Oxygen-isotopic compositions of minerals from the Baszkówka chondrite

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Oxygen isotopic compositions of two picotite-bearing chondrules from Baszkówka L5(S1) equilibrated ordinary chondrite have been determined by secondary ion mass spectrometry. The O-isotopic compositions of the minerals in the picotite-bearing chondrules are slightly more ^{16}O-rich than the bulk O-isotopic composition of Baszkówka. The petrological properties and the O-isotopic compositions of these chondrules suggest that they have closer relationship to ferromagnesian chondrules than CAIs. The ^{16}O-enrichment of the picotite-bearing chondrules may result from incomplete O exchange reaction between ^{16}O-rich chondrule precursors and the ^{16}O-poor solar nebular gas. This implies that the picotite-bearing chondrules are more primitive than ordinary ferromagnesian chondrules in Baszkówka. The O-isotopic compositions of the minerals in one of these chondrules relate to the crystallization sequence. These O-isotopic variations of minerals within the chondrule may result from incomplete O exchange between the chondrule melt droplet and the nebular gas. The heterogeneity of the O-isotopic composition in Baszkówka indicates that Baszkówka has not been homogenized completely during thermal metamorphism and/or secondary alteration.

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INTRODUCTION

Chondrites are the most major type of meteorites which fall on the Earth. Main texture components of chondrites are ferromagnesian mm-sized spherules, refractory inclusions known as Ca-Al-rich inclusions (CAIs) and fine-grained dust (matrix), grains of metallic iron-nickel and sulphides. Chondrites can be regarded as mechanical aggregations of these objects that were mutually formed in the different conditions and by the different processes.

CAIs are widely believed to be among the oldest materials in the solar system. Minerals comprising CAIs are known to show large anomalies in the isotopic abundances of oxygen (e.g. Clayton, 1993). One of the ^{16}O-rich end-members among CAI minerals is spinel which shows ~4% enrichment of [16]O relative to the standard mean ocean water (SMOW), whereas the O-isotopic compositions of melilite and anorthite are O 0% relative to the SMOW. Knowledge of the nature of the O-isotope anomaly is important for understanding the formation processes of the solar nebula. Therefore, numerous studies of CAIs have been made, and there are a lot of published analyses of spinels in CAIs.

On the other hand, some Al-rich chondrules contain spinel grains, which are often Fe-Cr-bearing. The study of spinels in chondrules may make it possible to obtain the new information about precursory materials of meteorites. Especially, O-isotopic compositions of spinels and coexisting minerals in chondrules may provide key evidence of the origin of precursors of chondrules (Sheng *et al.,* 1991; Misawa and Fujita, 1994; Russell *et al.,* 1994).

There are many analyses of O-isotopic compositions of Al-rich chondrules in carbonaceous chondrites and unequilibrated ordinary chondrites (e.g. Simon *et al.,* 1994, 2000; Russell *et al.,* 1997). However, the O-isotopic compositions of spinels in equilibrated chondrite have been much less analysed. In this paper, I describe the O-isotopic compositions of two chondrules, named panda and chevron, which include picotite (appreciable Cr, Al > Cr, 1 < Fe/Mg < 3) from Baszkówka L5(S1) equilibrated ordinary chondrite, and discuss the conceivable process of the formation of them. Preliminary reports of the results were given by Maruyama *et al.* (1999*a*, 2000).

SIMS condition for oxygen isotope analyses of panda and chevron

Conditions	Panda	Chevron
Primary beam	Cs^+, 20 keV, 5 µm in diameter	Cs^+, 10 keV, 5 µm in diameter
Secondary ion (counting time of mass)	$^{16}O_{tail}$ (5.0s) ^{16}O (2.0s) ^{17}O (7.0s) ^{16}OH (2.0s) ^{18}O (3.0s)	$^{16}O_{tail}$ (5.0s) ^{16}O (1.0s) ^{17}O (20.0s) ^{16}OH (2.0s) ^{18}O (10.0s)
Deadtime of EM	21.2±0.8 ns	28.1±2.4 ns
Measurement time	43 min (10 block — 10 cycle: total 100 cycle)	46 min (6 block — 10 cycle: total 60 cycle)
Entrace slit Exit slit Field aperture Energy slit Mass resolution	20 µm 150 µm 2000 µm 150 µm 6000 (10% valley)	

ANALYTICAL METHODS

OBSERVATION OF PETROLOGICAL PROPERTIES OF PANDA

Back-scattered electron imaging (BSEI) and quantitative analyses of a chondrule of the Baszkówka thin section were performed on the *JEOL JSM-5310LV* scanning electron microscope (SEM) equipped with the *Oxford LINK* energy dispersive system (EDS) at Tokyo Institute of Technology. The concentrations of Si, Ti, Al, V, Cr, Mg, Ca, Mn, Fe, Ni, Zn, Na and K were determined using the EDS. The combination of elements was selected according to analysed minerals. The quantitative analyses were carried out at an accelerating voltage of 15kV with 1.0 nA probe current with counting times of 100 s. Conventional ZAF methods were used for correction from X-ray intensity to concentration.

