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The magmatic plumbing systems during the continent-ocean transition: the example of the Erta Ale rift, in Afar

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The Afar region provides a rare onshore glimpse into the dynamic processes of magmatic continental rifting and the progression towards continental break-up. This area features multiple active magmatic segments distinguished by varied morphologies, crustal thicknesses, rates of magma production, and magmatic-tectonic styles. In the Erta Ale Range rift segment, extension is accommodated magmatically, making it an ideal location to study the magmatic behavior of a mature rift segment. The Erta Ale Range includes sub-segments with magma compositions ranging from basalts to rhyolites, but only the Erta Ale Volcano (EAV) sub-segment is currently active, where only basaltic compositions have been reported so far. Our analyses of major and trace elements, along with isotopic studies of olivine crystals, interstitial glasses, and melt inclusions, combined with oxy-thermo-barometry and thermodynamic modeling, delineate the evolution of magma beneath EAV. We reveal extensive in-situ fractional crystallization within a shallow magmatic reservoir, evidenced by unique cognate gabbroic and microgabbroic blocks. These cognate samples uncover previously unknown mushy and evolved parts (up to 75 wt.% SiO2) of the EAV plumbing system. These findings highlight a sophisticated, transcrustal magmatic plumbing system that contrasts with typical oceanic rift systems, indicating a transitional phase in rift evolution. Our results suggest a magmatic plumbing system that extends up to 12 km in depth, accommodating the rift's extensional dynamics through both magmatic differentiation and tectonic processes. This system is indicative of a rift in an advanced stage of development yet not fully matured to oceanic spreading. Our findings contribute to refining the conceptual models of rift evolution by providing detailed insights into the magmatic and tectonic processes at a critical junction of the Afar rift system. The study emphasizes the complex nature of magmatic systems during the transitional phases of break-up and highlights the need for reconsidering the criteria used to determine the stages of continental break-up. We discuss this model within the geological contexts of the Erta Ale Range rift segment and the larger Afar region, and highlight contrasts with mature oceanic systems to argue that the region is not in the final stages of continental break-up.

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