**Sulfides from martian and lunar basalts: Comparative chemistry for Ni, Co, Cu, and Se. Average sample analyses and WDS mapping of grains**

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**Introduction:** This study examines the average trace element chemistry for planetary sulfide grains from the Moon and Mars. The work was conducted as part of our ongoing campaign in comparative planetary mineralogy, which serves to identify crystal chemical differences between equivalent phases on differing planetary bodies, and to examine the possible causes for those differences. This abstract also serves to complement [1]; here we discuss the average sulfide chemistry observed in our sample suite (consisting of 14 total samples, 6 lunar [12040, 15555, 15016, 15058, 12021 and 75038], and 8 martian [Yamato 980459, Sayh al Uhaymir 005, Dar al Gani 476, LEW 88516, ALHA 77005, Shergotty, Los Angeles 751, and QUE 94201]). For a description of sample petrological characteristics, the reader is referred to the Lunar Sample Compendium (http://curator.jsc.nasa.gov/lunar/Compendium.cfm) and the Mars Meteorite Compendium (http://curator.jsc.nasa.gov/antmet/mmc/index.cfm), both compiled by Charles Meyer.

**Analytical Techniques:** All sample analyses were obtained using a combination of electron probe micro analysis (EPMA) techniques, including wavelength-dispersive mapping (WDS), and backscattered electron imaging (BSE), and synchrotron x-ray microprobe analysis (SXRF). The nuances of the analytical technique are discussed in [1].

**Results:** Before discussing our analytical results, we would like to address some of the limitations of our sample set. Many of the grains we observed display a high degree of chemical variability. Due to small grain size, obtaining a robust, statistically significant average is problematic. This is compounded by the fact that the spatial resolution of our analytical instrumentation vary, with EPMA providing the greatest spatial resolution (spot size <1 micron) , and SXRF varying from 2-7 microns, dependent on the facility. While acknowledging our analytical complexity, we argue that averages are essential if we are to understand the igneous partitioning between sulfide and melt. Furthermore, we attempted to attenuate any sampling bias and enhance our counting statistics by conducting more analyses using EPMA, with its greater spatial resolution. Finally, the systematics of the averages are entirely consistent with the bulk compositions of the rocks.

Table 1 presents the average composition of sulfides in our study; Figure 1a. is a ternary plot for Ni, Co, and Cu, weight %. It is clear that the highest proportions of Ni are found in the olivine-bearing martian sulfides and the highest Co proportions in the lunar sulfides. Copper shows no significant difference between martian and lunar sulfides. Figure 1b., Ni (log scale) vs. Co (linear scale) shows, despite compositional complexities in individual grains, the average compositions clearly discriminate martian from lunar sulfides. Martian sulfides range to much higher Ni values and are displaced to higher Co concentrations when compared to lunar sulfides.

**Single sulfide grain chemical variability:** The primary reason for the chemical variability seen in the sulfides (pyrrhotite and troilite) is rapid diffusion of Cu, Co, and Ni during cooling, leading to phase separation. Our observations suggest the relative diffusion trajectories are distinctly different for Cu relative to Ni and Co based on the qualitative WDS maps in Figure 2. Both Ni and Co travel together, most likely to nucleate pentlandite while Cu travels independently, likely nucleating chalcopyrite. See [2] for a review of high-temperature sulfide phase equilibria. Etschmann et al. (2004) [3] present a kinetic study of the exsolution of pentlandite from the monosulfide solid solution (Fe,Ni)S. Farrell and Fleet (2002) [4] conduct a similar study using Co instead of Ni.

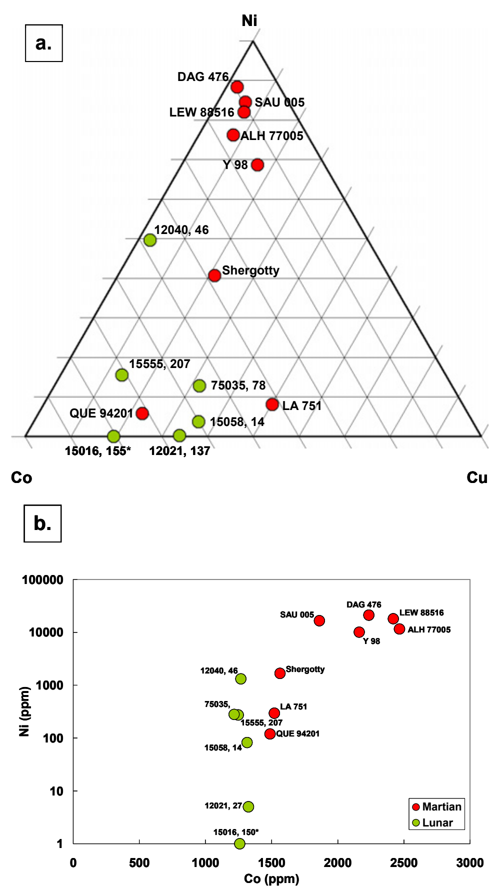


**Figure 1. Samples indicated with an asterisk fall below the detection limit but have been included for illustrative purposes.**

**References:** [1] Papike et al. (2011) LPSC abstract. [2] Fleet (2006) RiMG 61, 365. [3] Etschmann et al. (2004) Am. Min. 89, 39. [4] Farrell and Fleet (2002) Canadian Min. 40, 33.

