PETROLOGY OF A VERY-LOW TITANIUM BASALT (OR PICRITE) CLAST IN LUNAR HIGHLAND REGOLITH BRECCIA 15295.

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Introduction: Very low Ti (VLT) mare basalts (TiO_2 <1.5 wt%) were first recognized in Apollo 17 and Luna 24 drill cores [1,2], and have been identified in other Apollo samples [3,4] and lunar meteorites [5,6]. These basalts may be related to VLT basaltic glasses that have been identified at every lunar sample locality and that are especially abundant at the Apollo 14 and 15 sites [7]. In this study, we describe a holocrystalline clast in regolith breccia 15295 that is mineralogically similar to VLT mare basalt but has a bulk composition like those of Apollo green (picritic) glasses.

Samples and Methods: Thin section 15295,100 contains a ~6 mm^2 igneous clast broken into 7 fragments. We obtained BSE imagery and chemical cartography of the whole thin section using the JEOL JSM6500 FEG-SEM at JSC (15kV, 900pA). Phase compositions were obtained on the 7 fragments of the clast using the Cameca SX-100 EMPA at JSC (15kV, 10nA).

Petrography and chemistry: The clast has a medium-grained, holocrystalline texture (Fig. 1). Fragments are fractured, but the absence of crushing and optical randomization suggests that the clast did not undergo in-situ cataclasis. Mineral abundances, determined from point counting on BSE images, are 65.2vol% pyroxene, 16.4vol% olivine, 16.4vol% plagioclase, 1.3vol% spinel, and 0.7vol% ilmenite. Accessory phases are Fe-Ni and Fe metal, schreibersite, K-spar, Ca-phosphate, and silica.

Pyroxene grains exceed 1.5 mm in subhedral to anhedral crystals. Neither strong cleavage nor twinning was observed. *Olivine* occurs as smaller (to 0.5 mm) equant to slightly elongated crystals displaying subhedral to anhedral shapes. It is in contact with or enclosed by pyroxene. *Plagioclase* occurs as lathy (to 0.5 mm long) crystals and mosaic masses of smaller anhedral crystals conforming to the adjacent crystal margins of olivine and pyroxene. It may be enclosed by pyroxene, but never by olivine. Twinning is visible in every crystal. *Chromite spinel* grains (to 150 µm) are found within pyroxene, olivine, and plagioclase, and along grain boundaries. Spinel grains are mostly anhedral, though euhedral grains were found in olivine. *Ilmenite* occurs rarely as small (to 50 µm), anhedral inclusions in pyroxene and plagioclase; and mainly as larger (to 200 µm), irregular masses along grain boundaries where it may be in contact with spinel. *Metal* and *schreibersite* occur as small (to 25 and 50 µm, respectively), irregular grains within pyroxene and plagioclase, and along grain boundaries where they may be in contact with each other, spinel, and ilmenite. *K-spar* (to 100 µm), *Ca-phosphate* (to 20 µm), and *silica* (to 100 µm) comprise residual pockets enclosed within the framework of major minerals. Grains of troilite and ilmenite may also occur in the residual pockets. We identified *melt inclusions* in both olivine and pyroxene.

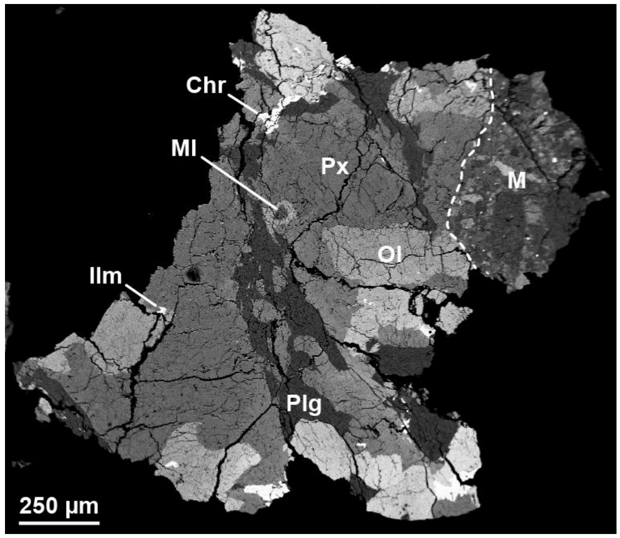

Fig. 1. BSE image of the rock fragment in 15295,100. Note the chemical zoning (BSE brightness) in pyroxene and olivine. Px = Pyroxene; Ol = Olivine; Plg = Plagioclase; Chr = Chromite; Ilm = Ilmenite; M = Matrix; MI = Melt inclusion.

