Clay mineral evolution

R.M. HAZEN[1*,2], D.L. BISH, [3] D.A. SVERJENSKY[4]
AND S.C. ELMORE[2]

[1]*Geophysical Laboratory, Carnegie Institution, Washington DC 20015, USA (rhazen@ciw.edu)
[2]George Mason University, Fairfax VA 22030 USA (elmore.stephen@gmail.com)
[3]Department of Geological Sciences, Indiana University, Bloomington IN 47405 USA (bish@indiana.edu)
[4]Department of Earth & Planetary Sci., Johns Hopkins Univ. Baltimore MD 21218 USA (dsverje1@jhu.edu)

Phyllosilicate clay minerals were absent prior to nebular and planetessimal formation approximately 4.56 billion years ago, but today they are found in all near-surface Earth environments. The evolution of clay minerals as products of physical, chemical and biological alteration, weathering and other processes is thus an important part of Earth's mineralogical history and it exemplifies principles of mineral evolution [1].

Five primary modes of clay mineral paragenesis commenced at different stages of Earth history: (1) subsurface aqueous/ hydrothermal alteration (with significant serpentinization); (2) authigenesis, especially from solution in marine sediments (e.g. illite and glauconite); (3) low-grade metamorphism (to greenschist facies) and subsequent exposure through orogenesis related to plate tectonics (e.g. chlorite); (4) near-surface weathering reactions, especially under oxic and/or acidic conditions (e.g. halloysite and vermiculite); and (5) the rise of a terrestrial biosphere, most notably the advent of soil-forming microbes, fungi and plants and associated biological weathering (e.g. kaolinite and vermiculite).

The earliest clay minerals, including talc, smectite and montmorillonite, may have played critical roles in the origin of life, including the selection, concentration and organization of essential biomolecules [2]. Life has subsequently played dramatic roles in the production of near-surface clay minerals. Clay minerals thus underscore the co-evolution of Earth's geosphere and biosphere.

[1] Hazen *et al.* (2008) *Amer. Mineral.* **93**:1693. [2] Lahav *et al.* (1978) Science **201**:67; [3] Ferris *et al.* (1996) *Nature* **381**:59.

U and Th mineral evolution

R.M. HAZEN[1]*, R.C. EWING[2] AND D.A. SVERJENSKY[1,3]

[1]Geophysical Laboratory, Carnegie Institution, Washington, DC 20015, USA (rhazen@ciw.edu)
[2]Department of Geological Sciences, University of Michigan, Ann Arbor MI 48109 USA (rodewing@umich.edu)
[3]Department of Earth & Planetary Sci., Johns Hopkins Univ. Baltimore MD 21218 USA (dsverje1@jhu.edu)

Origins and near-surface distributions of ~250 known U and/or Th minerals elucidate principles of mineral evolution. This history has been divided into four phases [*1*]. The first, from ~4.5 to 3.5 Ga, involved concentration of U and Th from initial uniform trace distribution into magmatic-related fluids. The second period, from ~3.5 to 2.2 Ga, saw the formation of large low-grade concentrations of detrital uraninite deposited in anoxic fluvial environments. Abiotic alteration of uraninite and coffinite, including radiolysis and auto-oxidation caused by radioactive decay and the formation of helium from alpha particles, may have resulted in the formation of a limited suite of uranyl oxide-hydroxides.

Earth's third phase of uranium mineral evolution, during which most known U minerals first precipitated from reactions of soluble uranyl $(U^{6+}O_2)^{2+}$ complexes, followed the Great Oxidation Event (GOE) at ~2.2 Ga and thus was mediated indirectly by biologic activity. The fourth phase of U mineralization began approximately 400 million years ago, as the rise of land plants led to non-marine organic-rich sediments that promoted new sandstone-type ore deposits.

U and Th mineralogy provide a measure of a planet's geotectonic and geobiological history. In the absence of surface oxidation, all but a handful of the known uranium minerals are unlikely to form.

[1] Hazen *et al.* (2009) *Amer. Min.* **94**: 1293.