

HEATING EXPERIMENTS OF THE HaH 262 EUCRITE AND IMPLICATION FOR THE METAMORPHIC HISTORY OF HIGHLY METAMORPHOSED EUCRITES. A. Yamaguchi¹ and T. Mikouchi², ¹ National Institute of Polar Research, Tokyo 173-8515, Japan (yamaguchi@nipr.ac.jp), ² Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo, Tokyo 113-0033, Japan.

Introduction: Eucrites and eucritic clasts in mesosiderites are the oldest records of igneous activities that happened shortly after the formation of parent bodies. Almost all eucrites and eucritic clasts in mesosiderites are metamorphosed in varying degrees [1-3]. Recent studies showed that some eucrites and basaltic clasts in mesosiderites experienced peak temperatures over the solidus of eucrites at $\sim 1060^\circ\text{C}$ for a short time [3,4]. The high temperature metamorphism could have caused partial melting and changed the textures and mineral chemistries of eucrites [3,4]. We have performed a series of heating experiments of a basaltic eucrite to understand mineralogical and textural changes of eucrites by heating near the solidus temperatures.

Experiments and analytical techniques: We prepared a thin slice ($\sim 5 \times 3 \times 1$ mm) of Hammadah al Hamra (HaH) 262 and placed it inside the Pt foil suspended in an alumina tube of a vertical 1 atm gas-mixing furnace. The heating time was for 24 hours at 1050, 1070, and 1100°C and the samples were quenched in air. Two samples were cooled from 1070 and 1100°C to 1030°C at 10°C/day and were quenched in air. Experimental temperatures were measured with thermocouples calibrated by using a melting point of gold (1064.4°C). Gas mixture of $\text{CO}_2\text{-H}_2$ was used to control the oxygen fugacity at $\log f_{\text{O}_2} = \text{IW}-1$ for the all experiments, which were measured by an oxygen electrolytic zirconia cell (SIRO2 C700+). Polished thick and thin sections (PTs) of the starting material and heated samples were examined by optical and scanning microscopy, and with a SEM, and EPMA.

Unheated HaH262: The PTs show a subophitic to ophitic texture composed of anhedral pyroxene (~ 0.6 mm) (52 vol%) and plagioclase lath ($\sim 0.15 \times 0.7$ mm) (43 vol%). Minor minerals (~ 4 vol%) include quartz, ilmenite, chromite, Ca-phosphate, troilite, and Fe-metal. Recrystallized mesostasis interstitially occurs in plagioclase and pyroxene crystals, and is mainly composed of fine-grained quartz. Pyroxene is mainly pigeonite with fine augite lamellae and has a remnant Ca zoning. Pyroxene shows a cloudy appearance due to the presence of minor oxide minerals. Pyroxene compositions are scattered along a single tie line ($\text{Wo}_{5.4}\text{En}_{33.9}\text{-Wo}_{42.4}\text{En}_{28.8}$). Plagioclase is chemically zoned from $\text{An}_{91.4}\text{Or}_{0.4}$ to $\text{An}_{75.6}\text{Or}_{1.5}$, and has minute inclusions (mainly silica minerals) in the cores. This meteorite

has cracks and fractures but is not brecciated. The texture and mineral chemistry indicate that HaH262 is a typical type 4 ordinary eucrite [1]. The absence of brecciation textures, and the low degree of shock metamorphism and weathering (W0) [5] make HaH262 a suitable starting sample for the experiments.

Results: In the sample heated at 1050 and 1070°C for 24 hours, the basaltic texture is mostly preserved. Mesostasis portions still remain. However, we observed very minor melting ($< 1\%$) in the both runs (Fig. 1). There are very thin films (< 1 μm thick) rich in P and Ti along preexisting fractures mainly in plagioclase and grain boundaries. In the sample heated at 1070°C, there are thicker melt veins ($\sim 1\text{-}2$ μm thick). Melt veins in pyroxene are less clear in pyroxenes than in plagioclase. However, the presence of P-rich veins may suggest that some amounts of melts exist in pyroxene.

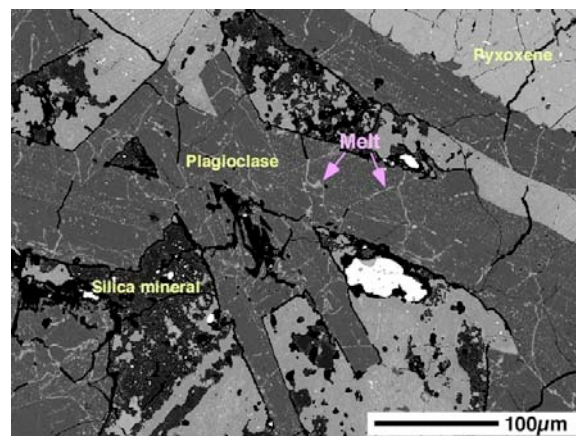


Fig. 1. Sample heated at 1070°C for 24 hrs.

In the sample heated at 1100°C for 24 hours, the sample is clearly melted (> 10 vol%) with abundant vugs (~ 10 vol%), but still roughly preserves original basaltic texture. The melts mainly occur along the boundaries between pyroxene and plagioclase as melt pockets as well as thin veins in minerals along cracks. Mesostasis portions seem to be totally melted. Ilmenite and Ca-phosphate also were melted although we observed a few tiny patches rich in Ti. There are aggregates of fine-grained cristobalite laths that are likely to have been formed during quenching. Plagioclase crystals roughly show original lath shape, but are complexly corroded by melt and contain

narrow veins and channels of melts. Pyroxene is mostly melted with subrounded to irregular relict core, surrounded by fine grains of newly formed pyroxenes crystallized during quenching.

