Introduction: Breccias and melt rocks found at possible meteorite impact structures on Earth may contain a minor extraterrestrial component. In the absence of evidence of shock metamorphic effects in such rocks, the unambiguous detection of an extraterrestrial component can be of diagnostic value regarding the impact origin of a geological structure. The verification of an extraterrestrial component in impact-derived melt rocks or breccias can be of diagnostic value to provide confirming evidence for an impact origin of a geological structure. Similar approaches are of great value in the investigation of distal ejecta layers (as we are taught by the case history of the Cretaceous-Tertiary boundary).

Qualitatively speaking, a small amount of the finely dispersed meteoric melt or vapor is mixed during the impact event with a much larger quantity of target rock vapor and melt, and this mixture later forms impact melt rocks, melt breccias, or impact glass. In most cases, the contribution of meteoric matter to these impactite lithologies is very small (<<1%), leading to only slight chemical changes in the resulting impactites. Geochemical methods can be used to determine the amount of such a meteoritic component (see below). However, there are plenty of open questions.

Methods: The detection of such small amounts of meteoric matter within the normal upper crustal compositional signature of the target rocks is rather difficult. Only elements that have high abundances in meteorites, but low abundances in terrestrial crustal rocks (e.g., the siderophile elements) are useful. Another complication is the existence of a variety of meteorite groups and types, with widely varying siderophile element compositions. Distinctly higher siderophile element contents in impact melts, compared to target rock abundances, can be indicative of the presence of either a chondritic or an iron meteoritic component. A chondritic projectile (stony meteorites that underwent magmatic differentiation) are much more difficult to discern, because they have significantly lower abundances of the key siderophile elements. Furthermore, in order to reliably constrain the target rock contribution of such elements, i.e., the so-called indigenous component, absolute certainty must be attained that all contributing terrestrial target rocks have been identified and their relative contributions to the melt mixture are reasonably well known.

Geochemical methods have been used to determine the presence of the traces of such an extraterrestrial component (see review [1]). Meteoritic components have been identified for just over 40 impact structures [1], out of the more than 160 impact structures that have so far been identified on Earth. The identification of a meteoritic component can be achieved by determining the concentrations and interelement ratios of siderophile elements, especially the platinum group elements (PGEs), which are several orders of magnitude more abundant in meteorites than in terrestrial upper crustal rocks. Iridium is most often determined as a proxy for all PGEs, because it can be measured with the best detection limit of all PGEs by neutron activation analysis (which was, for a long time, the only more or less routine method for Ir measurements at sub-ppb abundance levels in small samples).

The use of PGE abundances and ratios avoids some of the ambiguities that result if only moderately siderophile elements (e.g., Cr, Co, Ni) are used in an identification attempt. However, problems may arise if the target rocks have high abundances of siderophile elements or if the siderophile element concentrations in the impactites are very low. In such cases, the Os and Cr isotopic systems can be used to establish the presence of a meteoritic component in a number of impact melts and breccias (e.g., [2]). In the past, PGE data were used to estimate the type or class of meteorite for the impactor, but these attempts were not always successful. It is difficult to distinguish among different chondrite types based on siderophile element (or even PGE) abundances, which has led to conflicting conclusions regarding the nature of the impactor at a number of structures (see [1]). Clearly, the identification of a meteoritic component in impactites is not a trivial problem.

Open Questions: Apart from analytical challenges, there is a whole suite of problems or questions associated with the identification of projectiles, which will be listed here in no particular order.

Some meteorite types do not have chemical compositions that are well enough separated from terrestrial rocks to allow a geochemical distinction in melt rocks. The chemical composition of specimens of the same meteorite type is not uniform, but shows a range of compositions. In addition, only a few samples of each type have been analyzed with enough detail to allow use of the data for mixing calculations. It is not yet possible to distinguish between comet and asteroid sources due to the lack of trace element data on a sufficient number of comet nuclei samples.
More peculiar, and possibly a point in which modeling calculations can be of use, is the very strange discrepancy between the interelement ratios of siderophile elements in impact glasses found at small impact craters and equivalent ratios in corresponding meteorite fragments found at the same craters (e.g., Meteor Crater, Wolfe Creek, Henbury, Wabar). No immediate physical explanation, or correlation with chemical and physical parameters, which could explain this fractionation, is available. In some other cases (e.g., Tswaing-Saltpan, Bosumtwi) there is a good fit for, e.g., Cr, Co, and Ni ratios and abundances between a particular meteorite type (e.g., chondrite), but the Ir abundances are about a factor of 2-10 too low for a chondritic projectile (which might otherwise also be confirmed by isotopic data). Why are some of the more refractory siderophile elements depleted? Is there some non-equilibrium process going on in the impact vapor plume?

Another interesting item are tektites. Tektites are natural glasses occurring on earth in four distinct strewn fields: Australasian, Ivory Coast, Central European, and North American. Ages of these strewn fields range from 0.78 to 35 million years. Geochemical arguments have shown that tektites have been derived by hypervelocity impact melting from terrestrial upper crustal rocks. Tektites are distal ejecta, which do not occur directly at a source crater, in contrast to impact glasses, which are found directly in or at the respective source crater. This has made the identification of the source crater somewhat difficult. Nevertheless, at least two of the four Cenozoic tektite strewn fields have been associated with known impact craters: the Ries crater in southern Germany and the Central European field, and the Bosumtwi crater in Ghana and the Ivory Coast field are rather firmly linked. In addition, the 85 km diameter Chesapeake Bay impact structure is a likely source crater for the North American tektites. This leaves the Australasian tektites as the only strewn field without a clear choice for a source crater.

Not much is known about the source meteorites (projectiles, meteorite types) for the four tektite fields. Attempts to determine of a meteoritic component in Australasian tektites has not yielded unambiguous results. Some Ni-Fe-rich spherules in philippinites, which were suggested to be a remnant of meteoritic matter, were later concluded to have formed by in-situ reduction from target material. Analyses of australites by radiochemical neutron activation analysis for a selection of volatile and siderophile element concentrations was not very conclusive either - only one of these samples showed a distinct enrichment in siderophile elements, while the other five do not indicate such an enrichment. On the other hand, Ir enrichments were found in several microtektite-bearing deep-sea sediment layers.

Regarding the Ivory Coast tektites, some researchers suggested an iron meteorite projectile (based on chemical data), others (more recently suggested a chondritic projectile). Os isotopic data clearly showed the presence of a meteoritic component in the tektites. Unfortunately, the Bosumtwi crater is in an area of known gold mineralization, which lead to high and irregular siderophile element contents in the target rocks.

Not much information is available regarding the Central European tektites, where an achondrite has been proposed for the Ries crater bolide. No information at all is available regarding the Chesapeake Bay crater/North American tektites. Thus, the question of projectile identification for tektites is still an open one.

In general, tektites are very poor in meteoritic matter, which led to the suggestion that they cannot form by jetting, as products formed by jetting should have high meteoritic components. On the other hand, tektites clearly formed from the rocks closest to the terrestrial surface – in some cases there is a soil component discernable. However, some recent data show that high-Mg microtektites do seem to have a significant (a few percent) meteoritic component. It seems that natural observations are still able to provide some puzzling constraints for future modeling calculations.