SHOCK TEMPERATURE RECORDS IN GRAPHITE FROM THE NORTHWEST AFRICA 6871 UREILITE

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Introduction

The aim of this work is to characterize carbon phases in the highly shocked ureilite NWA 6871.

Ureilites are ultramafic coarse-grained achondrites which originate from the ureilite parent body (UPB) [1]. This UPB was destroyed due to impact event(s) [2]. In comparison to other meteorite groups, ureilites contain significant amounts of carbon (up to 8 vol.%) [3]. Depending on the individual sample, carbon occurs mainly in form of graphite and diamond. Recent studies have shown that (large) diamonds in ureilites formed during shock, where metallic melts catalyzed the direct transformation of graphite to diamond [4-7].

Sample

NWA 6871 is a highly shocked (S6) ureilite fund from 2011 in Morocco [8]. We analyzed a larger thick-section and a smaller thin-section (Fig. 1). Polishing NWA 6871 was very hard due to presumed diamonds but eventually it succeeded.

Methods

The sample was analyzed by scanning electron microscopy (SEM) in low vacuum mode without carbon coating to localize carbon-bearing aggregates. After localization by SEM, the carbon aggregates were cut out and mounted on glass fibers for further analysis by X-ray diffraction (XRD) and micro-Raman spectroscopy (MRS). XRD was performed using a Rigaku Oxford Diffraction SuperNova single-crystal diffractometer equipped with a 200K Dectris detector operating with monochromatized micro-source MoKα X-ray radiation at a wavelength of 0.71073 Å (X-ray beam diameter was 0.120 mm, the sample-to-detector distance 68 mm).

MRS was done using a Thermo Scientific DXR spectrometer (wavelength = 532 nm). In addition to the phase identification, we applied a graphite based geothermometer, which uses the full width half maximum (Γ_G) of the graphite G-band at ~1575 cm^{-1} to calculate the experienced temperature [9,10]:

$$T_{max}(°C) = 1594.4 - 20.4\Gamma_G - 5.8 * 10^{-2}\Gamma_G^2$$

Results

NWA 6871 contains large olivine grains (of up to 1 mm) which upon closer inspections consist of multiple smaller grains (40 µm) meeting in triple junctions (black lines in Fig. 2).

XRD on carbon-bearing aggregates revealed *d*-spacings of graphite, diamond, iron, troilite and pentlandite. Graphite peaks at *d*-spacing = 3.34 Å show asymmetric shapes towards lower d-spacings. The highest peak of diamond at *d*-spacing = 2.06 Å shows a shoulder towards higher *d*-spacings (Fig. 3 (a) and (b)).

A representative Raman spectra of carbon aggregates can be seen in Fig. 4 showing only graphite bands. In total 22 measurements were conducted. The graphite based geothermometer yields a temperature of 1412 ± 120 °C, whereof the error originates from Cody *et al*. (2008) [9].

