Long-term sediment-generation rates derived from ^{10}Be in river sediment of the Susquehanna River basin

Joanna M Reuter[1], Paul R. Bierman[1], Milan J. Pavich[2], Allen C. Gellis[2], Jennifer Larsen[1], and Robert C. Finkel[3]

[1] University of Vermont, [2] USGS, [3] Lawrence Livermore National Laboratory

Overview

We are using cosmogenic ^{10}Be measurements of quartz extracted from sediments of the Susquehanna River basin to address geomorphic questions of where and how quickly Earth's surface erodes. We seek to determine if long-term (10^4-10^5 year) rates of sediment generation, as inferred from cosmogenic ^{10}Be, correlate with GIS-measurable components of the present-day landscape, such as topography, relief, and precipitation. Such correlations, or a lack thereof, will provide insight into the tempo and pattern of landscape erosion and change.

Though we currently have results for only a small subset of the collected samples, the ^{10}Be-based sediment-generation rates (10-20 meters per million years) agree broadly with other erosion rate estimates for the Susquehanna basin.

Basin-scale sediment-generation rates from in-situ-produced ^{10}Be

The continual bombardment of Earth's surface by cosmic rays results in the production and accumulation of cosmogenic nuclides in near-surface materials. One such nuclide, ^{10}Be, is often measured in purified quartz (Lal and Peters, 1967). In an eroding landscape, quartz grains accumulate ^{10}Be as they approach the surface (Lal, 1991). When such grains enter a river system, they carry isotopic concentrations that record their near-surface exposure histories (Bierman et al., 2001; Brown et al., 1995).

Rivers collect, transport, and mix grains from various parts of the basin. The abundance of cosmogenic nuclides in stream sediments reflects the integrated cosmic ray dosing and thus, by inference, the erosional history of the basin. For example, slowly eroding basins have relatively high nuclide activities because quartz grains, on average, have spent a long time near the surface. Measurement of ^{10}Be in sediment provides sediment generation rates on a 10^3-10^6 year time scale, depending on the erosion rate and the associated sediment residence time in the basin.

Susquehanna River and sampled basins

The Susquehanna River drains >70,000 km^2 of the North American passive margin (Figure 1). The basin spans three major physiographic provinces: the Appalachian Plateaus, Valley and Ridge, and Piedmont. We sampled two groups of drainage basins. The first 26 samples were collected from USGS gage sites representing basins that range in size from 15 km^2 to 62,400 km^2 (Figure 1 and Figure 2). These gages have sediment yield records with which we can compare the ^{10}Be-estimated sediment-generation rates. The ^{10}Be data are relatively insensitive to land use impacts (Bierman and Steig, 1996; Brown et al., 1995; Granger et al., 1996), while the sediment yields may be affected by post-settlement land use (Trimble, 1977). The USGS gage samples are spread among each of the physiographic provinces, and most basins incorporate more than one lithology. Seven of these samples are north of the Late Pleistocene glacial margin, and an additional three sites, located on the mainstem Susquehanna and its major branches, are associated with basins that were partially glaciated. We currently have ^{10}Be activities for 15 of the samples from USGS gage sites, including 12 unglaciated basins and the three partially glaciated basins.

The second sample group consists of sixty small (3-10 km^2) basins. The small basins are unglaciated, span a range of mean basin slopes, and are scattered among the major physiographic provinces; each basin is mapped as a single lithology (Figure 1). Results from these basins will be used to assess relationships between basin-scale characteristics and sediment generation rates. Furthermore, data from these small, simple basins will aid in the interpretation of the larger, more complex USGS gage basins, where factors including multiple lithologies, glaciation, and mining must be considered.

