THE SEDIMENTARY CHARACTER OF PRE-VEGETATION ALLUVIUM

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SUMMARY

- This poster describes 3 unidirectional changes to alluvial facies diversity and frequency, in stratigraphic alliance with the plant fossil record

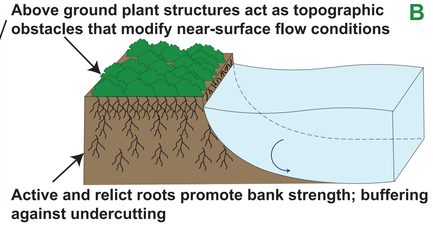
1) 'Sheet-braided' strata become extremely uncommon in the Silurian having been the near-ubiquitous architectural style since the Archean

2) There is an upsurge in the proportion of mudrock contained in alluvium coeval with vegetation evolution

3) Strata that conform to 'classic meandering river facies models' become far more widespread after plant evolution

1. HOW PLANTS SHAPE RIVERS

- Land plants affect multiple aspects of river functioning[A-B] and so those rivers that operated before plant evolution lack modern sedimentological analogue

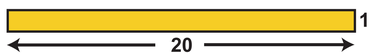


- It is now 50 years since Stanley Schumm's seminal paper in which he described the ways in which rivers that operated before the evolution of land plants would have differed from their more recent counterparts[1]

- During the last five decades there has been increasing recognition that pre-vegetation alluvium consists of anactualistic sedimentary facies[2]

2. 'SHEET-BRAIDED' ALLUVIUM IS A PRE-VEGETATION ARCHETYPE

- The term 'sheet-braided' was introduced by Cotter[3] to describe single genetic units (i.e., beds) of sandstone with aspect ratios >20:1[CD]



- He explicitly stated that the term was independent of any conceptual models of fluvial planform

Neoproterozoic Applecross Fm, UK

Mesoproterozoic Meall Dearg Fm, UK

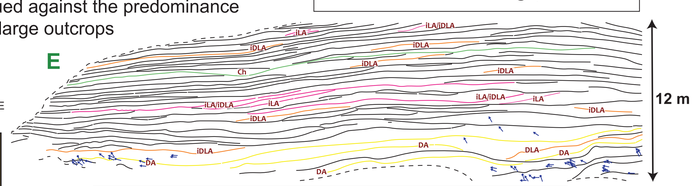
- Recently the term has increasingly become conflated with having geomorphological significance

- In response to this conflation, a number of papers have argued against the predominance of 'sheet-braided' pre-vegetation alluvium, on the basis that large outcrops may permit a refined interpretation of fluvial planform

- However, even in these instances, most examples of pre-vegetation alluvium remain 'sheet-braided' *sensu* Cotter[E]

The ubiquity of pre-vegetation 'sheet-braided' strata means that it may be mistakenly perceived as a bucket term, but its true merit lies in the converse fact that there are no known examples of post-Silurian 'sheet-braided' successions[4]

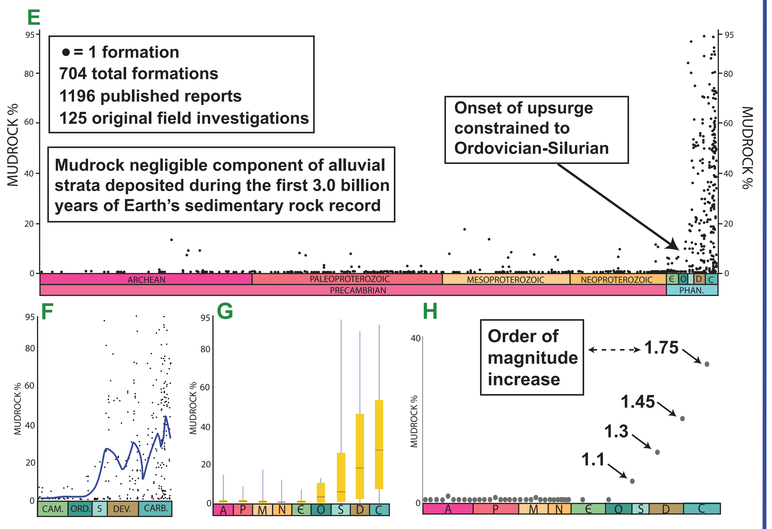
Cambrian Series Rouge, France



Multiple architectural elements are represented in this outcrop, yet it retains a predominant 'sheet-braided' architecture[5]

3. MUDROCK IS RARE OR ABSENT

- Mudrocks are a primary archive of Earth's history from the Archean eon to recent times
- Using original and published stratigraphic data from all known alluvial formations from the Archean to Carboniferous, we prove contentions of an upsurge in the proportion of mud retained on land coeval with vegetation evolution[e-h, 6]

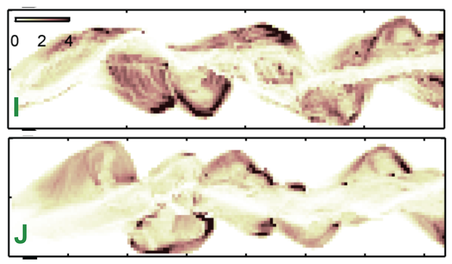


WHY MIGHT PLANTS HAVE TRIGGERED THIS?

1. **Plants increase directly weathered mud production**
2. **Plants increase mud retention through binding[B]** *(the fastening of masses of grains by plant parts such as roots)*
3. **Plants facilitate mud retention through baffling[I-J]** *(the capture and forced deposition of grains from within a moving fliud passing over and around plant parts)*

- The onset of the mudrock upsurge is constrained to the Ordovician-Silurian[E-F], before the Devonian evolution of rooting.

