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Cautionary tales about comparing meteorites to asteroids

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Abstract

Some of the more subtle aspects of meteoritics important for planetary science are often misunderstood. Most carbonaceous chondrite meteorites are not rich in carbon and water. Shock can turn meteorites darker than most carbonaceous chondrites. And while most HED basaltic achondrite meteorites may come from Vesta, many similar achondrites are almost certainly not related to the HED/Vesta clan.

1. Introduction

Meteorites are the most readily available examples of extraterrestrial material and as such give us our best evidence for the sort of material that makes up asteroids, ice-rich bodies, and early planetesimals. But many widely-held generalizations are not strictly true and adopting them uncritically leads to serious misunderstandings and misinterpretation of data. (We ourselves have been guilty of propagating some of these oversimplifications in our own work [1].)

2. Carbonaceous chondrites

Meteorites are classified as carbonaceous chondrites (CCs) if their O isotopes lie near or below the terrestrial fractionation line and their refractory lithophile/Mg ratio (normalized to CI) is greater than or equal to 1. Note that neither the presence of carbon nor of chondrules figures in this definition. The term "carbonaceous chondrite" is often used to signify a meteorite that is rich in carbon and hydrous minerals, and very low in albedo. In fact, that description is only correct for two relatively rare types of CCs, the CI and CM classes (and one-of-a-kind samples like the meteorite Tagish Lake). The most common examples of CCs are types CO and CV, neither of which has a significant carbon or water content – no more than ordinary chondrites. Another subgroup of the CC class is quite rich in metallic iron: CRs have as much metal as H class chondrites, CHs even more, and the CB class metal content is so high (around 50%) that it could easily be considered a stony-iron.

An important consequence of this misunderstanding is the blanket assumption that all dark C-class asteroids are made of material that has a bulk density around 2 g/cc, as seen in CI or CM meteorites. In fact, most of the C class asteroids for which densities are available also show an absence of water bands near three microns, implying that (at least at their surfaces) they are devoid of the volatiles that make CI or CM meteorites so low in density. If an asteroid like Mathilde is actually made of CO or CV (or shock-blackened ordinary chondrite) material, then its very low density may in fact imply a macroporosity not of 50% (like sand) as usually suggested (by the current authors, among others; see [1]) but it could be closer to 80% macroporous, similar to that inferred for comets. With the data in hand, we cannot definitively put an upper limit on its macroporosity.

3. Meteorite albedo and spectra

The dark albedo of carbonaceous chondrites makes them an obvious candidate for material analogous to the darker asteroids. But in fact most CC meteorites (notably, but not only, Allende) are rich in white inclusions and so their average albedo is actually much higher than the dark matrix, and certainly higher than that of shock-blackened meteorites. We have argued elsewhere [2] concerning the similarities, and differences, between shock-blackened ordinary chondrites and CC meteorites. We want to point out here shock and metal can affect the albedo of other meteorite types as well. Enstatite chondrites can be as dark as CC meteorites, and shocked lunar meteorites that are chemically identified as highland samples (coming from the highest albedo regions of the Moon) can themselves be jet black.

In addition, virtually all libraries of meteorite spectra are based on the spectra of powders. This is a reasonable first guess, since presumably the surfaces of asteroids are covered in regolith. But the process of grinding samples in the laboratory is vastly different in terms of chemistry, heating, particle size, and shock processes than the grinding process that creates regolith soil. It is clear that most meteorites contain little if any materials that have been exposed on the surface of an asteroid. Simply attempting to match asteroid spectra with library spectra of meteorites can be potentially misleading.

Furthermore, a number of meteorites are breccias containing different types of meteoritic material. Indeed, the wide variety of meteorite types found in the strewn field of the Almahata Sitta fall of asteroid 2008 TC_3 reminds us that asteroids may well contain a variety of different meteorite types. All of these different meteorite types will contribute to an asteroid's average spectrum.

4. Basaltic achondrite origin

The connection between basaltic achondrites and asteroid Vesta has been made for so long that it is now almost assumed as a given [3]. But the nature of this tie, while quite reasonable, is still based only on a series of assumptions and coincidences and the full story is almost certainly more complicated than it is usually portrayed.

It is not sufficient to merely note the agreement of the spectrum of Vesta with that of HED meteorites, since that alone does not rule out the possibility that other asteroids melted, differentiated, and then were fully destroyed. We only argue for Vesta itself, and not a Vesta clone, as the source of the HEDs on the basis that our models for producing these basalts require the presence of a large dunite mantle with several times the amount of material as the HED crust. Given the hundreds of HED meteorites without a single dunite candidate, we infer that the parent of the HEDs is intact and thus look to the only extant candidate, Vesta.

But we know that indeed there must have been many other differentiated asteroids, now completely destroyed, to account for the myriad varieties of iron and stony irons (whose rocky portion is igneous) and the rarer achondrite classes that appear to have originated from at least partially differentiated bodies, like the angrites, aubrites, and ureilites. And on the basis of differences in oxygen isotopes it has been suggested that even some unusual HED meteorites may come from parent bodies other than Vesta [4].

The absence of dunite from HED meteorites points to Vesta as their source, but if that is the case we should expect to find dunite among other achondrite types. But we don't. The absence of complementary dunite from these other parent bodies might be attributed to sheer chance; given that they are so rare, presumably it is not utterly improbable that they happen to be the only exemplars from their given parent. But other possibilities exist. Perhaps our understanding of the HED parent body is wrong. The presence of these other igneous meteorites raises the question of why they exist with significantly different chemistries than that inferred for our HED origin models. Or perhaps the missing dunite problem has some other, still unknown, explanation.

5. Summary and Conclusions

In solving issues as unconstrained as the origin of meteorites and the evolution of the solar system, it is unavoidable that reasonable assumptions must be made. But it is important to remember that these are indeed merely assumptions, no matter how reasonable. It is especially problematical when these assumptions come from an incomplete understanding of what we actually do know from the evidence of meteoritics.

Acknowledgements

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