The Sarah Formation: A Glaciogenic Reservoir Analogue in Saudi Arabia*

Nikolas A. Michael¹, Salem Shammari¹, David LePain³, Abduljaleel AbuBshait¹, Martin Guy², Clemens Van Dijk¹, and Rainer Zuhlke¹

Search and Discovery Article #51167 (2015)**
Posted October 13, 2015

*Adapted from oral presentation given at AAPG Annual Convention & Exhibition, Denver, Colorado, May 31-June 3, 2015

¹GTT/EXPEC ARC, Saudi Aramco, Dhahran, Saudi Arabia (nikolaos.michael@aramco.com)

Abstract

The Sarah Formation is a glaciogenic sedimentary unit of the latest Ordovician (Ashgillian) ice age deposited along the Gondwana Margin. It forms part of an extensive, but discontinuous belt of outcrop deposits that extends from the Arabian Peninsula to westernmost North Africa. The short-lived ice age resulted in initial incision and large-scale palaeovalley (PV) generation. Subsequent filling of the PVs juxtaposed the Sarah reservoirs against different older Ordovician marine source rocks and sealed them with a major Silurian source rock. This unique setting makes these Sarah glacial deposits one of the main reservoir targets in the subsurface of Arabia. Our study currently focuses on PV fills exposed in the Tayma area, northwestern Saudi Arabia. The exposures provide excellent reservoir analogs for the glaciogenic PV fills in the subsurface and for other time-equivalent units on the Arabian Peninsula and in North Africa. Outcrop-based reservoir characterization provides a unique insight to the 3D architecture and heterogeneity of PV reservoirs and allows the pre-drill prediction of reservoir quality distribution.

Based on our work in the Rahal Daba'a PV, which includes sedimentological sections, general depositional environment mapping and architectural analysis (photomosaics), we present a preliminary 3D static reservoir analogue model. We deduce the evolution of the complex network of the Sarah PVs to the shoreline as well as depositional controls on facies change and reservoir architecture. This initial model captures the spatial and temporal lithofacies' heterogeneity within the Rahl Daba'a and the 3D connectivity of reservoir geobodies. Reservoir quality data and mechanical properties derived from samples tied to measured sections are assigned to sandstone geo-bodies and lithofacies. They provide the crucial link between the Sarah outcrops in northwestern Saudi Arabia and equivalent subsurface reservoirs. The static 3D model incorporates porosity/permeability and density/velocity cubes for forwards seismic modeling, which is an important approach to reservoir architectural prediction in the subsurface. The approaches taken so far are part of a larger workflow, which will incorporate terrestrial LiDAR, near-surface seismic, calibration wells behind the outcrop and dynamic modeling approaches.

^{**}Datapages © 2015 Serial rights given by author. For all other rights contact author directly.

²ERAD, Saudi Aramco, Dhahran, Saudi Arabia

³DGGS, Alaska Department of Natural Resources, Fairbanks, Alaska, United States



The Sarah Formation: A glaciogenic reservoir analogue in Saudi Arabia

N. Michael*, S. Shammari*, D. Le Pain*,†, A. AbuBshait*, M. Guy*, C. Van Dijk* and R. Zuhlke*

*Saudi Aramco, †now at Geological Survey of Alaska

AAPG ACE 2015, Denver

Outline

Introduction

The Sarah Formation Rational Overview map

Methods

Results

Correlation panel
Facies associations
Sedimentological architecture
Stratigraphic architecture
Depositional model of Rahal Dhab
Reservoir characterization
Geocellular models

Outline

Introduction

The Sarah Formation Rational Overview map

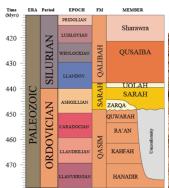
Methods

Results

Correlation panel
Facies associations
Sedimentological architecture
Stratigraphic architecture
Depositional model of Rahal Dhab
Reservoir characterization

The Sarah Formation

- Peri-glacial valley-fill of the Upper Ordovician in SA (Saudi Arabia).
- Hirnantian age (ca. 444 Ma)
- Part of extensive (from SA to NW Africa) but discontinuous belt of glaciogenic deposits
- Overlies a glacigenic erosional unconformity that cuts down into Qasim Formation and, in turn, is overlain by the Qalibah Formation

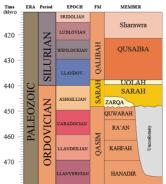




Michael etal. Sarah Fm Analogue

Rational

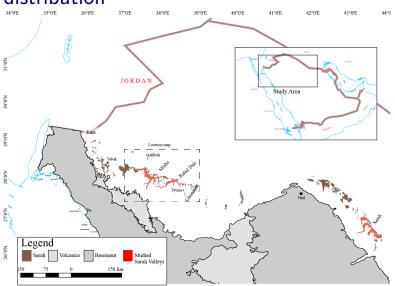
- Depositional model of Rahal Dhab for understanding the distribution of facies and acies associations.
- Cellular model for better reservoir characterization linked with petro-physical data.



