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Mid- and Late Cretaceous N American Kimberlite Magmatism: A comprehensive Tectonic model

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Introduction

Kimberlites are almost invariably interpreted as products of rift-related mantle upwelling, upper mantle convective processes, or the ascent of deep-seated mantle plumes (Giuliani et al., 2023). Less often, kimberlites have been explained as upper plate responses to shallow subduction or changes in the geometry of subducting oceanic plates (Heaman et al., 2004). Kimberlite provinces that are characterized by age progressions are assumed to be products of the drift of continents over relatively stationary mantle plumes or stagnated slabs of previously subducted oceanic lithosphere (Heaman and Kjarsgaard, 2000). These 'intrinsic' models ascribe kimberlite magmatism to mantle processes and assume that the lithosphere's role is negligible. Here we use the Cretacoues kimberlites of North America to explore the suggestion that kimberlite emplacement may be opportunistic, and dependent upon the lithosphere and the processes acting upon it.

Cretaceous Kimberlites of North America

North American Cretaceous kimberlites yield a complicated space-time distribution. Mid-Cretaceous kimberlites defines a N-S trending, continental-scale kimberlite magmatic belt referred to as the Central Cretaceous kimberlite corridor (CCKC, Kjarsgaard et al., 2017). The CCKC extends from Somerset Island, Nunavut, in the north, through Saskatchewan, Canada, to Kansas in the south. CCKC kimberlite magmatism began at ~110 Ma and ended abruptly at 95 Ma. Termination of CCKC kimberlite magmatism was followed by the emplacement of kimberlites of the Northern Alberta Kimberlite Province (Eccles et al., 2004) beginning with the Mountain Lake kimberlite swarm at ~90 Ma, >600 km west of the CCKC. The Mountain Lake swarm was followed at 85 Ma by emplacement of the Buffalo Head Hills kimberlite swarm, ~200 km east of the Mountain Lake Swarm. Finally, the Birch Mountains Field kimberlite swarm was emplaced at 75 Ma, almost 150 km east of the Buffalo Head Hills swarm (Chen et al., 2020).

We previously showed that CCKC kimberlite magmatism was coeval with the voluminous intrusions of the arc-related Omineca Magmatic Belt (OMB) that characterizes the eastern Cordilleran Orogen of Alberta and BC (Zhang et al., 2019). Models of the OMB as a product of west-dipping subduction of North American oceanic lithosphere beneath the eastern side of the Cordillera (Johnston, 2008; Johnston and Borel, 2007) explains the CCKC. In this model, CCKC magmatism contemporaneous with the OMB is attributable to extensional stress acting on the continent as it flexed upon entry into the trench. Using a semi-infinite elastic beam model, we demonstrated that flexure of a subducting continental plate (elastic thickness = 120 km) produces tensile stresses in the deep continental lithosphere, coincident with the location of the CCKC (Zhang et al., 2019). Slab break-off upon entry of continental North American lithosphere into the Cordilleran trench terminated both OMB and CCKC magmatism.

Slab breakoff may also explain the origin of the eastward-migrating Late Cretaceous kimberlite swarms of the Northern Alberta Kimberlite Province. Assuming that the west-subducting oceanic lithosphere broke off beneath the OMB arc at a depth of 100 km and that the detached slab sank at a rate of 1 cm/a while the overriding North American lithosphere (now including the Cordillera) continued to migrate west in a mantle reference frame at 2.5 cm/a, the top of the subducting slab will, from a North American perspective, appear to descend to the east beneath the continent. Mapping the broken slabs eastward descent reveals that the eastward migrating Alberta kimberlite swarms track the descending top of the broken off slab. In this model the Late Cretaceous kimberlite swarms resulted from continental flexure, yielding an extensional stress across the base of the lithosphere. Flexure here was a response to dynamic subsidence induced by passage over the vertically sinking slab. The top of the sinking slab likely intercepted the 410 km mantle discontinuity at ~70 Ma. Stalling of the slab in the transition zone, followed by renewed sinking, may explain the even more easterly Paleogene Lac des Gras kimberlites, including those of the Ekati and Diavik mines.

Discussion

Our model explains the CCKC, the westward jump of kimberlitic magmatism upon termination of CCKC magmatism, and its subsequent eastward migration as opportunistic responses to: 1) flexure of the cratonic lithosphere as it attempted to subduct beneath the east margin of the Cordillera, and 2) dynamic subsidence as the continent travelled west over the broken off oceanic slab that had been subducting beneath the Cordillera, respectively. Our explanation of the North Alberta Kimberlite Provinces differs from previous models, all of which favoured intrinsic mantle processes, including either the presence of a deep seated mantle plume, or convective upwelling, potentially above a slab remnant of a plate subducted to the east beneath the west side of the continent that had stalled in the transition zone (Chen et al., 2020). The intrinsic models predict mantle upwelling beneath the westward-drifting cratonic lithosphere, whereas our opportunistic model predicts downwelling, providing us with a test of the models.

Kimberlites of the North Alberta Kimberlite Province intrude Cretaceous and older strata of the Western Canadian Foreland Basin. Foreland basin subsidence has been explained as a product of crustal loading by the emplacement of the thrust sheets of the Rocky Mountain fold and thrust belt (Beaumont, 1981). However, geodynamic studies show that thrust load related subsidence is significant only within ~200 km of the thrust front (Liu et al., 2014; Liu and Nummedal, 2004) and that dynamic subsidence explains the majority of the Cretaceous strata of the foreland basin (Tufano and Pietras, 2017). Significantly, not only are the Cretaceous strata intruded by the Late Cretaceous kimberlites attributable to dynamic subsidence, but the locus of dynamic subsidence similarly migrated eastward at the same rate as the kimberlite magmatism (Chang and Liu, 2020). The intrusion of kimberlites into the locus of a dynamically subsiding, easterly-migrating basin strongly supports an opportunistic model of kimberlite emplacement into cratonic lithosphere being dynamically pulled down, likely due to westward drift over the sinking of a broken-off slab that subducted beneath the eastern margin of the Cordillera.

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