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Basal conditions and flow dynamics of the Rhine glacier, Alps, at the Last Glacial Maximum

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The safe disposal of radioactive wastes in deep geological repositories requires their containment and isolation for up to one million years. In Switzerland, repositories are planned in the northern Swiss lowlands near the marginal zone of the former Rhine glacier that repeatedly formed two extensive piedmont lobes (the Rhine and Linth lobes) over the Swiss Plateau. Future ice-age conditions may thus impact the repositories due to erosion by glaciers, permafrost conditions, and changes in groundwater fluxes. We use the Last Glacial Maximum (LGM) as a representative future ice-age scenario over northern Switzerland and model the Rhine glacier at the LGM using a full three-dimensional, thermo-mechanical model that solves Stokes flow in ice and the heat equation in both ice and rock. Permafrost in rocks and sediments is implemented using an effective heat capacity formulation. The Rhine glacier at the LGM is one of the best studied paleo-glacier with geomorphic reconstructions of terminal moraines, equilibrium lines, provenance of erratics, till extent and provenance, and evidences of cold vs warm subglacial environments. These data are compared with modeled ice ice thickness, cold vs warm basal condition, and flow paths. Numerical results indicate that LGM modeled ice extent and ice thickness are not fully consistent with geomorphic reconstructions and known climate proxies: ice is either too thick in the accumulation zone or summer temperatures are too cold at the terminus. Simulations with different climate parameters all indicate, however, that the beds of the Rhine and Linth lobes were at the melting temperature except above local topographic highs and along a thin marginal zone. Sliding speed was highest along topographic lows with ice moving at 20 to 80 m a^{-1} depending on mass balance gradients. Basal shear stress was low (< 30 kPa). Melt water was probably abundant due to above-freezing temperatures in summer. Thus, melt water was likely routed over large fractions of the bed. These conditions indicate the possibility of erosion by ice through the process of quarrying and by subglacial fluvial action both of which are thought to be responsible for the many overdeepenings present in the Swiss Plateau.