Letter
Earth’s “missing” minerals

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ABSTRACT
Recent studies of mineral diversity and distribution lead to the prediction of >1563 mineral species on Earth today that have yet to be described—approximately one fourth of the 6394 estimated total mineralogical diversity. The distribution of these “missing” minerals is not uniform with respect to their essential chemical elements. Of 15 geochemically diverse elements (Al, B, C, Cr, Cu, Mg, Na, Ni, P, S, Si, Ta, Te, U, and V), we predict that approximately 25% of the minerals of Al, B, C, Cr, P, Si, and Ta remain to be described—a percentage similar to that predicted for all minerals. Almost 35% of the minerals of Na are predicted to be undiscovered, a situation resulting from more than 50% of Na minerals being white, poorly crystallized, and/or water soluble, and thus easily overlooked. In contrast, we predict that fewer than 20% of the minerals of Cu, Mg, Ni, S, Te, U, and V remain to be discovered. In addition to the economic value of most of these elements, their minerals tend to be brightly colored and/or well crystallized, and thus likely to draw attention and interest. These disparities in percentages of undiscovered minerals reflect not only natural processes, but also sociological factors in the search, discovery, and description of mineral species.

Keywords: Mineral diversity, nickel, sodium, tellurium, mineral ecology, mineral evolution, chance vs. necessity, philosophy of mineralogy, sociology of mineralogy

INTRODUCTION
Earth’s near-surface mineralogy has diversified significantly over 4.5 billion years as a consequence of physical, chemical, and biological processes (Hazen et al. 2008, 2011, 2012; Hazen and Ferry 2010). Hazen (2013) estimated that 420 mineral species may have been present in the Hadean Eon, whereas as many as 1500 species arose from physical and chemical events prior to 3 billion years ago. Biological processes, most notably near-surface environmental changes following the Great Oxidation Event at 2.4 to 2.2 Ga and Phanerozoic biomaterialization subsequent to ~540 Ma, have led to numerous additional phases (Hazen et al. 2008, 2013a, 2013b; Sverjensky and Lee 2010; Dove 2010), including an estimated 70% of the ~5000 minerals approved by the International Mineralogical Association (http://rruff.info/ima; Downs 2006).

Earth’s mineralogical diversity and distribution arise from both deterministic processes and frozen accidents (Grew and Hazen 2014; Hazen et al. 2015). For example, chance and necessity both play a role in the distribution of mineral species among the 72 essential mineral-forming chemical elements. Previous authors have identified a correlation between the crustal abundance of an element and the number of mineral species incorporating that element (Fig. 1; Yaroshevsky and Bulakh 1994; Higgins and Smith 2010; Christy 2015; Hazen et al. 2015).

Deviations from this trend arise from several factors. On the one hand, fewer mineral species than predicted by the general trend occur for rare elements that mimic more abundant elements (e.g., Ga for Al, Hf for Zr, and rare earth elements for Ce and Y). On the other hand, significantly more mineral species tend to occur for elements with multiple oxidation states (e.g., Cu,