A Catastrophic Plate Tectonics Explanation for Earth's Large Low Shear Velocity Provinces (Also Known as Superplumes)

Evan Arthur Navarro*

Abstract

This paper provides a hypothesis to account for the two Large Low-Shear-Velocity Provinces (LLSVPs) and discusses evidence supporting this hypothesis. These features are located in the lower mantle just above the core-mantle boundary and display strikingly low seismic-shear wave speed relative to adjacent rock. They are nearly antipodal to each other, with one lying roughly beneath Africa and the other beneath the central Pacific Ocean. While secular literature does not have an explanation for how these structures arose or even why they display such low seismic speeds, we postulate that LLSVPs are a direct consequence of catastrophic plate tectonic activity during the Genesis Flood. This paper posits that LLSVPs correspond to hot lower-mantle rock that was forcibly shoved aside by subducted lithospheric slab material as it reached the core-mantle boundary during the Flood. The large contrast in seismic speed between the LLSVP material and the surrounding rock is due primarily to the large difference in temperature. The apparent paradox of why these two LLSVPs, if their low seismic speed is due to high temperature and reduced density, did not rise to the surface millions of years ago is resolved by the realities that the Flood occurred only a few thousand years ago and that mean mantle viscosity returned quickly to its present value at the end of the cataclysm. Numerical simulations with the mantle dynamics code, terra, support this scenario.

Introduction

Seismic tomography has revealed the existence of two provinces of anomalously slow seismic-wave propagation in the lowermost regions of Earth's mantle (McNamara, 2019). These provinces are nearly antipodal to each other, with one beneath the central Pacific Ocean and the other roughly below the African continent. These zones, which exhibit such a striking reduction in seismic wave speed, are generally referred to as Large Low-Shear-Velocity Provinces (LLSVPs), but sometimes as thermochemical piles (Deschamps et al., 2012). In the 1990's they were widely referred to as "super-

* Evan Arthur Navarro, Lynchburg, Virginia, en8hb@virginia.edu
Accepted for publication January 23, 2021

