

Chemical compositional characteristics of CBb and CH chondrites

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Introduction: CB and CH chondrites are metal-rich chondrite groups [1, 2] and their oxygen isotopic compositions show a close relationship to CR chondrites [3]. The petrogenesis of CB chondrites came to be considered as the condensation from impact-induced vapor plume [4, 5]. According to the similarity of oxygen isotopic composition between CB and CH chondrites, the parent bodies of these chondrites might exist close to each other. Then, how impact processes affected the origin and the evolution of CH chondrites? What was the difference between CB and CH chondrites? Impact-induced vaporization should cause volatility loss of elements, so chemical compositions and isotopic compositions must become powerful tool to discuss these issues.

Bulk chemical compositions of CB and CH chondrites have been scarcely reported and have been poorly discussed. Here, we report and characterize the results of our bulk chemical analyses for one CB and 4 CH chondrites and discuss their formation processes.

Samples & methods: Bulk chemical compositions of 1 CBb chondrite (MacAlpine Hills (MAC) 02675) and 4 CH chondrites (Asuka 881020, Asuka 881451, Patuxent Range (PAT) 91546 and Pecora Escarpment (PCA) 91467) have been determined by PGA, INAA, ICP-AES and ICP-MS. A chip sample weighing 130-440 mg of each meteorite was crushed into small chips and fine grains. Small fractions weighing ~40 mg of each meteorite were used for INAA, ICP-AES and ICP-MS, respectively. To evaluate the sample heterogeneity, 3 fractions of MAC 02675 and 2 fractions of PAT 91546 and PCA 91467 were subjected to INAA. Remaining chip samples weighing 150-400 mg of each meteorite were used for PGA.

The elements analyzed by INAA are Na, Mg, Al, Ca, Sc, V, Cr, Mn, Fe, Co, Ni, Zn, Se, Sm, Ir and Au, and by ICP-AES are Na, Mg, Al, P, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, Sr and Ba, and by ICP-MS are Ga, Ge, As, Mo, Ru, Rh, Pd, Sn, Sb, W, Re, Ir, Pt and La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th and U, and by PGA are Na, Mg, Al, Si, S, Cl, Ca, Ti, Cr, Mn, Fe, Co and Ni.

Results: The Mg-, CI-normalized and Ni-, CI-normalized chemical compositions of CBb and CH chondrites are shown in Fig. 1. In Fig. 1a, refractory lithophile element (V to Al) to Mg ratios in CBb chondrite ($CI \times \sim 1.5$) are slightly fractionated and significantly higher than those of CH chondrites ($CI \times \sim 1$). In moderately volatile elements, Si/Mg, Cr/Mg, Mn/Mg and P/Mg ratios in CBb chondrite (0.61, 2.5, 0.27 and 3.6) are clearly different from those of CH chondrites (0.96, 1.1, 0.45 and 0.96). In volatile elements, although the Na/Mg ratio in CBb chondrite (0.26) is comparable with those of CH chondrites (0.24), the S/Mg and Zn/Mg ratios are higher in CBb chondrite (0.19 and 0.17) than those in CH chondrites (0.11 and 0.11).

In Fig. 1b, refractory siderophile elements to Ni ratios, except for W/Ni, are nearly identical between CBb and CH chondrites, but as volatility increases, CBb and CH chondrites show obviously different chemical compositional characteristics. Moderately volatile elements and volatile elements are more severely depleted in CBb chondrites than CH chondrites and the ratios of Cr/Au, As/P and Ga/S are clearly different in CBb chondrite (0.95, 0.52 and 1.0) from those of CH chondrites (0.72, 1.3 and 3.9). In addition to these differences, W/Ni ratio is clearly depleted in CBb chondrite (0.67) but is not depleted in CH chondrites (1.1) and the Re/W ratios are also different in CBb chondrite (1.9) from those of CH chondrites (1.2).

The CI-normalized and Mg-, CI-normalized REE abundances of CBb and CH chondrites are shown in Fig. 2. In Fig. 2a, REE abundances of CBb chondrite ($CI \times \sim 0.6-0.8$) and CH chondrites ($CI \times \sim 1.1-1.4$) are lower and higher than CI chondrites, respectively, and are slightly fractionated from CI chondrite composition. The La/Yb ratios of CBb chondrite is 1.2 and those of CH chondrites are 0.94. In Fig. 2b, CBb chondrite shows enrichment of REE abundances compared to CH chondrites in Mg-normalized values.

