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## Gorbachev[1] N.S., Ravna[2] E., Kostyuk A.V., Nekrasov[1] A.N., Kullerud[2] K. Phase relationship and geochemistry of garnet-bearing carbonatites of Trosø area, Norway

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**Abstract.** The phase composition and geochemistry of garnet-containing carbonatites UHPC Tromsø area studied. The matrix of UHPC calcite-dolomite composition contains inclusions of garnet, and accessory minerals - apatite, sphene, ilmenite, rutile. There are three generation of garnet: Grt1, depleted in REE ($<2.10^{-2}$ wt.%); Grt2-3, anomalously enriched (up to 4-8 wt.%) in LREE. Carbonate Cb and silicate Si components of UHPC differ on concentration of trace elements. Anomalous REE distribution in UHPC indicates a lack of equilibrium between Grt and carbonatite melt.

*Keywords: carbonatite, high pressures, phase composition, geochemistry, experiment.*

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In connection with the problem of the existence of carbonate magmas in the upper mantle studied the phase relations and geochemistry of garnet-bearing ultra-high pressure carbonatites (UHPC) Tromsø area, Norway. UHPC is intimately associated with eclogite, carbonate-bearing phlogopite-rich garnet pyroxenite, clinopyroxene glimmerite and banded calc silicate marble. They occur in the lower parts of the Tromsø Nappe of the Caledonide orogen of Scandinavia and Greenland [Gee, Fossen et al. 2008].

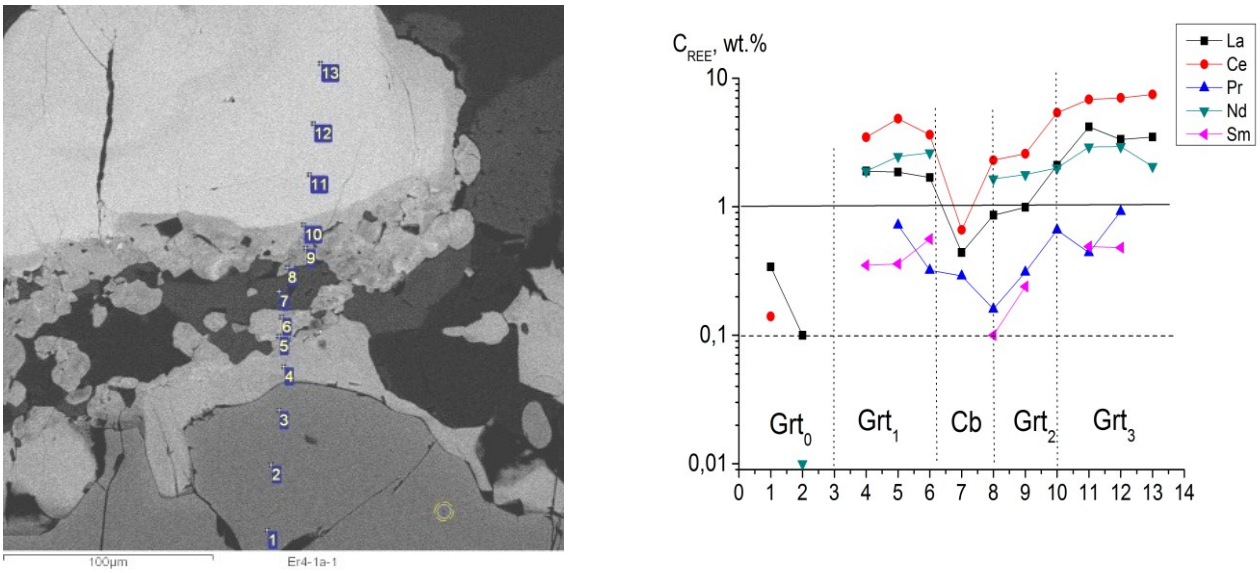
Samples of UHPC have been selected during of fieldwork and research trips. The samples were studied and analyzed on a scanning electron microscope TESCAN VEGA II XMU. Trace elements in silicate and carbonate components of UHPC were determined by ICP MS in Chernogolovka. Taking into account that UHPC contain up to 20% of garnet, carbonate (Cb) and silicate (Si) components are pre-separated by chemical methods and were analyzed by ICP MS separately. Cb converted into solution by treating the powder of UHPC by 1 N solution of HCl. The insoluble residue formed on the filter after filtration of Grt was dissolved in a mixture of acids HCl, $H_2SO_4$, HF. The resulting solutions were analyzed. Results of the analysis characterized the concentration of trace elements in the Cb and Grt of UHPC. Concentration of $SiO_2$ in Cb ($<n10^{-2}$ wt.%) indicate low solubility of Grt in HCl solution during the procedure of separating Cb from UHPC. The calculation of the Si balance between UHPC and Cb (assuming that the source of Si in Cb was Grt), shows that the proportion of dissolved Grt not exceeds hundredths of %.