The X-ray images (speedmaps) of panda were also made by the *JEOL JSM-5400* SEM-EDS system at University of Tsukuba. The speedmapping was carried out at an accelerating voltage of 20 kV with 1.0 nA probe current. Total counting time of image acquisition was up to 2 hours.

ANALYSES OF OXYGEN ISOTOPES

The polished thin sections were coated with ~30 nm of gold film for SIMS analysis. The oxygen isotopic compositions of each phase in thin sections of chondrules were determined with the *CAMECA IMS-1270* SIMS instrument at Tokyo Institute of Technology.

Oxygen isotopic measurements of chondrules were made with a focussed positive primary ion beam of cesium. Primary beam currents were adjusted for each run to obtain a ^{16}O count rate of ~4.0 10^5 counts per second. The typical current was ~4.0 nA and the beam size was 5 µm in diameter. The electron flood gun was used to compensate the electrostatic charging on the sample surfaces. The energy slit was set to select an energy bandpass of 150 µm. The field aperture of 2000 µm was used. The mass resolution power (MRP) was set to ~6000 (10% valley) to resolve ^{17}O from the interference of ^{16}OH. Measurements were made from scanning through the mass sequences the tail of ^{16}O (15.99152 amu), ^{16}O, ^{17}O, ^{16}OH (17.00274 amu), and ^{18}O in a magnetic peak jumping mode. The counting times of these masses are shown in Table 1. Measurements of the tail of ^{16}O and ^{16}OH were performed for the purpose of removing the ^{16}OH contribution to ^{17}O peaks owing to the contamination of vapor while the thin sections and the standards were exposed to the air. Secondary ion signals were detected with an electron multiplier (EM) operated in a pulse counting mode.

Signals measured in the EM were corrected for the counting system deadtime. All of the measured counts of the analyses of the O isotopic compositions were corrected for the deadtime shown in Table 1.

Total time and cycles of each run are shown in Table 1. A run through the mass sequence was divided into blocks of 10 cycles. Isotope ratios and the standard deviations of a run were computed from the average of the all isotope ratios.

The isotopic composition measured by the SIMS differs from the true isotopic composition of the sample by the matrix-dependent instrumental mass fractionation. The instrumental mass fractionation varies with the geometry of the

Oxygen isotopic composition (permil) for terrestrial mineral standards

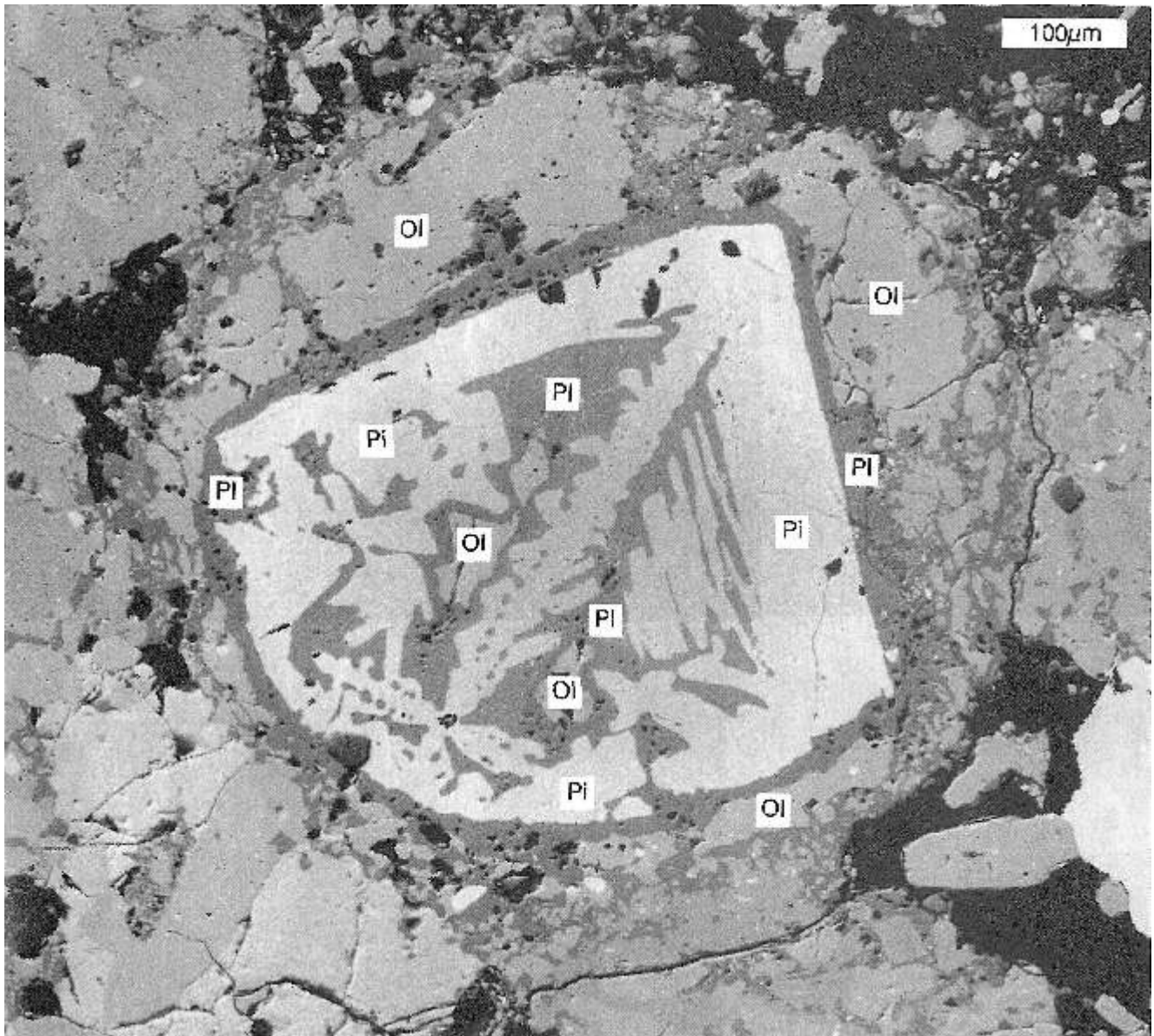| Mineral	Occurrence	$^{17}O_{SMOW}$	$^{18}O_{SMOW}$
Spinel	Russia	4.3	8.5
Olivine	San Carlos, USA	2.7	5.3
Anorthite	Miyake-jima, Japan	3.2	6.4

