

COLD PEGMATITES

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The large-crystal dikes and seams we know as pegmatites have fascinated geologists, geology students, and rock hounds for centuries. Most are barren of exotic minerals, but the large sizes of quartz, feldspar, and mica are thrilling. Others, not barren, are unusually enriched in B (tourmaline), P (apatite), and F (fluorite and micas). These “fluxing” components, along with H₂O, dramatically change the behavior of these residual-magma systems. Also enriched in such pegmatites are Nb, Ta, Sn, Be, Li, Ce, U, Th, and REE, whose concentrations are recorded in minerals such as rutile and titanite (Sn, Nb, Ta), spodumene (Li), and allanite and zircon (Ce, U, Th, REE).

London and Kontak (2012 this issue) appropriately note that pegmatites display aspects of both igneous and hydrothermal systems, including inwardly coarsening crystals, concentric layering, and core seams of quartz. The origin of pegmatites continues to be debated on some fronts, but most researchers see them as fluid-saturated residual melts with near-haplogranitic compositions. These melts evolved from granitoid intrusions at a late stage and at emplacement depths sufficient to prevent the vapor loss typical of volcanic and near-surface magmatic systems. A range of isotopic studies has been carried out over many years, including work on the stable isotopes of O, H, C, Li, Be, and B and the radiogenic isotopes of Sr and Pb. The roles of multiple sources and open-system behavior in the genesis of pegmatites are without debate.

Černý et al. (2012 this issue) show how pegmatites reflect their sources. Such work is challenging as all residual liquids derived from granitic magmas have near-eutectic compositions in the Ab–Or–Qz system and are thus far removed from the composition of primary melts derived from the original source or mixture of sources; in addition, they may have been modified through interaction with other magmas and/or through contamination. Černý et al. (2012) also conclude that pegmatites are most prevalent in S-type and A-type granitic suites but not those of I-type affinity. This is a rather surprising statement. Many of the world’s A-type granites are Mesoproterozoic, with ages between 1.0 and 1.6 Ga (Anderson and Morrison 2005). As part of the well-known “anorthosite event,” these granites represent rather dry magmatic systems, as evidenced by late crystallization of hydrous phases, high crystallization temperatures, and the noticeable scarcity of pegmatites and related hydrothermal veins over vast areas. Moreover, I-type “granites,” mostly of tonalite to granodiorite composition, often host pegmatites—the continental margin–related Mesozoic batholiths of the western U.S. are examples (Figs. 1, 2). Early studies of the Sierra Nevada batholith of California noted the occurrence of pegmatites (Rose 1957). The Mt. Stuart batholith, the largest Cretaceous batholith in the Washington Cascades, also contains pegmatites (Anderson et al. 2012).

The contributions by London (2008, 2009) are certain to be seen as seminal contributions to research on the origin of pegmatites. For many years, the work by Jahns and Burnham (1969) focused on the role of water in the formation of pegmatites. London’s work and that of others (see London and Morgan 2012 this issue) have brought to the forefront the role of fluxing agents like B, P, and F, which lower solidus temperatures well below that of the water-saturated granite minimum,



FIGURE 1 Tourmaline-bearing pegmatites, presumably derived from the Cathedral Peak granodiorite, intruding the Soldier Peak granodiorite and mafic enclaves in the eastern Sierra Nevada batholith, California

confirming earlier work by Cameron et al. (1949) and Jahns (1953). With H₂O, the elements B, P, and F lower melt viscosity and increase the diffusivity of Al and Si, thus enhancing the growth of silicate minerals. Experiments by Swanson (1977) and Fenn (1977) presented earlier evidence. The former view was that pegmatites formed via slow cooling and long periods of crystal growth. London’s recent models, based on controlled experiments, argue for short time frames, on the scale of hours to days, as previously proposed by Lofgren (1980).

Another important aspect of current work is that H₂O, B, F, and P also suppress mineral nucleation, causing the melt to be metastable and supersaturated. This condition is termed “undercooling” (Fenn 1977; London et al. 1989), and such cooling is considered to be 75 to 100 °C below the liquidus before the onset of crystallization. The nucleation delay is thought to be caused by reactions between fluxing components and major elements in the melt. Further cooling of the supersaturated, undercooled melt then causes rapid crystal growth, from the margins inward, enhancing the growth of large crystals and leading to the oriented textures commonly observed in pegmatites.



FIGURE 2 Close-up view of late-forming tourmaline in a pegmatite near the locality in Figure 1

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Isotope and geothermometry studies support the conclusion that pegmatitic melts crystallize at temperatures below the wet solidus of granite and in the range of 500–600°C, if not lower. Fluid inclusion studies of spodumene, beryl, tourmaline, and quartz by London (1986) determined crystallization temperatures in the range of 425–475°C. Likewise, Taylor et al. (1979) determined late pegmatite crystallization at 525–565°C, based on both fluid inclusions and the isotopes of O, H, and C. Other studies supporting the idea that pegmatites crystallize well below the wet granite solidus include Thomas et al. (1988), Nabelek et al. (1992), Morgan and London (1999), and Sirbescu and Nabelek (2003). As fluxing agents, H₂O, B, F, and P lower crystallization temperatures, to approximately 650°C for pegmatite liquidus conditions and <500°C for the solidus (London et al. 1989, 1993). Enrichment in alkalis, including Li and Cs, further lowers the temperature of pegmatite crystallization.

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Experiments by Pichavant (1981) were among the earliest to document the lowering of the granite solidus due to boron—by as much as 135°C, with 5 wt% B₂O₃ and at 1 kbar, relative to the conventional water-saturated granite solidus.

Hence, pegmatites, particularly those bearing tourmaline, apatite, fluorite, and/or mica, are cold relative to the granitic magmas that spawn them. After all, the K-feldspar in pegmatites is microcline and not orthoclase and pegmatites have minimal to nonexistent contact aureoles. But they are “cool” rocks! Although representing only a small portion of the Earth’s crust, pegmatites offer huge insights into processes in magma systems and they provide many materials needed for current technological applications. They also continue to attract geology students and others because of their wonderfully large crystals. ■

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