Data used to Sample African Anomaly.

The great circle paths of the source-receiver combinations used in this study are shown in Fig. S1. The event information is given in Table S1.

Abrupt Changes across WB and EB

We are able to document the abrupt changes which occur when crossing the WB and EB boundaries with additional record sections, as emphasized in Fig. S2. The observations at the South African array, WB(970903) show about the same delay in travel times (about 6 s) as in Fig. 2A. There is also some evidence of waveform complexity near the jump (93º to 94º) which could be multipathing. The waveform complexity is more obvious in the EB(950214) profile observed at the Tanzania Array (Fig. S1). Although some of these records are observed at stations with similar epicentral distances (for example KIBA and TARA at 101º or PUGE and MITU at ~98º), these stations are at different azimuths. These differences seem to be changes in geometry implying 3D structure.

Influence of Shallow Structure

In the main body of the text, we described how *SKS* is delayed about 5 s for epicentral distances smaller than 97º and becomes normal beyond 99º as recorded by the Tanzania array (Fig. 2B). Such a feature could be caused by the shallow structure beneath this array (African Rift Zone). However, a detailed study of the travel time delays of *SH* phases (*1*) finds that TARA, KOMA and neighboring stations should be delayed by 4 to 5 s relative to stations to the west if the delay is caused by the rift zone. Thus, the effect of shallow structures on SKS arrivals is opposite to the data. If the shallow effect is corrected, the data across the EB are delayed about 6 s, similar to that across the WB. This *SKS* delay pattern was noted earlier in (*1*) for an event located beneath the Drake Passage (Fig. S1) at a similar azimuth where they report an abrupt change of 7 s in *SKS* when crossing this edge.

To demonstrate that the complication of waveforms is not caused by stations, in Fig. S2 (right) we show waveforms from another event (950214) with each trace of seismogram aligned on *SH* arrivals. The *SH* waveforms are quite consistent for all the epicentral distances while *SKS* waveforms show a similar pattern as event 941020 (Fig. 2B).

Development of the LVZ2 Model

We processed the data for the above stations in terms of waveforms and differential travel times to develop the LVZ2 model. As discussed in (*2*), we enhanced the tomographic features assuming a variety of possible perturbations and compared the synthetics predicted from these test models against data or their travel time differentials. Fig. S3 displays an example set of (S_cS-S) and (*SKS*-*S*) times against data from station LSZ. The *SKS* paths for various events always sample the ALVS due to its location and these plots display the sensitivity of these differentials to this particular geometry. Direct evidence for the large delay of *S* when encountering the ALVS is discussed in (*1*) using events located beneath Sandwich Island (Fig. S1).

Setup of Dynamic Models

Two parameters controlling the dynamic models described in the main body of the text are specifically defined as:

The Rayleigh number, $Ra=\rho_0\alpha_0\Delta TgR^3/\kappa\eta$, where ρ_0, α_0, ΔT, g, R, κ, and η are the reference density, reference coefficient of thermal expansion, temperature jump across the whole layer, gravitational acceleration, radius of the Earth, thermal diffusivity, and viscosity, respectively

The buoyancy number, $B = \Delta\rho_{ch}/\rho_0\alpha\Delta T$, where $\Delta\rho_{ch}$ is the density anomaly associated with the basal layer.

We use the material line method (*3, 4*) to represent the boundary between ambient mantle and an homogeneous dense layer, which pre-exists at the base of the mantle. The coefficient of thermal expansion, α, has a five-fold decrease with depth, consistent with mineral physics data (*5*). In some cases, a constant α is used. The temperature-dependent viscosity changes by 4 orders of magnitude across the bottom thermal boundary layer. These material properties are chosen to enhance the stability of the basal layer. The modeling geometry is a two-dimensional quarter-cylinder, with inner and outer radii equal to 0.5462 and 1, respectively. This domain is evenly divided into 300x70 elements in the azimuthal and radial directions. The surface temperature is fixed at 0, and the bottom temperature is fixed at 1. For models with imposed surface velocity, the surface boundary conditions are temperature fixed at 0.5 and velocity fixed at 1.5 cm/yr (when scaled to the Earth). Additional details on our methods can be found in (*6*).

