Review

Fluids and trace element transport in subduction zones

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ABSTRACT

Melt inclusion data from primitive arc basalts from Mexico and Kamchatka show clear positive correlations of “fluid mobile element”/H2O ratios with the Cl/H2O ratio, suggesting that the trace element content of subduction zone fluids is strongly enhanced by complexing with chloride. This effect is observed for large-ion lithophile (LILE) elements, (e.g., Rb and Sr), but also for the light rare earth elements (REE, e.g., La and Ce) as well as for U. The correlations of these elements with Cl/H2O cannot be explained by the addition of sediment melts or slab melts to the mantle source, since Cl has no effect on the solubility or partitioning of these elements in silicate melt systems. On the other hand, the observed relationship of trace element abundance with Cl is consistent with a large body of experimental data showing greatly enhanced partitioning into aqueous fluid upon addition of chloride. Accordingly, it appears that a dilute, Cl-bearing aqueous fluid is the main carrier of LILE, light REE, and U from the slab to the source of melting in arcs. Moreover, elevated Ce/H2O ratios clearly correlate with fluid salinity and therefore are not suitable as a “slab geothermometer.” From a synopsis of experimental and melt inclusion data, it is suggested that the importance of sediment or slab melting in the generation of arc magmas is likely overestimated, while the effects of trace element scavenging from the mantle wedge may be underestimated. Moreover, establishing reliable data sets for the fluid/mineral partition coefficients of trace elements as a function of pressure, temperature, and salinity requires additional efforts, since most of the commonly used experimental strategies have severe drawbacks and potential pitfalls.

Keywords: Subduction zones, trace elements, halogens, chlorine, fluid flow, percolation, mantle wedge, slab geothermometer, arc magmas, Invited Centennial article, Review article

INTRODUCTION

Together with mid-ocean ridges, subduction zones are the main sources of magma on Earth today, and there is increasing evidence that this has been so for billions of years (e.g., Tang et al. 2016). The continental crust is largely a product of calc-alkaline magmas produced in subduction zones. Accordingly, understanding magma generation in this environment is essential for any global picture of planetary evolution. Early studies suggested that calc-alkaline magmas may form by direct melting of the basaltic layer in the subducted slab (Green and Ringwood 1968). However, models of the thermal structure of subduction zones (Davies and Stevenson 1992; Rüpke et al. 2004; Syracuse et al. 2010) imply that at present geothermal gradients, the temperatures required for melting the basaltic layer may only be reached under unusual circumstances. Therefore, the “standard model” of magma generation in subduction zones (Gill 1981; Arculus and Powell 1986; Tatsumi 1989; Peacock 1990) assumes that aqueous fluids are released from the subducted slab during the breakdown of hydrous minerals such as amphibole. These fluids migrate upward and trigger melting in the mantle wedge above the slab. Trace element abundances in calc-alkaline magmas likely reflect to some degree the chemical mobility in aqueous fluids. In particular, the “negative Nb-Ta anomaly,” i.e., the strong depletion of Nb and Ta relative to many other incompatible elements, is believed to be due to the poor solubility of Nb and Ta in aqueous fluids. On the other hand, “fluid mobile elements,” such as Rb or Ba are often strongly enriched in calc-alkaline magmas due to selective transport from the subducted slab to the mantle wedge by aqueous fluids. The detection of cosmogenic 10Be in subduction zone magmas (Brown et al. 1982) provides direct evidence for the transport of material that one resided on Earth’s surface into the zone of melting above the slab. Already Armstrong (1971) noted a close correlation between the 206Pb/204Pb ratio of arc magmas and the sediments in front of some arcs.

Research in the last decades has very much improved our understanding of subduction zone processes. Experimental studies demonstrated that amphibole dehydration is not the only source of aqueous fluids; instead there are numerous hydrous phases in the basaltic (MORB) layer and the sediments, including lawsonite and phengite, that may provide a source of water beyond the depth of amphibole dehydration (Schmidt and Poli 1998). Serpentine could be a very important source of water in the peridotitic part of the slab (Ulmer and Trommsdorff 1995; Rüpke et al. 2004), provided that deep fracturing allows some hydration to occur. The direct observation of complete miscibility between silicate melts and water (Shen and Keppler 1997; Bureau and...