MODERATELY VOLATILE ELEMENT CONTENT OF APOLLO 17 SOIL SAMPLE 74220 ORANGE GLASS BEADS; INSIGHTS INTO THE MOON'S INTERIOR.

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Introduction: The Giant Impact theory is the predominant model applied to the formation of the Moon. This model dictates that a Mars sized planetesimal obliquely collided with the very early, yet already differentiated, Earth [1]. The material from this collision then coalesced and generated heat to ultimately form a partially or entirely molten Moon. The depth of the resulting lunar magma ocean (LMO) is not known, and ranges from the entire Moon to only the outer ~400-500 km (e.g., [2,3])., Modeling the crystallization of the LMO begins with olivine and pyroxene forming the first mantle cumulates, floatation of plagioclase forming the lunar crust, and the late stage Fe-rich (e.g., ilmenite, cpx) phases forming above the first mantle cumulates. The gravitational instability created by having dense ilmenite on top of Mg-rich phases caused some form of cumulate overturn resulting in mixing of unknown extent [4].

Lunar volcanism represented melted products from the lunar interior and these can give information regarding the mantle source regions. They are represented by two broad categories; crystalline mare basalts that erupted as lava flows that filled craters on the near side of the Moon, and pyroclastic glass beads that are the result of gas-driven fire-fountaining events. It has been shown that the outside of the glass contains a higher volatile content than the interior, likely the result of the volatiles driving the eruption condensing onto the outside of the bead as it cools [5]. The volcanic glass beads have been the most important for understanding the lunar interior for volatile content [6-8]. The Giant Impact produced conditions that would promote the melting and volatilization of material. The presence of gas-charged pyroclastic deposits shows that the Moon contains endogenous volatiles [5-8]. Except for degassing, the volcanic glass beads have been largely unmodified by post eruption events (relative to the crystalline mare basalts) and represent some of the most primitive samples of the lunar mantle that have been collected to date [9]. While both the mare basalts and the volcanic glass beads are sourced from the lunar mantle, the two have not been petrologically linked [10]. Experimental studies on the volcanic glasses indicate derivation from pressures in the region of 18-25 kbar (360-520 km), which may be, at least in part, below the cumulate lunar mantle formed from the LMO (e.g., [11-13]). Longhi [11] reported the pressures of multiple saturation for primitive mare basalts to be between 5 and 12.5 kbar (100-250 km). Even though multiple saturation pressures and temperatures of the basalts may have been conducted on evolved (i.e., nonprimary) compositions,

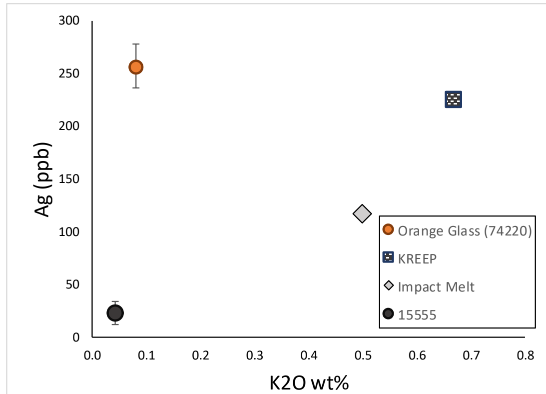

Figure 1: K2O vs Ag. A MVE vs a tracer of a possible KREEP (15386) component. The MVE is enriched to KREEPy concentrations, but almost no KREEP component is found.

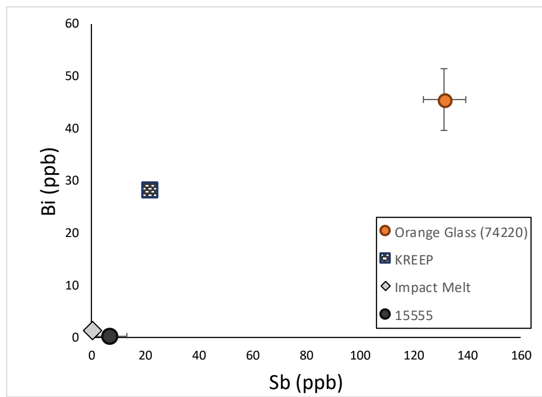

Figure 2: Sb vs Bi. Two MVEs that are essentially absent in the impact melt (14310), and both become enriched to above KREEPy concentrations in the orange

thus yielding a minimum depth, volatile contents and isotope ratios demonstrate the derivation of the mare basalts and volcanic glasses from compositionally distinct and separate sources (e.g., [14,15]).

We have quantified the moderately volatile elements (MVEs) present in the Apollo 17 orange pyroclastic glass beads from sample 74220. These beads have been shown to have volatile element enriched coatings that formed as condensation deposits as the magma was ejected into the lunar vacuum and cooled [5]. The MVEs of interest are those that have condensation temperatures between 350-1350K (Zn, Rb, Ag, Cd, In, Tl, Bi, Pb, and Sb). These provide further insights into the volatile content of the deep lunar interior. The analytical difficulties in quantifying these elements in geological samples have been overcome by using the method of [16].

Methods: Solution mode inductively coupled plasma mass spectrometry (ICP-MS) was used to measure the MVEs within 74220, an orange glass soil sample. Pristine orange glass beads were handpicked from 74220, rinsed in 18Ω MilliQ water in an ultrasonic bath for 10 mins to remove any surface coatings to give the degassed MVE content of the glass beads. The samples were digested using an HF-HNO_3 digestion and data reduction procedure as outlined in [16].

