IGNEOUS PETROGENESIS OF YAMATO NAKHLITES. N. Imae[1], Y. Ikeda[2] and H. Kojima[1], Antarctic Meteorite Research Center, National Institute of Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173-8515, Japan (imae@nipr.ac.jp), Department of Material and Biological Sciences, Ibaraki University, Mito 310-8512, Japan.

Introduction: We have carried out detailed petrographical-mineralogical description of three Yamato nakhlites (Y000593, Y000749 and Y000802). These three are paired. We clarified chemical compositional differences between the Yamato nakhlites and other nakhlites, and subclassified the Yamato nakhlites as an intermediate type between NWA817 and others (Nakhla, Governador Valadares and Lafayette) based on the compositional variation of pyroxenes and olivines [1].

In the present study, we summarize analytical results of the Yamato nakhlites obtained by electron probe microanalyzer, and discuss the peterogenesis of nakhlites using the bulk chemical composition of magmatic inclusions in olivine phenocrysts and mesostasis.

Results: *Augites:* Augite phenocryst cores are homogeneous ($En_{38-40}Fs_{24-26}Wo_{40-41}$), and the rims consist of two thin layers, inner and outer (Fig. 1). Ferrosilite contents increase continuously from inner rim to outer rim. Though wollastonite contents are constant in the inner rim, it drastically decreases in the outer rim (Fig. 1). The aluminum content increases in the inner rim, and drastically decreases in the outer rim.

Olivines: Olivines occur as phenocrysts and show normal zoning (Fa_{58-80}, CaO = 0.05~1 wt%). In olivine phenocrysts, symplectic lamellae consisting of two phases (magnetite and augite; [3]) are observed, and symplectites of the same two phases commonly occur at the grain boundaries.

Inclusions in olivines: Three types of large (~100 μm) inclusions occur in olivine phenocrysts; they are augite monocrystalline inclusions, angular vitrophyric inclusions (AVIs) and rounded vitrophyric inclusions (RVIs). RVIs may represent the parent magma formed nakhlites as discussed by [2].

Mesostasis: Mesostasis consists predominanltly of needle-like plagioclases. Minor phases are K-feldspar, augite, pigeonite, fayalitic olivine, titanomagnetite, pyrrhotite, apatite and tridymite.

Discussion: Olivine phenocrysts and titanomagnetite phenocrysts in the Yamato nakhlites co-crystallized based on the textural evidence, and titanomagnetite inclusions occur sometimes in aguite phenocryst cores. Therefore, we suppose that cumulus phases are augite phenocryst cores, olivine phenocryst cores, and titanomagnetite phenocrysts. The fration of 0.5 and 0.8 of the olivine modal abundance (12.2 vol%) were used for the calculation in Fig. 2 and Table 1. The chemical composition of olivine cores must be in equilibrium with augite cores in the magma chamber. The partition coefficient of Mg/Fe is nearly unity between augite and olivine [4], then the equilibrium composition in the magma chamber is Fa_{39-41}. This is more magnesian than the cores (Fa_{58}) of olivine phenocrysts of the Yamato nakhlites, suggesting that the magnesian olivines have changed to the ferroan olivines during the late stage of crystallization.

The interstitial melt composition was calculated from the difference between the Yamato nakhlite bulk and the cumulus phases (augite core, olivine core and titanomagnetite). It is consistent with the parent magma composition derived from RVI (Table 1 and Fig. 2).

In the late stage of crystallization, two types of rims, inner and outer, surround augite cores. During the formation of the inner rim, mesostasis have not crystallized (Fig. 2), and the melt composition changes continuously from *a* to *b* in Fig. 2. Then supercooling of the interstitial melt nucleates plagioclase, resulting in the formation of mesostasis. The rapid crystallization of plagioclase consumes aluminum and calcium in the melt, and the chemical composition of the growing pyroxene in the outer rim drastically change the aluminum and calcium contents to decrease, forming Ca-poor pyroxene in the outer rim (Fig. 2).

If the lamellae formation in olivine phenocrysts is controlled by volume diffusion of oxygen in olivine [5], slow cooling should be necessary in the magma chamber. However, in order to preserve zoning profiles of olivine phenocrysts in the Yamato nakhlites, the cooling rate must be much larger. This requires two stage cooling from slow to fast. Alternatively, the lamellae may be produced much faster by the high-speed diffusion with defects in olivines [6]. Then the lamellae in olivines may have formed during a single cooling process. We prefer the single cooling stage model.

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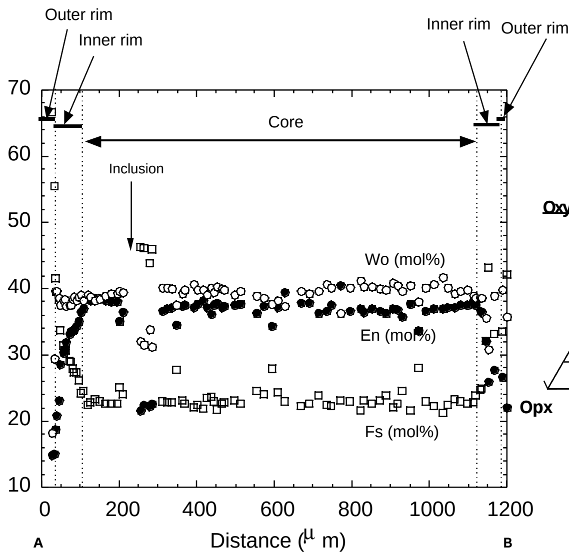

