[PS]Stratigraphy, Seismic Characteristics, and Reservoir Properties of the Desmoinesian Granite Wash, Buffalo Wallow Field Area, Anadarko Basin, Texas*

Doga E. Senoglu[1], Matthew J. Pranter[1], and Kurt J. Marfurt[1]

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[1]ConocoPhillips School of Geology and Geophysics, University of Oklahoma, Norman, Oklahoma (dogaecem@ou.edu)

Abstract

The Desmoinesian Granite Wash is a productive oil and gas play of the southern Anadarko Basin. It includes a series of alluvial fans, fan-deltas, proximal turbidites, and debris flows deposited in association with the Amarillo-Wichita Uplift. The deposits occur as several thousand feet of conglomerates, sandstones, carbonates, and shales that form complex low-permeability and generally low-porosity reservoirs. The stratigraphic and structural framework and reservoir characteristics of the Desmoinesian Granite Wash are established using a 28 mi^2 (72 km^2) 3-D seismic survey, logs from 450 wells, and petrophysical data derived from published cores. The lithologies and well-log signatures of the different reservoirs are highly variable. The dominant lithofacies include cross-bedded sandstone, parallel-stratified sandstone, planar-laminated sandstone, structureless sandstone, bioturbated sandstone, and silt-rich mudstone.

Artificial-neural-network (ANN) techniques are used to estimate lithology logs in non-cored wells by utilizing core and well logs. Key stratigraphic surfaces are commonly related to laterally extensive shales. The Desmoinesian Granite Wash is subdivided into 10 intervals based on net-to-gross ratio, regional trends in well-log signatures, and seismic reflection character. Detailed interpretation of 3-D seismic data also illustrates that the Granite Wash interval exhibits several high-angle reverse faults with significant offset. Results from P-impedance inversion are used with the estimated lithology logs, and the established stratigraphic and structural framework to constrain the spatial distribution of lithology and petrophysical properties in 3-D reservoir models. The models illustrate the stratigraphic architecture, main structural elements, and their relationship to Granite Wash reservoir quality distribution for the study area.

Stratigraphy, Seismic Characteristics, and 3-D Reservoir Modeling of the Granite Wash, Buffalo Wallow Field Area, Anadarko Basin, Texas

The UNIVERSITY of OKLAHOMA
Mewbourne College of Earth and Energy
ConocoPhillips School of Geology and Geophysics
ConocoPhillips

Doga E. Senoglu, Matthew J. Pranter

ConocoPhillips School of Geology and Geophysics, University of Oklahoma, Norman, Oklahoma

RCML
Reservoir Characterization and Modeling Laboratory
The University of Oklahoma

Abstract

Granite wash is a both oil and gas productive play of Soutern Anadarko Basin, which extends over 130 miles across 7 counties. It is Pennsylvanian in age and mainly formed by alluvial fans, fan-deltas and proximal turbidites and debris flows during Amarillo-Wichita Uplift which also caused the region to be complex because of deformational features like faults and folds. These deposits, which are immediately adjacent to the uplift, occurred as several thousand feet of conglomerate, sandstone, carbonate wash and shale have formed a complex of low-permeability and generally low-porosity reservoirs.

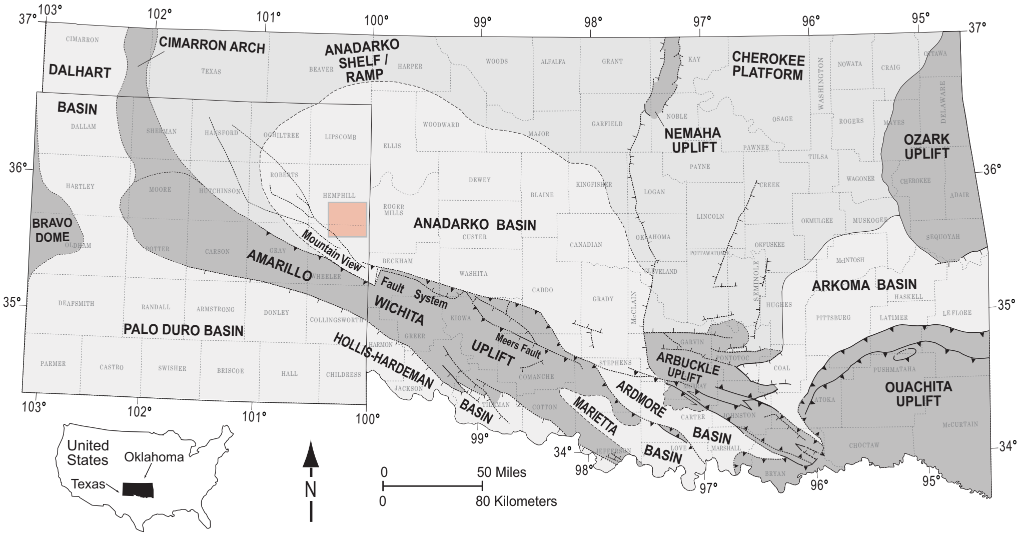
The Desmoinesian Series of Granite Wash in the Buffalo Wallow at Wheeler and Hemphill counties, Texas, also exhibits a fan-delta system, it is formed by terriginous clastics of the fan delta and turbidite lobes and these are interbedded with limestones. These reservoirs are highly variant in mineralogy, grain size, sorting and lithofacies. Lithofacies of the interest area are defined through a core and calibration of that core to the matching well logs. Furthermore detailed 3-D lithological model that are constrained to cores, seismic and logs from a 69 wells, and 3-D seismic data illustrate the reservoir characteristics and main structural elements like major faults of the Desmoinesian Series of Granite Wash, Buffalo Wallow. Also calculated lithology logs and seismic-inversion-derived P-Impedance data are used as constraints in these 3-D reservoir model for better illustration of the stratigraphic architecture and petrophysical properties.

