Elemental partitioning between olivine and lunar basalts

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Element partitioning between olivine and melt has been used as geothermometer, geohygrometer, geobarometer, and in geochemical models as well. However, there are still no systematic data tailored to lunar basalts. In this study, element partitioning was investigated between the host mineral olivine and melt inclusion from lunar mare basalts. Partition coefficient for most elements are in similar range as terrestrial basalts except for V and Cr. The data may help improve our understanding of lunar basalt evolution.

1. Sample selection

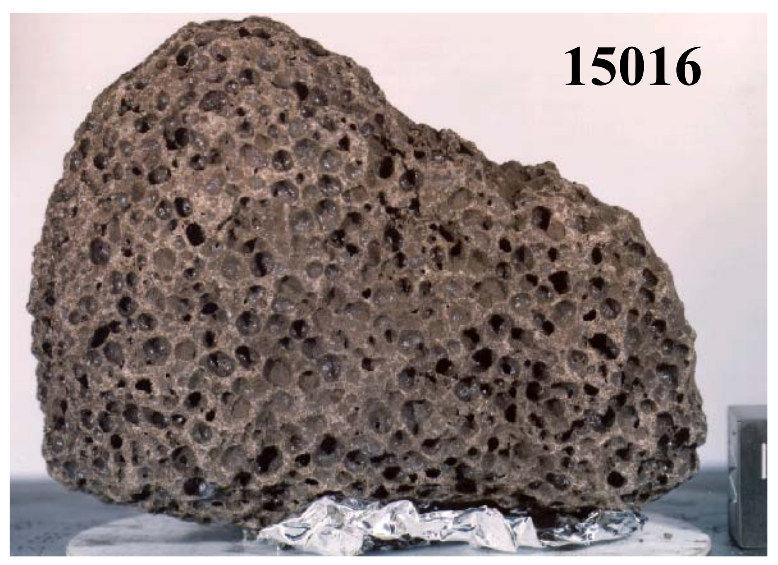

Fig. 1. Photograph of vesicular basalt 15016 (Lunar sample compendium*)*

39 olivine crystals with melt inclusion inside were picked up

- 74220 (10): from Apollo 17, soil
- 15016 (6): from Apollo 15, basalt
- 15647 (3): from Apollo 15, basalt
- 12040 (14): from Apollo 12, basalt
- 74235 (6): from Apollo 17, basalt

- If melt inclusions are glassy/partially glassy, polish directly to expose melt inclusion
- If melt inclusions are crystalline: heated to 1453 - 1603 K for 2 mins to homogenize, then polish to expose melt inclusion (Fig. 2)

2. Analytical methods

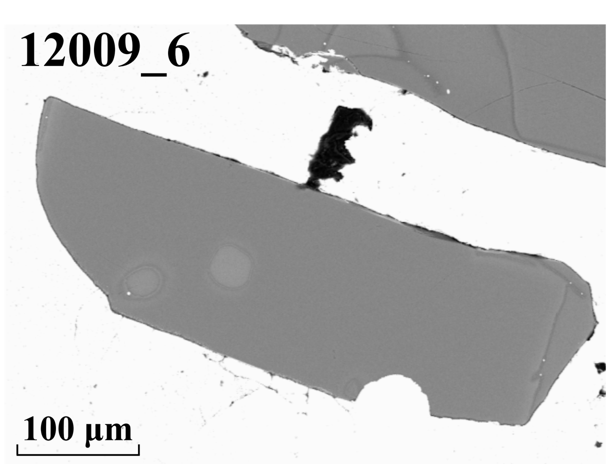

Fig. 2. SEM image of a olivine crystal with two homogenized melt inclusions.

Both major and trace element concentrations in olivine and melt inclusion are measured.

