THE EL ALI (SOMALIA) IAB IRON METEORITE: NEW MINERALS REFLECTING UNUSUAL CONDITIONS OF FORMATION .

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Introduction: The El Ali meteorite is a 15.2 ton iron meteorite from Somalia, originally known by camel herders and others in the region as “Nightfall” [1]. The meteorite was classified as belonging to the IAB Complex as defined by [2]. Notably, this group comprises a diversity of bulk compositions as well as a high number of meteorites containing silicate or other inclusions. For this, and other reasons, [2] suggest that IAB irons formed by melting due to impact heating on a porous chondritic body.

During the process of classification of the meteorite, we noted phosphate inclusions that could not be readily identified by semi-quantitative methods (e.g., energy dispersive spectroscopy, EDS). More detailed study in the Electron Microprobe Laboratory (University of Alberta) on specimen MET11814/2-1/EP1 of the University of Alberta Meteorite Collection revealed the occurrence of two new iron phosphate minerals: elaliite ($Fe^{2+}_8Fe^{3+}(PO_4)O_8$, IMA 2022-087) and elkinstantonite ($Fe_4(PO_4)_2O$, IMA 2022-088) [3], with the suggestion of a third, K-rich iron phosphate. Further nanomineralogy investigation confirmed elaliite and elkinstantonite and enabled the description of the third new phosphate mineral: olsenite ($KFe_4(PO_4)_3$, IMA 2022-100) [4], described in a companion abstract [5]. Here, we present elaliite and elkinstantonite and discuss their origin and the implications of their occurrence for the petrogenesis of the El Ali meteorite.

Elaliite is a mixed-valence iron phosphate with an orthorhombic *Cmmm* structure, as revealed by electron back-scatter diffraction (EBSD) at Caltech. EBSD patterns give a perfect fit to the unit cell of synthetic $Fe_9(PO_4)O_8$ of [6] with a mean angular deviation of 0.32º-0.37º, showing the unit cell parameters: a = 5.95(1) Å, b = 25.69(1) Å, c = 3.06(1) Å, V = 468(2) Å^3, Z = 2. Elaliite has a calculated density of 5.15 g/cm^3. The chemical composition of elaliite by electron microprobe analysis (Table 1) yields an empirical formula, on the basis of 12 oxygen atoms, of $(Fe^{2+}_{7.943}Fe^{3+}_{1.020}Cr_{0.010}Ni_{0.006}Ca_{0.004}Mn_{0.004})_{\Sigma 8.987}(P_{0.932}Si_{0.077}S_{0.005})_{\Sigma 1.014}O_{12}$. The simplified formula is the same as the ideal formula: $(Fe^{2+}_8Fe^{3+})(PO_4)O_8$, which requires: P_2O_5 9.78, FeO 79.22, and Fe_2O_3 11.00, Total 100 wt.%. Raman spectra obtained at MacEwan University using a 532 nm diode laser (using only ~1 mW of laser power to protect the sample from damage) and 1800 grooves / millimeter grating yields a sharp peak at ~938 cm^{-1}, which is assigned to the PO_4 symmetric stretching mode, and a broad hump at ~487 cm^{-1}. The name recognizes the occurrence of the mineral within the El Ali meteorite.

Elkinstantonite is an iron phosphate with a monoclinic $P2_1/c$ structure, as shown by EBSD patterns, which give a perfect fit to the unit cell of synthetic $Fe_4(PO_4)_2O$ of [7] with a mean angular deviation of 0.22º-0.36º, showing the unit cell parameters: a = 6.56(1) Å, b = 11.27(1) Å, c = 9.38(1) Å, β = 104.0(1)°, V = 673(2) Å^3, Z = 4. Elkinstantonite has a calculated density of 4.22 g/cm^3. The chemical composition of elkinstantonite (Table 1) yields an empirical formula, on the basis of 9 oxygen atoms, of $(Fe^{2+}_{3.947}Mn_{0.016}Ni_{0.003}Ca_{0.001}Cr_{0.001})_{\Sigma 3.968}(P_{1.986}Si_{0.014}S_{0.013})_{\Sigma 2.013}O_9$. The simplified formula is $(Fe^{2+},Mn)_4(P,Si,S)_2O_9$. The ideal formula is $(Fe)_4(PO_4)_2O$, which requires P_2O_5 33.06 and FeO 66.94, Total 100 wt.%. Raman spectra obtained under the same conditions using the same instrument yields peaks between ~930 and 1020 cm^{-1}, including a doublet at ~ 940 cm^{-1} and ~975 cm^{-1} that is assigned to phosphate symmetric stretching modes. The name honors Prof. Lindy Elkins-Tanton, whose expertise includes the formation of planetary cores.

Table 1. Electron microprobe data

Constituent (wt%)	elaliite (mean)	σ	elkinstantonite (mean)	σ
n	28		5	
P_2O_5	9.16	0.37	32.91	0.51
CaO	0.03	0.03	0.01	0.01
FeO_{total}	89.20	0.60	66.21	0.29
FeO*	79.07	0.72	n/a	-
Fe_2O_3*	11.26	0.77	n/a	-
Cr_2O_3	0.10	0.13	0.01	0.01
SO_3	0.06	0.21	0.24	0.26
MnO	0.04	0.02	0.26	0.02
SiO_2	0.64	0.25	0.20	0.16
NiO	0.06	0.06	0.06	0.02
Total	100.42	0.54	99.90	0.78

*Oxygen corresponding to Fe^{3+} calculated on the basis of 10 cations and 12 anions.