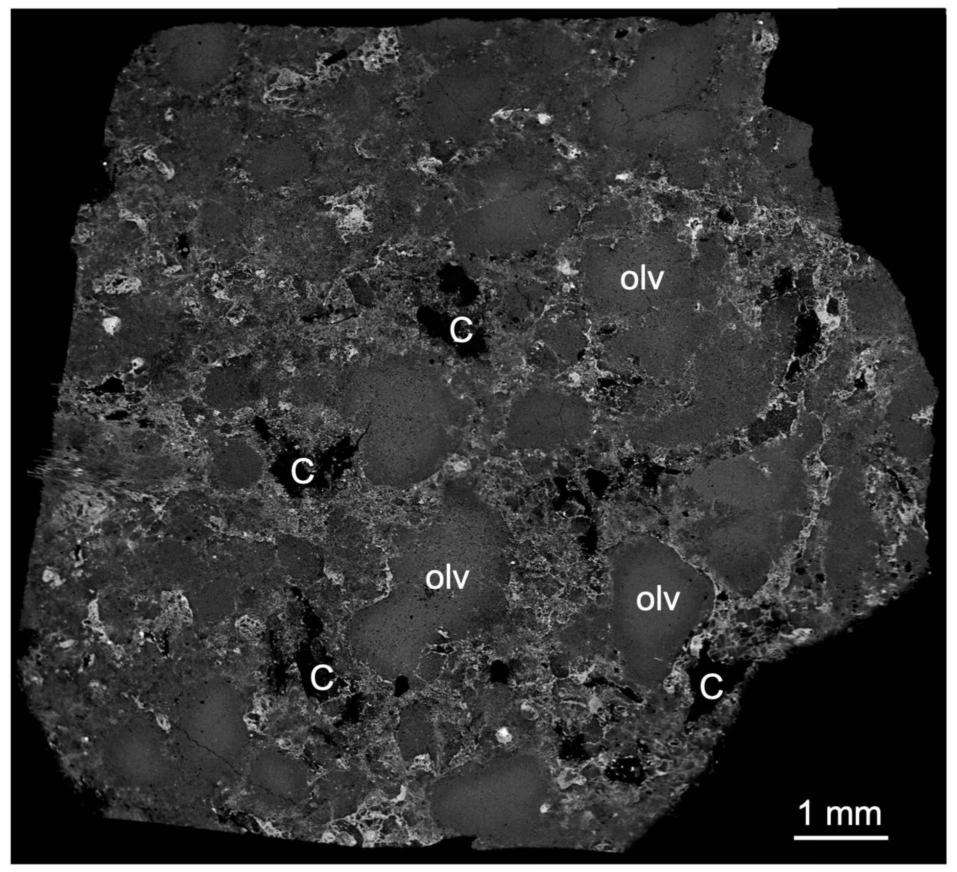

Fig. 1: Backscattered electron image of the NWA 6871 thin-section. C = carbon aggregates, olv = olivine.

