**SHOCK METAMORPHISM OF THE NORTHWEST AFRICA 7203 ANGRITE.** H. Hayashi[1], A. Takenouchi[1], T. Mikouchi[1] and M. Bizzarro[2], [1]Department of Earth and Planetary Science, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan, [2]Center for Star and Planet Formation, University of Copenhagen, Øster Voldgade 5-7, 1350 Copenhagen, Denmark (E-mail: h.hayashi@eps.s.u-tokyo.ac.jp)

**Introduction:** Angrite is one of the oldest differentiated meteorites in the solar system, depleted in alkaline elements and enriched in refractory elements. Angrite mainly consists of Ca-rich olivine, Al-Ti-rich diopside-hedenbergite ("fassaite") and anorthitic plagioclase with accessory phases of kirschsteinite, ulvöspinel and troilite [e.g., 1]. Almost all angrites show either quenched or relatively slowly-cooled textures. Angrites showing quenched textures have an older crystallization age (*ca.* 4564 Ma) than those showing slowly-cooled textures (*ca.* 4558 Ma) [e.g., 2]. One of the most striking characteristics about angrites is the lack of shock metamorphism except for Northwest Africa (NWA) 1670 [3], which leads to interpret that angrites remain as small asteroids during late heavy bombardment [4]. Recently, we have found remarkable textures of shock metamorphism in the NWA 7203 angrite. In this study, we report observation and analysis of shock textures, and discuss the impact history of the angrite parent body.

**Sample:** NWA 7203 is a quenched angrite found in Morocco in 2011 with a total mass of 107 g. Its brief petrology and mineralogy are found in [5]. We prepared two thin sections for detailed analysis of its shock textures.

**Analytical Methods:** We first observed the thin sections by optical microscopy. Both quantitative and chemical mapping analyses were performed using JEOL JXA-8530F electron probe micro analyzer (EPMA) at the University of Tokyo. We used 15 kV accelerating potential. The beam currents were 6 nA and 60 nA for quantitative analysis and mapping analysis, respectively. We obtained Raman spectra of minerals and glasses using JASCO NRS-1000 Raman microscope at NIPR. The laser wavelength is 531.9 nm.

**Results:** The NWA 7203 angrite shows a quenched texture, but grain size exhibits large variations from fine grains (~1 µm) to coarse grains (>100 µm). As a typical texture of quenched angrites, NWA 7203 consists of a dendritic texture of olivine and anorthite, and pyroxene fills gaps of the dendrites. Olivine is a solid solution of Mg, Fe and Ca ($Fo_{65}La_2$~$Fo_0La_{19}$ for Ca-poor olivine and $Fo_8La_{36}$~$Fo_1La_{21}$ for Ca-rich olivine). Al-Ti-rich diopside-hedenbergite contains $Al_2O_3$=3-9 wt% and $TiO_2$=1-5 wt%, and most pyroxenes are hedenbergite. Anorthite includes almost no Na.

Black shock melt veins are pervasively present in the thin sections (Fig. 1) and their maximum width is ~500 µm (Fig. 2). Shock veins cut dendrites, and pre-existing textures were sometimes displaced by up to 1 mm (Fig. 3). Shock veins often exist in the part of fine-grained textural areas. Narrower shock veins are composed of shock melt glass, fragments of pre-existing relict minerals, and recrystallizing pyroxenes (Fig. 4). The chemical composition of the shock melt glass is given in Table 1, but they are heterogeneous because of incorporation of multiple phases with different abundances. In shock melt glasses, there are recrystallizing pyroxenes precipitated after the shock melt generated (Fig. 5). These pyroxene grains are Al-Ti-rich diopside-hedenbergite, whose compositions are slightly different from pre-existing pyroxenes outside the shock melt veins and are more Al-rich ($Al_2O_3$=10-13wt%) and Ca-depleted (CaO=14-18wt%). The size of recrystallizing pyroxene is around 10 µm and is usually rounded in shape with strong chemical zoning. The relict mineral fragments are rounded in shape, and their sizes vary from <1 to 100 µm. In the shock melt glasses, there are opaque phases (around 1 µm). No significant vesicles are observed in the shock melt veins, suggesting that high pressure was retained during shock melting. However, we have not found any high pressure phases so far by Raman spectroscopic analysis of minerals in or around shock veins. Around shock veins, olivine, anorthite and pyroxene show undulose extinction by optical microscopic observation. Anorthite close to shock veins becomes maskelynite as indicated by broad Raman peaks and isotropic nature by optical microscopy.

