Lithos 112S (2009) 747–757

Contents lists available at ScienceDirect

Lithos

journal homepage: www.elsevier.com/locate/lithos

Sulphide survival and diamond genesis during formation and evolution of Archaean subcontinental lithosphere: A comparison between the Slave and Kaapvaal cratons

Sonja Aulbach [a,*], Thomas Stachel [a], Robert A. Creaser [a], Larry M. Heaman [a], Steven B. Shirey [b], Karlis Muehlenbachs [a], David Eichenberg [c], Jeff W. Harris [d]

[a] Earth & Atmospheric Sciences, University of Alberta, Edmonton AB, Canada
[b] Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington DC, USA
[c] Diavik Diamond Mines, Yellowknife, NT, Canada
[d] Department of Geographical and Earth Sciences, University of Glasgow, Glasgow, UK

ARTICLE INFO

Article history:
Received 26 September 2008
Accepted 28 March 2009
Available online 17 April 2009

Keywords:
Sulphide inclusion Re/Os
Diamond formation
Peridotite
Eclogite
Subduction
Subcontinental lithospheric mantle

ABSTRACT

Sulphide inclusions from 35 eclogitic and 7 peridotitic diamonds from the Diavik kimberlites in the central Slave craton have been characterized to address questions of diamond age and craton formation. Eclogitic sulphide inclusions occur in diamonds with mantle-like $\delta^{13}C$ (-4.94 ± 0.72 1σ) and low N aggregation states (%N as $B = 8.2 \pm 10.0$, average N contents of 720 ppm) indicative of relatively low mantle residence temperatures. A 1.86 ± 0.19 Ga Re–Os age array for eclogitic sulphides with suprachondritic initial $^{187}Os/^{188}Os$ of 0.13 (± 0.10) indicates a close temporal link between eclogitic diamond formation, eclogite emplacement and collisional events affecting the Slave craton. Sulphides in peridotitic diamonds plot on older, previously established 3.3 and 3.5 Ga isochrons, consistent with higher average N aggregation states (~20%) despite lower N contents (~230 ppm) for their host diamonds compared to eclogitic diamonds.

Two intriguing observations emerge from a comparison of diamond populations and formation ages between the Slave and Kaapvaal that indicate fundamentally different and common diamond formation mechanisms, respectively: (1) Despite the general abundance of peridotitic silicate inclusions, peridotitic sulphide inclusions are rare in the Kaapvaal and occur in relatively young diamonds whereas in the central Slave there is a sizable Archaean population. (2) Compared to the distribution of silicate inclusions in diamonds, both cratons have an overabundance of eclogitic relative to peridotitic sulphide inclusions.

During Kaapvaal lithospheric mantle formation, large melting intervals, as gauged by extremely depleted silicate inclusions in diamonds, led to exhaustion of sulphide in the residue. Formation of peridotitic sulphide inclusion-bearing diamonds occurred only significantly later, after re-sulphidation accompanying metasomatism. By contrast, the less depleted deep lithospheric mantle beneath the central Slave craton may have formed during plume subcretion, leading to smaller melting intervals due to the presence of a pre-existing lithospheric mantle lid, thereby allowing for coeval precipitation of sulphide inclusion-bearing diamonds.

Abundant eclogitic sulphide inclusion-bearing diamonds that can be related to accretionary processes along the edges of the Slave and Kaapvaal craton indicate that sulphide-saturated eclogite is a fertile source for diamond formation. Reduced fluids from dehydration of underlying seawater-altered peridotite may react with the overlying oceanic crust to precipitate eclogitic sulphide-bearing diamonds penecontemporaneously with metamorphism and tectonic emplacement of eclogite into the subcratonic lithosphere.

1. Introduction

The study of mineral inclusions in diamonds not only allows insights into conditions of diamond formation but such inclusions also preserve signatures of lithospheric mantle processes uncorrupted by later modification. Sulphides are frequently included in diamond (Harris, 1992) and contain sufficiently high amounts of Re and Os to allow analysis of single grains for Re–Os isotope compositions. For syngenetic sulphide inclusions Re–Os isotopic analyses yield model or isochron ages that date diamond formation events. Such work has provided valuable information on diamond formation ages for the well-studied Kaapvaal craton (e.g. Pearson et al., 1998; Richardson et al., 2001, 2004) and the Siberian craton (Pearson et al., 1999a,b). For the Slave craton in northern Canada, so far only one set of exclusively peridotitic diamonds from the Panda kimberlite has been analysed (Westerlund et al., 2006).