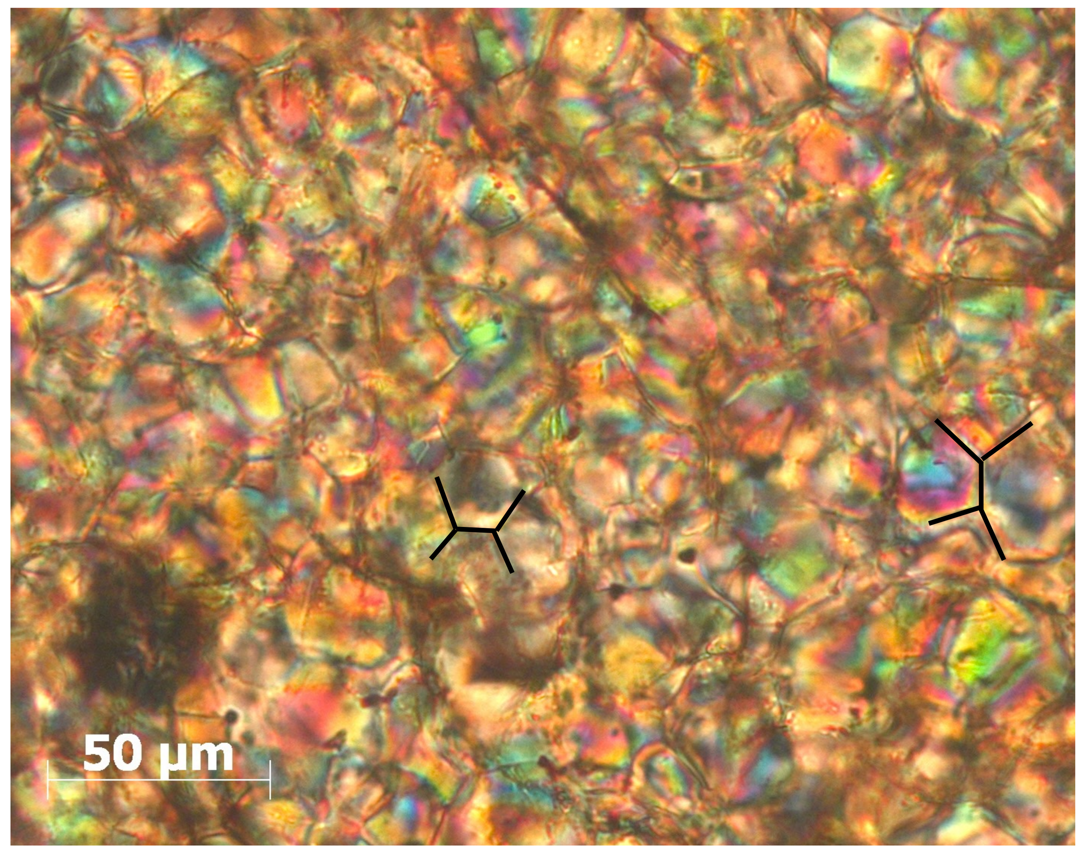

Fig. 2: Close-up of an olivine grain under crossed polars revealing various small olivine grains which meet in triple junctions.

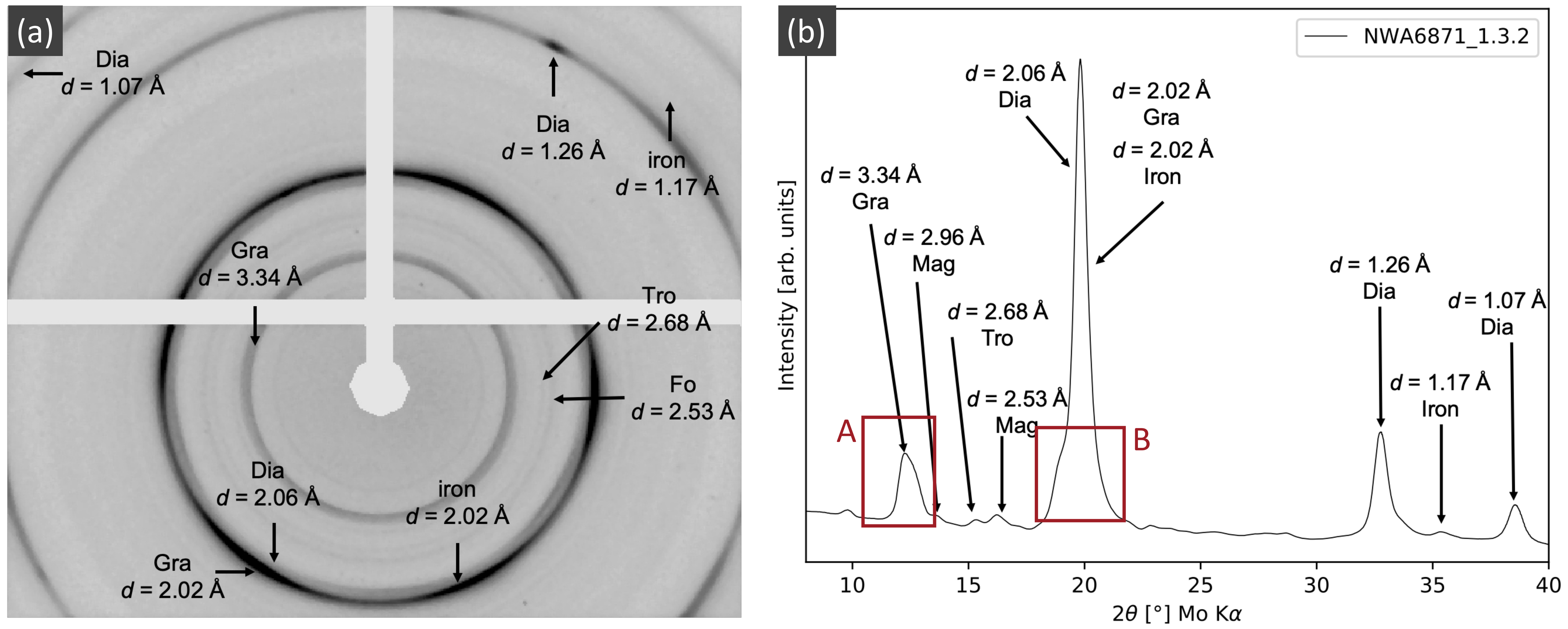

Fig. 3: (a) Reconstructed diffraction image of a carbon aggregate in NWA 6871. (b) Corresponding diffractogram. Gra = graphite, Dia = diamond, Fo = Forsterite, Mag = magnetite, Tro = troilite.