Although we do not yet have ^{10}Be data for these small basin samples, observations of channel morphology provide insight about landscape behavior. At sizes between 3-10 km^2, the basins have well developed stream channels, most of which carried moderate flow during our sample collection visits in the relatively wet summer of 2003 (Figure 3). Of the basins we visited, few had exposed bedrock in the channel or lower valley walls near the sampling sites; the streams meander on a veneer of alluvium. A notable exception occurs in the vicinity of the Holtwood Gorge on the lower Susquehanna River. Tributaries entering directly into Holtwood Gorge have substantial exposed bedrock in their downstream reaches. Although the October 2003 SEFOP group will not have time to visit any of these streams, they are easily accessed by foot trails, and they are worth visiting independently. The waterfalls and local bedrock valley walls make these tributaries to Holtwood Gorge some of the most scenic small streams south of the glacial margin in the Susquehanna basin. It remains to be seen whether these basins are eroding more rapidly than more alluviated basins in the ^{10}Be data set.

The first 15 data points

The sediment-generation rate results presented here are preliminary; they were calculated using ^{10}Be production rates based on basin hypsometry under the assumption of equal quartz contribution from all parts of the basin. Fine tuning of this calculation will take place when data for the small basins are available, but the results presented here are a reasonable first estimate.

Table 1.

USGS Gage	Station ID	Basin area (km^2)	^{10}Be sediment generation rate (m/My)	Erosion rate inferred from sediment yield (m/My)	Percent of basin glaciated
Bald Eagle Creek below Spring Creek at Milesburg	1547200	686	16 ± 4	12	0
Bixler Run near Loysville	1567500	39	8 ± 2	9	0
Conestoga River at Conestoga	1576754	1217	18 ± 2	24	0
Cordorus Creek near York	1575500	575	14 ± 3	46	0
Dunning Creek at Belden	1560000	445	9 ± 1	8	0
Little Conestoga Creek near Churchtown	1576085	15	10 ± 1	400	0
Mill Creek at Eshelman Mill Road near Lyndon	1576540	140	11 ± 1	17	0
Raystown Branch Juniata River at Saxton	1562000	1958	9 ± 1	12	0
Sherman Creek at Shermans Dale	1568000	536	11 ± 2	12	0
Susquehanna River at Danville	1540500	29060	18 ± 2	19	93
Susquehanna River at Harrisburg	1570500	62419	34 ± 7	15	49
Swatara Creek at Harper Tavern	1573000	873	14 ± 2	30	0
West Branch Susquehanna River at Bower	1541000	816	19 ± 4	16	0
West Branch Susquehanna River at Lewisburg	1553500	17734	29 ± 4	16	17
Yellow Breeches Creek near Camp Hill	1571500	559	19 ± 4	18	0

The sediment generation rates calculated from ^{10}Be activities measured in unglaciated basin fluvial sediment range from 9 to 20 meters per million years (Figure 4 and Table 1). These results agree broadly with estimates of the erosion of the Susquehanna obtained using other methods including suspended sediment yield, saprolite production rates, thermochronologic data, and incision rates (see Pazzaglia, this volume).

In general, ^{10}Be-based erosion estimates and the sediment yield data for the same basins are correlated well, implying broadly consistent rates of sediment yield on decadal time scales and erosion on millennial timescales. However, two groups of basins deviate from the trend. (1) Basins influenced by continental glaciation have relatively low nuclide activities (or high calculated ^{10}Be sediment-generation rates). A lower nuclide concentration in sediment from glaciated basins is consistent with shielding by glacial ice and removal of the most highly irradiated portion of the soil and rock profile by glacial erosion. (2) Several of the basins in the southern part of the Susquehanna have ^{10}Be-inferred sediment generation rates in the 10-20 m/My range, but sediment yields that are much higher. While the basins with high sediment yields do have high percentages of agricultural land, not all of the basins with comparable percentages of agricultural land use have such high sediment yields.

The correlations explored thus far between ^{10}Be sediment-generation rates and basin characteristics are very weak. For example, ^{10}Be sediment-generation rates from the unglaciated basins appear to be uncorrelated to mean basin slope (Figure 5). The small size of the present data set limits our ability to apply multivariate statistical techniques, which will be used when the full data set is available.

