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Composition of the slab-derived fluids released beneath the Mariana forearc: Evidence for shallow dehydration of the subducting plate

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A B S T R A C T

In cold subduction systems, the downgoing plate is thought to mostly dehydrate (≥90% water) beneath the arc front. However, the composition of aqueous fluids released from the shallow subducting slab is poorly constrained because the occurrence of melt inclusions is rare in forearcs. The Southeast Mariana Forearc Rift (SEMFR) is a recently discovered site where extensionally induced magmatism occurred in Pliocene time unusually close to the trench. SEMFR basalts sampled fluids derived from the subducted plate at ∼30 to 100 km deep. Here, we use SEMFR basalts to obtain new insights into the composition of shallow slab-derived fluids by evaluating major element, trace element and volatile contents of olivine-hosted melt inclusions and glassy rinds. Olivine-hosted melt inclusions and their host glassy rinds both contain at least ∼2 wt% H_2O, representing minimum estimates for magmatic water content. Melt inclusions have the highest volatile and alkali ratios (i.e., $H_2O/Ce = 6000–19000$; $Rb/Th = 200–2600$; $Cs/Th = 0.4–20$) yet recorded in glasses from subduction zones (arc magmas have mean $H_2O/Ce < 2700$; $Rb/Th < 40$; $Cs/Th < 2$). Our results indicate that shallow slab-derived fluids are water- and alkali-rich as compared to the deeper fluids released beneath the arc system. Shallow subduction outfluxes peak at ∼70–80 km slab depth, demonstrating that significant slab dehydration occurs beneath the forearc.

1. Introduction

Subducting oceanic lithosphere and sediments (slab) carry fluids and volatiles from the Earth surface down into the mantle and recycle most of them back to the surface through arc magmatism. Aqueous fluids released from the breakdown of hydrous minerals from subducting slabs play a key role in subduction recycling. Fluids released from the slab at shallow depths promote serpentinization of the forearc mantle, but typically do not trigger melting due to low temperatures (Fryer et al., 1995; Hyndman and Peacock, 2003; Schmidt and Poli, 1998; Tatsumi, 1989). In contrast, deeper slab fluids interact with hot asthenospheric mantle to generate magmas beneath active arc volcanoes and backarc basin spreading centers (Gill, 1981; Grove et al., 2012; Schmidt and Poli, 1998).

Convergent margin magmas capture slab-derived fluids and retain these geochemical signatures better than serpentinites because magma can be trapped as olivine-hosted melt inclusions and as quenched rims on pillow basalts. Quenched, glassy melt inclusions in particular may preserve the chemical imprint of their subduction components (e.g., Kent, 2008; Ruscitto et al., 2012; Shaw et al., 2008), as their host mineral can protect them from alteration and low pressure degassing (e.g., Schiano, 2003). Melt inclusions also provide snapshots of the melt evolution during crystallization; and because olivine fractionates early in basaltic systems, their melt inclusions can record early stages of magmatic processes (e.g., Kelley et al., 2010).

Recent thermal models along with estimates of the dehydration efficiency of global subduction zones suggest that the downgoing plate in cold subduction systems such as the Mariana system can retain mineral bound-water to depths >80 km before mostly

