Geometry, Spatial Arrangement and Connectivity of Grain-Dominated, Storm-Event Deposits in Outcrop Analogues of Upper Jurassic Arab-D Reservoir, Saudi Arabia*

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Abstract

The Upper Jurassic Arab-D reservoir, composed of the Arab-D Member of the Arab Formation and upper part of the underlying Jubaila Formation, is highly prolific in several supergiant oil and gas fields in the Middle East. An outcrop analogue of equivalent age in central Saudi Arabia shows depositional facies and stratigraphic architecture that are similar to those inferred in the subsurface. This analogue has been studied using a high-resolution digital outcrop model integrated with measured sections, in order to understand and quantify facies relationships in storm-dominated, shallow-marine carbonates. Outcrops of the lower to middle Arab-D reservoir reveal a succession of interbedded, muddy and grainy rocks that occur as a series of thin (0.5–1 m) fining-upward cycles. Cycles typically comprise a coarse-grained grainstone-to-rudstone lower part that contains muddy intraclasts and, locally, stromatoporoid and coral fragments, and that fines upward into a wackestone cap. The finer portions of these cycles are bioturbated, and swaley cross-stratification occurs locally in both mud- and grain-dominated beds. Cycles are separated by sharp-to-erosional bases of varying relief, which cause cycle thickness to vary laterally. Locally, 1–3-m thick chaotically bedded conglomeratic intervals containing overturned stromatoporoid and coral clasts up to 1 m in diameter infill scours with steep-to-vertical walls that incise several meters into underlying deposits. The fining-upward cycles are interpreted to result from storm events that locally scoured and reworked sediments. The occurrence of swaley cross-stratification suggests deposition below fair weather wave base but above storm wave base. Larger storm events produced steep-sided scours that were filled by conglomeratic debris transported offshore from shallower water settings. Storm-event deposits vary laterally and vertically in their geometry, spacing and connectivity. Few coarse-grained beds extend across outcrop (<1 km) but instead pinch-out laterally. Their lateral extent and degree of vertical amalgamation is controlled by erosional relief and paleotopography at bed boundaries. Conglomeratic scour fills show symmetrical and asymmetrical cross-sectional profiles, implying 3D variation in scour geometry and orientation. The heterogeneity observed in these outcrops has implications for the identification and correlation of reservoir flow units between wells and for the effective properties of the flow units.

References Cited

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Handford, C.R., D.L. Cantrell, and T.H. Keith, 2002, Regional facies relationships and sequence stratigraphy of a super-giant reservoir (Arab-D Member), Saudi Arabia, *in* J. M. Armentrout, editor, Sequence Stratigraphic Models for Exploration and Production: Evolving Methodology, Emerging Models and Application Histories: 22nd Annual Bob F. Perkins Research Conference: Gulf Coast Section SEPM, p. 539–564.

Lindsay, R.F., D.L. Cantrell, G.W. Hughes, T.H. Keith, H.W. Mueller, and S.D. Russell, 2006, Ghawar Arab-D reservoir: Widespread porosity in shoaling upwardcycles, Saudi Arabia, *in* P.M. Harris and L.J. Weber, editors, Giant Hydrocarbon Reservoirs of the World: From Rocks to Reservoir Characterization: AAPG Memoir 88, p. 97–138.

Geometry, spatial arrangement and connectivity of grain-dominated, storm-event deposits in outcrop analogues of Late Jurassic Arab-D reservoir, Saudi Arabia

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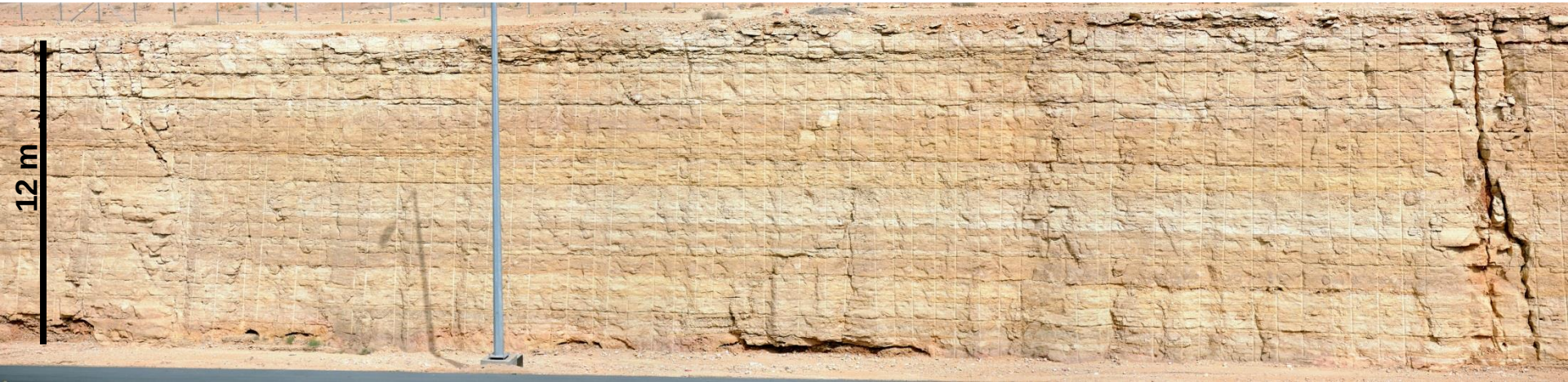
Motivation

- Cores of lower Arab-D reservoir zones show rudstone intervals that are interpreted as storm reworking (Lindsay, 2006)
- Potentially great heterogeneity
- Uncertainty in lateral continuity, geometry, dimensions and distribution of rudstones

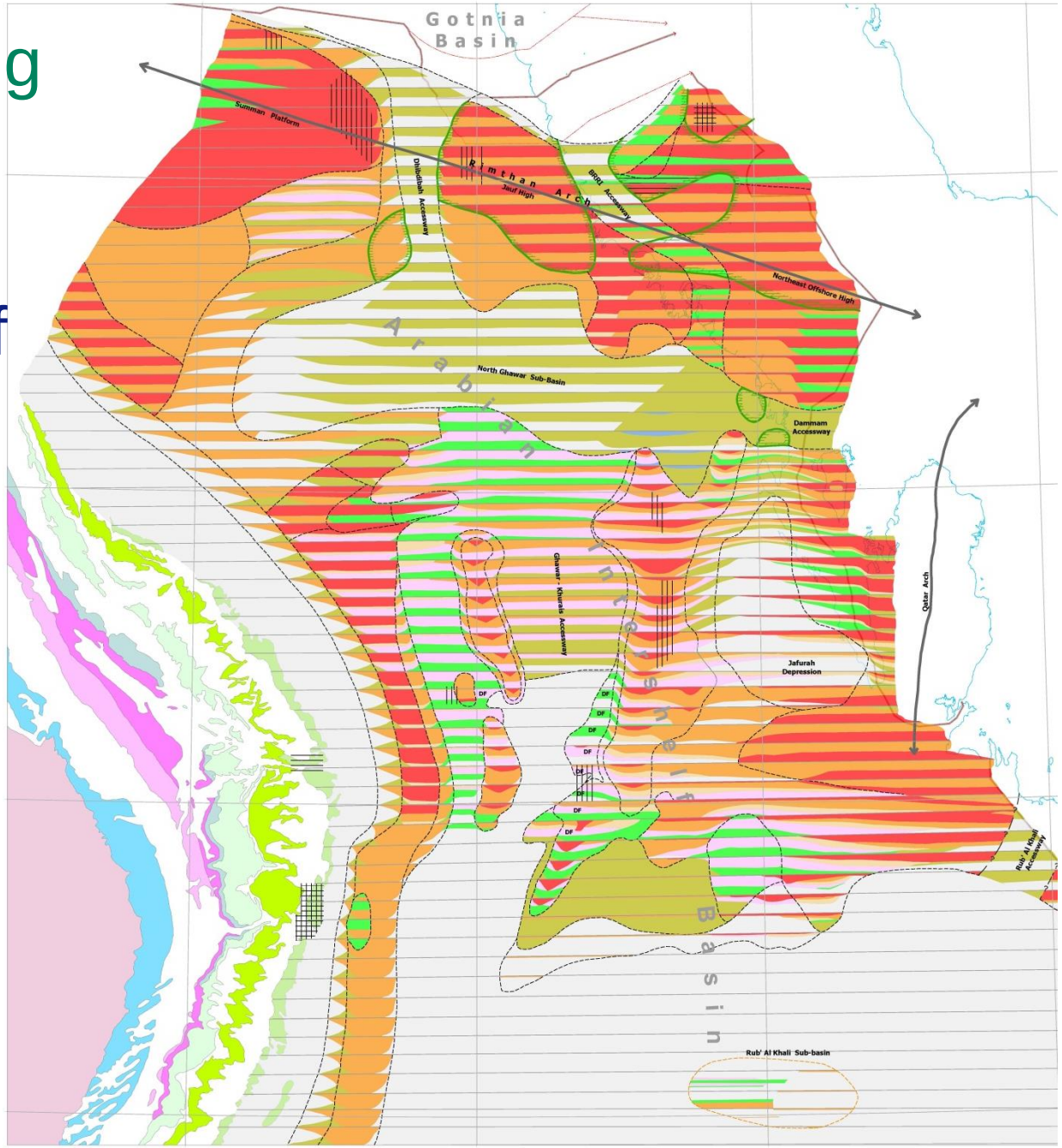


Aims

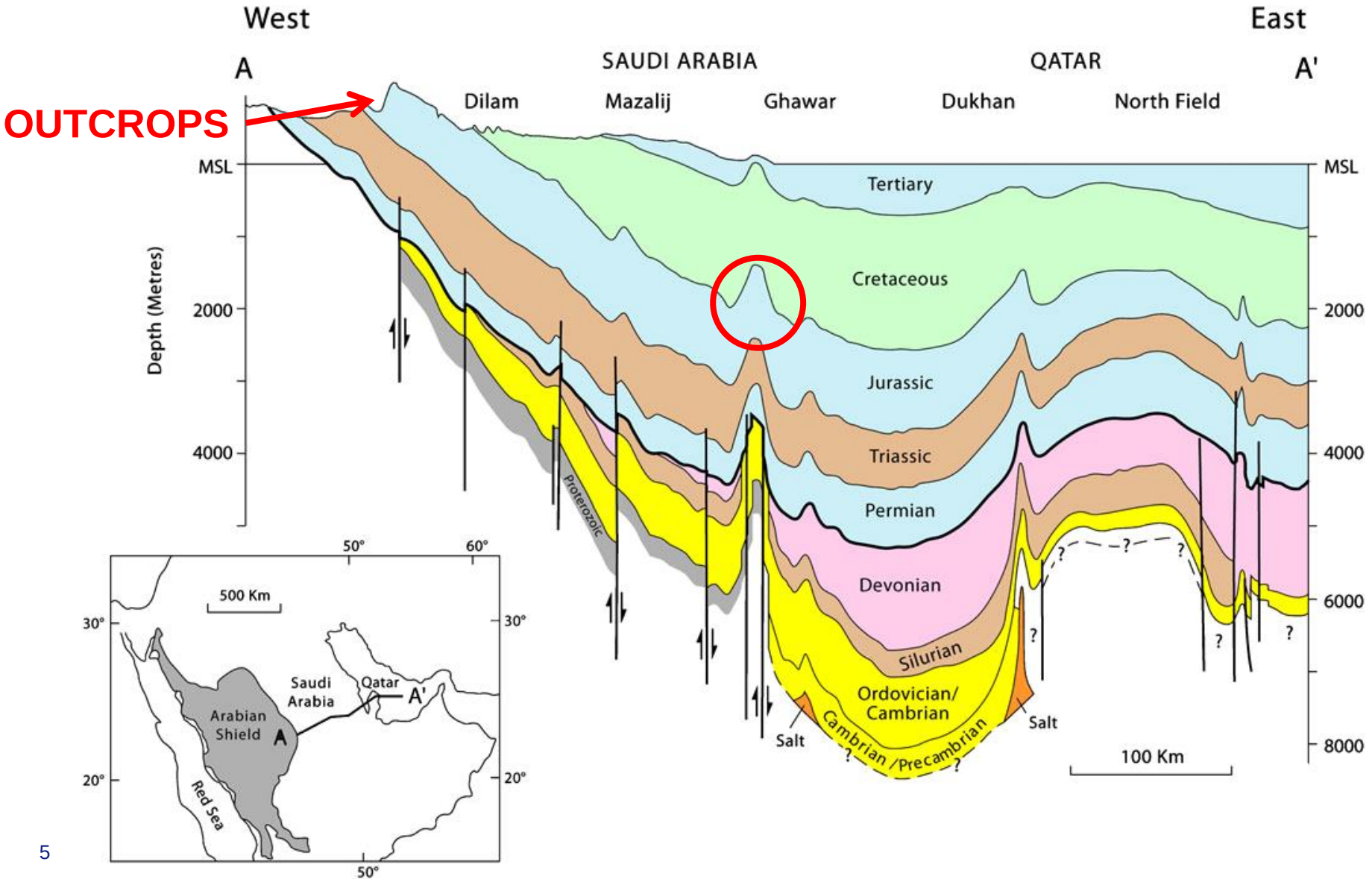
- Quantify the geometry, lateral continuity and spatial distribution of rudstone intervals exposed at outcrop
- Consider implication for flow

