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# Metamorphic chemical geodynamics of subduction zones

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## Abstract

Study of metamorphic suites directly representing the deep subduction of altered oceanic crust and sediments can help elucidate the geochemical evolution of the forearc-to-subarc slab–mantle interface, the nature of slab-derived fluids added to arc lava source regions, and the chemical changes in subducting rocks potentially contributing to the geochemical heterogeneity of the deeper mantle. The stage is set for more focused geochemical study of high-pressure (HP) and ultrahigh-pressure (UHP) metamorphic suites incorporating knowledge of mineral chemistry and reactions, kinetics and disequilibrium, prograde and exhumation-related  $P$ – $T$  paths, fluid flow and fluid–rock interactions, and experimental evidence for the physical and chemical properties of fluids at the pressures and temperatures experienced by subducting slabs. Detailed studies of HP and UHP metamorphism published thus far provide some insight regarding the geochemical effects of devolatilization and the element transport capabilities of metamorphic fluids in forearc regions of subduction zones (<100 km). Future research in this rapidly developing field should prioritize study of UHP suites metamorphosed at depths >100 km, which have potentially experienced partial melting, with the goal of better characterizing fluid additions to arcs from subducting slabs and sediments and the compositions of dehydration and melting residues that could impact geochemical compositions of the mantle including source regions for ocean island basalts.

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## 1. Introduction

High-pressure (HP) and ultrahigh-pressure (UHP) metamorphic suites that experienced pressure–temperature ( $P$ – $T$ ) conditions similar to those thought to occur deep in modern subduction zones (Stern, 2002; Carswell and Compagnoni, 2003) would seem to present a chemical and isotopic treasure trove of testable hypotheses bearing on the geochemical evolution of arc lavas (Elliott, 2003; Tatsumi, 2005), the direct igneous products of subduction, and contributions of subducted materials to chemical/isotopic heterogeneity in deeper parts of the mantle (Hofmann,

2003; McKenzie et al., 2004; Fig. 1). In the best case, these metamorphic suites, which contain sedimentary and igneous lithologies with appropriate seafloor protoliths, directly reflect geochemical evolution at/near the slab–mantle interface and can help us further characterize slab processes only inferred in the many geochemical studies of arc lavas and ocean island basalts (OIB). Thus, the field of “metamorphic chemical geodynamics” (after Allègre, 1982; Zindler and Hart, 1986) comprises characterizing the geochemical changes in deeply subducted lithologies and determining the roles of various types of fluids in element transfer at depth in subduction zones.

In general, the seafloor sediments and altered oceanic basalts subducting into modern convergent margins are

