[PS]Digital Outcrop Modeling of the Lower Silurian Qusaiba Shale Member - Implications for Reservoir Quality and Architecture, Central Saudi Arabia*

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Search and Discovery Article #11322 (2020)**
Posted May 11, 2020

*Adapted from poster presentation given at 2019 AAPG Annual Convention and Exhibition, San Antonio, Texas, May 19-22, 2019
 DOI:10.1306/11322Osman2020

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Abstract

The hot shale (organic-rich) of the Lower Silurian Qusaiba Member of the Qalibah Formation is one of the most prolific source rocks in the Arabian Peninsula. Almost 90 % of the Paleozoic light oil and gas accumulations are well-known to be sourced by Qusaiba Shale unit. Also, recently this unit is believed to act as a potential unconventional shale gas reservoir. The understanding of the Qusaiba as tight gas reservoir is critical and mysterious. This study aims to characterize and model the reservoir quality and architecture using outcrop analog for Qusaiba Shale Member.

Traditional geological field data such as vertical stratigraphic sections, structural measurements, sampling and photographs were acquired. In addition, Terrestrial Laser Scanning (LiDAR) was the main tool utilized to model the Qusaiba outcrop digitally. The scanner operated in this study is manufactured by Optech company and has a range of up to 1000 m.

An external high-resolution digital camera was mounted with the scanner to obtain better photos. Three scan positions were selected to scan the outcrop of the Qusaiba Member with a resolution of about 30 mm. VRGS and GIS software were utilized to process and interpret the digital model and integrate it with the traditional geological data from the field. The lithofacies of the studied sections can be described as interbedding and alternation between fine-laminated fissile grey and black shales with a few cycles of sandstone and siltstone. The lithofacies and their associated sedimentary structures indicate a shallow marine depositional environment with high energy. One of the important results of this study and revealed by the digital model is the percentage of fractures in the Qusaiba outcrop. The intensity of fractures is higher in the fissile shale and mudstone lithofacies than sandstones lithofacies. The average spacing between fractures is smaller in the fissile shale and mudstone lithofacies than sandstones lithofacies. The continuity of the units in the Qusaiba Shale model is highly affected by the fractures network. The results of this work may be a significant contribution to tight shale exploration plans in the subsurface by providing information about the fractures network of Qusaiba Shale Member of Qalibah Formation.

Digital Outcrop Modeling of the Lower Silurian Qusaiba Shale Member; Implications for Reservoir Quality and Architecture, Central Saudi Arabia

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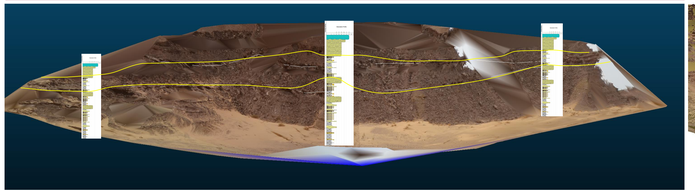
AAPG ACE 2019 ANNUAL CONVENTION & EXHIBITION
19-22 May • San Antonio, Texas

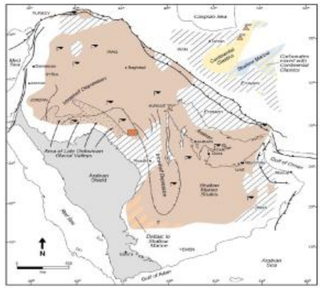
Abstract: The hot shale (organic-rich) of the Lower Silurian Qusaiba Member of the Qalibah Formation is one of the most prolific source rocks in the Arabian Peninsula. Almost 90 % of the Paleozoic light oil and gas accumulations are well-known to be sourced by Qusaiba Shale unit. Also, recently this unit is believed to act as a potential unconventional shale gas reservoir. The understanding of Qusaiba as tight gas reservoir is critical and mysterious. This study aims to characterize and model the reservoir quality and architecture using outcrop analog for Qusaiba Shale Member. Traditional geological field data such as; vertical stratigraphic sections, structural measurements, sampling and photographs were acquired. In addition to that, Terrestrial Laser Scanning (LiDAR) was the main tool utilized to model Qusaiba outcrop digitally. The scanner operated in this study manufactured by Optech company and it has a range reach up to 1000 m. External high resolution digital camera was mounted with the scanner to obtain better photos. Three scan positions were selected to scan the outcrop of Qusaiba Member with resolution about 30 mm. VRGS and GIS softwares were utilized to process and interpret the digital model and integrate it with the traditional geological data from the field. The lithofacies of the studied section can be described as interbedding and alternation between fine laminated fissile grey and black shales with few cycles of sandstone and siltstone. The lithofacies and their associated sedimentary structures indicated shallow marine depositional environment with high energy. One of the important results of this study and revealed by the digital model is the percentage of the fractures within Qusaiba outcrop. The intensity of the fractures are higher in the fissile shale and mudstone lithofacies than sandstones lithofacies. The average spacing between fractures is smaller in the fissile shale and mudstone lithofacies than sandstones lithofacies. The continuity of the units within the Qusaiba shale model is highly affected by the fractures network as reservoir architecture point of view. Generally, the interested results of this work may have a significant contribution to tight shale exploration plans in the subsurface by providing information about the fractures network of Qusaiba shale member of Qalibah Formation.