Research Objectives

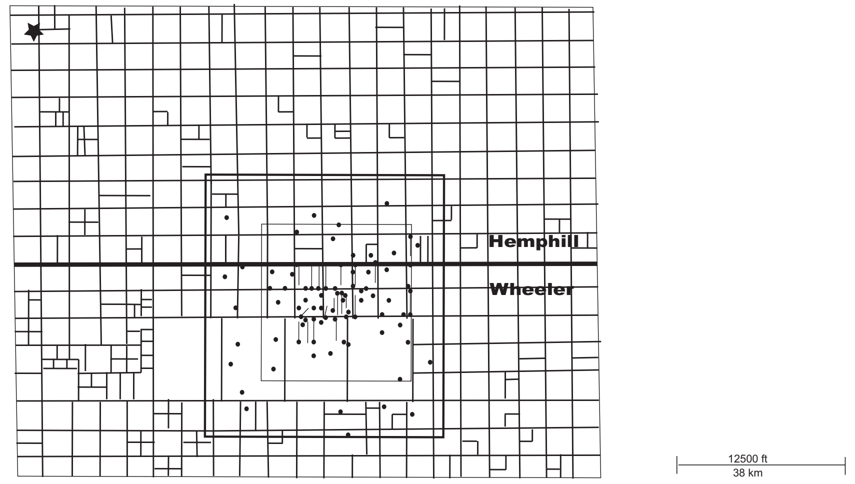
This study addresses the following questions for the Desmoinesian Granite Wash:

-What are the dominant lithologies and lithofacies?
-What are the ranges of petrophysical properties associated with each lithology?
-What are the well-log signature of the key lithologies and petrophysical properties?
-What is the stratigraphic and structural framework - can distinct shales be used to correlate to establish a sequence-stratigraphic framework as in other areas of the Granite Wash?
-Within the stratigraphic and structural framework, what is the spatial distribution of lithology and petrophysical properties?
-Does the spatial distribution of lithology and petrophysical properties relate to the 3-D seismic response?

Study Area



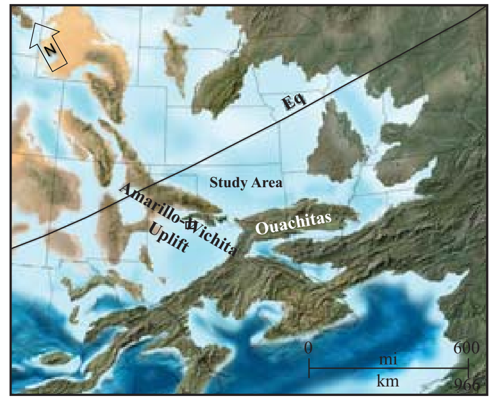
Map of tectonic provinces for Oklahoma and Texas Panhandle. The study area is shown in red. (modified from Johnson and Luza, 2008; Northcutt and Campbell, 1995; Campbell, et al., 1988; Dutton, 1984; LoCriccho, 2012, McConnell, 1989).



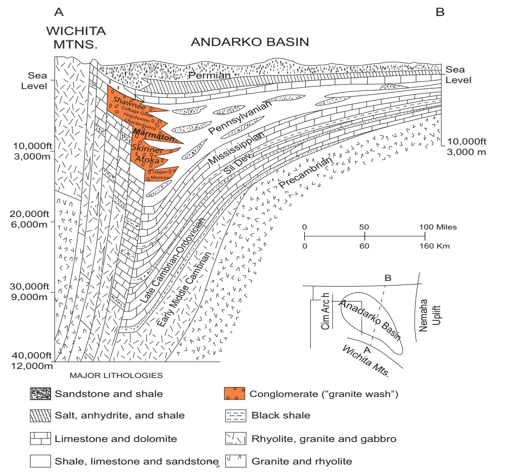
Detailed map of the study area. The area encompasses parts of Wheeler and Hemphill counties, Texas. Within the defined limits there are: indicating the locations of 69 wells with logs, 31 horizontal wells and a cored well (star). All of the 69 vertical wells have the combinations of the following logs: gamma-ray, resistivity, density porosity, neutron porosity, sonic, spontaneous potential while most of the horizontal wells have only gamma ray logs.

The seismic survey is composed of two 3D stacked volumes (prestack migrated and postack migrated) and is located in Wheeler and Hemphill counties, Texas. The survey was acquired and processed by a third party in 2011. The survey area is 28 square miles and roughly square in shape.

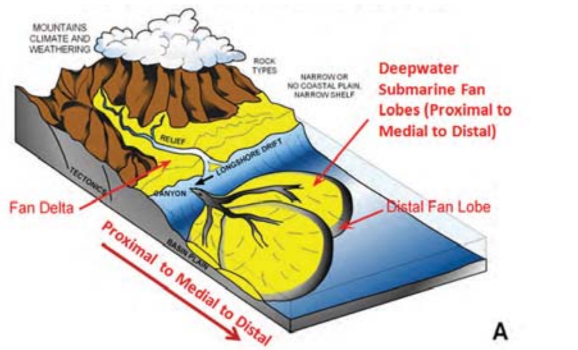
Geologic Setting



Middle Pennsylvanian (308 Ma) paleogeographic map (modified from Blakey, 2013). The building of 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).

