Seismological constraints on structure and flow patterns within the mantle wedge.

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Seismic velocity and attenuation measurements provide important constraints on melt source regions and geodynamic processes in the mantle wedge of subduction zones. At temperatures below the solidus, both *P* and *S* velocities are linear functions of the homologous temperature. Low velocity regions generally indicate areas that are hot and/or volatile rich. The presence of melt has a much greater effect on the *S* velocity than on *P* velocity, suggesting it is possible to detect melt using *S/P* anomaly ratios [*Hammond and Humphreys*, 2000]. Since seismic attenuation shows a different relationship with physical properties such as temperature and melt content, the combination of velocity and attenuation data may place unique constraints on physical parameters [*Roth et al.*, 2000].

The mantle wedge, extending from the volcanic front into the backarc region, is generally characterized by extremely low seismic velocities and high attenuation, indicative of high homologous temperatures and/or the presence of melt. Seismic body wave tomography can provide important constraints on the localization of magma source and transport regions in the wedge. P-wave tomographic images, such as those of Japan [*Zhao et al.*, 1992] and Tonga (figure 1)[*Zhao et al.*, 1997], often show a low velocity region above the slab extending from about 150 km depth up to the volcanic front. The low velocities in this region probably result largely from volatiles fluxed off the slab, which lower the solidus of the wedge material and thus raise the homologous temperature. The low velocities may also denote the presence of small quantities of partial melt. In either case, these low velocities probably delineate the region where island arc magmas are produced through the interaction of slab volatiles with relatively hot mantle wedge material.

The Tonga Subduction Zone also shows a large broad low velocity seismic anomaly beneath the active Lau backarc spreading center [*Zhao et al.*, 1997] (figure 1). This probably represents the source region for MORB-type spreading center magmas. Geochemical considerations suggest that the primary melting of MORB magmas occurs at depths between about 20 and 80 km [*Shen and Forsyth*, 1995], consistent with the depth of the largest anomalies. The backarc region also shows exceptionally high seismic attenuation. The large lateral extent of the backarc anomaly suggests that a broad zone of magma production feeds the Lau spreading center. The anomaly pattern indicates that the zone of backarc magma production is separated from the island arc source region within the depth range of primary magma production (20-80 km). However, the anomalies merge at greater depths, suggesting that small slab components of backarc magmas may originate through interactions at depths greater than 100 km. The largest velocity anomaly is offset by about 150 km towards the west from the spreading center axes. Such an offset of the magma production region might result if the pattern of mantle flow at shallow levels is from west to east, as would be expected for slab induced flow. The degree to which these anomalies represent the presence of melt is uncertain; the magnitude of the anomalies would suggest melt, but observed ratios of S to P anomalies suggest the velocity variations result largely from temperature effects [*Koper et al.*, 1999]. One possible interpretation is that melt is immediately removed from the matrix as it is produced, such that the velocity signature is that of a simple temperature anomaly.

The role of deeper processes in arc and backarc processes is unclear. Both waveform inversion and seismic tomography suggest that slow velocity seismic anomalies extend to depths as great as 400 km beneath the Lau backarc basin [*Zhao et al.*, 1997]. Slow velocity anomalies have also been found in other subduction zones using lower resolution tomographic methods. These slow velocity anomalies may result from water and other volatiles that may be transported to depths of 300-500 km by hydrous minerals in the slab [*Nolet*, 1995]. Such deep release of volatiles may be very important in localizing backarc spreading and other dynamic processes in the mantle wedge.

The mantle flow pattern in arcs probably influences or controls many processes, such as the path of melt from the source region as well as the distribution of geochemical anomalies. Observations of seismic anisotropy can provide direct evidence for the pattern of solid flow in the mantle. Seismic anisotropy in the mantle generally results from lattice preferred orientation of olivine produced by deformation that accompanies solid flow in the mantle. Experimental and modeling work suggest that the olivine fast axes should be oriented in the direction of maximum extensional strain, which is approximately the flow direction. Slab parallel fast directions, suggesting along-arc flow within the mantle wedge, are found in several subduction zones, including New Zealand, Aleutians, and Kurile subduction zones. In contrast, convergence-parallel fast directions are found in Izu-Bonin and the Tonga backarc region.

The diverse observations of wedge mantle flow indicate that it may be a complex process. Geodynamic modeling suggests several possible patterns of flow within the mantle wedge. Viscous coupling between the backarc flow and the downgoing plate should produce induced flow within the backarc, with flow directions parallel to the convergence direction. In contrast, subduction zone rollback may produce along-arc flow. Possible backarc spreading and the motion of the overriding plate or platelets relative to the mantle will also affect the flow pattern. Finally, large-scale flow patterns in the upper mantle, such as subduction zone return flow and flow between different ocean basins may control the flow pattern.

