MM-CM SCALE CHEMICAL HETEROGENEITY OF PARTIALLY-MOLTEN PLANETISMALS: EVIDENCES FROM METEORITES AND METEORS.

T. Arai[1], T. Kasuga[2], K. Otsuka[3], [1]Planetary Exploration Research Center (PERC), Chiba Institute of Technology, 2-17-1 Tsudanuma, Chiba 275-0016, Japan, (tomoko.arai@it-chiba.ac.jp), [2]National Astronomical Observatory of Japan, 2-21-1 Osawa, Tokyo 181-8588, Japan, [3]Tokyo Meteor Network, 1-27-5 Daisawa, Tokyo 155-0032, Japan.

Introduction: Recent studies of asteroid 2008TC$_3$ and meteorite Almahta Sitta provide us with new insights into planetary and asteroidal sciences. First, they tell us that one asteroid do not necessarily represent a single type of meteorite, but instead, consists of a mixture of multiple different types of meteorites, which include a variety of chondrites and achondrites (ureilites) [1]. Second, the 2008TC$_3$ was previously reported to be B(F)-type asteroid on the basis of ground-based telescopic observation prior to the fall [2], although it has been generally considered that ureilite parent bodies were S-type asteroid [e.g. 3]. The mismatch between the mineralogy of the recovered meteorites and the spectral type of the parent body implies either compositional heterogeneity of the parent body, or biased sampling by recovered meteorites.

Primitive achondrites, such as acapulcoites, lodranite, etc. have bulk chemical compositions relatively close to those of chondrites, but affected by partial melting proccese to some extent.They record chemical and physical state of the earliest melting on planetismals. Here, we explore the effect of the incipient melting on chemical heterogeneity within asteroids, based on studies of meteorites and meteor (streams).

Samples & methods: Unusual primitive achondrite, LEW 86220 and silicate inclusions in IAB iron meteorite, Caddo County were used in this study. A polished thin section (PTS) LEW 86220, 4, which has been studied by McCoy et al. [4] was provided by NASA/Smithonian Antarctic Meteorite Working Group. The PTS 3A of Caddo County, which has been reported by Takeda et al. [5], was kindly provided by Prof. Hiroshi Takeda of Chiba Institute of Technology (ChiTech). Mineralogical analyses were conducted, using a JEOL JSM-6510 analytical SEM of PERC, Chitech and a JEOL JXA-8200 EPMA of National Institute of Polar Research of JAPAN (NIPR). Analyses of elemental maps were conducted with ENVI.

Results:

LEW86220: Mineralogy of this meteorite has been preliminary reported [4]. In spite of its small size, 4 × 1.5 × 1 cm, weighing 25.0 grams, the texture and modal abundance is heterogeneous. The PTS (about 1 × 1 cm area) consists of two distinct lithologies: fine-grained acapulcoitic lithology and coarse-grained gabbroic lithology (Fig. 1a). The two contrastive lithologies co-exist with smooth embayed boundaries. The former lithology consists of olivine (Fo$_{92.6\text{-}93.1}$), orthopyroxene (Fs$_{8.2\text{-}9.1}$Wo$_{1.3\text{-}2.2}$), plagioclase (An$_{14.7\text{-}16.8}$Or$_{3.4\text{-}4.5}$), troilite and FeNi metal with silicate grain sizes ranging from 100-250 µm. The modal abundance is broadly chondritic with <10 vol% plagioclase, troilite and FeNi metal (Fig. 2a). The latter lithology is composed dominantly composed of coarse-grained (up to 7 mm across) plagioclase (An$_{9.5\text{-}18.8}$Or$_{3.1\text{-}6.5}$) and chromian diopside (up to 2.5 mm across) (Fs$_{3.7\text{-}4.8}$Wo$_{40.5\text{-}45.6}$, Cr$_2$O$_3$=1.0-1.3 wt%), with FeNi metal, troilite and accessory phosphate. While some of troilite and FeNi metal are found within the plagioclase grains, most of them occur in the boundary between the two lithologies (Fig. 2a). The result is consistent with the previous studies [4]. Modal abundances of plagioclase and chromian diopside in the latter lithology are 64 and 15 vol%, respectively.

