An anomalous eucrite, Dhofar 007, and a possible genetic relationship with mesosiderites. A. Yamaguchi[1,2], T. Setoyanagi[3], and M. Ebihara[3], [1]Antarctic Meteorite Research Center, National Institute of Polar Research, Tokyo 173-8515 (yamaguch@nipr.ac.jp), [2]The Graduate University for Advanced Studies, Tokyo 173-8515, [3]Department of Chemistry, Tokyo Metropolitan University, Hachioji, Tokyo 192-0397.

Introduction: An achondrite, Dhofar 007 (~27 kg) was found in the Oman desert and was initially classified as a cumulate eucrite [1]. However, Yamaguchi et al. [2] showed that a coarse-grained clast (CG clast) in Dhofar 007 has a high abundance of metallic phases and the high bulk Ni and Co contents, and suggested a possible relationship with mesosiderites. We performed an additional petrologic and geochemical study to better understand the differentiation, shock, and thermal history of Dhofar 007. We compared Dhofar 007 to HED meteorites and mesosiderites to fill the gap in our knowledge of the geologic history of these meteorite groups.

Analytical techniques: We made polished thick and thin sections (PTSs) of several portions of Dhofar 007. A portion of the CG clast (0.882 g) was powdered for INAA, PGA, and ICP-MS. We visually inspected the portion for the chemical analyses to insure that it did not contain any material from the breccia matrix. PTSs were examined by optical microscope, SEM, and EPMA. The modes of various phases were determined by X-ray mapping of EPMA.

Texture and mineral chemistry: Dhofar 007 is a breccia, mainly composed of coarse-grained clasts set in a brecciated matrix. Although most of the matrix materials are similar to the CG-clast, we found xenolithic components such as an impact melt clast (1.9 x 2.0 mm), a Mg-rich orthopyroxene fragment (1.5 x 2.5 mm), and a recrystallized plagioclase. This suggests that Dhofar 007 is a polymict breccia. The boundaries between clast and brecciated portion is in many cases gradational. Clasts and brecciated matrix are transected by glassy impact melt veins (10-30 μm thick), indicating that Dhofar 007 experienced at least two shock events after crystallization.

The PTSs of the CG clast show a granular texture composed of pyroxene (~51 vol%) and plagioclase (~47 vol%) with minor amounts of silica minerals (0.7 vol%), chromite (0.3 vol%), troilite (0.6 vol%), kamacite (0.02 vol%), taenite (0.04 vol%), Ca-phosphate (0.06 vol%) and weathering products often associated with metallic phases. Pyroxenes in the CG clast are pigeonites that have closely spaced, very fine augite exsolution lamellae (<<1 μm wide). Chemical compositions of pyroxenes are scattered on a single tie line from $Wo_{2.9}En_{53.3}$-$Wo_{16.7}En_{48.2}$ because thin augite lamellae are unresolvable by electron beam. Orthopyroxene grain is chemically homogeneous ($Wo_{1.3}En_{83.0}$). The FeO/MnO ratios of these pyroxenes are 29-35, similar to the ratios in eucritic pyroxenes. Plagioclase has slight chemical variation ($An_{94.5}Or_{0.3}$ to $An_{90.8}Or_{0.3}$). We could not find any difference of plagioclase chemistry in plagioclase from clast and matrix. Chromite shows slight chemical variation ($Ulv_{24.0}Chm_{61.1}$-$Ulv_{10.4}Chm_{70.9}$) and contains fine needles of Ti-rich phases, possibly ilmenite.

We found taenite and kamacite closely associated with troilite. These phases are in most cases rimmed by weathering products. In taenite that is in contact with kamacite, the Ni profile of the core (~10 μm) shows a flat pattern (39.6-40.6 wt%) with a sharp zoning (up to 47.8 wt%) near (~4 μm) the boundary. There are several cloudy taenite grains rimmed by clear taenite (Fig. 1). The cloudy zones are composed of bright island regions (~0.2 μm wide) and dark honeycomb regions.

The impact melt clast is composed of polymineralic clasts and mineral fragments. The texture and chemical compositions of the pyroxene and plagioclase are similar to those in the CG clast. The clasts are composed of pyroxene and plagioclase in which the grain boundaries are melted forming thin glassy rim (~5-20 μm thick), and the minerals contain melt pockets. Pyroxene contains very thin augite lamellae (<1 μm) like those observed in the CG clast, and parts of them are vesiculated. This indicates that the clasts and mineral fragments are shock-heated severely.

Bulk chemistry: The REE data show a slight increase from light to heavy REE (1.3 - 2.0 x chondrites) with a positive Eu anomaly (normalized Eu/Eu^* ratio = 3.14), and are within the range of cumulate eucrites (Fig. 2). Compared to eucrites, siderophile elements in the CG clast are highly enriched; Ni at 265 x the bulk of Moore County (MC) [3], Pd at 93 x MC, Os at 10 x MC, and Au at 40 x MC. The CI-normalized Ir/Ni (Ir/Ni_{CI}) (= 1.21), Au/Ni_{CI} (= 0.78), and Ni/Co_{CI} (= 0.85) ratios are similar to the metallic portions of mesosiderites (Ir/Ni_{CI} = 1.31, Au/Ni_{CI} = 1.01, and Ni/Co_{CI} = 0.85 for normal mesosiderite average) [4].

Discussion: Except for some features such as high abundances of siderophile elements, Dhofar 007 is petrologically similar to cumulate eucrites. The oxygen isotopic composition of Dhofar 007 implies a possible genetic relationship with these meteorites [5]. The coarse-grained granular texture and the chemistry of pyroxene and plagioclase are consistent with its being a cumulate. The REE data of the CG clast also indicate that the CG clast is a cumulate eucrite. It appears that the impact melt clast and Mg-rich orthopyroxene fragment were incorporated during brecciation on the surface. These observations indicate that the parent body of Dhofar 007 experienced similar shock history to that of the HED parent body surface.

