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The fate of subducted oceanic slabs in the shallow mantle: Insights from boron isotopes and light element composition of metasomatized blueschists from the Mariana forearc

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ABSTRACT

Serpentine muds from South Chamorro Seamount (SCS), drilled during ODP Leg 195 at Site 1200 contain metamafic clasts that experienced blueschist-facies metamorphism (including the critical mineral assemblage pumpellyite – Na-amphibole – epidote). These schists represent fragments from the actual slab–mantle interface at ~27 km depth. Their heterogeneous lithology with a metasomatic character indicates significant mobility of major elements in the Mariana forearc, a region of mélange formation as it can also be observed in onland exposures such as the Catalina Schist. As the Mariana forearc blueschists show no late stage alteration they permit the direct study of material transfer during the subduction processes at an active convergent margin.

This study presents the first data of detailed B isotope ($\delta^{11}B$) and light element variations in blueschist-facies minerals from the Mariana arc system. The primary foci are B and Li concentrations and $\delta^{11}B$ values analyzed by SIMS and ToF-SIMS techniques. Minerals such as (Na-rich) amphibole, phengite and chlorite are found to be strongly enriched in Li (up to 70 µg/g), Be (up to 8 µg/g) and B (up to 35 µg/g) and with $\delta^{11}B$ values of -6 ± 4‰. These new data are consistent with isotopically heavy B being released into the Mariana forearc mantle wedge (serpentinization of dry mantle peridotite after interaction with B-rich slab-released high pH fluids) and confirm models of significant B-loss and B isotope fractionation during forearc (shallow) slab dehydration. The elevated Li, Be and B concentrations in minerals that comprise the bulk of the rocks, namely, amphibole, phengite, and chlorite bear a strong potential to further transport Li and B as well as the isotopically light component of B to greater depths in the mantle, where ongoing metamorphism is responsible for further isotope and elemental fractionation and the formation of distinct mantle reservoirs, e.g. volcanic arc and oceanic intra-plate (OIB) magmas.

1. Introduction

Convergent plate margins are the most dynamic and complex global structures in the Earth's interior. For example at subduction zones input and output 'materials' account for global elemental cycling, where elements are transported from the ocean waters to the sediments and subducted oceanic crust, towards the deep mantle and then back to the surface via arc magmatism. Studies on cross-arc volcanic chains reveal that light element concentrations and isotopic ratios change with increasing depth of the slab and/or distance from the volcanic fronts (or trenches) and that light element contents are always enriched in the metasomatized portion of the mantle (e.g., Chan et al., 1999, 2002; Ishikawa and Nakamura, 1994; Ishikawa and Tera, 1999; Leeman, 1996; Ryan et al., 1995, 1996; Savov et al., 2005b; Tatsumi et al., 1986; Tomascak et al., 2002). Recent light element studies on enriched mantle wedge serpentinites, serpentinite muds, slab-derived pore waters, and metamafic rocks (Bebout et al., 1999; Benton et al., 2001, 2004; Deschamps et al., 2011; Fryer et al., 1999; Kodolányi and Pettke, 2011; Maekawa, 1995; Maekawa et al., 1992,

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1993; Mottl et al., 2003; Savov et al., 2004, 2005b, 2007) stress the importance of forearc processes controlling the element recycling within the 'Subduction Factory'.

One of the most complex and lithologically and geochemically diverse region of subduction zones is the slab–mantle interface (décollement) – a region known as a tectonic mélange. Although rarely well preserved, such tectonic mélanges could be exhumed in collision zones and orogenic belts (e.g., Bebout and Barton, 1989; King et al., 2006). Most observations so far were made upon experiments and partially preserved onland exposures, where erosion has exposed ancient subduction-related metamorphic rocks such as those from the Catalina Island in California and Syros Island in Greece (e.g., Bebout, 1995; Bebout et al., 1999; Breeding et al., 2004; Coleman and Clark, 1968; Essene and Fyfe, 1967; King et al., 2006, 2007; Marschall et al., 2006a; Peacock and Hervig, 1999; Sorensen and Grossman, 1989).

In the Izu-Bonin-Mariana convergent margin in the Western Pacific (Fig. 1), the ongoing extrusion of vast amounts of serpentinite muds at large forearc-situated seamounts such as Big Blue, Conical and South Chamorro seamounts (Fryer et al., 2006), emplaces not only serpentinized mantle wedge material, but also a unique suite of metamafic rocks and minerals from depths of up to ~27 km (Fryer et al., 1999, 2000, 2006; Gharib, 2006; Maekawa, 1995; Maekawa et al., 1992, 1993; Savov et al., 2004). The largest volumes of such metamafic clasts are recovered from the South Chamorro Seamount, with Conical, Pacman and Big Blue Seamounts having less of these forearc sourced metamorphic rocks (Fryer et al., 2006; Gharib, 2006; Savov et al., 2004) and no high-pressure minerals were recovered from seamounts closer to the trench (<70 km distance; Gharib, 2006; Maekawa, 1995; Maekawa et al., 1992; Savov et al., 2005a). Up to 8% of the fragments found within the serpentinite mudflows have mafic composition (Fryer, 1992; Fryer and Mottl, 1992; Fryer et al., 1990, 1999, 2006; Gharib et al., 2002; Johnson, 1992; Johnson and Fryer, 1990; Lagabrielle et al., 1992; Maekawa, 1995; Maekawa et al., 1993; Savov et al., 2004, 2005a). Most of these mafic clasts are of blueschist-facies metamorphic grade representing material shed from the downgoing, Jurassic in age, Pacific slab (Fryer et al., 1999; Maekawa, 1995; Maekawa et al., 1993). Due to these recent discoveries, it appears that the Mariana forearc serpentinite seamounts (Figs. 1 and 2) offer an exceptional location for detailed petrological investigation of a great variety of slab-derived material which is the only opportunity to investigate in-situ the workings of an ongoing plate convergence.

