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Lower-mantle plume beneath the Yellowstone hotspot revealed by core waves

Peter L. Nelson* and Stephen P. Grand

Department of Geological Sciences, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX, USA. *e-mail: plnelson@utexas.edu

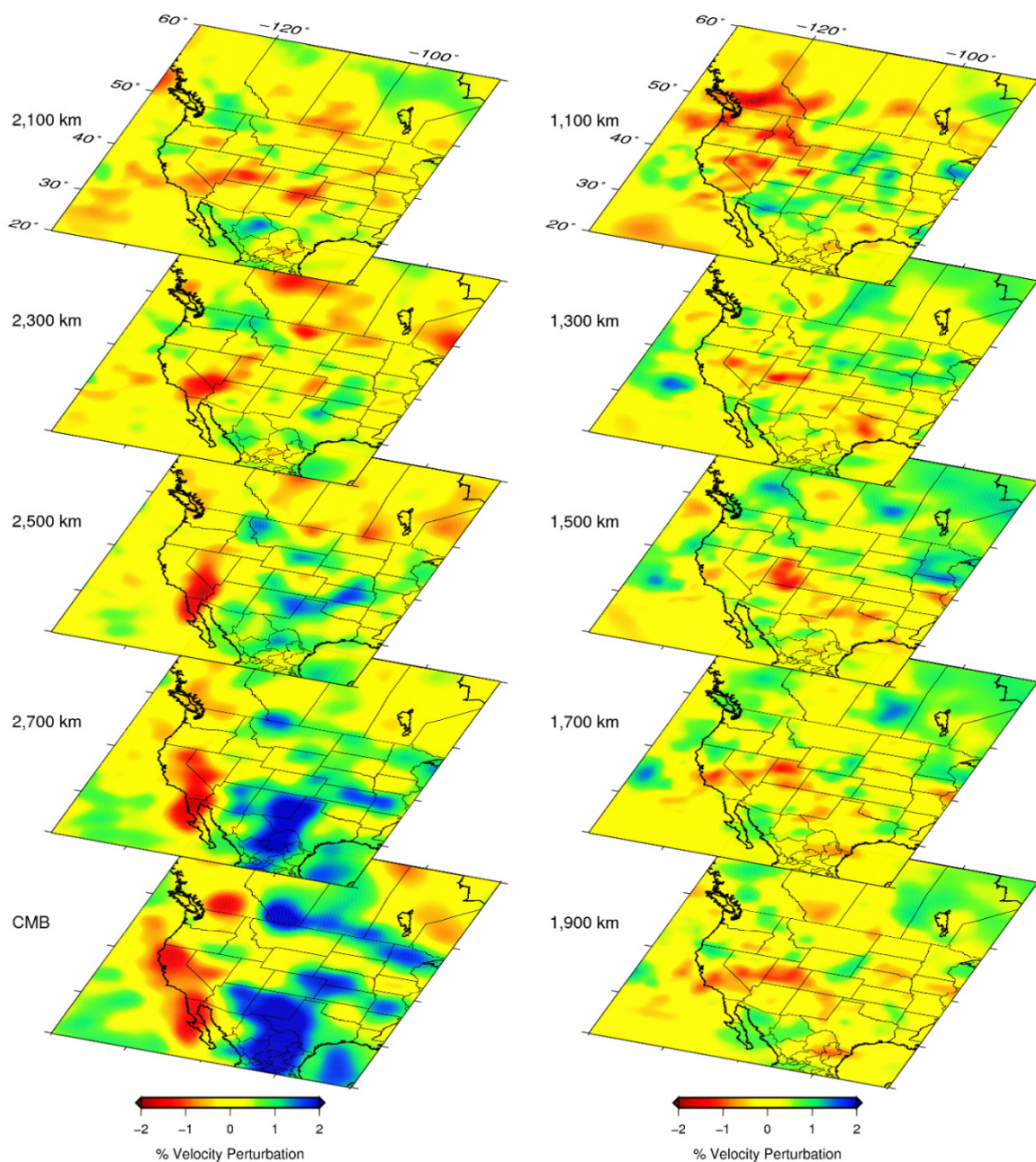
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Supplementary Information

