CHARACTERISTICS OF A NEW CARBONACEOUS, METAL-RICH LITHOLOGY FOUND IN THE CARBONACEOUS CHONDRITE BRECCIA AGUAS ZARCAS. I. Kerraouch[1,2], A. Bischoff[1], M. E. Zolensky[3], A. Pack[4], M. Patzek[1], E. Wölfer[1], C. Burkhardt[1], and M. Fries[3]. [1]Institut für Planetologie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm Str. 10, D-48149 Münster, Germany. ikerraou@uni-muenster.de, [2]Department of Geology, University of Science and Technology Houari Boumediene (USTHB), Alger, Algeria, [3]NASA Johnson Space Center, Houston TX, USA, [4]Universität Göttingen, Geowissenschaftliches Zentrum, Goldschmidtstr. 1, D-37077 Göttingen, Germany.

Introduction: The Aguas Zarcas meteorite fell in Costa Rica on 23 April 2019 at 21:07 local time, with a total mass of about 27 kg. Hundreds of fusion-crusted stones ranging from 0.1 to 1868 g were recovered (The Meteoritical Bulletin).

The meteorite was classified as a CM chondrite, but some lithologies show a different texture to that of CM. In this study, we investigated the petrography, mineralogy, chemistry, and isotopic composition of an unusual "metal-rich lithology" from this fresh fall.

Methods: Back-scattered electron imaging (BEI), elemental mapping, electron microprobe analysis (EMPA), and Ti isotope analysis were conducted at the Institut für Planetologie (IfP), University of Münster. Bulk oxygen isotopes were obtained using the IR-laser fluorination line at the Universität Göttingen. Chondrule diameters were measured with two different methods: (a) by light microscopy in transmitted light (MTL) using a calibrated reticle and (b) by using backscattered-electron images (BSE). The maximum length and the greatest width perpendicular to the long axis of each chondrule were measured and averaged; the size is the mean of the length and width. Chondrule abundances were also calculated.

Results: The main stone of our study (1.8 x 1.2 x 1 cm) is quite dark with visible chondrules, metal, and olivine and pyroxene grains. The sample is a breccia. We have noted clasts of two main lithologies: (1) Metal-rich lithology (84 vol%) and (2) brecciated CM-lithology (16 vol%) with clasts of at least three different petrologic subtypes.

Metal, sulfides, olivine, pyroxene, and carbonate represent major phases in the metal-rich lithology (Fig.1). Olivine and pyroxenes occur both in the chondrules and as clasts in the matrix, having similar compositions in both areas. The average composition of olivine is $Fa_{13\pm20}$ (n=120). Zoned olivine is abundant in the majority of chondrules. The mean compositions of low-Ca pyroxene and diopside are $Fs_{2.4\pm3.3}$ $En_{95\pm5}$ $Wo_{2.5\pm2.4}$. and $Fs_{1.9\pm1.5}$ $En_{61\pm6}$ $Wo_{37\pm6}$, respectively. Phyllosilicates, both of matrix and rims have similar composition with the mean total of ~83.2 (±1.6 wt%).

Metal and sulfides represent 3 vol% in the whole sample. The metal (2.25 vol%) is kamacite and taenite, ranging from a few µm up to 550 µm. Most have circular shapes, but others are sometimes irregular in shape having well-rounded edges. Taenite occurs sometimes as exsolutions in the kamacite. Sulfides (0.75 vol%) are pyrrhotite and pentlandite. Pentlandite occurs as exsolutions in pyrrhotite. Some sulfides contain inclusions of metal grains. Often metal and sulfide show indications of pre-terrestrial aqueous alteration.

The chondrules are round to slightly irregularly-shaped having rather thick, fine-grained, phyllosilicate-rich rims (up to 160 µm thick). Several chondrule types have been identified (PO, BO, POP, RP). Most of them contain a high abundance of metal and sulfide grains either inside and/or at their edges and are similar in texture to typical chondrules in CR2 chondrites. In addition, the metal-rich lithology also contains chondrules, in which the olivine is aqueously-altered to phyllosilicates.

Chondrule sizes vary from 14 to 800 µm. The different methods used for size determination of chondrules give almost the same average chondrule size and modal abundance: A mean size of 186 µm and 29 vol% by means of optical microscopy, and 149 µm and 31.5 vol% by using BSE mosaic maps, respectively.

Two types of Ca,Al-rich inclusions (CAIs) can be distinguished. The first type has a rounded shape and is spinel- or hibonite-rich. The spinel-rich CAIs are surrounded by an Al-rich diopside rim. The second type is irregularly-shaped and large (~500 µm), very complex, and unusual in mineralogy. On average they have a remarkably high abundance of calcite (~53 vol%). They are typically composed of calcite and spinel with some small perovskite grains (<2 to 10 µm). In some cases, minor fassaite was found enclosed within the spinel. These CAIs are surrounded by an Al-rich diopside rim of variable thickness.

The O-isotope composition of the metal-rich lithology falls below the terrestrial fractionation line (TFL) and far from the field of CM chondrites ($\delta^{18}O$=3.8; $\delta^{17}O$=2.7) (Fig. 2). While the Ti isotope compositions are $\varepsilon^{46}Ti = 0.55 \pm 0.14$, $\varepsilon^{48}Ti = -0.03 \pm 0.04$, and $\varepsilon^{50}Ti = 2.55 \pm 0.24$ (n = 6; uncertainties are Student-t 95% confidence intervals) (Fig. 3) and agree within error with literature values for CR chondrites [1-2].

