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Reexamining Mesosiderite Classification Schemes

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Monnig METEORITE GALLERY

ABSTRACT

Mesosiderites are a group of stony-iron meteorites that contain roughly equal amounts of core material (metal) and crust (silicates) from one or more asteroid parent body. The core material is predominantly Fe,Ni-metal, with some troilite (FeS), and is found as clasts and/or intimately mixed within the meteorite matrix. Silicate clasts are basaltic or gabbroic in origin, representing different formation depths within the crust, and are predominantly plagioclase and pyroxene. The formation of mesosiderites is not fully understood, but observed features require a three stage process: (1) formation of asteroidal silicate crust; (2) metal-silicate mixing, where molten metal is injected into the solid silicates; (3) deep burial, as reflected by the extremely slow cooling rates of less than 1ºC/My. Mesosiderites are classified by pyroxene content and degree of metamorphism, which focuses only on the silicate phases. That not only ignores half of their mineralogy, but also the third stage of their formational history. Additionally, only 15% of known mesosiderites have been studied in detail. This research aims to 1) investigate five previously understudied and ungrouped mesosiderites and 2) determine if metal within mesosiderites can be used to refine current classification schemes.

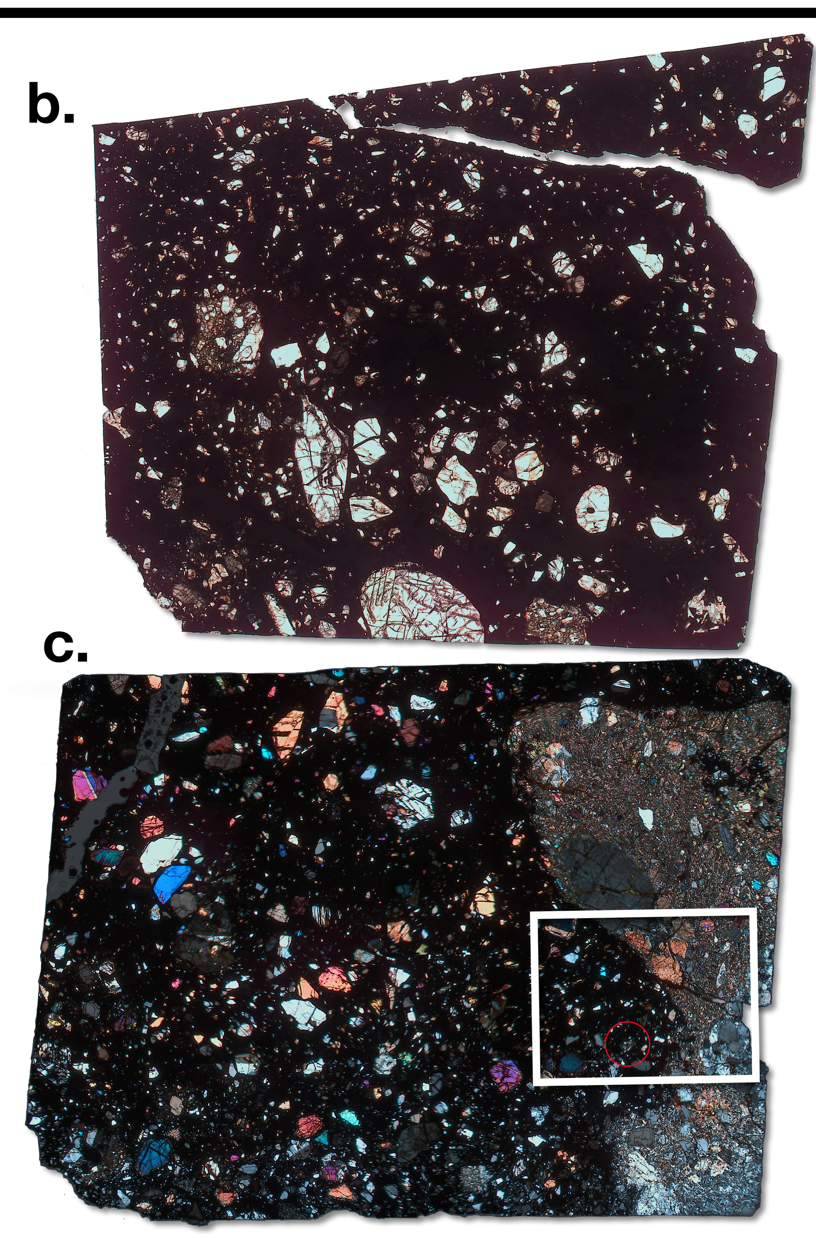

Figure 1: Hand sample (a) and thin section (b and c) images of sample NWA10882. Thin sections are plane-polarized (b) and cross-polarized light (c) of different pairs; Magnification: 1.25x; dimensions of b. and c. are 17x14mm and 16x12mm, respectively. Boxed region is field of view of SEM image (Fig.2).

History and Classification

At least two differentiated parent bodies were involved in mesosiderite formation: the progenitor of the crustal silicates and that of the Fe,Ni metal impactor.[2,4] The silicate crust solidified prior to impact, while most of the metal was liquid during impact.[4] Figures 1c. and 2a.,c. show the thorough, intimate mixing of metal and silicate at the matrix scale. Additionally, the metal phase displays the slowest cooling rate in the Solar System, suggesting deep burial after mixing.[3] The metal phase contains high-Ni taenite and low-Ni kamacite (2d,e).

Although it comprises 50wt% of mesosiderites, the metal phase is not considered during classification. Instead, the ratio of orthopyroxene and plagioclase is compared, which produces a noticeable trend (Figure 3).[1,5] A-type mesosiderites have more plagioclase, in lieu of orthopyroxene. B-types are ultramafic and C-type, the rarest, have an almost entirely orthopyroxene silicate phase. The second classification scheme is a scale of 1, 2, and 3, in order of increasing metamorphism. Grade 4 display igneous textures (Table 1).[1]

