

EVIDENCE FOR EXTRANEEOUS PEROVSKITES IN CAIs FROM THE EFREMOVKA (CV3) METEORITE: A COMBINED PETROGRAPHIC, TRACE ELEMENT, AND ISOTOPIC STUDY; Ernst Zinner¹ and Ahmed El Goresy²; ¹McDonnell Center for the Space Sciences and Physics Department, Washington University, St. Louis, MO 63130, USA; ²Max-Planck-Institut für Kernphysik, Postfach 103980, D-69029 Heidelberg, Germany.

A petrographic and trace element study of perovskites in several CAIs from the Efremovka CV3 chondrite revealed the presence of several populations of perovskites with different Zr/Y ratios. Zr/Y ratios are higher than chondritic, chondritic, lower, or much lower than chondritic. Perovskites with chondritic, higher, or much lower than chondritic Zr/Y ratios cannot have crystallized from CAI melts and are hence of extraneous origin. Different origins for individual perovskite grains are also indicated by Ca-isotopic heterogeneities.

Equilibrium condensation calculations indicate that perovskite is one of the earliest condensates from a gas of solar composition [1]. In many CAIs from CV and CM chondrites perovskite is believed to have crystallized from refractory liquids [2]. Considerable effort has been devoted to the search for perovskites of extraneous origin, i.e., perovskites which formed elsewhere, were captured by the CAI liquid and survived as relict grains or were incompletely dissolved [3,4]. This search included screening of areas in melilite crystals, in which relict perovskites were believed to have been resorbed [3,4]. This procedure is difficult and trace element data obtained for the analyzed areas were either non-conclusive or the evidence was circumstantial [4]. An additional difficulty arises from the fact that captured and resorbed perovskites may have crystallized from a liquid before their release from the parental CAIs and incorporation into other CAIs. It appears to be of utmost importance to use trace element abundance patterns to establish whether individual perovskites in CAIs formed by condensation from a gas or by crystallization from a liquid [5,6]. In this respect, the relative abundances of the ultrarefractory elements Hf, Zr, Sc, and Y are especially diagnostic for revealing the formation process because crystal/liquid distribution coefficients for these elements differ markedly from one another [4,5] and their relative abundances in igneous perovskites are expected to deviate from chondritic abundances [5,6,7]. Criteria for the identification of extraneous perovskites in CAIs are: a) deviation of relative refractory lithophile trace element abundances from abundances predicted for crystal/liquid fractionation, and b) occurrence of perovskite in mineral assemblages texturally different from those in which perovskites, whose relative trace element abundances are compatible with the predicted crystal/liquid fractionation ratios, occur [7]. Criterion b) is important because an assemblage could be a fragment of another CAI and was captured in the host CAI. Trace element abundances are insufficient for deciding whether such perovskites are indigenous or extraneous to the CAI.

We have undertaken a petrologic, trace element, and isotopic investigation of perovskites in several CAIs from the Efremovka (CV3) chondrite. Perovskites were categorized according to occurrence (e.g., in spinel clusters or frambooids, in the rim sequence, in xenoliths that petrographically differ from the host CAI and appear to have been captured) Here we concentrate on two Type A inclusions, 101.1 and E2. Efremovka CAI 101.1 contains captured sinuous fragments and perovskites attached to these fragments may be of extraneous origin [7]. In addition, a few perovskites are associated with or enclosed in fine-grained Cr-spinel-bearing xenoliths in the core. Many perovskites in 101.1 are amoeboid in shape and entirely enveloped by reaction rims of Sc-, Zr-rich fassaite [7]. Trace element analyses revealed the presence of different perovskite types: (1) perovskites with higher than chondritic Zr/Y ratios (Per A in Fig. 1a), (2) perovskites with chondritic Zr/Y ratios (Per B in Fig. 1a), and (3) perovskites with lower than chondritic Zr/Y ratios. The first two types are probably condensates. Subsequent electron microprobe analyses confirmed the existence of groups 2 and 3 (Fig. 2a). In addition, there appears to be a fourth group with high Y₂O₃ (up to 1.4 wt.%) and very low ZrO₂ (< 0.02 wt.%) (Data points close to the y-axis in Fig. 2a). 40% of the analyzed perovskites belong to this category. Group 1 seems to be very rare in this CAI since no such grain was encountered during electron probe analyses. 21% of the perovskites have close to chondritic ZrO₂/Y₂O₃ ratios (2.7; Fig. 2a). These perovskites must be of extraneous origin. The ZrO₂/Y₂O₃ ratios of group 3 perovskites (0.15 < ZrO₂/Y₂O₃ < 1.0) are similar to ratios obtained from crystal/liquid fractionation experiments (0.386 in air and 0.484 at low f_{O₂} [5]). Perovskites highly depleted in ZrO₂ (members of group 4 plotting close to the y-axis in Fig. 2a) cannot have crystallized

