MAGMATIC EVOLUTION ESTIMATED FROM TRACE ELEMENTS IN PLAGIOCLASE FROM PROCELLARUM KREEP TERRANE BRECCIAS S. Togashi [1], N. T. Kita[2] , A. Tomiya[1] and Y. Morishita[13], [1]Geological Survey of Japan, AIST, (Central 7, Tsukuba, 305-8567, Japan, s-togashi@aist.go.jp). [2]Department of Geoscience, University of Wisconsin, Madison, WI. [3]Department of Geoscience, Shizuoka University, Japan.

Introduction: Typical plutonic rocks in the Procellarum KREEP (K, Rare Earth Elements, and P) Terrane (PKT) are of the Mg suite, i.e., cumulates containing calcic plagioclase (An98–84) coexisting with Mg-rich mafic silicates (Mg# 95–60) (e.g., [1, 2]). While Mg-suite plutonic rocks outside of the PKT do not necessarily show KREEP signature, those within the PKT paradoxically have both Mg-rich components (primary melt or cumulate) and a KREEP component (incompatible element enriched) [e.g. 3–5]. The trace element abundance of PKT Mg-suite rocks may be keys to unveil "urKREEP", a late KREEP-enriched residuum of the lunar magma ocean that was proposed as a common reservoir of KREEPy rocks [6]. Although urKREEP has not been found in its original form [6, 7], its signature might be recorded in cumulate minerals [8, 9].

Here we estimate the concentrations of Ba, Sr, and Ti in the host magmas of the plagioclase in breccias from the PKT by using secondary ion mass spectrometry (SIMS) analyses. We then discuss the formation of a highly evolved urKREEP magma from bulk silicate moon (BSM) by applying three models: lunar primitive upper mantle (LPUM [10]), Taylor whole Moon (TWM [11]), and crustal-component-enriched BSM with sub-chondritic Ti/Ba ratio (cBSM [12]), which we previously proposed from the study of ferroan anorthosites (FANs [12]). New trace element analyses of PKT Mg-suite rocks further test above BSM models with respects to chemical characters of urKREEP and the formation of KREEPy rocks.

Methods and Results: We analyzed plagioclase trace-element contents in breccias from the Apollo (Ap) 12 and 14 landing sites in the PKT using the same SIMS analytical method in [12]. For the samples that show minimal trace element evidence of post-magmatic processes (Group a1 [12]), the plagioclase contained 84–1,550 ppm Ba, 220–700 ppm Sr, and 0.022–0.086 wt% TiO_2 (Fig. 1).

We estimated the concentrations of Ba, Sr, and Ti of the plagioclase host magmas from SIMS analyses using plagioclase-melt trace element partition coefficients ($D_{Element-Pl}$). We adopted values of 0.14–0.23 for the D_{Ba-Pl}, 1.5–1.8 for the D_{Sr-Pl} and 0.009–0.030 for the D_{Ti-Pl}, depending on X_{An} (0.97–0.77). The host magmas for the Group a1 samples contained 570–6,800 ppm Ba, 148–390 ppm Sr, and 0.8–6.2 wt% TiO_2, with sub-chondritic Ti/Ba ratios (Fig. 1).

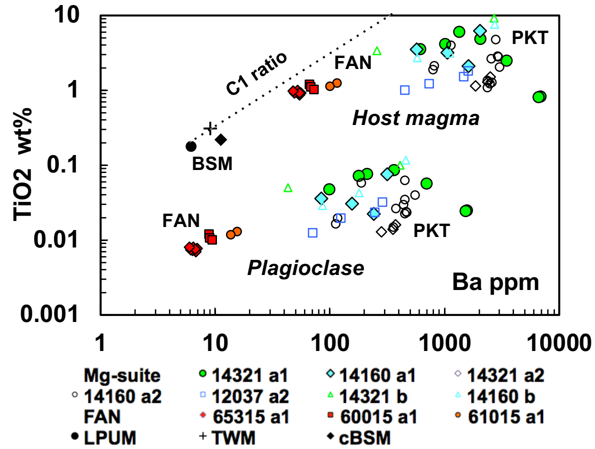

Fig. 1. TiO_2-Ba variations of plagioclase in FANs [12] and PKT breccias (this study), and those estimated for their host magmas. Groups (a1, a2, and b) are grades indicating post-magmatic processes [12], where Group a1 is least affected. C1 (dotted line) represents the chondritic ratio.

Discussion:

Polybaric multi-step BSM evolution model. A polybaric multi-step evolution model using MELTS [13, 14] was applied to the BSM by extending the two-step model [12, 15] (Fig. 2).

