Solar Wind-derived He and Ne in Sediment-Dispersed Extraterrestrial Chromite Grains from the mid-Ordovician Lynna River Section in Russia

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Chromite grains that came to Earth as parts of micrometeoritic dust produced in the catastrophic break-up of the L chondrite parent body (LCPB) at 470 Ma, have been found before in mid-Ordovician rocks from Sweden [1] and China [2]. Here we report that the sediment-dispersed chromite (SEC) grains recently found in highly condensed sediments from the Lynna River section in Russia [3] are indeed of extraterrestrial, micrometeoritic origin, as they contain high concentrations of solar wind (SW)-derived He and Ne. For three of the grains, the SW-Ne concentration was low enough that a ^{21}Ne cosmic ray exposure (CRE) age could be determined. While two of the grains have short (<1 Ma) CRE ages compatible with Poynting-Robertson orbital decay, a third grain has been irradiated in the regolith of the LCPB.

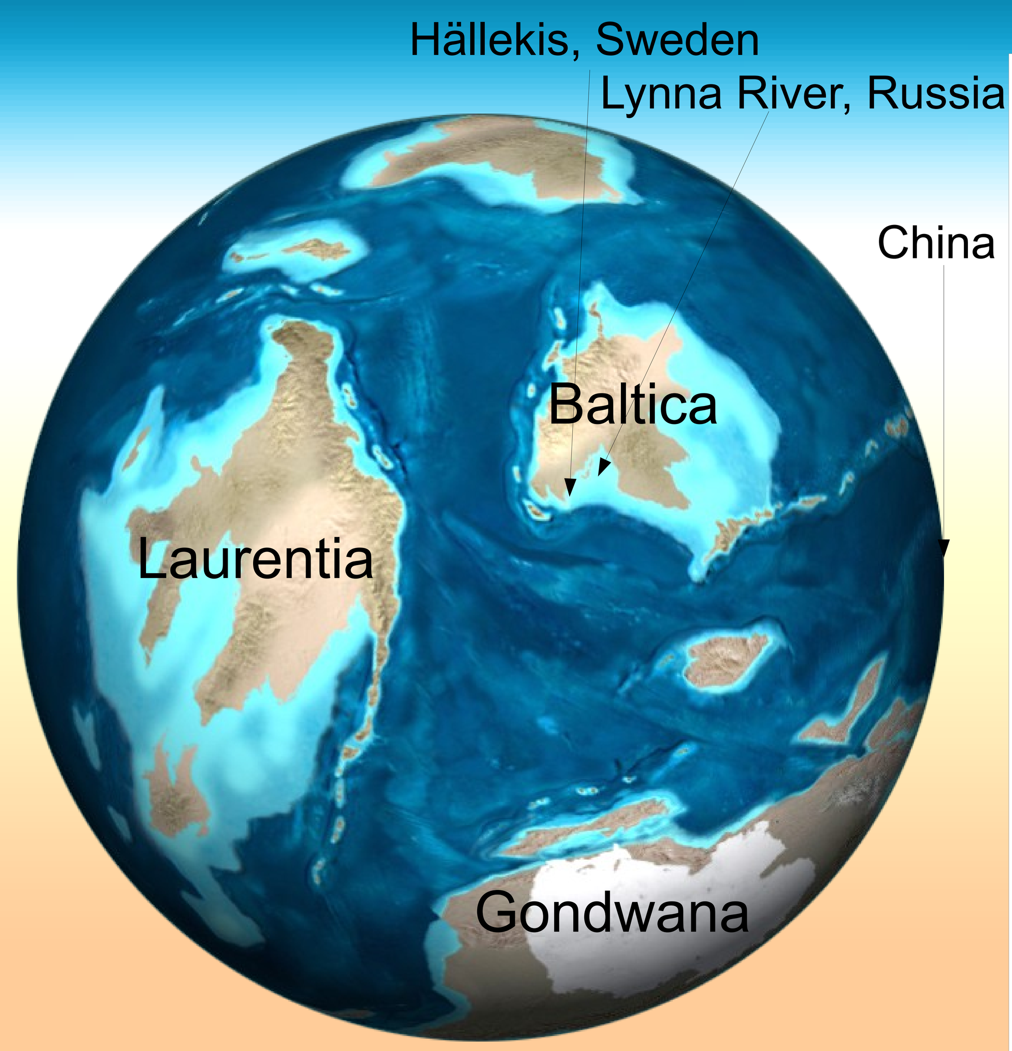
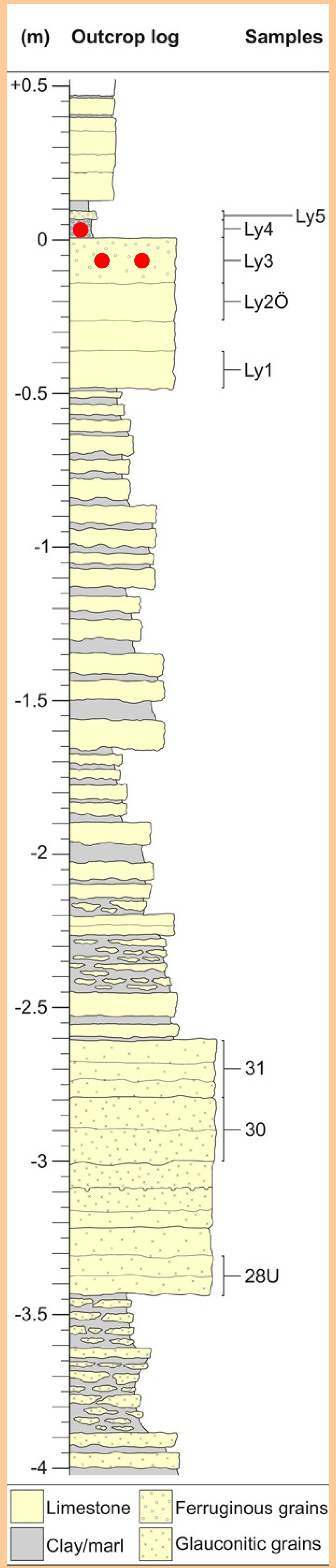


