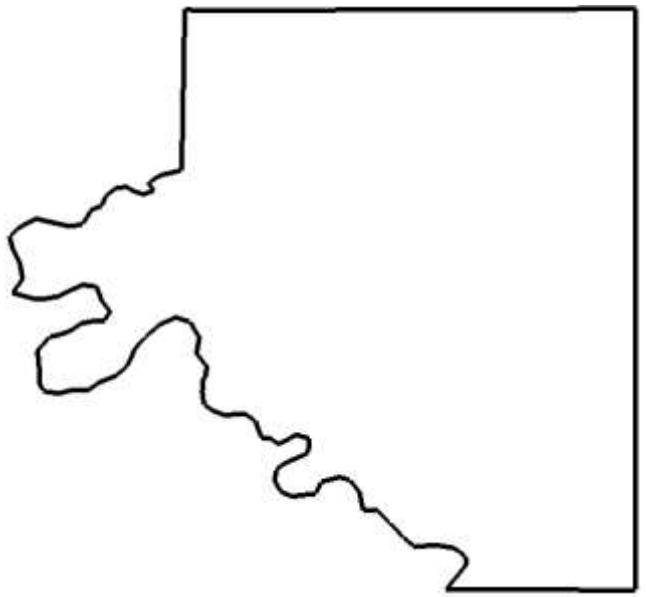
Arbuckle Base Elevation (ft)	
Min	Max
2246	4462

Arbuckle thickness from logs and model

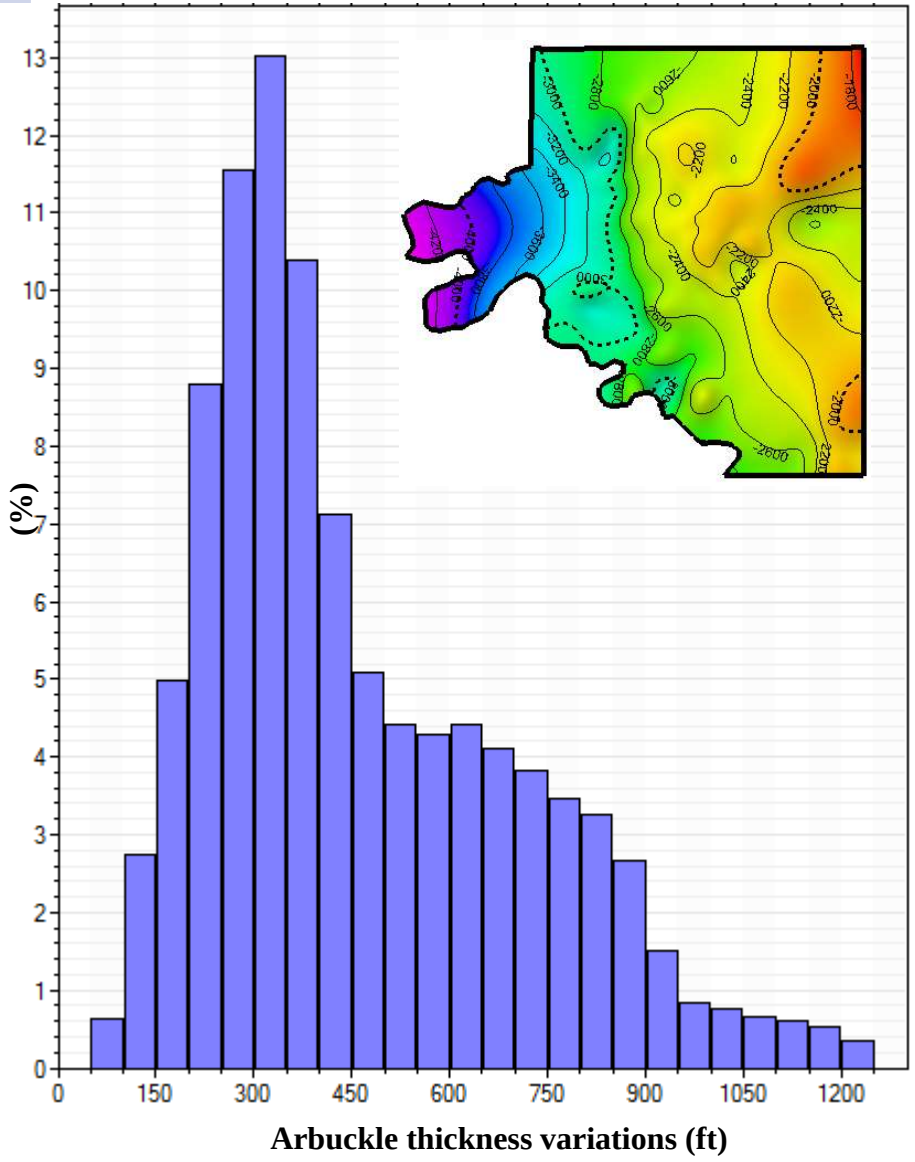
Arbuckle thickness from well logs



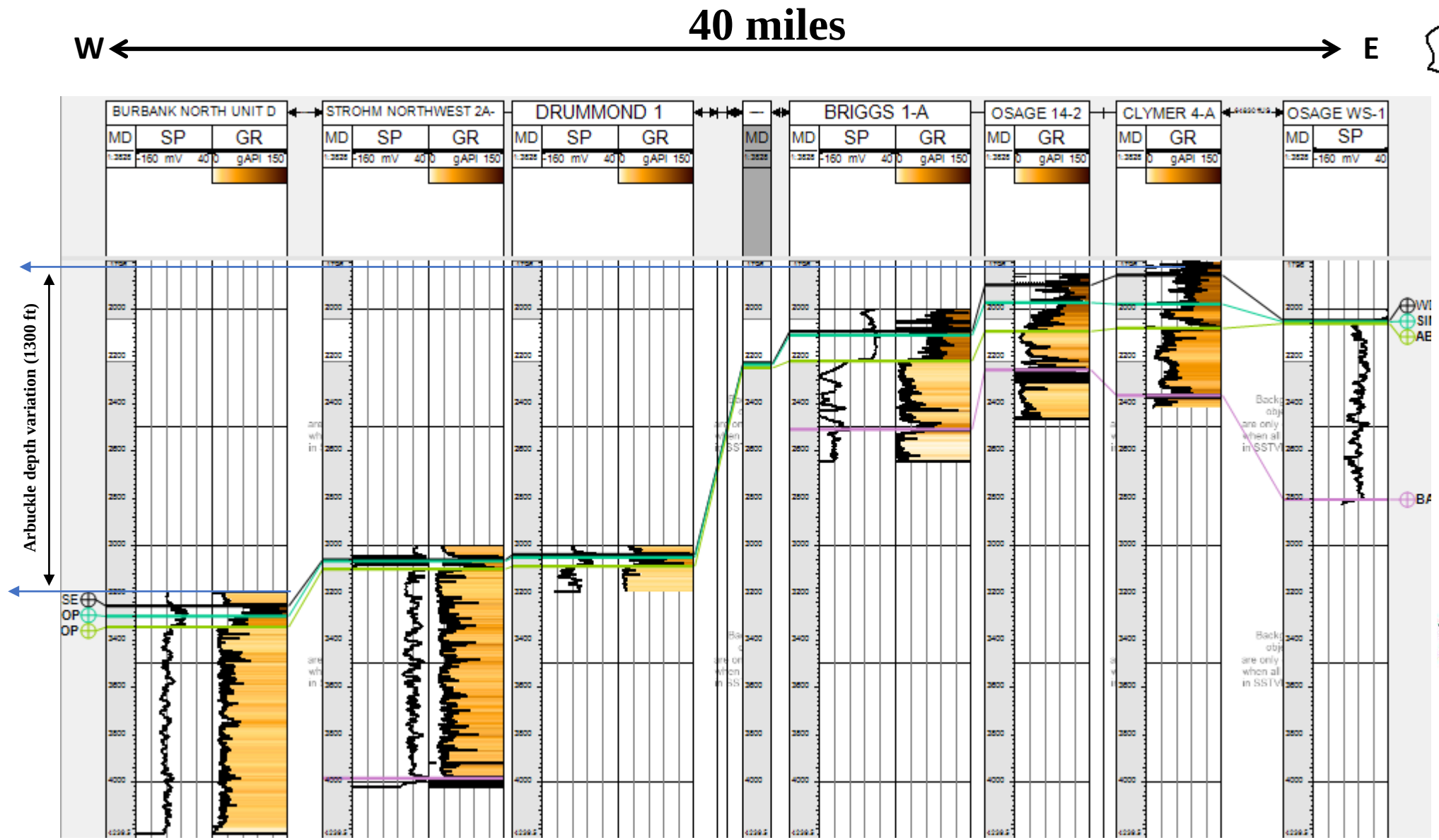
Arbuckle Thickness (ft)		
Min	Max	Mean
82	1236	460