Novel above-ground baffling effects provide a mechanism by which even early rootless vegetation may have affected preserved fluvial facies[I-J, 7]



Models I & J simulate mud storage under identical flow conditions

Model I includes rootless vegetation and shows an increased fraction of mud retention

Model J includes no vegetation and retains a lesser total fraction of mud

4. WHY MEANDERING RIVER FACIES ARE BOTH RARE AND UNEXPECTED

The frequency of meandering rivers on pre-vegetation Earth can be estimated using:
1. Modern geomorphic observations; 2. Experimental models; 3. Sedimentary geology

Modern observations

Problems with approach: 1) There are no modern fully-unvegetated rivers; 2) It is impossible to observe systems operating outside of the present Earth condition (i.e., on a post-glacial planet with a specific tectonic make-up on which plants have existed).

Lessons learned: 1) Meandering is promoted by flow resistance and bank stability-vegetation promotes these parameters[A-B]; 2) Bank stability can also be afforded abiotically by clay, ice or salt[K] (note the former of these increased in abundance after plant evolution[E]; 3) Analogies with unvegetated tidal channels[L] and sinuous channel patterns on the surface of Mars and Titan should be discouraged as these systems develop under differing (and unknown) parameters

Meandering on unvegetated salt flat

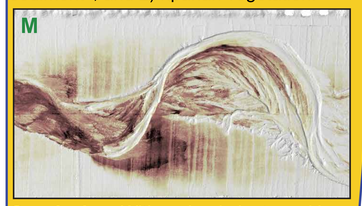
Unvegetated meandering tidal channel

Conclusion: In the absence of vegetation-induced biostabilization, it can be reasoned that, with fewer potential causes, bank stability, bar cover, and thus meandering, was likely less frequent

Experimental models

Problems with approach: 1) Reliant on understanding of the pre-vegetation laws of nature, which are only inferable from partial modern analogus; 2) Scaling issues

Lessons learned: In order to model a self-sustaining meander, it is necessary to reduce the development of recurring chute cutoffs which straighten a channel course[8]. Chute cutoffs have been curtailed in flume experiments by adding: 1) fine cohesive sediment[M]; and 2) riparian vegetation.

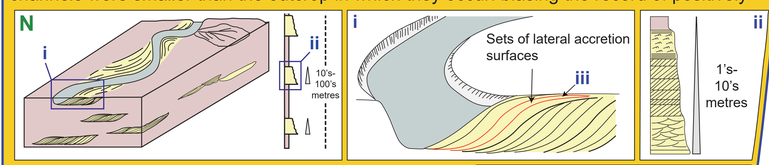


Conclusion: With no land plants and less mud, most meandering river planforms were likely transient landscape features

Sedimentary geology

Problems with approach: Ascertaining how geomorphic information is archived in rock.

Lessons learned: 1) Classic meandering river facies model (CMFM) strata are dominated by thick mudrock intervals in association with fining-up sandstones and laterally-accreting inclined heterolithic stratification (LA-IHS)[N]; 2) The CMFM is most equipped to recognise rivers whose channels were smaller than the outcrop in which they occur: biasing the record of positively*



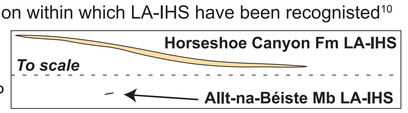
*identified meandering rivers to alluvium of small-sized channels; 3) CMFM strata overlook the deposits of meandering rivers where mud contributes insignificantly to the overall fraction of grains within the system;
4) LA-IHS has only been recognised in 1 pre-vegetation alluvial formation (the Allt-na-Béiste Mb, UK)[9]; 5) CMFM strata increase in abundance in strata that post-date the evolution of vegetation[2]

The Allt-na-Béiste Mb 'meanders'

- **Only** pre-vegetation alluvial formation within which LA-IHS have been recognisted[10]

However.....

- LA-IHS restricted to **1** outcrop
- The largest of which is **41 cm** thick[O]
- LA-IHS record minor channels feeding a lake system in a near-filled localized palaeovalley[10] and **not** large-scale pre-vegetation meanders as previously preposed[9]



Conclusion: While the recognition that the virtual absence of pre-vegetation CMFM strata cannot be used to impy that no meandering rivers existed before plants, it does reflect the fact that vegetation evolution engineered profound geomorphic innovation.

The universal conclusion from different strands of evidence is that meandering rivers were much less common on Earth prior to the evolution of land plants

Research at Cambridge University was supported by Shell Global.
Research at Utrecht University was supported by the European Research Council

REFERENCES

1. Schumm, *Geol. Soc. Am. Bull.* **79**, 1573-1588 (1968)
2. Davies & Gibling, *Earth. Sci. Rev.* **98**, 171-200 (2010)
3. Cotter, in *Memoir* vol. 5, *Fluvial Sedimentology*: Miall (Ed.) (Canadian Soc. of Pet. Geol, 1978), 361-383
5. McMahon & Davies. *Journal of the Geol. Soc.* **175**, 13-32 (2018)
6. McMahon *et al., Precambrian Res.* **292**, 13-34 (2017)
7. McMahon & Davies, *Science*, **359**, 1022-1024 (2018);
8. Kleinhans *et al., Earth Surf. Processes and Landforms*, (in press)
9. Van Dijk *et al., Earth Surf. Processes and Landforms*, **117**, F03023 (2013)
10. Santos and Owen, *Precambrian Res.* **272**, 226-243 (2016)
11. McMahon and Davies. *IAS Special Publication* (in press)