SUBDUCTION INITIATION AND THE NEED TO STUDY FOREARC CRUST

Authors:

Mark K. Reagan, Geoscience, University of Iowa, Iowa City, IA 52242 USA (mark-reagan@uiowa.edu)

Robert J. Stern, Geosciences, University of Texas at Dallas, Richardson TX 75080 USA

David W. Scholl, US Geological Survey, Menlo Park, CA 94025 USA

Osamu Ishizuka, Geological Survey of Japan, AIST, Japan

Yasuhiko Ohara, Hydrographic and Oceanographic Dept., Tokyo 104-0045, Japan

Kenichiro Tani, IFREE, JAMSTEC, Yokosuka, 237-0061, Japan

James Gill, Earth Sciences, University of California, Santa Cruz, 95064 USA

Julian Pearce, School of Earth and Ocean Sciences, U. Cardiff, Cardiff, Wales UK

The draft science plan for the Subduction Cycles and Deformation (SCD) initiative of GeoPRISMS poses as one of its key questions: *What are the physical and chemical conditions that control subduction zone initiation (SI) and the development of mature arc systems?* Understanding how subduction begins and evolves is important for this effort because: (1) a significant proportion of oceanic arc crust is generated during SI, thus understanding its composition is crucial for understanding the overall mass balance of this potential source of continental crust; (2) SI appears to occur nearly simultaneously over length-scales of many thousands of kilometers, and thus affects global plate motions, volatile fluxes, and rates of volcanism; and (3) asthenospheric flow and geological structures including those generating seismicity in modern subduction zones, depend in part on how subduction starts and evolves through time.

SI and the transition to mature, central-vent arc volcanism is best preserved in the rock record of oceanic forearcs. For example, the Izu-Bonin-Mariana (IBM) forearc has long been known to have sequences of unusual volcanic rocks related to arc infancy (e.g. Meijer, 1980; Stern and Bloomer, 1992). Recent Shinkai 6500 diving has further shown that this forearc preserves the entire magmatic history from SI through arc maturity. Similar SI lithologies with similar ages have been encountered in the Tonga-Kermadec and Aleutian forearcs. Siletzia (the Cascadia forearc) may be another SI-related forearc, but this is not yet clear. Thus, we propose that to address the question posed above, some SCD research should be focused on *in-situ* Pacific forearcs.

The IBM forearc provides a rich example of what such focused studies can reveal. The results from on-land studies of forearc islands as well as drilling, dredging and Shinkai 6500 diving since the 1970's (e.g. Hussong et al., 1981; Fryer et al., 1992; Taylor et al., 1992; Reagan et al., 2008; Ohara et al., 2010) has allowed construction of a rough geological map of the IBM forearc (Fig. 1), as well as delineation of its magmatic stratigraphy related to SI. The deepest parts of the inner trench slope consist of depleted peridotites overlain by a thin layer of gabbroic rocks. Above and to the west of the gabbros, the most abundant igneous rocks are MORB-like basalts and associated diabases termed "forearc basalts" (FAB; Reagan et al., 2010). These rocks are the first volcanic manifestations of SI. Several $^{40}Ar/^{39}Ar$ and U-Pb ages from the Bonin-islands region and near Guam place the age of FAB eruption at ~52 Ma (Tani et al., 2009; Ishizuka et al., 2009; Ishizuka unpublished data, 2010). Lavas with compositions transitional to boninite have ages of about 49 Ma (Cosca et al., 1998). Low- to high- Ca boninites are upslope and west of the FAB, and have ages of 48 to 44 Ma (Ishizuka et al., 2006). Eruption of tholeiitic and calcalkaline arc lavas have ages stretching back to 45 Ma (Reagan et al., 2008), thus the transition from SI to "normal" arc volcanism required 6-7 million years of subduction-zone development.

The SI-related stratigraphy preserved in the Tonga-Kermadec forearc appears to be nearly identical to that of the IBM forearc. Peridotites are at the deepest levels, with sequences of gabbroic rocks and basaltic through rhyolitic lavas cropping out up-section and to the west (Bloomer and Fisher, 1987; Bloomer et al., 1994). The oldest radiometrically dated igneous rocks are gabbros with ages of ~52 Ma (K. Tani, unpublished data 2010), and a 46.6 Ma basalt from Eua island (Ewart et al., 1977). Early-arc volcanics also are preserved on Fiji, with basaltic through boninitic and tonalitic rocks having ages stretching back to more than 45 Ma (Todd et al., 2007).