References Cited

Bierman, P., Clapp, E., Nichols, K., Gillespie, A., and Caffee, M.W., 2001, Using cosmogenic nuclide measurements in sediments to understand background rates of erosion and sediment transport: New York, NY.

Bierman, P., and Steig, E.J., 1996, Estimating rates of denudation using cosmogenic isotope abundances in sediment: Earth Surface Processes and Landforms, v. 21, p. 125-139.

Brown, E.T., Stallard, R.F., Larsen, M.C., Raisbeck, G.M., and Yiou, F., 1995, Denudation rates determined from the accumulation of in situ-produced (super 10) Be in the Luquillo experimental forest, Puerto Rico: Earth and Planetary Science Letters, v. 129, p. 193-202.

Granger, D.E., Kirchner, J.W., and Finkel, R., 1996, Spatially averaged long-term erosion rates measured from in situ-produced cosmogenic nuclides in alluvial sediments: Journal of Geology, v. 104, p. 249-257.

Lal, D., 1991, Cosmic ray labeling of erosion surfaces; in situ nuclide production rates and erosion models: Earth and Planetary Science Letters, v. 104, p. 424-439.

Lal, D., and Peters, B., 1967, Cosmic ray produced radioactivity on the earth, *in* Sitte, K., ed., Handbuch der Physik: New York, Springer-Verlag, p. 551-612.

Trimble, S.W., 1977, The fallacy of stream equilibrium in contemporary denudation studies: American Journal of Science, v. 277, p. 876-887.

