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Mössbauer study of Slovak meteorites

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Abstract ^{57}Fe Mössbauer spectroscopy was used as an analytical tool in the investigation of iron containing compounds of two meteorites (Rumanová and Košice) out of total of six which had fallen on Slovak territory. In the magnetic fraction of the iron bearing compounds in the Rumanová meteorite, maghemite, troilite and Fe-Ni alloy were identified. In the non-magnetic fraction silicate phases were found, such as olivine and pyroxene. The paramagnetic component containing Fe^{3+} ions corresponds probably to small superparamagnetic particles. The Košice meteorite was found near the town of Košice in February 2010. Its magnetic fraction consists of a Fe-Ni alloy with the Mössbauer parameters of the magnetic field corresponding to kamacite α-Fe(Ni, Co) and troilite. The non-magnetic part consists of Fe^{2+} phases such as olivine and pyroxene and traces of a Fe^{3+} phase. The main difference between these meteorites is their iron oxide content. These kinds of analyses can bring important knowledge about phases and compounds formed in extraterrestrial conditions, which have other features than their terrestrial analogues.

Keywords Meteorite · Mössbauer effect

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1 Introduction

A meteorite, Rumanová, was found by J. Tehlár during field work in August 1996 near the village Rumanová in western Slovakia. Its weight was 4.3 kg and its density was 3.53 gcm^{-3} [1]. Meteorite Košice fell down on 28th of February, 2010, near the town Košice in the form of many small stone pieces. Both these meteorites were classified as ordinary chondrites H5 [2, 3]. The radioactive clock methods have established that the chondrites were formed 4.5 billion years ago. These meteorites remained in Slovakia as museum pieces and for scientific investigation. Mössbauer spectroscopy was used for the analysis of iron bearing compounds in ordinary chondrites in various works [4–9]. Due to the high abundance of iron in the solar system and its chemical and physical properties, we can gain insight into the formation and evolution of planets through the study of iron compounds in planetary bodies. These kinds of analyses can bring important knowledge about phases and compounds formed in extraterrestrial conditions, which have other features than their terrestrial analogues. ^{57}Fe Mössbauer spectroscopy is one of the most sensitive methods for such studies. In this work Mössbauer spectroscopy is used for phase analysis from the point of iron bearing compounds with the aim to identify magnetic and non-magnetic fractions and to compare these two meteorites.

2 Experimental details

The samples were prepared in powder form. The spectra were measured at room temperature using a Wissel Mössbauer spectrometer with a $^{57}Co(Rh)$ source in transmission geometry. Hyperfine parameters of the spectra including spectral area (A_{rel}), isomer shift (IS), quadrupole splitting (QS), as well as hyperfine magnetic field (B_{hf}), were refined using the CONFIT fitting software [10]. The accuracy in their determination is of the order of ±1 % for the relative area A_{rel}, ±0.04 mm/s for the isomer shift and quadrupole splitting/shift and ±0.5 T for the hyperfine field respectively. Mössbauer measurements showed a spectrum with many overlapping subspectra. In order to fit them a fitting procedure was applied with a superposition of magnetic and non-magnetic components.

3 Results and discussion

The Mössbauer spectra of Rumanová and Košice meteorites are given in Fig. 1. The spectra consist of components related to iron-bearing phases with different content. After the evaluation process we found that the magnetic fraction consists of two or three components and the non-magnetic fraction consist of three components.

The magnetically split part of the spectrum of the Rumanová meteorite was fitted by three sextets and the non-magnetic part by three doublets. The Mössbauer parameters of all components are summarized in Table 1.

The sextet with B_{hf} of 29.5 T can be assigned to troilite. The other sextet with B_{hf} of 33 T belongs to metal inclusions containing iron as Fe-Ni alloy. The sextet with B_{hf} of 48.7 T corresponds to iron oxide and according to its hyperfine parameters is very close to maghemite. The non-magnetic part of the spectrum was

