A REPORT ON 63 NEWLY SAMPLED STONES OF THE ALMAHATA SITTA FALL (ASTEROID 2008 TC_3) FROM THE UNIVERSITY OF KHARTOUM COLLECTION, INCLUDING A C2 CARBONACEOUS CHONDRITE.

A.M. Fioretti[1], C.A. Goodrich[2,3], M. Shaddad[4], P. Jenniskens[5], M. Zolensky[6], I. Kohl[7], E. Young[7], D. Rumble[8], N. Kita[9], T. Hiroi[10], B. Turrin[11] and G. Herzog[11]. [1]CNR – Istituto di Geoscienze e Georisorse, I-35131 Padova, Italy (anna.fioretti@igg.cnr.it). [2]Lunar and Planetary Inst., Houston, TX 77058, USA (goodrich@lpi.usra.edu). [3]PSI, Tucson AZ 85719 USA. [4]Dept. Astronomy, Univ. of Khartoum, Khartoum 11115 Sudan. [5]SETI Inst., Mountain View, CA 94043 USA. [6]ARES, JSC, Houston, TX 77058 USA. [7]UCLA, Los Angeles CA 90095 USA. [8]Carnegie Inst., Washington DC 20015 USA. [9]Univ. Wisc., Madison, WI 53706 USA. [10]Brown Univ., Providence, RI 02912 USA. [11]Rutgers Univ., Piscataway, NJ 08854 USA.

Introduction: The Almahata Sitta (AhS) meteorite fell in 2008 when asteroid 2008 TC_3 impacted over Sudan [1,2]. It is the first meteorite to originate from a spectrally classified asteroid [1-3], and provides an unprecedented opportunity to correlate properties of meteorites with those of their parent asteroid. This makes AhS unique for studies in planetary science and planetary defense.

AhS is also a unique meteorite because its fragments comprise a wide variety of meteorite types. Of ~110 stones studied to-date, ~69% are ureilites (carbon-rich ultramafic achondrites) and 31% are various types of chondrites [4]. AhS is classified as an anomalous polymict ureilite. It has been inferred that 2008 TC_3 was loosely aggregated and porous, so that it disintegrated in the atmosphere and only its most coherent clasts fell as individual stones [5]. Understanding the structure and composition of this asteroid is critical for missions aimed at sampling asteroid surfaces.

However, current understanding is limited by an incomplete and possibly biased sampling of the fallen material. The main collection of >700 AhS samples (with find coordinates) is curated at the University of Khartoum [1]. Only 24 of these have been studied [6-8]. A second collection made by a private collector currently represents the bulk of the studied samples. This collection shows a very high proportion of enstatite chondrites [4], but because find coordinates are not available for these samples, it is not known whether they represent the whole strewn field.

We have begun a systematic study of the main AhS collection in Khartoum, with the goals: 1) to accurately determine the proportion of ureilitic to various non-ureilitic (including new) materials in AhS; 2) to determine the distribution of various types of materials in the strewn field, in order to constrain the compositional and physical structure of 2008 TC_3; and 3) to determine when and where ureilitic and non-ureilitic material became mixed in 2008 TC_3, in order to constrain the formation mechanism of this asteroid.

Selection and Processing of Samples: Members of our team convened at the University of Khartoum in late November, 2016, to improve storage conditions for the collection and select priority samples for characterization and analyses. Subsamples of individual stones were taken either as loose fragments from crumbly stones or by cutting with a diamond blade for compact ones. In order to accurately determine the proportion of ureilitic to various non-ureilitic materials in AhS, we focused on the largest fragments that fell between ~32.48° and 32.53° East longitude [1]. All stones were photographed and, after visual examination and tentative classification, in some cases using a portable XRD-XRF, all non-ureilitic and a representative selection of ureilitic materials were sampled (38 stones). In addition, we sampled smaller stones from across the strewn field [1], to improve petrographic characterization of the entire collection.

Altogether we sampled 63 AhS stones, 54 of which had not previously been studied. From 36 of these we obtained ~0.1-5.6 g subsamples, which were subsequently split into aliquots for thin section preparation (ongoing) and (for 23 larger samples) O-isotope analysis, Ar-Ar analysis, and/or reflectance spectroscopy.

