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**NEW DATA ON CARBON ISOTOPIC COMPOSITIONS OF SOME UREILITES.** C. L. Smith<sup>1,2</sup>, I. A. Franchi<sup>1</sup>, I. P. Wright<sup>1</sup>, M. M. Grady<sup>2</sup> and C. T. Pillinger<sup>1</sup>. <sup>1</sup>Planetary and Space Sciences Research Institute, The Open University, Walton Hall, Milton Keynes, Bucks, MK7 6AA, UK, <sup>2</sup>Department of Mineralogy, The Natural History Museum, Cromwell Road, London, SW7 5BD, UK. (C.L.Smith@open.ac.uk)

**Introduction:** The ureilites are an unusual class of carbon-rich, ultramafic, achondritic meteorites, which display both primitive and evolved characteristics. For example, their noble gases (which are carried largely in the diamond phase) display a planetary or fractionated signature, and their O isotopes retain a heterogeneity imparted from the solar nebula [1,2]. Paradoxically, though, the mineralogical and textural characteristics displayed by the ureilites are seemingly indicative of extensive igneous processing on the ureilite parent body (UPB), a fact which is supported by chemical evidence such as depleted lithophile element abundance [3].

It is clearly apparent that models aiming to resolve the question of ureilite petrogenesis must satisfy the seemingly inconsistent chemical, mineralogical and isotopic evidence. We have previously suggested that studying carbon, and the role it plays in the formation of the ureilites, may be a step forward in the understanding of these perplexing meteorites [4].

High precision O isotope analyses by Franchi *et al.* [5,6] indicated that the group 1 ureilites [7] may be resolved into four distinct sub-groups (A, B, C, D) on the basis of  $\Delta^{17}\text{O}$  values. The consistency of  $\Delta^{17}\text{O}$  within each sub-group implies homogenisation, occurring either in discrete local regions on a single ureilite parent body, or perhaps, on four separate ureilite parent bodies. A pathfinder study [6] utilising bulk carbon analyses (samples pre-combusted at 400°C for two hours then combusted at 1000°C overnight) indicated a clear co-variation of  $\delta^{13}\text{C}$  with  $\Delta^{17}\text{O}$ . The present study expands on this work by undertaking a more detailed analysis of carbon within samples from sub-groups B and sub-group D ( $\Delta^{17}\text{O} = -0.633 \pm 0.025$  and  $-0.989 \pm 0.025$  respectively).

**Samples and Method:** Five ureilites from sub-groups B and D have been analysed for their carbon stable isotopic compositions and overall carbon distribution using a combination of mass spectrometry and stepped combustion. The five samples are; RKPA 80239, PCA 82506, Sahara 99201 (provisional name), META 78008 and LEW 85328. High resolution stepped combustion experiments are a powerful tool when investigating carbon distributions and isotopic compositions. These high resolution experiments allow different species of carbon to be determined e.g. organic contaminant, graphite, carbide, according to characteristic combustion temperatures, from a whole

rock sample. Although low temperature organic contaminants can be removed by pre-combusting samples at 400°C prior to a bulk analysis, the resolution of distinct carbon components and isotopic compositions is impossible. Importantly, carbonates are not removed by pre-combustion, which can skew both carbon yields and isotopic compositions, if carbonate is present in the sample. The high resolution stepped combustion analyses on samples from sub-groups B and D will better constrain carbon yields and isotopic compositions and, allow both inter- and intra- group relationships to be better determined. Detailed mineralogical and petrographic examination of these samples is also being carried out which, in combination with our carbon investigation, may shed light on the formation conditions and processes occurring on the ureilite parent body(ies).

Chips were taken from internal portions of the samples (to reduce the effects of contamination and weathering and also to exclude fusion crust) and were crushed in an agate pestle and mortar. Small fractions of the powdered sample were then loaded into Pt buckets and high resolution stepped combustion experiments were carried out. The stepped combustion experiments were carried out on MS86, a fully automated, high-sensitivity, static-vacuum mass spectrometer at the Open University [8]. Experiments were carried out from 300°C to 1400°C with the 500°C to 900°C temperature range studied at high resolution (25°C steps).

**Results and Discussion:** The results of the carbon analyses are shown below in table 1. In all the ureilites studied there is a common phase liberated at temperatures below ~500°C with a weighted average  $\delta^{13}\text{C}_{(\text{PDB})}$  of -20 to -30‰, which is indicative of terrestrial organic carbon [9]. Considering the presence of this low temperature organic contaminant the values given in table 1 below for  $\delta^{13}\text{C}_{(\text{PDB})}$  and wt % C are weighted averages for temperature steps between 500°C and 1300°C.

Sample	Sample wt. (mg)	Wt % C	$\delta^{13}\text{C}$
RKPA 80239	0.271	6.9	-9.2
PCA 82506	0.396	5.9	-8
Sahara 99201	0.215	3.2	-2.7
META 78008	0.194	1.5	-1.3
LEW 85328	0.336	3.7	-2.3

Table 1. Summary of average  $\delta^{13}\text{C}$  and wt% C.

