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

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Search and Discovery Article #51186 (2015)**
Posted October 19, 2015

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

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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 glacigenic sedimentary system or a pro-glacial outwash fan where these parameters are quantified. In this study, we examine outcrops and glacigenic valley fill deposits of the Sarah Formation in the Northwest of Saudi Arabia. The Sarah Formation is a glacigenic 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 diamictites 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.

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AAPG ACE 2015, Denver

Outline

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Introduction
- The Sarah Formation
- Controls on sedimentary systems
- Motivation

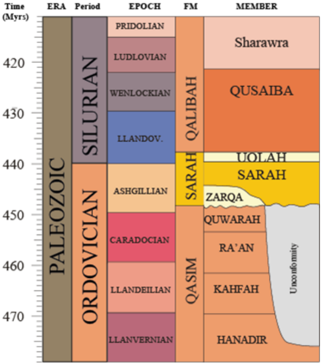
Methods

Rahal Dhab palaeo-valley
- Sedimentology
- Correlation panel

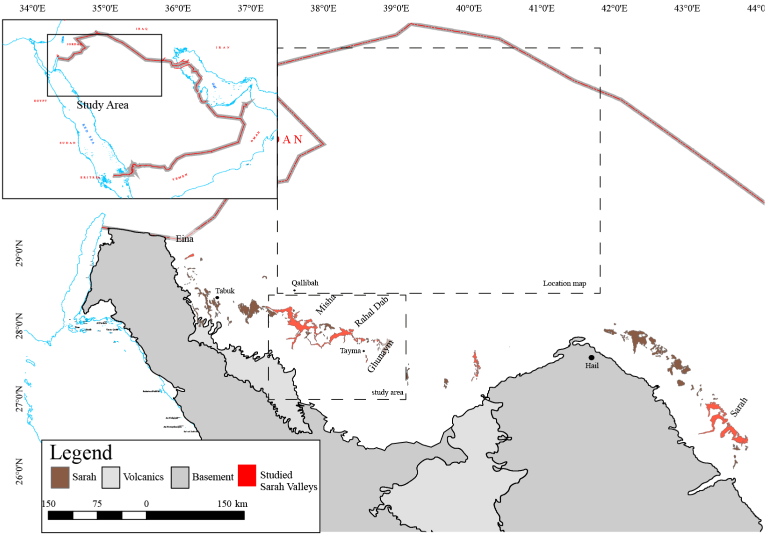
Results
- Volumetric calculations from the whole basin
- Sedimentary fairway provenance work and seismic mapping
- Volumetric calculations from Rahal Dhab

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 Fm and in turn is overlain by the Qalibah Formation

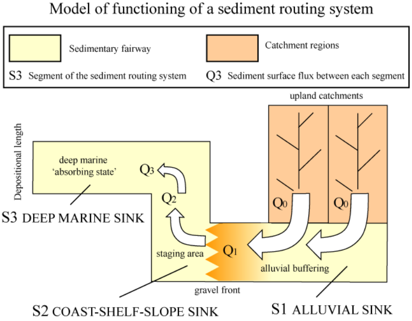


Study area and Sarah FM outcrop distribution



Sediment routing systems

Allen & Allen 2013



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

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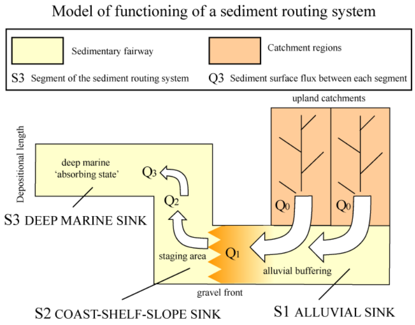


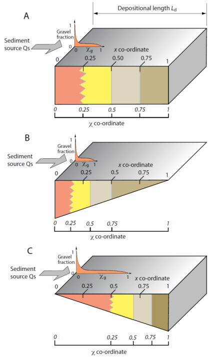
Sediment routing system: all the processes of erosion, sediment transport and dispersal along the sedimentary fairway.

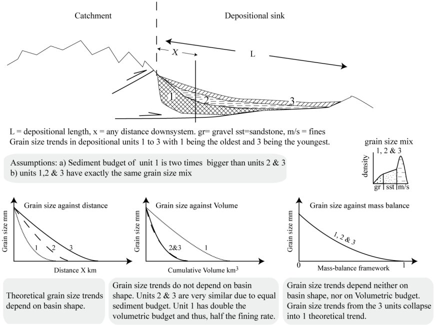
Reconstructing such a system is the first step into modelling it.

