Abstract

A key question that sedimentologists and stratigraphers face is, what controls sedimentary facies and grain-size trends in a depositional basin? Crucial parameters that control grain-size trends are the sediment discharged into the basin, the characteristic grain size mix of the supply, and the spatial distribution of accommodation. In this paper we present an outcrop case study of the latest Ordovician Sarah Formation, in Saudi Arabia, that represents the proximal part of a glaciogenic sedimentary system or a pro-glacial outwash fan where these parameters are quantified. In this study, we examine outcrops and glaciogenic valley fill deposits of the Sarah Formation in the Northwest of Saudi Arabia. The Sarah Formation is a glaciogenic sedimentary unit of latest Ordovician age deposited along the palaeo-Gondwana Margin and as part of the an extensive, but discontinuous belt of outcrop deposits that extend from Saudi Arabia to westernmost North Africa. This is a 600 km sedimentary system and stretches from the northern outcrop belt of Saudi Arabia to at least the borders with Iraq. This source to sink system spans a great range of depositional environments from proximal coarse sand to pebble pro-glacial outwash fan deposits to distal diamicmites and offshore fine deep marine deposits. The proximal part is an extraordinary sedimentary unit that is preserved along an elongated and complex network of palaeo-valley fill deposits. It is represented by coarse to medium sand and pebbly deposits of around 250 m thick deposited in a short time span of around 250 ky (mean sedimentation rate of 1 mm/yr). We attribute this large feature to high sediment load and bypass during the interglacial periods. We apply a source to sink approach to calculate the volume of bypassed sediment from specific regions to deposit and preserve the high abundance of coarse grained sediment. We consider controls on the sedimentary architecture with respect to observed grain sizes. We present a model of the evolution of this sedimentary system based on sedimentological and provenance work that includes petrography, heavy mineral analysis, and zircon U/Pb geochronology, both in outcrop and core from wells. In addition to provenance, we try to map out sedimentary fairways from seismic regional lines. In this study we teleconnect, reconstruct, and calculate sediment budgets for the sedimentary system from the outcrop to the subsurface.
References Cited


Source to Sink Analysis of the Sarah Formation, Latest Ordovician, NW Saudi Arabia

N. Michael*, C. Allen*, Y. Xu*, C. Saragiotis*, E. Garzanti†, P. Vermeesch‡, S. Shammari*, P. Allen††

*Saudi Aramco, †University of Milano Bicocca, ‡UCL, ††Imperial College London

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Outline

Introduction
   The Sarah Formation
   Controls on sedimentary systems
   Motivation

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Rahal Dhab palaeo-valley
   Sedimentology
   Correlation panel

Results
   Volumetric calculations from the whole basin
   Sedimentary fairway provenance work and seismic mapping
   Volumetric calculations from Rahal Dhab
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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 glaciogenic erosional unconformity that cuts down into Qasim Fm and in turn is overlain by the Qalibah Formation
Study area and Sarah FM outcrop distribution
Sediment routing systems

Model of functioning of a sediment routing system

Sedimentary fairway
Catchment regions

S3 Segment of the sediment routing system
Q3 Sediment surface flux between each segment

Sediment routing system: all the processes of erosion, sediment transport and dispersal along the sedimentary fairway.
Sediment routing systems

Allen & Allen 2013

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Reconstructing such a system is the first step into modelling it.
Mass balance coordinates $\chi$

**Mass balance (MB):**

$$\chi(x) = \frac{\text{dep. volume}}{\text{total sediment budget}}$$

**Grain size specific MB (e.g. gravel):**

$$\chi(x)g = \frac{\text{dep. vol. of gravel}}{\text{total dep. gravel}}$$

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**Assumptions:**
- Sediment budget of unit 1 is two times bigger than units 2 & 3.
- Units 1, 2 & 3 have exactly the same grain size mix.

**Theoretical grain size trends depend on basin shape.**

**Grain size trends do not depend on basin shape.** Units 2 & 3 are very similar due to equal sediment budget. Unit 1 has double the volumetric budget and thus, half the fining rate.