Discussion

NWA 6871 is a highly shocked ureilite as seen in completely recrystallized and mosaicized olivine grains. Further shock indicators can be seen in the diffractograms of carbon aggregates which show compressed graphite and diamond stacking fault features in the form of asymmetric peaks towards lower *d*-spacings (red box A in Fig. 3 (b)) [11] and a shoulder towards higher *d*-spacings (red box B in Fig. 3 (b)) [12,13], respectively.

The temperature obtained by the graphite based geothermometer exceeds all temperatures in literature for ureilites which were either obtained by the same method [5, 10] or by a two-pyroxene thermometer [14].

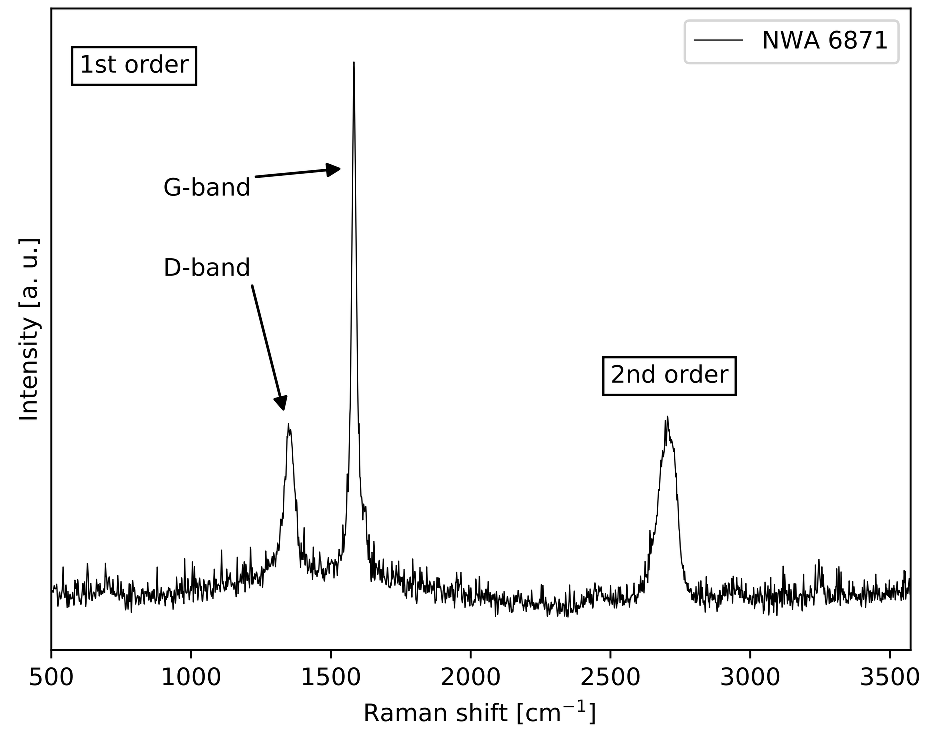

Fig. 4: Raman spectra of a carbon aggregate in NWA 6871 showing only graphite bands.

Conclusion and Outlook

Carbon aggregates in shocked ureilites are composed of nano-graphite and diamond. Both polymorphs occur in different grain sizes ranging from nanometers (both diamond (5 to 7 nm) and graphite (5 to 10 nm)) up to several tens of micrometers (diamond). Further, we observe a strong correlation between carbon aggregates and Fe, Ni bearing phases, suggesting the important role of these phases as catalysts during the formation of carbon polymorphs during shock event(s) (e.g., micro-diamond formation).

NWA 6871 shows several shock features and the highest temperature in a ureilite measured so far. Thus, we conclude that graphite records the temperature which was reached during the shock event.

The graphite based geothermometer will be applied to more ureilites, preferably of different shock degrees to obtain an overview of the temperatures which the parent body experienced during its breakup.

References

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