Peter L. Nelson^{1*}, Stephen P. Grand¹

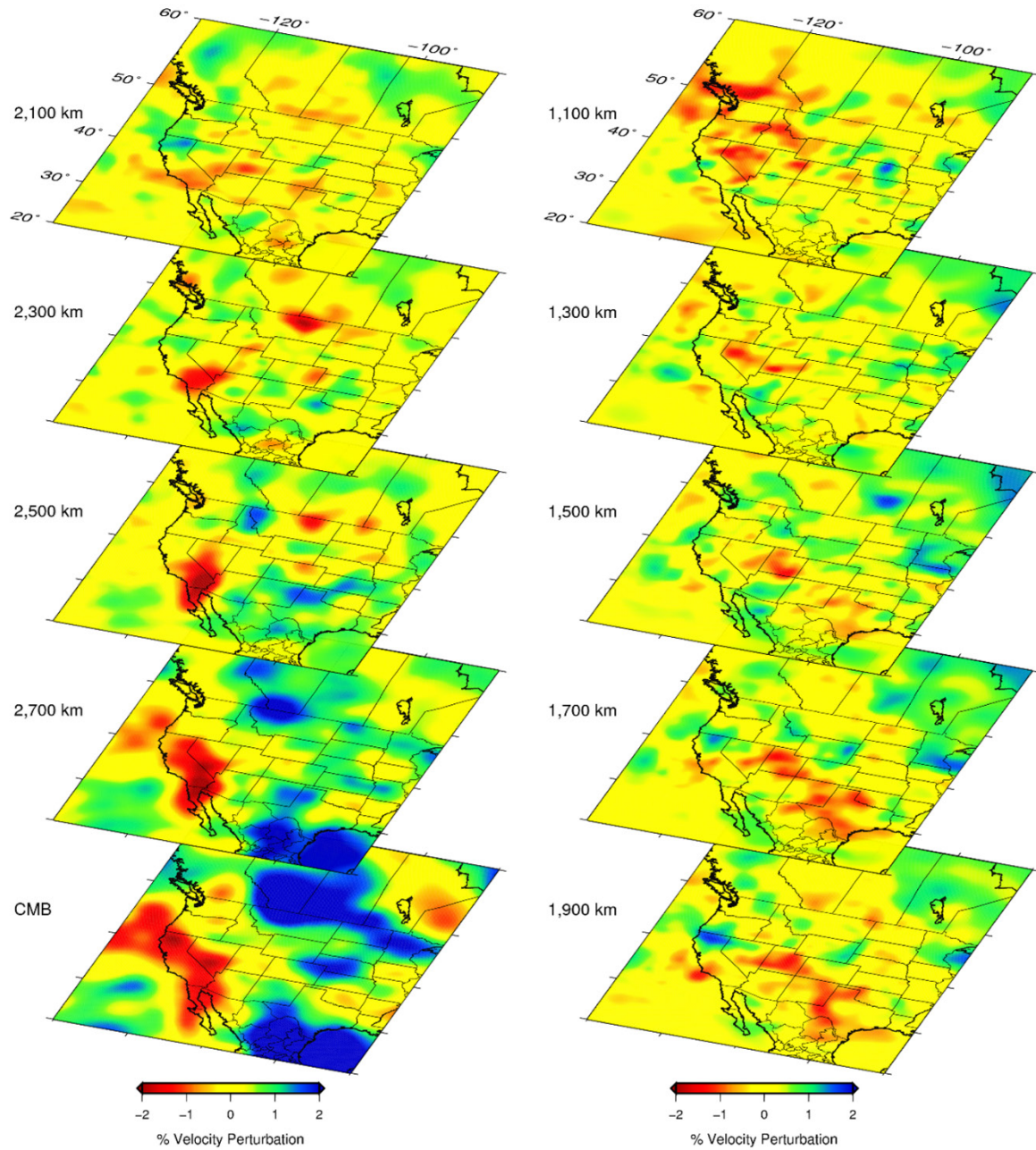
¹Department of Geological Sciences, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX 78712, USA.*e-mail: plnelson@utexas.edu

