

EFREMOVKA CAI'S: MINERALOGICAL AND PETROLOGICAL DATA. A. A. Ulyanov, M. I. Korina, M. A. Nazarov, and E. Ya. Sherbovsky. V. I. Vernadsky Inst. of Geochemistry and Analytical Chemistry, USSR Academy of Sciences, Moscow, USSR.

**Introduction.** As well 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 (C3V) 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. 2349) 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 the one individual grain (~20µm) was observed also. Fe-Ni metal contains Mo-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, gabbroic-like texture. Here numerous small rounded spinel crystals are sprinkled in major phases. The crystallization order is: spinel → Ti-Al-pyroxene → melilite → anorthite. Rims on Type B CAI's consists of diopside only. Type I (intermediate) 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. Accessories are presented by 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 only two hibonite-bearing fine-grained CAI's (E8 and E13) 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-Åk end (0-10 mol.% Åk) while melilite in Type B CAI's is highest in Mg (70-80 Åk) and contains relatively high Na<sub>2</sub>O 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. Spinel of Type A CAI's is obviously higher in V relatively to one in other CAI's (Fig. 4). In turn spinel from Type F CAI's has the highest Cr contents. CAI's of Type B contain spinel which is intermediated in Cr and V. Spinel low both in Cr and V is in hibonite-bearing CAI's. High Fe contents (~5 wt.%) were detected in spinel from fine-grained CAI's only. Plagioclase are presented by almost pure anorthite in all the studied grains. Perovskite are usually poor in minor elements. The E2 core perovskite is lower in Zr content than rim one, excluding perovskite surrounded by Sc-rich pyroxene. The latter perovskite has high Zr contents (up to 1.5wt.% ZrO<sub>2</sub>) 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.%): SiO<sub>2</sub>, 27.64; TiO<sub>2</sub>, 16.47; Al<sub>2</sub>O<sub>3</sub>, 20.55; Cr<sub>2</sub>O<sub>3</sub>, .05; FeO, .03; MgO, 4.07; CaO, 24.30; Na<sub>2</sub>O, .02; K<sub>2</sub>O, .03; V<sub>2</sub>O<sub>5</sub>, 1.33; Sc<sub>2</sub>O<sub>3</sub>, 6.24; ZrO<sub>2</sub>, .67; sum, 101.40; and SiO<sub>2</sub>, .57; TiO<sub>2</sub>, 2.71; Al<sub>2</sub>O<sub>3</sub>, 3.14; Cr<sub>2</sub>O<sub>3</sub>, .94; FeO, 23.44; Fe<sub>2</sub>O<sub>3</sub>, 29.11; MnO, .02; MgO, 6.45; CaO, 1.67; V<sub>2</sub>O<sub>5</sub>, 31.71; Sc<sub>2</sub>O<sub>3</sub>, .13; 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-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> system (7). But colloform-like texture are not typical for textures resulting from silicate melts. Examination of the section of CaO-MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> 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 cotectic. 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 Zr contents and may be xenocrysts, i.e., be entered in the inclusions as solid 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.

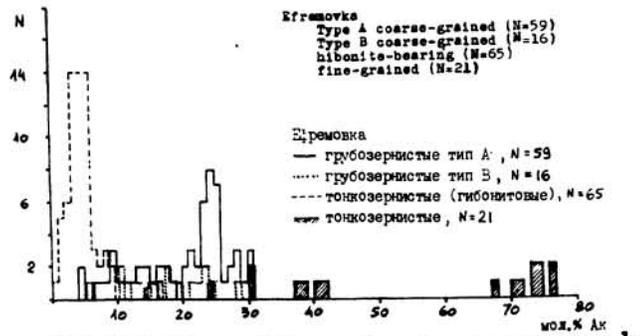


Fig. 1. Состав меллита из САI-включений метеорита Ефремовка. mol.% Al<sub>x</sub>

