ORIGIN OF JADEITE-UREYITE-BEARING PYROXENE IN ORDINARY CHONDRITES: EVIDENCE FOR SIGNIFICANT PRESSURES IN THE PARENTAL BODIES
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The crystallization of unusual, ureyite- and jadeite-rich pyroxene in the chondrules of ordinary chondrites is demonstrated to be indicative of significant pressures in the parental bodies.

Ureyite was found in several iron IAB and IIA meteorites [14, for references], for example, the Toluca IA meteorite was determined to contain diopside-bearing ureyite in association with chromite and plagioclase [15]. Occasional ureyite and jadeite grains were found in carbonaceous chondrites (ureyite was detected in the matrix of the Orgueil chondrite [4], and thin jadeite rims around olivine crystals and small jadeite grains were found in the albite glass of the Kainsaz chondrite [2]). Pyroxenes of jadeite-ureyite composition are relatively rarely encountered in ordinary chondrites, but a significant ureyite admixture was described in augite of the Yamato-74160 LL7 chondrite [13], and pyroxene identified as ureyite was detected in assemblage with tridymite in the Odessa H4 chondrite [9]. We described [6, 8] acicular crystals with exsolution textures (regularly oriented aggregates of chromite and plagioclase) in the pyroxene-olivine porphyritic chondrules of the Berdyansk L6 chondrite. The bulk composition of the protocrystalline phase corresponds to a complex Na-Cr-Al pyroxene. An analogous situation was observed in a chondrule from the Elenovka L5 meteorite. P.Ramdorh [11] hypothesized that part of chromite objects contained in ordinary chondrites are pseudomorphs after earlier minerals, for example, ureyite.

Recently, we detected pyroxene of complex composition in some ordinary chondrites of intermediate and high petrological types. Figures 1a, b demonstrate pseudomorphs of normative complex-pyroxene composition from a pyroxene-olivine chondrule of the Berdyansk L6 meteorite. The pseudomorphs display an elongated tabular morphology and consist of aggregates of Al-bearing chromite (up to 10 wt % Al₂O₃, white in Fig. 1a,b) and plagioclase (the dark gray phase in interstices between chromite crystals), which is more calcic (An₃₀) than the plagioclase from chondrule interstices (An₁₀, nearly black in Fig. 1a). The bulk composition of the pseudomorphs (Table 1), which was determined by means of scanning by electron beam over an area, can be readily recalculated to complex pyroxenes with variable concentrations of the ureyite (Ur), jadeite (Jd), and diopside (Di) end-members with tschermakite (Ca-Tch; Fe,Mg-Tch). To understand the conditions under which the complex Na-Cr-Al pyroxenes crystallized, it is important to examine their textural relationships with other minerals within the chondrules. Bundles of elongated protopyroxene crystals (15 by 200 µm at Dchondrule ~ 600 µm) commonly started to crystallize from either the boundary of the chondrule or large grains of olivine (Fa₂₅) and orthopyroxene (Fs₂₀). These Na-Al-Cr pyroxene grains are euhedral with respect to plagioclase. In the Raguli H3.8 chondrite (Fig. 2), Na-Cr-Al pyroxene occurs in the form of relatively large porphyritic grains (15 by 30 µm at Dchondrule ~ 100 µm), which grow inward the chondrule from its boundary with the matrix, are euhedral, coexist with barred olivine (Fa₁₈), and are cemented by feldspar glass (An₃₂Ab₆₇Or₁ with minor amounts of normative chromite and ilmenite). It follows that the original Na-Cr-Al pyroxene crystallized in the chondrites from melt nearly simultaneously with or immediately after the olivine, before the onset of plagioclase crystallization.
It was established for various pyroxene isomorphous series that an enrichment in jadeite can proceed only under elevated pressures. Experimental studies of the ureyite-jadeite system [1] demonstrate that, in an isothermal section at 800°C, the stability of jadeite-bearing ureyite depends on pressure. At 1 bar, ureyite can accommodate no more than 14 ± 2.5% jadeite, and an increase in the jadeite concentration in pyroxene to 35% can be caused by a significant increase in the pressure (up to 17 kbar). At pressures in excess of 18 kbar, a continuous jadeite-ureyite solid-solution series becomes stable. An increase in the content of the jadeite component of omphacite [10] or enstatite-jadeite solid solution [7] is also indicative of higher pressures.

| Average of bulk microprobe analyses (wt% of oxidized) of Na-Cr-Al-Px | Cation proportions (normalized to 6 oxygens) of Na-Cr-Al-Px |
|---|---|---|---|---|
|  | B02 | R01 | B02 | R01 |
| SiO₂ | 46.69 | 43.31 | 1.72 | 2.00 | 1.62 | 2.00 |
| Al₂O₃ | 18.34 | 20.56 | 0.80 | 0.90 | 0.90 | 0.90 |
| TiO₂ | 0.21 | 0.52 | 0.01 | 0.01 | 0.01 | 0.01 |
| Cr₂O₃ | 15.63 | 12.21 | 0.46 | 1.28 | 0.36 | 1.30 |
| FeO | 7.49 | 10.62 | 0.23 | 0.33 | 0.33 | 0.33 |
| MgO | 1.02 | 1.49 | 0.06 | 0.08 | 0.08 | 0.08 |
| CaO | 2.61 | 4.16 | 0.10 | 0.17 | 0.17 | 0.17 |
| Na₂O | 7.42 | 6.90 | 0.53 | 0.65 | 0.50 | 0.68 |
| K₂O | 0.50 | 0.24 | 0.02 | 0.01 | 0.01 | 0.01 |

A diopside admixture in ureyite is also possible only under elevated pressures (~15 kbar [5]). It is worth noting that Na-Cr-Al clinopyroxene (44 mol % Ur, 20 mol % Jd, and 25 mol % Di with minor enstatite and acmite) of composition close to that of the protopyroxene from the Berdyansk and Ragudi chondrites was detected in diamondiferous kimberlites from Yakutia [12], a fact that also validates the probably high-pressure conditions under which the pyroxene of complex composition crystallized. The pressures could hardly be as high as those of the eclogite facies, because the normative composition of the protopyroxene from the examined chondrites (and the Yakutian kimberlites) is characterized by an excess of the Na-component, which points to elevated concentrations of Na in the melt. This could be favorable for the crystallization of complex jadeite-bearing ureyite under lower pressures [3]. Nevertheless, the occurrence of such pyroxene in meteorites of the chondritic type not only corroborates the conclusion of the magmatic genesis of chondrites but also provides evidence for significant pressures in their parental bodies.

Acknowledgments - We are grateful to Prof. A.A. Ilyanov who kindly provided us with literature on ureyite. This work was supported by the Foundation of Russian Universities, grant 5014 and the Russian Foundation for Basic Research.