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A new parameterization of regolith formation and the response time of weathering front propagation to climate and tectonic forcing

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The thickness of the regolith remains one of the most difficult elements of the critical zone to predict or quantify. The regolith hosts a substantial proportion of the world's freshwater reservoir and its shape and physical properties control the hydrology of most river catchments, which is essential to the development and evolution of many eco-systems. The base of the regolith is controlled by the propagation of a weathering front through a range of chemical and physical processes, such as primary mineral dissolution, frost cracking or fracturing helped by topographic stress. We have recently parameterize the evolution of the weathering front under the relatively well accepted assumption that the rate of weathering front propagation, $\dot{B}$, is directly proportional to the velocity of the fluid circulating within the regolith v, i.e. $\dot{B} = Fv$. This approach is justified in most situations where chemical dissolution of highly soluble minerals is thought to dominate the transformation of bedrock into regolith. Under this assumption, the thickness of the regolith reaches a steady-state under the combined effects of weathering front propagation at its base and surface erosion, and the distribution of the regolith is controlled by two dimensionless numbers. The first : $\Omega = FKS/\dot{\epsilon}$ depends on the surface slope, S, and the steady-state erosion rate, $\dot{\epsilon}$, through the hydraulic conductivity K and F; the second: $\Gamma = KS^2/P$ depends on the surface slope and the mean precipitation rate, P. Ω controls the mean thickness of the regolith layer and needs to be larger than unity (i.e. $\dot{\epsilon} < FKS$) for the regolith layer to exists. We have also shown that Ω is the ratio between the erosional response time of the system $LS/\dot{\epsilon}$ and the weathering response time of the system LF/K implying that where regolith is present at the Earth surface and erosional steady-state, i.e. between uplift and surface erosion, has been reached, the regolith thickness must have reached steady-state as well. On the other hand, Γ controls the shape of the regolith layer and, more precisely, whether it thickens towards the top ($\Gamma > 1$) or towards the base ($\Gamma < 1$) of topographic features. Our simple parameterization therefore explains why the regolith is thickest on top of hills in tectonically active areas, i.e. where slopes are elevated, and more uniformly distributed or even thickest near base level in tectonically quiescent areas, i.e. in anorogenic areas such as in most continental interiors. These fundamental results have now been expanded to more realistic two-dimensional numerical simulations in which drainage density is dynamically determined by the onset of surface flow, i.e. where the water table intersects the topographic surface. In this way, the length scale of water table connectivity, L, which controls the value of all of the system response times (erosional, weathering and hydraulic) is determined in a self-consistent manner which allows us to predict more accurately the range of responses of the system to tectonic and climatic changes at a variety of forcing periods.