PS Seismic Data Conditioning for Identification of Sand Dunes in the Early Jurassic Nugget Formation in the Moxa Arch*

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Abstract

The Moxa Arch has been an important geologic structure for hydrocarbon exploration since the mid-1940s in the Green River Basin. It is also recognized by the US Department of Energy as one of two carbon sequestration sites within Wyoming. The Early Jurassic Nugget Formation within the Moxa Arch is a possible reservoir for carbon sequestration, however past drilling may have compromised it as such. The Nugget Formation is an eolian sandstone that was deposited as part of the Early Jurassic sand sea that covered Arizona, Utah, and southwestern Wyoming. Seismic attribute analysis shows the presence of northwest-southeast trending linear geologic features believed to be eolian dunes and inter-dunal deposits. Previous works, using outcrop study, on the Nugget Formation have measured a northeast-southwest general paleo-wind direction during the time of deposition.

The petrophysical analysis of three surrounding wells also shows that the eolian sands have high porosity resulting in low impedance, while the inter-dunal deposits, composed of halite and anhydrite, are impermeable barriers and have high impedance. Furthermore, the structure-oriented filtering (SOF), when applied on the prestack data during seismic processing, improves the overall data quality and increases the resolution of the discontinuities seen in the coherence based attributes. After SOF, the time slices look sharper with preserved discontinuities and suppressed acquisition footprints. Analysis of co-rendered coherence and curvature clearly displays the extent and nature of the eolian dunes within the 3D volume. The seismic attribute analysis on the lineaments and the Ant Track workflow on the curvature attribute shows that the average paleo-wind direction was around N-225 degrees E which supports the previous outcrop studies.

Seismic Data Conditioning for identification of Sand Dunes in the Early Jurassic Nugget Formation in the Moxa Arch

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1. Abstract

The Moxa Arch has been an important geologic structure for hydrocarbon exploration since the mid-1940s in the Green River Basin. It is also one of the two carbon sequestration sites in Wyoming. The early Jurassic Nugget formation within the Moxa Arch is a possible reservoir for carbon sequestration, however, past drilling may have compromised it as such. The Nugget formation is an eolian sandstone that was deposited as part of the early Jurassic sand sea that covered Arizona, Utah, and southwestern Wyoming. Seismic attribute analysis shows the presence of NW-SE trending linear geologic features believed to be eolian dunes and inter-dunal deposits. Previous works, using outcrop study, on the Nugget formation have measured a NE-SW general paleo-wind direction during the time of deposition, supporting the seismic attributes. The petrophysical analysis of the three surrounding wells also shows that the eolian sands have high porosity resulting in low impedance, while the inter-dunal deposits, composed of halite and anhydrite, are impermeable barriers with high impedance. Analysis of co-rendered coherence and curvature clearly displays the extent and nature of the eolian dunes within the 3D volume.

2. Study Area, Paleo-environment and Wind Direction

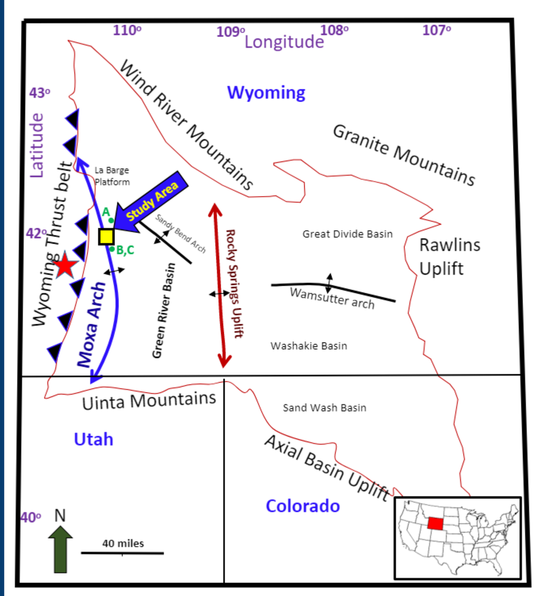


Figure 1. Location map of the Moxa Arch and Rock Springs Uplift in SW Wyoming (modified after Verma et al., 2016). A, B and C are the wells used for the study. Red star is Naughton Power Plant.

