MINERALOGIC AND PETROLOGIC CHARACTERIZATION OF A NEW SILICIC CLAST IN LUNAR BRECCIATED METEORITE, NORTHWEST AFRICA 2727. H. Nagaoka[1], T. J. Fagan[2], M. Kayama[3,4], Y. Karouji[5], N. Hasebe[6,7], M. Ebihara[2], [1]Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), 3-1-1 Yoshinodai, Chuo-ku, Sagamihara 252-5210, Japan (hiroshi-nagaoka@planeta.sci.isas.jaxa.jp), [2]Department of Earth Science School of Education, Waseda University, 1-6-1 Nishiwaseda, Tokyo 169-8050, Japan, [3]Department of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University, Aramaki aza Aoba 6-3, Aoba-ku, Sendai 980-8578, Japan, [4]Creative Interdisciplinary Research Division, Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, Aramaki aza Aoba 6-3, Aoba-ku, Sendai 980-8578, Japan, [5]Space Exploration Center, Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara 252-5210, Japan, [6]Research Institute for Science and Engineering, Waseda University, 3-4-1 Okubo, Shinjuku, Tokyo 169-8555, Japan, [7]School Advanced Science and Engineering, Waseda University, 3-4-1 Okubo, Shinjuku, Tokyo 169-8555, Japan

Introduction: Some candidates for silicic localities on the Moon have been found by remote sensing: Guithuisen Domes, Hansteen alpha, and Lassell Massif occur in the Procellarum-KREEP Terrane (PKT, [1]) and have infrared spectra indicating silica-rich compositions [2]. Guithuisen domes and Hansteen alpha are topographic highs that may have formed from rhyolitic volcanism whereas intrusive granites may be exposed at Lassell and parts of Aristarchus crater [2,3].

Although granitic rocks are rare on the Moon and comprise well under 0.1% by mass of the Apollo collection [4] in contrast to basalts, their presence is an indicator of igneous processes in the lunar interior. Petrologic characterization of samples of lunar granitic rocks is an essential step toward evaluating the processes that led to the compositional range of igneous rocks on the Moon.

We have found a silicic clast in the lunar meteorite breccia Northwest Africa 2727 (NWA 2727), which is included in the NWA 773 clan of lunar meteorites. NWA 773 clan meteorites share a distinctive olivine cumulate gabbro (OC) lithology, and have rare earth elements (REE) patterns with light REE enrichments and negative Eu anomalies similar to KREEP [5-8]. In addition to the OC lithology, NWA 773 clan meteorites share a variety of basaltic clasts, feldspar+pyroxene gabbro, olivine-pyroxene-silica symplectites and silica-bearing alkali-rich phase ferroan (ARFe) clasts. Several of these clast-types have been linked together to represent a common igneous differentiation suite [5,6,9,10]. In this study, we characterize mineralogic and petrologic characteristics of the silicic clast in NWA 2727, compare the silicic clast with other silica-bearing lithic clasts of the NWA 773 clan, and discuss the petrogenesis.

Samples and Methods: In this work, we focus a silicic clast in NWA 2727. Lunar meteorite NWA 2727 is a polymict breccia belonging to NWA 773 clan [11-13]. The diversity of clast-types in our polished thin section (PTS) has been investigated in Kayama et al. [12] and is consistent with previous work on NWA 2727 [11,13].

The PTS of NWA 2727 was investigated by a combination of petrographic and chemical microanalysis. Back-scattered electron (BSE) images were collected by an Electron Probe Micro-Analyzer (EPMA) (JEOL JXA-8900) at Kobe University. Clast-scale X-ray elemental maps were obtained using the Hitachi S-3000 N scanning electron microscope. Quantitative analyses of minerals were performed using a JEOL JXA-8900 EPMA at Waseda University. Silica phases in the clast were identified by laser micro-Raman spectroscopy using a Thermo Electron (Nicolet Almega XR) with the 532 nm excitation line of the Nd:YAG laser at Okayama University of Science.

Results and Discussion: BSE and elemental RGB images of the silicic clast in NWA 2727 are presented in Fig. 1. This clast consists mostly (>80% of the mode) of plagioclase feldspar, alkali feldspar and silica. Iron-rich olivine and high-Ca-pyroxene also occur in the clast. Ca-phosphate, ilmenite, chromite and troilite are present in minor abundances. Silica occurs as: (1) massive to elongate grains (upper right in Fig. 1b); (2) narrow domains enveloping thin plagioclase feldspar laths (upper center in Fig. 1b); and (3) elongate crystals intercalated with K-Ba-feldspar (labelled Kfs + Si in Fig. 1b). Textures indicate an igneous origin of silica in the clast, and co-crystallization of K-feldspar with silica. Most Raman spectra of silica showed weak bands indicating poor crystallinity, but tridymite, cristobalite and quartz were identified at some analyzed points.

Olivine has fayalite composition with Fe# (molar Fe/[Fe+Mg] × 100) of 99−100. Two general compositional types of pyroxene were found: (1) hedenbergitic pyroxene with Fe# and Ti# both ≥98 (Ti# = molar Ti/[Ti+Cr] × 100); (2) a zoned ferro-augite with Fe# ≥79 and Ti# ≥91. The ferro-augite crystals are coarser than the hedenbergite crystals. Coarse ferro-augite is zoned in Ca/Mg ($Wo_{32}En_6Fs_{62}$ – $Wo_{21}En_{17}Fs_{62}$). Plagioclase feldspar has compositions near An_{87}. Alkali feldspar has variable Ba contents ($Ab_4An_2Or_{95}Cn_0$ − $Ab_4An_2Or_{81}Cn_{13}$).

