

LINKING METEORITES TO ASTEROIDS: HOW MANY PARENT BODIES DO WE SAMPLE IN OUR METEORITE COLLECTIONS? R. C. Greenwood¹, T. H. Burbine², I. A. Franchi¹ ¹Planetary and Space Sciences, School of Physical Sciences, The Open University, Walton Hall, Milton Keynes MK7 6AA, United Kingdom r.c.greenwood@open.ac.uk, ²Astronomy Department, Mount Holyoke College, South Hadley, MA 01075, USA.

Introduction: Meteorites provide us with a great diversity of extraterrestrial materials. However, to interpret this record effectively we need to evaluate its relationship, both to the contemporary asteroid population and to how that population has evolved with time. This involves addressing a number of key issues: i) how many asteroids/parent bodies are represented in the worldwide meteorite collection? [1,2,3]; ii) how representative is the meteorite record of both the NEO (near-Earth object) and main belt populations? [1,4,5]; iii) how useful are contemporary meteorites and asteroids as indicators of the composition and structure of first generation planetesimals; those that accreted within 1-2 Myr of Solar System formation? [6]. Relevant to this final point are the proposals that: (i) giant planet migration was a major control on main belt structure [7] and (ii) that early planetesimal fragmentation resulted in a differential loss of mantle materials [8].

Previous parent body estimates: Burbine et al. [2] estimated that meteorites could sample as few as ~100 asteroids (~27 chondritic, ~2 primitive achondritic, ~6 differentiated achondritic, ~4 stony irons, ~10 iron groups, ~50 ungrouped irons). Hutchison [3] suggested that meteorites are sourced from approximately 120 asteroids, with about 80 being ungrouped irons. In contrast, Wasson [9] argued that only 17 asteroids are sampled by the ungrouped irons, making a total of 26 asteroids for the irons as a whole.

Evidence from O-isotope studies: Here we use primarily the results from high-precision O-isotope studies, to reassess the likely number of parent bodies represented in the meteorite record [10].

Primitive achondrites. With the exception of the brachinites, the main primitive achondrite groups (acapulcoite-lodranite clan, ureilites and winonaites/IAB-IIICD irons) are each derived from a single parent body (Fig. 1). Considerable uncertainty exists about the number of parent bodies sampled by the brachinites and brachinite-like achondrites [10]. A conservative estimate would require 2, one for the “main-group” brachinites, and a second for Mg-rich, brachinite-like samples such as Divnoe, NWA 4042, NWA 4518, RBT 04255, RBT 04239 and Zag (b) (Fig.2).

Differentiated achondrites and stony-irons. Apart from the pallasites, which appear to be derived from 6 distinct parent bodies [10] and the aubrites which are probably samples from 2 [11], the other main differentiated groups (angrites, HEDs, main-group pallasites,

mesosiderites) are each derived from unique parent bodies (Fig. 1). Mesosiderites and HEDs may be from the same parent body [10], but here we adopt a conventional approach and assign each to a distinct source.

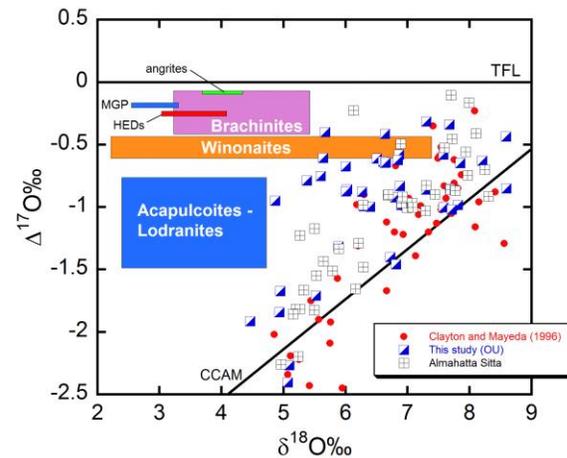


Fig. 1. O-isotope composition of primitive and differentiated achondrites [10].

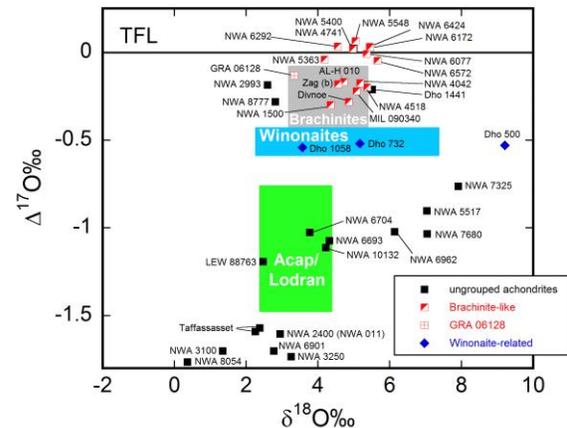


Fig. 2. O-isotope composition of ungrouped primitive achondrites [10].

