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Earth Surface Dynamics Discussions

Interactive comment on "Short Communication: Earth is (mostly) flat, but mountains dominate global denudation: apportionment of the continental mass flux over millennial time scales, revisited" *by* J. K. Willenbring et al.

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We thank the reviewers for contributing to the ongoing debate over where and how much denudation occurs on Earth's continents. We appreciate the opportunity to clarify our work and to address questions related to the timing and authorship of various works that have been published since the publication of the original Willenbring et al. (2013a) paper that instigated this submission to Earth Surface Dynamics. We hope to have an opportunity to revise the discussion paper based on this useful feedback into one that provides some rigorous, testable hypotheses and offers a way forward for future

studies.

There has been some concern from the first reviewer's editor-retracted review regarding the authorship and timing of this and other papers. We welcome the opportunity to address this issue. Willenbring, Codilean and McElroy wrote the original Geology 2013a paper after presentation of various versions at national scientific meetings over the course of the preceding five years. Kirchner and Ferrier (2013) independently wrote the News and Views Nature comment about the published Willenbring et al. (2013a) paper, and highlighted the promise of the work while also pointing out some potential problems. After the publication of Kirchner and Ferrier (2013), Willenbring, Codilean and Kirchner quantified some of the flaws in the paper and, together with McElroy and Ferrier, immediately (1) submitted abstracts to present the corrections at the two main national geological and geophysical society meetings (Willenbring et al., 2013b; 2013c), and (2) decided to submit a paper correcting the mistakes made in Willenbring et al. (2013a). We submitted our new manuscript correcting previous issues to Geology in 2013. While our paper was in review at Geology, we were invited to reply (Willenbring et al., 2014) to the comment by Warrick et al. (2014), but were not allowed by the handling editor to reference the paper in review or the findings already published in abstracts. The Geology editor eventually rejected the paper. We then submitted a new version of the manuscript to Earth Surface Dynamics to make our errors known as quickly as possible to the geologic community who had not attended the presentations at the national meetings. The 'discussion' version of the paper is the one we intend to revise to take into account the valuable comments and suggestions from the anonymous reviewers.

The aim of revising this discussion paper is still to rigorously explore the idea: if the observed relationship between denudation rate and slope also holds in places where cosmogenic nuclide measurements haven't been made, then lowland denudation rates should not be trivially small. This concept of lowlands and gently sloping hills contributing substantively to Earth's total denudation is relatively new to the Earth's science

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community and bears on the potential of Earth's surface to change globally as a result of mountain building events in small regions. It also indirectly bears on the potential of mountain building to accelerate silicate weathering and significantly change climate through CO2 sequestration. Excluding techniques using the volumes of terrigenous material and the products of chemical weathering in the oceans as indicators of continental denudation that are subject to reworking and cannibalization (e.g., Ronov, 1983; Wilkinson and McElroy, 2007), there were no global estimates of continental denudation from long-term recorders before our past and current work on the topic. There is still much to be done to understand the large denudation rate dataset that now exists. In the revised version of this paper, we will correct previous methodological and conceptual errors that some of the authors of this current paper made in Willenbring et al. (2013). Our proposed revision will include the following additions that would correct the manuscript as requested by the reviewers. Our revision will:

1.) Provide an expanded compilation that includes the hundreds of newly published measurements and the associated metadata necessary to reproduce the locations and the denudation rates, including areas in mountainous area with very high denudation rates; 2.) Propagate uncertainties in our method, including uncertainties related to using a finer topographic resolution than the 250-m DEM and uncertainties related to adding other environmental variables in addition to slope, which alone explains ca. half the variance in denudation rate over the entire Earth in our analysis.

This expanded dataset with the uncertainty analysis will allow us to go beyond previous work understanding more than just the first-order controls on global denudation using cosmogenic nuclides. For example, previous work has noted the lack of a precipitation or temperature effect on denudation rates (e.g. von Blackenburg et al., 2004; Portenga and Bierman, 2011). However, these papers did not determine whether high rates or amounts of modern precipitation are correlated with high rates of denudation after controlling for the first-order effect of topography (i.e. slope). This is one avenue we could explore as part of the resubmission.

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We submit that our revision will clarify what cosmogenic nuclides have added to understanding long-term denudation rates over the Earth's surface that were previously impossible without the technique. At the same time, we acknowledge that all global denudation rate datasets, even the expanded cosmogenic nuclide dataset, (1) have methodological limitations that hamper comparisons to river load data; (2) do not, on their own, provide a satisfactory answer to the question of how much continental material is moved into the ocean every year; and (3) do not directly quantify chemical weathering fluxes resulting from the uplift of mountain ranges.

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