Little is presently known about the oceanic portion of the Aleutian forearc. Nevertheless, Eocene-aged lavas and sediments crop out on or near islands in the central and western Aleutians islands. The oldest two radiometrically dated samples of the Aleutian arc massif have $^{40}Ar/^{39}Ar$ ages of ~46 Ma. One was dredged from just offshore of Kiska Island (Jicha et al. 2006); the other was collected from Medny Island (Layer et al., 2007). Compositionally, both samples are basalt, but closely associated rocks on Medny Island are more evolved. These islands cap the thickest part of the arc crust and both have fossiliferous sediment derived from a middle Eocene ridge. Arc plutonic bodies increase in age southward toward the Aleutian Trench, and it is thus presumed that SI-related lavas that could be as old as ~50 Ma exist within the deeply submerged and thinner crust of the forearc (Scholl, 2007).

It is remarkable that SI occurred nearly simultaneously during the Eocene over this broad an area, and by studying Pacific oceanic forearcs, we should gain a much better understanding of SI and its dynamic consequences. One of the most fundamental remaining questions about SI is whether it occurs spontaneously or requires an initial stage of active compression (Stern, 2004; Hall et al., 2003). Gaining a better understanding of lava geochemistry through time and space for all three forearcs should resolve this question. Studying SI over this broad scale also would lead to a clearer understanding of crustal production rates, the compositions of bulk arc crust, and the effects of subduction on asthenospheric flow.

We therefore propose that one focus of SCD should be to advance studies of SI by focused investigations of circum-Pacific forearcs. We need to assess the diversity of forearc structure, composition, and evolution in order to decide if the IBM model is globally applicable or not. Doing so in concert with geodynamic modeling and studies of on-land ophiolites would promote a much better understanding of the geochronology, petrology, and geodynamics of SI overall. Our studies of these forearcs are necessarily at different stages of maturity, and further studies should take advantage of the different glimpses of forearcs that these provide. We know enough about the IBM forearc to target additional geophysical surveys and forearc diving and drilling towards robustly defining the structure, age, and composition of crust associated with SI and arc infancy. Thus, proposals should be invited for further study the IBM forearc. More foundational studies of the Tonga-Kermadec and Aleutian forearcs also should be invited, and an investigation of the record of Cascadia SI preserved in the Oregon-Washington forearc should begin.

References

Bloomer, S.H., and Fisher, R.L., 1987. Petrology and geochemistry of igneous rocks from the Tonga Trench—a nonaccreting plate boundary. J. Geol., 95, 469-495.

Bloomer, S. H., et al., . 1994, Geochemistry and origin of igneous rocks from the outer Tonga forearc (Site 841). In Proceedings of the ODP, Scientific Results, 135, 625-646.

Cosca, M., et al., 1998, ^{40}Ar/ ^{39}Ar and K-Ar geochronological age constraints for the inception and early evolution of the Izu-Bonin-Mariana arc sys-tem, The Island Arc, 7, 579-595.

Ewart, A., et al., 1977, An outline of the geology and geochemistry, and the possible petrogenetic evolution of the volcanic rocks of the Tonga-Kermadec-New Zealand island arc. Journal of Volcanology and Geothermal Research, 2, 205-250.

Fryer, P., Pearce, J. A., Stokking, L. B., et al., 1992. Proc. ODP, Sci. Results, 125: College Station, TX (Ocean Drilling Program).

Hall, C.E., et al., 2003, Catastrophic initiation of subduction following forced convergence across fracture zones, Earth and Planetary Science Letters 212, 15 – 30.

Hussong, D. M., Uyeda, S., et al., 1981. Init. Repts. DSDP, 60: Washington (U.S. Govt. Printing Office).

Ishizuka, O., et al., 2006, Early stages in the Evolution of Izu-Bonin Arc volcanism: new age, chemical, and isotopic constraints, Earth and Planetary Science Letters, 250, 385-401.

Ishizuka et al., 2009, In-situ arc crustal section formed at the initial stage of oceanic island arc -Diving survey in the Izu-Bonin forearc. Eos 90-, Abstract T32A-05.

Jicha, B.R., et al., 2006, Revised age of Aleutian Island Arc formation implies high rate of magma Geology 34, 661-664.

Layer, P.W., et al., 2007, Ages of igneous basement from the Komandorsk Islands, far western Aleutian Ridge. Eos, 88, Abstract V43D-1645.

Meijer, A. (1980), Primitive arc volcanism and a boninite series; example from western Pacific Island arcs, in The tectonic and geologic evolution of Southeast Asian seas and islands. 269-282.

Ohara, Y., et al., 2010, Structure and composition of the Southern Mariana Forearc: new observations and samples from Shinkai 6500 dive studies in 2010, Eos, 91, Abstract T13C-2205

Pearce, J.A. 2003. Supra-subduction zone ophiolites: The search for modern analogues. In Dilek, Y., and Newcomb, S., eds., Ophiolite concept and the evolution of geological thought: Boulder, Colorado, Geological Society of America Special Paper 373, p. 269–293

Reagan, M.K., et al., 2010, Fore-arc basalts and subduction initiation in the Izu-Bonin-Mariana system. Geochemistry, Geophysics, Geosystems 11, Q03X12, doi:10.1029/2009GC002871

Reagan, M.K., et al., 2008, Petrogenesis of volcanic rocks from Saipan and Rota, Mariana Islands and implications for the evolution of nascent island arcs. Journal of Petrology. 49, 441-464.

