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Millennial-scale erosion rates in the Harz Mountains (Germany) from cosmogenic ^{10}Be: Implications for landscape evolution of basement highs in Central Europe

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Understanding how landscapes evolve under changing tectonic and climatic boundary conditions requires the quantification of erosion rates on different temporal scales. Rates and spatial patterns of erosion exert a major control on the topographic evolution of mountain ranges, in particular when rock uplift due to tectonic processes has ceased to be the dominant relief-forming factor. Here we present newly quantified ^{10}Be-based erosion rates for the Harz Mountains, a typical Variscan basement high in Central Europe. The present fault-bounded mountain range formed as a result of tectonic inversion of the Central European Basin during the Late Cretaceous with a further phase of post-Oligocene uplift. The summit region of the Harz (Brocken peak 1 141 m a.s.l., Permian granite) is morphologically surrounded by remnants of an Oligocene low-relief bedrock surface that was carved into Palaeozoic metasediments. This planation surface ranges in elevation between 500–700 m a.s.l. and thus stands 200–300 m above the Harz foreland. The origin of this morphology and particularly its uplift history has been under debate for more than a century (e.g. Philippi 1910; Mücke 1966; Thiem 1974; König et al. 2011), with widely differing views on proposed physical processes, tectonic triggers and the timing of uplift. In recent years it has also been suggested that a significant amount of Harz uplift may have been caused by glacial isostatic adjustments in response to ice sheet loading of the Subhercynian Basin during the Middle Pleistocene (Diercks et al. 2021), or other mechanisms causing a neotectonic reactivation of the Harz Northern Boundary Fault (Müller et al. 2020).

An important aspect for a better understanding of the morphological evolution of the Harz is the determination of local and spatially averaged catchment-wide erosion rates. To achieve this, we measured concentrations of in situ-produced cosmogenic ^{10}Be in quartz-rich bedrock outcrops and stream sediment of rivers directly draining the Brocken area (Ecker, Ilse, Warme Bode, Kalte Bode). Our ^{10}Be erosion rates derived from four catchments with a size of 0.3–24 km^2 range from 24 to 54 mm/kyr. The data integrate over the past ~25 kyrs. We found that catchment portions situated within the low-relief surface and with mean slope angles < 10° erode at rates of 24–30 mm/kyr, whereas catchments portions characterized by steeper slopes (20–35°) erode at higher rates of 30–54 mm/kyr. Bedrock outcrops on the planation surface erode at a rate of only ~20 mm/kyr. We note that the magnitude of these erosion results for the Harz Mountains is similar to ^{10}Be erosion rates derived from other bedrock ranges in Germany (e.g. Wolff, Hetzel & Strobl 2018, Meyer et al. 2010). As expected, our data document that erosion rates correlate well with mean hillslope angles showing that hillslope steepness exerts a major control on local erosion dynamics. The data also show that bare bedrock erodes at a rate which is lower than that for catchments with the lowest hillslope angles, corroborating the view that the absence of soil reduces the intensity of physical disintegration and weathering of granitic bedrock compared to parts of the landscape that are soil-covered.

We suggest that comparing our erosion data with uplift rates implied by different proposed Harz uplift models may help to assess their plausibility. For example, assuming that our reconstructed ^{10}Be erosion rates also applies to the Neogene period, it appears unlikely that a Harz uplift of c. 300 m since the Early Miocene (as proposed by Thiem 1974) represents a realistic scenario, as this would compute to an average uplift rate of 15–20 m/Myr (i. e., 15–20 mm/kyr), which is lower than our reconstructed catchment-wide erosion rates (24–54 mm/kyr). We argue that under such scenario with low uplift rates, it would have been impossible to generate significant post-Miocene relief uplift of the Harz, because at these rates any evolving mountainous topography would be efficiently removed by the accompanying rate of erosion. Conversely, neotectonic uplift models, such as suggested by Diercks et al. (2020) who propose a strong Harz uplift pulse of 80–90 m during the Middle Pleistocene, implies high uplift rates in the order of 350–400 mm/kyr, which we also consider as unrealistic. Assuming instead an amount of 300 m of uplift since the Late Pliocene (i. e., during the past ~3.5 Ma; König et al. 2011), we derive an average uplift rate of ~86 mm/kyr. Moreover, if the uplift stopped ~0.5 Ma ago (Thiem 1974), the resulting uplift rate would be in the order of ~100 mm/kyr. Given that both estimates exceed our catchment-wide ^{10}Be erosion rates by a factor of 2–4, the amount and timing of uplift would be compatible with the generation of the observed relief in the Harz during the Pliocene and Quaternary periods, despite the continued removal of surface material by erosion in the Harz Mountains at rates determined in this study.

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