

EFFECT OF TITANIUM ABUNDANCE ON SILICA VS. IRON ENRICHMENT IN LUNAR BASALTS: MODELING & COMPARISON WITH NORTHWEST AFRICA 773. T. J. Fagan¹, ¹Department of Earth Sciences, Waseda University, 1-6-1 Nishiwaseda, Shinjuku, Tokyo, Japan (fagan@waseda.jp).

Introduction: Lunar basalts exhibit a wide range of Ti-concentrations [1-3]. High-Ti concentrations lead to early stability of Ti-rich oxides, whereas in low-Ti and very low Ti (VLT) liquids, Ti-oxides form at late stages of crystallization [1,4]. Consequently, fractional crystallization of a high-Ti basaltic liquid results in Ti-depletion as Fe# (molar Fe/[Fe+Mg]x100) increases; in contrast, TiO₂ concentrations and Fe# both increase during crystallization of low-Ti and VLT basalts (e.g., [1]).

This study makes use of: (1) pyroxene Fe# and Ti# (molar Ti/[Ti+Cr]x100) to show that many clasts of the Northwest Africa 773 (NWA 773) lunar breccia crystallized during progressive increasing Fe# and Ti#, as expected for a VLT parent; and (2) MELTS [5] models to evaluate the effects of TiO₂ concentrations on FeO-enrichment vs. SiO₂-enrichment in lunar mare basalts.

Analytical Methods: The main textural observations and mineral analyses of this study are from one polished thin section of NWA 773, a basaltic lunar breccia with several pairs or related meteorites [6-9]. Mineral analyses and imaging were collected using a JEOL JXA-8900 electron microprobe. Fractional crystallization models were collected using MELTS [5] at 1 bar, at temperatures decreasing from the liquidus at 5°C intervals until approximately 20% of original liquid was remaining. Oxygen fugacity was set at the Fe-FeO buffer—high for lunar conditions, but almost all Fe was speciated as FeO as expected for lunar basalts. Initial liquid compositions for modeling are from: Apollo 10024 [10] and 70215 [11] for high-Ti; NWA 032 [12] for low-Ti; NWA 773 “parent” [7] for VLT; Apollo 15405,12 [13] for KREEP basalt.

NWA 773, example of VLT differentiation: All meteorites of the NWA 773 clan have a relatively magnesian (pyroxene Fe# ~25-30) olivine cumulate (OC, [6-9]). Pyroxenes from pyroxene gabbro clasts in the breccia show a correlated variation from Fe# and Ti# near the OC to much higher values. Full ranges of Fe# and Ti# from pyroxene gabbro occur in a single zoned clast, in which Fe# and Ti# increase with proximity to late-stage K,Ba-feldspar and K-rich glass (Fig. 1), indicating that Fe# and Ti# increased during magmatic crystallization. Symplectites composed of fayalite, silica and hedenbergitic pyroxene are interpreted as late-stage rocks. Alkaline-phase-ferroan clasts are characterized by fayalite, K,Ba-feldspar and/or K-rich glass, ±hedenbergitic pyroxene, and may have formed from alkali-rich ferroan liquids that were immiscible

pairs of liquids from which the symplectites formed. The OC, pyroxene gabbro and symplectite + alkaline-phase-ferroan clasts are interpreted as co-magmatic products of differentiation of a VLT parent.

Effect of TiO₂ on SiO₂- vs. FeO-enrichment: All of the MELTS models show increasing Fe# during fractional crystallization. The high-Ti basalts show steady increases in SiO₂ mirrored by decreasing TiO₂, due to fractionation of Ti-rich oxides (Fig. 2a). In contrast, the low-Ti and VLT basalts do not show significant SiO₂ increases or TiO₂ decreases until late stages of crystallization. The KREEP basalt always has higher SiO₂-concentrations at comparable Fe# in comparison to the mare liquids.

Model results show long intervals of strong FeO-enrichment in the low-Ti and VLT basalts (Fig. 2b), which are preceded by a switch from olivine to pyroxene crystallization. In contrast, the high-Ti and KREEP basalts have either moderate FeO-enrichments or progressive FeO-depletions. In all of the model liquids, MgO is steadily depleted during fractional crystallization. Thus the increase in Fe# during crystallization of the high-Ti and KREEP liquids is due more to MgO-depletion rather than FeO-enrichment.

The distinction between strong FeO-enrichment in the low-Ti basalts vs. moderating to depleting FeO in the high-Ti and KREEP liquids is masked by closure when only AFM (A = alkalis Na₂O + K₂O, F = FeO, M = MgO) components are considered (see [14] for discussion of closure of compositional data). Most of the mare liquids evolve toward the FeO-apex of an AFM diagram (Fig. 3). High-Ti basalt 10024 has more K₂O than the other mare liquids and progresses toward a more alkaline, but still ferroan composition. The model KREEP basalt evolves toward the alkali-FeO join of the AFM diagram along a path similar to experiments on the same composition [15]; however, the [15] experiments show that silicate liquid immiscibility occurs at moderate Fe# in the KREEPy liquid (Fig. 3).

Based on the models, TiO₂ in lunar basalts plays a role similar to that of oxygen fugacity in some terrestrial magmas. In terrestrial systems, high f(O₂) results in high Fe³⁺/Fe²⁺ and can stabilize early Fe-bearing oxide, limiting FeO-enrichment and enhancing SiO₂-enrichment in residual liquids [16]. In mare basalts, early Fe-oxide can be stabilized by high TiO₂.