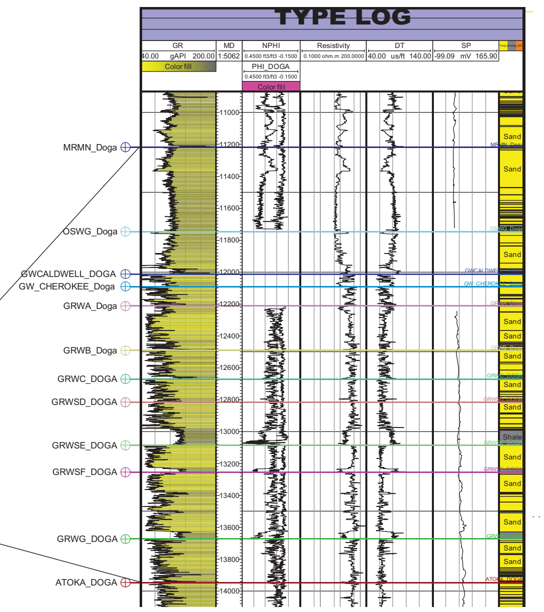


Cartoon for the environment of deposition. The mountains are analogous to the Amarillo-Wichita uplift. Coarse proximal deposits belong to alluvial fan and fan delta systems. Distal submarine fan lobes contain finer grains. This study focuses on proximal to distal deposits that span grain sizes of cobbles to mud (Bouma and Stone, 2010).

Lithology Descriptions and Petrophysical Properties

STRATIGRAPHIC CHART

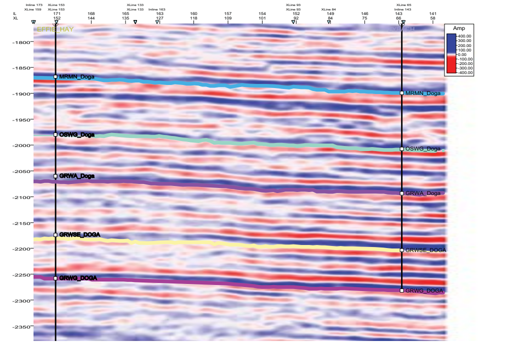
SYS.	SERIES	GROUP	UNIT
PENNSYLVANIAN	VIRGILIAN	Shawnee/Cisco	Shawnee Wash Heebner Sh
		Douglas/Cisco	Haskell Sh Tonkawa Ss
	MISSOURIAN	Lansing/Hoxbar	Cottage Grove Wash
		Kansas City/Hoxbar	Hoxbar Wash/Shale Hogshooter Wash Checkerboard Wash Cleveland Wash
	DESMOINESIAN	Marmaton	Marmaton Wash
		Cherokee	Caldwell Cherokee GWA GWB GWC GWD GWE GWF GWG
	ATOKAN	Atoka	Atoka Wash 13 Finger Ls
	MORROWAN	Morrow	Upper Morrow Lower Morrow



Stratigraphic column for the Texas Panhandle Granite Wash. The Desmoinesian zones are based on shale breaks and regional flooding surfaces throughout the study area. As Desmoinesian Granite Wash has different nomenclature in different states and petroleum companies, the following guide can be used to correlate between Texas and Oklahoma Granite Wash intervals:

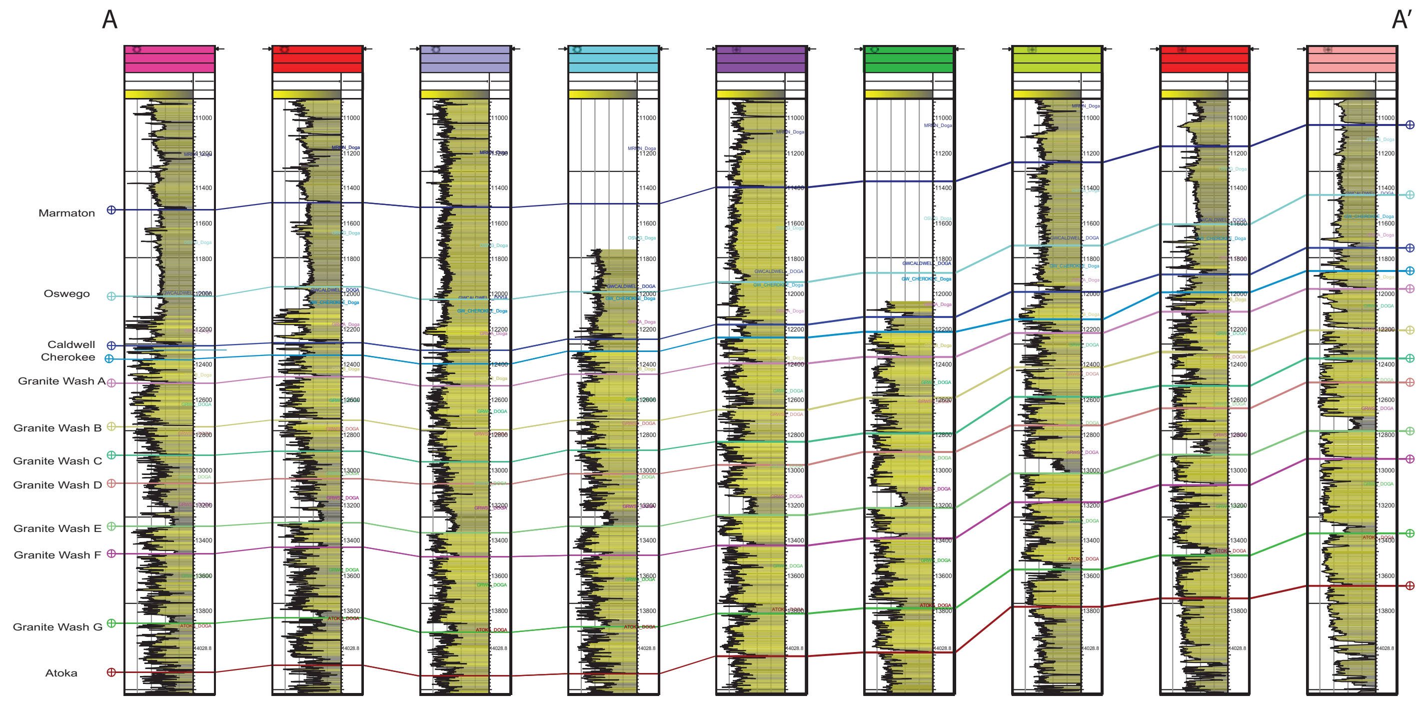
Marmaton = Marmaton A
Caldwell = Marmaton B
Cherokee = Marmaton C
GWA through GWG= Marmaton D through F

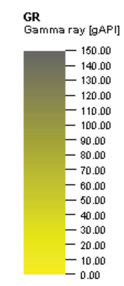
Type log with wireline logs majorly used for the well top correlation throughout the study area and all 11 formation tops. To the right, lithology log, created with Artificial Neural Network, is also shown.

