A petrologic study of metal-rich nodules in anomalous EL3 meteorite Northwest Africa (NWA) 8785

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INTRODUCTION: NWA 8785 is a remarkable, recently identified unequilibrated enstatite chondrite. It was classified as an EL3 based on the Si content in the metal and the presence of ferroan alabandite [1], but contains unusual characteristics unobserved in other EL3s. For example, it has a high abundance of FeO-rich (magnentite-bearing) matrix (34% by area) [2]. Our aim is to study the mineral assemblages and compositions in metal-rich nodules in this anomalous EL3 chondrite and compare them to nodules in other EL3s. The goals are to evaluate formation of metal-rich nodules in EL3 chondrites, identify primary phases and any evidence of secondary alteration to gain insight into secondary processes on the EL3 parent body asteroid. Most notable in NWA 8785 is the abundance of the rare mineral roedderite ($(Na,K)_2(Mg,Fe)_5Si_{12}O_{30}$), an alkali-rich silicate that may reveal more about the meteorite's origin and evolution.

METHODS: Polished thin section NWA 8785-2 was studied using:

- Petrographic Microscope
- Hitachi S4700 FE-SEM equipped with Bruker Energy Dispersive Spectrometer (EDS) and BackScattered Electron (BSE) imaging.
- Element maps and mineral compositions were obtained using the Cameca SX100 electron probe.

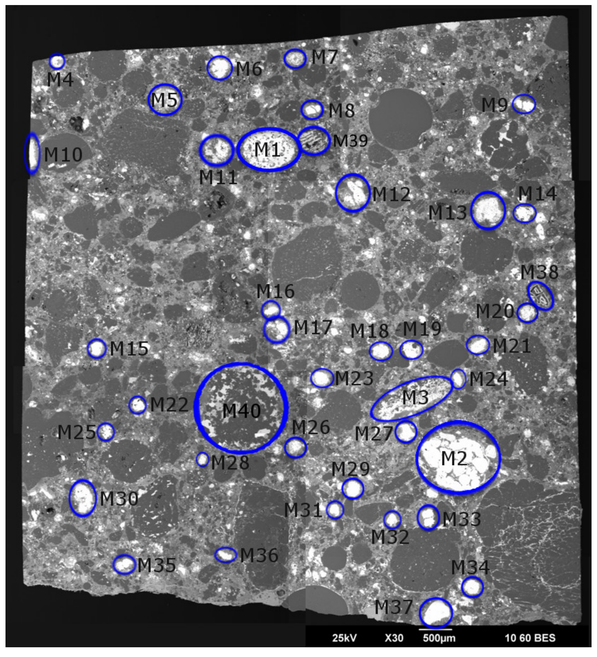

Figure 1: BSE of polished thick section NWA 8785-2. Metal-rich nodules circled in blue were studied.

RESULTS: 10 out of 40 identified metal-rich nodules were selected for study and grouped into three types based on mineral assemblage:

(1) Roedderite-bearing
(2) Rodderite-free, kamacite-rich
(3) Roedderrite-free, kamacite-poor

Roedderite-Bearing Nodules: The presence of roedderite and djerfisherite in M1, M2 and M7 is significant because these minerals have been previously reported in EH chondrites [3], but not in an EL3. Additionally, the association of roedderite with djerfisherite may indicate a relationship between the two minerals.

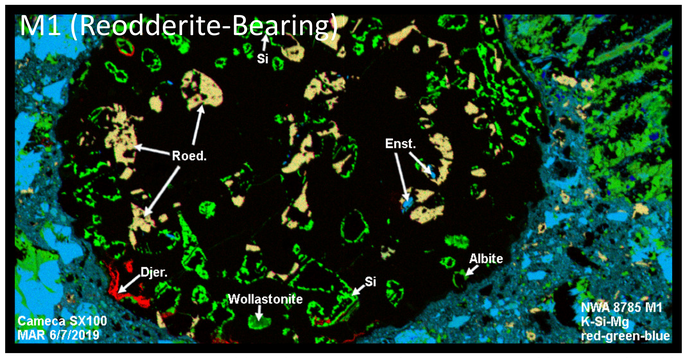

Figure 2: K-Si-Mg red-green-blue element map of M1 consisting of kamacite (black) surrounding assemblages of roedderite (yellow) and silica (green), with minor enstatite (blue), djerfisherite ($K_6(Fe,Cu,Ni)_{25}S_{26}Cl$) (red) and albite.