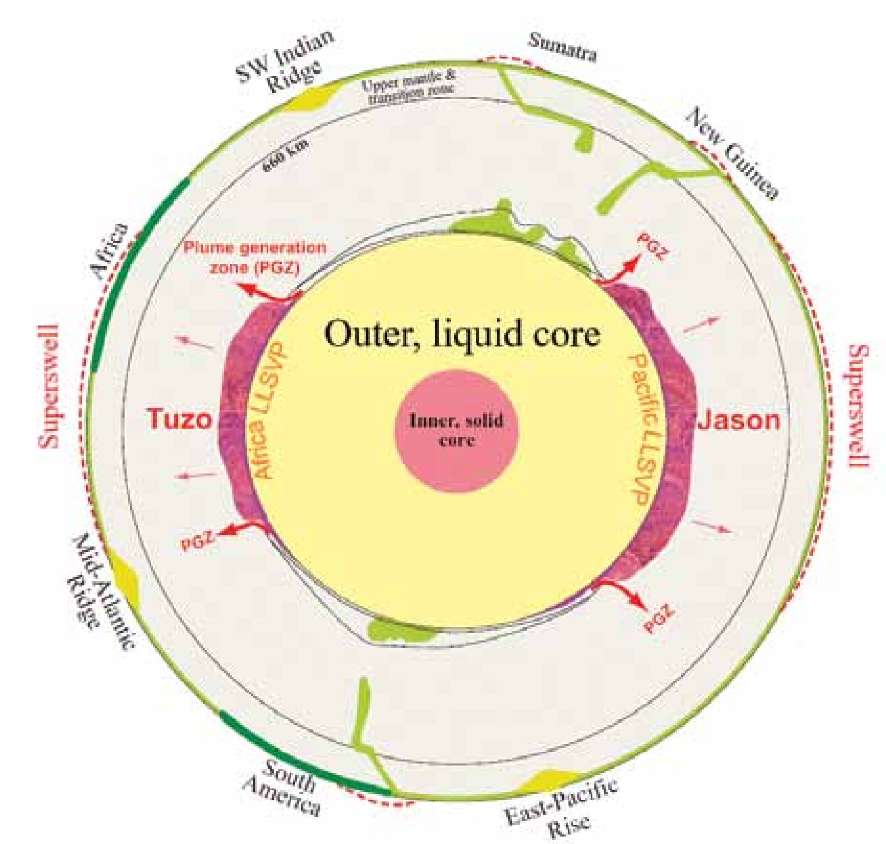

Figure 1. Cartoon cross-section of the Earth as viewed from the South Pole, modified and adapted from Torsvik et al. (2014). Two large low-shear-wave velocity provinces (LLSVPs) are present at Earth's lower mantle: one beneath Africa (Tuzo) and one beneath the central Pacific (Jason). Plume generation zones (PGZs) along the LLSVP margins are the principal source regions for Earth's large igneous provinces. Elevated regions in Earth's gravitational potential field (or geoid) are marked by red dashed lines. The broad regions of elevated geoid above the LLSVPs have been called "superswells."

plumes" (Kellogg et al., 1999). Recently, the African LLSVP has been designated Tuzo (**T**he **U**nmoved **Z**one **O**f Earth's deep mantle) and the Pacific LLSVP as Jason (**J**ust **A**s **S**table **On** the opposite meridian), in honor, respectively, of Tuzo Wilson and Jason Morgan, both of plate tectonics fame (Niu, 2018). Each LLSVP consists of hot material of unknown chemical/physical composition (McNamara, 2019) surrounded by colder silicate rock. Secular scientists have only been able to speculate as to the origin of LLSVPs and are still without a strong explanation (McNamara, 2019). However, it is speculated that LLSVPs may be composed of material enriched by iron and magnesium, and thus may be of a primitive origin (Maruyama et al., 2007; Deschamps et al., 2012). The secular community requires that LLSVPs have a chemical composition different from the bulk mantle to offset the positive buoyancy caused by their high temperature in order for these features to be neutrally buoyant and gravitationally stable.

As previously mentioned, the name for these structures most widely accepted by the scientific community has undergone a significant evolution since their initial discovery in the latter 1980's. Initially nothing was known about these structures save for their low seismic-wave speed. The natural interpretation of this low seismic-wave speed was initially that of elevated temperatures and, therefore, reduced density. Reduced density implies that these structures are buoyant relative to the surrounding mantle and therefore ought to be rising like plumes towards the Earth's surface. Given their large size, it is not surprising that the popular name for these features within the Earth science community was that of "superplume" (Fukao et al., 1994). It was eventually realized, however, that such an interpretation presented a severe problem for uniformitarian thinking and deep-time considerations. A density difference of the magnitude inferred between these superplumes and the surrounding mantle ought to result in strong instability and a rapid rise of the structures to the Earth's surface in a time span far shorter than the hundreds of millions of years the secular paradigm requires. This realization prompted that community to propose that the chemical composition of the rock within these structures must be different from that of the surrounding mantle to make their intrinsic density higher and compensate for their higher temperature (Kellogg et al., 1999). This chemical difference could make the "superplumes" neutrally buoyant and gravitationally stable, thus able to persist in place over spans of hundreds of millions of years. This prompted the general change in nomenclature from "superplume" to Large Low-Shear-Velocity Province (LLSVP), a name agnostic relative to their buoyancy and stability. The name "superplume" is still used, but is representative of the more traditional view for these phenomena.

Closely akin to LLSVP research, the later 20th century also saw research into superswell phenomena. Geophysicists such as Marcia McNutt published several papers on what are termed "superswells," namely regions of uplifted seafloor dotted with countless underwater volcanoes (McNutt, 1998). The volcanic nature of these geoid anomalies can be accounted for by a higher concentration of melt in the shallow ocean floor as compared with the surrounding lithosphere. It was typically posited that these volcanoes were being fed by sub-surface plumes. However, McNutt contradicted this theory with a seismically-defended assertion that a hot layer of mantle above the transition zone at the base of the upper mantle fed this volcanic activity (McNutt, 1998). Figure 1 displays a cartoon of the relationship between a superplume and a superswell, and identifies several other key aspects of the surrounding geology.

As seen in Figure 1, LLSVPs are flanked by the aptly termed plume generation zones (PGZs), which are conventionally regions of approximately 1% slow shear velocity located at the intersections of the outer core, mantle, and LLSVPs (Burke et al., 2008). The steep temperature gradient between the LLSVP margin at the mantle and the interior of the plume is critical in the plume generation that takes place at the zones. The PGZs and superswells consequently all feed the visible Large Igneous Provinces (LIPs), shown at the top of the figure. The LIPs represent massive eruptions of basalt on the Earth's surface (Wignall, 2001).