Geological setting

- Late Jurassic
- Carbonate shelf (1000x2000 km)

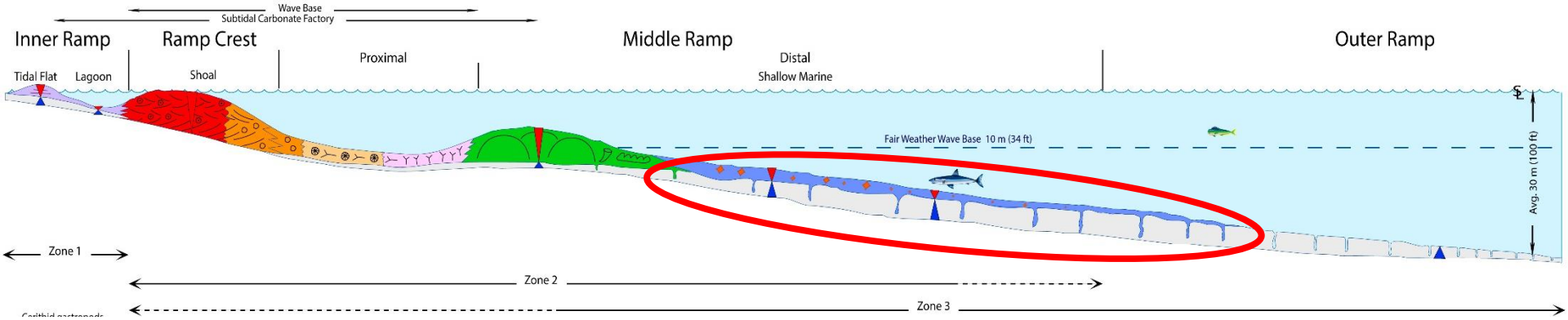


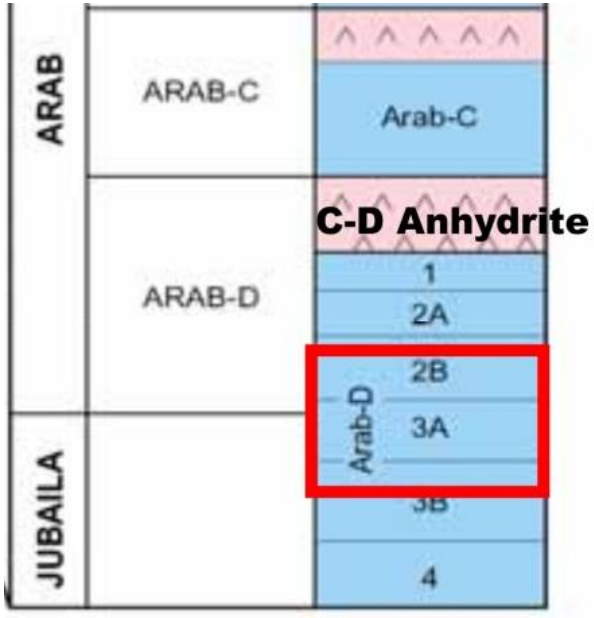
Geological setting

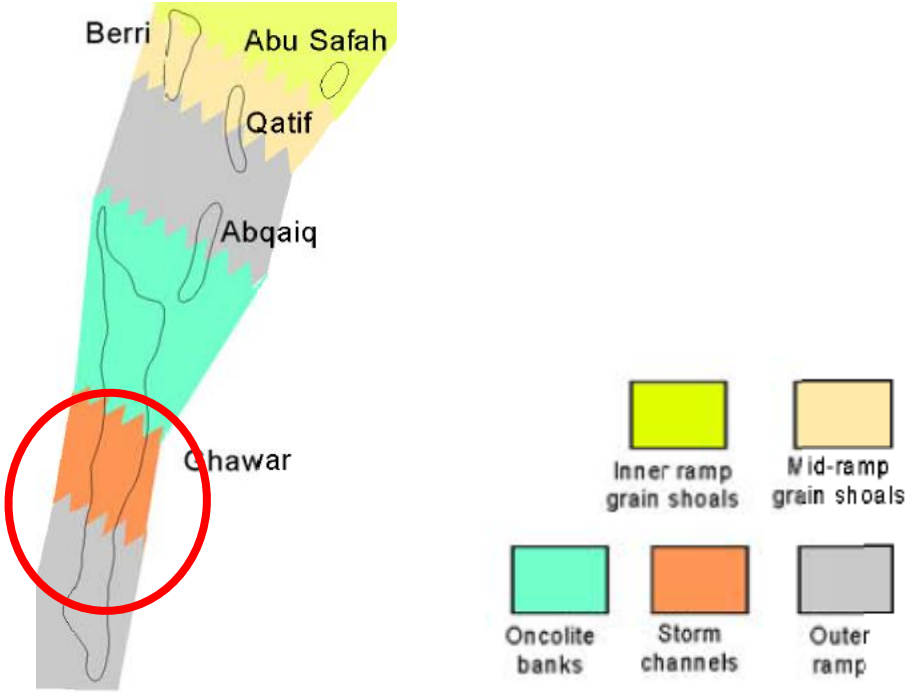


Glennie 2010

Carbonate shelf



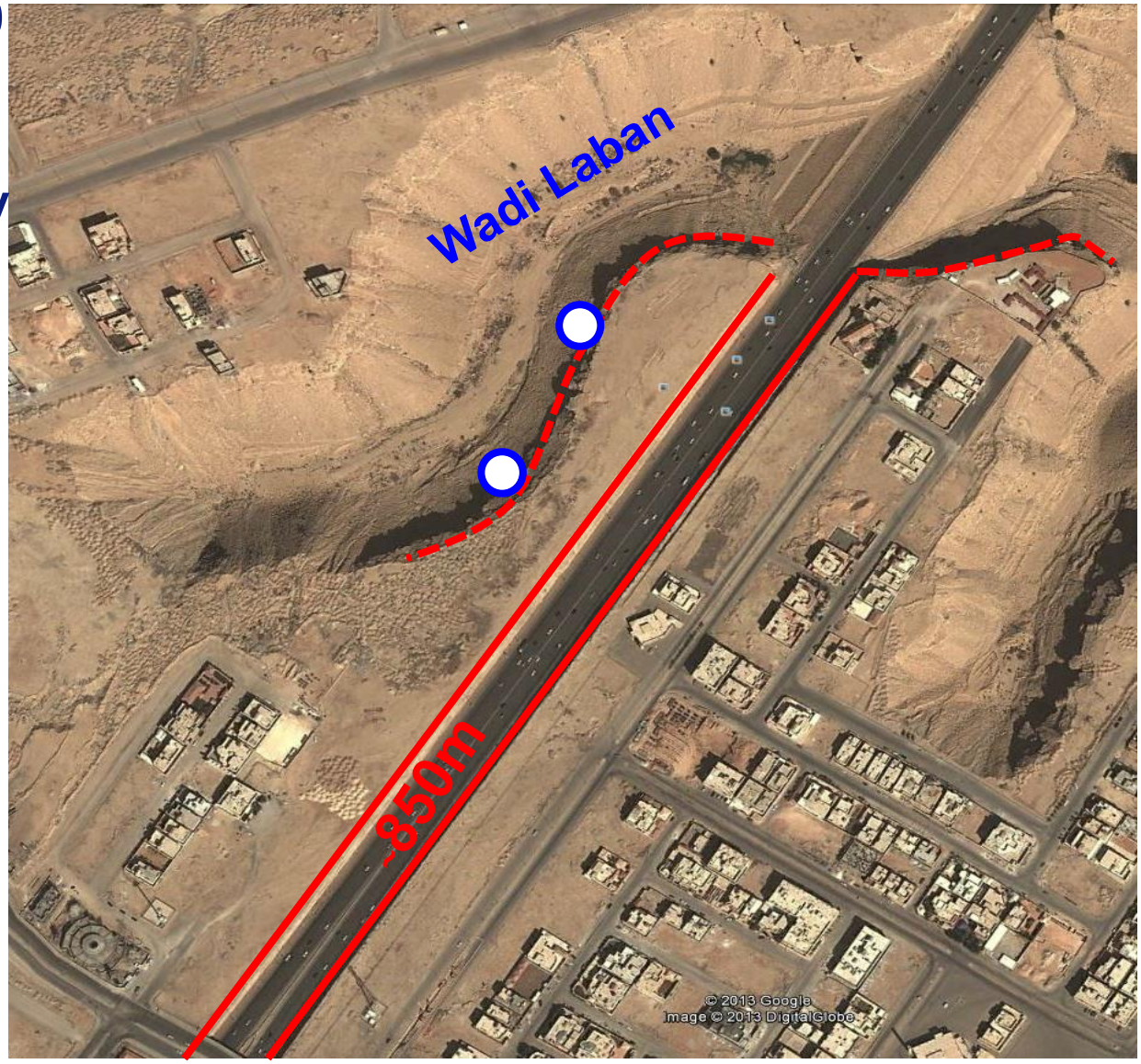




Handford (2002); Lindsay et al. (2006)