- Major element: Electron Microprobe Probe Analysis
- Trace elements in melt inclusion: SIMS GOR128-G and GOR132-G for calibration, two NIST standards and KL-2 were measured to monitor data quality
- Trace elements in olivine: LA-ICP-MS NIST 610, 612 and 614 for calibration San Carlos olivine and two MPI-DING standard to monitor data

Partition coefficient of an element is defined as the concentration ratio in two phases when in equilibrium.

$$D = C_{olivine}/C_{melt}$$

3. Equilibrium determination

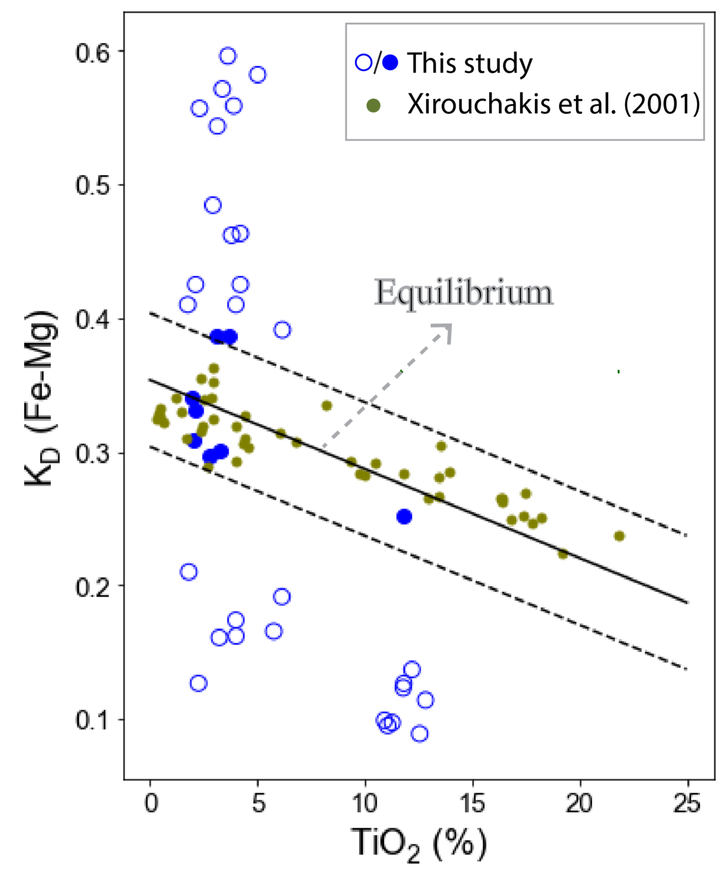

Fig. 3. Equilibrium determination based on exchange coefficient of Mg-Fe in olivine and melt. Solid line is the estimated equilibrium equation in Xirouchakis et al. (2001). Measurements within the two dashed lines are assumed to be in equilibrium.

Fe^{2+}-Mg exchange coefficient (K_D) in olivine and silicate melt is used to assess whether rough equilibrium is reached. Only samples in Fe-Mg equilibrium are used for our partition study.