The models are initial value problems in which a dome-like dense structure is situated in the middle of the domain so as to center any subsequent instability. The topography, h, of the layer is initially given by:

$$h(\phi) = \begin{cases} h_0 + b * \cos(\pi\phi / \lambda) & \text{, if } |\phi| \leq \lambda \\ h_0 & \text{, if } |\phi| > \lambda \end{cases}$$

where h_0=0.02, b=0.12, λ=0.8636, and ϕ is the azimuth away from the central plane of symmetry. The initial temperature is given by: $T(r,\phi)=1-0.5*\mathrm{erf}((r-0.5462)/h(\phi))$, where r is the radius (Fig. S4A).

When converting the model output to V_s, we use the method in (*6*) for temperature- and pressure-dependence of V_s, and $(\partial \log Vs / \partial \log \rho)_{P,T}=-1$ (*7*) for the composition dependence.

No	Date	time	lat(deg)	Lon(deg)	depth(km)
1	941020	01:15:16	-39.19	-70.80	164
2	940819	10:02:51	-26.65	-63.38	565
3	980729	07:14:24	-32.31	-71.29	51
4	970902	12:13:22	3.85	-75.75	199
5	971028	06:15:17	-4.37	-76.60	112
6	971128	22:53:41	-13.74	-68.79	586
7	981008	04:51:42	-16.12	-71.40	136
8	991130	04:01:53	-18.78	-69.05	127
9	970123	02:15:22	-22.00	-65.72	276
10	950923	22:31:58	-10.53	-78.70	73
11	950208	18:40:25	4.16	-76.64	69
12	971015	01:03:33	-30.93	-71.22	58
13	980403	22:01:48	-8.15	-74.24	164
14	990403	06:17:18	-16.66	-72.66	87
15	990525	16:42:05	-27.93	-66.93	169
16	950214	15:53:56	-23.29	-67.70	156
17	970903	06:22:44	-55.19	-128.99	10
18	970529	17:02:38	-35.96	-102.51	10
19	950103	16:11:57	-57.69	-65.88	33
20	941212	07:41:55	-17.50	-69.65	151

Table S1. South America Events used in this study.

Figure S1. Map displaying a shear velocity tomographic map (*8*) of the bottommost layer of the mantle along with the seismic paths. The slowest velocities are in gold, a reduction of up to 2%. The triangles beneath the mid-Atlantic indicates the S_cS bounce points at the CMB, smallest are array stations and largest correspond to the IRIS network, denoted by dark squares. The Tanzania, Namibia and South African array stations are displayed as small gray triangles. WB and EB indicate the approximate edges of the ALVS structure at the CMB. The heavy green lines indicate the average ray paths of *SKS* phases arriving at the arrays and sampling the two boundaries. The anomalous S_cS-*S* waveforms displayed in Fig. 1 were obtained from the South American event labeled with a large grey star with heavy lines denoting the envelopes of S_cS paths.

Figure S2. (left) Record section sampling the WB for event 970903. (right) record section sampling the EB for event 950214. Note that the direct S-phase (950214) aligned at O and bracketed by heavy lines does not change shape while SKS does. This feature argues for multipathing of *SKS*.

Figure S3. Sensitivity tests between the thickness and velocity contrast associated with ALVS. Cross-sections with various layer thickness are presented on the left along with ray paths where the travel times of *SKS* have been preserved (bottom three plots). The upper plot has a smaller *SKS* delay of 6s relative to 8s for the bottom models. The velocity reduction of the basal layer on the left is maintained at 3%. The ALVS thickness varies from 300, 1000, 1500, and 2000 km with velocity reduction of 12 to 2.25%. The associated differential travel times (*SKS*-*S*) and (*ScS*-*S*) are displayed with solid and dashed lines, respectively, on the right along with data from station LSZ. Note the shift downward of the (*SKS*-*S*) predictions as *S* is delayed when encountering the ALVS.

Figure S4. (A) The initial temperature field and chemical layer thickness used for all dynamic models. (B) As in Fig. 3A, but $Ra = 10^7$, $B = 0$. (C) As in Fig. 3B but with $Ra = 10^6$, $B = 0.23$.

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