Climate signals lost and found in stratigraphy

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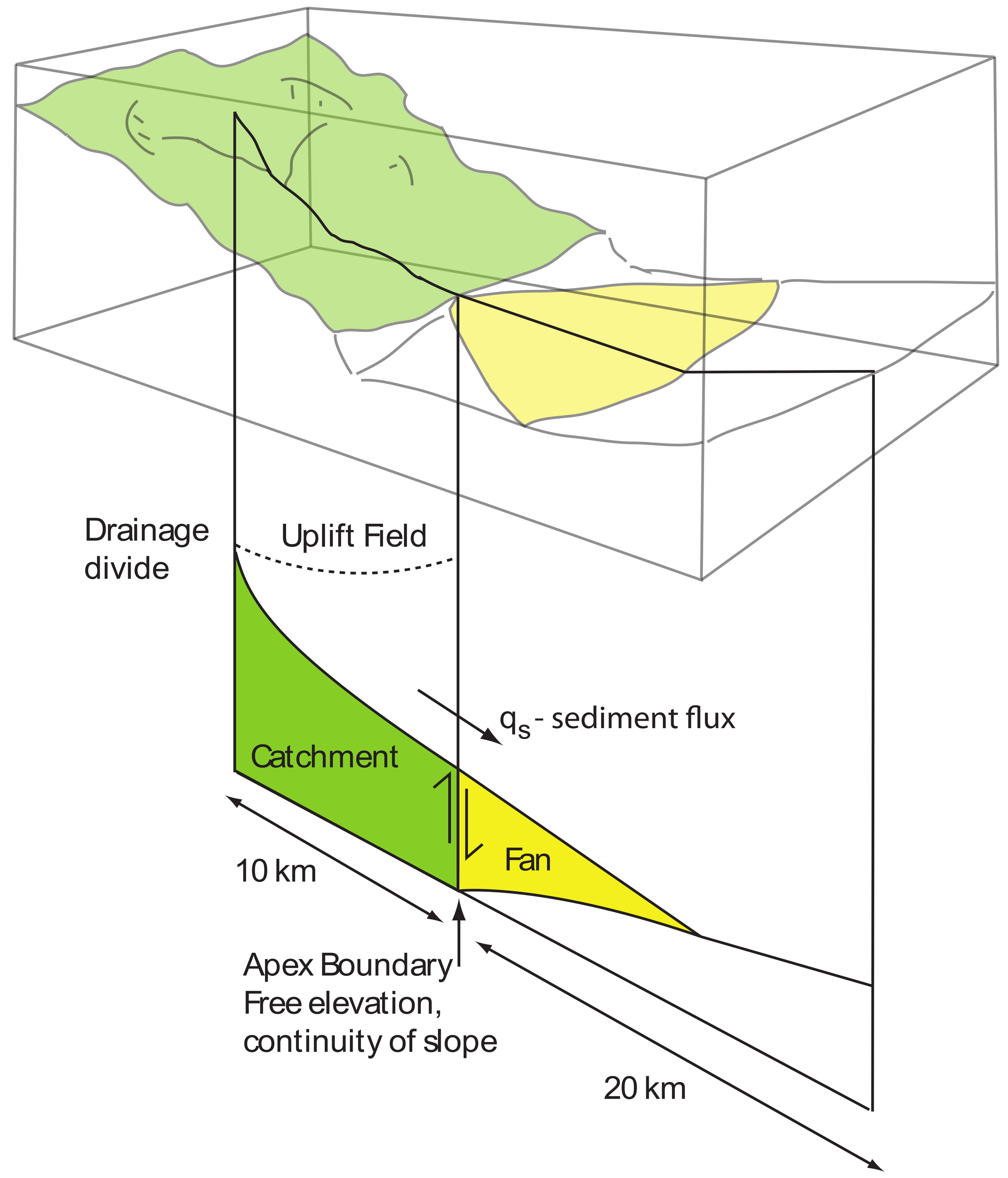

Figure 1: Idealised catchment fan. Erosion within the uplifting catchment is treated through a non-linear diffusional equation (see Armitage et al., 2011). Deposition is calculated from a sediment volume balance with the grain size distribution down system calculated assuming selective deposition by grain size (Duller et al 2010; Fedele & Paola, 2007), assuming fan structure is the time averaged deposit of millions of years of continuing surface processes (Figure 2). All changes in precipitation are imposed once steady state has been achieved.