Figure 1 *The Earth at 470 Ma (middle Ordovician) © Ron Blakey, Colorado Plateau Geosystems, Inc*



Sample retrieval, preparation & analysis

The chromite grains were extracted by acid-dissolution (HCl/HF) from mid-Ordovician limestone from the „Lynna River“ outcrop (Fig. 2) near the city of Volkov in north-western Russia. Like the orthoceratite limestones of southern Sweden, where many SEC grains have been found [1], these rocks formed in a shallow, epicontinental sea on the ancient continent of Baltica (Fig. 1). The residues from the acid dissolution were sieved, the 63 – 355 µm section was searched for opaque grains. Determination of major and minor elements with SEM-EDS analysis was used to tell apart SEC and terrestrial chromite (Fig. 4), as described in detail in [3]. Several beds from the section were sampled for [3], but so far we have only analyzed grains from beds Ly3 and Ly4 (Fig. 3). These beds lie below, and above of the tentative boundary between the *Lenodus variabilis* (Ly3) and *Yangtzeplacognathus crassus* (Ly4) conodont stratigraphic zones – the same zones to which the SEC-bearing sediments from Sweden [1] and China [2] belong. SEC grains were analyzed using a high-sensitivity noble gas mass spectrometer. The sample gas was extracted using an IR laser to heat the chromite grains to the point of melting or vaporization. He, Ne was then measured as described in [4].

To calculate the CRE ages, for micrometeorites (diameter < 1 mm) we have to take into account both galactic and solar cosmic rays (GCR, SCR). GCR production rates were based on the model by [5], while the SCR production rates were based on the model by [6].

