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Kinetics of Clay Mineral Formation in Weathering Environments: From Aqueous Solutions to Crystals

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Clay minerals play an important role in many biogeochemical reactions on the Earth surface. Their genesis and stability have been the focus of many studies, yet clay formation in weathering environments in soils and sediments is poorly understood. Structural intricacies and contrasting Al and Si aqueous chemistry poses a problem for identifying reaction mechanisms responsible for clay mineral formation and their rates. Among different hypothesised mechanisms, progressive weathering of mica and formation of 2:1 and 1:1 layered silicates is considered an easier pathway for clay formation. Traces of biotite in ocean basalts can be a precursor for clay formation; however, this mechanism alone cannot explain the clay abundance in ocean sediments and in mica-free systems. Scavenging of dissolved Al by amorphous silica (e.g., diatoms) and subsequent precipitation of layered silicates, and through epitaxial growth on seeds of other layered surfaces can be other potential pathways.

We examined formation of clays from the weathering of non-hydrous basalts, such as ocean island basalts from Hawaii archipelago and their soil climo- and chrono-sequences, to understand the rates of formation of clay minerals and their structural evolution with time and climate. We used synchrotron X-ray spectroscopy, spectromicroscopy and infrared spectroscopy to identify crystalline and disordered clays. Our studies show that weathering under dry, low-moisture conditions promoted the initiation of X-ray amorphous clay-like phases and with very slow kinetics. Appearance of crystalline clays took ~10^5 years to form in optimum subaerial conditions, hinting at very slow kinetics.

Adsorption of Al^{3+} on amorphous silica and precipitation of Al-silicate gels can lead to the formation of clay minerals. These gels are amorphous, and could progressively evolve into nano-crystalline layered silicates with time. However, dissolved Al^{3+}, which is octahedral, rapidly converts to stable tetrahedral Al-silicate complex on amorphous silica surfaces during adsorption. Formation of such Al-complexes poisons the growth of clays that require octahedrally coordinated Al. Examination of particles from sediment-water interface and soils show ubiquitous and stable tetrahedrally coordinated Al complexes on silica supporting this observation. A summary of clay formation mechanisms and their kinetics in terrestrial and marine systems will be discussed.