10IKC-095

Mantle-derived morphologies of diamond: records of diamond-destroying mantle metasomatism

Zhihai Zhang [1, 2] and Yana Fedortchouk [1]
1.Department of Earth Sciences, Dalhousie University, Halifax - B3H 4R2, Canada
2.Faculty of Earth Sciences, China University of Geosciences, Wuhan - 430074, China

INTRODUCTION

The prolonged mantle residence back to the Archaen (e.g. Richardson et al. 1984) allows diamonds to suffer diamond-destroying metasomatism, and to bear the footprints of those mantle-derived resorption events, which are documented by truncated growth zoning of inner parts of diamonds (Bulanova 1995) and resorption morphology of xenolithic diamonds (Robinson 1979; Viljoen et al. 2004). Study of genetic micro-cavities in fibrous and cloudy kimberlitic diamonds revealed diamond resorption by oxidizing H_2O-rich metasomatic fluid/melts in the mantle (Klein-BenDavid et al. 2007). Our knowledge of diamond-destroying mantle metasomatism, including their compositions and conditions, however, is still very limited.

Variable dissolution features on diamond indicate different compositions of oxidizing media. Since the first diamond-etching experiments at 1892 (Luzi 1892), our knowledge of resorption features on diamonds has been progressively increasing (e.g. Arima and Kozai 2008; Fedortchouk et al. 2007; Khokhryakov and Pal'yanov 2010). Not only those experiments reproduced many of diamond-resorption features, they also disclosed that: 1) temperature and oxygen fugacity (fO_2) mainly control resorption rate, and 2) volatile components of etching media decide resorption characters, which provide the basis to use the morphology of natural kimberlite-hosted diamond to constrain the presence and composition of diamond-destructive fluids in the mantle (Fedortchouk and Zhang 2011) and kimberlite (Fedortchouk et al. 2010).

In this study, we perform systematic and comprehensive investigation of relationships among morphology, internal textures (CL images), and nitrogen defects (from FTIR) of diamond from the Slave craton, further develop the resorption-based classification, and apply our results to the known data from xenoliths and experiments to learn about the resorption conditions and metasomatic processes in these different mantle reservoirs.

RELATIONSHIP BETWEEN MORPHOLOGIES AND INTERNAL PROPERTIES

The optical investigation of the diamond population (total 630 stones) from Grizzly, Misery, Koala and Leslie kimberlites, Ekati Mine property, Canada, allowed to distinguish four resorption-based groups: 1) unresorbed stones (UnR); 2) stones with kimberlite-induced resorption features (KIM); 3) stones with variable resorption features produced in the mantle (MR); and 4) undefined stones, and to refine our resorption-based classification (Fedortchouk and Zhang 2011). The MR group is further broken into morphologies with complex features (CM) and various step-faces (SM) (Fig. 1). All CM morphologies have deep pits often hexagonal shape with deep step-walls (CM-1), very deep but small trigonal etch-pits (CM-2), and numerous trigonal pits (CM-3). Although the kimberlite-induced resorption morphology differ greatly in the four studied kimberlites (Fedortchouk et al. 2010), the mantle-derived features are very similar. CM-1 group is present in three kimberlites except Koala, and SM-2 group is widespread in all four pipes. SM-1 and SM-3b groups are common in Misery, Koala, and Leslie, while SM-3a in Misery and Leslie. We interpreted the MR similarities and their distribution to be the results of the four kimberlites sampling variable proportions of the same diamondiferous reservoirs of sub-cratonic mantle that experienced similar diamond-destroying metasomatism.

Towards this end, we polished selected diamond crystals (total 109 stones, including typical KIM diamonds and all unresorbed and MR diamonds in the four pipes) parallel or sub-parallel to {100}and identified eleven growth patterns through the analysis of CL images. The revealed growth patterns show that step-faced (SM) diamonds have clearly preferred layer-by-layer octahedral growth zoning as rims, while CM-1 to -3 and KIM diamonds do not depend on the rim patterns, e.g. any combinations between surface features and rim patterns are possible. We distinguished resorption from growth morphology of step-faced crystals