S40RTS



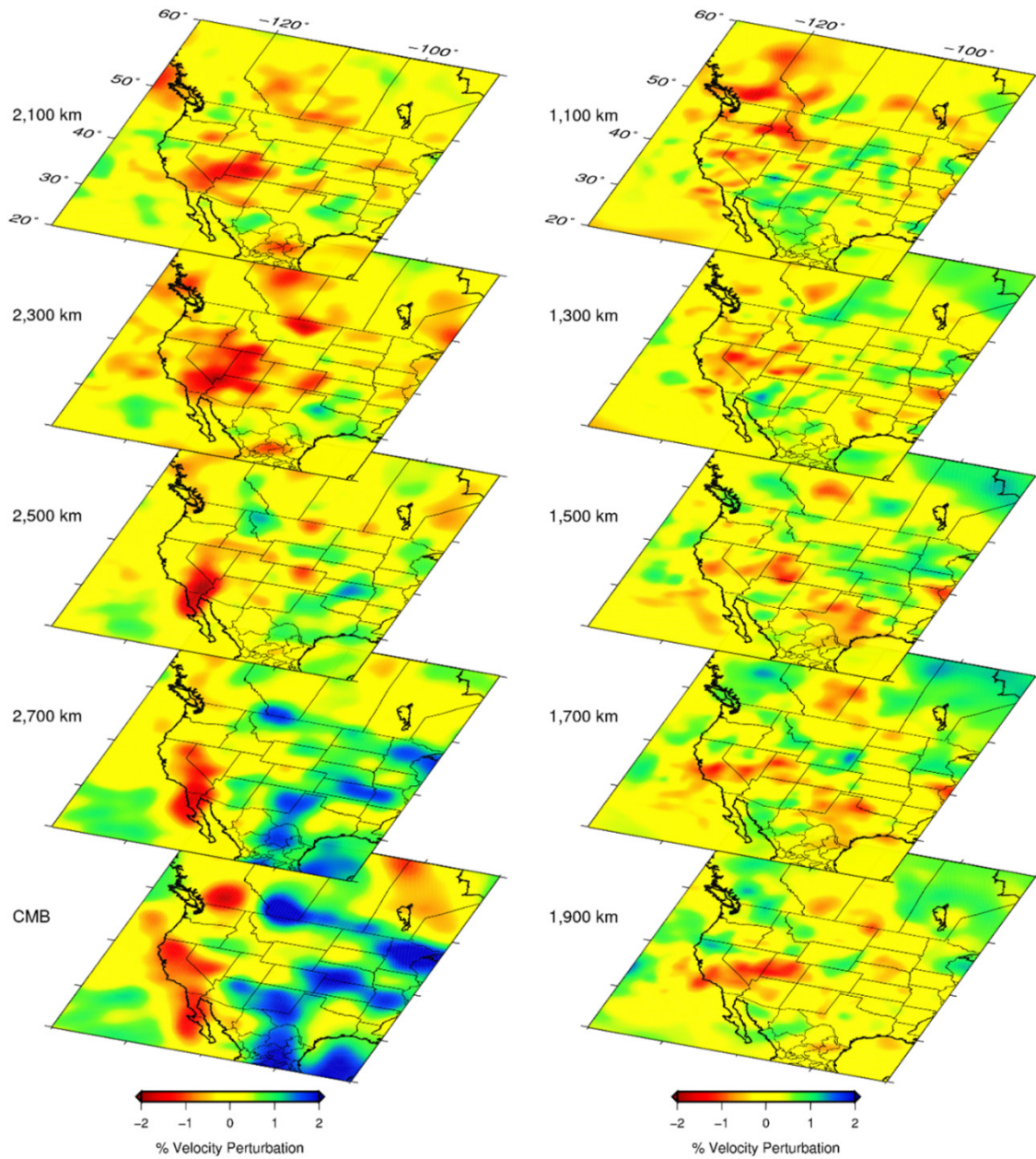
Supplemental Figure 1 Tomographic images of the lower mantle using model S40RTS as the starting model. Slow anomalies are shown in red while fast anomalies are shown in blue with depth indicated to the left of each slice. Note the same color bar is used for all depth slices. The location of the plume is very similar to what is shown by dashed circles in Fig 2.

