MINERALOGY AND PETROLOGY OF THE NORTHWEST AFRICA 12774 ANGRITE. H. Hayashi[1], H. Kim[2], C. Park[2], T. Mikouchi[3] and V. H. Hoffmann[4,5], [1]Dept. of Earth & Planet. Sci., The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan, [2]Korea Polar Research Institute (KOPRI), Incheon, Korea, [3]University Museum, The University of Tokyo, Tokyo, Japan, [4]Dep. of Geo-& Environ. Sci., University of Munich, Munich, Germany, [5]Dep. of Geosci., University of Tübingen, Tübingen, Germany, E-mail: h.hayashi@eps.s.u-tokyo.ac.jp.

Introduction: Angrite is one of the oldest basaltic achondrites showing unusual chemistry enriched in refractory elements and depleted in volatiles [e.g., 1]. Most angrites show two distinct textures, either "quenched" or "slowly-cooled". Quenched angrites have older crystallization ages (*ca*. 4564 Ma) compared to slowly-cooled samples (*ca*. 4558 Ma), and thus quenched angrites can be good time anchors [e.g., 2]. Until now, 10 quenched angrites are known (LEW (Lewis Cliff) 87051, Asuka-881371/12209, D'Orbigny, NWA (Northwest Africa) 1296, NWA 1670, NWA 7203, NWA 7812, NWA 12004, NWA 12320 and Sahara 99555). These quenched angrites show ophitic, dendritic or coarse-grained textures perhaps depended upon slight difference of cooling rates [e.g., 3]. In this study, we performed mineralogical and petrological study of a new quenched angrite NWA 12774 and discuss its relationship to other quenched angrites, especially NWA 1670 and LEW 87051, in order to better understand formation history of quenched angrites.

Sample and Analytical Methods: NWA 12774 is a quenched angrite found in 2019 (total mass: 454 g). We studied 1 slice and 1 thin section. Observation was performed by optical microscope and FE-SEM (JEOL JSM-7200F). Mineral compositions were analyzed by FE-EPMA (JEOL JXA-8530F). All instrumental analysis was carried out at KOPRI.

Results: NWA 12774 shows a porphyritic texture with relatively large olivine and clinopyroxene phenocrysts (~1 mm) set in the fine-grained ophitic matrix. NWA 12774 mainly consists of olivine, clinopyroxene, anorthite and accessory phases such as spinel, native iron and troilite. Chemical compositions of the constituent minerals are listed in Table 1.

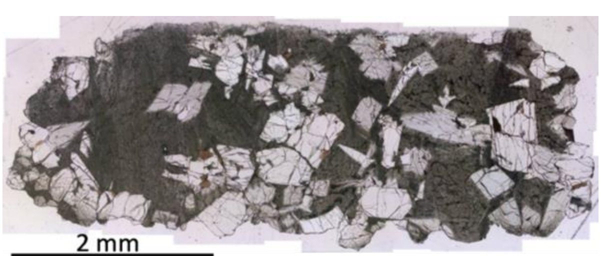

Fig. 1: Optical photomicrograph of the thin section of NWA 12774 (open nicol).

Olivine occurs as large phenocrysts (around 1 mm) or as micro-phenocrysts in the matrix. Large olivine phenocrysts show euhedral to subhedral shapes, and under optical microscope, they show sharp extinction. Some large olivine grains show several different extinction angles in part. As getting closer to the boundary to the part with the different extinction angle, chemical composition changes more Fe-rich. The core part of large olivine phenocrysts in the thin section is $Fo_{87}Fa_{12}La_{1}$ ~ $Fo_{41}Fa_{58}La_{1}$. All large olivine phenocrysts show extensive chemical zoning. The edge composition of the large olivine phenocryst is around $Fo_{28}Fa_{69}La_{3}$. In the slice sample, some large olivine grains (~3 mm) are more Mg-rich (up to Fo_{92}). They are considered to be xenocrysts. We measured line profile of olivine xenocryst to estimate a cooling rate of this angrite (Fig. 2). Olivine micro-phenocrysts in the matrix are $Fo_{46}Fa_{52}La_{2}$ ~ $Fo_{15}Fa_{81}La_{4}$.

