TRACE ELEMENT ABUNDANCES IN MICRO-OBJECTS FROM TIESCHITZ (H3.6), KRYMKA (LL3.1), BISHUNPUR (LL3.1) AND MEZÖ-MADARAS (L3.7): IMPLICATIONS FOR CHONDRULE FORMATION.

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Introduction: Crypto-crystalline to fine-grained and radiating pyroxene and pyroxene/olivine chondrules are particular chondrules, which occur in all chondrites. Their textures imply that they represent quickly quenched liquids. The origin of the liquids, however, still remains unresolved. There are several possible ways to generate these liquids; the most popular process is melting of solid precursors in either a nebular or planetary set-up. Another possible way to create in particular the liquids of quench-textured chondrules is to condense them directly out of the solar nebula. Bulk major, minor and trace element abundances in chondrules should allow us to distinguish between these different possibilities. Unfractionated relative solar abundances of trace elements indicate that the precursors consist of primitive matter, possibly solar nebula condensates [e.g. 1-7]. In some cases certain fractionated refractory lithophile element abundances in chondrules have been reported to suggest that they originated by direct condensation from the solar nebula [e.g., 4, 8, 9].

In this study, 40 crypto-crystalline to fine-grained and radiating pyroxene, olivine and olivine/pyroxene as well as barred olivine micro-objects (chondrules and fragments) from Tieschitz, Mezö-Madaras, Krymka and Bishunpur were analyzed for their bulk trace element contents with the aim to gain more insight into the genesis of these peculiar nonporphyritic objects.

Samples and Methods: Type 3 ordinary chondrites were chosen for this study to minimize effects of sample alteration due to metamorphic events.

Forty micro-objects were selected with diameters that range from about 40 µm to 2 mm. Detailed petrographic studies and mineralogical analyses were carried out by optical microscopy, scanning electron microscopy as well as electron microprobe. Lithophile trace element abundances in individual micro-objects were determined by Laser Ablation ICP-MS following the procedure of [10].

Results: The main silicate phases occurring in the objects are opx (En_{60-97}), ol (Fo_{60-100}), glass/mesostasis, Ca-px (pigeonite-augite) and in some cases SiO_2. Grain sizes of minerals in chondrules and chondrule/irregular fragments range from <1 µm to a maximum of about 10 µm, except for barred olivine chondrules, which contain coarser-grained olivines.

Individual micro-objects have variable abundances of refractory, moderate volatile and volatile lithophile elements: *Refractory element abundances* vary mostly around 0.6 – 5 x CI, except for some highly fractionated objects in Tieschitz and Mezö-Madaras, which have lower abundances (between 1 and <0.1 x CI), and some more refractory barred olivine chondrules/fragments (up to 10 x CI). Abundance anomalies in refractory to moderately volatile elements are frequent. The most common anomalies affect the elements Eu, Sr, Ba, U and Ca. A characteristic abundance pattern occurs in Krymka chondrules: All objects analyzed have a positive U anomaly, a negative Zr anomaly and three (out of seven) objects show a strong negative Ti anomaly. Normalized REE abundance patterns of all objects are either roughly flat (with or without a variably strong Eu anomaly), or irregularly fractionated. Refractory lithophile trace elements (RLE) display broadly four different patterns (Selected trace element abundance patterns are shown in Figs 1-4):

a) Relatively flat RLE abundance pattern with some minor irregularities (Fig. 1).

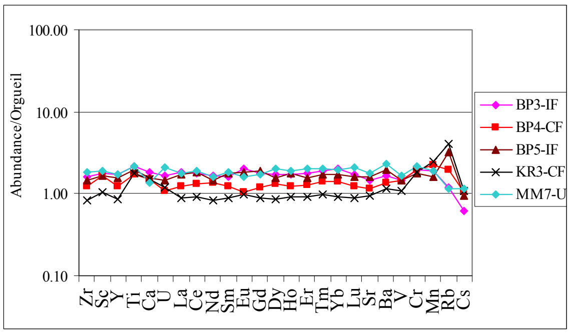
b) Roughly flat RLE abundance pattern with Sr or Sr/Ba fractionation (usually depletion) ± Eu anomaly, ± U anomaly (Fig. 2).

c) Strongly fractionated RLE abundance pattern with fractionated/irregularly fractionated REE abundances and strong Ti, U and Ce anomalies; especially in Tieschitz and Mezö-Madaras (Fig. 3).

d) Trace element abundance pattern with positive U and negative Zr and Ti abundance (observed only in Krymka objects; Fig.4).