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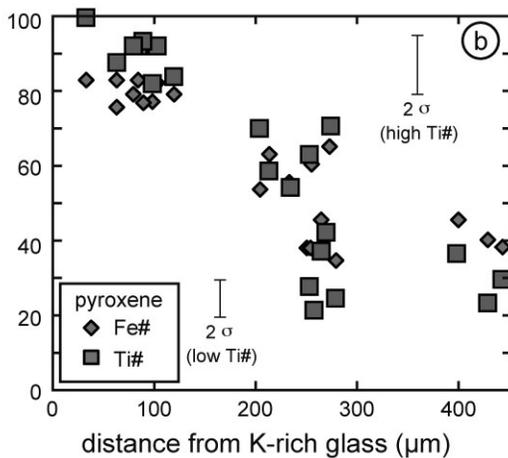
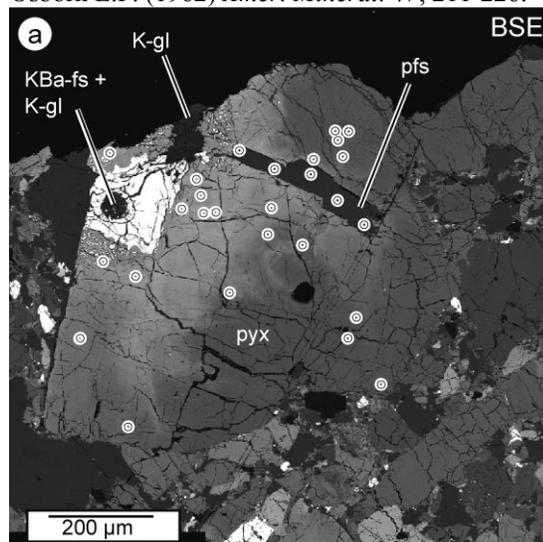


Fig. 1. (a) BSE image of zoned pyroxene (pyx) gabbro clast from NWA 773 breccia, with locations of quantitative analyses. Phases include K,Ba-feldspar (KBa-fs), K-rich glass (K-gl) and plagioclase feldspar (pfs), (b) Pyroxene Fe# and Ti# vs. distance from K-rich glass and K,Ba-feldspar.

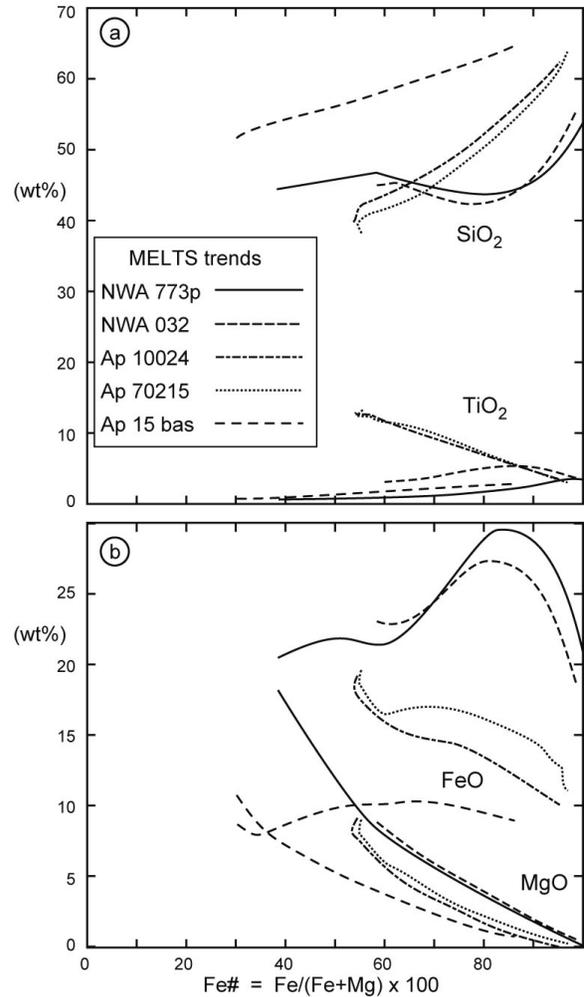


Fig. 2. Model compositional evolution of lunar basalts by fractional crystallization for wt% SiO₂ and TiO₂ (a), and FeO and MgO (b) vs. Fe#.

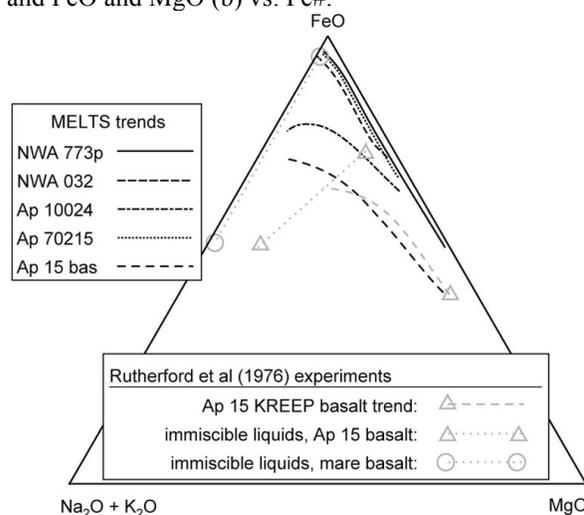


Fig. 3. Model fractional crystallization trends of lunar basalts in AFM components. The three trend lines close to the FeO-MgO join are slightly offset.