Imaging mantle melting processes beneath island arcs and backarc spreading centers

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We use arrays of land and ocean bottom seismographs to image melting processes in the Mariana and Tonga-Lau mantle wedges. Both regions show arc volcanism, active backarc spreading, and overlie active intermediate and deep seismic zones making them optimal for imaging mantle melting processes. Deployments of land and ocean bottom seismographs in the Mariana Islands (2003-2004) and Tonga-Lau (2009-2010) provide large datasets for detailed imaging. In both cases we find significant slow velocity and high attenuation anomalies in the upper 100 km of the mantle beneath the volcanic arc and the spreading center. In the Mariana region, the anomalies are separated by a high velocity, low attenuation region at shallow depths (< 80 km), implying distinct arc and backarc melting regions, with the anomalies coalescing and possibly allowing material interchange at greater depths. The maximum anomaly in the backarc is shallower (~ 30 km) than in the arc (~ 65 km), consistent with geochemical indications on the depth of melt production. The strongest anomaly beneath the backarc spreading center is narrow (~ 70 km) and extends from close to the moho to 80 km depth. The magnitude of the backarc spreading center anomaly is greater than the arc anomaly for both attenuation and seismic velocity.

Data analyses for the Tonga-Lau project are ongoing and the results are preliminary, but show some similarities to the Mariana images. Extremely low seismic velocity and high attenuation are found in a 100 km wide region beneath the spreading center in the upper 80 km, with minimum Qp of about 50, similar to the Mariana backarc. At deeper depths the anomaly is displaced westward in both velocity and attenuation images, suggesting that partial melting occurs along an upwelling limb of mantle flow originating west of the backarc. 3-D images from Rayleigh wave tomography show a much stronger anomaly along the Central Lau Spreading Center when compared to the Eastern Lau Spreading Center.

Both Q and velocity anomalies are larger than expected for temperature effects based on laboratory-derived relationships, and their configuration is inconsistent with the expected temperature field. However, experimental results suggest that seismic attenuation and velocity are highly sensitive to the presence of even very small amounts of partial melt. Therefore we interpret the high attenuation and low velocity anomalies as delineating the region of partial melting beneath the ridge axis and volcanic arc, but that only small melt fractions (< 1 %) are required to explain the seismic data. Smaller amplitude anomalies along the southernmost Eastern Lau spreading center (Valu Fa), where large amounts of subduction-derived water are incorporated into the melt, may indicate lower mantle melt content due to low melt viscosity and more efficient transport of the water-rich melt, or a different topology of melt in the matrix.