Meteorites
2, Nos. 1–2, 2012, 73–77
www.meteorites.pwr.wroc.pl
DOI 10.5277/met120109

MÖSSBAUER STUDIES OF SOŁTMANY METEORITE – PRELIMINARY RESULTS

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Abstract: In Mössbauer spectra of the Sołtmany meteorite we identified four iron-bearing minerals: olivine, pyroxene, kamacite and troilite. The distribution of iron among these minerals is different in the Sołtmany meteorite from this distribution in the Baszkówka meteorite. As Sołtmany and Baszkówka meteorites are ordinary chondrites type L (both falls), differences in the distribution of iron over the four main iron-bearing mineral phases could be the basis for a new classification of L-type ordinary chondrites. Small amounts of taenite were also observed in the Sołtmany meteorite. The ratio of iron in kamacite and taenite in the Sołtmany meteorite was found to be about 3. No Fe^{3+} could be detected.

Key words: Mössbauer spectroscopy, Sołtmany meteorite, Baszkówka meteorite, ordinary chondrites classification

INTRODUCTION

The application of Mössbauer spectroscopy to meteorites studies started shortly after the discovery of the Mössbauer effect. The first paper dealing with this subject was published in 1964 (Sprenkel-Segel & Hanna, 1964). Mössbauer spectroscopy has several advantages for investigating iron in meteorites: it distinguishes unequivocally between divalent (Fe^{2+}) and trivalent iron (Fe^{3+}), it may identify iron-bearing compounds and there is no oxidation or spin state of iron which is Mössbauer silent. Mössbauer spectra usually show a single spectral line (singlet) or a characteristic symmetric doublet for each non-equivalent position of iron atoms in the crystal lattice of non-magnetic compound and a characteristic sextet for each position of iron atoms in a magnetic compound. Components of Mössbauer spectra can serve as fingerprints, when the identification of an iron-bearing compound is done by comparing Mössbauer parameters obtained from Mössbauer spectra of an investigated sample to those of known materials.

Typical Mössbauer spectra of freshly fallen ordinary chondrites show a superposition of two doublets and two sextets. In Mössbauer spectra of weathered meteorites additional subspectra can be observed. Components of Mössbauer spectra are characterized by the following Mössbauer parameters: the isomer shift (IS), the quadrupole interaction parameter ($e^2qQ/2$, sometimes denoted as QS – quadrupole splitting for doublets), the line widths (w) and the value of the internal magnetic field (H). The values of the isomer shifts, quadrupole splittings and line widths are usually given in velocity units (mm/s) and the values of the hyperfine magnetic fields in kOe or in Tesla. The relative amounts of iron present in different mineral phases in a compound (which in total make 100%) are proportional to the relative areas of the corresponding subspectra. The application of Mössbauer spectroscopy to mineral samples is discussed in a review by Kuzman et al (2003).

In our laboratory Mössbauer studies of some different Polish meteorites were performed. Möss-

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bauer studies of the Baszkówka meteorite, classified as ordinary chondrite type L5, were published in 1998 (Gałązka-Friedman et al., 1998) and in 2001 (Gałązka-Friedman et al., 2001). Mössbauer studies of the enstatite meteorite Zakłodzie (Maliszewski et al., 2008) and the iron meteorite Morasko (Wojnarowska et al., 2008) were published in 2008.

Here we present preliminary results of Mössbauer studies of a new Polish meteorite, Sołtmany, classified as an ordinary chondrite type L (Karwowski, 2012).

MATERIALS AND METHODS

A finely powdered sample of the Sołtmany meteorite was obtained from Prof. Tadeusz Przylibski from Wrocław University of Technology. A Mössbauer spectra of this unaltered sample (sample S) was performed and then a permanent magnet was used to separate the magnetic phase from the non-magnetic phase. The original sample S was thus divided into two samples: SM – containing mainly the magnetic phase and sample SNM – containing mainly the non-magnetic phase. Mössbauer measurements were then performed on these two samples.

Mössbauer spectra of ^{57}Fe were obtained at room temperature using a conventional Mössbauer spectrometer. A 15 mCi ^{57}Co-in-Rhodium source, giving a narrow, un-split emission line, was used. The 14.4 keV gamma rays were detected by a proportional counter. The velocity scales were calibrated using an iron foil absorber at room temperature and isomer shifts are given relative to this absorber. The Recoil program written by Denis Rancourt (http://www.is-apps.ca/recoil/) and "Full Static Hamiltonian analysis" were used to fit the experimental spectra.

RESULTS

Figure 1 shows the Mössbauer spectrum obtained from sample S. Four main subspectra are observed in this spectrum: two doublets and two sextets. The Mössbauer parameters obtained from the best fit to this spectrum are given in Table 1.

