MORE ON THE MINERALOGICAL DIVERSITY OF THE C1 CLASTS IN KAIDUN METEORITE. K. Ogiya[1,2], T. Mikouchi[1,2], M. E. Zolensky[3], [1]Dept. of Earth and Planet. Sci., University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan, [2]University Museum, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan, [3]ARES, NASA Johnson Space Center, Houston, TX 77058, USA, E-mail: ogiya-kenei886@g.ecc.u-tokyo.ac.jp.

Introduction: The Kaidun meteorite, which fell in 1980 in what is now Yemen, is a polymict micro breccia with an extremely rare feature: it contains achondrite materials in addition to chondrite materials. The chondritic materials include various types such as C1, C2, CM1, CM2, CV3, EH3-5, EL3, R, and OC-related materials [e.g., 1]. This study specifically focuses on the C1 materials undergoing significant aqueous alteration in Kaidun (referred to as Kaidun C1). Most of the Kaidun C1 materials are CI-like [e.g., 2], and it is known that the petrological characterization of CI chondrites is challenging compared to other petrologic types because C1 materials are petrographically fairly featureless. In addition, the number of discovered CI chondrites is very small (less than 10 to date). However, studies of CI-like clasts and dark inclusions in certain meteorites, or returned samples from asteroids Ryugu and Bennu reveal the widespread presence of CI materials in the early solar system [e.g., 3,4]. Furthermore, the existence of CI-like clasts with textural and isotopic characteristics between CI, CM, and CR types, such as CI chondritic but with CM and CR chemical properties, have been noted in carbonaceous clasts in Kaidun [5]. This study specifically analyzed the chemical compositions of phyllosilicates and carbonates, which are the major minerals in Kaidun CI-like clasts, because they have not been comprehensively analyzed in previous studies. Since these clasts possibly underwent aqueous alteration in different asteroidal parent bodies before accumulating in the Kaidun parent body, we aim to provide quantitative constraints on the formation and evolutionary history of CI chondritic parent bodies.

Additionally, given that Kaidun is a unique meteorite containing clasts with varied origins, it is also expected to contain C1 material that is non-CI-like and has chondrule pseudomorphs. The purpose of this study is thus to systematically understand the mineralogical diversity of C1 materials, especially by discovering and describing ungrouped C1 materials other than the CM1 clasts previously described in Kaidun [6].

Samples and Analytical Methods: Six polished thin sections of Kaidun were analyzed in this study. Observations and analyses were conducted using FE-EPMA (JEOL JXA-8530F) at the Department of Earth and Planetary Science, University of Tokyo.

Results and Discussion: The six sections have a total area of 138.399 mm^2. From these, 40 C1 clasts were identified, covering 36.428 mm^2 or 26.3% of the analyzed samples. Among them, 27 clasts (13.952 mm^2, 10.1%) are CI-like clasts, lacking chondrule pseudomorphs, and are texturally similar to CI chondrites. The remaining 13 clasts (22.476 mm^2, 16.2%) are petrologically type 1, featuring rare anhydrous silicates, but contain chondrule pseudomorphs.

The CI-like clasts were analyzed for the major carbonate mineral, dolomite, and for the chemical composition of the phyllosilicates that constitute the bulk of the clasts. Twenty CI-like clasts contained sufficiently coarse-grained dolomite for quantitative analysis, and 187 dolomite grains were analyzed. The matrix texture of the clasts containing dolomite exhibits features akin to those of CI. Most dolomite compositions are more enriched in Mg than Ca, consistent with trends observed in CI [7,8]. However, some dolomite grains with Ca-rich compositions exist (Fig. 1). Such a dolomite composition is absent in CIs and is known to be exclusive to CM in known meteorites, suggesting that dolomite might have formed metastably at temperatures lower than those for dolomite in CI chondrites. Analysis of trace elements such as Mn and Fe in dolomite also showed it to be Fe-rich, contrasting with CI chondrites (Fig. 1). Textural observations indicated that dolomite formed surrounding Ca-carbonate (Fig. 2), a texture not observed in CI chondrites. Additionally, no breunnerite was found in Kaidun CI-like clasts.

Phyllosilicate analysis revealed the composition much more enriched in Fe than CI chondrites (Fig. 3). The resemblance of the texture to CI chondrites suggests that precursors similar to CI chondrites might have undergone aqueous alteration under CM chondritic fluid compositions and at low temperatures.

C1 clasts with chondrule pseudomorphs, displaying a texture distinct from the recognized Kaidun CM1, were also identified. Specifically, minerals such as Ca, Fe-silicate, andradite, and phyllosilicates rich in Ca, Fe, and Mg were detected in the matrix of certain C1 clasts. This suggests that they might represent petrologic type 1 clasts in CV chondrites (Fig. 4). Such Ca, Fe-silicates have only been reported in CV and CO chondrites among carbonaceous chondrites [e.g., 9,10]. Given that CV2 clasts have been reported [11], these might correspond to CV3 clasts already reported in Kaidun, having experienced intense aqueous alteration to become CV1. However, we cannot rule out the possibility that some clasts with smaller chondrule pseudomorphs might relate to CO chondrites or might be unknown clast types derived from a parent body different from the known carbonaceous chondrites.

Conclusion: The oxygen isotope study of Kaidun carbonaceous fragments [5] indicated the presence of clasts that are CI chondritic but exhibit features intermediate to those of CM chondrites. We support this previous research from a mineralogical point of view, including textural and mineral composition features. This finding suggests the potential diversity of CI chondrite parent bodies or the possibility that CI chondritic precursors accumulated in CM chondrite parent bodies and subsequently underwent aqueous alteration under CM chondrite-like conditions.