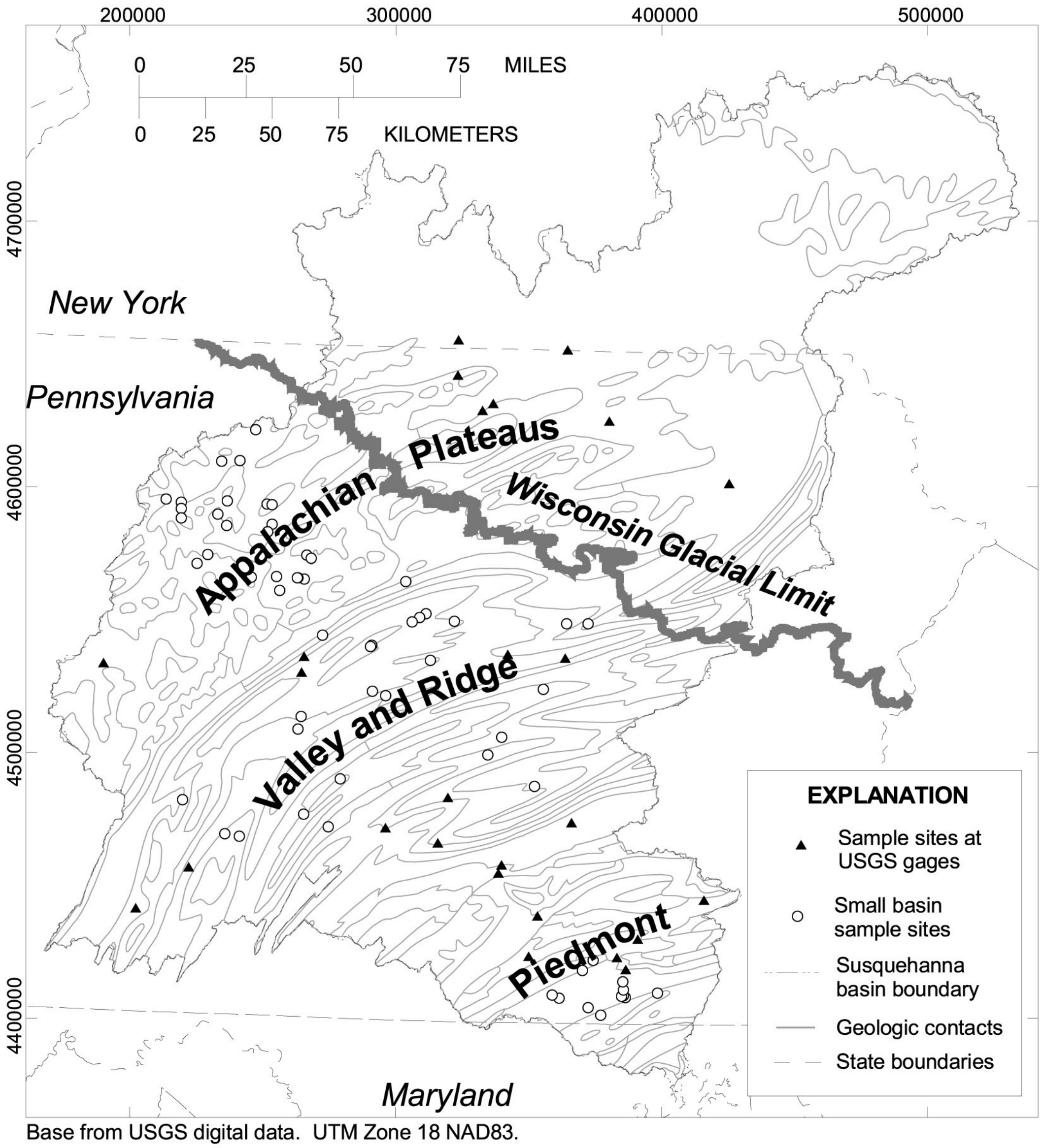

Figure 1. Map of the Susquehanna River basin. Geologic contacts (shown within the Susquehanna basin boundary) help to distinguish the major physiographic provinces: relatively flat-lying sedimentary rocks of the Appalachian Plateaus; folded sandstone, shale, and carbonate of the Valley and Ridge; and metamorphic, igneous, and sedimentary rocks of the Piedmont. Coordinates are UTM Zone 18.

