PETROLOGY OF THE JUVINAS EUCRITE: IMPLICATIONS FOR EVOLUTION OF VESTAN CRUST.

R. Kanemaru[1], A. Yamaguchi[1, 2] and H. Nishido[3], [1]Department of Polar Science, School of Multidisciplinary Science, SOKENDAI (The Graduate University for Advanced Studies), Tokyo 190-8518, Japan, [2]National Institute of Polar Research (NIPR), Tokyo 190-8518, Japan, [3]Okayama University of Science (OUS), Okayama 700-005, Japan. E-mail: kanemaru.rei@nipr.ac.jp

Introduction: Eucrites are a class of differentiated achondrites, and are considered to have originated from an asteroid 4 Vesta (~520 km in diameter). Eucrites make up the outermost crust of Vesta formed after global melting of the parent body. After the initial crystallization, most of the eucrites experienced complex secondary processes such as impact, brecciation, melting, thermal metamorphism and metasomatism. The textures and the occurrences of secondary minerals in eucrites provide us with valuable information about post-magmatic processing of the eucritic crust.

Juvinas is a typical basaltic eucrite, and is classified into a monomict eucrite [e.g. 1]. With respect to the bulk compositions, Juvinas is a main group eucrite. However, it has been suggested Juvinas experienced a complex formation history on the basis of textures and mineral chemistry and that the Juvinas records information on processes of early crustal evolution such as metamorphism [2, 3]. Hence, Juvinas is a suitable sample to better understand the early geologic history of the Vestan crust. We performed a detailed petrological study of Juvinas, and discussed the formation history of Juvinas to understand the evolution of the Vestan crust.

Samples and analytical techniques: We examined five polished thin and thick sections (PTSs) an optical microscope and FE-SEM (JEOL JSM 7100) equipped with an energy dispersive spectrometer (EDS) (Oxford AZtec Energy) and a cathodeluminescence (CL) system (GATAN Chroma CL) at NIPR. Compositional data for mineral phases were obtained with an EPMA (JEOL JXA-8200) at NIPR. For identification of silica minerals, we used luminoscope (ELM-3) at OUS and a Raman spectroscope (JASCO NRS-1000) at NIPR.

Textural observation: Juvinas is a breccia composed of crystalline clasts set in a porous clastic matrix (CM) (Fig. 1). The crystalline clasts are composed of coarse-grained gabbroic portion (CG), poikilitic fine-grained portion (FG), and granoblastic pyroxene (GP). The boundaries of the CG and FG are gradational.

The CG portion has a coarse-grained (up to 1mm) subophitic texture of low-Ca pyroxene ($Ca_{2.9}Mg_{37.8}Fe_{59.3}$) and plagioclase ($An_{80-96}$) with minor minerals. Pyroxene grains in the CG portion show brown color under optical microscope (clouding) due to the presence of tiny opaque (chromite?) minerals [4]. In many cases, chromite inclusions are aligned to a certain crystallographic orientation.

The GP portion shows a granoblastic texture with lots of 120° triple junctures, and consists of fine-grained (<100 µm), polygonal pigenite with augite lamellae, and subordinate amounts of irregular silica minerals (tridymite and quartz), and rounded grains (~5-10 µm or >100 µm) of ilmenite, troilite, olivine, and chromite (Fig. 2). The pyroxene in this portion does not show clouding.

The FG portion is composed of acicular plagioclase (~200 µm), anhedral pyroxene and large lathy tridymite (~2-3 mm long). Some of the acicular plagioclase are intruded in large pyroxene grains in the CG portion. Pyroxene in the FG portion has a small amount of tiny inclusions (chromite?). The inclusions have more Ti-rich composition than those in the CG portion by EDS analysis. An acicular plagioclase does not contain inclusions.

The CM is composed of lithic clast of the crystalline clasts described above (i.e., CG, FG, and GP), and mineral fragments. The lithic clasts and mineral fragments are joined smoothly, and welded. This portion has a large amount of pore spaces.

We observed several secondary minerals likely formed by metamorphism and metasomatism. Fe-rich olivine (Fa_{67-77}), chromite and Ca-rich plagioclase ($An_{\sim 97}$) occur in pyroxene in the CG and GP portions as veins or small particles (~20 µm). Apatite occurs in the CG, GP and FG portions. In the CG and GP portions, apatite in the CG and GP portions occur as veins (~10 µm thick) along the cracks of pyroxene grain. In the FG portion, apatite occurs as small (~20 µm) grains in contact with quartz and opaques minerals. Veins (~50 µm wide, ~500 µm long) of troilite occur in the CG, GP and FG portions. In the CM, there are small silicate fragments bounded by anhedral troilite. Boundaries between the troilite and exsolved pyroxene has a saw zigzagged shape.

Discussion: On the basis of the texture, the CG portion is igneous (subophitic) (i.e., crystallized from an initial melt). The plagioclase in the CG portion shows a positive correlation between Na and K from a core to a rim (normal igneous zoning). The CG portion crystallized from magma at or near the surface of Vesta. Subsequently, the CG portion suffered from thermal metamorphism, and formed a clouding in pyroxene grain (type 5) [5]. This process is commonly found in in basaltic eucrites.

The granoblastic texture indicates that the GP portion formed by recrystallization of brecciated areas or shock melts. Takeda et al. [3] conclude that the GP portion formed by a shock and reheating without melting. During recrystallization of the CG clast, the grains of Ti-rich phases coalesced or grew to larger crystals of ilmenite and chromite.