The identification of the minerals in each sample was performed by comparing the Mössbauer parameters given in Table 1 with data given in the Mössbauer Mineral Handbook (Stevens et al., 1998). This comparison showed that doublet 1 is a subspectrum due to iron in olivine, doublet 2 is due to iron in pyroxene, sextet 1 corresponds to iron in troilite and sextet 2 is with iron present in kamacite.

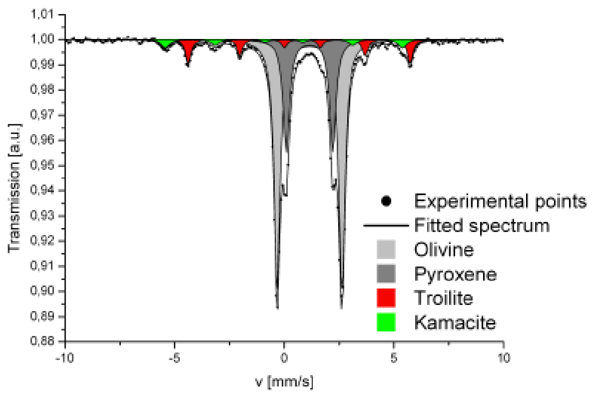

Fig. 1. Mössbauer spectrum obtained from sample S of the Sołtmany meteorite

As seen in Table 1, the Mössbauer line-width in the subspectrum attributed to kamacite was somewhat broader than the line widths obtained in the other subspectra. We suspected therefore that sextet 2, which is the subspectrum identified as kamacite, might be composed of two subspecra, one due to kamacite and one due to another magnetic compound. We therefore tried to separate sample S, as described in the Materials and Methods section, into the magnetic (SM) and non-magnetic (SNM) part. The Mössbauer spectrum of sample SM is shown in Figure 2.

As seen from the figure, the magnetic separation was not perfect and in sample SM the four subspectra of olivine (gray in the figure), pyroxene (dark gray), troilite (red) and kamacite (green) are still present,

Table 1. Mössbauer parameters obtained from the best fit to the experimental spectrum of sample S. Mössbauer parameters are: *IS* – isomer shift, *H* – internal magnetic field, $e^2qQ/2$ – quadrupole interaction parameter, *w* – HWHM (half width at half maximum), θ – angle between direction of magnetic field and the main axis of the electric field gradient and *A* – the share of iron atoms in the phase

	IS [mm/s]	*H* [T]	$e^2qQ/2$ [mm/s]	*w* [mm/s]	θ [deg]	*A* [%]
doublet 1	1.14(2)	–	2.94(2)	0.17(2)	–	60(1)
doublet 2	1.15(2)	–	2.11(2)	0.17(2)	–	26(1)
sextet 1	0.75(2)	30.9(2)	0.98(12)	0.14(2)	62(2)	9(1)
sextet 2	0.02(2)	33.5(2)	0.01(2)	0.22(2)	–	5(1)

Table 2. Mössbauer parameters obtained from the best fit to the experimental spectrum of sample SM. Mössbauer parameters are: *IS* – isomer shift, *H* – internal magnetic field, $e^2qQ/2$ – quadrupole interaction parameter, w – HWHM (half width at half maximum), θ – angle between direction of magnetic field and the main axis of the electric field gradient and A – the share of iron atoms in the phase

	CS [mm/s]	*H* [T]	$e^2qQ/2$ [mm/s]	*w* [mm/s]	θ [deg]	*A* [%]
olivine	1.14(2)	–	2.94(2)	0.17(2)	–	56(1)
pyroxene	1.14(2)	–	2.10(2)	0.16(2)	–	32(1)
troilite	0.74(2)	31.1(2)	0.73(2)	0.13(2)	63(2)	4(1)
kamacite	0.02(2)	33.8(2)	0.05(2)	0.14(2)	–	6(1)
taenite	0.07(2)	32.1(2)	0.31(2)	0.10(2)	–	2(1)