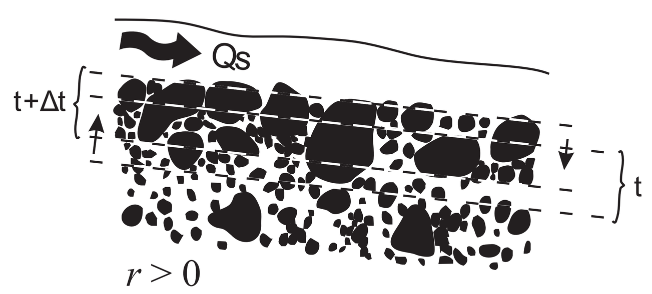

Figure 2: Conceptual diagram of the vertical flux of sediment that is transported from the surface to the subsurface and preserved within stratigraphy.

Introduction

The prevalence of Milankovitch-period cyclicity in the deep-marine stratigraphic record is now widely acknowledged. This is commonly expressed as a regular cyclicity in sediment composition (e.g. marl/limestone cycles), trace element abundance (Fe, Mn) or stable isotope compositions. The driving mechanism of this cyclicity is attributed to orbital-controlled variablity in regional or global climate. In contrast to the the marine record, it is much less apparent if and how high frequency (< 1 Myr) climate cycles are expressed in mountain landscapes and manifested their alluvial basin-fill. Modelling suggests that such landscapes respond transiently to high frequency forcing and may, therefore, obliterate signals of sediment discharge (Jerolmack & Paola, 2010; Armitage et al., 2011). Here we demonstrate that climate-driven signals in particulate sediment discharge and sediment grain size are damped through time, and signals are likely lost in fluvial successions.

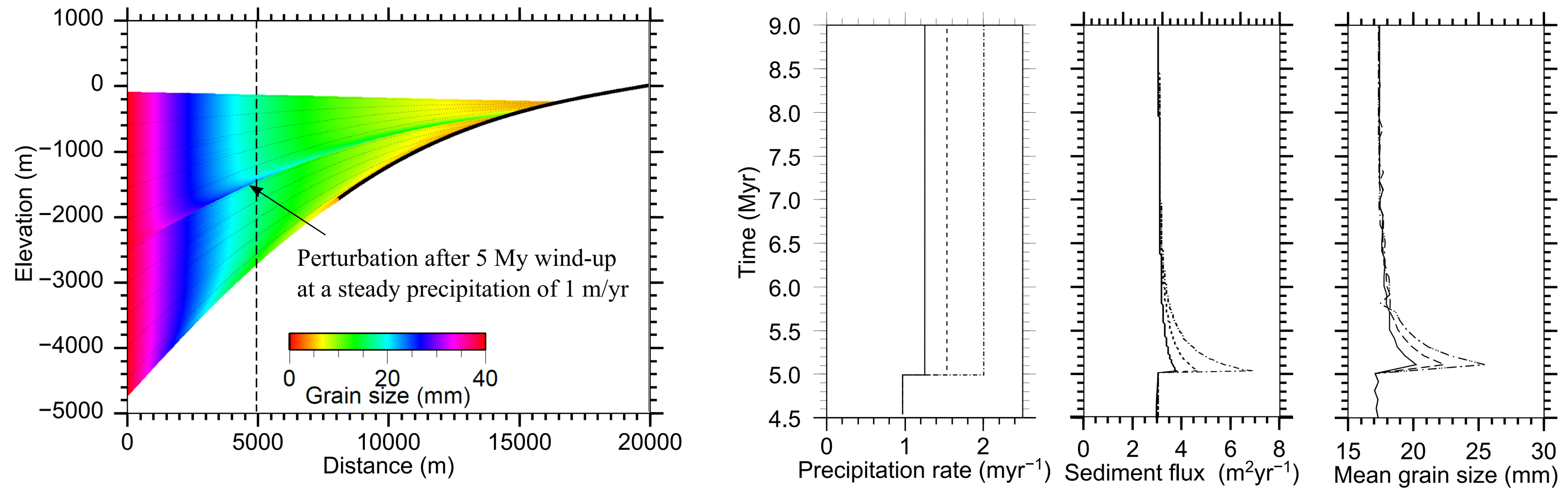

Figure 3: Response recrded within the fan succession to a single step increase in precipitation rate within the catchment. From left to right, mean grain size deposited within the fan for a precipitation increase from 1 to 2 m/yr; input precipitation; sediment efflux out of the catchment; and mean grain size 5 km from the fan apex.

