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Large-scale, Long-term Erosion Rates Determined from ^{10}Be in European River Sediments

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Traditional estimates of large-scale, continental erosion rates are based upon measurements of solid and dissolved loads of rivers (1). This method requires long-term (at least several decades), frequent (preferably daily) measurements, to account for temporal variability of water discharge and sediment transport. Even where these requirements are met, erosion rate estimates are not necessarily robust, because 1) they may not have captured rare, high-magnitude flood events, and 2) sediment transport rates may have been affected by river engineering works.

We have determined large-scale, continental erosion rates, using the concentration of the rare cosmogenic nuclide ^{10}Be in quartz from the bedload of rivers. This technique exploits the continuous bombardment of the Earth's surface by cosmic rays which induce nuclear reactions in the upper meter of rocks. Nuclide concentration in the shallow subsurface is controlled by the surface erosion rate. It can be demonstrated that river sands contain a cosmogenic nuclide inventory that reflects the ensemble of erosion events distributed across a catchment. Assuming steady state erosion and nuclide production, the catchment-wide erosion rate can be determined from a sample of well-mixed sand (2, 3, 4).

We have tested this approach in four medium sized (10^3-10^4 km^2) rivers draining the middle European uplands. The four test catchments are the Regen (SE Germany, crystalline bedrock), the Loire and Allier (France, crystalline bedrock), the Neckar (SW Germany, Mesozoic sediments), and the Meuse (NE France, Belgium, Netherlands, Mesozoic sediments and Palaeozoic schists). Erosion rates were estimated from cosmogenic nuclide concentrations in river quartz, using production rates and absorption depth lengths for fast and stopped muons given by Heisinger (5) and Kubik et al. (6). Production rates have been scaled to the mean altitude of the upstream area of individual sampling locations. These estimates were compared with erosion rates calculated from suspended and dissolved loads measured during the last 30 years.

There is good first-order agreement between river load-based and cosmogenic erosion rate estimates. However, close comparison between the methods shows that the river load-based rates are always 2-5 times lower than the cosmogenic rates. This difference may have at least three causes. Firstly the suspended loads do not necessarily include rare, high-magnitude events, such as centennial or millennial floods, which possibly carry the bulk of the sediment. In contrast, cosmogenic rates integrate over several kilo years (5-10 ka Neckar; 10-30 ka Loire, 20-30 ka Regen, Meuse) and thus capture the full range of event magnitudes. Secondly the steady-state assumption of homogeneous downwearing is violated by linear dissection processes such as rilling and gullying. Third, and most important, the cosmogenic rates carry a "memory" of past erosion rates that prevailed during the last cold period in Middle Europe. The latter possibility will be evaluated in a second contribution (von Blanckenburg et al., this volume).

Observed spatial uniformity of erosion rates within catchments shows that the cosmogenic technique has considerable potential for the estimation of time-integrated denudation rates. The method is now maturing to become applicable to studies of active mountain belts. Moreover, it might allow estimation of natural soil erosion (time-averaged cosmogenic erosion rates) vs. soil erosion induced by man (short-term rates from river gauging), and could facilitate an evaluation of the effects of climate and climate change on continental erosion.

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