Spectroscopic Study of Iron-Based Minerals on Earth and Mars

Project Purpose

- Identify the common magnetic minerals found on Earth and Mars
- Characterize the magnetic signature of those iron-bearing minerals
- Determine the morphological and magnetic properties of those minerals comprising of nanophased components that are not well understood using existing theoretical models.
- Through the characterization of those minerals in conjunction with modeling, determine the relationship between crystal formation and geological processes on Mars.

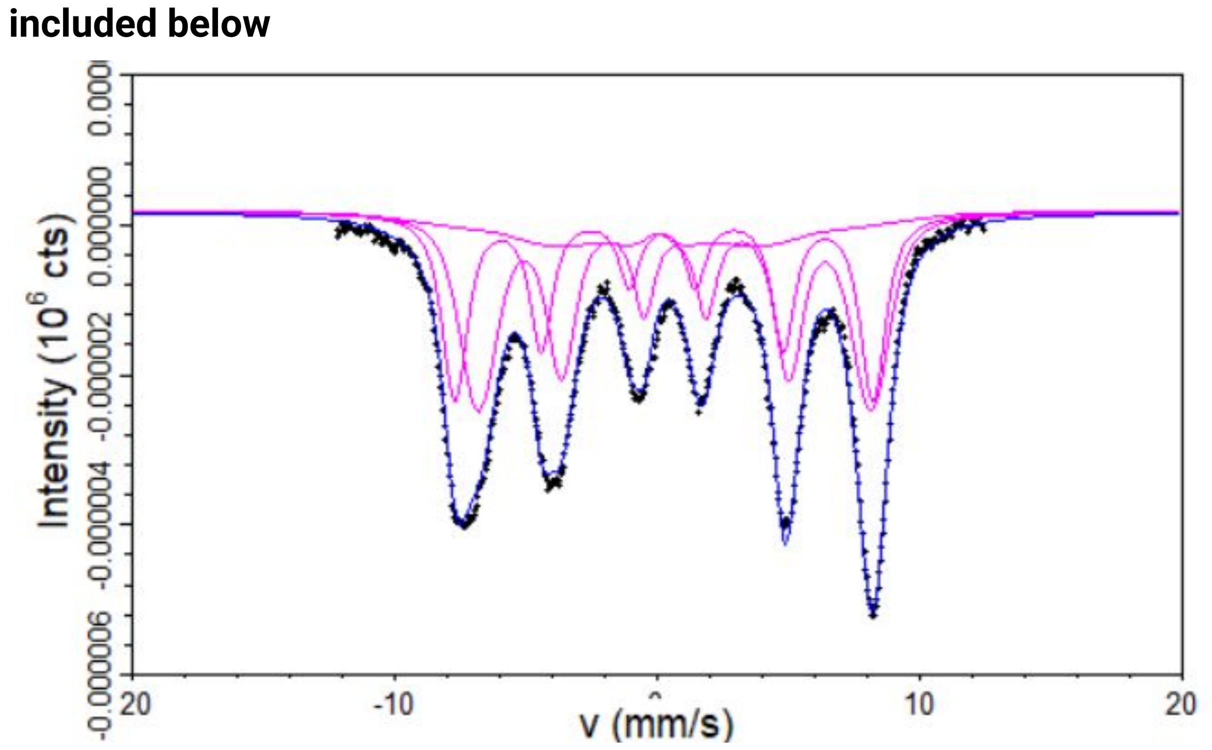
Background

- Mössbauer spectroscopy is a method of measuring the recoilless emission of gamma rays released from the decay of cobalt-57 to iron-57 and its absorption in samples (Klingelhöfer et al., 2003, p. 2).
- This absorption is recorded in a spectrometer as a function of velocity where the source is Doppler shifted up to ±15 mm/s.
- The data from iron-bearing minerals are analyzed by fitting the spectra to sub-spectral components referred to as sites hereon.
- Sites that conform to theoretical values are considered “bulk sites,” while sites that do not conform are indicative of nanophase components.
- The research uses Mossbauer spectroscopy to characterize iron-bearing magnetic minerals, such as magnetite, commonly found on Earth and Mars.

