PS Stratigraphy and Reservoir Characteristics of the Desmoinesian Granite Wash (Marmaton Group), Southern Anadarko Basin*

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Abstract

The Desmoinesian-age Granite Wash (Marmaton Group) within the southern Anadarko Basin was deposited as a series of alluvial fans, fan deltas, and deepwater deposits derived from the Amarillo-Wichita Uplift. Deposits include stacked conglomerates, tight-gas sandstones, and organic-rich shales that are stratigraphically complex with variable lithofacies and exhibit heterogeneous reservoir properties. The stratigraphic and reservoir characteristics of the Marmaton Group are investigated based on cores, well logs, and XRF measurements. The deposits contain interbedded sandstones and conglomerates of mixed lithology that commonly thin into shales basinward. Four regional flooding surfaces cap laterally extensive organic-rich shales have been identified based on well-log signatures and mapped across the study area to establish a stratigraphic framework. In the southern portion of the study area, the proximal deposits of the Marmaton Group exhibit frequent lithology and lithofacies changes. XRF analyses of cuttings and cored intervals shows how elemental concentrations vary stratigraphically with lithology. The flooding surfaces and other key surfaces that define the stratigraphic framework are used with calculated lithology and effective-porosity logs to construct 3-D reservoir models to evaluate stratigraphic and lithological controls on reservoir heterogeneity and to illustrate stratigraphic variability in static sandstone-body and reservoir connectivity of the Marmaton Group.

Stratigraphy and Reservoir Characteristics of the Desmoinesian Granite Wash (Marmaton Group), Southern Anadarko Basin

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Abstract

The Desmoinesian Granite Wash, specifically the Marmaton Group, is a hydrocarbon-bearing interval within the Anadarko Basin of Oklahoma and Texas that is composed of clastic and carbonate sediments derived primarily from the Amarillo-Wichita Uplift. The Marmaton Group, located in Beckham County, Oklahoma and Wheeler County, Texas, includes a series of vertically stacked conglomerates and tight-gas sandstones and shales that exhibit a complex stratigraphic architecture, highly variable lithologies, and correspondingly heterogeneous reservoir properties.

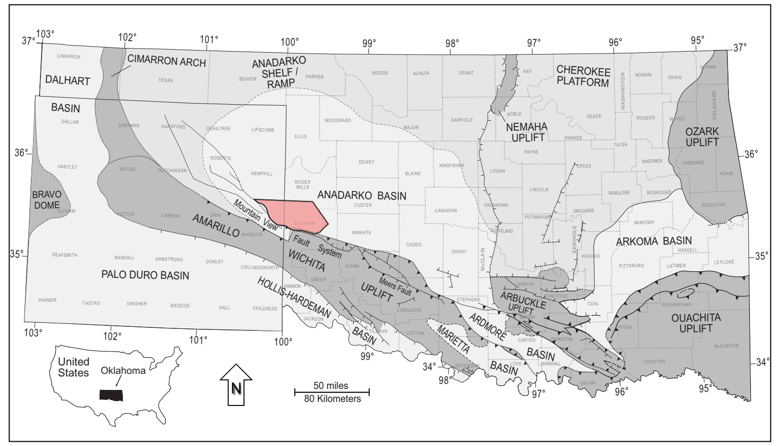
The stratigraphic and reservoir characteristics of the Marmaton Group, are established based on cores, x-ray fluorescence (XRF) measurements, and well-log signatures. The Marmaton Group in the southern Anadarko Basin contains interbedded arkosic sandstones and conglomerates that thin laterally into shales to the north (basinward). At least four regional, correlatable flooding surfaces (and associated organic-rich shales) subdivide the Marmaton Group and are thought to be self-sourcing in this liquids-rich interval. Porosity in this interval varies from 2-18% with low permeabilities on the order of 10 μD.

Proximal to the Amarillo-Wichita Uplift, the Marmaton Group is highly lithologically heterogeneous. XRF analyses of cored intervals show that elemental concentrations vary stratigraphically in conjunction with lithology. Characteristic well-log signatures correspond to different intervals and can be correlated laterally through the study area. Cluster analysis implemented on well-log data resulted in a 63% correlation to the Mayfield 1-34 core description but achieved low correlations for the Mayfield 1-2 (0%) and Sage 1-34H (53%). Well-log cutoffs performed on well-log data have a 74% correspondence rate to Mayfield 1-34 core description. Overall the well-log cutoff techniques provides an approximation of lithologies in non-cored: 62% sandstone, 23% conglomerate, and 15% shale. A compiled lithology model of the Marmaton Group displays spatial patterns by zone constrained to the vertical lithology proportion trend, vertical variograms, horizontal variograms, and lithology percentages. Using the lithological trends as an input, effective porosity and water saturation show that conglomerates on average have a higher effective porosity (by 1%) lower water saturation (by 1%) throughout the Marmaton Group.