Bebout et al. (1993, 1999) examined Li, Be and B whole rock abundances of metasediments and metamafic rocks from the Catalina Schist in California. These rocks exhibit a range of metamorphic grades from lawsonite-albite to greenschist and epidote-amphibolite facies. The high B/Be ratios typically found in both oceanic sediments (B/Be 50–200) and altered oceanic crust (B/Be 5–200; Bebout et al., 1993; Moran et al., 1992; Ryan and Langmuir, 1988, 1993; Spivack et al., 1987) overlap with B/Be ratios in subduction related metamorphic rocks. However, decreasing B concentrations (from ~180 to ~1 µg/g) and decreasing B/Be ratios (from ~140 to ~4) with increasing metamorphic grade in Catalina rocks imply that B, compared to Be, is preferentially removed from the subducting slab during prograde metamorphism and that high B/Be ratios are not retained to subarc depths (Bebout et al., 1993, 1999). Also, B and other highly fluid-mobile elements are initially lost from compacting subducting sediments by devolatilization at shallow depths (Bebout et al., 1993; Kastner and Elderfield, 1993; Kastner et al., 1993; Underwood et al., 2010; You et al., 1993, 1995). Further evidence for light element fractionation and progressive fluid- and fluid mobile element (B, As, Cs, Sb, I) loss from the subducted sediments during subduction is evident by enriched Li, Be and B concentrations in serpentinites of the overlying mantle wedge material,

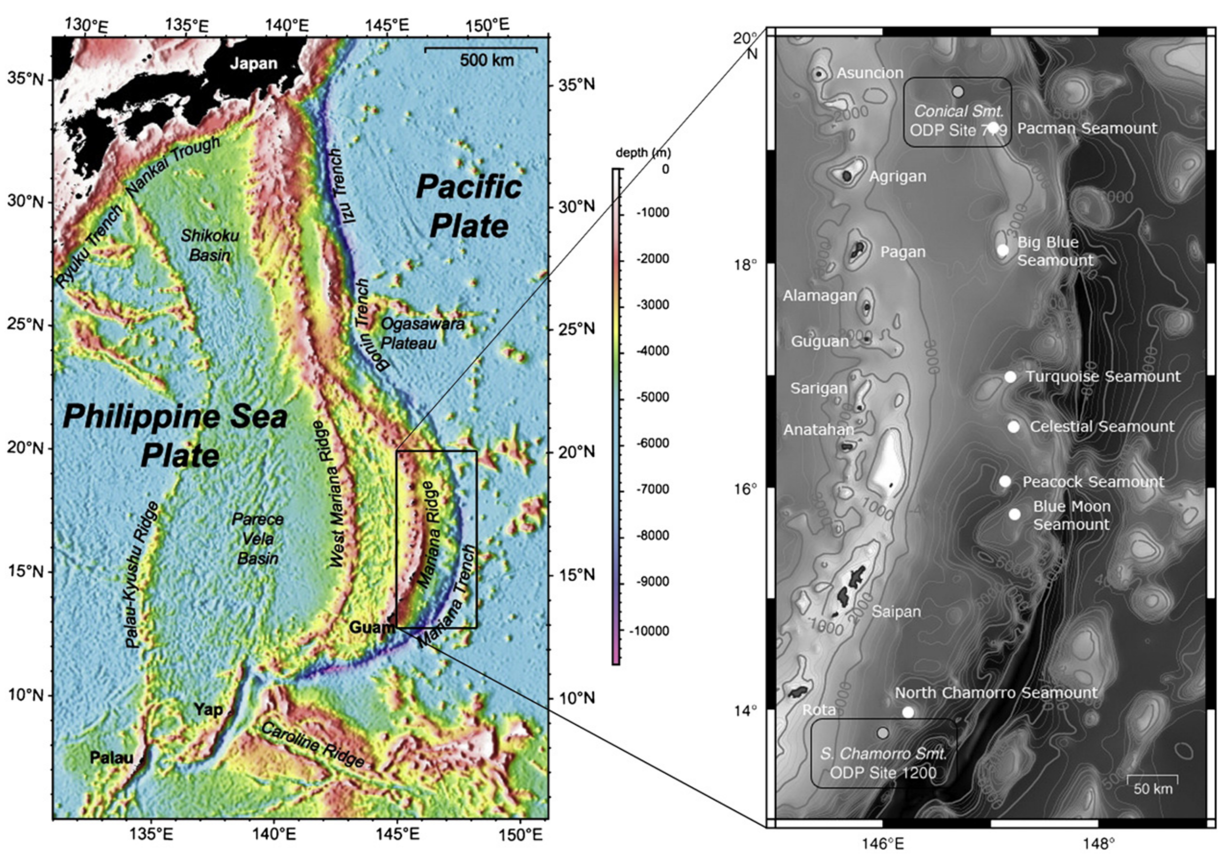

Fig. 1. a) Bathymetry color map of the Izu-Bonin-Mariana arc-basin system (from and after Fryer and Salisbury, 2006), black rectangle indicates the area of figure b), b) Bathymetry map showing volcanic islands and serpentinite mud volcanoes, the seamounts relevant for this study are Conical and South Chamorro Seamount (modified after Snyder et al., 2005).