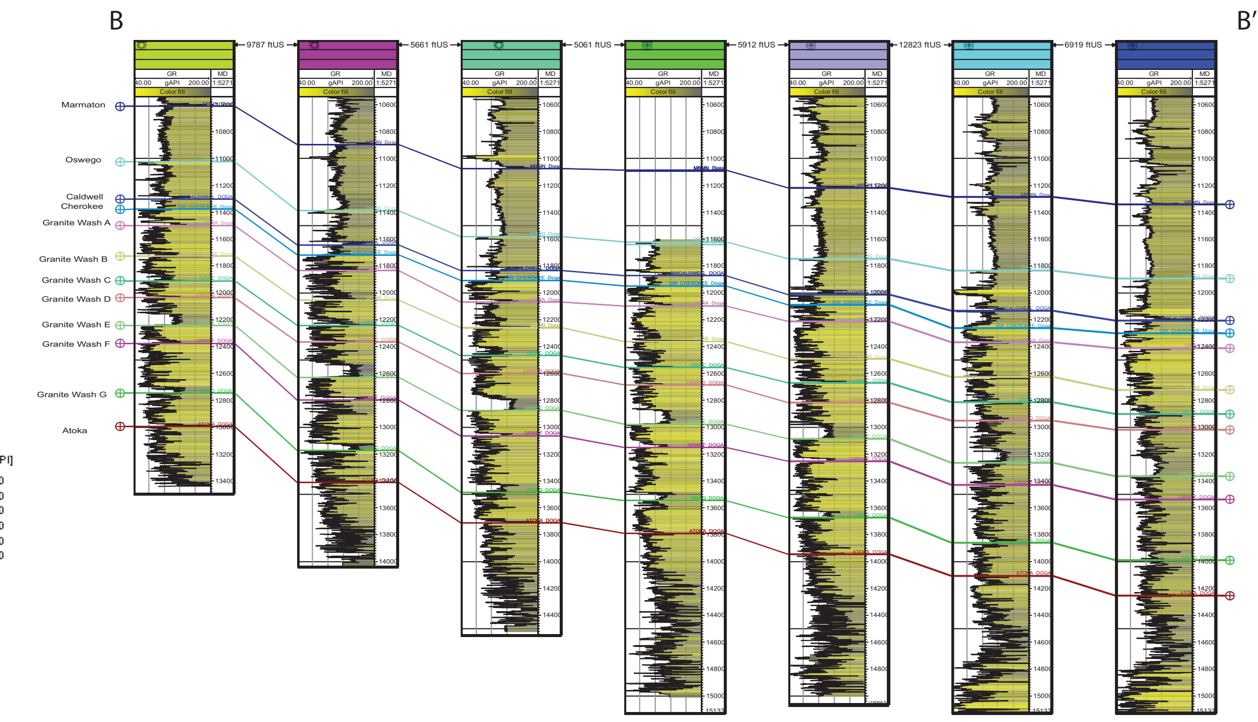


A composite section through seismic volume from Northeast to Southwest, between two wells that are used for well-to-seismic tie. Quality of the raw data was not very good at the first sight and there were lots of footprints and noise that prevent clear interpretation of structural and stratigraphical features. Thus, footprint suppression is done and then the data is subjected to structure-oriented filtering with the help of AASPI. Well-to-seismic tie application was done with the Hampson and Russell software, after tying, 5 horizons that match well tops, were picked. These 5 seismic horizons for Marmaton, Oswego, GWA, GWE and GWG intervals are also shown.

