A central Appalachian EarthScope transect in Virginia: Examining upper mantle interaction with Paleozoic sutures, Eocene magmatism, and modern seismicity

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Proposed site: *Virginia (Appalachian Valley & Ridge - Piedmont - Atlantic Coastal Plain)*

The central Appalachian orogen, with its well-developed foreland fold-and-thrust belt and paired metamorphic hinterland, is a classic example of an ancient collisional mountain belt. The orogen has been modified by Mesozoic rifting and, in western Virginia, Eocene volcanism. In addition, Cenozoic erosion and uplift, along with recent seismic events suggest a dynamic modern landscape influenced by crustal structures, some of which may link to upper mantle structures. This region of the central Appalachians, often considered a type section for a "passive margin", is quite dynamic.

To address the poorly understood dynamism of this region, we propose a 300 km transect across the Virginia Appalachians, extending from the Appalachian Structural Front in the northwest to the accreted terranes and Mesozoic rift basins buried beneath the Atlantic Coastal Plain in the southeast (Fig. 1). This is a superb locale for testing a number of hypotheses concerning lithospheric structure and dynamics in eastern North America using the EarthScope Transportable and Flexible Arrays. The Virginia transect crosses from thin-skinned foreland to a thick-thinned Laurentian basement massif to accreted terranes in the metamorphic hinterland that were later modified by Mesozoic Atlantic basin rifting and post-rift contractional reactivation. Although the Appalachians are a Paleozoic orogeny built upon a Proterozoic foundation, this section of the central Appalachians is particularly noteworthy as it experienced mantle-derived magmatism during the Eocene (Southworth et al., 1993; Furman and Gittings, 2003) and, as evidenced by the 2011 M_w=5.8 earthquake in central Virginia, is seismically active.

Key Scientific Questions and Background

Seismic refraction data indicate that the crust in the central Appalachians thins from ~50 km along the Appalachian Structural Front (western margin of the Valley & Ridge) to ~35 km at the Coastal Plain's westward edge (Fig. 1) (James et al., 1968; Taylor and Toksoz, 1982). Existing seismic reflection profiles are replete with east-dipping reflectors imaged to depths of 10 to 12 km (Harris et al., 1986). Deep crustal reflectors occur above the Moho (Pratt et al., 1988), however the origin and significance of these reflectors is less clear. Mantle anomalies in seismic velocity, discontinuity depth, and reflectivity indicate that variations in temperature and/or chemistry are present in the mantle beneath the study area (e.g. van der Lee et al., 2008; Courtier and Revenaugh, 2006). Shear wave splitting and receiver function analysis suggest subvertical mantle flow beneath the Piedmont and Coastal Plain, although the flow direction is unclear (van der Lee and Frederiksen, 2005; Long et al., 2010). Clearly, there is much work to be done to better image how structures throughout the crust and upper mantle may be interlinked.

The allochthonous Blue Ridge basement massif was thrust over early Paleozoic strata of the Valley & Ridge and structural relief across this boundary exceeds ~8 km in north-central Virginia (Fig. 1) (Evans, 1989). A major unresolved issue concerns the geometry of the Blue Ridge Fault zone (BRFZ) in the subsurface. Existing reflection profiles illustrate gently-dipping to sub-horizontal reflectors beneath Blue Ridge basement, which have traditionally been interpreted as Paleozoic shelf strata (Harris, et al., 1986; Pratt et al., 1988; Lampshire, 1994). However, mylonite zones exposed at the surface merge into these reflectors at depth (Bailey and Simpson, 1993; Chapman et al., 2003), suggesting that the BRFZ extends into the lower crust. Thus, the "thin-skinned" component of the orogen may not extend nearly as far eastward as previously thought.

