COMPARATIVE PLANETARY MINERALOGY: CO, NI SYSTEMATICS IN CHROMITE FROM PLANETARY BASALTS

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Introduction: Spinel is a minor but important phase in planetary basalts because its variable composition often reflects basalt petrogenesis. For example, complicated zoning trends in spinel can give clues to melt evolution [1], and V concentrations in chromite lend insight into magma oxygen fugacity (fO_2) conditions [2]. Nickel and Co are two elements that are commonly used as a measure of melt fractionation, and their partitioning between olivine and melt is fairly well understood. Less clear is their partitioning into spinel, although [3] has explored Ni and Co systematics in experimental charges. This study documents Ni and Co behavior in early crystallizing spinel (chromite) from several planetary basalts in an attempt to compare our results with [3], and also gain insight into basalt evolution on the three planets.

Samples: The samples used in this study are basalts containing chromite from the Earth, Moon, and Mars. Terrestrial samples include a glassy ocean floor basalt, an Ankaramite from Mauna Kea, HI, and basaltic glasses from both the Makaopuhi lava lake, and Kilauea Iki, HI. Lunar samples are from Apollo 12 and 15: samples 12020 and 12075 are Olivine basalts, 12063 is an Ilmenite basalt, and 15595 is a Pigeonite basalt. The martian sample is EETA 79001 (lithology B), a basaltic shergottite.

Analytical Methods: Chromium-rich spinel grains from the basalts were first identified by energy dispersive spectrometry and back-scattered electron imaging. Textural relationships between chromite and olivine were also documented in order to assess the crystallization sequence of early phases. Chromite grains were then analyzed on a JEOL JXA 8200 electron microprobe (EMP) to determine their major and minor element compositions. The cores of these grains, as defined by high Cr_2O_3 and low TiO_2 and FeO contents, were then analyzed by SIMS.

Trace element intensities were measured in the spinel grains using the Cameca ims 4f ion microprobe at the Institute of Meteoritics. Analyses were made using a primary beam of O^- ions accelerated through a nominal potential of 10 kV. A primary beam current of 10 nA yielded a beam size of ~10 µm. Sputtered secondary ions were energy filtered using an offset voltage of 105 V and an energy window of ± 50 V in order to reduce isobaric interferences. Repeated cycles of peak counting on ^{51}V, ^{56}Fe, ^{59}Co, and ^{60}Ni, yielded intensities that were normalized using the relationships of trace element/ ^{56}Fe ratios (normalized to known spinel FeO content). Normalized intensities were then related to absolute concentration using a set of spinel standards with 13 to 14 wt% FeO. Vanadium was also measured by EMP, and concentrations determined by EMP and SIMS show a very near 1:1 correlation.

Results and Discussion: Figures 1 and 2 show the concentration of Ni and Co in planetary chromite grains plotted against V chromite / V rock. Here we used the measured V in the chromite with literature values of V in the rock, and we call this value V*. We note that V* is not necessarily a true partition coefficient (*D*-value) as several of our basalt samples are not melts, but cumulates. The V* values serve to separate the three planetary bodies and also illustrate the fO_2 dependence of V partitioning into chromite [4]. For example, at the relatively high fO_2 conditions on Earth (IW+4), $V^{4+} > V^{3+}$, and thus V* is < 10. Conversely, at the low fO_2 conditions on the Moon (IW-1), $V^{3+} > V^{4+}$, and thus V* is > 30, as V^{3+} is more compatible in chromite than V^{4+}. Martian fO_2 conditions are ~IW+2, $V^{4+} \approx V^{3+}$, and thus V* is ~20. Figure 1 shows that Ni is highly enriched in terrestrial chromite compared with chromite from Mars and Moon (note log scale). Several studies have concluded that the mantle of the Moon is depleted in Ni by a factor of 3-4 compared with the terrestrial mantle [e.g. 5]. The depletion of Ni in the lunar mantle is also reflected in lunar olivine [6], and now we see these depletions in lunar chromite. Martian chromite contains higher Ni than lunar chromite; this is puzzling as Ni in the martian mantle is predicted to be half that of the lunar mantle [7]. The same systematics are seen for Co in chromite (Fig. 2), although with smaller differences. Mantle values for Co are highest in the Earth, with Mars and Moon being very similar.

Figure 3 shows the measured Ni in the chromite grains normalized to literature values for Ni in the bulk rock to give Ni* values for chromite from the three planets. The terrestrial Ni* values cluster around 6-15, martian values around 7, and the lunar values are < 2. The terrestrial values are similar to those determined by [3] and approach "real" *D*-values as these rocks are glasses and approach true melts. The martian Ni* values are slightly lower than the terrestrial values, while the lunar Ni* values are significantly lower. Work by [8] suggests that Ni and Co partitioning are not affected by fO_2, but do show an increase in *D* with increasing Mg content of spinel. We believe in this case that the low lunar Ni* values reflect the sequence of crystallization in mare

basalts. On Earth as compared with the Moon, relatively high fO_2 leads to low Cr in basaltic melts, but high Cr^{3+} / Cr^{2+} (Fig. 3). The high activity of Cr^{3+} in terrestrial melts leads to the early crystallization of chromite (prior to olivine) and D-values for Ni into this chromite range from 6-15. Low fO_2 on the Moon leads to high Cr in basaltic melts, but low Cr^{3+} / Cr^{2+}. Consequently, lunar olivine crystallizes slightly before chromite, and both phases compete for Ni in the melt. Thus, the low lunar Ni* values are just low Ni concentrations in chromite due to competing olivine; and true Ni D-values would be comparable to the terrestrial values. Martian Ni* values are also a bit low, and are probably affected by the early crystallization of chromite (i.e. Ni* increases) and low Mg content (i.e. Ni* decreases).

Figure 4 shows the Co data and the systematics are similar to those seen in Figure 3. Here Co* values range from 4 to 8 in both terrestrial and martian chromite grains, and are slightly lower for lunar chromite grains.

Conclusions: SIMS trace element analysis shows that terrestrial chromite is enriched in Ni and Co compared with chromite from Mars and Moon. This finding is consistent with a Ni and Co-enriched terrestrial mantle as compared with Mars and Moon. Ni* and Co* values for terrestrial and martian chromite grains are similar to D-values determined experimentally, but lunar values are quite low. We believe that the prior crystallization of olivine in lunar rocks affects the concentration of Ni and Co in chromite, thus showing very low Ni* and Co* values.

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Figure 1.

Figure 2.

Figure 3.

Figure 4.