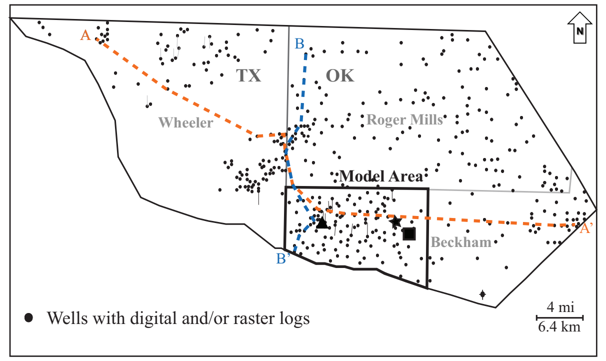
Research Objectives

This study characterizes the Marmaton group in the Desmoinesian Granite Wash as well as the reservoirs within the group. In order to properly assess the attributes within this interval, the following objectives are explored:
1) Determine the key lithologies, petrophysical properties, and unique well-log signatures or values associated with certain lithologies or petrophysical properties.
2) Define the structural and stratigraphic framework of the Marmaton Group throughout the region.
3) Map the spatial distribution of lithology, porosity, and water saturation.

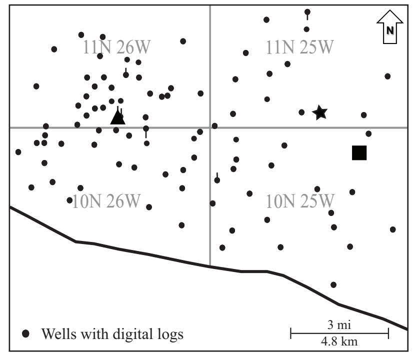
Study Area



Map of tectonic provinces for Oklahoma and Texas. The study area is shown in red (modified from Johnson and Luza, 2008; Northcutt and Campbell, 1995; Campbell, et al., 1988; Dutton, 1984; LoCricchio, 2012; McConnell, 1989).

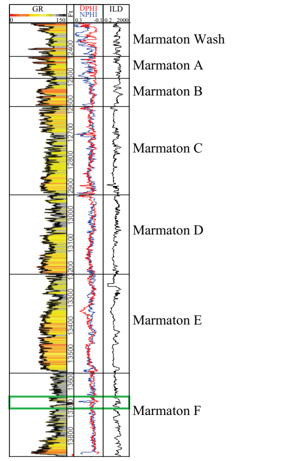


Regional extent map of this study. The area encompasses parts of Wheeler County, Texas, Roger Mills County, Oklahoma and Beckham County, Oklahoma. Within the defined limits there are: 430 wells in total, 353 wells with digital well-logs, 77 wells with raster well-logs, 19 horizontal wells, and 3 wells with cored intervals (star=Mayfield 1-34, triangle= Sage 1-34H, and square=Mayfield 1-2). Lines A-A' and B-B' are regional cross-sections that are examined later.



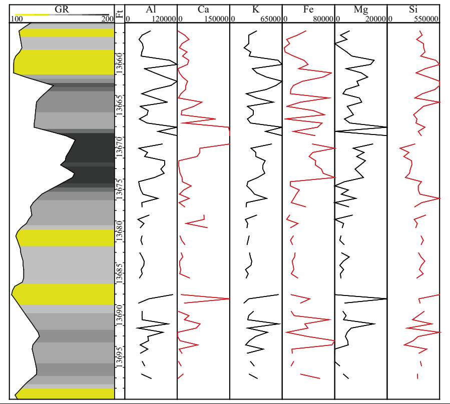
Zoomed in view of the model area situated in Beckham County. It lies in front of the Mountain View Fault system in the Mayfield West vicinity. There are 60 wells that have the following digital well-logs: gamma ray, deep resistivity, neutron porosity, and density porosity.