The Virginia Piedmont includes a number of distinct terranes (e.g. the Hardware, Chopawamsic, and Goochland terranes) separated by dextral transpressive high-strain zones and faults (Fig. 1). Orogen-parallel displacement was significant, prior to the Alleghanian orogeny Virginia's Piedmont terranes were located from 100 to 500 km to the northeast in the north-central and northern Appalachians (Bobyarchick, 1981; Gates et al., 1988; Bailey et al., 2004). A number of distinct geophysical anomalies are imaged beneath Coastal Plain sediments (Fig. 1), although the significance and origin of these anomalies (Paleozoic sutures, Mesozoic mafic complexes, etc.) is uncertain (Snyder, 2005, Horton et al., 2010). The deep structure of these possible terrane-bounding zones and linkage to mantle structures is poorly resolved but can be addressed using the EarthScope Arrays.

The central Appalachians experienced rifting during the early Mesozoic, which reactivated Paleozoic structures and created the Culpeper/Barboursville, Scottsville, Richmond/Taylorsville basins (Fig. 1). The proposed Virginia transect crosses from an unrifted margin into the thinned crust beneath the Coastal Plain and would provide comparative data on basin geometry across the rift. Withjack et al. (1998) recognize post-Triassic tectonic inversion structures in many basins, but the magnitude and extent of inversion across the orogeny is unclear. Existing seismic data does not adequately discern whether basin-bounding faults are deep structures with an expression in the lower crust and mantle or are shallow localized structures consistent with an upper-plate rift setting.

Preliminary geochemical and petrographic analyses of alkaline Eocene volcanic rocks at Mole Hill in the central Shenandoah Valley indicate the presence of an Al-augite (clinopyroxenite) mantle with a temperature of ~1220° C at a pressure of 13 kbar, corresponding to a minimum Moho depth of ~39 km (Sacco et al., 2011). More detailed work on these enigmatic, young intrusive suites will test models of the thermal structure of the mantle and mechanisms of magma generation at passive continental margins. By matching crustal xenoliths to their parent rock formations through petrography and geochemistry (Kiracofe et al., 2011), existing structural models of the crust can be evaluated and provide a connection between surface observations and seismic data.

The proposed transect crosses the central Virginia Seismic Zone (CVSZ), a diffuse zone of moderate seismicity between Richmond and Charlottesville (Fig. 1) (Bollinger, 1973; Bollinger and Sibol, 1985). CVSZ earthquakes occur in the upper crust (<10 km) typically along moderately dipping reverse faults consistent with a subhorizontal σ_1 oriented northeast-southwest (Kim and Chapman, 2005). The magnitude 5.8 earthquake in August, 2011 was the largest seismic event in eastern North America in over a century and caused damage from central Virginia to Washington, D.C. The causative mechanism for seismicity in the CVSZ is poorly understood. Does faulting in the central Appalachians result from distal ridge-push stresses or from underlying mantle-derived stress fields?

<u>Summary</u>

The central Appalachians, and specifically the region of the proposed Virginia transect, demonstrate features not expected in a "typical" passive margin setting. Either this region is anomalous, or our preconceptions of old orogens and passive margins are too simplistic. In either case, we maintain that this central Appalachian transect has great potential to yield fundamental discoveries of the type that have characterized the best EarthScope projects to date. In addition, the Mid-Atlantic region has several large population centers, including Washington, D.C. Viewed from an education and outreach perspective, the recent D.C. area earthquake was a timely event that will enable us to highlight the arrival of the Transportable Array in the political center of the U.S. This will be a fantastic opportunity to showcase EarthScope science to policy makers. A focused project in the region, such as the one proposed here, has the potential to produce fundamental earth science discoveries and enhance public perception of our discipline.