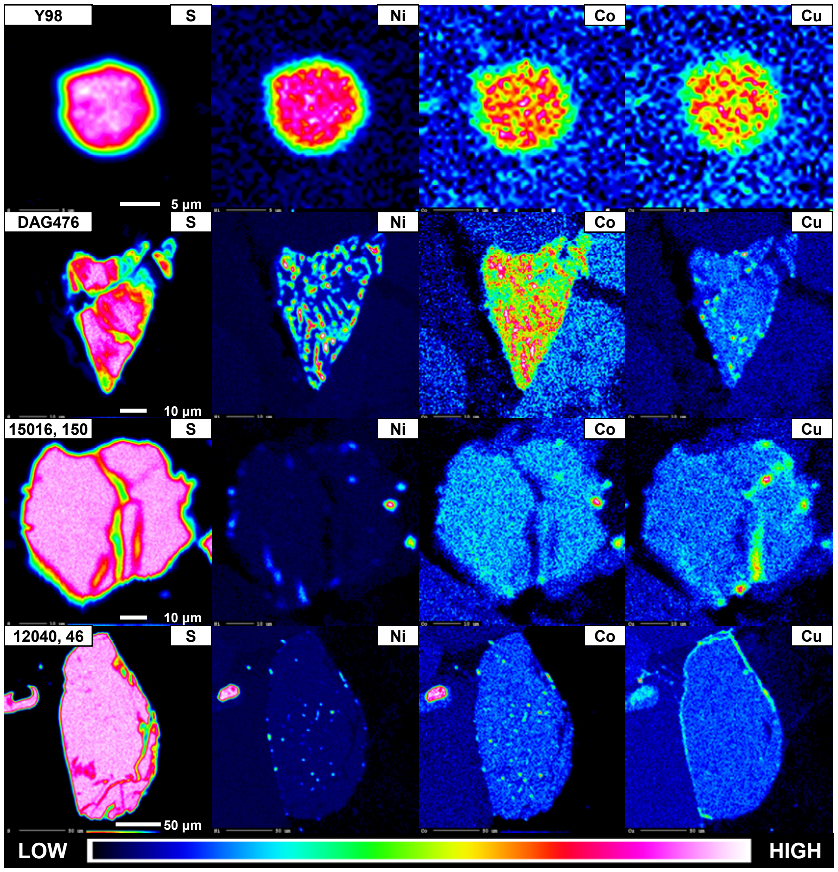


**Figure 2. Electron microprobe WDS maps for S, Ni, Co, and Cu for 2 martian meteorite sulfides and 2 lunar sample sulfides. Warmer colors represent higher intensities. See text for discussion.**

Table 1. Average composition of sulfides from each sample in the planetary suite.*

| Sample: | Y98 | QUE 94201 | Shergotty | LA 751 | SAU 005 | DAG 476 | ALH 77005 | LEW 88516 |
|---|---|---|---|---|---|---|---|---|
| Analyses By Mass (wt.%) | | | | | | | | |
| Fe | 58.71 | 58.22 | 60.45 | 61.72 | 59.40 | 58.67 | 59.10 | 60.18 |
| S | 36.75 | 37.24 | 37.91 | 37.08 | 36.78 | 37.89 | 37.69 | 37.43 |
| Atoms Per Formula Unit$ | | | | | | | | |
| Fe | 0.92 | 0.90 | 0.92 | 0.96 | 0.93 | 0.89 | 0.90 | 0.92 |
| S | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1 - Fe | 0.08 | 0.10 | 0.08 | 0.04 | 0.07 | 0.11 | 0.10 | 0.08 |
| Trace/Minor Elements (ppm) | | | | | | | | |
| Se | 79 | 92 | 58 | 79 | 96 | 84 | 44 | N/A |
| Co | 1713 (56) | 1495 (33) | 1563 (39) | 1521 (34) | 1861 (55) | 2235 (51) | 2467 (70) | 2420 (63) |
| Ni | 8437 (240) | 19 (<20) | 1669 (83) | 294 (25) | 16584 (310) | 21156 (300) | 11545 (370) | 18040 (250) |
| Cu | 681 | 397 | 873 | 1826 | 1207 | 564 | 1153 | 1549 |

| Sample: | 12021, 27 | 12040, 46 | 15016, 150 | 15058, 14 | 15555, 207 | 75035, 78 |
|---|---|---|---|---|---|---|
| Analyses By Mass (wt.%) | | | | | | |
| Fe | 61.72 | 62.66 | 63.22 | 62.47 | 62.34 | 63.05 |
| S | 35.91 | 36.12 | 36.43 | 36.38 | 36.41 | 36.38 |
| Atoms Per Formula Unit | | | | | | |
| Fe | 0.99 | 1.00 | 1.00 | 0.99 | 0.98 | 1.00 |
| S | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1 - Fe | 0.01 | 0.00 | 0.00 | 0.01 | 0.02 | 0.00 |
| Trace/Minor Elements (ppm) | | | | | | |
| Se | 50 | 69 | N/A | 49 | 62 | N/A |
| Co | 1325 (36) | 1268 (60) | 1259 (56) | 1315 (42) | 1248 (62) | 1217 (18) |
| Ni | <5 (13) | 1313 (101) | <211 (74) | 82 (31) | 273 (90) | 280 (11) |
| Cu | 678 | 70 | 305 | 794 | 237 | 700 |

*Average of analyses meeting stoichiometric constraints.

$Normalized to S = 1.00.

N/A = not applicable / not measured

() = Values in parenthases represent bulk-rock Ni and Co contents from the Mars and Lunar Meteorite Compendia (http://curator.jsc.nasa.gov/antmet/mmc, and http://curator.jsc.nasa.gov/lunar/compendium.cfm, respectively).