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Craton reactivation on the Labrador Sea margins: $^{40}Ar/^{39}Ar$ age and Sr–Nd–Hf–Pb isotope constraints from alkaline and carbonatite intrusives

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Abstract

The once-contiguous North Atlantic craton (NAC) is crosscut by the Labrador Sea that opened during the Early Cenozoic after extensive Mesozoic continental rifting and removal of cratonic mantle. This large-scale structural change within the cratonic lithosphere was followed at about 150 Ma by the cessation of ultrapotassic and potassic-to-carbonatitic magma production, which had prevailed throughout much of the NAC history. At Aillik Bay, a sequence of olivine lamproites (1374.2±4.2 Ma, 2σ), aillikites/carbonatites (590–555 Ma), and nephelinites (141.6±1.0 Ma, 2σ) erupted through the southern NAC edge on the present-day Labrador Sea margin. Links between these alkaline magma types with diverse petrogeneses as a consequence of large-scale processes in the lithospheric mantle over a period of 1200 Myr are demonstrated utilizing their Sr–Nd–Hf–Pb isotope compositions.

The Mesoproterozoic olivine lamproites are characterized by unradiogenic Nd ($\varepsilon_{Nd(i)}=-8.4$ to -5.4), Hf ($\varepsilon_{Hf(i)}=-11$ to -7.8), and Pb ($^{206}Pb/^{204}Pb_{(i)}=14.2$–$14.8$) but moderately radiogenic Sr isotope compositions ($^{87}Sr/^{86}Sr_{(i)}=0.7047$–$0.7062$) fingerprinting long-term enriched cratonic mantle, which must have reached to depths of more than 150 km at this time. In contrast, Neoproterozoic carbonate-rich aillikites and carbonatites have fairly radiogenic Nd ($\varepsilon_{Nd(i)}=0.1$–1.8), Hf ($\varepsilon_{Hf(i)}=-0.9$ to $+2.6$), and Pb ($^{206}Pb/^{204}Pb_{(i)}=17.5$–$18.8$) but unradiogenic Sr isotope compositions ($^{87}Sr/^{86}Sr_{(i)}=0.7033$–$0.7046$) that point to the involvement of convective upper mantle material during melting. Simple binary mixing calculations coupled with the observation that carbonate-rich magmatism prevailed for over 30 Myr in the area imply a complex pattern of lithosphere–asthenosphere interaction at depths between ~180 and 140 km. The Cretaceous nephelinites have slightly unradiogenic Nd ($\varepsilon_{Nd(i)}=-4$ to -1.4), moderately radiogenic initial $^{87}Sr/^{86}Sr$ (0.7044–0.7062), but initial ε_{Hf} (-3.3 to $+1.4$) similar to the aillikites and highly radiogenic Pb ($^{206}Pb/^{204}Pb_{(i)}=19.1$–$20.2$) isotope compositions. Their sodic mafic alkaline nature reflects partial melting at a higher level of

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the cratonic mantle tapping metasomatic components that had been introduced during the >30 Myr of Neoproterozoic aillikite/carbonatite magmatism.

The new $^{40}Ar/^{39}Ar$ age and Sr–Nd–Hf–Pb isotope data, along with petrological arguments, suggest that at least 30 km of the cratonic mantle beneath the southern NAC edge had been replaced by the hotter upwelling asthenosphere between ca. 550 Ma, when a thick diamond-bearing lithosphere was present, and 150 Ma. This lithospheric thinning presumably occurred shortly prior to Cretaceous continental rifting in response to enhanced plate-tectonic stresses focused at this zone of persistent lithospheric weakness. It appears, however, that the recurrent volatile-rich alkaline magmatism and associated mantle metasomatism played an important role in destroying the structural integrity of the cratonic mantle thereby aiding the subsequent lithosphere thinning.

Keywords: aillikite; carbonatite metasomatism; lamproite; lithosphere thinning; nephelinite; North Atlantic craton

1. Introduction

Cratons are crustal domains that have remained stable since the Early Precambrian and now form continental nuclei. Their apparent stability with long preservation of ancient felsic crust has been demonstrated to be linked to the composition and structure of the underlying lithospheric mantle roots [1–3]. These cratonic roots may reach to depths of more than 200 km and have been depleted in melt and dehydrated during Archean geodynamic processes [4]. They are chemically buoyant and highly viscous, and are able to reside in a dynamic mantle for billions of years [5]. However, this paradigm is in conflict with cratonic lithosphere reactivation being increasingly recognized as an alternative process that shapes the continents [6–10]. The best documented example for removal of ancient lithosphere is the North China craton where Archean crust is underlain by young and hot oceanic-type mantle [6,11,12]. A case for even more advanced cratonic lithosphere destruction can be made for the separated North Atlantic craton (NAC; Fig. 1), with remnants being preserved in West Greenland and coastal Labrador [13,14]. The NAC has experienced several aborted rifting events since Mesoproterozoic time ([10] and references therein), but convective thinning of the cratonic lithospheric mantle culminated during the Early Cenozoic opening of the Labrador Sea followed by a short period of ocean floor formation [15,16].

The West Greenland margin of the Labrador Sea rift has been known for the recurrence of deep alkaline magma production for 15 yrs, and this was explained in terms of zones of persistent lithospheric weakness spatially controlling the magmatism [17]. This is further substantiated by recent discoveries of analogue alkaline rock associations at the conjugate Canadian margin, which precisely fit into this temporal pattern [10,18–21]. To date, Mesoproterozoic lamproites (ca. 1400–1200 Ma), Neoproterozoic ultramafic lamprophyres (UML) plus related carbonatites (ca. 610–550 Ma), and Cretaceous mafic alkaline rock suites (ca. 150–100 Ma) have been found forming dyke swarms or central-complex intrusions on either side of the Labrador Sea (Fig. 1). However, the Aillik Bay locality at the central Labrador coast is unique in that all three magmatic pulses have been identified cutting through the NAC crust in a small area [10].

We have undertaken a $^{40}Ar/^{39}Ar$ geochronology, chemical, and Sr–Nd–Hf–Pb isotope study on the lamproites, UMLs/carbonatites, and mafic alkaline rock suites from the Aillik Bay area in an attempt to understand the nature and evolution of their source regions. The time-integrated isotope data, combined with findings from experimental petrology, allow evaluation of compositional and structural changes that occurred within the NAC mantle lithosphere before its break-up. Our proposed model suggests that at least 30 km of lithospheric mantle at the craton margin had been convectively removed by ca. 150 Ma, prior to the initiation of Cretaceous continental rifting that eventually led to sea-floor spreading in the Labrador Sea basin at ca. 60 Ma.

2. Geological background

2.1. Rifted North Atlantic craton

The Early Archean tonalitic crust of northern Labrador and western Greenland is among the oldest preserved on Earth [14]. It shares many compositional and structural features that allow assignment to a common Archean province [13,22]. This ancient micro-continent, which is commonly referred to as the North Atlantic craton (Fig. 1), was incorporated into the Laurentia plate assembly [23] during a sequence of subduction and collision events with neighbouring continental terrains between ca. 1900 and 1700 Ma [24]. The Paleoproterozoic collision zones are preserved