Results and Discussion: The three 74220 orange glass analyses are compared to four other lunar samples analyzed using the same method; KREEP sample 15386, impact melt 14310, and two daughter samples of the olivine basalt 15555 (,924 and ,1068). Averages of three analyses of 74220, and the two daughter samples of 15555 are shown.

74220 orange glass has been used to quantify the edogenous content of highly volatile elements [8]. It as been experimentally shown to have come from a deeper region of the Moon than the mare basalts [11,12]. This deep, possibly unprocessed mantle source region of the orange glass is a volatile-rich reservoir.

The assumption thast the MVEs will behave similarly to the highly volatile elements holds true in most cases (**Figs. 1 & 2**). However, for Rb & Tl the orange glass is depleted relative to KREEP and a KREEP-rich impact melt (14310), and have concentrations similar to mare basalts (**Figs. 3 & 4**). These two elements have condensation temperatures near both the high, and low end of the MVE spectrum (Rb = 800 K, Tl = 532 K), so their depletions relative to KREEP must be due to geochemical conditions separate from volatility. The fact that the orange glass is enriched in Ti is a possible line of evidence for a cumulate overturn incorporating shallower, late stage cumulates into earlier, deeper cumulates. Alternatively, an unprocessed mantle source melted and obtained the high-Ti (low Rb & Tl) signature via assimilation [13,17].

As KREEP is the final crystallizing dregs of the LMO, it should be the most enriched in incompatible elements such as the MVEs. The higher than KREEP concentrations in the orange glass indicates the incorporation of a reservoir that is distinct in volatile content from LMO crystallization models to form KREEP.

Summary: While most of these MVEs follow the trends of their incompatible highly volatile counterparts, two (Rb & Tl) do not. The calculated depth of formation and generally high volatile content indicate the source region for the orange glass is a deep (possibly sub-cumulate), volatile rich reservoir that has possibly undergone assimilation of Ti-rich late stage cumulates. It is evident that modeling of such processes will require understanding how MVEs partition beween melt and crystallizing phases. This work highlights the need for quantification of such partition coefficients.

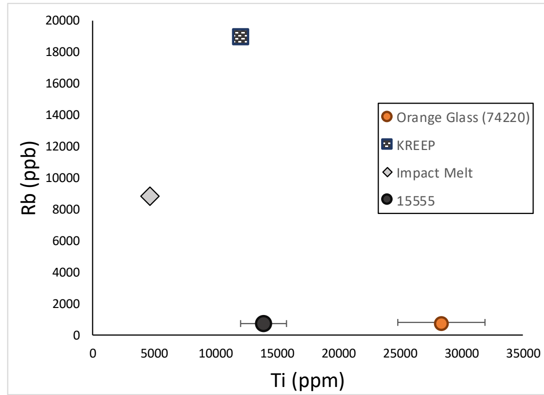

Figure 3: Ti vs. Rb. A tracer of a late stage cumulate component vs a MVE. While the orange glass is enriched in Ti, it is relatively depleted in Rb.

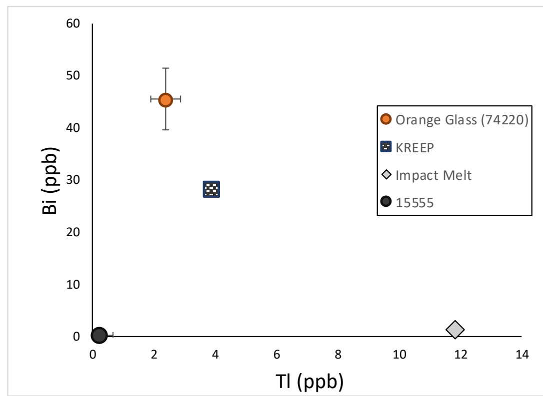

Figure 4: Tl vs. Bi. 74220 is enriched in Bi but not Tl relative to KREEP-rich lithologies.

References: [1] Hartmann W.K. & Davis D.R. (1975) *Icarus 24*, 504-515. [2] Hess P.C. & Parmentier E.M. (1995) *EPSL 134*, 501-514. [3] Warren P.H. (1985) *EPSL 13*, 201-240. [4] Spera F.J. (1992) *GCA 56*, 2253-2265. [5] Meyer C. et al. (1975) PLSC 6, 1673-1699. [6] Hauri E. et al. (2011) *Science 333*, 213-215. [7] McCubbin F. et al. (2015) *Amer. Mineral. 100*, 1668–1707. [8] Saal A. et al. (2008) *Nature 454*, 192-195. [9] Delano J.W. & Livi K. (1981) *GCA 45*, 2137-2145. [10] Delano J.W. (1986) *PLPSC 16 in JGR 91*, D201-D213. [11] Longhi J. (1992) *GCA 56*, 2235-2252. [12] Longhi J. (1993) *Lunar Planet. Sci. XXIV*, 895-896. [13] Neal C.R. (2001) *JGR 106*, 27865-27885. [14] Tatsumoto M. et al. (1973) *Science 180*, 1279-1283. [15] Tatsumoto M. et al. (1987) *PLPSC 17 in JGR 92*, E361-E371. [16] Burney D.C. et al. (2017) LPSC 48, #1068. [17] Wagner T.P. & Grove T.L. (1997) *GCA 61*, 1315-1327.