An evolutionary system of mineralogy. Part III: Primary chondrule mineralogy (4566 to 4561 Ma)

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ABSTRACT

Information-rich attributes of minerals reveal their physical, chemical, and biological modes of origin in the context of planetary evolution, and thus they provide the basis for an evolutionary system of mineralogy. Part III of this system considers the formation of 43 different primary crystalline and amorphous phases in chondrules, which are diverse igneous droplets that formed in environments with high dust/gas ratios during an interval of planetesimal accretion and differentiation between 4566 and 4561 Ma. Chondrule mineralogy is complex, with several generations of initial droplet formation via various proposed heating mechanisms, followed in many instances by multiple episodes of reheating and partial melting. Primary chondrule mineralogy thus reflects a dynamic stage of mineral evolution, when the diversity and distribution of natural condensed solids expanded significantly.

Keywords: Classification, mineral evolution, natural kinds, chondrules, chondrite meteorites, planetesimals

INTRODUCTION

The “evolutionary system” of mineralogy focuses on the inexorable emergence of mineral diversity and distribution through billions of years of cosmic evolution. This data-driven approach emphasizes the numerous information-rich aspects of minerals—attributes that point to various physical, chemical, and ultimately biological mineral-forming processes (Hazen et al. 2008; Hazen and Ferry 2010; Hazen 2019). The first three parts of this evolutionary system focus on relatively unaltered components of chondrite meteorites: presolar “stardust” grains (see Part I; Hazen and Morrison 2020); refractory inclusions [i.e., calcium-aluminum-rich inclusions (CAIs), amoeboid olivine aggregates (AOAs), and ultra-refractory inclusions (URIs), as described in Part II; Morrison and Hazen 2020]; and primary chondrule phases (Part III, this study), all of which preserve episodes of mineral evolution prior to their incorporation into planetesimals (the subject of Part IV of this series) and extensive alteration by planetesimal processing, as recorded, for example, in both highly altered chondrite and achondrite meteorites (to be reviewed in Part V).

This system builds on classification protocols of the International Mineralogical Association (IMA), as codified by the Commission on New Minerals, Nomenclature and Classification (e.g., Burke 2006; Mills et al. 2009; Schertl et al. 2018). We attempt to amplify and modify the IMA approach, which distinguishes each mineral “species” based on unique combinations of end-member composition and idealized crystal structure, leading to >5500 approved mineral species (rruff.info/ima; accessed 7 April 2020).

The power and simplicity of the IMA classification system lie in its recognition of mineral species based on the minimum information (measured in bits; e.g., Krivovichev 2012, 2013) necessary to distinguish among species. By design, IMA protocols do not consider such revelatory aspects of minerals as trace and minor elements, fractionated isotopes, structural defects, varied electromagnetic properties, textures and morphologies, compositional zoning, or inclusions. Neither does the IMA take into account mineral ages or petrologic contexts when classifying mineral species. However, these and many other characteristics of minerals and their assemblages collectively provide powerful testimony regarding each mineral’s origins, as well as its subsequent deep-time interactions with changing chemical and physical environments. The evolutionary system, by distinguishing minerals formed in different paragenetic contexts from stars to nebulae to dynamic planetary surfaces and interiors, thus provides a framework for classifying minerals in their spatial and temporal context.

The evolutionary system employs IMA nomenclature for most natural condensed solids, but it deviates from those protocols in three important ways. In some instances, we split IMA species into two or more “natural kinds,” based on diagnostic combinations of attributes that arise from distinct paragenetic modes. Thus, isotopically anomalous hibonite condensed in the expanding, cooling atmospheres of AGB stars (labeled “AGB hibonite”) is measurably distinct from hibonite condensed from the solar nebula to form a primary phase in a calcium-aluminum-rich inclusion (“CAI hibonite”). Many of the most common rock-forming minerals display multiple paragenetic contexts, each of which tells a different story about stages of planetary evolution; these species are thus split into two or more “natural kinds” in our system (Hazen 2019). Note that we employ a binomial nomenclature, with the first name designating the paragenetic mode and the second name the mineral species, which in the great