Discussions: We could find the several characteristic points of bulk chemical compositions in CBb and CH chondrites. The first is the differences of partitioning behaviors of P, Mn and Cr (Figs. 1a and 1b). The Cr-bearing troilite and daubréelite have been reported in CB chondrites [2], but not in CH chondrites, so Cr behaved as chalcophile elements only in CB chondrites. These data suggest that CB chondrites were more reduced than CH chondrites and in such highly reduced conditions, Mn and P might be partitioned into sulfides and metals, respectively. However, Mg# (molar $Mg/[Fe+Mg] \times 100$) in olivine and pyroxene are similar in CB chondrites (96-99 [2, 6]) and in CH chondrites (94-99 [7, 8]), so the redox states recorded in silicate minerals in CB and CH chondrites should not be so different. Therefore, in this timing, we are not sure what was a key role for changing partitioning behaviors of P, Mn and Cr between CB and CH chondrites.

The second is depletion patterns of volatile and moderately volatile elements (Figs. 1a and 1b). In both CBb and CH chondrites, the refractory lithophile and siderophile element patterns are not fractionated, but clear depletions can be seen on

more volatile elements than Na in lithophile elements and more volatile elements than Cr or Au in siderophile elements. In lithophile elements, CBB and CH chondrites show similar degree of depletion, but in siderophile elements, CBB chondrite shows more severe depletion than those of CH chondrites. In addition, there are some remarkable points present, such as Si-Mg fractionation and W depletion in CBB chondrite. For Si-Mg fractionation, it is known that chondrule and matrix show complementarily low and high Si/Mg ratios [9], and CBB chondrites are lack in matrix [2]. Therefore, one simple explanation is that the precursor materials of CBB chondrites were quickly isolated from gas reservoir before Si-rich matrix fractions condensed. In this case, very small and local gas reservoir should be required, such as impact vapor plume. For the W depletion, it is suggested that oxidizing conditions during evaporation process is required, such as impact vaporization process [5]. We guess that the chemical compositional trend of CBB and CH chondrites can be interpreted as the results of fractional condensation from chondritic gas reservoir.

The third is slightly fractionated REE patterns (Figs. 2a and 2b). CBB chondrite shows LREE-enriched and CH chondrites show HREE-enriched REE patterns. In Mg-normalized data, REE abundances are higher in CBB chondrite relative to CH chondrites and seem to be complementary between CBB and CH chondrites. It can be interpreted as the results of differentiation and/or evaporation as follows: CBB chondrites were melt and/or vapor components and CH chondrites were residues.

