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## An integrated mineralogical, petrographic, light stable isotope and noble gas investigation of Sahara 99201 ureilite

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**AN INTEGRATED MINERALOGICAL, PETROGRAPHIC, LIGHT STABLE ISOTOPE AND NOBLE GAS INVESTIGATION OF SAHARA 99201 UREILITE.** C. L. Smith<sup>1, 2</sup>, I. A. Franchi<sup>1</sup>, I. P. Wright<sup>1</sup>, A. B. Verchovsky<sup>1</sup>, M. M. Grady<sup>2</sup> and C. T. Pillinger<sup>1</sup>. <sup>1</sup>Planetary Space and Space Sciences Research Institute, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK (C.L.Smith@open.ac.uk), <sup>2</sup>Department of Mineralogy, The Natural History Museum, Cromwell Road, London, SW7 5BD, UK.

**Introduction:** Sahara 99201 (provisional name) is a new ureilite weighing 91g collected from the Sahara desert during 1999. The sample has been analysed to determine both mineralogy and petrography and also its light element stable isotopic composition.

**Methodology:** Mineralogical analyses were carried out using a Cameca SX100 electron microprobe, with a beam current of 20nA, accelerating voltage of 20kV and a 10 $\mu$ m spot size in WDS analytical mode. At least 6 analyses were taken from each mineral grain to ensure good experimental precision.

A ~200mg chip was taken from an internal portion of a 35g sample (to reduce the effect of contamination and weathering) and crushed in an agate pestle and mortar. Small fractions of powdered sample were loaded into Pt buckets and high resolution stepped combustion experiments were performed from 300°C to 1400°C to determine the yield and isotopic composition of C, N and Ar. C stable isotope analyses were carried out using *MS86*, a fully automated high-sensitivity static-vacuum mass spectrometer, whilst a separate aliquot of material was analysed for N and noble gases using *Finesse*, a multi-element static-vacuum mass spectrometer [1,2]. O isotope analyses were carried out on a dual inlet mass spectrometer (*VG PRISM*) following the method of Miller *et al.* [3].

**Results: Mineralogy and petrography.**

The sample is a coarse-grained (average grain size 1-2mm) olivine pigeonite ureilite displaying typical monomict texture. The sample is relatively unweathered compared with other desert ureilites with a weathering grade of W0-W1[4]. The sample is also of low shock with undulatory extinction in olivine implying a shock classification of S2 [5]. Olivine grains within the sample are quite fractured although one prominent grain displays very little fracturing. Reduction rims occur in olivines in two forms: as typical 50-100 $\mu$ m rims at the grain boundaries of the unfractured olivine, and also as "rosettes" which mainly occur in the more fractured olivine (figure 1). The rosettes consist of globular masses of metal blebs approximately 100 $\mu$ m in diameter. The rosettes occur in groups adjacent to the grain boundaries of the olivine and can be up to 800 $\mu$ m in thickness. These rosettes are apparently a primary texture and not related to weathering. The pigeonite grains do not display reduction rims as seen in the olivine although they do contain trails of metallic inclusions. These inclusions appear to follow both

cleavage planes in the pigeonite and also fracture zones. A single blade of graphite can be seen at the boundary of a fractured olivine which is surrounded by a ~100 $\mu$ m thick zone of reduction. Interestingly, C-rich matrix material is apparently lacking in the section. Mean mg# from olivine cores is Fo78.2  $\pm$  0.5 (1 $\sigma$ ) with mean pyroxene core compositions of Wo 9.6  $\pm$  0.1, En 72.4  $\pm$  0.4.

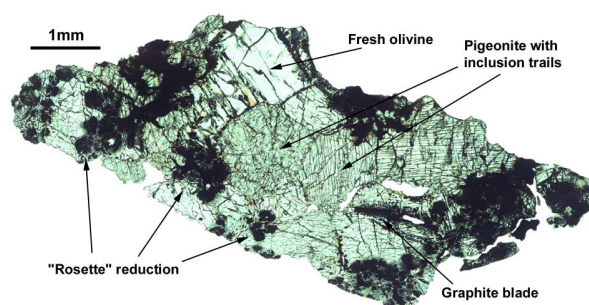


Figure 1. Plane polarised light image of Sahara 99201 showing rosettes of reduction and other features of interest.