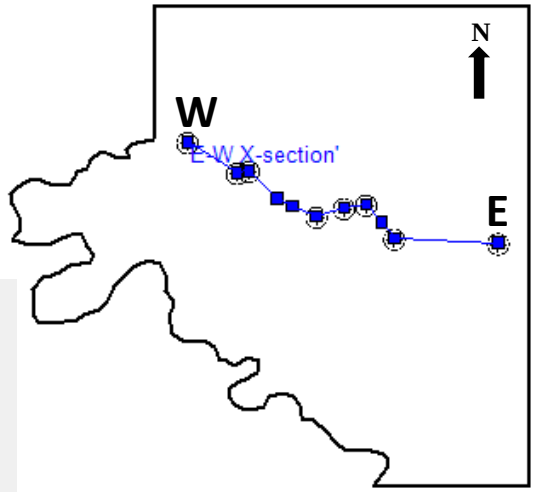


Arbuckle thickness from the model

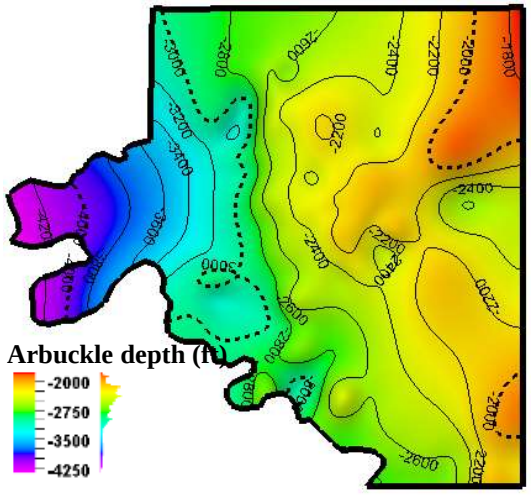


E-W cross section

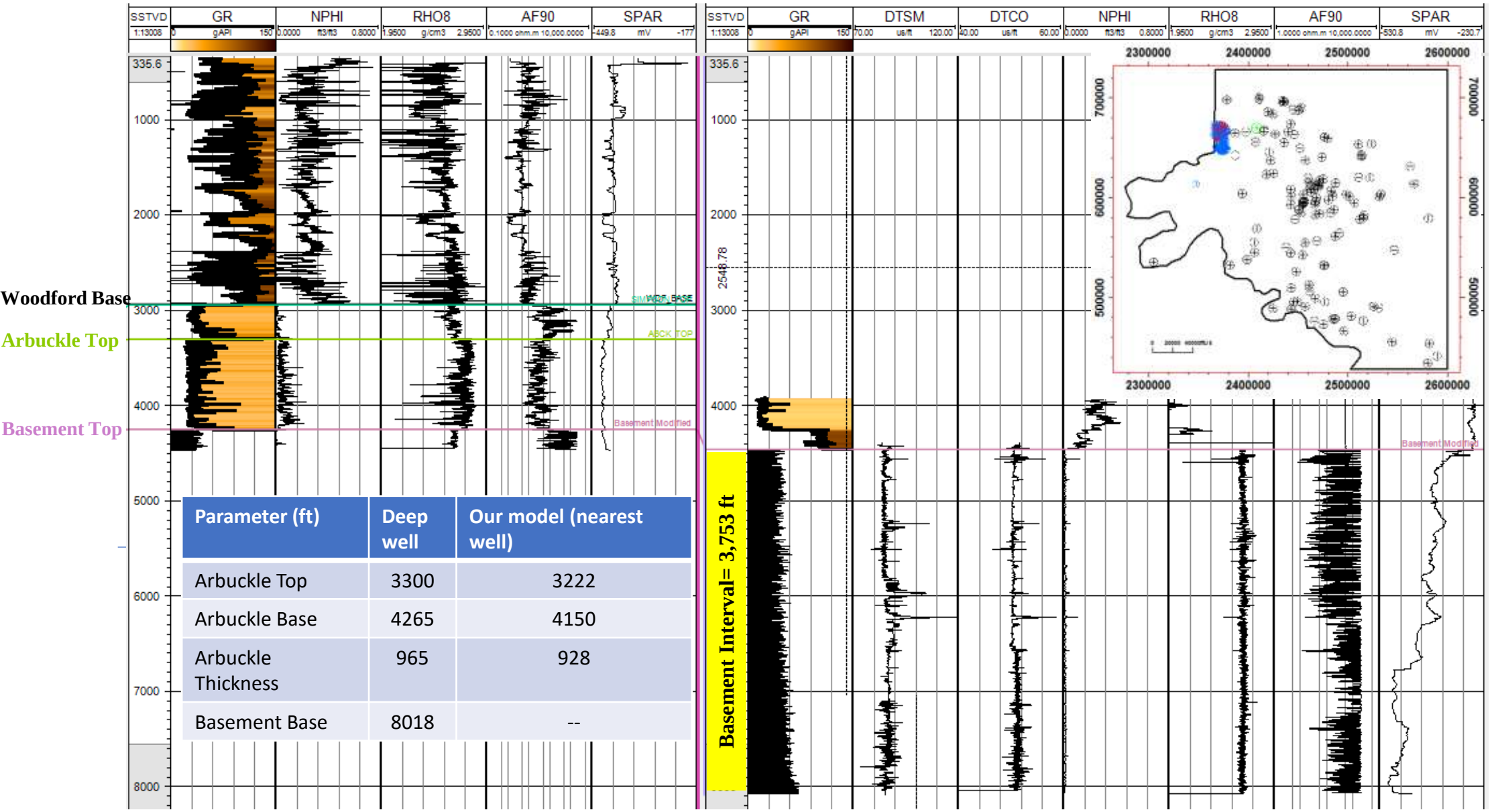




Arbuckle top deeper towards the west



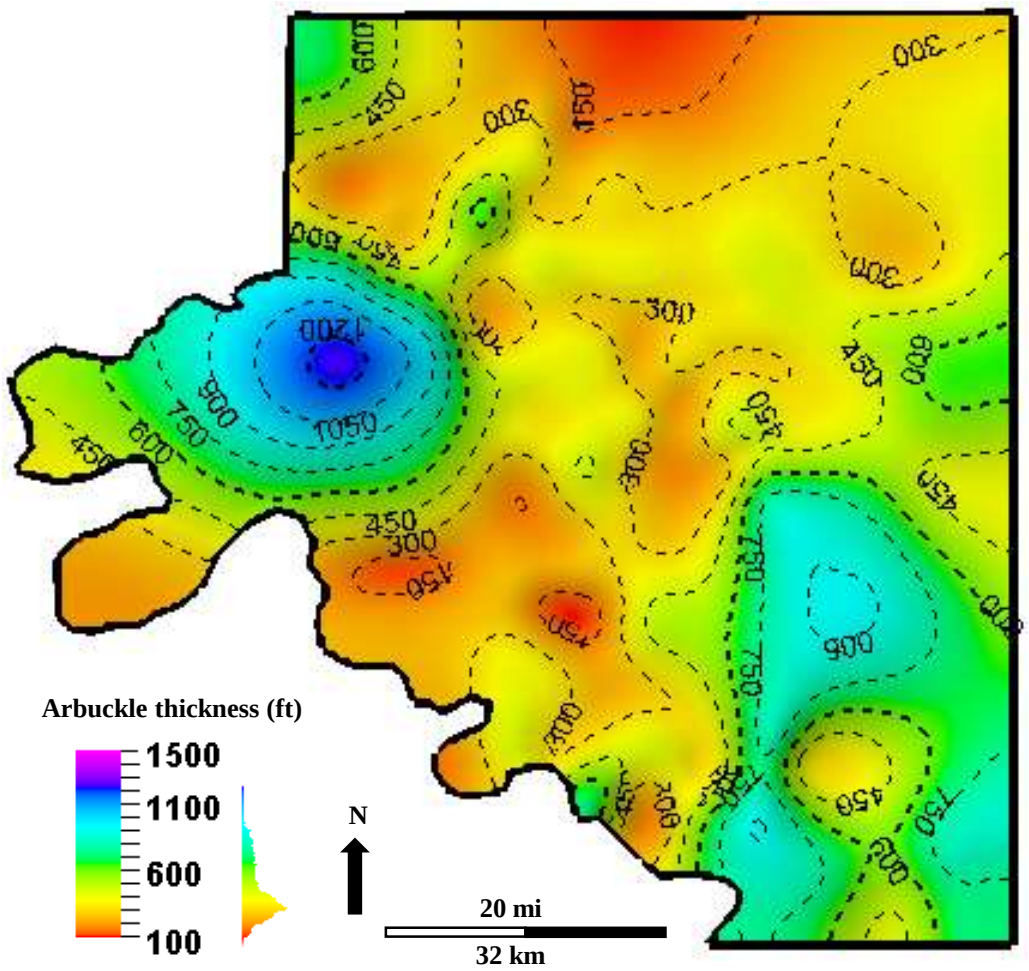
Deep well- Model Validation