Mass balance coordinates χ

Michael et al., 2013, Strong & Paola 2005

Michael (PhD thesis) 2013





Mass balance (MB):

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

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

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

Motivation

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- These rates can be used to understand the controls on grain size architecture.

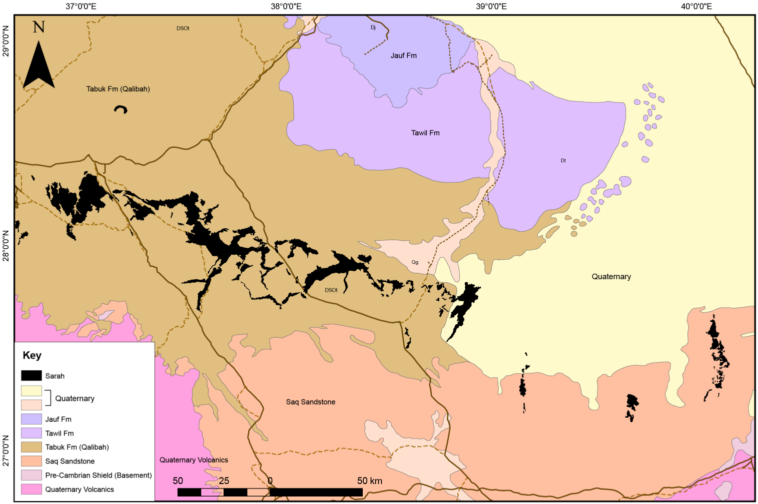
Outline

Methods

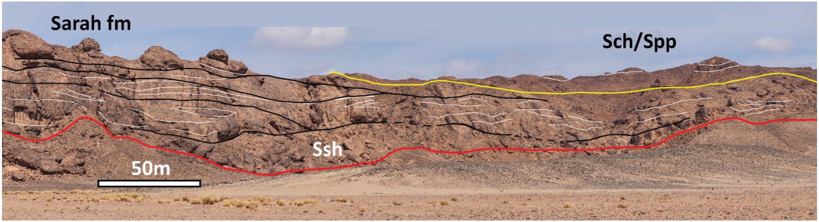
- Outcrop data
  - Sedimentology
  - Provenance work
- Subsurface work
  - 2D-seismic interpretation and mapping
  - Wells and core
- Volume calculations from outcrop and subsurface