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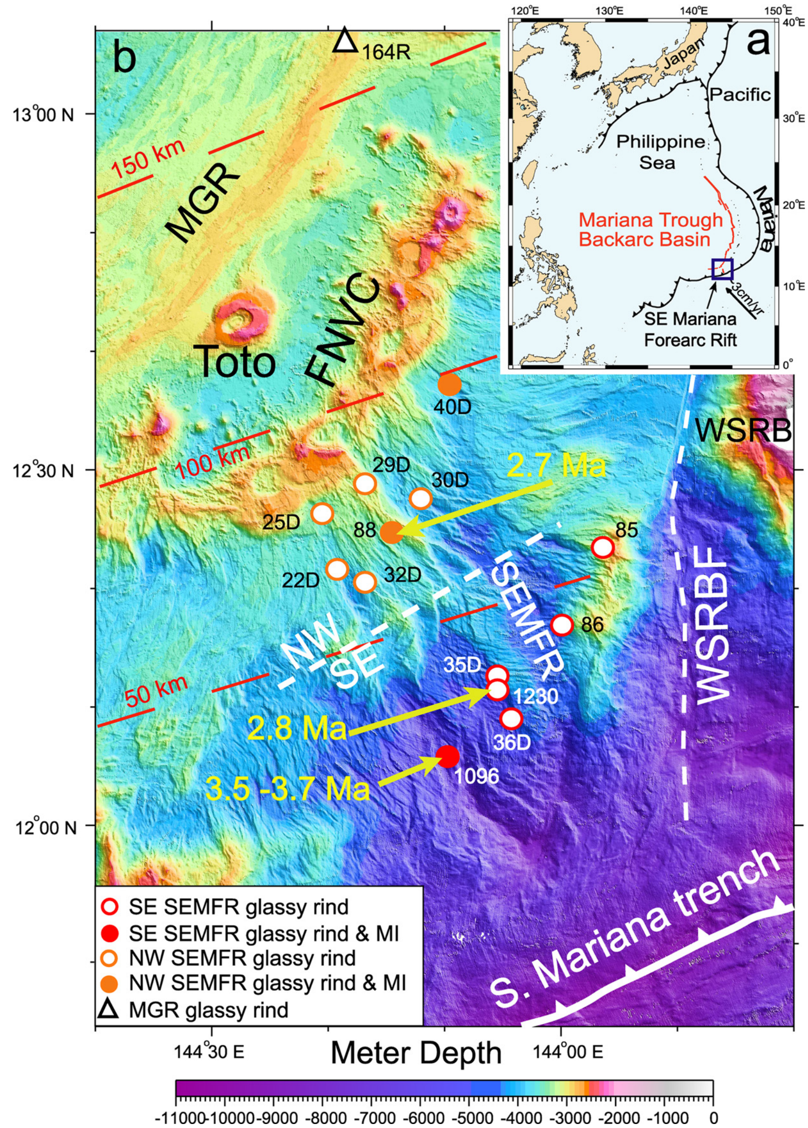

Fig. 1. Locality maps and sketch showing the plate tectonic setting of samples in this study. a) Location of the Mariana intraoceanic arc system in the Western Pacific. The arrow represents convergence direction and rate (Kato et al., 2003). The blue box shows the area of b. b) Detailed bathymetric map of the Southeast Mariana Forearc Rift (SEMFR) in the southeastern Mariana arc. SEMFR is divided into SE and NW sectors, separated by a thick white dashed line. Numbers with D indicate TN273 dredging sites; other numbers represent sampling sites for JAMSTEC Yokosuka (YK08-08 Leg 2 and YK10-12) and Kairei (KR00-03 Leg 2) cruises. Large yellow numbers are ^{40}Ar–^{39}Ar ages (Ribeiro et al., 2013b). Toto: Toto caldera, FNVC: Fina Nagu volcanic chain, WSRBF: West Santa Rosa Bank Fault, MGR: Malaguana-Gadao Ridge. The thin red dashed lines with numbers denote approximate depths to the subducted Pacific plate (Becker, 2005). Map generated with GMT (Smith and Wessel, 1990; Wessel and Smith, 1995, 1998) using a compilation from the University of New Hampshire/Center for Coastal and Ocean Mapping/Joint Hydrographic Center. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

dehydrating beneath the arc volcanoes (Van Keken et al., 2011; Wada et al., 2008). Mass balance calculations indicate that less than 10% of subducted water is available to be recycled deeper into the lower mantle (Shaw et al., 2012, 2008; Van Keken et al., 2011). Shallow dehydration of the subducting plate is central in assessing the fluid budget; yet, we can rarely sample such shallow subduction fluids released beneath forearcs despite their importance.

Forearc rifts can provide critical insights into shallow subduction processes because they may erupt basalts unusually close to the trench (Ribeiro et al., 2013b). Such basalts form by decompression melting of the asthenospheric mantle wedge fluxed by shallow slab-derived fluids (Ribeiro et al., 2013a). Identifying and examining forearc rift basalts and their olivine-hosted melt inclusions thus provides a unique opportunity to investigate the composition of shallow slab-derived fluids. Here, we report results from studying olivine-hosted melt inclusions and glassy rims from young basalts erupted from a forearc rift in the southern Mariana convergent margin and use these results to advance our understanding of shallow slab-derived fluid compositions. We present major element, volatile (H_2O, CO_2, S, Cl, F) and trace element contents of their olivine-hosted melt inclusions and glassy pillow rinds. We use this new dataset to constrain the composition of aqueous fluids released from the shallow subducted slab and explore how such fluids have triggered flux melting of shallow hot mantle unusually close to the trench. We show that the shallow subduction component is enriched in water and alkalis relative to the fluids released deeper. We find that the contribution of shallow water-rich fluids becomes most important when the slab is ∼70–80 km depth, indicating that the downgoing plate significantly dehydrates beneath the forearc.

2. Geological setting

The Mariana convergent margin results from subduction of the Pacific Plate beneath the Philippine Sea Plate (Fig. 1a; Meijer and