SEMUCB-WM1



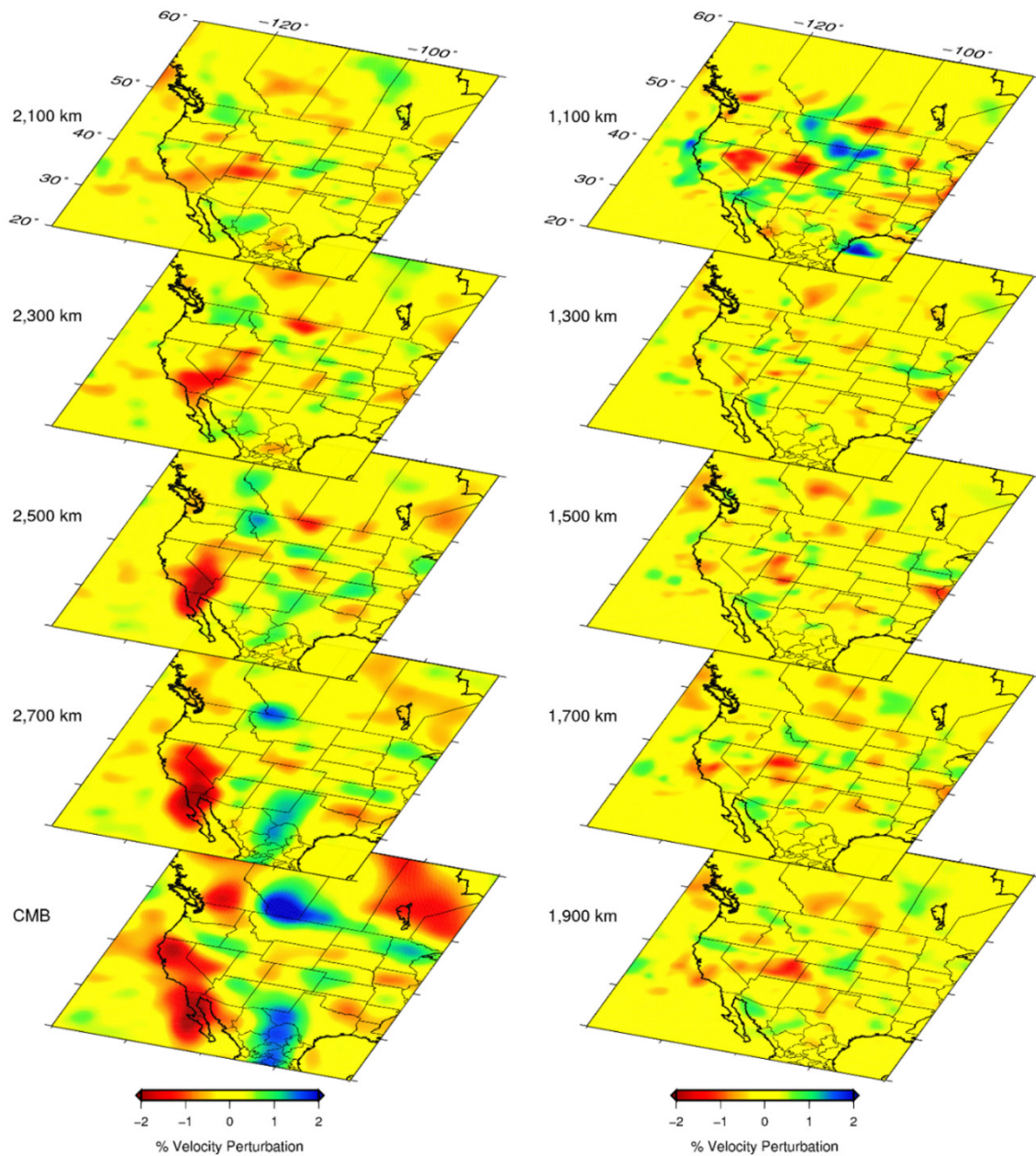
Supplemental Figure 2 Tomographic images of the lower mantle using model SEMUCB-WM1 as the starting model. Slow anomalies are shown in red while fast anomalies are shown in blue with depth indicated to the left of each slice. Note the same color bar is used for all depth slices. The location of the plume structure is similar to what is shown by dashed circles in Fig 2.

