P-BEARING OLIVINES IN LUNAR ROCKS: A NEW VIEW ON LUNAR PHOSPHORUS.

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Introduction: Phosphorus is the only highly incompatible element, which has a higher partition coefficient in olivine relative to pyroxene [1-4]. Extremely rare P-rich olivines (3-8 wt.% P_2O_5) were described in some unusual terrestrial and extraterrestrial associations. Their appearance is favored by a set of several factors, such as: low oxygen fugacity, high phosphorous and low silica activities, but a rapid growth of olivine from P-rich liquids is considered as a major factor of this enrichment. [e.g. 3 and references therein]. P-bearing olivine (up to 0.4 wt. % P_2O_5) has been described in typical olivine-bearing rocks such as terrestrial peridotites, basalts, andesites, dacites [3] and martian shergottites [5].

Phosphorus is an important minor element of lunar rocks. A highly differentiated igneous melt may produce phosphate minerals, typically merrillite and apatite. Schreibersite has also been reported as a trace mineral in some highland rocks [6]. Until recently these phases were supposed to be the main P repositories. However, after the finding of P-bearing olivines in the Luna 20 site and Dhofar 961 lunar meteorite [7,8] this assessment should be revised.

Results: Olivine with variable modal composition is present in highland anorthositic-noritic-troctolitic rocks (ANT) and rare ultramafic rocks (dunite-pyroxenite). It is also a major mineral of deep-seated crustal rocks - spinel cataclasites. Most mare basalts contain traces or even significant amounts of olivine [e.g. 6]. However in typical KREEP basalts (containing up to 0.7 wt.% P_2O_5 [9]) olivine is rare, which is thought to be a result of P enrichment [10].

We analyzed olivine with focus on its P-contain from the lunar samples of Luna 16 and 20, Apollo 14 and in Dhofar 025, 961, 287 lunar meteorites. The extremely rare olivine grains contain up to 0.5 wt.% P_2O_5. P-bearing olivine occurs in form of mineral fragments in breccias and in igneous rocks as well [8]. P content may vary in a single grain from below detection limit to tenths of a percent.

Three types of P-bearing olivines were observed. 1) P-bearing olivine (Fo_{51-88}) is present in rock and mineral fragments of anorthositic-noritic (gabbro-noritic)-troctolitic composition, which are enriched in incompatible elements. They are observed in Luna 20 [8], Luna 16, Apollo 14 sites and Dhofar 961 lunar meteorite. 2) P-bearing fayalite (Fo_{2-4}) was found in the late-stage mesostasis of Dhofar 287A basalt and in the Luna 16 coarse-grained anorthite-fayalite-Fe-rich pyroxene-silica rock. 3) Two large zoned olivine grains (Fo_{68-95}) with oriented enstatite inclusions were found in the Dho 025, 961 meteorites [7].

Implications for Lunar Petrology and Geochemistry:

Olivine is a common liquidus phase in lunar magmas. Slow diffusion rate of P in silicate melts and crystals [11] makes it promising indicator of magmatic processes. Once appearing, P zoning cannot be easily obliterated by subsequent annealing and may be used for estimation of the T-t history of the host olivine [12].

According to the known values of olivine/melt partition coefficient for phosphorus $D_P^{ol/melt}$ [e.g. 4] P-bearing olivines should crystallize from P-rich melts, which are not common among lunar rocks. However, it has been experimentally shown that $D_P^{ol/melt}$ increases under reduced conditions that might indicate the presence of P^{3+} [2]. This raises the question about mechanisms of P incorporation into lunar olivines. Along with the importance of oxygen fugacity, evaporation processes may influence the P behavior as well [13].

The source(s) of the P-bearing olivine may be both Fe-rich residues after mare basalts crystallization and highland Mg-rich melts of ANT composition enriched in KREEP. The source of the olivine-enstatite objects (type 3) is not clear yet however could be either of meteoritic [14] or lunar origin [7].

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References: [1] Brunet F. and Chazot G. (2001) *Chem. Geology* 176: 51-72. [2] Mallmann G. and O'Neill H. St. C. (2009) *J. Pet., 50,* 1765-1794. [3] Millman-Barris M. S. et al. (2008) *Contrib. Min. Pet., 155*, 739-765. [4] Grant T. B. and Kohn S. C. (2013) *Am. Min., 98,* 1860-1869. [5] Shearer C. K. et al. (2013) *GCA, 120*, 17-38. [6] Heiken G. H. et al. (1991) *Lunar sourcebook*. [7] Demidova S. I. et al. (2015) *Petrology, 23, 116-126*. [8] Demidova S. I. et al. (2017) *LPSC 48th,* Abstract #1409. [9] Rhodes J. M. and Hubbard N. J. (1973) *Proc. LPSC 4th,* 1127–1148. [10] Toplis et al. M. J. (1994) *GCA, 58,* 797-810. [11] Spandler C. et al. (2007) *Nature, 447,* 303–306. [12] Watson E. B. (2015) *Am. Min., 100*, 2053-2065. [13] Yakovlev O. I. et al. (2006) *Geochem. International, 44,* 847-854. [14] Joy K. et al. (2012) *Science, 336,* 1426-1429.