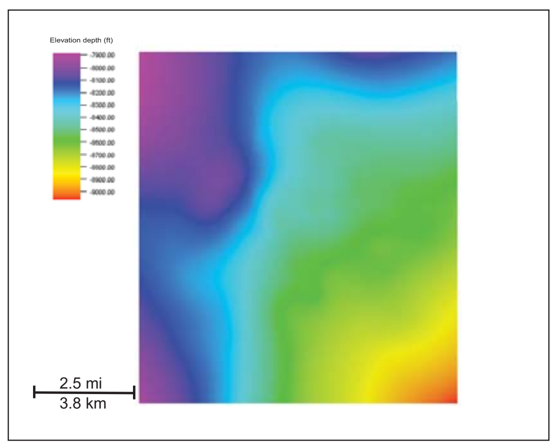
Stratigraphic and Structural Framework



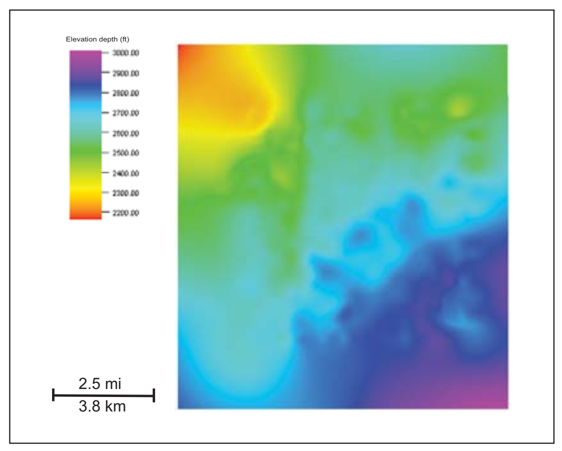




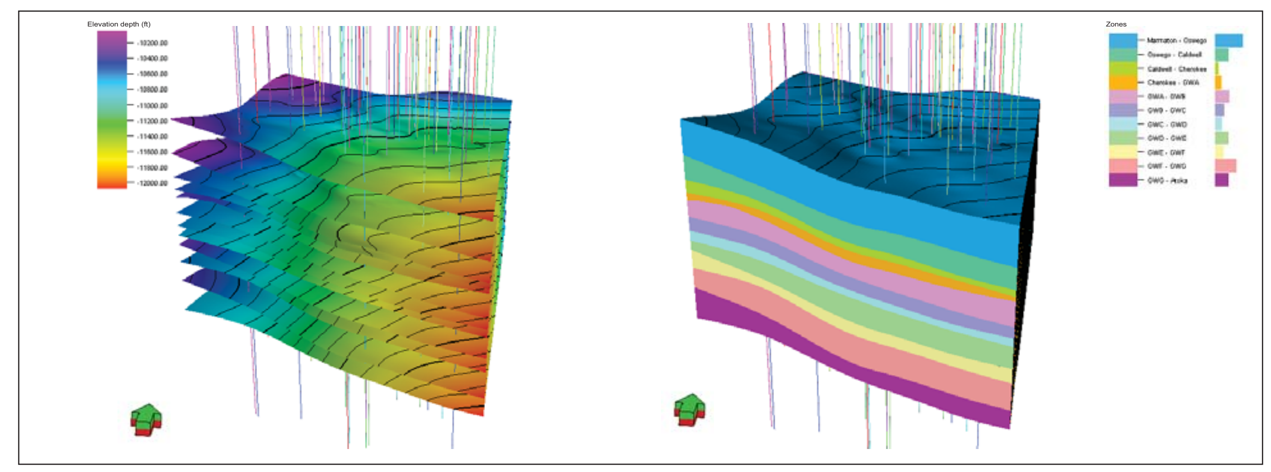
These representative structural cross sections show the ten Desmoinesian-age Granite Wash zone. Continuous shale intervals, that have been used to define the zones in this study, are traceable throughout the cross-sections. There is a trend of increasing net-to-gross with depth, and towards south.



Structure map for the top of the Desmoinesian-age Granite Wash shows a trend of increasing structural elevation to the northwest.



The isopach map for the Desmoinesian-age Granite Wash shows patterns of thick and thin deposits. Thicker sediment accumulations occur towards the southern boundary of the study area.



3-D view of the wells, 11 surfaces of Desmoinesian-age Granite Wash and the resultant 3-D grid for all 10 zones (15x exaggerated view). Sixty-nine wells and a 28 mi^2 (72 km^2) seismic data is used as guides for modeling. The 3-D grid has dimensions of 89 x 98 x 1525 (i x j x k) and 13301050 cells in total, and each cell is 500x500 ft (150m), and layer is 4 ft (1.2 m) thick.

Core Description

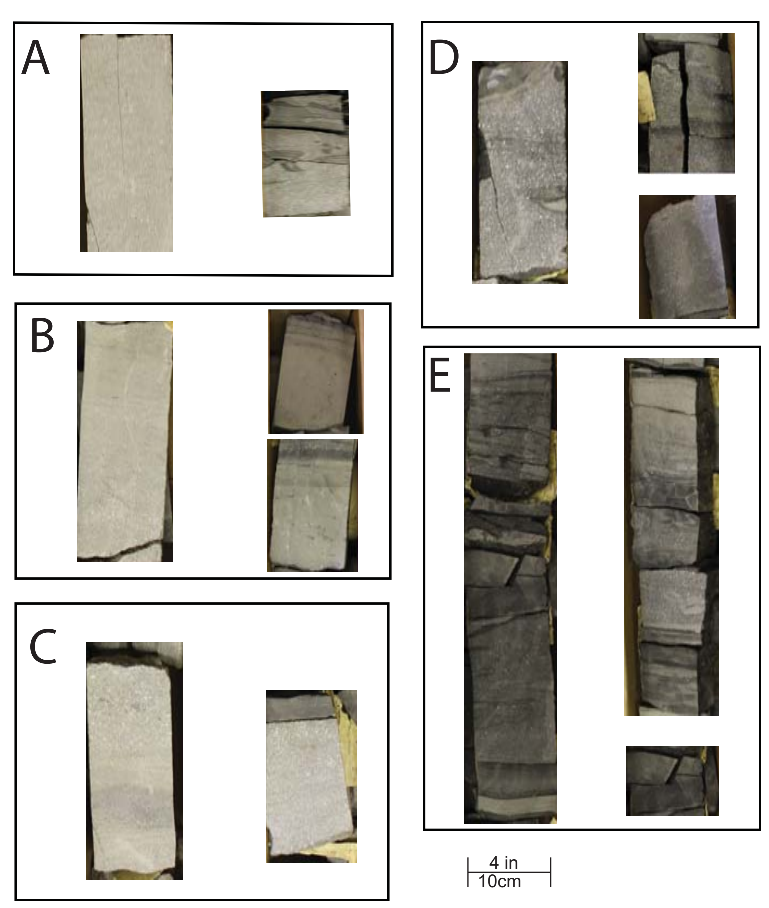
A. Structureless Sandstone
Massive medium- to coarse-grained gray sandstone, well-sorted. No vertical grain size change. Rare occurrences of rip-up clasts, flame structures and soft-sediment deformation.

B. Fining Upward Sandstone
Coarse- to very fine-grained gray sandstone, well sorted. Scoured base, some parallel mud laminations near the top of the interval. Dish structures and several amalgamated surfaces are present together with some bioturbation.

C. Coarsening Upward Sandstone
Fine- to very coarse-grained, light gray colored, well sorted sandstone. Abrupt transition to mudstone at the top. Bioturbarion observed.

