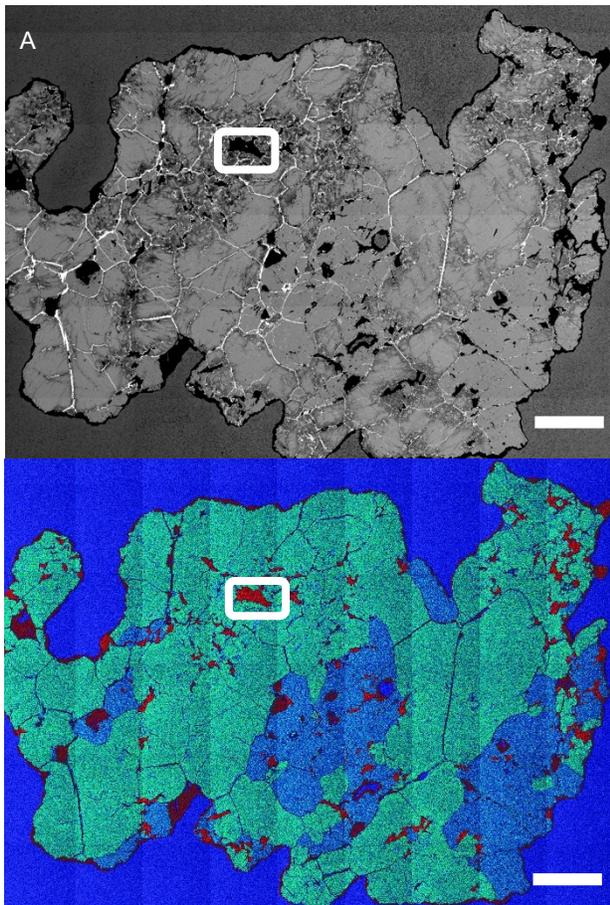


**X-RAY ANALYSES OF CARBON-RICH PHASES IN UREILITES.** A. C. O'Brien<sup>1</sup>, L. J. Hallis<sup>1</sup>, A. Steele<sup>2</sup>, L. G. Benning<sup>3</sup>, C. L. Smith<sup>1,4</sup>, L. Daly<sup>1</sup> and M. R. Lee<sup>1</sup>, <sup>1</sup>School of Geographical and Earth Sciences, University of Glasgow, UK (a.obrien.1@research.gla.ac.uk), <sup>2</sup>Geophysical Laboratory, Carnegie Institute of Washington, USA, <sup>3</sup>German Research Center for Geosciences, Potsdam, Germany, <sup>4</sup>Natural History Museum, London, UK.

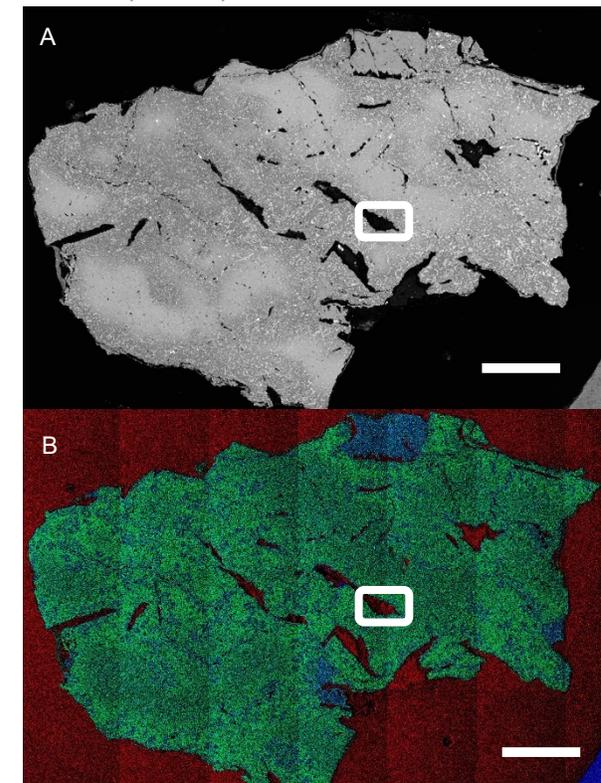
**Introduction:** Ureilites are carbon-rich achondritic meteorites thought to originate from a partially melted asteroid, the Ureilite Parent Body (UPB) [1]. Goalpara and Hajmah (a) are two of the 516 meteorites in the ureilite group. Goalpara was found in India in 1868, and contains carbon in the form of graphite, diamond, and organic matter (OM) [2]. Similar C-rich phases have also been found in Hajmah (a), an unbrecciated ureilite found in Oman in 1958 [3]. It has been suggested that diamond was formed by impact into the UPB, converting some of the primary igneous graphite into diamond via shock ([2],[4]). This idea has been contested, however, on the basis of unevenly distributed impurities (hydrogen, nitrogen, oxygen and noble gases) found within diamond crystals which would not normally be found in shock-formed diamond [5]. It has been proposed that the



**Fig. 1** Montaged BSE image (A) and EDS map (B) of the Hajmah (a) thin-section P15176. White boxes indicate where focused ion beam (FIB) samples were extracted. In (B) red represents carbon, green magnesium and blue silicon. Scale bars = 1 mm.

diamonds formed slowly, perhaps deep within the molten interior of the UPB or through chemical vapour deposition in the solar nebula [5]. It is thought that the UPB predates the Earth [1]. Understanding formation scenarios of the carbon in the UPB will enable a better insight into primitive solar system conditions that led to the Earth's formation and Earth's initial carbon content - which is so vital for life - a component of which may have been delivered by meteorites.

