MAGNETITE IN MARTIAN METEORITE MIL 03346 AND GUSEV ADIRONDACK CLASS BASALT: MÖSSBAUER EVIDENCE FOR VARIABILITY IN THE OXIDATION STATE OF ADIRONDACK LAVAS.

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Introduction: The Mössbauer spectrometers on the Mars Exploration Rovers Spirit (Gusev crater) and Opportunity (Meridiani Planum) have returned information on the oxidation state of iron, the mineralogical composition of Fe-bearing phases, and the distribution of Fe among oxidation states and phases [1,2,3]. To date, ~100 and ~85 surface targets have been analyzed by the Spirit and Opportunity spectrometers, respectively. Twelve component subspectra (8 doublets and 4 sextets) have been identified and most have been assigned to mineralogical compositions [4].

Two sextet subspectra result from the opaque and strongly magnetic mineral magnetite (Fe_3O_4 for the stoichiometric composition), one each for the crystallographic sites occupied by tetrahedrally-coordinated Fe^{3+} and by octahedrally-coordinated Fe^{3+} and Fe^{2+}. At Gusev crater, the percentage of total Fe associated with magnetite for rocks ranges from 0 to ~ 35% (Fig. 1) [3]. The range for soils (~5 to ~12% of total Fe from Mt, with one exception) is narrower. The ubiquitous presence of Mt in soil firmly establishes the phase as the strongly magnetic component in martian soil [4,5].

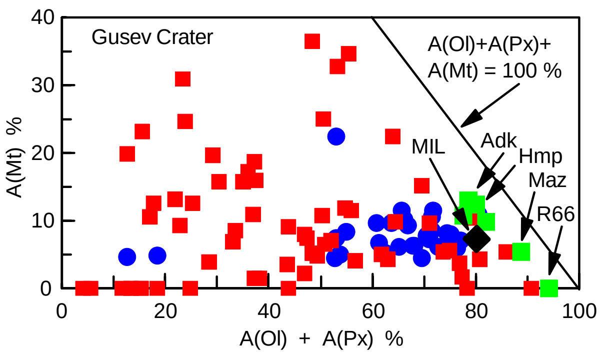

Fig. 1. Percentage of total Fe from Mt (A(Mt)) versus percentage of total Fe from olivine (Ol) plus pyroxene (Px) (A(Ol)+A(Px)) for Gusev crater rocks (square symbols) and soils (circle symbols). Adirondack class rocks (green squares) Adirondack (Adk), Humphrey (Hmp), Mazatzal (Maz), and Route66 (R66), and martian meteorite MIL 03346 (MIL) are indicated by arrows. A is the percentage of total Fe in a sample associated with a particular Fe-bearing phase.

Although Mt is abundant in Gusev crater rock and soil, its origin is equivocal. On the Earth, Mt can result from both igneous (i.e., crystallization from silicate liquids) and non-igneous processes (e.g., serpentinization [6] and precipitation from alkaline solutions [7]). In this paper, we argue by analogy with martian meteorite MIL 03346, a nakhlite which contains Ti-bearing magnetite in the mesostasis [8], that the Mt in Adirondack class basalt is igneous in origin and present as a mesostasis phase. We further suggest that the range in concentration (0 to 13% of total Fe from Mt) results from variation in the oxidation state of the lavas from which the rocks crystallized. To establish a basis for comparison, we obtained Mössbauer (MB) spectra for a whole-rock (WR) sample of MIL 03346.

Mössbauer Mineralogy of MIL 03346: Approximately 100 mg of the 75-150 µm size fraction of WR MIL 03346,56 [9] was analyzed "as is" under clean conditions to minimize potential contamination for possible future analyses. MB measurements were done at room temperature with a spectrometer configured in a vertical orientation, permitting horizontal sample orientation.

The MB spectrum (Fig. 2f) can be characterized by two Fe^{2+} doublets, one Fe^{3+} doublet, and two sextets. The least squares fit using Lorentzian lineshapes is shown in Fig 2f, and the calculated MB parameters and mineralogical assignments, in the context of MER spectra [1,2,3] are in Table 1. The proportions of total Fe associated with Px, npOx, and Mt are 80, 12, and 7%, respectively, and the Fe^{3+}/Fe_T ratio is 0.17 (f-factor corrected). For comparison, the spectrum for the MER magnetite compositional calibration target (CCT) is shown (Fig. 2e). To our knowledge, the spectrum for MIL 03346 is the first reported Mt spectrum for a WR sample of a martian meteorite.

Table 1. MB parameters (295 K) for MIL 03346.

Site	Phase	δ (mm/s)	ΔE_Q (mm/s)	B_{hf} (T)	A (%)
Oct-Fe^{2+}	Px	1.15	1.99	---	53
Oct-Fe^{2+}	Px	1.15	2.78	---	27
Oct-Fe^{3+}	npOx	0.39	0.74	---	12
Oct-$Fe^{2.5+}$	Mt	0.67	0.00	45.5	5
Tet-Fe^{3+}	Mt	0.27	-0.01	48.6	2

Previous MB measurements for MIL 03346 are reported by [10], and they found for a WR sample that Mt is not present within detection limits (<1% of total

Fe). We suggest that their result is an artifact of having acquired MB spectra over a narrow velocity range (±4 mm/s) rather than the ±10 mm/s range as in Fig 2f. The only Mt peak not obscured in the ±4 mm/s range is centered near -3.6 mm/s, and its area is 1% of total Fe in our spectrum..