In a survey of the latest publications, it is clear that there are still more questions than answers as to the nature of the LLSVPs, especially concerning possible chemical differences relative to the bulk mantle. Beyond the issues relating to spatial resolution of their structure are the following more important questions:

- What were the processes responsible for their formation?
- When did they first appear?
- Are they stationary or buoyant and mobile?

The answer to each of these questions has profound impact on a correct understanding of mantle dynamics and Earth history in general. We will address these questions in the remainder of this paper.

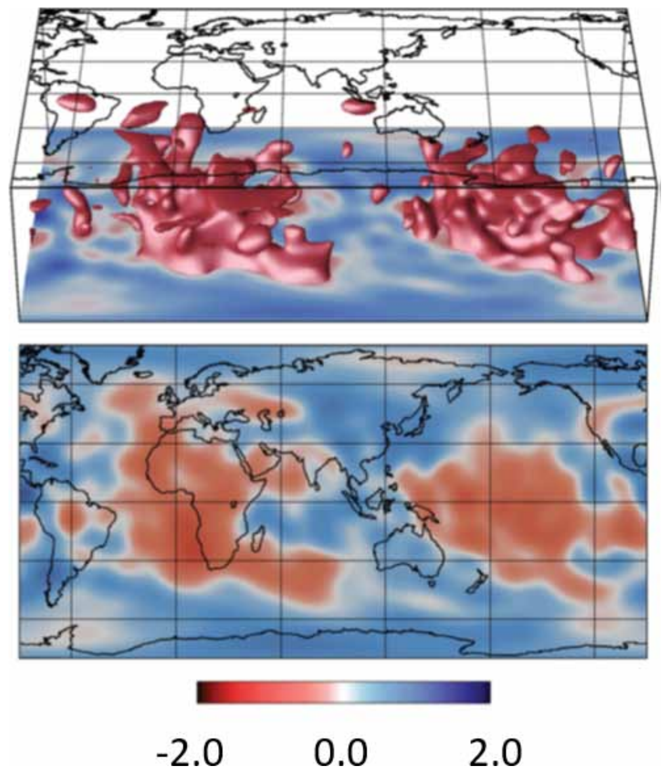

Figure 2. Maps of Large Low-Shear-Velocity Provinces, with 3D iso-surface depiction in top panel and 2D average across the lowermost mantle at 2750 km depth in the bottom panel. Colors represent the percentage of shear wave deviation from the mean value. Figure modified from (Ritsema et al., 2011).

A Brief History

Over the past thirty years, several differing approaches have been taken to understand and explain the LLSVP anomalies. Early in that history, it was found that shear-wave tomography provided the clearest definition and resolution of these features. Figure 2 displays a relatively recent map of the variation of seismic shear-wave speed in the lowermost mantle and includes 3-dimensional iso-surfaces for the LLSVPs (Ritsema et al., 2011). However, the features also appear in compressional wave tomography. Figure 3 displays the results of several joint shear and compressional wave seismic tomography models, with regions of low shear-wave speed distinguished by color from regions of low compressional-wave speed. Notice the gradient in wave speed that so famously prompted the recognition of these phenomena.

Has anyone in the secular scientific community provided a plausible explanation for the formation of LLSVPs? The short answer is no. Not only is there