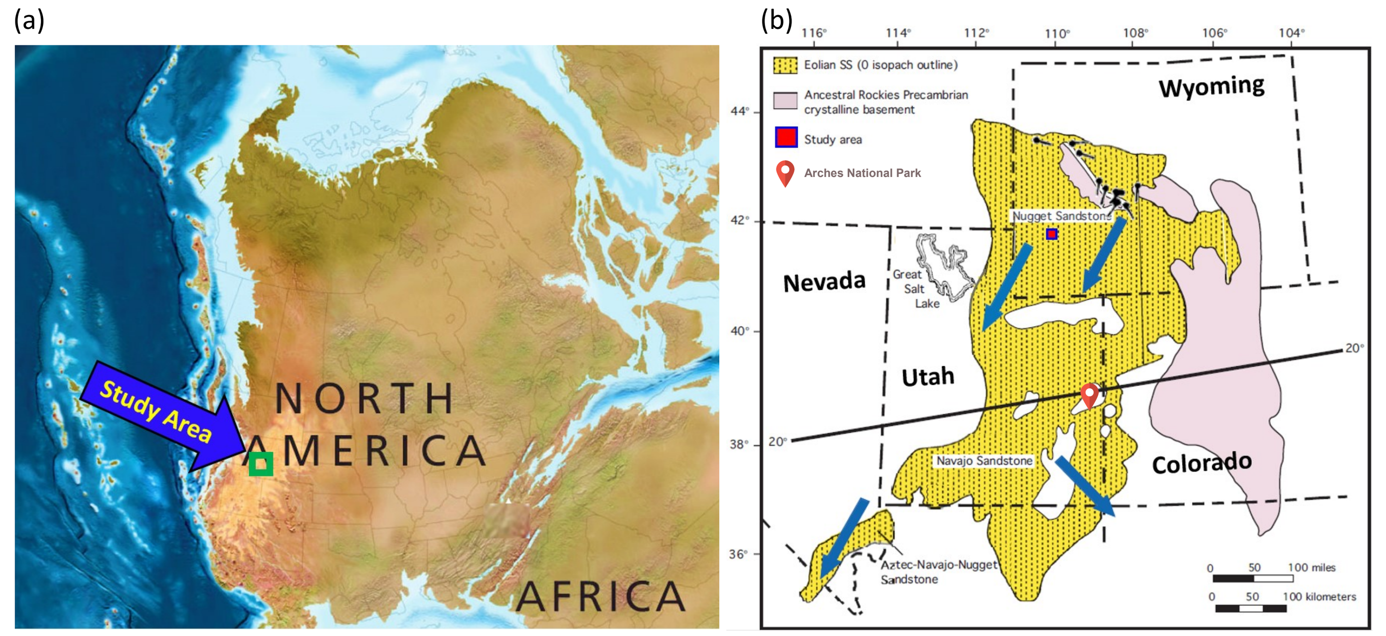
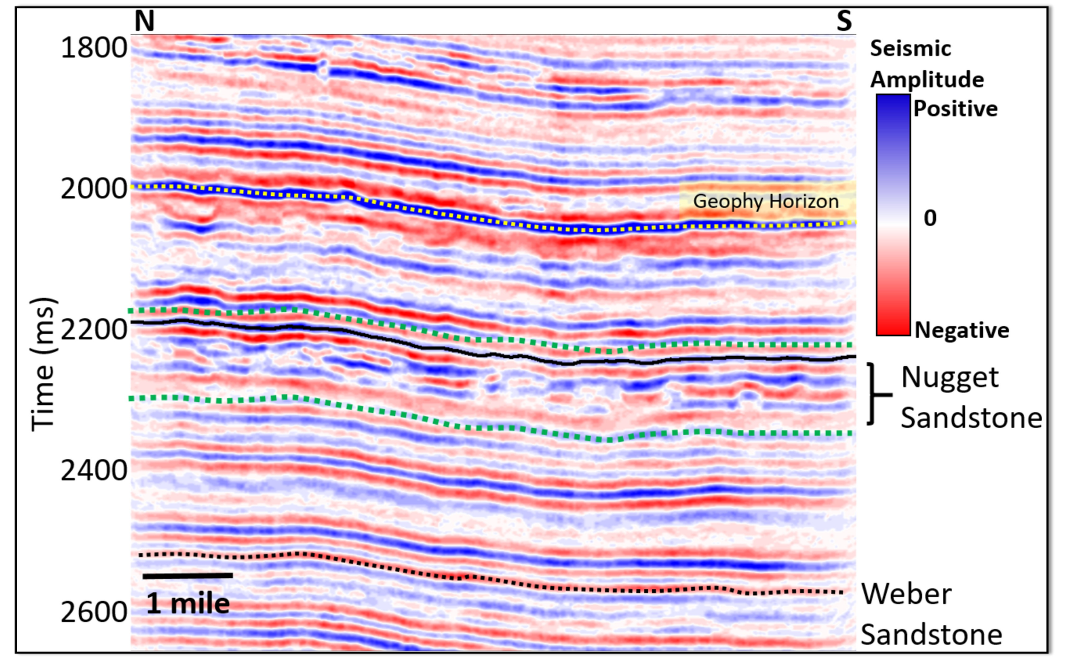


Figure 2. (a) North American continent during early Jurassic (after National Park Services, 2018), (b) Paleo wind direction of Nugget and Navajo Sandstone. Note the black dipoles in Wyoming state close to Precambrian uplift showing the outcrop locations of Nugget Sandstone where the wind direction measurement was taken (after Parrish and Peterson, 1988; Chan and Archer, 2000). The blue arrows show the general wind direction. Please refer to Figure 10 (b) for the significance of the Arches National Park here.