The matrix of UHPC is represented by carbonate calcite-dolomite composition with inclusions of garnet (Grt) and accessory minerals - apatite, sphene, ilmenite, rutile. On structure and composition it is allocated three generation of Grt: early, $Grt_1$, of $pyr_{15}$-$gros_{25}$-$alm_{60}$ composition, depleted in REE ($< 2 \cdot 10^{-2}$ wt.%); reacting $Grt_{2-3}$ of $pyr_5$-$gros_{65}$-$alm_{30}$ composition, anomalously enriched (up to 4-8 wt.%) in LREE (tabl.1, fig. 1).

The abundances of trace elements in the UHPC, it's carbonate Cb and silicate Si fraction were examination. Carbonate fraction is enriched in Ba, Rb, Nb, Sr, P, Zr, depleted in Hf, Ti, Th, Ta compared to silicate fraction (tabl. 2, fig. 2, 3).

**Table 1. Chemical composition (wt.%) of Grt, Cb and UHPC rock**

| | Dol | Cal | $Grt_0$ | $Grt_1$ | $Grt_2$ | $Grt_3$ | UHPC |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 0.13 | - | 39.83 | 35.58 | 35.99 | 34.74 | 15.48 |
| $TiO_2$ | 0.21 | 0.09 | - | 0.14 | 0.17 | - | 0.69 |
| $Al_2O_3$ | 0.16 | 0.06 | 21.92 | 22.48 | 22.47 | 22.03 | 5.16 |
| FeO | 6.82 | 2.10 | 25.29 | 9.75 | 9.13 | 8.93 | 1.44 |
| MnO | 0.13 | 0.34 | 0.31 | - | - | 0.02 | |
| MgO | 16.50 | 1.79 | 5.04 | 0.77 | 0.96 | 1.69 | 5.65 |
| CaO | 28.97 | 49.14 | 10.49 | 19.17 | 17.63 | 15.95 | 35.36 |
| $Na_2O$ | 0.21 | - | 0.22 | - | 0.13 | 0.04 | 2.18 |
| $K_2O$ | - | - | - | - | - | 0.18 | 1.51 |
| $Cr_2O_3$ | 0.10 | - | - | - | 0.07 | 0.07 | - |
| SrO | 0.31 | 0.74 | 0.40 | 1.40 | 1.27 | 1.05 | - |
| $Y_2O_3$ | 0.27 | 0.37 | 0.09 | 0.43 | 0.51 | 0.29 | - |
| $La_2O_3$ | 0.45 | 0.45 | - | 1.67 | 1.82 | 4.06 | - |
| $Ce_2O_3$ | 0.01 | 0.07 | - | 4.63 | 4.98 | 7.41 | - |
| $Pr_2O_3$ | - | 0.02 | - | 0.33 | 0.77 | 0.54 | - |
| $Nd_2O_3$ | 0.05 | - | - | 2.11 | 2.57 | 2.81 | - |
| $Sm_2O_3$ | 0.04 | - | - | 0.35 | 0.11 | - | - |
| Total | 54.36 | 55.18 | 103.60 | 98.82 | 98.52 | 99.81 | 67.47 |




a) b)

**Fig.1.** UHPC: a) Back-scattered electron (BSE) images showing the zonal Grt in carbonatic matrix calcite -dolomite composition; b) distribution of LREE for profile 1-13.

**Table 2. Content of trace and REE in UHPC,in Cb и Si components (ICP MS, ppm)**

| | UHPC | Cb component | Si component |
|---|---|---|---|
| Li | 5.1 | 8.7 | 2.8 |
| K | 13689 | 25337 | 3206 |
| Rb | 43.4 | 109 | 8.7 |
| Cs | 0.00 | 2.8 | 0.22 |
| Pb | 16.4 | 36.2 | 4.9 |
| Ba | 1363 | 2765 | 241 |
| Th | 2.6 | 1.1 | 4.0 |
| U | 0.78 | 0.50 | 1.0 |
| Nb | 10.1 | 3.6 | 16.3 |
| La | 146 | 16.9 | 252 |
| Ce | 339 | 53.3 | 539 |

| | UHPC | Cb component | Si component |
|---|---|---|---|
| Sr | 1832 | 3772 | 190 |
| Pr | 43.5 | 9.3 | 69.0 |
| Nd | 174 | 57.9 | 239 |
| Zr | 18.0 | 1.8 | 18.6 |
| Sm | 29.8 | 18.1 | 36.3 |
| Eu | 6.5 | 4.3 | 6.8 |
| Gd | 23.3 | 20.4 | 24.7 |
| Tb | 3.0 | 2.7 | 3.4 |
| Ti | 14080 | 9574 | 18527 |
| Dy | 14.6 | 12.0 | 16.1 |
| Y | 63.9 | 51.4 | 64.8 |
| Ho | 2.3 | 1.8 | 2.7 |
| Er | 5.0 | 3.5 | 6.0 |
| Tm | 0.53 | 0.33 | 0.66 |
| Yb | 2.8 | 1.8 | 3.7 |
| Lu | 0.34 | 0.22 | 0.44 |
| Sc | 42.2 | 11.6 | 60.9 |
| V | 246 | 235 | 296 |
| Zn | 159.7 | 200 | 137 |

