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Investigation into the formation of large igneous provinces from the perspective of Earth's breakup and induced decompression melting

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After fifty years of mantle plume theory, the cause and effect remain subjects of intense debate. The scientific community is divided between those who believe that mantle plumes are fueled by a deep mantle source and those who argue for a shallow process related to plate tectonics. Although both the plume and plate hypotheses relate to the effect of thermal anomaly, few studies have attempted to explain the formation of initial thermal instability or the maintenance of magma sources for volcanism and large igneous provinces (LIPs). In this study, by considering the putative link between mantle dynamics, lithospheric breakup and flood basalts, we employ a three-dimensional spherical shell model to simulate the Earth's rifting process under thermal expansion. Based on the physical principles for the phase change of materials, we invoke a qualitative model of decompression-melting generation in rifting-induced abnormally-hot asthenosphere to explain that extra volume growth during the material phase change from solid to liquid can promote the coupling effect between pressure and temperature. Our fracture modeling shows that the shallow-based lithospheric process favors a no-root mantle plume as the source for volcanism. Continental rifting and breakup may be caused by the heat accumulation within the asthenosphere underneath the lithosphere, without the need for the existence of deep mantle plumes. Inversely, the fractures, particularly around triangle conjunctions, may release the stresses around their tips and accelerate the decompression melting, which in turn results in the thermal anomaly underneath the lithosphere inside which fractures develop. Our results reveal that pressure drops caused by uplift-induced rifting can accelerate decompression melting and provide the magma source for potential eruptions. Additionally, the significant increase in magma pressure, resulting from the abrupt volume expansion during the solid-to-liquid phase change, may act as the driving force of magma production. This process can become unstable if the coupling between melting pressure and temperature operates as a positive feedback loop. Such instability may lead to mantle dynamics emerging in a top-down pattern, offering insights into the rapid and voluminous magma eruptions characteristic of LIPs. Namely, the accumulated heat may result in expansion in the mantle which may promote uplifting, weakening and eventual breakup of the lithosphere, with huge outpouring of flood basalts, leading to the great events of LIPs. Furthermore, the associated cooling of the lithosphere occurs due to heat absorption during melting and heat loss during eruptions. This process provides a clear understanding of the short-lived yet massive nature of LIPs.

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