

TRACE ABUNDANCES OF PHOSPHORUS (P) IN PRISTINE LUNAR GLASSES.

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Introduction: Phosphorus (P) is an important element in all discussions of lunar core formation and the origin of the Moon [e.g. 1-5]. Depending upon the oxygen fugacity and temperature during igneous processes, P behaves both as an incompatible lithophile element and as a moderately siderophile element. Newsom and Drake [1] found that under lunar conditions in the presence of a Fe-rich metal and mafic silicate melt, P has a metal/silicate melt partition coefficient of about 160. However, in the absence of a Fe, Ni-rich metallic phase, P behaves as an incompatible lithophile element [e.g. 6]. Among terrestrial basalts, P is known to correlate well with La [e.g. 1,2] and Nd [e.g. 3].

Disagreement exists concerning the P/La ratio in the silicate portion of the Moon. For example, Newsom [1,2] estimated a depletion factor for P relative to the Earth's mantle of 2-3, whereas Wänke and Dreibus [3] favor a value of <2. Although this disagreement among workers may appear small, it contributes to different conclusions about the Moon's origin [e.g. 1-5]. In an attempt to clarify the issues, P abundances have been measured by electron microprobe in eighteen varieties of mare volcanic (i.e. pristine) glasses [7]. Since these volcanic glasses appear to be primary magmas from the lunar mantle [e.g. 7,8], they may provide a better set of constraints on the P abundance in the Moon's silicate portion.

Analytical Techniques: A wavelength dispersive spectrometer with a PET crystal was used to collect the x-rays. The electron microprobe was operated at 20 keV acceleration potential and 250 nanoamps beam-current. Since a second-order K-beta peak for Ca overlaps the P K-alpha peak, it was necessary to count x-rays at four spectrometer positions (i.e. lower background, second-order Ca K-beta, P K-alpha, and upper background). Counting-times for each spectrometer position for each sample ranged from 200 seconds to 400 seconds. High-purity diopside was used to determine the exact magnitude of Ca interference at the P K-alpha peak position. Fused samples of USGS rock standards were used for calibration: W-1 (610 ppm P); BHVO-1 (1220 ppm P); AGV-1 (2140 ppm P). Reproducibility of replicate analyses on lunar glasses was typically ± 20 ppm. From two to ten spherules were analyzed for each of the 18 groups of volcanic glass.

Results: The data collected in this study (Table) display a good correlation with La (Figure). The abundances of La in the pristine lunar glasses are from other investigations [9-14]. For comparison, data for crystalline mare basalts and highlands rocks are also plotted [15-20]. For a chondritic P/La = 5150 [21], the line of constant P/La = 36, as shown in the Figure, represents a depletion of P relative to La by about a factor of 140, as concluded by [1,2].

Wänke and Dreibus [3] proposed that the linear trend among most lunar samples was actually a mixing line with KREEP, and that care was required in interpreting these data. Wänke and Dreibus [3] also noted that there appeared to be no clear correlation between P and La among the crystalline mare basalts, but that the low-Ti basalts had higher P/La ratios than the high-Ti basalts. They [3] concluded that the depletion of P indicated by the low-Ti basalts was within a factor of 2 of the value in the Earth's upper mantle.

The data acquired in the present study on the pristine mare glasses support the views of Wänke and Dreibus [3]. The low-Ti (<4 wt.% TiO₂) pristine glasses all plot above the line of P/La = 36 in the Figure, whereas the high-Ti (>8 wt.% TiO₂) pristine glasses plot below the line. Consequently, the depletion-factors for P in the silicate portion of the Moon relative to the Earth's upper mantle are <2 (low-Ti glasses) and 5 (high-Ti glasses). In fact, the Apollo 15 green glasses, which are the most chemically primitive samples yet known on the Moon, have P/La ratios that overlap the terrestrial value. However, additional data needs to be acquired on the Apollo 15 green glasses by analytical techniques having greater accuracies than the present study. The P and La abundances among the low-Ti and high-Ti pristine glasses show strong correlations. A correlation is not, however, evident among the crystalline

mare basalts due to the relatively small range of abundances for P and La in those samples [3].

