MINERAL ECOLOGY: CHANCE AND NECESSITY IN THE MINERAL EVOLUTION OF TERRESTRIAL PLANETS. Robert M. Hazen,[1] Edward S. Grew,[2] Robert T. Downs,[3] Joshua Golden,[3] and Grethe Hystad,[4] [1]Geophysical Laboratory, Carnegie Institution, 5251 Broad Branch Rd., Washington DC, 20015 USA; rhazen@ciw.edu. [2]School of Earth and Climate Sciences, University of Maine, Orono ME, 04469 USA. [3]Department of Geosciences, University of Arizona, Tucson AZ, 85721-0077 USA. [4]Department of Mathematics, University of Arizona, Tucson AZ, 85721-0089 USA.

Earth is unique among known terrestrial planets in the co-evolution of its geosphere and biosphere. Minerals are suspected to have played key roles in life's origins and evolution [1], while life in turn was central to the diversification of minerals on Earth [2]. We explore the relationships between mineral diversity and distribution in the context of the evolving biosphere—a field we call "mineral ecology."

Three factors contribute to the roles played by necessity and chance in determining mineral distribution and diversity at or near the surfaces of terrestrial planets: (1) crystal chemical characteristics; (2) planetary stoichiometry; and (3) the probability of occurrence for rare minerals [3].

Crystal chemical analysis reveals that the most abundant elements generally have the largest numbers of mineral species, as modeled by relationships for Earth's upper continental crust (E) and the Moon (M), respectively:

$$\mathrm{Log}(N_{\mathrm{E}}) = 0.22\mathrm{Log}(C_{\mathrm{E}}) + 1.70 \quad (R^2 = 0.34)$$

$$\mathrm{Log}(N_{\mathrm{M}}) = 0.19\mathrm{Log}(C_{\mathrm{M}}) + 0.23,$$

where C is an element's abundance in ppm and N is the number of approved International Mineralogical Association mineral species in which that chemical element is essential (rruff.info/ima). Several elements that mimic other more abundant elements are less likely to form their own species. Similar relationship are found for Earth and the Moon.

Measurements of stellar stoichiometry reveal that stars can differ significantly from the Sun in relative abundances of rock-forming elements [4], for example in the ratio of O, S, Fe, Mg, and Si, which implies that bulk compositions of some extrasolar Earth-like planets likely differ significantly from those of Earth. Consequently, the distribution of the most common rock-forming minerals will differ, as well.

Of 4933 approved mineral species, 34% are known from only one or two localities, and more than half are known from 5 or fewer localities. Statistical analysis of these mineral frequencies [4] reveals that minerals conform to Large Number of Rare Event (LNRE) distributions. Our LNRE models suggest that thousands of plausible rare mineral species await discovery or could have occurred at some point in Earth's history, only to be subsequently lost by burial, erosion, or subduction.

We conclude that the distribution of common mineral species represents a diagnostic characteristic of "Earth-like" planets, whereas the distribution of rare species is unique to Earth and reflects the evolution of the biosphere. Were Earth's history to be replayed, and thousands of mineral species discovered and characterized anew, it is probable that at least 25% of those minerals—more than 1000 species—would differ from species known today.

References: [1] Hazen R.M. (2006) *Am. Mineral. 91,* 1715–1729. [2] Hazen R.M. et al. (2008) *Am. Mineral. 93,* 1693-1720. [3] Hazen R.M. et al. (2015) *Canadian Mineral., in press*. [4] Young P. A. (2014) *Astrobiology* 14, 603-626. [5] Hystad G., Downs R.T., and Hazen R. M. (2015) *Mathematical Geoscience, in press*.