Measuring the timescales of sediment production, transport, and deposition - U-234 sediment comminution ages

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Isotopic and paleontological methods exist to estimate the ages of clastic sediment provenance, the age of sediment deposition, and the timescales of diagenesis. An additional interesting timescale is that encompassing the transformation of bedrock to sediment, including the time required to break down rock into transportable fragments, and the residence time of these particles in soils, streambeds, floodplains, dunes, and moraines prior to deposition on the seafloor or in lakes. The 234U/238U ratio of sediment particulates can provide such information. The "clock" is provided by the loss of the 238U decay product, 234Th, by recoil associated with alpha emission and the concomitant lowering of the 234U/238U ratio in small sediment grains. The timescale is set by the mean life of 234U (240,000 years) which is appropriate to the expected timescales of sediment production and transport. The recoil distance is a about 0.1 micron in silicates. Sand-size grains lose negligible 234Th by recoil, but the recoil effects become significant and measurable when the grain diameter is about 50 microns or smaller. Measurements of sediment 234U/238U ratios suggest that the fraction of 234Th atoms lost by recoil is typically greater than that predicted by the spherical grain model (fractional loss $=$ 3L/2d, where L is the recoil distance and d is the grain diameter). In deep sea sediments, grains with dimensions of 1 to 10 microns exhibit fractional depletions of 20 to 30 percent, which can now be measured with an accuracy of 0.05 percent. When a small grain is produced by erosion, it begins to leak 234Th to its surroundings and its 234U/238U ratio starts to decrease. To reach the steady state 234U/238U ratio appropriate to its size and fractional loss rate requires about 1 million years. In the meantime the 234U/238U is measuring the time since the small grain was produced, which we refer to as the "comminution age." Since the 234U/238U ratio continues to decrease after sedimentation and burial, the method can also potentially be used to measure sedimentation rates and the age of clastic sediments in the range 10,000 to 1 million years. Measurements of sediment size fraction 234U/238U ratios as a function of depth below the seafloor or age allows retrieval of the effective fractional loss rate, and the comminution age at the time of deposition. The latter can be considered to be the "sediment production time." Our measurements of Late Pleistocene sediment retrieved from ODP Site 984 in the North Atlantic (mean grain size 10 - 20 micron, fractional loss rate 0.20) suggest that the timescale for sediment production there is about 20 kyr. Measurements of Bering Sea and North Pacific sediments from the literature (Yamada and Tsunogai, Marine Geol., v.54, 1983) suggest sediment production times of 60 and 250 Kyr respectively. Broader application of the technique will require further work to establish reliable approaches to removing diagenetic components.