TRACE ELEMENTS AND REE GEOCHEMISTRY OF OLIVINE AND ENSTATITE CHONDRULES IN ORDINARY CHONDRITES: INSIGHTS INTO THEIR COSMOCHEMICAL GENESIS.

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Introduction: We report in situ LA-ICP-MS (Quadrapole) trace elements and REE analyses of silicate mineral phases (particularly olivine and enstatite) in chondrules from the four (04) ordinary chondrites e.g. Assam (L5), Devri-Khera (L6), Muddoor (L5) and Pulsora (H5). The partitioning of different trace elements and REE among the various silicate phases, in particular olivine, enstatite chondrules and mesostasis, is very sensitive to its nebular formation conditions [1, 2]. The relative distribution and fractionation of the trace elements and REE among these chondrites (having different chemical groups) may lead to validate the chondrule formation process under specific cosmochemical environments.

Analytical Setup: Trace elements were analysed using the 213 nm, Teledyne Cetac Technologies, LSX G2 laser ablation unit installed at GSI, Faridabad and coupled with a Agilent Technologies 7700x mass spectrometer. The ICP-MS was operated at 1350 W plasma power. Ablations were performed in pure He-atmosphere (550ml min^{-1}) mixed before entering the Plasma torch with a flow of Ar (830 ml min^{-1}). Laser ablation conditions are: Laser power ~ 55% (2.5mJ) with pulse frequencies varying between 5 and 10 Hz and spot sizes of 50 - 100 µm, carrier gas flow (He + Ar) is 1.38 L min^{-1} in ICP unit. With such pulse frequencies, depth speed for silicates analysis is about 1 µm s^{-1}. Each analysis consists of 60 s of background analyses and 30 s of ablation or sample run time. Data reduction was carried out using the GeoPro software. Calibration for the analysis was carried out using NIST 610 and NIST 614 glasses as external standards [3].

Results and Interpretation: X_{Mg} of olivine and enstatite particularly in Assam (L5) chondrite show significant variation/dispersion, in the order of 0.69 - 0.91 and 0.70 – 0.94 respectinvely, suggesting presence of chemically disequilibrated micro-domains. For the other ordinary chondrites the X_{Mg} in olivine and enstatite varies in between 0.75 – 0.81 and 0.75 – 0.83, showing near equilibrium conditions. Depending upon Mg-Fe, Mg-Ca and Ca-partitioning in co-existing Opx – Cpx pairs (mostly clinoenstatite – augite to diopside compositions) provide equilibration temperatures in the range of 940 - 1240°C (± 52°C) [4,5,6]. In situ laser ablation was performed from olivine and enstatite chondrules (e.g. BO, PO, GO, POP, PP and RP [7]) and mesostases. Assam (L5), Devri-Khera (L6) and Muddoor (L5) show comparable LREE vs. HREE fractionation trend (normalized against CI Chondrite), probably suggesting a state of equilibrium with each other in respect of REE reservoir. Both REE concentrations and budget (∑REE) for olivine and enstatite chondrules are slightly enriched and the LREE – HREE fractionation is minimum. The REE fractionation trend of enstatite chondrules is comparable to olivine in Pulsora (H5), where LREE is relatively depleted and HREE is slightly enriched. Coherent trends in elemental plots indicate that each chondrite formed essentially by progressive (closed-system) fractional crystallization. Compared with other L-type chondrites, slightly enriched HREE trend with negative Ce, Nd and Yb anomaly is observed in Assam. Muddoor shows strong negative Sm anomaly where as Devri-Khera exhibits Nd and Ho negative anomaly. Mesostases contain the highest REE budget (∑ REE) of the studied meteorites. Mesostases of Pulsora chondrite exhibit relatively enriched REE patterns with slight LREE enrichment trend over HREE [$(Ce/Yb)_N \geq 2.0$]. Trace elements distribution among these L and H-type chondrites show positive correlation between Co and Ni, suggesting preferential partitioning of Ni and Co can be attributed to the modal proportions of kamacite and taenite in the analyzed chondrite samples.

Conclusion: Considerable mineral chemical disequilibria with wide range of equilibration temperatures across the chemical – petrologic types (L5-6 to H5) of studied ordinary chondrites show distinct fractionation and enrichment trends of REE. The REE concentrations of core and rim of enstatite and olivine chondrules is comparable, indicative of equilibrium partitioning where as mesostases exhibit considerable REE fractionations with positive Eu and Tm anomaly likely governed by presence of albitic plagioclase in matrix, and negative Ce and Yb anomaly. A fractional crystallization model can be suggested, where the olivine and pyroxene cores did not change their composition since they solidified and are thus in equilibrium with the starting liquid compositions. The olivine chondrules are in disequilibrium compared to the REE budget of its melt components which now solidified as the chondrule's mesostases.

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