

ELECTRON MICROSCOPIC STUDY OF GRAPHITE IN THE VACA MUERTA MESOSIDERITE

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Introduction: Mesosiderites, stony-iron meteorites consisting of silicate clasts and Fe-Ni metal in about equal proportions, can have graphite (Gr) occurring as cliftonite grains and aggregates up to 20 μm in size as well as graphite veinlets decorating the kamacite-kamacite and kamacite-taenite borders [1-3]. The low carbon content (115 ppm) measured in cloudy taenite in the Reckling Peak A79015 and Estherville could explain the absence of graphite in these two mesosiderites [4]. There is still no consensus regarding the processes responsible for the formation of graphite in the metal phase (e.g., deposition from a mobile vapor phase [3] or solid-state precipitation of graphite from carbon previously dissolved in the metal [4]). Here scanning electron microscopy (SEM) and transmission electron microscopy (TEM) studies coupled with energy dispersive X-ray (EDX) analysis in the Vaca Muerta mesosiderite give some hints about graphite formation.

Result and Discussion: In the studied Vaca Muerta DR sample (Icate collection), silicate aggregates are preferentially cemented by troilite and metal filling large and small spaces between these aggregates. Each kamacite domain contains one, or occasionally two, irregularly shaped taenite domains at its interior. The latter is never in direct contact with silicates. We can distinguish between two types of metal areas: 1) those with fine-grained graphite filigree enveloped by thick graphite veins (C-rich areas) and 2) those without graphite. In all C-rich areas, graphite distribution is heterogeneous, i.e. having kamacite-taenite (K-T) grain boundaries with, or without, thinly decorated graphite. SEM-BEI and EDX show that the taenite-kamacite (T-K) pairs have the typical Ni diffusion profiles across T-K interface for the diffusion-controlled $\gamma_1 = \alpha_2 + \gamma_2$ transformation (with Ni contents decreasing toward the center of the residue taenite). The characteristic Ni-profiles remain even if the T-K interface is rimmed by C+Fe+O+H veinlets. SEM-BEI shows that the thick graphite veins (C-rich area) ends in a sharp contact at metal-silicate interface. These features indicate that C-emplacement postdated fcc-1 \rightarrow fcc-2 + bcc transformation.

TEM observations of the graphite-rich veinlet in focused-ion-beam section showed sub micrometer-sized (50-150 nm) taenite (γ -phase of fcc Fe-Ni not the $L1_2$ type γ' -phase of ordered fcc Fe_3Ni) crystallites with irregular shape yet almost the same crystallographic orientation in a matrix of turbostratic graphite with preferred orientations. Seven or eight of such crystallites occasionally coalesced in the γ +Gr eutectic colony/veinlet were identified by the point-count TEM-EDX analyses to have varied Fe/Ni atomic ratio (1 to 32). This indicates that the Fe-richer γ -particles were formed by the tie lines in the large two-phase region (fcc+L) with varied liquid composition before liquid reaching the co-tectic point in the Fe-Ni-C ternary [5] near 600°C where the γ -FeNi+Gr eutectic colony forms. Off-eutectic solidification of such a Fe-Ni-C fluid accounts for the formation of γ - α core-shell nodules. The residual C-rich liquid moved and deposited along the shrinkage fissures/cracks, in particular along the physico-chemically vulnerable γ - α interface and the advancing-retreating serrated edge of kamacite shell/grains to form graphite with embedded taenite aggregates upon continuous cooling. The cooling rate was high enough to suppress coarsening but allowed coalescence of the nano-sized taenite to form aggregates and enhanced turbostratic faulting (shifting)/bending/folding of the graphite ribbons. The inhomogeneous distribution of graphite in metal seems to be related to the presence (C-rich area) or absence (C-free area) of such fissures/cracks.

Finally, shock event induced the emplacement of non-equilibrium phase assemblages of amorphous carbon and nanocrystals of α -Fe + ferric oxide (hematite) + ferric hydrous sulfate (hydronium jarosite) ca. 20 to 300 nm in size in enstatite, whereas later terrestrial oxidation/alteration caused the fine veinlets of aragonite + amorphous Fe-OH along the pre-existing C-veinlets in metal grains.

References: [1] Ramdohr P. (1973) Elsevier Scientific Publishing, 245 p.; [2] Mason and Jarosewich (1973) Mineralogical Magazine 39, 204-215; [3] Maruoka et al., (2006) Lunar and Planetary Science Conference 37, 1449; [4] Goldstein et al. (2017) Geochimica et Cosmochimica Acta 200, 367-407; [5] Pavel et al. (1991) Physica B 175, 354-360.