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Mössbauer study of glasses in meteorites: the D'Orbigny angrite and Cachari eucrite

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Abstract Mössbauer spectroscopy measurements at room temperature (RT) and at liquid helium temperature (4.2 K) were carried out on bulk and glass samples from the D'Orbigny (angrite) and Cachari (eucrite) meteorites. The RT Mössbauer spectrum of the bulk sample of D'Orbigny shows the presence of Fe^{2+} in olivine and pyroxene and that of bulk Cachari contains only pyroxene. Very small amounts of Fe^{3+} are also present in the bulk samples, but are attributed to surface contamination. The RT spectra of the D'Orbigny and Cachari glasses are fitted with three doublets, which are assigned to Fe^{2+} at three different octahedral positions. No Fe^{3+} was detected in the glass samples. The spectra of the glasses measured at 4.2 K show the presence of relaxation effects. The results suggest a certain degree of structural ordering in these glasses.

Key words Mössbauer spectroscopy · glasses · meteorite · angrites · eucrites · relaxation effects

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1 Introduction

The D’Orbigny meteorite belongs to the angrites, which is a small and rare group of achondrites. It was found in the Buenos Aires province of Argentina (1979) and is very rich in glasses, a feature that makes it an exceptional member of the angrites [1]. The Cachari meteorite, found in Argentina (1916), belongs to another group of achondrites known as eucrites. It is also an unusual meteorite as it contains appreciable amounts of glasses occurring mainly as dark glass veins [2]. Glasses in eucrites, as well as those in all achondrites, are believed to result from impact processes on the eucrite parent body. This is mainly because these glasses have practically the same composition as that of their respective bulk host rock. However, recent Secondary Ion Mass Spectrometry (SIMS) studies that compare glasses from eucrites with those from other achondrites proposed a different hypothesis on the origin of glasses envisaging a new role for silicate liquids in the genesis of meteorites [3].

^{57}Fe Mössbauer spectroscopy has been used successfully in studying Fe-bearing glasses, e.g. borate, phosphate, and silicate glasses [4]. For example, the technique has been used to determine Fe^{3+}/Fe^{2+} ratio in natural basalt glasses in order to reveal the oxygen pressure in the melt [5]. Here we report on the Mössbauer results on glasses from the D’Orbigny and Cachari meteorites in an attempt to contribute to the understanding of their possible origin(s).

2 Experimental

Glasses from D’Orbigny belong to the Glass Patches population described in [1]. Small chips of these glasses were separated under a binocular microscope and used for the preparation of the Mössbauer absorber. For Cachari, glasses cannot be separated by hand and therefore a double polished thin section of a glass-filled fracture was specially prepared for Mössbauer measurements. Mössbauer spectra were recorded in transmission geometry using a ^{57}Co(Rh) source. The spectrometer was calibrated with the RT spectrum of α-Fe. The low temperature spectra were collected using a liquid helium bath cryostat with the source and absorber being at 4.2 K.

3 Results and discussion

The room temperature (RT) Mössbauer spectra of the bulk samples of the D’Orbigny and Cachari meteorites are shown in Figure 1. The spectrum of D’Orbigny is fitted with four doublets resulting from the presence of Fe^{2+} in olivine (two outer doublets) and pyroxene (two inner doublets). On the other hand, the spectrum of Cachari consists of two strong doublets emanating from Fe^{2+} in pyroxene. Both meteorites contain very small amounts of Fe^{3+}. The Mössbauer results are consistent with the mineralogical and petrological studies reported for these meteorites [6, 7].