Fig. 1. Back-scattered electron image (BSEI) of chevron chondrule

Pi — picotite, Ol — olivine, Pl — plagioclase

sample measured, tuning condition of the instrument, and the position of the energy window, *etc*. (Fahey *et al.*, 1987a). From these reasons, it is very difficult to determine precisely the intrinsic mass fractionation of the sample. In order to correct the instrumental mass fractionation, terrestrial single crystals were prepared as standards for each mineral phase of chondrules. The terrestrial single crystals used as the standards for spinels, olivines, and plagioclases of chondrules were a spinel called "SPU" found from Russia, a olivine found from San Carlos in USA, and an anorthite found from Miyake-jima in Japan, respectively. The values of oxygen isotope ratios relative to the SMOW, $^{18}O_{SMOW}$, for these standards were determined by the gas mass spectrometry method (Yurimoto *et al*., 1994). The oxygen isotopic compositions of the standards are shown in Table 2. The $^{18}O_{SMOW}$ values were determined by the gas

mass spectrometry method, and the $^{17}O_{SMOW}$ values were obtained by assuming terrestrial mass fractionation.

The standards were measured repetitiously during analysis. The SPU, the San Carlos olivine, and the Miyake-jima anorthite were measured for the analysis of panda. On the other hand, the only SPU was measured for the analysis of chevron. Since statistical errors of the isotopic ratios from total ion counts were less than ±4‰, the large daily variation includes some accidental fluctuations in analytical condition, such as variations in small electrostatic charging on the analytical area.

The tailing of ^{16}OH peak plays as a background counts for ^{17}O peak. The true ^{17}O value was corrected by the following:

$$^{17}O_{corr.} = {}^{17}O - {}^{16}OH \frac{^{16}O_{tail}}{^{16}O} \qquad [1]$$

Representative chemical compositions of minerals in chevron and bulk compositions of panda and chevron