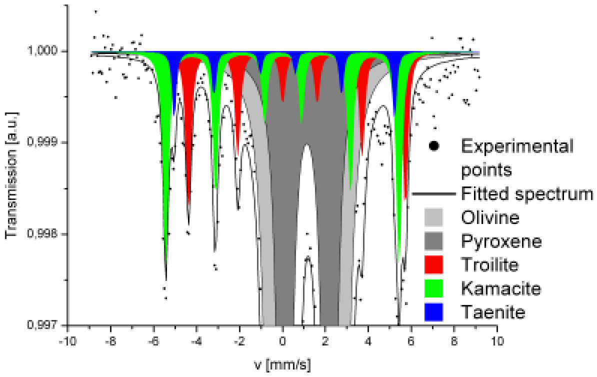

Fig. 2. Mössbauer spectrum obtained from sample SM of the Sołtmany meteorite

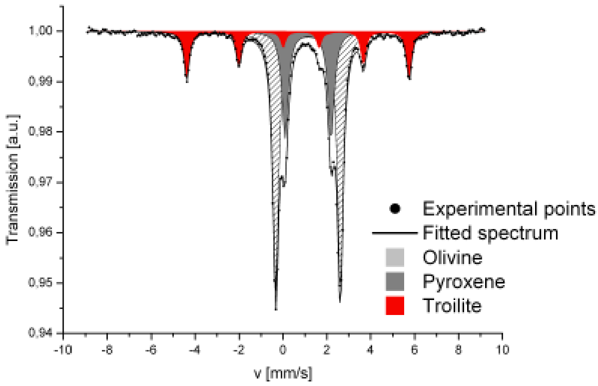

Fig. 3. Mössbauer spectrum obtained from sample SNM of the Sołtmany meteorite

Table 3. Mössbauer parameters obtained from the best fit to the experimental spectrum of sample SNM. Mössbauer parameters are: *IS* – isomer shift, *H* – internal magnetic field, $e^2qQ/2$ – quadrupole interaction parameter, *w* – HWHM (half width at half maximum), θ – angle between direction of magnetic field and the main axis of the electric field gradient and *A* – the share of iron atoms in the phase.

	CS [mm/s]	*H* [T]	$e^2qQ/2$ [mm/s]	w [mm/s]	θ [deg]	A [%]
olivine	1.14(2)	–	2.94(2)	0.16(2)	–	56(1)
pyroxene	1.15(2)	–	2.10(2)	0.17(2)	–	25(1)
troilite	0.76(2)	30.8(2)	1.00(2)	0.14(2)	62(5)	19(1)

yet the relative area of the subspectrum attributed to kamacite was somewhat higher. In the analysis of this spectrum we were able to fit another subspectrum whose parameters showed this to be due to iron in taenite (blue). The Mössbauer parameters obtained from this fit are given in Table 2.

The Mössbauer spectrum obtained from sample SNM is shown in Figure 3. Three subspectra related to olivine, pyroxene and troilite could be seen. Mössbauer parameters obtained from this spectrum are given in Table 3. The subspectra related to two magnetic minerals, kamacite and taenite, are observed only in sample SM.

DISCUSSION

The meteorite Sołtmany was classified as an ordinary chondrite type L. We compared the Mössbauer results obtained for the Sołtmany meteorite with those obtained earlier for another Polish meteorite, also classified as ordinary chondrite type L – the Baszkówka meteorite (Gałązka-Friedman et al., 2001). In Table 4 the relative amounts of iron present in the mineral phases in four samples of the Baszkówka meteorite (B1, B2, B3, B4) and in one sample of the Sołtmany meteorite (S) are listed. B-mean gives the mean values of the iron contribution to the phases in Baszkówka (obtained from B1 to B4).

As only one sample of the Sołtmany meteorite was investigated, we are not able to construct any distribution of the iron content of the main iron-bearing mineral phases present in this meteorite. It is therefore

Table 4. Iron distribution (atomic %) over mineral phases in four samples of the Baszkówka meteorite (B1-B4) and one sample of the Sołtmany meteorite (S).

Subspectrum	B1	B2	B3	B4	Bmean	S
kamacite	23	14	13	29	19.6 ± 3.8	4.5
troilite	25	28	33	26	28.5 ± 1.7	10
olivine	33	35	28	26	30.3 ± 2.1	59.5
pyroxene	16	21	24	18	19.8 ± 1.7	26
Fe^{3+}	3	2	2	1	2.0 ± 0.4	n.d.

n.d. – not detectable.

difficult to judge whether the differences between the relative amounts of iron present in the four mineral phases (kamacite, troilite, olivine, and pyroxene) in Baszkówka and Sołtmany meteorites are statistically significant.

To better visualize of the results listed in Table 4, Figure 4 was drawn. This figure shows the distributions of the iron content present in the Baszkówka meteorite in kamacite, troilite, olivine, and pyroxene. The area in grey shows the mean values (B-mean) and their uncertainties. The Gaussian curves show the probable distribution of each mineral phase in the Baszkówka meteorite. Each distribution diagram also contains a red arrow marking the relative iron content found in the one sample of the Sołtmany meteorite (sample S). These results show that the relative iron content in olivine in the sample of Sołtmany differs by about 7 standard deviations from the mean value of the iron content in olivine present in Baszkówka and 5.5 standard deviations from the iron content in troilite in the Baszkówka meteorite.