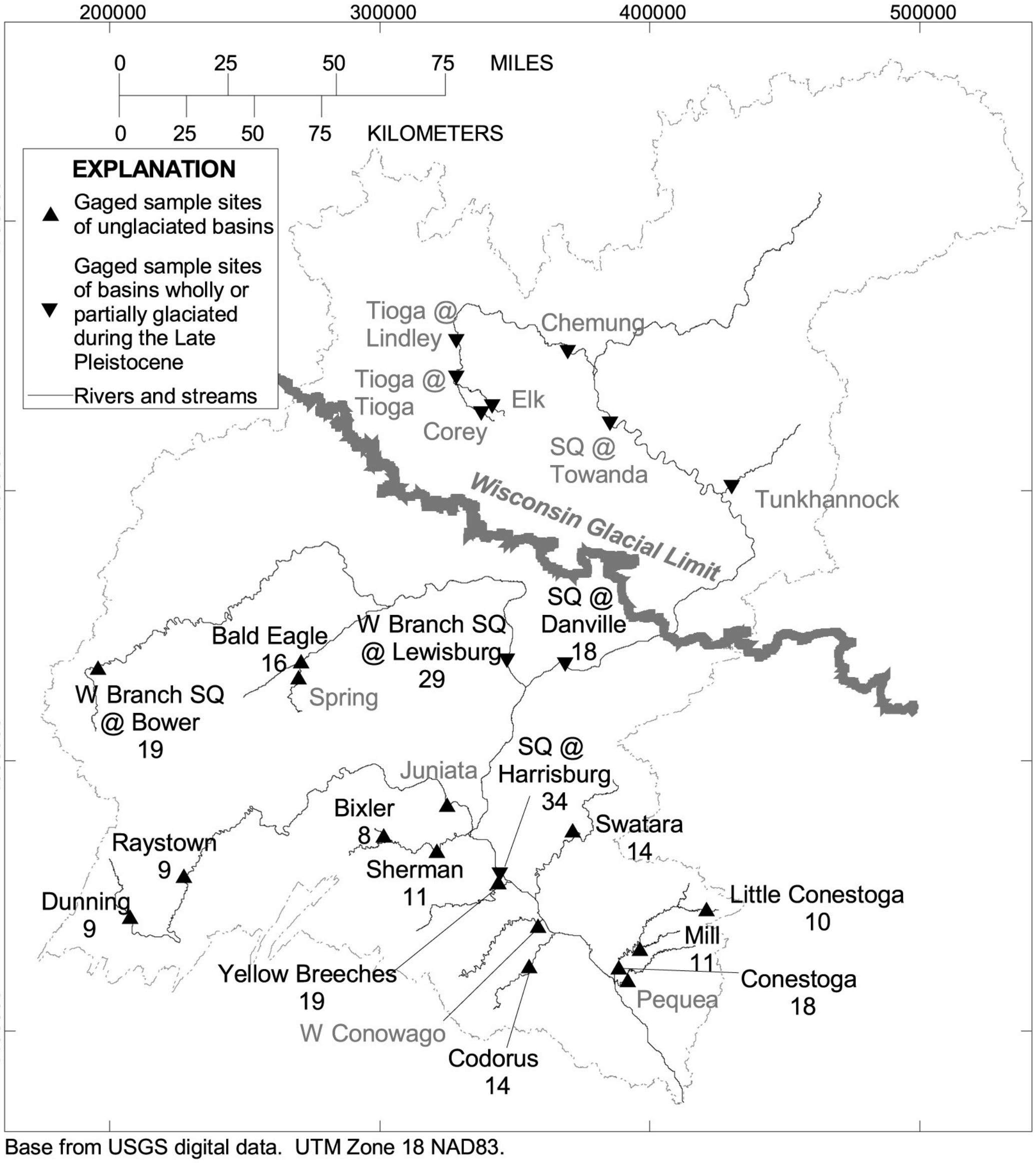

Figure 2. Map of the Susquehanna River basin showing USGS gages that were sampled. ^{10}Be sediment generation rates, in meters per million years, are shown where data are currently available. Susquehanna abbreviated as SQ.

Figure 3. Photo of the sample site for a 5 km^2 Piedmont basin, tributary to Tucquan Creek. Person on the right side of the photo is sieving sediment from the stream channel to obtain an appropriate grain size for analysis.

