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Reclassification of CK chondrites confirmed by elemental analysis and Fe-Mössbauer spectroscopy

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Abstract Twenty CK chondrites collected in the Antarctica Continent were characterized by inductively-coupled plasma mass spectrometry (ICP-MS), prompt gamma ray analysis (PGA), instrumental neutron activation analysis (INAA), X-ray diffractometry (XRD) and ^{57}Fe-Mössbauer spectroscopy. As a result of elemental analysis, it was revealed that 18.2∼26.4 mass% of iron was included in the each chondrite. Mössbauer spectrum of LEW86258, classified as a typical CK chondrite, was found to be composed of two paramagnetic doublets and two magnetic sextets. Mössbauer spectra were assigned to the absorption due to forsterite ($Mg_{1.36}Fe_{0.64}SiO_4$) and magnetite (Fe_3O_4), as also confirmed by XRD. XRD study of LAP03834, reclassified from CK to R chondrite, revealed the presence of crystalline phase due to forsterite. These results indicate that LAP03834 and related chondrites, *i.e.*, MET01149, LAP03923 and MAC02453, should be reclassified as R or LL chondrite.

Keywords CK Chondrite · ^{57}Fe-Mössbauer spectroscopy · X-ray diffractometry

1 Introduction

Chondrites are defined as stone meteorites mainly composed of silicates with spherical particles called chondrules, providing us information about the earlier stage of the

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Solar System formation. Chondrites are now classified into fifteen groups, depending on the chemical composition and mineralogy [1]. They are petrologically classified into seven groups of group 1 to 7, depending on the degree of aqueous alteration and thermal metamorphism. CK chondrites are characterized by 1 mm diameter and 15% of modal abundances of chondrules. However, classification of CK chondrites is known to be relatively difficult because of less availability of the samples [2]. In order to investigate the relationship between the chemical composition and the structure of CK chondrites collected in the Antarctica Continent, measurements of neutron activation analyses (PGA and INAA), inductively coupled plasma-mass spectrometry (ICP-MS), X-ray diffractometry (XRD), and ^{57}Fe-Mössbauer spectroscopy were carried out.

2 Experimental

Antarctic CK chondrites tentatively classified as CK3 (LAP03834, MET01149), CK4 (ALH85002, DAV92300, EET99430, LAR04318, LEW86258, PCA91470), CK4/5 (PCA 82500), CK5 (EET83311, EET87507, EET90015, LAP03784, LAP3923, LAR06874, MAC02453, RBT03522), CK5/6 (EET87860) and CK6 (LAR06872, LEW87009) were loaned by the Meteorite Working Group (NASA / Johnson Space Center, USA). Several hundred mg of powdered samples were irradiated with neutron at JRR-3 and JRR-4 of Japan Atomic Energy Agency. JB-1 and Allende were used as the standard materials. Elemental abundances were determined by PGA and INAA by using JRR-3 and JRR-4 reactors of Japan Atomic Energy Research Institute, respectively. The detailed procedures of PGA and INAA are given in [3]. Mössbauer spectra were recorded by a constant acceleration method with a source of ^{57}Co(Rh) and a reference of α-Fe foil. Mosswinn 3.0i XP was used for the spectral analysis. XRD pattern was recorded from $2\Theta = 10$ to 80° at 0.02° intervals at a scanning rate of 5° min^{-1}. Cu-K$_\alpha$ X-rays ($\lambda = 0.1541$ nm) were used for XRD study, generated under the tube voltage and the current of 50 kV and 300 mA, respectively. Crystalline phases were identified with a standard compiled by the International Center for Diffraction Data (ICDD).

3 Results and discussion

As a result of elemental analysis, Fe/Mn abundance ratios of LAP03834, MET01149, LAP 03923 and MAC02453 were calculated to be 94.0, 111.9, 66.3 and 70.5, respectively. These values are much lower than that of typical CK chondrite, *i.e.*, *ca.* 200. Hence, we suggest that LAP03834 and MET01149 should be classified as R chondrite, having Fe/Mn ratio of around 100, while LAP 03923 and MAC02453 as LL chondrite with the Fe/Mn ratio of *ca.* 70 [4].

Mössbauer spectrum illustrated in Fig. 1a is typical of CK chondrite containing about 20% of magnetite. Mössbauer spectrum of LAP03834 is composed of two paramagnetic doublets with isomer shift (δ) values of 1.17 ($\pm$0.01) and 1.40 ($\pm$0.01) mm s^{-1}, as illustrated in Fig. 1b. The former δ value is attributed to octahedral Fe^{II}, and the latter to dodecahedral one [5]. A similar spectrum was obtained for