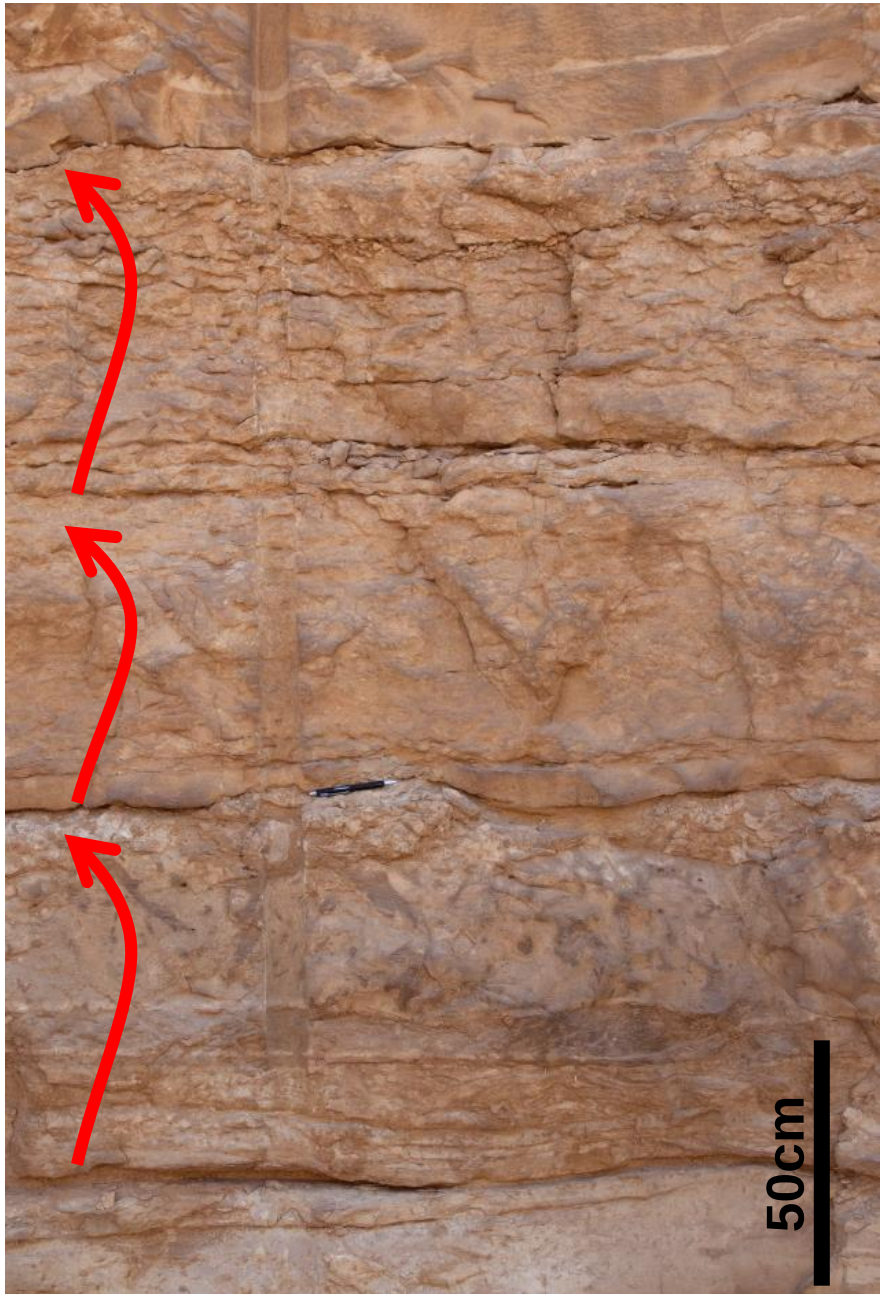
Methodology

- digital outcrop model
- 4 sedimentary logs

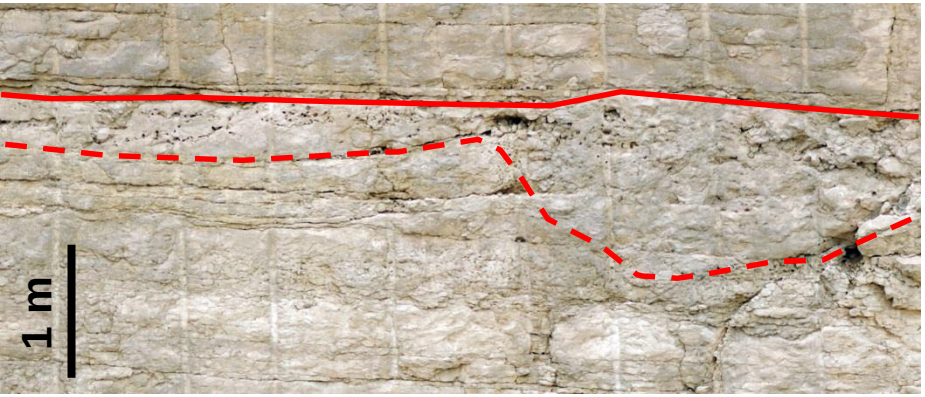


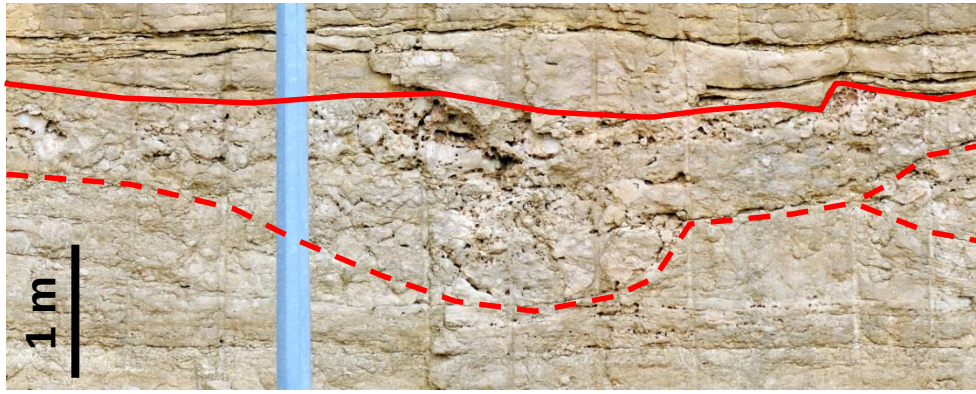
Storm deposits

- Fining upward cycles
  - Base: Swaley cross stratified packstone
  - Fines into wackestone
  - Firmground cap
- Extensive bioturbation in upper part of cycles



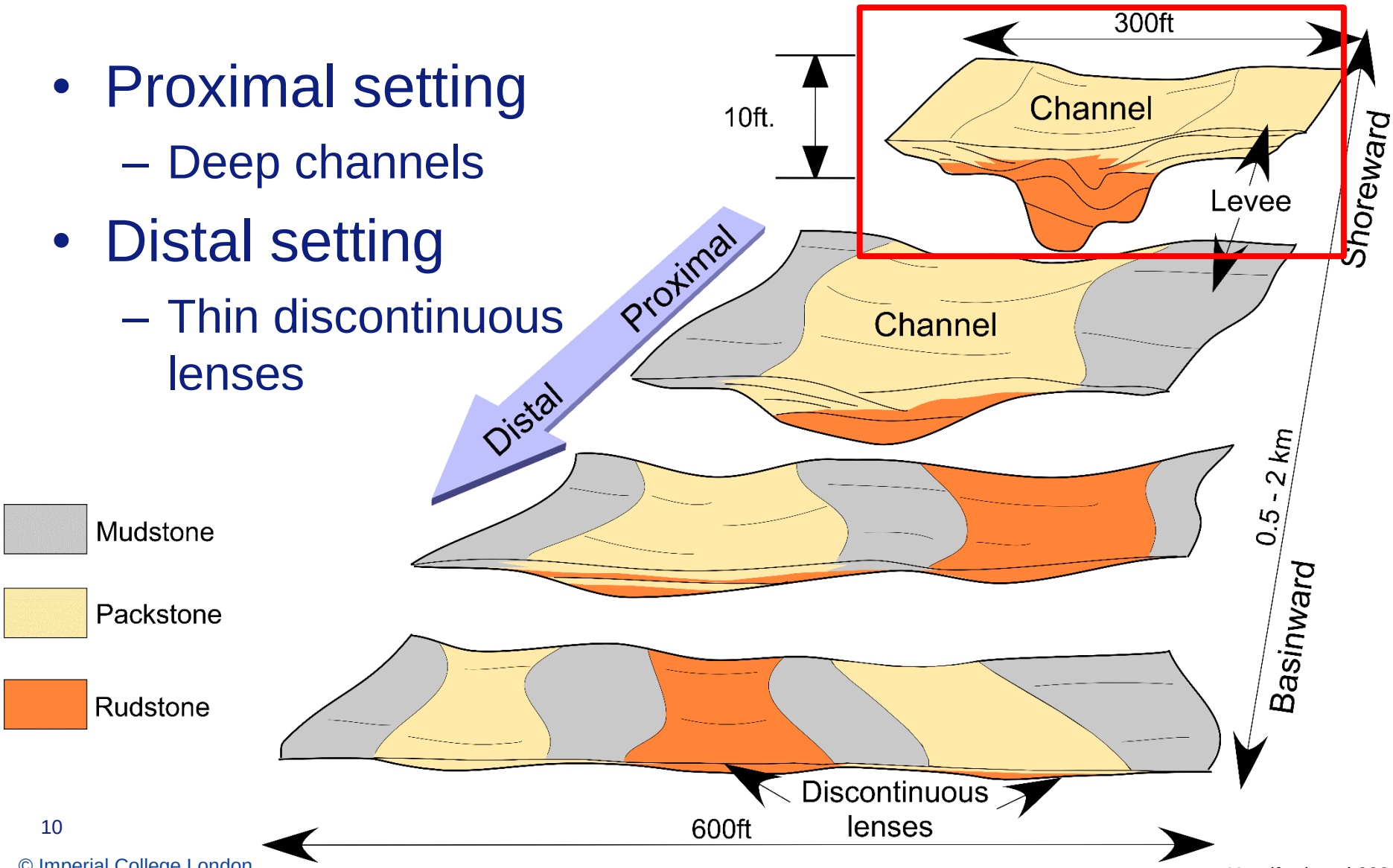
Rudstone scours





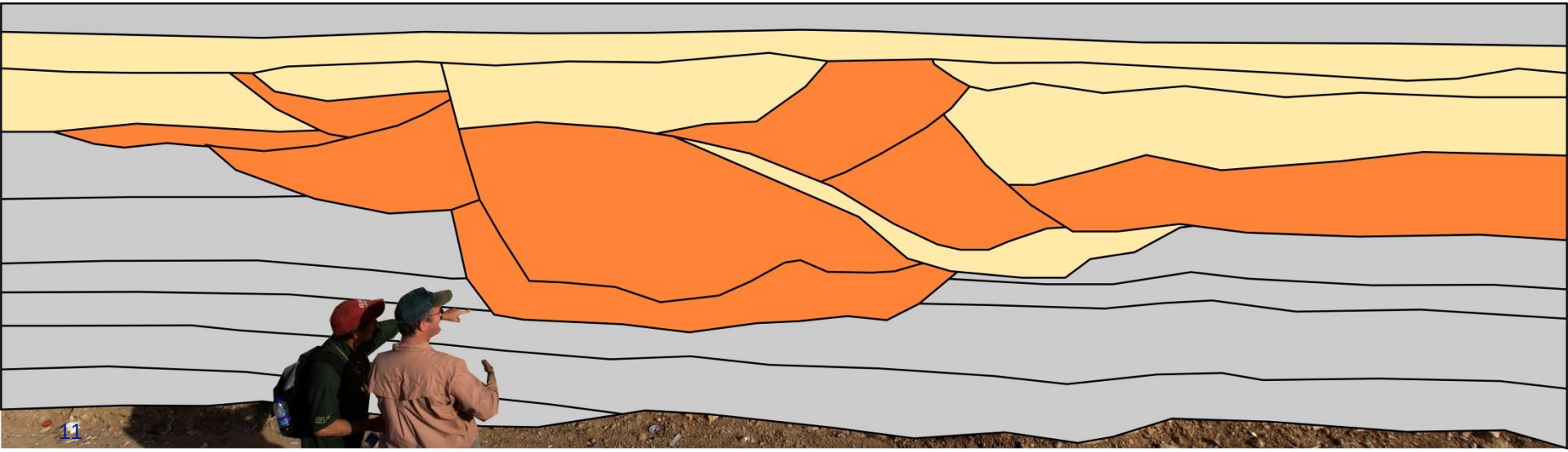
Storm Channels

- Proximal setting
  - Deep channels
- Distal setting
  - Thin discontinuous lenses



