The Southeast Mariana Forearc Rift: A Modern Analague for Forearc Extension during Subduction Initiation

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Subduction initiation (SI) is associated with broad zones of extension and volcanism in what becomes the forearc. These "infant-arc" tectono-magmatic regimes erupt voluminous MORB-like tholeiites (FAB of Reagan et al., 2010) to form forearc crust, Yet, the nature of protoforearc extension during SI remains speculative because such short-lived spreading regimes have no counterpart among presently active arc systems. We assume SI seafloor spreading is like modern mid-ocean ridges but the different tectonic regimes and especially different water fluxes suggest there may be significant differences. The SE Mariana Forearc Rift (SEMFR; Fig. 1A, B) provides an actualistic example of forearc extension that illuminates SI protoforearc extension. This unusual region of forearc extension results from the opening of the Mariana Trough back-arc basin ~4.5 cm/year at the latitude of Guam (Kato et al. 2003), causing the southern Mariana convergent margin to reform as it rapidly lengthens. The SE margin is rapidly evolving and has yet to stabilize as a convergent plate margin, as evidenced by the fact that it has no well-defined magmatic arc, in spite of a subducted slab at the appropriate depth, and widely melted mantle. Forearc rifts like SEMFR are uncommon, because forearcs are generally relatively cold, strong, and stable. Rifts near convergent plate boundaries occur at other locations where trenches bend sharply and rollback induces extension in the overlying plate, such as at the northern end of the Tonga Trench and at the southern end of the New Hebrides Trench. The lesson from SEMFR is that SI infant arcs are likely to have had broad, poorly localized zones of extension and volcanism

SEMFR is bathymetrically defined by a complex, diverging set of NE-SW trending ridges SW of Guam (Fig. 1A, B). So defined, it encompasses a region ~150 km NW-SE and ~70 km NE-SW. Sidescan sonar imagery reveals high acoustic backscatter over the region from the backarc spreading ridge to the trench, indicating broadly distributed basement exposure and volcanism (Martinez et al., 2000). Seafloor imaging reveals abundant normal faulting, volcanic ridges composed of pillowed basalts, abundant talus of fresh basalt, and little sediment cover. 6 samplings of SEMFR seafloor during 2008 and 2010 recovered only fresh basalt. SEMFR is flanked to the E by a N-S ridge of gabbro and peridotite (Michibayashi et al., 2009). Detailed petrologic studies at Shinkai dive 1096 indicate these basalts are essentially siilar to back arc basin basalt (BABBl Ribeiro et al., 2010). Earthquake locations confirm that deformation is broadly distributed, with both extensional and strike-slip focal mechanisms. These datasets reveal pervasive, diffuse, and complex extension, with an axis that is oriented at high angles to the trench and backarc spreading ridge and parallel to the plate convergence vector. Trench-parallel rifting of the southern Mariana margin ruptured the pre-existing forearc lithosphere and caused mantle wedge asthenosphere to flow from the backarc region over the subducting slab to near the trench. This flow of asthenosphere towards the trench over a very shallow subducting slab is similar to what is thought to occur during SI.

The diffuse nature of SEMFR extension and volcanism may be caused by high water flux from the slab to the overlying mantle. Water reduces olivine and thus mantle strength by orders of magnitude relative to anhydrous mantle (Peslier et al., 2010). At mid-ocean spreading centers mantle dehydration accompanies melt extraction yielding a strong compositional lithosphere and a narrow plate boundary zone (Fig. 1C; Phipps-Morgan 1997). Beneath the southern Mariana convergent margin (and during SI), however, continuous water flux from the subducting slab may effectively counter mantle dehydration as a result of melting. Water flux from any subducting plate is at a maximum beneath the forearc, decreasing rapidly with increasing depth (Hacker, 2007). High water content of mantle beneath SEMFR may result in weak mantle which stimulates melting at the same time that is precludes formation of strong compositional lithosphere and thus localization of extension. SI magmatism and extension may be similarly diffuse, for similar reasons.

One complication is that early SI magmatism (FAB) shows little evidence that water was important during melting (only one FAB glass has been analyzed, with 0.1% H_20). If this is representative of FAB, what happened to the water that must have been released from the slab during this time? Was it absorbed by the overlying mantle before it reached the region of melt generation? Certainly water has effectively permeated and presumably weakened the mantle above the slab by the time that upper boninites are generated, but what happened to the water at the beginning, when FAB formed? There were clearly heterogeneous influences of subducted materials in FAB; the nature of the heterogeneity in time and space, the causes, and the dynamic implications need further work to evaluate.

