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An evolutionary system of mineralogy. Part I: Stellar mineralogy (>13 to 4.6 Ga)

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Abstract

Minerals preserve records of the physical, chemical, and biological histories of their origins and subsequent alteration, and thus provide a vivid narrative of the evolution of Earth and other worlds through billions of years of cosmic history. Mineral properties, including trace and minor elements, ratios of isotopes, solid and fluid inclusions, external morphologies, and other idiosyncratic attributes, represent information that points to specific modes of formation and subsequent environmental histories—information essential to understanding the co-evolving geosphere and biosphere. This perspective suggests an opportunity to amplify the existing system of mineral classification, by which minerals are defined solely on idealized end-member chemical compositions and crystal structures. Here we present the first in a series of contributions to explore a complementary evolutionary system of mineralogy—a classification scheme that links mineral species to their paragenetic modes.

The earliest stage of mineral evolution commenced with the appearance of the first crystals in the universe at >13 Ga and continues today in the expanding, cooling atmospheres of countless evolved stars, which host the high-temperature (T > 1000 K), low-pressure ($P < 10^{-2}$ atm) condensation of refractory minerals and amorphous phases. Most stardust is thought to originate in three distinct processes in carbon- and/or oxygen-rich mineral-forming stars: (1) condensation in the cooling, expanding atmospheres of asymptotic giant branch stars; (2) during the catastrophic explosions of supernovae, most commonly core collapse (Type II) supernovae; and (3) classical novae explosions, the consequence of runaway fusion reactions at the surface of a binary white dwarf star. Each stellar environment imparts distinctive isotopic and trace element signatures to the micro- and nanoscale stardust grains that are recovered from meteorites and micrometeorites collected on Earth's surface, by atmospheric sampling, and from asteroids and comets. Although our understanding of the diverse mineral-forming environments of stars is as yet incomplete, we present a preliminary catalog of 41 distinct natural kinds of stellar minerals, representing 22 official International Mineralogical Association (IMA) mineral species, as well as 2 as yet unapproved crystalline phases and 3 kinds of non-crystalline condensed phases not codified by the IMA.

Keywords: Classification, mineral evolution, mineral ecology, natural kinds, vapor deposition, condensation, astromineralogy, stardust, diamond, graphite, corundum, moissanite, hibonite, amorphous phases