American Mineralogist, Volume 106, pages 1559–1573, 2021

Formation of miarolitic-class, segregation-type pegmatites in the Taishanmiao batholith, China: The role of pressure fluctuations and volatile exsolution during pegmatite formation in a closed, isochoric system

Yabin Yuan[1,2,4], Lowell R. Moore[2], Ryan J. McAleer[3,†], Shunda Yuan[1], Hegen Ouyang[1], Harvey E. Belkin[3], Jingwen Mao[1], D. Matthew Sublett Jr.[2], and Robert J. Bodnar[2,*,‡]

[1]MLR Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China
[2]Department of Geosciences, Virginia Tech, Blacksburg, Virginia 24061, U.S.A.
[3]U.S. Geological Survey, 12201 Sunrise Valley Drive, Reston, Virginia 20192, U.S.A.
[4]Department of Earth and Space Sciences, Southern University of Science and Technology, Shenzhen, Guangdong 518055, China

Abstract

The Taishanmiao granitic batholith, located in the Eastern Qinling Orogen in Henan Province, China, contains numerous small (mostly tens of centimeters in maximum dimension) bodies exhibiting textures and mineralogy characteristics of simple quartz and alkali feldspar pegmatites. Analysis of melt inclusions (MI) and fluid inclusions (FI) in pegmatitic quartz, combined with Rhyolite-MELTS modeling of the crystallization of the granite, have been applied to develop a conceptual model of the physical and geochemical processes associated with the formation of the pegmatites. These results allow us to consider the formation of the Taishanmiao pegmatites within the context of varios models that have been proposed for pegmatite formation.

Field observations and geochemical data indicate that the pegmatites represent the latest stage in the crystallization of the Taishanmiao granite and occupy ≤4 vol% of the syenogranite phase of the batholith. Results of Rhyolite-MELTS modeling suggest that the pegmatite-forming melts can be produced through continuous fractional crystallization of the Taishanmiao granitic magma, consistent with the designation of the pegmatites as a miarolitic class, segregation-type pegmatites rather than the more common intrusive-type of pegmatite. The mineral assemblage predicted by Rhyolite-MELTS after ~96% of the original granite-forming melt had crystallized consists of ~51 vol% alkali feldspar, 34 vol% quartz, 14 vol% plagioclase, 0.1 vol% biotite, and 1 vol% magnetite, similar to the alkali feldspar + quartz dominated mineralogy of the pegmatites. Moreover, the modeled residual melt composition following crystallization of ~96% of the original melt is similar to the composition of homogenized MI in quartz within the pegmatite. Rhyolite-MELTS predicts that the granite-forming melt remained volatile-undersaturated during crystallization of the batholith and contained ~6.3 wt% H_2O and ~500 ppm CO_2 after ~96% crystallization when the pegmatites began to develop. The Rhyolite-MELTS prediction that the melt was volatile-undersaturated at the time the pegmatites began to form, but became volatile-saturated during the early stages of pegmatite formation, is consistent with the presence of some inclusion assemblages consisting of only MI, while others contain co-existing MI and FI. The relationship between halogen (F and Cl) and Na abundances in MI is also consistent with the interpretation that the very earliest stages of pegmatite formation occurred in the presence of a volatile-undersaturated melt and that the melt became volatile saturated as crystallization progressed.

We propose a closed system, isochoric model for the formation of the pegmatites. Accordingly, the Taishanmiao granite crystallized isobarically at ~3.3 kbar, and the pegmatites began to form at ~734 °C and ~ 3.3 kbar, after ~96% of the original granitic melt had crystallized. During the final stages of crystallization of the granite, small pockets of the remaining residual melt became isolated within the enclosing granite and evolved as constant mass (closed), constant volume (isochoric) systems, similar to the manner in which volatile-rich melt inclusions in igneous phenocrysts evolve during post-entrapment crystallization under isochoric conditions. As a result of the negative volume change associated with crystallization, pressure in the pegmatite initially decreases as crystals form, and this leads to volatile exsolution from the melt phase. The changing *PTX* conditions produce a pressure-induced "liquidus deficit" that is analogous to liquidus undercooling and results in crystal growth as required to return the system to equilibrium *PTX* conditions. Owing to the complex closed system, isochoric *PVTX* evolution of the melt-crystal-volatile system, the pressure does not decrease rapidly or monotonically during pegmatite formation but, rather, gradually fluctuates such that at some stages in the evolution of the pegmatite the pressure is decreasing while at other times the pressure increases as the system cools to maintain mass and volume balance. This behavior, in turn, leads to alternating episodes of precipitation and dissolution that serve to coarsen (ripen) the crystals to produce the pegmatitic texture. The evolution of the pegmatitic melt described here is analogous to that which has been well-documented to occur in volatile-rich MI that undergo closed system, isochoric, post-entrapment crystallization.

Keywords: Melt inclusion, fluid inclusion, Taishanmiao batholith, liquidus deficit, volatile-saturated melt, Rhyolite-MELTS, pegmatite; Experimental Halogens in Honor of James Webster

* E-mail: rjb@vt.edu
† Orcid 0000-0003-3801-7441
‡ Special collection papers can be found online at http://www.minsocam.org/MSA/AmMin/special-collections.html.

0003-004X/21/0010–1559$05.00/DOI: https://doi.org/10.2138/am-2021-7637