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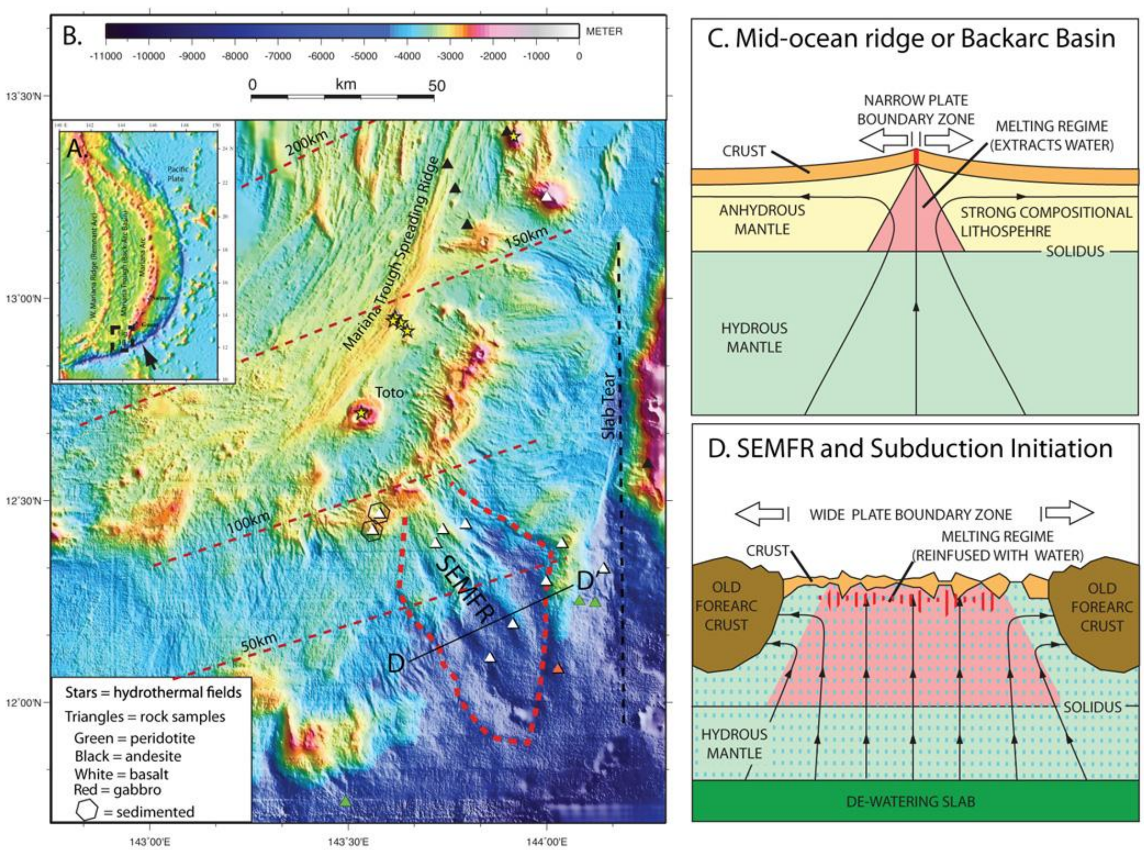

Figure 1. A) Location of SE Mariana Forearc Rift (SEMFR) in Mariana arc (dashed box). Arrow shows plate convergence vector. B) S. Mariana Trough and SEMFR showing location and lithologies of seafloor samples. Dashed red lines show approximate depth of subducted Pacific plate; note inferred position of slab tear beneath major N-S fault (West Santa Rosa Bank Fault). The andesitic volcano ~13°15'N, 144°E is as far SW as the Mariana volcanic arc can be traced; BAB spreading axis may have captured arc magma supply SW of this point. Magma chamber beneath BAB spreading axis imaged by Becker et al. (2010) is at 13°05'. C, D: Model for narrow vs. wide plate boundary zones. Diagrams depict cross-sections perpendicular to a mid-ocean spreading center (C) and parallel to but behind the trench at a convergent margin (D, profile location is shown on B as D-D'). C) Beneath mid-ocean ridges asthenosphere with modest water content (green) flows upward (black arrowed lines indicate mantle flowlines) due to plate separation leading to pressure release melting (pink region) and extraction of water from the mantle with the melt. Residual mantle (yellow) is anhydrous and much more viscous than the underlying modestly hydrous mantle. The generation of strong compositional (dry) lithosphere thus helps focus deformation and crustal magmatism (red vertical line) to a narrow plate boundary zone. D) Beneath convergent margins the underlying subducted slab (dark green) continually releases water to the overlying mantle, leading to low mantle wedge viscosities. Extension, breakup and separation of the pre-existing forearc (dark brown) leads to upward advection of mantle and pressure release melting augmented by hydrous melting (note deeper solidus than in C) and formation of a broad melting regime (pink). Flowlines show only components in plane of cross-section. Actual flow is three-dimensional with significant flow perpendicular to plane of section. Although melt extraction removes water, continual water flux from subducting slab

(blue dashes) prevents mantle dehydration and formation of strong lithosphere. Extension (indicated by region bounded by white divergent arrows) and magmatic crustal emplacement (red vertical lines) are broadly distributed and variable with possible mantle exposure at the seafloor.