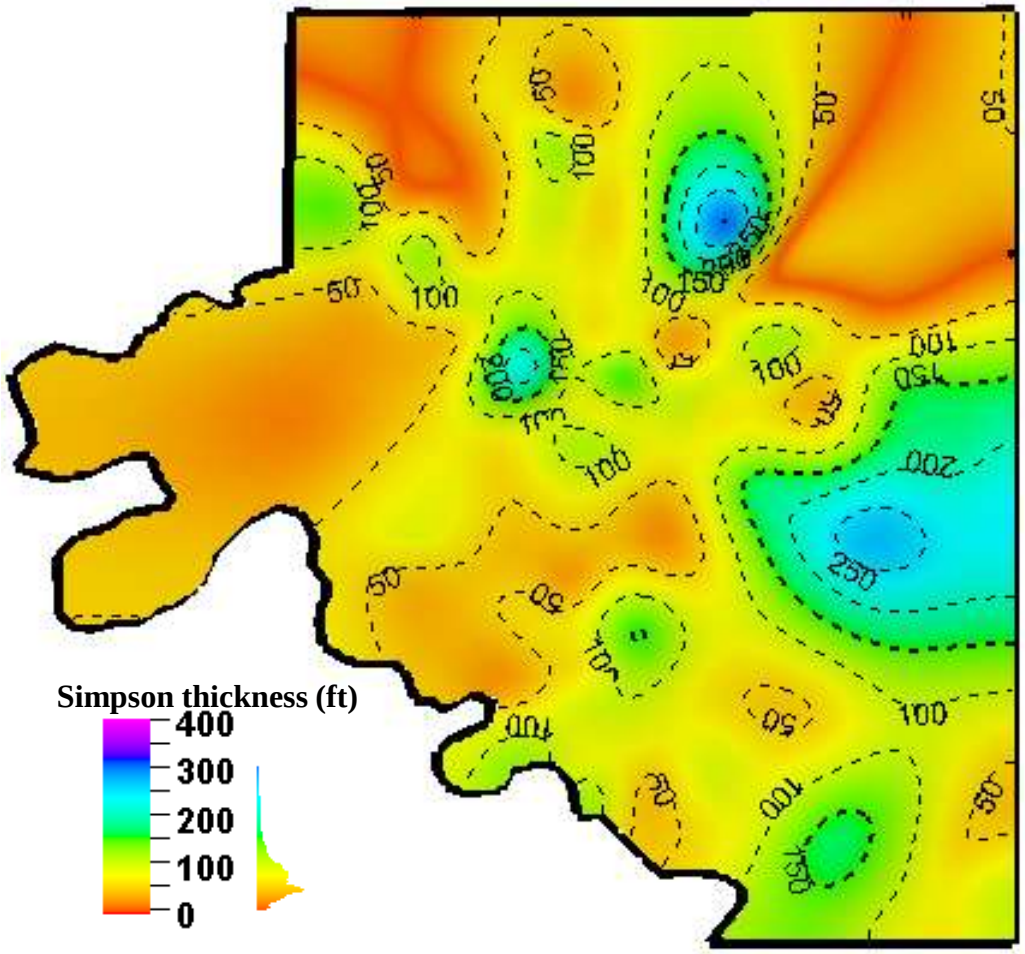
Parameter (ft)	Deep well	Our model (nearest well)
Arbuckle Top	3300	3222
Arbuckle Base	4265	4150
Arbuckle Thickness	965	928
Basement Base	8018	--

Isopach maps: Arbuckle and Simpson Groups

Arbuckle thickness (ft)

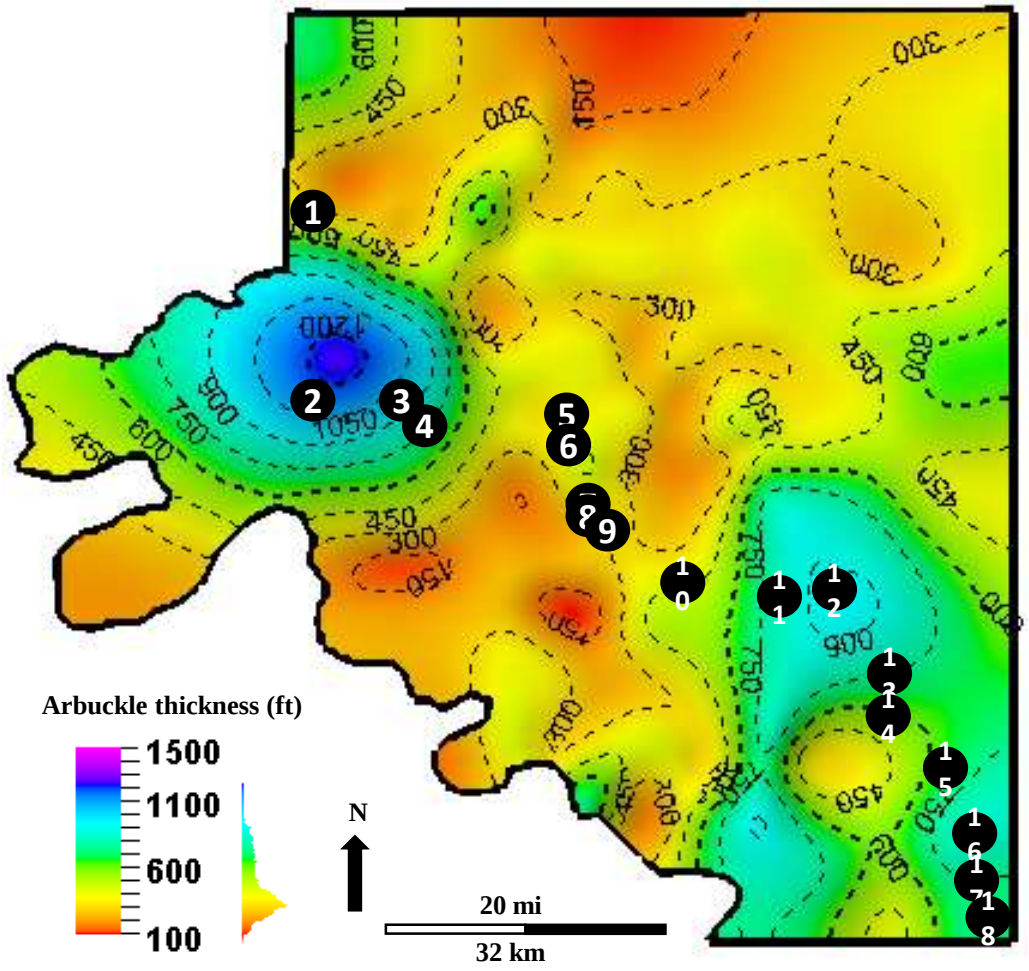


Simpson thickness (ft)