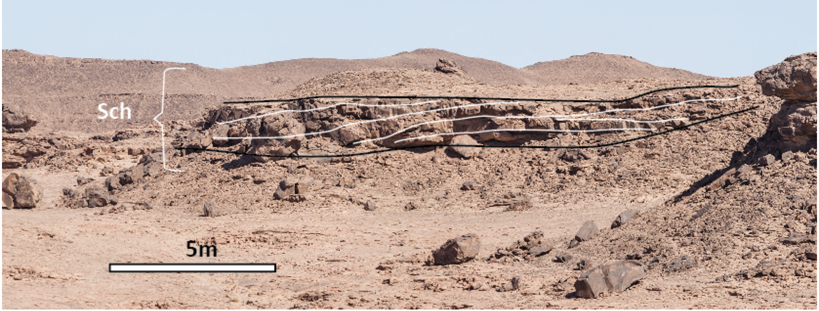
Outline

Rahal Dhab palaeo-valley location

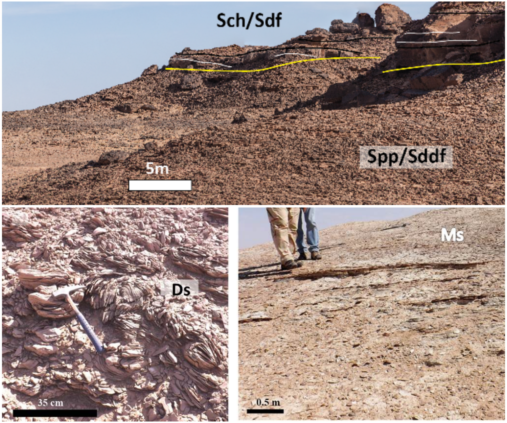


Facies associations



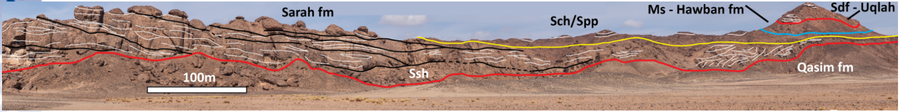


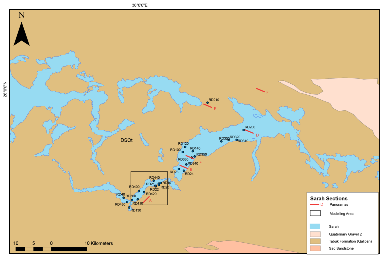
Facies associations Spp/Ds/Ms



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

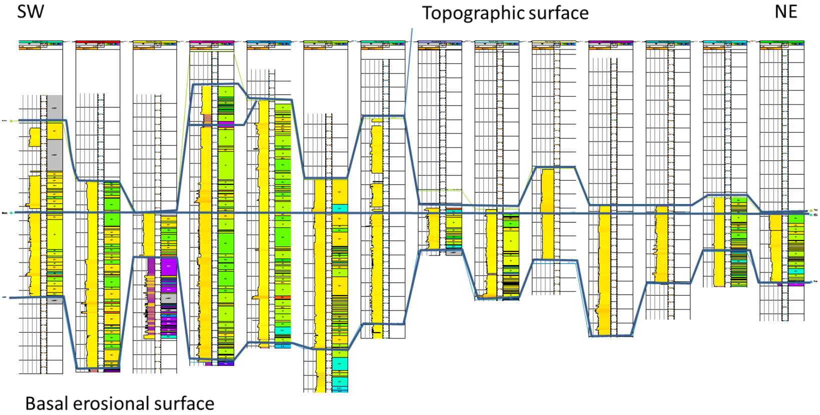
General architecture





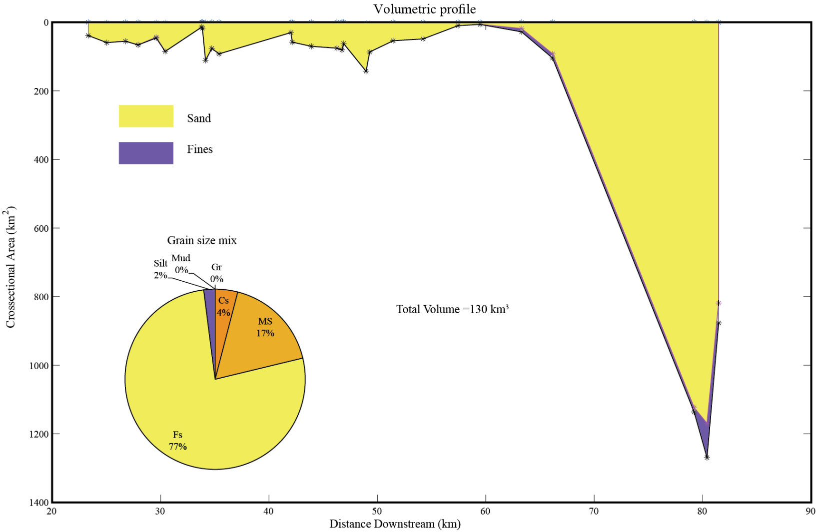
- Qasim Fm —represents a lower shoreface environment
- Erosional unconformity (red line)
- Lower Sarah Formation dominated by Ssh
- Upper Sarah Formation dominated by Sch/Spp
- Flooding surface coincides with top of Sarah (blue line) — Hawban Fm
- Overlain by sequence boundary (red line)