Application to Gusev Adirondack Class Rock: Combined Mössbauer, petrographic, and electron microprobe analyses show that WR martian meteorite MIL 03346 has 7% of total Fe from Ti-Mt (located primarily in a glassy mesostasis phase (~20 vol.% [8])) and that Fe^{3+}/Fe_T ~0.17. The Adirondack class Gusev basalts have very similar chemical compositions, are olivine normative, and have Ol, Px, npOx, and Mt as their major Fe-bearing phases (Figs. 1 and 2a-2c) [3,11,12,13]. From MB (interior samples except for R66), the proportion of total Fe from Mt ranges from 0% (R66) to 13 % (Adk and Hmp) and the corresponding range for Fe^{3+}/Fe_T is 0.07 to 0.19. The low spectral contrast and low albedo of Pancam multispectral data for the post-RAT surfaces of Adk, Hmp, and Maz [11] are consistent with dessimination of Mt (an opaque mineral) as small grains throughout interior rock volumes.

By analogy with MIL 03346, the percentage of total Fe from Mt in Adirondack class basalts is at a level that is consistent for its occurrence in a mesostasis phase. The percentage of total Fe from Mt for MIL 03346 (WR) is intermediate to that measured for Maz (interior) and either Adk or Hmp (Fig. 1). The range in Mt contents could be indicative of either distinct lavas that are characterized by different initial oxidation states or a single lava that was stratified with respect to oxidation state. For the Adirondack class basalt, the least oxidized (lowest Mt concentration) rock is Route66 and the most oxidized rocks (highest Mt concentration) are Adirondack and Humphrey.

References: [1] Morris R.V. et al. (2004) *Science*, *305*, 833-836. [2] Klingelhoefer G. et al. (2005), *Science*, *306*,1740-1745. [3] Morris R.V. et al. 2006, *JGR*, in press. [4] Morris et al. (2006) *LPS XXXVII*, this volume. [5] Goetz W. et al. (2005) *Nature*, *436|7*, doi:10.1038/nature03807. [6] Berndt, M.E. et al. (1996) *Geology*, *24*, 351-354. [7] Bigham et al. (2002) In *Soil Mineralogy with Environmental Applications*, SSSA Book Ser. 7, 323-366. [8] Treiman A.H. (2005) *Chemie der Erde*, *65*, 203-270. [9] Shih C.Y. (2006) *LPS XXXVII*, this volume. [10] Dyar M.D. et al. (2005) *JGR*, *110*, doi:10.1029/2005JE002426. [11] McSween H.Y. (2004) *Science*, *305*, 842-845. [12] Gellert R. (2004) *Science*, *305*, 829-832. [13] McSween H.Y.et al. (2006) *JGR*, *111*, doi:10.1029/2005JE002477.

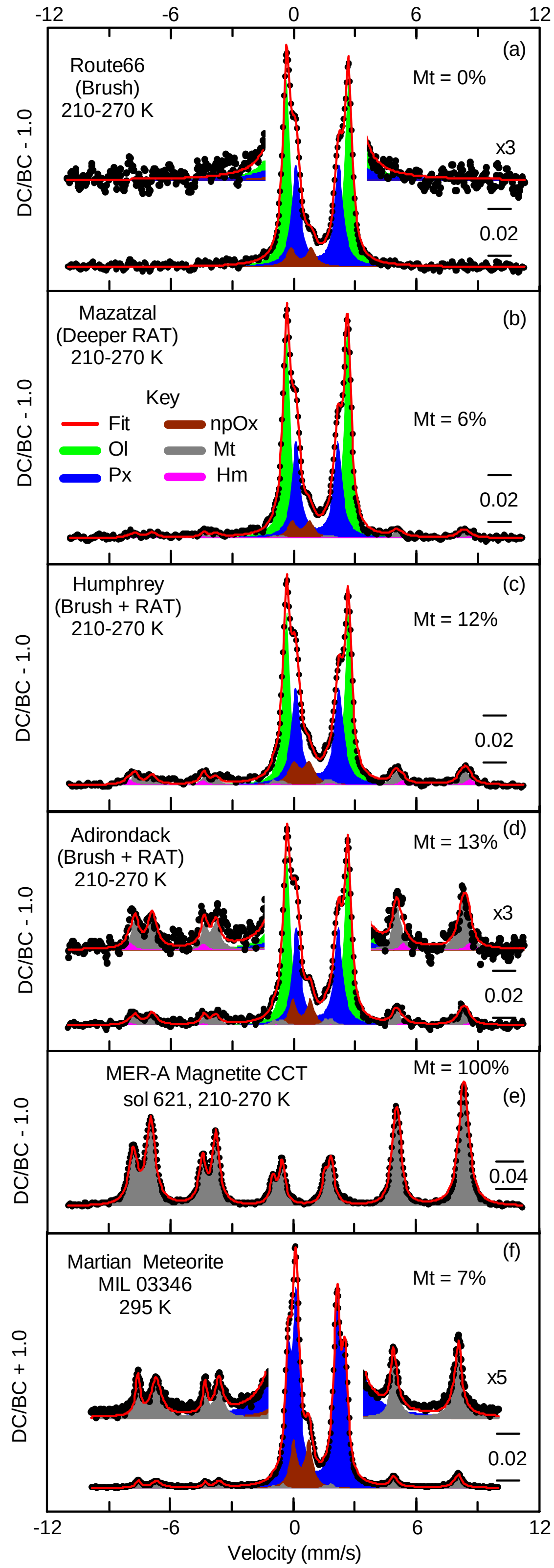

Fig. 2. Mössbauer spectra for (a-d) Gusev crater Adirondack class rocks, (e) MER CCT target, and (f) MIL 03346 (inverted transmission spectrum). DC = data counts; BC = baseline counts.