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1 **Discussion on ‘Tectonic and environmental controls on Palaeozoic fluvial**
2 **environments: reassessing the impacts of early land plants on sedimentation’.**
3 ***Journal of the Geological Society*, <https://doi.org/10.1144/jgs2016-063>.**

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19 The first order importance of tectonic and environmental controls for terrigenous sediment supply
20 has rarely been questioned, but the role of vegetation in the modification of alluvial signatures has
21 been observed since the mid-20th Century (Vogt, 1941). Studies of sparsely vegetated rivers (Schumm,
22 1968) and alluvial stratigraphic variation (Cotter, 1978; Davies & Gibling, 2010) led to observations of
23 (1) plant modulation of alluvial signatures; and (2) Palaeozoic facies shifts (PFS): unidirectional changes
24 to facies diversity and frequency, in stratigraphic alliance with the plant fossil record. One PFS is the
25 Siluro-Devonian appearance of mud-rich, architecturally complex alluvium, traditionally ascribed to
26 meandering rivers, and sedimentologically distinct from pre-vegetation strata (Davies & Gibling, 2010;
27 Long, 2011). Using selected secondary data, Santos et al. (2017) dispute the correlation of these
28 observations using three key points: 1) The mid-Palaeozoic was typified by orogenic assembly of low-
29 gradient equatorial continents and elevated sea level, which led to tropical weathering (abundant
30 fines) and extensive alluvial plains. This drove the PFS by promoting river meandering independently
31 of vegetation. 2) Meandering does not require vegetation; shown by examples in Precambrian
32 deposits, on other planets, and in “non-vegetated” deserts. Meandering rivers were more abundant
33 than the pre-vegetation rock record suggests, due to selective bypass and deflation of fines. 3) Early
34 Siluro-Devonian (meaning Ludlow-Early Devonian) land plants were too small, their biomass and cover
35 too limited, and their wetland habitat too narrow to have stabilized meandering channels, influencing
36 landscape little more than earlier microbial communities. We contest the conclusions and
37 methodology of the paper, and deal with each point in turn.

38 1) *Palaeogeographic setting* – The paper argues that the PFS towards a “fine-grained meandering
39 fluvial-style” was solely due to tectonic and sea-level conditions, but fails to explain how non-unique
40 conditions, cyclic since the Archean, initiated a tangible unidirectional singularity in the stratigraphic
41 rock record. The paper does not explain why similar shifts are not reported from pre-Silurian instances

42 of enhanced chemical weathering (Corcoran and Mueller, 2002), orogenies (e.g., Hudsonian,
43 Grenvillian; Bradley, 2011) or extensive equatorial plains (e.g., in Rodinia; Li et al., 2008), nor other
44 intervals of high sea-level, platforms and mountain-building (e.g., the Cretaceous; Seton et al., 2012).
45 Without quantifying global facies during these intervals for comparison, Santos et al.'s (2017)
46 conclusions rely on limited correlation between partial Palaeozoic sea-level curves and facies data,
47 constructed from non-comparable secondary datasets (their Figures 3-4): the most obvious
48 correlation in these figures remains that between rooting and interpreted meandering style. The
49 claim for identifying a tectonic cause for these shifts is undermined by basing assertions on literature
50 pre-dating the plate tectonics paradigm (i.e., palaeogeographic data from Weller (1898); sediment
51 accumulation within geosynclines).

52 The implication that this PFS was restricted to equatorial, orogenic Euramerica is untrue (known bias
53 was previously discussed: Davies & Gibling, 2010, p. 182). Siluro-Devonian vegetated muddy overbank
54 deposits are also known from non-orogenic settings such as high-latitude Gondwana (Hunter & Lomas,
55 2003) and palaeoequatorial South China (Xue et al., 2016).

56 2) *Meandering without vegetation* – Previous authors have emphasised: (1) a distinction between
57 modern river planform and “fluvial style” in ancient facies; and (2) no physical reasons precluding
58 meandering rivers before vegetation, through stabilizing agents such as clay, mineral cements and ice
59 (Cotter, 1978, p. 362; Davies & Gibling, 2010, p. 184; Long, 2011). However, the PFS is a tangible
60 change to the spectrum of fluvial styles preserved in the rock record; the first widespread appearance
61 of a certain recurring type of meandering-fluvial succession, observable in younger strata of any age,
62 but absent in older strata (and interpretable as fine-grained meandering systems; see Long, 2011).
63 Such heterolithic successions are 10's-100's m-thick, and contain at least 10% mudrock (often >50%)
64 *and* repeated or pervasive outcrop-scale architectural evidence for channel sinuosity *throughout* their
65 stratigraphic thicknesses (see Davies & Gibling, 2010, for associated facies characteristics).