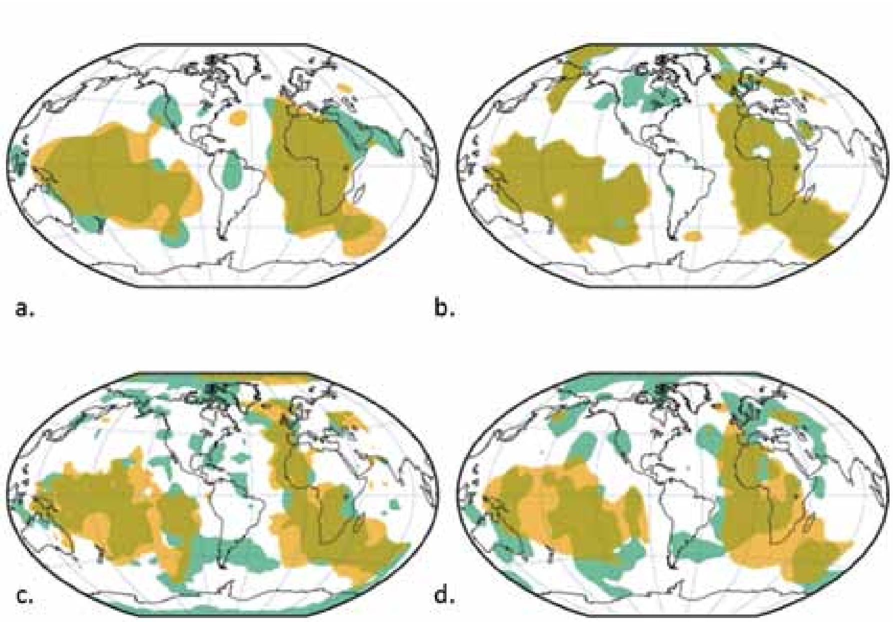

Figure 3. Joint shear- (S-wave) and compressional- (P-wave) tomography models. Yellow denotes regions with low S-wave speed, while green denotes regions of low P-wave speed, within the lowest portion of the mantle. a. SP12RTS model (Koelemeijer et al., 2016); b. GyPsum model (Simmons et al., 2010); c. HMSL model (Houser et al., 2008); d. An average of earlier models (Becker and Boschi, 2002). Plots modified from Garnero et al. (2016).

a lack of agreement among the proposed explanations, but there is a general perception that no solution to date is anywhere close to a satisfying one. Let us survey briefly several of the more recent attempts to account for the LLSVPs.

In its explanation of LLSVP formation, a paper published in 2007 hypothesized that a partial melting of recycled Mid-Oceanic-Ridge Basalt (MORB) caused a phase change at the core-mantle boundary (CMB), raising its temperature and causing the residual solid MORB to rise and leave behind anti-crust. The repetition of this process over millions of years slowly formed the LLSVPs (Maruyama et al., 2007). The issue of LLSVP stability, although briefly mentioned, is not adequately considered and is largely avoided.

In a 2018 paper, Niu valiantly posited that the LLSVPs are composed of subducted oceanic crust that has somehow separated from the remainder of the subducted slab due to its density difference (Niu, 2018). Niu's scenario consists of the subduction of oceanic plates to the CMB where they then separate into subducted oceanic crust (SOC) and slab mantle lithosphere (SML) (Niu, 2018). This separation is far more easily said than done, as it is not easy to imagine how the thin SOC layer might separate from the SML as they fold together at the CMB.

Mulyukova also discusses the formation of LLSVPs from SOC accumulation at the CMB in her 2015 paper (Mulyukova et al., 2015) and offers an explanation for the apparent stability of LLSVPs. The formation of LLSVPs from SOC also appears in a paper by Huang et al. (2020).

LLSVPs and Terra

An exciting development relating to LLSVPs is the enhancement they provide to current Pangea breakup simulations using the terra code. Terra (Baumgardner, 1985) is a mantle dynamics simulation program that utilizes the equations of force balance, conservation of mass, and conservation of energy in the framework of a 3D spherical-shell grid of cells. The number of cells depends on the resolution chosen. The grid for the case described here has 1.35 million cells. Terra utilizes the finite-element method to solve these equations for the three components of velocity at each grid point plus pressure and temperature as the calculation steps through time. It employs a powerful solver technique known as multigrid to solve 5.4 million simultaneous equations for 5.4 million unknowns on each time step in about 0.5 seconds on a current generation laptop. It represents tectonic plates on the Earth's surface using particles that track each plate in a highly accurate manner. When terra cases are run using postulated initial conditions, the code simulates the breakup of the Pangea supercontinent during the Flood.

It must be understood that such Pangea breakup simulations have been discussed in previously published papers, namely Baumgardner (1993, 1994a, 2003). The following discussion is, however, an explanation of an attempt to improve simulation realism. The following results differ from previous calculations only slightly and yield slightly improved results.

Results

The African LLSVP anomaly was recently included in the terra Pangea calculations as a cluster of four distinct