Handford et al 2002

Storm Channels



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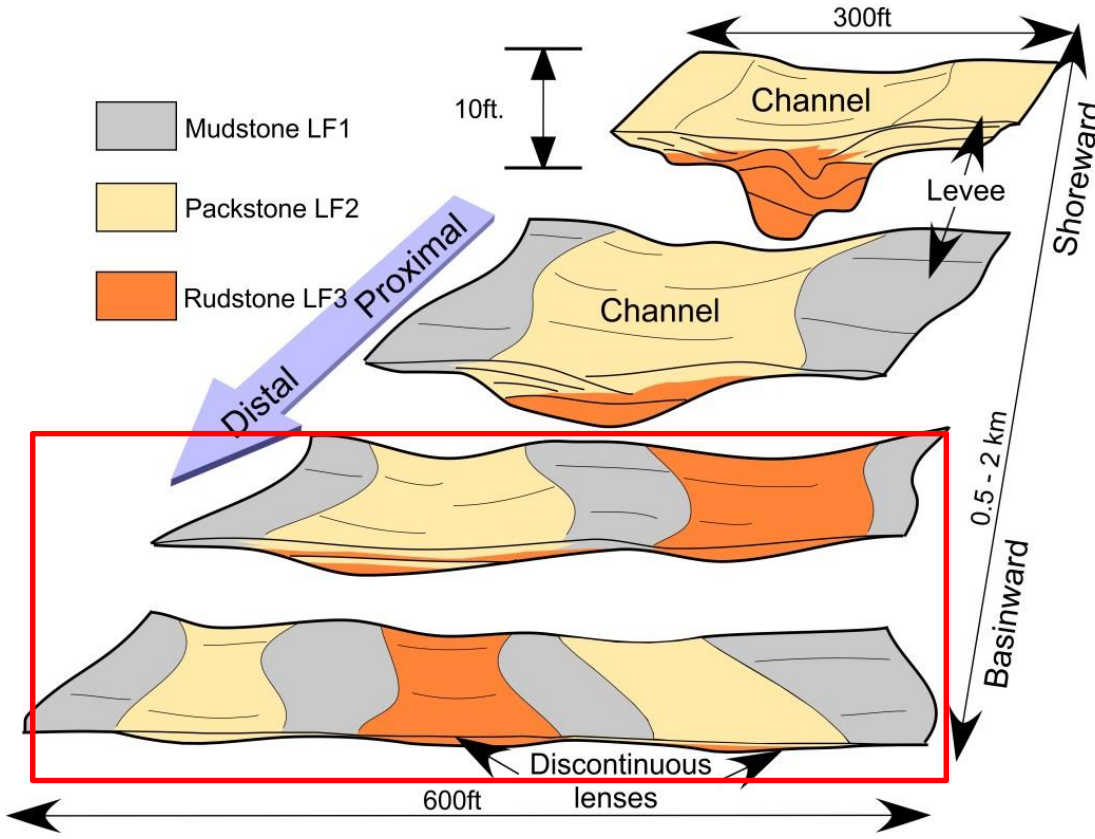
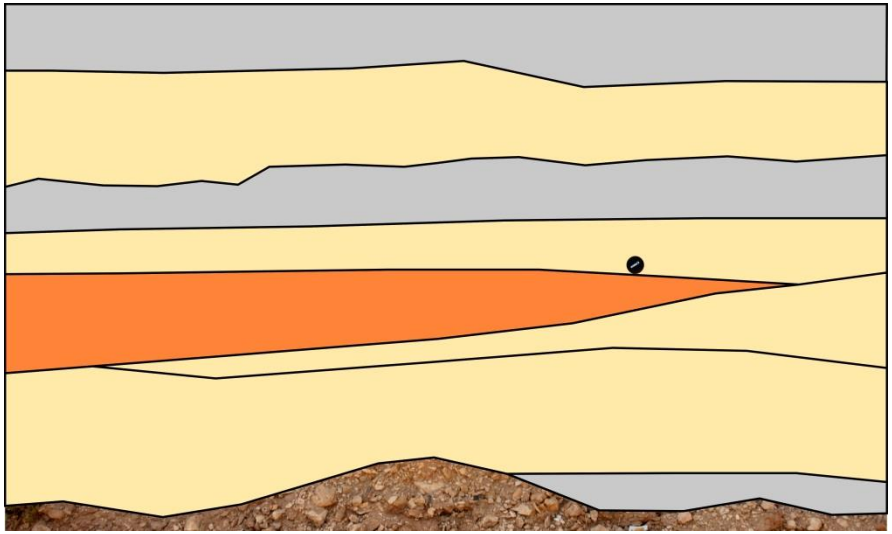
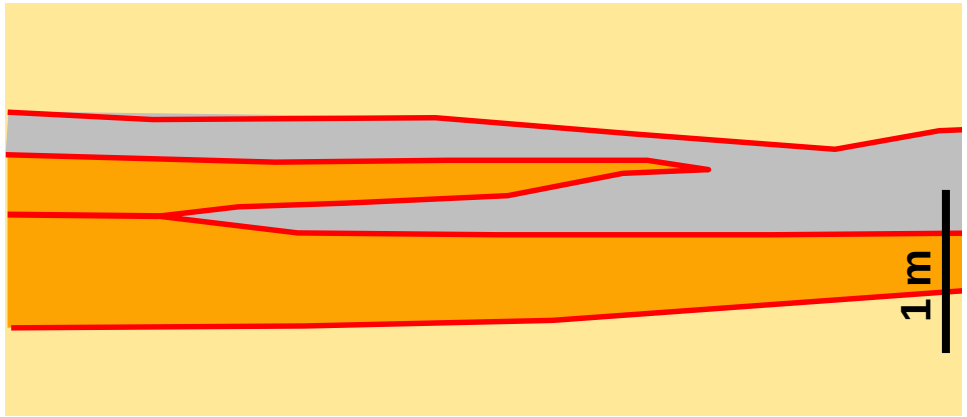