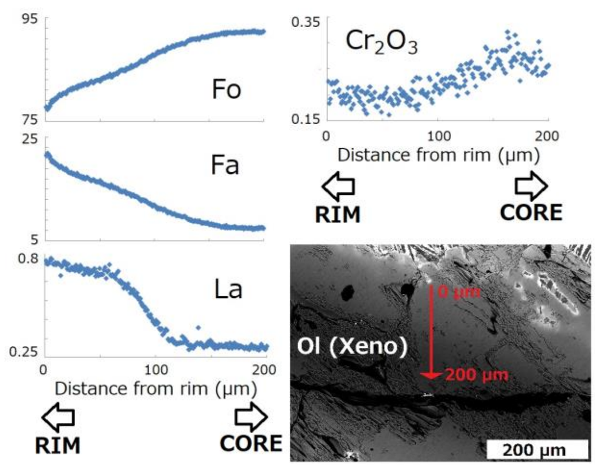

Fig. 2: EPMA line profiles of NWA 12774 olivine xenocryst with a back-scattered electron (BSE) image.

Clinopyroxene also crystallized as euhedral large phenocrysts (~1 mm) or as micro-phenocrysts in the matrix. Large clinopyroxene phenocrysts show both high-Al and low-Al parts in one grain. Large clinopyroxene contains Ti (TiO_2 = 1-2 wt%) and remarkably high amount of Al (Al_2O_3 = 10-12 wt%, 16-18 wt%), and their chemical composition of the high-Al part is $Di_{12}Hd_{37}Ksh_{35}Tp_{3}En_{13}$ ~ $Di_{23}Hd_{27}Ksh_{36}Tp_{4}En_{10}$, and thus some part of the clinopyroxene is kushiroite (Fig. 3). Clinopyroxene micro-phenocrysts occurring in the matrix contain TiO_2 = 1-2 wt% and Al_2O_3 = 4-6 wt%.

Anorthites show lath textures, and their grain sizes are up to 1 mm in length and 10 μm in width. Their chemical composition is almost pure anorthite ($An_{>99.5}$). Spinel occurs associated with large olivine grains. The size is up to 200 μm, and their chemical composition is $(Fe_{0.49-0.56}, Mg_{0.51-0.44})(Al_{0.81-0.93}, Cr_{0.19-0.07})O_4$. Spinel close to large olivine phenocrysts is more Fe-poor and Cr-rich. There are also small ulvöspinel grains in the matrix. The grain size of ulvöspinel is *ca.* 10 μm. Native iron (up to 100 μm) occurs in large olivine phenocrysts. Troilite occurs between anorthite laths. The grain size is up to 100 μm, but most grains are ~10 μm.

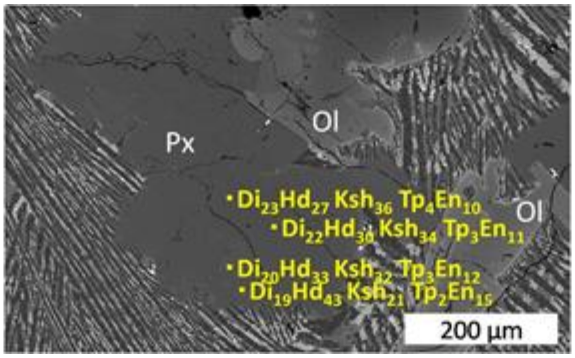

Fig. 3: BSE image of clinopyroxene phenocrysts in NWA 12774 with chemical compositions (in yellow).

Discussion and Conclusion: In NWA 12774 abundant clinopyroxene phenocrysts are present and their high Al content is unusual among quenched angrites. Because large euhedral olivine phenocrysts exist inside large euhedral clinopyroxene grains (Fig. 3), we consider that clinopyroxene in NWA 12774 crystallized after the crystallization of large olivine phenocrysts, and thus large clinopyroxene grains are phenocrysts. These clinopyroxene phenocrysts crystallized just after crystallization of olivine, but it was before crystallization of anorthite. Because the melt composition was enriched in Al, crystallizing clinopyroxene became extremely Al-rich. On the other hand, clinopyroxenes in other quenched angrites crystallized after crystallization of anorthite, and they are more Al-poor.