from the host CAI liquid and are probably also extraneous to the CAI. These perovskites and those with higher than chondritic ZrO_2/Y_2O_3 (Per -A in Fig. 1a) are of special interest, since they either condensed from a reservoir with non-chondritic Zr/Y ratio, or formed by fractional condensation. Perovskites coexisting with the Cr-spinel xenoliths fall into groups 1-3, indicating diverse origins (Fig. 1b). Some of these perovskites with low ZrO_2/Y_2O_3 ratios (e.g., Per F in Fig. 1a) are probably of igneous origin, but CAI 101.1 is their second host. The REE and refractory lithophile abundance patterns of three perovskites coexisting with Cr-spinel xenoliths (Fig. 1b) differ from the patterns of perovskites in the host CAI (Fig. 1a) in several ways: a) the former perovskites are more enriched in the light REEs, b) their HREE abundances from Gd to Er do not increase as steeply as those of perovskites A-C, c) compared to the host perovskites, they are much more enriched in Nb. It is remarkable that, although characteristic differences are seen in the abundance patterns of individual perovskites, all of them have the same basic ultrarefractory REE pattern with depletions not only in Eu and Yb but also in Tm. This indicates formation from a common reservoir with an ultrarefractory REE signature but by different processes, causing differences in the abundances of Zr, Y and Nb in individual grains. Different individual formation histories are also indicated by preliminary ion probe measurements of Ca and Ti isotopes in three perovskites. Grain A (Fig. 1a) has a clearly resolved ^{48}Ca excess of 9.8 ± 3.4 (2σ) ‰, the others have normal Ca; all Ti-isotopic ratios are normal. Previously, Goswami et al. [8] have reported ^{50}Ti -isotopic heterogeneities among single perovskites from Efremovka inclusion E-50.

In the Efremovka inclusion E2 [9] perovskite occurs in the melilite-rich core, between spinel framboids and clusters in the core, and in a separate layer in the rim sequence. Data points of grains of all three occurrences cluster around the chondritic ratio line (Fig. 2b). ZrO_2/Y_2O_3 ratios of perovskites in the core and in the rim are similar. However, perovskites captured between spinels in the core have distinctly lower concentrations (Fig. 2b). The ZrO_2/Y_2O_3 ratios of perovskites in E2 cannot have resulted from crystal/liquid fractionation during cooling of the E2 liquid. These grains probably condensed from a gas of solar composition. However, the bimodality in their ZrO_2/Y_2O_3 ratios suggests two distinct sources.

REFERENCES: [1] Grossman L. (1972) *GCA* **36**, 597; [2] MacPherson G. *et al.* (1988) in *Meteorites and the Early Solar System*, p. 746; [3] Johnson M. L. *et al.* (1988) *Meteoritics*, **23**, 276; [4] Kennedy A. K. *et al.* (1991) *LPS XXII*, 709; [5] Simon S. B. *et al.* (1993) *GCA*, in press; [6] Kennedy A. K. *et al.* (1993) *LPS XXIV*, 793; [7] El Goresy A. *et al.* (1993) *Meteoritics*, **28**, 344; [8] Goswami J. N. *et al.* (1991) *Meteoritics* **26**; [9] Fahey A.J. *et al.* (1987) *GCA* **51**, 3215.