Figure 1 below shows the  $\delta^{13}\text{C}$  plotted against  $\Delta^{17}\text{O}$  for the samples. Other data points on the graph are from the pathfinder study [6].

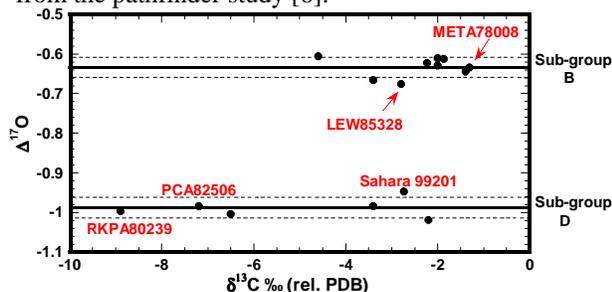


Figure 1. Co-variation of  $\delta^{13}\text{C}$  with  $\Delta^{17}\text{O}$  for group 1 ureilites in sub-groups B and D. Dashed lines =  $1\sigma$  from mean. After [6].

**Sub-group D:** (RKPA 80239, PCA 82506, Sahara 99201) These samples show the largest range in  $\delta^{13}\text{C}$ ,  $-9.2\text{‰}$  to  $-2.2\text{‰}$ , with samples falling into both the “heavy” and “light” groups according to isotopic composition as described by Grady *et al.*[9]. Interestingly, samples with the lightest carbon isotopic composition contain the most carbon. However, two of the samples (unlabelled) are bulk analyses from the pathfinder study and as such the presence of any carbonate within them may result in unrepresentative carbon yield and isotopic compositional data.

Investigation of the stepped combustion profiles for graphite release in the samples reveals that, in addition to the relationship seen between carbon yield and isotopic composition there is also a bi-variate relationship between graphite combustion temperature and isotopic composition. Figure 3 shows the stepped combustion profiles for the three samples analysed.

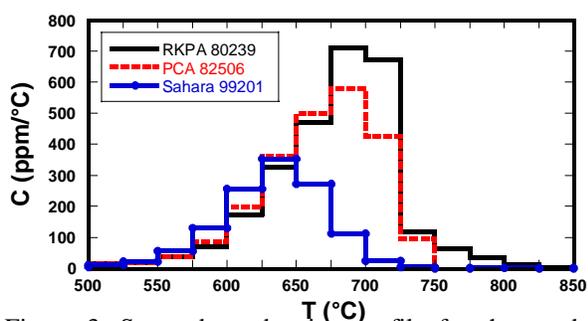


Figure 3. Stepped combustion profile for three sub-group D ureilites.

Sahara 99201, which is the isotopically heaviest of the three samples, also has the lowest peak combustion temperature ( $650^\circ\text{C}$ ) and the narrowest range in combustion temperatures ( $\sim 550\text{--}725^\circ\text{C}$ ). Conversely RKPA 80239, which has the lightest isotopic composition of the samples, shows the highest peak combustion tem-

perature ( $700^\circ\text{C}$ ) and the broadest range of combustion temperatures ( $\sim 575\text{--}825^\circ\text{C}$ ). It is believed that this temperature range difference is a real feature and not due to experimental artefact or sampling effects. The crystallinity of graphite influences the combustion temperature, with greater crystallinity resulting in higher combustion temperatures. It may be the case then, that graphite within Sahara 99201 is less crystalline than that found in RKPA 80239. All the samples have low shock grades [10] which would suggest that the elevated combustion temperatures are unlikely to be due to the presence of diamond.

**Sub-group B:** (META 78008, LEW 85328) Samples from this sub-group show a narrower range in  $\delta^{13}\text{C}$  ( $-4.6\text{‰}$  to  $-1.3\text{‰}$ ) compared with sub-group D. However, unlike sub-group D, sub-group B shows no relationship between isotopic composition and carbon yield. Indeed, the carbon yields for this sub-group have a narrower range (1.5 to 1.6 wt%). It should be noted, however, that most of the sub-group B carbon data is from the pathfinder study [6] and as has been mentioned previously caution should be exercised when interpreting this data.

It is apparent from this work that, in addition to O isotopic composition, group 1 ureilites display marked differences in carbon yields and isotopes. The differences in carbon between the two sub-groups would seem to confirm the suggestion, based on  $\Delta^{17}\text{O}$  values, that the group 1 ureilites, whilst displaying similar mineral chemistries, may have originated from discrete regions on a single body or perhaps separate parent bodies entirely. It does not seem unlikely then, that in addition to being heterogeneous in terms of O, that the different regions on the UPB or individual parent bodies may also be heterogeneous in terms of carbon distribution and/or isotopic composition.

Continued work on ureilite carbon, in conjunction with detailed mineralogical and petrographic investigation, will help to unravel the petrogenetic history of these enigmatic meteorites.

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