NWA 12774 is most similar to NWA 1670 and LEW 87051 in texture. However, the texture of NWA 12774 is slightly different from NWA 1670 (olivine xenocrysts in NWA 1670 are abundant and show mosaicism or undulose extinction [4], spinel occurs only in olivine xenocryst [5], and pyroxne xenocrysts of NWA 1670 are rare and small (*ca*. 100 μm) although they are Al-rich [5]). NWA 12774 is also slightly different from LEW 87051. NWA 12774 pyroxenes contain 10-18 wt% of Al_2O_3, but LEW 87051 pyroxenes contain 4-6 wt% of Al_2O_3 [6]. Also, grain size of groundmass minerals in LEW 87051 is larger. In addition, spinel in NWA 12774 is unusually large compared to other quenched angrites. Thus, NWA 12774 is not paired with either NWA 1670 or LEW 87051, but they are closely related in petrogenesis because all of them contain similar olivine xenocrysts.

The EPMA line profile of a large olivine xenocryst in NWA 12774 (Fig. 2) is also similar to LEW 87051 [6], where the Cr_2O_3 content is high (around 0.27 wt%) at the core and slightly increases to the rim (0.19 → 0.23 wt%). Only the La profile of the olivine xenocryst shows a plateau of chemical composition and the compositional gradient at the rim. This is probably due to a smaller diffusion coefficient of Ca compared with those of Fe and Mg. We calculate a cooling rate of NWA 12774 by the Fe-Mg diffusion profile with a similar manner to [7]. We assume that atomic diffusion starts from 1400 °C and ends at 900 °C. The best-fit cooling rate is 3.5 °C/h (Fig. 4). This result is consistent with [3], that the cooling rate of quenched angrites which crystallizes an ophitic texture is faster than 1 °C/h. The cooling rate of NWA 1670 quenched angrite (which shows an ophitic texture like NWA 12774) is estimated to be 4 °C/h [3], and this is close to the cooling rate of NWA 12774 estimated in this study.

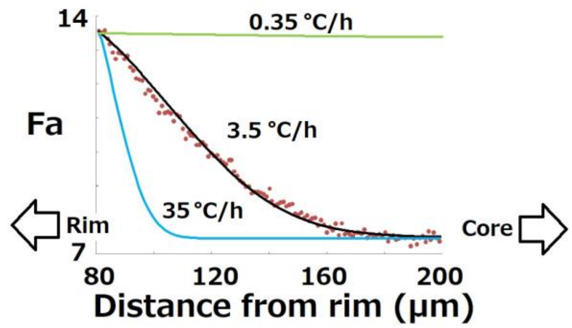

Fig. 4: Estimation of the cooling rate of NWA 12774 by Fe-Mg zoning of olivine xenocryst.

Table 1. Mineral compositions of NWA 12774.

	Ol (Xeno)	Ol (Micro-pheno)	Px (Large)	An (Micro-pheno)
SiO_2	41.58	30.76	41.31	43.99
Al_2O_3	0.04	0.26	17.83	34.89
TiO_2	*b.d.*	0.09	1.51	0.19
FeO	7.35	60.40	8.46	1.83
MnO	0.09	0.78	0.12	0.05
MgO	51.06	4.39	7.76	0.27
CaO	0.23	1.78	22.15	19.91
Na_2O	*b.d.*	0.13	*b.d.*	0.04
K_2O	0.02	*b.d.*	*b.d.*	*b.d.*
Cr_2O_3	0.25	0.02	0.45	0.01
Total	100.62	98.61	99.59	101.19

b.d.: Below detection limit.

References: [1] Keil K. (2012) *Chem. Erde, 72*, 191-218. [2] Amelin Y. (2008) *GCA, 72*, 221-232. [3] Hayashi H. and Mikouchi T. (2019) *The 10th Symp. of Polar Sci.* [4] Mikouchi T. et al. (2003) *66th Annual MetSoc Meeting*, #5218. [5] Jambon A. et al. (2008) *Meteorit. & Planet. Sci., 43,* 1783-1795. [6] Mikouchi T. et al. (1996) *Proc. NIPR Symp. Antarct. Meteorites, 9*, 174-188. [7] Mikouchi T. et al. (2001) *Meteorit. & Planet. Sci., 36*, 531-548.