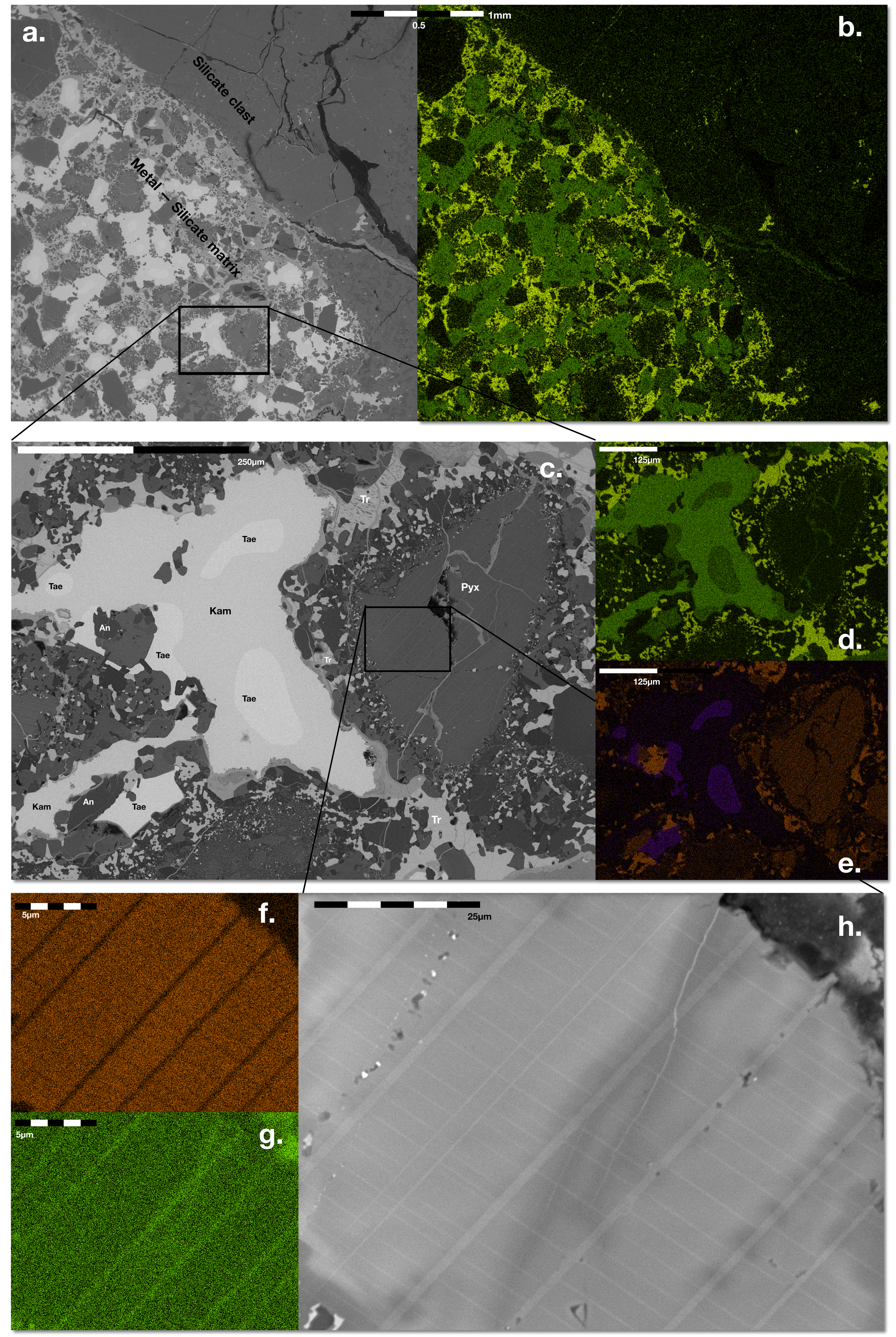

Figure 2: SEM imaging of NWA10882. a.) A silicate clast is embedded in metal-silicate matrix. b.) Sulfur-rich regions (yellow) limited to matrix (green, Fe), where reaction rims formed between silicate grains and metal during mixing event. c.) Within the matrix, a pyroxene grain (Pyx) is surrounded by sulfides, likely troilite (Tr). and phosphate (not pictured) reaction rims. High-Ni taenite (Tae) appears as lighter blebs within surrounding grey, low-Ni kamacite (Kam). d.) Taenite appears as lower-Fe blebs (dark green). e.) Ni (purple) corresponding to taenite. Anorthite (An) is suspected based on Ca (orange) and Al occurrence, and due to mesosiderite plagioclase generally being anorthitic.[3] f.) Moderately Ca-rich pyroxene shows two low-Ca exsolution lamellae, which correspond to high-Fe in the larger lamellae (g). h.) The larger lamellae are continuous across entire grain, at a high angle from finer, discontinuous lamellae.

Methods

Five mesosiderites in the Monnig Meteorite Collection were identified and selected for meeting our criteria of being both understudied (i.e., not present in published literature) and ungrouped (classified only as a mesosiderite but not into a petrologic or metamorphic type). The samples chosen were: North West Africa (NWA) 10882 (Figures 1, 2), NWA 2639, NWA 4230, NWA 1827, and Sahara (SAH) 98088. NWA 10882 only meets one of our criteria, as it has been assigned as an A2-type mesosiderite; however, as it has not been thoroughly characterized, the decision was made to still include it.

Each sample was examined in hand specimen and photographed. Thin section locations were chosen to include both silicate and metal portions of each mesosiderite, where possible. In total, 10 paired and 2 unpaired thin sections were created: NWA 10882 (2 pairs), NWA 2639 (2 unpaired), NWA 4230 (2, paired), NWA 1827 (2, paired), and Sahara (SAH) 98088 (2, paired). Images were collected in plain polarized and cross polarized light for all sections using an Olympus BX51 petrographic microscope (Fig 1b-c). A Hitachi TM4000 tabletop scanning electron microscope (SEM) was used for preliminary textural analysis. Both backscatter electron images and elemental X-ray maps were collected of areas of interest (Fig 2). Images were processed in Adobe Photoshop.

