

Evaluation of chemical methods for projectile identification in terrestrial and lunar impactites. R. Tagle and L. Hecht, Institute of Mineralogy, National History Museum, Berlin, 10099 Berlin, Germany, Roald.Tagle@rz.hu-berlin.de

Identification methods: The three main chemical methods currently applied to identify the impactors of terrestrial craters are the following:

Os isotopes. Due to relative enrichment of Re over Os during differentiation of the Earth crust from the mantle and the decay of ^{187}Re to ^{187}Os , the $^{187}\text{Os}/^{188}\text{Os}$ ratios in crustal rocks are strongly enriched compared to the Earth's mantle and most extraterrestrial material (e.g., chondrites). Thus, Os isotope ratios can be used to identify a meteoritic component in impactites formed on the Earth [1, 2]. Even proportions of less than 0.05 wt.% projectile can be detected in the case of an almost pure continental crustal target. A disadvantage of this method is that it does not allow the clear differentiation between a possible Earth mantle and a meteoritic component. Furthermore, this method can not be used to identify the type of impactor, since the variation of the Os isotope ratios between different meteorite types is much smaller than the those that could be inferred from projectile contaminated impactites.

Cr isotopes. Studies of Cr isotope ratios have significantly contributed to the recognition and identification of the extraterrestrial component in impactites [3]. The Cr isotope ratios of extraterrestrial materials differ from those of the Earth and Moon. In addition, differences in Cr isotope ratios exist between some groups of meteorites. It is, therefore, possible to identify an extraterrestrial component in impactites and to distinguish between three groups of meteorites: a) carbonaceous chondrites, b) enstatite chondrites, and c) all other types of meteorites. However the relatively high background of Cr in terrestrial and lunar rocks restricts the identification of an extraterrestrial component in impactites [2]. A proper characterization of the impactor generally needs a high proportion of projectile contamination in impactites of several wt.%, which is not very common in terrestrial craters.

Impactor relevant elements. In the following we define the platinum group elements Os, Ir, Ru, Pt, Rh, Pd (PGE), as well as Au, Ni, and Cr, as the impactor relevant elements (IRE). Terrestrial crustal rocks are usually depleted in the IRE, compared to most meteorite types. However, the IRE concentrations in mafic and ultramafic rocks are significantly higher compared to crustal rocks. Therefore, it has been argued that the amount of mafic to ultramafic components need to be estimated by reconstructing the pre-impact stratigraphy in order to obtain the impactor composition [2]. The

complete determination of this so-called “indigenous component” is for most craters difficult. This correction, however, is not necessary when specific element ratios are used, as shown below. The IRE can be divided in two groups; at one side PGE with Ni and, Au with a siderophile behavior and at the other side Cr which is a lithophile element [4]. As a result of differentiation of the Earth into metallic core, mantle, and crust, most of the PGE's are partitioned into the core; whereas, Cr remained mostly in the mantle. Because of the later veneer of $\sim 0.8\%$ chondritic material, the composition of the Earth's mantle became slightly enriched in PGE but it retains the relative high Cr concentrations from the primary differentiation. Therefore, Cr/PGE ratios in the Earth's mantle and crust are significantly higher than in most extraterrestrial materials. Figure 1 shows Cr and Ir contents of extraterrestrial material and common terrestrial rocks. The field “Earth” represents the composition of terrestrial rocks, including averages of the continental crust and upper mantle, and various metasediments, basalts, dunites, and peridotites [5]. The lines crossing the diagram represent constant elemental ratios. The gray field represents the most likely the mixing trajectory of projectile contaminated impactites produced by the impacts of chondrites (the most common projectile) into the continental crust. The numbers along the mixing trajectories indicate the amount of projectile contamination in wt.%. The results of mixing of even small amounts of extraterrestrial material, between 0.05 and 0.1 %, to the UCC/CC changes significantly the Cr/Ir composition of the impact melt. The composition of impactites from three different impact craters, Morokweng [6], Popigai [7] and Lappajärvi [8], plot in the field along the mixing trajectories between the continental crust and an extraterrestrial component, most likely a chondrite. The same holds true for an example of impactites from the Moon (landing site of Apollo 17, [9]), however, the mixing trajectories suggest the Lunar target composition to be somewhat chromium-rich, compatible with Cr-rich Low-Ti basalts in the target. A more precise identification of the projectiles can be achieved by the determination of the PGE ratios of contaminated impactites [6,7]. The linear regression of PGE concentration of several impactite samples that display some variation in the amount projectile contamination indicates a slope that is dominated by the PGE ratio of the projectile (Fig. 2) and can, therefore, be used for its identification [7,11].

Therefore, the slope of the mixing line reflects the projectile elemental ratio (PER). Sufficient resolution is obtained by using ratios of those PGE that represent the highest difference in condensation temperatures (Fig. 3).

Conclusion: Among the three methods discussed in this paper, the Os isotope method is most sensitive for the identification of low amounts of extraterrestrial components in impactites. However, this only holds true for target lithologies with almost no mantle chemical signature. Furthermore, this method is not suitable for the characterization of the projectile type. The Cr isotope method needs the highest amount of projectile contamination in order to identify an extraterrestrial component. Nevertheless, at high levels of projectile contamination (several wt.%), the methods allows the identification of at least three different groups of extraterrestrial material including the PGE-poor differentiated achondrites. In addition, this method is independent of the target lithology and post-impact alteration.

