APOLLO 14 OLDEST MARE BASALT REVISITED: POSSIBLE PETROGENETIC CONNECTION BETWEEN MG GABBRONORITE AND VHK BASALT. T. Arai[1], H. Takeda[2], M. Miyamoto[3], and H. Kojima[1], [1]Antarctic Meteorite Research Center, National Institute of Polar Research, 1-9-10 Kaga Itabashi Tokyo 173-8515, Japan, tomoko@nipr.ac.jp, [2]Research Institute, Chiba Institute of Technology, Tsudanuma, Narashino, Chiba, 275-0016, Japan. [3] Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo, Hongo, Tokyo 113-0013, Japan.

Introduction: Timing of onset of mare-basalt volcanism and relation in time and space with highland crustal formation has been one of the biggest un-answered questions in lunar science. In contrast to relatively well studied younger (post-Imbrium) mare basalt volcanism, pre-Imbrium "Crypt-mare" magmatism is not well defined because these older terrains have been exposed to intensive impact events and are difficult to be studied by either remote sensing or sample analysis. Taylor et al. (1983) [1] reported the oldest olivine-rich mare basalt cumulate clast with 4.23 Ga in Apollo 14 breccia 14305, suggesting that mare-type volcanism commenced at least as early as 4.23 Ga in the Fra Mauro region and probably across much of the lunar surface. Since this has been only one crypt-mare clast classified as a mare basalt to date, we expect this sample to serve both as a missing link to connect the crypt-mare and young-mare and as an important clue to understand crypt-mare basalt magmatism. In this study, the three-dimensional feature of this crypt-mare basalt is reconstructed based on the cross sections found in the three thin sections, in an attempt to further delve into the petrogenesis of the crypt-mare magmatism and to evaluate the petrogenetic relationship between crypt mare and young mare.

Sample and Method: As a result of the survey of over fifty PTSs made from the common parent rock chip as the PTS 14305, 92 including the oldest mare basalt [1] at Lunar Sample Lab at NASA JSC, we found that two thin sections, 14305, 91 and 14305, 512 including relatively large coarse-grained basaltic clasts, 7.5 × 6 and 5 × 5 mm, that are comparable in size to the clast in 14305, 92, 10 × 6 mm. Because the two PTSs were made from the potted butt 14305, 35 from which the PTS 14305, 92 was made, and were originally located adjacent to the PTS 14305, 92, it is highly likely that the basalt clasts in the three PTSs are cross sections of the same basalt. Mineral compositions were investigated by electron microprobes at the Ocean Research Institute, the University of Tokyo, and National Institute of Polar Research.

Results: The three PTSs studied are polymict breccias containing relatively large clasts of various lithologies. Common occurrences of multiple lithic clasts in the three PTSs strongly indicate the close spatial relation among them (Fig. 1). A PTS 14305, 92 consists of the oldest basalt [1], a fine-grained olivine-phyric basalt and a large plagioclase fragment probably of ferroan anorthosite. The oldest basalt is also petrographically an Mg-olivine gabbronorite, which is generally referred to highland lithology [2]. The basalt clast shows a poikilitic texture with cumulus olivines 0.2 – 1.2 mm across enclosed by Mg-rich pigeonite, augite, plagioclase, ilmenite. Modal abundance is given in Table 1. Mineral compositions are shown in Fig. 3. Noted that this clast shows systematic compositional variation from "primitive" to "evolved", in major silicate phases across the clast.

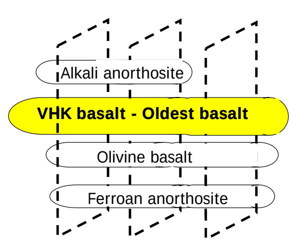


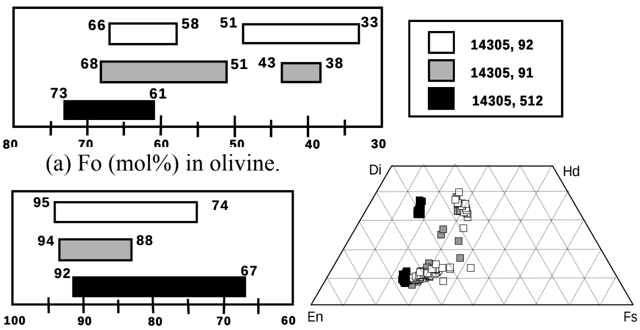
Fig. 1. Schematic showing occurrences of multiple clasts across the three PTSs

A PTS 14305, 91 includes a coarse-grained basalt, an alkali anorthosite, a fine-grained olivine-phyric basalt and a large plagioclase fragment probably of ferroan anorthosite. Based on the location within the PTS and the estimated special relation with other clasts, the coarse-grained basalt is likely another section of the basalt in 14305, 92. It shows an ophitic texture and consists of pigeonite, augite, plagioclase, olivine, K-feldspar, ilmenite, titanian chromite, Fe-metal, troilite, Ca-phosphate and Si, Al, K-rich glass. Modal abundance is given in Table 1. Systematic variations in modal abundance and mineral compositions across the clast are observed, as well as that in the 14305, 92. K-feldspar is ubiquitous and its mode reaches as high as 3.6 vol. %. Based on the extremely high modal K-feldspar and the similarity in mineralogy to the reported Apollo 14 VHK basalts [e.g. 3], this basalt clast is a VHK basalt, although it has been originally described as an olivine-pigeonite basalt [4].