3. Seismic and Well data



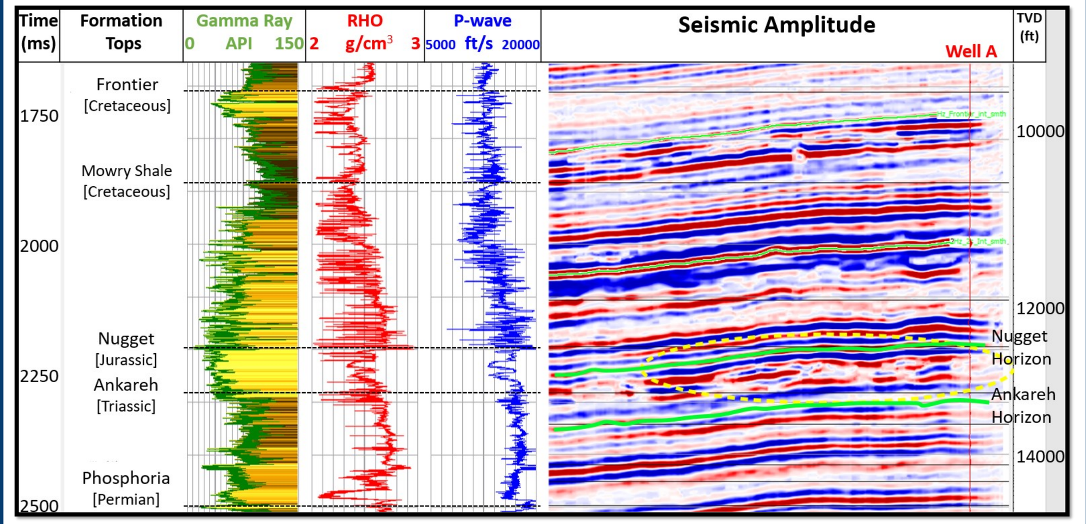


Figure 3. (Top) Seismic amplitude vertical (north - south) section. The Nugget formation is approximately 75ms thick. The geophysical horizon on top is a very distinct seismic reflector below the Mowry Formation.

Figure 4. (Bottom) Well to seismic tie – Well A. Well A highlighted as red vertical line. The yellow ellipse exhibits the structures we are interested in.