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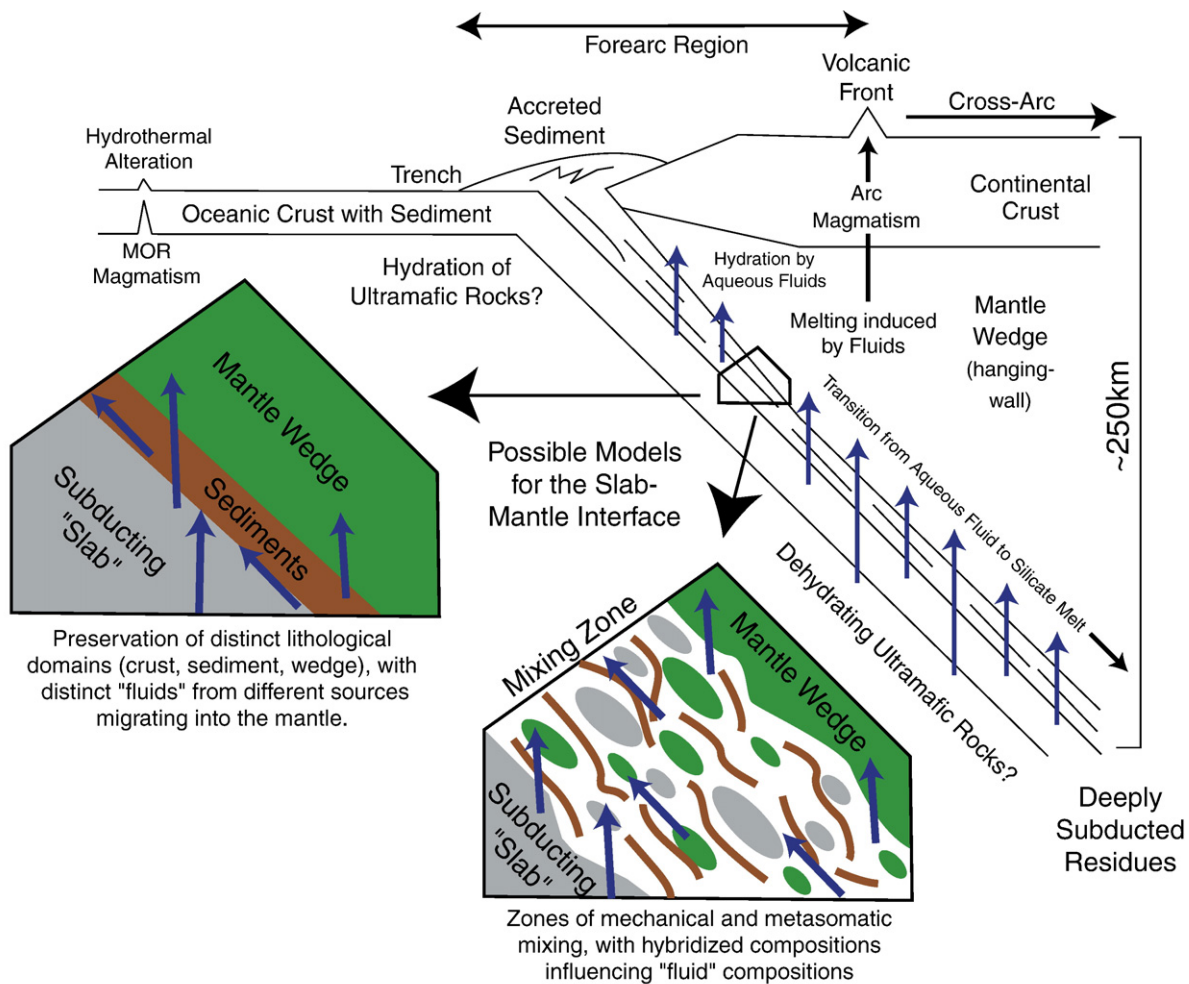


Fig. 1. Sketch of an ocean–continent subduction zone, illustrating key structural elements, some selected flux pathways, areas of remaining uncertainty in considerations of subduction-zone recycling, and two models for the nature of the slab–mantle interface (Stern, 2002; see text for discussion). Oceanic crust (and its associated mantle part of the oceanic lithosphere), variably altered geochemically at mid-ocean ridges (MOR), and sediment deposited onto this crust, are deeply subducted, contributing fluids and elements to the mantle wedge (hanging wall). It is possible that fluids are also contributed from the ultramafic part of the subducting oceanic lithosphere previously hydrated during slab bending in trench regions. On this figure (insets and main figure), the blue arrows indicate additions of slab-derived “fluids” to the mantle wedge. At shallower levels (forearc regions, in particular), these fluids are thought to be aqueous fluids, whereas the fluids added to the mantle wedge at greater depths (beneath volcanic arcs and into the deeper mantle) likely transition into being silicate melts.

enriched in the same chemical species thought to be enriched in subduction-related lavas by fluids released by subducting rocks and ascending into the mantle wedge (e.g., Rb, Cs, Ba, B, and Li, in addition to Th, U, Pb,  $^{10}\text{Be}$ , and the LREE; (see Elliott, 2003; Morris and Ryan, 2003; Tatsumi, 2005; see Fig. 2). Attempts to quantify this slab-to-mantle chemical flux rely on a modest number of experimental studies investigating the partitioning of these and other elements among minerals and various types of fluid (alkali-chloride aqueous fluids, hydrous silicate melts, and transitional supercritical liquids (Manning, 2004; Kessel et al., 2005a,b; Hermann et al.,

2006). Although it appears that aqueous fluids are the dominant fluid type released by subducting sediment and basalt in forearc regions (Hermann et al., 2006; see Fig. 1), the supercritical liquids and hydrous silicate melts may be more important beneath volcanic fronts and across arcs (e.g., for transporting Be, Th; Elliott, 2003; Morris and Ryan, 2003). Many geochemical studies of OIB invoke the presence, in mantle source regions, of subducted slabs chemically modified by metamorphism (e.g., loss of Pb and U; Hart and Staudigel, 1989; Chauvel et al., 1995; Bach et al., 2003; Kelley et al., 2005). In this paper, I discuss recently published field and geochemical

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