Figure 3 *(Top) Beds at Lynna River [3]. The three red dots indicate the position of the grains with unambigous CRE ages.*

Figure 2 *The outcrop at Lynna River*

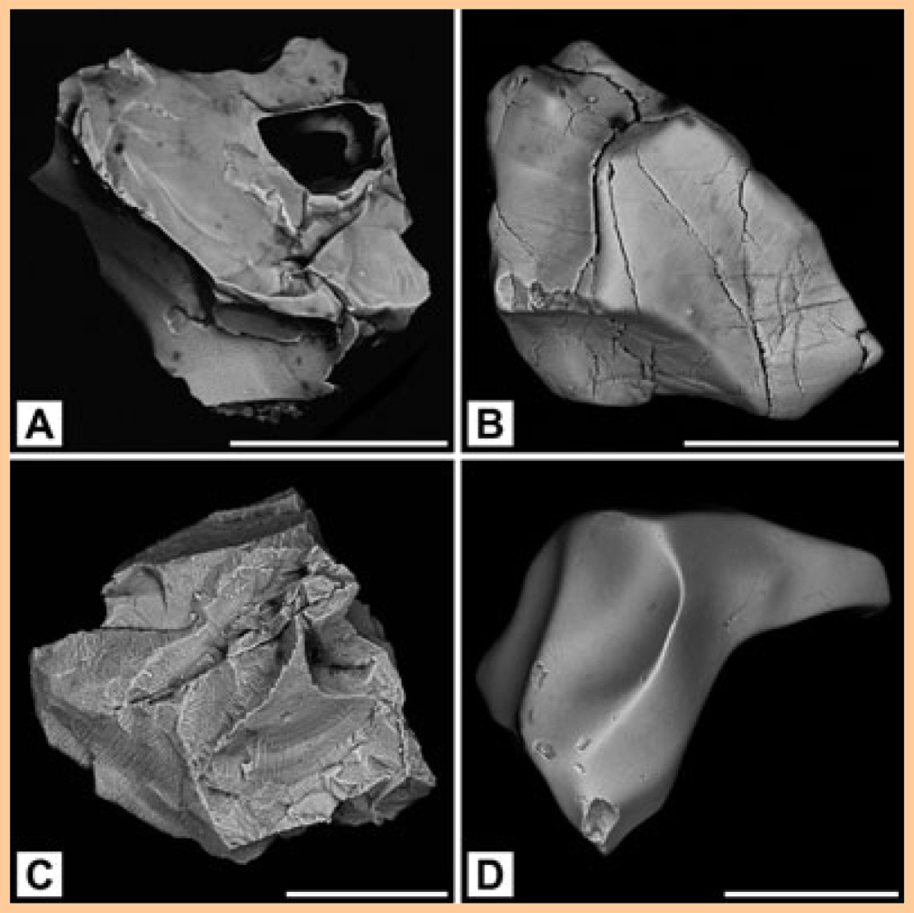


Figure 4 *(Right) SEC grains from Lynna River, imaged in SEM (backscattered images). A) and C) have sharp edges (typical), while B) and D) have been transported and are partly rounded (rare). The scale bar is 50 µm. [3]*