4. Petrophysical Analysis and Lithological Heterogeneity

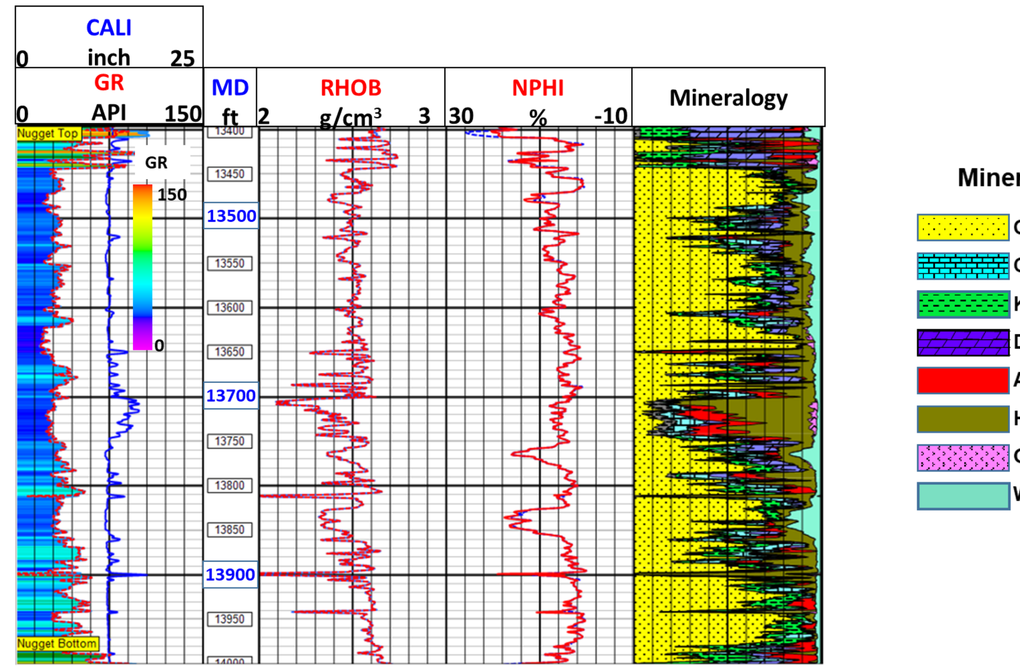


Figure 5. A stochastic mineral solution from the well C showing actual and synthetic well logs (marked by R). The first three tracks show the common well logs – gamma ray, bulk density and neutron porosity. The fourth track shows the multi-mineralogical solution. The overlapping pattern of all synthetic logs on the actual well logs indicates significantly less error in inversion. The Nugget Sandstone formation is composed of multiple minerals in different proportions, including quartz, illite, kaolinite, calcite, dolomite, anhydrite, halite, gypsum, and water (Verma et al., 2018).

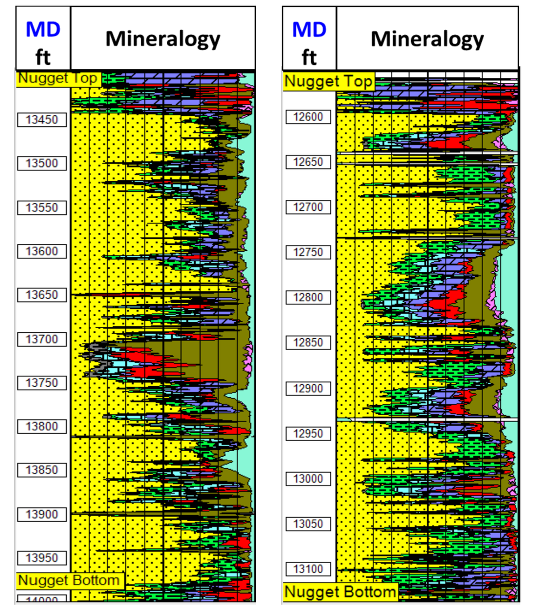


Figure 6. Statistical multi-mineralogical solutions for the wells C and A. Although the solutions indicate the Nugget Formation is predominantly sandstone, there is a significant amount of internal heterogeneity present. Based on our analysis, it appears that the well C is more representative of a sand dunal environment, whereas the well A suggests more of an interdunal environment (Verma et al., 2018).

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ASTER, 2005, NASA's satellite image of Rub' al Khali, Arabia , https://www.nasa.gov/multimedia/imagegallery/image_feature_1200.html; accessed 10 December 10, 2017.

5. Seismic Attribute Analysis

(I)