We investigated the textural changes during slow cooling after melting. Two samples were cooled from 1100°C to 1030°C at 10°C/day. There are remnant melts that occur along plagioclase and pyroxene in the both samples although these samples were cooled to significantly below the solidus (~1060°C). The original pyroxene with exsolution texture still remains and the portions of pyroxene are replaced by newly formed crystals (10-30 µm in size). In these areas, the cloudy inclusions of opaque minerals are wiped out. There are new, fine-grained plagioclase laths. Silica minerals occur as aggregates of laths up to 200-300 µm, similar to those observed in the sample heated at 1100°C for 24 hours. There are fine grains of ulvöspinel (up to 33.1 wt% TiO₂) which have not been found in the unheated sample and in other eucrites.

Chemical compositions of plagioclase remain unchanged except the sample heated at 1100°C whose plagioclases have compositions (An_{91.8}Or_{0.2} to An_{81.2}Or_{1.35}) slightly narrower than those of the unheated sample, probably due to the preferential melting of the Na-rich rim near the mesostasis. The chemical compositions of relict pyroxene are unchanged by heating. Compared to the bulk composition estimated from the modes and mineral compositions, the melts are enriched in K₂O (x ~2-3), TiO₂ (x 2-3), P₂O₅ (x 2-15). The P₂O₅ is extremely enriched (bulk x 15) in the sample heated at 1070°C, compared to the 1100°C sample. This indicates melting of Ca-phosphates at lower temperatures.

Discussion: The textures of highly metamorphosed basaltic eucrites and basaltic clasts in mesosiderites are granular due to recrystallization and in some cases have remnant basaltic textures at a large scale [4,6,7]. In these basaltic rocks, mesostasis portions are generally absent; instead they have isolated Ca-phosphate and tridymite grains. There are Ti-rich spinels associated with ilmenites, probably decomposed from ulvöspinel. These basaltic rocks have geochemical evidence for REEs redistribution by possible melting of Ca-phosphate grains. These meteorites are inferred to have experienced metamorphic temperatures over the solidus (~1060°C) [3,4]. Mineralogical evidence suggests that the heating event occurred in a relatively short period at ~900-1000°C [4]. Wadhwa et al. [6] suggested that some basaltic clasts of mesosiderites also experienced similar thermal history at high temperatures.

Our heating experiments are relevant to some characteristics observed in the highly metamorphosed eucrites. The samples heated up to 1100°C showed that <~10 vol% of melting do not destroy the original igneous texture if the heating event is short and the cooling rate is rapid (i.e., by impact). Minor textural change includes irregular boundaries between pyroxene and plagioclase, the formation of vesicles. This is consistent with the results from hot shock experiments although the basaltic textures are more disturbed by shock deformation [8].

The extreme enrichment of P in the sample heated at 1070°C compared to the samples heated at 1100°C suggests that preferential melting of Ca-phosphate occurs at lower temperatures. Progressive heating causes the melting of mesostasis composed of silica minerals, Ca-phosphates, and ilmenite, the grain boundaries of the constituent minerals. As a result, partial melts are enriched in Fe, Ti, P compared to the bulk. The presence of such melt veins in the run product only for 24 hours heating suggests that the melt mobilization occurs very rapidly probably by capillary effect. This infers that REEs redistribution among minerals occurs at ~1050-1070°C in a short time (~day) because Ca-phosphates are major carrier phases of REEs in eucritic basalts. This may also explain the disturbance of Sm-Nd ages of some highly metamorphosed eucrites [4].

However, our experiments are not always consistent with the observations from natural samples. We do not observe melt pockets and thin veins in minerals because of crystallization to form new minerals. Ulvöspinel would have been decomposed to ilmenite and Cr-spinel during cooling. Overall textures would have been recrystallized to form granular pyroxenes observed in metamorphosed eucrites, but some eucrites preserve original basaltic textures at large scales (e.g., Ibitira, basaltic clasts in Mt. Padbury, [6,7]). Larger degree of melting and brecciation would have caused more drastic textural changes, producing complicated metamorphosed shock textures (e.g., Juvinas) [9].

References: [1] Takeda H. and Graham A.L. (1991) *Meteoritics* 26, 129-134. [2] Yamaguchi A. et al. (1996) *Icarus* 124, 97-112. [3] Wadhwa M. et al. *GCA* 67, 5047-5069 [4] Yamaguchi A. et al. (2001) *GCA* 65, 3577-3599. [5] Grossman J.N. (2000) *Meteoritics & Planet. Sci.* 35, A199-A255. [6] Steele I.M. and Smith J.V. (1976) *EPSL* 33, 67-78. [7] Tamaki M. et al. (2003) *Antarctic Meteorites XXVIII*, 85-86. [8] Yamaguchi A. et al. (2002) *High-Pressures Shock Compression of Solid V*, 29-45, Springer-Verlag. [9] Takeda H. and Yamaguchi A. (1991) *Meteoritics* 26, 400.