Chevron	Picotite		Olivine				Plagioclase	Bulk composition	
Oxide [wt.%]	core[1]	rim[2]	surrounded by picotite[3]		surrounding picotite[4]			panda[5]	chevron
			core[1]	rim[2]	core[1]	rim[2]			
SiO$_2$	0.17	0.13	38.10	38.37	38.18	37.96	59.35	38.62	30.95
TiO$_2$	0.29	0.40	0.25	0.10	0.10	0.06	–	0.72	0.17
Al$_2$O$_3$	51.19	44.12	0.08	0.08	0.03	0.01	25.56	24.68	27.02
V$_2$O$_3$	0.21	0.15	–	–	–	–	–	0.00	0.00
Cr$_2$O$_3$	15.25	21.60	0.19	0.19	0.04	0.03	–	5.70	7.30
MgO	12.81	10.97	39.39	38.01	37.41	37.14	0.19	10.53	14.64
CaO	0.05	0.04	0.05	0.08	0.02	0.07	6.79	5.65	2.40
MnO	0.18	0.13	0.48	0.41	0.44	0.55	–	0.19	0.18
FeO	19.82	21.50	21.62	21.32	23.65	23.03	0.61	11.26	14.31
NiO	–	–	0.07	0.19	0.04	0.04	–	0.00	0.02
ZnO	0.22	0.18	–	–	–	–	–	0.00	0.00
Na$_2$O	–	–	–	–	–	–	7.37	2.43	2.57
K$_2$O	–	–	–	–	–	–	0.42	0.00	0.15
Oxide total	100.19	99.22	99.23	99.75	99.91	98.89	100.29	99.78	99.71
Cations									
Si^{4+}	0.00	0.00	1.00	1.00	1.00	1.00	2.65	5.75	4.75
Ti^{4+}	0.01	0.01	0.00	0.00	0.00	0.00	–	0.08	0.02
Al^{3+}	1.66	1.49	0.00	0.00	0.00	0.00	1.35	4.33	4.89
V^{3+}	0.00	0.00	–	–	–	–	–	0.00	0.00
Cr^{3+}	0.33	0.49	0.00	0.01	0.00	0.00	–	0.67	0.89
Mg^{2+}	0.52	0.47	1.49	1.51	1.46	1.46	0.01	2.34	3.35
Ca^{2+}	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.90	0.39
Mn^{2+}	0.00	0.00	0.02	0.02	0.02	0.02	–	0.02	0.02
Fe^{2+}	0.46	0.52	0.47	0.46	0.52	0.51	0.02	1.40	1.84
Ni^{2+}	–	–	0.00	0.00	0.00	0.00	–	0.00	0.00
Zn^{2+}	0.00	0.00	–	–	–	–	–	0.00	0.00
Na^{2+}	–	–	–	–	–	–	0.64	0.35	0.38
K$^+$	–	–	–	–	–	–	0.02	0.00	0.01
Cation total	2.98	2.98	2.98	3.00	3.00	2.99	5.02	15.49	16.15
O^{2-}	4.00	4.00	4.00	4.00	4.00	4.00	8.00	24.00	24.00
Cr/(Cr+Al)	0.17	0.25	–	–	–	–	–	–	–
Fe/(Fe+Mg)	0.47	0.53	–	–	–	–	–	–	–
Fayalite (mole%)	–	–	Fa$_{24}$	Fa$_{23}$	Fa$_{26}$	Fa$_{26}$	–	–	–
Anorthite (mole %)	–	–	–	–	–	–	An$_{34}$	–	–

1 — core part of mineral; 2 — rim part of mineral; 3 — olivines which exist within picotite; 4 — olivines with surround picotite; 5 — calculated from the values in Borucki and St pniewski (2001)

The average ^{16}OH contribution for the standard and the samples was calculated to ~0.6‰.

The ^{17}O$_{SMOW}$ and ^{18}O$_{SMOW}$ values of the standard were calculated as follows:

$$^i\mathrm{O}^{standard}_{SMOW} = \left(\frac{R^i_{standard}}{R^i_{SMOW}} - 1\right) \cdot 1000 \qquad [2]$$

where: $R^i = {^i\mathrm{O}}/{^{16}\mathrm{O}}$ ($i = 17$ or 18); the $^i\mathrm{O}/^{16}\mathrm{O}_{SMOW}$ are as follows: $^{17}\mathrm{O}/^{16}\mathrm{O} = 0.00038288\pm0.00000028$ (2 $_{mean}$) (Fahey *et al.*, 1987b), and $^{18}\mathrm{O}/^{16}\mathrm{O} = 0.0020052$ (Baertschi, 1976).

The degrees of instrumental mass fractionation F^{17} and F^{18} were determined by the following:

$$F^i_{instr.} = {^i\mathrm{O}}^{standard}_{SMOW} - {^i\mathrm{O}}^{standard}_{SMOW} \qquad [3]$$

where: $i = 17$ or 18; the $^i\mathrm{O}_{SMOW}$ values are shown in Table 2.

