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Modelling astronomical climate signals in fluvial stratigraphy

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Orbital climate forcing is demonstrated to result in cyclic changes as reflected in the catchment, including precipitation, temperature, vegetation, sediment supply and water discharge. All of these are known to largely impact alluvial architecture. Climate change related to the 21-kyr precession cycle was proposed as driver of regularly-alternating river avulsion and overbank phases in the Eocene Willwood Formation of the Bighorn Basin, Wyoming, USA (Abels et al. 2013; 2016). This study aims to explore the conditions that are favourable for these climate cyclic signals to be preserved in the fluvial stratigraphy.

The 3D numerical forward model of Karssenberg and Bridge (2008) based on Mackey and Bridge (1995) is used. Key parameters for this fluvial numerical modelling are sediment supply (Q_s), water discharge (Q_w) and fluvial basin geometry. In this model, the timing and location of channel bifurcation is stochastically controlled as a function of the relative slope advantage as well as the flood magnitude and frequency. An avulsion originates from an unsuccessful bifurcation when relative discharge of one branch over the total discharge is less than a set threshold value. Tectonic subsidence was mimicked by continuous base-level rise set at accommodation space creation rates as measured in the Bighorn Basin. Sensitivity tests were run for basin size, cycle duration, slope, and water/sediment ratio.

Core of our output is that cyclic inputs are necessary to generate cyclic stratigraphy. Cyclic output is observed in the alluvial elevation profiles with step-like aggradation phases, while the constant inputs only lead to relative continuous alluvial aggradation. Phases of average rapid floodplain aggradation relate to phases of multiple river avulsions, while phases of relative stability of alluvial profiles relate to phases of channel belt stability. These results perfectly match field observations with laterally continuous heterolithic avulsion-belt deposits alternating with true overbank fines (Abels et al. 2013). Cyclic concentration ($Q_s:Q_w$) variations, which result from the phase shift between water discharge and sediment load cycles, are thought to cause the cyclic alluvial stratigraphy. We find that increasing concentration causes the start of an avulsion phase and decreasing concentration triggers a stability phase. From upstream to downstream, we find decreasing impact of these cycles in the resulting alluvial stratigraphy, which may (partially) relate to the increasing influence of the gradually rising base level.