SI Text

Synthetic record sections for event 970529 are displayed in SI Fig. 7. The model is a 2D section containing the HBMS model embedded in PREM. These synthetics were generated with the WKM technique introduced in Ni *et al*. (1). The method is basically analytical, which satisfies the wave equation assuming tomographic-type models. A comparison of synthetic seismograms for the model displayed in Fig. 1*b*, using the above semianalytical code with a 2D numerical technique, is given in Ni *et al*. (2). A similar record section of data and synthetic for this event is discussed by Helmberger and Ni (3). The event occurred on Feb. 10, 2002 at South Sandwich Island at a depth of 200 km. This depth allows the direct arrivals to be well separated from the depth phases, sSKS, etc. The event is well recorded by the Ethiopia/Kenya array and provides ideal geometry for studying the structure directly beneath a superplume (SI Fig. 8). Both the HBMS model and Ni's model displayed in Fig. 1*b* (box I) can not produce the large separation between S and SKS at small distances (~ 82-84°) (SI Fig. 9 *a* and *b*). Adding the extra box II, with the 2% velocity reduction, slows the arrival time of S and has no effect on the SKS phase, and produces the observed differential time between S and SKS in SI Fig. 9*c*. In the HBMS model, there are some extra small arrivals between S and S_CS caused by the down-welling. All three models in SI Fig. 9 fail to explain the observed Scd phase. Moreover, the S_CS on the synthetics appear to be too late at the smaller ranges, which suggest the addition of a fast zone near the top of D". Both data and synthetics are aligned on the arrival of S by cross-correlation.

To fit the observed Scd phase, we first assume a model with an abrupt shear velocity jump across the boundary. By grid search, we derive a model (CM) with 4% jump located 100 km above the CMB (Fig. 5*b*). The synthetics for this model are shown in SI Fig. 10*a*. A significant feature in the HBMS model is the down-welling region near the center, which will cause a diffuse increase in seismic velocity. To mimic this structure, we adopted a model (hybrid model) with one linear gradient followed by a small velocity jump (1.7%) shown in Fig. 5*b*. Both models provide a reasonable fit to the data (SI Fig. 10). The small velocity jump in the hybrid model supports the possible PV-to-PPV transition across the boundary seen globally, whereas the CM model appears more unique. Because the down-welling in the HBMS model raises the possibility of the occurrence of phase transition in this area, we prefer the hybrid interpretation.

The position and the magnitude of the negative velocity jump beneath the boundary is not well constrained, although adjustments can be made to correct the travel time of S_CS. Because a velocity reduction is more difficult to detect than a velocity increase (4, 5), there is no constraint on the exact velocity structure below the boundary of the positive velocity jump in both models.

The P-wave velocity structures in HBMS are not anomalous on average as pointed out earlier with respect to P_d. Moreover, many phases that travel horizontally encounter both fast and slow zones, such as P, P_CP, etc. Vertically traveling phases have the best chances of detecting the abrupt lateral changes near the edges, in particular the differential branches of PKP phases. Although the edge anomalies are narrow, they are easily detected in data. As first pointed out by Shearer and Toy (6), the differential travel delays between PKPdf and PKPab is not PREM-like or well behaved in many regions. Global studies of these phases indicate that the mid-Pacific contains some of the strongest anomalies (7, 8). SI Fig. 11 displays synthetics for the two PKP branches (DF and AB) sampling the edge structure of HMBS.

In the HBMS model, the conversion from temperature (*T*) and composition (*C*) to seismic velocities is based on the following parameters:

$$(\delta K_S / \delta C)_T = 6\%$$

$$(\delta \mu / \delta C)_T = 1.5\%$$

$$(\delta K_S / \delta T)_C = -6\%$$

$$(\delta \mu / \delta T)_C = -15\%$$

Here, $(\delta X/\delta Y)_Z$ is the abbreviation for $(\partial \ln X/?Y)_Z$, K_S is the bulk modulus, and μ is the shear modulus. The value of $(\delta K_S/\delta C)_T$ is dictated by the dynamic model. The value of $(\delta \mu/\delta C)_T$ is a free parameter and is chosen to fit the seismic observation. When scaled, the dimensional values of $(\delta K_S/\delta T)_C$ and $(\delta \mu/\delta T)_C$ used in the conversion are -3.33×10^{-5} K^{-1} and -8.33×10^{-5} K^{-1}, respectively. More information about the conversion is described by Tan and Gurnis (9). For reference, the dimensional values of $(\delta K_S/\delta T)_C$ and $(\delta \mu/\delta T)_C$ for $MgSiO_3$ perovskite are calculated to be -3.29×10^{-5} K^{-1} and -8.62×10^{-5} K^{-1}, respectively (10).

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