A PTS 14305, 512 contains a coarse-grained basalt, an alkali anorthosite, a fine-grained olivine-phyric basalt and a large plagioclase fragment probably of ferroan anorthosite. With a common spacial relation with other clasts, the coarse-grained basalt is likely another section of the basalt in 14305, 92 and 91. The basalt clast shows an ophitic texture, with pigeonite overgrown by augite, plagioclase, olivine, K-feldspar, ilmenite, titanian chromite, Fe-metal, troilite, Ca-phosphate and Si, Al, K-rich glass. Modal abundance is given in Table 1. With high modal abundance (7.1 vol. %) of K-feldspar and Si, Al, K-rich glass, the basalt clast is also a VHK basalt. No apparent systematic variation either in modal abundance or mineral compositions is found.

Table 1. Modal abundance (vol. %) of each basalt clast.

	14305, 92	14305, 91	14305, 512
olivine	36.3	15.5	2.4
pyroxene	37.9	52.5	47.4
plagioclase	21.5	25.8	40.1
K-feldspar + glass	< 0.1	3.6	7.1
ilmenite	2.0	1.8	2.1
titanian chromite	2.3	0.6	0.5
Ca-phosphate	< 0.1	< 0.1	< 0.1
FeS + Fe metal	< 0.1	0.2	0.4



(a) Fo (mol%) in olivine.

(b) An (mol%) in plagioclase.(c) Fe-Mg-Ca variation in pyroxene.

Fig. 2 Mineral compositions of the basalt clasts.

Discusssions: Systematic variations in the modal abundances and mineral compositions are observed both within the basalt clasts and among the clasts in the sequence from 14305, 92, 14305, 91 to 14305, 512. This is in agreement with the study of [3], proposing that VHK basalts constitute a layered basalt flow, due to the variations in texture and phenocryst content. Considering the amount of material lost by sawing, grinding and polishing during the sample processing procedure cut surfaces in the successive thin sections made from the same potted butt would have been originally located less than 1 cm apart from each other (C. Meyer, pers.comm.) Thus, each cross section represents different position of a vertical stratified basalt within a range of as long as a few cm: 14305, 92 at the bottom, 14305, 91 in the middle and 14305, 512 on the top (Fig. 3). Since only three cross sections of the layered basalt unit are available here, the entire range of the basalt unit is unknown. However, compared with olivine compositions (Fo_{73-33}) in known VHK basalts [e.g. 3] and those (Fo_{73-68}) in an Apollo 16 olivine gabbronorite 67667 [2], the three clasts in this study might likely cover the entire compositional range of the representative Mg gabbronorite - VHK basalts layered units. Although a required setting for olivine accumulation of 14305, 92 is proposed to be a basalt unit of 15 m thick at minimum [1], the extreme modal and compositional change within the cm-meter scale in the three dimensions, rather implies derivation of isolated small pockets of magma chamber at shallow depth, which is more effective for enrichment of K and alkali elements.

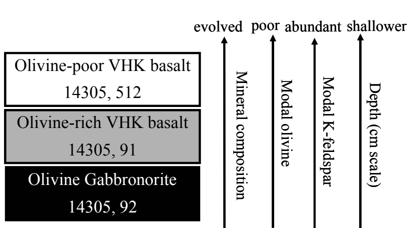


Fig. 3 Hypothetical 14305 layered basalt unit

Mg-gabbronorites are subdivision of the Mg norites and only a few samples are found respectively from Apollo14, Apollo 16 and Apollo 17 sites [2]. Its petrogenesis remains obscure because of the paucity of the samples. VHK basalts are restricted to Apollo 14 site, dominantly in breccia samples 14303, 14304, and 14305 [e.g. 3]. Shervais et al. [3] reported the VHK basalts are formed in the layered basalt flow, and Goodrich et al. [13] described both Mg-gabbronorite and VHK basalt in a breccia 14304. However, there is no reference to report a kinship between Mg-gabbronorites and VHK basalts to date. Our results first present a strong evidence to show that Mg-gabbronorites and VHK basalts constitute a single layered basalt as differentiates from a common magma. This further suggests any bulk-clast compositions of known VHK basalts do not represent primary magma compositions, but, instead, more evolved compositions after the low-pressure partial crystallization of olivine cumulate in the small magma chamber.

Formation ages of Mg-gabbronorites in Apollo 14, 16 and17 sites are all restricted around 4.2 Ga [1, 6]. Previously known Apollo 14 VHK basalts show much younger ages around 4.0 – 3.8 Ga [7, 8]. In contrast, the VHK basalts in 14305, 91 and 14305, 512 have a crystallization age of 4.23 Ga, because it should be identical to the Mg-gabbronorite in 14305, 92 as a single continuous basalt unit. This age is about 0.2 Ga older than those previously reported, indicating the VHK basalts of this study are derived from distinct magma generated at much older time. This older age reveals that the VHK basalt magmatism has lasted from 4.23 Ga to 3.8 Ga.

Apollo and Luna mare basalt samples are typically enriched in Fe and including pyroxenes which are extensively zoned to the Fe-rich compositions [e.g. 9]. In contrast, the 14305 layered basalt shows no strong Fe-enrichment trend, instead, an extreme K and Si- enrichment fractionation trend is present. The absence of the Fe-enrichment trend in pyroxene can be explained with olivine resorption by which MgO activity of the trapped interstitial liquid is buffered to relatively constant. The contrast between the K, Si-enrichment in 14305 crypt-mare basalts and the Fe-enrichment in post-Imbrium young-mare basalts may be attributed to differences in physical conditions of the magma, such as rates of crystal accumulation and solid/liquid separation, which are controlled by volume of magma, cooling rate, the shape of magma chamber (for intrusive case), thickness and mobility of the basalt flow (for extrusive case).

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