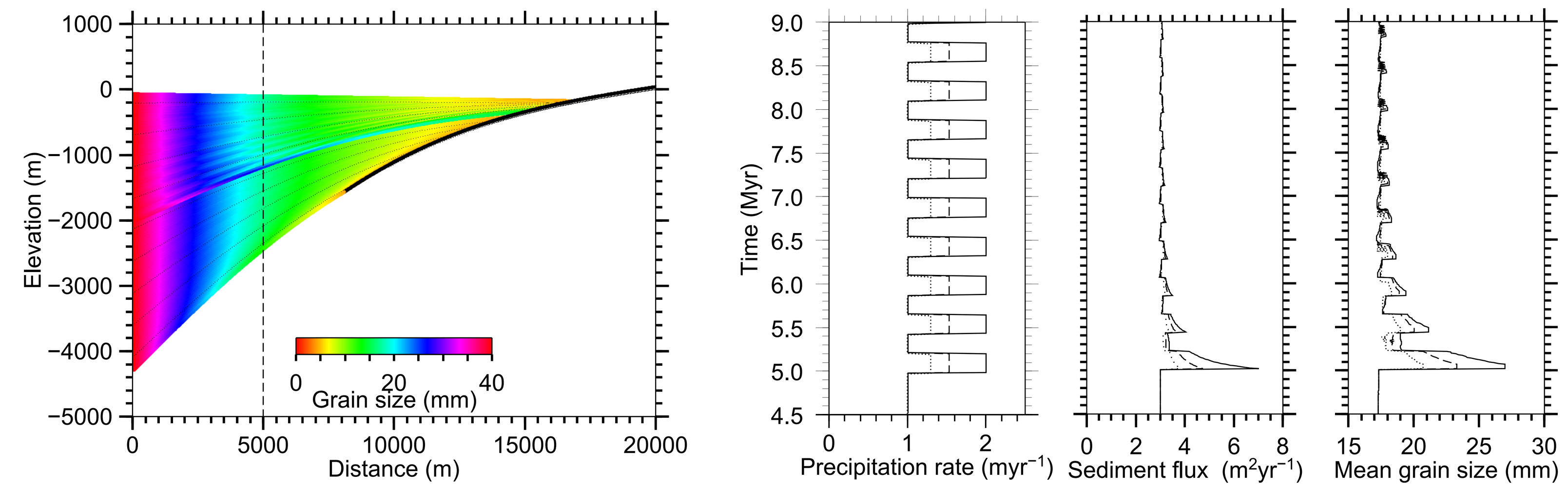

Figure 4: Response of the sedimentary fan succession to a saw tooth oscillating change in precipitation with a period of 400 kyr. Left panel shows mean grain size for oscillations in precipitation of 1 to 2 m/yr.

400 kyr long eccentricity orbital oscillations

When the catchment is subject to a single, stepped increase in precipitation the catchment topography adjusts to a new steady state such that slopes are lower and sediment efflux returns to the initial state within roughly 500 kyr (Figure 3). The response of the catchment to oscillations in precipitation is similar, whereby topography cannot adjust rapidly enough to each individual jump in precipitation and so adapts to a new pseudo-steady state after roughly 1 Myr. Over time the sedimentary response to continued oscillations in precipitation is damped.