Type Log



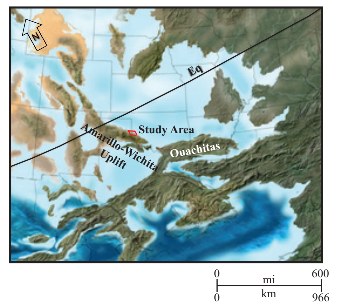
Type log from the Mayfield 1-34 (API 35009202830000) wire-line logs with formation tops (for location refer to Figure 2). The green box encapsulates the 40 ft (12.2 m) of core described and used in this study.

Chemostratigraphy

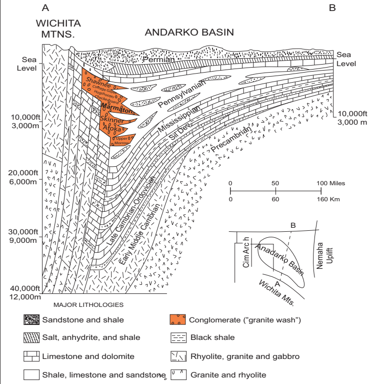


Concentrations of the six major light elements (Al, Ca, K, Fe, Mg, and Si), vary throughout the Mayfield 1-34 cored interval and through the different lithologies. The trends for Al and K mimic each other suggesting they are linked (perhaps by potassium feldspar concentrations). Low Si values coincide with the start of the shale lithology. Transitions between sandstone and conglomerate lithologies is often marked by a decrease followed by a sharp increase in light element concentration.

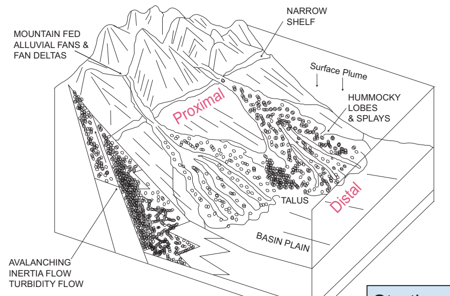
Geologic Setting



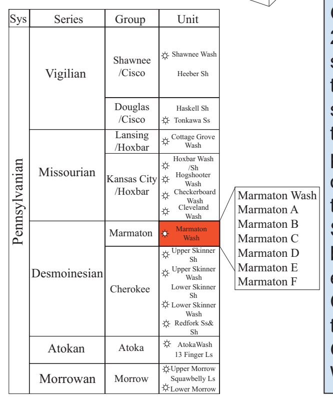
Middle Pennsylvanian (308 Ma) paleogeographic map (modified from Blakey, 2013). The Amarillo-Wichita uplift started prior in the Early Pennsylvanian and continues through to the end of the Pennsylvanian. Even though the mountain range is still undergoing positive uplift, there is still a stark contrast between the elevation between the mountains and Anadarko Basin. The study area is located just south of the Equator.



SE-NW structural cross section of the Anadarko Basin. Adjacent to the Amarillo-Wichita uplift is the deepest part of the basin, producing a significant asymmetry. Accommodation space juxtaposed to the uplift allowed for a large sediment accumulation (after Johnson, 1989; Dutton and Garnett, 19889; Pippin, 1970).

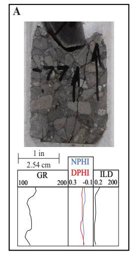


Cartoon for the environment of deposition. The mountains are analogous to the Amarillo-Wichita uplift. Coarse proximal deposits belong to alluvial fan and fan delta systems. Distal submarine fan lobes contain finer grains. This study focuses on proximal deposits that span grain sizes of cobbles to mud (modified from Reading and Richards, 1994).

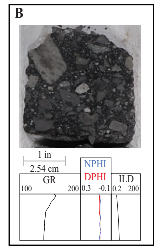


Stratigraphic column for the Oklahoma Granite Wash (modified from Mitchell, 2011). The Marmaton zones are based on shale breaks and regional flooding surfaces throughout the study area. The Desmoinesian Granite Wash has different nomenclature in different states and petroleum companies. In order to draw comparisons to other literature, the following is a guide for the nomenclature adopted in this study. Seven intervals of the Marmaton Group has been divided into (Wash, A-F) and their equivalents are as follows: Marmaton B = Carr, Marmaton C = Caldwell/Britt, Marmaton D = Granite Wash A, Marmaton E = Granite Wash B, and Marmaton F = Granite Wash C.