The relative iron content in kamacite and pyroxene in the sample of the Sołtmany meteorite differs by about 2 standard deviations from the analogue values in the Baszkowka meteorite. The above analysis suggests that the relative iron content in the four mineralogical phases of the Sołtmany and Baszkówka meteorites are significantly different. As these are only preliminary results, measurements of other samples of the Sołtmany meteorite are needed to confirm the results.

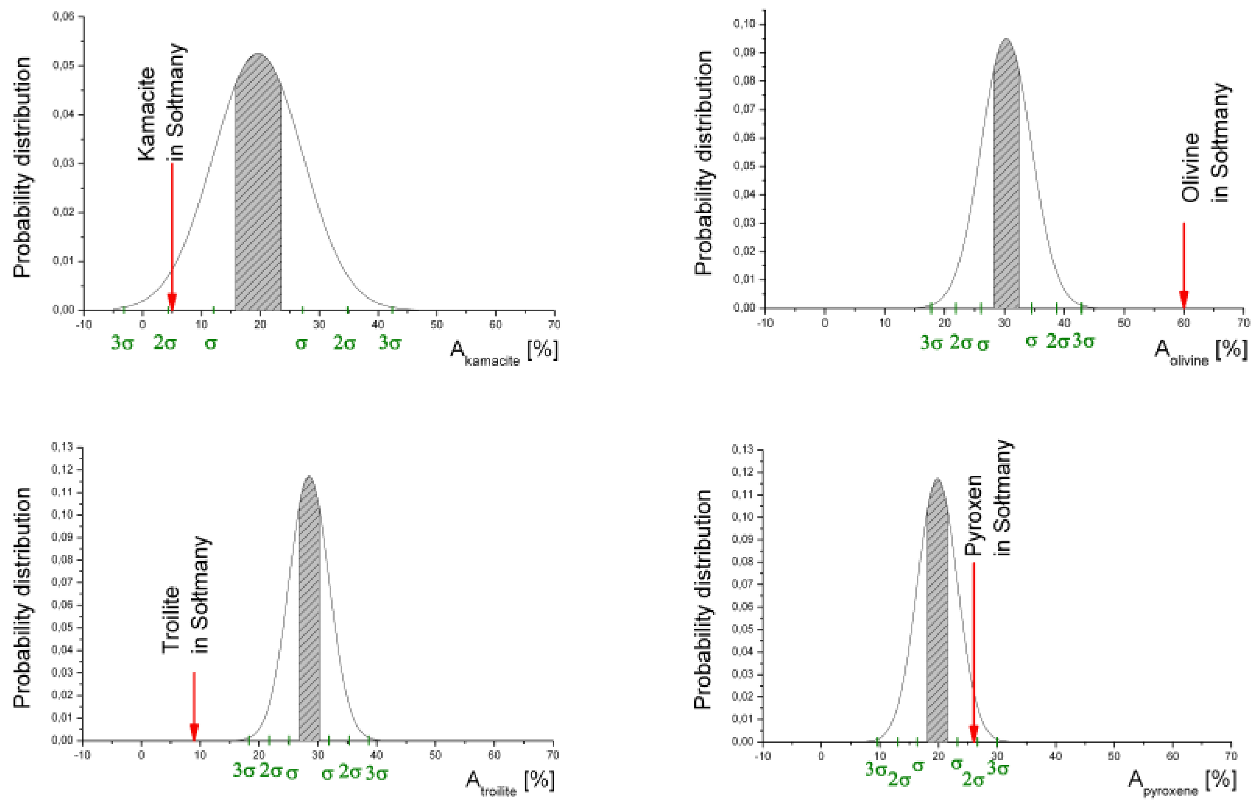

Fig. 4. Distribution of iron within different mineral phases from 4 different samples of Baszkówka meteorite

No Fe^{3+} was observed in the Mössbauer spectrum of the Sołtmany meteorite. This lack of Fe^{3+} is likely due to the immediate preservation of the meteorite and transfer to conditions preventing oxidation.

The results summarized in Table 2 show that in the Sołtmany meteorite the ratio between the contribution of iron in kamacite and taenite is about 3:1. For comparison, the similar ratio in a sample of the Morasko meteorite (Iron, IAB-MG) was 12:1.

CONCLUSIONS

Our preliminary results suggest that in the two ordinary L-type chondrite meteorites, Baszkówka and Sołtmany, there is a different distribution of iron over the four mineral phases typical for ordinary chondrites: olivine, pyroxene, kamacite, and troilite. This observation should be confirmed by additional Mössbauer measurements on a larger number of samples of the Sołtmany meteorite and it should also be verified whether similar differences are present in other L-type ordinary chondrites. In the future, Mössbauer investigations related to the ratio of iron (Fe^{2+}) in kamacite and taenite in different meteorites should also be explored. These simple Mössbauer studies could become the basis for formulating a new criterion for the classification of ordinary chondrites.

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