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Early-stage pedogenesis on volcanic substrates: Contrasting geochemical trajectories of volcanic ash and scoria on Miyake-jima Island, Japan

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Volcanic islands provide natural laboratories for examining the transition from raw volcanic materials to soil following major disturbance. On Miyake-jima Island, Japan, the 2000 eruption deposited volcanic ash over extensive areas of the island. In addition, multiple scoria cones formed by eruptions during the 1900s are distributed across the island. This geological setting enables a comparison of early surface soil development on contrasting parent materials under broadly similar climatic conditions.

This study examined how substrate properties regulate elemental cycling and weathering trajectories during early pedogenesis in volcanic surface soils. We examined multiple sites developed on (i) fine-grained ash deposits and (ii) coarse scoria substrates of different eruption ages. Soil profile characterization was combined with bulk geochemical analyses (XRF), selective dissolution (Al_o, Fe_o, Si_o, and Al_p), total C and N measurements, and weathering indices (Parker Index and Product Index). Particle-size-resolved geochemical signatures were used to distinguish in situ mineral transformation from the redistribution and accumulation of fine materials.

Ash-derived surface soils show measurable desilication and base cation depletion within two decades, accompanied by increasing short-range-order Al and Fe phases, indicating rapid geochemical reorganization associated with vegetation establishment and enhanced near-surface biogeochemical cycling. In contrast, scoria-derived substrates remain structurally coarse and geochemically immature, with limited shifts in weathering indices and minimal accumulation of secondary amorphous phases. However, vegetated scoria sites exhibit enrichment of fine fractions (<0.5 mm) with distinct geochemical signatures, suggesting that early soil formation on coarse terrains depends strongly on particle-size redistribution and external fine-material inputs rather than intrinsic scoria weathering.

These results demonstrate that early surface soil development on volcanic terrains is strongly substrate-dependent, with ash facilitating rapid elemental redistribution and secondary mineral formation, whereas scoria imposes physical and mineralogical constraints that delay pedogenic transformation. These findings highlight the importance of parent material heterogeneity in understanding the geochemical onset of soil formation in newly disturbed volcanic landscapes.