Scholl, D.W., 2007, Viewing the Tectonic Evolution of The Kamchatka-Aleutian (KAT) Connection With an Alaska Crustal Extrusion Perspective. In Volcanism and Subduction: The Kamchatka Region Geophysical Monograph Series 172, 3-35.

Stern, R. J., and Bloomer, S. H., 1992, Subduction zone infancy; examples from the Eocene Izu-Bonin-Mariana and Jurassic California arcs, Geological Society of America Bulletin, 104, 1621-1636.

Stern, R.J. 2004. Subduction Initiation: Spontaneous and Induced. Earth Planet. Sci. Lett. 226, 275-292.

Tani et al., 2009, Evidence for silicic crust formation in an incipient stage of intra-oceanic subduction zone: discovery of deep crustal sections in Izu-Bonin forearc. Eos 90, Abstract T23A-1877

Taylor, B., Fujioka, K., et al., 1992, Proc. ODP Sci Results, 126: College Station, TX (Ocean Drilling Program)

Todd, E., et al., 2007, A trace-element and radiogenic-isotopic pattern of oceanic arc inception, maturity, demise, and rejuvenation; Viti Levu, Fiji. Eos, 88, Abstract V43D-1646.

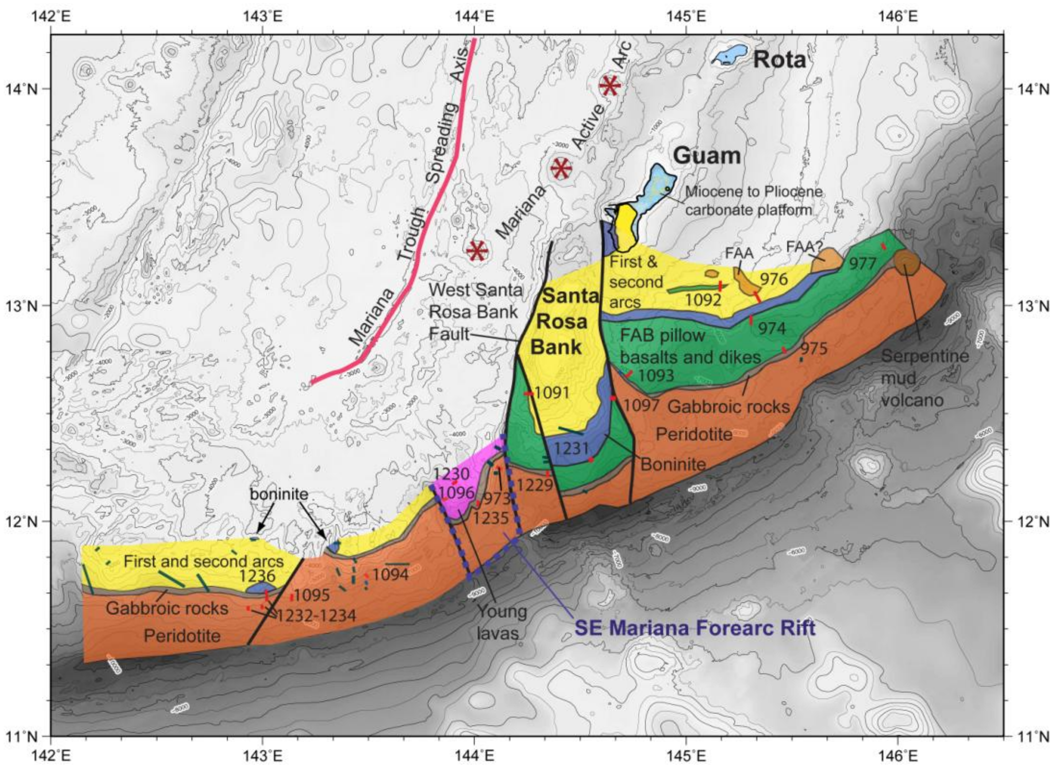

Figure 1 – Geological map of the Mariana forearc near Guam. The red lines with numbers represent locations of Shinkai 6500 dives. Dredges are shown with green lines. The SI and early-arc sequence is west of the West Santa Bank Fault. Most lithological units are descriped in the text. “First and second arcs” refers to the Eocene to Oligocene and Miocene arcs respectively. FAA are “forearc andesities”, which are Oligocene-aged high-Mg andesites.