TX2016

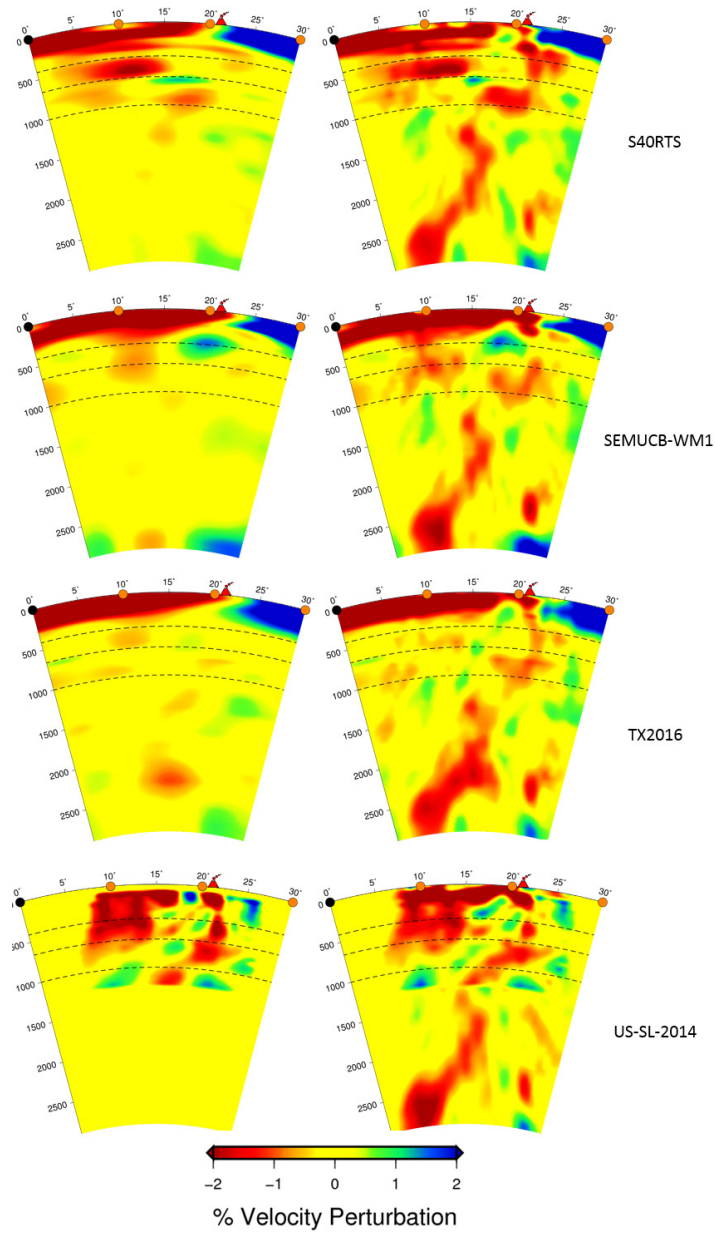


Supplemental Figure 3 Tomographic images of the lower mantle using model TX2016 as the starting model. Slow anomalies are shown in red while fast anomalies are shown in blue with depth indicated to the left of each slice. Note the same color bar is used for all depth slices. The location of the plume structure is similar to what is shown by dashed circles in Fig 2.

