

***P-T* PARAMETERS OF MAGMATIC REPLACEMENT IN UREILITES.** N. G. Zinovieva, P. Yu. Pletchov, N. P. Latyshev, and L. B. Granovsky, Department of Petrology, Faculty of Geology, Moscow State University, Vorob'evy Gory, Moscow 119992, Russia ([zinov@geol.msu.ru](mailto:zinov@geol.msu.ru)).

**Introduction:** The petrology of the Novo-Urei, Dyalpur, and Kenna ureilites was examined and the *P-T* parameters of their crystallization were evaluated to elucidate the physicochemical conditions of magmatic replacement in these meteorites.

**Methods:** The crystallization temperatures were assayed based on the compositions of ortho- and Ca-rich clinopyroxene that were formed in zones where the primary olivine-pyroxene material underwent replacement near diamond-bearing graphite-kamacite veinlets. Using a selection of experimental data, we tested twelve previously published versions of the orthopyroxene-clinopyroxene thermometer. The best compatibility with the experimental data was shown by the models [1-4]. These models were also tested against the olivine-clinopyroxene geothermometer [5] in application to naturally occurring (terrestrial) mineral assemblages. The temperature values yielded by all of the aforementioned models vary within  $\pm 48^\circ\text{C}$ . However, most Ca-rich pyroxene of ureilites and chondrites typically bear high  $\text{Al}_2\text{O}_3$  и  $\text{TiO}_2$  concentrations, which cannot be taken into account within the framework of the models [3, 4], and this leads to widely scattered temperature values yielded by these thermometers. Because of this, we compared various types of meteorites and calculated the temperatures of their crystallization (to estimate the pressures on the basis of the calculated temperature values) by the models [1, 2], which make it possible to account for the effects of Al, Ti, Cr, Mn, and Na on the Ca, Fe, and Mg distribution in pyroxenes. The tables report the average temperatures obtained by these two models (if the differences between the values did not exceed  $50^\circ\text{C}$ ; otherwise the corresponding mineral assemblages were rejected).

In order to evaluate the pressures under which the pyroxene crystallized, we applied the model proposed by Nimis [6], which makes use of the baric function of the unit cell parameters (the unit cell volume and the volume of the M1 polyhedron) of crystallizing

pyroxenes. Compared to the earlier versions, this model is less sensitive to the chemistry of the melt and to the association of coexisting minerals. The validity of the application of this model to the evaluation of the crystallization pressures of clinopyroxene in chondrites was discussed in our earlier publications [7-9].

**Results and Discussion:** Ureilites contain Ca-rich clinopyroxene in association with orthopyroxene in zone of the magmatic replacement of the primary pyroxene-olivine material around diamond-bearing graphite-kamacite veinlets. The magmatic nature of the diamondiferous graphite-kamacite veinlets follows from morphological criteria: the pervasive occurrence of droplet-shaped kamacite inclusions in graphite and, occasionally, also in diamond, which reflects the liquid immiscibility of the melts. During the crystallization of the veinlets, diamond was the first to form euhedral cubic crystals in the marginal parts of these veinlets, with the vertices of the crystals oriented toward their central parts. The sulfides and moissanite are characterized by an analogous setting. Graphite composes the central parts of the veinlets and contains kamacite droplets (or 8-shaped coalescent droplets) that were captured when the mineral grew. These droplets bear tiny inclusions of cohenite, daubreelite, and perryite, which develop as rims around kamacite droplets. Some diamond grains are minute cubic crystals abounding in fluid inclusions, which testifies that the mineral crystallized under a high fluid pressure [10]. The diamond-bearing graphite-kamacite melt intruded ureilites, penetrated them along olivine and pyroxene grain boundaries, and obviously replaced these minerals.

The material in which olivine is the most strongly modified in contact with graphite-kamacite veinlets contains tiny (no larger than  $1\ \mu\text{m}$ ) pyrope grains [11]. The mineral assemblage in the zone of the strongest alteration of olivine in the Novo-Urei ureilite is presented in Table 1.

Table 1.  
Composition (wt %) of minerals in garnet-bearing zones in ureilites

	<i>Ol</i>	<i>OPx</i>	<i>CPx</i>	<i>Grt</i>	<i>Gl</i>
SiO <sub>2</sub>	42.97	57.89	52.62	47.64	69.07
TiO <sub>2</sub>	-	-	0.36	0.36	-
Al <sub>2</sub> O <sub>3</sub>	-	-	5.37	20.45	1.70
Cr <sub>2</sub> O <sub>3</sub>	0.20	0.39	0.70	-	1.40
FeO	1.67	1.70	1.06	5.99	9.02
MnO	0.31	0.29	0.38	0.23	0.47
MgO	54.67	39.30	20.46	21.51	16.54
CaO	0.18	0.42	19.05	3.82	1.81

*Ol* – olivine; *OPx* - orthopyroxene; *CPx* – clinopyroxene; *Grt* – garnet; *Gl* – glass

The alterations of the pyroxene occur more locally, in the form of narrow zones that unevenly penetrate grains along cracks and are associated with newly formed grains of native Fe (which is Ni-free). The magmatic nature of pyroxene replacement in the ureilite material is evident from the occurrence of very small grains of Si-rich glass, quartz, and plagioclase [10].

The average crystallization temperature of the newly formed pyroxene in the magmatic replacement zone in the ureilite material around graphite-kamacite veinlets was equal to 1384°C at a pressure of 3.3 kbar (Table 2).

Table 2.  
P-T parameters of the magmatic replacement process in the Novo-Urei ureilite

Novo-Urei	T, °C*	P, kbar**
1	1280	5.7
2	1381	1.1
3	1389	3.4
4	1404	2.8
5	1466	0
Average (5) <sup>#</sup>	1384	3.3

\* — temperature values calculated by orthopyroxene-clinopyroxene thermometers [1, 2]

\*\* — pressure values calculated by the clinopyroxene barometer [6]

<sup>#</sup> — number of analyzed pyroxene pairs.

As was previously determined in [12, 13], diamond in ureilites was formed in two stages: the primary nucleation of diamond grains in the Ni-Fe matrix melt of carbonaceous chondrites under a high pressure and the subsequent metastable growth of diamond grains during the emplacement of the graphite-kamacite veinlets into the primary pyroxene-olivine material of ureilites. The temperature and pressure values presented above correspond to the intrusion of the diamond-bearing graphite-kamacite melt.

**Summary:** Our thermo- and barometric results obtained on ureilites indicates that their pyroxene-olivine material was replaced by diamond-bearing graphite-kamacite veinlets at temperatures of 1280-1466°C and pressures of 0-5.7 kbar.

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