Figure 2 shows the RT Mössbauer spectra of glasses from the D’Orbigny and Cachari meteorites. The relevant hyperfine parameters are presented in Table I. The spectra can be well fitted with at least three overlapping doublets, which are

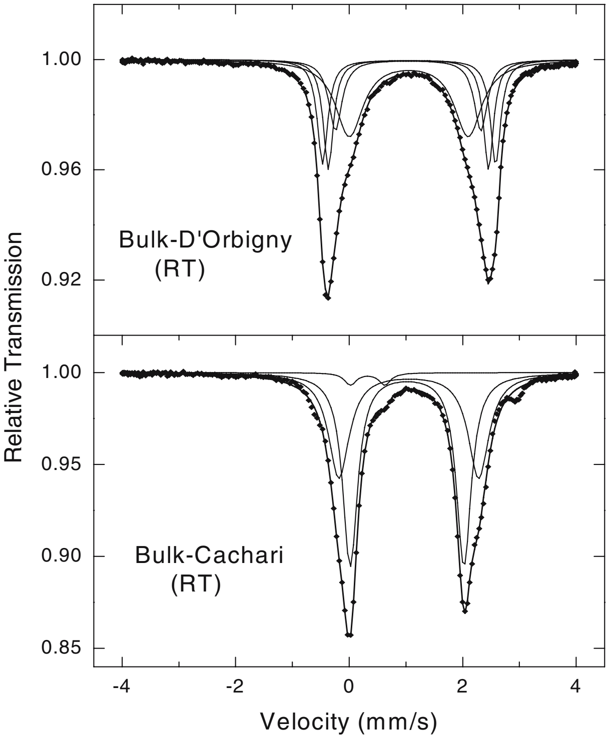


Figure 1 RT Mössbauer spectra of bulk samples of D'Orbigny and Cachari meteorites. The small absorption near the high velocity peak of the spectrum of bulk Cachari is ignored in the fitting.

assigned to Fe^{2+} at three different octahedral sites A, B, and C. The quadrupole splitting of the doublets decreases from A to C, which indicates that distortion from octahedral symmetry is increasing in that direction (see Table I). In contrast to natural basalt glasses, which generally contain Fe^{3+} [4], the studied meteoritic glasses do not contain Fe^{3+}. The hyperfine parameters for sites A and B in the D'Orbigny and Cachari glasses are very close to the values obtained for the M1 and M2 sites in pyroxenes in these meteorites (e.g. D'Orbigny: IS = 1.15 mm/s, QS = 2.56 mm/s for M1; IS = 1.16 mm/s, QS = 2.09 mm/s for M2, Cachari: IS = 1.16 mm/s, QS = 2.46 mm/s for M1; IS = 1.13 mm/s, QS = 2.00 mm/s for M2).

The spectra of the D'Orbigny and Cachari glasses measured at 4.2 K are shown in Figure 3. They clearly indicate the presence of relaxation effects. A spectrum of pyroxene separated from D'Orbigny also exhibited a similar behaviour when measured at 4.2 K (unpublished data). This feature has been observed in natural orthopyroxenes at low temperatures, and was attributed mainly to spin–spin relaxation of Fe^{2+} ions [8]. The spectrum of D'Orbigny glass at 4.2 K shows a broader pattern compared to that of Cachari (see Figure 3). This implies a slower relaxation in the former and indicates a higher Fe^{2+} concentration in the D'Orbigny glass [9].

The similarity between the low temperature spectra of glasses from D'Orbigny and Cachari and those of natural and meteoritic pyroxenes, along with the RT hyperfine parameters suggest a certain degree of structural ordering in these glasses. Probably, cooling below the glass transformation temperature was slow enough to allow for elemental exchange processes like the replacement of Mg by Fe^{2+} [1].

Figure 2 RT Mössbauer spectra of D'Orbigny and Cachari glasses.

