The links between climate, tectonics, and denudation from cosmogenic nuclides in river sediment

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Two different schools of thought have dominated the debate over the Earth's long-term climate regulation through silicate weathering and CO_2 drawdown. One has been suggesting a climate-controlled feedback mechanism; the other promoted mountain building as primary requirement. A consensus has not been reached partly because the rates of the contributing processes are not known with sufficient reliability. Previous estimates of weathering fluxes in any given tectonic or climate environment did not allow for conclusive support of either hypothesis.

In situ-produced cosmogenic nuclides now provide the means to determine rates of denudation on time scales typical for weathering processes (roughly the residence time of a 0.5-1m soil layer). Measuring ^{10}Be or ^{26}Al in sediment from streams allows a convenient spatial integration on a wide range of scales (ranging from a small creek to an entire drainage basin).

A somewhat surprising pattern is now emerging from a global compilation of such denudation rates of non-glaciated areas that allows to identify the sites and processes of high denudation. (1) Neither precipitation nor mean annual temperature appears to correlate in any way with total denudation. (2) Topographic relief alone does not result in high rates of denudation (an extreme example are the high, steep, wet, and hot tropical highlands of Sri Lanka that features some of the lowest rates measured to date). (3) Denudation rates are high in areas of landscape rejuvenation; which is triggered and controlled by tectonic activity (faulting, escarpment formation and retreat, rifting, surface uplift). These areas include, but are not limited to active orogens. (4) Rates of weathering (using cosmogenic nuclides with zirconium-normalised cation loss balances, Riebe et al. EPSL 2004) depend mainly on physical erosion rate and only to a lesser degree on climate. (5) If climate control plays a stronger role it does so through climate cycling (e.g. waxing and waning of periglacial processes).

These new findings allow the possibility that tectonic activity exerts the primary control over weathering and erosion. This leads to base level lowering, readjustment of drainage networks, reduced soil pore water saturation by re-arranged subsurface hydrology, therefore increased rates of mineral dissolution and, finally, higher physical erosion.

Rapid response of erosion to recent climatic changes: New insights from uranium-series

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Previous studies have used the composition of river-borne material to estimate, at the scale of a drainage basin, continental erosion rates (e.g. Martin and Meybeck, 1979; Milliman and Meade, 1983; Gaillardet et al., 1997). All these studies are based on the assumption that erosion operates at steady-state, i.e. that there is a perfect balance between the amount of rock converted into soil and the amount of erosion products exported by the river. To test this hypothesis, major and trace elements have been used (e.g. Gaillardet et al, 1997), but in that case, major assumptions must be made about the composition of the eroded bedrock. Uranium-series can be used to address this question because they are in secular equilibrium after 1Ma. Hence for a bedrock older than 1Ma, its U-series composition is known and no starting composition assumption is required.

In the present study (Dosseto et al., submitted), U-series isotopes have been measured in riverwaters from the Amazon basin. Our results suggest that (1) erosion in the Andes is clearly not in steady-state and destruction of soils is faster than production, (2) erosion is characterized by short timescales (a few ka). Combining these two observations, we propose that the deviation of erosion from steady-state is the result of a recent change in the erosional regime probably linked to climatic changes in the basin. The implication is that erosion can respond rapidly to high frequency external forcings.

References

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