DISTINGUISHING DIFFERENT TYPES OF PROJECTILES FROM TERRESTRIAL IMPACT CRATERS – CLEARWATER EAST (CANADA) AND ROCHECHOUART (FRANCE) RE-INVESTIGATED.

G. Schmidt, Institute of Earth Sciences, Heidelberg University, D-69120 Heidelberg, Germany, Gerhard.Schmidt@geow.uni-heidelberg.de

Introduction: Nebular processes have produced some compositional variation in the platinum group element chemistry of chondrites. This compositional variation makes it possible to identify projectiles from impact craters. The refractory metals Os, Ir, Ru, Pt, and Rh (T_C > 1360 K) are abundant in most meteorites but depleted in crustal rocks. For Ir and Os, there is a difference of four orders of magnitude, and Rh three orders of magnitude between their meteoritic and crustal abundances. The Ir/Rh, Ru/Rh and Os/Ir mass ratios are particularly suitable for distinguishing projectile types from impact melt rocks (Figs. 1 and 2). In this study I review diagnostic element ratios of less mobile elements in the Earth's crust with respect to the chemical impactor compositions of Clearwater East and Rochechouart impact craters.

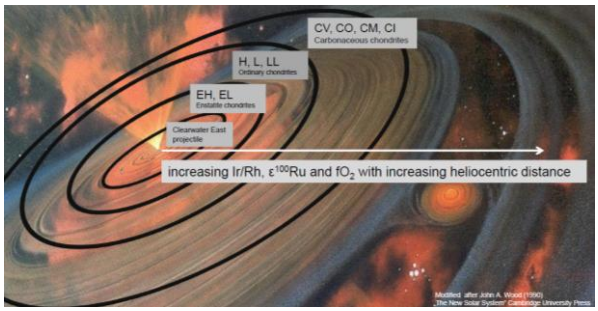

Fig. 1. Nebular processes have produced compositional variation in the Ir/Rh chemistry of chondrites.

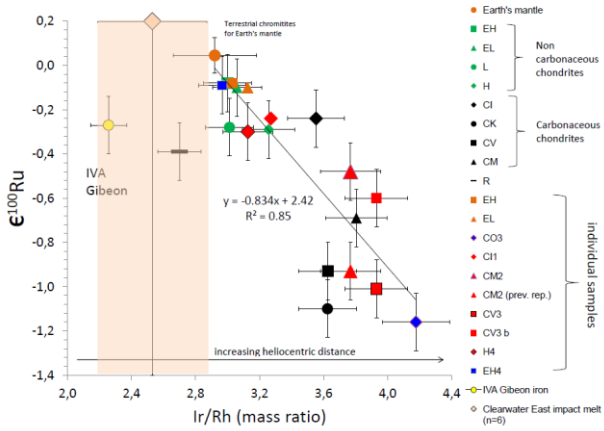

Fig. 2. Correlation of Ir/Rh mass ratios and heliocentric distance of the formation region of chondrites. ϵ^{100}Ru, Ir, and Rh data from [1-9]. No ϵ^{100}Ru data for Clearwater East melt samples available. Commas in axis label represent points.

Impact crater on Earth: The Moon can provide insight into the early development of the Earth, where the direct record of early evolution was destroyed by geological activity. During solidification of the Earth's crust the surface was exposed to a similar flux of impacting asteroids as the Moon. In 1991 about 130 terrestrial impact craters were known. The Earth Impact Database comprises a list of currently about 190 confirmed impact structures (http://www.passc.net). The chemical composition of impacting asteroids can be obtained from relative abundances of platinum group elements (PGE) in impact melts. The determination of these elements is a difficult challenge because of the low contents in the pg/g to ng/g range. However, high quality data especially of Rh and Ir might answer fundamental questions of cosmochemistry. Studying the nature of impactors is crucial to understand the characteristics and origin of material delivered to planets.