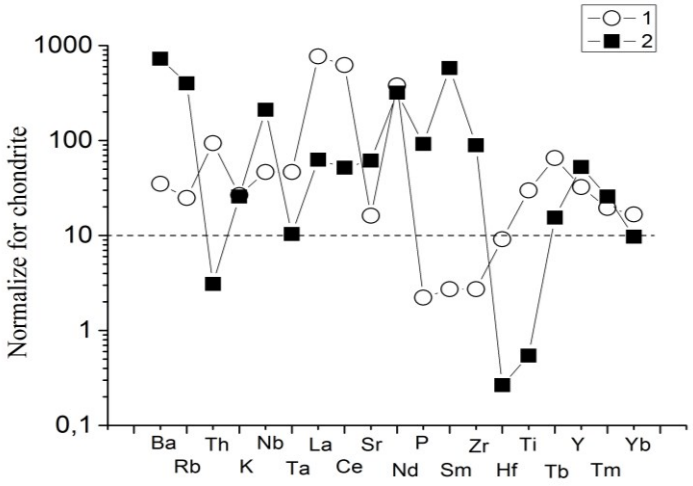



**Fig. 2.** Normalize for chondrite [McDonough, Sun, 1995] concentration of trace elements in carbonate Cb and silicate Si components of UHPC.

Carbonate and silicate fraction of UHPC differ in REE concentrations and the character of its dependence from atomic number N REE. Silicate fraction enriched in REE, the dependence of the normalized for chondrite REE concentrations CN from N REE has negative slope with slight Eu minimum. In the carbonate fraction to the dependence of CN-N REE has an extreme character with maximum at Gd-Tb. The largest differences are observed in the distribution of LREE. In the silicate fraction CN REE reduced from 500 at La to 50 for Sm, in carbonate fraction CN REE rise from 30 to 45 at La to Sm. Starting from Gd to Lu REE behavior is similar in silicate fraction CN REE reduced to 8, and in carbonate C fraction up to 5 (fig. 3).

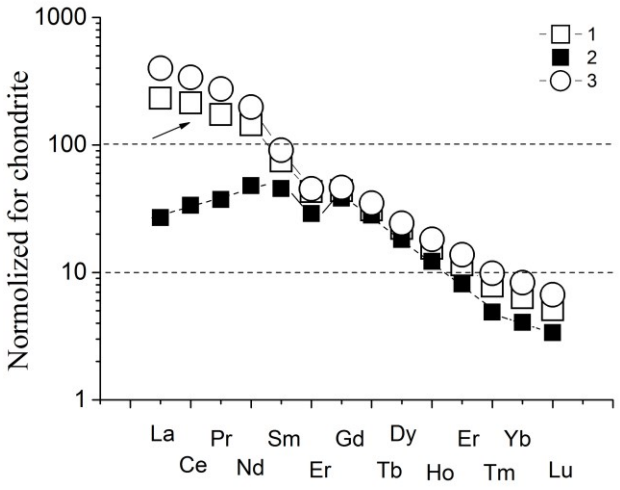



**Fig. 3.** Normalize for chondrite [McDonough, Sun, 1995] concentration of REE in UHPC (1), its carbonate (2) and silicate (3) components.

On the fig. 4 and 5 show ratio of trace and REE between Si and Cb components of UHPC. These data more effective show difference in distribution of these elements.