Rahal Dhab PV: Correlation panel

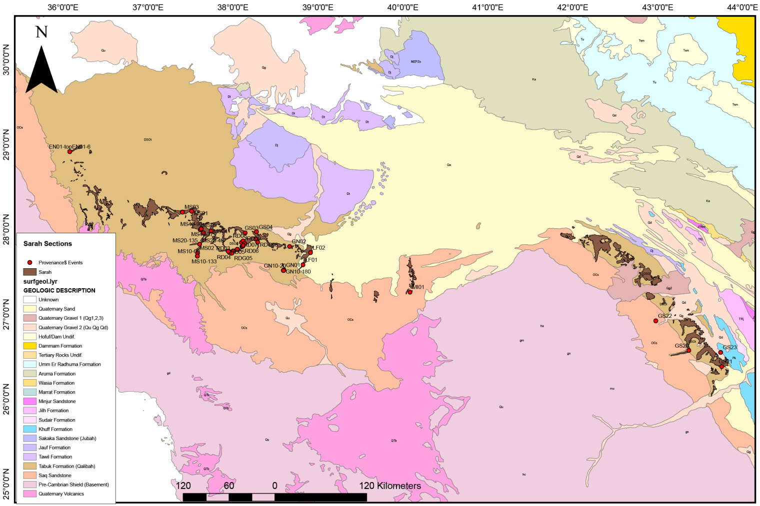


Outline

Volumetric profile of Rahal Dhab



Provenance work



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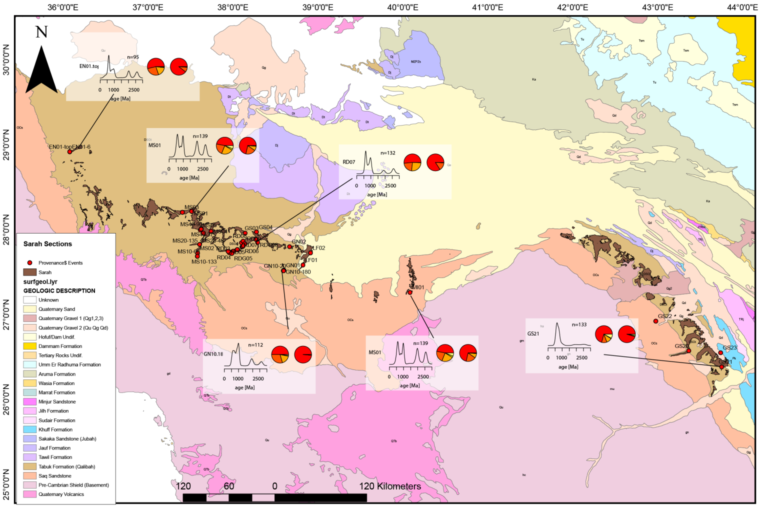
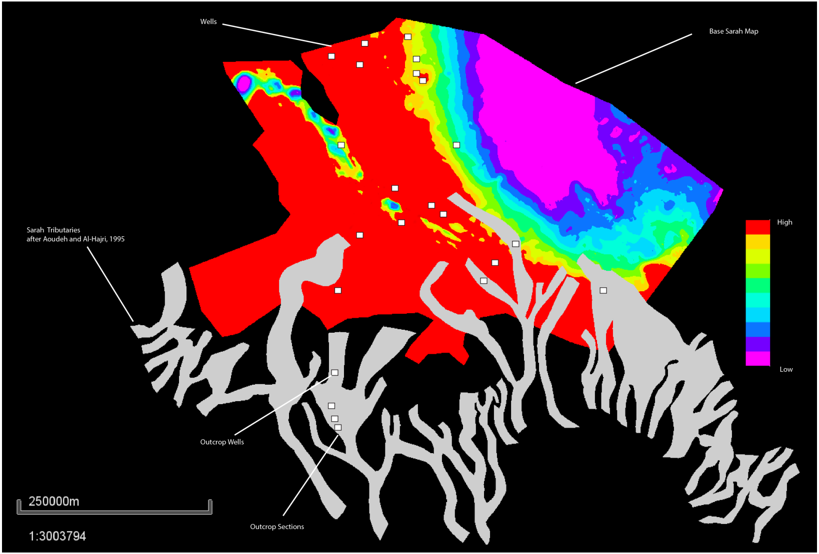
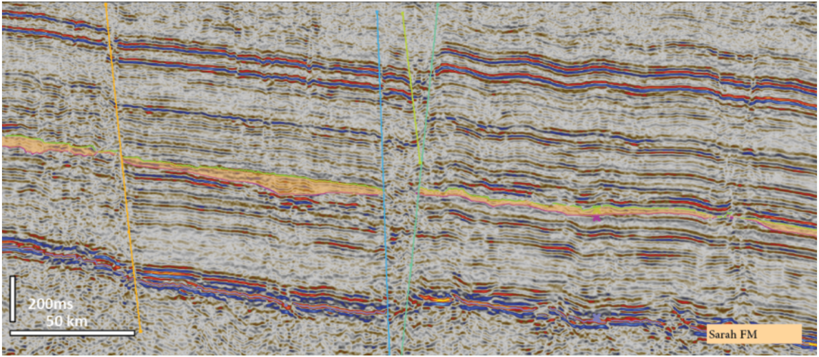