Smaller, loose grains collected from other samples during sample selection (or generated during splitting) were mounted in groups of 4–10 individuals in 1 inch epoxy mounts, and then polished for scanning electron microscope (SEM) imaging and electron microprobe analysis (EMP). These were studied using the Cameca SX50 EMP at CNR, the CamScan MX3000 SEM and a FEI Quanta 200 ESEM at the University of Padova, and the JEOL 8530F EMP at ARES, JSC. So far, we have obtained back-scattered electron images (BEI) and WDS analyses of olivine, pyroxenes, metal, sulfide and matrix phases in grain mounts of 34 stones.

Results: Of 34 stones for which we have obtained data so far, 32 are ureilites of a large variety of types, as previously found for AhS samples [4]. Many of them are similar to AhS ureilites previously described [2,4-9], but several show new features that will be investigated in detail. Of the 7 samples that had previously been studied, 5 had not been classified with certainty due to insufficient material [6]. Our new sampling of these stones allows us to classify them now (all ureilites). Two of the new samples studied so far are non-ureilitic. AhS 38 is an E6 chondrite that will be studied further. AhS 202 is tentatively classified as C2 with uncertain affinities, and is described below.

AhS 202: This sample has a chondritic texture, consisting of chondrules (altered or partially altered, some flattened) in a fine-grained matrix (Fig. 1,2). The chondrules are olivine- (Fig. 2) or pyroxene-rich, with varying abundances of phyllosilicates and rims or partial rims of opaques, which are mainly magnetite with various morphologies (Fig. 1,2) plus minor Fe,Ni sulfides. The magnetite is often porous. Matrix consists largely of phyllosilicates, but also contains olivine, pyroxene, magnetite, and minor sulfides (Fig. 3).

Olivine composition is equilibrated at Fo 68.0±0.7, with ~0.14 wt.% NiO and molar Fe/Mn ~21. Pyroxenes are Wo 21-27, Mg# 84-92. Magnetite contains ~0.9% Cr_2O_3, 0.4% TiO_2, 0.4% MgO and 0.2% NiO, with no detectable Al_2O_3. Analytical totals and Si-Mg-Fe ratios suggest that the matrix is mainly saponite and serpentine phases, but this requires verification.

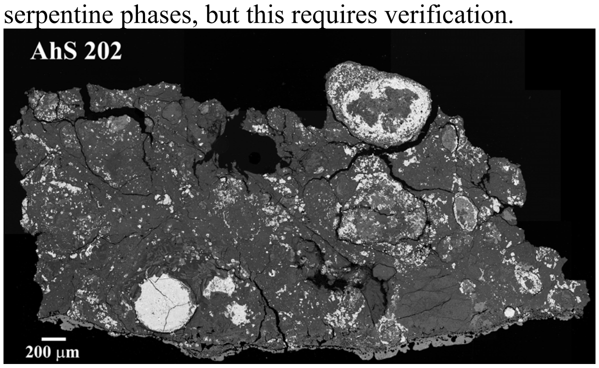

Fig. 1. Collage of BEI of AhS 202. Sample has a chondritic texture of chondrules (altered or partially altered) in fine-grained matrix. Most of the brightest grains are magnetite.

Discussion: Nineteen of the samples we have studied so far are from the area of the strewn field in which the largest stones fell. All of these samples are ureilites. Although we have only begun to study this new selection of AhS samples, results so far, as well as observations of the whole collection, suggest that the fraction of non-ureilitic material in AhS is significantly less than the ~30% found by [4,9]. If this result holds up with further study of the whole collection, it would support the hypothesis that the fraction of non-ureilitic material in AhS is similar to that in typical polymict ureilites [5], and therefore an exotic formation mechanism [9,10] may not be required for AhS.