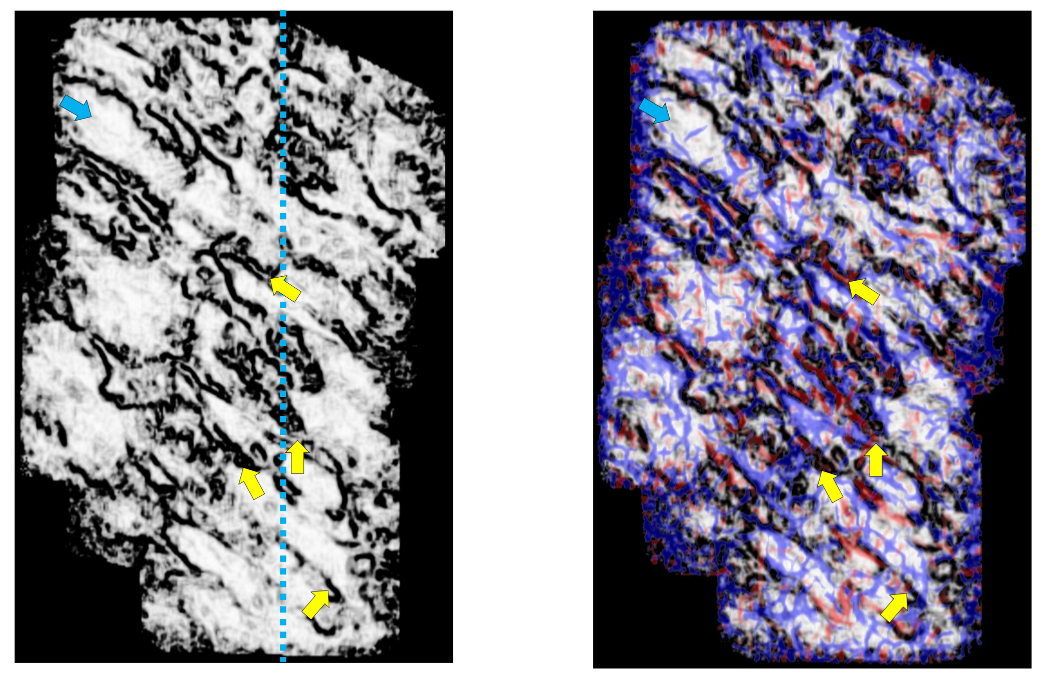
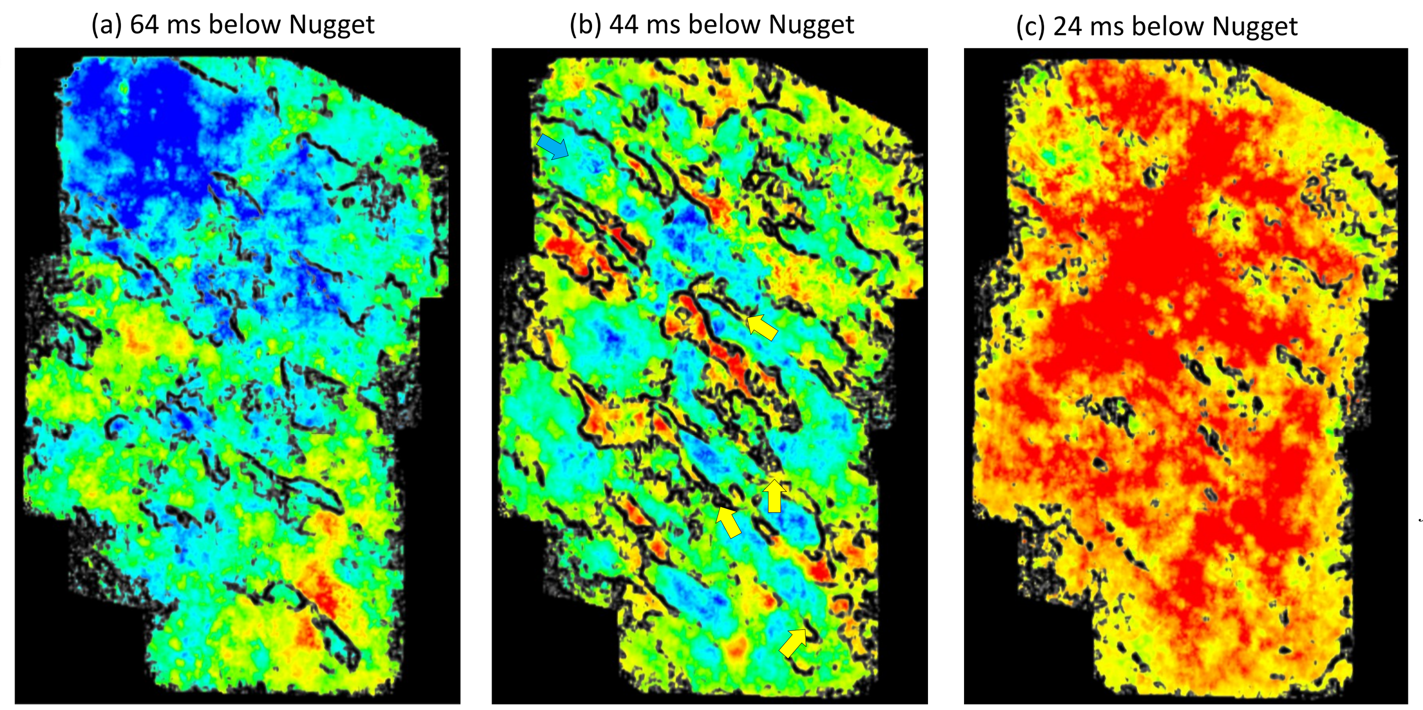


Figure 7. (I) Stratal slice of the Coherence attribute, 1 represents maximum similarity and 0 represents maximum dissimilarity, and Stratal slice of most positive curvature (k_1), co-rendered with most negative curvature (k_2) and coherence, both slices are 44ms below Nugget (II) Stratal slices of P-Impedance (Z_p) co-rendered with coherence attribute. All slices are taken with respect to the Nugget Sandstone reflector. The eolian dune lineaments begin to appear 24 ms below Nugget (fig. c), become prominent around 44 ms (fig. b), and then start disappearing about 64 ms below Nugget (fig. a). The eolian dune lineaments begin to become prominent around 42ms. Note the blue arrow indicates the inter-dunal whereas the yellow arrow indicates the well developed sand dunes.