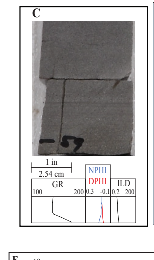
Core Description



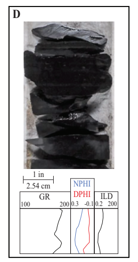
A) Typical closed-framework conglomerate found throughout the core and has large variation of grain size. Low GR and ILD. DPHI is consistently higher in value than NPHI.



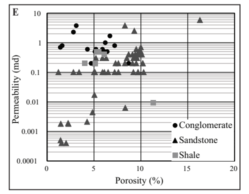
B) The dark grey, matrix-supported conglomerate, has higher GR, ILD compared to the closed-framework conglomerate. The NPHI values cross-over with the DPHI values frequently. In well-log curves, this open framework conglomerate appears to be closer to a sandstone signature.



C) Massive medium grained sandstone with fine, dark grey layers of silt throughout.

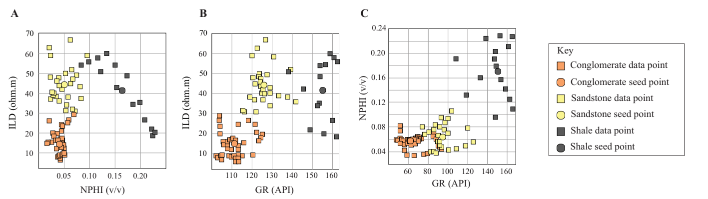


D) Black shale break in the cored interval that has a very high GR signature and NPHI values greater than DPHI values. Core photographs courtesy of OPIC.



E) Porosity-permeability cross plot for the Mayfield 1-2, Mayfield 1-34, and Sage 1-34H wells. Conglomerate has a cluster of data points with porosity between 4 and 8% with permeabilities of 0.2-4 md. Most sandstone data points lie between 5 and 10% porosity with greatly varying permeability (between $3x10^{-4}$ and 8 md). Shale, as expected have low, porosities (4-6%) and permeabilities (0.2-0.4 md).

Lithology Estimation



Cross plots of A: NPHI vs. ILD, B: GR vs. ILD, and C: GR vs. NPHI. Using the 40 ft (12.2 m) of core from the Mayfield 1-34 well, k-mean algorithm cluster analysis was performed to establish electrofacies. Three logs were used: GR, ILD, and NPHI. The data points have been classified into three clusters: conglomerate, sandstone, and shale. Overall, the three cross-plots show tighter cluster groupings for conglomerate and sandstone compared to the spread out data distribution for shale.

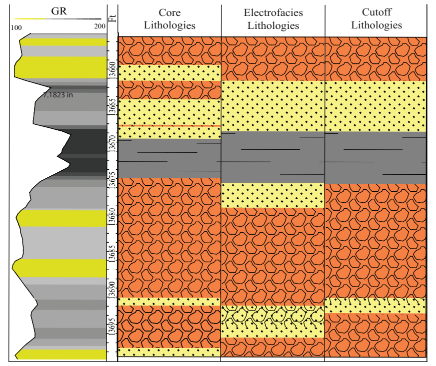
Cluster	# Data Points	NPHI (V/V)		GR (API)		ILD (ohm.m)	
		Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.
Conglomerate	41	0.0552	0.01	111.7	6.128	14.619	1.161
Sandstone	28	0.06325	0.01978	126.06	6.135	44.003	9.432
Shale	14	0.17007	0.04548	154.67	6.852	41.318	15.13

Distribution of data points for the k-means cluster analysis.

Zone	Shale	Sandstone	Conglomerate
Wash	GR ≥ 105	RHOB > 2.52	RHOB ≤ 2.52
A	GR ≥ 105	RHOB > 2.57	RHOB ≤ 2.57
B	GR ≥ 105	RHOB > 2.55	RHOB ≤ 2.55
C	GR ≥ 110	RHOB > 2.52	RHOB ≤ 2.52
D	GR ≥ 120	RHOB > 2.52	RHOB ≤ 2.52
E	GR ≥ 125	RHOB > 2.52	RHOB ≤ 2.52
F	GR ≥ 135	RHOB > 2.56	RHOB ≤ 2.56

