Modeling the flexural and thermal subsidence of the 1.1 Ga Midcontinent Rift

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Abstract

The Midcontinent Rift (MCR) is a failed rift system that formed within the interior craton of Laurentia (Mesoproterozoic North America) and was active from ∼1110 to 1084 Ma. The MCR is notable in both its total volcanic output, which qualifies it as a large igenous province ($\geq 10^5$ km^3 by the criterion of Ernst et al., 2013), and its geometry, which qualifies it as a rift system. These two characteristics, while present together in the MCR, are not typically associated with each other as they are thought to derive from separate mechanisms. The MCR is therefore of great interest from a standpoint of geodynamics. No consensus has yet been reached on the geodynamic evolution and tectonic history of this ancient system.

A widely accepted timeline of MCR development has been inferred through seismic, geochemical, geochronologic and structural measurements (Cannon, 1989, 1992; White, 1997; Stein et al., 2015). However, there is no consensus on the syn- and post-rift flexural and thermal subsidence of the MCR. Understanding MCR subsidence is critical for inferring past structure from present observations. This study compiles and reviews the estimates of past investigations of MCR subsidence in the context of the MCR's broader developmental timeline. In doing so, I hope to produce a comprehensive overview of the MCR system similar to that presented by Stein et al. (2015) but with a more detailed treatment of the MCR's subsidence history.

INTRODUCTION

The Mesoproterozoic Midcontinent Rift (MCR) is the most prominent feature on gravity and magnetic maps of North America. The MCR primarily consists of thick flood basalt successions confined to a narrow zone extending northward from the Midwestern United States and looping back southward through Michigan, U.S. The origin of the MCR is an outstanding question in its scientific investigation. While the volume of volcanic rock in the MCR (∼1-2 $\times 10^6$ km^3; Hutchinson et al. (1990)) necessitates a mantle plume origin, it is unclear whether the plume had any role in the initiation of the rift itself. Recent studies suggest that the MCR formed in response to far-field tectonic stresses as Amazonia rifted from Laurentia, and ended once oceanic spreading between the two continents was successfully established Stein et al. (2014). This hypothesis (of an already active rift encountering a mantle plume by chance) is consistent with the idea that the small temperature perturbations (∼100-150° C above normal mantle temperatures) of hotspots can dramatically amplify the decompression magmatism of rift zones (White and McKenzie, 1989). Constraining the geodynamic evolution of the MCR is critical for evaluating such hypotheses and understanding the interaction of continental rifting with a mantle plume.

Cannon and Hinze (1992) used seismic data across Lake Superior to map the structure of the MCR and infer discrete stages of faulting and volcanism. This resulted in what is now generally accepted as the timeline of the MCR's geodynamic evolution. At ∼1110 Ma, rifting and incipient volcanism occur, followed by an outburst of "main" stage flood basalts confined to the central graben until ∼1095 Ma. Continued volcanism until the end of rifting at 1085 Ma results in flexural subsidence and sedimentation. While it has been proposed that crustal thickening also occurred during this last stage of rifting (Stein et al., 2015), it is unclear whether any significant thermal subsidence would have been prevented by the upwelling mantle plume (White, 1997).

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Hutchinson, D., White, R., Cannon, W., and Schulz, K., 1990, Keweenaw hot spot: Geophysical evidence for a 1.1 ga mantle plume beneath the midcontinent rift system: Journal of Geophysical Research: Solid Earth (1978–2012), vol. 95, pp. 10,869–10,884.

Stein, C. A., Kley, J., Stein, S., Hindle, D., and Keller, G. R., 2015, North america's midcontinent rift: When rift met lip: Geosphere, URL `http://geosphere.gsapubs.org/content/early/2015/08/13/GES01183.1.abstract N2 - Rifts are segmented linear depressions that are filled with sedimentary and igneous rocks; they form by extension and often evolve into plate boundaries. Flood basalts, a class of large igneous provinces (LIPs), are broad regions of extensive volcanism formed by sublithospheric processes. Typical rifts are not filled with flood basalts, and typical flood basalts are not associated with significant crustal extension and faulting. North America's Midcontinent Rift (MCR) is an unusual combination, because its 3000-km length formed during a continental breakup event 1.1 Ga, but it contains an enormous volume of igneous rocks that are mostly flood basalt. We show that MCR volcanic rocks are significantly thicker than other flood basalts, due to their deposition in a narrow rift rather than across a broad region, giving the MCR a rift's geometry but a LIP's magma volume. Structural modeling of seismic-reflection data shows that LIP volcanics were deposited during two phasesan initial rift phase where flood basalts filled a fault-controlled extending basin and a postrift phase where LIP volcanics and sediments were deposited in a thermally subsiding sag basin without associated faulting. The crust thinned during the initial rifting phase and then rethickened during the postrift phase and later compression, yielding the present thicker crust observed seismologically. The restriction of extension to a single normal fault in each rift segment, steeply inward-dipping rift shoulders with sharp hinges, and persistence of` `volcanism after rifting ended gave rise to a deep flood basaltfilled rift geometry not observed in other presently active or ancient rifts. The unusual coincidence of a rift and LIP arose when a new rift associated with continental breakup interacted with a mantle plume or overrode anomalously hot or fertile upper mantle.`

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