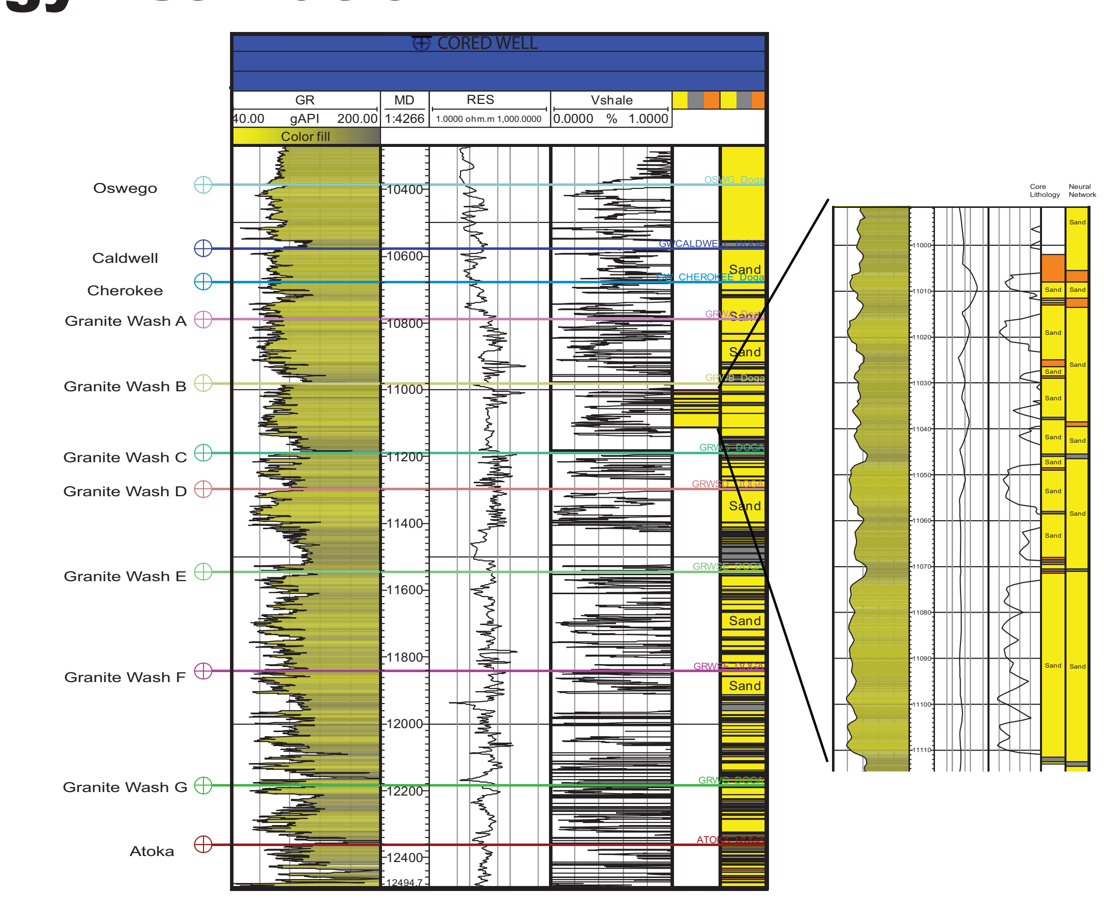
D. Dark Gray Muddy Sandstone
Fine- to coarse-grained, dark gray colored muddy sandstone. Poorly sorted. Chaotic structures are observed like, slumping, convolute bedding, flame structures, and very common soft sediment deformation. Large clasts are also observed.

E. Interbedded Sandstone-Mudstone
Interbedded and laminated mudstone-muddy sandstone-sandstone. Grain size changes from fine sand to mud. Color is varying from gray to very dark gray/black. Very poorly sorted. Convolute bedding, flaser bedding and soft -sediment deformation is present.



Based on core and well logs, the depositional environment is preliminarily interpreted to be a deep-marine setting which consists of channels (dominated by facies A), amalgamated and layered sheet sandstones (commonly facies B and C) and slump deposits (commonly facies D and E). However additional work is needed to confirm this interpretation.

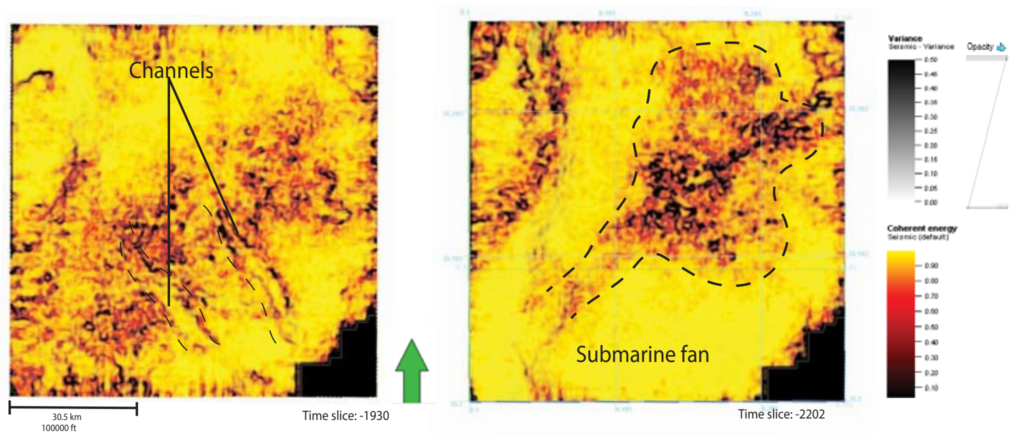
Lithology Estimation



To estimate lithology in non-cored wells, an artificial neural network approach was used with a core and well logs. Part of the core is used to train the well logs, due to the lacking of another core to test. In order to train the core, it is best to use litholog-descriptive logs. In this study, different sets were tried, but Gamma-ray, Resistivity and Vshale set gave the best results. After training the specific part of the core, the remaining part was tested with the resultant algorithm. 85% of a match between lithologies is achieved for the core lithology and Neural Network lithology. With this satisfying match, the same algorithm then applied to the all the other non-cored-wells and wells in the study area with Gamma-ray, Resistivity and Vshale logs, and lithology log for those wells also obtained.

