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Hydromechanical Coupling and Damage at a Retreating Glacier Margin

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In deglaciating environments, rock slopes are affected by stress perturbations driven by mechanical unloading due to ice downwasting and concurrent changes in thermal and hydraulic boundary conditions. Since in-situ data is rare, the different processes and their relative contribution to slope damage remain poorly understood. Here we present detailed analyses of subsurface pore pressures and micrometer scale strain time-histories recorded in three boreholes drilled in a rock slope aside the retreating Great Aletsch Glacier (Switzerland). Additionally, we use monitored englacial water levels, climatic data, and annually acquired ice surface measurements for our process analysis.

At the timescale of days, diurnal meltwater cycles and rainfall infiltration into the glacier during summertime cause strong pressure fluctuations in the subglacial drainage channel that diffuse into the adjacent rock aquifer. We show that the pressure diffusion from the subglacial meltwater channel, through the fractured bedrock below the glacier ice, to the ice-free bedrock slope occurs under predominantly confined conditions. In the adjacent ice-free bedrock, rainfall infiltration can cause strong variations in the phreatic groundwater table of the slope. *On the seasonal timescale*, glacial hydraulic boundary conditions vary with high, relatively constant englacial water levels during wintertime and lower mean englacial water levels during summertime. Above ice elevations, snowmelt infiltration during springtime causes yearly maximum phreatic groundwater tables and a general recession over the rest of the year, that is interrupted by summertime rainfall infiltrations. The seasonality in hydraulic head levels of both the glacier and the rock slope controls the interaction of the two systems. *On timescales of decades*, phreatic groundwater levels in the rock slope are often assumed to be linked to the ice elevation of temperate glaciers. According to our data, this head boundary effect of the glacier is mainly effective during wintertime when it controls the minimum groundwater level in the slope.

Our results show that the variations in mechanical boundary conditions (or loads) caused by a temperate valley glacier on the adjacent rock slope are more complex than had been previously described. Our observed rapid bedrock strain signals coincide with some of the extreme englacial water level states, and are likely caused by rapid changes in the mechanical load of the glacier with an empty or water filled englacial drainage system. Similarly, but at seasonal timescales, the spring and fall transition time of the englacial hydrological system coincides with characteristic strain

reactions in our bedrock slope. Our in-situ data show that these effects also promote progressive rock mass damage, probably similar to hydromechanical effects. Additionally, we show how a single extreme rainstorm event triggers hydromechanical damage exceeding the levels of two years exposition to all the other drivers for progressive rock mass damage in this environment.

The magnitude and impact of coupled cyclic processes in a paraglacial rock slope vary with location on the slope and the process considered. The strongest damage is observed directly at the actively reteating glacer margin and moves through the slope at relatively high speed.