**Discussion and Conclusion:** Fritz et al. [6] proposed that the shock stage used for chondrites can be applied to other meteorite groups with some revisions. According to their paper, the estimated shock stage of NWA 7203 is S3 although other angrites are essentially shock free (S1) except NWA 1670 which has 1-20 µm shock melt veins. In this study, we found that NWA 7203 has a ~500 µm shock vein and is the most heavily shocked angrite. Scott et al. [4] suggested that almost all of the angrites show no shock textures and therefore angrites remain as small asteroids during late heavy bombardment. The discovery of strong shock metamorphism in NWA 7203 suggests that some angrites might remain as big asteroid(s) during late heavy bombardment. Alternatively, there remains the possibility that angrites are indeed from small asteroids and most angrites escaped shock metamorphism, but some angrites suffered from local shock metamorphism.

**References:** [1] Keil K. (2012) *Chem. Erde*, *72*, 191-218. [2] Kleine T. et al. (2009) *GCA*, *73*, 5150-5188. [3] Mikouchi T. et al. (2003) *Meteoritics &*

*Planet. Sci.*, *38*, A115. [4] Scott E. R. D. et al. (2011) *Meteoritics & Planet. Sci.*, *46*, 1878-1887. [5] Mikouchi T. and Bizzarro M. (2012) *Meteoritics & Planet. Sci.*, *39*, Suppl., id.5120. [6] Fritz J. et al. (2017) *Meteoritics & Planet. Sci.*, *52*, 1216-1232.

Table 1. Chemical compositions of shock melt glass (blue point in Fig. 3) and recrystallizing pyroxene (blue point in Fig. 5).

| | Shock melt glass | Recrystallizing pyroxene |
|---|---|---|
| $SiO_2$ | 40.50 | 37.48 |
| $Al_2O_3$ | 12.44 | 11.07 |
| $TiO_2$ | 0.92 | 1.02 |
| FeO | 24.99 | 32.19 |
| MgO | 6.62 | 5.79 |
| CaO | 14.59 | 13.87 |
| $Na_2O$ | 0.02 | *b.d.* |
| $K_2O$ | 0.02 | *b.d.* |
| $Cr_2O_3$ | 0.11 | 0.08 |
| NiO | 0.06 | *b.d.* |
| Total | 100.62 | 101.52 |

*b.d.*: Below detection limit.

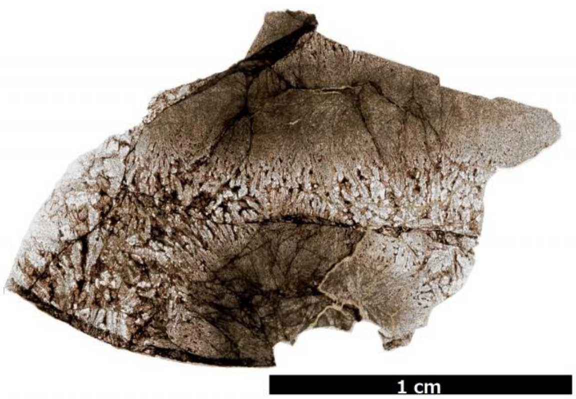


Fig. 1: Entire thin section view of NWA 7203 under optical microscopy (open nicol). Black curve at the end of the thin section is fusion crust.