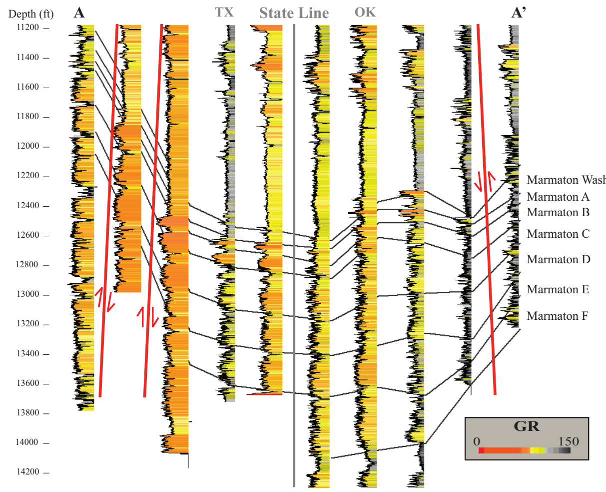
Wire-line values used to define various lithologies.

Lithology Estimation

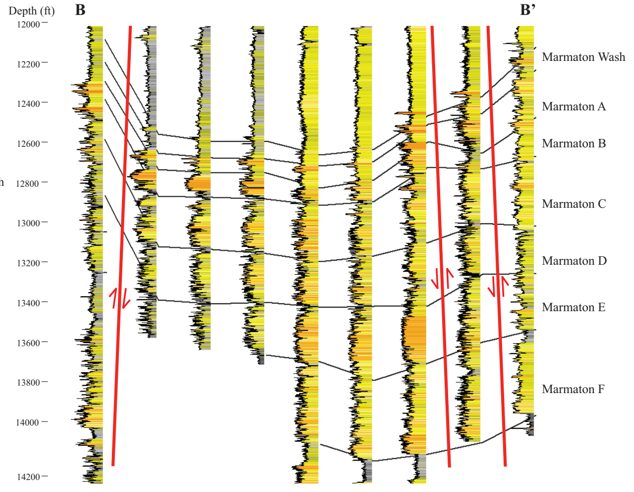


GR, core lithologies, electrofacies lithologies, and cutoff lithologies for the Mayfield 1-34 well. The electrofacies do not capture thin beds. There is also a predicted sandstone package immediately following the shale lithology in the electrofacies that is not seen in core. It is described as a conglomerate containing mostly pebble sized clasts, which the algorithm classified as a very coarse sandstone. That mismatch of predicted electrofacies lithologies and actual lithologies is seen to the bottom in the cored interval. The cutoff lithologies do not show the thin conglomerate around 3,667 ft [4,166 m] as well. It does decipher between the conglomerate and sandstones lithologies similarly to the physical description of the core. Overall, the cutoff predicted lithologies match the core lithologies better than the electrofacies predicted lithologies (74% and 63% respectively).

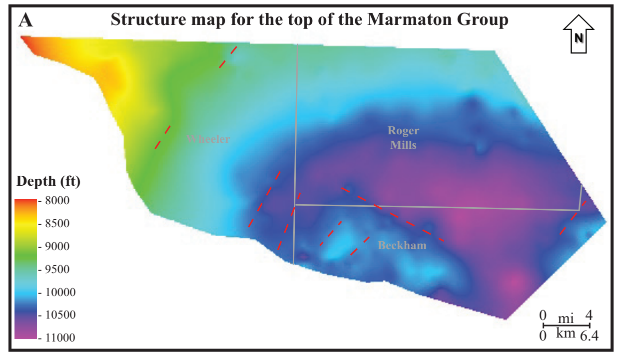
Structural and Stratigraphic Framework



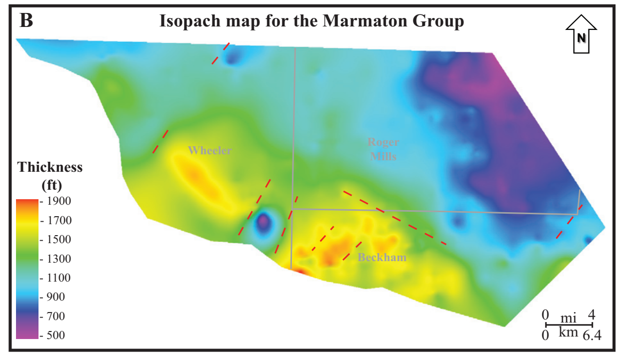
This structural cross section (refer to regional map for location) has equally spaced wells that are not to scale. Structure elevation decreases to the southeast and zones have much higher GR readings. The red lines denote possible regional reverse faults with displacements of 600 ft (183 m).