Moderately volatile and volatile lithophile elements are usually strongly fractionated and therefore show complex trace element abundance patterns (either depleted or enriched, Figs. 1-4).

Discussion and Conclusion: The cryptocrystalline to fine-grained objects of the different chondrites show mostly flat RLE trace element abundance patterns, with or without certain abundance anomalies. Those flat RLE abundance patterns can not be produced by magmatic fractionation during melting of solid precursors and could therefore indicate an origin through condensation out of the solar nebula. (Figs. 1,2,4).



Figs.1-4: Elemental abundances are normalized to those of Orgueil [11]. (BP=Bishunpur, KR=Krymka, TS=Tieschitz, MM=Mezö-Madaras; C=chondrule, CF=chondrule fragment, IF=irregular fragment, U= undefined particle, BOC=barred olivine chondrule, BOF=barred olivine chondrule fragment). Elements are arranged in order of increasing volatility, except for REE.

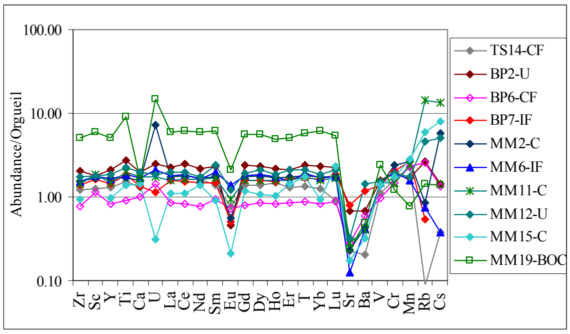


Fig.2

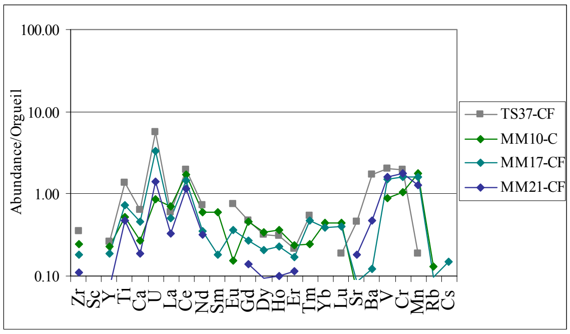


Fig.3

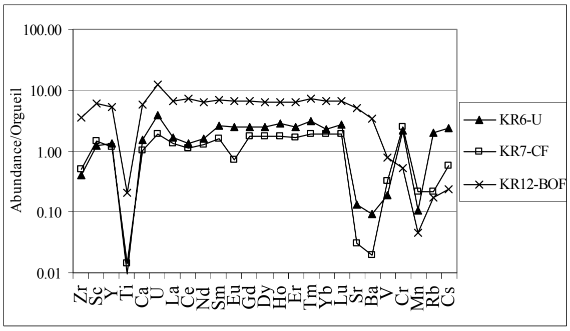


Fig.4

The flat RLE abundance patterns are commonly accompanied by depletions of less refractory elements (Sr, Ba) which are interpreted as vapor-solid/liquid fractionations (Figs. 2, 4 [e.g., 4]). Further anomalies of Ti, Zr, U, Ca, and Eu (Figs. 2-4) can either indicate a fractionation by isolation of certain mineral phases (condensation out of a fractionated nebula) or a mobilization of those elements in metasomatic processes. For the origin of the combination of Ca, Eu and Sr anomalies, plagioclase fractionation can be ruled out because the REE are roughly unfractionated instead of being LREE-depleted. A Ti-phase (perovskite?) could be responsible for the negative Ti (and Zr) anomaly in some Krymka objects.

In some Tieschitz and Mezö-Madaras objects some low and fractionated abundance patterns occur. They could be the result of a fractionation via a mineral phase with high abundances of HREE as well as Sc and Zr (Fig. 3).

Moderately volatile elements have comparable abundances independent of other elements in most objects (e.g., V, Cr, Mn), which could indicate efficient metasomatic addition (all elements are olivine/pyroxene compatible). Volatile lithophile elements usually display strong fractionation indicating variable efficiency of metasomatic processes having taken place during and/or after chondrule formation [e.g., 12].

In conclusion, trace element abundances in non-porphyritic objects from type 3 ordinary chondrites indicate that condensation of liquids from vapors with unfractionated and fractionated solar RLE abundances is a possible chondrule formation process [13]. Metasomatic processes probably played an important role in the distribution of moderately volatile and volatile elements during chondrule evolution.

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