

ISOTOPIC FRACTIONATION OF Zn DURING IMPACT ON EARTH. Frederic Moynier^{1, 2}, Fred Jourdan³, Qing-zhu Yin², Pierre Beck⁴, Christian Koeberl⁵ and Uwe Reimold⁶, ¹Department of Geology, University of California Davis; ²(present address) Department of Earth and Planetary Sciences, Washington University in St Louis; ³Western Australian Argon Isotope Facility, Department of Applied Geology, Curtin University of Technology, Perth, Australia; ⁴Laboratoire de Planetologie, Universite Joseph Fourier, Grenoble, France; ⁵Department of Geological Sciences, University of Vienna, Austria; ⁶Museum für Naturkunde (Mineralogie), Humboldt-Universität Berlin, Germany (moynier@geology.ucdavis.edu).

Introduction: The isotope fractionation of Zn in lunar soils [1] is surprisingly large (up to 3 per mil per amu). These fractionations have been attributed to vaporization due to impact by micrometeorites onto the surface of the moon. Recently, Albarede et al. [2] extended the study of isotopic fractionation of Zn to shocked rocks from a terrestrial impact site, Meteor Crater. They observed a negative correlation between isotope compositions and shock grade in 7 samples of Coconino sandstone and concluded that, even on Earth, vaporization at high temperature due to impact is capable to fractionate the isotopic compositions of rather heavy elements to a measurable extent. Here, we investigate the degree of isotopic fractionation of Zn in rocks from two terrestrial impact craters: (1) impactites from the Lonar crater, India, and (2) the impact melt rocks from the Bosumtwi crater (Ghana), as well as the related Ivory Coast tektites (IVC).

Samples and analytical methods: We analyzed the Zn isotopic composition of 5 impact melt samples (LO-13-1-3, LO-10-2-1, LO-10-5, LHN05-65, LHN05-7) from Lonar crater. Lonar crater is one of only two terrestrial impact structures that formed on continental flood basalt. The crater has been excavated in the Deccan Trap of India. The age of the impact is not well constrained and different studies dated the crater between 15,000 (by fission track study) and 50,000 years (by thermoluminescence). To refine the age of the impact, ⁴⁰Ar/³⁹Ar ages will be measured at Curtin University of Technology in Perth on the same set of samples analyzed for the present study. The Lonar crater samples investigated here have already been described and analyzed for their major and trace element abundances by Son and Koeberl [3].

We also measured the Zn isotopic composition of three IVC tektites. Tektites are centimeter-sized glasses formed and ejected during a hypervelocity impact on Earth and essentially have the same chemical composition as the uppermost target rock [4]. Tektites have been severely heated to more than 2000K [5]. The ~1.07 Ma Bosumtwi impact crater in Ghana is recognized as the source for the IVC, based on similar geochemistry and ages of tektites and crater-based impact melt [4, 6]. Our samples (IVC-2014, IVC-3395, IVC-8902) have already been

analyzed for their major and trace element composition by Koeberl et al. [4]. We also analyzed the Zn isotopic composition of two impact melt clasts from suevite samples from the Bosumtwi crater, Ghana (samples 2004/3 and LB-43). Different target rocks exist at Bosumtwi crater and so these 2 suevites are not fully representative of the Bosumtwi crater, however, for now we consider these samples as our best estimate for the target rocks of the IVC tektites. Details for sample LB-43 are described in [7]

Zn was purified by anion-exchange chromatography using a procedure adapted from Maréchal et al. [8] and Moynier et al. [1]. Briefly, samples were loaded in 1.5N HBr on 0.25 ml AG-1x8 (200-400 mesh) chromatographic columns and Zn was extracted in 0.5N HNO₃. The process was repeated on a 100 µl column to further purify Zn. Zn isotopic composition were measured on a Nu Plasma HR MC-ICP-MS at the University of California, Davis, as described in [1].

Results: Isotope ratios are expressed in δ permil units with respect to the standard JMC 0749 L. As expected from mass-dependent isotopic fractionation, all the samples fall onto a straight line of slope 1 in a δ^{68/64}Zn/2 vs δ^{66/64}Zn plot (Fig. 1). The typical external precision on δ^{66/64}Zn is 0.10 ‰. The full range in δ^{66/64}Zn is about 0.9 permil for the Lonar crater samples. Zn isotopes are very homogeneous in terrestrial rocks with a typical isotopic composition in δ^{66/64}Zn between 0 and 0.40 ‰ [9, 10]. Two samples from the Lonar crater (LHN05-65 and LO-13-1-3) have a “normal” terrestrial isotopic composition in Zn (0 < δ^{66/64}Zn < 0.4), whereas the three other samples are clearly enriched in light isotopes (-0.39 < δ^{66/64}Zn < -0.30) beyond our analytical uncertainties. In contrast, the IVC tektites are greatly enriched in the heavy isotopes (+1.40 < δ^{66/64}Zn < +1.86) and are to our knowledge the isotopically most Zn-fractionated terrestrial samples analyzed to date. In the solar system, the only samples known so far to be heavier in Zn are lunar regoliths with δ^{66/64}Zn up to +6.39 ‰ [1].