Ungrouped primitive achondrites. Based on the evidence presented by Greenwood et al. [10], ungrouped primitive achondrites and related samples appear to be derived from about 16 distinct parent bodies (Fig. 2). However, there is considerable uncertainty associated with this figure [10].

Anomalous basaltic achondrites. The origin of HED-like meteorites with anomalous O-isotope compositions is the subject of ongoing research [10,12,13]. A conservative estimate of their source asteroids is 4 (one for NWA 011 and pairs; one for Ibitira; one for

A-881394, Bunburra Rockhole, Emmaville, Dho 007, EET 92023; and one for Pasamonte and PCA 91007). A more extreme position is that each anomalous basaltic achondrite is from a distinct source, in which case about 9 parent bodies are required.

Irons: Here we accept the conventional view that iron meteorites are derived from ~60 parent bodies [2], but note that this might be as few as 26 [9].

Chondrites: A minimum of ~8 parent bodies are required as sources for the main carbonaceous chondrite groups (CB, CH, CI, CK, CM, CO, CR, CV), 2 for enstatite chondrites (EH, EL), between 3 and 5 for ordinary chondrites (Low-FeO subgroup, H, L, L/LL, LL) and 1 each for K and R chondrites [14]. The Met. Bull. Database [15] currently lists 65 ungrouped chondrites, of which the majority (~42) are carbonaceous chondrite-related. It is unclear how many of these ungrouped chondrites are from distinct sources. A conservative estimate would be between 10 and 15, making the total number of chondrite sources ~ 25 to 32.

Inclusions: Breccias such as Kaidun and Almahata Sitta are known to contain inclusions derived from distinct asteroidal sources [16, 17]. However, these appear to be relatively few in number and we have not included them in our analysis.

Updated parent body inventory: We can now update the parent body inventory of Burbine et al. [2] as consisting of ~120 to 132 asteroids (~60 irons, ~35 to 40 achondrites and ~25 to 32 chondrites). Note that the meteoritic record is dominated by differentiated asteroids (irons and achondrites) ~ 95 to 100, compared to ~25 to 32 chondritic bodies. This is in clear contrast to the sample statistics, in which chondrites represent approximately 88% of all falls [15].

Relationship to asteroids: In the main belt the number of asteroids with diameters >1, 50 and 100 km is 1.36×10^6 , 680 and 220 respectively [18]. Provided meteorites are just sampling the larger bodies (e.g., diameters >100 km), then our estimate of ~120-132 parent bodies could be taken as an indication that we have a representative sampling of material from the main belt. However, the mechanisms involved in meteorite delivery are complex and it seems unlikely that we have material exclusively drawn from larger asteroids in our collections [2]. However, interestingly, 122 notable asteroid families were identified by Nesvorný et al. [19], which is similar to the number of meteorite parent bodies identified here. Maybe, only the formation of an asteroid family causes a significant flux of meteoritic material to reach Earth-crossing orbits.

Remote sensing observations provide another means of assessing how representative meteorites are of the main belt and NEO populations [10]. Remote sensing observations have broadly identified possible

parent bodies for all the main chondritic and achondritic types [10]. However, apart from a few exceptions (e.g., Vesta, Hebe), it is extremely difficult to unambiguously link specific groups to asteroids.

Asteroid belt evolution: Dynamic models suggest that inward-then-outward migration of the gas giants first cleaned out the main belt, then repopulated its inner regions with planetesimals that accreted in the inner Solar System (1 to 3 AU) and repopulated its outer regions with bodies that formed between and beyond the orbits of the giant planets [7]. The distribution of asteroid taxonomic classes in the main belt is consistent with this scenario, as is the distinct separation of carbonaceous chondrites from most other meteorite groups on plots such as $\Delta^{17}\text{O}$ vs. $\epsilon^{54}\text{Cr}$ [20].

In addition, the remnants of the planetesimals that were scattered into the main belt would have become highly deformed during multiple impact encounters [21]. Even apparently intact asteroids such as (4) Vesta may be main-belt interlopers [22]. So, do we have any samples of these first generation asteroids? As discussed earlier, differentiated meteorites appear to represent the majority of known parent bodies and are probable remnants of early-formed planetesimals. However, at best they are highly deformed and numerically depleted vestiges of the original population [10].

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Acknowledgements: THB would like to thank RIS⁴E for support. Oxygen isotope studies at the Open University are funded by a consolidated grant from STFC, UK.