Shear wave splitting observations from a large land and OBS seismograph deployment in the Lau basin show that the flow patterns in individual island arcs may be complex (figure 2) [*Smith et al.*, 2000]. The pattern of fast axis orientations shows a strong arc-parallel flow direction near the arc, a north-south fast axis sub-parallel to the backarc spreading center in the central Lau basin and a convergence-parallel fast axis in the western (Fiji) region. One interpretation of this pattern is that strong southward arc-parallel flow exists immediately above the slab due to the fast rollback of the Tonga slab during the last few million years, with a larger-scale and deeper flow dominated by viscous coupling with the downgoing plate. This is consistent with geochemical observations of southward flow of Pacific mantle from the Samoa hotspot into the northern Lau basin [*Turner and Hawkesworth,* 1998].

Future progress in understanding arc dynamics will relay on larger seismological datasets to increase the resolution of tomographic inversions and anisotropy observations. For example, a US-Japan program for a one year ninety station (20 land stations and 70 passive OBSs) deployment for the Mariana island arc has been funded for 2002 (Taylor, Wiens, Klemperer, Hildebrand, Suyehiro, PIs). Further extensive datasets are also being compiled from permanent networks, such as those in Japan. Progress will also require better experimental and theoretical constraints linking seismological observables with physical parameters such as temperature, composition, volatile content, and the presence of melt. The use of geodynamic models to predict seismic observations will allow seismological constraints to be directly incorporated into the modeling through hypothesis testing [*Fischer et al.*, 2000].