The two melt rock samples from the Bosumtwi crater have normal terrestrial isotopic compositions in Zn (δ^{66/64}Zn = +0.17 and +0.46).

Discussion: This study shows that, even on Earth, physical processes associated with impacts are able to fractionate the isotope compositions of rather heavy and volatile elements to a measurable extent. Because the exact Zn isotope compositions of the target rocks and of the meteorites are not known exactly, an origin of the isotopic fractionation by mixing or by secondary alteration can, at this time, not be totally excluded. However, the isotopic variation of Zn on Earth known so far is limited between 0.00 and 0.70 ‰ for igneous rocks [9], and some sedimentary rocks and ores [10], and thus it would be very unlikely that the isotopic fractionation observed in the IVC tektites (up to 1.86 ‰) is related to alteration.

The isotopic fractionation observed for Lonar melt rocks is much less than the effects observed for either lunar regolith [1] or shocked rocks from Meteor Crater [2]. The enrichment in light isotopes is unusual and in contrast to the large enrichment in heavy isotopes observed in lunar regolith and at Meteor Crater. None of these Lonar melt rocks has any indication of a meteoritic component [3] and, therefore, a meteoritic contribution cannot explain the Zn values. The re-condensation of a volatile-rich vapor originating from the impact can also be rejected based on both petrology and on the chemical composition (almost identical to the target basalts) of the samples [3]. Therefore the origin of the enrichment in light isotopes is still puzzling and our best interpretation would be that the isotopic compositions of the Lonar melt rocks reflect the one of the target rocks. This conclusion will be tested by measuring Deccan basalt samples.

The enrichment in heavy isotopes of Zn in tektites can be explained by the loss of isotopically light Zn that was concentrated in the vapor fraction during the impact. Stable isotopes of light elements, notably Mg [11], B [12] and K [13] have already been measured in tektites without any clear indication for isotopic fractionation with respect to terrestrial rocks. Mg is fairly refractory and is not fractionated in lunar regolith. It is thus not surprising that this element does not show fractionation in tektites. Absence of K isotope fractionation is a surprise because it is a moderately volatile element with a 50% condensation temperature (T_c) of $\sim 1000\text{K}$ [14], and K isotopes are fractionated strongly in lunar regolith [15]. Based on the absence of K isotopic fractionation in tektites, Humayun and Koeberl [13] placed an upper limit of loss of K at $<2\%$ and concluded that any other less volatile elements should not be fractionated during the heating events experienced by tektites. Also B is a moderately volatile element ($T_c(\text{B})\sim 800\text{K}$ [14]) and does not seem to show any fractionation in tektites [12]. Zn is a more volatile element than both B and K

($T_c(\text{Zn})\sim 730\text{K}$ [14]) and the isotopic fractionation of Zn measured in this study may reflect the loss of Zn during the heating of the tektites. This conclusion is supported by the strong depletion of Zn in tektites compared to target rocks, more than many other similarly volatile elements [16, 17]. Target rock samples (meta-greywacke and shale) from Bosumtwi will be analyzed. Assuming that evaporation obeys a simple Rayleigh fractionation law, the calculated lost fractions for Zn are 9-12%. Vaporization enriched the residue in the heavier isotopes, whereas the vapor becomes isotopically lighter than the residue. A more realistic dynamic model of isotopic fractionation by vaporization in a sphere needs to be developed to calculate the temperature peak that is necessary to explain the data.

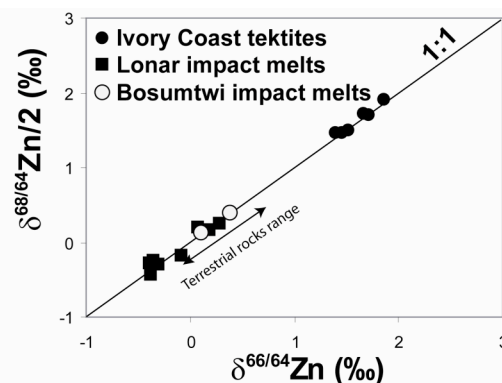


Fig.1: $\delta^{68/64}\text{Zn}/2$ vs $\delta^{66/64}\text{Zn}$ in Ivory Coast tektites, Lonar crater samples (impact melts) and Bosumtwi crater samples (glassy inclusions in suevites). "Terrestrial rocks range" represents all terrestrial rocks measured to date [10].

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