EarthScope in the New England Appalachians: Structural inheritance and the long-term strength of continental lithosphere

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Introduction

Eastern North America is essentially the birthplace of the Wilson Cycle concept (Wilson, 1966). Since the Mesoproterozoic, the Appalachian region has undergone two cycles of supercontinent assembly and breakup. As a result, it is an ideal place to examine the problems of orogenic segmentation, structural inheritance, and the long-term strength of continental lithosphere, all of which are fundamental issues to orogenic belts worldwide. In the Appalachians, one long-standing hypothesis holds that 1) large, lithospheric-scale anisotropies were established during the Late Proterozoic–Early Cambrian rifting of eastern Laurentia and 2) these features have had a first-order influence on lithospheric behavior during subsequent contractional and extensional events. An evaluation of this hypothesis is essential, not only for understanding the origin of abrupt along-strike changes in the structure and tectonic history of the Appalachians, but also for determining the long-term (≥ 100 m.y.) strength and rheology of continental lithosphere.

Previous work in the northern Appalachians of Quebec and New England suggests that large, cross-strike fault systems in basement rocks partition the orogen into segments at scales ranging from 50 to 100's of km. These fault systems appear to have created long-lived zones of weakness that were reactivated repeatedly during the Paleozoic Taconian and Acadian orogenies and the Mesozoic opening of the Atlantic Ocean (Thomas, 2006). However, there is uncertainty about the size and spatial distribution of these features (Allen et al., 2009) and their possible effects on Appalachian tectonics. Much of the uncertainty comes from inadequate information on the structure of the deep crust and upper mantle beneath the New England Appalachians. Despite the recognition of large basement anisotropies, there is great uncertainty about their depth and character and how they may have affected the behavior of deforming continental lithosphere during a ≥ 500 million year period involving several orogenies and the opening of two ocean basins.

Specific questions include: 1) Are lithospheric-scale, cross-strike anisotropies present in the crust and mantle of the New England Appalachians, and, if so, do these anisotropies reflect segmentation inherited from the Neoproterozoic Iapetan rift margin of Laurentia? 2) What is the relationship between large, cross-strike anisotropies and the stratigraphy and structure of the upper crust, including Neoproterozoic rift and Cambro–Ordovician passive margin strata, Appalachian basement massifs, and early Mesozoic rift basins? 3) How did the geometry and spatial distribution of relic Neoproterozoic faults affect crustal and lithospheric strength and how did these variations affect subsequent orogenic and rifting events?

Possible long-lived crustal anisotropies beneath Vermont and Quebec

Using data collected from over 400 seismic lines and 120 wells, Theriault and Laliberte (2006) constructed several 3-D structural maps of Precambrian basement that underlies the St. Lawrence Lowlands Province of southern Quebec. The data reveal the presence of swarms of SSE-deepening normal faults that compartmentalize the crust and display an asymmetric, segmented pattern that is remarkably similar to the crustal- and lithospheric-scale segmentations observed in the East African rift system (Wolfenden et al., 2004; Mackenzie et al., 2005). Theriault and Laliberte (2006) also identified a second system of orthogonal E-W (cross-strike) faults that are interpreted to be genetically related to the formation of grabens and transforms during the drift phase of Iapetus. These faults typically form km-wide linear collapse zones and are postulated to have been reactivated during the early Paleozoic Taconian orogeny and again during subsequent rifting.

A similar reactivation of basement anisotropies also has been inferred for other parts of the New England Appalachians, including Vermont (Doolan et al., 1982; Crespi et al., 2010). In the Champlain Valley, abrupt changes in the thickness of synrift and postrift stratigraphy, facies transitions, and differential subsidence occur along the strike of the orogen (Dorsey et al., 1983; Cherichetti et al., 1998; Thompson et al., 2004; Kim et al., 2007). These zones appear to coincide with abrupt changes in depth to basement and thrust style (Doolan et al., 1982; Stanley and Ratcliffe, 1985), suggesting they represent long-lived basement anisotropies that partition the orogen into segments that differ in structure and tectonic history. Their apparent origin during or prior to the Late Proterozoic–Early Cambrian rifting of eastern Laurentia and influence on subsequent orogenic and rifting events suggest the heterogeneities are crustal or lithospheric in scale, making them prime targets for the USArray.

Basement massifs and inherited strength of continental lithosphere

In the New England Appalachians, Mesoproterozoic rocks are exposed in a series of basement massifs that lie along the outboard edge of Laurentia. The massifs are common in the New York promontory, disappear in the Quebec embayment, and reappear north of Quebec City, indicating that both their presence and behavior during orogenesis is spatially variable. Recent work in the Berkshire massif by Karabinos et al. (2008) suggests the massif behaved as a rigid block during the Middle to Late Ordovician Taconian orogeny. Previous workers (Stanley and Ratcliffe, 1985) suggested that the massif had undergone significant internal shortening via displacement along a network of Taconic-age thrust faults. However, new isotopic dates and field observations (Karabinos et al., 2008) contradict this interpretation and highlight this issue as an important problem to resolve.

