**INHOMOGENEITY OF BASALTIC ROCKS AT GUSEV CRATER ON MARS.** H. P. Gunnlaugsson[1], H. Rasmussen[2], M. B. Madsen[3], P. Nørnberg[2]. [1]Institute for Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Århus C, Denmark, [2]Department of Earth Sciences, Aarhus University, Ny Munkegade, DK-8000 Århus C, Denmark, [3]University of Copenhagen, Juliane Mariesvej 30, 2100 Copenhagen, Denmark (hpg@phys.au.dk)

**Introduction:** The Mars Exploration Rovers (MERs) both carry backscattering Mössbauer spectrometers [1] that can give fingerprints of Fe containing minerals. Spectra are obtained by using a radioactive source containing $^{57}$Co ($T_{½}$ = 272 d) that feeds the 14.4 keV Mössbauer state of $^{57}$Fe ($T_{½}$ = 140 ns). Part of this radiation is emitted without recoil and can be resonantly absorbed by $^{57}$Fe in the sample and re-emitted. In most cases, internal conversion takes place, where an electron is emitted from the inner shells of the $^{57}$Fe, and a 6.4 keV X-ray is emitted as a result. The hyperfine pattern of the sample is probed by modulating the energy of the source by relative movement with respect to the sample. Detection of both the backscattered 14.4 keV and the 6.4 keV radiations will give information on the hyperfine pattern. The basic difference between the two types of spectra obtained is in the depth below the surface from which they originate. Taking penetration depth of the incoming and emitted radiation into consideration for samples of typical basaltic composition and density (~3 g/cm$^3$), the 14.4 keV radiation originates from the top ~150 $\mu$m while the 6.4 keV radiation originates from the top ~75 $\mu$m.

Mössbauer spectroscopy of relatively unaltered basaltic rocks at Gusev crater has revealed considerable difference between these two types of spectra [2-5]. This has partly been attributed to thickness effects [4] or enhancement of olivine in the surface layer due to high temperature alteration of the mineral [3].

**Results:** The spectra were analysed simultneously, making use of temperature dependent parameters of Mössbauer spectroscopy. Example spectra are shown in Fig. 1.

Inhomogeneity in the surface layer is clearly seen in the ratio of olivine vs. pyroxene. The analysis of the spectra in Fig. 1 reveals olivine/pyroxene ratio of 1.51(4) in the 14.4 keV spectra while this ratio is 3.3(2) in the 6.4 keV spectra.

Supporting the conclusion that this effect is real, is seen in the correlation of iron oxides vs. the amount of olivine. One of the characteristics seen in Mössbauer spectra of partially oxidized olivine basalt is a negative correlation between the amount of Fe in olivine and iron oxides [2, 3, 5]. This is due to oxidation of olivine according to

$$\underset{\text{(olivine)}}{6\cdot FeMgSiO_4} + O_2 \rightarrow \underset{\text{(magnetite)}}{2\cdot Fe_3O_4} + \underset{\text{(enstatite)}}{6\cdot MgSiO_3}$$

However, this trend is not observed in the 14.4 keV nor 6.4 keV spectra (cf. Fig. 2). However, if one calculates the interior composition by subtracting the 6.4 keV results from the 14.4 keV results according to

$$p_{\text{interiour}}(c) = \frac{p_{14.4\,\text{keV}}(c) - h\cdot p_{6.4\,\text{keV}}(c)}{(1-h)}$$

with $h$ = 0.5, the espected trend is observed (cf. Fig. 2).

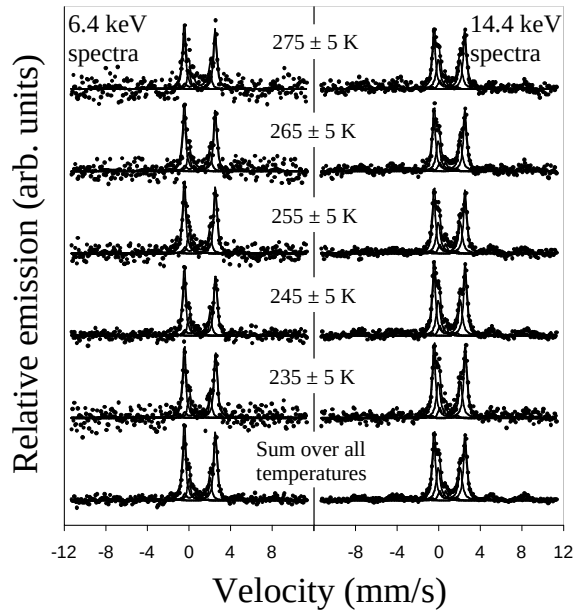


Fig. 1: Mössbauer spectra obtained of the rock target Adirondack after grinding at the temperatures indicated.

