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Orogenic bending around a rigid Proterozoic magmatic rift beneath the Central Appalachian Mountains

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ABSTRACT

The transition zone between the modern northern and southern Appalachian Mountains is located in Pennsylvania, where the structural orientation of the fold-and-thrust belt changes from north–south to east–west, and the orogeny narrows significantly. Vintage studies of wide-angle reflection and temporary broadband seismic data suggest that the crust beneath the ∼8 km of foreland basin sequences was thickened and heavily intruded around the margins of and beneath a failed Neoproterozoic rift. We use receiver function analysis of broadband seismic data recorded by additional and permanent stations, along with forward and inverse modeling of Bouguer gravity data to constrain the geometry and depth extent of mafic intrusion and underplating in the rift, as well as the role of this Proterozoic heterogeneity on the location and geometry of the curvature of the Appalachian orogen. The receiver function analyses suggest that the crust is ∼47–49 km thick beneath the ancient rift, about 5–7 km thicker than the surrounding area. Inverse models of gravity data indicate that the ∼300 km-long zone of thickened, high density crust is bounded on both the NW and SE sides by steep contacts; its shorter NE and SW margins are also steep contacts interpreted as crustal-scale faults. Forward modeling of the gravity data, constrained by the receiver function crustal thickness estimates, sparse seismic reflection data and Euler deconvolution solutions, implies that the Proterozoic rift has been heavily intruded as well as thickened by a 7–10 km mafic underplate. Its margins appear to have been sheared along NE-striking fault zones that parallel Appalachian thrust sheet transport directions. These combined results suggest that the mid- and lower-crust of the Proterozoic rift was enriched with pyroxene, which strengthened the crust locally and localized compressional strain along its margins during the North American–African collision. Compressional strain in the pre-Appalachian crystalline crust to the southwest and northeast of the Proterozoic rift may have been more distributed, leading to the formation of oblique-slip faults orthogonal to the axes of folds, and leading to the curvature in the Pennsylvania salient. Additionally, the thrust sheets are stacked most thickly in front of the rift, suggesting that the rift served as a backstop during collision.

1. Introduction

The origin of the curvature of the Central Appalachian mountains has been a topic of considerable debate for decades (e.g., Lefort and van der Voo, 1981; Gates and Valentino, 1991; Gray and Stamatakos, 1997; Wise, 2004; Ong et al., 2007). The Pennsylvania salient accommodates a nearly 90° bend in the structural orientation of the Appalachian orogen, where the fold-and-thrust belt orientation changes from a roughly north–south direction in southern Pennsylvania to a more east–west orientation (Fig. 1). The Pennsylvania salient also marks a narrowing of the Appalachian orogen, suggesting a change from thin-skinned to thick-skinned deformation, to be tested with future EarthScope data. Curved sections of orogens (salients and recesses) are common features in fold-and-thrust belts around the world, and there are a number of common interpretations for their origin, including primary curvature, rotational displacements, secondary curvature, rigid indenters, and the influence of irregular coastlines (Tapponnier and Molnar, 1976; Weil and Sussman, 2004). Models for the Pennsylvania salient include a rigid indenter on the African plate south of the bend (e.g., Lefort and van der Voo, 1981), and the New York promontory as a buttress (Gates and Valentino, 1991).

A combination of paleomagnetic, kinematic, and modeling studies of surface and shallow subsurface structural patterns have been used to assess the mechanism(s) for curvature, but there are

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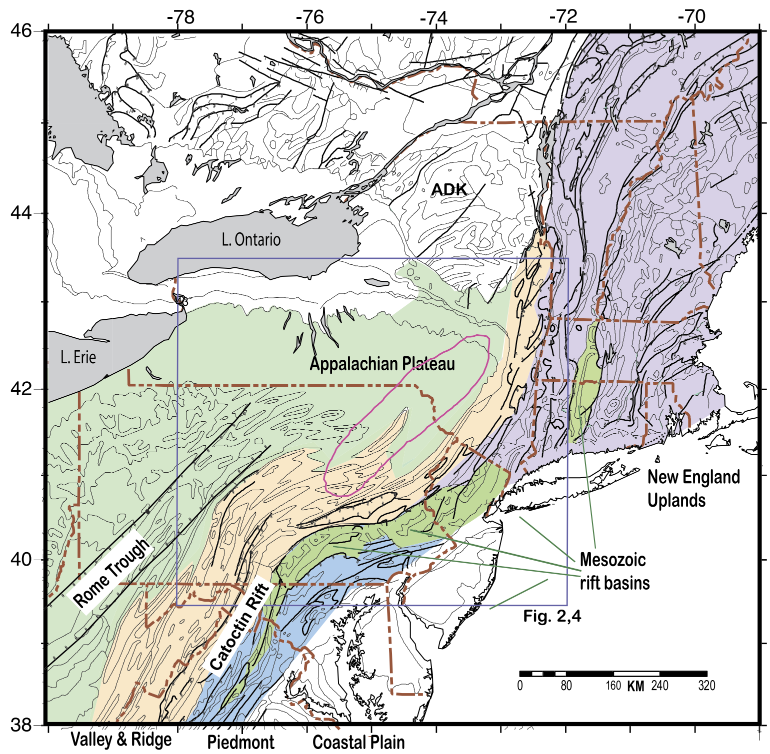

