SILICA MINERALS IN NON-CUMULATE EUCRITES WITH HIGH THERMAL METAMORPHISM. H. Ono[1], A. Takenouchi[1], M. Koike[1], T. Iizuka[1] T. Mikouchi[1], A. Yamaguchi[2], [1]Department of Earth and Planetary Science, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan, [2]National Institute of Polar Research (NIPR), 10-3 Midori-cho, Tachikawa, Tokyo 190-8518, Japan. E-mail: o-haruka@eps.s.u-tokyo.ac.jp.

Introduction: Eucrites are one group of basaltic achondrites and constitutes an HED (Howardite-Eucrite-Diogenite) clan [e.g., 1]. Eucrite is believed to have originated from the crust of asteroid 4 Vesta [e.g., 1]. There are two subgroups for eucrites: cumulate and non-cumulate (basaltic) eucrites [e.g., 2]. Almost all non-cumulate eucrites underwent various degrees of thermal metamorphism and the metamorphic grades are classified into 7 types based on their textures and mineralogy [3,4]. Additionally, eucrites are known to contain up to 10 vol% silica minerals [5]. However, in most cases they are simply described as "silica" and the mineral species is not identified.

Silica minerals have many polymorphs including metastable phases [e.g., 6]. Especially, tridymite contains ~10 polymorphs and its transformation processes are very complex [e.g., 7]. There are roughly two polymorphs of tridymite: monoclinic and orthorhombic (including pseudo-orthorhombic) at a room temperature and meteorites usually contain monoclinic tridymite [7]. Monoclinic tridymite transforms from hexagonal tridymite via orthorhombic tridymite during temperature drops below 400 ^oC (Fig. 1) [7]. Thus, we consider that identification of different tridymite phases in highly metamorphosed achondrites allows us to estimate thermal histories at such low temperature conditions.

In our previous studies, we have studied silica minerals in 3 cumulate eucrites and 4 non-cumulate eucrites [8-10]. All cumulate eucrites contain monoclinic tridymite and all non-cumulate eucrites have quartz [10]. Moama (cumulate eucrite) has a unique tridymite texture consisting of orthorhombic tridymite lamellae in monoclinic tridymite [8], suggesting more rapid cooling below 400 ^oC compared to other cumulate eucrites [8]. Monoclinic tridymite is also found in basaltic clasts in Millbillillie, a non-cumulate eucrite that is classified into the high metamorphic type (type 5 or 6) [11]. On the other hand, orthorhombic tridymite exists in the low metamorphic type (type 2) eucrite Pasamonte [9]. In this study, we focus on highly metamorphosed non-cumulate eucrites to clarify the formation of monoclinic tridymite.

Samples: We analyzed polished sections of Agoult and Ibitira.

Agoult is classified into a type B granulite eucrite that shows a fine-grained texture (~100 µm in size) and contains homogeneous low-Ca pyroxene and augite grains [12]. Pyroxene and plagioclase grains have 120^o triple junctions and curved grain boundaries. These observations suggest that Agoult has undergone high thermal metamorphism caused by reheating events [12]. It is reported that the occurrence of such events is consistent with the light REE depletions [12]. The presence of tridymite is reported and it is considered to have formed by partial melting as a high-temperature phase [12].

Ibitira is an unbrecciated basaltic achondrite and almost identical to eucrites in mineralogy and mineral compositions [13]. However, it is not considered to be a eucrite because of anomalous features including its distinct oxygen isotopic ratios [e.g., 14]. Ibitira has a fine-grained texture with vesicles [15] and mainly comprises pyroxene and plagioclase. Ibitira is considered to have undergone high temperature metamorphism due to burial under successive lava flows [13]. The presence of tridymite is also reported and it is considered to have formed by a rapid cooling process [13].

Analytical Methods: We observed polished sections using FE-SEM (JEOL JSM-7100F at NIPR). Quantitative chemical analyses were performed using FE-EPMA (JEOL JXA-8530F at the University of Tokyo). The analytical conditions were 15 kV accelerating voltage and 6 nA beam current for silica minerals. We identified silica phases using EBSD patterns by a FE-SEM and Raman shift spectra by a micro Raman spectrometer (JASCO NRS-1000 at NIPR).

Results: *Agoult* is mainly composed of fine-grained (~150 µm in size) plagioclase and pyroxene, and pyroxene has thin exsolution lamellae (<1 µm in thick), which is identical to [12]. We found many silica minerals in this sample (Fig. 2). They are a little smaller (50~120 µm in size) than pyroxene and plagioclase, but the texture of silica mineral is similar to those of pyroxene and plagioclase. Raman spectra show that all silica minerals are monoclinic tridymite and their EBSD patterns are consistent with the crystal structure of monoclinic tridymite as well.

