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Kimberlite ascent by rift-driven disruption of cratonic mantle keels

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Kimberlites are volatile-rich, occasionally diamond-bearing magmas that have erupted explosively at Earth's surface in the geologic past [1,2,3]. These enigmatic magmas, originating from depths exceeding 150 kilometres in Earth's mantle, occur in stable cratons and in pulses broadly synchronous with supercontinent cyclicity [4]. Whether their mobilization is driven by mantle plumes [5] or by mechanical weakening of cratonic lithosphere [4,6] remains unclear. Here we show that most kimberlites spanning the past billion years erupted about 30 million years after continental breakup, suggesting an association with rifting processes. Our dynamical and analytical models show that physically steep lithosphere-asthenosphere boundaries formed during rifting generate convective instabilities in the asthenosphere that slowly migrate many hundreds to thousands of kilometres inboard of rift zones. These instabilities endure many tens of millions of years after continental breakup and destabilize the basal tens of kilometres of the cratonic lithosphere, or keel. Displaced keel is replaced by hot, upwelling asthenosphere in the return flow, causing partial melting of decoupled, volatile-rich lithospheric material. Our calculations show that this process can generate small-volume, low-degree, volatile-rich melts, closely matching the characteristics expected of kimberlites [1,2,3]. Our model reconciles diagnostic kimberlite features including association with cratons and geochemical characteristics that implicate a common asthenospheric mantle source contaminated by cratonic lithosphere [7]. Together, these results provide a quantitative and mechanistic link between kimberlite episodicity and supercontinent cycles via progressive disruption of cratonic keels.

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