MARGINS Successor Program White Paper: Roots of Arc Volcanoes

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Topics/Themes: Subduction Zones, Fluids and Magmas

We propose the fundamental topic of "Roots of Arc Volcanoes" (RAV) as a major theme for the MARGINS Successor program. This theme is specifically identified in the MARGINS 2009 Review. We envision this initiative as encompassing the arc volcano system from the slab to the surface, involving a comprehensive suite of geophysical, geochemical, and geological studies of submarine and subaerial arc volcanoes over a broad range of spatial and temporal scales. This initiative embodies some of the elements of the original MARGINS program (magma genesis, fluids, and volcanism), but with a change in focus to a specific theme of how arc volcanoes work, from bottom to top. A broad analogy can be made to the vast suite of multidisciplinary, multi-scale studies of the Hawaiian volcanoes and hotspot, funded by multiple NSF programs, and involving: "passive" seismic studies from the scale of Halema'uma'u crater to the mantle plume track; marine seismic profiling and offshore-onshore imaging; deep drilling; petrology and geochemistry of lavas; gravity, magnetic, and electromagnetic field studies; geodesy; and much more. Thus, there is great potential for synergistic work on this theme across disciplinary boundaries. Studies in Cascadia and Alaska can take advantage of recent ARRA initiatives, future USArray deployments, and cooperation with U.S. volcano observatories. The "roots of arc volcanoes" theme also has direct societal relevance in terms of providing a deeper understanding of volcano behavior and hence volcanic hazards and environmental impacts.

The potential components of the RAV initiative cut across many earth science disciplines. Overall, the research components for the RAV initiative would largely mirror those of the Subduction Factory, but with a different focus: experimental and theoretical analyses; bathymetry, swath mapping, and dredging; active- and passive-source seismology; drilling; magnetotellurics; heat flow; geodesy; field studies; petrologic, geochemical and isotopic analyses; and database development. The suite of studies would of course vary for submarine volcanoes versus subaerial volcanoes.

Considerable debate exists, especially in Cascadia and Alaska, regarding the role of the subducting slab during magma genesis. Geochemical studies of primitive lavas in these arcs indicate that magmas are generated via fluid-flux melting, adiabatic decompression melting of hot, nearly anhydrous mantle, partial melting of the slab, or some combination of these processes. The recent work by Grove et al. (2009) on the primary control that slab dip has on arc volcano location is an example of the type of fundamental issue that requires cross-cutting research that could be supported by the RAV initiative. In this case, a combination of experimental work on chlorite stability, geodynamic modeling of subduction zone thermal structure, and seismic estimates of slab dip led to the conclusion that the melting zone is controlled by the intersection of zones of chlorite dehydration with the (vapor-saturated) peridotite solidus, which in turn is controlled primarily by slab dip and, to a lesser degree, by convergence rate. An ultimate goal is to understand how slab petrology (Figure 1) is linked to its seismic structure and seismicity (Figure 2). Given the recent advances in locating non-volcanic tremor on plate interfaces and relating tremor to fluids, earthquakes, and aseismic slip, there is currently a rich dataset available to explore the link between seismicity and magma generation processes in subduction zones.

Another example of a critical issue that requires multi-disciplinary research is the spatial and temporal characterization of crustal magma storage. Key aspects related to mitigating volcanic hazards include identifying conditions and processes that trigger magmatic ascent, improving our ability to recognize and interpret real-time signs of magma ascent, and discriminating between the movement of magma versus aqueous fluids. From the geophysics side, seismology (passive and active, on-land and ocean-bottom), geodesy, and potential field and electromagnetic studies can provide information on the depth and geometry of magma storage zones at a variety of spatial scales, and they can also detect various aspects of temporal changes. Determination of regional and local stress fields, via focal mechanisms and shear wave splitting, will be valuable for monitoring temporal changes and evaluating the dynamical effects of regional tectonics (i.e., large earthquakes or aseismic slip) on magma reservoirs. Another key element is studies that would improve our ability to identify and understand the tell-tale signs of fluid and magma movement such as long-period and very-long-period earthquakes, volcanic tremor, and repetitive or "drum-beat" earthquakes. From the geochemistry side, petrologic, isotopic, and experimental studies of minerals within individual lavas and tephras can quantify crystal residence times and magma storage depths. Coupling these constraints with geophysical observations would provide unprecedented spatial characterization of magma storage in the crust. Moreover, geochemical investigation of a geochronologically constrained suite of lavas from an active arc volcano can constrain the long-term record of eruptive and crustal processes and provides an opportunity to quantify the timescales and kinetics of these processes.

We also identify the lower crust as a key area where we can hope to make some advances. One hazards-related issue is the basaltic magmas thought to trigger some eruptions through injection into a mid- or upper-crustal magma chamber, for example in the recent eruptions at Augustine and Redoubt volcanoes. Where are the sources of these magmas and what are the characteristics of these source zones? Can deep long-period earthquakes or detailed geochemical studies provide clues? It has recently been hypothesized that "deep crustal hot zones" (Annen et al., 2006) are the source of two distinct magma types, one from partial crystallization of basalt sills producing H_2O-rich melts, and the other from partial melting of pre-existing crustal rocks. Studies of young submarine volcanoes may have the potential for providing insight into the lower crust, combining active-source seismology, passive OBS studies, petrologic and geochemical analyses of drilling and dredging samples, etc.