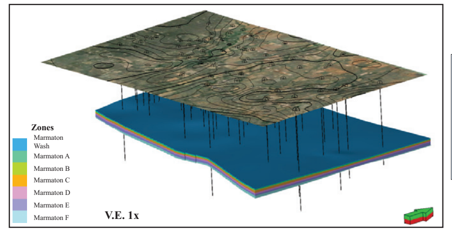
This structural cross section of the Marmaton Group (refer to regional map for location) has equally spaced wells that are not to scale. Generally, the structural elevation of the formation tops increase going south and zones Wash-F increase in thickness. The red lines denote possible reverse faults showing possible reverse faulting as well, with displacements of 50-400 ft (15-122 m).



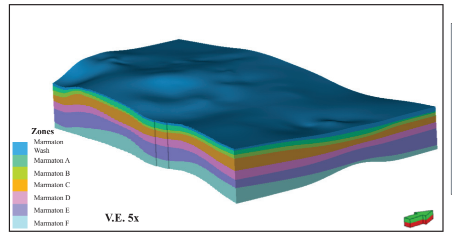
Structure map for the top of the Marmaton Group shows a trend of increasing structural elevation to the northwest. The deepest elevations occur on the county border between Beckham and Roger Mills counties which coincides with the axis of the basin. The red dashed lines are possible faults within the study area.



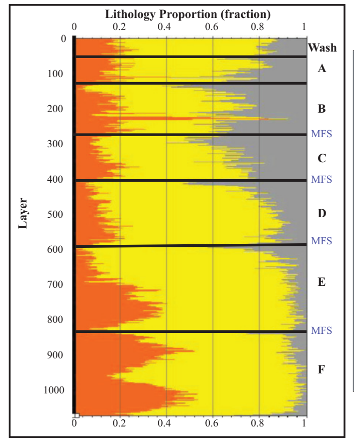
The isopach map for the Marmaton Group shows patterns of thick and thin deposits that line up with the interpreted faults. The thin syndepositional deposits correspond to the up-thrown side of the reverse faults, while thick syndepositional deposits correspond to the down-thrown side. Thicker sediment accumulations occur along the southern boundary of the study area, which coincides with the Amarillo-Wichita uplift.



Wells used for modeling with the KB service and unexaggerated model. 56 vertical and 4 horizontal wells were used as guides for the modeling.



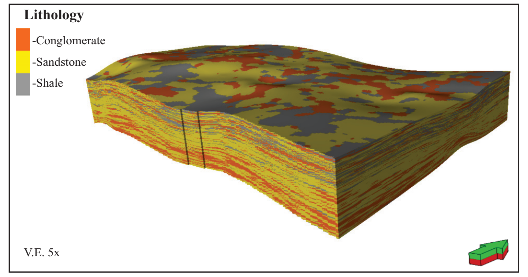
The exaggerated model grid shows in greater detail changes in zone thicknesses. The model grid dimensions are approximately 11.9 mi x 8.33 mi x 0.49 mi (19.2 km x 13.4 km x 0.79 km) for a total of 47.2x10⁶ cells.



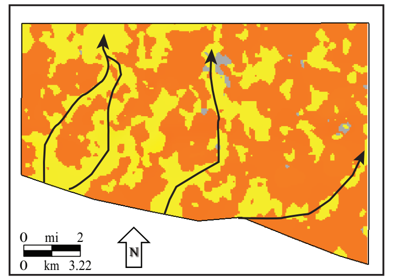
Vertical proportion curve of the three different upscaled modeled lithologies by layer and zone. Orange is conglomerate, yellow is sandstone, and grey is shale. MFS stands for marine flooding surface which show up as high GR, high NPHI, and low DPHI readings on wire-line logs. There are pulses of conglomerate followed by shale caps, indicating a cyclic deposition controlled by relative rise and fall of sea level.

