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Microanalysis of Fossil Micrometeorites and Meteorites to Study A Major Asteroid Collision ~470 Million Years Ago.

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Collisions of small bodies and their fragments among themselves and with terrestrial planets are among the most dominant processes in the evolution of our Solar System. Much of the knowledge of this collisional history is based on observations of cratered surfaces and on the laboratory study of surface-recovered extraterrestrial (ET) matter. The latter represents matter that fell in a time period from the present to tens of thousands of years ago in hot deserts, to about a million years ago in Antarctica. The rich archive of ET material from earlier time periods preserved in the subsurface has been barely touched with the exception of a few well-studied time windows, e.g. [1]. Upon arrival on Earth, during burial and diagenesis of terrestrial sediments embedded ET matter gets altered and eventually becomes fossilized, analogous to biological fossils [2]. Only few types of minerals survive fossilization. Chromite and chrome-spinel (hereafter called chromites) are the most abundant coarse-grained minerals that are preserved almost unaltered in fossil meteorites and micrometeorites. The study of major and minor elemental compositions of chromites, e.g., [3,4] and their oxygen isotopic compositions [5-7] in comparison with modern meteorite falls allows the classification of their host and determination of their asteroidal source. In this invited paper we review selected microanalytical investigations of ET chromites from one well-studied time window, ~470 Ma ago, immediately after one of the major asteroid collisions in the last billion years, the L chondrite parent-body breakup (LCPB).

ET chromites are extracted from fossil meteorites by acid dissolution of subsamples. The more abundant sediment-dispersed ET chromites are extracted from large blocks of limestone through acid-dissolution, followed by sieving and picking. Qualitative EDS analysis distinguishes extraterrestrial from terrestrial chromite, based on characteristic major and minor elemental compositions, in particular narrow ranges of vanadium and titanium e.g., [3,4]. Average elemental concentrations determined by quantitative EDS and WDS analyses already enables a tentative classification for ordinary chondritic material based on a larger number of samples, e.g., [4]. Individual grains can be classified more accurately by combining quantitative elemental analysis with high-precision oxygen isotopic analysis with SIMS [6-9]. Selected grains have been analyzed for helium and neon isotopes with noble gas mass spectrometry coupled to laser extraction to determine if they originate either from micrometeorites or if they were components of meteorites. The presence of surface-implanted noble gases indicate that grains were parts of micrometeorites, whereas an origin from a larger meteorite would be indicated by absence of solar wind and the presence of abundant cosmic-ray produced nuclides [10-13]. The latter allows calculating cosmic-ray exposure ages, the time periods after ejection into interplanetary space until arrival on Earth [10,11]. Selected chromites were also analyzed with synchrotron X-ray tomography to locate silicate inclusions that can be used for classification [14]. Recently, we started to look with Raman Spectroscopy and TEM for effects of high-pressure shock-induced transformations in chromites that could have formed during collisions on the parent body [15].

A hundredfold overabundance of L chondritic material was discovered in ~470 Ma old (mid-Ordovician) marine limestone from Sweden, Russia and China [1] and linked to the LCPB in the asteroid belt, one of the major asteroid disruption events in the last billion years, e.g., [16]. Short cosmic-ray exposure ages indicate the breakup event happened close to one of the major orbital resonances in the inner asteroid belt that resulted in rapid delivery times to Earth (~10^5 to 10^6 Ma) [10,11]. All but one of the 101 recovered fossil meteorites that were found in the mid-Ordovician in Sweden are L chondritic and most likely were ejected during the LCPB. There is only one fossil meteorite whose chromites have a different composition that was classified as winonaite-like [9]. The Lockne impact crater in Sweden preserved impactor material that was classified unambiguously as L chondritic, linking this impact to the LCPB [8]. ET chromites from fossil micrometeorites were found in correlated sediments at several locations in Sweden, Russia and also in China at similarly high relative abundances, clearly indicating a global event [1]. Almost all of the analyzed fossil micrometeorites are L chondritic in composition, only ~1% of them are H chondritic, based on elemental and oxygen isotopic compositions [6,7]. This is very different from today, where the H and L chondritic meteorites and coarse micrometeorites essentially fall with the same frequency (Meteor. Bull. Database http://www.lpi.usra.edu/meteor; [17,18]). All these studies indicate that material from the LCPB dominated the ET flux in the mid-Ordovician and suggest a prolonged rain of L chondritic material in the inner Solar System that lasted at least 2 Ma after the LCPB. There might have been significant environmental effects on Earth after the LCPB [19,20]. Even today, 470 Ma later, the LCPB is one of the main sources of meteorites that fall on Earth, e.g., [16]. Our new preliminary results indicate that the composition of the ET flux to Earth was very different also before the LCPB compared to today.

[1] B. Schmitz, Chemie der Erde **73** (2013), p. 117.
[2] P. Thorslund, F. E. Wickman and J. O. Nyström Lithos **17** (1984), p. 87.
[3] B. Schmitz, M. Tassinari and B. Peucker-Ehrenbrink. Earth. Planet. Sci. Lett. **194** (2001), p. 1.
[4] B. Schmitz and T. Häggström. Meteoritics Planet. Sci. **41** (2006), p. 455.
[5] R. C. Greenwood *et al,* Earth Planet. Sci. Lett. **262** (2007), p. 204.
[6] P. R. Heck *et al*, Geochim. Cosmochim. Acta **74** (2010), p. 497.
[7] P. R. Heck *et al*, Geochim. Cosmochim. Acta **177** (2016), p. 120.
[8] B. Schmitz *et al*, Earth Planet. Sci. Lett. **306** (2011), p. 149.
[9] B. Schmitz *et al*, Earth Planet. Sci. Lett. **400** (2014), p. 145.
[10] P. R. Heck *et al,* Nature **430** (2004), p. 323.
[11] P. R. Heck *et al*, Meteorit. Planet. Sci. **43** (2008), p. 517.
[12] M. M. M. Meier *et al*, Earth Planet. Sci. Lett. **290** (2010), p. 54.
[13] M. M. M. Meier *et al*, Geochim. Cosmochim. Acta **125** (2014), p. 338.
[14] C. Alwmark *et al,* Meteorit. Planet. Sci. **46** (2011), p. 1071.
[15] S. S. Rout, P. R. Heck, and B. Schmitz, Lunar Planet. Sci. **47** (2016), p. 3043.
[16] D. Bogard, Chemie der Erde **71** (2011), p. 207.
[17] M. Van Ginneken *et al*, (2012). Meteorit. Planet. Sci. **47** (2012), p. 228.
[18] M. S. Prasad *et al*, (2015) Meteorit. Planet. Sci. **50** (2015), p. 1013.
[19] J. Parnell, Nat. Geosci. **2** (2009), p. 57.
[20] B. Schmitz *et al,* Nat. Geosci. **1** (2008), p. 49.
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