(II)



Note the blue arrow indicates the inter-dunal whereas the yellow arrow indicates the well developed sand dunes. The coherence determines the lateral changes in the lithology. The corendered figure of curvature and coherence implies that the distinct features seen in coherence slices are surrounded by antiforms and synforms. Notice that the low P-impedance values are bounded by low coherence anomaly.

(III)

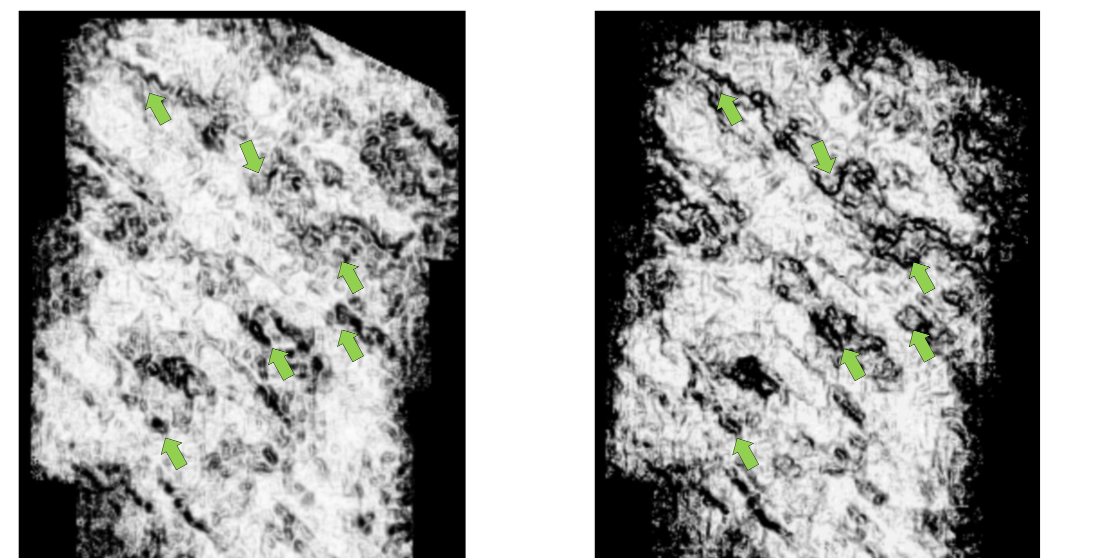
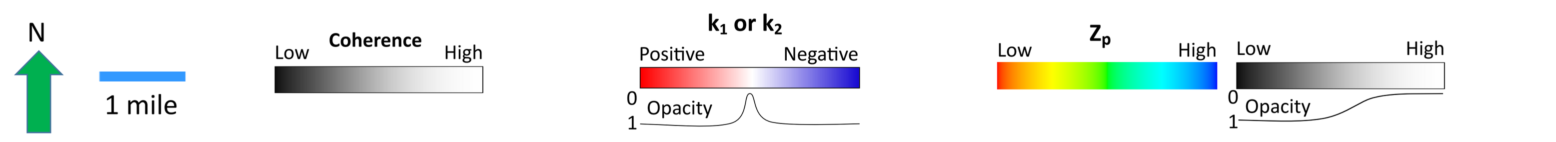
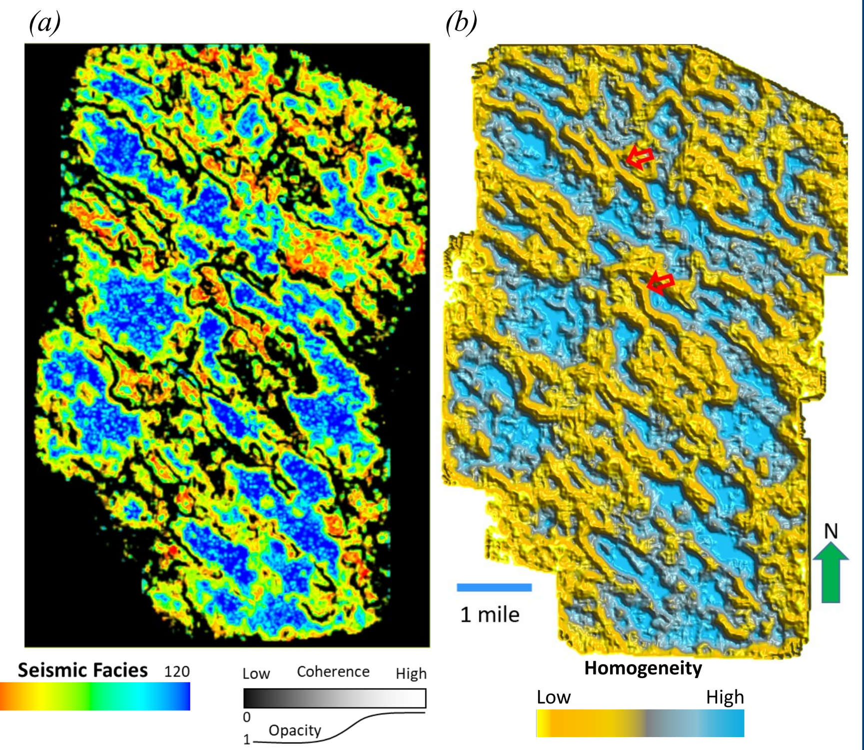


