Depth Profiling of Iron Species in Sooke #1 Find with Mössbauer Spectroscopy

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In our paper #6005 to be presented at this conference we have reported our first Raman analyses of 13-kg Sooke #1 find in Sooke Basin near Juan de Fuca Strait. Having an opportunity of examining more samples from this unusually large object, here we report on the heat-affected transformation of Fe-bearing minerals in it as observed by Mössbauer transmission spectroscopy of 14.4-keV gamma rays in ^{57}Fe nuclei.

Keywords: aerodynamic heating, iron species, magnetite, iron silicates

In general, the Mössbauer spectra of Sooke #1 samples are very similar to the spectra of Martian takhlite meteorite examined by Morris et al. (2008). Mössbauer spectra of such stony meteorites usually consist of three doublets due to paramagnetic Fe(II) in olivine and pyroxene and two sextuplets of absorption lines due to magnetically ordered iron represented by hyperfine magnetic field B_{hf} of 49.1 T at tetrahedral A sites and 45.7 T at octahedral B sites of magnetite Fe_3O_4.

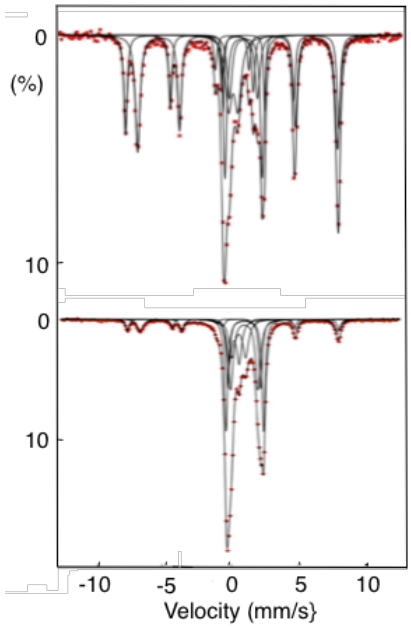

Fig. 1. Examples of Mössbauer spectra of Sooke #1 samples: Top - sample from the fusion crust, bottom - sample from 5 mm under the crust.

Two overlapping doublets with the largest quadrupole splitting $\Delta \sim 2.85$ to 3.0 mm/s were fitted as one and ascribed to Fe in 4-coordinated M1 and M2 sites in forsterite-fayalite olivine series $(Mg,Fe)_2SiO_4$. The magnitude of Δ in this doublet decreases with increase of Fe/(Fe+Mg) from the value ~3.0 mm/s characteristic of forsterite in crust samples to 2.85 mm/s characteristic of fayalite in deep samples. Similarly, as in Morris et al. (2008) study of MIL 03346 crust the values of δ and Δ for the olivine doublet in crust samples of Sooke #1 indicate that this crust is richer in forsterite.

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In Sooke #1 samples Fe(II) ions are also observed in doublets from octahedral M1 and M2 sites of clinopyroxene diopside $(Ca,Mg,Fe^{2+})Si_2O_6$ or ferrosilite $Fe^{2+}MgSi_2O_6$. The obtained average values of isomer shift δ and quadrupole splitting Δ for Fe(II) in these two doublets in the spectra recorded vs. depth of samples were: δ = 1.13 and Δ = 2.56 mm/s in 4-coordinated M1 site and δ = 1.14 and Δ = 2.00 mm/s in 6-coordinated M2 site along the diopside-hedenbergite tie-line. The fourth doublet with parameters on average δ = 0.36 mm/s and Δ = 0.76 mm/s has been ascribed by us to 6-coordinated Fe(III) fraction in M1 sites in hedenbergite; similarly as in Eeckhout & DeGrave (2003) article.

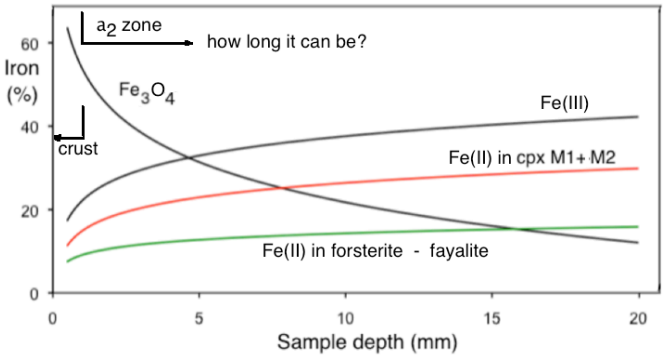

Fig. 2. The fractions of different iron species versus distance from fusion crust surface in Sooke #1 find.

As shown in Fig. 2, with increasing distance of samples from crust to ~5 mm inside the fraction of Fe in magnetite decreased rapidly from 65% to 30% and then slowly to ~15% at 20 mm inside. In parallel, the total fraction of Fe(II) ions in clinopyroxene M1 and M2 sites increased from ~15% to 30% and in olivine from 10 to ~15%; while the fraction of Fe(III) increased from 15% to 40%.

The results presented in Fig. 2 may pose the question: how deep is the heat-affected zone a_2 in this find and in general in stony meteorites. It is usually assumed that this zone is not deeper than 4 mm. However, in some reports (UCLA Meteorite Collection https://meteorites.ucla.edu/faq) the heat-affected zone may be even as deep as 2 cm. Many known and unknown factors may play a role here: meteoroid origin and history in space, inner structure, velocity and angle of descent, size and surface shape, thermal conductivity, surface emissivity, thickness of the fusion crust, composition and grain size of the mineral matrix and temperature gradient inside during its passage through the Earths atmosphere.

In conclusion, Mössbauer spectroscopy analyses of Sooke #1 samples showed much larger amount of magnetite in the crust and in heat-affected α_2 zone than in the inner samples. The enrichment of crust and heat-affected zone in magnetite as well as fayalite to forsterite transformation trend are most likely caused by aerodynamic heating during hypersonic entry at Mach 60+ and faster diffusion and evaporation of Mg than Fe atoms during ablation. As a result, such abrupt heating during meteoroid fall enriches pyroxene and olivine grains near its surface in Fe(II) and adds Fe(III) needed for magnetite formation in crust and near inner cracks. The variations in Fe species reflect the temperature distribution inside meteoroid during its fall and thus Mössbauer spectroscopy depth profiling may become a useful tool for studying thermal history of meteoroids and meteorites.