Constraints on the mineral evolution of planetary crusts using statistical correlations and anti-correlations among the mineral-forming elements

DANIEL R HUMMER,[1] ROBERT M HAZEN,[1] XIAOGANG MA,[2] JOSHUA J GOLDEN,[3] ROBERT T DOWNS[3]

[1]Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015
[2]Rensselaer Polytechnic Institute, Troy, NY 12180
[3]Department of Geosciences, University of Arizona, Tucson, AZ 85721

The mineralogy of terrestrial planets is governed not only by size, bulk composition, differentiation processes, and secondary geochemical processes, but also by the way a planet's constituent elements parse themselves into mineral species [1]. To gain insight into how elements associate into minerals when planetary crusts form, we used a mineral database (mindat.org, as of 12/17/2015) to conduct a statistical analysis of the number of mineral species containing both elements X and Y for every possible X-Y pair (and X, Y and Z for every possible X-Y-Z triplet) of 30 major mineral-forming elements. The frequency with which an element pair or triplet occurred together in the nominal formula of a mineral was compared with the expected frequency if elements were distributed among mineral species randomly. This analysis was conducted for both a list of Hadean minerals likely present when the continental crust first formed [2], and for the full list of 5027 presently known minerals. We employ new 3-dimensional data visualization techniques to examine correlations among element triplets, which cannot be systematically represented in traditional 2-dimensional tables.

Results reveal that the most strongly correlated element pairs are H-O, Na-Si, Al-Si, S-Ag, and O-Si, whereas strongly anti-correlated pairs include O-S, O-Ag, Si-S, O-Sb, and O-Se. The strength of these correlations and anti-correlations ranged from ~1 to 10^{-304} (as measured by their p-value in a chi-squared test for variable dependence). Comparing element correlations between Hadean vs. Cenozoic minerals reveals that Si-O is the most important correlation in the early continental crust, whereas O-H is the most important in Earth's present crust. The systematic differences observed in our pair and triplet analyses of element correlations provide valuable clues as to how tectonic and biological processes, which only operated on the post-Hadean Earth [3], can dramatically affect the mineralogical content of terrestrial planetary crusts.

[1] Christy, A.G. (2015) *Mineral. Mag.* **79**, 33-49.
[2] Hazen, R.M. (2013) *Am. J. Science* **313**, 807-843.
[3] Hazen, R.M. et al. (2008) *Am. Mineral.* **93**, 1693-1720.