

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 igneous province ($\geq 10^5 \text{ km}^3$ 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. While the volume of volcanic rock in the MCR ($\sim 1\text{--}2 \times 10^6 \text{ km}^3$; 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 further interprets the MCR as a rift system that coincidentally encountered a mantle plume capable of generating LIP flood basalts, consistent with the idea that the small temperature perturbations ($\sim 100\text{--}150^\circ \text{ C}$ above normal mantle temperatures) of hotspots can dramatically amplify the decompression magmatism of rift zones White and McKenzie (1989). In order to resolve the broad-scale geodynamics of this LIP/rift duality, it becomes important to better understand the wholesale development of the MCR.

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, the post-rift thermal subsidence of the MCR and the development of the resulting sedimentary basin remains a more complicated and contentious storyline. This post-rift stage of final development is critical to inferring past structure from present observations. White (1997) inferred melting depth from REE inversion techniques, estimating that the lithosphere thinned from an original crustal thickness of 40 km with a β stretching factor of 6 McKenzie (1978). Significant thermal subsidence in the MCR would likely have been delayed until the hot, buoyant plume source died off, minimizing the subsidence that did occur before its interruption by the $\sim 1080 \text{ Ma}$ Grenville Orogeny White (1997). The magnitude of the Grenville compressional event may have been underestimated, as new paleomagnetic data suggest a total of 4000 km of crustal shortening Halls et al. (2015). Previous models of MCR subsidence should be reevaluated in this context. Flexural models of the MCR, e.g. Nyquist and Wang (1988), should also be revisited with considerations of longer wavelength loading, potentially greater erosion levels of the surface load, and/or possible correlation between flexural bulges susceptible to erosion and stratigraphic unconformities in the MCR.

This study will compile and review the estimates of past investigations of MCR subsidence as well as its broader developmental timeline. This will hopefully allow a comprehensive view of a multifaceted problem, similar to the overview presented by Stein et al. (2015) but with a more quantitative treatment of the MCR's subsidence history. I hope to update certain parameters of past models and reevaluate them in the context of recent work on the MCR. Just as White (1997) showed a buoyant plume and the syn-rift crustal upwarping to likely be responsible for the limited thermal subsidence in the MCR,

a thorough review of MCR syn- and post-rift development could prove to have important implications for the larger scale geodynamics of this ancient volcanic structure.

INTRODUCTION

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 igneous province ($\geq 10^5$ km³ 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. While the volume of volcanic rock in the MCR ($\sim 1\text{--}2 \times 10^6$ km³; 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 further interprets the MCR as a rift system that coincidentally encountered a mantle plume capable of generating LIP flood basalts, consistent with the idea that the small temperature perturbations ($\sim 100\text{--}150^\circ$ C above normal mantle temperatures) of hotspots can dramatically amplify the decompression magmatism of rift zones White and McKenzie (1989). In order to resolve the broad-scale geodynamics of this LIP/rift duality, it becomes important to better understand the wholesale development of the MCR.

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- 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 basalt-filled 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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