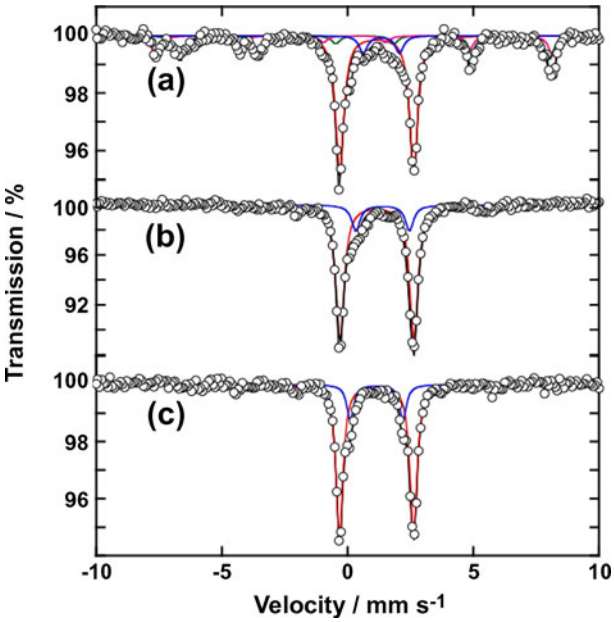

Fig. 1 Mössbauer spectra of **a** LEW86258 (typical CK chondrite), **b** LAP03834 (R chondrite reclassified from CK3), and **c** LAP03923 (LL chondrite reclassified from CK5)

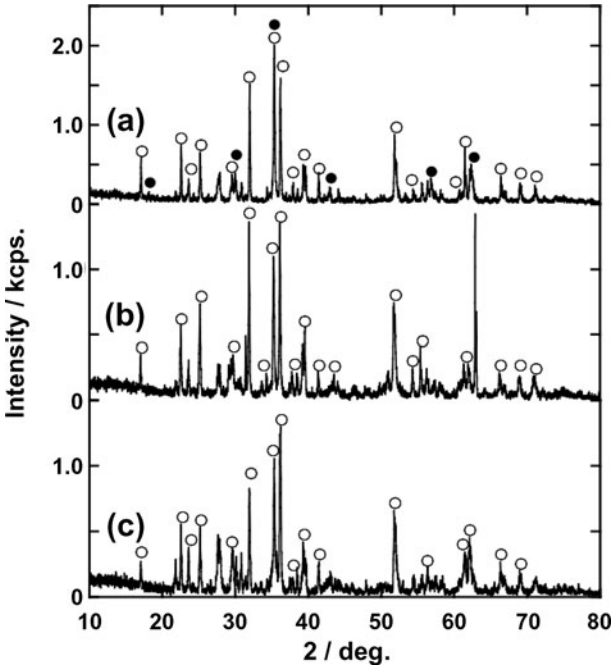

Fig. 2 XRD patterns of **a** LEW86258 (typical CK chondrite), **b** LAP03834 (R chondrite reclassified from CK3), and **c** LAP03923 (LL chondrite reclassified from CK5). Open and solid circles denote forsterite and magnetite, respectively

LAP03923 (Fig. 1c). It is noteworthy that all CK chondrite contain two magnetic components as shown in Fig. 1a, while reclassified four chondrites, *i.e.*, LAP03834, MET01149, LAP03923 and MAC02453 show no magnetic components.

XRD patterns of LEW86258 (typical CK chondrite), LAP03834 (R chondrite reclassified from CK3), and LAP03923 (LL chondrite reclassified from CK5) are shown in Fig. 2. The XRD pattern of CK chondrite (Fig. 2a) shows intense peaks at 2Θ of 35.2, 36.3 and 31.9° due to forsterite $Mg_{1.36}Fe_{0.64}SiO_4$ and also at 35.4, 30.2 and 62.4° due to magnetite Fe_3O_4. It is noted that XRD patterns of LAP03834 (Fig. 2b) and LAP03923 (Fig. 2c) showed no peaks due to magnetite phase. Similar results were observed for MET01149 and MAC02453, indicating that the mineral compositions of these four chondrites are clearly different from that of CK chondrite, as confirmed from the Mössbauer spectra. We can conclude that these chondrites should be distinguished from others on the basis of the difference in the crystalline phase and chemical environment, as respectively detected by XRD and ^{57}Fe-Mössbauer spectroscopy.

4 Summary

Twenty CK chondrites collected in the Antarctica Continent were characterized by elemental analysis, X-ray diffractometry (XRD) and ^{57}Fe-Mössbauer spectroscopy. Mössbauer spectrum of LAP03834, previously classified as a member of CK chondrite, consists of two paramagnetic doublets due to Fe^{II} with δ values of 1.17 $\pm$ 0.01 and 1.40 $\pm$ 0.01 mm s^{-1}. Forsterite phase ($Mg_{1.36}$ $Fe_{0.64}SiO_4$) was confirmed from the XRD study. Similar results were obtained for MET01149, LAP03923 and MAC02453, indicating that the mineral compositions of these four chondrites are quite different from that of typical CK chondrite which generally has magnetite phase (Fe_3O_4). LAP03834 and MET01149 could be classified as R chondrite, while LAP 03923 and MAC02453 as LL chondrite.

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