The oxygen isotopic compositions of minerals of chondrules were measured under the same condition as the standards, and all of the measured counts were corrected for the deadtime and the ^{16}OH contribution. The $^i\mathrm{O}_{SMOW}$ values of
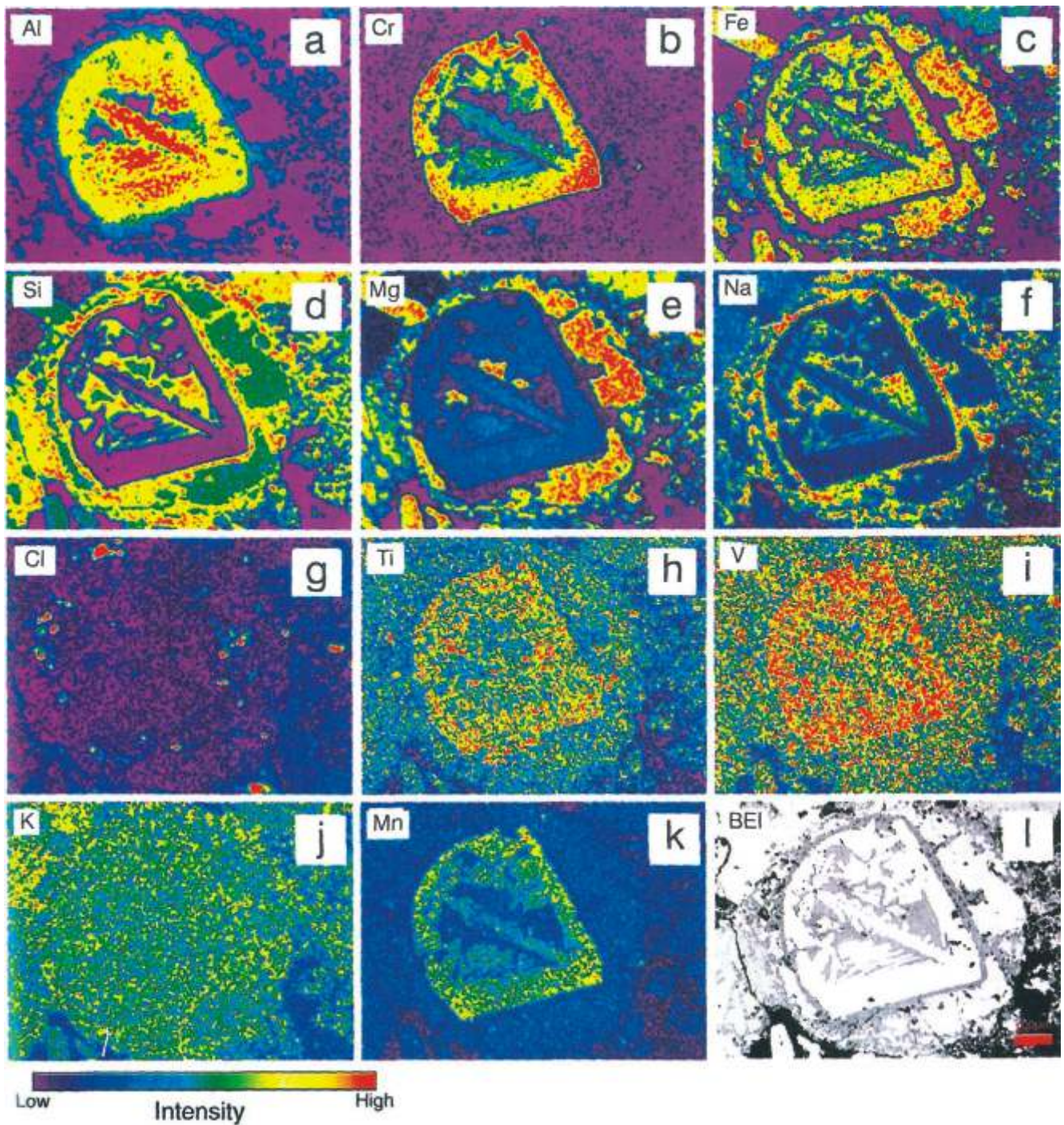
Fig. 2. X-ray images (speedmaps) of chevron

chondrule minerals corrected the instrumental mass fractionation were calculated as follows:

$$^i O_{SMOW}^{chondrule} = \left(\frac{R_{chondrule}^i}{R_{SMOW}^i} - 1 \right) 1000 + F^i \qquad [4]$$

The critical parameter to be determined from the O isotope measurements is the magnitude of deviation of the data points from a reference line, taken as the fractionation line for the terrestrial materials. The terrestrial fractionation (TF) line is defined as: $^{17}O = 0.52\ ^{18}O$. For chondrules, an excess in ^{17}O can be defined as follows:

$$^{17}O_{chondrule} = ^{17}O_{chondrule} - 0.52\ ^{18}O_{chondrule} \qquad [5]$$

The magnitude of the ^{16}O-excess of chondrule minerals can be simply shown by the ^{17}O values.