Silicate inclusion in Caddo County: The PTS 3A consists of coarse-grained gabbroic lithology, fine-grained mafic-rich lithology, and metal-rich lithology within about 1 cm distance (Fig. 1B). These distinct lithologies co-exist continuously without apparent boundaries. The boundaries between the gabboic area and metal-rich area are embayed and subrounded (Fig. 2B). Mineral compositions of all the lithogies are nealy constant. The gabbroic lithology includes extremely coarse-grained (up to 9 mm across) plagioclases (An$_{16.5\text{-}18.2}$Or$_{2.9\text{-}3.3}$), which enclose chromian diopside grains (Fs$_{2.4\text{-}2.9}$Wo$_{43.8\text{-}45.5}$, Cr$_2$O$_3$=0.7-1.0 wt%), up to 2 mm across, with less amount of smaller (<1 mm across) orthopyroxene (Fs$_{6.5\text{-}7.1}$Wo$_{2.0\text{-}2.9}$) and olivine (Fo$_{96.8\text{-}97.0}$). The modal abundance in this lithology is 59 vol% plagioclase, 28 vol% diopside, 7 vol% olivine, and 5 vol% orthopyroxene. The result is line with the previous study [5]. The metal-rich lithology in direct contact with gabbroic lithology includes rounded isolated grains of plagioclase and diopside, and aggregates of these two minerals. The mafic-rich lithology also in direct contact with the gabbroic lihology contains finer-grained (≦1 mm across) olivine, orthopyroxene and diopside with less amount of plagioclase (≈ 10 vol%).

Discussions:

The gabbroic lithology present in the both samples above represent silicate partial melts upon incipient melting of chondrites. The low-degree partial melting of chondrites generate nearly peritectic composition of the Fo-An-Qz system, which contains about 55% plagioclase, together with FeNi-FeS eutectic melts. The modal abundance of plagioclase in the gabbroic lithologies are broadly consistent with the peritectic composition. In the primitive achondrites studied here, silicate partial melts co-exist with residues, FeNi-FeS melts, and even chondritic precursors within the scale of 1 cm. Modal abundances of plagioclase greatly affect NaO content of multiple lithologies generated by incipient melting, since plagioclase is a dominant carrier of Na. Relative to chondrites with <10 vol% plagioclase and NaO<1 wt% (0.2-0.6 wt%), an enrichment in Na occurs in the silicate partial melt, while depletion in Na occurs in the residue. In the case where NaO=9 wt% and plagioclase mode is 60 vol%, the silicate partial melt has 5.4 wt% NaO. On the other hand, the residues after removal of a plagioclase-rich melt tend to show NaO$\ll$1 wt%, probably <0.1 wt%.

Na depletion and variation relative to the solar abundance (≈ chondritic) has been reported for the Geminid meteor shower [6-8], of which parent is considered to be B(F)-type asteroid 3200 Phaethon [9]. Since the grain size of the dust is 1-10 mm [10], the depletion and variation in Na abundance occur in the mm-cm scale, which is consistent with the above observation in primitive achondrites. With a perihelion distance of < 0.1 AU, Na depletion in meteor showers is likely caused by solar heating [7]. Since the perihelion distance of the Geminid meteor (0.14 AU) exceeds 0.1 AU, the Na depletion/variation should be originated from the chemical signature of the parent asteroid Phaethon. Mm-cm scale chemical heterogeneity, especially in Na, caused by low-degree partial melting may be universal even in primitive B/F type asteroids.

References: [1] Bischoff A. et al. (2010) *MPS 45*, 1638-1656. [2] Jenniskens P. et al. (2009) Nature 458, 485-488. [3] Gaffey M. J. et al. (1993) ICARUS 106, 573-602. [4] McCoy T. J. et al. (1997) *GCA 61*, 639-650. [5] Takeda H. et al. (2000) *GCA 64*, 1311-1327. [6] Kasuga T. et al. (2005) *A&A 438*, L17-L20. [7] Kasuga T. et al. (2006) *A&A 453*, L17-L20. [8] Torigo-Rodriguez J. M. et al. (1993) *MPS 38*, 1283. [9] Whipple F. L. (1983) *IAU Circular* 3881. [10] Borovicka J. B. et al (2010) *Proc. IAU Symp. 263*, 218-222.

