Traces of an H chondrite in the impactites from Lappajärvi Crater, Finland. R. Tagle[1*], Ph. Claeys[1], T. Öhman,[2] R.T. Schmitt[3], J. Erzinger[4], [1]Dept. of Geology, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium (*roald.tagle@vub.ac.be), [2]Dept. of Geosciences, FI-90014 University of Oulu, Finland, [3]Institute of Mineralogy, Natural History Museum, Berlin, 10099 Berlin, Germany, [4]GeoForschungsZentrum Potsdam, 14473 Potsdam, Germany.

Introduction: The Lake Lappajärvi (63°12´N, 23°42´E) has a diameter of ~ 23 km and is 73.7 ± 5.3 Ma old [1]. The target rocks of the Svecofennian basement are mainly composed of quartz- or biotite-rich mica schist and minor amounts of granite, pegmatite, granodiorite and amphibolite [2]. Previous work based on siderophile elements concluded that the projectile was a chondrite [2, 3]. Recent studies of Cr isotopes of the Lappajärvi impact melt also suggested an ordinary chondrite as projectile [4].

Samples and Methods: To refine the identification of the Lappajärvi projectile, 14 samples of impact melt and 2 shocked granite fragments from the melt were studied. The samples were collected from two quarries at of shore the Kärnänsaari-island as well as from glaciofluvial deposits south of the Lappajärvi Lake. The samples were analyzed for PGE by Nickel sulfide fire assay combined with ICP-MS according to the procedure described in [8]. Siderophile elements (Ni, Co, Cr) were also measured by ICP-MS.

Results: In agreement with [2, 3], the new analyses confirm the presence of an extraterrestrial component in the Lappajärvi impact melt (Fig. 1). The Cr and Ir values of Lappajärvi plot in the gray field representing the mixing "range" between upper continental crust and chondritic material.

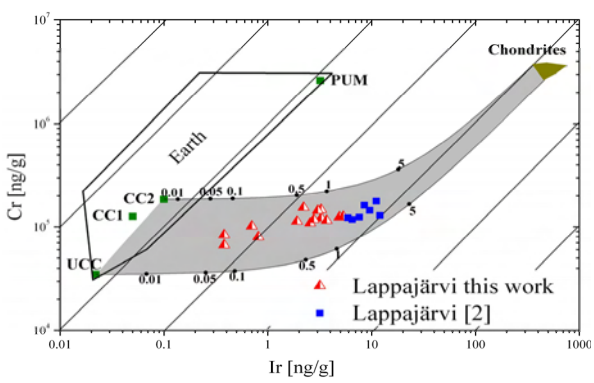

Fig. 1 Double log. plot of the concentrations of Cr vs. Ir of terrestrial lithologies compared to the composition of the Lappajärvi impact melts. The gray field indicates the most likely mixing zones between chondritic projectiles and common terrestrial targets. UCC = upper continental crust, CC = continental crust, PUM = primitive upper mantle. Lappajärvi literature values [2].

The CI chondrite normalized PGE compositions of the Lappajärvi impact melt display a flat element pattern. However, the pattern for the two shocked granites is similar to the average continental crust. Results show that all analyzed impact melt samples clearly contain an extraterrestrial component. The element pattern supports the previous assumption of a chondritic projectile [2, 3, 4].

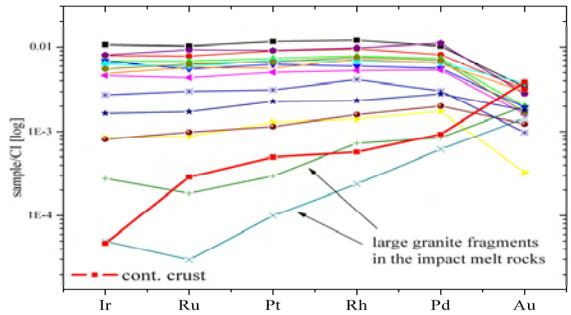

Fig. 2 CI-normalized PGE and Au concentration in Lappajärvi impact melt samples and granites from the target compared with the composition of the continental crust.

