METAMORPHOSED CM AND CI CARBONACEOUS CHONDRITES COULD BE FROM THE BREAKUP OF THE SAME EARTH-CROSSING ASTEROID

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Far from being the relatively unprocessed materials they were once believed to be, we now know that a significant number of carbonaceous chondrites were thermally metamorphosed on their parent asteroid(s). Numerous studies indicate that 7 "CM" and 2 "CI" chondrites (Table 1) have been naturally heated, variously, at from 400 to over 700ºC on their parent asteroid(s) [1-13]. Petrographic textures reveal that this thermal metamorphism occurred after the dominant aqueous alteration phase, although some meteorites show evidence of a heating event between two aqueous alteration episodes, i.e. pro- and- retrograde aqueous alteration.

Aside from the issues of the identification of the transient heat source, timing of metamorphism, and the relation of these materials (if any) to conventional CM and CI chondrites, there is also a mystery related to their recovery. All of these meteorites have been recovered from the Antarctic; none are falls or finds from anyplace else. Indeed, the majority have been collected by the Japanese NIPR field parties in the Yamato Mountains. In fact, one estimate is that these meteorites account for ~ 64 wt% of the CM carbonaceous chondrites at the NIPR [14]. The reasons for this are unclear and might be due in part to simple sampling bias. However we suggest that this recovery difference is related to the particular age of the Yamato Mountains meteorite recovery surfaces, and differences in meteoroid fluxes between the Yamato meteorites and recent falls and substantially older Antarctic meteorites.

Of all desert meteorite recovery surfaces, those in the Antarctic are best for preserving friable CM and CI carbonaceous chondrites. Measured terrestrial ages for these particular Antarctic C chondrites vary up to 0.5 Myr [K. Nishiizumi, unpublished data], but because of the difficulties in obtaining ages by ^{36}Cl or ^{41}Ca techniques (due to large neutron capture effects and the paucity or total lack of metal), these ages are actually lower estimates only. CM chondrites are abundant at all Antarctic meteorite recovery locations, and at least two CIs have been found by NIPR Expeditions (Table 1). It thus appears odd that the majority of the metamorphosed C chondrites are from one stranding site. Are these paired? The answer appears to be *No*, based on mineralogical differences. We think that a critical factor is the age of the Yamato Mountains recovery surface relative to the other dominant Antarctic collection sites. The Yamato Mountains site is the youngest, with approximately 50% of the dated meteorites having terrestrial ages less than 25 ka [15] (see Figure 1).

Others have previously remarked on the remarkable fact that alone among all analyzed meteorite types, the CI and CM chondrites all have cosmic-ray exposure ages below 5 Myr, suggesting derivation from Earth-crossing asteroids rather than directly from the main asteroid belt [16]. The fact that the metamorphosed C chondrites all have very young terrestrial ages (where measured), and come from the youngest Antarctic stranding surfaces suggests further that they derive from Earth-crossing asteroids that broke up very recently – as little as 200 ky in the past. The fact that there are no metamorphosed CM or CI chondrites among modern falls, could represent statistical bias, or suggest that the delivery of the products of the circa 200 kya breakup was very efficient. This might explain why there are no metamosphosed CM or CI chondrites from the Nullarbor, where terrestrial ages only range up to 35kyr [17], or among modern falls.

In addition, if these metamorphosed CM and CI chondrites were from the *same* asteroid, we evade the coincidence of *two* metamorphosed C-type asteroids being disrupted by the Earth at precisely the same time. The oxygen isotopic composition of these meteorites are co-linear, consistent with a genetic relationship [13].

Detailed spectroscopic investigations of near-Earth asteroids have shown that some of these objects have affinities to carbonaceous meteorites. In particular, observations of asteroid 1998 ST_{27} demonstrate that this object is a good analog to the CM2 (or CI1) class of meteorites based on its low albedo (5%) and phyllosilicate absorption feature (Abell et al., 2002a,b; Abell, 2003). It is to date the only confirmed object of this composition found among the near-Earth asteroid population, although undoubtedly there are other CM2 and/or CI1 parent asteroids that may exist in near-Earth space. Asteroid 1998 ST_{27}, is also one of the first binary near-Earth asteroids to be recognized from radar observations (Benner et al., 2003).

One of the formation mechanisms that have been proposed for binary near-Earth asteroids involves tidal interactions during close approaches to either Earth or Venus, in which the initial parent body can become disrupted (Richardson et al., 1998). Such disruptive events of this nature only occur for those objects that are weakly bound "rubble-piles" as opposed to objects which have a high degree of internal strength. During the disruption event, a significant amount of material is lost from the parent body, some of which becomes gravitationally bound and accretes to form a secondary object (Richardson et al., 1998). The remaining matter from the disruption event is left to form a stream of material along the orbit of the asteroid. This material is repeatedly swept up as Earth intersects the orbit of the initial asteroid parent body, resulting in a pulse of material delivered to Earth over a discrete amount of time. Such a stream of material would not likely be very long lived due to repeated encounters with Earth.

Radar observations of 1998 ST_{27} demonstrate that the orbital dynamics of the secondary suggest that this system formed relatively recently in geologic time (Benner et al, 2003). This finding supports the hypothesis that such objects have formed recently in the past by close encounters with the Earth and that a significant amount of CM (and possibly CI) material was likely to have been placed in an Earth approaching orbit due to this event. This is not to say that 1998 ST_{27} is the parent body of these Antarctic meteorites, but rather that it is plausible that such an object/event could have produced these CM and CI chondrites.

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Table 1 Metamorphosed CM & CI Chondrites

Meteorite	Type	Terrestrial Age (kyr)
Y 86720	CM	<70
Y 86789	CM	nd (not determined)
Y 793321	CM	<70
A 881655	CM	nd
B 7904	CM	<70
WIS 91600	CM	<70
PCA 91008	CM	180
Y 82162	CI	nd
Y 86029	CI	nd

Data from [23&24] and K. Nishiizumi (unpublished)

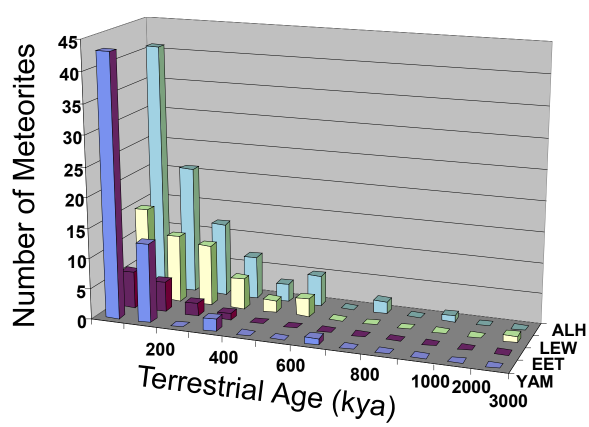

Figure 1 Terrestrial ages of c. 280 Antarctic meteorites, sorted by stranding site. YAM - Yamato Mountains, EET – Elephant Moraine, LEW – Lewis Cliff, ALH – Allan Hills Main Field. Data are from [25-28].