C1 clasts containing chondrule pseudomorphs were found in this study, some of which were specifically classified as CV1. These clasts originate from CV3, already described in Kaidun, and may have undergone aqueous alteration strong enough to alter them to petrologic type 1 materials under conditions similar to those of the CI. However, based on the size of the chondrule pseudomorphs, it is also conceivable that some other clasts are related to CO chondrites or originate from an unidentified parent body with precursors and alteration processes conducive to the formation of Ca and Fe silicates. Notably, CV1-like clasts have never been reported previously, suggesting further diversification of Kaidun C1 lithologies and offering valuable insights for classifying future meteorites and returned samples.

References: [1] Zolensky M. and Ivanov A. (2003) *Chem. Erde*, *Geochem*., *63*, 185-246. [2] Harries D. and Zolensky M. (2016) *Meteoritics & Planet. Sci.*, *51*, 1096-1109. [3] Russell S. et al. (2022) *Meteoritics & Planet. Sci*., *57*, 277-301. [4] Nakamura T. et al. (2022) *Science*, eabn8671. [5] MacPherson G. J. et al. (2009) *Geochim. Cosmochim. Acta*, *73*, 5493-5511. [6] Zolensky M. et al. (1996) *Meteoritics & Planet. Sci*., *31*, 484-493. [7] Johnson C. A. and Prinz M. (1996) *Geochim. Cosmochim. Acta*, *57*, 2843-2852. [8] de LEUW S. et al. (2010) *Meteoritics & Planet. Sci*., *45*, 513-530. [9] MacPherson G. and Krot A. (2014) *Meteoritics & Planet. Sci*., *49*, 1250-1270. [10] Krot A. et al. (2022) *Meteoritics & Planet. Sci*., *57*, 392-428. [11] Tomeoka K. and Ohnishi I. (2011) *Geochim. Cosmochim. Acta*, *75*, 6064-6079.

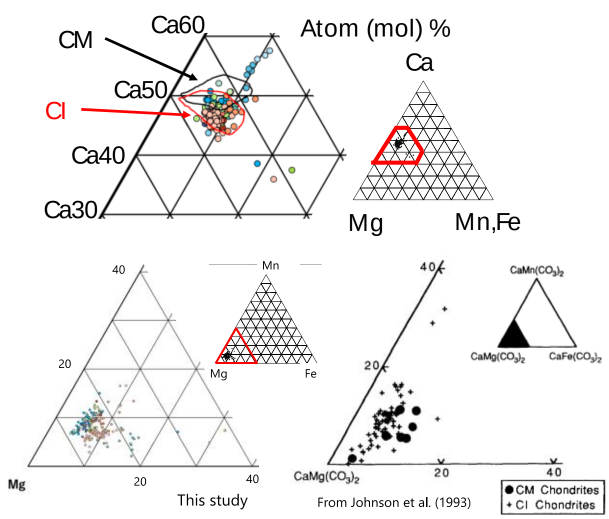

Fig. 1. Chemical composition of dolomites in Kaidun CI-like clasts. Data from [7].

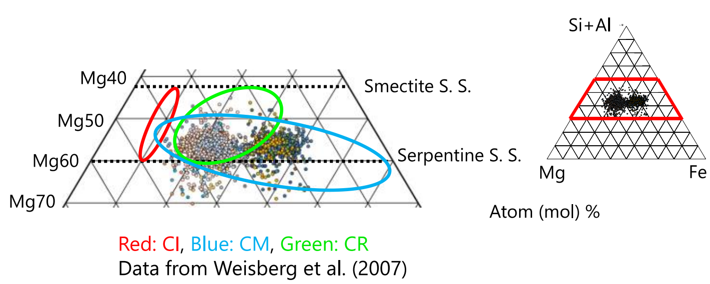

Fig. 3. Chemical composition of phyllosilicates in matrix of Kaidun CI-like clasts.

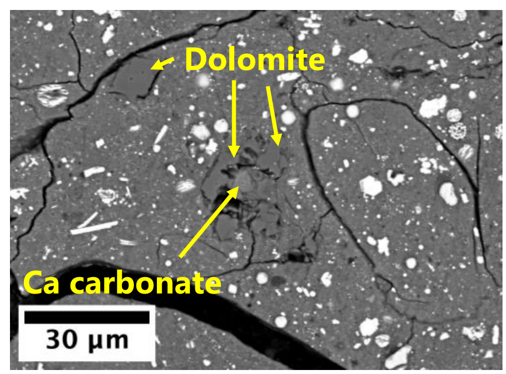

Fig. 2. Dolomites in some Kaidun CI-like clast, which surrounds Ca carbonate.

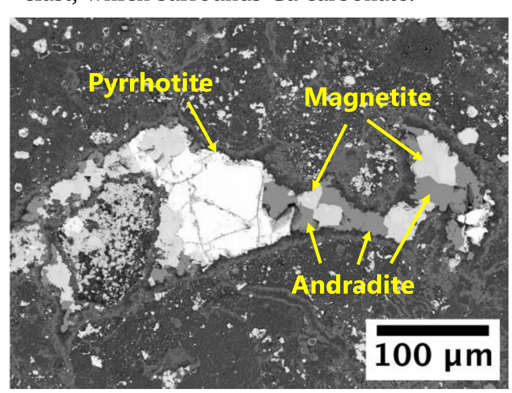

Fig. 4. Andradite garnet in a Kaidun C1 clast which contained chondrule pseudomorphs and could be classified as CV1.