

### Tarda an unusual carbonaceous chondrite meteorite fall from morocco.

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**Fireball description and eye testimonies:** A fireball with a SW to NE trajectory was widely witnessed from the towns of Alnif, Zagora, Tazarine, and Rich in southern Morocco on the 25th of August 2020, around 2:30 pm Moroccan time (GMT+1). The fall was followed immediately by a search campaign by hundreds of Moroccan hunters and curious people in the area of the likely fall zone. On the following day, the first piece was found close to the village of Tarda between Goulmima and Errachidia. A field mission was conducted, and several eyewitnesses were interviewed. They describe a yellow and bright, barrel-sized fireball with green edges lasting ~3s, and accompanied by a whistling sound, followed by multiple detonations. The meteor produced a thick trail of white smoke that remained suspended for several minutes. The fireball was reported to release little pieces around its edges [1].

**Strewnfield:** A small strewnfield of about 3 km long was drawn, it is consistent with the testimonies of all eyewitnesses.

**Physical description:** An estimation of the total recovered mass gives around 4 kg of very small (less than one gram up to 99g), black and very friable pieces. Most pieces are complete, and fusion crusted. Fusion crust shows on some pieces an iridescence similar to Aguas Zarcas [2]. The meteorite rapidly slakes in contact with water or alcohol making the preparation of samples for petrography and mineralogy studies challenging. The interior of the stones is dull black with white and light-colored grain and clasts. Magnetic susceptibility measured by SM30 gives an average of values of  $\log \chi$  4.92±0.10.

**Petrography:** Tarda is a matrix-rich breccia containing small chondrules (granular, BO) and chondrule fragments, fine-grained ameboid olivine aggregates AOA, forsterite grains, and other clasts set in a fine-grained matrix (~80 vol.%, opaque in thin section). No CAIs were identified. The dominant chondrule phase is forsterite. Matrix is composed of abundant phyllosilicates with lesser magnetite, pyrrhotite, pentlandite, troilite, Fe-Mn dolomite, and siderite. Magnetite (<20µm) is scattered throughout the sample in the form of framboids, platelets, and individual spherules.

**Geochemistry:** Tarda matrix composition is comparable to Ivuna (CI1), although Tarda contains a representable amount of S in its matrix as well, likely owing to Fe-sulfides. Forsterite is (Fa<sub>1.0±0.6</sub>, FeO/MnO = 10±6, n=35), while ferroan olivine (Fa<sub>26.5±1.6</sub>, FeO/MnO = 91±7). Achondrite clast EMPA gives anorthite (An<sub>99.7±0.4</sub>, range n=2), forsterite (Fa<sub>1.1</sub>, FeO/MnO = 7, n=1), enstatite (Fs<sub>1.1±0.1</sub> Wo<sub>3.2±0.5</sub>, range Fs<sub>1.0-1.2</sub> Wo<sub>2.7-3.7</sub>, FeO/MnO = 3, n=3), diopside (Fs<sub>1.7</sub> Wo<sub>44.0</sub>, FeO/MnO = 3, n=1).

**Oxygen isotopes:** Isotopic values do not overlap with those of any established carbonaceous chondrite group: it has a bimodal distribution of the δ<sup>18</sup>O-values of CI chondrites, and Yamato-type (CY) carbonaceous chondrites [3] and Δ<sup>17</sup>O values are lower than for CI and CY chondrites, it plots below the TFL.

**Soluble Organic Matter (SOM):** FTICR-MS (Fourier transform ion cyclotron resonance mass spectrometry) of the SOM extracted by methanol from Tarda show high abundance of Nitrogen compounds and sulfurization compared to Flensburg (C1-ungrouped) and Orgueil (CI) with less SOM in general. SOM in Orgueil as well as Ivuna show high abundance of multiple sulfurisations compared to Tarda. Almost no Mg-SOM was detected supporting a low temperature and no shock stress.

**Conclusion:** Based on petrography and geochemistry Tarda is a carbonaceous chondrite. The bulk mineralogy is consistent with a petrologic grade 2, based on the predominance of smectite and serpentine together with the presence of anhydrous mafic silicates, AOA, and chondrules. The oxygen isotopic values do not overlap with those of any established carbonaceous chondrite group. Tarda is high SOM contents, it has high abundance of Nitrogen compounds and sulfurization different from CI and mostly no Mg, consistent with a low temperature and no shock stress. These analyses allow a classification of Tarda as an ungrouped C2 not belonging to any known CC group [1,4]. Tarda is a remarkably interesting material to be used for the space mission to the C- type asteroids.

[1] Chennaoui Aoudjehane et al. (2021) LPSC abstract 1928 [2] Garvie L.A.J. (2021) *Am. Mineral.* in press. [3] King et al., (2019) *Geochemistry*, 79, Issue 4 [4] [www.lpi.usra.edu/meteor/metbull.php?code=72644](http://www.lpi.usra.edu/meteor/metbull.php?code=72644)