Accumulation of Meteoritic Nickel on Mars

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I. Introduction

Martian surface materials could include a significant exogenous component, as is the case on the Moon. If so, this should be reflected in the siderophile geochemistry of the martian soil: many elements are enriched in meteorites compared to planetary crusts, particularly nickel and iron (see Table 1). Any iron signal from meteoritic influx to Mars would be obscured by iron in basaltic materials common on the surface. In contrast, nickel is much more abundant in asteroidal material than the basaltic crust. Thus, its abundance on the martian surface can be potentially used to trace meteoritic addition and quantify the impact contribution to surface materials [1-3].

Table 1. Nickel abundances of selected materials

Sample	*Ni abundance*	*Ref.*
Mean C1 Chondrite (typical of impactors)	**1.1%**	[12]
SNC meteorites (martian crust)	5-500 ppm **μ~80 ppm**	[13, 14]
Adirondack basalt (e.g., primary igneous crust)	**200 ppm**	[15]
Gusev basaltic soils (APXS)	200-700 ppm **μ~470 ppm**	[2]
Meridiani soils (APXS) (*soils may have complicated exhumation history)	600-1300 ppm **μ~840 ppm**	[2]
Gale Crater high-Ni layered target Natkusiak (ChemCam; calibration refinements in progress [16])	700-2900 ppm **μ~1800 ppm**	N/A

Several factors help bolster the likelihood that meteoritic nickel should be concentrated at the martian surface:

- Rates inferred for surface erosion are very slow [4-6], so exogenous material has time to accumulate and mix with surface materials.
- Ancient surface materials (billions of years old) are common on Mars, and sedimentary material at Gale crater are probably Late Noachian or Early Hesperian, >3.5 Ga [7,8]
- The impact flux was much higher in this early period, enhanced ~20-50× higher at the Late Noachian/Early Hesperian boundary than it is today [9,10].

Here, we consider the abundance of exogenous material that may be in martian soils, as well as complications that need to be addressed to make progress on using nickel to trace the meteoritic contributions. Constraining this addition of exogenous material has astrobiological implications because organic matter is also likely added to Mars [e.g., 11].

II. Mass Flux

Most of the meteoritic mass that accumulates on Mars is expected to do so as micrometeorites or as much larger impactors (Fig. 1), with little mass addition in the intermediate size range.

Micrometeorites: In 1990, Flynn and McKay [3] estimated the mass flux of micrometeoritic material as between 2,700 and 59,000 tons/yr by taking then-current estimates of the micrometeoritic flux to Earth (~15,000 to ~80,000 tons/yr) and scaling the results to Mars. Estimates for the micrometeoritic flux at Earth have subsequently been substantially refined and reduced to 7,400±1,000 tons/yr [17]. Scaling this to Mars would suggest a mass flux in the micrometeorite range of ~1,250 tons/yr or ~9 g/km^2/yr. At the current impact flux, this would deliver the equivalent of ~3 mm/Ga of meteoritic material to the surface.