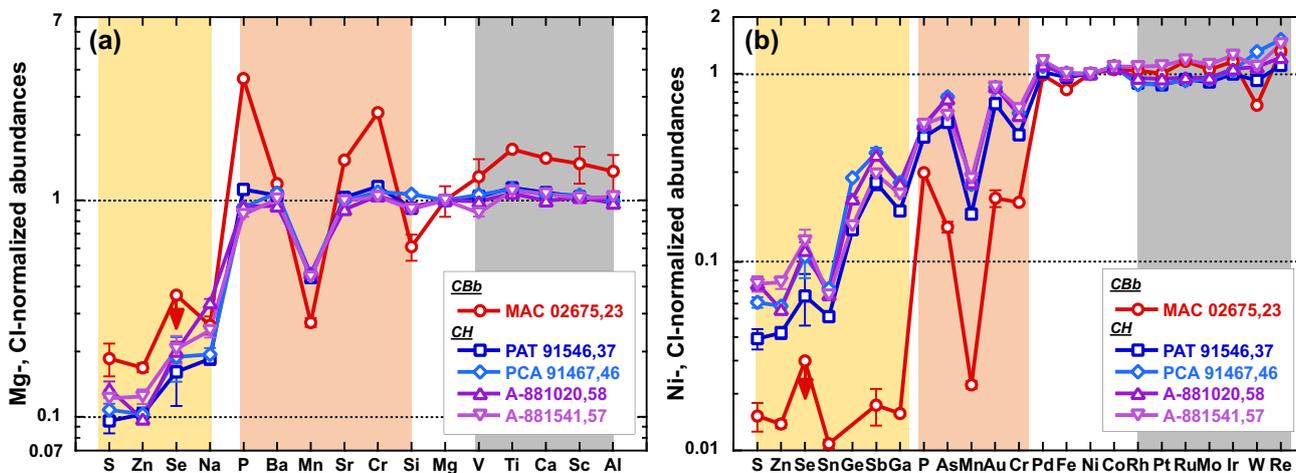


Fig. 1. Bulk chemical compositions of CBB and CH chondrites. (a) Mg- and CI-normalized lithophile element compositions. (b) Ni- and CI-normalized siderophile element compositions. The elements are sorted in decreasing order of volatility [9, 10]. Yellow-shaded areas indicate volatile elements. Orange-shaded areas indicate moderately volatile elements. Gray-shaded areas indicate refractory elements. CI chondrite values are from [10].

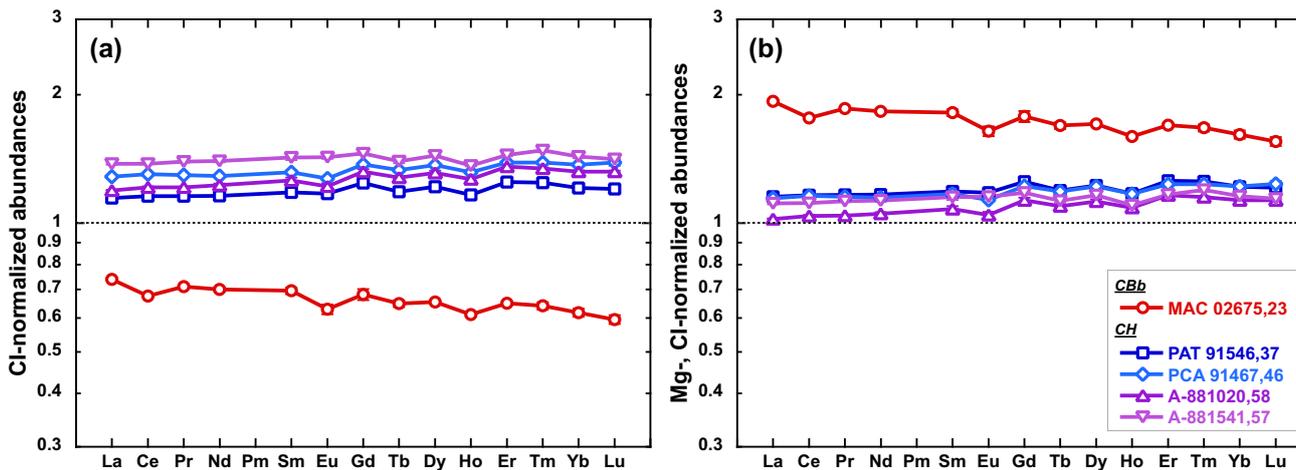


Fig. 2. Bulk REE abundances of CBB and CH chondrites. (a) shows CI-normalized values and (b) shows Mg-, CI-normalized values, respectively. CI chondrite values are from [10].

References: [1] Bischoff A. et al. (1993) *GCA*, 57, 2631-2648. [2] Weisberg M. K. et al. (2001) *Meteoritics & Planet. Sci.*, 36, 401-418. [3] Krot A. N. et al. (2002) *Meteoritics & Planet. Sci.*, 37, 1451-1490. [4] Fedkin A. V. et al. (2015) *GCA*, 164, 236-261. [5] Weyrauch M. et al. (2019) *GCA*, 246, 123-137. [6] Rubin A. E. (2003) *GCA*, 67, 3283-3298. [7] Scott E. R. D. (1988) *EPSL*, 91, 1-18. [8] Weisberg M. K. et al. (1988) *EPSL*, 91, 19-32. [9] Palme H. et al. (2015) *EPSL*, 411, 11-19. [10] Anders E. and Grevesse N. (1989) *GCA*, 53, 197-214.