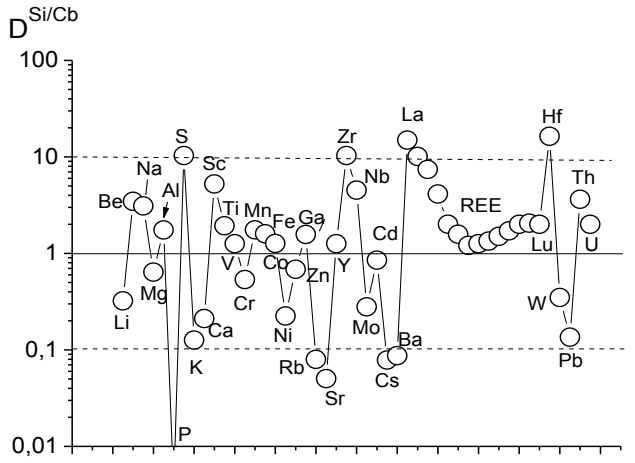



**Fig. 4.** Distribution (D Si/Cb) of trace elements between silicate and carbonate components of UHPC.

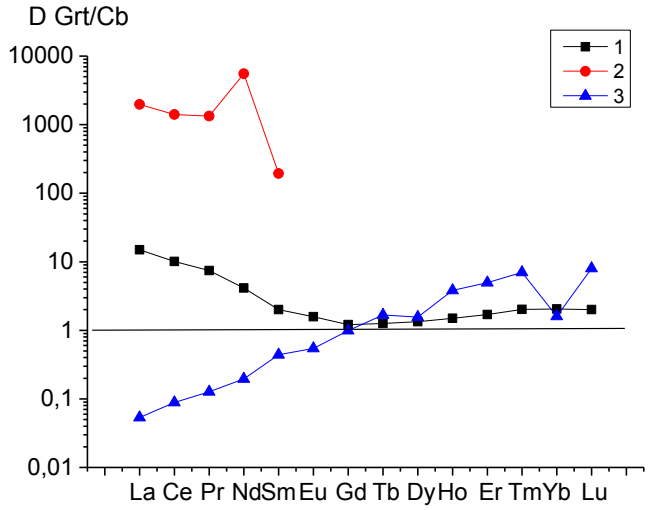



**Fig. 5.** Distributon of REE between silicate and carbonate components fraction of UHPC (1) , D REE Si/Cb; secondary, enrich in LREE $Grt_{1-3}$ (2) and partition coefficients REE between Grt and carbonatite melt (D REE Grt/CbL) our experimental data, T= 1250ºC, P=4 GPa [Gorbachev et al., 2014]

The anomalous distribution of REE is observed between Si and Cb components in UHPC compared with experimental D REE Grt /CbL. Since, in the Si component of UHPC dominated Grt, it can be assumed that the ratio of rare earth elements between Si and Cb components of UHPC R Si/Cb characterizes the combined distribution coefficients D REE between Grt and CbL: R Si/Cb ~ D Grt/CbL. However, as can be seen from Fig. 5, R Si/Cb in UHPC differ from the experimental D Grt/Cb. Dependence R Si/Cb in UHPC has an extreme character with a minimum in the field of Gd, decreasing from La to Gd, and gradually increasing to Lu. According to experimental data D REE Grt/CbL increases from La to Lu. Relationship between R REE $Grt_2$ , enriched in LREE and Cb even more different from the experimental D REE Grt/CbL (Fig. 5). This feature can be explained as enrichment of the later generations of garnet $Grt_2$ and $Grt_3$ by LREE under the influence of carbonatite melt into the primary mantle material under non-equilibrium conditions.

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## Gorbachev[1]N.S., Kostyuk[1]A.V., Ravna[2]E., Nekrasov[1]A.N., Kullerud[2]K. The melting of ultra-high-pressure garnetbearing carbonatite (UHPC) of Tromsø area, Norway, at mantle PT

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**Abstract.** Melting of ultra-high-pressure garnet-bearing carbonatite (UHPC) in "dry" conditions and with $H_2O+CO_2$ fluid experimentally studied at $P$ = 4 GPa in the range $T$ = 950-1400°C. The temperature of the "dry" liquidus UHPC is about 1270ºC, T of solidus ~ 1050ºC. Liquidus and solidus temperatures drop to 100-150ºC during melting with $H_2O+CO_2$ fluid. At $T$ = 1400ºC observed separation of carbonatite melt on high- and low-calcium carbonate-silicate liquid with separation of graphite. In sub-liquidus fields carbonatite melt reacts with Grt, thereby forming a bordure of reaction Grt, enriched in CaO, $TiO_2$, SrO, depleted in FeO, MgO, MnO. The experimental results indicate the formation of characteristic UHPC association of carbonate- zone garnet in the range of $T$ = 1200-1250ºC.

*Keywords: experiment, melting, phase relationship, high PT carbonatite*

Citatian: Gorbachev N.S., A.V. Kostyuk, E. Ravna, A.N. Nekrasov., K. Kullerud (2015) The melting of ultra-high-pressure garnet-bearing carbonatite (UHPC) of Tromsø area, Norway, at mantle PT. Experimenal geochemistry. V. No . PP.

Particular phase relationships at melting of UHPC in "dry" conditions and with $H_2O+CO_2$ fluid experimentally studied at P = 4 GPa in the range T = 950-1400°C to determine the physical and chemical conditions of formation UHPC.