AhS 202 is a new type of material for AhS (previously, the only CC reported in AhS was a CB [4]). It has similarities to, but is distinct from, CC-like dark clasts in typical polymict ureilites [11-13]. It also resembles a common C2 lithology in Kaidun, but with a far higher magnetite:sulfide ratio [14]. The high abundance of magnetite suggests CK. However, several mineral chemical parameters do not fit CK. Abundances of Cr, Al, and Mg in magnetite are not consistent with CK but could match CV [15,16]. Also, no aqueously altered CK are known. AhS 202 has experienced oxidation and metamorphism followed by aqueous alteration, similar to C2 clasts in Kaidun [14]. Oxygen isotope analyses will be conducted to compare 202 with known meteorites

The discovery of AhS 202 shows that further work to completely characterize the AhS collection is needed to understand the composition, structure, and origin of this meteorite and its parent asteroid 2008 TC_3.

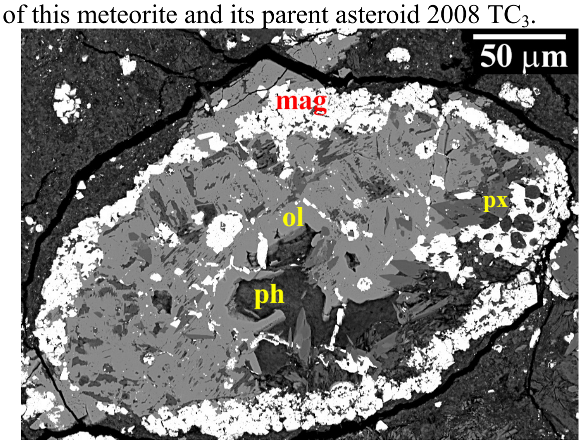

Fig. 2. Altered olivine-rich chondrule, consisting of olivine (ol), pyroxene (px), phyllosilicate(s) (ph), and rim of dominantly magnetite (mag). BEI.

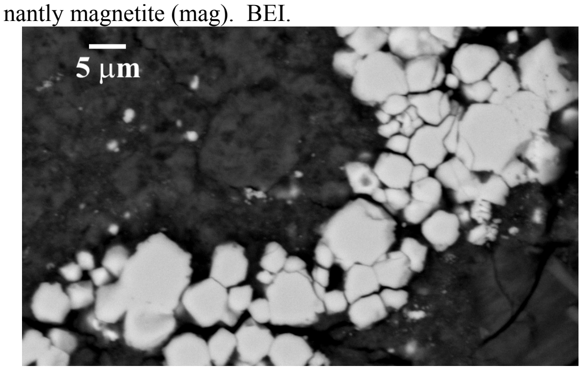

Fig. 3. Magnetite in matrix of AhS 202. BEI.

References: [1] Shaddad M. et al. (2010) *MAPS* 45, 1557-1589. [2] Jenniskens P. et al. (2010) *Nature* 12, 458-488. [3] Jenniskens P. et al. (2010) *MAPS 45*, 1590-1617. [4] Horstmann M. and Bischoff A. (2014) *Chemie der Erde* 74, 149-183. [5] Goodrich C.A. et al. (2015) *MAPS* 50, 782-809. [6] Zolensky M. et al. (2010) *MAPS* 45, 1618-1637. [7] Herrin J. S. et al. (2010) *MAPS* 45, 1789-1803. [8] Mikouchi T. et al. (2010) *MAPS* 45, 1812. [9] Bischoff A. et al. (2010) *MAPS* 45, 1638-1656. [10] Gayon-Markt J. et al. (2012) *Monthly Notice Royal Astr. Soc.* 424, 508-518. [11] Brearley A. and Prinz M. (1992) *GCA* 56, 1373-1386. [12] Ikeda Y. et al. (2003) *Ant. Met. Res.* 16, 105-127. [13] Goodrich C.A. et al (2004) *Chemie der Erde* 64, 283-327. [14] Zolensky M. and Ivanov A. (2003) *Chemie der Erde* 63, 185-246. [15] Dunn T.L. et al. *MAPS* 51, 1701-1720. [16] Greenwood R. et al. (2010) *GCA* 74, 1684-1705. *Acknowledgement: We thank D. Blake for providing the portable XRD-F.*