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Letters

Lithospheric and asthenospheric contributions to shear-wave splitting observations in the southeastern United States

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ABSTRACT

We present observations of both null and non-null SKS splitting from temporary deployments across the southeastern United States in order to evaluate the relative contributions of lithospheric deformation and asthenospheric flow to regional anisotropy. Data for this study come from four temporary broadband seismic deployments: the Appalachian Seismic Transect (AST), the Test Experiment for Eastern North America (TEENA), the South Carolina Earth Physics Project (SCEPP), and the Florida to Edmonton Array (FLED). In general, we find fast directions aligned roughly parallel to absolute plate motion of the North American plate (APM) within and west of the Southern Appalachians, whereas to the southeast, we find a broad area dominated by complex splitting patterns consisting of well-constrained null splitting measurements over a range of backazimuths along with a very small number of resolved non-null measurements. This change in splitting patterns is consistent with a transition from drag induced asthenospheric flow beneath the older sections of the North American continent to vertical or incoherent mantle flow, likely in combination with complex lithospheric anisotropy, beneath the younger accreted terranes to the southeast. In addition to these general patterns, we find a number of non-null splitting measurements that are not aligned with APM, but are instead aligned with prominent magnetic anomalies that may correspond to ancient continental suture zones or faults. This would suggest that in these areas, a strongly anisotropic (but localized) lithospheric fabric dominates over any ambient asthenospheric anisotropic signature. In areas with generally strong APM parallel splitting, this would imply a thick sheared mantle lithosphere whose deformation-induced anisotropy is strong enough to overprint the anisotropy induced by APM, and is aligned with the shallower crustal structures responsible for generating the observed magnetic anomalies. In the southeastern areas dominated by null splitting measurements, there may be no strong signature from asthenospheric anisotropy to override, but a substantial lithospheric thickness is still required to generate the magnitude of the observed SKS splitting ($\sim$1 s). More data are required to verify these results, but future datasets including data from USArray may be able to exploit the correlations between null and non-null SKS splitting measurements and magnetic lineaments to better constrain the provenance of the regional anisotropic signature.

1. Introduction

Because of the causative link between deformation and seismic anisotropy, observations of anisotropy can provide some of the most direct observational constraints available on past and present mantle deformation (e.g., Long and Becker, 2010). Observations of seismic anisotropy in continental regions can yield particular insight into the history of past deformation episodes, as the signature of past events is often preserved in the continental lithosphere (Fouch and Rondenay, 2006). Because there may be many contributions to the observed signal from anisotropy in different depth ranges, however, the interpretation of anisotropic indicators such as SKS splitting in continental regions is not straightforward. In the eastern United States, observations of seismic anisotropy may be attributed to drag induced asthenospheric flow parallel to the absolute plate motion (APM) of the North American plate (Fouch et al., 2000), asthenospheric flow resulting from edge driven convection along the continental margin (King, 2007), asthenospheric flow associated with buoyant upwelling hydrated mantle material (Van Der Lee et al., 2008), lithospheric deformation resulting from repeated collisional events over the course of a full Wilson cycle (Vauchez and

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Barruol, 1996; Barruol et al., 1997a; Barruol et al., 1997b), or various combinations of these (Deschamps et al., 2008; Long et al., 2010).

Previous work on SKS splitting in the southeastern US has noted a pattern of fast SKS splitting that is often close to APM parallel (Barruol et al., 1997b; Fouch et al., 2000; Long et al., 2010). Long et al. (2010) also noted a contrast in splitting behavior between stations located in the Appalachian orogen and those located closer to the coast, which are often dominated by null SKS splitting over a range of backazimuths. Absolute plate motion across our study area varies depending on the reference frame used (HS3 or no-net-rotation) (Gripp and Gordon, 2002), but generally ranges between 250° and 280° (measured in degrees east of north). Fouch et al. (2000) proposed that variations in fast directions from APM can be explained by asthenospheric flow around a thick lithospheric root beneath cratonic North America. However, such a model does not explain the pervasive null splitting measurements further to the southeast observed by Long et al. (2010). These might be explained by the presence of such a cratonic keel if a sharp variation in lithospheric thickness induces localized edge-driven convection and associated vertical mantle flow (King, 2007). Vertical upper mantle flow has also been proposed beneath the east coast based not on shear-wave splitting but on tomographic S-wave velocity models that indicate the presence of a large low velocity "dike" extending from what is interpreted to be the subducted Farallon plate to the surface (Van Der Lee et al., 2008). Van Der Lee et al. (2008)propose that this low velocity anomaly represents buoyant hydrated mantle material that could help explain post-Triassic uplift along the eastern continental margin, and may eventually promote subduction initiation.

The argument for a lithospheric component to the observed anisotropy in the eastern United States is based on the short spatial scale variations in both fast directions and delay times (ϕ and δt, respectively) of splitting observations from within the orogen to areas just east of the orogen (Vauchez and Barruol, 1996; Barruol et al., 1997a; Barruol et al., 1997b). Barruol et al. (1997b) noted that the APM parallel fast directions are also parallel to local fabrics in the deformed orogenic lithosphere, and interpreted null splitting observations further east as being due to the intrusion of rifting-induced magmatism that would serve to weaken pre-existing fabrics.