Experimental Procedure

- Publicly available data collected by the Miniaturized Mössbauer Spectrometer (MIMOS-II) onboard NASA’s rover, *Spirit*, from Mars samples between Sols 14-200 was analyzed in this research (Mössbauer Summed, 2020).
- Spectral data for lab-synthesized magnetite crystals of varying sizes (12-200 nm) provided by Dr. Rama Balasubramanian, Roanoke College, VA, was also used to compare and contrast mineral formation on Earth and Mars.
- Both sets of spectra (9 Mars spectra and 4 magnetite spectra) were analyzed using *Recoil*© software, through a multi-iterative fitting process, by fitting them to multiple Voigtian distribution functions ie. sub-spectral sites (Fig. 1a & 1b).
- This enabled the characterization of the hyperfine properties such as isomer shift, quadrupole splitting, the magnetic field, and other inherent properties of these minerals (Fig. 1a & 1b).
- The hyperfine properties of the magnetite crystals were statistically analyzed using lines of regression to determine the relationship between the relative areas of the nanophase vs. bulk sites as a function of crystal size (Fig. 2)
- This relationship from magnetite samples was used to provide a baseline of comparison for the evolution of crystals at specific locations on Mars used in this research (Fig. 4&5).

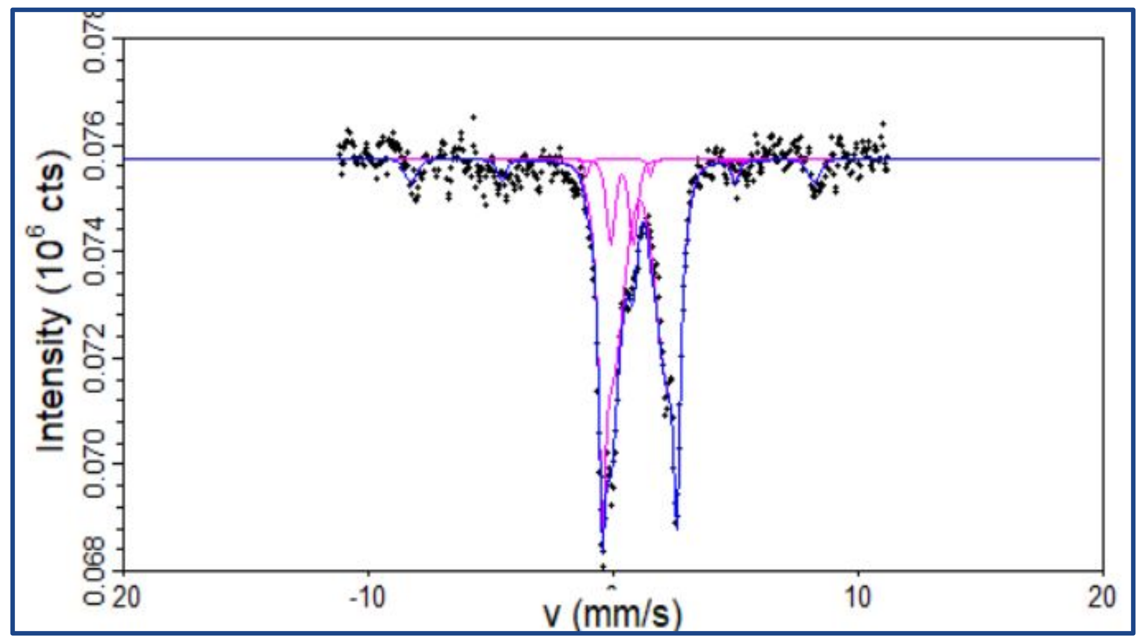
Fig. 1a: 100 nm Magnetite Spectrum fitted using *Recoil*©; values included below



Site 1		Site 2		Site 3	
<H> Value:	49.40	<H> Value:	46.40	<H> Value:	44.0/22.5
Sigma Value:	1.22	Sigma Value:	2.88	Sigma Value:	12.9/7.0
% Area:	35.85%	% Area:	49.44%	% Area:	14.64%

Relative area of nanophase to bulk site: 0.054

Fig. 1b: Sol 50 *Spirit* MIMOS-II Spectrum fitted using *Recoil*©; values included below



Site 1		Site 2		Site 3	
QS Value:	2.67	QS Value:	0.93	<H> Value:	50.99
Sigma Value:	0.52	Sigma Value:	0.26	Sigma Value:	1.32
% Area:	82.23%	% Area:	10.10%	% Area:	7.67%

Relative area of nanophase to bulk site: 1.3164

Fig. 2: Relation Between Crystal Size and Relative Area of Nanophase Components to Bulk Site

