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Mineralogy of the 2019 Aguas Zarcas (CM2) carbonaceous chondrite meteorite fall

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Abstract

The 2019 Aguas Zarcas CM2 meteorite is the most significant carbonaceous chondrite CM2 fall since Murchison in 1969. Samples collected immediately following the fall and studied here provide the rare opportunity to analyze the bulk mineralogy of a CM2 largely free of terrestrial contamination. Bulk samples were analyzed by powder X-ray diffraction (XRD), thermal gravimetric (TG) analysis, evolved gas analysis (EGA), and scanning electron microscopy (SEM) with an electron-probe micro-analyzer (EPMA). Water-extracted salts were analyzed by XRD. In hand specimen, the stones are brecciated and dominated by chondrule-rich and chondrule-poor lithologies, and locally, a matrix-rich lithology. Powder XRD patterns from multiple stones are dominated by reflections from serpentine group minerals, on which are superimposed reflections for ferrotochilinite, 1:1 regularly interstratified ferrotochilinite/cronstedtite, anhydrous silicates, calcite, pentlandite, pyrrhotite, and minor phases. Reflections for magnetite are present only from a metal-rich breccia clast. The serpentine XRD reflections from the chondrule-rich and chondrule-poor lithologies match those from 1*T* cronstedtite, whereas those from the matrix-rich lithology match the 1*M* polytype. Patterns with the 1*M* polytype also show a distinct low-angle scattering to the serpentine basal reflection centered near 8.6 Å, the origin of which is obscure. Further matching of the known serpentines to the Aguas Zarcas data shows that cronstedtite accounts for a subordinate amount of the clays, and at least three other chemically and structurally distinct serpentines are likely present. A typical fragment of Aguas Zarcas yielded 0.6 wt% water-extractable salts. The powder XRD pattern of the dried water extract shows reflections for halite = NaCl; chlorartinite = $Mg_2(CO_3)(OH)Cl{\cdot}2H_2O$; thenardite = Na_2SO_4; and sodium chlorate = $NaClO_4$. The TG mass losses of 11.4 to 14.7 wt% are consistent with other CM2 chondrites. The gases detected by EGA are dominated by H_2O and CO_2, largely derived from the dehydroxylation and decomposition of serpentine and calcite, respectively. Also detected are gases with masses matching SO_2/S_2 and H_2S, which are primarily released below 480 °C, and a mass of 30, which matches the molecular weight of formaldehyde and ethane, shows a maximum at 376 °C. These organic gases likely derive from the pyrolysis of indigenous organic matter. Taken together, the millimeter-scale mineralogical study of Aguas Zarcas reveals a complex breccia dominated by CM2-like clasts. The detailed study of this meteorite, together with similar studies from a range of carbonaceous chondrites, provides the foundations for studying and interpreting the samples returned from the NASA OSIRIS-REx and JAXA Hayabusa2 missions.

Keywords: Meteorite, carbonaceous chondrite, serpentine, ferrotochilinite, cronstedtite