‘Supercritical flows, bedforms, and deposits’

Organizers [1]:

- Fabien Laugier (Chevron)
- Emma Morris (University College Dublin)
- Lilian Navarro (University of Ottawa)

Panelists:

- Tim Demko (ExxonMobil)
- Andrea Fildani (Equinor)
- Sophie Hage (National Oceanographic Centre, Southampton)
- Stephen Hubbard (University of Calgary)

Panelist presentations and general discussions:

1) ***Tim Demko***: *Connecting facies and architecture to flows*
   a) Improve deepwater reservoir prediction using adequate models for a known set of initial settings, through fieldwork, core, seismic and experiments, and computation.
   b) Comparing bedform stability diagrams for fluvial, open channel-flows and turbidity currents
   c) Distinguishing and differentiating supercritical bedforms
   d) Subcritical vs supercritical fan models
      i) Supercritical flows build bedforms such as cyclic steps and antidunes; subcritical flows build deepwater depositional systems.
      ii) Supercritical flows exist outside small, tectonically active basins
      iii) It is easier to scale supercritical flows compared to subcritical flows
      iv) Subcritical fans are dominated by depositional channels while supercritical fans tend to be bypass and are avulsion dominated...is this a consistent theme?

2) ***Andrea Fildani***: *20 years of Cyclic Steps in 10 minutes*
   a) Changing ideas from a prevalence of subcritical flows in deepwater literature
   b) Initial reactions and difficulties in the DW community to accept his seminal ideas related to cyclic steps (Fildani et al., 2006)

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b) Importance of studying the modern sea-floor using high resolution bathymetric datasets e.g., MBARI studies such as those of the Lucia Chica system (e.g. Fildani et al., 2013)
   i) What can we learn by extracting data from the seafloor to allow for a better understanding of the flow dynamics and depositional features? (e.g., the channel lobe transition zone of the Navy Fan – Carvajal *et al.*, 2017; occurrence of erosional cyclic steps, low-relief and wide channel, and scours in the proximal parts of the fan)

c) Acknowledgement of the work being done on visualization, monitoring, mapping and sampling of modern seafloor by MBARI and NOC Southampton.

3) ***Sophie Hage****:* *What is the depositional signature of crescentic bedforms formed by supercritical turbidity currents? Insights from active submarine channels*

Use modern, active flows to determine what they deposit, and how to recognise it in the rock record. Daily seafloor mapping to what the sea floor looks like after multiple events over four months (120 days).

a) Two types of bedding architecture observed: backstepping bedforms and lens-shaped bodies.
b) Hydraulic jumps at the base of a turbidity current, resulting in intense erosion of the lee side and deposition on the stoss, creating a fining-upward turbidite deposit.
c) Crescentic bedforms on the modern seafloor (e.g. Squamish Delta, Hughes-Clarke *et al.*, 2016) and their migration upstream. Hage *et al.*, 2018 – Crescentic bedforms 2m high, passing flows at 2ms^{-1} removed 2m of sediment. Powerful/erosive flows, previously recorded deposits tend to be partially or almost totally removed, resulting in massive sands that amalgamate overtime. Therefore, only a partial record of cyclic steps are preserved.
d) A single event could not be distinctly or confidently correlated between cores – all structureless sands.

4) ***Stephen Hubbard****:* *Supercritical flows and associated bedforms and deposits in deepwater settings – an outcrop perspective*

a) What products do we expect to find with supercritical flows (in channels like the Squamish and Monterey Canyon)? In these examples, the products are very similar.. The Nanaimo Group exposed on Gabriola Island record numerous discontinuous features as a series of nested scours and remnant sandbodies (comparable to the deposits recovered from the crescentic bodies in Squamish).
b) What can we recognise in outcrops? Is there a unique fingerprint for these deposits? (Postma and Cartigny, 2014) How can you tell in a 1D core or 2D outcrop section? Evaluate grain size trends, and characteristics sedimentary structures (Ono and Plink-Björklund, 2018)
c) Urgent need to link facies, processes and conceptual models
d) Subcritical versus supercritical-related deposits: recognition potential, geomorphic vs stratigraphic surfaces.

