METAMORPHISM OF UREILITES AND LUMINESCENCE SPECTROSCOPY OF DEFECTS IN UREILITIC DIAMONDS.

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Introduction: Ureilites is the largest group of primitive achondrites [1] composed mainly of olivine and pyroxene and usually enriched in carbon [2]. The main carbon minerals of ureilites are graphite, various diamond polytypes, and chaoite [3]. The diamond-bearing ureilites are shocked over S2 shock stage (>10GPa) [4, 5]. Diamond contains numerous defects, which may serve as indicators of formation processes and subsequent thermal history of a diamond. Here we present results of photoluminescence (PL) investigation of defects in diamonds of four ureilites Jiddat al Harasis 054 (JaH 054), Dhofar 1285 (Dho 1285), Ramlat as Sahmah 007 (RaS 007) and Sayh al Uhaymir 525 (SaU 525) which differ in their shock and thermal metamorphic history with the aim to constrain diamond formation mechanism(s).

Results: Dho 1285 is similar to Type I, RaS 007 and JaH 054 - to Type II ureilites [6]. The texture and composition of interstitial pyroxene-carbon aggregate indicate that the ureilites were partially melted during the impact decompression that was followed by reaction of the melt with carbon, partial solid reduction of iron from the silicates by carbon and CO_x release [7]. Dho 1285 and RaS 007 were shocked up to the S3 stage (<20 GPa) and had post-shock temperature increase (PTI) ≤150°C [5]. JaH 054 indicates shock compression in the range 30 – 45 GPa (S4-S5) corresponding to PTI ~250 - 850°C [5]. Granular texture indicates post-shock thermal annealing of the olivine mosaicized at S4-5 at a temperature of ~900°C [8]. The meteorite was not shocked over the S2 after the annealing. SaU 525 is a vesicular melt rock resulted from the shock loading of a preceding ureilite over 90 GPa corresponding to PTI >1500°C [5]. A composition of relic olivine inclusions resembles that of Type I ureilites [6]. The grain size and zoning of olivine crystals in the main mass correspond to cooling rates >50°C/hr [9] indicating that the impact event took place near the parent body surface. SAU 525 was shocked up to 20 GPa.

Photoluminescence spectra were acquired from diamond inclusions free from graphitic component as indicated by absence of sp^2-related Raman features. The PL spectra of all studied diamond grains are dominated by two broad bands centered at approximately 500 and 700 nm with superposed oscillations of variable intensity. These features are clearly related to point defects due to nitrogen and a vacancy present in neutral or in negatively charged states (NV^0 at 575 and NV^- at 638 nm). We observe significant variations in degree of lattice perfection and impurity content of diamonds even in a single ureilite specimen. Detailed investigation of diamond grains from acid-resistant residue of JaH 054 also shows important variations between spectra of individual diamond crystallites. In SAU525 occasional variations in width of the PL and Raman peaks in individual diamond grain were observed and might indicate presence of fine zoning, probably similar to that observed in the Almahata Sitta ureilite [10].

Discussion: Medium degree of impact metamorphism of Dho 1285, RaS 007 and JaH 054 indicates that post-shock temperature increase by itself was not responsible to observed partial melting and silicate-carbon reactions. Thus the ureilites should had have high (~1000°C) indigenous temperature before their impact excavation from a deep layer to the parent body surface as it was proposed by [7] that excludes a diamond formation at estimated shock pressure. Therefore, the most of the diamonds should be formed near the parent body surface as a result of late impact events. SAU 525 probably contains the diamonds of several generations. The simplest explanation of the observed sample-dependent variations in impurity content and spectroscopically-active features is that the ureilite diamonds were formed by shock processing of a carbonaceous matter. Depending on the shock wave orientation and local peculiarities efficiency of sp^2-C to diamond transformation varies widely. A type of the carbonaceous precursor on a local scale determines nitrogen content of the diamonds. Annealing of the newly formed crystals could have happened both during cooling after the formation event or during eventual subsequent shocks. The scatter of properties of individual diamond crystallites, sometimes located in few microns in mineralogically and texturally homogeneous matrix, is hard to reconcile with formation by a chemical vapor deposition.

References: [1] Meteoritical Bulletin Database (2017) https://www.lpi.usra.edu/meteor/. [2] Mittlefehldt D. W. et al. (1998) Reviews in Mineralogy 36:4-1–4-195. [3] Vdovykin G. P. (1972) *Meteoritics* 7:547–552. [4] Bischoff A. et al. (1999) LPS XXX, Abstract #1100. [5] Stöffler D. et al. (1991) *Geochimica et Cosmochimica Acta* 55: 3845-3867. [6] Ikeda Y. et al. (2000) *Antarctic Meteorite Research* 13:177-221. [7] Warren P. H. and Rubin A. E. (2010) *Geochimica et Cosmochimica Acta* 74:5109–5133. [8] Rubin A. E. (2006) *Meteoritics and Planetary Science* 41:125–133. [9] Miyamoto M. et al. (1985). LPS XVI Proceedings, Supplement of Journal of Geophysical Research 90:D116–D122. [10] Miyahara M. et al. (2015) *Geochimica et Cosmochimica Acta* 163:14–26.