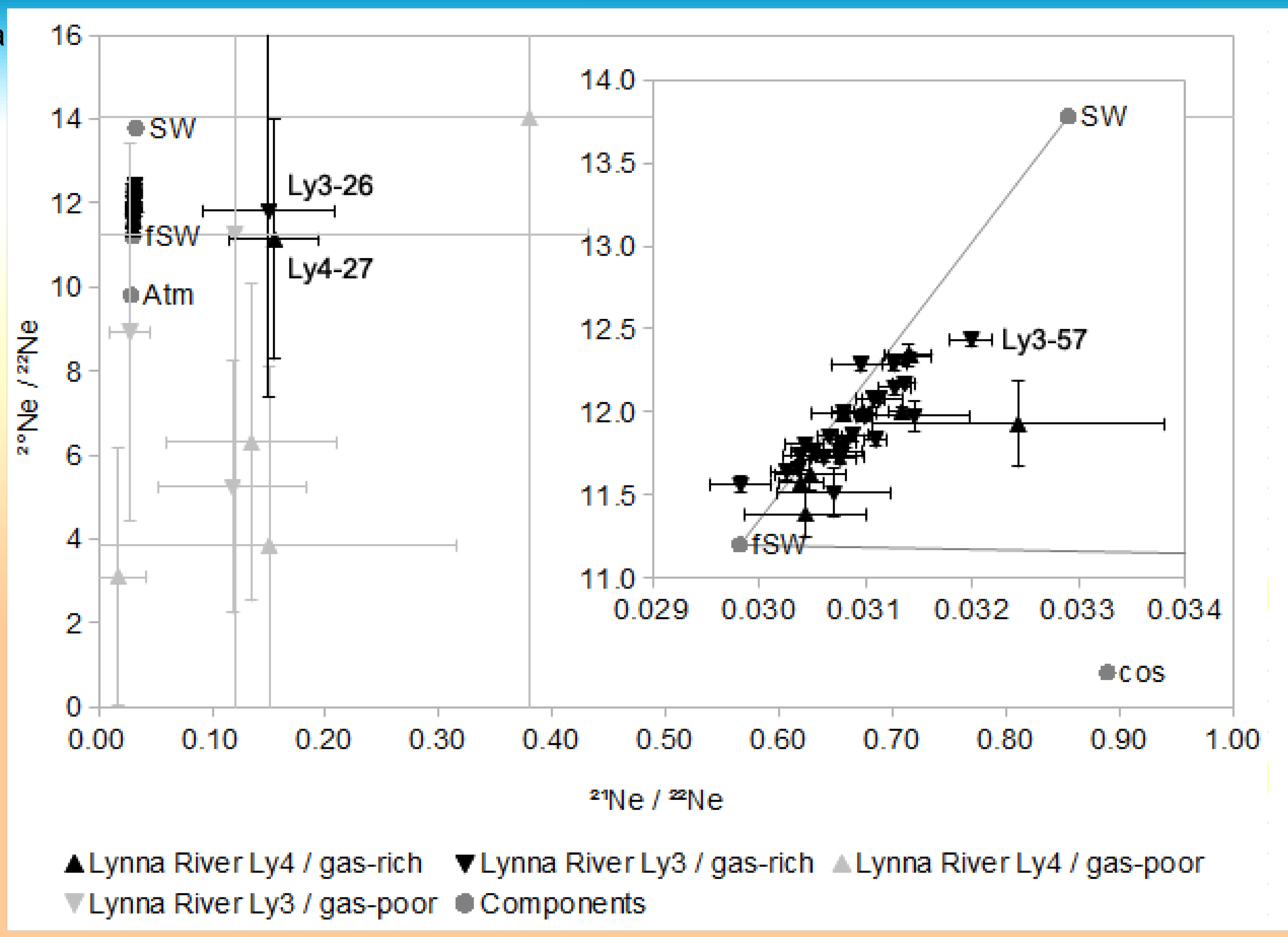


Figure 5 *Ne three isotope diagram. SW = solar wind, fSW = fractionated solar wind, Atm = Earth's atmosphere, cos = cosmogenic Ne (GCR)*

Results & Discussion

All gas-rich grains in the Ne three-isotope diagram (Fig. 5) plot near the line connecting the SW with the „fractionated“ SW typically found in materials where SW ions have been implanted (e.g., lunar dust, recent micrometeorites). Most of the grains plot to the right of this line, indicating a contribution of cosmogenic ^{21}Ne. However, only for three grains is this contribution unambigous (>2 σ): Ly3-26, Ly4-27 and Ly3-57. Using the GCR+SCR production rate, the CRE ages of the first two grains are 0.17±0.03 and 0.25±0.03 Ma. These ages are compatible with Poynting-Robertson (PR) decay times, i.e., the time it takes a sub-mm sized particle to spiral in from an initial position in the asteroid belt. These CRE ages also date the sediment relative to the LCPB breakup event, and give an age difference of 0.08±0.04 Ma between Ly3 and Ly4. The third grain with an unambigous CRE age has 4.95±1.65 Ma, significantly longer than a PR decay time. If this grain formed in the same event as the other two, it must have been pre-irradiated near the surface of the LCPB, i.e., in the regolith layer. There, the grain is shielded from SCR and half of GCR, implying a lower production rate and thus a higher (2π, GCR only) CRE age of 13.0±4.3 Ma.

