TIN-ESSAKO 001: A METAL-RICH UREILITE?

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Introduction: Metal-rich achondrites include a variety of types, and likely have a variety of origins. Models range from gravitational mixing at the core-mantle boundaries of differentatiated asteroids, to complex impact mixing scenarios. We describe a new type of metal-rich achondrite that might be the first metal-rich ureilite.

Sample: Tin-Essako (TE) 001 (~4.3 kg) was found in Mali in 2020 and purchased by Jay Piatek in 2021. It was classified as a metal-rich ungrouped achondrite, with olivine and oxygen isotope (avg. δ^{18}O=8.281‰, δ^{17}O=3.718 ‰, Δ^{17}O=-0.654‰) compositions suggesting affinity to ureilites [1]. We studied one polished section (~188 mm^2).

Petrography: TE 001 consists of ~60% metal and 40% silicates, heterogeneously distributed (Fig. 1a). The metal is largely fresh, but iron oxides (presumably terrestrial) occur along one edge and in some patches and veins. The silicates are ≥90% olivine, plus melt-textured areas of plagioclase + Si-rich glass. Minor phases are chromite and carbon. Olivine occurs as rounded grains (≤2.5 mm) in metal, commonly with rims of melt-textured plagioclase + glass. Olivine also occurs in massive areas having a "honeycomb" texture (Fig. 1b), with olivine "cells" surrounded by a network of interstitial reduced olivine (full of tiny metal grains) plus melt-textured plagioclase + Si-rich glass (Fig. 1c). Chromite occurs as subhedral to rounded grains (~30-500 µm) included in olivine or metal. A carbon phase occurs as lacy-textured (fibrous) rims around olivine grains or patches within metal.

Mineral Compositions: The olivine (excluding interstitial areas) is Fo 73.9±0.5, with 0.25±0.02 wt.% CaO, 0.31±0.01 wt.% Cr_2O_3, 0.01 wt.% NiO, and molar Fe/Mn=49.8±2.2 (53 analyses). Olivine in interstitial areas has Fo up to at least 91. Smaller chromite grains have Fe# (molar Fe/[Fe+Mg]) = 0.54±0.01, Cr# (molar Cr/[Cr+Al]) = 0.52±0.01, 0.52±0.02 wt.% V_2O_3 and 0.21±0.04 wt.% ZnO (28 analyses). One larger grain is zoned from Fe# = 0.45, Cr# = 0.52 to Fe# = 0.40, Cr# = 0.57, and contains thin Al-rich lamellae not resolved by EMPA. One irregularly shaped patch of chromite in olivine has Fe# = 0.26 and contains no ZnO. Plagioclase laths are An ~53-60, with ≤0.01 wt.% K_2O. Glass contains 75-76 wt.% SiO_2 and ~16 wt.% Al_2O_3. The metal contains 5.2±0.2 wt.% Ni, 0.46±0.02 wt.% Co, and 0.01±0.01 wt.% Cr, with Si and P below detection (168 analyses).

Discussion: The olivine + chromite assemblage in TE 001 is suggestive of the most ferroan ureilites (Fo ~75-77 [2]), as are the oxygen isotopes [1]. The presence of a carbon phase supports this, though the identity of this phase (graphite as in ureilites?) remains to be determined. The "honeycomb" textured areas, in particular, the presence of "reduction rims," resemble shock-smelted olivine in ureilites [3], but melt-textured areas of plagioclase laths + glass like those in TE 001 have not been reported in such (or any) ureilites. Olivine in TE 001 is marginally more ferroan than in the most ferroan ureilite, with Fe/Mg-Fe/Mn offset from the trend of olivine + low-Ca pyroxene ureilites (similar to augite-bearing ureilites) [2]. CaO and Cr_2O_3 contents are in the range of those in ureilite olivine [4], though Cr_2O_3 is at the extreme low end of the range [5]. Chromites (except the unusual one) have similar Fe# to the most ferroan chromites in ureilites [2], but lower Cr# (0.52 vs. 0.71). Metal compositions are in the range for metal in ureilites [6]. The absence of pyroxene and sulfide, and high abundance of metal, in TE 001, are unlike ureilites.

One possibility is that a ferroan, chromite-bearing, pyroxene-poor ureilite was invaded (possibly due to impact) by a metallic liquid (the low S content suggests very high temperature), resulting in complete melting of pyroxene and smelting of olivine, with rapid recrystallization of melted silicate as plagioclase + glass. Alternatively, a pre-existing metal-rich ureilite assemblage may have been impact melted. Additional types of data will be obtained to evaluate these and other hypotheses (i.e., is the metal indigenous?) and assess affinity to ureilites.

References: [1] Meteoritical Bulletin Database. [2] Goodrich C. A. et al. (2014) *Geochimica et Cosmochimica Acta* 135:126-169. [3] Warren P.H. and Rubin A. (2010) *Geochimica et Cosmochimica Acta* 74:5109-5133. [4] Goodrich C.A. et al. (2017) *Meteoritics & Planetary Science* 52:949-978. [5] Collinet M. and Grove T. L. (2020) *Meteoritics & Planetary Science* 55:832-856. [6] Goodrich C. A. et al. (2013) *Geochimica et Cosmochimica Acta* 112:340-373.

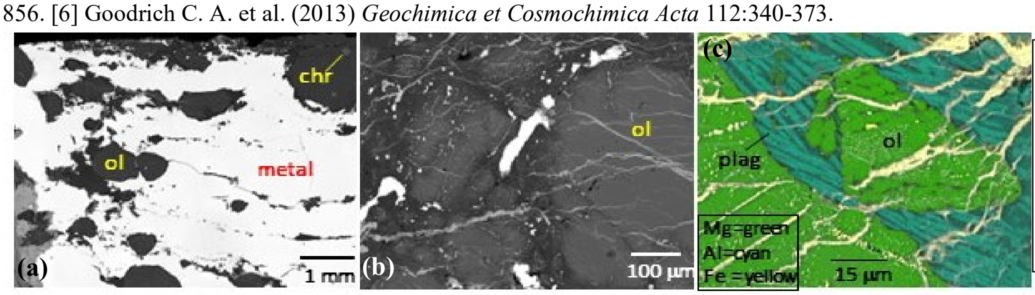

Fig. 1. Tin-Essako 001. (a,b) back-scattered electron images; (c) x-ray map: Mg = green, Al = cyan, Fe = yellow.