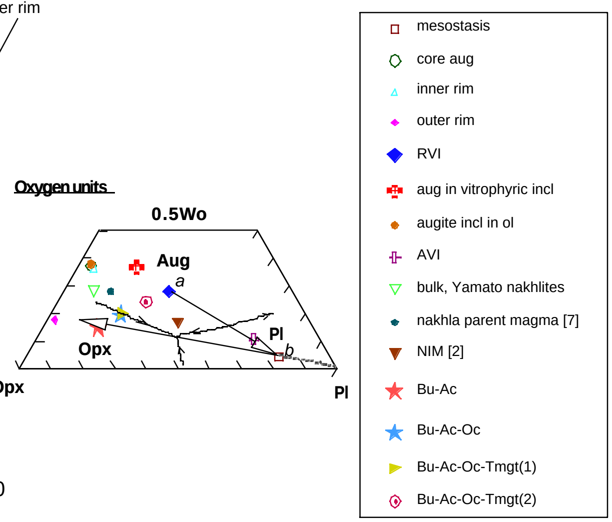

Fig. 1. A zoning profile of a cumulus augite phenocryst in Y000593. The inner rim is thicker than the outer rim. Thicker left rim (A) contacts with mesostasis, and the thinner right rim (B) contacts with augite.

Fig. 2. Pseudoternary phase diagram showing the formation of the inner and outer rims and the mesostasis in the Yamato nakhlites.

Table 1. Bulk compositions of the Yamato nakhlite, calculated possible magmas, inclusions and mesostasis.

	Average of Y000593 and Y000749*1)	Yamato(Bu-Ac)*2)	Yamato(Bu-Ac-Oc)*3)	Yamato(Bu-Ac-Oc-Tmgt)(1)*4)	Yamato(Bu-Ac-Oc-Tmgt)(2)*4)	Bulk of RVI*5)	Bulk of AVI*6)	Mesostasis *7)	NIM *8)	Longhi (1989)*9)
SiO_2	48.35	43.41	44.96	44.19	45.32	53.29	60.94	66.74	46.27	49.01
TiO_2	0.47	0.81	0.99	0.47	0.54	1.09	0.88	0.18	3.69	1.06
Al_2O_3	1.96	3.74	4.55	4.48	5.13	7.46	12.69	14.57	7.66	2.85
Fe_2O_3	2.04	5.31	6.47	6.35	7.29					
FeO	19.51	26.67	25.30	22.78	21.27	12.71	8.83	6.93	24.68	26.23
MnO	0.59	0.83	1.02	1.00	1.14	0.30	0.13	0.10		
MgO	11.09	9.01	4.37	4.30	0.46	6.28	1.94	0.88	5.42	5.22
CaO	14.90	8.92	10.87	10.68	12.25	15.38	7.44	5.66	10.04	13.92
Na_2O	0.66	1.35	1.64	1.61	1.85	0.87	4.06	3.68	1.46	0.97
K_2O	0.17	0.43	0.52	0.51	0.59	1.56	0.71	1.26	1.20	0.20
$H_2O(-)$	0.03	0.07	0.08	0.08	0.09					
$H_2O(+)$	0.00	0.00	0.00	0.00	0.00					
P_2O_5	0.21	0.48	0.59	0.58	0.66					
Cr_2O_3	0.26	0.15	0.18	0.18	0.20	0.19	0.00	0.00		
FeS	0.08	0.21	0.25	0.25	0.29					
NiO										
Total	100.30	101.33	101.75	100.00	100.00	99.13	100.00	97.62	100.42	99.46
Norm calculation as oxygen units (molecular %)										
Plagioclase	9.3	17.2	22.1	22.7	27.5	33.4	68.6	79.7	34.2	14.5
Wollastonite	28.4	15.2	19.6	20.1	24.4	28.0	10.6	4.3	16.1	28.3
Opx	62.4	67.5	58.3	57.2	48.1	38.6	20.8	16.1	49.7	57.2
Density(g/cm^3)	3.29*10)	3.27*11)	3.19*12)	3.16*13)	3.13*13)					
Mode (vol%)	100	38.6*11)	32.5*12)	31.9*13)	28.3*13)					

*1) Averaged bulk composition of Y 000593 and Y000749 analysed by H. Haramura.
*2) (Averaged bulk of Yamato nakhlites) - (Augite core), where "-" means subtraction.
*3) (Averaged bulk of Yamato nakhlites) - (Augite core) - (Olivine core).
*4) (Averaged bulk of Yamato nakhlites) - (Augite core) - (Olivine core) - (Titanomagnetite).
*5) Bulk of rounded vitrophyric inclusion (RVI), detemination from modal abundance of augite and mesostasis.
*6) Bulk of angular vitrophyric inclusion (AVI), point anlyses, average of 10 point anlyses.
*7) Bulk of mesostasis, broad beam analyses of 50μm, average of 3 mesostases.
*8) The chemical composition of parent magma by [2]. NIM=nakhlite inclusion median.
*9) The chemical composition of parent magma by [8].
*10) [9].
*11) Augite core mode = 61.4% (assumed rim thickness = 20 μm, Assumed rectangular shape of augite phenocrysts = 0.5 x 0.5 x 1 mm^3, Augite phenocrysts mode = 76.7%), Augite core density = 3.3.
*12) Fa_{38} core mode = 6.1% (assumed of half of olivine phenocryst mode 12.2%), Fa_{38}density = 3.7.
*13) Fa38 core mode = 6.1% and 9.8%, Titanomagntite mode = 0.6%, Titanomagnetite density = 5.