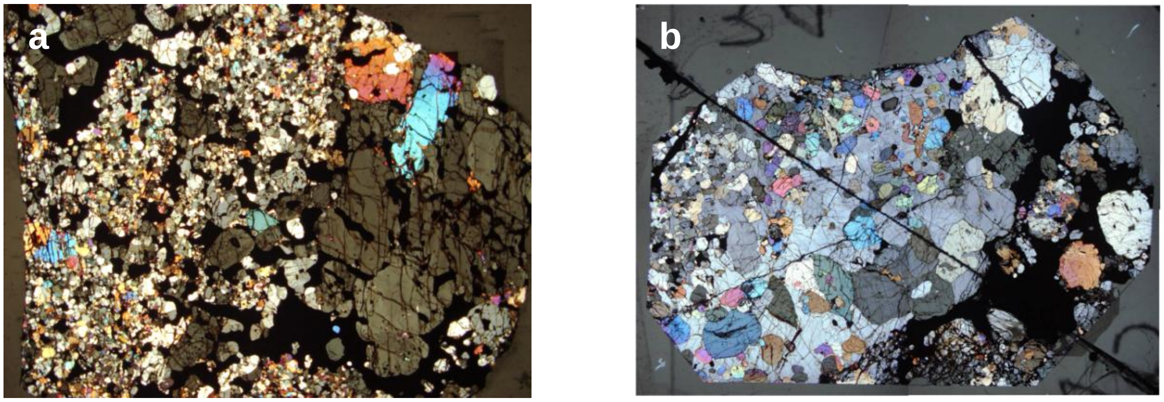

Fig. 1. Photomicrographs in crossed nicole of (a) LEW 86220 (FOV: 1.2 cm) and (b) silicate inclusion of Caddo County (FOV: 2.1 cm). Modal abundance and chemical composition of major mineral phases.

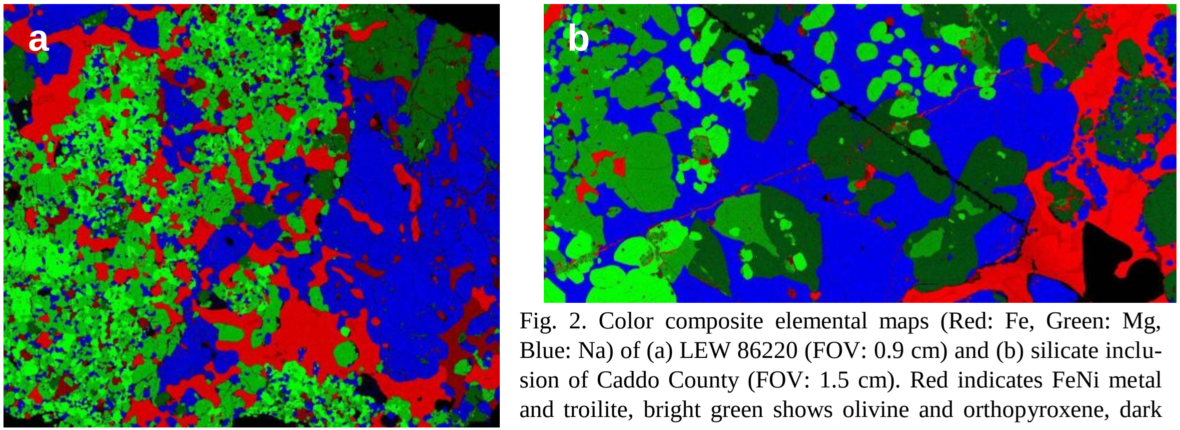

Fig. 2. Color composite elemental maps (Red: Fe, Green: Mg, Blue: Na) of (a) LEW 86220 (FOV: 0.9 cm) and (b) silicate inclusion of Caddo County (FOV: 1.5 cm). Red indicates FeNi metal and troilite, bright green shows olivine and orthopyroxene, dark green shows diopside, and blue indicates Na-rich plagioclase.