118–120 Vol. 78 No. 1 ACTA GEOLOGICA SINICA Feb. 2004
http://www.geojournals.cn/dzxbcn/ch/index.aspx

Assortment of Deep Mantle Fluids and Their Products in Kimberlites from China

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Abstract Based on studies of petrography, mineralogy and mineral chemistry, deep mantle fluids and their products in kimberlites and diamonds can be assorted into the ultradeep fluid-transmitted minerals with an oxygen-free feature, the deep fluid metasomatized-minerals characterized by enrichment in TiO_2, K_2O, BaO, REE and Fe^{3+}, and the deep fluid-reformed minerals. The three types show a successive descent in fluid origin depth and metasomatism strength, and they have brought forth a series of corresponding metasomatic products.

Key words : kimberlite, diamond, assortment of deep mantle fluids, products

1 Introduction

On the basis of observations and researches in petrography, mineralogy and mineral chemistry, the behaviors of deep mantle fluids and their products in kimberlites and diamonds fall into three forms: ultradeep fluid-transmitted minerals, deep fluid-metasomatized minerals and deep fluid-reformed minerals. They are successive in terms of fluid origin depth and metasomatism strength, and form a series of corresponding metasomatic products (Zhao, 1996).

2 Ultradeep Fluid Transmitted Minerals

Ultrahigh-pressure experiments, geophysical data and studies of rare inclusions in diamonds have been deepened into the seismic discontinuity zone, 670 km beneath the Earth's surface (Harte and Harris, 1994). Very likely, most of the siderophile elements, such as Fe, Ni, Co, Cu, W, As, Ge, Ag and Au, are components of the core (Haggety, 1994). We call the "ultradeep fluid-transmitted minerals" which have the same elements as those involved in core-mantle differentiation, with strong reduction characteristics and a far higher formation temperature than that of kimberlite magmas. With the delivery and participation of the ultradeep fluids, they became the forerunner or entered the mother magmas of kimberlites and diamonds, and then reached or nearly reached the surface of the Earth. These minerals include WC, WC_2, native silicon, native iron, native silver and the Ag-bearing Fe-Au alloy inclusions interacted with the fluids (Zhao et al., 1995).

Recently, idiomorphic K, B and Cl crystals (unnamed) are found in two spherical inclusions named In-1 and In-3 in a macrocrystal pyrope (Zhao et al., 2003). In the inclusions In-1 and In-3 the mineral assemblages are both K-B-Cl inclusions + oxygen-free phase + volatile-bearing garnet (Fig. 1 and Table 1).

There are some evidences about the activity of mantle fluids in the research field. It is the first time that K-B-Cl inclusions and oxygen-free phase in In-1 and In-3, and garnet with volatile components included in macrocrystal garnet have been found. The main conclusions are given below.

The early mantle fluids crystallized slowly during the growth of garnet, suggesting that the liquid phase with K, B and Cl existed in parts of the mantle. The oxygen-free phase and K-B-Cl inclusions belong to fluid compositions of the early mantle. The main parts of In-1 and In-3 are garnet with volatile components. Their formation is

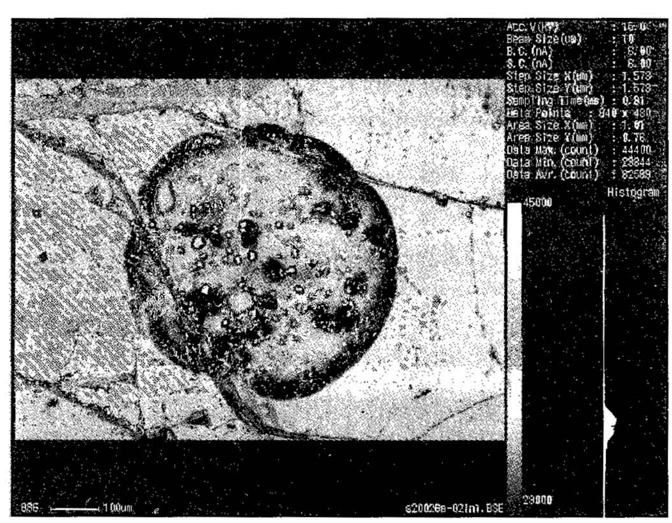

Fig. 1. A BSE image of the spherical inclusion.

Table 1 Compositions (wt%) of the unnamed K-B-Cl inclusions determined with the electron probe microanlysis

No.	K	Cl	B	Si	Al	Mg	Fe	Ca	Na	P	S	Ti	Cr	Total
1	47.66	38.15	9.65	0.65	0.31	0.22	0.40	0.00	0.70	0.99	0.16	0.01	0.00	99.25
2	48.94	38.34	9.64	0.72	0.23	0.17	0.44	0.00	0.15	0.41	0.19	0.02	0.00	99.25
3	44.67	32.95	7.56	1.70	0.82	0.68	0.61	0.00	0.51	0.78	0.43	0.04	0.00	90.74
4	43.42	34.36	9.92	0.94	0.52	0.35	0.53	0.00	1.01	1.15	0.43	0.00	0.00	96.64
5	41.10	33.91	10.91	1.28	0.78	0.62	0.76	0.00	0.53	0.71	0.24	0.03	0.00	90.87

Note: Tested in the EPMA laboratory of the China University of Geosciences.

associated with mantle fluids, which remolded the mantle garnet and enrich it in H_2O and volatiles. The elements, such as Na, K, P, S, Cl and Ti, should be derived from the mantle fluids.