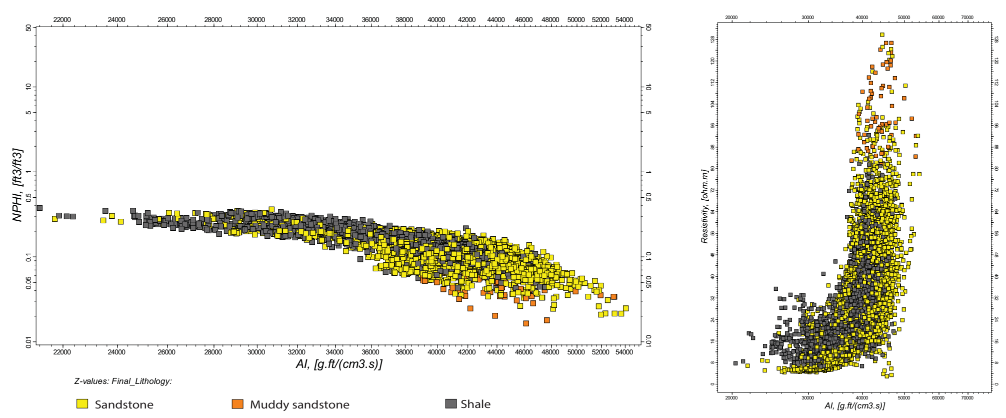
Seismic Characteristics

Surface Attributes

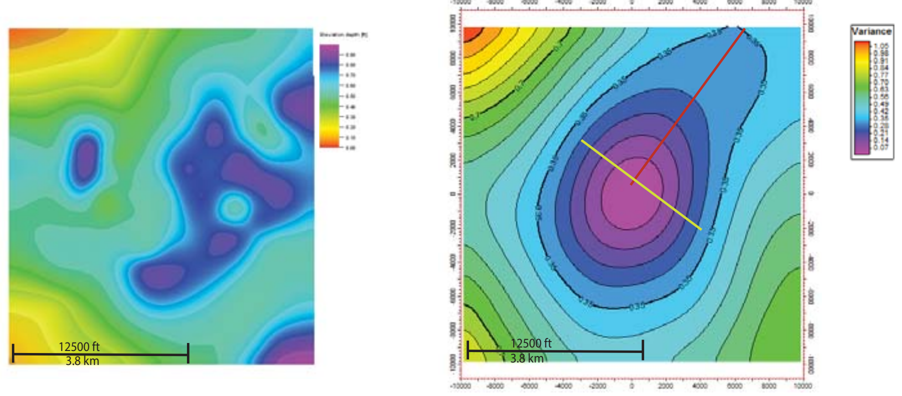


Seismic surface attributes were used in order to highlight the features that may relate to the depositional environment. For this purpose two different attributes were chosen and co-rendered, coherent energy and variance, as they may indicate and outline chaotic structures. The image on the left is from the uppermost zone, Marmaton Wash, and the image on the right is from Granite Wash E as examples. The areas with high variance and high-to- moderate coherent energy are interpreted to be delineations of channels, turbidite fans or slump deposits.

Acoustic Impedance



Crossplots of impedance versus porosity and resistivity (as calculated from the logs) and color coded by lithology showing the relatively high impedance values are associated with sandstone. Depending on that correlation, an acoustic impedance (AI) volume that is previously calculated by Gavidia (2012) is used. As AI is increasing with depth, an average AI surface attribute map is generated for each zone and different cut-off values are determined in order to be used for probability maps.



Probability and variogram maps of the Marmaton zone. Probability map is generated with the help of average AI map for the seismic area, and for the outer model area without the seismic, sand percentages from the wells are calculated and used to obtain sandstone probability, and then these were merged with the seismic map, to achieve a sandstone probability map for the entire model area. And the horizontal variogram of those probobility maps are also generated for each zone. Horizontal variograms are used to see how the data varies throughout the model area and as a guide for the determination of the dimension and direction of sandstones within the model. Red line is showing the major direction whereas yellow line representing the minor direction, which is perpendicular to the major one.

