BRACHINITE-LIKE CLAST IN THE KAIDUN METEORITE: FIRST REPORT OF PRIMITIVE ACHONDRITE MATERIAL. K. Higashi[1], H. Hasegawa[1], T. Mikouchi[1], and M. E. Zolensky[2], [1]Department of Earth and Planetary Science, The University of Tokyo, Bunkyo-ku, Tokyo 113-0033, Japan, [2]XI2, NASA Johnson Space Center, Houston, TX 77058, USA (e-mail: k.higashi@eps.s.u-tokyo.ac.jp)

Introduction: Kaidun is a brecciated meteorite containing many different types of meteorites. It is composed of carbonaceous, enstatite, ordinary and R chondrites with smaller amounts of basaltic achondrites, impact melt products and unknown materials [1, 2]. Because of the multiple components and high abundance of carbonaceous chondrites, the Kaidun parent body was probably a large C-type asteroid in order to have accumulated clasts of many unrelated asteroids, and thus Kaidun contains previously unknown materials [1]. It has been suggested that the Kaidun parent body trawled through different regions of the solar system [3], but the formation of Kaidun meteorite is still uncertain. In this abstract, we report the first discovery of a brachinite-like clast in Kaidun.

Sample and method: We observed a polished thin section of Kaidun #4 (Fig. 1) by optical microscopy. An Electron Probe Micro Analyzer (EPMA: JEOL JXA-8530F at the University of Tokyo) was employed to obtain X-ray elemental maps and analyze mineral compositions.

Petrography: The clast (*ca.*, 0.4 x 0.4 mm) studied mostly consists of olivine (~0.4 mm) with small amounts of Fe-Ni metal and Fe sulfide (~0.1 mm) (Fig. 2). At the grain boundaries of olivine and in some olivine minerals, fine-grained (~10 µm) assemblages of Fe sulfide and orthopyroxene are present (Fig. 3).

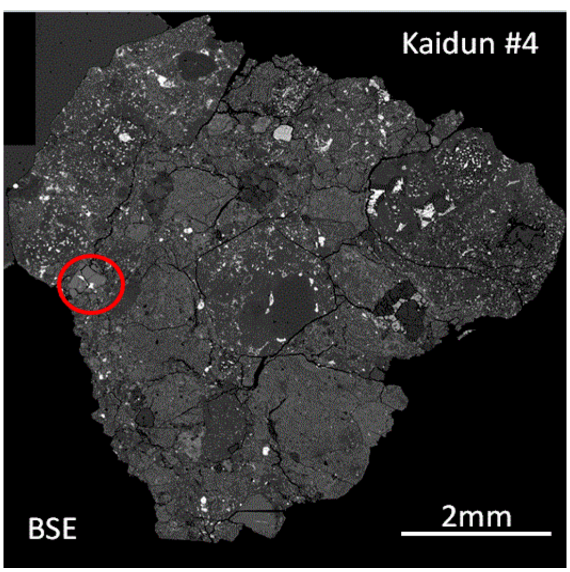

Fig. 1. Backscattered electron (BSE) image of Kaidun #4, showing mm-sized clasts with variable lithologies. The clast studied is surrounded by a red circle.

Mineral chemistry: Olivine grains are essentially homogeneous except for the ~10 µm Mg-rich rims where fine-grained assemblages of orthopyroxene and Fe sulfide are associated (Fig. 3). The core composition of olivine is $Fo_{69\text{-}70}$. The compositional ranges of minor elements are 0.3-0.5 wt% MnO, 0.2-0.3 wt% CaO, and 0.1-0.2 wt% Cr_2O_3. The rim composition of olivine reaches up to Fo_{81}. The Fe-Ni metal is kamacite, but the Ni content is slightly different between the core (5 wt%) and the rim (9 wt%) (Fig. 4). Tiny Fe phosphide grains (~2 µm) are present at the boundary between the Ni-poor core and Ni-rich rim of kamacite. The orthopyroxene composition is $En_{81\text{-}97}Wo_{\text{-}2}$.

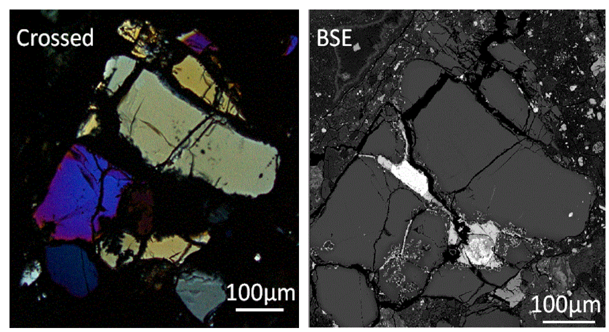

Fig. 2. A crossed polarized image (left) and a BSE image (right) of the brachinite-like clast in Kaidun #4, mainly consisting of olivine (dark gray), Fe-Ni metal (white) and Fe sulfide (light gray).

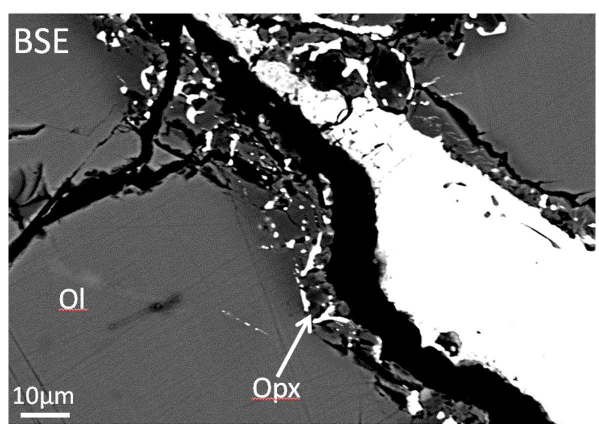

Fig. 3. BSE image of the boundary between olivine (grey) and opaque minerals (white). Olivine shows reverse chemical zoning at the rim associated with opaque minerals and orthopyroxene (“opx”).

