NORTHWEST AFRICA 11024 – THE FIRST CM3 CHONDRITE OR A DEHYDRATED ANOMALOUS CARBONACEOUS CHONDRITE? S. Ebert[1], A. Bischoff[1], D. Harries[2], J.-A Barrat[3], A. Pack[4], S. Lentfort[1], S. Kimpel[1], S. Vasilev[5], and S. Wengert[6]. [1]Institut für Planetologie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm Str. 10, D-48149 Münster, Germany. [2]Friedrich-Schiller-Universität Jena, Institut für Geowissenschaften, Carl-Zeiss-Promenade 10, D-07745 Jena, Germany. [3]Université de Bretagne Occidentale, Institut Universitaire Européen de la Mer, Place Nicolas Copernic, F-29280 Plouzané Cedex, France. [4]Universität Göttingen, Geowissenschaftliches Zentrum, Goldschmidtstr. 1, D-37077 Göttingen. [5]U. Dalnice 2684/1, Prague, 15500, Czech Republic. [6]Koksche Str. 21, D-49080 Osnabrück, Germany.

Introduction: The very small meteorite Northwest Africa 11024 (NWA 11024; 4.69 g) was purchased in Ensisheim from a Moroccan dealer in June 2014 and classified as a CM-an [1]. It is suggested that it was found in Morocco. After thin section preparation it was found that the rock does not fit into the meteorite classification scheme. Based on the high abundance of fine-grained material (dust rims, matrix) it was soon recognized to be a carbonaceous chondrite, but different from those of the so far defined carbonaceous chondrite classes. As will be seen in detail below, NWA 11024 has textural characteristics very similar to CM2 chondrites and the oxygen isotope composition plots close to the field of CM chondrites, but so far no preserved hydrous phases or carbonate grains were observed among the distinct meteorite constituents.

Results: Two thin sections were prepared for optical and electron microscopy and microprobe analysis.

Mineralogy. The chondrite consists of 32% chondrules and chondrule fragments (mainly PO and POP), about 54% fine-grained opaque matrix, 9.5% fine-grained dust rims, and 1.2% refractory Ca,Al-rich inclusions (CAIs). Most chondrules have a size of 150-300 µm and many are surrounded by fine-grained dust rims. Typically, chondrule olivines have $Fa_{<4}$, but also chondrules and chondrule fragments with olivine of higher Fa-content (up to Fa_{63}) exist. Similarly, most low-Ca pyroxenes are enstatites ($Fs_{<2}$), but also some low Ca-pyroxenes with somewhat higher Fs-contents exist (e.g., Fs_{5-13}); in addition, a compound chondrule with abundant low-Ca pyroxene of ~Fs_{45} has been observed. The still-existing unweathered large metal grains are Ni-poor (~6 wt% Ni). Most of the 82 CAIs studied are fine-grained, fluffy, spinel-rich inclusions. Many are rimmed by fine-grained dust. As opaque phases sulfide and some metals have been observed. Most of the Ni-poor metal grains have been destroyed by terrestrial alteration processes. Carbonate grains are absent.

TEM study. Some areas have been found that appear as if phyllosilicates would exist as constituent minerals. However, TEM investigations of several areas and lithologies (fine-grained dust rims (Fig. 1), matrix portions) could not show the occurrence of any preserved phyllosilicates. Instead, the fine-grained inter-chondrule materials mainly consist of clumpy nanocrystalline Fe-rich olivine, troilite and sub-µm-sized grains of Ni-rich metal (~$Fe_{50}Co_3Ni_{47}$), which are unaffected by aqueous alteration. Among these phases also well-preserved highly magnesian olivines and pyroxenes (Mg# 98-99 mol%) occur. One aggregate of typical phyllosilicate morphology sampled by FIB turned out to be almost entirely composed of nanocrystalline fayalitic olivine (~Fa_{90}).

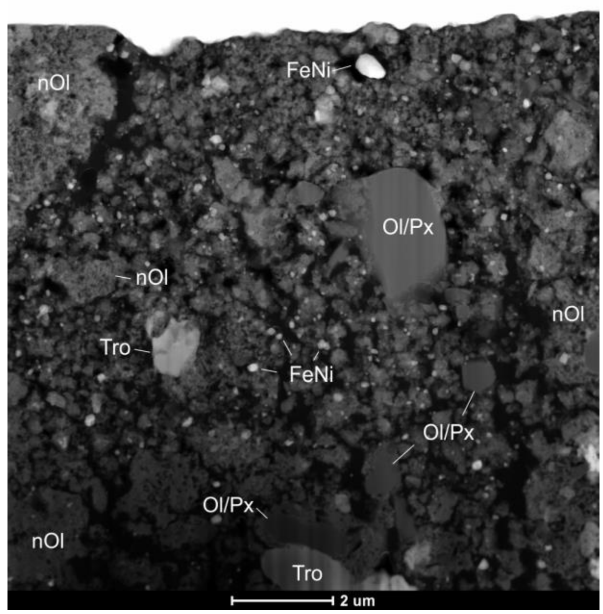

Fig. 1: STEM-HAADF image of a FIB-sectioned fine-grained rim surrounding a chondrule in NWA 11024. The texture is porous with large magnesian silicate grains (Ol/Px), troilite (Tro), FeNi metal, and clumps of Fe-rich, nanocrystalline olivine (nOl).

We cannot rule out that the Fe-rich matrix olivine and troilite/metal formed by dehydration/desulfurization of phyllosilicates and pyrrhotite/pentlandite. The fayalitic replacement of the former phyllosilicate aggregate (likely cronstedtite) certainly points to this direction. Similar processes have been observed in serveral anomalous CM/CI-like chondrites of the Belgica grouplet [2-4].