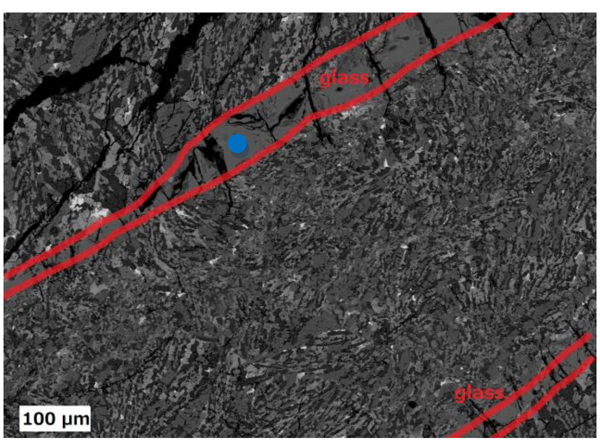


Fig. 2: Back-scattered electron (BSE) image of a shock vein with the maximum width (~500 µm) in the observed NWA 7203 thin sections. The portions traced by two red lines are glass at the both rims of this vein. Fine-grained dendritic textures are disordered between these two glassy rims.

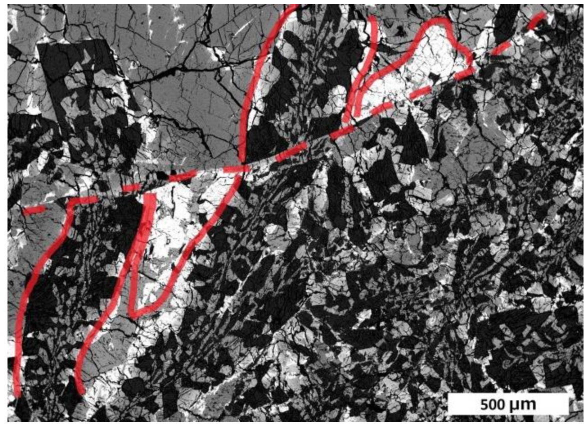


Fig. 3: BSE image of dendrites and pre-existing textures displaced by up to 1 mm as indicated by red lined areas. A shock vein (dotted line) cut them.

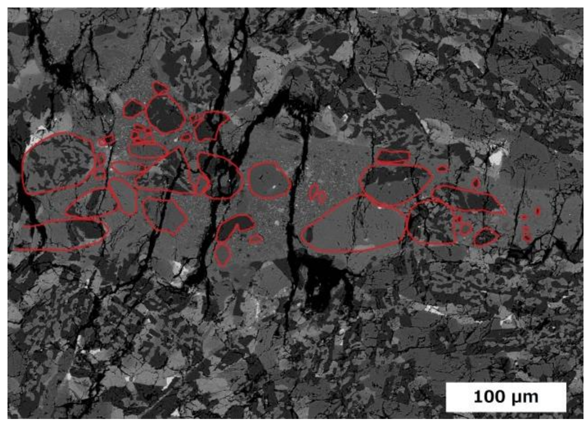


Fig. 4: BSE image of a relatively narrow shock vein which is composed of shock melted glass, relict mineral fragments (surrounded by red lines) and recrystallizing pyroxenes.

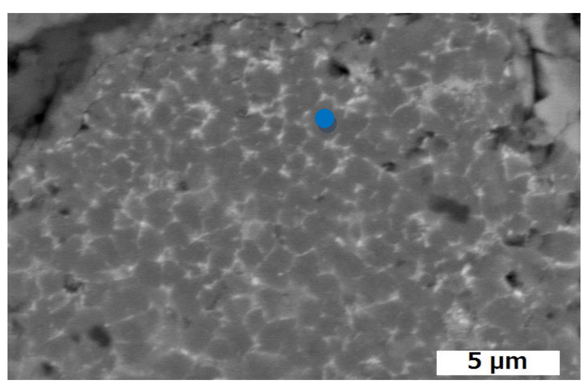


Fig. 5: BSE image of an enlarged potion of recrystallizing pyroxenes in a narrow shock vein.