

14160,214: A KREEPy ENDOGENOUS BASALT. EVIDENCE FOR MAGMA CHAMBER PROCESSES

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Introduction: The lunar “KREEP” component is hypothesized to have been produced by the crystallization of the Lunar Magma Ocean (LMO) and represents the last ~0.5% of liquid. It is represented in the lunar sample collection as basaltic materials and plutonic rocks. KREEPy basaltic rocks fall into 2 categories: endogenous melts of the lunar interior and melts induced by meteoroid impacts. Differentiation between these two basalt types has proven to be difficult. Quantifying the abundances of Highly Siderophile Elements (HSEs) is the usual method used for classification, as impact melts are enriched in HSEs when compared to other lunar materials (e.g., [1]). Such analyses require the destruction of a relatively large amount of sample, which is often not possible for small, valuable KREEP samples. Qualitative petrographic methods have also been used to differentiate the two hypotheses for KREEP basalt formation, such as [2], although this method is not without error [3].

Noting the high HSE content, (14310 in particular) led [4] and others to conclude that Apollo 14 KREEPy basalts were generated by impact-induced melting. The impact melts are best represented by two end members; a KREEP- and ilmenite-rich end member, likely the remnants of the LMO, and a low-Ti, high-Al highlands component [4-6]. In this paper we challenge the assumption that all Apollo 14 KREEP basalts are of impact origin, based upon new

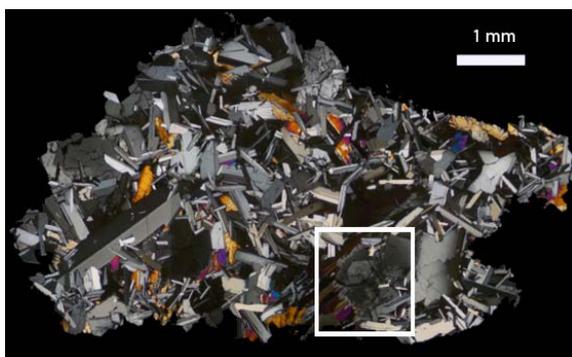


Fig. 1. Photomicrograph of 14160,214.

detailed observations of Apollo 14 KREEP samples, at least one of which contains signs of a complex igneous differentiation process.

It has been hypothesized that relatively high radioactive element abundances in the Procellarum KREEP Terrain (PKT) would enable long-lived volcanism on the Moon [7] with eruptions being more

recent than indicated by the Apollo samples and lunar meteorites [8]. The Discovery of 'recent' (<100 Ma) lunar volcanism in and around the PKT by Braden et al. [9] supports this.

Sample: 14160 is a bulk soil sample comprised of 4-10 mm coarse fine collected from a small crater near the Apollo 14 Lunar Module. 14160,214 is typical of KREEP basalts, being relatively small (7x4 mm). Pigeonite and plagioclase form the larger mineral phases, while smaller plagioclase, glass, and ilmenite form the groundmass (**Error! Reference source not found.**).

Methods: Electron Probe Micro-Analysis (EPMA) was carried out at Washington University in St. Louis using a JEOL JXA-8200 electron microprobe to quantify mineral compositions and zonation. Acceleration voltage was set to 15kv, beam current was 25nA and spot size varied between 3µm and 5µm (spot size was reduced do to size constraints). Four phases were studied: plagioclase, pyroxene ilmenite, and K-feldspar. A total of 53 points were analyzed using EPMA. Element maps were also constructed in addition to spot analyses

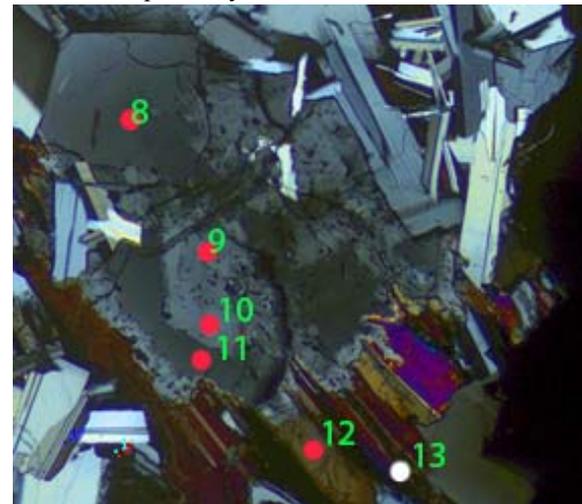


Fig. 1: close up of a pyroxene exhibiting several cycles of resorption and overgrowth. Green numbers are EPMA spots. Red Circles are LA-ICP-MS and EPMA locations. See white box in fig 1 for location.