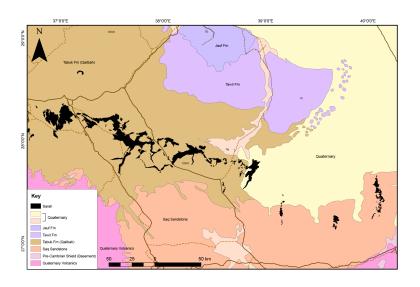


Michael etal.

Study area and Sarah FM outcrop distribution



Study area map



Michael etal. Sarah Fm Analogue AAPG ACE 2015, Denver 7/29

Outline

Introduction

The Sarah Formation

Rational

Overview map

Methods

Results

Correlation panel

Facies associations

Sedimentological architecture

Stratigraphic architecture

Depositional model of Rahal Dhak

Reservoir characterization

Geocellular models

Methods

- Sedimentological analysis
- Petrophysical analysis (Phi/K)
- Provenance study to link outcrop to the subsurface
 - Heavy mineral and petrographic analysis
 - ▶ U/Pb in Zircons
 - Chemostratigraphy
 - Palynological study
- Photomosaics
- Photogrammetry
- Digital outcrop model

Outline

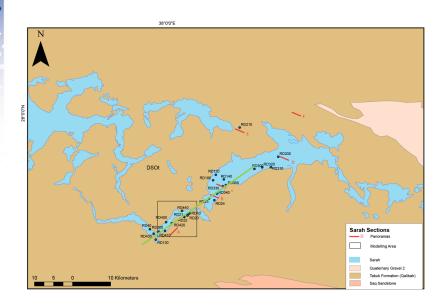
ntroduction
The Sarah Formation
Rational
Overview map

Methods

Results

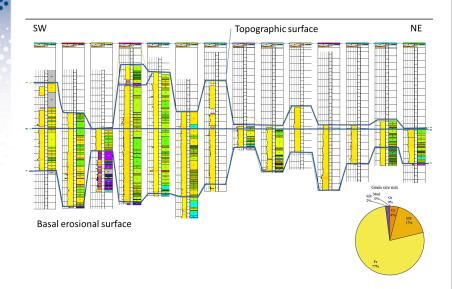
Correlation panel
Facies associations
Sedimentological architecture
Stratigraphic architecture
Depositional model of Rahal Dhab
Reservoir characterization
Geocellular models

Results from Rahal Dhab palaeo-valley



Michael etal. Sarah Fm Analogue AAPG ACE 2015, Denver 11/29

Correlation panel and important surfaces



Michael etal. Sarah Fm Analogue AAPG ACE 2015, Denver 12/29

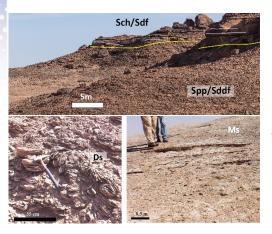
Facies associations Ssh-Spp-Sch





Michael etal. Sarah Fm Analogue AAPG ACE 2015, Denver 13/29

Facies associations Spp/Ds/Ms



Sch: Channelized Spp: Thinly bedded

interval

Sdf: Thickly bedded interval with marine influence interpreted as delta front

Sddf: Distal delta front MS: Marine shales

DS: Convoluted bedding

Michael etal.

Locality - A





- Qasim Fm —represents a lower shoreface environment
- Erosional unconformity (red line)
- Lower Sarah Formation dominated by Ssh
- Upper Sarah Formation dominated by Sch/Spp
- Flooding surface coincides with top of Sarah (blue line) —
 Hawban Fm
- Overlain by sequence boundary (red line)

Michael etal. Sarah Fm Analogue AAPG ACE 2015, Denver 15/29

Locality - B





- Qasim Fm at the base of the outcrop
- Erosional unconformity (red line)
- Lower Sarah dominated by Spp/Sdf
- It grades laterally into Sch and at the top of the Section Ssh

Locality - C





- Qasim Fm is absent
- Lower Sarah dominated by Spp/Sdf and greats into Sch
- The Ssh either has been eroded or absent from this locality

Locality - D

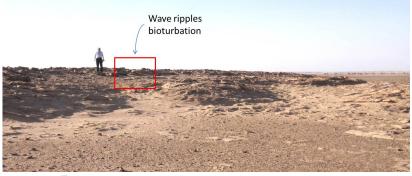




Ds - Convoluted bedding facies association with varying percentages of sand, silt and mud.

Michael etal.

Locality - E







Michael etal. Sarah Fm Analogue

Locality - F

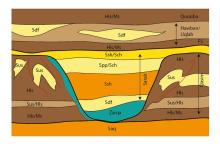


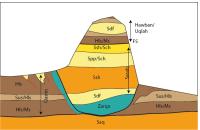


MS - Fine grained interval usually bioturbated.

Michael etal. Sarah Fm Analogue AAPG ACE 2015, Denver 20/29

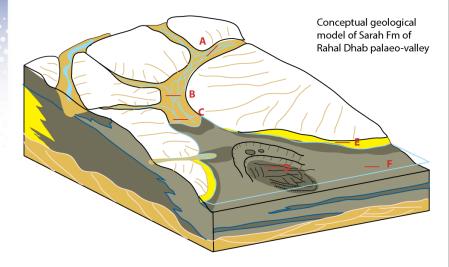
Stratigraphic architecture





Michael etal.