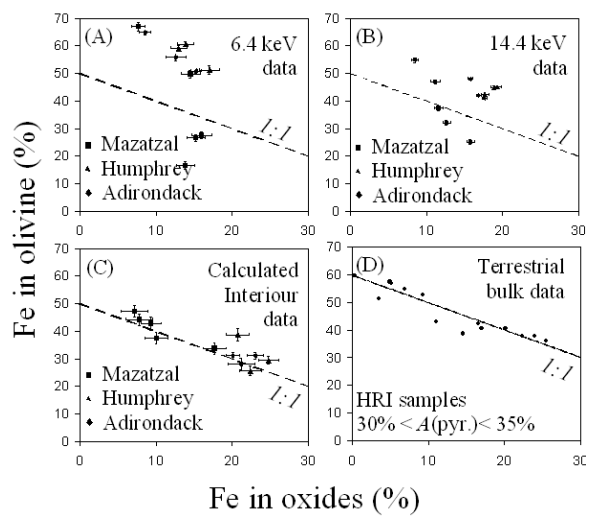


Fig. 2: Correlation between Fe in oxides (magnetite and ferric oxide(s)) and Fe in olivine. (A) Based on 6.4 keV Mössbauer data from Mars, (B) based on 14.4 keV Mössbauer data from Mars, (C) calculated interior of the samples obtained by subtracting 6.4 keV data from the 14.4 keV data, (D) Terrestrial bulk data obtained by transmission Mössbauer spectroscopy on powder samples (from [2]).

**Discussion:** Inhomogeneities in the surface layer have been observed for olivine basalt where oxidation of olivine

has taken place at high temperatures. Fig. 3 shows a SEM image of a sample from the Stardalur magnetic anomaly (in Iceland).

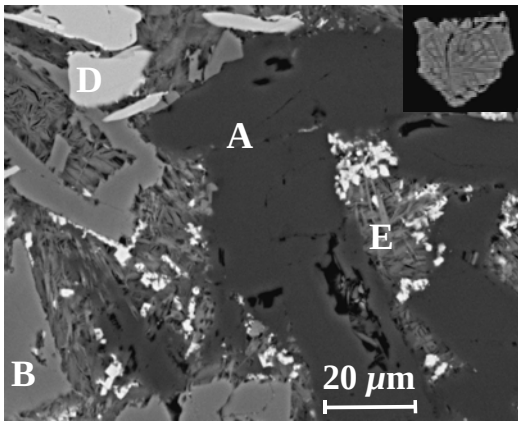


Fig. 3: SEM backscatter image of a Stardalur sample (STI-60). A: Plagioclase, B: Pyroxene, D: Fe-Ti oxides, contrast enhanced in the upper right corner, E: pure Fe oxides embedded in partially serpentinized olivine.

The oxidized olivine become mechanical weaknesses in the material, and when cracks form, either due to sample preparation or mechanical weathering, cracks will develop preferentially through these areas, thus enhancing the olivine signal in the surface layer.

In our collection of terrestrial samples, we have still not been able to find samples with exactly the same properties, and conversion electron Mössbauer spectroscopy is needed to observe the olivine enhancement in the surface layer (cf. Fig. 4).

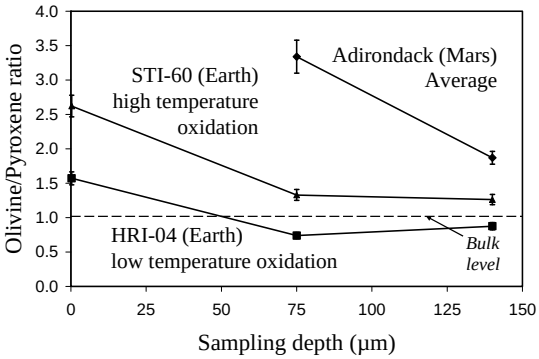


Fig. 4: Olivine/pyroxene ratio determined by Mössbauer spectroscopy using CEMS, backscatter and transmission methods, of two Icelandic analogues (STI-60 and HRI-04) compared to the rock target Adirondack on Mars.

Depending on the conditions, high temperature (> 1000°C) oxidation of olivine can produce single domain (SD) magnetite. The remanence magnetization of such magnetite can be as high as 30 A/m per weight percentage of magnetite. Based on the chemistry and Mössbauer spectra of rocks at Gusev crater, it can be argued that the samples contain up to 2 wt.% of magnetite. If these rocks solidified in an external magnetic field of terrestrial standard, one could expect that they had aquiered remanence magnetization of ~60 A/m, more than sufficient to explain the magnetic anomalies on Mars.

**Conclusion and summary:** Mössbauer spectra of samples from Mars show inhomogeneities in the surface layer (50-200 μm). Applying simple methods to calculate the interiour composition, gives a correlation between olivine and magnetic phases, which is also known from terrestrial samples. Similar inhomogeneities are observed in terrestrial samples, where the oxidation of olivine has taken place at high temperatures. Possible consequences are formation of SD magnetite. If the rocks investigated at Gusev crater solidiefied in a external magnetic field of terrestrial standard, one would have high enough remanence magnetization to explain the magnetic anomalies on Mars.

**References:** [1] Klingelhöfer et al., *JGR* **108** (2003) 8067. [2] Rasmussen et al., Hyp. Int. 166 (2005) 561-566. [3] Gunnlaugsson et al., Phys. Earth Planet. Int., 154 (2006) 276-289. [4] Fleischer et al., *JGR*, **113** (2008) E06S21. [5] Gunnlaugsson *et al*., *Planet. Space Sci.* (2009) in press.