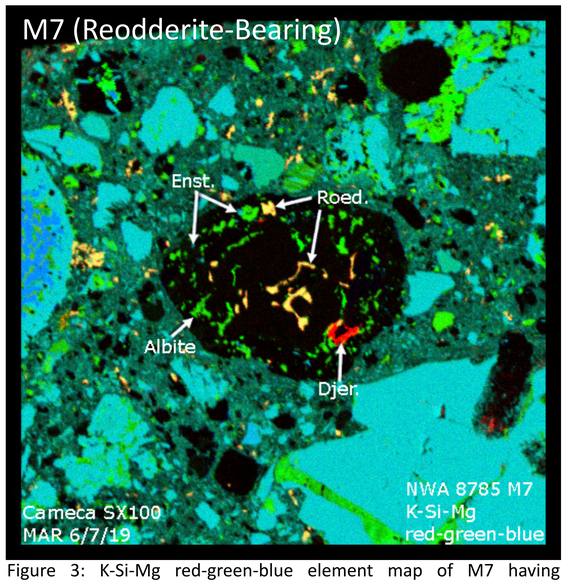

Figure 3: K-Si-Mg red-green-blue element map of M7 having concentric layers of kamacite and troilite (black), with roedderite (yellow), djerfisherite (red), silica (green) and enstatite (blue).

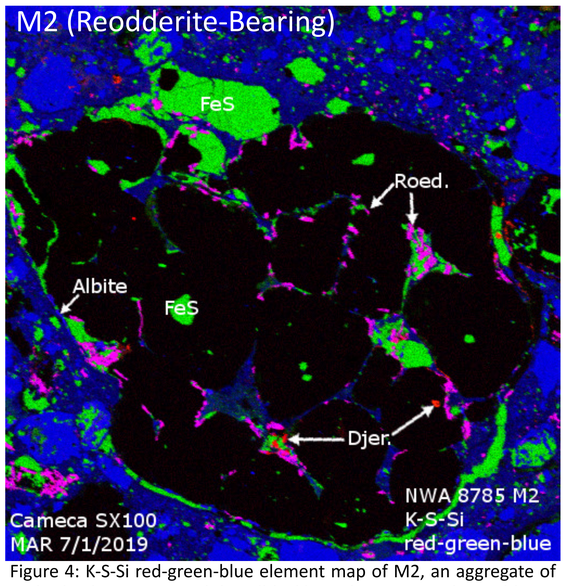

Figure 4: K-S-Si red-green-blue element map of M2, an aggregate of multiple kamacite nodules (black) with interstitial roedderite (purple) and troilite (green) and minor djerfisherite (red) and albite.

Textural and Compositional Variation of Nodules:

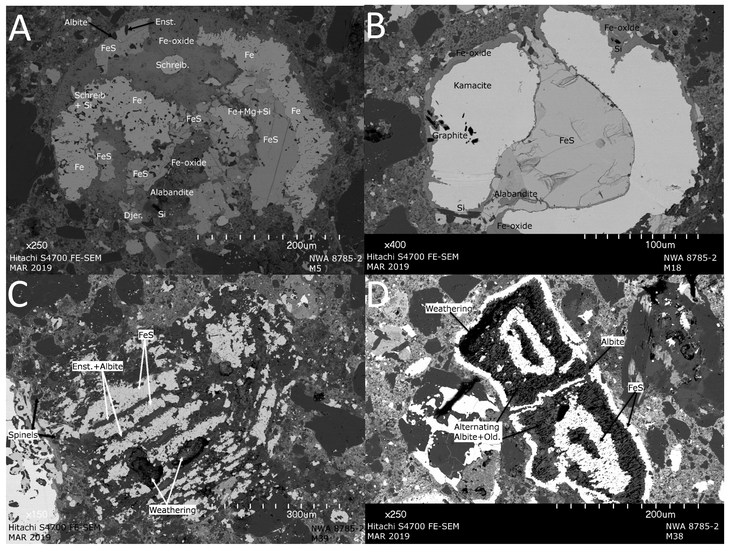

Figure 5: (a) BSE image of M5 with a highly weathered layered structure. (b) BSE image of M18 featuring Kamacite and troilite with some alabandite. (c) A BSE image of M39 with a barred structure of alternating sulfides and enstatite and albite. (d) M38, an unusually layered sulfide-rich nodule.

Table 1: Average compositions (wt%) of metal and sulfides in NWA 8785. "-" indicates below detection. Values generally match the values reported by the Meteoritical Bulletin Database (2017) for NWA 8785.