Shock effects and weathering. The olivines within chondrules and chondrule fragments do not show undulatory extinction. Thus, the rock is unshocked (S1) based on [5,6]. Since most of the Ni-poor metals are destroyed, the sample is strong weathered (W3) based on the weathering scale of [7] developed for ordinary chondrites.

Chemistry. The bulk trace element composition was obtained by the analyses of two aliquots of together ~250 mg. Normalized to CI they show flat REE-patterns (>1.5 x CI). The REE-enrichments relative to CI may be partly related to water-loss during dehydration. The high concentrations of Sr, Ba, and U clearly indicate contamination due to terrestrial alteration.

Oxygen isotopes. The oxygen isotope composition of NWA 11024 was analyzed by means of laser fluorination in combination with gas source mass spectrometry. Two aliquots of the sample were analyzed. The two samples have a $\delta^{17}O$ of -1.6 ‰ and -1.44 ‰ and a $\delta^{18}O$ of 6.85 ‰ and 6.07 ‰, respectively. The data plot at the ^{16}O- and ^{18}O-rich edge of the CM-field (Fig. 2) clearly distinct from the O-isotope field of the CO3 chondrites.

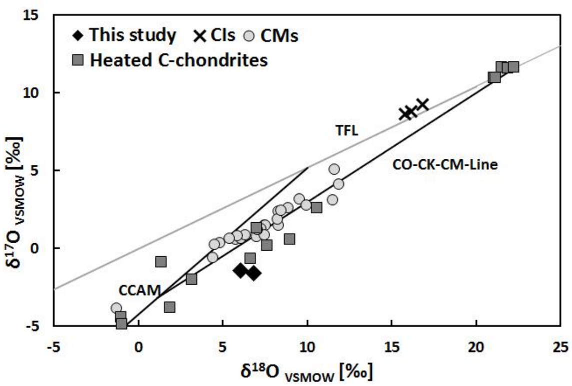

Fig. 2: O-isotopes: Data from heated C-chondrites and CM-chondrites fall on or close to the CO-CK-CM-line connecting the carbonaceous chondrite anhydrous mineral (CCAM) line and the terrestrial fractionation line (TFL). Data from this study plot at the ^{16}O- and ^{18}O-rich edge of the CM-field. Data for CI, CM, and heated C-chondrites are from [8,9].

Classification: The textural observations including the abundances of fine-grained, "opaque" materials and of CAIs (Fig. 3) clearly speak for a CM classification of this rock. This is also supported by the O-isotope composition. However, the lack of hydrous minerals and of carbonates strongly points towards the determination of a type 3 petrologic type. Since the olivines do not show undulatory extinction and most of the Ni-poor metals are destroyed the degrees of shock metamorphism and weathering have to be classified as S1 and W3, respectively.

Based on the nanomineralogical observations phyllosilicates have been dehydrated by a thermal event. The observations point to relatively high temperatures due to the relatively good crystallinity of the fayalitic replacement olivine and a lack of substantial amorphous reaction products. We tentatively assign the meteorite to heating stage III defined by [3], with temperatures attained in the range of 500-750 °C. This likely led to the conversion of pentlandite to Ni-rich metal, but probably did not allow the desulfurization of troilite to form Ni-poor metal as observed in samples of heating stage IV [4].

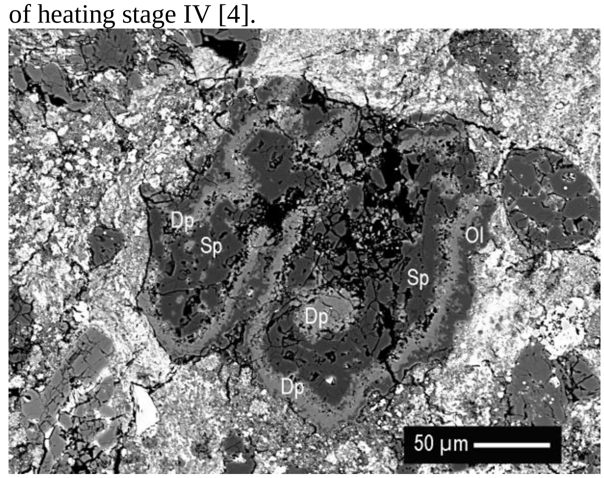

Fig. 3: BSE image of a fine-grained CAI with mainly spinel (Sp) in the center and a rim of diopside (Dp) and olivine (Ol).

Given the well-preserved, highly porous, fine-grained chondrule rims and the preserved anhydrous silicates within them, NWA 11024 might have been initially among the least aqueously altered CM chondrites. This and the O-isotope composition distinguished it from most of the known anomalous CM/CI-like chondrites. The source of heating is debated but was likely restricted to the outermost part of the parent body due to its inferred short duration, both impact heating and solar irradiation have been discussed [3,4].

References: [1] Bouvier A. et al. Meteorite Bulletin 105 (in preparation). [2] Bischoff A. and Metzler K. (1991) *Proc. NIPR Symp. Antarctic Meteorites* 4, 226-246. [3] Nakamura T. (2005) *J. Min. Pet. Sci.* 100, 260-272. [4] Harries D. and Langenhorst F. (2013) *Meteoritics & Planetary Science* 48, 879-903. [5] Stöffler et al. (1991) *Geochim. Cosmochim. Acta* 55, 3845-3867. [6] Bischoff A. and Stöffler D. (1992) *Europ. J. Mineral.* 4, 707-755. [7] Wlotzka (1993) *Meteoritics 28,* 460. [8] Clayton R. N. and Mayeda T. K. (1999) *Geochim. Cosmochim. Acta* 63, 2089-2104. [9] Tonui E. K. et al. (2003) *Meteoritics & Planetary Science* 38, 269-292.