Handford et al 2002

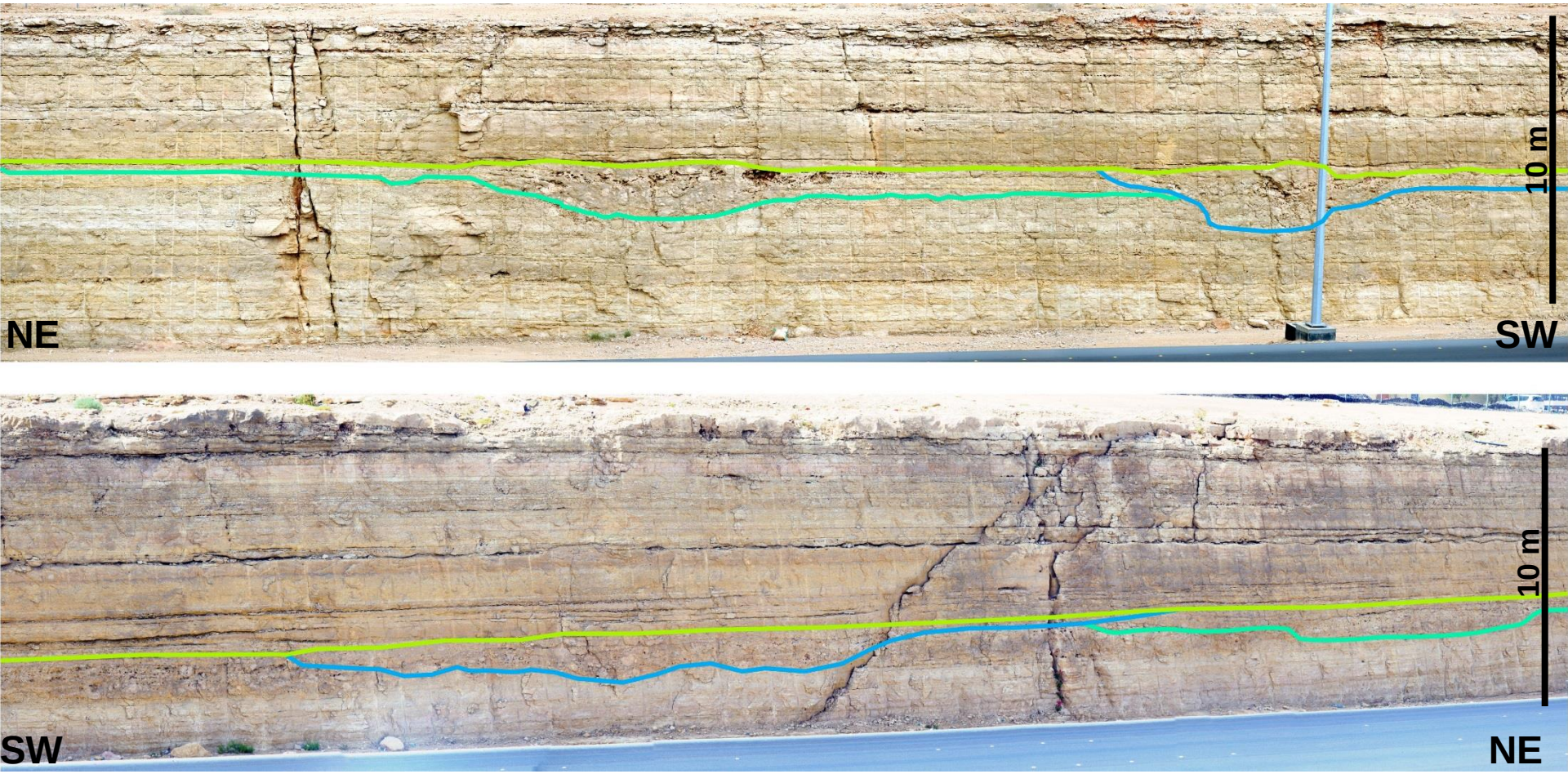


Lateral connectivity

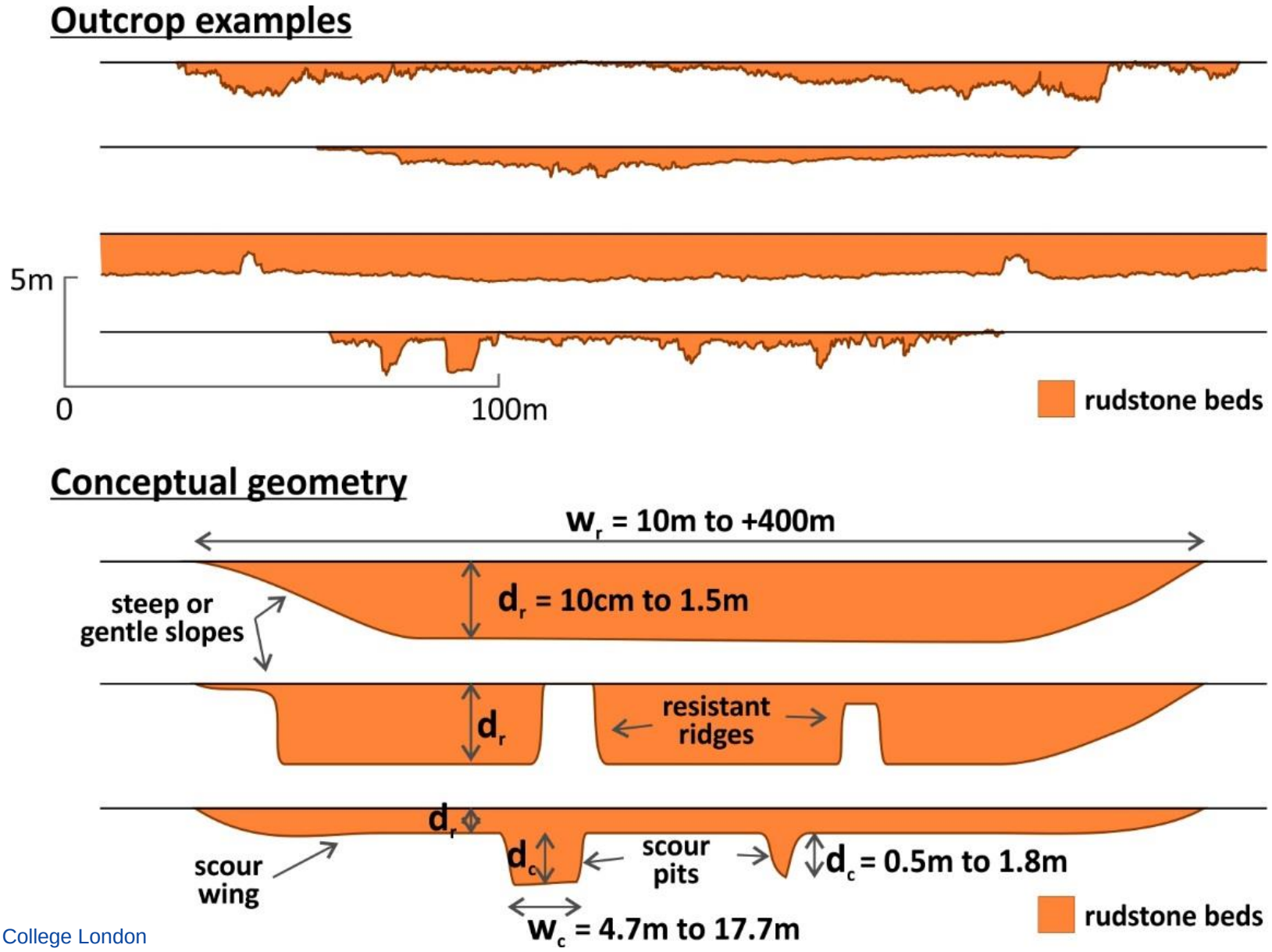
- Grain-dominated portion of cycles pinch out
- Rudstones are not continuous



Scour 2D geometry

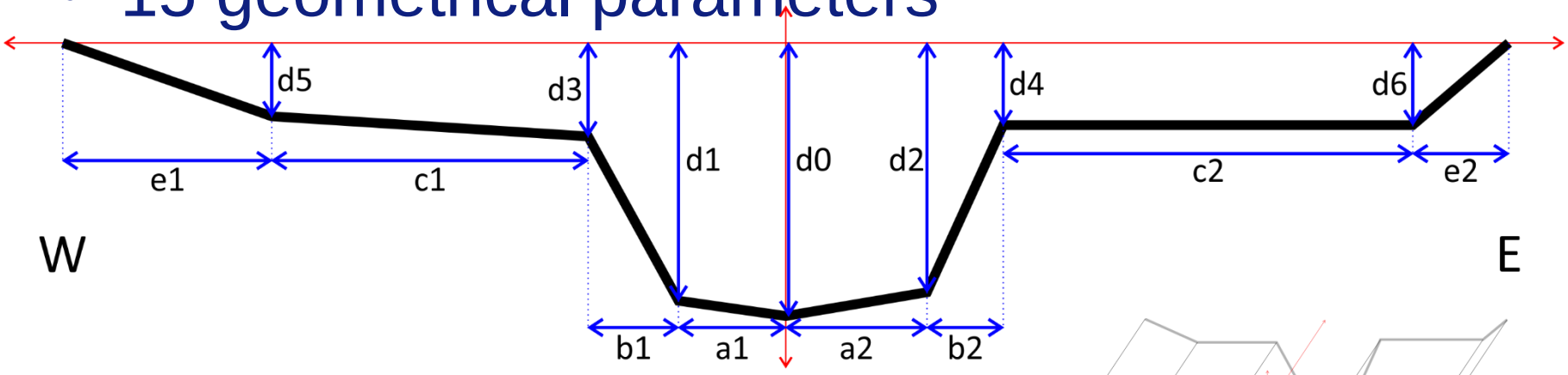


Rudstone beds – conceptual geometry

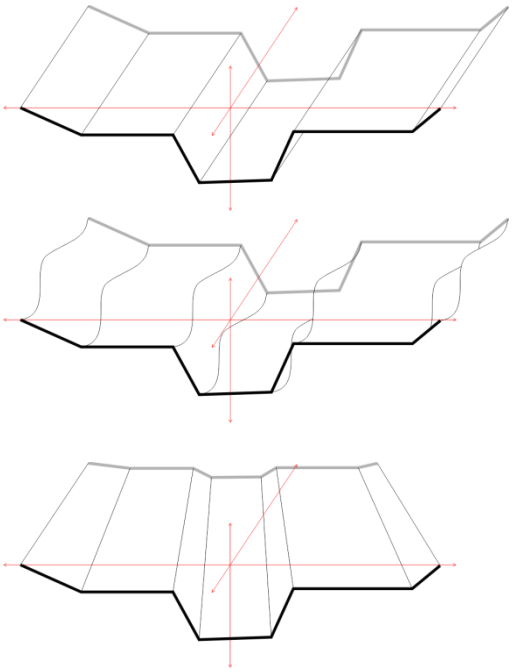


Modelling 2D scour geometries

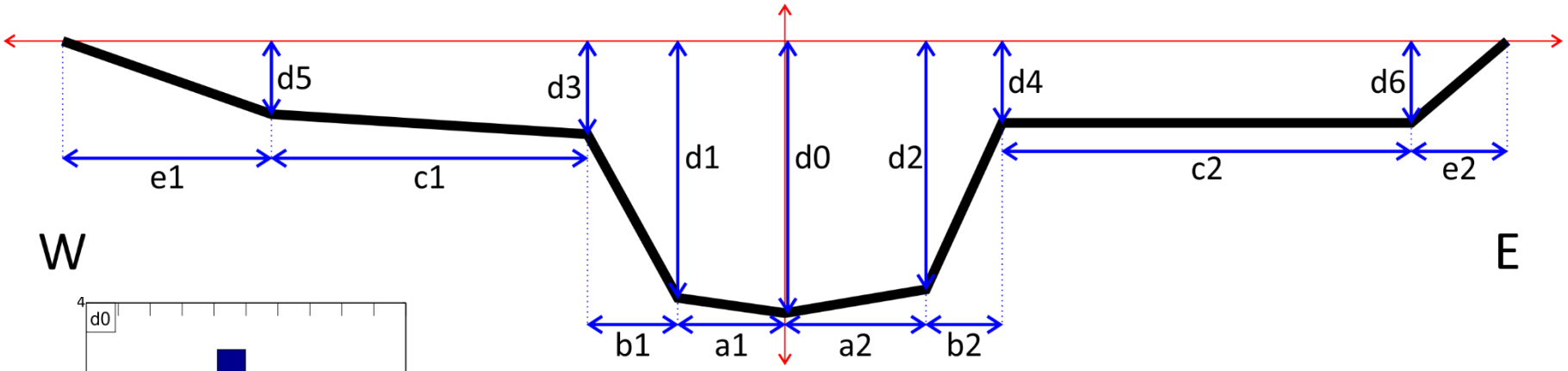
- 15 geometrical parameters

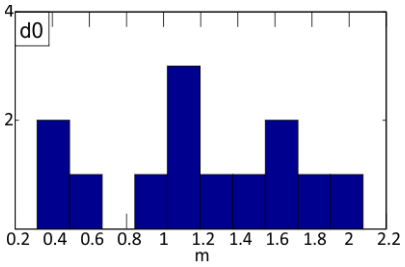


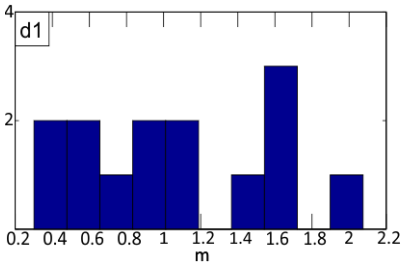
- Location parameters
  - Stratigraphic height
  - Lateral position