Conclusions: The present data support the views of Wänke and Dreibus [3]. The low-Ti volcanic glasses display P depletions that differ from those of high-Ti glasses by a factor 2. If the low-Ti volcanic glasses are assumed to provide a better sampling of the Moon than the high-Ti glasses, then the depletion-factor for P in the lunar mantle is within a factor of 2 of the Earth's upper mantle [3-5]. Since the Apollo 15 green glasses are of particular importance, additional analyses for P having higher accuracies than the present study should be performed.

REFERENCES: [1] Newsom and Drake (1983) GCA, 47, p. 93-100. [2] Newsom (1986) Origin of the Moon, p. 203-229. [3] Wänke and Dreibus (1986) Origin of the Moon, p. 649-672. [4] Ringwood (1986) Origin of the Moon, p. 673-698. [5] Ringwood (1989) Origin of the Earth, p. 101-134. [6] Watson (1980) EPSL, 51, p. 322-335. [7] Delano (1986) PLPSC 16, p. D201-D213. [8] Longhi (1987) PLPSC 17, p. E349-E360. [9] Hughes et al. (1988) GCA, 52, p. 2379-2391. [10] Hughes et al. (1989) PLPSC 19, p. 175-188. [11] Hughes et al. (1990) PLPSC 20, p. 127-138. [12] Galbreath et al. (1990) GCA, 54, p. 2565-2575. [13] Shearer et al. (1990) GCA, 54, p. 851-867. [14] Shearer et al. (1990) EPSL, in press. [15] Palme et al. (1978) PLPSC 9, p. 25-57. [16] Wänke et al. (1973) PLSC 4, p. 1461-1481. [17] Wänke et al. (1974) PLSC 5, p. 1307-1335. [18] Wänke et al. (1975) PLSC 6, p. 1313-1340. [19] Wänke et al. (1976) PLSC 7, p. 3479-3499. [20] Wänke et al. (1977) PLSC 8, p. 2191-2213. [21] Anders and Ebihara (1982) GCA, 46, p. 2363-2380.

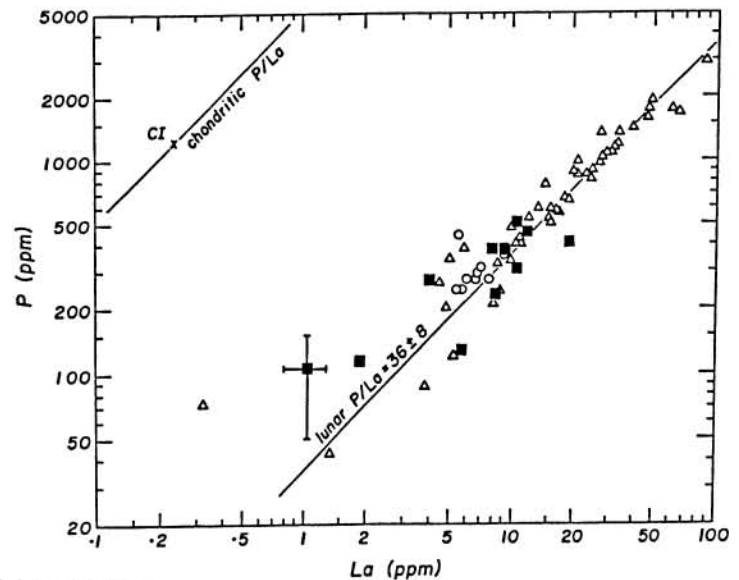


Table. Phosphorus abundances (ppm) in 18 varieties of pristine mare glasses

GROUP*	P (ppm)
Apollo 15 green A	100
Apollo 15 green B	115
Apollo 15 green C	75
Apollo 15 green D	120
Apollo 15 green E	120
Apollo 11 green	120
Apollo 14 green A	375
Apollo 14 green B	275
Apollo 14 yellow	525
Apollo 11 orange	130
Apollo 14 orange	(400 ± 50)
Apollo 17 orange	125
Apollo 14 red/black	230
Apollo 17 VLT	115
Apollo 14 VLT	450
Apollo 15 yellow/brown	375
Apollo 15 red	(350 ± 50)

PRISTINE GLASSES ■
MARE BASALTS ○
Other lunar samples △

Data for "mare basalts" and "other lunar samples" are from [15-20]. Data for pristine glasses are from the present investigation.

*Major-element compositions are listed in Delano [7].