Trace element spot analyses were conducted at the University of Notre Dame MITERAC lab using a Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA-ICP-MS). A UP213 laser system was used in conjunction with a Thermo Scientific Element 2 high resolution ICP-MS. A spot size of 55 µm, fluence of 10 to 11 J/cm², and a frequency of 5 Hz

was used. The analyses gathered background for 1 minute, 1 minute for analysis, followed by at least a 45 second washout time. Argon was used as the sample gas with a flow of 0.6 l/min and Helium was used as the carrier gas at 1.0 l/min. 17 sites were ablated (12 Pyroxene, 5 Plagioclase; Figs. 2 and 3).

Rare Earth Element (REE) partition coefficients for calculating pyroxene equilibrium liquids were calculated using the method of [10]. Partition coefficients for calculating plagioclase equilibrium liquids were determined using the method of [11] and [12]. Calculated plagioclase and pyroxene equilibrium liquids are shown in Figures 4 and 5, respectively.

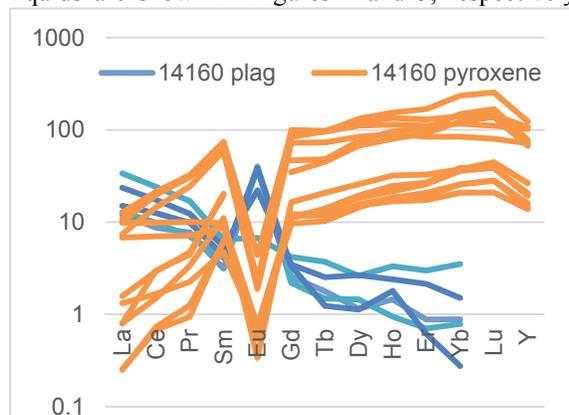


Fig. 2 Chondrite normalized pyroxene and plagioclase profiles. Chondrite values from [13]

The range of trace element compositions (Fig. 3) cannot be generated through simple closed-system crystal fractionation. Therefore, combined assimilation and fractional crystallization (AFC) was used to model the range of equilibrium liquids derived from 14160,214. The most primitive equilibrium liquid composition was used as the parent and High-K KREEP [14] as an assimilant (Fig. 5). Orthopyroxene, clinopyroxene, and plagioclase are the crystallizing phases.

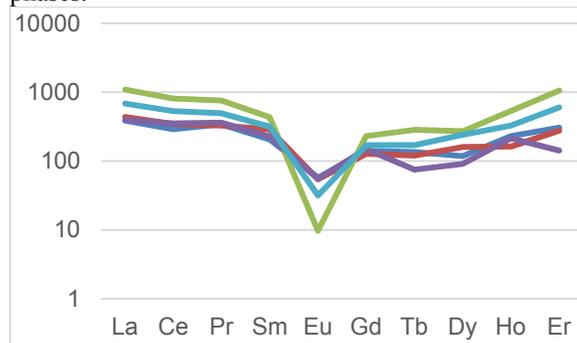


Fig. 3 Chondrite normalized equilibrium liquids of Plagioclase from 14160,214. Chondrite normalized. Values from [13]

Results: Several resorption and overgrowth events are recorded by the pyroxene highlighted in Figures 1

and 2. The cycles of resorption and growth are consistent with the pyroxene forming in a magma chamber, where pyroxene could come on and off the liquidus several times either through magma convection moving the crystal to areas where pyroxene is not on the liquidus. Alternatively, the magma chamber could have been periodically recharged. We interpret this texture as being inconsistent with a petrogenesis through impact melting.

Using AFC modeling, similar REE profiles can be made using calculated equilibrium liquids taken from 14160,214 (Fig. 5). Using a liquid composition relatively depleted in REE as the initial liquid fraction (F) (from analysis 8, Fig. 2) and the High-K KREEP assimilant (r value of .22) a relatively REE enriched pyroxene equilibrium liquids can be modeled successfully. 14160.214 is a fragment of an endogenous KREEP basalt as indicated by petrographic and chemical evidence.

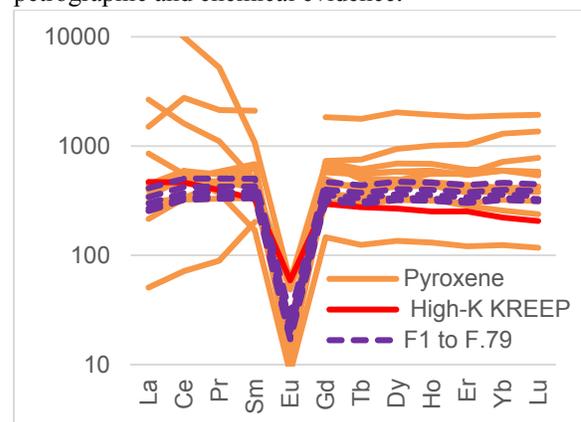


Fig. 5: Pyroxene equilibrium liquids (shown in Orange) orthopyroxene AFC model of the instantaneous solid form a (liquid) Fraction of 1 to .79 (in Purple). Chondrite normalized. Values from [13]

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