Figure 7. (III) Stratal slices of the Coherence attribute before and after the seismic data conditioning (both are 44 ms below Nugget). Note the green arrows indicate the features which look sharper and more resolved after applying the structured oriented filtering (SOF). There is some signal that goes missing during the seismic conditioning because of the smoothening that happens during the process. But those minor features are insignificant when trying to resolve and understand the bigger sand dunes.



6. Seismic Facies Analysis

Figure 8. (a) Stratal slice of the seismic facies, generated with Self Organizing Map (SOM) algorithm, (b) GLCM homogeneity with bump map. Both are taken 42 ms below the Nugget reflector (Verma et al., 2018). Based on the correlation with Z_p, the blue colored facies are inter-dunal deposits and the red ones are dunal deposits.



7. Paleo-wind Direction

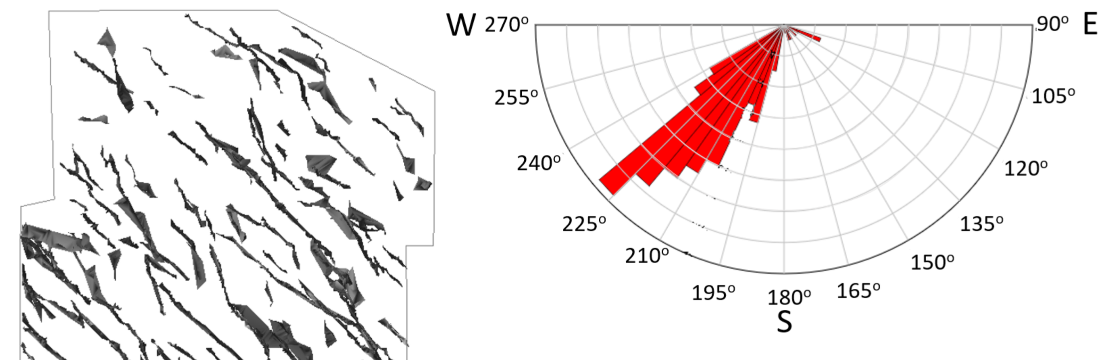
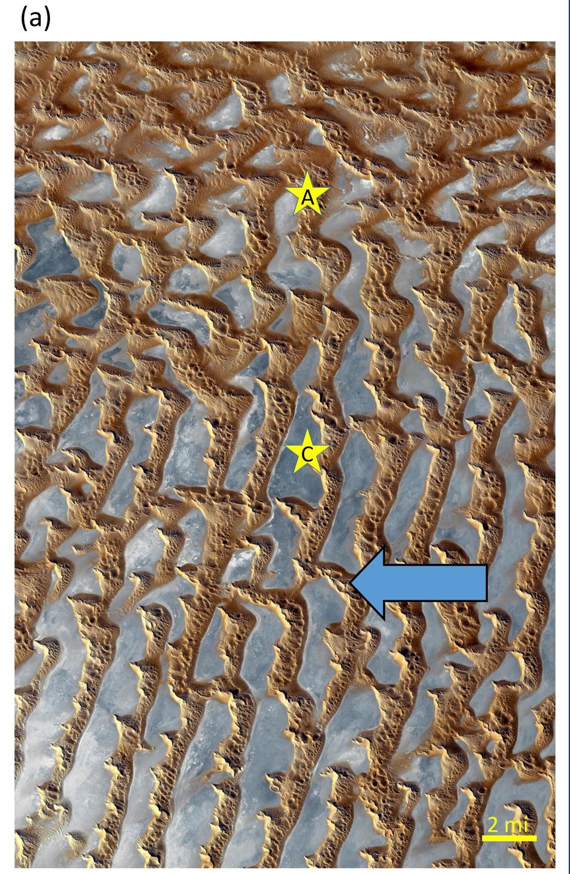


Figure 9. (a) The discontinuity surfaces obtained by applying Ant Track workflow (Silva et al., 2005) on curvature k_1 volume (Figure 4). Note that all the small north to east striking lineaments were filtered out, (b) The rose diagram, showing the derived direction; which is simply the perpendicular direction to the strike of the lineaments.

