

**INTERPRETING MARTIAN PHYLLOSILICATES: TRANSFERABILITY OF AN INFERENTIAL FRAMEWORK FROM TERRESTRIAL EXPERIENCE TO MARS.** Michael A. Velbel, Department of Geological Sciences, 206 Natural Science Building, Michigan State University, East Lansing, MI 48824-1115, velbel@msu.edu.

**Introduction:** Orbiter and lander/rover studies of Mars' surface have identified and provided preliminary characterization of surficial materials including igneous and sedimentary rocks, possible volcanoclastic/pyroclastic rocks, and unconsolidated sediment. Some surfaces expose unaltered anhydrous silicates (militating against extensive interactions with water), but most results (including studies of Mars meteorites) indicate at least minor aqueous alteration of exposed surface materials. The extent of any chemical/mineralogical alteration, the relative importance of physical and chemical processes, the timing of any chemical alteration that may have occurred, and what information the surficial materials contain about the chemical history of Mars' surface and atmosphere are all matters of continuing research interest.

Clay minerals (phyllosilicates and other related alteration products) form by deuteric and hydrothermal alteration of igneous parent materials; weathering of any parent-rock type; and diagenesis of sediments (including volcanoclastics). This contribution reviews what can be inferred about mineral-environment interactions from the study of the clay-mineral products of mineral-water interactions, emphasizing low-temperature surface phenomena (weathering).

**Rock and mineral weathering.** During weathering, primary rock-forming minerals react with solutions and/or volatiles. Reactants (minerals and mobile species) are consumed through processes governed by interactions among structure, composition, surface properties, and solute composition (the latter itself influenced by the history of the solution, including its origin and other reactions the solution participated in prior to arriving at the current reaction site) [1-5]. Weathered regoliths produced by weathering reactions contain residual primary rock-forming minerals (remnant reactants) and secondary minerals (weathering products), and the composition of the solutions and/or volatiles are modified [1-5].

In many situations of interest, the solutions left the system long ago, and it is from the surviving solids that the former processes must be inferred [1-5]. Although reactant and product solutions and volatiles may no longer exist, considerable insight into their nature, abundance, and properties can be achieved by examining the reactant and product minerals. The compositional and textural relationships among reactants and products record mineral stability and elemental mobil-

ity, which in turn result from the thermodynamics and kinetics of the weathering reactions. Even on Earth, where high temperatures and abundant water facilitate relatively rapid kinetics (at least in comparison with present conditions on Mars), the mechanisms of weathering reactions often prevent the attainment of thermodynamic equilibrium. Most naturally weathered materials therefore represent various intermediate stages between unaltered parent materials and the ultimate weathering products [1-5].

**Formation of phyllosilicates as weathering products.** On Earth, clays formed by weathering vary with the interplay between (1) the dissolution mechanisms and kinetics of primary minerals and (2) the leaching intensity of the weathering environment. There are two grain-scale mechanisms by which primary silicate minerals in general, and chain silicates in particular, weather to secondary minerals; transformation and neoformation [1,6,7].

*Transformation.* In transformation, the bonds linking the apical oxygens of the silica tetrahedra in the chains of, for example, chain silicates are locally broken and remade, allowing single- and double-width chains to rearrange and reattach themselves laterally into extensive tetrahedral-octahedral-tetrahedral (T-O-T) sheets, the basic structural unit of 2:1 phyllosilicate minerals [3]. The earliest-formed products of transformation reactions retain large parts of the parent-mineral structure (e.g., mica to vermiculite or smectite; pyroxene to smectite [3]). Solution composition has only modest influence on the structure and composition of the alteration product, which at least initially consists dominantly of cations and structural units inherited from the parent mineral [3,8-11].

*Neoformation.* In neoformation, destruction of primary-mineral bonding is more complete [12], and secondary minerals are formed (often at some distance from the site of primary-mineral destruction) by crystal-growth of secondary minerals from solutes. Because secondary-mineral formation by precipitation does not require any specific structural relationship with the primary reactant-mineral surface (from which precipitation may be separated by considerable distance), there is no necessary crystallographic orientation relationship between primary (reactant) minerals and their neoformation products [12,13].

**Clay minerals and environmental conditions.** Secondary minerals vary among different geochemical

and leaching environments; terrestrial regolith geoscientists use a classification based on the major clay minerals formed [3]. At early stages of weathering (in the case of phyllosilicate formation by transformation) and/or under conditions of minimal leaching of dissolved products (in both transformation and neof ormation), 2:1 clay-minerals form as weathering products; such weathering, forming products comprising two tetrahedral silicate sheets per octahedral sheet (e.g., smectite-group minerals), is termed *bisiallitic*. At intermediate degrees of weathering and/or leaching intensity, 1:1 clay-minerals form; such weathering, forming products comprising one tetrahedral silicate sheet per octahedral sheet, is termed *monosiallitic*. When weathering has been sufficiently extensive or intense that silica has been essentially completely leached from the weathering profile, hydroxides and oxyhydroxides of Fe and Al are the dominant weathering products; such weathering is termed *ferrallitic*.

With increased weathering, the influence of parent material on the structure and composition of weathering products diminishes, and the composition of the products is increasingly influenced by the compositions of the solutions driving the alteration. Solution composition during advanced weathering influences compositions of product minerals in terms of both the elements left behind in the products, and the elements transferred between the product-forming environment and other nearby weathering micro- and (if enough water is present) macro-environments. On Earth, leaching in wet climates removes those elements overabundant in parent minerals relative to products; in dry terrestrial environments such elements are retained in the local regolith [1-3,14]. On Mars such mobile products (esp. Si) appear not have moved far, suggesting that there was little water to carry them.

**What can clay minerals tell us about alteration conditions on Mars?** For most of Mars' natural history, Martian environments of aqueous alteration (surface and shallow subsurface environments like those sampled by Mars meteorites) were likely characterized by low fluid-rock ratios, negligible leaching, and highly reactive (mafic) parent materials. Rapid reaction rates of the mafic silicates and negligible leaching produce conditions more similar to closed-system conditions than in most other terrestrial weathering environments. Consequently, much analysis of Mars-surface mineralogy assumes that thermodynamic equilibrium adequately describes parent-product mineral relationships of weathered planetary surface materials [15-17]. However, metastability (not thermodynamic equilibrium) is common in low-temperature mineral-water systems, even for reactive primary minerals and soluble product minerals commonly assumed to easily

attain equilibrium [18], so observations of kinetically controlled textures and mineral associations are more likely than thermodynamic modeling to detect evidence of processes and reaction paths [1-5, 14,18].

Smectites are widely distributed on the surface of Mars [19-22]. Smectites indicate either inheritance of structure and major elements from parent material with minimal modification by leaching (transformation) or precipitation from cation- and silica-rich solutions (neof ormation). Optical-petrographic and electron-microscope-scale textural observations are required (from Mars meteorites or returned samples) to fully distinguish phyllosilicates formed by transformation from those formed by neof ormation [8-13]. However, associations of phyllosilicates (especially smectite-group minerals) can be linked to categories of parent-material types from orbital imagery and spectroscopic data, so informed preliminary inferences about transformation or neof ormation origins and their environmental significance are possible even in the absence of returned samples [19-22].

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