**CO-EXISTING PYROXENES IN THE NORTHWEST AFRICA 2977 WITH REFERENCE TO THE SOURCE REGION.** H. Nagaoka[1], Y. Karouji[1], H. Takeda[2], T. J. Fagan[3], M. Ebihara[4], N. Hasebe[1], [1]Research Institute for Science and Engineering, Waseda University, 3-4-1 Okubo, Shinjuku-ku, Tokyo 169-8555, Japan (hiroshi-nagaoka@asagi.waseda.jp), [2]Department of Earth & Planetary Science, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan, [3]Department of Earth Science, Waseda University, 1-6-1 Nishiwaseda, Shinjuku-ku, Tokyo 169-8050, Japan, [4]Department of Chemistry, Tokyo Metropolitan University, 1-1 Minamiohsawa, Hachiohji, Tokyo 192-0397, Japan.

**Introduction:** Lunar meteorite Northwest Africa (NWA) 2977 is an olivine gabbro cumulate, which is texturally and mineralogically similar to the olivine gabbro cumulate (OC) clasts as found in NWA 773 and NWA 2700 [1]. Borg et al. [2], Fagan et al. [3] and Jolliff et al. [4] have previously analyzed the isotopic data, the bulk chemical and mineralogical compositions of NWA 773. They have discussed the petrogenesis of NWA 773. Jolliff et al. [4] has suggested that the OC clasts in NWA 773 have KREEP-like trace element ratios, and this KREEP-like signature indicates that KREEP-like materials were incorporated in NWA 773. Preliminary mineralogical [1] and isotopic [5] data show that NWA 2977 has the same feature. However, the $\varepsilon_{Nd}$ value of NWA 2977 ($\varepsilon_{Nd}$ = -3.74 ± 0.26) [5] is slightly different from that of NWA 773 ($\varepsilon_{Nd}$ = -4.53 ± 0.27) [2]. The cosmic ray exposure (CRE) age of NWA 2977 (12 Ma) [6] is much shorter than that of NWA 773 OC (73 Ma) [7]. Here we analyzed bulk chemical composition and observed mineralogical characteristics of NWA 2977. Then we report the preliminary chemical and mineralogical data of NWA 2977, and discuss the petrogenesis of this rock, in comparison with those data of NWA 773 and other lunar rocks.

**Methods:** The bulk chemical composition of NWA 2977 was determined by neutron-induced prompt gamma-ray analysis (PGA), instrumental neutron activation analysis (INAA) at the Japan Atomic Energy Agency (JAEA) on powder samples of NWA 2977 (99.8 mg for PGA and 43.3 mg for INAA). A polished thin section (PTS) of NWA 2977 was prepared at National Institute of Polar Research (NIPR). The PTS of NWA 2977 was examined using petrographic microscope. The backscattered electron (BSE) images were collected using a HITACHI S-3000N scanning electron microscope at Waseda University. The compositions of minerals in NWA 2977 were analyzed by a JEOL JXA-8900 electron probe micro-analysis (EPMA) at Atmosphere and Ocean Res. Inst., Univ. of Tokyo (AORI), with well-characterized oxide and silicate standards at 15 kV, $1.2\times10^{-8}$ A.

**Chemical compositions of minerals:**

*Olivines*. The individual olivine crystals ($Fo_{69}$) are large, subhedral to euhedral, cumulate grains with pyroxene and plagioclase filling interstices, and occupy approximately a half of this lithology. The olivine crystals appear to be unzoned. Average CaO concentration (0.10 %) in olivine in NWA 2977 is close to that in intrusive lunar olivine in lunar Mg-suite dunite 72415 [8].

These features indicate that NWA 2977 was crystallized more slowly than lunar volcanic rocks such as mare basalts.

*Pyroxenes*. Chemical compositions of pyroxenes are Mg' (73) of orthopyroxene ($Ca_4Mg_{70}Fe_{26}$), Mg' (72) of pigeonite ($Ca_{10}Mg_{65}Fe_{25}$), Mg' (76) of augite ($Ca_{33}Mg_{51}Fe_{16}$). These data suggest affinities with the Mg-suite rocks among lunar rocks, as discussed by Bridges et al. [9]. Polarized microscope observation revealed the micrometer or submicrometer-scale exsolution lamellae in both augite and pigeonite grains (Fig. 1). The exsolution lamellae are slightly thicker than those found in NWA 773 OC [4]. This difference may indicate that the cooling rate of NWA 2977 was slower than that of NWA 773 OC. One inverted pigeonite is found near the residual pockets of phases enriched in incompatible trace elements, in the PTS of NWA 2977 (Fig. 2). The blebs of augite ($Ca_{38}Mg_{47}Fe_{15}$) are distributed in the host orthopyroxene ($Ca_4Mg_{70}Fe_{26}$). The bulk composition of this area ($Ca_{12}Mg_{65}Fe_{23}$) gives pigeonite composition (Fig. 2). Some pigeonites which are distant from the residual pockets were not inverted.

The un-inverted and inverted pigeonite are both present because of small variations in cooling rates of different crystals in the olivine cumulated.