Discussion and conclusion: From the mineralogical study, silicates and phyllosilicates within the metal-rich lithology show similar compositions as those of CM-chondrites [3], but texturally the sample has some similarity with CRs (chondrules surrounded by metals) [4-6]. On the other hand, the chondrule size data are clearly different to those of the CM-chondrites (~270 µm) [7]. The data also show that CM chondrites have a significantly lower chondrule abundance of approximately 20 vol% compared to the abundance within the metal-rich lithology (30 vol%). CR chondrite are even more different with mean chondrules diameters of ~700 μm and a chondrule abundance of 55 vol% [4].

However, based on the oxygen isotopes the stone is neither CM nor CR (Fig. 2), while the Ti isotopes might suggest a relationship to the CR-chondrites (Fig. 3), although the magnitude of the anomalies are strongly dependent on the amount of CAIs in the sample.

These characterizations lead to some important statements and questions. (1) Based on previous data the fresh fall Aguas Zarcas is not a homogeneous CM2 chondrite as it has been classified (according to the Meteoritical Bulletin). (2) What is the nature of the metal-rich lithology and what is its relationship with CR-chondrites? (3) Why are the CAIs so unusually-rich in calcite?

Acknowledgements: We thank the German Research Foundation (DFG) for support within the SFB-TRR 170 "Late Accretion onto Terrestrial Planets" (subproject B05; AB).

References: [1] Trinquier A. et al. (2009). *Science* 324, 374-376. [2] Zhang J. et al. (2012). *Nature Geoscience* 5, 251-255. [3] Zolensky M. E. et al. (1993) *Geochim. Cosmochim. Acta* 57, 3123-3148.[4] Weisberg M. K. et al. (1993) *Geochim. Cosmochim. Acta* 57, 1567-1586. [5] Bischoff A. (1992). *Meteoritics* 27, 203-204. [6] Bischoff A. et al. (1993) *Geochim. Cosmochim. Acta* 57, 1587-1603. [7] Rubin A. E. and Wasson J. T. (1986). *Geochim. Cosmochim. Acta* 50, 307-315.

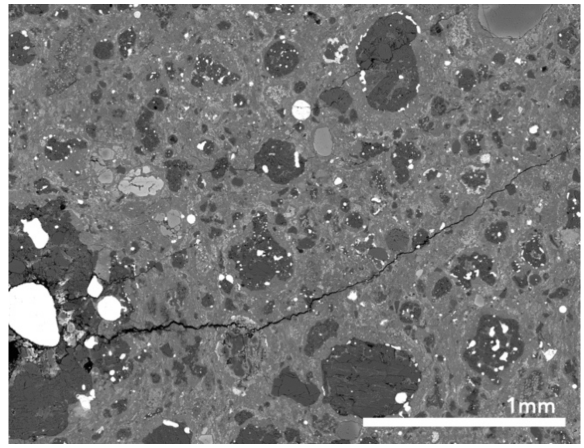

Fig. 1: BSE image of the metal-rich lithology.

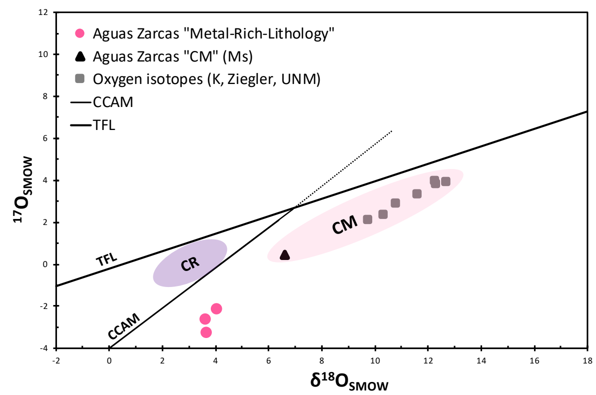

Fig. 2: Bulk oxygen isotopes of the metal-rich lithology compared to those of CM lithologies found in Aguas Zarcas (data from this study and from K. Ziegler (Meteorite Bulletin Database)).

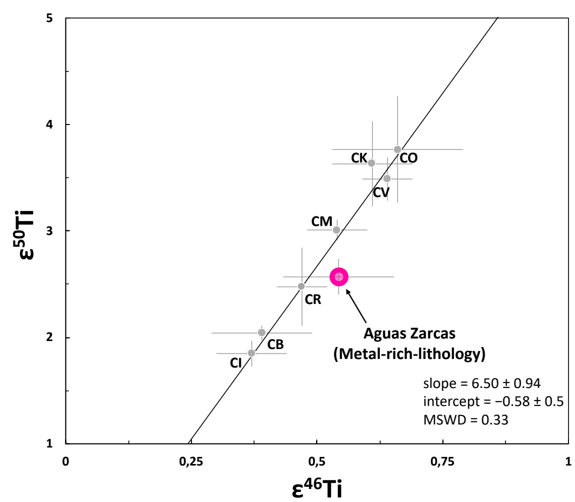

Fig. 3: The $\varepsilon^{50}Ti$ vs. $\varepsilon^{46}Ti$ values for the metal-rich lithology overlap with CR-chondrite values.