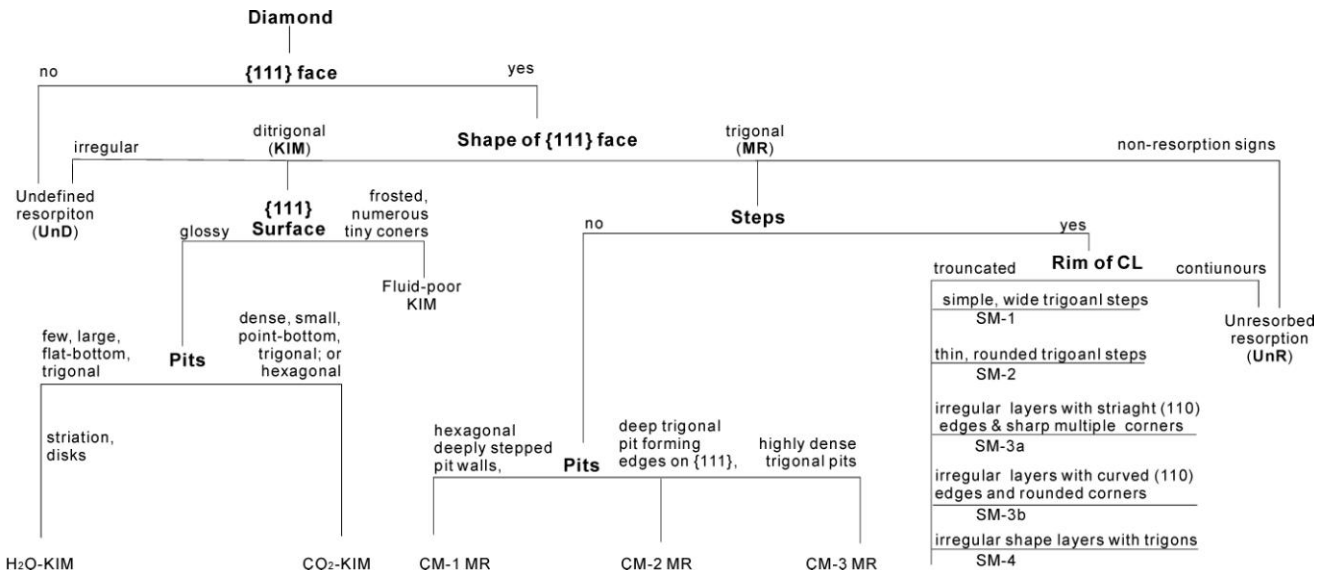

Fig.1 Resorption-based classification tree of diamond (modifyed from Fedortchouk and Zhang, 2011).

using zoning continuity of diamond rims (truncated zoning indicating resorption). The surface morphology of all KIM and CM-1 to -3 diamond crystals resulted from resorption, while that of all unresorbed diamonds studied resulted from growth. Even though step-faced diamonds are typically considered to be a result of growth (e.g. Sunagawa 1984) only 40% of the step-faced diamonds studied here show growth patterns on their rims. In the diamond population we identified four main internal textures: 1) layer-by-layer octahedral growth; 2) four-sided star cores surrounded by layer-by-layer octahedral growth; 3) oscillating smooth or bumpy oval zoning; and 4) multi-seed core. These four styles may indicate similar growth or deformation history.

FTIR spectra collected through the polished stones show that all diamonds belong to IaA–IaB type. When plotted on nitrogen aggregation diagram (Fig.2), they defined two distinct clusters: one cluster with high nitrogen content (above ~ 400 ppm) and low state of aggregation (typically below 40 % of B centers), and the second cluster with low nitrogen content (< 1000 ppm, mostly below 400 ppm) and B centers ranging from ~ 20 to 98 %. Morphological groups and internal textures of studied diamonds show correlation with nitrogen data. All unresorbed diamonds are plotted in the first cluster, while 10 out of 11 CM-1 diamonds are in the second cluster. Step-faced and KIM diamonds are scattered in the two clusters. Diamonds with similar nitrogen data in the same resorption groups reflect their similar residing environment in the mantle. Since the amount of unresorbed, non-step-faced and KIM diamonds is small, only step-faced diamonds are tested. The observed correlations of resorption morphology, internal patterns and nitrogen data support the hypothesis that these morphological types represent various diamondiferous mantle reservoirs and, therefore, can be used to investigate the composition of the mantle metasomatic fluids.

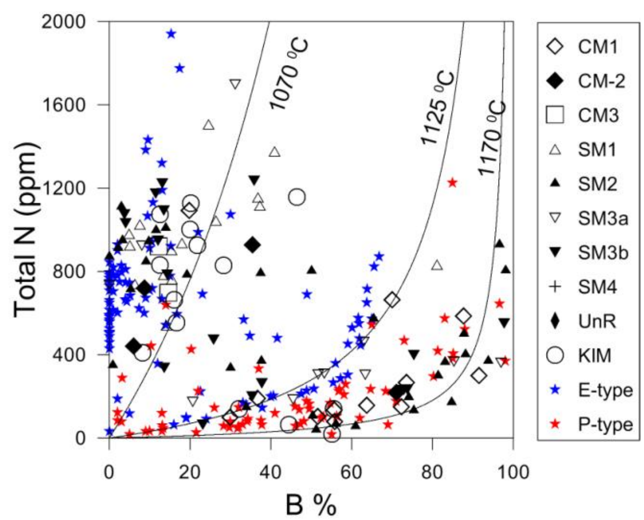

Fig. 2 Nitrogen contents and aggregation states of diamonds from this study compared to the data for diamonds extracted from eclogite (blue stars) and peridotite (red stars) in the Slave craton (Aulbach et al. 2011), Siberia (Stepanov et al. 2007) and south Africa (Viljoen et al. 2004). The isotherms were calculated using the equation from Taylor et al. (1990) at a given 3.5 Ga mantle residence time (Westerlund et al. 2006).