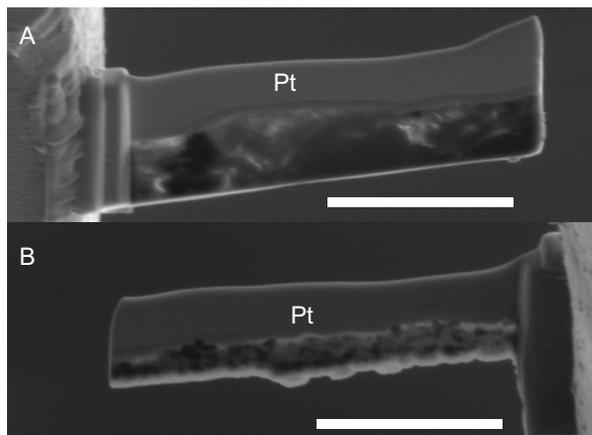
The aim of this study is to investigate the presence, nature and structure of putative ureilitic carbon and OM in Goalpara and Hajmah (a) via backscattered electron imaging and Energy Dispersive X-ray spectroscopy (BSE, EDS), and C K edge X-ray absorption near edge structures (XANES).



**Fig. 2** Montaged BSE image (A) and EDS map (B) of the Goalpara thin-section P9492. White boxes indicate where focused ion beam (FIB) samples were extracted. In (B), red represents carbon, green represents magnesium and blue represents silicon. Scale bars = 1 mm.

**Methods:** Polished and carbon coated thin sections of Hajmah (a) (P15176) and Goalpara (P9492), loaned by the Natural History Museum, London, were initially characterized using a scanning electron microscope (SEM) at the University of Glasgow (UoG). Carbon-

rich areas of Hajmah (a) and Goalpara were located using EDS. The EDS carbon signal from the carbon coat/epoxy resin was less intense than that of OM in the meteorite so the extraterrestrial carbon could be readily distinguished from that used in sample preparation (see Figures 1B and 2B). The UoG FEI Ga Focused Ion Beam SEM (FIB-SEM) was used to mill two 100 nm thick FIB-section lamellae from selected carbon-rich regions of each meteorite. Extracted FIB foils were mounted on copper grids designed for transmission electron microscopy. A scanning tunneling X-ray microscope (STXM) was then used, with a 50 nm spot size and 10 ms integration time, to perform carbon K edge XANES on the samples at beamline I08 at the Diamond Light Source synchrotron, UK. STXM XANES energy stack maps helped characterize the distribution of the various OM functional groups related to the meteoritic carbon and identify the presence or absence of nano-diamonds/OM heterogeneity in the FIB lamellae.

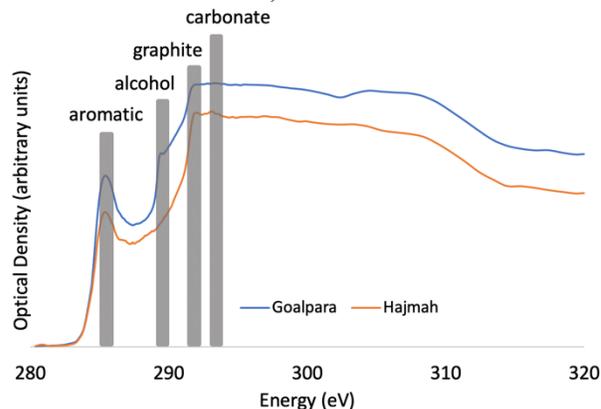


**Fig. 3:** BSE images of 100 nm thick lamellae of Goalpara (A) and Hajmah (a) (B) extracted using a FIB-SEM. FIB-deposited platinum used to protect sample surface during milling is labelled. Scale bars represent 5  $\mu\text{m}$

**Discussion:** C K edge XANES data clearly differentiated regions containing organic meteoritic carbon, from those containing thin-section preparation polymer (epoxy resin). Yet, diamonds could not be detected. The difficulty of performing K-edge C-XANES analyses on meteoritic diamond, due to differential FIB milling speeds of diamond, graphite and OM, is known [6] and also affected our FIB-section preparation, which resulted in uneven thickness across each FIB-section. This led to some sample loss (Fig. 3 B), and some areas being thicker than ideal for XANES analysis (100 nm). This effect was noted by [6] when analysing meteoritic diamonds; they were unable to perform XANES directly on the diamonds as they were much thicker than the rest of the sample.

Figure 4 shows average C K edge STXM XANES spectra from carbon rich regions in the Goalpara and

Hajmah (a) FIB sections. Preliminary analysis of the spectra indicates that aromatic, graphitic and alcohol functional groups are present in both samples, with a carbonate stretch also visible for the Hajmah (a) sample. The presence of carbonate in Hajmah (a) may be due to terrestrial contamination, since it is a hot desert find.



**Fig. 4:** Representative carbon k edge STXM XANES spectra acquired from the carbon-rich lamellae milled from Goalpara (a) and Hajmah, as displayed in Figure 3.

**Future Work:** Further spectral analysis is needed to identify the origin of the functional groups in Figure 4 (ie. differentiate between terrestrial and ureilitic OM). These analyses will be presented at the meeting.

Inclusions found in terrestrial diamonds provide information relating to their formation within the Earth. Nanoscale analyses of ureilite diamond could allow us to improve our understanding of UPB formation [7]. Our FIB-sections appear not to contain diamonds as the characteristic diamond stretch that was noted by [6] was not observed. Future work will include the use of techniques such as cathodoluminescence or X-ray fluorescence (see [8]) to identify ureilite diamonds within the thin-sections. These diamonds could then be extracted by FIB-SEM and analysed by atom probe tomography (APT) in addition to STXM XANES. APT would allow us to probe the composition and structure of ureilite diamonds atom by atom. Generating a nanoscale picture of ureilitic diamonds will help us understand possible UPB formation scenarios through locating and characterising hosted impurities.

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