In cumulate eucrites, pyroxenes are generally orthopyroxenes partly or totally inverted from pigeonite and have thick augite lamellae because of the very slow cooling rate under plutonic conditions [6]. However, pyroxenes of Dhofar 007 are not inverted to orthopyroxene, and instead they have very fine augite exsolution lamellae. This indicates that the CG clast was cooled very rapidly at high temperature. In contrast, the textures of metallic phases suggest the very slow cooling rates. The Ni profile of the taenite grain indicates a very slow cooling rate (<1-10 K/Ma) from ~700 °C to 400 °C [7]. These cooling rates are almost comparable to those of mesosiderites [8]. The presence of cloudy taenites also suggests a slow cooling rate below 300 °C [9].

The high abundance of siderophile elements in the CG clast could not be explained in terms of igneous processes. Thus, these elements were incorporated from projectile materials. It is unlikely that siderophile elements were incorporated by the later shock events that produced impact melt veins and breccia texture because kamacite and taenite, the most likely carrier phases of siderophile elements, in the CG clast are not associated with these shock textures. The meteoritic contamination could have taken place before recrystallization or even during initial crystallization from melt.

It is possible that the Dhofar 007 may have been a silicate fraction in mesosiderite based on the thermal history and siderophile data. However, in Dhofar 007, we could not find mineralogical evidence for gabbroic clasts in mesosiderites. For example, the modal abundance of silica minerals and Ca-phosphates in Dhofar 007 are very low compared to mafic clasts in mesosiderites [10] and the FeO/MnO ratios in pyroxenes are in the range of HED meteorites. As some gabbroic clasts in mesosiderites may be mineralogically indistinguishable from HED meteorites, we cannot rule out the possibility that Dhofar 007 is a mesosiderite. Recently, Kaneda et al. [11] showed that EET92023 (26 g) is a coarse-grained rock with similar REE abundances to those of Moore County and highly enriched siderophile abundances. The thermal history of EET90203 is similar to that of the Dhofar 007 CG clast. These facts imply that EET92023 came from the same source.

Several eucrites such as Moore County show of evidence for rapid cooling from high temperature, implying a large-scale impact event during thermal metamorphism [12, 13]. It is likely that the eucrites excavated from hot interior of the parent body were again buried deeply and cooled very slowly at low temperature although actual cooling rates at low temperatures are not well known. Because the cooling rates estimated from the metallic phases require a large body [8], it is more likely that Dhofar 007 came from the mesosiderite parent body.

References: [1] Afanisiev S.V. et al. (2000) MAPS 35, A19. [2] Yamaguchi A. et al. (2002) Antarctic Meteorites 27, 177. [3] Morgan J.W. et al. (1978) GCA 42, 27. [4] Hassanzadeh J. et al. (1990) GCA 54, 3197. [5] Miura Y.N. and Kusakabe M. (2002) personal communication. [6] Takeda H. (1997) MAPS 32, 841. [7] Saikumar V. and Goldstein J.I. (1988) GCA 52, 715. [8] Scott E.R.D. et al. (2001) MAPS 36, 861. [9] Yang C.-W. et al. (1997) MAPS 32, 423. [10] Rubin A.E. and Mittlefehldt D.W.G. (1992) GCA 56, 827. [11] Kaneda K. and Warren P.H. (1998) MAPS 33, A81. [12] Miyamoto M. et al. (2001) MAPS 36, 231. [13] Yamaguchi A. et al. (2001) GCA 65, 3577. [14] Barrat J.-A. et al. (2000) MAPS 35, 1087.

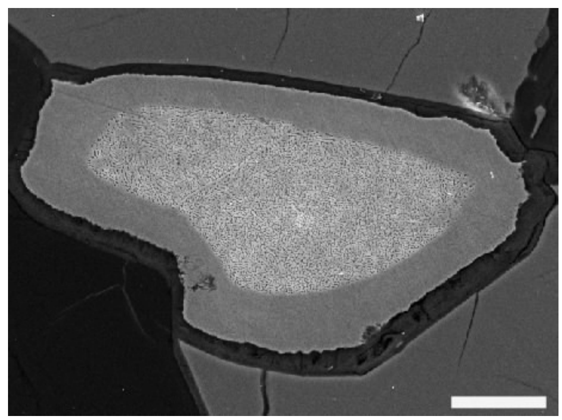

Fig. 1. SEM image of cloudy taenite rimmed by clear taenite. The sample was etched with ~2% nital. The scale bar is 10 μm.

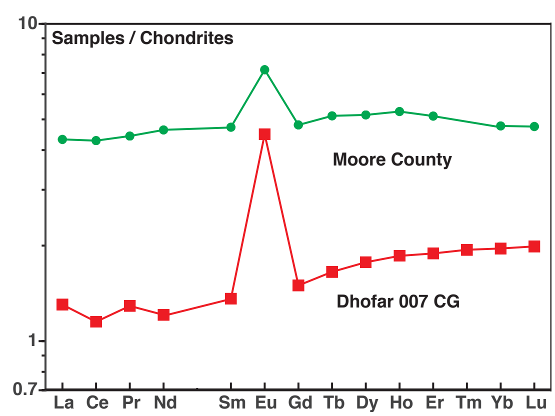

Fig. 2. Chondrite-normalized REE patterns of CG clast in Dhofar 007 and a cumulate eucrites, Moore County [14].