Graphite-diamond relations in mantle rocks: Evidence from an eclogitic xenolith from the Udachnaya kimberlite (Siberian Craton)

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ABSTRACT

Relations of graphite and diamond have been studied in a garnet-kyanite-clinopyroxene+sulfide+coesite/quartz+diamond+graphite eclogite xenolith from the Udachnaya-East kimberlite pipe in the Yakutian diamond province. Euhedral crystals of diamond and graphite occur in the intra- and intergranular space. The equilibrium conditions of diamond formation reconstructed by geothermobarometry for the Grt-Cpx-Ky-Coe mineral assemblage are 1020 ± 40 °C and 4.7 GPa. Raman imaging of graphite enclosed in diamond shows high ordering and a 9 cm⁻¹ shift of the ~1580 cm⁻¹ band. This Raman shift of graphite, as well as a 5 cm⁻¹ shift of the 1332 cm⁻¹ band of diamond, indicate large residual stress in graphite and in diamond around the inclusion, respectively. According to FTIR spectroscopy, nitrogen in diamond is highly aggregated and exists mainly as the A centers, while no other phases occur near graphite inclusions. Therefore, diamond in the analyzed eclogite sample must be quite old: it likely had crystallized long (~1 Byr) before it became entrained with kimberlite melt.

New data show that graphite can stay in the upper mantle for billions of years without converting to diamond. Crystallization of various carbon polymorphs, both in laboratory and natural systems, remains poorly constrained. Graphite present in mantle and UHP rocks may be a metastable phase crystallized in the diamond stability field. This fact should be taken into consideration when deducing petrological constrains and distinguishing diamond and graphite subfacies in upper mantle.

Keywords: Diamond, graphite, metastable graphite, pseudomorphs, UHPM

INTRODUCTION

Graphite and diamond were identified as two upper mantle subfacies proceeding from graphite-to-diamond phase change (Dobretsov et al. 1974). The crystallization conditions for various polymorph modifications of carbon can be inferred from data on diamond- and graphite-bearing mantle rocks. The genesis of these rocks has been a subject of discussions for decades (Bobrievich et al. 1959; Pokhilenko et al. 1982; Robinson 1979; Hatton 1978; Robinson et al. 1984; Smyth and Caporuscio 1984; Field and Haggerty 1990; Pearson et al. 1990, 1994; Deines et al. 1991; Viljoen 1995; Korsakov et al. 2010; Naemura et al. 2011). According to earlier models (Bobrievich et al. 1959; Hatton 1978; Robinson 1979; Pokhilenko et al. 1982), diamond- and graphite-bearing eclogitic xenoliths entrained with erupting kimberlite magma crystallized close to the graphite-diamond equilibrium reaction curve. Pearson et al. (1994) hypothesized metastable growth of graphite within the diamond stability field and obtained the respective P-T (pressure and temperature) values for some graphite-bearing xenoliths.

Experimental studies of diamond crystallization from C-O-H fluids and in non-metallic systems provide evidence that only diamond crystalizes at high temperatures, while metastable graphite crystallization occurs at lower temperatures (Fig. 1) (Pal’yanov et al. 1999, 2002, 2006 Akaishi and Yamaoka 2000; Akaishi et al. 2000; Yamaoka et al. 2000, 2002a; Sokol et al. 2001b; Davydov et al. 2004). According to the experiments, carbon polymorphs crystallize in several successive steps with increasing temperatures and pressures: nucleation and growth of metastable graphite → nucleation and growth of metastable graphite → growth of diamond → nucleation and growth of diamond (Sokol and Pal’yanov 2004; Pal’yanov et al. 2005).

Indeed, some graphite in UHP metamorphic rocks can crystallize within the diamond stability field (Korsakov et al. 2010) and survive in the metastable state due to very short duration of high-pressure metamorphism. On the other hand, diamond in mantle xenoliths crystallized in Archean-Proterozoic time (Jacob and Foley 1999; Pearson et al. 1999), long before kimberlite intrusion, and all graphite in such xenoliths would have converted to diamond since then.

Graphite in mantle xenoliths is commonly found as isolated crystals among HP rock-forming minerals or as inclusions in them (Harris 1972; Sobolev 1974; Hatton and Gurney 1979). Graphite inclusions in diamond are proto-, syn-, or epigenetic (Harris and Gurney 1979; Sobolev 1974; Glinnemann et al. 2003; Nasdala et al. 2005; Bulanova et al. 1998; Meyer 1987; Harris 1992). Epigenetic graphite results from post-growth graphitization (Kuharenko 1955) and occurs as disks or rosettes around fluid or mineral inclusions in diamond (Harris 1972; Efimova et al. 1983). Protogenetic graphite, which serves as seeds for diamond crystallization, is euhedral and occurs mainly in the