THE NEEDLE IN THE HAYSTACK PROBLEM: SEARCH FOR METEORITIC CONTAMINATION AND IDENTIFICATION OF PROJECTILE TYPE IN TERRESTRIAL IMPACT EVENTS.

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Introduction: The recognition of geological structures and ejecta layers on Earth as being of impact origin requires the detection of either shock metamorphic effects in minerals and rocks, and/or the presence of a meteoritic component in these rocks. Apart from studying meteorite impact craters, information can also be gained from the study of impact ejecta. In some cases, impact events have been identified solely from the discovery and study of regionally extensive or globally distributed impact ejecta. Geochemical methods have been used to determine the presence of the traces of such an extraterrestrial component. In the absence of actual meteorite fragments (which is most often the case due to size and age of a structure), it is necessary to chemically search for traces of meteoritic material that is mixed in with the target rocks in breccias and melt rocks. Both trace element and isotope methods are used. Meteoritic components have been identified for just about 50 out of the about 200 impact structures or events that are currently known on Earth (see [1] for details).

Importance and Problems: The search for meteoritic components in various impact-related rocks is on the one hand not easy, and on the other hand has important implications for understanding the dynamical history of the solar system. As the mass of the impactor is small compared to the terrestrial component in the total mass of melt rock or breccia (or in most ejecta), the amount of meteoritic component in such rocks is small, and often irregularly distributed, not unlike the famous “needle in the haystack” analogy. This makes it very challenging to detect such meteoritic components. Therefore, only elements that have high abundances in meteorites but low abundances in terrestrial crustal rocks, such as Ir and other platinum-group-elements (PGEs), or isotopic values (e.g., γOs, ε^{54}Cr, ε^{50}Ti, ε^{62}Ni) that are different for different planetary bodies or meteorite parent bodies, can be used. For example, typical terrestrial crustal abundances of Ir are on the order of 0.02 ppb, whereas chondritic meteorites contain on the order of 500 ppb; therefore adding even only 0.5 percent of a meteoritic component results in a drastically elevated Ir content of the resulting breccia or melt rock. Similar considerations exist for Os isotopes, where small amounts of extraterrestrial admixture result in significant changes of the isotopic composition of the melt rocks. However, neither of these two methods allows the straightforward derivation of the meteorite type that was involved, unless the amount of meteoritic contamination is very high and there are characteristic differences between the PGE and other siderophile element abundances and inter-element ratios. In contrast, the Cr isotopic method allows to distinguish between at least some meteorite types (such as, ordinary vs. carbonaceous chondrites, or certain iron meteorites), but require much higher meteoritic contributions that in case of the Ir elemental or Os isotopic methods. To distinguish between, for example, enstatite and ordinary chondrites, or various types of achondrites, is again much more complicated [see [1] for discussion).

Implications and Outlook: While it is already difficult to not only identify the presence of a meteoritic component for most impact craters, to derive the projectile type is even more challenging. This problem is even more pressing for ancient terrestrial rocks. The first unambiguous impact record exists in the form of various spherule layers found in South Africa and Australia with ages between about 3.2-3.4 Ga, and 2.5 Ga. These layers represent several (the exact number is still unknown) large-scale impact events. Many of these layers contain very high amounts of PGEs, in some cases exceeding the chondritic abundances, indicating that the depots must have been altered somehow. Both Os and Cr isotopic data indicate a meteoritic source. However, the impactor-specific Cr isotopic data have, so far, only been obtained for a few of the ca. 30 to 40 different layers (which represent a smaller but not yet clearly known number of large-scale impact events, see, e.g., [2]). In addition, Cr isotopic data are not currently used to distinguish between ordinary and enstatite chondritic signatures, even though such a distinction would yield information on the different source reservoirs in the early solar system bombardment environment. Recent dynamical simulations coupled with cosmochemistry [3-5] suggest that enstatite chondrites might have been the dominant source of impactors to the Archean Earth during late accretion. Thus, clarifying the record of terrestrial impact spherules has important implications for inner solar system bombardment models, the evolution of the Earth’s lithosphere and how late accretion affected the ocean-atmosphere system.

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