**Carbon isotopes:**

A sample of 0.215mg was combusted; results are shown in figure 2. The total C yield for this sample is 3.3 wt% which is comparable with other ureilites [6]. At temperatures below 500°C, 844ppm C is released with a weighted average  $\delta^{13}\text{C}_{\text{(PDB)}}$  of -21.5 ‰, indicative of organic contamination. The main release occurs between 500 and 750°C, a temperature characteristic of graphite combustion, where 3.1 wt% C is liberated, of average  $\delta^{13}\text{C}_{\text{(PDB)}}$  -2.5 ‰, which is also within the observed range of ureilites [6]. At temperatures above 750°C only 424ppm C is released with a mean  $\delta^{13}\text{C}_{\text{(PDB)}}$  of -23 ‰. This is close to that of system blank, although it may be associated with carbide or carbon in metal.

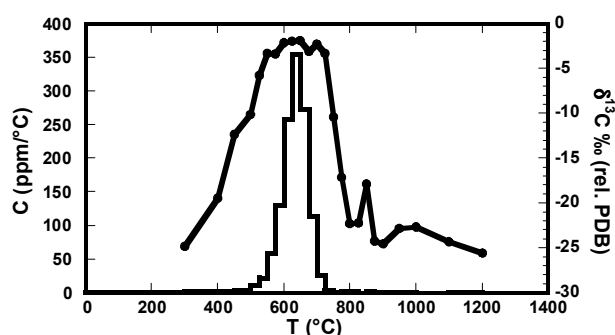


Figure 2. Carbon step combustion profile.

*Nitrogen:*

A 3.13mg sample was combusted and found to contain 78ppm of N, within the range reported for other ureilites [7]. The stepped combustion profile (figure 3) indicates three main N releases at low, mid and high temperatures. The first, low temperature release of 34ppm N occurs below 500°C with a weighted average  $\delta^{15}\text{N}_{(\text{AIR})}$  of +26.8 ‰ and is presumably related to the low temperature organic contaminant fraction. The second N release occurs between 550 and 800°C with 19ppm N and  $\delta^{15}\text{N}_{(\text{AIR})}$  of -54 ‰. This release is related to the main C release associated with the graphite combustion at these temperatures. The third N release occurs at temperatures above 900°C with 102ppm N being liberated with a weighted average  $\delta^{15}\text{N}_{(\text{AIR})}$  of -16 ‰ which is similar to reported values for other ureilites [7]. This high temperature release is most likely related to metal and silicate fractions [8].

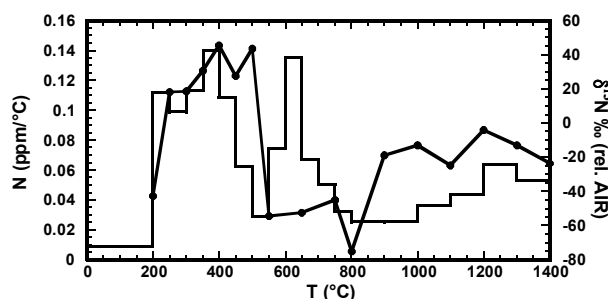


Figure 3. Nitrogen step combustion profile.

*Argon:*

The sample shows a peak  $^{36}\text{Ar}$  release ( $856\text{ccx}10^{-8}/\text{g}$ ) at temperatures between 500 and 700°C which again is presumably related to the combustion of graphite. The  $^{36}\text{Ar}$  release and its  $^{36}\text{Ar}/^{38}\text{Ar}$  and  $^{40}\text{Ar}/^{36}\text{Ar}$  ratios are within values reported for other ureilites [9]. No other  $^{36}\text{Ar}$  or Ne releases above levels of system blank were detected.