Average wt% Values for Select Minerals:					
Element:	Kamacite	Troilite	Schreib.	Alabandite	Sphalerite
Na:	-	-	-	0.15	0.46
Mg:	-	0.08	-	1.57	0.12
Si:	0.93	0.17	0.07	0.32	-
P:	-	-	15.11	0.17	-
S:	-	35.28	0.58	34.63	35.39
K:	-	-	-	-	-
Ca:	-	-	-	0.33	-
Ti:	-	0.22	-	-	-
Cr:	-	1.81	0.05	0.19	-
Mn:	0.05	0.77	-	49.7	15.38
Fe:	93.68	61.89	48.6	17.78	32.29
Co:	0.33	-	0.06	-	-
Ni:	6.06	0.3	38.57	0.36	0.08
Cu:	-	-	-	-	-
Zn:	-	-	-	-	19.75
Totals:	101.05	100.54	101.36	105.15	103.46

Textural Relationship Between Roedderite, Djerfisherite, and Albite:

Table 2: Average composition (wt%) of roedderite ($(Na,K)_2(Mg,Fe)_5Si_{12}O_{30}$) in NWA 8785 compared to that of various meteorites and terrestrial examples. (*Rambaldi et al. (1986), **Fuchs et al. (1966), ***Olsen (1967), ****Hentschel et al. (1980))

Literature Comparisons of Roedderite Composition Values					
Oxides:	NWA 8785:	Quinzhen:*	Indarch (EH4) Chondrite: **	Wichita County (IA) Iron:***	West Germany Volcanic Ejecta:****
SiO_2:	70.1	70.5	71.0	68.0	71.0
Al_2O_3:	0.79	0.43	0.40	2.5	0.50
FeO:	1.7	1.9	2.0	0.40	2.4
MgO:	20.3	19.1	19.5	19.0	17.5
CaO:	0.01	0.13	-	-	-
Na_2O:	3.0	3.4	4.0	5.3	3.5
K_2O:	4.3	4.2	3.3	3.8	4.2
SO_2:	0.15	-	-	-	-
TiO_2:	0.004	-	-	-	-
Cr_2O_3:	0.04	-	-	-	-
MnO:	0.02	-	-	-	-
NiO:	0.03	-	-	-	-
Totals:	100.444	99.66	100.2	99.0	99.1

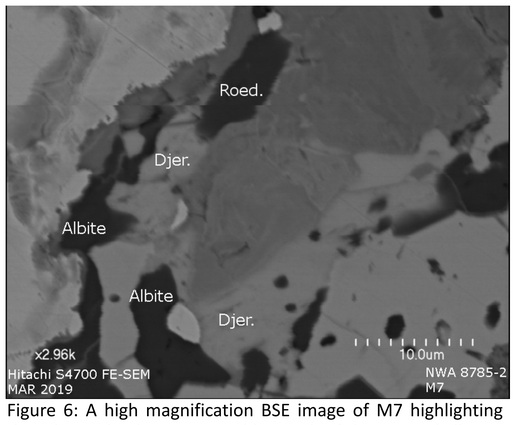

Figure 6: A high magnification BSE image of M7 highlighting the relationship between roedderite, djerfisherite, and albite.

Possible Origins for Roedderite in NWA 8785:

Formation hypotheses:

- Due to alkali-rich fluids formed during alteration on the EL chondrite parent asteroid [2]
- Crystallization from a peralkaline melt [7]

CONCLUSIONS: (1) NWA 8785 is an EL3 chondrite based on mineral compositions, but the abundance of matrix and presence of roedderite, djerfisherite, and a magnetite-rich matrix make it anomalous. (2) The diversity of metal-rich nodules in NWA 8785 suggests that each nodule formed independently and supports an origin by primary processes prior to accretion. Presence of roedderite, a first in EL3 meteorites, as well as the magnetite-bearing matrix, suggests the possibility of hydrothermal alteration occurring on the E chondrite parent body.

Refernces: [1] The Meteoritical Bulletin Database of the Meteoritical Society (2017). [2] Weisberg M. K. et al. (2019), Meteoritics & Planet. Sci., 54, 6340. [3] Rambaldi et al. (1986) Meteoritics, 21, 141-149. [4] Weisberg M. K. and Kimura M. (2012) Chemie der Erde, 72, 101-115. [5] Fuchs L.H. et al. (1966) Amer. Mineralogist, 51, 949-955. [6] Hentschel, G., et al. (1980) Contrib. Mineral. and Petrol., 73, 127-130. [7] Fogel R. A. (2001) LPSC XXXII, #2177. [8] Olsen, E. (1967) Am Mineral 52, 1519-1523.