66 Santos et al. (2017) cite rare Neoproterozoic examples of inclined heterolithic strata (IHS) from the
67 Torridon Group of Scotland (similar to common post-Palaeozoic motifs; their Figure 1) as evidence for
68 long-lived floodplains and meandering channels before vegetation. However, both these IHS are <2
69 m-thick, are associated with interpreted overbank mudrocks <2 m-thick, and are atypical of the c.190
70 m-thick Allt na Béiste Member in which they occur (Stewart, 2002); mudrock accounts for c.0.2% of
71 Torridon Group alluvium as a whole, otherwise dominated by archetypal pre-vegetation sandstone
72 strata (based on estimated thicknesses of alluvial formations in Owen & Santos (2014), less if Stewart's
73 (2002) estimates are used). Flow resistance is fundamental for channel sinuosity (Lazarus &
74 Constantine, 2013); in modern rivers resistance may involve vegetation or not, but fewer causes
75 existed prior to vegetation and thus evidence for solely abiotic resistance promoting sinuous channels
76 is as rare as these examples. A literature survey reveals 366 sand-dominated Precambrian and
77 Cambrian formations where abundant mudstone and IHS are apparently absent (see Supplementary
78 Material). By contrast, ~40% of all Earth's recorded Upper Devonian fluvial formations have been
79 attributed to meandering rivers by virtue of containing such facies signatures throughout their
80 stratigraphic thicknesses (Davies et al., 2011).

81 Santos et al. (2017) miscite Long (2011) in suggesting that silt-grade sediment is common in pre-
82 vegetational systems: it is not. Our original data confirm that only 3% of Archean-Cambrian alluvial
83 successions contain >10% fines, compared to 74% in the Silurian-Devonian (Figure 1; Davies & Gibling,

84 2010). The paper infers bypassing and deflation could account for the scarcity of IHS in pre-vegetation
85 settings. Although undoubtedly significant, these processes are unlikely to have selectively removed
86 heterolithic lateral-accretion deposits with sand and mud layers.

87 Santos et al.'s (2017) use of satellite imagery to justify pre-vegetation rivers on Earth is inappropriate,
88 not least because it conflates plan-view imagery of channels as synonymous to vertical facies
89 signatures in the pre-vegetation rock record. The "non-vegetated" channel images (their Figure 2)
90 lack ground-truthing of bank stability controls and, magnified, observably host shrubs and trees
91 (images lack resolution to determine smaller plants). Figure 2A is particularly inappropriate as it
92 displays relict channels feeding Lake Chad that were last active before desertification, when
93 vegetation canopy cover and number of plant species were far greater (Drake et al., 2011). The
94 Martian analogues are eroded >3 Ga inverted channel-belt deposits. Because Martian inverted
95 channel-belts have not been investigated by rovers, our understanding of these features is limited to
96 orbital observations, with few constraints on their sedimentology. We consider it dangerous to use
97 Martian analogues that have not been investigated in situ and for which we have a very poor
98 understanding of formative conditions to make interpretations of terrestrial systems. Martian
99 planetary conditions suggest that their formation may anyway have been less reliant on bank cohesion
100 (Matsubara et al., 2015). The scale (100's m-width) and compound nature of these geomorphic
101 features also means that they are fundamentally different geological phenomena to IHS in the
102 Torridonian (outcrop-scale vertical sections of rock, revealing deposits of small single channels)
103 (*contra* Santos et al., 2017). Titan analogues of methane-ethane rivers are irrelevant as all controls
104 are radically different to those of Earth (e.g., Gilliam & Lerman, 2016).