**Grain size trends depend neither on basin shape, nor on Volumetric budget.**
Grain size trends from the 3 units collapse into 1 theoretical trend.
Motivation

• In outcrop, the Sarah Formation (Fm) is an extraordinary sedimentary unit, preserved along an elongated and complex network of palaeo-valley fill deposits.

• Represented by coarse to medium sand and pebbly deposits of around 250 m thick deposited in a short time span of around 1 Myr (mean sedimentation rate of 0.25 mm/yr).

• High sediment loads and high rates of bypass occurred during interglacial periods.

• Apply a source to sink approach to calculate how much is bypassed and discharged from outcrop to the subsurface and how it compares with other units.

• These rates can be used to understand the controls on grain size architecture.
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- Outcrop data
  - Sedimentology
  - Provenance work
- Subsurface work
  - 2D-seismic interpretation and mapping
  - Wells and core
- Volume calculations from outcrop and subsurface
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Facies associations

Sarah fm

Sch/Spp

Ssh

50m

Sch

5m

Michael et al.

Sarah Fm source to sink

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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
General architecture

- 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)
Rahal Dhab PV: Correlation panel

Basal erosional surface

Topographic surface
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Volumetric profile of Rahal Dhab

Volumetric profile

- Sand
- Fines

Grain size mix:
- Cs 4%
- MS 17%
- Fs 77%
- Silt 2%
- Mud 0%
- Gr 0%

Total Volume = 130 km³

Distance Downstream (km)

Cross-sectional Area (km²)
Provenance work

Sarah Sections

GEOLOGIC DESCRYPTION
- Unknown
- Quaternary Sand
- Quaternary Gravel 1 (CQP 1)
- Quaternary Gravel 2 (CQP 2)
- Holocene Unit
- Danian Formation
- Tertiary Rocks Unit
- Lower Eocene Rattlesnake Formation
- Arara Formation
- Wetalk Formation
- Menel Formation
- Menel Sandstone
- Jill Formation
- Sudal Formation
- Kuhl Formation
- Sutaka Sandstone (Jubail)
- Seal Formation
- Tread Formation
- Tabuk Formation (Qattara)
- Mubak Sandstone
- Pre-Cambrian Shield (Basement)
- Quaternary Volcanics
Seismic fairway map, base Sarah
Seismic interpretation and fairway mapping
Sediment fractionation

- Lithofacies profile from proximal to distal.
- Conglomerate fraction stays at \(\approx 5\%\) of the total
- Sand from 95\% to 40\%
- An increase in sand at \(\approx 300\) km
Volumetric calculations

- Mapped the extent of the system
- Assumed one-origin model
- Calculated volume incrementally from origin to $D = L$
Cumulative volumes and sediment fluxes of the Sarah Fm

- **Total volume:** $1.99 \times 10^5 \text{ km}^3$
- **Duration:** 1 Ma
- **Sedimentation discharge:** $\approx 2 \times 10^4 \text{ km}^3\text{Ma}^{-1}$
- **Contributing palaeovalleys:** 16
- **Discharge:** 250 $\text{km}^3\text{Ma}^{-1}$ per palaeovalley
Comparison with Qasim Fm and Eocene Escanilla Fm

- **Total volume:** $3.15 \times 10^5 \text{ km}^3$
- **Duration:** 30 Ma
- **Sedimentation discharge:** $\approx 1050 \text{ km}^3\text{Ma}^{-1}$
- The Escanilla Fm (an Eocene sedimentary system in the active Pyrenees) showed sediment discharges from 250–670 km$^3$Ma$^{-1}$
Conclusions

- In outcrop, the Sarah Formation has as much as 90% of sand with a total sediment volume of $130 \text{ km}^3\text{Ma}^{-1}$.
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- Spatial distributions of the Qasim and Sarah Formations show a slight shift of the depositional locus in the Sarah Formation.
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- A high percentage of sand in outcrop was due to very high sand grain size fraction in sediment load and the environments of deposition at the outcrop level.
- Spatial distributions of the Qasim and Sarah Formations show a slight shift of the depositional locus in the Sarah Formation.
- During Sarah Formation sediment discharge doubled.
- Each palaeovalley contributed $\approx 250$ km$^3$Ma$^{-1}$ low compared with active orogen sediment discharges.
Thank you!