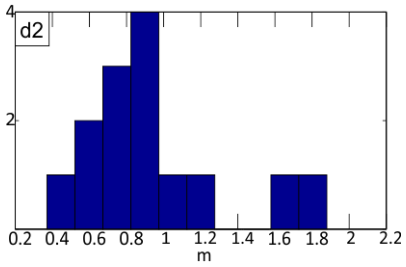


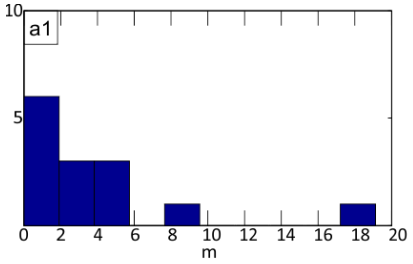
Outcrop measurements

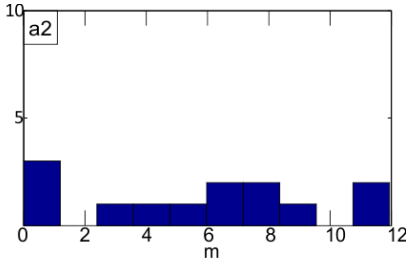


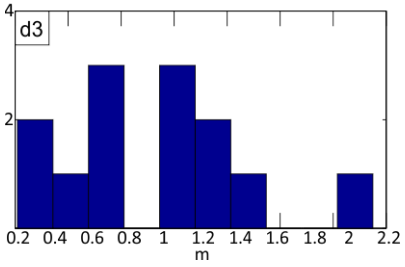


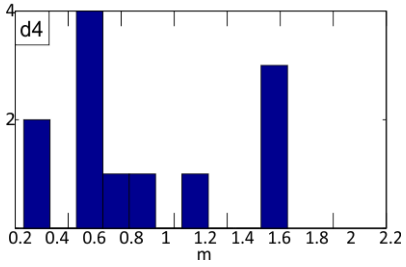


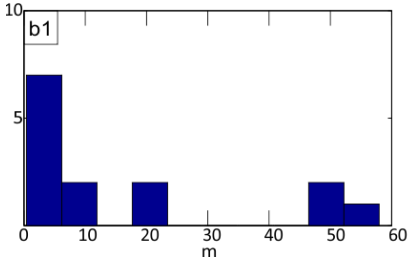


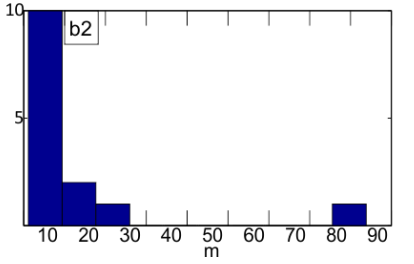












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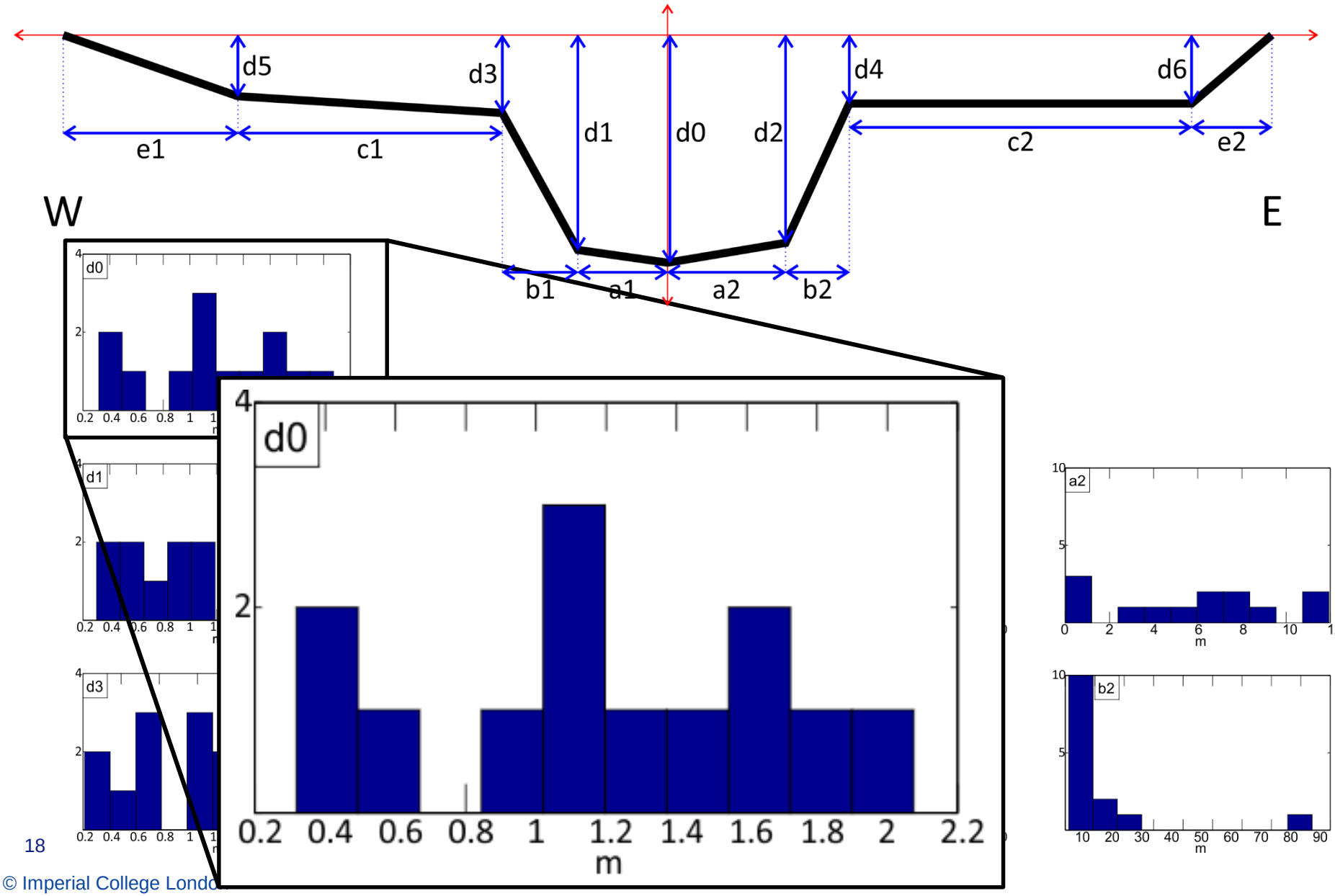
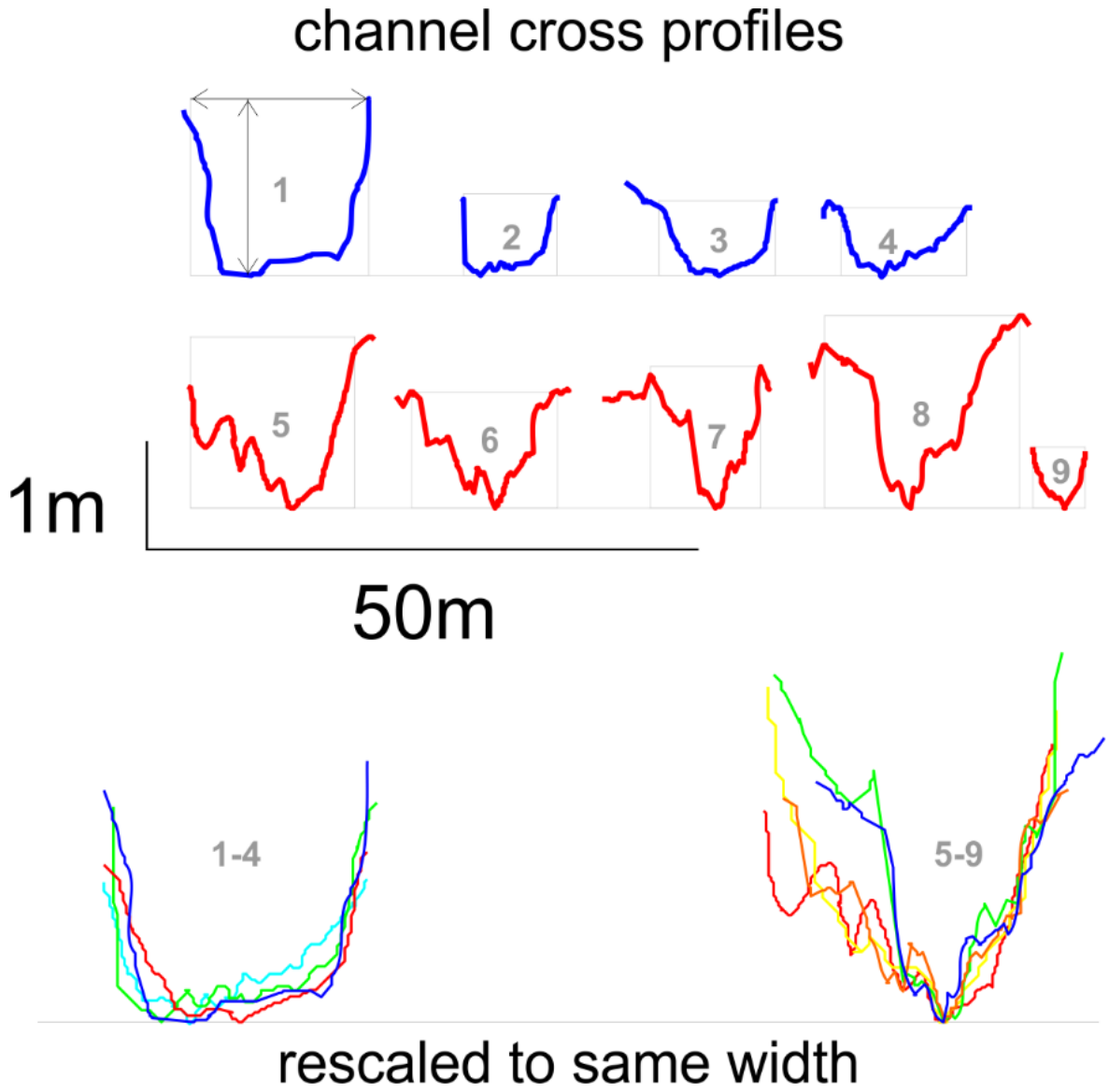
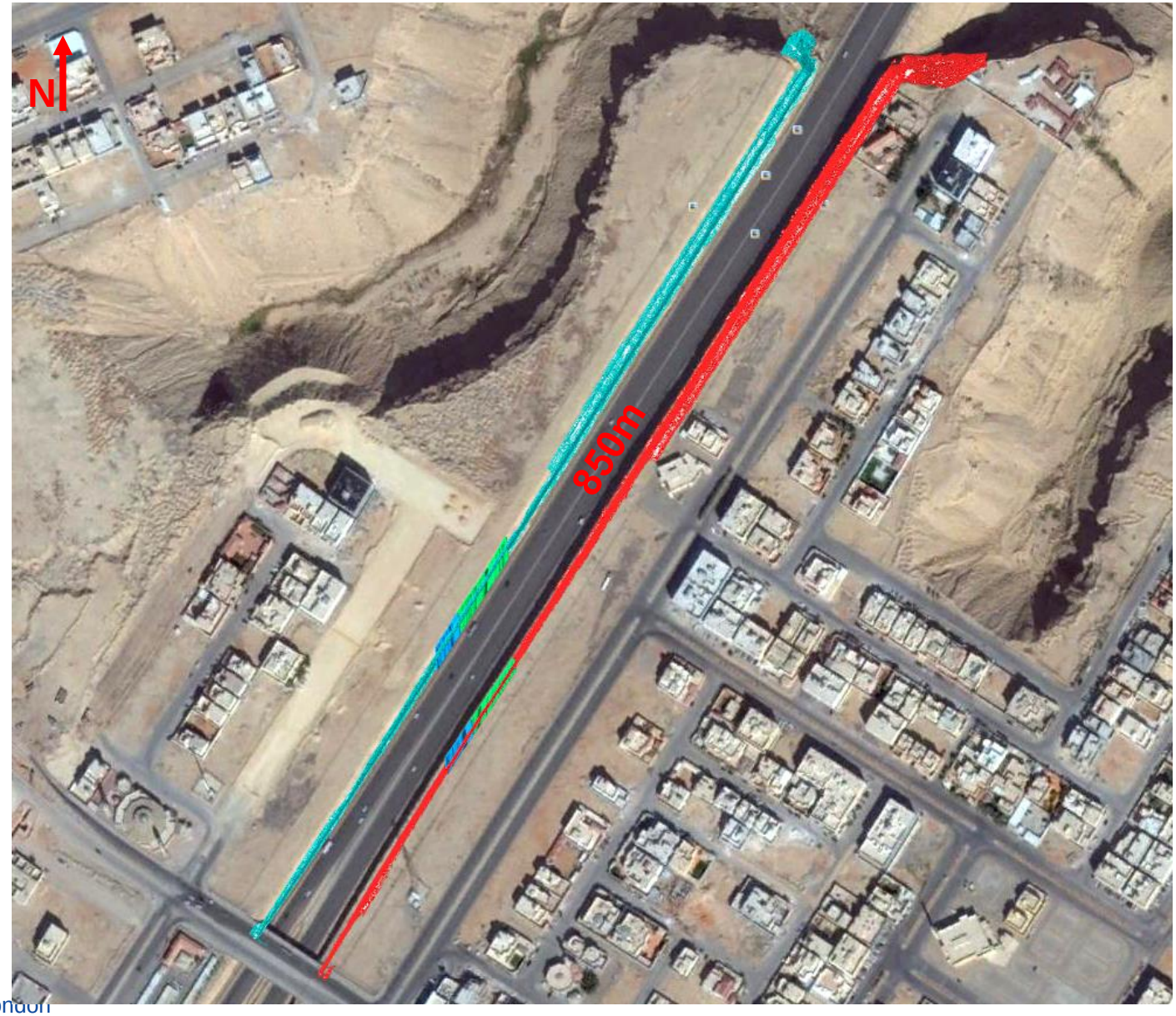