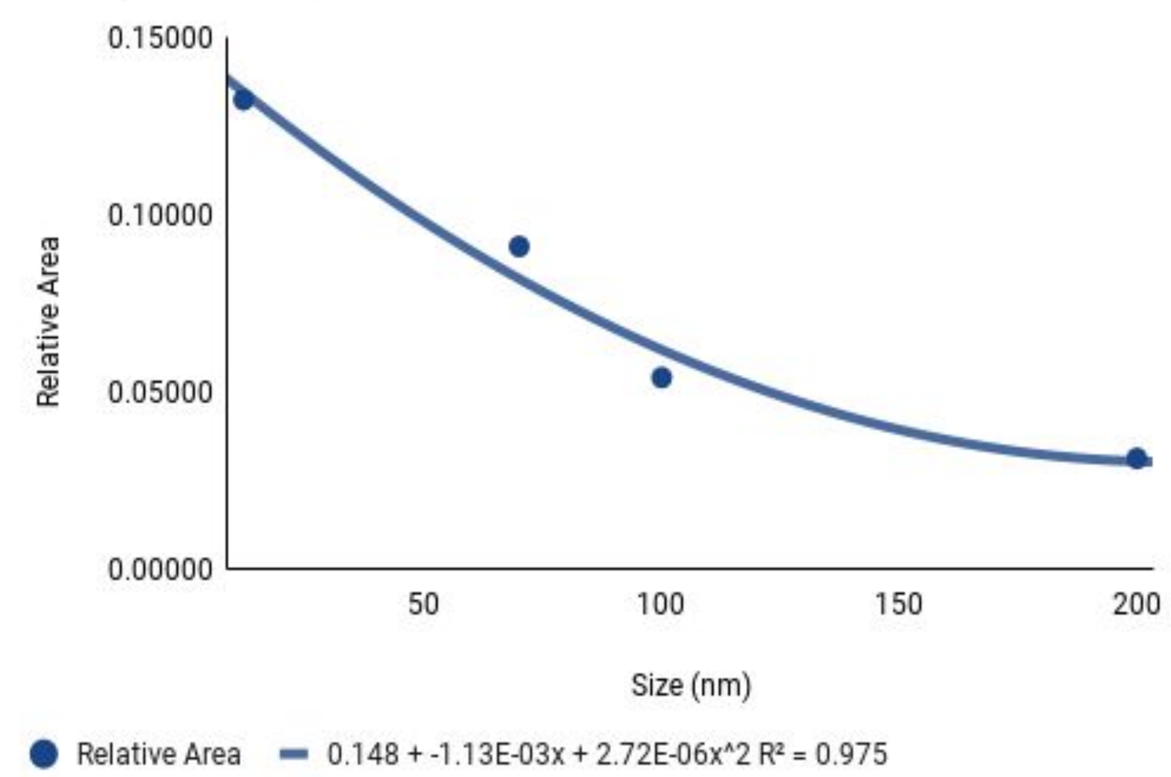


Fig. 3: <H> Field (HF) Values at Different Sites for Varying Crystal Sizes