The application of IRE ratios (Cr/Ir, PGE/PGE) represents a very powerful method for the identification and characterization of the projectile within terrestrial and lunar impactites, as it does not require an indigenous component correction. This also applies in the case of terrestrial target lithologies with a high component of upper mantle material. In addition, for the most common extraterrestrial material reaching Earth, the chondrites, it has been shown that it is even possible to identify the specific chondrite type with a high degree of confidence, such as a L-chondrite in case of Popigai (Fig. 3) or a LL-chondrite for Apollo 17 [11].

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References: [1] Koeberl C. and Shirey S.B. (1997) *Pal. Pal. Pal.*, 132, 25-46. [2] Koeberl C. et al. (2002) *GSA, Spec. Pap.*, 356, 607-617. [3] Lugmair G.W. and Shukolyukov A. (1998) *GCA*, 62, 2863-2886. [4] Lodders K. (2003) *Astrophysical Journal*, 591, 1220-1247. [5] Tagle R. and Hecht L. (in preparation). [6] McDonald I. et al. (2001) *GCA*, 65, 299-309. [7] Tagle R. and Claeys P. (2005) *GCA*, in press. [8] Reimold U. (1982) *GCA*, 46, 1203-1225. [9] Norman et al. (2002) *EPSL*, 202, 217-228. [10] Tagle R. (2004) PhD, Humboldt University Berlin. [11] Tagle R. (2005) *LPS XXXVI*, Abstract. [12] Koblitz J. (2000) *MetBase 5.0*, CD-ROM.

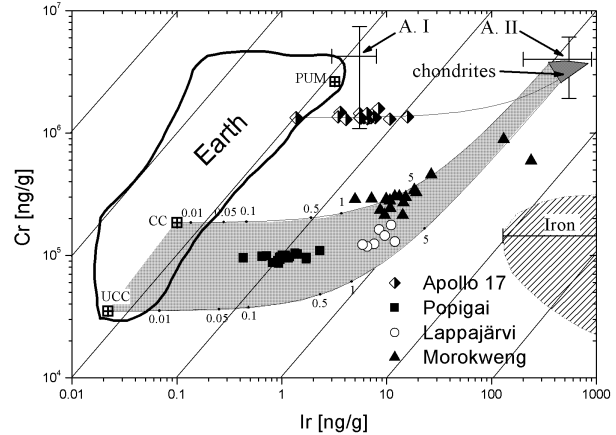


Fig. 1: Cr versus Ir of terrestrial and extraterrestrial rocks. Source of meteorite data: chondrites [10], iron meteorites, A.I = PGE poor achondrites (HED, angrites, and aubrites), A.II = PGE rich achondrites (ureilites, acapulcoites, lodranites, and brachinites) [12]. UCC=upper continental crust, CC=continental crust, PUM=primitive upper mantle.

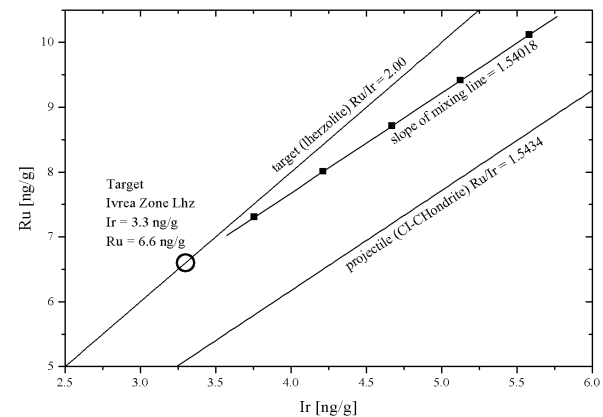


Fig. 2: Simulated formation of an impactite with varying amounts of projectile contamination (0.1, 0.12, 0.15, 0.18 and 0.2 wt.% projectile). The projectile elemental ratio (PER) is determined by using the slope of the mixing line, in this example between a PGE-rich target lithology (herzolite) and a chondrite projectile.

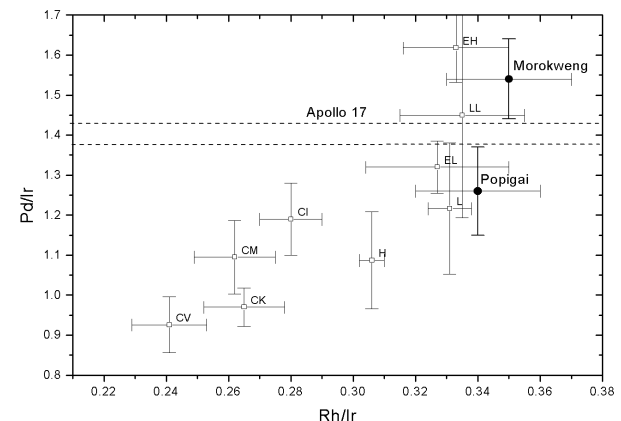


Fig. 3 PGE ratios of chondrites [10] and PER of Popigai [7], Morokweng [6], and Apollo 17 [9] impact melts.