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Oceanic isostasy and the transition from continental rifting to seafloor spreading

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The transition from continental rifting to mature seafloor spreading is a key moment in rift evolution. This transition is central to the creation of new plates and the self-sustained nature of plate tectonics. However, reasons why rifts like the Mid-Continent rift in North America fail while the Laurasian and Gondwanan rifts progressed to become the Mid-Atlantic ridge are not well understood. The number of failed rifts across the planet suggest that some impetus must be reached before spreading becomes a self-sustaining process. A common supposition is that the transition occurs when a particular threshold of strain is met. However, the marked differences in strain history along the three limbs of the Afar Triple Junction run counter to this notion. While all three limbs exhibit a similar amount of extension starting before 20Ma, they show very different histories in their transitions to seafloor spreading. The transition from rifting to seafloor spreading in the Gulf of Aden occurred almost immediately after rift initiation. The transition in the Red Sea occurred as much as 15Myr later. Of course, the East African rift is still undergoing continental rifting. A long-overlooked process to facilitate stable seafloor spreading is outward directed mantle flow due to isostatic adjustment in the presence of an ocean atop a differentially subsiding substrate.

The presence of an ocean mass on subsiding lithosphere drives a small degree of flow in the asthenosphere to accommodate the excess mass accumulated on top during subsidence. The basic mathematics behind isostasy demonstrates that asthenospheric flow is systematically driven via isostasy from beneath younger seafloor toward older seafloor (Conder, 2012). This systematically directed flow is then always in the direction of relative plate motions, if not absolute plate motions. So, while the maximum flow rate may be small and variable, the drag is systematically positive - mantle push - on the overlying lithosphere. The rate of flow peaks beneath seafloor of about one-quarter the plate age, but continues to any age seafloor that is still subsiding. This flow may impart a plate-driving enhancement in early plate development. This isostatically-driven flow could lower the threshold that must be reached, making plate tectonics easier to self-sustain on a planet with a liquid ocean than on one without. The differences in strain history along the three Afar limbs may be an indicator of the efficacy of this mechanism. The Gulf of Aden, open to the Indian Ocean, was flooded virtually immediately upon rifting and made the transition to seafloor spreading with only minimal extension. The Red Sea limb remained disconnected from the sea for a much longer time and correspondingly transitioned to seafloor spreading at a much later date. The never-flooded East African limb exhibits a similar degree of stretching as the other limbs but remains in a stage of continental rifting. Whether the East African Rift eventually transitions to seafloor spreading or stalls as a failed rift may depend more strongly on becoming literal seafloor than previously recognized.