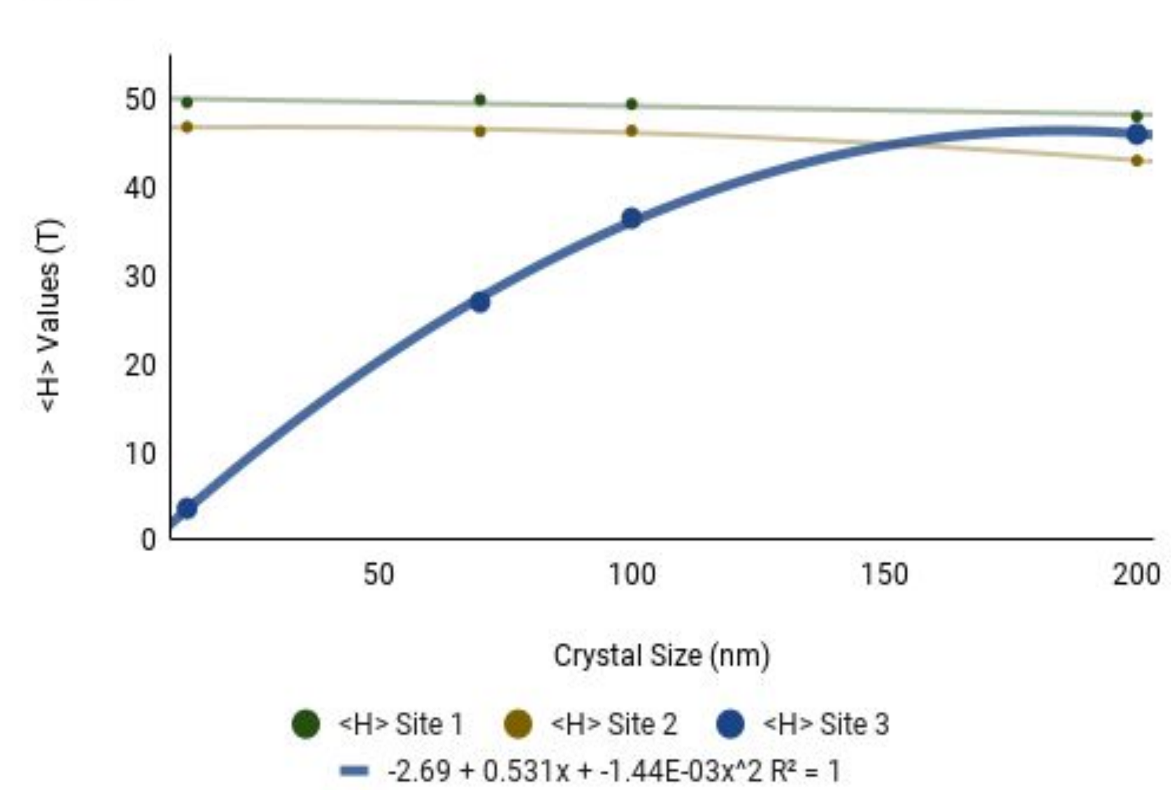
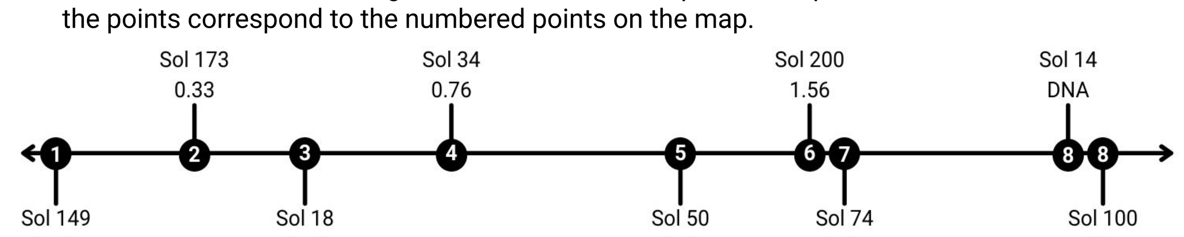


Fig. 4: Relative Area of Nanophase to Bulk Sites for Mars Sample:

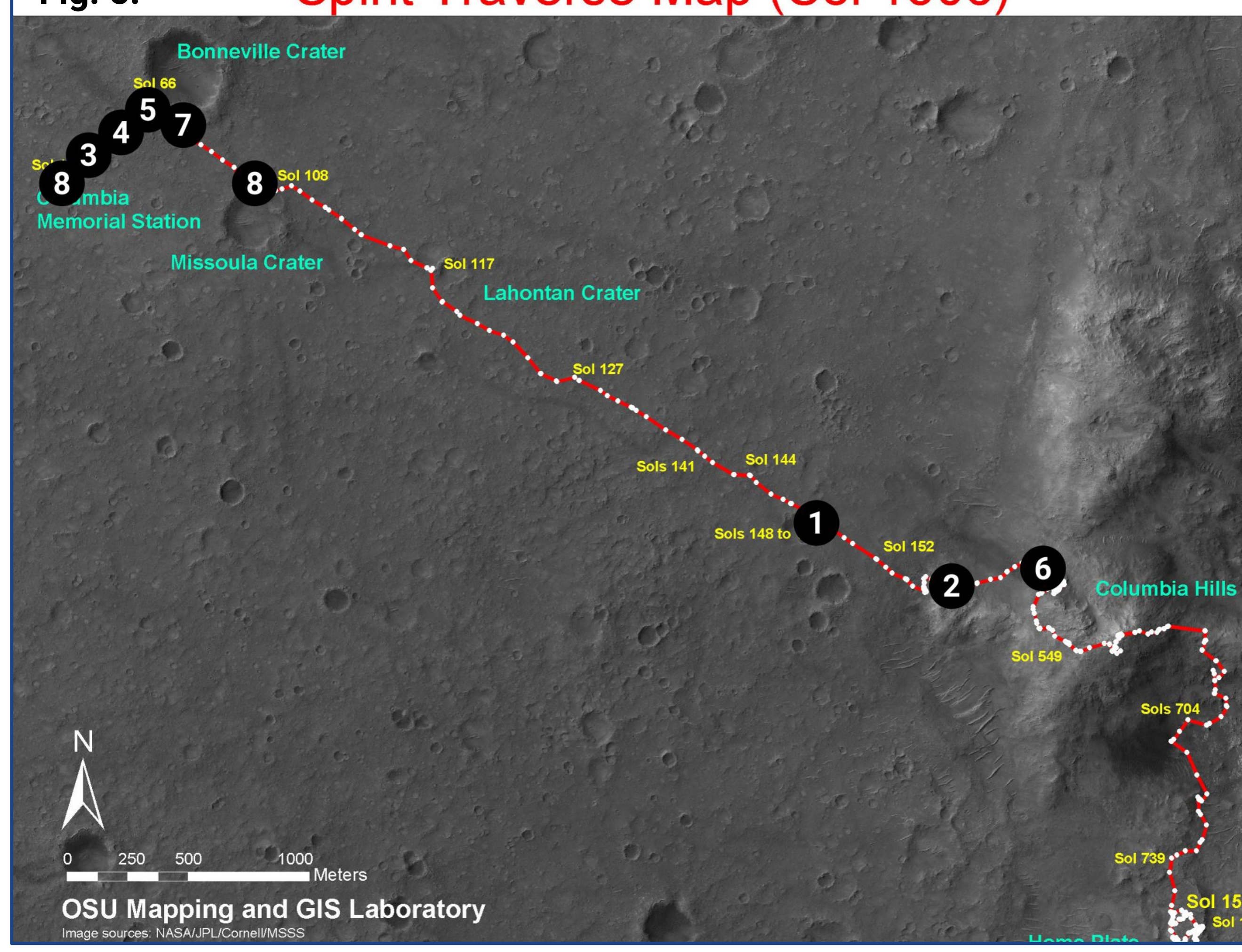
The relative area is here organized by the solar day or “sol” when the sample was analyzed, and is ranked from least to greatest amount of nanophase components. The numbers on the points correspond to the numbered points on the map.



Results & Discussion

1. As particle size of magnetite crystals increased from 12 to 200 nm, the magnetic field corresponding to bulk remained relatively constant between 48-50T, following the theoretical model (Fig. 3).
2. The nanophase contribution for these crystals increased with decrease in particle size (Fig. 2).
3. An inverse polynomial relation was determined between the relative area of nanophase components and bulk site and crystal size (Fig. 2).
4. The common mineral/iron-oxides found on Mars at the locations in question were olivine, pyroxene, and magnetite (Fig. 1b).
5. An increased contribution was detected from the nanophase components to the spectra of the minerals found at the edges of craters compared with plain rocky terrain along the rover’s path (Fig. 4 & 5).
6. Increased amounts of nanophase crystals is indicative of nucleation and crystal growth. Data from this research shows active nucleation sites at the crater edges (Klingelhöfer et al., 2004, p. 1740).
7. The increased nanophase contribution to magnetite-phase on Mars and well documented research on nanophase magnetite, indicates active crystal nucleation and growth stages.

Fig. 5: Spirit Traverse Map (Sol 1506)



Summary: Using magnetite, a common magnetic mineral found both on Earth and on Mars, and characterizing its magnetic properties, creates a clearer image of the contribution of nanophase components in crystals of different sizes. The analyzed spectra revealed that there is active crystal nucleation and growth stage minerals on Mars due to the high volume of nanophase component and prior Earth-based research on magnetite which determined that high nanophase component volume of magnetite is indicative of active crystal nucleation

Applications & Further Research: There may be active nucleation processes taking place on Mars as signified by the nanophase components. Previous research conducted using Mössbauer spectroscopy on Mars samples identified iron-based minerals such as jarosite that are indicative of aqueous environments on Mars (Klingelhöfer et al., 2004, p. 1740).). This could be further investigated by looking deeper below the surface of Mars in future missions for aqueous environments, sulfur vents, and/or other growth-inducing circumstances.

Citation: Figures 1-4 were generated by the author of this research using the data. Figure 1 uses *Recoil* generated spectral analysis. Figues 2 and 3 use Google Sheets statistical analysis and graph functions. Figure 4 uses *Canva*, a graphic design tool to generate the graphic. Figure 5 is obtained from NASA in April 2008 (see below).

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