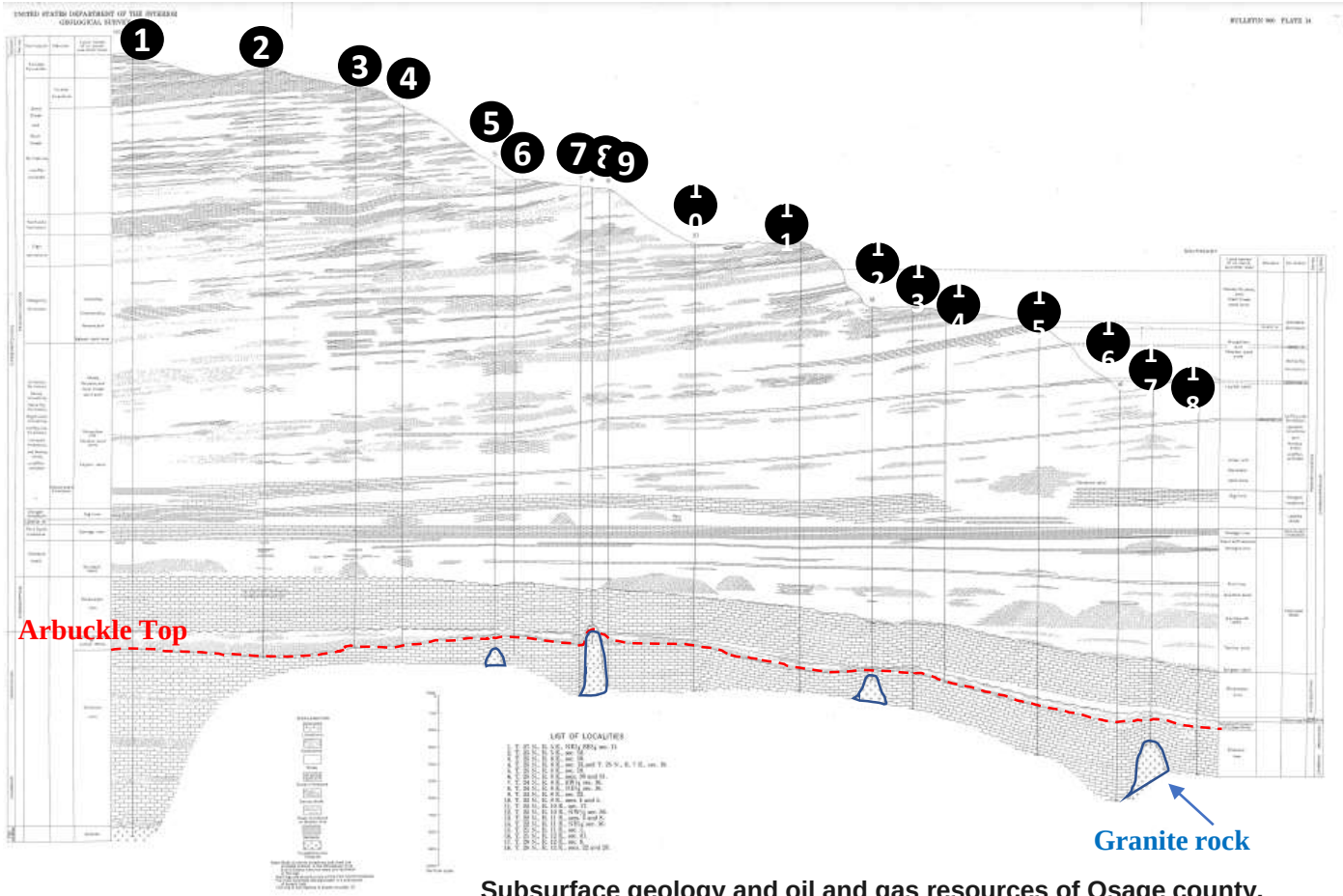


Isopach map: Arbuckle Group-Model Validation

Arbuckle thickness (ft)



