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Synchroneity of cratonic burial phases and gaps in the kimberlite record: Episodic magmatism or preservational bias?

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ABSTRACT

A variety of models are used to explain an apparent episodicity in kimberlite emplacement. Implicit in these models is the assumption that the preserved kimberlite record is largely complete. However, some cratons now mostly devoid of Phanerozoic cover underwent substantial Phanerozoic burial and erosion episodes that should be considered when evaluating models for global kimberlite distributions. Here we show a broad temporal coincidence between regional burial phases inferred from thermochronology and gaps in the kimberlite record in the Slave craton, Superior craton, and cratonic western Australia. A similar pattern exists in the Kaapvaal craton, although its magmatic, deposition, and erosion history differs in key ways from the other localities. One explanation for these observations is that there is a common cause of cratonic subsidence and suppression of kimberlite magmatism. Another possibility is that some apparent gaps in kimberlite magmatism are preservational artifacts. Even if kimberlites occurred during cratonic burial phases, the largest uppermost portions of the pipes would have been subsequently eroded along with the sedimentary rocks into which they were emplaced. In this model, kimberlite magmatism was more continuous than the preserved record suggests, implying that evidence for episodicity in kimberlite genesis should be carefully evaluated in light of potential preservational bias effects. Either way, the correlation between burial and kimberlite gaps suggests that cratonic surface histories are important for understanding global kimberlite patterns.

1. Introduction

Cratons preserve Earth's oldest rocks, are underlain by cold, thick, chemically-depleted mantle roots, and form the most stable portions of continents. Many cratons were pierced by kimberlite magmatism in a seemingly episodic fashion. Kimberlites are small-volume, volatile-rich, locally diamondiferous magmas (Mitchell, 1986) derived from hundreds of kilometers deep in the Earth (Ringwood et al., 1992) that are mostly restricted to cratonic regions. There is intense interest in the origin of kimberlites because they are the world's major source of diamonds, entrain rare mantle and lower crustal xenolith suites (Carlson et al., 1999; Griffin et al., 1999; Pearson et al., 2003; Kopylova and Caro, 2004; Canil, 2008), and offer an unusual window into mantle processes. Subduction (Sharp, 1974; Currie and Beaumont, 2011), continental rifting (Phipps, 1988), changes in plate motion (England and Housemann, 1984; Snyder and Lockhart, 2005), supercontinent amalgamation and breakup (Heaman et al., 2003; Jelsma et al., 2009; Tappe et al., 2014), plumes (Haggerty, 1994; Torsvik et al., 2010; Chalapathi Rao and Lehmann, 2011), and hot spot tracks (Crough et al., 1980; Heaman and Kjarsgaard, 2000) have all been invoked to explain episodic kimberlite magmatism. Documenting the spatial and temporal patterns of kimberlites is fundamental for evaluating models for their distribution.

The fact that kimberlites can be buried or eroded (Hawthorne, 1975) is well-recognized. For example, much exploration is focused on locating kimberlites buried under younger sedimentary cover, and detrital diamond deposits sourced from eroded pipes have long been mined (e.g., de Wit, 1999). Erosion also inherently biases global kimberlite age compilations toward the youngest pipes. However, little attention has been paid to systematic relationships that may exist between cratonic surface histories and these kimberlite distributions. This is partly because of the perception of extreme cratonic stability following cratonization, which in turn suggests that many present-day exposures of Precambrian cratonic basement were at near-surface conditions throughout the Phanerozoic.

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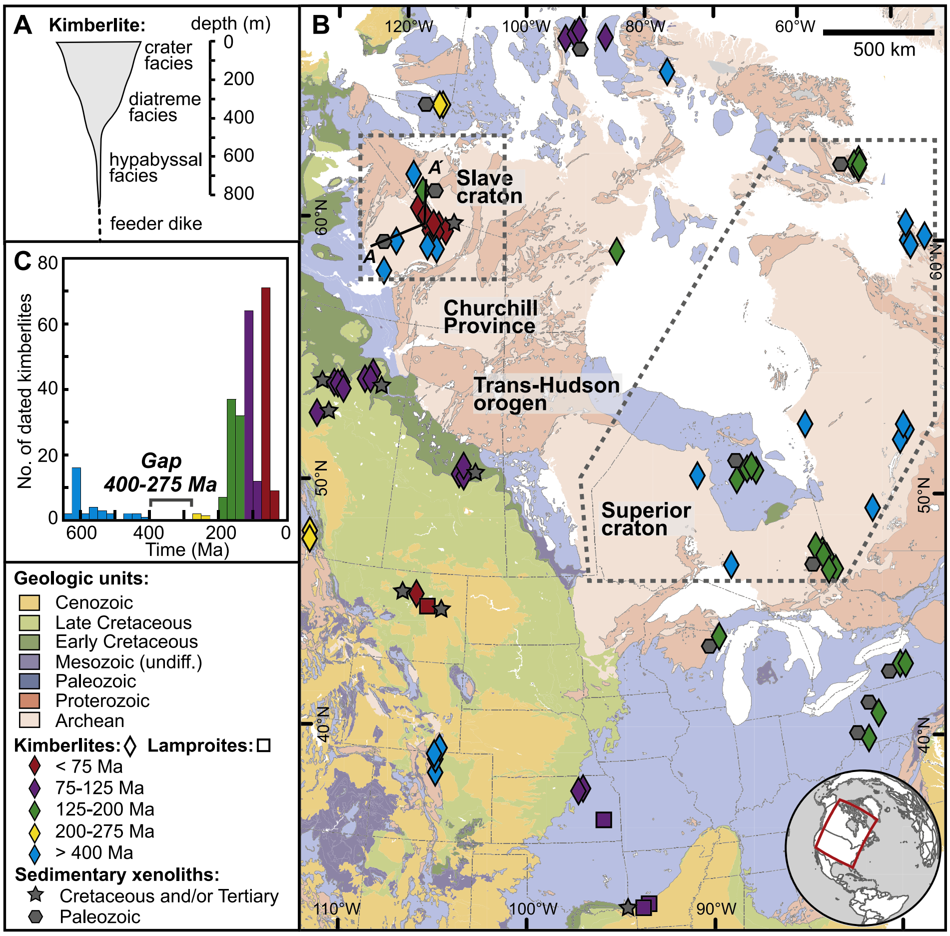

