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Comets have been often considered as potential sources of meteorites [e.g., 1], but there are no meteorites currently believed to have come from comets. Recent developments, including the identification of comet-asteroid transition objects, new information on the collisional history of Jupiter-Family comets, and on the composition of cometary solids, provide new insights into the topic of cometary meteorites. We have revisited this question [2] and conclude that comets do indeed yield meteorites, which have either not been found or recognized. Here, we will summarize the arguments that we should have comets from meteorites, and consider the expected characteristics of cometary meteorites.

Jupiter-Family comets as parent bodies

Jupiter-Family (JF) comets are those with low inclinations and short period orbits, dominated by the gravitational influence of Jupiter [3]. A number of arguments summarized by Wetherill [1] suggest that if cometary meteorites exist, they are most likely derived from the nonvolatile residues of JF comets. Two of the main predictions reviewed by [1] have been confirmed.

First, several arguments support the notion that JF comets leave behind nonvolatile residues strong enough to survive as meteorites if they have low Earth-encounter velocities. Observations of the nuclei of three low-activity comets have shown that the active fraction of their nuclear surface was less than 1% in each case. Analysis of fireballs believed to be of cometary origin suggests a small fraction (perhaps 10^{-3}) of cometary material is relatively strong ($\sim 10^7$ dynes/cm²), and is abundant enough to account for the number of recovered weak carbonaceous meteorites [4]. In addition, [5] argues that the densities of many shower meteors have been underestimated, and can be as high as carbonaceous chondrites or even ordinary chondrites.

Second, the identification of 4015 1979VA as Comet Wilson-Harrington 1949 III [6], and 3200 Phaethon as the (probably cometary) parent body of the Geminid meteor shower, confirms that some fraction of Earth-crossing asteroids have a cometary origin. Orbital characteristics make 4015 W-H particularly interesting, even among the comet-asteroid transition objects. It has a low inclination orbit (2.6 degrees), perihelion just inside Earth's orbit (0.995 AU), and aphelion in the asteroid belt (4.3 AU). This orbit has the potential of

delivering meteoroids to Earth at lower velocities than most other near-Earth objects; hence, 4015 W-H is a potentially meteorite producing comet [7].

Anders [8] argued against a cometary origin for all stony meteorites classes that have gas-rich members. He used the implanted solar wind noble gases and the cosmic ray exposure ages to infer the approximate heliocentric distance (4-8 AU) and cratering rate (10^2 - 10^3 higher than for the Moon) where the regolith formed, and concluded they were inconsistent with Oort Cloud comets. However, JF comets most likely originate in the Kuiper belt [3], where the cratering rate is approximately the same as in the asteroid belt, but 10^7 - 10^9 greater than in the Oort cloud [9]. In addition, the uncertainties in solar wind implanted gas concentrations and surface residence times used by [8] may be sufficiently large to include at least the inner Kuiper belt. Besides, these arguments do not apply to rare classes without gas-rich members.

Expected characteristics

Based on studies of cometary dust [10], interplanetary dust particles (IDPs) [11], and cometary meteors and fireballs [4], we have compiled a list of the main characteristics we expect in cometary meteorites:

1. Rare (as rare as CI carbonaceous chondrites)
2. Dark ($\sim 5\%$ geometric albedo)
3. Weak ($\sim 10^7$ dynes/cm²)
4. High porosity ($\geq 35\%$), low density (≤ 2 g/cm³)
5. Highly unequilibrated Fe/(Mg+Fe) in silicates
6. Nearly Solar elemental abundances
7. High abundance of C, N, and organics
8. Anhydrous silicates
9. More likely than asteroidal meteorites to contain interstellar grains with peculiar isotopic ratios
10. Likely not to have chondrules
11. Unremarkable cosmic ray exposure ages ($\sim 10^7$ years)
12. Presence of polymerized hydrocarbons resulting from galactic cosmic ray exposure of ices, and different types of organics in cometary material than in asteroidal meteorites
13. Presence of cosmogenic nuclides from galactic cosmic ray exposure of ices

The low abundance of cometary meteorites (#1) is based on studies of cometary fireballs, which suggest that only a small fraction of cometary material might survive as meteorites. The next seven

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characteristics (#2-#8), are based the properties of cometary dust and "cometary" IDPs. Although it might seem that the meteoritic products of a cometary mixture of ice and dust would be hydrated, both observation [10,11] and theoretical studies [12] suggest that little, if any, material is hydrated. The abundance of interstellar grains (#9) is based on the assumption that lower processing of cometary material will lead to the survival of more presolar grains than in asteroidal meteorites. The lack of chondrules (#10) is postulated because models of chondrule formation [13] generally require higher nebular densities and/or more solar heating than we would expect in the Kuiper Belt. The cosmic-ray exposure age (#11) is the average lifetime of a typical meteorite producing orbit, and it is not diagnostic of cometary origin. The last two characteristics (#12 and #13), which are potentially quite diagnostic, are based on the fact that exposure of ices to cosmic rays for extended periods is indicative of a cometary origin, and could lead to molecular and isotopic effects in the material that would survive [14].

Where are the Cometary Meteorites?

So far no single meteorite looks unequivocally cometary. i.e., none has all the predicted characteristics. Depending on which of the items can be relaxed, different pictures of cometary meteorites emerge. We consider three alternatives:

1. Assuming all items apply, a cometary meteorite could be classified as an achondrite, and would have roughly chondritic chemistry, with high abundances of carbon and nitrogen. Known achondrites have igneous textures, and are all too highly equilibrated to be cometary.

2. If an unknown process produced extensive aqueous alteration in the material that formed cometary meteorites, then CI chondrites are the meteorites most likely to be cometary, since they match most of the other characteristics, including chemical composition, strength, relative abundance, and abundance of interstellar grains..

3. If cometary meteorites do contain chondrules, then carbon-rich, unequilibrated COs, CVs, or ordinary chondrites might be good candidates. However, these all seem to be closely related to classes that are probably asteroidal.

Since we have not identified any meteorite class or even an individual meteorite likely to be cometary, are there any good candidates among xenoliths within other meteorites? Carbonaceous, or carbon-rich, clasts are found within regolith breccias of many types of meteorites. The most common

clasts apparently match known types of meteorites [15], but there are some xenoliths which do not match known meteorites, and might be promising candidates to be cometary. Some unequilibrated ordinary chondrite breccias have clasts containing unequilibrated anhydrous silicates and carbon-rich aggregates [16]. However, these clasts contain chondrules.

Perhaps even more promising are some rare volatile-rich clasts that have been identified in the Krymka [17] and Supuhee [18] unequilibrated ordinary chondrites. These clasts tend to have roughly chondritic chemistry, though they are enriched in some volatiles ("mysterite"). The silicates are anhydrous and highly unequilibrated. Noble gases are abundant, and have isotopic ratios suggesting the presence of large amounts of interstellar grains [19]. To this point, this sounds more like a cometary sample than any other material we have described. However, one of the clasts contains some chondrules and chondrule fragments, and another seems to be intimately related to a chondrule, and a third may have carbonate (produced by aqueous alteration?).

In summary, we have not identified any individual meteorite that looks cometary. However, based on studies of cometary fireballs, we should have collected approximately the same number of cometary meteorites as CI chondrites. In other words, we should be on the verge of collecting or identifying a cometary meteorite.

References:

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