X-Section: NW-SE across Osage County, Ok

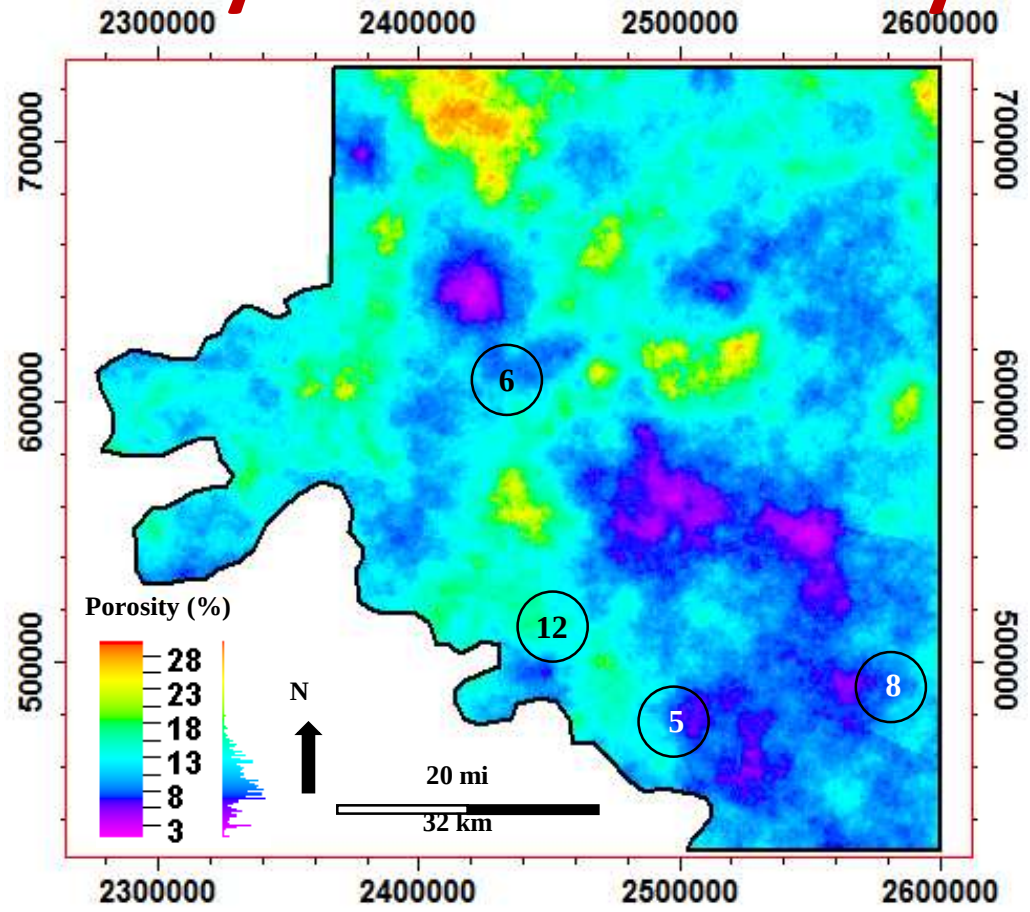


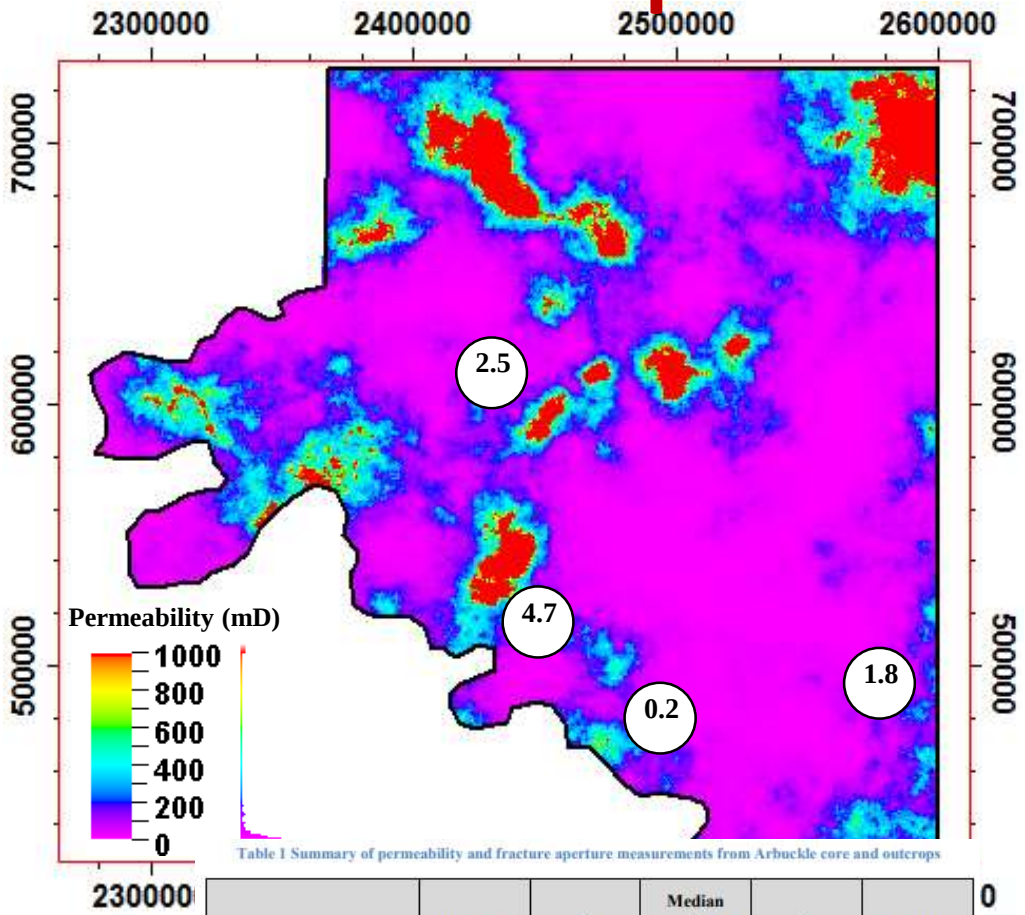
Low Arbuckle thickness: 3 4 5

No Arbuckle thickness: 8 12 17

Subsurface geology and oil and gas resources of Osage county, Oklahoma
Bulletin 900, Plate 14, By: N. Wood Bass, 1942
Publisher: USGS and U.S. Government Printing Office https://doi.org/10.3133/b90

Porosity and Permeability maps for Arbuckle Group





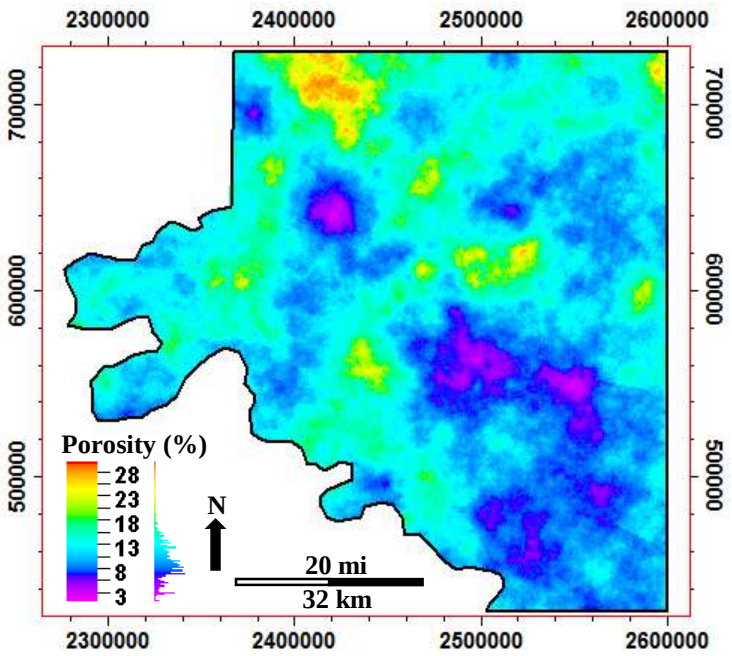
- Susan Hovorka reported Arbuckle porosity varies between 0-10%.
- "It is often true that reported porosity and permeability values are much lower than the true values (Puckette, 1996)."
- Example of that, Cottonwood Creek field, Oklahoma, has produced > 4,000 bopd. Yet the reported porosity and permeability are 2 to 3 % and < 0.01 mD (after Read and Richmond, 1993).

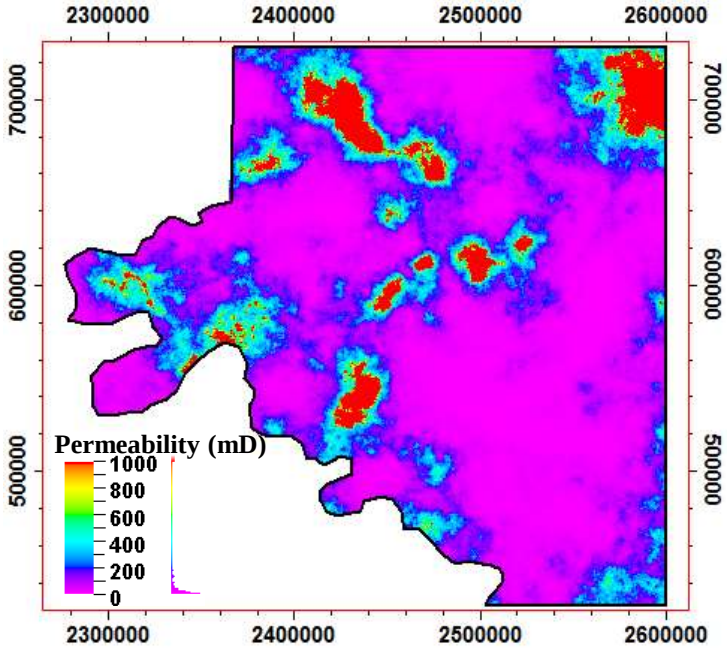
Table 1 Summary of permeability and fracture aperture measurements from Arbuckle core and outcrops

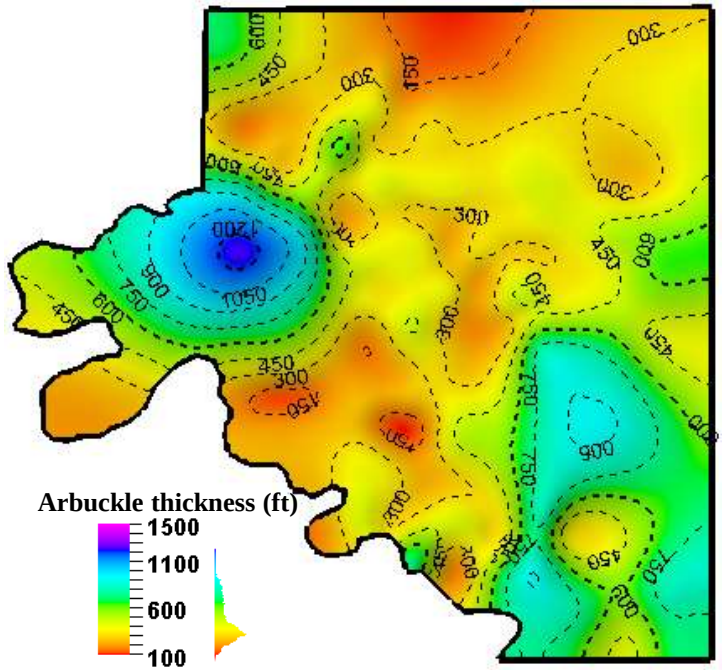
Category	Minimum	25th %	Median (50th %)	75th %	Maximum
Core, Vertical Matrix Permeability (mD), (n=23)	<0.16	<0.16	<0.16	24.31	1407.83
Core, Horizontal Matrix Permeability (mD), (n=144)	<0.16	<0.16	6.62	18.83	3088.61
Core, Fracture Permeability (mD), (n=20)	<0.16	4.06	18.97	161.73	2610.04
Arbuckle Mtns Outcrop, Horizontal Matrix Permeability (mD), (n=17)	<0.16	15.37	20.34	55.86	171.63
Slick Hills Outcrop, Horizontal Matrix Permeability (mD), (n=11)	4.23	22.62	115.87	145.95	977.53

Chance Morgan and Kyle E. Murray (2015) OGS

Porosity, permeability, and thickness maps:





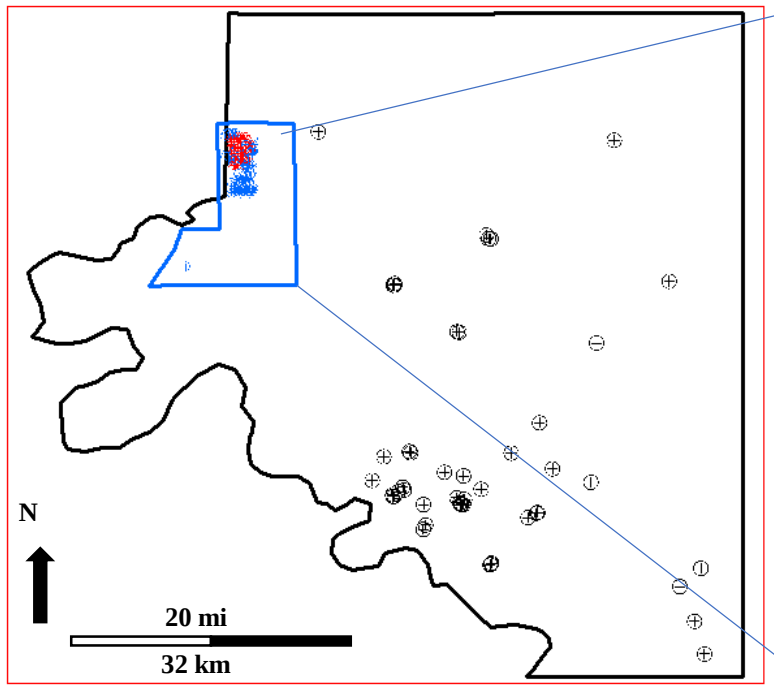


- **Lower the thickness, the higher porosity and permeability. This is most likely due to karstification.**

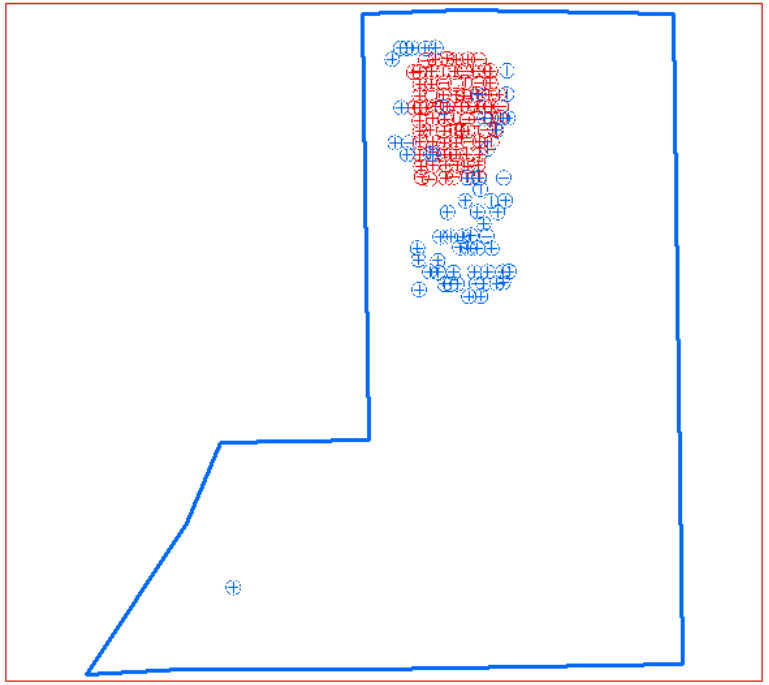
"It is these karsted zones that contain significant amounts of porosity and permeability in what are otherwise low porosity and low-permeability rocks." (Arbuckle Report by BEG, Susan Hovorka).

Cumulative water injection map for Arbuckle Group

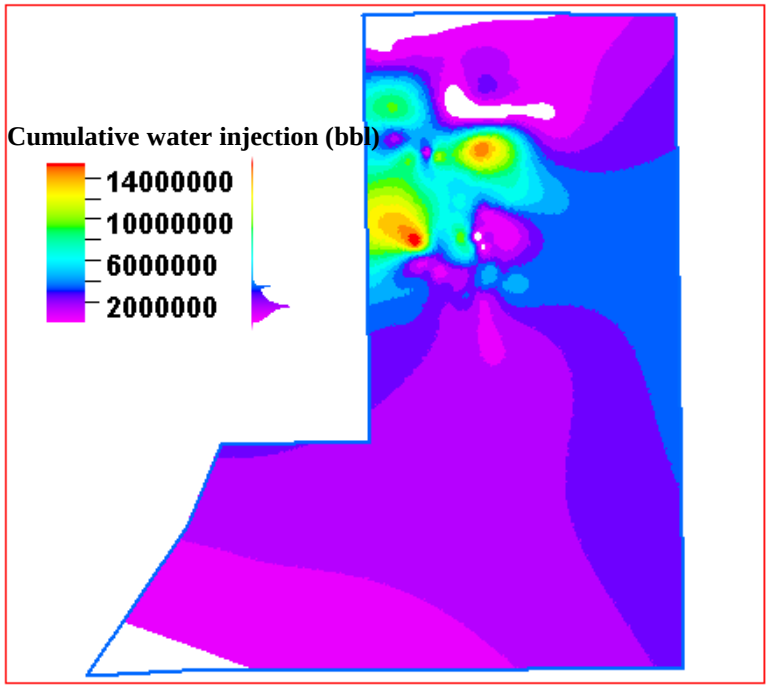
Injection and hydrocarbon production wells in Osage



Injection wells in Osage



Cumulative water injections for 63 disposal wells in Osage



Hydrocarbon production wells

Injection wells, Osage

Injection wells, NBU

Phase Two: Injection Volume from 582 wells collected, in process for Uploading into Petrel

CO_2 storage for AOI that meets the criteria

Three trapping mechanisms for this study:

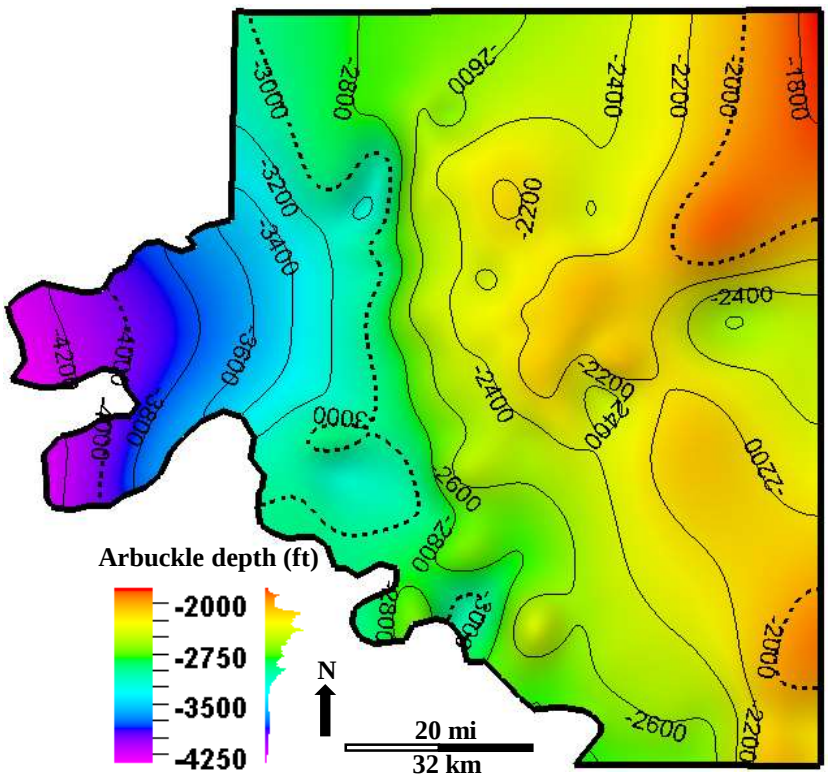
1- caprock above CO_2 Arbuckle group: Woodford Shale available

2- storage potential (porous and permeable) of Arbuckle rocks: vuggy porosities may contribute to the porosity and permeability.

3- supercritical **depth** of Arbuckle group: The depth of west side wells in Osage is >2500 ft.

