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Eclogitic diamonds from variable crustal protoliths in the northeastern Siberian craton: Trace elements and coupled $\delta^{13}C$–$\delta^{18}O$ signatures in diamonds and garnet inclusions

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ABSTRACT

Diamonds of eclogitic assemblages are dominant in the placer diamond deposits of the northeastern Siberian platform. In this study we present new trace elements and stable isotopes ($\delta^{13}C$ and $\delta^{18}O$) data for alluvial diamonds and their garnet inclusions from this locality. Cr-rich garnets of peridotitic affinity in the studied diamonds have a narrow range of $\delta^{18}O$ values from 5.7‰ to 6.2‰, which is largely overlapping with the accepted mantle range. This narrow range suggests that the garnet inclusions showing different REE patterns and little variations in oxygen isotopes may have formed by different processes involving fluid/melts that, however, were in oxygen isotopic equilibrium with the mantle.

The trace element composition of the eclogitic garnet inclusions supports a crustal origin for at least the high-Ca garnets, which show flat HREE patterns and in some cases a positive Eu-anomaly. High-Ca eclogitic garnets generally show heavier oxygen isotope compositions ($\delta^{18}O$ 6.5–9.6‰) than what is observed in low-Ca garnets ($\delta^{18}O$ 5.7–7.4‰). The variability in oxygen isotopes and trace elements is suggested to be inherited from contrasting crustal protoliths. The relationship between the high $\delta^{18}O$ values of inclusions and the low $\delta^{13}C$ values of the host diamonds implies that the high-Ca garnet inclusions were derived from intensely hydrated (e.g., $\delta^{18}O$ >7‰) and typically oxidised basaltic rock close to the seawater interface, and that the carbon for diamonds was closely associated with this protolith.

1. Introduction

Diamond is the most common stable form of carbon that we have samples from mantle depths and thus natural diamonds carry valuable information about the composition and thermodynamic conditions of the Earth's mantle. Both the geochemistry and mineralogy of diamonds and of their inclusions provides constraints on the conditions and processes of diamond formation. Previous studies of inclusions in diamonds have demonstrated that formation of diamonds in subcontinental lithospheric mantle occurs predominantly in peridotite (P-type, harzburgitic and lherzolitic) and eclogite (E-type) assemblages (Sobolev, 1977; Meyer, 1987; Harris, 1992; Stachel and Luth, 2015). Diamonds that contain pyroxenite and websterite inclusion assemblages are much rarer. Studies of mineral equilibria suggest that the formation of diamonds in these suites takes place at 900–1400 °C at depths of 150–200 km (Boyd and Finnerty, 1980; Rudnick et al., 1998; Sobolev, 1977; Stachel and Harris, 2008; Cartigny et al., 2014; Shatsky et al., 2015). Despite having resided in the hot mantle for millions or even billions of years, diamonds can preserve chemical zoning and composition that are not mantle-like. Experimental and natural data (Koga et al., 2005; Craven et al., 2009) have for example demonstrated that carbon and nitrogen diffusion in diamonds is extremely slow and original isotopic signatures can survive at mantle temperatures over long geological times. Therefore, when diamonds in eclogitic assemblages preserve C and/or O isotopic signatures deviating from typical mantle values, these have been ascribed to inheritance from a crustal protolith (e.g., Sobolev et al., 1979; Kirkley et al., 1991; Eldridge et al., 1991; Schulze et al., 2003; Jacob, 2004; Ickert et al., 2013; Burnham et al., 2015), even though alternative views exist (Cartigny et al., 2014). As a consequence, mineral inclusions in eclogitic diamonds that are transported to the Earth's surface in kimberlite pipes could represent a unique record of the deepest subducted crustal rocks (Walter et al., 2011; Zedgenizov et al., 2014; Burnham et al., 2015).

The Siberian platform is an important region of occurrence of many economic diamondiferous kimberlite pipes. The placer diamond

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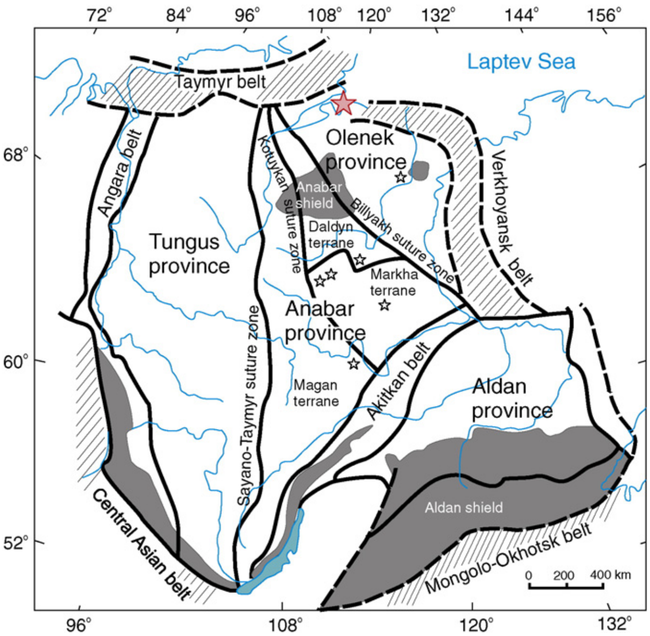

