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Rapid evolution of material characteristics in subaerial and submarine basaltic tuff 50 years after eruption, Surtsey volcano, Iceland

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Rates of alteration in oceanic basalts proceed through geochemical, mineralogical and microbiological processes that are strongly influenced by temperature, reactive surface area, the structure and growth rates of authigenic mineral phases, fluid properties, flow rates, and evolving porosity, permeability, and thermal properties. Alteration rates and their response to changing rock material properties through complex feedback loops are exceedingly difficult to measure in submarine volcanic deposits, yet they are responsible for determining the large scale properties of Earth's oceanic crust and the propensity for recurrent explosive eruptive activity in emergent and submarine environments. Time-lapse drill cores acquired in 1979 [1] and in 2017 from the 25–141 °C hydrothermal laboratory of Surtsey Volcano, Iceland, however, provide a precise record of alteration rates of basaltic tephra in an isolated oceanic island created by explosive 1963–1967 basaltic magma-seawater interactions in the SE offshore extension of Iceland's East Rift Zone. Measured changes in the density, water sorption characteristics, and porosity of the basaltic tuff drill core from the 1979 drilling project [1] and the 2017 SUSTAIN drilling project, sponsored by the International Continental Scientific Drilling Program, correlate with the development of authigenic mineral cements, principally zeolites, Al-tobermorite, and anhydrite, as well as the transformation of fresh basaltic glass to nanocrystalline clay mineral, principally nontronite and clinochore, determined through microstructural maps produced with synchrotron X-ray microdiffraction and X-ray microfluorescence investigations. Furthermore, the material properties of sixteen 2017 lapilli tuff drill core specimens measured over 290 m vertical depth show dramatic variations in connected porosity, bulk dry density, permeability, thermal conductivity, thermal diffusivity, specific heat capacity, and ultrasonic P-wave velocities. The porosity of the tuff ranges from 21–41 %, yet permeability varies over five orders of magnitude, from $\sim$1x10E-17 m2 in the subaerial tuff cone, to $\sim$1x10E-13 m2 in poorly-consolidated glassy tuff near the seafloor, to $\sim$1x10E-18 m2 in the lower submarine hydrothermal zone, and $\sim$1x10E-14 m2 in the diatreme excavated from seafloor sedimentary rocks. P-wave velocities and thermal properties correlate with the wide-ranging permeability measurements. These large variations reflect exceedingly rapid alteration rates in the tuff within the lower submarine hydrothermal zone of the volcano that appear highly sensitive to decreasing permeability, which encourages the rapid precipitation of self-sealing mineral cements in alkaline microenvironments. Glassy, permeable tuff near the seafloor may, by contrast, act as an insulator for the hydrothermal system. The influence of the diverse and dynamic material properties on the evolution of the active hydrothermal system will inform mechanisms of recurrent explosive eruption in older Surtseyan systems.

[1] Jakobsson, S., and Moore, J.G. (1986) GSA Bulletin, 97, 648–659.