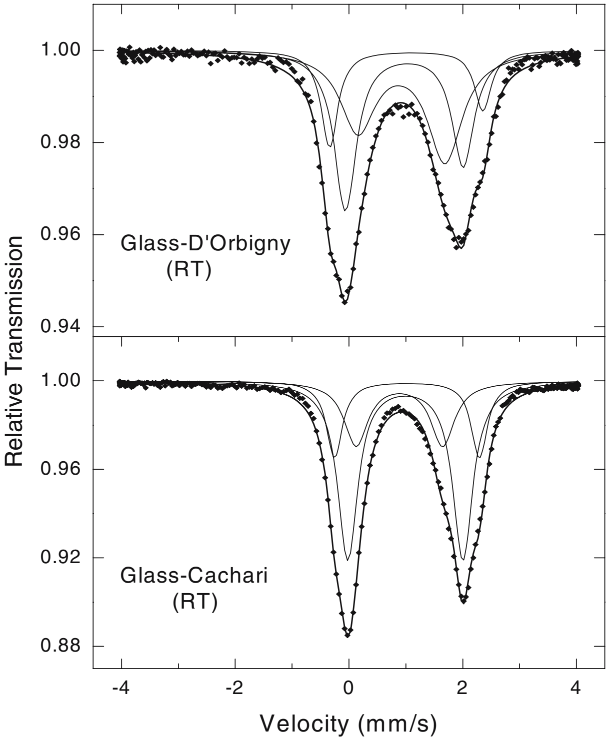


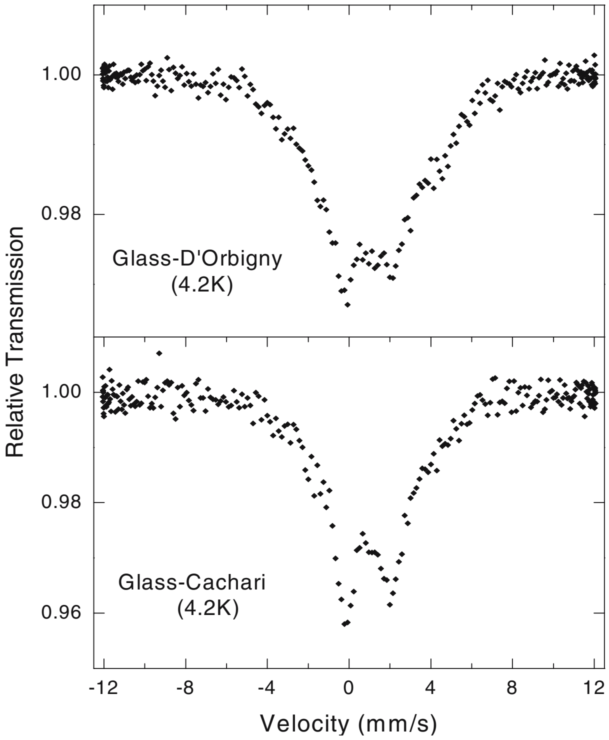
Table I Mössbauer hyperfine parameters of glasses from D'Orbigny and Cachari meteorites. A, B, and C are three octahedral sites occupied by Fe^{2+}

	IS (±0.02 mm/s)	QS (±0.02 mm/s)	*W* (±0.02 mm/s)	*A* (±5%)
D'Orbigny				
Fe^{2+} (A)	1.12	2.70	0.36	17
Fe^{2+} (B)	1.08	2.07	0.47	40
Fe^{2+} (C)	1.03	1.53	0.74	43
Cachari				
Fe^{2+} (A)	1.13	2.55	0.34	20
Fe^{2+} (B)	1.10	2.02	0.43	56
Fe^{2+} (C)	1.00	1.52	0.51	24

IS Isomer shift relative to α-Fe, *QS* quadrupole splitting, *W* line width, *A* relative area.

From the above discussion, it appears that glasses from D'Orbigny and Cachari are similar to each other. None of them appears to have any memory of a shock event but they have experienced some ordering, which could be related to a sub-solidus elemental exchange process as identified for D'Orbigny silicates [1, 6]. Further variable temperature and in-field Mössbauer measurements are in progress

Figure 3 Mössbauer spectra (at 4.2 K) of glasses from D'Orbigny and Cachari meteorites.



in order to better determine Fe^{2+} distribution between the different octahedral sites in theses glasses, and to examine the temperature dependence of the relaxation.

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