Oxygen isotopic compositions of the minerals in panda

Analysis	$^{17}O_{SMOW}$ ($\pm 1_{mean}$)	$^{18}O_{SMOW}$ ($\pm 1_{mean}$)	^{17}O ($\pm 1_{mean}$)
Picotite			
Pi#01	−3.3±2.7	−2.7±2.1	−1.9±2.9
Pi#02	−6.9±2.8	−3.4±2.1	−5.1±3.0
Pi#03–1	−0.2±2.9	−0.3±1.9	0.0±3.1
Pi#03–2	−6.6±3.0	−6.0±2.4	−3.5±3.2
Pi#04	−7.0±2.8	−2.7±2.0	−5.6±3.0
Pi#05	−6.6±3.6	−3.6±1.9	−4.7±3.7
Average*	−5.1±1.1	−3.1±0.7	−3.5±0.9
Olivine			
Ol#01	−4.0±2.8	−2.5±1.7	−2.7±3.0
Ol#02	−2.0±3.1	−4.3±2.3	0.2±3.3
Ol#06	6.1±2.9	−2.0±2.0	7.1±3.1
Ol#07	6.4±2.9	1.1±2.3	5.8±3.2
Ol#09	−4.5±2.6	−2.7±2.2	−3.1±2.8
Average*	0.4±2.4	−2.1±0.9	1.5±2.1
Plagioclase			
Pl#01	−0.8±2.9	5.9±1.8	−3.8±3.0
Pl#02	2.4±2.8	3.0±2.0	0.9±3.0
Pl#03	3.5±3.2	2.0±1.9	2.4±3.4
Average*	1.7±1.3	3.6±1.2	−0.2±1.9

* — average of each mineral and the standard error of the mean were calculated from the values of each spot

RESULTS

PETROLOGICAL PROPERTIES OF CHEVRON

Baszkówka chondrite contains ~0.1% of ferroan chromian spinel grains (St pniewski *et al.*, 1998*b*). Only two picotitic spinel-bearing chondrules, which were named panda and chevron, have been found from Baszkówka until now. The petrographic description of these chondrules using the optical microscope is given by Borucki and St pniewski (2001). The chemical compositions of the minerals of panda using the electron microprobe analysis (EMA) are also shown in Borucki and St pniewski (2001). In this paper, the results of the observation and the chemical analysis of chevron using the SEM-EDS are described.

Figure 1 is the back-scattered electron image (BSEI) of chevron. The most striking feature is a coarse, skeletal picotite crystal which occupies ~38 vol.% of chevron. The olivine grains surround the picotite, and some olivine grains are enclosed by the picotite. The surfaces of olivine grains adjacent to the picotite are generally in parallel with that of the picotite. The olivine grains occupy ~27 vol.% of chevron. Plagioclases (~34 vol.%) exist as the groundmass of the other minerals. The plagioclases are peppered with numerous grains of ilmenites and Cr-rich spinels (< 10 µm in diameter). The texturally inferred crystallisation sequence of the major phases in chevron is as follows: picotite, olivine, and then plagioclase.

The representative chemical compositions of the major phases in chevron are shown in Table 3. The bulk chemical compositions of panda and chevron are also shown in Table 3. The olivine grains show no Fe-Mg zoning structure (Fig. 2c, e). The mean composition of the olivines surrounding the picotite (~Fa_{26}) is very close to those of ferromagnesian chondrules in Baszkówka ($Fa_{25.7}$; Borucki and St pniewski, 2001). The olivines enclosed by the picotite ($Fa_{23–24}$) are slightly more forsteritic than those surrounding the picotite. The plagioclase in chevron is heterogeneous ($An_{15–51}$), and is more calcic than those in ordinary ferromagnesian chondrules in Baszkówka ($An_{12–15}$; Borucki and St pniewski, 2001).

The composition of the picotite in chevron is close to that of the picotites in panda described by St pniewski *et al.* (1998*a*). The picotite exhibits the Al-Cr zoning structure (Fig. 2a, b). The Cr/(Cr+Al) ratio of the picotite decreases from the rim part (~0.25) to the core part (~0.17). The width of the Cr-rich rim is ~100 µm. The picotite also shows the Fe-Mg zoning structure (Fig. 2c, e): the rim part is more Fe-rich (Fe/(Fe+Mg) 0.53), the core part is more Fe-poor (~0.47).