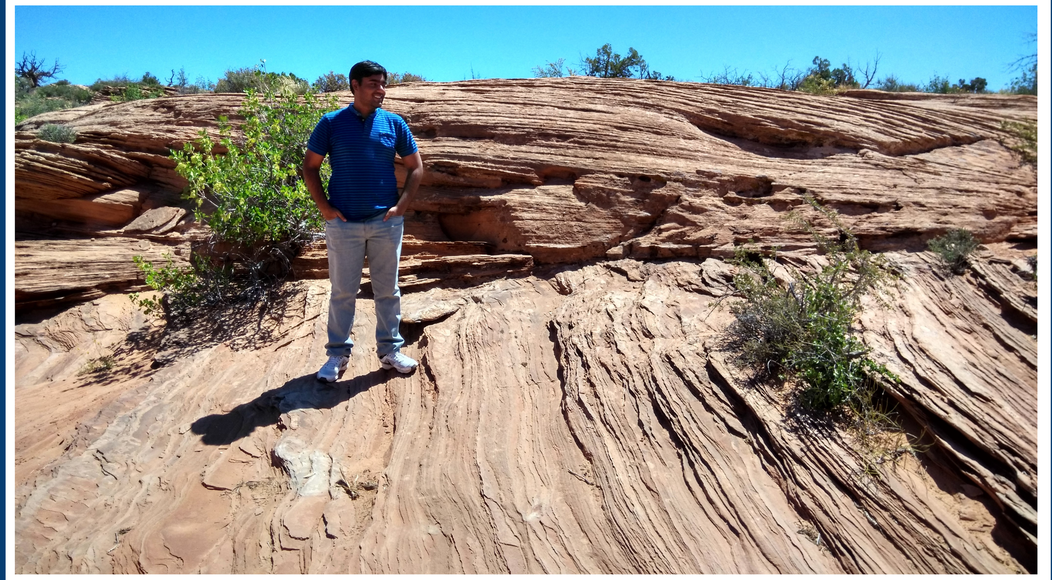
8. Modern-day Analog

Figure 10. (a) Satellite image of Rub' al Khali, Arabia – one of the largest desert in the world. The blue arrow shows the wind direction, brown color shows dunes and blue/white color shows interdunes (modified after ASTER, 2005). The stars represent the approximate analogical relative location of wells A and C in a dunal/ interdunal deposit area. (b) My picture with an outcrop in the Arches National Park which shows the cross beddings of the sand dunes from the Navajo Sandstone of Utah, the dominant wind direction here is from NW to SE which matches with the research from Parrish and Peterson, 1988.

(a)



(b)



9. Conclusions

The Nugget Sandstone is an eolian deposit, characterized by dunal and interdunal deposits. High correlation in the well to seismic tie, confirms that the lineaments seen in the seismic data are within the Nugget Sandstone. The petrophysical analysis indicated that the Nugget Sandstone interval consists of sandstone (dunal deposits) and clay along with carbonates (interdunal deposits). Multi-well analysis suggests that the overall lithology of the Nugget Sandstone may be uniform (i.e. sandstone); however, there is a significant amount of internal heterogeneity present in the wells that can be correlated laterally. Coherence and curvature (seismic) attributes show NW-SE lineaments in Nugget Sandstone, we hypothesize that these lineaments correspond to the transverse dunes, and the predominant paleo-wind direction resulting in formation of these dunes would be NE-SW. Acoustic impedance and petrophysical analysis helped in discriminating dunal and interdunal deposits. The seismic conditioning in the form of structured oriented filtering (SOF) can increase the resolution of discontinuities seen in the coherence based attributes. The seismic facies calculated based on the Self Organizing Maps (SOMs) also prove the presence of more sand facies at the top and more evaporites and carbonates at the bottom. Based on the lithology, porosity, fluid saturation, and vertical and lateral extent of the Nugget Sandstone, it appears to have a good potential for carbon storage.

Acknowledgements

Attribute Assisted Seismic Processing & Interpretation (AASPI, The University of Oklahoma) software was used to compute the seismic attributes. We would also like to thank Schlumberger for providing the Petrel & Techlog licenses to UTPB. Quantitative Interpretation was performed using HampsonRussell, thanks to CGG GeoSoftware for the licenses. Thanks to University of Wyoming for providing us the seismic survey and the well logs. The seismic data was obtained with the research grant provided by the United States Department of Energy: Contract No: DE-FE0023328. Thanks to Society of Exploration Geophysicists for funding the research through the Scholarship and giving us an opportunity to present this research here.

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