In a word, they are all special minerals composed of simple substances and correspond to the ultradeep fluids in kimberlites and diamonds. If conditions are suitable the fluids can be the forerunner of kimberlites. They have an oxygen-free feature, and are therefore significant indicators for an ultradeep and very strongly reducing environment.

3 Deep Fluid-Metasomatized Minerals

All of the characteristics of the composition, reduction-oxidation state, deformation and occurrence of the deep fluid-metasomatized minerals indicate that they are not products of the kimberlite magmatic crystallization but come from mantle materials. They are rich in TiO_2, K_2O, BaO and REE, which are all characteristic compositions of mantle metasomatic fluids, indicating that they have experienced a series of metamorphism and deformation processes. The main minerals include lindsayite, mathiasite, yimengite and Na-Si-rich orthopyroxenite. The element Fe in these minerals occurs in the form of Fe^{3+}, probably reflecting the deep mantle reaction related to Fe as: $3Fe^{2+}—2Fe^{3+}+Fe^0$, where Fe^{3+} is transported upward by the fluids in the deep mantle, and combines with the elements Cr and Mg of the mantle to form metasomatic minerals. The Fe^0 in the equation is carried to the core and accumulated there. During this course, native iron occurs in kimberlites and diamonds as inclusions.

The occurrence of this kind of minerals indicates that the composition and character of the mantle fluids have been notably changed, varying from oxygen-free or oxygen-deficient ultradeep fluids rich in metallic elements to oxygen-bearing fluids rich in Ti, K, Na, Ba and REE. At the same time, the changed fluids are metasomatized with mantle materials to generate metasomatic minerals.

4 Mantle Fluid-Reformed Minerals

The mantle fluid-reformed minerals refer to those whose compositions have been changed to some extent by interaction with mantle fluids but still remain stable in the mantle. They are phlogopite, pyrope, chromite, olivine and pyroxene. Among them the hydrous ones contain extra structural H_2O and are deficient in SiO_2. On the other hand, the theoretically anhydrous ones, e.g. olivine and pyroxene, contain some H_2O.

Mantle olivine (in peridotites or as macrocrystals) may be serpentinized strongly or completely by the shallow mantle fluids. Lizardites are dominant among mantle xenoliths, while the majority of macrocrystals is antigorite. Lizardites are formed in a neutral medium or environment, but antigorites grow in an alkali medium after the formation of lizardites. Olivine in xenoliths or as macrocrystals gives birth to different kinds of serpentines, which indicates that the serpentinization of peridotite xenoliths has already begun while or before the xenoliths come into kimberlite magmas. The mantle fluids of that time are neutral. The macrocrystals are further altered to antigorites through the action of an alkali medium, and eventually mixed fluids are formed by mixing of the mantle fluids with the fluids from kimberlites.

Theoretically, the ultradeep fluids should come at least from the core-mantle boundary. However, though the crystallization temperature of WC is as high as 2765°C, almost equal to the core's temperature, there is no adequate evidence to confirm that the material comes from the core.

The mantle deep fluids can be divided, in an ascending order, into the ultradeep oxygen-free (or oxygen-deficient) fluids, the deep oxygen-bearing fluids which are rich in Ti, K, Na, Ba and REE, and the water-rich alkali fluids evolved from the above two.

The representatives of the ultradeep oxygen-free (or oxygen-deficient) fluids are natural elements and/or their similarities, for example, Au, Ag, Cu, Fe, Zn, Sn, Pb, W and S transported by ultradeep fluids. In the area affected by this kind of fluids, there is the trend that the deeper the depth is, the richer the Fe content will be.

Deep oxygen-bearing fluids interact with solid mantle materials rich in Cr and Mg to form minerals, in which cations of large radii coexist stably with those of small radii, indicating a high pressure. Nearly all of Fe exists in the form of Fe^{3+}, reflecting an oxidization feature. The distinction between the above two kinds of fluids lies in whether there exists stable wüstite.

Water-rich alkali fluids are evolved from the former two fluids, with a water-rich character. Their main behavior is to reform the stable rock-forming minerals in the mantle until antigorites appear. Under the effect of these fluids, cubic diamonds, diamond coatings and microgranular diamonds are generated, which may contain inclusions of KCl, NaCl, calcite, feldspar, $CuCl_2$ and so on.

Acknowledgement

This study was supported by the National Natural Science Foundation of China grants 40273016 and 49973013, for which sincere thanks are expressed here.

Manuscript received April 10, 2003
accepted Feb. 3, 2004
edited by Zhu Xiling

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