Occurrence: Elaliite, elkinstantonite and olsenite occur along with wüstite, troilite, sarcopside and/or graftonite ($Fe^{2+}Fe^{2+}_2(PO_4)_2$), and magnetite within inclusions in El Ali. Most inclusions are ~100 µm across

(Figure 1), although larger inclusions (up to 1500 µm) are present (Figure 2). Elaliite typically occurs as euhedral elongate laths up to 10 µm across and 50 µm long at the interfaces of troilite+wüstite symplectites and troilite+graftonite/sarcopside intergrowths, in larger inclusions (Fig. 2). In smaller inclusions, elaliite occurs with small grains of troilite set in a matrix of sarcopside/graftonite; this is the typical setting for olsenite [5]. Elkinstantonite typically occurs as subhedral grains associated with troilite+wüstite symplectites, troilite, and elaliite, in smaller inclusions (Fig. 3).

Minor terrestrial alteration extends along fractures and grain boundaries; this is consistent with the specimen being taken from the exterior of the meteorite. In this context, magnetite (Fig. 2) may be due to terrestrial alteration. The petrography of the other minerals in the inclusions is inconsistent with terrestrial alteration.

Implications: The inclusions in El Ali reflect a diversity of iron valence states, from Fe^{2+}-dominant minerals (troilite, wüstite, graftonite/sarcopside, olsenite and elkinstantonite) to mixed-valence state elaliite.

The symplectitic texture of the troilite+wüstite, as well as the overall texture of the troilite (Fig. 2), suggests the presence of an immiscible sulfide melt; troilite, or troilite+wüstite is present on the margins of the inclusions (Fig. 2). This texture suggests that a sulfide-rich melt was first to solidify within this type of inclusion. A more O- and P-rich, sulfide-poor melt is now represented by the graftonite/sarcopside-rich areas. Elaliite appears to have nucleated at the interface of these two melts, presumably where the O (and thus Fe^{3+}) content was highest. In smaller inclusions there is a similar occurrence of troilite±wüstite and elaliite at the margins of the inclusions, with graftonite/sarcopside, elkinstantonite (Fig. 3), and/or olsenite (see [5]) comprising most of the inclusions.

The diverse mineralogy of the inclusions in El Ali results from the relative proportions of Fe, S, P, K, and O, with the redox state of Fe changing as a result of O behaving incompatibly in a low-oxygen fugacity system. Our results have implications for the formation of IAB iron meteorites, including the nature of the nonmetallic material involved in their petrogeneses.

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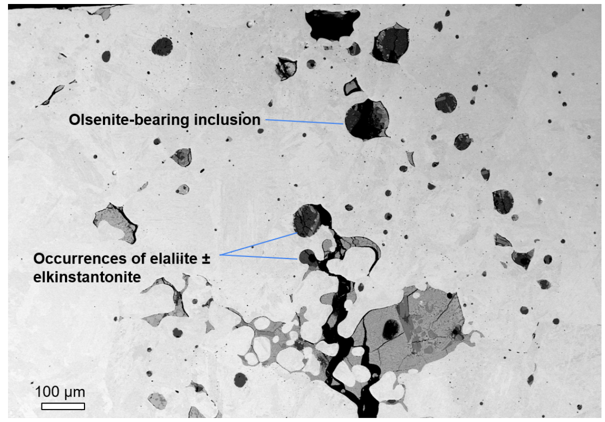

Figure 1. Backscattered electron (BSE) image of inclusions within the El Ali meteorite. Occurrences of new minerals are shown. See [5] for details on olsenite.

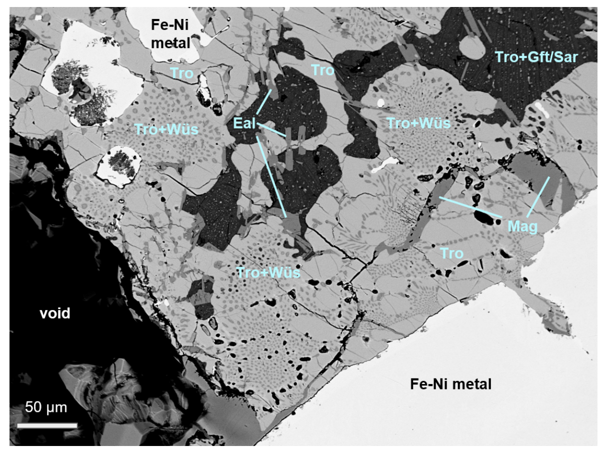

Figure 2. BSE image of an inclusion in El Ali showing troilite-wüstite symplectites (Tro+Wüs), wüstite-free troilite (Tro), elaliite (Eal) laths, troilite+graftonite (Gft)/sarcopside (Sar) intergrowths, and possibly terrestrial magnetite (Mag). The host IAB Complex meteorite is "Fe-Ni metal".

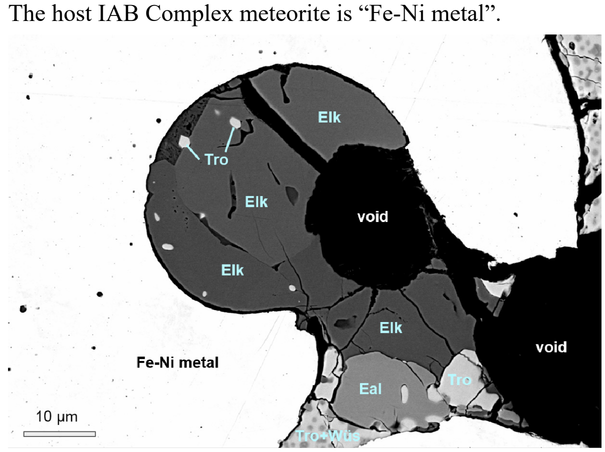

Figure 3. BSE image showing an occurrence of elkinstantonite (Elk), along with elaliite (Eal), troilite-wüstite symplectite (Tro+Wüs), and wüstite-free troilite (Tro).