105 Santos et al. (2017) also support their hypothesis by citing modelling studies that have experimentally
106 created meandering channels in the absence of vegetation (e.g., using mud, Peakall et al., 2007).
107 However, when considering the greening of the continents, the pertinent question is not "can
108 meandering channels be made in an unvegetated flume tank?" (evidently yes, in certain
109 circumstances), but rather "what happens when plants are introduced to an unvegetated flume
110 tank?". Studies that have considered this latter question show a strong influence of vegetation in
111 promoting and sustaining meandering channels (e.g., Tal & Paola, 2007; Braudrick et al., 2009; albeit
112 using small angiosperms in the experiments, due to scaling issues).

113 *3) Early terrestrial life* – The paper equates the earliest vegetation as having similar sedimentological
114 effects to pre-existing microbial mats, but this is unfounded: the latter are mechanically different
115 biotic components of fluvial systems (surficial, elastic features: see McMahon et al., 2017). The paper
116 raises the valid point that it is presently uncertain exactly *how* primitive land-plants, with apparently
117 only limited root-like organs, forced the PFS (compare Lenton et al., 2012; Quirk et al., 2015; Xue et
118 al., 2016). Although far less effective than later trees in modulating surface processes, testable
119 hypotheses are known by which the earliest plants *could have* forced the PFS: (1) plants acted alone:
120 resistance to shear in even the earliest root-like organs, whatever their extent, was sufficient to bind
121 floodplains; or (2) plants acted vicariously through fine-grained sediment which was potentially (a)
122 increasingly baffled against winnowing/bypass due to the reduction of near-surface flow velocity by
123 above-ground plant structures (e.g., see Moor et al., 2017, for modern analogues), or (b) produced in
124 increasing amounts by the earliest plants (+/- symbiotic interaction with existing microbial
125 communities). While, at present, the relative role of these remain speculative, what is geologically
126 certain is the observable global facies difference between alluvium deposited when only microbial life

127 was present (pre-Ordovician) and that deposited when both microbiota and primitive land plants were
128 present (post-Silurian).

129 The paper's palaeobotany section also contains numerous errors and contradiction, arising from
130 selective reading of secondary literature: as examples, (1) there is insufficient data on the precise
131 palaeogeographic aspects of early land plant radiation (Wellman et al., 2013); (2) isotopic data and
132 early coals suggest a considerable Early Devonian plant cover (Małkowski and Racki, 2009; Kennedy
133 et al., 2013); (3) Middle Devonian cladoxylopsid and archaeopterid roots include large systems in soils
134 other than swamps (e.g., Morris et al., 2015). Furthermore, the paper also overlooks the fact that,
135 through a combination of sediment baffling and adventitious recruitment, plants build-up cumulative
136 soil profiles, rich in root biomass, far thicker than the product of a single cohort. The papers
137 compilation of root depth evolution (their Figure 3), based on a selective reading of literature that
138 intermixes single-cohort and multi-cohort palaeosol profiles, is inaccurate.

139 Additionally, just because the first plant *fossils* occur within sediments deposited in wet, muddy
140 settings (i.e., depositional/preservational not erosional) does not preclude the existence of
141 earlier/other plants in non-preserved environments - as attested by the palynological record (Wellman
142 & Strother, 2015) and exceptionally preserved intramontane floras (e.g., the Rhynie Chert). The well-
143 documented taphonomic megabias against Palaeozoic dryland plants (Falcon-Lang et al., 2009) is
144 especially pertinent because dryland ecosystems show generally deeper rooting and a greater
145 proportion of below-ground biomass (Jackson et al., 1996).

146 Santos et al. (2017) propose tectonics/sea-level forced changes to fluvial systems and acted as a
147 catalyst for the evolution of terrestrial flora. The adaptive radiation of land plants, however, requires
148 no such geological trigger. If the primary barrier to terrestrial vegetation was environmental we could
149 expect a polyphyletic radiation of plant-like photosynthetic terrestrial organisms once the requisite
150 conditions were met. The monophyly of land plants (e.g. Karol et al., 2001) attests against this, instead
151 suggesting that the limiting factors were intrinsic, i.e. acquisition of novel developmental pathways
152 involved in embryogenesis/organogenesis. Furthermore, claims that (often braided) rivers operating
153 before the PFS were sub-optimal for initial land plant terrestrialization are unfounded: the very first
154 land plants pre-date the PFS by c. 50 Ma.