Main Questions and Points of the conversation:

1) Datasets examining the sea-floor have been instrumental in helping us to understand these flows…how much of a paradigm shift has there been and have we gone too far?

    - Channels with supercritical flows are typically bypass (i.e. keep the channels free of sediment). Great strat-traps, limiting the connectivity of the lobe and underfilled channel.

2) What is a supercritical lobe? Are most flows on lobes subcritical?

    - Avulsion-related deposits and bedforms build the supercritical lobe.
    - See the work from the Congo – they can change, for example, the levee can support and tune the flow transitioning it from subcritical to supercritical.
    - Equilibrium profile is a poor term to be used in association with deepwater channels. Local topography, flow height etc. are all factors that are not controlled by the equilibrium profile.

3) What keeps sediment coarser than silt off the sea-floor? Are there such a thing as subcritical flows?

    - Critical shear stress is most important and can be present in both sub- and supercritical flows. Subcritical flows are more likely to be stratified.
    - What support mechanism is keeping the sediment in suspension?

4) How much would be preserved in the rock record? Preservational thickness? What is the maximum size of these bedforms? How do bedforms in modern systems compare (e.g. the Squamish versus Monterey)?

    - 10-12 m thickness, several hundred metres wide and several kilometres long (from the Golo Fan system and the East Breaks) but they can't be observed in high resolution seismics, since they are sub-seismic resolution and have no acoustic impedance.
    - Crescentic bedforms in Squamish delta is comparable in size to those observed in Monterey (2-5 m in height) and strikingly similar geometries.
    - Crescentic bedforms can form a package that are up to 50m thick

5) Is it only the last one (supercritical flow bedforms) that gets preserved? How much is lost from the rock record? Do big, rare events dominate in the rock record? How much of the everyday events are preserved? What are the range of supercritical bedforms that tend to

be formed? Could supercritical flow conditions be inferred on the basis of distinct large-scale architecture rather than dominant bedforms?

- < 20% of flows are preserved inside the channel over a four-month period.
- The upper reaches of the Monterey system are highly active however, very little/few ever reach the lower areas of the system let alone the basin floor lobe (as shown by the work done by Andrea Fildani and Charles Paull).
- Even though the "characteristic" supercritical flow features may not be preserved, the very fact that some fan systems developed under supercritical conditions may be important to predicting the spatial heterogeneity. Are there distinctions to the overall architecture of the fan system formed under supercritical flow regimes compared to one developed under subcritical conditions?
- The implications for reservoir characterization and prediction may only be related to the presence of supercritical flow bedforms, but the identification of those bedforms might not be the only criteria to be used in differentiate some turbidite systems.
- It is critical to understand the range of supercritical bedforms, and their preservation. For example, if a submarine fan developed under supercritical flow conditions, the supercritical flow structures/features might be only be preserved in the CTLZ. How different is the internal architecture and facies distribution within a fan that was not developed under supercritical flow conditions?

6) How do you recognise cyclic steps in core?

- Evidence of a backstep
- Structured to fluidised beds
- Presence of local rip-up clasts present along the backstep (locally imbricated), not along the erosion surface
- Shallowing bedding dips are more characteristic of antidunes.

7) Where are the dunes?

- Sigmoidal geometry = dune-like features but sustained supercritical flow with no flow separation that transitions to downstream migrating antidunes – so are they transitional rather than stable bedforms within the stability field?

Additional remarks:

- It is essential for those who are evaluating numerical and physical experiments to consider the existing rock datasets, and for those who are looking at outcrops and/or cores to consider the conditions and results from numerical and physical experiments, when trying to think outside the box and make their interpretations.
- The DW community might need to carefully re-evaluate classic outcrops with fresh eyes to determine if previously unexplained or mysterious features and/or architecture might

be associated to supercritical flows. Nevertheless, it is equally important not to indiscriminately re-labelling everything as supercritical flow structures.

- Crucial to emphasize the use of sound and clear descriptions, evidences and observations among the DW community, and then to test and discuss possible hypotheses, assumptions and interpretations.

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