The high Fe# of mafic silicates combined with the abundance of silica suggests that the clast crystallized from a residual liquid after fractional crystallization. The occurrence of three low-pressure silica polymorphs indicates rapid, near-surface cooling and disequilibrium. The poor crystallinity of much silica may be due to shock.

Other silica-bearing igneous clasts in the NWA 773 clan are symplectite and the ARFe clasts. The symplectite is composed of fine-grained intergrowths of fayalite, silica and hedenbergitic pyroxene [5,6,9]. These minerals also occur in the NWA 2727 silicic clast, but with abundant feldspars, which are not characteristic of the symplectite lithology. Textures are also distinct and point to different formation processes: the fine, interwoven texture and mineral abundances of the sympletite indicate formation by pyroxferroite breakdown [9], whereas the presence of elongate interlocking crystals in the silicic clast indicate crystallization from igneous melt. Mineral assemblages in NWA 773 ARFe clasts [9] are similar to the NWA 2727 silicic clast, but mineral abundances are distinct. The silicic clast has much higher ratios of silica+feldspars/olivine+pyroxene compared with the ARFe clasts described by [9]. The difference of such mineral mode reflects the bulk SiO_2 content, suggesting differences in origin. The NWA 773 ARFe clasts formed after fractional crystallization in a magmatic system that also produced the OC, pyroxene gabbro and symplectite [9,10]. Although the NWA 773 ARFe clasts and the NWA 2727 silicic clast both crystallized from igneous liquids that were depleted in MgO, the silicic clast is relatively enriched in SiO_2 and alkalis. Therefore, it is likely that the silicic clast formed from an independent igneous setting, which is distinct from the NWA 773 OC magmatic system.

Conclusion: The NWA 2727 silicic clast described in this study is a lithology that has not been reported previously from the NWA 773 clan. The high Fe# and Ti# of pyroxenes in the silicic clast are consistent with crystallization from magma at late stages of fractional crystallization. This origin is similar to that of ARFe clasts that were co-magmatic with the NWA 773 OC, but the silicic clast has higher modes of feldspars and silica minerals, and probably formed in an independent magmatic setting. The occurrence of quartz, tridymite and cristobalite in the clast indicate rapid cooling in a near-surface setting.

Acknowledgement: This work was supported in part by Research Fellowships for Young Scientists from the Japan Society for the Promotion of Science 18J01786 (PI: Hiroshi Nagaoka).

References:

[1] Jolliff B. L. et al. (2000) *JGR*, 105, 4197-4216. [2] Glotch T. D. et al. (2010) *Science*, 329, 1510–1513. [3] Hawke B. R. et al. (2003) *JGR*, 108, 5069. [4] Seddio S. M. et al. (2015) *Am. Mineral.*, 100, 1533-1543. [5] Fagan T. J. et al. (2003) *Meteorit. Planet. Sci*., 38, 529-554. [6] Jolliff B. L. et al. (2003) *GCA*, 67, 4857-4879. [7] Nagaoka H. et al. (2015) *Meteorit. Planet. Sci*., 50 (Issue S1), A29-A414 (abstr. #5185). [8] Zhang A.-C. et al. (2011) *Meteorit. Planet. Sci*., 45, 1929-1947. [9] Fagan T. J. et al. (2014) *GCA*, 133, 97-127. [10] Shaulis B. J. et al. (2017) *GCA*, 213, 435-456. [11] Bunch T. E. et al. (2006) *LPS*, *XXXVII*, Abstract #1375. [12] Kayama M. et al. (2018) *Science Advances*, 4, eaar4378. [13] Zeigler R.A. et al. (2007) *LPS*, *XXXVIII*, Abstract #2109.

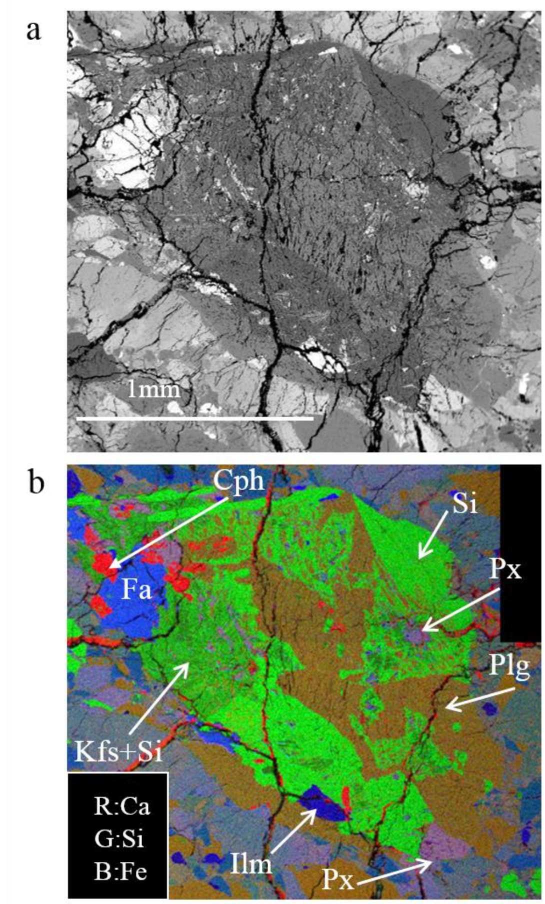

Figure 1. Images of silicic clast: (a) BSE images; (b) RGB elemental map with R = Ca, G = Si, B = Fe. Mineral abbreviations: Cph = Ca-phosphate; Fa = fayalite; Ilm = ilmenite; Kfs = K-feldspar; Plg = plagioclase; Px = pyroxene; Si = silica.