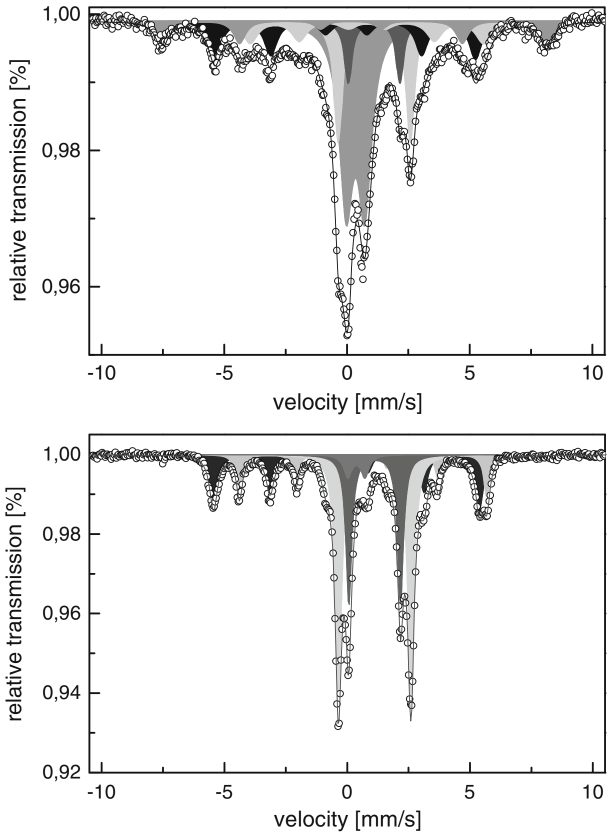

Fig. 1 Mössbauer spectrum of Rumanová meteorite (*upper part*) and Košice meteorite (*lower part*)

Table 1 Mössbauer parameter of Rumanová meteorite

	A_{rel} [%]	IS [mm/s]	QS [mm/s]	B_{hf} [T]	Γ [mm/s]
Rumanová					
Maghemite	10	0.23	0.13	48.7	0.60
Kamacite	17	−0.05	−0.04	33.0	0.63
Troilite	11	0.81		29.5	0.75
Olivine	16	1.11	2.94		0.43
Pyroxene	8	1.10	2.10		0.40
Fe^{3+}	38	0.35	0.77		0.69
Košice					
Kamacite	29	0.01	−0.01	33.6	0.39
Troilite	12	0.75	−0.16	31.3	0.30
Olivine	36	1.14	2.95		0.32
Pyroxene	18	1.14	2.09		0.30
Fe^{3+}	5	0.40	0.73		0.49

identified as two Fe^{2+} doublets and one Fe^{3+} doublet. The doublet with the largest quadrupole splitting corresponds to olivine and the doublet with QS close to 2.1 mm/s corresponds to pyroxene. The doublet with QS of 0.77 mm/s has a typical isomer shift for Fe^{3+} ions. In order to identify this component, a measurement at liquid nitrogen temperature was carried out. At this temperature the Fe doublet decreases, whereas the total area of magnetic part of the spectrum increases. Such behaviour of the component related to ferric iron is typical for a system containing superparamagnetic particles [11].

The values of the internal magnetic field derived from the hyperfine magnetic splitting of the Košice meteorite and the quadrupole splitting of the non-magnetic components are given in Table 1.

The Mössbauer spectrum consists of approximately 40 % of magnetic components while the rest is non-magnetic components. From the analysis of the magnetic part we can find that the first sextet with hyperfine magnetic field of 33.5 T corresponds to bcc Fe-Ni alloy (kamacite) and the second one with field of 31.5 T corresponds to FeS (troilite). The doublet with quadrupole splitting of ∼3.0 mm/s represents olivine $(Mg,Fe)_2SiO_4$, the second doublet with QS of 2.09 mm/s corresponds to pyroxene $(Ca,Mg,Fe)SiO_3$. Both these minerals contain iron in the form of Fe^{2+}. The third doublet corresponds to small particles of iron. Its contribution is smaller than 5 %.

4 Conclusion

Comparing Mössbauer parameters of the spectra measured on our meteorite samples we can conclude that the Rumanová and Košice meteorite contain similar components. The main difference between these meteorites is in the presence of iron oxide, according to its MS parameters, probably maghemite. On the other hand, Funaki et al. proposed ferric hydrous oxide instead of maghemite or some mixtures [12]. The Rumanová H5 meteorite was found and examined after an unknown period of time since its fall. On the other hand, the Kosice H5 meteorite was measured a few weeks after its fall. The unusual lower value of the magnetic field for troilite in Rumanová H5 can be a result of partial oxidation and/or non-stoichiometry of troilite as it was proposed by Oshtrakh et al. [8]. In this work Mössbauer spectroscopy was used for the phase analysis of iron containing components with the aim to identify magnetic and non-magnetic fractions and to compare them. These kinds of analyses can bring important knowledge about phases and compounds formed in extraterrestrial conditions, which have other features than their terrestrial analogues.

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