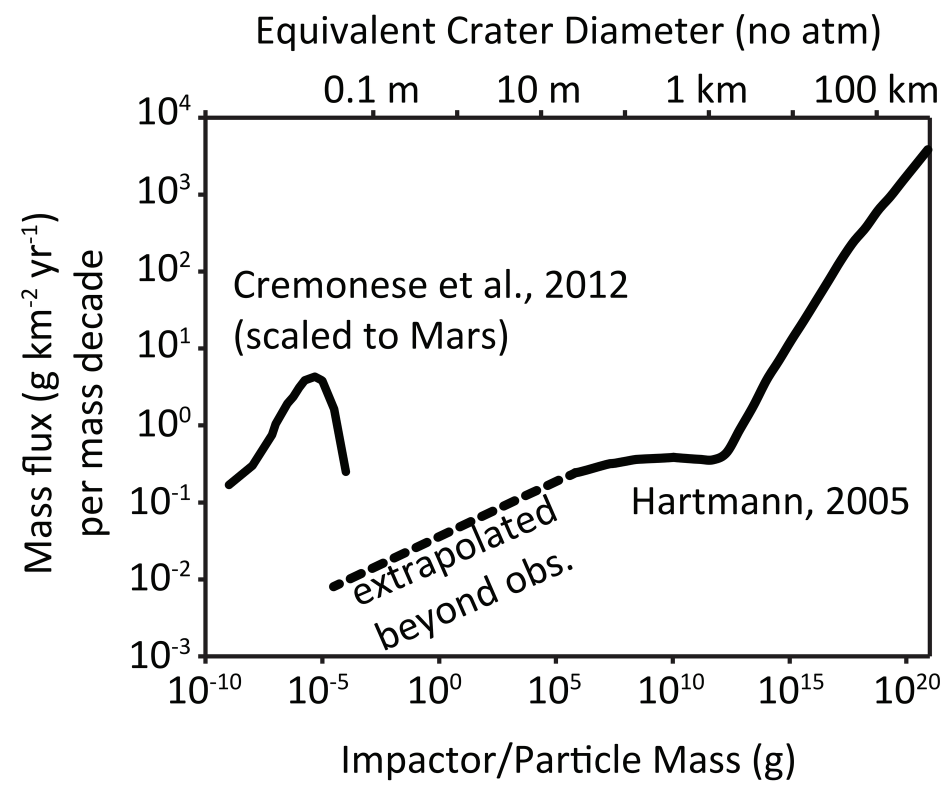

Figure 1. Mass flux of meteoritic material to Mars with estimates scaled to Mars from [17] and from the impact flux of [10].

Crater-forming Impactors: We have assessed the importance of larger impactors by converting the Hartmann isochrons [9] back to the projectile mass using Schmidt-Housen-Holsapple scaling [e.g., 18,19]; a similar approach was taken by [1] with different assumptions about cratering efficiency. These calculations illustrate that the crossover point where the mass delivered to Mars from projectiles forming impact craters is larger than the mass from micrometeorites occurs at a mass of ~2×10^{14} grams, corresponding to impactors that form craters of ~5.75 km in diameter. Because impacts at these scales are comparatively rare, the contribution of meteoritic material from these events will be highly stochastic – enhanced in the crust in the vicinity of large craters, and relatively unimportant elsewhere.

III. Mixing of Nickel into Soils

The growth and gardening of Mars regolith is much less well-studied than that of the Moon [20-21]. In addition, micrometeorites delivered to Mars interact with and are potentially ablated by its atmosphere [3]. To calculate nickel abundances, we assume (1) that all of the mass delivered as micrometeorites ultimately reaches the surface and (2) that the flux of micrometeorites scales like the flux of larger impactors from [10].

Ultimately, we aim to model the concentration of nickel in sedimentary sequences where the burial of surface materials was fast relative to the accumulation of exogenic materials. In this case, it may be possible to use the abundance of meteoritic material as a tool for understanding the surface exposure history, major hiatuses in deposition, and regolith evolution.

Example: Gusev Hesperian volcanic plains:

- Regolith thickness of the plains is ~10 m [5].
- Given its age, we expect ~1.6 cm of meteoritic material added to this regolith.
- This would represent a ~0.2% contaminant if fully mixed to 10 m, or 10% enhancement in the Ni concentration in the soil (220 ppm).
- This is much less than estimated from APXS (Table 1) [1-2].
- Reaching the observed factor of ~2.35× would require the accumulating meteoritic material be concentrated in the upper 68 cm of soil.
- Because gardening of the regolith is expected to be enhanced near the surface, this is plausible.
- Alternatives are: (1) Ni abundances might be enhanced during aeolian deflation of the soil [5], (2) the basaltic soil on the Gusev plains may not be entirely derived locally, or (3) nickel may have been concentrated by fluids.

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