**Bulk chemical composition:** Whole rock abundances of Ti, Sc and Sm are useful as discriminators among lunar rock types [10]. Figure 3 shows Ti/Sm and Sc/Sm ratios versus Mg' in NWA 2977, NWA 773 (Breccia matrix (Bx), olivine gabbro cumulate (OC) clasts) [3, 4], Mg-suite rocks, KREEPy basalts [10] and Apollo mare basalts [11]. These ratios of NWA 2977 are very similar to those of Mg-suite rocks. The Ti/Sm and Sc/Sm ratios of NWA 2977 are slightly different from those of NWA 773 OC.

The incompatible trace element abundances in NWA 2977 (e.g. 2.02 ppm Sm) are apparently lower than those in NWA 773 OC (4.06 ppm Sm [3], 4.22 ppm Sm [4]). This is why the Ti/Sm and Sc/Sm ratios of NWA 2977 are different from those of NWA 773 OC. If the NWA 2977 and NWA 773 OC came from the same gabbroic body on the Moon, NWA 2977 represents a residual liquid-poor sample of that body.

**Summary:** The Sm-Nd age of NWA 2977 is 3.10 ± 0.05 Ga [5]. This crystallization age is much younger than the crystallization age of Mg-suite rocks (>4.1 Ga) [e.g. 11]. Therefore, it is generally understood that the petrogenesis of NWA 2977 should be similar to that of mare basalt with younger crystallization age than Mg-suite rocks. Furthermore, un-inverted pigeonites are found in this sample. This indicates that NWA 2977 was crystallized more rapidly than lunar intrusive rocks such as Mg-suite rocks. However, trace element ratios of NWA 2977 indicate that NWA 2977 is associated with Mg-suite rocks.

The NWA 2977 includes two lithologies, based on these features:

Lithology (1) is similar to a slowly-cooled mare basalt.

Lithology (2) is an intrusive rock crystallized more rapidly than Mg-suite rocks.

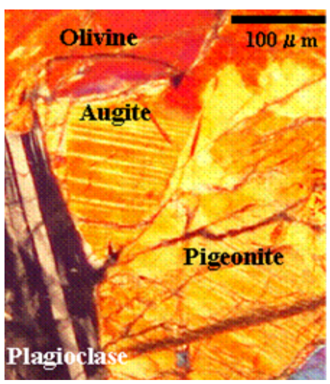


Fig. 1. Cross-polarized thin section image of exsolution lamellae occurring in some pyroxene grains in NWA 2977.

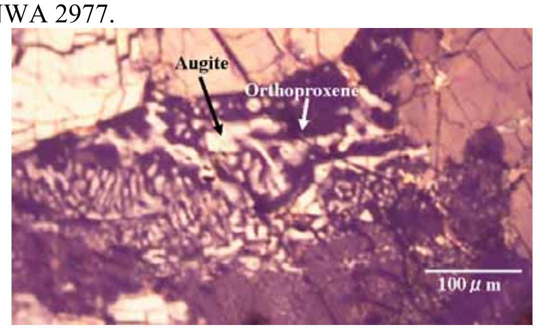


Fig. 2. Cross-polarized thin section image of inverted pigeonite in NWA 2977.

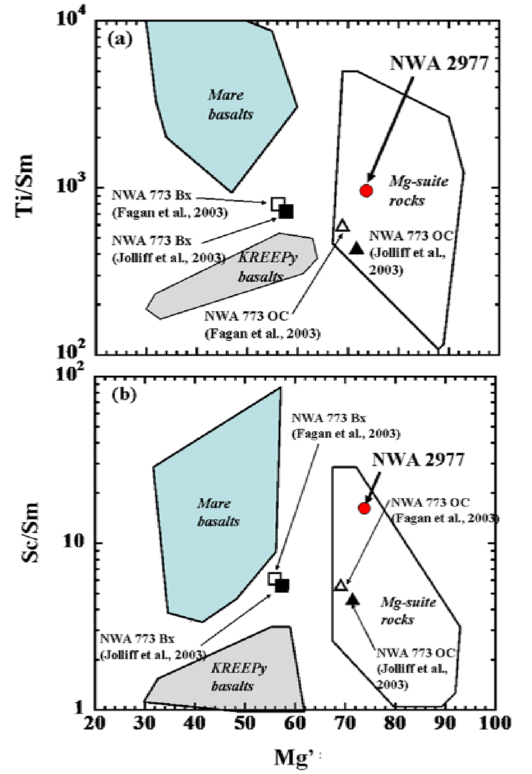


Fig. 3. (a) Ti/Sm vs. Mg' (molar 100×Mg/(Mg+Fe)) and (b) Sc/Sm vs. Mg' for NWA 2977, NWA 773 (Breccia matrix (Bx), olivine gabbro cumulate (OC) clasts), Mg-suite rocks, KREEPy basalts and mare basalts. Fields for Mg-suite rocks and KREEPy basalts are after Norman et al. [10]. Field for mare basalts refers to Heiken et al. [11].

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