DIAMOND-DESTROYING METASOMATISM

According to our classification, reported morphologies of diamond crystals from eclogitic (e.g. Robinson 1979) and peridotitic xenoliths (e.g. Viljoen et al. 2004) are similar to the MR resorption groups defined in the present study. All unresorbed and some of the SM morphological groups have nitrogen data similar to diamonds from eclogitic xenoliths (Fig. 2). The CM-1 diamond group from this study has similar nitrogen content and aggregation state to the diamond crystals recovered from peridotite xenoliths from Ekati kimberlites (Aulbach et al. 2011) (Fig. 2). Some experiments have produced morphologies with step-faces and deep hexagonal pits at high pressure (Arima and Kozai 2008; khokhryakov and Pal'yanov 2002). Comparison with the existing experimental data indicate hydrous metasomatism causing diamond resorption in sub-continental lithosphere of the Slave craton (Fedortchouk and Zhang 2011). However, experimental studies of diamond resorption at pressures similar to the mantle conditions are very limited. In order to further constrain the forming conditions of MR features, systematic studies of diamonds from xenoliths and related etching experiments at high pressure are needed.

References

Arima, Makoto, and Yusuke Kozai. 2008. Diamond dissolution rates in kimberlitic melts at 1300-1500^{0}C in the graphite stability field. Eur J Mineral, 20 (3):357-364.

Aulbach, Sonja, Thomas Stachel, Larry M. Heaman, and Jon A. Carlson. 2011. Microxenoliths from the Slave craton: Archives of diamond formation along fluid conduits. Lithos, 126 (3-4):419-434.

Bulanova, G. P. 1995. The formation of diamond. Journal of Geochemical Exploration, 53 (1-3):1-23.

Fedortchouk, Yana, Dante Canil, and Elena Semenets. 2007. Mechanisms of diamond oxidation and their bearing on the fluid composition in kimberlite magmas. American Mineralogist, 92 (7):1200-1212.

Fedortchouk, Yana, Sergei Matveev, and Jon A. Carlson. 2010. H_2O and CO_2 in kimberlitic fluid as recorded by diamonds and olivines in several Ekati Diamond Mine kimberlites, Northwest Territories, Canada. Earth and Planetary Science Letters, 289 (3-4):549-559.

Fedortchouk, Yana, and Zhihai Zhang. 2011. Daimond resorption: link to metasomatic events in the mantle or rescord of magmatic fluid in kimberlitic magam? The Canadian Mineralogist, 49 (3):707-719.

khokhryakov, A. F., and N. Yu. Pal'yanov. 2002. Crystal morphology as an indicator of redox conditons of natural diamond dissolution at the mantle PT parameters. Doklady Earth Sciences, 385 (5):534-537.

Khokhryakov, Alexander F., and Yuri N. Pal'yanov. 2010. Influence of the fluid composition on diamond dissolution forms in carbonate melts. American Mineralogist, 95 (10):1508-1514.

Klein-BenDavid, O., R. Wirth, and O. Navon. 2007. Micrometer-scale cavities in fibrous and cloudy diamonds -- A glance into diamond dissolution events. Earth and Planetary Science Letters, 264 (1-2):89-103.

Luzi, W. 1892. Ueber Allotropie des amorphen Kohlenstoffes. Berichte der deutschen chemischen Gesellschaft, 25 (1):1378-1385.

Richardson, S. H., J. J. Gurney, A. J. Erlank, and J. W. Harris. 1984. Origin of diamonds in old enriched mantle. Nature, 310 (5974):198-202.

Robinson, Derek N. 1979. Surface textures and other features of diamonds. Ph.D. thesis, The Univeristy of Cape Town, Cape Town.

Stepanov, A. S., V. S. Shatsky, D. A. Zedgenizov, and N. V. Sobolev. 2007. Causes of variations in morphology and impurities of diamonds from the Udachnaya Pipe eclogite. Russian Geology and Geophysics, 48 (9):758-769.

Sunagawa, I. 1984. Morphology of natural and synthetic diamond crystals. *In* Materials science of the Earth's interior, *Edited by* I. Sunagawa. Terra Scientific, Tokyo, pp. 303-330.

Taylor, Wayne R., A. Lynton Jaques, and Michael Ridd. 1990. Nitrogen-defect aggregation characteristics of some Australasian diamonds; time-temperature constraints on the source regions of pipe and alluvial diamonds. American Mineralogist, 75 (11-12):1290-1310.

Viljoen, K. S., René Dobbe, Braam Smit, Emilie Thomassot, and Pierre Cartigny. 2004. Petrology and geochemistry of a diamondiferous lherzolite from the Premier diamond mine, South Africa. Lithos, 77 (1-4):539-552.

Westerlund, K., S. Shirey, S. Richardson, R. Carlson, J. Gurney, and J. Harris. 2006. A subduction wedge origin for Paleoarchean peridotitic diamonds and harzburgites from the Panda kimberlite, Slave craton: evidence from Re–Os isotope systematics. Contributions to Mineralogy and Petrology, 152 (3):275-294.