For the precise identification of the impactor component the linear regression method described in detail by [5] was applied. All PGE show a good correlation (R > 0.96); this allows an exact determination of all PGE element ratios from the slope of the linear regression. The linear regressions including Pd have a slightly lower correlation coefficient. A similar effect was noted for Popigai [6] and Morokweng [7] impact melt rocks but is absent for the Serenitatis impact melts [8]. This may be due to hydrothermal effect (note that the Moon is dry), that preferentially affects Pd because of its relatively higher mobility compared to the other PGEs. The identification of the Lappajärvi projectile is carried out by comparing the projectile elemental ratios derived from the linear regression with the ratios of chondrites compiled by [8]. The projectile elemental ratios calculated from the Lappajärvi impact melt are compatible with both ordinary H chondrite and CI chondrite projectile (Fig. 4).

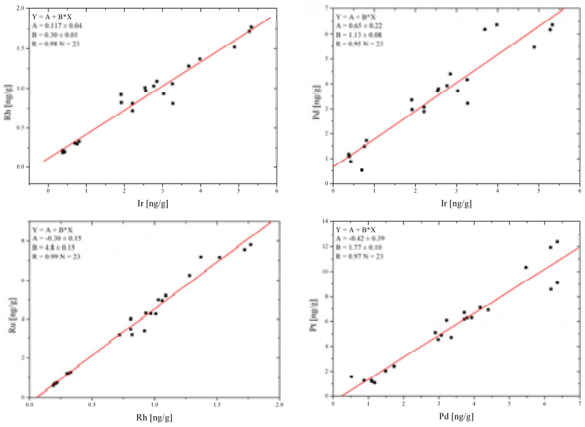

Fig. 3 a -d. Regression analyses of Ru, Rh and Pd vs. Ir and Pt vs. Pd in the impact melt of Lappajärvi. The slope represents the projectile elemental ratio.

The Cr isotopic ratios clearly exclude a carbonaceous chondrite projectile [4]. Therefore, the projectile for the Lappajärvi impact crater is likely to be an H ordinary chondrite.

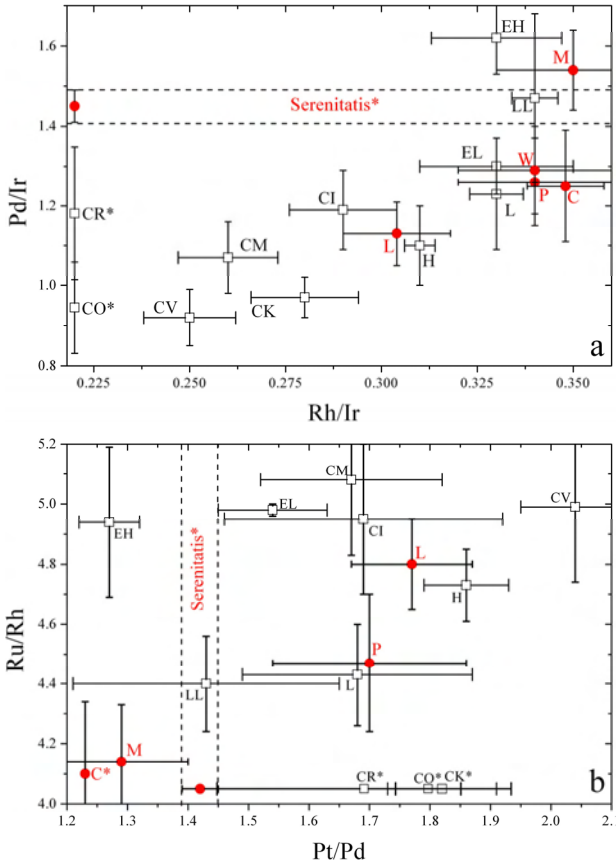

*Fig. 4 a-b Comparison of the PGE projectile elemental ratios of the impact melt rocks from Wanapitei (W), Popigai (P), Lappajärvi (L), Serenitatis basin on the Moon [8], Morokweng (M)[7] and Clear Water East (C) [9] with those of different types of chondrites calculated from the database of [8]. The error bars represent one standard deviation. * only one element ratio known.*