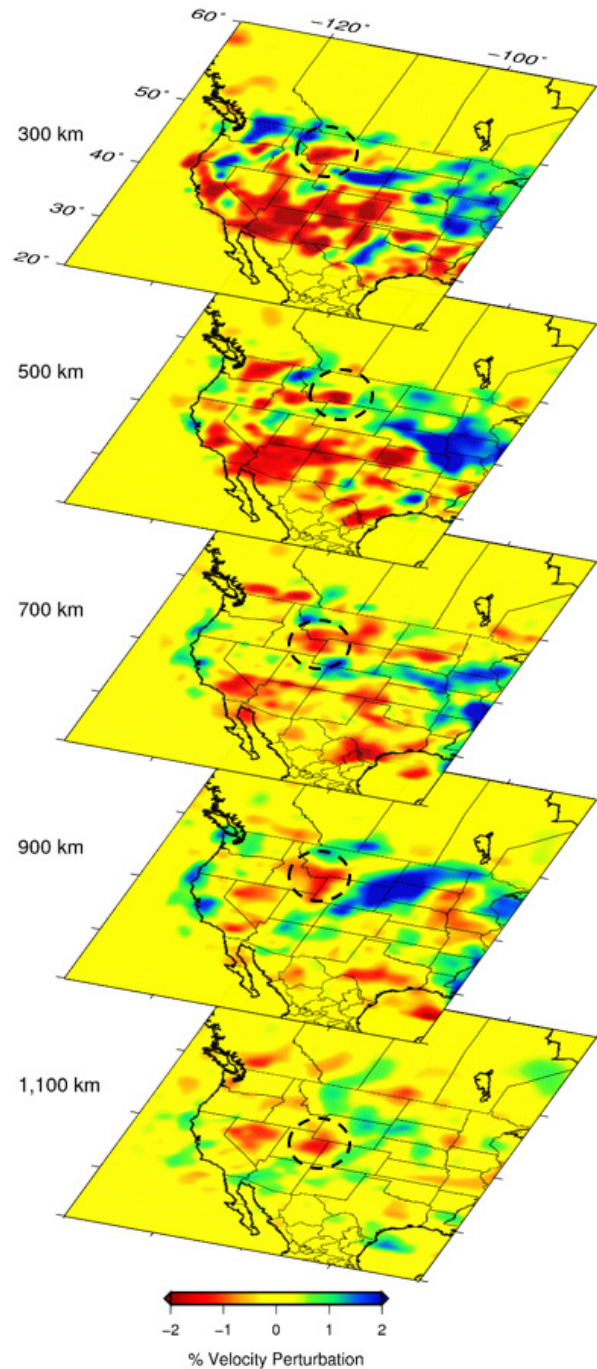
US-SL-2014



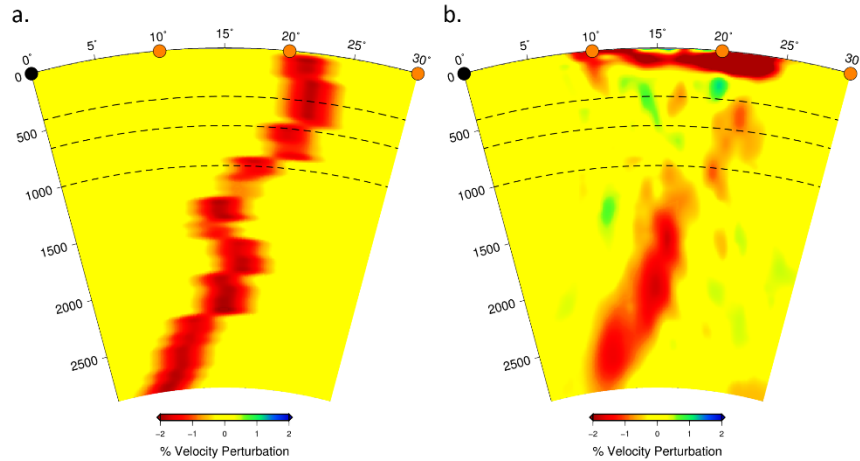
Supplemental Figure 4 Tomographic images of the lower mantle using model US-SL-2014 as the starting model. Slow anomalies are shown in red while fast anomalies are shown in blue with depth indicated to the left of each slice. Note the same color bar is used for all depth slices. The location of the plume structure is similar to what is shown by dashed circles in Fig 2.