Ibitira also mainly consists of fine-grained (~150 µm in size) pyroxene and plagioclase, and there are thin exsolution lamellae (1~3 µm in thick) in pyroxene. There are many silica grains and they show various sizes (0.2~1 mm in size), but silica grains are generally larger than pyroxene. Silica grains are intergrown with plagioclase and severely cracked compared to pyroxene and plagioclase (Fig. 3). The occurrence of silica minerals is similar to cristobalite that formed by crystallization experiment in our previous study [16].

However, all silica grains in Ibitira are identified as monoclinic tridymite by both Raman spectra and EBSD patterns, likewise Agoult.

Discussion: We found only monoclinic tridymite in Agoult and Ibitira. In our previous study, we found monoclinic tridymite in Millbillillie that is a non-cumulate eucrite and has experienced high degree of metamorphism. However, we found not only monoclinic tridymite but also quartz in Millbillillie as aggregates of both phases. Such aggregates are considered to form by partial transformation from cristobalite because tridymite and quartz are successively formed from initially crystallized cristobalite as temperature drops [16]. Alternatively, monoclinic tridymite was transformed from hexagonal tridymite which was formed from partial melt due to high grade thermal metamorphism [12]. Therefore, we consider that monoclinic tridymite in Agoult and Ibitira is completely transformed either from cristobalite or hexagonal tridymite by slow cooling after higher grades of thermal metamorphism compared to Millbillillie (type 5 or 6).

In cumulate eucrites, all silica grains identified in our previous study are monoclinic tridymite except Moama and Y 980433 [8]. Because monoclinic tridymite is transformed from orthorhombic tridymite as temperature drops at low temperature below 400 ^{o}C [7], the presence of monoclinic tridymite (without orthorhombic tridymite) in Agoult and Ibitira suggests that they underwent slow cooling processes to completely transform from orthorhombic tridymite to monoclinic tridymite. Thus, Agoult and Ibitira slowly cooled below 400 ^{o}C after reheating events.

Conclusions: We studied silica grains in Agoult and Ibitira and identified them as monoclinic tridymite. We consider that monoclinic tridymite is transformed from cristobalite via orthorhombic tridymite by thermal metamorphism. The presence of monoclinic tridymite suggests very high degrees of thermal metamorphism and a slow cooling process below 400 ^{o}C in both samples, which is a similar case to silica minerals in cumulate eucrites.

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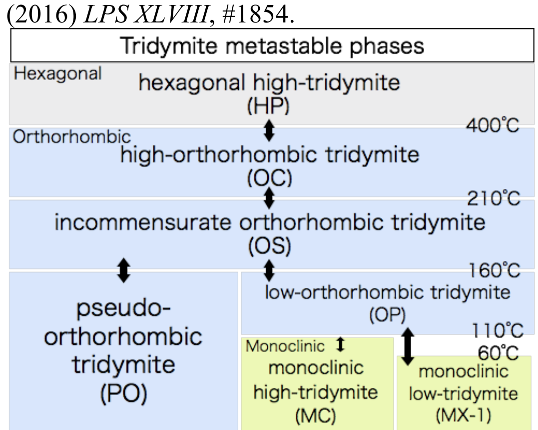

Fig 1. Metastable phases of tridymite below 400 ^{o}C (after [7])

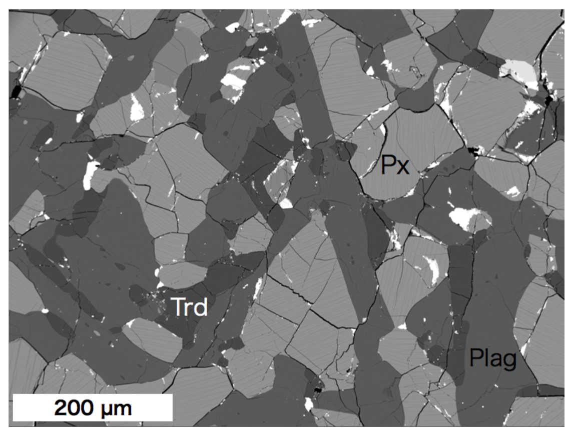

Fig 2. Back-scattered electron (BSE) image of monoclinic tridymite in Agoult. Px: pyroxene, Plag: plagioclase, Trd: monoclinic tridymite

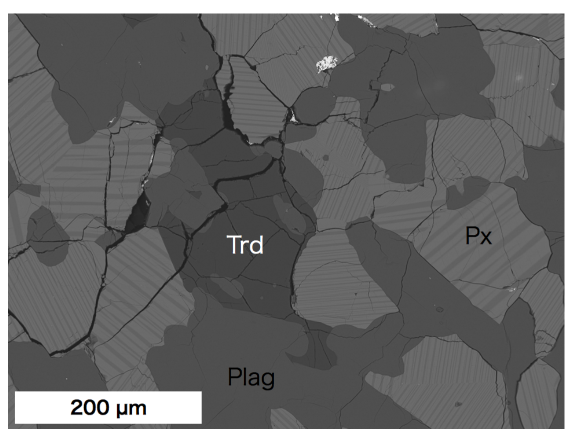

Fig 3. BSE image of monoclinic tridymite in Ibitira.