The clast's minerals are all chemically heterogeneous, and pyroxene, olivine, and plagioclase are zoned. Pyroxene is mostly pigeonite ($En_{43-62}Fs_{28-44}Wo_{8-17}$) with exsolutions of augite ($En_{37-50}Fs_{19-38}Wo_{22-39}$), and individual augite crystals may be present (Fig. 2); Mg# = 49-70, Al_2O_3 = 0.78-2.82wt%, TiO_2 = 0.31-1.36wt%, Cr_2O_3 = 0.30-1.09wt%, MnO = 0.21-0.47wt%. Olivine ranges from Fo_{40} to Fo_{62}, with a maximum observed zonation of 5 Mg# units; MnO = 0.31-0.46wt%, CaO = 0.26-0.39wt%, Al_2O_3 = 0-0.34wt%, Cr_2O_3 = 0.08-0.23wt%. Plagioclase crystals are An_{88-92} with minimal Or content; Mg# = 36-48, FeO = 0.44-0.91wt%, MgO = 0.16-0.34wt%, TiO_2 = 0-0.14wt%. Spinel ranges from Ti-rich to Ti-poor chromite: $Cr_{29-69}Uvp_{4-58}Hc_{12-27}Mt_{0-2}$, Mg# = 5-17, MnO = 0.25-0.36 wt%. Ilmenite grains are $Ilm_{85-93}Gk_{7-15}$, with MgO = 1.86-

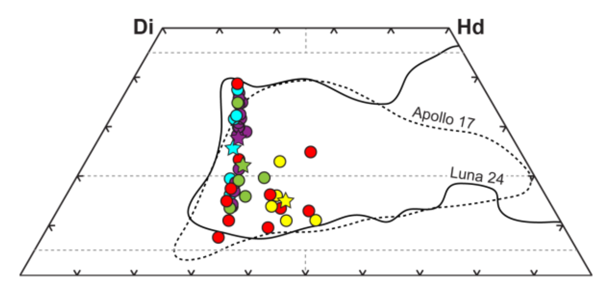

Fig. 2. Composition range of pyroxenes in clast 15295,100. Red circles = individual crystals; Yellow circles = single crystal at different locations; Blue, green, and purple circles = traverses through pyroxene grains; Stars = average compositions. Apollo 17 and Luna 24 VLT basalts fields from [9] and [10].

Table 1. Mineral and bulk rock compositions of clast 15295,100. Bulk rock calculated from modal abundances, densities, and average compositions of the component minerals. Also shown an Apollo 14 green glass composition for comparison.

	Px	Ol	Plg	Sp	Ilm	BR	GG
SiO_2	51.25	35.23	46.63	bdl	bdl	46.5	44.65
TiO_2	0.85	0.03	0.08	17.69	52.92	1.4	1.34
Al_2O_3	1.83	0.05	32.23	6.82	0.10	5.7	6.92
Cr_2O_3	0.63	0.11	bdl	26.02	0.60	0.9	0.63
FeO	19.13	40.02	0.65	44.44	41.75	20.8	22.16
MnO	0.35	0.39	bdl	0.30	0.46	0.3	0.15
MgO	16.86	23.91	0.26	2.41	2.90	15.4	15.91
CaO	8.90	0.32	17.74	0.02	0.08	8.4	8.15
Na_2O	bdl	bdl	1.16	bdl	bdl	0.2	0.27
K_2O	bdl	bdl	0.04	bdl	bdl	0.0	0.00
Total	99.78	100.07	98.79	97.70	98.81	99.6	100.18

Px = Pyroxene; Ol = Olivine; Plg = Plagioclase; Sp = Spinel; Ilm = Ilmenite; BR = Calculated Bulk Rock; GG = Green Glass A14 Green A, Table 1 from [17]; bdl = below detection limit.

3.94wt%, Cr_2O_3 = 0.58-62wt%, and MnO = 0.40-0.51wt%. Mineral and calculated bulk rock compositions are given in Table 1.

