The Carbon Mineral Challenge: a worldwide effort to find Earth's missing carbon minerals

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Abstract

The emerging field of mineral ecology combines large databases of mineral occurrences with new statistical and visualization approaches to explore and quantify the diversity of minerals on Earth. These approaches have made possible the estimation of Earth's total number of unique mineral species, the number of species in subsets of the mineral kingdom, and the potential identities and locations of minerals that remain undiscovered. The Carbon Mineral Challenge was a first-of-its-kind worldwide collaboration that united the scientific and collector communities to predict and then search for specific, undiscovered carbon-bearing mineral species. Since the start of the challenge in December 2015, no fewer than 30 new carbon-bearing mineral species have been identified, with two exactly corresponding to specifically predicted species and many more as close cousins to predicted species. The newly discovered minerals represent the extreme geochemical diversity of carbon, ranging from complex carbonates, to carbides, to entirely organic species that highlight the disproportionate role of life in enhancing Earth's mineral diversity. Future efforts should combine the unique talents and perspectives of the academic, industrial, and collector communities to predict and identify Earth's remaining undiscovered minerals.

KEYWORDS: Carbon mineral challenge, mineral ecology, new minerals, carbon minerals, mineral species, mineral diversity

Mineral Ecology

The discovery and classification of naturally occurring objects and phenomena, whether animate or inanimate, has been a driving force of human exploration since ancient times. In the case of minerals, there are now over 5400 unique species approved by the International Mineralogical Association (IMA), with 100 or more being discovered annually owing to the development of new analytical techniques such as electron microscopy. There is little doubt that many more remain to be discovered. But how many more? And are there any reliable patterns or relationships among the known mineral species and the way they are spatially distributed across our particularly mineral-rich corner of the cosmos? If so, can these patterns point us towards the minerals that remain missing?

The emerging field of mineral ecology is seeking answers to these questions by using large datasets of mineral occurrences in conjunction with new statistical and visualization techniques. Lists of IMA-approved mineral species are available from databases such as RRUFF (http://rruff.info/ima) and lists of the localities at which each of these species can be found are tabulated in the crowd-sourced database Mindat (https://www.mindat.org). Using a combination of these databases, Hystad et al. (2015) revealed for the first time that the frequency distribution of minerals conforms to a large number of rare events (LNRE) model, exactly the same statistical distribution as words in a book (Baayen, 2001) or biological species in an ecosystem (Shen et al., 2003). In this style of distribution, only a few species are common, while most species are rare. For example, in the case of language, words such as 'a', 'and', and 'the' are common, while most words in the English language (such as 'superfluous' and 'xylophone') are rare. Likewise, in the world of minerals, only a few species are common enough to be found at thousands of localities (e.g. quartz, calcite, feldspars), while most species are actually rare and occur at only a few localities (e.g. hazenite, abelsonite, lalondeite; Fig. 1A). In fact, 34% of mineral species occur at only one or two localities around the world (Hystad et al., 2015), much to the consternation of avid mineral collectors.

Because mineral frequencies fit the LNRE distribution so well, it is possible to plot an "accumulation curve" of the number of unique mineral species discovered as a function of the number of observed mineral occurrences (Fig. 1B). At the far left of the accumulation curve, for small numbers of observations, each new observation is likely to yield a new mineral species because so few are known at the beginning of the process. This causes the number of unique species (plotted on the vertical axis) to rise rapidly in the early going. When a large number of observations has been reached and most mineral species have already been discovered (the right portion of the curve), each new observation is much less likely to yield an undiscovered species, causing much slower growth of the number of known species. However, by extrapolating the curve to infinite observations (impossible in practice but mathematically simple), one can estimate the total number of unique species in the system (Fig. 1B).

Performing this analysis for mineral species discovered up through February 2014, Hystad et al. (2015) predicted that there were a total of 6394 mineral species on Earth, with only 4831 being known at that time. This implied that over 1500 minerals remained to be discovered. However, given that over 100 new minerals continue to be described each year with no sign of abatement, this estimate seems uncomfortably low. In fact, Christy (2018) recently discussed estimates of mineral diversity and noted that some estimates reach 10 000 or more (Pring, 1995).

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