These results agree with the suggestion of [4] that a large fraction of SEC grains in mid-Ordovician sediments show signs of regolith pre-exposure to GCR in the regolith layer of the LCPB. This is further supported by a general trend of increasing content of cosmogenic ^{21}Ne with increasing SW gas concentration (Fig. 6), a feature also observed in many regolith breccia meteorites [7]. This is the first time the destruction of an asteroidal regolith layer has been clearly documented by grains from a terrestrial sediment.

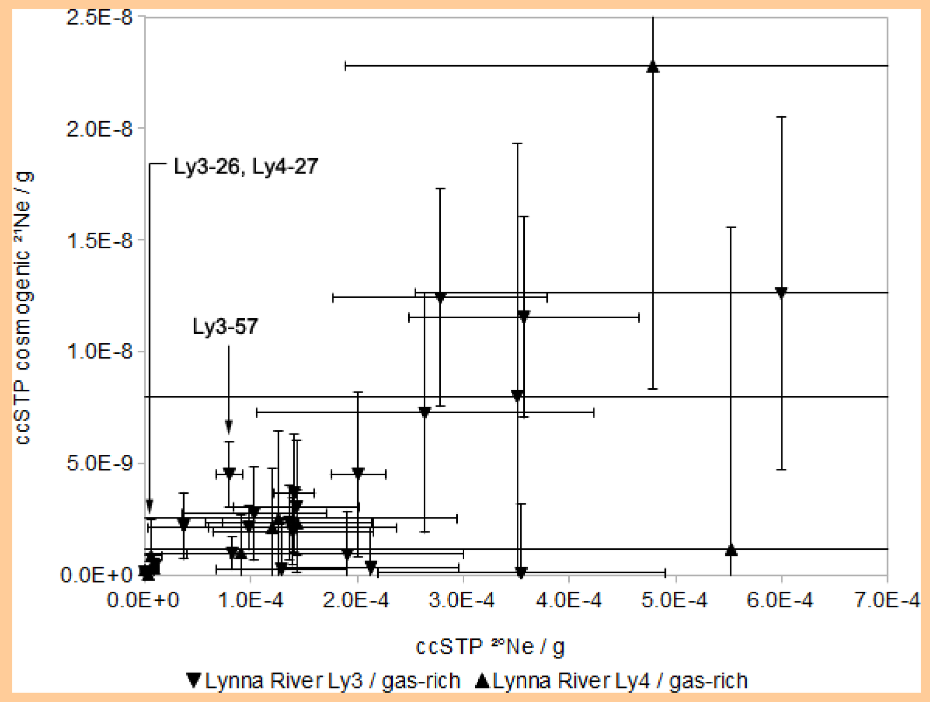


Figure 6 *Cosmogenic vs. SW Ne*

In a hurry? Here are the conclusions / highlights

- Chromite grains from a russian outcrop of mid-Ordovician rocks contain solar wind (SW) He, Ne, demonstrating they were once micrometeorites
- In three grains low in SW He, Ne, cosmic-ray exposure (CRE) ages of 0.17±0.03, 0.25±0.03 and 4.95±1.65 Ma were determined
- These are the first CRE ages of such grains that are consistent with Poynting-Robertson orbital decay, and with CRE ages of fossil meteorites from sediment beds of the same age in Sweden
- The third grain likely comes from the regolith layer of the parent asteroid

References: [1] Schmitz et al. 2003, Science 300:961. [2] Cronholm & Schmitz 2010, Icarus 208:36. [3] Lindskog et al. 2012 MAPS 47:1247. [4] Meier et al. 2010 EPSL 290:54. [5] Leya & Masarik 2009, MAPS 44:1061. [6] Trappitsch & Leya 2013, MAPS 48:195. [7] Wieler et al. 1989 GCA 53:1441.