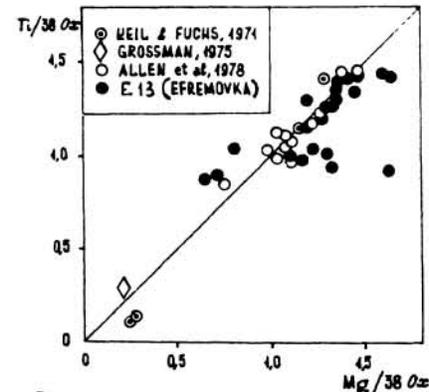


Fig. 2a. Ti vs Mg in hibonite of Allende, Leville and Efremovka CAI's.

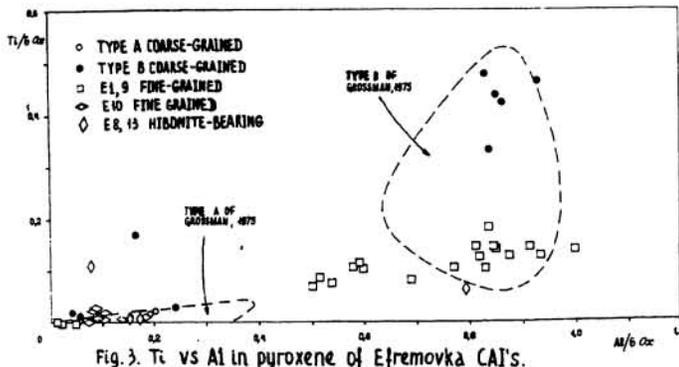


Fig. 3. Ti vs Al in pyroxene of Efremovka CAI's.

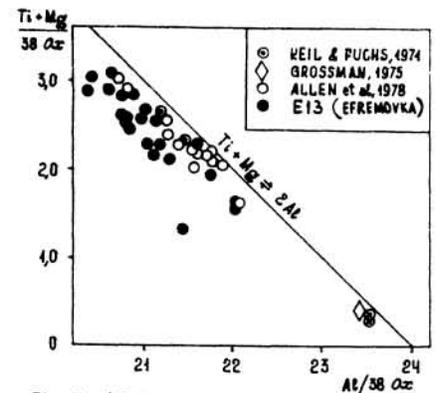


Fig. 2b. (Ti-Mg) vs Al in hibonite of Allende, Leville and Efremovka CAI's.

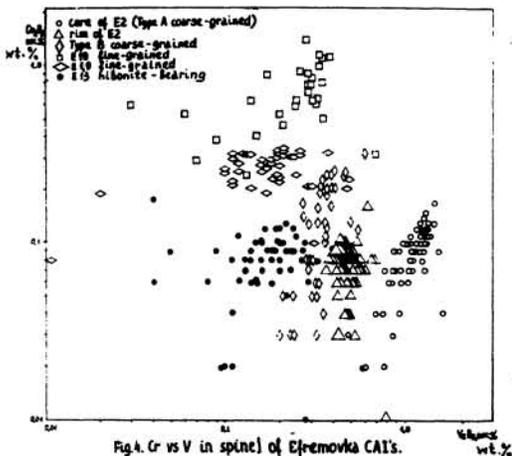


Fig. 4. Cr vs V in spinel of Efremovka CAI's.

## REFERENCES:

- Grossman L. (1972) GCA, 36, 597.
- Blander M. & Fuchs L.H. (1975) GCA, 39, 1605.
- Nazarov M.A., et al. (1982), this volume.
- Grossman L. (1975) GCA, 39, 433.
- Korina M.I., et al. (1982), this volume.
- Allen J.M., et al. (1978) PLSC 9th, 1209.
- Берешной А.С. (1970) Многокомпонентные системы окислов. Киев, „Наукова Думка“.
- Grossman L. & Larimer J.W. (1974), RGSP, 12, 71.
- Keil K. & Fuchs L.H. (1971) EPSL, 12, 184.