American Mineralogist, Volume 102, pages 931–947, 2017

Review

A review and update of mantle thermobarometry for primitive arc magmas

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Abstract

Erupted lavas and tephras remain among the best tools we have to ascertain the mantle processes that give rise to the compositional diversity and spatial distribution of near-primary magmas at volcanic arcs. A compilation of mantle-melt thermobarometry for natural, primitive arc magmas to date reveals published estimates vary between ~1000–1600 °C at ~6–50 kbar. In addition to the variability of mantle melting processes within and between different arcs, this range of conditions is the result of different methodology, such as the nature of reverse fractional crystallization calculations, the choice of thermobarometer, how magmatic H_2O was quantified and its calculated effect on pressure and temperature, and choices about mantle lithology and oxygen fugacity. New and internally consistent reverse fractionation calculations and thermobarometry for a representative subset of the primitive arc samples with adequate published petrography, measured mineral and melt compositions, and constraints on pre-eruptive H_2O content suggest a smaller range of global mantle-melt equilibration conditions (~1075–1450 °C at ~8–19 kbar) than the literature compilation. The new pressure and temperature estimates and major element modeling are consistent with a model whereby several types of primitive arc magmas, specifically hydrous calc-alkaline basalt, primitive andesite and hydrous high-MgO liquid such as boninite, first form at the location of the water-saturated mantle solidus at pressures of ~20–35 kbar and rise into the hot core of the mantle wedge reacting with the mantle en route. Due to their re-equilibration during ascent, these hydrous magmas ultimately record the conditions in the hot, shallow nose of the mantle wedge at the end of their mantle ascent path rather than the conditions at their point of origin as often interpreted. When the mantle residue for this process is lherzolite, calc-alkaline basalt is generated. When the mantle residue is harzburgite to dunite, either high-Mg primitive andesite or high-MgO liquid is generated, depending on the H_2O content. A different type of primitive arc magma, specifically nominally anhydrous arc tholeiite, is generated by near-fractional decompression melting at or near the anhydrous lherzolite solidus in the upwelling back limb of corner flow at ~25–10 kbar and is focused into the same region of the shallow mantle wedge as the hydrous melts. The similarity in the terminus of the mantle ascent paths for both wet and dry primitive arc magmas likely explains their eruption in close spatial and temporal proximity at many arcs. The conditions of last mantle equilibration for primitive arc tholeiites generated by decompression melting also imply that the convecting mantle extends to 10 kbar (~30 km) or less below most arcs. The range of mantle-melt equilibration conditions calculated here agrees well with the range of temperatures predicted for the shallow mantle wedge beneath arcs by geodynamic models, although it suggests some subduction zones may have higher maximum temperatures at shallower depths in the wedge than originally predicted. Primitive hydrous arc magmas also constrain natural variation on the order of 200–250 °C in the maximum temperature in the hot shallow nose of the mantle wedge between arcs. Thus the new primitive magma thermobarometry presented here is useful for understanding melt migration processes and the temperature structure in the uppermost part of the mantle wedge, as well as the origin of different primitive magma types at arcs.

Keywords: Arc, subduction, primitive, barometry, thermometry, mantle, magma, lherzolite, Invited Centennial article, Review article