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Invited review article

A petrologic assessment of internal zonation in granitic pegmatites

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A R T I C L E I N F O

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A B S T R A C T

Cameron et al. (1949) devised the nomenclature and delineated the patterns of internal zonation within granitic pegmatites that are in use today. Zonation in pegmatites is manifested both in mineralogy and in fabric (mineral habits and rock texture). Although internal zonation is a conspicuous and distinctive attribute of pegmatites, there has been no thorough effort to explain that mineralogical and textural evolution in relation to the zoning sequence presented by Cameron et al. (1949), or in terms of the comprehensive petrogenesis of pegmatite bodies (pressure, temperature, and whole-rock composition). This overview of internal zonation within granitic pegmatites consists of four principal parts: (1) a historic review of the subject, (2) a summary of the current understanding of the pegmatite-forming environment, (3) the processes that determine mineralogical and textural zonation in pegmatites, and (4) the applications of those processes to each of the major zones of pegmatites. Based on the concepts presented in London (2008), the fundamental determinates of the internal evolution of pegmatite zones are: (1) the bulk composition of melt, (2) the magnitude of liquidus undercooling prior to the onset of crystallization, (3) subsolidus isothermal fractional crystallization, by which eutectic or minimum melts fractionate by sequential, non-eutectic crystallization, (4) constitutional zone refining via the creation of a boundary layer liquid, chemically distinct from but continuous with the bulk melt at the crystallization front, and (5) far-field chemical diffusion, the long-range and coordinated diffusion of ions, particularly of alkalis and alkaline earths, through melt.

Contents

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1. Introduction

Granitic pegmatites (*pegmatites* for short here) have intrigued earth scientists for centuries. Graphic granite (Fig. 1), the defining texture of pegmatites, was singled out and illustrated by Patrin (1801). Rare minerals from pegmatites attracted some of the earliest practitioners of mineralogy (e.g., Brush and Dana, 1878), and mineralogical studies of pegmatites have dominated the field for the past four decades. Economic geologists placed pegmatite deposits on a par with other granite-associated ores (e.g., Lindgren, 1913), and pegmatites continue to be sole or important sources of rare metals, industrial minerals for glasses and ceramics, and colored gemstones (see reviews by Glover et al., 2012; Linnen et al., 2012; Simmons et al., 2012). Although pegmatites have been studied exhaustively in their many individual parts, they have received surprisingly little investigation as a whole; that is, as rocks, through the methods of petrology.

Most definitions of pegmatites contain genetic interpretations; these rocks are difficult to characterize on a purely descriptive basis. London (2008) defined pegmatites as: "*essentially igneous rock, mostly of granitic composition, that is distinguished from other igneous rocks by its extremely coarse but variable grain-size, or by an abundance of crystals with skeletal, graphic, or other strongly directional growth habits*." The modifiers "*essentially*" and "*mostly*" introduce purposeful ambiguity to the nouns they modify: pegmatites may not be entirely igneous, and they are not always or entirely granitic in composition. In this definition, the textural attributes are related by the conjunction "*or*", meaning that any one of them might, in a particular instance, be diagnostic of pegmatite. Exceedingly coarse crystal size is a hallmark of pegmatites for most geoscientists, but the other mineral textures and rock fabrics cited above are prevalent and may be defining characteristics of some bodies.

The vast majority of pegmatites possess compositions close to the minimum or eutectic assemblage of granite (e.g., Jahns and Tuttle, 1963; London et al., 2012b; Norton, 1966). These *common* pegmatites (London, 2008) contain biotite and muscovite and accessory garnet, tourmaline, and apatite. Pegmatites that host appreciable beryl, lithium aluminosilicates, phosphates other than apatite, oxides other than magnetite or ilmenite, and other rarer minerals are regarded as *rare-element* pegmatites. The compositions of even the most chemically complex rare-element pegmatites plot close to the hydrous granite minimum composition at elevated pressure (Stilling et al., 2006). For this reason, most geoscientists have ascribed pegmatites to a fundamentally igneous origin, though exclusively hydrothermal models have persisted since the beginning of modern geology (e.g., Gresens, 1969; Hunt, 1871; Ramberg, 1952; Reitan, 1965; Roedder, 1981).

A genetic link between granites and pegmatites is beyond reasonable doubt. How pegmatites are derived from, and what makes them different from granites has been debated for more than a century. Whereas granites form large masses of comparatively uniform and mineralogically homogeneous rock, pegmatites are precisely the opposite. Most pegmatite bodies are small, with dimensions on the scale of meters rather than kilometers, and internally heterogeneous in their composition and rock fabrics. They occur as segregations along the margins of the cupolas of granites and as sharply discordant dikes that intrude igneous and metamorphic rocks. Zonation in pegmatites occurs at two scales: (1) regional zonation, manifested as increasing chemical complexity with distance from their granitic or other thermal source, and (2) internal zonation, the mineralogical and textural changes within individual pegmatite bodies. This review mostly concerns the latter topic, because it has been the focal point of most petrologic research and opinion on pegmatites.