References

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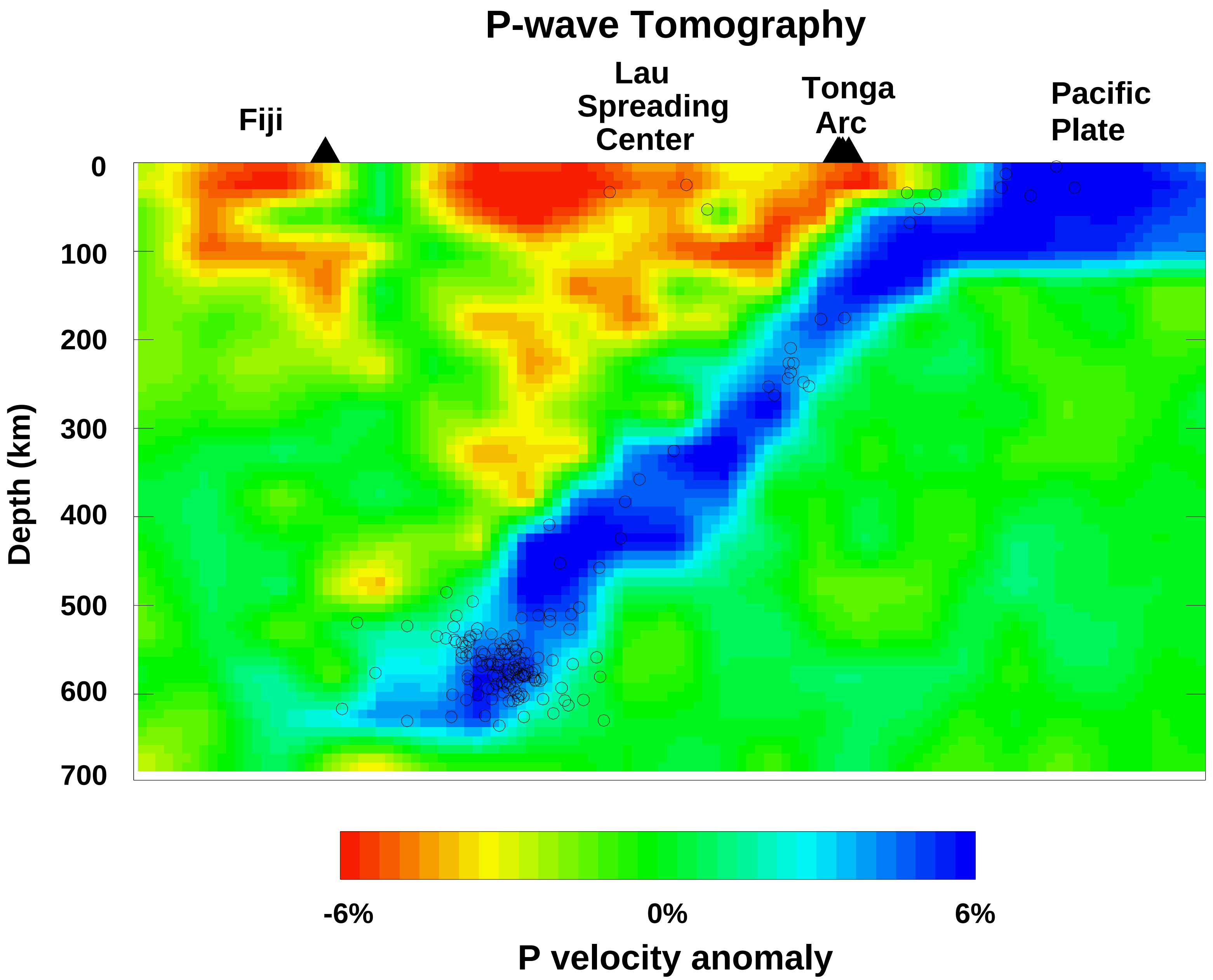
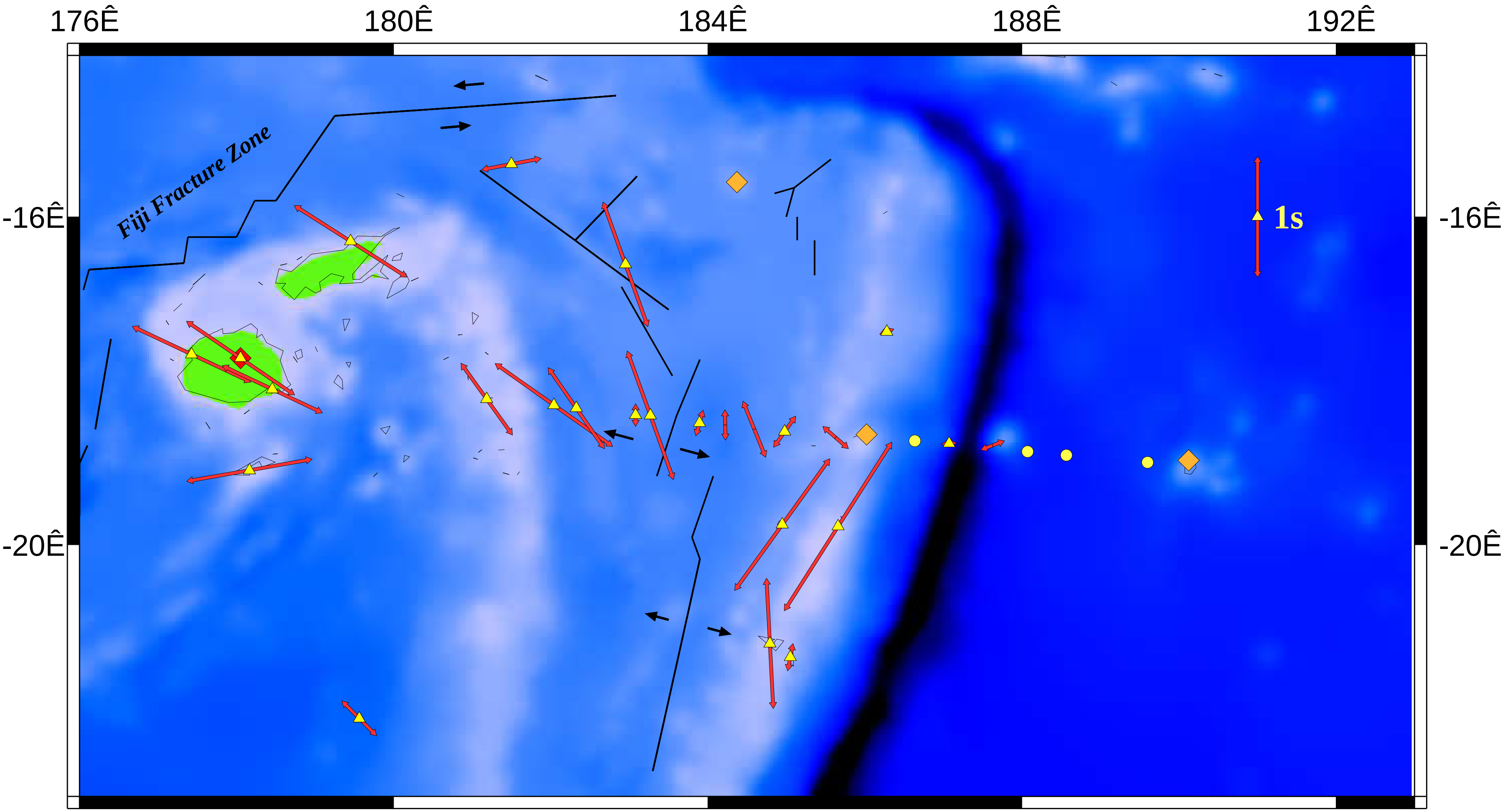
Figure Captions

Figure 1. East west vertical cross-section of a *P*-wave tomographic image of the Tonga Subduction Zone and Lau Backarc Basin from *Zhao et al.*, [1997]. The image was determined by inversion of ~41,000 P-wave arrival times from 926 earthquakes recorded by portable land seismic stations, ocean bottom seismographs, and teleseismic stations. Red and blue colors denote slow and fast velocities, respectively, and the velocity perturbation scale is shown at the bottom.

Figure 2. Shear wave splitting observations from land seismic stations and ocean bottom seismographs in the Tonga-Fiji region. Each red arrow represents the average fast splitting direction at a particular station, with the length indicating the magnitude of the splitting delay time. Black lines denote spreading center and transform fault orientations.


P-wave Tomography
Fiji
Lau
Spreading
Center
Tonga
Arc
Pacific
Plate
Depth (km)
0
100
200
300
400
500
600
700
-6%
0%
6%
P velocity anomaly


176Ê
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Fiji Fracture Zone
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