Sulphide inclusions in diamonds from two Lac de Gras kimberlites (A154 South and North pipes, Diavik Diamond Mines) in the central Slave craton were studied in order to characterize these sulphides

* Corresponding author. Tel.: +1 780 492 8668; fax: +1 780 492 2030.
E-mail address: aulbach@ualberta.ca (S. Aulbach).

0024-4937/$ – see front matter © 2009 Published by Elsevier B.V.
doi:10.1016/j.lithos.2009.03.048

with regard to their major element and Re–Os elemental and isotopic compositions, to obtain the first diamond formation ages for this locality. The diamond hosts were analysed for their carbon isotope composition, nitrogen content and aggregation state (mainly temperature-dependent coalescence of singly substituted N into pairs and aggregates of four; Evans and Harris, 1989; Taylor et al., 1990) to obtain further constraints on diamond formation conditions.

Combining these results with a previous study on peridotitic sulphide inclusions from the nearby Panda kimberlite (Ekati Mine; Westerlund et al., 2006) allows for a preliminary comparison of the timing and conditions of diamond formation within and between the Slave and in the Kaapvaal cratons (the latter summarized in Shirey et al., 2004; Stachel and Harris, 2008). This comparison shows that diamond formation beneath the two cratons differed in terms of the timing of diamond crystallisation relative to lithosphere formation and with respect to the relative abundances and ages of peridotitic and eclogitic sulphide inclusion-bearing diamonds.

2. Geology and samples

The evolution of the Slave craton crust and subcontinental lithospheric mantle has been recently summarized in Davis et al. (2003), Aulbach et al. (2007), Snyder (2008) and Helmstaedt (this issue). The Slave craton consists of an ancient central to western domain (4.0 to 2.8 Ga) that includes the 4.03–3.9 Ga Acasta Gneiss Complex and a juvenile eastern domain (~2.7 Ga), which may have been amalgamated during ca 2.7 Ga collision, with the north–south-trending suture at depth crossing through the Lac de Gras area (Bleeker et al., 1999a,b; Davis et al., 2003). Gneisses just west of Lac de Gras have been dated to >3 Ga, suggesting that this basement complex and possibly its mantle should extend to the east in the subsurface to at least the Lac de Gras area (Bleeker et al., 1999a), which is consistent with the Palaeoarchaean ages derived from samples of the underlying lithospheric mantle: shallow lithospheric mantle formation during accretionary processes at ca 3.5 Ga is deduced from a Re–Os isochron age of peridotitic sulphide inclusions in diamonds from the Panda kimberlite, central Slave craton (Westerlund et al., 2006). The deeper lithospheric mantle beneath the Slave has been suggested to derive from plume subcretion (Griffin et al., 1999; Aulbach et al., 2007) that was dated to 3.3 Ga based on Re–Os isotope systematics of sulphide inclusions in peridotitic kimberlite-hosted xenocrysts (Aulbach et al., 2004).

Although there is strong evidence for the crustal dichotomy between a west-central ancient basement complex and a more juvenile eastern Slave crust, it remains unresolved whether there actually was subduction and true arc accretion of an allochthonous arc; alternative explanations for such crustal heterogeneity include marginal basin and arc formation (Davis et al., 2003). Prior to any possible amalgamation (at ca 2.69 Ga), the Central Slave Basement Complex went through a rifting event, emplacing numerous tholeiitic dykes and thick basalt sequences between ca 2.73 and 2.70 Ga (Bleeker, 2003). This was followed by widespread calc-alkaline volcanism (2.70–2.66 Ga), deposition of turbidite sequences (2.66–2.63 Ga) and intrusion of voluminous granites (2.6–2.58 Ga) (Davis et al., 2003).

