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An evolutionary system of mineralogy, Part VII: The evolution of the igneous minerals (>2500 Ma)

Robert M. Hazen[1,*], Shaunna M. Morrison[1], Anirudh Prabhu[1,†], Michael J. Walter[1], and Jason R. Williams[1]

[1]Earth and Planets Laboratory, Carnegie Institution for Science, 5251 Broad Branch Road NW, Washington, D.C. 20015, U.S.A.

Abstract

Part VII of the evolutionary system of mineralogy catalogs, analyzes, and visualizes relationships among 919 natural kinds of primary igneous minerals, corresponding to 1665 mineral species approved by the International Mineralogical Association—minerals that are associated with the wide range of igneous rock types through 4.566 billion years of Earth history. A systematic survey of the mineral modes of 1850 varied igneous rocks from around the world reveals that 115 of these mineral kinds are frequent major and/or accessory phases. Of these most common primary igneous minerals, 69 are silicates, 19 are oxides, 13 are carbonates, and 6 are sulfides. Collectively, these 115 minerals incorporate at least 33 different essential chemical elements.

Patterns of coexistence among these minerals, revealed by network, Louvain community detection, and agglomerative hierarchical clustering analyses, point to four major communities of igneous primary phases, corresponding in large part to different compositional regimes: (1) silica-saturated, quartz- and/or alkali feldspar-dominant rocks, including rare-element granite pegmatites; (2) mafic/ultramafic rock series with major calcic plagioclase and/or mafic minerals; (3) silica-undersaturated rocks with major feldspathoids and/or analcime, including agpaitic rocks and their distinctive rare-element pegmatites; and (4) carbonatites and related carbonate-bearing rocks.

Igneous rocks display characteristics of an evolving chemical system, with significant increases in their minerals' diversity and chemical complexity over the first two billion years of Earth history. Earth's earliest igneous rocks (>4.56 Ga) were ultramafic in composition with 122 different minerals, followed closely by mafic rocks that were generated in large measure by decompression melting of those ultramafic lithologies (4.56 Ga). Quartz-normative granitic rocks and their extrusive equivalents (>4.4 Ga), formed primarily by partial melting of wet basalt, were added to the mineral inventory, which reached 246 different mineral kinds. Subsequently, four groups of igneous rocks with diagnostic concentrations of rare element minerals—layered igneous intrusions, complex granite pegmatites, alkaline igneous complexes, and carbonatites—all first appeared ~3 billion years ago. These more recent varied kinds of igneous rocks hold more than 700 different minerals, 500 of which are unique to these lithologies.

Network representations and heatmaps of primary igneous minerals illustrate Bowen's reaction series of igneous mineral evolution, as well as his concepts of mineral associations and antipathies. Furthermore, phase relationships and reaction series associated with the minerals of a dozen major elements (H, Na, K, Mg, Ca, Fe, Al, Si, Ti, C, O, and S), as well as minor elements (notably Li, Be, Sr, Ba, Mn, B, Cr, Y, REE, Ti, Zr, Nb, Ta, P, and F), are embedded in these multi-dimensional visualizations.

Keywords: Philosophy of mineralogy, classification, mineral evolution, igneous petrology, Norman L. Bowen, phase equilibria, network analysis, carbonatites, alkaline igneous complexes, Daly gap