Depositional model of Rahal Dhab



Michael etal. Sarah Fm Analogue AAPG ACE 2015, Denver 22/29

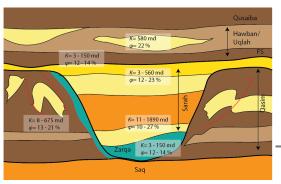
Outcrop based reservoir characterization

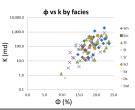
Facies	Min Φ	Av. Φ	Мах Ф	Min K	Av. K	Max K
Sm	14.7	19.2	23.75	11.24	269.2	1885.7
St	9.9	18.9	23.70	1.28	202.0	571.5
SI	11.9	17.2	23.21	3.21	125.7	842.9
Scl	16.4	18.6	20.40	14.67	236.8	579.6
Ds	10.7	13.6	15.93	0.64	62.8	151.7
Cong	14.7	15.5	16.24	106.97	205.9	304.8
Swl	15.7	18.5	21.04	8.78	122.6	254.6

Stratigr. level	Min Φ	Av. Φ	Мах Ф	Min K	Av. K	Max K
Qasim	13.1	18.0	21.5	8.8	242.2	673.9
Lower Sarah	9.9	19.2	27.4	0.6	214.6	1885.7
Upper Sarah	12.5	19.4	23.7	2.9	189.3	561.5
Hawban	11.9	13.0	14.0	3.2	77.4	151.7
Ugla	22.3	22.6	23.0	527.3	580.9	634.5

Michael etal.

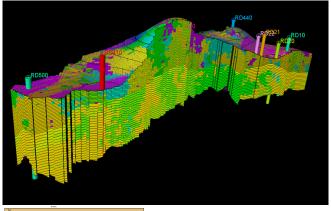
Outcrop based reservoir characterization

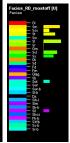




Michael etal.

Geocellular facies model



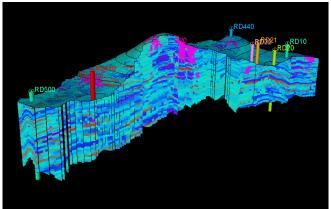


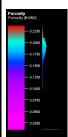


Geocellular porosity model – based on mesaured sections and photomosaics

Michael etal. Sarah Fm Analogue AAPG ACE 2015, Denver 25/29

Geocellular porosity model







Geocellular porosity model – from outcrop petrophysical data

Michael etal.

Sarah Fm Analogue

AAPG ACE 2015. Denver

Outline

Introduction

The Sarah Formation

Rational

Overview map

Methods

Results

Correlation panel

Facies associations

Sedimentological architecture

Stratigraphic architecture

Depositional model of Rahal Dhal

Reservoir characterization

Geocellular models

 The important permeability boundaries both vertically and laterally, are the Hawban Formation and the underlying Zarqa and deformed zones within the Qasim Formation.

Michael etal. Sarah Fm Analogue AAPG ACE 2015, Denver 28/29

- The important permeability boundaries both vertically and laterally, are the Hawban Formation and the underlying Zarqa and deformed zones within the Qasim Formation.
- The important surfaces are time transgressive.

Michael etal. Sarah Fm Analogue AAPG ACE 2015, Denver 28/29

- The important permeability boundaries both vertically and laterally, are the Hawban Formation and the underlying Zarqa and deformed zones within the Qasim Formation.
- The important surfaces are time transgressive.
- The depositional environments in this very complex peri-glacial coast are controlled by the dynamics of the coast and the interplay between sediment flux and relative sea-level fluctuations and which part of the system considered.

- The important permeability boundaries both vertically and laterally, are the Hawban Formation and the underlying Zarqa and deformed zones within the Qasim Formation.
- The important surfaces are time transgressive.
- The depositional environments in this very complex peri-glacial coast are controlled by the dynamics of the coast and the interplay between sediment flux and relative sea-level fluctuations and which part of the system considered.
- Apart from Zarqa facies, there is no clear evidence to show the glaciogenic origin of the Sarah Formation in the Rahal Dhab area. The creation of the valleys and the valley-fill do not have to be necessarily connected.

- The important permeability boundaries both vertically and laterally, are the Hawban Formation and the underlying Zarqa and deformed zones within the Qasim Formation.
- The important surfaces are time transgressive.
- The depositional environments in this very complex peri-glacial coast are controlled by the dynamics of the coast and the interplay between sediment flux and relative sea-level fluctuations and which part of the system considered.
- Apart from Zarqa facies, there is no clear evidence to show the glaciogenic origin of the Sarah Formation in the Rahal Dhab area. The creation of the valleys and the valley-fill do not have to be necessarily connected.
- Minimal variation in porosity and permeability between the various facies in the intervals modeled.