*Oxygen:*

O isotopic composition for this sample is  $\delta^{18}\text{O}_{(\text{SMOW})} = +8.07$  ‰ and  $\delta^{17}\text{O}_{(\text{SMOW})} = +3.25$  ‰ with  $\Delta^{17}\text{O}$  of -0.946. Accordingly this sample appears to be within sub-group D of Franchi *et al.* [10].

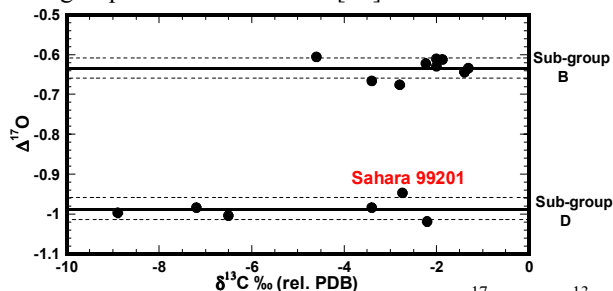


Figure 4. Graph to show co-variation of  $\Delta^{17}\text{O}$  and  $\delta^{13}\text{C}$  within ureilite sub-groups. Dashed lines =  $1\sigma$  on mean [10].

**Discussion:** In terms of its mineralogy and petrography the sample is fairly typical of monomict ureilites in general, although the low shock and low weathering grade (in terms of desert finds) of the sample is quite unusual. The rosette reduction is also fairly common and similar reduction textures can be seen in HH126 [11]. It appears that the rosette reduction is a primary feature as opposed to one developed during weathering, for example. It is perhaps relevant that the rosette reduction can only be seen in the fractured olivine grains as opposed to the typical reduction rim as seen on the fresh olivine. The rosette style of reduction may be related to a shock event. Perhaps C-rich fluids were mobilised during the shock event and were able to preferentially permeate the fractured olivine grains thus resulting in a localised but intense reduction.

C yield and isotopic composition is within range of other reported ureilites falling within the heavier of the two groups reported by [6]. A diamond component is apparently lacking from the stepped combustion profile. If a diamond component were present it is likely that it would be detected during stepped combustion analysis. Diamond has an elevated combustion temperature (~700 to 1000°C) compared with graphite (~600 to 900°C) [6], and accordingly a sample that contains diamond would be expected to show a broader release profile than that seen from this sample. This lack of diamond component in the step combustion profile is consistent with the low shock classification as suggested by the petrography.

Total N yield is also within the reported range. The isotopic composition of the release associated with graphite combustion ( $\delta^{15}\text{N}$  -54 ‰) is within values reported for similar stepped combustion experiments on bulk ureilite samples [6,7]. The multi-component release profile seen in this sample is also fairly typical to those observed for other ureilites.

$^{36}\text{Ar}$  yield is also within range reported for ureilites and its peak release also occurs at the range in temperatures for graphite combustion. This is to be expected, as it is believed that C in ureilites is the carrier phase for “planetary” type noble gases.

**References:** [1] Prosser, S. J. *et al.* (1990) *Chem. Geol.* 83, 71-88. [2] Verchovsky, A. B. *et al.* (1997) *MAPS*, 32, A131. [3] Miller, M. F. *et al.* (1999) *Rapid. Commun. Mass Sp.*, 13, 1211-1217. [4] Wlotzka, F. (1993) *Meteoritics*, 28, 460. [5] Stöffler, D. *et al.* (1991) *GCA*, 55, 3845-3867. [6] Grady, M. M. *et al.* (1985) *GCA*, 49, 903-915. [7] Yamamoto, T. *et al.* (1998) *MAPS*, 857-870. [8] Franchi I. A. *et al.* (1993) *GCA*, 57, 3105-3121. [9] Schultz L. & Kruze H. (1989) *Meteoritics*, 24, 155-172. [10] Franchi I. A. *et al.* (1998) *LPS*, XXIX, 1635. [11] Sexton, A. *et al.* (1996) *LPS*, XXVII, 1173.