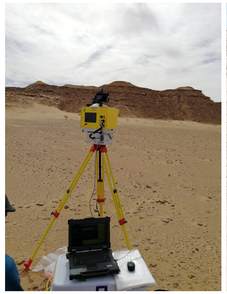
Introduction: Shale gas is a natural gas produced from shale. Shale gas has become an important source of energy in USA, Canada and of great potentials to many other countries worldwide. Saudi Arabia possesses "hundreds of trillions cubic feet of shale gas" (AlBawaba, Middle East Ltd, 2011). The Qusaiba shale is the main source rock for the Paleozoic petroleum system in Saudi Arabia. It has been estimated that 447 trillion cubic feet of unconventional gas has been produced from Qusaiba in a number of basinal areas in Saudi Arabia (Faqira et al., 2010; USGS, 2000). Shale gas is a prospect which to date remains largely unexploited not only in the Middle East but worldwide (Holditch, 2006). In the Middle East and North Africa tight sand gas resources are estimated at 823 TCF (Holditch, 2006). However, understanding the geological, structural, geomechanical and petrophysical properties of shale gas reservoir are important since they represent challenges to economic gas production from shale gas reservoirs (Ghassemi and Holditch, 2010; Engelder, 2009; Aschoff, 2008, , Pashin, 2007, Grammer, 2008 and Kent and Salehi, 2007). Challenges related to shale gas reservoirs include geology, litology, mineralogy, geochemistry, fracture and geomechanical behaviors. All these, parameters are important and vital for planning and designing any future hydrofracturing and development of shale gas reservoirs. For this purpose, outcrop analog studies of Qusaiba shale will provide data at different scales from microscale to macroscale which can enhance the data base that may that can be used to capture facies heterogeneities in Qusaiba Shale.

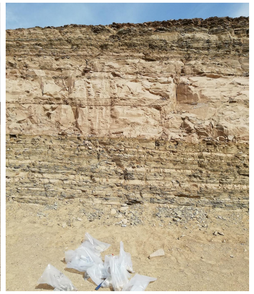
Methods: Field investigations have taken place on the cropped rocks of Qusaiba shale member of Qalibah formation in Central Saudi Arabia, to the west of Qusayba village in Al-Qasim area. One outcrop has been selected in order to do the digital outcrop model to describe the different lithologies of Qusaiba member, study the fractures system within them, and collect samples for further laboratory measurements. The outcrop is located near the coordination (26°56′23.1" N 43°31′55.6" E). The height of this outcrop is about 41 meters. Detailed stratigraphic description was conducted along the selected outcrops in order to create vertical stratigraphic sections that describe the vertical changes of the lithofacies. The digital data acquisition was done by usisng ILRIS-3D laser scanner manufactured by OPTECH company and it has a range of 1000 m.