Given the long and complex tectonic history of the eastern U.S., it is possible (and perhaps likely) that observed SKS splitting is due to a complex combination of several sources of anisotropy. Long et al. (2010) suggest that some degree of vertical mantle flow is likely in order to explain the large number of null splitting measurements across the area, though evidence for vertical mantle flow is not observed across the transition zone as constrained by receiver function measurements of transition zone thickness. Deschamps et al. (2008) argue for progressively frozen layers of differing asthenospheric flow patterns to explain the differing fast directions of anisotropic Rayleigh waves at different periods. Their study, however, did not extend east into the region dominated by null SKS splitting measurements. Other continental-scale studies for mantle anisotropy that include both surface wave and SKS splitting constraints have also suggested the presence of multiple layers of anisotropy in the eastern US (e.g., Yuan and Romanowicz, 2010), although given the generally poor station coverage in the area the resolution of the models in the southeastern US is likely limited.

The alignment of fast SKS splitting directions and indications of crustal deformation, such as the geometry of crustal faults, geodetic measurements, and magnetic and gravity anomalies, has been used to make arguments about the likely depth distribution of anisotropy and the vertical coherence of deformation in continental regions (e.g., Lev et al., 2006; Wang et al., 2008; Wüstefeld et al., 2010). For example, the alignment of SKS splitting fast directions and magnetic anomalies has been noted in central and northern North America (Bokelmann and Wuestefeld, 2009). Because magnetic anomalies decay as r^{-3}, they record dominantly shallower (crustal scale) structures. However, the limited thickness of the crust means it can typically account for only a few tenths of seconds of shear-wave splitting (e.g., Barruol and Mainprice, 1993; Savage, 1999; Long and Silver, 2009). If larger splitting is observed to be coincident with magnetic lineaments, this implies the presence of a thick mantle lithosphere whose anisotropic fabric is aligned with the crustal structures responsible for the magnetic anomaly.

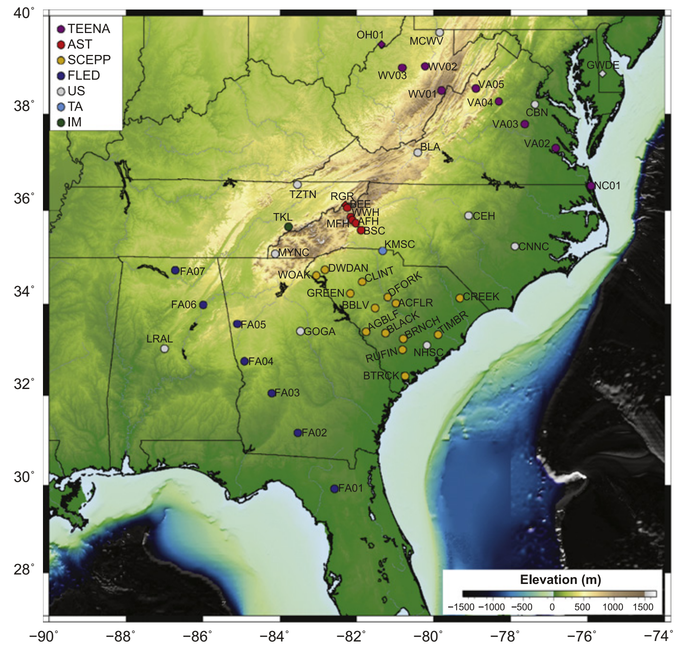

Fig. 1. Topographic map of the area showing circles at station locations, color coded by deployment/network.

Here we present new SKS splitting measurements for four temporary deployments in the southeastern US and combine them with previous results (Long et al., 2010) to produce a uniform compilation of null and non-null splitting measurements in the southeastern United States that we compare to APM, topography, surface geology, and magnetic and gravity anomalies in order to constrain the relative contributions of the lithosphere and asthenosphere to the observed anisotropy. We find predominantly null splitting measurements across broad areas in the southeastern U.S., and many APM parallel measurements further to the north and west. There are, however, a number of notable exceptions to these general patterns. Strikingly, in most of these cases, the station is located along a major magnetic anomaly or lineament, and the fast directions are anomaly/lineament-parallel. Two of these lineaments, the New York-Alabama (NY-AL) lineament (King and Zietz, 1978) and the Brunswick magnetic anomaly (BMA) (Taylor et al., 1968; McBride and Nelson, 1988) have been previously identified as possible locations of major terrane boundaries or faults. A third is more speculative, but may represent the boundary between the accreted Carolinia terrane and Grenville basement. Additional future data from the EarthScope Transportable Array and other temporary deployments will help to clarify whether this correlation between magnetic anomalies and SKS splitting is robust and to place tighter constraints on the depth distribution of anisotropy.