The Berkshire massif and other basement massifs provide a window into understanding the mechanical behavior of the middle crust during orogenesis, and modern collisions can guide our understanding of these rocks, which commonly have long, complex histories. For example, in the active arc-continent collision in Taiwan, the Sanyi-Puli seismic zone marks the location of a partially subducted transform fault. The interpreted boundary between continental crust of normal thickness and transitional crust makes a leftward step across the transform, and the corner region of partially subducted, normal-thickness continental crust has low seismicity and acts as a strong indenter (Byrne et al., 2011). The Berkshire massif may have occupied an analogous structural location in the Taconic arc-continent collision. This can be tested by identifying the location of relic Iapetan transform faults in the New England Appalachians, and it has implications for understanding the heterogeneity and inheritance of crustal strength.

Importance of the New England Appalachians and links to processes in active rifts

Active rifts, including the East African rift system, show the important effects of lateral variations in lithospheric strength on rift processes. For example, in Kenya and northern Tanzania, the eastern branch of the rift is deflected and changes geometry where it encounters the thick, cold lithosphere of the Archean craton (Macdonald et al., 2001). Focused studies in the New England Appalachians that target lithospheric-scale, cross-strike anisotropies have the potential to illuminate the geometry of these anisotropies, their longevity, their effect on Appalachian contraction and Mesozoic extension, and their relation to lateral and vertical variations in strength of continental crust and lithosphere. Results of this work would further bear on seismic hazards and geothermal energy potential in the region.

Establishing a New England Appalachian *EarthScope* and *GeoPRISMS RIE* “Discovery Corridor” would build on and benefit from existing synergies such as strong state agency-university partnerships in the region that provide important undergraduate and graduate research opportunities. High-quality results are anticipated from the New England Appalachians for the following reasons: 1) On-the-ground geological work over the past 200 years has resulted in an excellent understanding of the Late Proterozoic–early Paleozoic rift-drift stratigraphy. 2) A collaborative effort between the Vermont Geological Survey and the USGS has resulted in a new bedrock geologic map of the entire state (Ratcliffe, 2010; Walsh et al., 2010). 3) Preliminary work has identified specific candidates for large, cross-strike faults. 4) Studies in the Quebec Appalachians have produced a superb geological and geophysical database, providing important context for understanding the New England segment of the Appalachians.

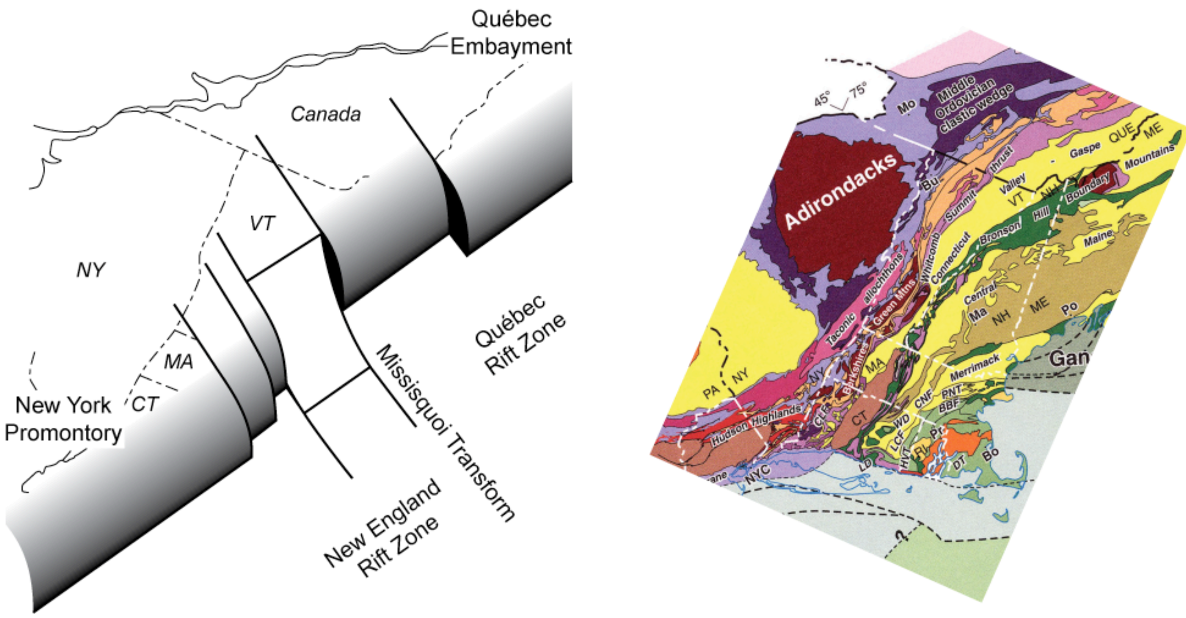

Figure 1. Interpreted segmentation of Iapetan rift margin and tectonic map of New England Appalachians. Modified from Fig. 3 of Allen et al. (2009) and Fig. 1 of Hatcher (2010), respectively.

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