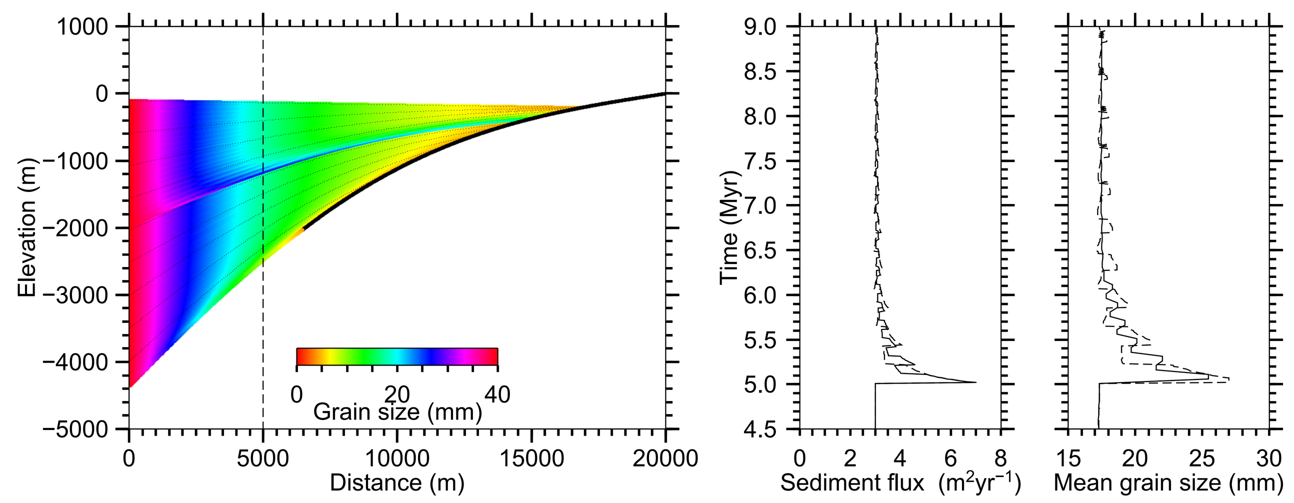

Figure 5: Response of the sedimentary fan succession to a saw tooth 200 kyr oscillation of 2 m/yr peak precipitation. The right panels show sediment efflux and mean grain size 5 km from the fan apex for 200 kyr periodicity (solid line) and 400 kyr periodicity (dashed line).

200 kyr periodicity

The responce to increased frequency oscillations in precipitation is a more rapid damping of the signal within the rock record. For 400 kyr cyclicity the signal diminshes in 1 Myr, for 200 kyr oscillations the damping time is 750 kyr.

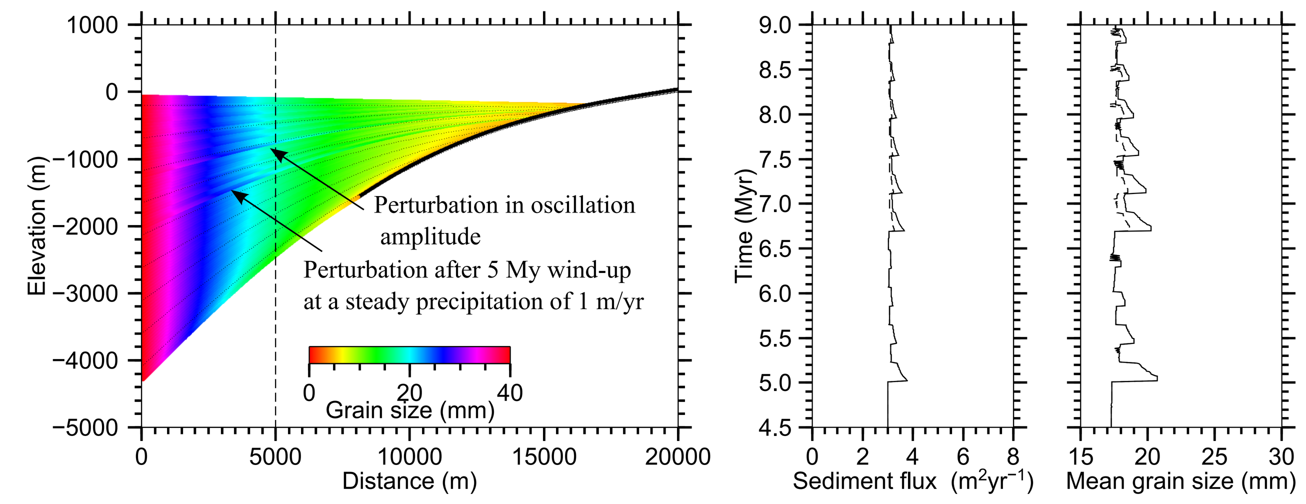

Figure 6: Response to a step change in amplitude for an oscillating climate. From left to right: mean grain size for an initial oscilllation of 1 to 1.25 m/yr for 1.6 Myr followed by oscillations of 1 to 2 m/yr. Sediment flux for as before (solid line) and a change to oscillations of 1 to 1.5 m/yr (dashed line). Mean grain size at 5 km from the fan apex.