$$K_D = \frac{(Fe/Mg)_{olivine}}{(Fe/Mg)_{melt}}$$

4. Results and discussion

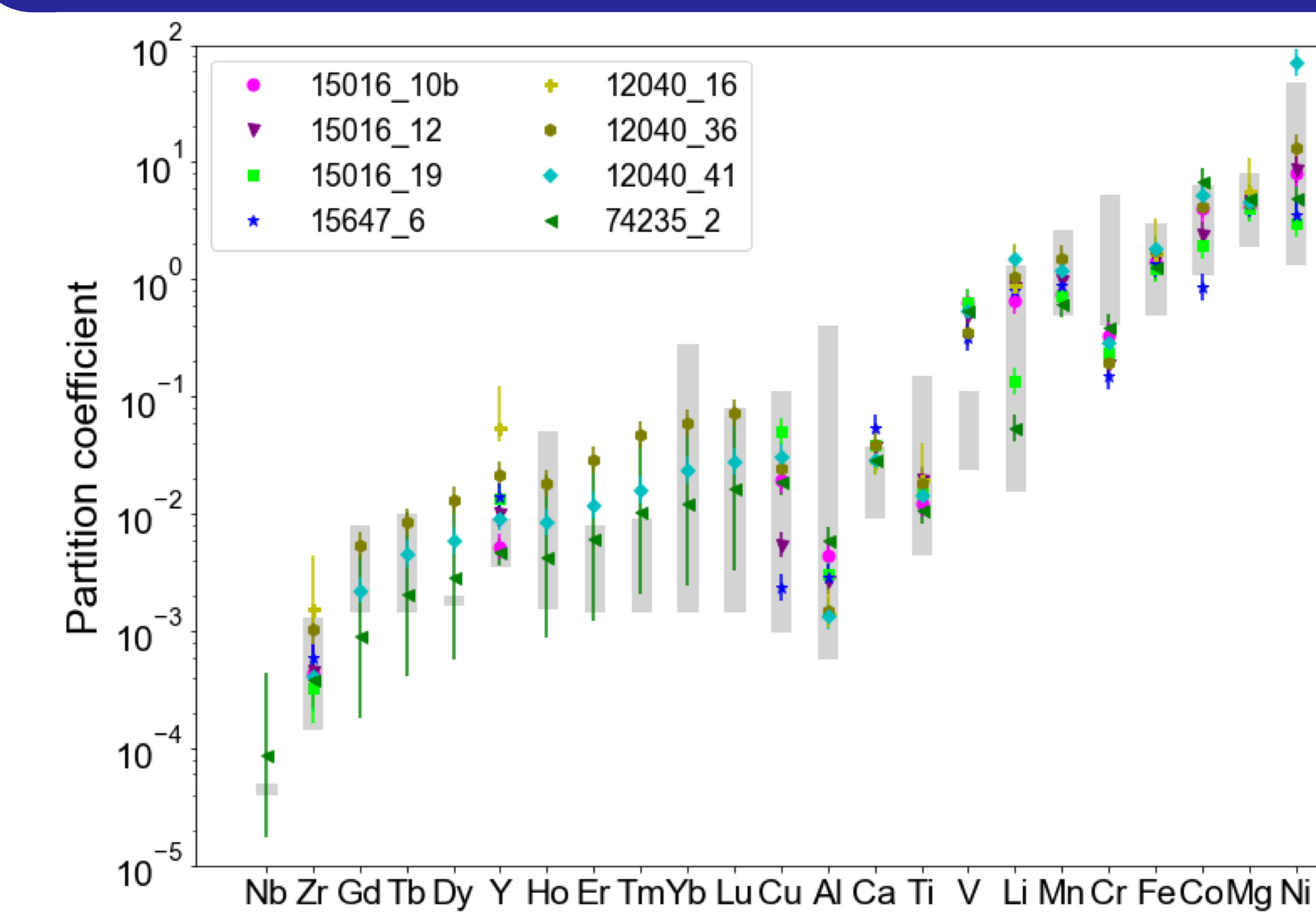

Fig. 4. Partition coefficient for samples that are considered to be in rough equilibrium. Grey bar for each element represents literature data for terrestrial samples.

Equilibrium partition coefficients of 23 elements (Li, Mg, Al, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Y, Zr, Nb, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu) were successfully measured.

- Most data fall into the range of terrestrial samples, except V and Cr
- Al: Al partitioning was reported to increase significantly with melting depth, which may explain the relative low D(Al) data in lunar samples.
- V: Vanadium partitioning in lunar samples are higher than terrestrial samples, which can be explained by reduced oxidation state of Moon than Earth's mantle, resulting in more V^{2+} in lunar rocks. The data indicate ~4% of V is V^{2+} based on Mallmann and O'Neill (2009) (Fig. 5).
- Cr: Lunar samples show slightly lower partition coefficient than terrestrial samples. Cr partitioning between olivine and melt has been shown to be independent of fO_2. The lower partition coefficient in lunar basalt may be due to difference in melt composition.