Fig. 1. Geological sketch map of the Siberian Platform showing the main features of the surface geology (after Rosen et al., 2006; Koreshkova et al., 2011) and the locations of major kimberlite fields (open black stars) and alluvial placers in the NE (red star). Grey areas are Precambrian rocks, white area is post-Riphean sedimentary cover, diagonally shaded areas are Phanerozoic mobile belts.

deposits in the northeastern Siberian platform are also highly productive, yet primary origin of the diamonds in these deposits is still undetermined. While diamonds in xenoliths can be classified according to the assemblage and composition of the of the host rocks (Sobolev et al., 1994; Jacob, 2004; Shirey et al., 2013) for diamonds found in placers, classification can only be based on the geochemistry of the diamonds itself and its inclusions. In placer diamonds different origins can be inferred from major and trace element patterns of the mineral inclusions, particularly garnet and pyroxene (Sobolev, 1977; Meyer, 1987; Taylor and Anand, 2004; Viljoen et al., 2014). Stable isotopes are another powerful geochemical indicator as the oxygen isotope composition of eclogitic inclusions in diamonds has been observed to be inversely correlated to $\delta^{13}C$ values of the host diamonds. This correlation has been used to suggest a crustal origin of both the diamond carbon and the diamond substrate (Schulze et al., 2003, 2013; Ickert et al., 2013, 2015). Previous studies of mineral inclusions in diamonds from Siberian placer deposits showed that, in contrast to the diamonds from kimberlite pipes of the Siberian Platform, the alluvial diamonds are mainly from eclogitic assemblages (72%) (Sobolev et al., 1999; Shatsky et al., 2015) with peridotitic diamonds being minor. In this paper we present new geochemical (major and trace elements) and stable isotopes ($\delta^{13}C$ and $\delta^{18}O$) data for diamonds and their garnet inclusions from northeastern Siberian Platform to constrain the origin of eclogitic diamonds and source of their host protoliths. Although abundant eclogitic inclusions and negative $\delta^{13}C$ of many diamonds from this locality (Shatsky et al., 2014, 2015) have previously been reported, this is the first study on diamonds from this locality, and one of the first worldwide, that investigates the correlation between $\delta^{13}C$ of diamonds and $\delta^{18}O$ in garnet inclusions in the same diamond crystals using in situ measurements.

2. Samples and methods

Diamond placer deposits of the northeastern region of the Siberian Platform are situated within the Paleoproterozoic Khapchan fold belt of the Olenek tectonic province (Fig. 1). The major and trace element composition and equilibrium temperatures of mineral inclusions in diamonds of peridotitic assemblages suggest that the lithospheric mantle from where the diamonds of this region originated had the composition and thermal regime typical of the mantle of ancient cratons (Shatsky et al., 2015). In contrast to the diamondiferous mantle of the Anabar tectonic province in the central part of the Siberian Platform, the mantle

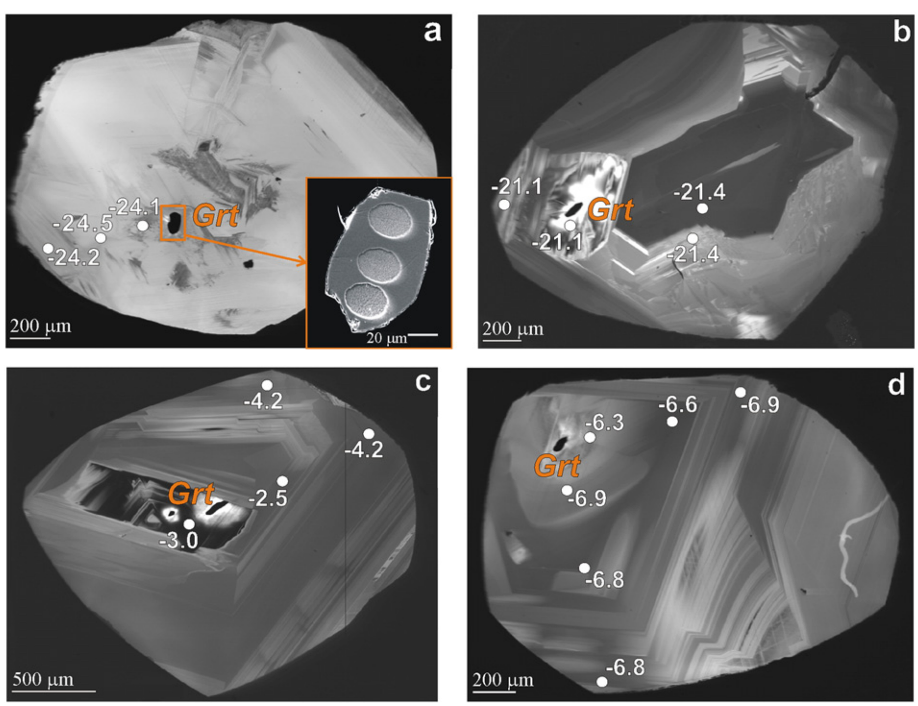

Fig. 2. Internal structure revealed by cathodoluminescence of diamonds with inclusions of eclogitic garnet from alluvial placers in the northeastern Siberian Platform: a — MT-138 (includes SEM image of garnet with multiple pits from SIMS analyses); b — MT-157; c — MT-78; d — MT-130. Each picture shows a CL image with location of inclusions (Grt) and carbon isotope analysis ($\delta^{13}C$, ‰).