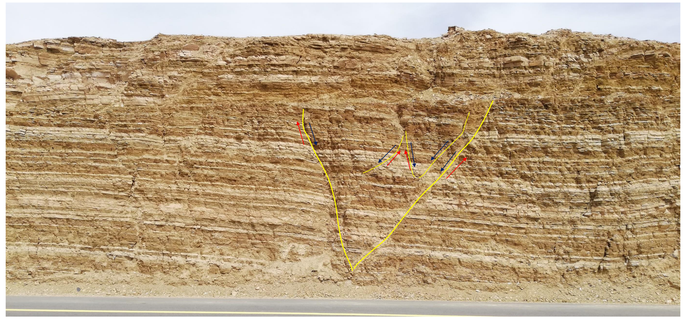


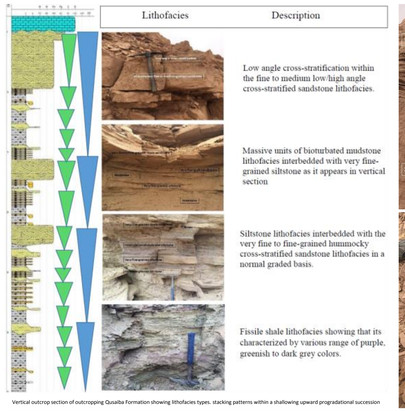
Results



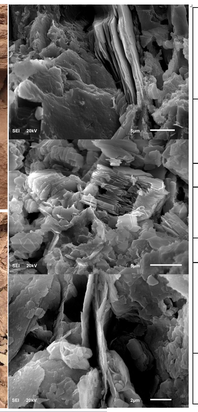




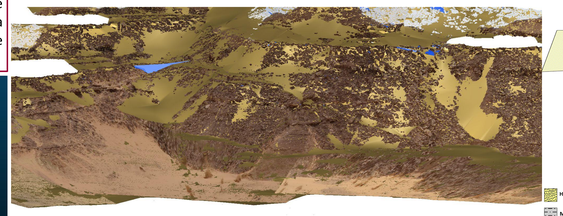


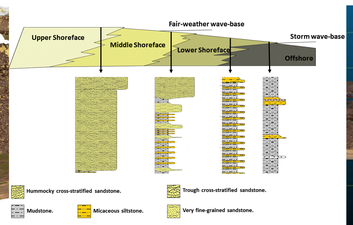


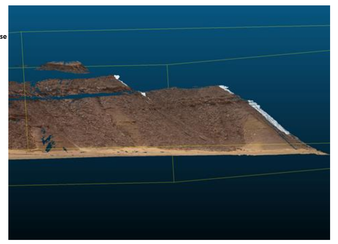
Vertical outcrop section of outcropping Qusaiba Formation showing lithofacies types, stacking patterns within a shallowing upward progradational succession



Facies	Fissile shale	Very fine-grained siltstone	Bioturbated mudstone	Very fine to fine-grained hummocky cross-stratified sandstone	Fine to medium-grained Low angle cross-stratified sandstone
Depositional environment	Offshore	Offshore transition to lower shore face	Shallow marine (Shelfal)	Lower shoreface	Middle to upper shoreface
Rock type	Shale	Siltstone	Mudstone	Sandstone	Sandstone
Mineralogy	Kaolinite, dickite, and halite	Quartz, muscovite, and kaolinite	Kaolinite and dickite	Quartz, muscovite, and dickite	Quartz
Ichnofacies	-	-	-	Skolithos	-
Sedimentary structures	Lamination	Lamination	Streaks, lenses, and moderate to strong bioturbation	Hummocky cross stratification, swelly, and ripple lamination	Low to high angle cross bedding and trough cross bedding
Colors	Greenish, brownish, and reddish	Brownish	Dark gray	Brownish to dark gray	Brownish to dark gray







Conclusions: The outcrops of the study area are located in Central Saudi Arabia to the west of Qusayba' village, in Al-Qasim area, and they are composed of the Silurian lower part of Qusaiba hot shale member of Qlibah formation. Qusaiba shale member in the study area consists of 5 main lithofacies, divided based on their sedimentary structures and petrophysical properties, from base to top; Fissile shale lithofacies, very fine-grained micaceous siltstone, bioturbated mudstone, very fine to fine-grained hummocky cross-stratified sandstone, and fine to medium-grained low/high angle cross-stratified sandstone.

The fissile shale deposited in an offshore depositional environment, siltstone and mudstone deposited in the transitional zone between offshore and lower shoreface depositional environments, hummocky cross-stratified sandstone deposited in the lower shoreface depositional environment, and low/high angle cross-stratified sandstone deposited in the middle to the upper shoreface depositional environment.

The 3D digital model of Qusaiba shale member showed the distribution of the lithofacies in the study area. Also, helped a lot in defining and delineating the fractures and small faults in the study area.

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Acknowledgments: The authors would like to acknowledge the support provided by King Abdulaziz City for Science and Technology (KACST) through the Science and Technology Unit at King Fahd University of Petroleum and Minerals (KFUPM) for funding this work through the project NSTIP-14-OIL310-04 as part of the National Science, Technology and Innovation Plan. Also, would like to acknowledge the support provided by the College of Petroleum Engineering and Geosciences at KFUPM for their support.