Spatial Distribution of Lithology and Petrophysical Properties

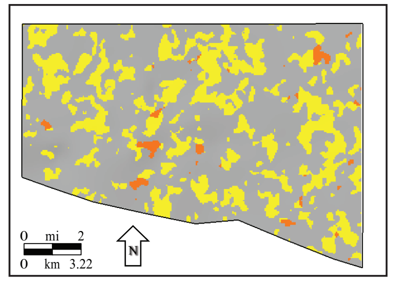
The following SIS lithology model was constructed using the following parameters:
1) Upscaled well logs
2) Histogram of lithology percentages
3) Vertical and horizontal variograms (by zone and lithology). Due to the different type of deposition for each rock type the following assumptions were made:
- Conglomerate and sandstone have relatively longer vertical ranges to shale
- Shale has relatively longer horizontal ranges compared to conglomerate and sandstone
4) Vertical lithology proportion curve



Lithology distribution throughout the whole model is as follows: 59% sandstone, 23% conglomerate, and 18% shale. Shale deposits appear as more laterally continuous deposits throughout the layers, while the sandstone is more channelized as expected with the associated fan delta deposits. Conglomerate deposit patterns depend on where in the cycle the system is. During high conglomerate deposition, it blankets the layers, where as in periods of decreased sediment input, channelized flows can be seen.

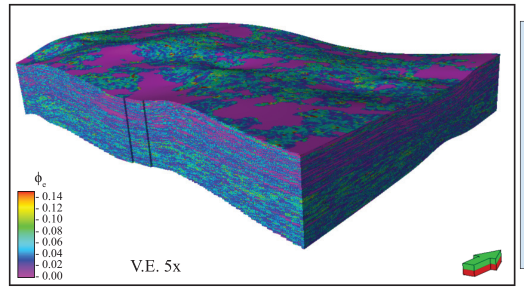


A layer from the Marmaton F zone where conglomerate and sandstone deposits are dominant (k slice 880). The sandstone deposits are interpreted to form channels in the north by northeast direction (arrows) while the conglomerate deposits are more laterally connected trending in the northeast direction.

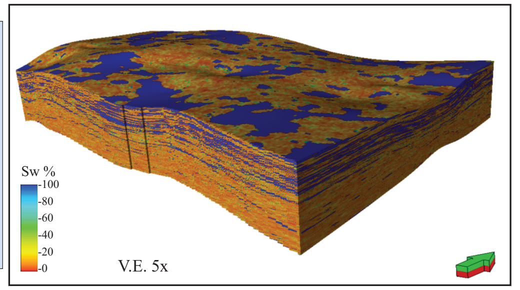


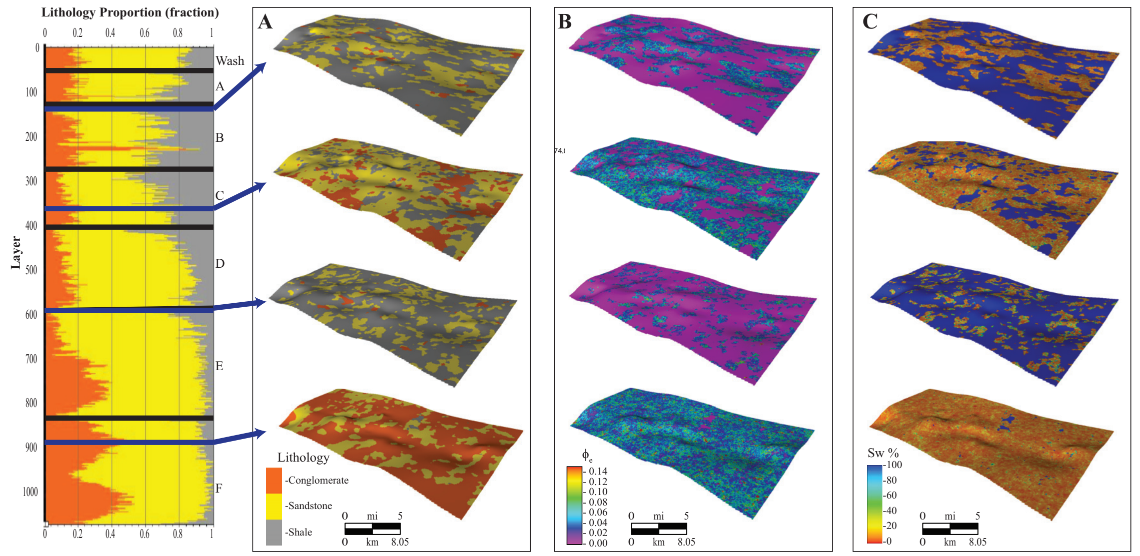
Shale is the dominate lithology in this layer (k slice 587) and appears very continuous with no apparent depositional trend azimuth. The sandstone bodies are too disconnected to decipher an azimuth.

