Applying the pedogenic threshold concept at the global scale

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Soils can change abruptly in response to environmental forcing: these nonlinear responses are called "pedogenic thresholds". A global pedogenic threshold occurs at the transition between arid climates and humid climates, where mean annual precipitation begins to exceed evaporative demand. At this climatic transition soil water fluxes increase and exchangeable monovalent and divalent cations are leached from the soil, forcing soil pH towards an aluminum-buffered acid equilibrium. The association between climate and soil pH can however be overridden by geologic state factors that control the input of cations to the soil solution. In particular, studies in Hawaii and elsewhere have suggested that old landscapes experiencing low erosion rates may become terminally depleted in primary minerals over long enough timescales, and thus may develop relatively acid soils even where modern climate is arid. Conversely, soils in young landscapes or high-erosion environments can retain large stocks of primary minerals, sustaining high weathering rates and maintaining higher soil pH than might be expected given climate. These site-specific insights can be tested at the global scale using extensive databases of total elemental abundance in soils. Geochemical databases from the USA, Europe, China and Australia reveal that the depletion of sodium (Na) in soils relative to estimated Na concentration in parent material is highly climate sensitive. In general, Na concentrations track parent material concentrations in arid climates whereas Na is depleted in humid climates. However, Na is retained even under humid climate in glaciated zones, areas of periglacial deposition, and high-erosion mountain belts; furthermore Na is depleted in the relatively ancient, low-erosion interior Australia, even under arid climate. A simple process-based model of Na weathering suggests that these geographic patterns could have emerged under a climate similar to that of the modern day. These results confirm that the climate-driven threshold in soil elemental depletion is global in scale, but also suggest that geologic factors can control elemental depletion—and by implication soil solution chemistry—at regional scales. More generally, while these results show that pedogenic thresholds are sensitive to complex interactions between state factors, they also indicate that the outcome of these interactions can be predicted quantitatively.