Change in amplitude - Signals Lost

Once the eroding catchment has achieved a pseudo-steady state topography, we subject the catchment to an increase in the amplitude of precipitation oscillations (Figure 6). As the catchment has already adapted to a changing climate, any further changes in amplitude of forcing are rapidly dissipated by the catchment. This means that the peak sediment flux out, and hence progradation of coarse gravel clasts into the basin, is diminshed. Therefore a landscape that is already in a state of adjustment to a constantly changing climate is strongly buffered to intensified climate oscillations. It is thus likely that the sedimentary expression of orbitally-forced precipitation changes are rapidly lost within upstream mountain catchments as the erosional engine responds on a time scale longer than the applied orbital forcing (Figure 4).

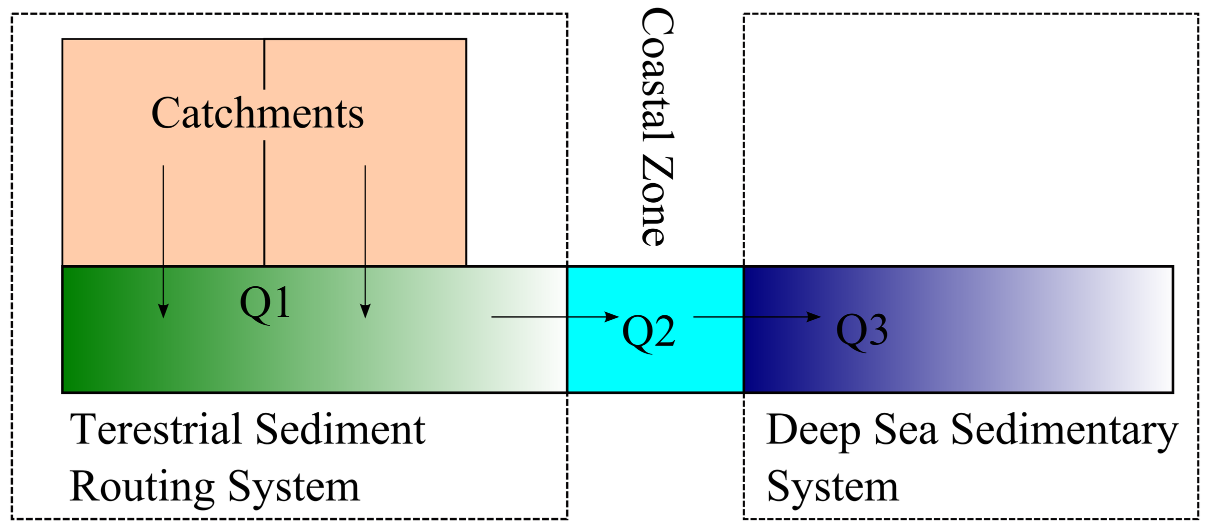

Figure 7: A simple sediment routing system

Land to Sea - Signals found

The terrestrial segments of sediment routing systems appear to buffer, damp and even obliterate the expression of high-frequency climate cycles (Castelltort & Van Der Dreisshe, 2003; Jerolmack & Paola, 2010; Armitage et al., 2011). The sediment efflux from catchments to the fluvial segment, Q1, is punctuated by transient signals due to major long-term changes in climate regime (Figure 3 & 6). Once these signals propagate through the sediment routing system, Q2, they become temporally and spatially buffered. This buffering means that the efflux of sediment to the coastal zone remains roughly constant through time (Blum & Tornquist, 2000). If correct, this implies that the terrestrial sediment supply plays little role in the development of marine sediment cycles, which are instead dominated by changes in sea level, ocean chemistry and aeolian sediment fluxes.

References: Armitage et al., Nature Geoscience (2011); Blum & Tornquist, Sedimentology (2000); Castelltort & Van Der Dreissche, Sedimentary Geolgy (2003); Duller et al., Jouranl of Geophysical Research (2010); Fedeler & Paola, Journal of Geophysical Research (2007); Jerolmack & Paola, Geophysical Research Letters (2010)