Discussion: Because this clast mainly consists of large olivine grains, it is considered to be a fragment of an achondritic rock. However, the texture of this clast is different from any other known achondrite clasts reported from Kaidun [1]. One of the most remarkable characteristics of this clast is reverse chemical zoning of olivine (core: Fo_{69-70} and rim: $Fo_{\sim 81}$) with fine-grained assemblages of Fe sulfide and orthopyroxene. This indicates that the zoning is caused by reduction of olivine. Similar olivine zoning is commonly observed in ureilites whose olivine core compositions are Fo_{74-95} [4] and is widely considered to be caused by reduction by carbon minerals. Ureilitic olivine is also characterized by high contents of CaO (0.30-0.45 wt%) and Cr_2O_3 (0.56-0.85%) (Fig. 5) [4]. Compared with olivine in the Kaidun clast studied, olivine in ureilites has clearly higher mg#, CaO and Cr_2O_3 contents. Also, carbon phases are completely absent in this Kaidun clast. Therefore, this olivine-rich clast in Kaidun is not a ureilite.

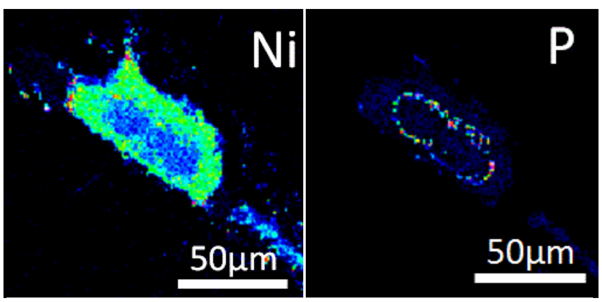

Fig. 4. Ni and P elemental maps of Fe-Ni metal in the Kaidun clast studied, showing different Ni contents between Ni-poor core and Ni-rich rim. Tiny Fe phosphides are sited at the core-rim boundary.

In a CaO wt% vs Cr_2O_3 wt% diagram (Fig. 5), the olivine composition of the Kaidun clast plots close to that of Brachina (type specimen of brachinites) [5]. The Fo content of the Kaidun clast (Fo_{69-70}) is also within the range of brachinite olivine (Fo_{64-70}) [e.g., 5]. At the olivine rims of brachinites, orthopyroxene and opaque minerals are often present as fine-grained assemblages [5]. The opaque minerals in these assemblages are Fe metal and Fe sulfide. Such fine-grained assemblages are similar to that in the Kaidun clast. However, olivine in brachinites is homogeneous and reverse zoning is not known except in NWA 1500 [5]. The olivine zoning in NWA 1500 is considered to be a product of reduction, similar to ureilites and orthopyroxene, metal and sulfide assemblages were also formed by reduction [5]. The olivine composition of NWA 1500 is Ca- and Cr-poorer compared to that of the Kaidun clast.

Thus, the Kaidun clast is most similar to a brachinite and distinct from a ureilite. Its mineral composition and olivine texture are especially close to Brachina and NWA 1500, respectively. Although the Fe-Ni metal with different Ni contents is not known from brachinites, the overall petrology and mineralogy of this clast indicate that it is most likely a fragment of brachinite (or brachinite-like meteorite).

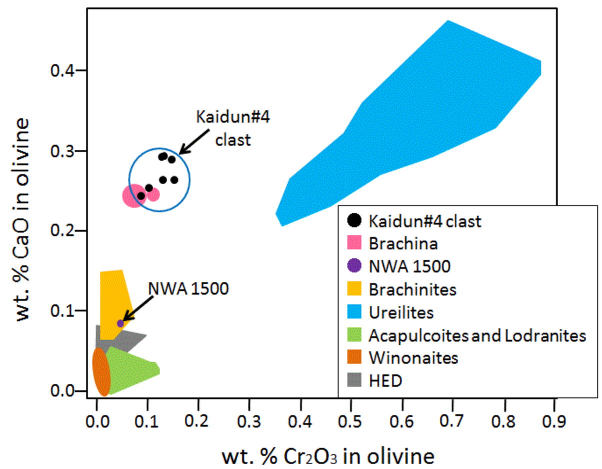

Fig 5. CaO vs Cr_2O_3 (in wt%) of olivine in various primitive achondritic meteorites and the Kaidun clast. Modified from [5].

Conclusion: This is the first report of primitive achondrite material in Kaidun, which shows a best match with brachinites in the known meteorite collection. This discovery widens the diversity of Kaidun components and is critical to discussion of the nature of the Kaidun parent body. Because the Mn-Cr age of Brachina is 4564.8 ± 0.5 Ma [6], the formation of Kaidun's parent body is probably be younger than this age.

References: [1] Zolensky M. E. and Ivanov A. V. (2003) *Chemie der Erde, 63*, 185-280. [2] MacPherson G. J. et al. (2009) *GCA, 73*, 5493-5511. [3] Ivanova M. A. et al. (2016) *79th Annual Meeting of the Meteorit. Soc.*, Abstract #6100. [4] Goodrich C. A. et al. (2004) *Chemie der Erde, 64*, 283-327. [5] Goodrich C. A. et al. (2011) *Meteoritics & Planet. Sci., 45*, 1906-1928. [6] Dunlap D. R. et al. (2016) *LPSC XLVII*, Abstract #3055.