We consider the FG portion crystallized from shock partial melting. The FG portion has greater amounts of silica minerals and plagioclase than those in the CG portion. The Mg# of low-Ca pyroxene in the FG portion has slightly lower (i.e., more Fe-rich) than the CG and portion. It is an expected feature of partial melt of basaltic eucrite [6]. The fine-grained implies that the FG portion cooled rapidly during crystallization. The FG portion suffered thermal metamorphism after the shock partial melting and rapid crystallization because of the lack of Fe/Mg variations in low-Ca pyroxene. The mineral composition of acicular plagioclase is fairly homogenous (An_{88-93}) compared to those in the CG portion. However, slight differences between Mg# in low-Ca pyroxene the FG and CG portions indicate that the equilibration was not completed. We did not found shock features such as shock veins and wavy extinction. Shock features may have been erased by later thermal metamorphism.

The CM portion formed by brecctation of crystalline clasts of the CG, GP and FG portions by impact event(s). After brecciation, this portion suffered from subsequent mild thermal metamorphism evidenced by slight recrystallization of the CM. A lot of pore spaces imply that the portion did not experience the strong compaction. Thus, Juvinas was located near the surface of Vesta.

Juvinas seems to have suffered from metasomatism. The veins or small particles Fe-rich olivine, Ca-rich plagioclase and chromite in host pyroxene in the CG and GP portion may have been produced by Fe-metasomatism [7]. This process should have taken place before formation of the FG portion since FG portion does not have these minerals. F-apatite is found in the CG, GP and FG portions. The occurrence indicates that F-apatite sealed cracks in CG and GP portion. On the other hands, phosphate in FG portion seems to have ingeniously crystallized (as a mesostasis mineral). Large veins of troilite and a saw zigzagged shape of anhedral troilite in CM portion formed after the formation of the CM (i.e., at the last stage, the anhedral troilite could be due to reaction of low-Ca pyroxene and sulfur rich fluid (vapor?)) [8].

We suggest that Juvinas is not a simple monomict breccia but a complex breccia. Juvinas formed by the following processes: (1) initial crystarization from a magma near the surface of Vesta (CG), (2) equilibration of pyroxene in the CG portion by thermal metamorphism, (3) shock melting and/or recrystallization impact event(s) (FG and GP), (4) metasomatism (?), (5) second thermal metamorphism, (6) second impact event (CM) and (7) mild recrystallization of the boundaries of the lithic clast and mineral fragment by third thermal metamorphism.

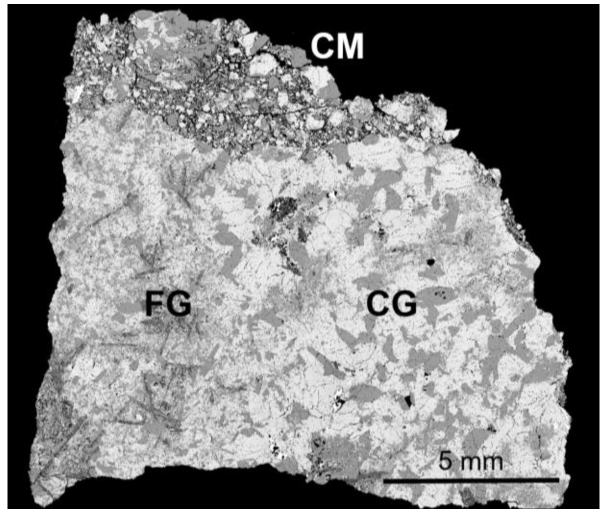

Fig. 1. Backscattered electron image of Juvinas (CG: coarse grained portion, FG: fine-grained portion, CM: clastic matrix).

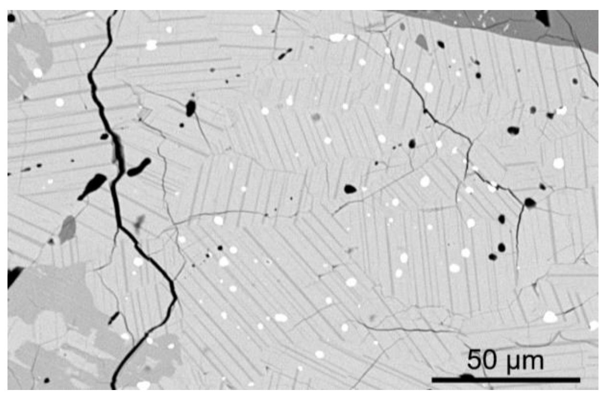

Fig. 2. Backscattered electron image of GP portion of Juvinas. Gray: pigeonite, dark gray: plagioclase, white: Fe-rich olivine or ilmenite.

References: [1] Delaney J. S. et al. (1983) *Meteoritics* 18, 103-111. [2] Takeda H. and Yamaguchi A. (1991) *54th MET SOC*, 228. [3] Takeda H. et al. (1998) LPS *XXIX*, Abstract #1168. [4] Harlow G. E. and Klimentidis R. (1980) *Proc. Lunar Planet. Sci. Conf. 11th*, 1131-1143. [5] Takeda H. and Graham A. L. (1991) *Meteoritics*, 26, 129-134. [6] Yamaguchi A. et al (2009) *Geochimica et Cosmochimica Acta, 73,* 7162-7182. [7] Barrat J. A. et al. (2011) *Geochimica et Cosmochimica Acta, 75,* 3839-3852. [8] Zhang A. C. et al. (2013) *Geochimica et Cosmochimica Acta,* 109, 1-13.