Clearwater East (Canada): Impact melts from Clearwater East crater with a diameter of ~22 km have the highest fraction of extraterrestrial component of any terrestrial impact structure. The crater was probably formed by a chondrite (e.g. [6,7,10-14]). However, element ratios of the IVA iron meteorite Gibeon [8] match with melt samples [6][7] (Figs. 3 and 4). Based on PGE and Ni excesses up to ~1.2 wt.% of a Gibeon-like component or about 7 wt.% of a member of a unknown chondrite group, not present in meteorite collections (H. Palme, pers. communication) is contained in melt. Contrary to an iron or unknown chondrite an ordinary chondrite as projectile is preferred by [14] based on Cr isotopic composition.

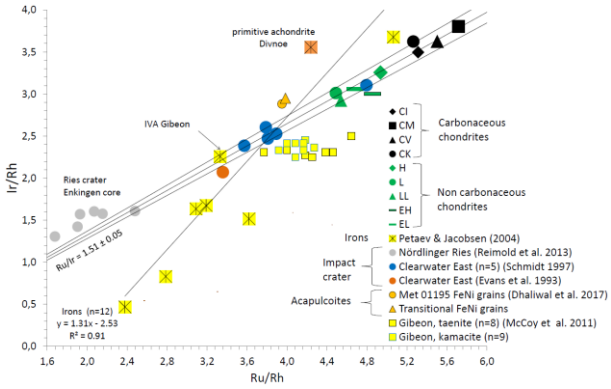

Fig. 3. Ru/Rh versus Ir/Rh mass ratios of Clearwater East melt samples [6,7] and meteorite groups [4,8]. Commas in axis label represent points.

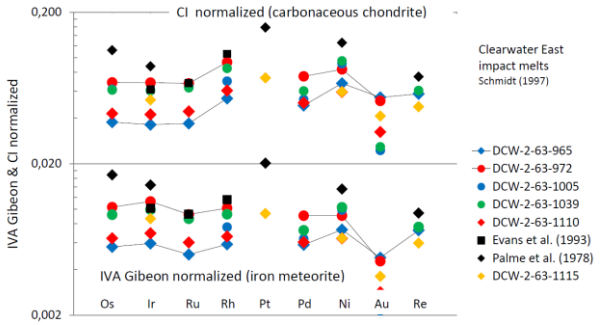

Fig. 4. CI chondrite normalized element ratios differ significantly from ratios in Clearwater melt samples (upper part of figure). Element ratios of IVA iron Gibeon agree with ratios in melt samples from Clearwater East. All elements shown in the figures normalized to Gibeon mean taenite and kamacite data (n=17, [15]) (log scale) plot more or less on a horizontal line (lower part of figure). Thus the most likely projectile type based on PGE and Ni would be an iron meteorite. Commas in axis label represent points.

Rochechouart (France): Based on the abundance of Os, Ir, Ni, and Pd in melt samples and subchondritic Os/Ir ratios a IIA magmatic iron asteroid fragment is favoured as projectile type by [16]. [17] report "The projectiles for Rochechouart and Sääksjärvi do not appear to be chondritic in composition but instead stem from fractionated asteroid fragments (Janssens et al., 1977; Palme et al., 1980; Schmidt et al., 1997)". [17] further report "The PGE patterns of IA and IIIC iron meteorites are identical to the element patterns in the impact melt rocks of Rochechouart and Sääksjärvi".

Contrary, based on ^{53}Cr excess an ordinary chondrite is favoured by [14]. These authors estimated about 3 wt.% of a chondritic component in the melt.