2D scour geometries

- Box-shaped
  - Flat based
  - Steep walls
- V-shaped
  - Walls less steep
  - Asymmetric



Scour 3D geometry



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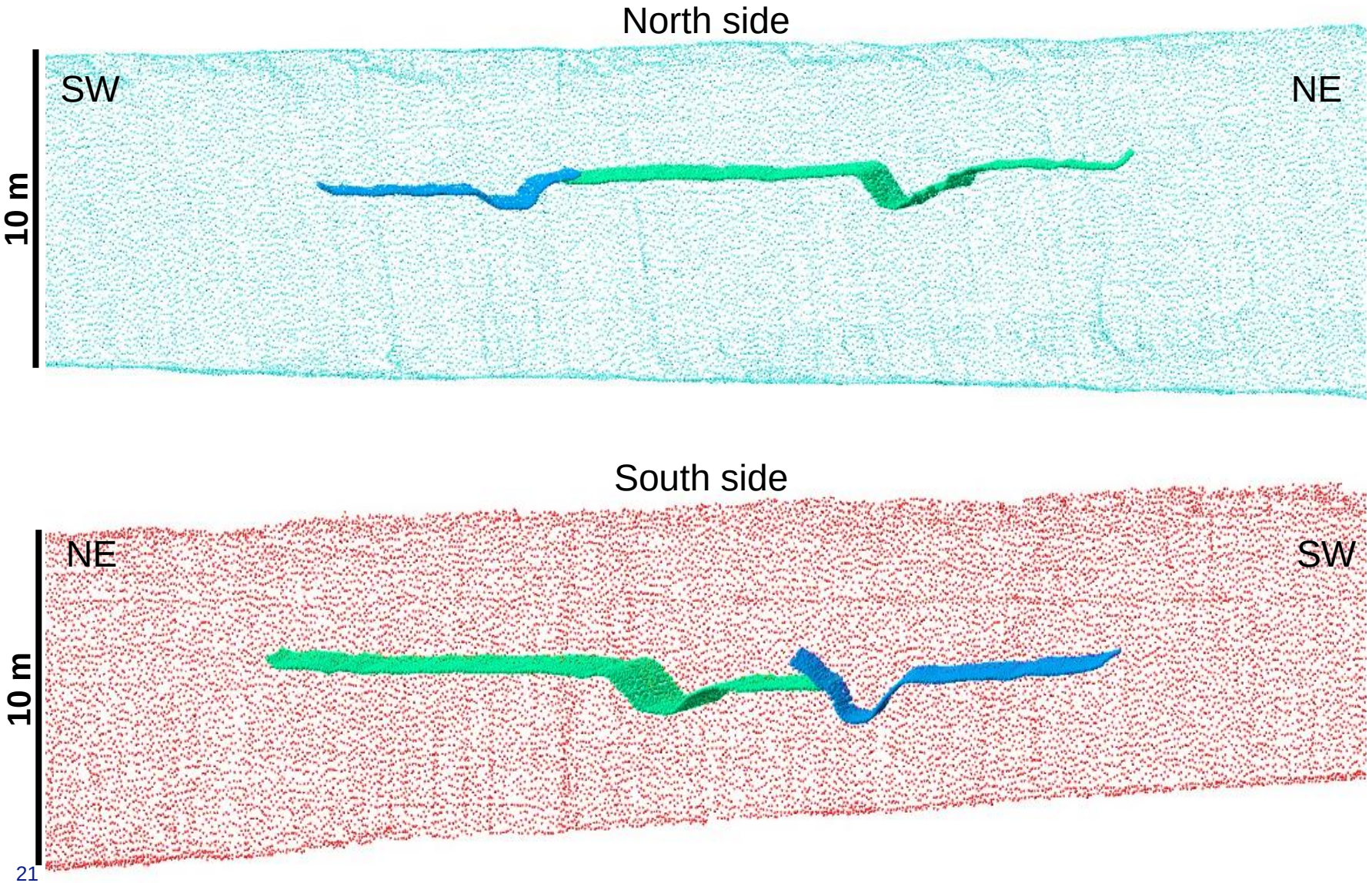

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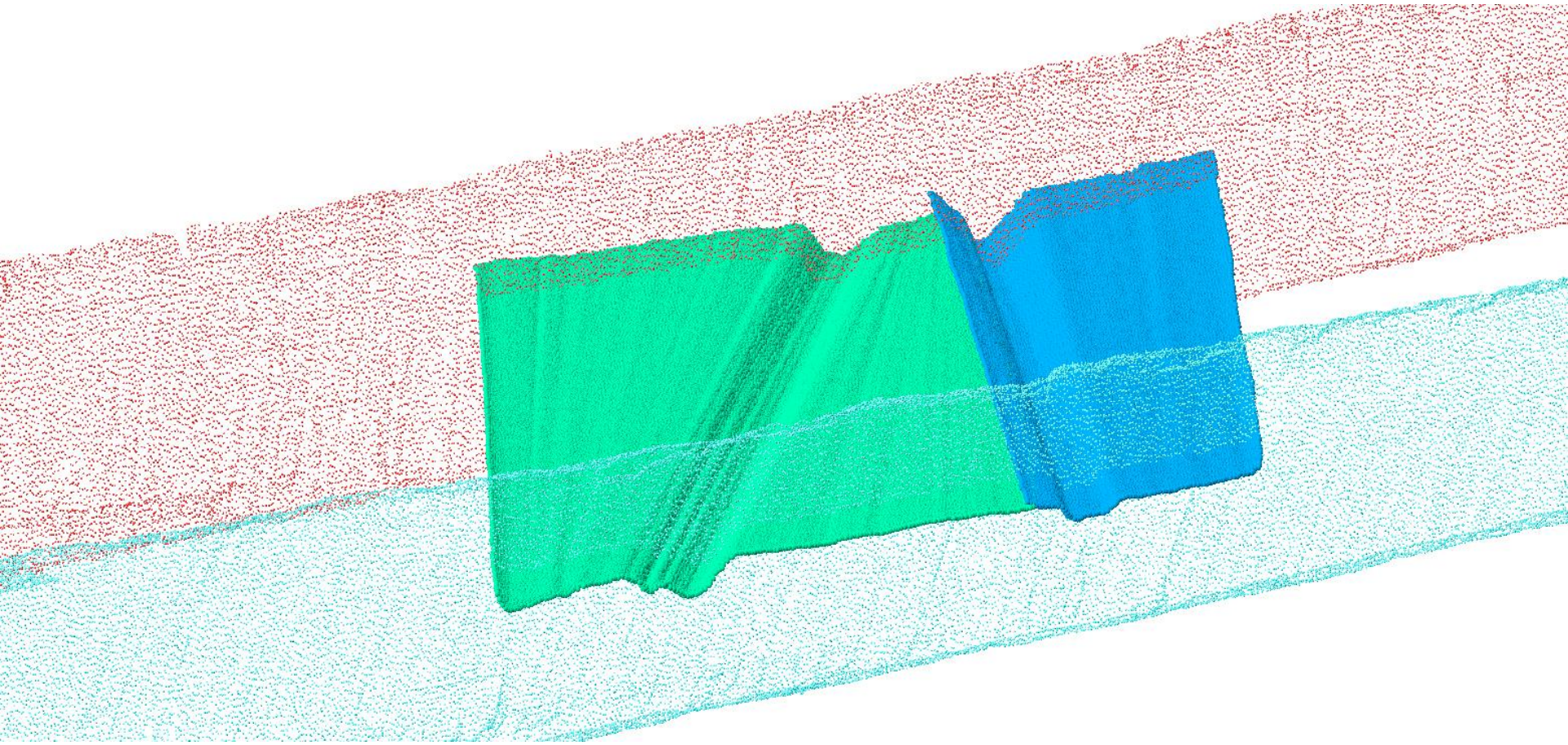
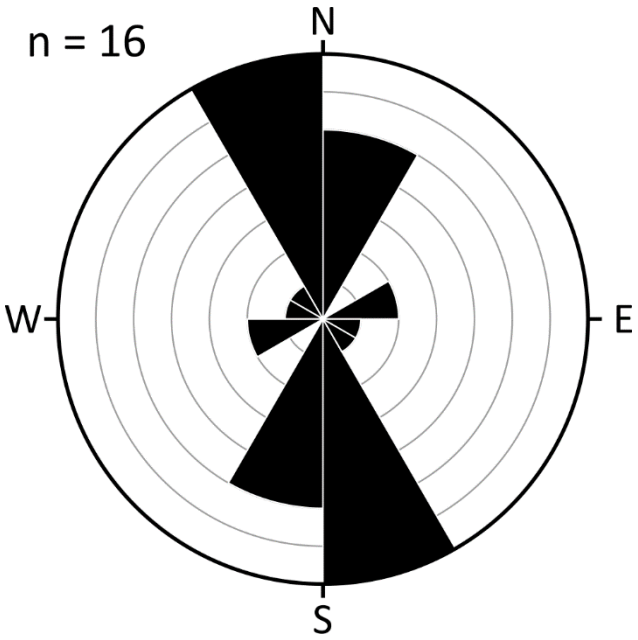
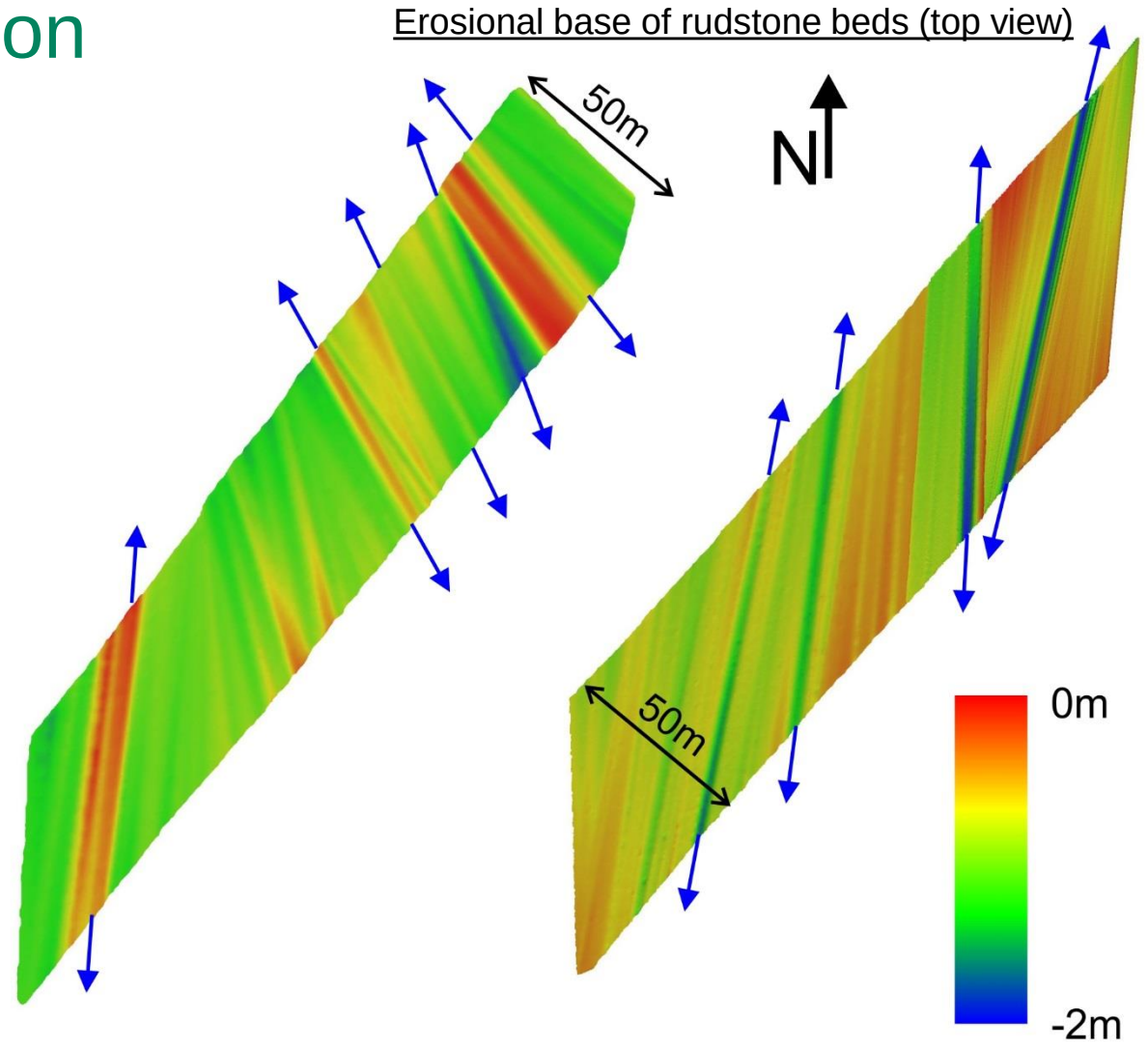