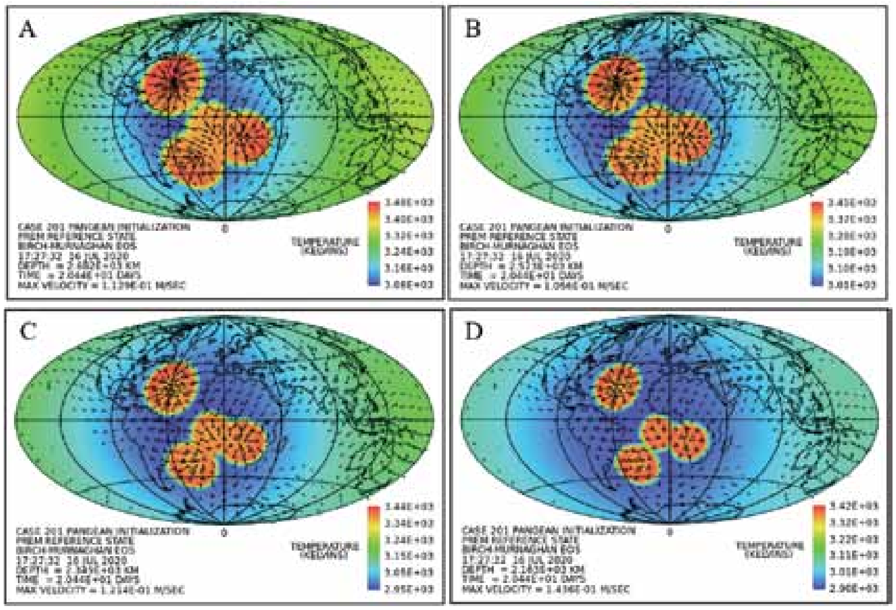

Figure 4. African LLSVP as a function of decreasing depth. (a) 2682 km (b) 2523 km (c) 2349 km (d) 2163 km.

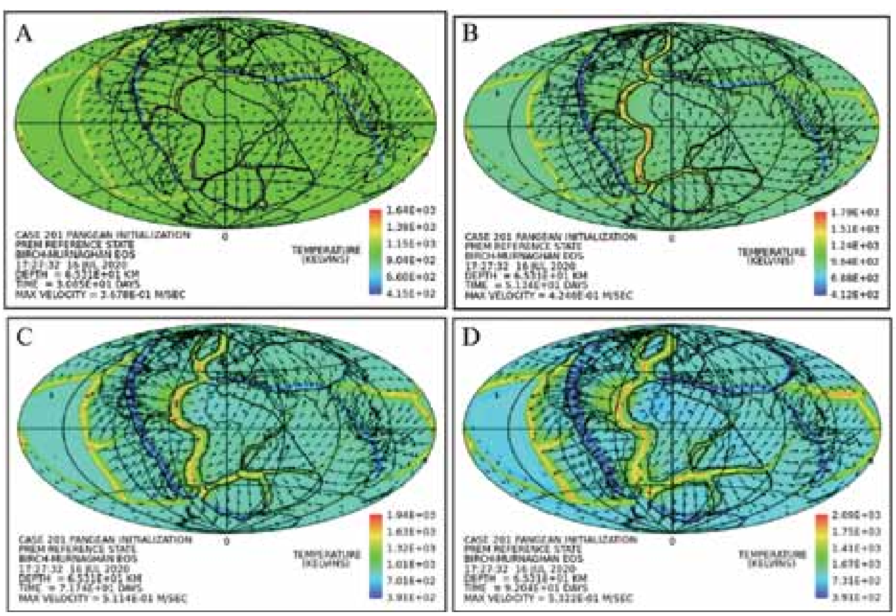

Figure 5. TERRA Pangea breakup simulation that includes the Africa LLSVP. (a) 31 days (b) 51 days (c) 72 days (d) 92 days.

blobs of buoyant mantle rock. Each was represented as a sphere with specified radius and specified distance of its center from the CMB. Figure 4 shows slices through the LLSVP blobs as a function of decreasing depth. Figure 5 displays a series of snapshots in time of the terra solution that includes the LLSVP implementation.

Discussion

While running these terra cases, it was realized that the principles of Catastrophic Plate Tectonics and the tumultuous upheaval during the Flood can provide a simple explanation for these enigmatic LLSVP structures. Let's briefly summarize these principles before we present our hypothesis for LLSVP formation.

Catastrophic Plate Tectonics, the Genesis Flood, and LLSVPs

Catastrophic plate tectonics (CPT) has demonstrated considerable explanatory power relative to the tectonic aspects of the Genesis Flood (Austin et al., 1994; Baumgardner, 1994a, 1994b, 2003). CPT relies on the experimentally measured properties of silicate minerals that show dramatic weakening under values of shear stress that can arise in Earth's mantle. This weakening allows runaway subduction to occur and catastrophic conditions for the wide-scale geological resurfacing during Noah's Flood to unfold (Austin et al., 1994; Baumgardner, 2003).