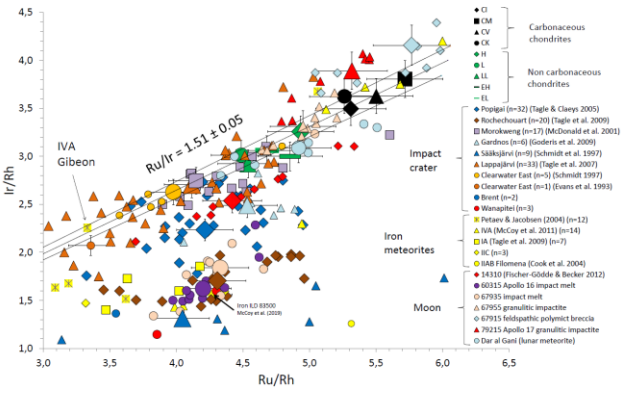

Fig. 5. Ru/Rh versus Ir/Rh mass ratios of Rochechouart [17] and Clearwater East melt samples [7] and meteorite groups [4,8]. Large symbols indicate ratios ±5% (error bars) of summed element masses. Element masses of each subsample, e.g. of the Moon (about 10 ~ 0.04 to 0.1 g subsamples [18]), were summed and the ratios were calculated. Subsample 60315#10 (Apollo 16 impact melt) excluded from calculation. Commas in axis label represent points.

However, Ru/Rh and Ir/Rh from Rochechouart [17] match melt rocks from Apollo 16 landing site [18], IA, IIC, IVA, and ILD 83500 irons [19] (Fig. 5).

Conclusion: The compositional variation in the Ir, Rh and Ru chemistry of chondrites is due to their formation region in the solar nebular. The Ir/Rh mass ratios increases with increasing distance from the sun. Therefore, Ir/Rh and Ru/Rh ratios in melt samples from impact craters allows the differentiation of projectile types. However, diagnostic ratios of Ir, Rh, Ru and Os in impact melts from Clearwater East and Rochechouart impact craters contradict projectile identification by Cr isotopes. Recently, a new indicator for the heliocentric distance of the formation region of chondrites was discovered. [1] report that more reduced materials like enstatite and ordinary chondrites have less negative ε^{100}Ru compared to more oxidized and volatile-rich materials such as carbonaceous chondrites that formed at greater heliocentric distance. The Ir/Rh mass ratios as an indicator for the heliocentric distance increases with increasing ε^{100}Ru anomalies. In the future, measurements of Ru isotopes in melt samples (Ru contents of up to 50 ng/g have been determined in Clearwater East melt samples [6,7]) could shed light in controversal projectile identification.

References: [1] Fischer-Gödde M. and Kleine T. (2017) *Nature 541*, 525-527. [2] Fischer-Gödde M. et al. (2011) *Chem Geol 280*, 365 - 383. [3] Palme H. et al. (2014) *Treatise on Geochemistry*, 15–36. [4] Tagle R. and Berlin J. (2008) *Meteoritics & Planet. Sci., 43*, 541–559. [5] Fischer-Gödde M. et al. (2010) *Geochim. Cosmochim. Acta 74*, 356–379. [6] Evans N. J. et al. (1993) *Geochim. Cosmochim. Acta 57*, 3737–3748. [7] Schmidt G. (1997) *Meteoritics & Planet. Sci., 32*, 761-767. [8] Petaev M. I. and Jacobsen S. B. (2004) *Meteoritics & Planet. Sci., 39*, 1685-1697. [9] Fischer-Gödde M. et al. (2015) *Geochim. Cosmochim. Acta 168*, 151-171. [10] Palme H. et al. (1978) *Geochim. Cosmochim. Acta 42*, 313–323. [11] Palme H. et al. (1979) *LPS X*, 2465–2492. [12] Grieve R. A. F. et al. (1981) *Contrib Mineral Petrol 75*, 187-198. [13] McDonald I. (2002) *Meteoritics & Planet. Sci., 37*, 459-464. [14] Koeberl C. et al. (2007) *Earth Planet Sci Lett 256*, 534–546. [15] McCoy T. J. et al. (2011) *Geochim. Cosmochim. Acta 7*, 6821-6843. App A. Supp data. [16] Janssens M.-J. et al. (1977) *JGR, 82*, 750–758. [17] Tagle R. et al. (2009) *Geochim. Cosmochim. Acta 73*, 4891-4906. [18] Fischer-Gödde M. and Becker H. (2012) *Geochim. Cosmochim. Acta 77*, 135-156. [19] McCoy T.J. et al. (2019) *Geochim. Cosmochim. Acta 259*, 358-370.