Fig. 1. A. Schematic cross-section of typical North American kimberlite with facies and associated depths. After Field and Scott-Smith (1999). **B.** Simplified geologic map of North America showing locations and ages of kimberlite and lamproite pipes. Kimberlite fields with sedimentary xenoliths of known age are marked with grey symbols. Solid line is cross-section A–A′ for Fig. 2B. Dashed polygons outline the regions considered in the kimberlite age histograms in Figs. 3A and 3D. **C.** Histogram of available kimberlite ages (Heaman et al., 2004, 2012) from 650 Ma to present illustrating a gap in reported ages from ∼400 to 275 Ma for the region in **A**. (For a color version of this and all other figures, the reader is referred to the web version of this article.)

Contrary to this view, it is now clear that some cratons experienced substantial burial (1–4 km), unroofing, and elevation change long after initial cratonic stabilization (e.g., Mitrovica et al., 1989; Gurnis, 1993; Pysklywec and Mitrovica, 1998; Flowers et al., 2012; Ault et al., 2013). The long wavelength (>1000 km) character of the elevation change, its occurrence distal from tectonic boundaries, and the lack of significant associated crustal deformation suggests dynamic topography as a probable cause (Flowers et al., 2012; Zhang et al., 2012; Ault et al., 2013). Here we evaluate the relationship between cratonic burial and unroofing histories and kimberlite distributions. We find that substantial burial phases coincide with recognized gaps in the kimberlite record in several cratons worldwide, and then highlight potential causes and consequences of this relationship.

2. Constraining burial and erosion histories in cratons

2.1. Approach

Low temperature thermochronology can constrain the thermal history associated with low amplitude depositional and erosional episodes across cratons, even when the deposited rocks were subsequently eroded. Apatite (U–Th)/He (AHe) thermochronology is sensitive to temperatures of 30–90 °C, depending on radiation damage (Farley, 2000; Shuster et al., 2006; Flowers et al., 2009). The influence of radiation damage can produce positive correlations between AHe date and effective U concentration (eU) for some types of protracted thermal histories, like those common in cratonic settings (Flowers, 2009). This effect can account for previously inexplicable dispersion in some AHe datasets from cratons, which has subsequently enabled the effective application and interpretation of AHe data from these regions (e.g., Ault et al., 2009; Flowers and Kelley, 2011). The apatite fission-track (AFT) method provides complementary information about thermal histories in the 60–120 °C temperature range, depending on apatite composition (Gallagher et al., 1998; Gleadow et al., 2002a). This technique has a longer history of application in cratonic settings (e.g., Crowley et al., 1986; Harman et al., 1998; Osadetz et al., 2002). Thermal histories derived from low temperature thermochronology data are converted into burial and unroofing histories assuming appropriate geothermal gradients and surface temperatures. Here we refer to burial and unroofing as addition or removal of sediments or rocks by deposition and erosion, respectively. This terminology is distinct from subsidence and surface uplift, which represent changes in elevation of the Earth's surface (e.g., England and Molnar, 1990).

Kimberlites provide a unique window into cratonic depositional and erosional histories (e.g., Hanson et al., 2009; Ault et al., 2013; Stanley et al., 2013). The presence of downrafted sedimentary xenoliths in kimberlites indicates that sedimentary rocks covered the cratonic basement at the time of pipe emplacement, even if the sedimentary cover was subsequently eroded away. The upper portions of kimberlites are characterized by diagnostic facies corresponding to specific depths that can be used to constrain erosion level (e.g., Fig. 1A). North American kimberlites are relatively