At the onset of the Flood, oceanic plates began to subduct along continental plate margins. The resulting geological upheaval simultaneously caused superheated steam jets to arise where plates pulled apart and tsunamis to form from the subduction zones. As subducted plates reached the core-mantle boundary, they began to push aside the hot rock just above that boundary and caused two antipodal patches of rock there to be squeezed together and then upwards akin to squeezing toothpaste from a tube. This hot material began to rise to the surface due to its buoyancy relative to the surrounding rock.

This, then, is the process we propose for LLSVP formation. When the runaway subduction had moved most of the cold plate material from Earth's surface and had carried it to the bottom of the mantle, the energy driving the process was largely exhausted. At this point, the high velocities plummeted and the silicate mantle viscosity, which had been temporarily dramatically reduced by the runaway process, then rapidly increased to modern levels. The newly emplaced hot material from the CMB, now also with dramatically higher viscosity, was essentially frozen in place—stable in terms of a time scale of a few thousand years—to become the LLSVPs of today.

LLSVPs Today

This explanation addresses the matters that are so problematic to the secular geoscience community, namely, LLSVP origin and stability. Indeed, LLSVPs have been shown to be in motion, though only at the rate of a few mm per year (Bono et al., 2019). Thus LLSVPs are buoyant and in motion, and this fact only reinforces the CPT explanation. Whereas the millions of years required by uniformitarianism leads to insurmountable difficulties in accounting for the apparent stability of LLSVPs, their formation only thousands of years ago eliminates this paradox. They have been mobile since their formation but have not traveled a substantial distance because that formation was very rapid and in the recent past, not millions of years ago.

Conclusion

Secular science has been unable to arrive at a reasonable explanation for the two antipodal structures that exist at the core-mantle boundary, originally known as superplumes but now known as Large Low-Shear-Velocity Provinces. Why are these structures so baffling? Psalm 19:1–3 (NKJV) states that "The heavens declare the glory of God; and the firmament shows His handiwork. Day unto day utters speech, and night unto night reveals knowledge. There is no speech nor language where their voice is not heard." Although this passage speaks of the heavens evoking the glory of the Creator, Earth bears such witness on a comparable scale. Earth does not show evidence for uniformitarian long ages, but loudly proclaims a recent global Flood cataclysm and bears witness to God's very real judgment on human sin. These elegant structures are simply additional features that testify to the truthfulness of God's Word, the power and sovereignty of God, and the reality of the global Flood. As Psalm 29:10 (NKJV) states: "The LORD sat enthroned at the Flood, and the LORD sits as King forever." We have endeavored to show that catastrophic plate tectonics offers a simple and reasonable explanation for the two structures, known as Large Low-Shear-Velocity Provinces, that are so baffling to the secular mind.

References

Austin, S.A., J.R. Baumgardner, D.R. Humphreys, A.A. Snelling, L. Vardiman, and K.P. Wise 1994. Catastrophic plate tectonics: A global Flood model of Earth history. In: Walsh, R.E. (editor), *Proceedings of the Third International Conference on Creationism*, pp. 609–621. Creation Science Fellowship, Pittsburgh, PA.

Baumgardner, J.R. 1993. 3-D numerical investigation of the mantle dynamics associated with the breakup of Pangea. In: Stone, D.B. and Runcorn, S.K. (editors), *Flow and Creep in the Solar System: Observations, Modeling and Theory*. NATO ASI Series (Series E: Applied Sciences), volume 391. Springer, Dordrecht. https://doi.org/10.1007/978–94–015–8206–3_14.

Baumgardner, J.R. 1994a. Computer modeling of the large-scale tectonics associated with the Genesis Flood. In: Walsh, R.E. (editor), *Proceedings of the Third International Conference on Creationism*, pp. 49–62. Creation Science Fellowship, Pittsburgh, PA.

Baumgardner, J.R. 1994b. Runaway subduction as the driving mechanism for the Genesis Flood. In: Walsh, R.E. (editor), *Proceedings of the Third International Conference on Creationism*, pp. 63–86. Creation Science Fellowship, Pittsburgh, PA.

Baumgardner, J.R. 1985. *A Three-Dimensional Finite-Element Model for Mantle Convection*. University of California, Los Angeles, CA. [No such book on Internet.]