Fig. 1. Simplified geological map of the Central Appalachian orogen and surrounding regions. Structural data and lithological contours from Garrity and Soller (2009) and Baranowski et al. (2007). Colors indicate the major tectonic provinces of the Appalachian Plateau (green), Valley and Ridge (yellow), Piedmont (blue), New England Uplands (purple), Mesozoic rifts (green), coastal plain (white). The magenta line represents the −40 mGal contour of the Scranton gravity high. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

inconsistencies in both the data and interpretations for the origin of the Pennsylvania salient (e.g., Gates and Valentino, 1991; Ong et al., 2007; Wise, 2004). Notable is the minimal tangential extension within the fold and thrust belt through this bend, which restricts simple geometric models (e.g., Wise, 2004). Yet, little is known of the distribution of strain within the crystalline basement to the fold and thrust belt, or the role of pre-Appalachian heterogeneities on compressional tectonics. While a full assessment of the timing and kinematics of orogenic processes are needed to parse out the relative contributions of the possible mechanisms of curvature, it is striking that the structural trends in the Appalachian Mountains curve around the Scranton Bouguer gravity anomaly high, an elongated NE–SW striking, +60 mGal anomaly relative to the comparatively smooth regional field (Figs. 1, 2). Based largely on sparse geophysical data, the Scranton High has been interpreted as an abandoned Neoproterozoic rift basin (e.g., Diment et al., 1972; Rankin, 1976; Hawman, 1980; Hawman and Phinney, 1992a, 1992b). Based on high lower crustal velocities and the elongate geometry of the anomaly, Hawman and Phinney (1992a, 1992b) proposed a pre-Appalachian mafic rift zone gives rise to the Scranton Bouguer anomaly high, but made no links between the pre-Appalachian structure and the Pennsylvania salient. Later seismic reflection profiles confirm normal faults in the pre-Appalachian basement, and provide a more detailed 2D picture of the Paleozoic fold and thrust belt (Harrison et al., 2004).

In this paper, we use a combination of receiver function analysis from passive seismic stations and gravity analyses of data within a sector of the Central Appalachian orogen encompassing the Scranton Gravity High (Fig. 1). Our aims are to explore the 3D geometry of the proposed Proterozoic rift zone, and its implications for crustal rheology at the onset of Appalachian collision. Forward and inverse models of gravity data constrained by receiver function and vintage wide-angle seismic data support

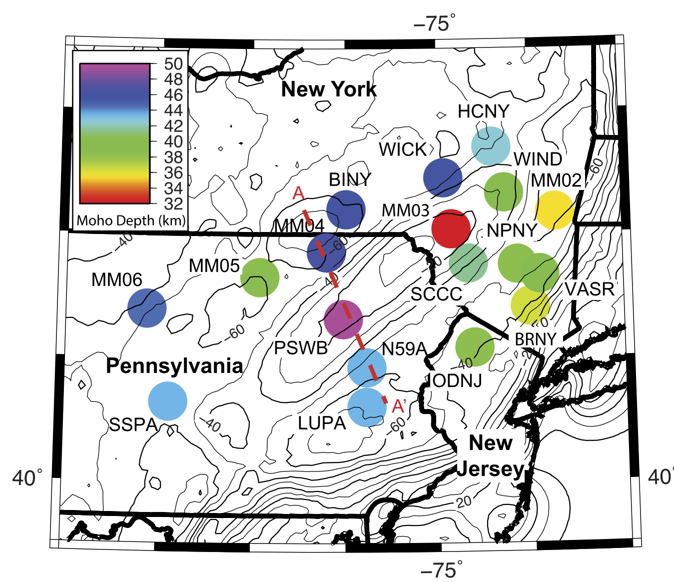

Fig. 2. Map of contours of Bouguer gravity anomalies and crustal thickness from H–k receiver function stacks (see Table 1).

the interpretation of a heavily underplated and intruded magmatic rift beneath the bend in the orocline. They also reveal evidence for steeply-dipping, NW-striking shear zones, suggesting thick-skinned, possibly transcurrent deformation along the SW and NE margins of the thickened crust. Using these results to build a geological model, we put forth the hypothesis that the mafic crustal block served as a rigid indenter to the overriding African plate during collision, with localized, thick-skinned compression along its margins, compared to more broadly distributed shorten-