Petrogenesis: The texture of 15295,100 suggests the following crystallization sequence: olivine, pyroxene, plagioclase and residual K-spar, Ca-phosphate, and silica. Plagioclase tends to occur in the interstices between mafic minerals, suggesting that it crystallized mainly after olivine and pyroxene. This interpretation is also supported by the low Ti/Al ratios in pyroxene (Fig. 3) [11]. Chromite formed throughout the crystallization process. Ilmenite, troilite and metal postdate olivine crystallization.

The granular to slightly elongated texture of olivine suggest that they grew at cooling rates slower than ~5°C/hr, as faster cooling rates would produce more elongated, hopper crystals [12]. The presence of exsolution lamellae of augite from pigeonite suggests slow, subsolidus annealing.

Crystallization at the base of a thick magma pile appears to be a viable model for the formation of 15295,100.

Origin of clast 15295,100: The mineralogy of 15295,100 places it in the mare basalt clan. Evidence in favor of mare basalt origin includes the non-uniform chemical compositions of minerals, the minor element relationship

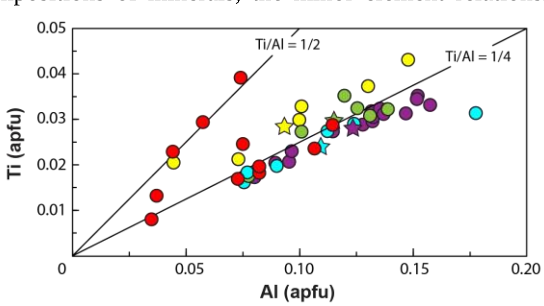

Fig. 3. Ti and Al concentrations in pyroxenes from clast 15295,100. The atoms per formula unit (apfu) is based on 4 cations. Ti/Al values near 1/4 are associated with crystallization prior to feldspar; Ti/Al values near 1/2 are interpreted as co-crystallization with feldspar [13]. Same symbols as in Fig. 2.

in pyroxenes (see below), and the high Fe content of the plagioclase.

The very low ilmenite content of clast 15295,100 and the low Ti content of its pyroxenes suggest an affinity with VLT mare basalts. Molar Ti/(Ti/Cr) as a function of molar Fe/(Fe+Mg) in pyroxene is a good discriminant for VLT basalt [14]; pyroxenes of 15295,100 plot in the field of Luna 24 VLT basalt (Fig. 4), further suggesting a VLT mare basalt origin. Furthermore, the limited range of plagioclase composition in 15295,100 is also a characteristic of VLT basalts, particularly Apollo 17 VLT's [15].

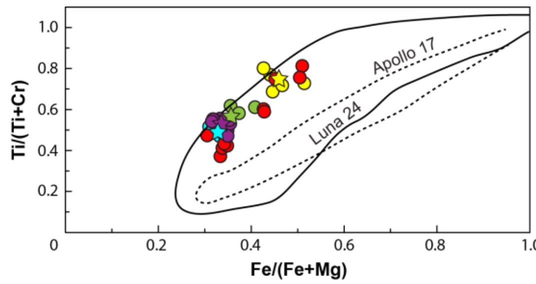

Fig. 4. Molar Ti/(Ti+Cr) *vs.* molar Fe/(Fe/Mg) for pyroxenes from clast 15295,100. Apollo 17 and Luna 24 VLT basalts fields from [14]. Same symbols as in Fig. 2.

Clast 15295,100 is, however, compositionally and texturally different from VLT basalts. The latter have extremely Fe-rich pyroxenes that are missing from 15295,100 (although the detailed chemical trend may not be identical because the cooling rate and the bulk chemical composition may influence the trend, and sampling may also be an issue). The observed VLT basalts are generally fine-grained, and show vitrophyric to (sub)ophitic textures [1,16]; 15295,100 has a much coarse-grained, slowly cooled texture.

It is notable that the bulk chemistry of 15295,100 presented here, although a rough estimate considering the small size and medium-grained texture of the clast, corresponds to VLT green glass compositions [17]. In addition, the Mg# of 15295,100 (57) is in the range of those of VLT picritic glasses (55 to 67, [17]). Further data are needed to test the origin of 15295,100, but this and a similar clast in 15146,1 [8] may indicate that a crystallized flow of picritic lava with a bulk composition like that of Apollo 14 green glasses exists at the surface of the Moon.

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