Discussion: The identification of an ordinary chondrite as impactor for the Lappajärvi crater supports the hypothesis that ordinary chondrites represent, not only as meteorites but also as crater forming projectiles, the main fraction of extraterrestrial material reaching Earth. Small craters are usually produced by iron projectiles. The vast majority of the craters larger than 1.5 km, where a chondritic projectile has been identified, was produced by ordinary chondrites (see Fig. 4). So far only Chicxulub and the Barberton spherule beds in South Africa appear to be related to carbonaceous chondrite [4, 11]. Curiously, these impacts seem to have been among the largest known to have occurred on Earth.

From the meteoritic point of view, ordinary chondrite asteroids appear rather uncommon objects in the asteroid belt, being only represented by 3 groups (H, L and LL) [12]. In contrast, ordinary chondrite meteorites seem from astronomical observation quite common. If the assumption, that at least a significant proportion of S-type asteroids are related to ordinary chondrites is accepted, and the differences in the spectra are mainly due to space-weathering [13, 14, 15]. S-type asteroids occur usually in the inner part of the main asteroid belt between 1.9 and 2.8 AU. Similar position within the asteroid beld is shared by the most notable resonances, the *v*6 secular resonance at inner edge of the asteroid belt (2.06 AU) and the mean motion resonances with Jupiter 3:1 and 5:2 at 2.5 and 2.8 AU respectively [17]. Numerical simulations have shown that most of the material injected within these positions becomes Earth crossing within less that 10 Ma [16]. Therefore, it is most likely that the relative position of ordinary chondrites' parent body with the asteroid belt is mainly responsible for the abundance of ordinary chondrites as projectiles in the Earth-Moon system. It may not only dominate the Phanerozoic projectile population, but also the late heavy bombardment population (see Serenitatis projectile, fig. 4). This hypothesis must be substantiated by the indentification of a larger number of projectiles in the crater record.

Conclusion: Lappajärvi crater was produced by the impact of an ~1.09 x 10^3 m (calculated after [18]) asteroid fragment of an H ordinary chondrite composition ~ 73.7 ± 5.3 Ma ago [1]. Ordinary chondrites are also found to be responsible for a significant number of impact craters on the Earth-Moon system, which may be related to the relative position of ordinary chondrites' parent bodies to resonance position in the asteroid belt.

Acknowledgments: Thanks to the Deutsche Akademie der Naturforscher Leopoldina for financial support (BMBF-LPD 9901/8-130).

Ref: [1] Earth Impact Database, 2003. http://www.unb.ca/passc/ImpactDatabase/; [2] Reimold (1980) GCA **46** 1203-1225; [3] Göbel et al. (1980) Z. Naturforsch. **35a** 197-203; [4] Shukolyukov & Lugmair (2000) LPI Contribution No. 1053, 197-198. [5] Tagle & Hecht (submitted) MAPS; [6] Tagle & Claeys (2005) GCA **69** 2877-2889. [7] McDonald et al. (2001) GCA **65** 299-309; [8] Tagle (2004) PhD. Humboldt Univ. Berlin; [9] McDonald (2002) MAPS **37** 459-464; [10] Shukolyukov & Lugmair (1998) Science **282** 927-929; [11] Kyte et al. (2003) Geology **31** 283-286; [12] Meibom & Clark (1999) MAPS Science **34** 7-24; [13] Chapman (1996) Meteoritics **31** 699-725; [14] Binzel et al. (2004) Icarus **170** 259–294; [15] Nesvorný et al. (2005) Icarus **173** 132-152; [16] Gladman et al. (1997) Science **277** 197-201; [17] Morbidelli et al. (2002) In Asteroids III, The University of Arizona Press, 409-421; [18] H. Jay Melosh & Ross A. Beyer, Computing Projectile Size from Crater Diameter http://www.lpl.arizona.edu/tekton/crater_p.html