A

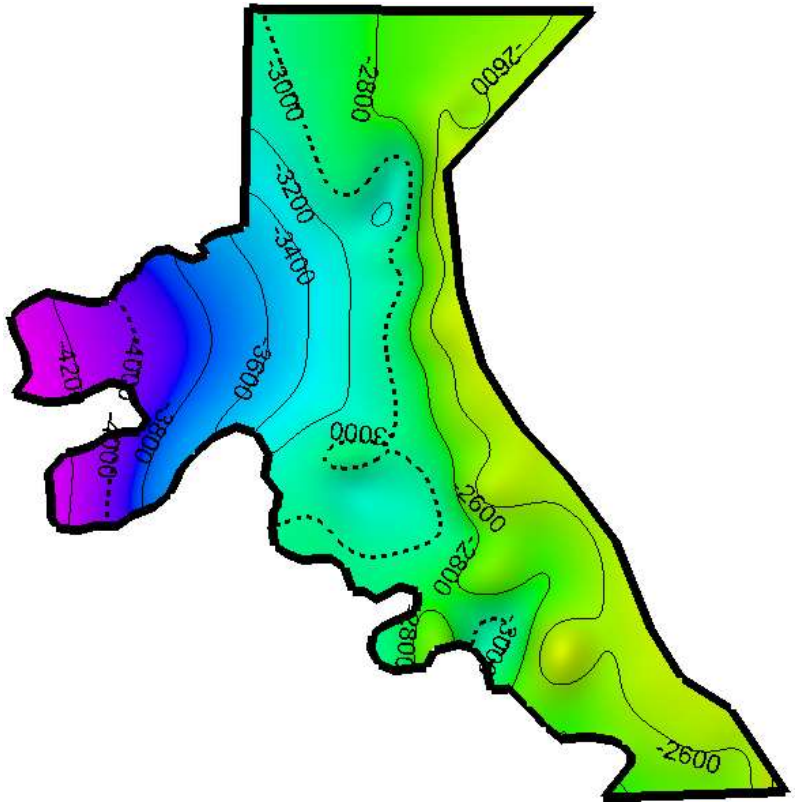
Site Screening



B

C

Site Selection



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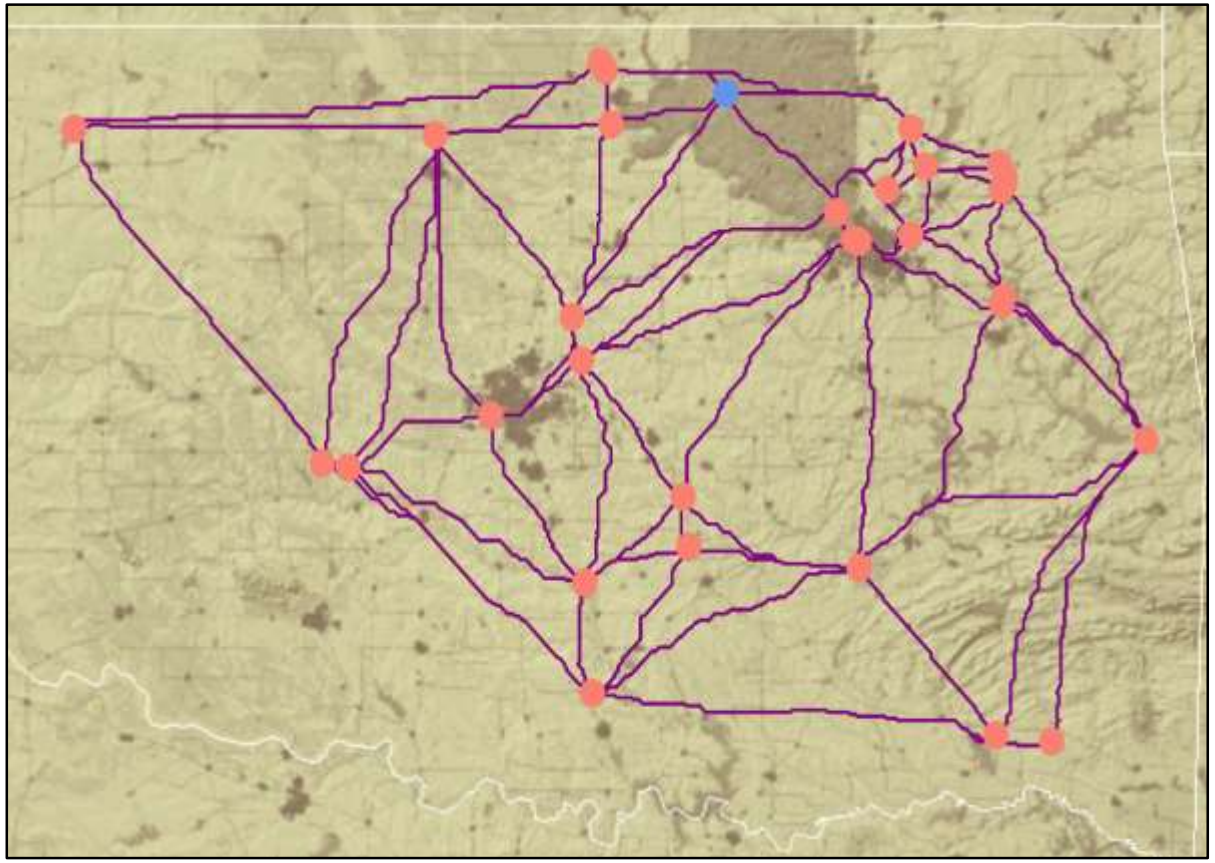
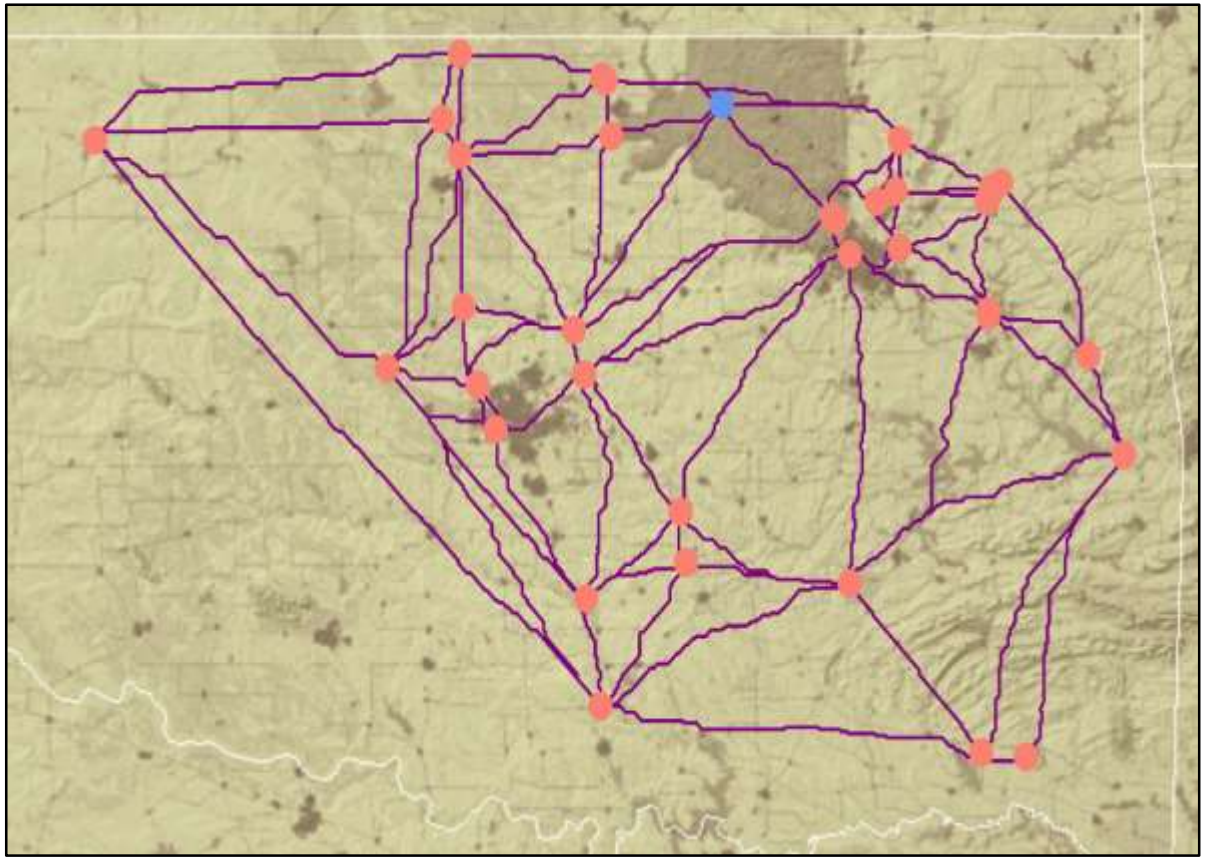
- Preliminary Results
  - Geological Characterization
    - Data collection
    - Building 3D geological model
  - CO_2 Transport-TEA