Baumgardner, J.R. 2003. Catastrophic plate tectonics: The physics behind the Genesis Flood. In: Ivey, Jr., R. L. (editor). *Proceedings of the Fifth International Conference on Creationism*, pp. 113–126. Creation Science Fellowship, Pittsburgh, PA.

Becker, T.W., and L. Boschi. 2002. A comparison of tomographic and geodynamic mantle models. *Geochemistry, Geophysics, Geosystems* 3(1): 2001GC000168.

Bono, R.K., J.A. Tarduno, and H.-P. Bunge. 2019. Hotspot motion caused the Hawaiian-Emperor Bend and LLSVPs are not fixed. *Nature Communications* 10(1): 1–9.

Burke, K., B. Steinberger, T.H. Torsvik, and M.A. Smethurst. 2008. Plume Generation Zones at the margins of Large Low-Shear-Velocity Provinces on the core-mantle boundary. *Earth and Planetary Science Letters* 265(1–2): 49–60.

Deschamps, F., L. Cobden, and P.J. Tackley. 2012. The primitive nature of large low-shear-wave velocity provinces. *Earth and Planetary Science Letters* 349–350:198–208.

Fukao, Y., S. Maruyama, M. Obayashi, and H. Inoue. 1994. Geologic implication of the whole mantle P-wave tomography. *The Journal of the Geological Society of Japan* 100(1): 4–23.

Garnero, E.J., A.K. McNamara, and S.-H. D. Shim. 2016. Continent-sized anomalous zones with low seismic velocity at the base of Earth's mantle. *Nature Geoscience* 9(7): 481–489.

Houser, C., G. Masters, P. Shearer, and G. Laske. 2008. Shear and compressional velocity models of the mantle from cluster analysis of long-period waveforms. *Geophysical Journal International* 174(1): 195–212.

Huang, C., W. Leng, and Z. Wu. 2020. The continually stable subduction, iron-spin transition, and the formation of LLSVPs from subducted oceanic crust. *Journal of Geophysical Research: Solid Earth* 125(1): 1–20.

Kellogg, L.H., B.H. Hager, and R.D. van der Hilst. 1999. Compositional stratification in the deep mantle. *Science* 283(5409): 1881–1884.

Koelemeijer, P., J. Ritsema, A. Deuss, and H.-J. van Heijst. 2016. SP12RTS: A degree-12 model of shear- and compressional-wave velocity for Earth's mantle. *Geophysical Journal International* 204(2): 1024–1039.

Maruyama, S., M. Santosh, and D. Zhao. 2007. Superplume, supercontinent, and post-perovskite: Mantle dynamics and anti-plate tectonics on the core–mantle boundary. *Gondwana Research* 11(1–2): 7–37.

McNamara, A.K. 2019. A review of large low-shear-velocity provinces and ultra-low-velocity zones. *Tectonophysics* 760: 199–220.

McNutt, M.K. 1998. Superswells. *Reviews of Geophysics* 36(2): 211–244.

Mulyukova, E., B. Steinberger, M. Dabrowski, and S.V. Sobolev. 2015. Survival of LLSVPs for billions of years in a vigorously convecting mantle: Replenishment and destruction of chemical anomaly. *Journal of Geophysical Research: Solid Earth* 120(5): 3824–3847.

Niu, Y. 2018. Origin of the LLSVPs at the base of the mantle is a consequence of plate tectonics—A petrological and geochemical perspective. *Geoscience Frontiers* 9(5): 1265–1278.

Ritsema, J., A. Deuss, H.-J. van Heijst, and J.H. Woodhouse. 2011. S40RTS: A degree-40 shear-velocity model for the mantle from new Rayleigh wave dispersion, teleseismic traveltime and normal-mode splitting function measurements. *Geophysical Journal International* 184(3): 1223–1236.

Simmons, N.A., A.M. Forte, L. Boschi, and S.P. Grand. 2010. GyPSuM: A joint tomographic model of mantle density and seismic wave speeds. *Journal of Geophysical Research* 115(B12). https://doi.org/10.1029/2010JB007631.

Torsvik, T.H., R. van der Voo, P.V. Doubrovine, K. Burke, B. Steinberger, L.D. Ashwal, R.G. Trønnes, S.J. Webb, and A.L. Bull. 2014. Deep mantle structure as a reference frame for movements in and on the Earth. *Proceedings of the National Academy of Sciences* 111(24): 8735–8740.

Wignall, P.B. 2001. Large igneous provinces and mass extinctions. *Earth-Science Reviews* 53(1–2): 1–33.