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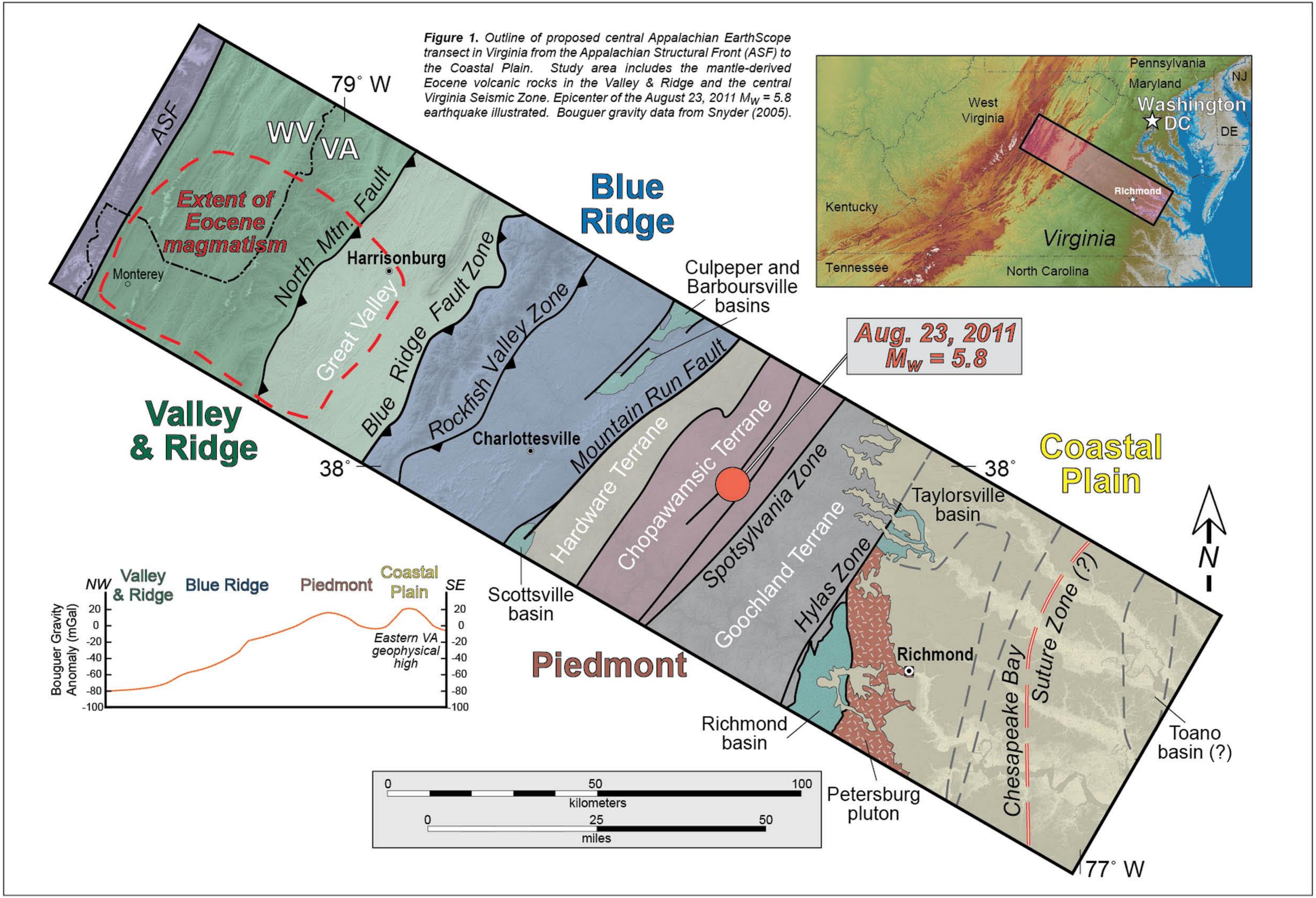

Figure 1. *Outline of proposed central Appalachian EarthScope transect in Virginia from the Appalachian Structural Front (ASF) to the Coastal Plain. Study area includes the mantle-derived Eocene volcanic rocks in the Valley & Ridge and the central Virginia Seismic Zone. Epicenter of the August 23, 2011* M_W *= 5.8 earthquake illustrated. Bouguer gravity data from Snyder (2005).*