SIMCCS EXTERNAL SOURCES AND SINKS GEOLOCATION



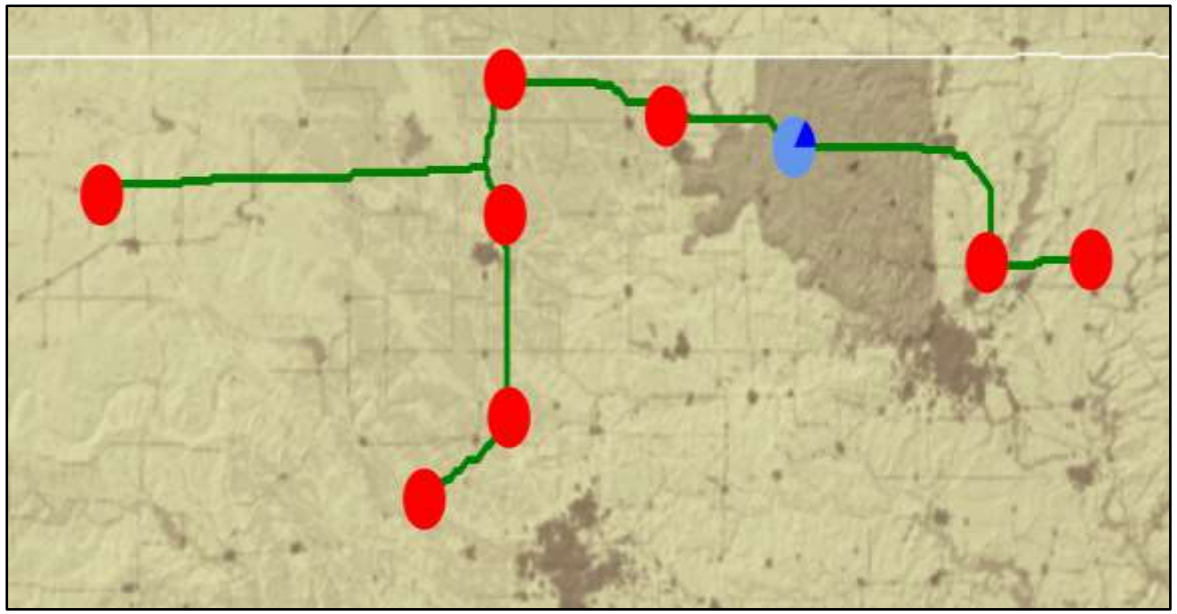
32 CO2 sources from Carbon Solutions LLC



36 CO2 sources from in-house evaluation

- **Osage county sink potential evaluated for the Arbuckle formation**
- **2 Cases for the CO2 sources are considered, one from the in-house evaluation, the other as published by Carbon Solutions LLC. Different capture costs also considered**
- **There are no existing class II wells in the Osage county, central geolocation from open source maps used**

SIMCCS PRICE MODE FOR IN-HOUSE SOURCES AND OSAGE ARBUCKLE SINK



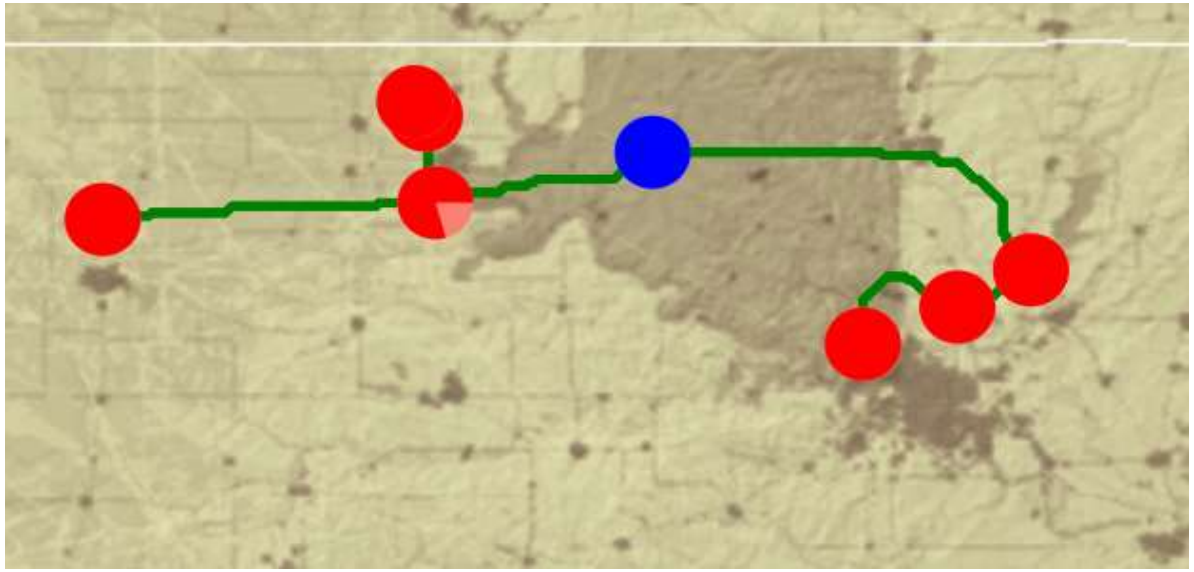
Summary

- **Price mode is run alone as we want to see the maximum we can store whilst making profit**
- **In this case the captured CO2 amount is 1.6MTCO2/yr. This annual injection is gotten from 8 sources and stored in the Arbuckle formation**
- **Project duration is 20 years indicating 32MtCO2 will be stored.**
- **For this to work, about 579km of pipeline is required, storage cost - $45/tCO2**
- **For this mode, there is net profit of ~$14.74/tCO2 sequestered**

Sources:	8	
Sinks:	1	
Annual CO2 Stored:	1.6	
Edges:	26	
Project Length:	20	
	Total Cost ($m/yr)	Unit Cost ($/tCO2)
Capture:	28.9	18.06
Transport:	19.52	12.2
Storage:	-72.0	-45.0
Total:	-23.58	-14.74

Source	Capture Amount (MTCO2/yr)	Capture Cost ($M/yr)
PRYOR CHEMICAL COMPANY	0.1	1.7
TERRA INTERNATIONAL (OKLAHOMA) INC	0.2	3.4
Cana Gas Plant	0.1	1.4
KOCH FERITLIZER ENID LLC ENID NITROGEN PLT	0.4	6.8
VERDIGRIS PLT	0.4	6.8
Chisholm Plant	0.1	1.4
CONTINENTAL CARBON Ponca City Plant	0.2	6
OHL NGLP Medford Plant	0.1	1.4

SIMCCS PRICE MODE FOR CARBON SOLUTION, LLC SOURCES AND OSAGE ARBUCKLE SINK



Summary

- Price mode is run alone as we want to see the maximum we can store whilst making profit
- In this case the captured CO2 amount is 9.63MTCO2/yr. This annual injection is gotten from 8 sources and stored in the Arbuckle formation
- Project duration is 20 years indicating 193MtCO2 will be stored.
- For this to work, about 320km of pipeline is required, storage cost - $45/tCO2
- For this mode, there is net profit of ~$5.44/tCO2 sequestered

Source	Capture Amount (MTCO2/yr)	Capture Cost ($M/yr)
VERDIGRIS PLT	2.1	75.6
Sooner	4.12589	167.098545
CONTINENTAL CARBON COMPANY	0.1	3.05
KOCH NITROGEN CO ENID NITROGEN PLT	1.7	61.2
HOLLY REFINING & MARKETING	0.3	10.5
Phillips 66 Ponca City Refinery	0.8	28
EAGLE MATERIALS, INC.	0.3	10.8
HOLLY REFINING & MARKETING	0.2	7

Sources:	8	
Sinks:	1	
Annual CO2 Stored:	9.63	
Edges:	15	
Project Length:	20	
	Total Cost ($m/yr)	Unit Cost ($/tCO2)
Capture:	363.25	37.74
Transport:	17.58	1.83
Storage:	-433.17	-45.0
Total:	-52.33	-5.44

Case	Total, MtCO2	# of Sources	Pipeline, Km	Total cost$/mT
Price-OK	1.6	8	579	-14.74
Price-CC	9.63	8	320	-5.44

1.6 MtCO2 is 16 times the minimum requirement to be qualified for current 45Q, tax credit

Ongoing work

- Dynamic simulation model is in progress with all injection wells into Arbuckle
- 3D seismic data acquisition is in progress to obtain from Osage Minerals Council to improve geological modeling for west part of Osage County
- A large campaign for collection of historic injection data for Arbuckle group in Osage Nation
- Core analysis to evaluate petrophysical& geotechnical properties
- Seismicity studies (SOSAT)
- Environmental and Social Justice studies

Thank you