Between ca 2.1 and 1.8 Ga, the craton was affected by repeated episodes of terrane accretion at its margins (summarized in Hoffman, 1989). Multiple events of mafic dike emplacement in the Proterozoic, most notably the ca 1.27 Ga Mackenzie dike swarm (LeCheminant and Heaman, 1989), also modified the Slave lithosphere. In the central Slave craton, Cretaceous to Eocene kimberlite magmatism (Creaser et al., 2004; Heaman et al., 2004) entrained eclogitic, websteritic/pyroxenitic, and peridotitic xenoliths and xenocrysts, including diamonds (Pearson et al., 1999a,b; Griffin et al., 1999; Davies et al., 1999, 2004; Stachel et al., 2003; Donnelly et al., 2007; Creighton et al., 2008).

Diamonds were selected from the A154 South and North kimberlites (Diavik Diamond Mines), which are located in the Northwest Territories, ~300 km northeast of Yellowknife and for which a 55 Ma emplacement age was determined (Graham et al., 1999). A previous study on silicate inclusion-bearing diamonds from these kimberlites has revealed a preponderance of peridotitic inclusions (83%) over eclogitic inclusions (12%; the remainder being ferropericlase and undetermined parageneses), with the former having higher overall CaO contents and lower Mg-numbers (100 Mg/(Mg + Fe)) compared to the Kaapvaal craton, as well as low N aggregation states, pointing to diamond formation in a less depleted, cool (i.e. shallow) mantle source (Donnelly et al., 2007). The paragenetic abundances at Diavik differ from those at neighbouring kimberlites, such as pipe DO27 where eclogitic and superdeep silicate inclusions are abundant (Davies et al., 1999) and Panda where

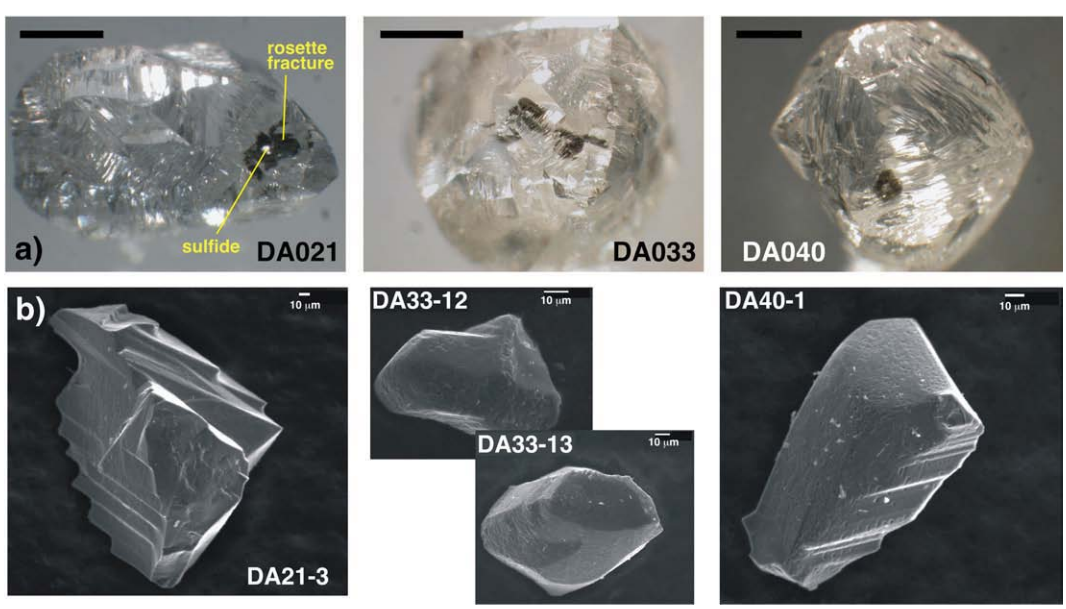

Fig. 1. a) Images (visible light) of some of the diamonds from the Diavik kimberlites containing sulphide inclusions displaying typical black rosette fractures; black bar corresponds to 1 mm. b) SEM images (in secondary electron mode) of sulphide inclusions visible in (a) and for which Re–Os isotope data have been obtained in the present study.