155 In summary, robust observations of sedimentary rock characteristics are distinct from subsequent
156 abstract steps of interpretation (e.g., of meandering). An observable, singular and unidirectional
157 facies shift occurs in the global rock record in close stratigraphic alliance with evolutionary
158 developments in the palaeobotanic record. Observations from modern plant-river interactions lend
159 credence to the notion that this alliance is not coincidental (Corenblit et al., 2014) and that it
160 represents a permanent increase in the global abundance of small (outcrop-scale), muddy meandering
161 channels. Unidirectional, irreversible changes to the rock record must reflect unidirectional changes
162 to the Earth system: they cannot be explained by cyclic phenomena such as plate tectonics or sea-
163 level.

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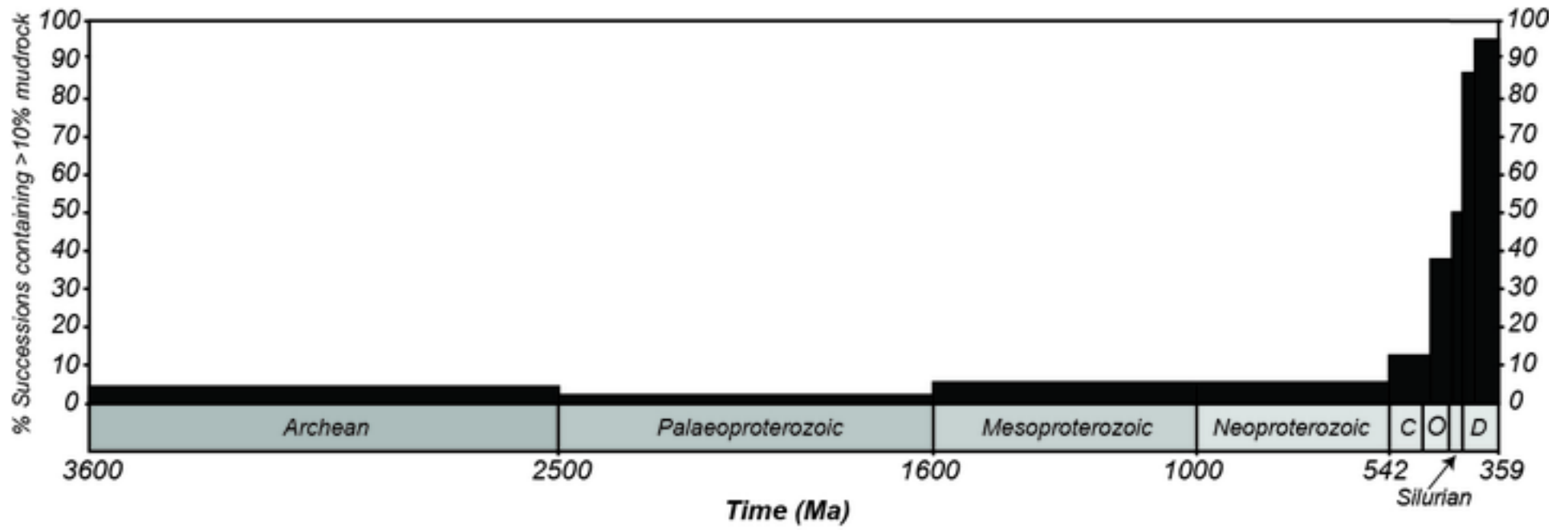
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259 **Figure Caption**

260 Figure 1 – Percentage of worldwide Archean- to Devonian-aged alluvial formations for which mudrock
261 strata make up >10% of their total stratigraphic thickness, primarily constructed using published data
262 (mudrock thickness determined as recorded by original authors, estimated from illustrated
263 stratigraphic sections, or estimated during original field visits). Archean to Neoproterozoic data drawn
264 from an original literature survey (see Supplementary Material). Cambrian to Devonian data from
265 Davies and Gibling (2010) (and subdivided using their ‘vegetation stages’ VS2 - VS6). Data from
266 formations whose age crosses stratigraphic boundaries are processed in accordance with
267 methodology outlined in Davies and Gibling (2010). Archean: n=45, Paleoproterozoic: n=98,
268 Mesoproterozoic: n=58, Neoproterozoic: n=94, VS2: n=16, VS3: n=8, VS4: n=10, VS5: n=14, VS6: n=16;
269 x-axis scaled to Ma duration.

Figure 1





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Supplementary material (not datasets)
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