3D scour orientation

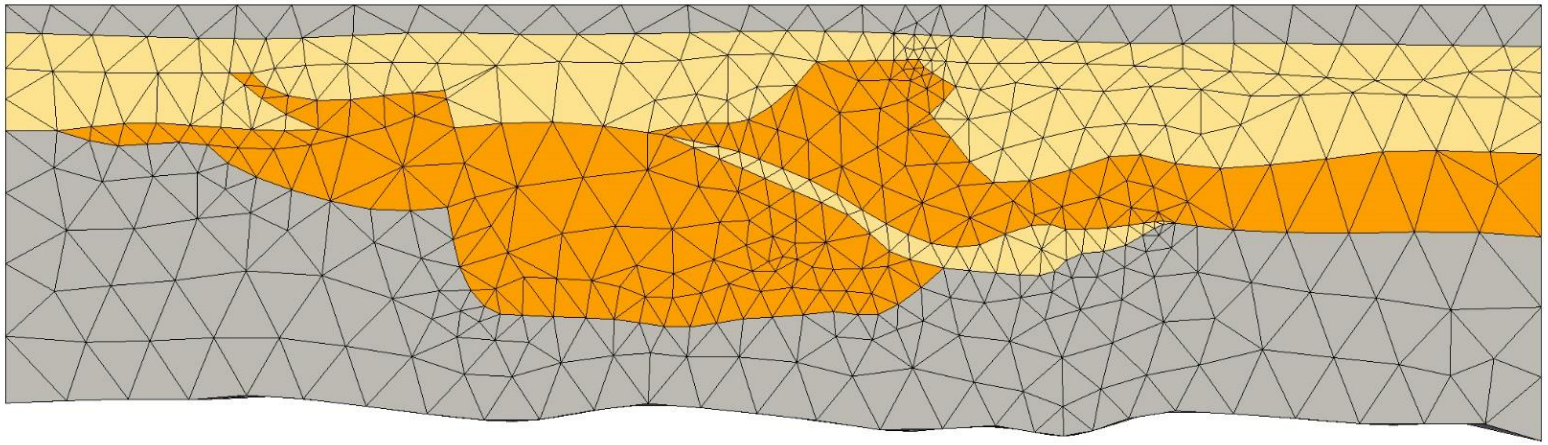
- NNW to SSE

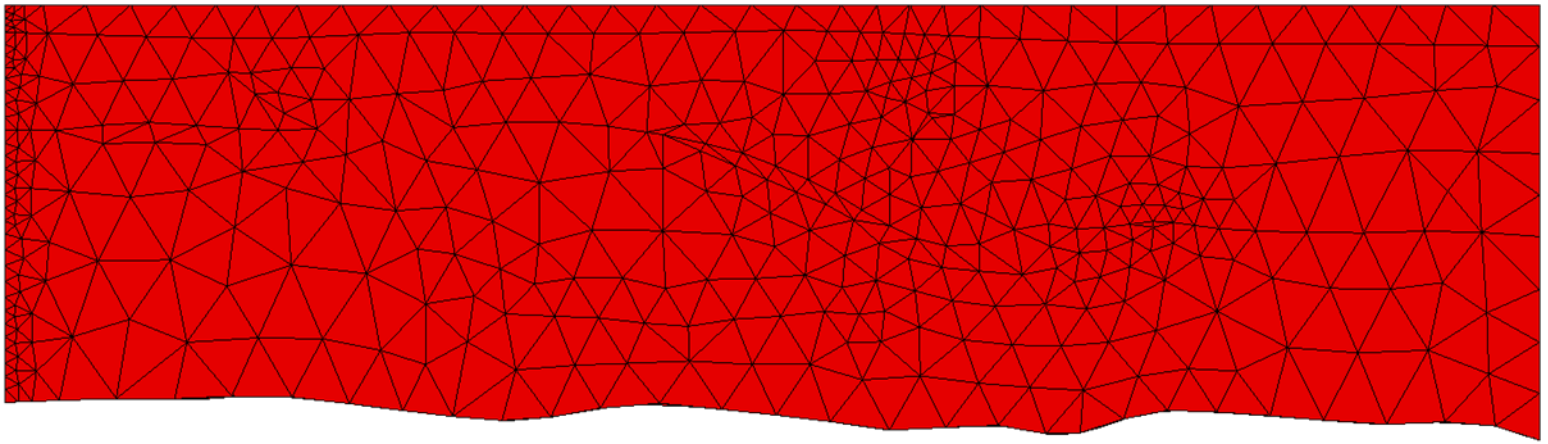




Future work

- Impact on fluid flow
- Surface-based modelling and simulation





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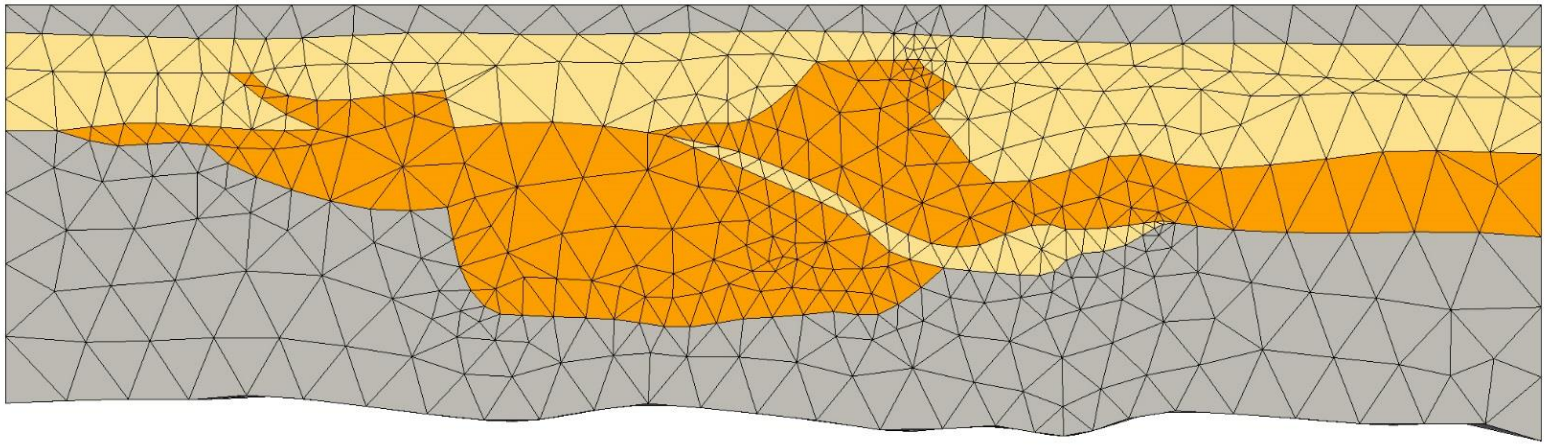

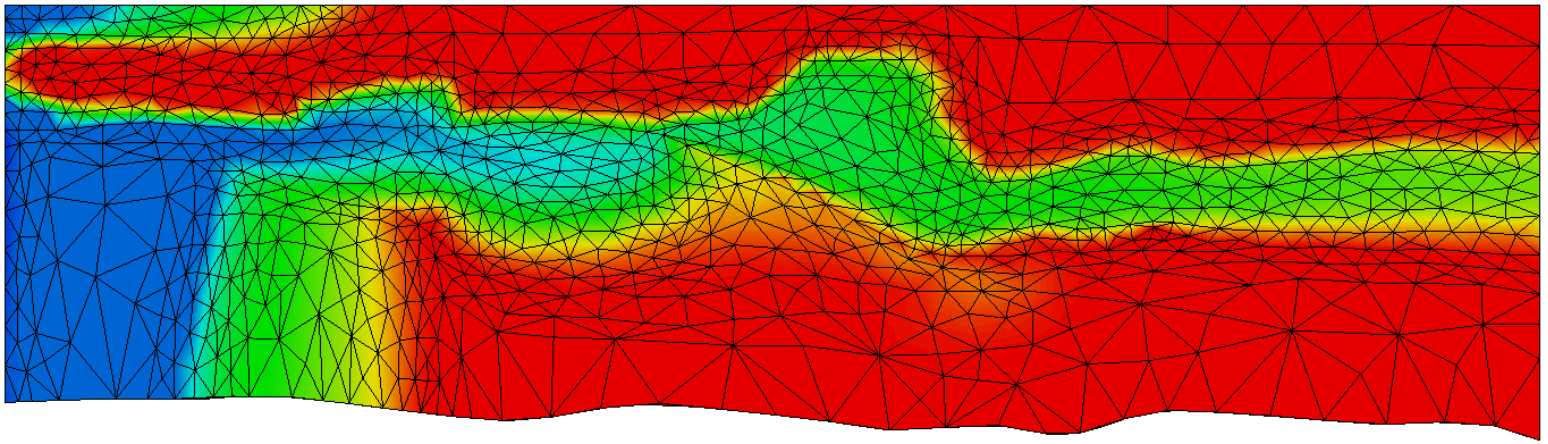

Conclusions

- Lateral connectivity
  - Pinch outs
- Rudstone storm deposits geometry
  - Laterally extensive over 10-400+ m
  - Scour pit and wings extent and depth quantified
  - Symmetric vs. Asymmetric
  - N-S orientation
- Non layer cake correlation between wells
- Connections vertically
- Potential for complex sweep patterns