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Did permafrost modify basal conditions during the Last Glacial Maximum? The case of the Rhine glacier, Swiss Alps

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During the Last Glacial Maximum (LGM), the Rhine glacier in the Swiss Alps formed a large transection glacial complex that drained ice from the central Alps into the central Swiss and southwest German Alpine Forelands. Repeated glacial advances into the lowlands during the Pleistocene sculpted the present-day landscape forming emblematic glacial troughs, deep and narrow overdeepenings now partially filled with glacial deposits and lakes, as well as moraines, outwash planes, terraces, and other depositional landforms in the lowlands. At the LGM in the lowlands, evidences of periglacial ice wedges, deformed frozen sediments in the form of push moraines, and perennially frozen sediments in karsts indicate extensive continuous permafrost in Central Europe. LGM paleo-climate records from pollen records also point towards very cold and dry conditions. Despite this climate of a cold desert, most numerical studies and geomorphological observations indicate that the bed of the Rhine glacier was at the pressure melting point temperature, and thus ice slid over its substrate and eroded it. It is unknown how the coeval development of permafrost at the LGM affected the basal conditions and the rates of glacial advance that led to the glacial maxima. Was the glacier bed cold or warm when ice advanced over permafrost? Did permafrost build up to significant depth prior to ice overriding the Swiss and German lowlands? Presumably, the glacier toe was frozen but how long did permafrost delay warm-bed conditions beneath the advancing ice lobe? To answer these important geomorphic questions, we developed a coupled model of ice-flow/permafrost interactions to simulate the temperature in ice and in the subsurface during the advance of the Rhine glacier at the LGM. Our simulations are two-dimensional, following a flowline that begins high up in the Hinterrhein and extends to near the actual Rhine river in north-eastern Switzerland. Preliminary results indicate that permafrost delayed warm-bed conditions by several hundred years, a significant fraction of the time the LGM glacier remained at or near its maximum extent, thus affecting basal conditions and the associated geomorphic process of erosion. Knowing permafrost distribution and depth under advancing glaciers and the timing of warm-bed, erosive basal conditions during glacial maxima is also important for the long-term safety of nuclear-wastes buried in geological repositories in mid- and high-latitude regions likely affected by future ice-age conditions.