The next phase of the research was to model petrophysical properties (SGS). Four sets of equations used to figure out the important petrophysical properties of effective porosity and water saturation:
1) Φtotal = √ (NPHI^2 + DPHI^2) **except for shale lithologies in which case Φtotal = DPHI**
2) Vshale = (GRlog - GRsand) / (GRshale - GRsand) **GRshale and GRsand were picked from the highest and lowest values of GR per zone (respectively.**
3) Φeffective = Φtotal - (Vshale * average shale Φ) ** average shale porosity was picked per zone**
4) Sw = ((a*Rw) / (Φ^m * Rt))^(1/n) **assuming ideal Archie equation and m and Rw picked from Pickett plot**



Left: The entire effective porosity model. Shale lithologies were given a value of zero, thus the effective porosities for conglomerates and sandstones are highlighted throughout. **Right**: The water saturation model also assigned a universal value to shales: 100%. Again, this allows for the focus of analyses to be on the conglomerates and sandstones.





Comparisons between A) lithology, B) effective porosity, and C) water saturation models. Layers 880 and 379 show times of maximum regression, thus high percentages of sandstone and conglomerate. In these slices there are higher effective porosities and lower water saturations. Layers 587 and 147 show points of maximum transgression, thus shales dominate. This drives down the average effective porosity closer to 0 and water saturation up to 100%. Overall, conglomerate has a higher effective porosity and lower water saturation than sandstone on average (5.7% vs. 4.5% and 11.7% vs. 13.5%, respectively. The highest effective porosities for conglomerate and sandstone were 6.7% and 5.1%, respectively and the lowest water saturations for conglomerate and sandstone were 9.47% and 9.93%, respectively.

Conclusions

The Desmoinesian Granite Wash, specifically the Marmaton Group, is a hydrocarbon-bearing interval within the Anadarko Basin of Oklahoma and Texas that is composed of clastic and carbonate sediments derived primarily from the Amarillo-Wichita Uplift. The Marmaton Group, located in Beckham County, Oklahoma and Wheeler County, Texas, includes a series of vertically stacked conglomerates and tight-gas sandstones and shales that exhibit a complex stratigraphic architecture, highly variable lithologies, and correspondingly heterogeneous reservoir properties.

The stratigraphic and reservoir characteristics of the Marmaton Group, are established based on cores, x-ray fluorescence (XRF) measurements, and well-log signatures. The Marmaton Group in the southern Anadarko Basin contains interbedded arkosic sandstones and conglomerates that thin laterally into shales to the north (basinward). At least four regional, correlatable flooding surfaces (and associated organic-rich shales) subdivide the Marmaton Group and are thought to be self-sourcing in this liquids-rich interval.

Proximal to the Amarillo-Wichita uplift, the Marmaton Group is highly lithologically heterogeneous. XRF analyses of cored intervals show that elemental concentrations vary stratigraphically in conjunction with lithology. XRF measurements show that concentrations of potassium and aluminum have the same increasing and decreasing trends suggesting that they may be associated (in minerals such as potassium feldspar). Characteristic well-log signatures correspond to different intervals and can be correlated laterally through the study area. Cluster analysis implemented on well-log data resulted in a 63% correlation to the Mayfield 1-34 core description but achieved low correlations for the Mayfield 1-2 (0%) and Sage 1-34H (53%). Well-log cutoffs performed on well-log data have a 74% correspondence rate to Mayfield 1-34 core description. Overall the well-log cutoff lithologies provides an approximation of lithologies in non-cored: 62% sandstone, 23% conglomerate, and 15% shale.

A compiled lithology model of the Marmaton Group displays spatial patterns by zone constrained to the vertical lithology proportion trend, vertical variograms, horizontal variograms, and lithology percentages. Sandstone and conglomerate deposits appear to have a dendritic channel trend perpendicular/sub-perpendicular to the Amarillo-Wichita uplift. Shale deposits display a more laterally continuous, vertically discontinuous trend with no discernable depositional azimuth trend. Using the lithological trends as an input, effective porosity and water saturation show that conglomerates on average have a higher effective porosity (by 1%) lower water saturation (by 1%) throughout the Marmaton Group.

Acknowledgements

I would like to thank the sponsors for the Granite Wash Consortium and the Reservoir Characterization and Modeling Laboratory. I also want to acknowledge the help and guidance from Deepak Devegowda, Doug Elmore, Mark Sitton, Phil Byrd, Amy Close, Suriamin, and John Mitchell.