In the first step, an equilibrium melt (of LPUM, TWM, or cBSM composition) accounting for 40 wt% of the BSM composition was generated at high pressure (0.8 GPa). In the second step, the magma ascended to a shallow depth (0.3 GPa), where it crystallized in equilibrium (equilibrium crystallization, EC) to 20 wt% melt, then evolved under fractional crystallization (FC) to 10 wt% melt. The 20–10 wt% melts represent the FAN-host magma [12]. We explored two cases of final magma evolution at a shallower depth (0.05 GPa). In Case A, the 10 wt% melt further evolved via FC to 1 wt% melt (Fig. 2). In Case B, the 10 wt% melt further evolved via EC to about 0.1 wt% melt (Fig. 2).

We compared our results with experimental results [16] for the multi-step fractional crystallization of LPUM and TWM, and with the estimated compositions of the plagioclase host magmas in the PKT (this study). In the TiO_2-Ba variation diagram (Fig. 2), Ba concentrations were calculated by assuming a constant Ba/K ratio for the BSM throughout its evolution.

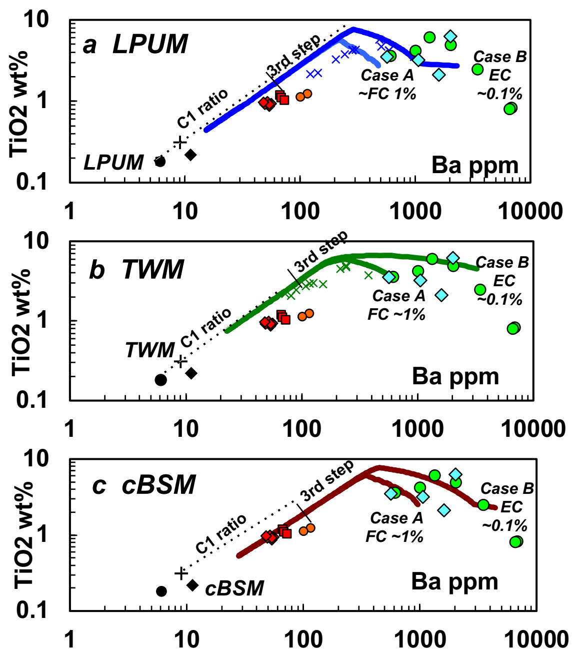

Fig. 2. TiO_2-Ba variation of estimated magmas evolved from the BSM. (a) LPUM, (b) TWM, and (c) cBSM initial melt compositions. A constant Ba/K ratio was assumed for experimental data (blue and green crosses) [16]. Other symbols are as in Fig. 1. See text for details.

LPUM: Neither the polybaric evolved LPUM magma model nor experimental data [16] match the high Ba and Ti contents of the estimated host magma in the PKT (Fig. 2a). Furthermore, the chondritic Ti/Ba ratio of LPUM disagrees with the sub-chondritic Ti/Ba ratio of the FAN-host magma estimated from plagioclase [12].

TWM: The polybaric evolved TWM magma and experimental data [16] are consistent with the host magma estimated from the PKT plagioclase (Fig. 2b). However, the chondritic Ti/Ba ratio of TWM is inconsistent with the FAN-host magma estimated from plagioclase [12].

cBSM: The polybaric evolved cBSM magma is fairly consistent with the plagioclase host magmas of both the PKT and FAN (Fig. 2c).

Comparison with bulk clasts from sites Ap14 and Ap16. The high-Ba and -Ti magmas estimated from plagioclase in the PKT and estimated by polybaric evolution from cBSM are 2–3 times higher than KREEP clasts from the Ap14 site (Figs. 2 and 3, [17–20]). These compositions would be a candidate for urKREEP if diluted by a Mg-rich component to form KREEP. Moreover, almost all Ap14 and Ap16 plutonic clasts show sub-chondritic Ti/Ba ratios, and some norites and gabbros from site Ap16 plot on the cBSM evolution line in the TiO_2-Ba variation diagram (Fig. 3, [2, 5, 17–37]).

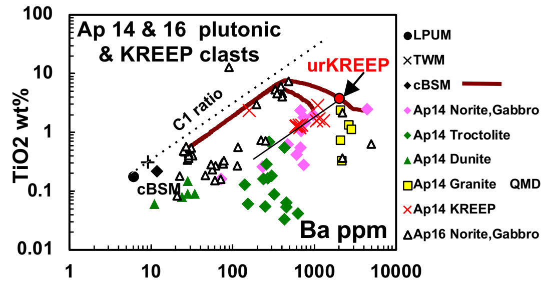

Fig. 3. TiO_2-Ba variation diagram of Ap14 and Ap16 plutonic clasts and Ap14 KREEP. Data from [2, 5, 17–37]; cBSM trend replotted from Fig. 2c.

Conclusions: The high-Ba and -Ti host magma estimated from plagioclase in the PKT is not consistent with the polybaric evolution of LPUM magma, but is consistent with the evolution of TWM and cBSM magmas. However, only cBSM model may explain both FAN and PKT Mg-suite host magmas. The high-Ba and -Ti magma from cBSM may represent a composition of urKREEP, which would have been diluted by Mg-rich components to form KREEPy rock from site Ap14 .

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