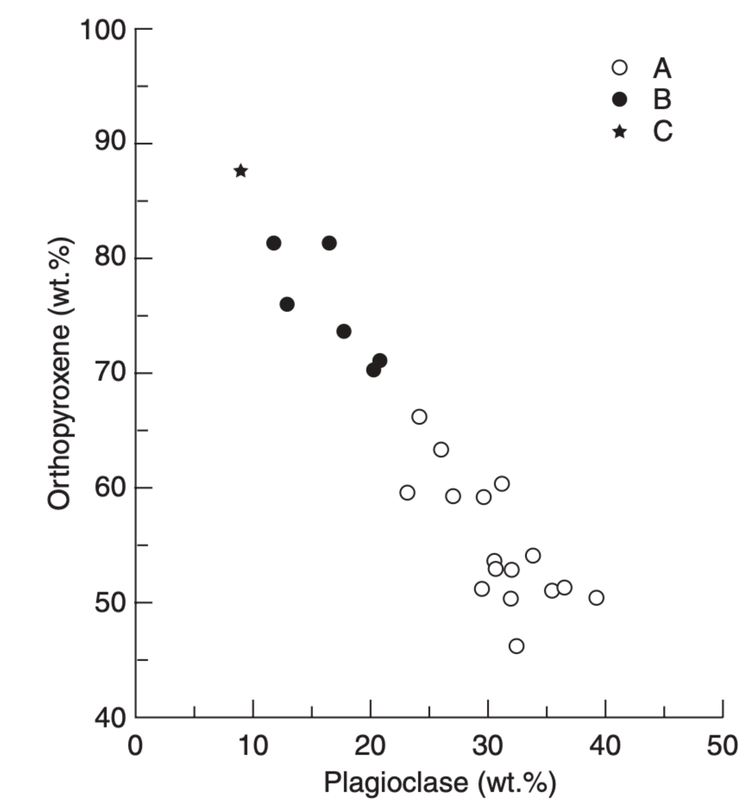

Figure 3: (above) Classification based on relative mineral abundances. Orthopyroxene abundances increase and plagioclase decreases from A to C. From Krot, et al. (2007).[5,3]

Metamorphic			Igneous
Group 1:	*Group 2:*	*Group 3:*	*Group 4:*
Slight recrystallization, angular clasts and matrix	Moderate recrystallization; rounded clasts, disequilibrium textures	Highly recrystallized; poikiloblastic textures	Impact melts and/ or metaigneous texture

Table 1: (left) Classification based on degree of metamorphism, increasing in intensity to grade 4. Reproduced from Floran (1978).[1]

Preliminary Investigation

NWA10882 was selected for preliminary based on metal-silicate texture and known classification. A silicate clast is embedded in an intimately mixed matrix of metal and silicates (1c,2a). The metal also appears as blebs with taenite centers (2e). Reaction rims are abundant at the metal-silicate boundaries, in particular the large pyroxene in 2c,d,e. Rims contain sulfur (yellow, 2b,d) and phosphorus (not pictured), as previously predicted during redox events after metal-silicate mixing.[8,9,6,7] Due to coincident occurrence of Fe, it is likely these regions are troilite (FeS). The silicate clast (2f.g.h) is likely a clinopyroxene of moderate Ca content with two low-Ca exsolution lamellae, the larger of which is higher in Fe than its surroundings. Previously classified as an A2-type, NWA10882 is expected to have a low-orthopyroxene, moderately metamorphosed composition; that is consistent with the findings shown in Figure 2: ubiquitous disequilibrium textures between clinopyroxene and metal.

Further Work

The remaining 10 thin-sections will be thoroughly characterized mineral chemistry, textures, and petrology following the Floran (1978) classification scheme.[1] Further petrographic observation, SEM elemental mapping, and electron microprobe (EMP) analysis of silicate phases of all sections will be completed. Metal phase will also be observed via SEM and EMP to determine any differences in metallography between or within existing mesosiderites types, which may be used to modify or enhance the existing classification scheme.

References: [1] Floran (1978). *Proc. LPSC,* **9.** [2] Wasson and Rubin (1985). *Nature,* **318.** [3] Mittlefehldt, et al. (1998). *Planetary Materials.* [4] Caves and Mayne, et al., (2021). *Met. Soc.* 2609. [5] Krot, et al., (2007). *Treatise on Geochem.,* 2nd ed., 1.05. [6] Hassanzadeh, et al. (1990). *Geochim. et Cosmo Acta.* **54.** [7] Harlow, et al. (1980). *Met Soc.* **15.** [8] Delaney, et al. (1982). *Proc. LPSC,* **12b.** [9] Caves and Mayne, et al. (2019). *LPSC,* 2132.