Acknowledgement

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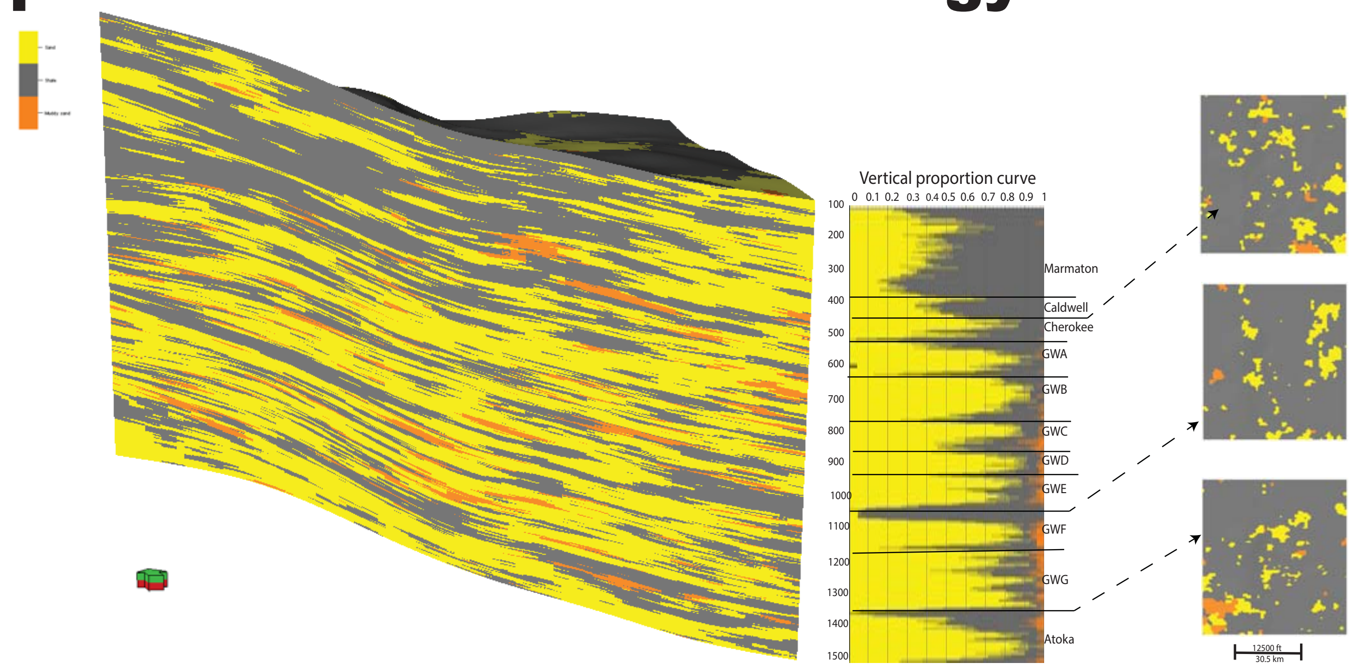
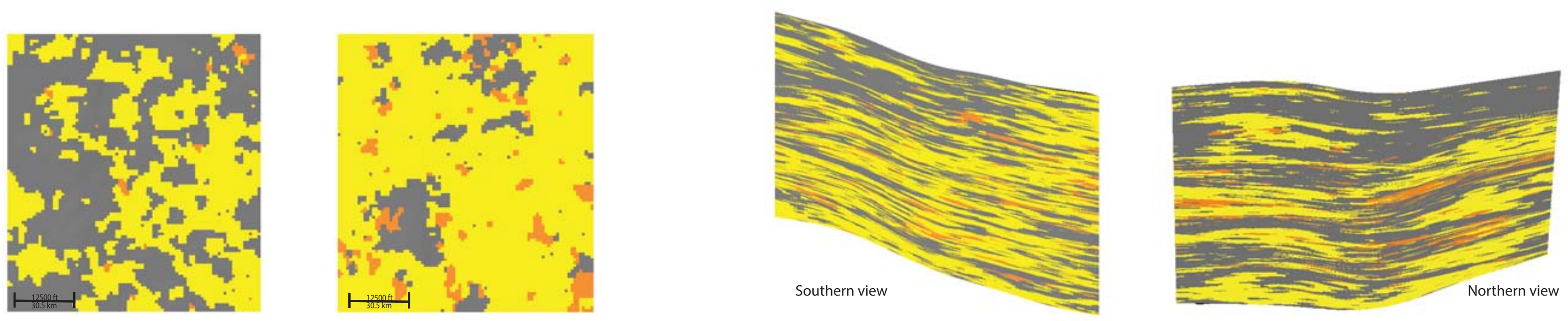
Spatial Distribution of Lithology



The above SIS lithology model was constructed using the following parameters:
1) Upscaled lithology logs obtained from Artificial Neural Network
2) Histogram of lithology percentages
3) Probability maps for sandstone for each zone calculated from AI volume
3) Vertical and horizontal variograms (by zone)
4) Vertical lithology proportion curves for each zone

Lithology distribution throughout the whole model is as follows: 62% sandstone, 36% shale, and 2% muddy sandstone. Shale deposits appear as more laterally continuous deposits throughout the layers, while the sandstone is more either more channelized or in lobes as expected with the associated deep marine sheet sand deposits. Muddy sandstone percentage is fairly low as they are related to the more slopeward deposition, they appear only times of regression, although they increase their abundance throughout the lower zones. also in the vertical proportion above, it can be seen that, times of flooding surfaces, which are also used to define the intervals of Granite Wash, are corresponding to levels with higher shale occurrence. Example surfaces from Caldwell, GWE and GWG are shown above that are dominated by shale.



Comparison of spatial distribution between different zones.
On the left a layer from Caldwell zone, showing higher percentage of shale, and very low muddy sandstone which can be also followed from vertical proportion curve. Shale is more continuous while sandstone is more patchy. In GWB, sandstone percentage is 77 which is very high, thus sandstone appear to be highly continuous for this zone. Also the muddy sandstone occurrence is increased. On the right, views from north and south, showing the vertical change. On the both sides, shale is highly continuous. whereas sandstone is observed to be more continuous on the southern side compared to the northern side, with the change from proximal to distal submarine lobes.

Conclusions

The Desmoinesian Granite Wash 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. Primary lithologies present within the Desmoinesian Granite Wash of Hemphill and Wheeler counties, Texas are determined by Artificial Neural Network approach successfully, and are vertically stacked sandstone, muddy sandstone and shale. Those lithologies exhibit a complex stratigraphic architecture, highly variable lithologies, and correspondingly heterogeneous reservoir properties.
In order to construct stratigraphic and structural framework and to understand reservoir characteristics of the Desmoinesian Group, well-logs, a core, seismic volume and its impedance inversion is used. A 3-D model of spatial distribution of lithology is then made with all of those inputs through Sequential Indicator Simulation technique.
Overall, it is found that the structure elevation of the Desmoinesian Group is increasing towards north, without a significant difference in thickness. All investigations are pointing deep marine as depositional environment. There is a satisfying correlation between acoustic impedance and lithology, so that it is used to constrain the 3-D model in terms of sandstone probability and major and minor directions of the sandstones for each zone. Lithology distribution throughout the whole model is 62% sandstone, 36% shale, and 2% muddy sandstone Shale deposits display a laterally continuous, vertically discontinuous trend with no discernable depositional azimuth trend, whereas muddy sandstones are relatively less continuous and less present with an increasing abundance with depth.

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