The bulk composition of chevron indicates chevron is closely related to Al-rich chondrules and POIs. This property is owing to the large amount of the picotite and the plagioclases (total ~72%). The texture and the bulk composition of panda are similar to those of POIs, whereas the texture of chevron is uncommon among POIs. Chevron should be classified as an Al-rich chondrule from the petrological properties.
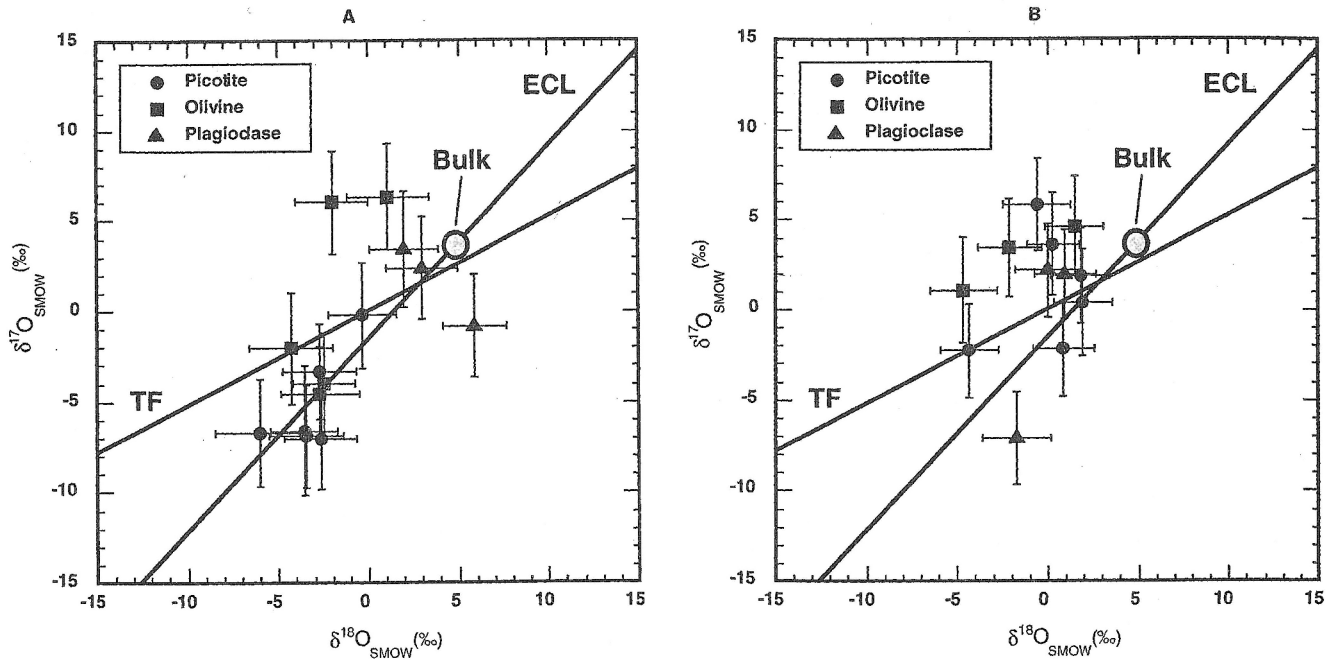
Fig. 3. Oxygen isotopic compositions of minerals in panda (A) modified by Maruyama *et al.* (1999*a*) and in chevron (B)

All errors are 1 ₘₑₐₙ; TF — terrestrial fractionation line (Clayton, 1993), ECL — equilibrated chondrite line (Clayton *et al.*, 1991)

OXYGEN ISOTOPIC COMPOSITIONS OF PANDA AND CHEVRON

The results of oxygen isotopic analysis for the minerals of panda are summarised in Figure 3 and listed in Table 4. The O-isotopic compositions of the minerals in panda are more ^{16}O-rich than the bulk O-isotopic composition of Baszkówka (^{17}O = 3.66‰, ^{18}O = 4.88‰; Stêpniewski *et al.*, 1998*a*). Moreover, the O-isotopic compositions of the minerals in panda have relation to the crystallisation sequence.

The results of oxygen isotopic analysis for the minerals of chevron are summarised in Figure 4 and listed in Table 5. The O-isotopic compositions of the minerals in chevron are also more ^{16}O-rich than the bulk O-isotopic composition of Baszkówka. However, the correlation between the oxygen isotopic compositions and the crystallisation sequence of the minerals is not clear. The ^{16}O-enrichment of the analysis point Pl#02 in comparison with the other analysis points of the plagioclase may be due to the contribution from the grain of ilmenite or Cr-spinel which exists within the plagioclase.

The O-isotopic compositions of the minerals in panda and chevron are scattered near the Equilibrated Chondrite Line (ECL) determined by Clayton *et al.* (1991). The ECL is the reference line formed by the "grand means" for the three iron groups (L, LL, H) of ordinary chondrites. The ECL is described by the following equation: ^{17}O = 1.074 ^{18}O – 1.53.

The O-isotopic compositions of the picotites in Baszkówka are close to those of Mg-Al spinels in Al-rich chondrules from unequilibrated ordinary chondrites (Russell *et al.*, 1997) and those of Cr-Al spinels in carbonaceous chondrites (Simon *et al.*, 1994, 2000).

DISCUSSION

Both panda and chevron have petrological properties indicating that the picotites apparently crystallised in molten droplets of chondrule precursors. Relict spinels in plagioclase-olivine inclusions (POIs) in CV chondrites exhibit a corroded or serrated appearance which results from reaction with chondrule melt droplets (Sheng *et al.*, 1991; Maruyama *et al.*, 1999*b*). The appearance of the picotites in both panda and chevron is quite different from that of spinels in POIs. Furthermore, unlike the spinels from CAIs, those studied here are very coarse and contain weight percent levels of FeO and Cr_2O_3. The relict spinels in chondrules were originally pure $MgAl_2O_4$ (Misawa and Fujita, 1994; Maruyama *et al.*, 1999*b*), whereas the picotites in these chondrules may have been naturally Fe-Cr-bearing.

