3.9 BILLION YEARS AGO AND THE ASTEROID BELT.

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Introduction: Melted materials from the Moon and other meteorites show a peak in ages at 3.9 billion years [1,2,3,4]. For the Moon, this phemonenon has resulted in the highly debated topic of the lunar cataclysm [5,6], in an attempt to understand whether this 3.9 Ga peak is just the end of a steep decrease in impact cratering in which earlier-formed impact melts were destroyed by later events [6], or if the absence of materials older than 3.9 Ga indicated that a terminal cataclysm occurred at that time, resetting the lunar isotopic clock [3,4,5].

A series of papers [7-9] has postulated that the orbits of the gas giants evolved early in Solar System history until Jupiter and Saturn crossed the 2:1 mean motion resonance, increasing eccentricities of the planets. As a consequence, Uranus and Neptune moved outward rapidly, scattering icy planetesimals that would have existed beyond the orbits of the gas giants. At 878 Ma years after Solar System formation, planetesimals scattered throughout the inner Solar System, perhaps explaining the late heavy bombardment. Consistent with the scattering of material into the inner Solar System, [10,11] have postulated that the widespread ~3.5-4.0 Ga younger ages among asteroidal meteorites suggest a Solar System-wide disturbance.

Ordinary Chondrites: The concept of the late heavy bombardment and the possible bombardment of the entire inner solar system (and the lack of measurements made on ordinary chondrites to this end) is the driving force behind this study to examine ordinary chondrite impact breccias/melts within the Antarctic Meteorite collection. With 20,000 meteorites in the collection thus far (and approximately 90% of those being ordinary chondrites), the United States Antarctic collection provides a vast resource for searching out ordinary chondrite impact melt rocks, impact breccias, and clasts within these. While classification of the Antarctic meteorites has not long distinguished impact breccias, it is now being recorded, when obvious in the small chips sent to the Smithsonian for classification, and/or the larger meteorites sent for long-term storage. Binns [13] studied large ordinary chondrites at the Natural History Museum in London and found that ~20% of all ordinary chondrites were breccias and that brecciation is often revealed during the study of large masses of the meteorite.

To this end, we have begun a study of the ordinary chondrite impact breccias within the U.S. Antarctic collection. We have focused our research on meteorites that are over 500g in weight, in order to maximize the ability to find impact melt clasts far enough from the fusion crusted surface and weathering to provide reliable age dates using Ar-Ar techniques. This study follows that of [12] who recognized that many large Antarctic masses previously described as unbrecciated, are in fact, ordinary chondrite regolith breccias containing a variety of clasts, some of which are regolith derived. In particular, [12] focused on MAC 87302 (and, it turned out, breccias paired with it), which is proving to contain numerous, large melt clasts, some of variable compositions relative to the classification of the host meteorite. Here we are focusing on L and LL chondrites, primarily, as there are fewer measurements made on impact melts within these meteorites than in H chondrites or HEDs [10, 14, 15], and the H chondrite parent body likely experienced a large break-up event, though we are not necessarily excluding H chondrites.

***Figure 1** - Plane polarized image of PCA 02071, melt clast circled. (FOV = 2 cm across)*

To date, in addition to further analyses of MAC 87302 pairing group, 12 ordinary chondrite impact breccias (Table 1) have been selected for this study. Impact melt clasts have been identified within these meteorites (Figure 1). These impact melt clasts have been analyzed with the FEI Nova NanoSEM Field Emission SEM and the JEOL JXA 8900R electron microprobe at the Smithsonian Institution. Backscattered electron mosaics and elemental maps (Figure 2) have been created for each impact melt clast large enough to potentially provide a successful Ar-Ar date (Table 1). These meteorites are currently being prepared for shock analysis, to ensure that the melt clasts reached high enough temperatures to reset the Ar isotopic systematics.

Table 1. *Meteorite breccias identified thus far.*

Name	Type	Melt clasts IDed
MAC 87302 prs	L4 breccia	
MET 01002	L5 breccia	1
MET 01004	LL5 breccia	2
MET 01052	L5 breccia	1
MIL 99303	H5 breccia	1
MIL 07010	L inpact melt	-
PCA 02070	H5 breccia	1
PCA 02071	L5 breccia	2
PCA 02072	LL6 breccia	1
PRE 95400	H5 breccia	3
QUE 99012	H4 breccia	1

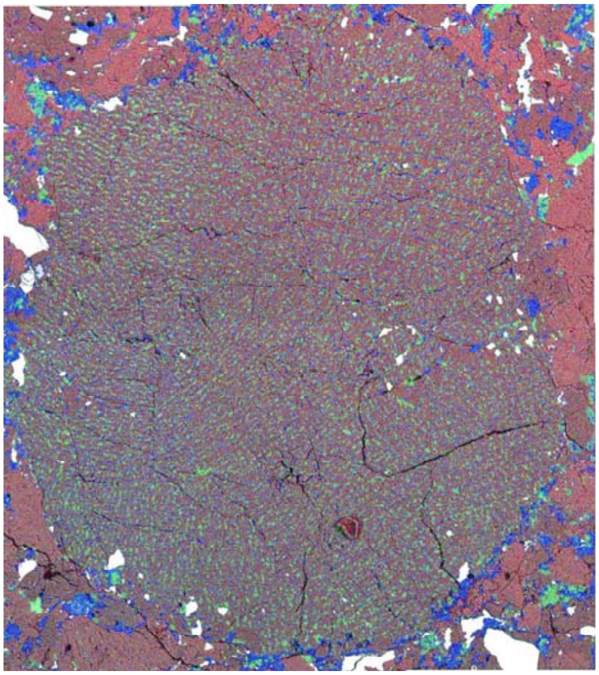

Figure 2 *– Elemental Map of Melt Clast in PRE 95400. Blue = Aluminum, Red = Magnesium, and Green = Calcium (FOV = 600 microns across)*

References: [1] Turner et al. (1973), *Proc. 4th LPSC*,1889-1914. [2] Tera et al. (1974), *EPSL* 12, 19-35. [3] Kring and Cohen (2001) *JGR* 107, doi: 10.1029/2001JE001529. [4] Cohen et al. (2005), *MAPS* 40, 755-777. [5] Ryder G. et al. (2002) *JGR* 107, 6-1. [6] Hartmann (2003) *MAPS* 38, 579-593. [7] Tsiganis et al. (2005) *Nature* 435, 459. [8] (2005) *Nature* 435, 462. [9] Morbidelli et al. (2005) *Nature* 435, 466. [10] Kring and Cohen (2002) *JGR* 107, 4.1-4.6. [11] Bogard and Garrison (2003) *MAPS* 38, 669-710. [12] Welzenbach L.C. et al., 2005, *LPSC XXXV*, #1425. [13] Binns R.A., 1967, *EPSL* 2, 23-28. [14] Swindle et al. (2008) *MAPS* 44, 762. [15] Wittmann (2010) *JGR* 115, doi: 10.1029/2009JE003433. [16] LaCroix and McCoy (2007) *LPSC XXXVIII* #1601.