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Characterization of deep weathering and nanoporosity development in shale—A neutron study

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Abstract

We used small-angle and ultra-small-angle neutron scattering (SANS/USANS) to characterize the evolution of nanoscale features in weathering Rose Hill shale within the Susquehanna/Shale Hills Observatory (SSHO). The SANS/USANS techniques, here referred to as neutron scattering (NS), characterize porosity comprised of features ranging from approximately 3 nm to several micrometers in dimension. NS was used to investigate shale chips sampled by gas-powered drilling ("saprock") or by hand-augering ("regolith") at ridgetop. At about 20 m depth, dissolution is inferred to have depleted the bedrock of ankerite and all the chips investigated with NS are from above the ankerite dissolution zone. NS documents that 5–6% of the total ankerite-free rock volume is comprised of isolated, intraparticle pores. At 5 m depth, an abrupt increase in porosity and surface area corresponds with onset of feldspar dissolution in the saprock and is attributed mainly to peri-glacial processes from 15 000 years ago. At tens of centimeters below the saprock-regolith interface, the porosity and surface area increase markedly as chlorite and illite begin to dissolve. These clay reactions contribute to the transformation of saprock to regolith. Throughout the regolith, intraparticle pores in chips connect to form larger interparticle pores and scattering changes from a mass fractal at depth to a surface fractal near the land surface. Pore geometry also changes from anisotropic at depth, perhaps related to pencil cleavage created in the rock by previous tectonic activity, to isotropic at the uppermost surface as clays weather. In the most weathered regolith, kaolinite and Fe-oxyhydroxides precipitate, blocking some connected pores. These precipitates, coupled with exposure of more quartz by clay weathering, contribute to the decreased mineral-pore interfacial area in the uppermost samples.

These observations are consistent with conversion of bedrock to saprock to regolith at SSHO due to: (1) transport of reactants (e.g., water, O_2) into primary pores and fractures created by tectonic events and peri-glacial effects; (2) mineral-water reactions and particle loss that increase porosity and the access of water into the rock. From deep to shallow, mineral-water reactions may change from largely transport-limited where porosity was set largely by ancient tectonic activity to kinetic-limited where porosity is changing due to climate-driven processes.

Keywords: SANS/USANS, regolith, porosity, fractal dimension, clay minerals, surface area