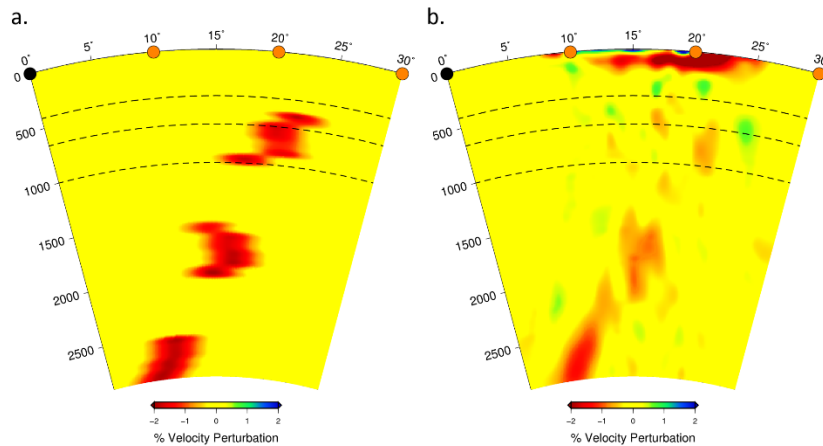
Supplemental Figure 5 Depth cross section comparisons between different inversions with the respective starting models. The location of the cross section is indicated by the purple line in Fig. 1. The surficial position of the Yellowstone Hotspot is shown on each section by the red volcano. *Left* cross section through starting models. *Right* cross sections through the inverted models. For the three global models (S40RTS²⁵, SEMUCB-WM1²⁶ and TX2016²⁷) we inverted for the whole mantle at once instead of inverting first for the top 100 km. We find that all the inverted models have a similar plume structure in the lower/mid mantle and start to show more variations above 1,300 km depth. The strong tilt of the plume between 900 and 1,200 km depth, as seen in the US-SL-2014²⁸ starting model, and the vertical orientation of the ray paths prevents us from imaging a fully continuous plume in the upper portions of the mantle for some of the models.



Supplemental Figure 6 Tomographic images of the upper most mantle using the preferred averaged model as the starting model. Slow anomalies are shown in red while fast anomalies are shown in blue with depth indicated to the left of each slice. Most of the structure shown is a reflection of the starting model we used for the upper mantle (US-SL-2014). The large upper mantle anomaly shown on the left side of Fig. 3 starts to appear at 700 km depth near the California/Nevada/Arizona border. It becomes widespread through the entire southwestern United States in the transition zone and above. In contrast, the lower mantle structure we imaged (dashed circles) appears to move north between 1,100 and 900 km depth and focus beneath the surficial position of the hotspot.



Supplemental Figure 7 Resolution test results investigating the ability to recover a tilted structure. *Left* starting model created by taking the location of the highest amplitude points in our plume structure from real data and putting a 350 km diameter synthetic plume with -2% Gaussian velocity distribution around them. *Right* recovered structure using the same inversion procedure as our real data. The test shows we recover 60-75% of the input model's amplitude below 1,300 km with the highest amount of recovery between 1,500 and 2,000 km depth. The drop in recovery in the upper portion of the mantle is caused by the vertical orientation of the SKS and SKKS ray paths which cannot distinguish between a shallow strong anomaly and a weaker deeper one.



Supplemental Figure 8 Resolution tests investigating the degree of vertical smearing in the lower mantle. *Left* input model which is the same as Supplemental Figure 6a with 500 km gaps added to the structure. *Right* recovered structure after adding a 0.5s random distribution to the data. The lower most mantle anomaly does show signs of vertical smearing although most of the artificial structure is much lower amplitude ($\sim 0.5\%$) compared to the recovered real structure ($>1\%$). The middle anomaly is smeared less than the bottom one because there are more rays crossing from different directions through it. While the top anomaly is not recovered because our two phase inversion method puts the signal from it into the upper 100 km because of the near vertical orientation of the SKS and SKKS ray paths in the upper mantle.