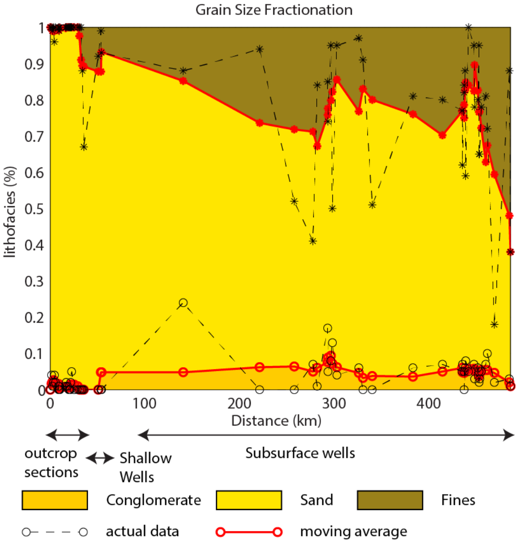
Seismic fairway map, base Sarah



Seismic interpretation and fairway mapping



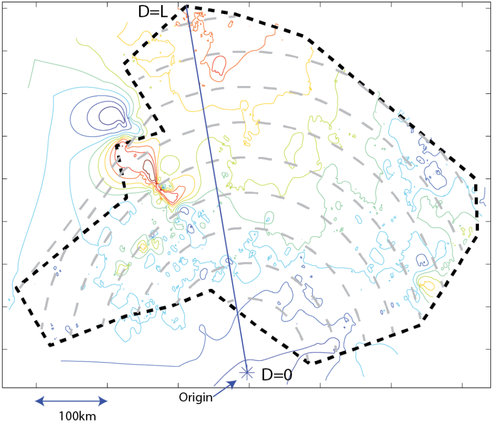
Sediment fractionation



- Lithofacies profile from proximal to distal.
- Conglomerate fraction stays at ≈5% of the total
- Sand from 95% to 40%
- An increase in sand at ≈300 km

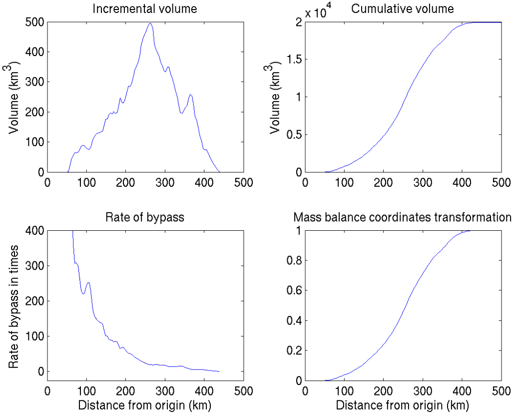
Volumetric calculations

Sarah Formation Sedimentary fairway



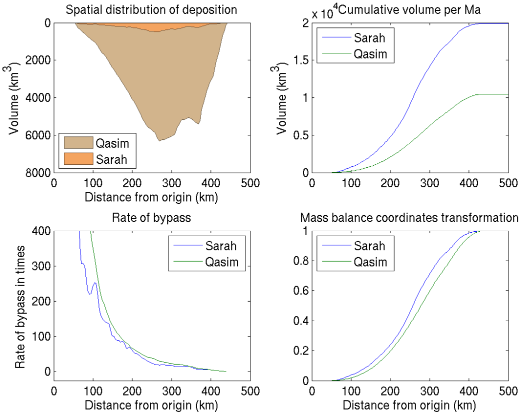
- Mapped the extent of the system
- Assumed one-origin model
- Calculated volume incrementally from origin to $D = L$

Cumulative volumes and sediment fluxes of the Sarah Fm



- Total volume: 1.99×10^5 km^3
- Duration: 1 Ma
- Sedimentation discharge: $\approx 2 \times 10^4$ km^{3}Ma^{-1}
- Contributing palaeovalleys: 16
- Discharge: 250 km^{3}Ma^{-1} per palaeovalley

Comparison with Qasim Fm and Eocene Escanilla Fm



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

Conclusions

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- 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!