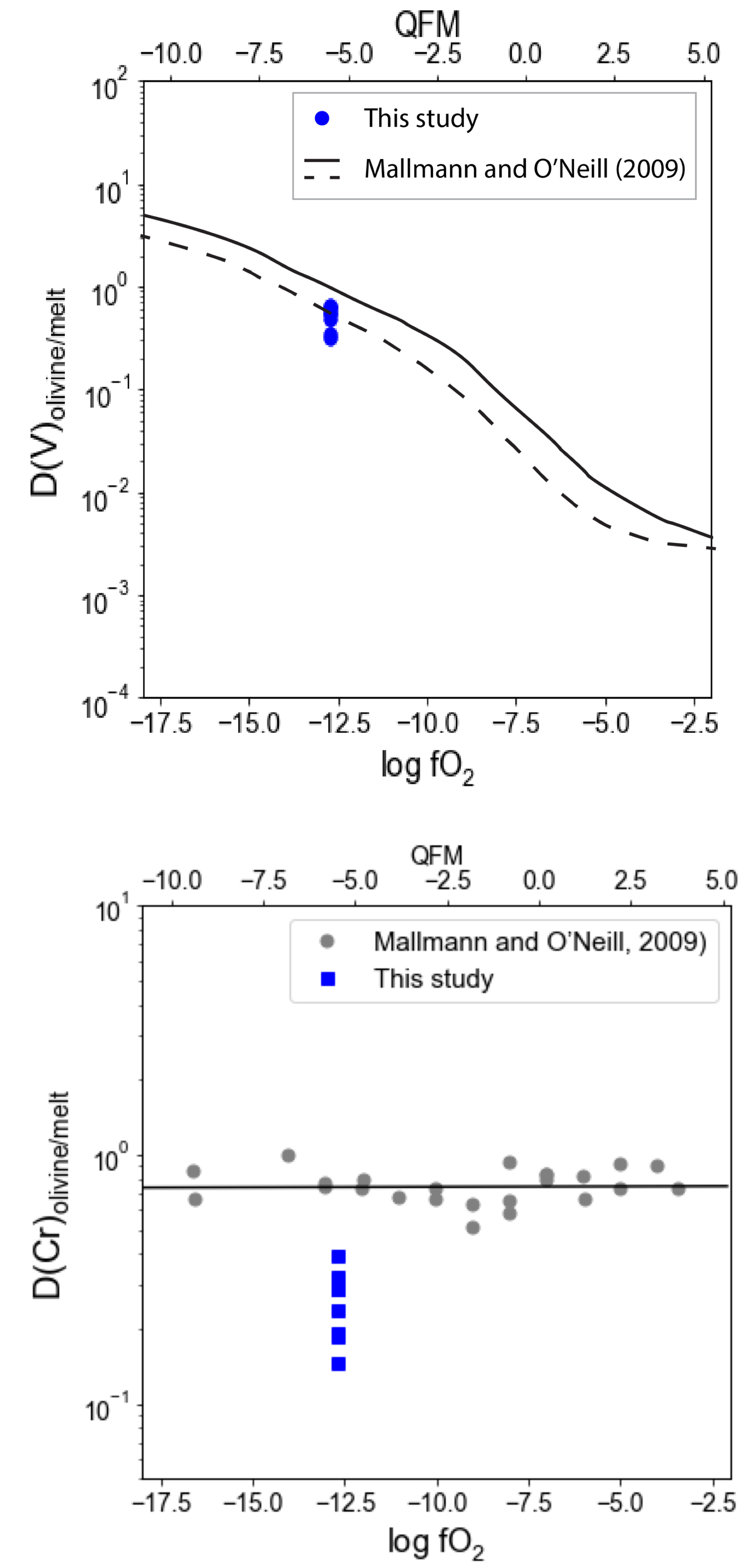

Fig. 5 Vanadium and chromium partitioning behavior between olivine and melt with increasing oxygen fugacity (revised from Mallmann and O'Neill, 2009). Colored points are samples in this study, and others are from the literature.

5. Conclusions

Partition coefficients between olivine and basaltic melt for lunar samples are estimated for 23 elements. Most of the data are in agreement with those in terrestrial basalts despite the large differences in basalt composition and oxygen fugacity, except for partition coefficients of V and Cr. Higher V partition coefficients in lunar basalts can be readily explained by the lower oxidation state of lunar compared to terrestrial basalts, however, the lower partition coefficients of Cr cannot be readily explained. The partition coefficients determined during this study can be applied to model lunar magma evolution, to infer melt composition from olivine composition, and to model partial melting of the lunar mantle.

References:

[1] Xirouchakis, Hirschmann, and Simpson, (2001) GCA, 65, 2201-2217.

[2] Mallmann and O'Neill, (2009) J. Petrol, 50, 1765-1794.