The skeletal texture of the picotite in chevron suggests that the picotite apparently crystallised in the molten droplet; the skeletal or dendritic texture of chondrules can be formed in rapidly cooled melts that have nuclei (Lofgren, 1996). Moreover, the compositional zoning structure in the picotite can be interpreted as fractional crystallisation from a Cr-Al-rich melt as suggested by McCoy *et al.* (1991) and Krot *et al.* (1993). The picotites in panda are almost homogeneous (Borucki and Stêpniewski, 2001); the homogeneous spinels in chondrules could have crystallised from melt droplets (Simon *et al.*, 1994).

In addition to the petrological properties, the O-isotopic compositions of the minerals in panda and chevron clearly indicate that the picotites in these chondrules are not the relict phase, but the primary phase which crystallised during chon-

Oxygen isotopic compositions of the minerals in chevron

Analysis	$^{17}O_{SMOW}$ ($\pm 1_{mean}$)	$^{18}O_{SMOW}$ ($\pm 1_{mean}$)	^{17}O ($\pm 1_{mean}$)
Picotite			
Pi#01	3.6±2.9	0.3±1.5	3.5±3.0
Pi#02	−2.2±2.6	0.9±1.7	-2.6±2.8
Pi#03	5.8±2.6	−0.6±1.9	6.1±2.7
Pi#04	1.9±2.6	1.8±1.6	0.9±2.8
Pi#05	0.4±2.9	2.0±1.6	−0.6±3.1
Pi#06	−2.3±2.6	−4.3±1.6	−0.1±2.7
Average*	1.2±1.3	0.0±0.9	1.2±1.3
Olivine			
Ol#01	3.4±2.8	−2.1±1.8	4.5±2.9
Ol#02	4.6±2.8	1.5±1.6	3.8±2.9
Ol#03	1.1±2.9	−4.6±1.9	3.5±3.1
Average*	3.0±1.0	1.7±1.8	4.0±0.3
Plagioclase			
Pl#01	2.2±2.6	0.0±1.8	2.1±2.8
Pl#02	−7.1±2.6	−1.7±1.9	−6.3±2.7
Pl#03	1.9±2.5	1.0±1.7	1.4±2.6
Average*	−1.0±3.1	−0.2±0.8	−0.9±2.7

* — average of each mineral and the standard error of the mean were calculated from the values of each spot

drule-forming events. The O-isotopic compositions of minerals in both panda and chevron are slightly more ^{16}O-rich than the bulk O-isotopic composition of Baszkówka. Moreover, the O-isotopic compositions of these chondrules are more ^{16}O-rich than the population of chondrules from equilibrated ordinary chondrites (3‰ < ^{18}O < 6‰) described in Clayton *et al.* (1991). However, The O-isotopic compositions of the picotites ($^{17}O_{panda}$ −4‰; $^{17}O_{panda}$ 1‰) are quite different from those of spinels in CAIs (−20‰).

Although the picotites have no direct relationship with spinels in CAIs, the precursors of panda and chevron may have been originally enriched in ^{16}O. Clayton *et al.* (1991) suggested that O-isotopic compositions within ordinary chondrites are due to high-temperature exchange between ^{16}O-rich chondrule precursors and ^{16}O-poor nebular gas. Panda and chevron may preserve the ^{16}O-enrichment as a result of incomplete exchange between chondrule precursors and the ambient nebular gas. As Russell *et al.* (1997) suggested from the study of Al-rich chondrules in unequilibrated ordinary chondrites, it is possible that chevron and panda are more primitive than ferromagnesian chondrules in Baszkówka.

The O-isotopic exchange reaction between chondrule precursors and the nebular gas may have also occurred during the solidification of the chondrule melt. The variations of the O-isotopic compositions observed among the minerals in panda may have been accomplished by incomplete O-isotopic exchange by nebular gas under late-limiting processes such as diffusion in melt and/or surface reaction, as suggested by Maruyama *et al.* (1999*b*). The molten droplet of precursors of chevron may have solidified so rapidly. Thus O-isotopic exchange reaction may have scarcely progressed during the formation of chevron.

CONCLUSION

Although both panda and chevron have closer relationship to ordinary ferromagnesian chondrules than CAIs, these picotite-bearing chondrules are more ^{16}O-rich than chondrules in ordinary chondrites. The ^{16}O-enrichment of panda and chevron may result from incomplete O-isotopic exchange reaction between ^{16}O-rich chondrule precursors and the ^{16}O-poor ambient nebular gas. The variations of O-isotopic ratios among the minerals in panda may indicate that O-isotope exchange reaction has occurred between the chondrule melt droplet and the nebular gas. The O-isotopic heterogeneity in Baszkówka meteorite may represent an older, early solar nebular material indicating that Baszkówka have not been completely homogenised through the thermal metamorphism and/or the secondary alteration in the parent body.

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