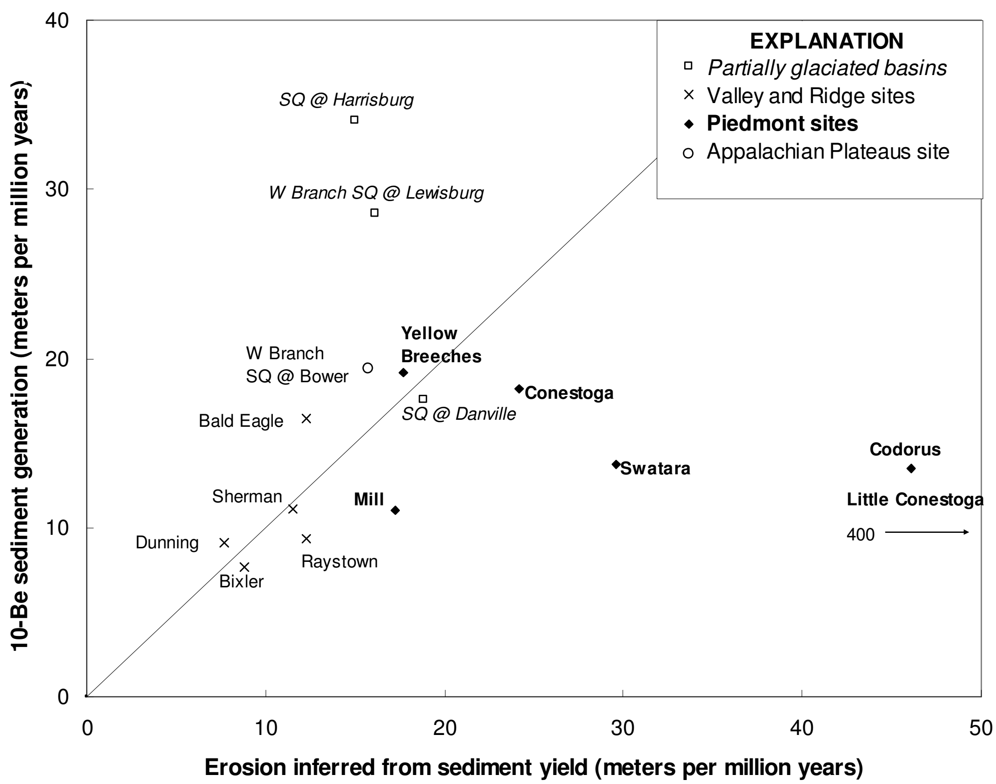

Figure 4. Scatter plot showing relation of sediment yield to ^{10}Be sediment generation rate, both expressed in meters per million years. Basins labeled in italics were partially glaciated during the Late Pleistocene. Basins labeled in bold are located at least partly in the Piedmont Province of the lower Susquehanna basin. Sediment yields were calculated by Allen Gellis and Milan Pavich (USGS).

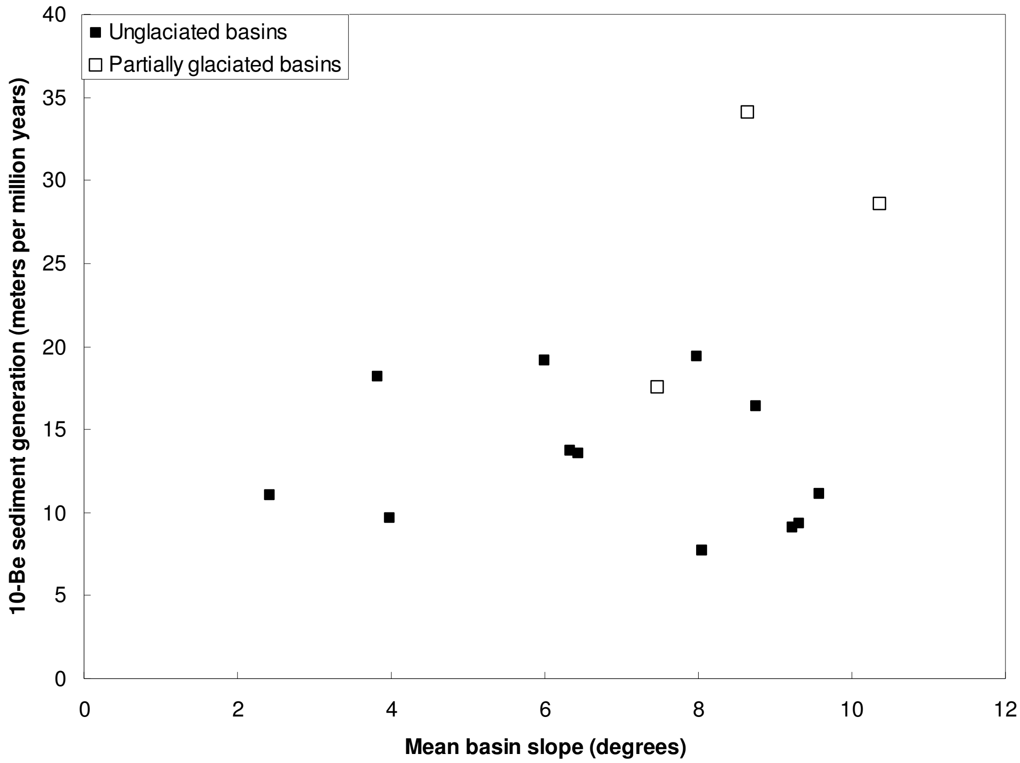

Figure 5. Based on the available data set, mean basin slope and ^{10}Be sediment generation rates for unglaciated basins appear to be uncorrelated.