The RAV initiative can be built upon a broad range of established research paradigms in geophysics, geochemistry, and geology. Perhaps as importantly, close collaboration among the scientists in these disciplines may lead to new avenues for exploring and understanding arc volcanoes and their roots.

References

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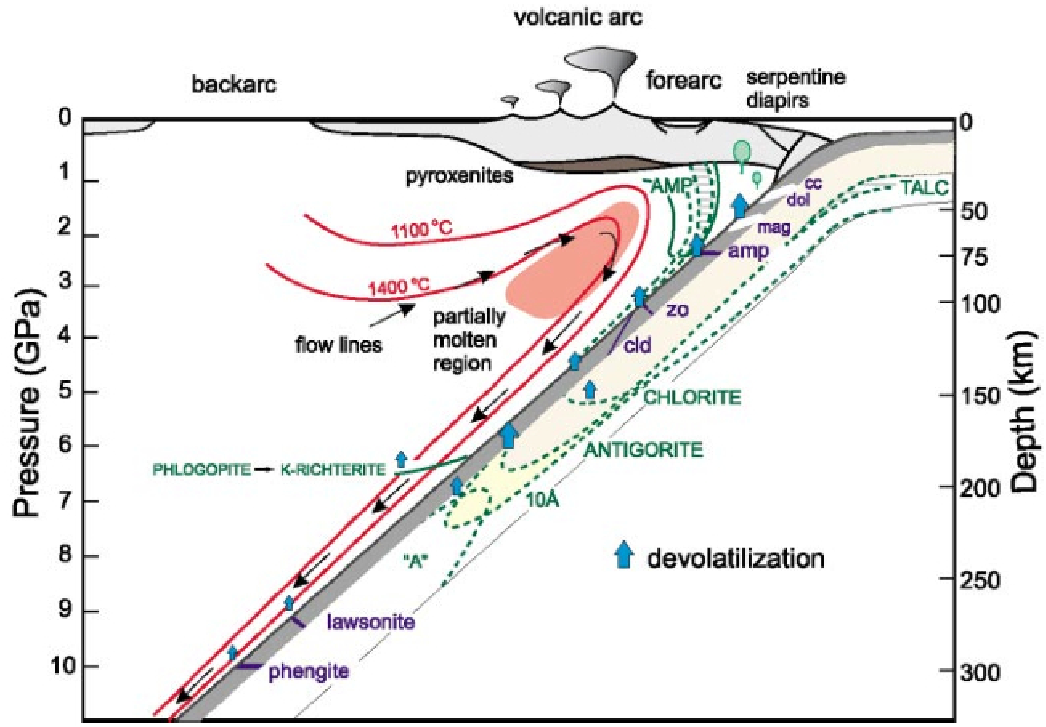

Figure 1. Petrologic view of a generic subduction zone, indicating major processes governing subduction zone dynamics. Mineral labels represent the potential stability fields of volatile-bearing phases. The location of the partially molten region (pink zone) is constrained by seismic tomography (Iwamori and Zhao, 2000). From Poli and Schmidt (2002).

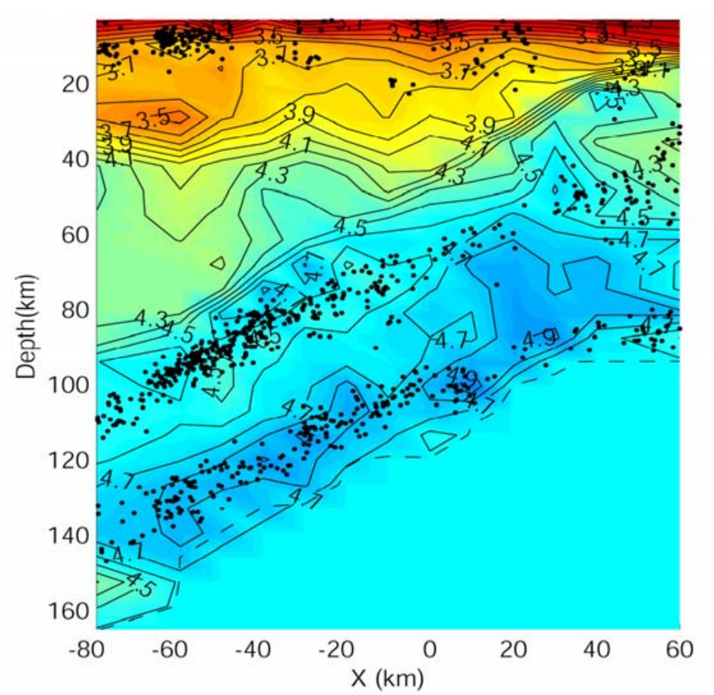

Figure 2. Seismic view of the Japan subduction zone. In this cross-section of shear wave velocity beneath northern Honshu at 39° N (Zhang et al., 2004), we see the dipping high-velocity subducting slab with two planes of seismicity. Note the significant heterogeneity in structure and seismicity within the slab, which are presumed to reflect the dehydration reactions that ultimately lead to arc volcanism. Above the slab on the left, low velocities in the mantle wedge (Vs < 4.3 km/s, 40-80 km depth) underlie the arc volcanoes, with the higher velocities of the "cold nose" (Vs > 4.3 km/s) evident between X = -40 and -10 km.