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Predicting landscape evolution for assessing erosion risks at nuclear waste storage sites in southwestern Germany

Daniel Peifer[1]

RESUMO

Safe long-term underground storage of nuclear waste depends on preventing erosion of overlying rock around storage sites to avoid eventual exposure of waste material. Selecting suitable storage locations therefore requires accurate predictions of future erosion rates and associated landscape evolution. To support the German government's search for suitable nuclear waste repository sites, numerical landscape evolution models were applied, generating a wide range of future topographic scenarios (n = 1,728), partly scaled by compiled and new geochronological and geochemical data. To assess potential erosion trajectories and account for uncertainties in these parameters, numerical simulations incorporated diverse geologically reasonable scenarios, including spatially variable rock uplift, climate-change projections, multi-layered 3D stratigraphy with spatially variable fluvial erodibility (K) and hillslope diffusivity (D), karst-related superficial water loss, and stream-power parameters. This approach enabled the identification of a broad spectrum of plausible erosion trajectories, both in detail for southwestern Germany and at a coarser resolution for Germany as a whole. Across all simulations, the Albtrauf cuesta front consistently emerges as a focal point of erosion, with rates reaching 0.42 mm/yr in the preferred configuration and 0.62 mm/yr in the Gipskeuper scenario, where a weak evaporite layer is incorporated. Mean erosion rates along the escarpment front across all parameterizations range from 0.145 to 0.296 mm/yr, significantly exceeding those of the adjacent Swabian Plateau, where mean values range from 0.054 to 0.163 mm/yr. In contrast, the Black Forest, despite experiencing higher uplift rates, exhibits more moderate erosion, with mean values across all parameterizations ranging from 0.088 to 0.23 mm/yr. Validation of the predicted landscape evolution is primarily derived from comparing modelled erosion rates and cosmogenically derived catchment-averaged erosion rates. The comparison of modelled erosion rates after 1 Myr of landscape evolution in both Germany-wide and southwestern Germany simulations with novel cosmogenic ^{10}Be and ^{36}Cl-derived rates (n = 114) and additional published data (n = 44) shows strong agreement. The median modelled-to-measured erosion rate ratio is 1.36 for novel-only samples and 1.56 when including all datasets, reinforcing the model's reliability in reproducing erosion patterns across Germany's diverse geological and climatic settings.

Palavras-chave: Landscape evolution modelling, Erosion rates, Nuclear waste repository.

[1]Department of Geosciences, University of Tübingen, Tübingen, Germany