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Beryllium mineral evolution

Edward S. Grew[1,*] and Robert M. Hazen[2]

[1]School of Earth and Climate Sciences, University of Maine, Orono, Maine 04469, U.S.A.
[2]Geophysical Laboratory, Carnegie Institution of Washington, Washington, D.C. 20015, U.S.A.

Abstract

Beryllium is a quintessential upper crustal element, being enriched in the upper crust by a factor of 30 relative to primitive mantle, 2.1 vs. 0.07 ppm. Most of the 112 minerals with Be as an essential element are found in granitic pegmatites and alkalic rocks or in hydrothermal deposits associated with volcanic and shallow-level plutonic rocks and skarns. Because of the extensive differentiation needed to enrich rocks sufficiently in beryllium for beryllium minerals to form, these minerals are relative latecomers in the geologic record: the oldest known is beryl in pegmatites associated with the Sinceni pluton, Swaziland (3000 Ma). In general, beryllium mineral diversity reflects the diversity in the chemical elements available for incorporation in the minerals and increases with the passage of geologic time. Furthermore, the increase is episodic; that is, steep increases at specific times are separated by longer time intervals with little or no increase in diversity. Nonetheless, a closer examination of the record suggests that at about 1700 Ma, the rate of increase in diversity decreases and eventually levels off at ~35 species formed in a given 50 Ma time interval between 1125 and 475 Ma, then increases to 39 species at 125 Ma (except for four spikes), before dropping off to ~30 species for the last 100 Ma. These features appear to reflect several trends at work: (1) diversifications at 2475, 1775, and 525 Ma, which are associated with highly fractionated rare-element granitic pegmatites and with skarns at Långban and similar deposits in the Bergslagen ore region of central Sweden, and which are inferred to correspond to the collisional phases of the supercontinents Kenorland, Nuna, and Gondwana, respectively; (2) diversification at 1175 Ma due to the rich assemblage of beryllium minerals in the Ilímaussaq peralkaline complex, Gardar Province, West Greenland, in an extensional environment; (3) diversification at 275 Ma, which is largely attributable to granitic pegmatites (Appalachian Mountains, U.S.A., and Urals, Russia) and the Larvik alkalic complex, Norway, but nonetheless related to continental collision; and (4) limited exhumation of environments where beryllium minerals could have formed in the last 100 Ma. That the maximum diversity of Be minerals in any one geologic environment could be finite is suggested by the marked slowing of the increase in the number of species formed in a given 50 Ma time interval, whereas the drop off at 100 Ma could be due to 100 Myr being too short a time interval to exhume the deep-seated occurrences where many Be minerals had formed. The relative roles of chance vs. necessity in complex evolving systems has been a matter of considerable debate, one equally applicable to what extent the temporal distribution of beryllium minerals is a matter of contingency. On the one hand, the appearance of the most abundant Be minerals, such as beryl and phenakite, early in the history of Be mineralization appears to be a deterministic aspect since these minerals only require the abundant cations Al and Si and crystallize at relatively low concentrations of Be in aqueous solution or granitic magmas. On the other hand, it could be argued that the very existence of most other Be minerals, as well as the temporal sequence of their appearance, is a matter of chance since 55 of the 112 approved Be minerals are known from a single locality and many of these phases require an unusual combination of relatively rare elements. Consequently, we cannot exclude the possibility that other equally rare and thus contingent potential Be minerals await discovery in as yet unexposed subsurface deposits on Earth, and we suggest that details of Be mineral evolution on other Earth-like planets could differ significantly from those on Earth.

Keywords: Mineral age, beryllium, mineral evolution, granitic pegmatites, peralkaline complexes, supercontinent cycle, crystal structure, beryl