
Academy of Sciences, Moscow, USSR.

Introduction. As known, Ca-Al-rich inclusions (CAI's) are unique material which records of earliest events in Solar System history. These refractory inclusions have been studied elaborately in Allende and some other carbonaceous chondrites (1, 2). In this paper we report on detailed mineralogical and petrological data on CAI's from Efremovka meteorite (39) and some constraints on their modes of formation. Major and trace element chemistry of Efremovka CAI's is considered in companion work (3).

Texture and mineralogy. The sample of Efremovka meteorite (KMET No. 2369) contains ~3.5 vol.% of CAI's. We classified 45 studied CAI's according to (4). Thus, Types A, B, and I inclusions are coarse-grained and Type F inclusions are fine-grained. We also used "hibonite-bearing" to designate inclusions containing hibonite. The most typical coarse-grained Type A CAI is E2 spheroid having 2 cm in diameter (the largest yet observed during this study). It consists of melilite 78.8, spinel 17.6, perovskite 3.2 and Fe-Ni metal 0.4 wt.%. As rare phase Sc-rich pyroxene was found. It forms thin rims on some perovskite and Fe-Ni metal grains, although one individual grain (~20 μm) was observed also. Fe-Ni metal contains Mn-V-W-Os-Ir-Pt-rich nuggets. In the one case coulsonite was established as coexisting with metal. E2 exhibits hypidiomorphic, somewhat poikilitic texture. Besides there is melilite + perovskite eutectic intergrowth in some places. The crystallization order is: spinel + perovskite + melilite. E2 has a multi-layered rim described in companion work (5). Type B CAI's contain Ti-Al-pyroxene (~50%), spinel (~30%) and minor melilite and anorthite. Accessory phases are nepheline and Fe-Ni metal. These CAI's have a poikilitic, gabbro-like texture. Here numerous small rounded spinel crystals are sprinkled in major phases. The crystallization order is: spinel + Ti-Al-pyroxene + melilite + anorthite + hibonite. E2 spheroid of Type B CAI's are rare. They are usually composed of melilite (~70%), Ti-Al-pyroxene (~20%), and spinel (~10%). Fine-grained Type F CAI's are the most abundant (~70% of number of all CAI's). Their major phases are spinel, plagioclase and pyroxene. Accessory phases are nepheline, olivine and Fe-Ni metal. Fine-grained CAI's have often colloform-like texture in which anhedral spinel surrounded by anorthite are in pyroxene matrix. Thus the order of crystallization is: spinel + anorthite + pyroxene. The two only hibonite-bearing fine-grained CAI's (E2 and E3) were found. These CAI's are coarse zoned and consist of melilite and spinel with minor amounts of hibonite, anorthite, pyroxene and perovskite. No order of crystallization can be established except that spinel and hibonite were first.

Mineral chemistry. The composition ranges of melilite (Fig. 1) are similar to those in the Allende CAI's (4, 6). Melilite from hibonite-bearing CAI's is low-Ak (0-10 mol.% Ak) while melilite in Type B CAI's is higher in Mg (70-80% Ak) and contains relatively high Na2O concentration (~2 wt.%). No certain zoning of melilite were determined in Efremovka CAI's. Pyroxene are characterized by large variations (Fig. 3) in Ti and Al contents such as in Allende CAI's. The highest Ti and Al contents were determined in pyroxene from Type B and I CAI's. Pyroxene of Type F CAI's is depleted in these elements. Spinels of Type A CAI's is obviously higher in V, Cr and Mg relatively to those in other CAI's (Fig. 4). In turn, spinel from Type F CAI's has the highest V, Cr, Mg contents. CAI's of Type F consists of Cr2O3-enriched (eucrite) CAI's are rare. High Fe contents (~5 wt.%) were detected in spinel from fine-grained CAI's only. Plagioclase are present almost pure anorthite in all the studied grains. Perovskite are usually poor in minor elements. The E2 core perovskite is lower in Na2O than rim one, excluding perovskite surrounded by Sc-rich pyroxene. The latter perovskite has high Fe contents (up to 1.5 wt.% ZrO2) such as rim perovskite. The obtained hibonite compositions are similar to those reported earlier for Allende (6) and Leoville (9) CAI's (Fig. 2). Sc-rich pyroxene and coulsonite from E2 CAI are (wt.%): SiO2, 27.64; TiO2, 16.47; Al2O3, 20.55; Cr2O3, 0.65; FeO, 0.3; MgO, 4.07; CaO, 24.30; Na2O, 0.2; K2O, 0.03; V2O3, 1.33; Sc2O3, 6.24; ZrO2, 0.67; sum, 101.40; and SiO2, 57; TiO2, 2.71; Al2O3, 3.14; Cr2O3, 0.94; FeO, 23.44; Fe2O3, 29.11; MnO, 0.22; MgO, 6.45; CaO, 1.67; V2O3, 31.71; Sc2O3, 13.0; sum, 100.07, respectively.

Discussion. Our data show that Efremovka CAI's are similar to Allende CAI's in mineralogy and petrography; however, secondary alteration is absent. Eutectic and poikilitic texture and mineral assemblages according to (2) suggest the melt origin of CAI's, but not origin as solid condensates. In support of this the order of crystallization of CAI phases, except of Ti-bearing phases, coincides with one of such composition melt in CaO-MgO-Al2O3-SiO2 system (7). But colloform-like texture are not typical for textures resulting from silicate melts. Examination of the section of CaO-MgO-Al2O3-SiO2 tetrahedron at 10 wt.% MgO (see Fig. 2 in ref. 5) shows that anorthite-spinel line may be reaction boundary, because anorthite composition resides in spinel field and anorthite liquid surface has a steep slope to pyroxene-anorthite eutectic. It assumes that anorthite during rapid crystallization of fine-grained CAI composition could be formed by partial reaction of spinel with melt followed by pyroxene precipitation. Nevertheless, some texture particularities of CAI's can not be explained by melt crystallization only. So the irregular perovskite grains rimmed by Sc-rich pyroxene in E2 CAI differ from other coexisting perovskite grains in morphology and in 2r contents and may be xenocrysts, i.e., be entered into inclusions as separate particles. Coarse zoning of hibonite-bearing CAI's are not compatible with melt crystallization also and rather have accretion origin. Moreover, despite melt CAI formation, spinel chemistry shows that CAI suite as a whole could not be generated by crystal-
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liquid fractionation. In fact Cr-V inverse correlation in spinels for CAI suite are not appropriate with crystal-liquid fractionation but can be understood from condensation theory since V condensates before Cr (8) and must be concentrated in high-temperature condensate fraction.

In general we conclude that Efremovka CAI's were formed from melt. However processes of accretion of solid particles perhaps too part in formation their compositions. In any case the origin of primary CAI matter is connected undoubtedly with condensation process.

REFERENCES:

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