**REPRESENTATIVE BULK ELEMENTAL COMPOSITIONS FOR A SUITE OF SHERGOTTITES.** T. J. Lapen[1], M. Righter[1], Y. Gao[1] and A. J. Irving[2] [1]Dept. of Earth & Atmospheric Sciences, University of Houston, Houston, TX 77004 (tjlapen@central.uh.edu), [2]Dept. of Earth & Space Sciences, University of Washington, Seattle, WA.

**Introduction**: A proper understanding of the magmatic evolution of Mars can only come from the assembly of a database of rock chemical analyses which accurately reflect true magma compositions. Scrutiny of the protocols for analysis of both Martian meteorites and *in situ* rocks on the Martian surface is necessary to be sure that the reported results are truly representative, and also to exclude effects of secondary weathering processes (both Martian and terrestrial). It is important to assess the bulk compositional data currently in use for modeling of Martian igneous evolution to ascertain whether they meet the necessary criteria, and here we present new major and trace element data for 13 Northwest African shergottites obtained with an improved set of sampling and analytical protocols.

**Is My Rock Analysis Representative of the Bulk Rock?**: This question has plagued analytical geochemists for many years, but in the case of terrestrial rocks we usually have ample access to very large volumes of outcropping rock, and the ability to avoid weathering rinds and most other secondary products. However, such is not the case for remote sampling of surface outcrops on Mars. Even some Martian meteorites are relatively small to begin with, whereas others are not available in large amounts for scientific study. Thus, obtaining a truly representative bulk analysis can be difficult.

These potential problems are especially relevant for specimens with coarse grainsize or heterogeneous textures. Over 50 years ago the problem of determining the true magma composition for terrestrial I-type and S-type granitoids was solved by Chappell and White [1] by simply pulverizing up to 100 kilograms of fresh rock sampled from industrial quarries or by dynamiting outcrops. On Mars the use of the RAT to grind through weathered surfaces of outcrops to reach fresher material is of some benefit, but the volume of rock so exposed may still not be sufficient to be representative of the magma from which it crystallized. In the case of Martian meteorites, which are typically characterized from portions much less than 20 grams, the challenge of obtaining truly relevant magma compositions for most elements is even greater still.

For several years we have advocated the use of clean fines produced in the course of cutting Martian meteorites as the best approach to obtaining representative bulk elemental compositions. Yet there are several pitfalls in this approach. Most obviously the equipment must be scrupulously cleaned between each use on samples of potentially diverse bulk compositions. Since the cutting of rocks usually involves the use of diamond-bearing metallic blades or wires, there will inevitably be contamination of the cutting dust by certain metallic constituents (notably minor Cu and Sn from alloy saw blades and substantial Ni from saw wires). However, the nature and level of such contamination can be quantitatively assessed by direct analysis of the specific metal tools and by analysis of fines obtained by cutting of pure materials of similar hardness (such as Herkimer quartz).

Powders produced in this manner would never be trusted for high precision analysis of highly siderophile trace elements, and in fact they are not necessary for that purpose. Since these siderophile elements are hosted in trace mineral phases, it is possible to obtain relevant abundances by use of relatively small subsamples [e.g., 2, 3] or by minimally destructive *in situ* LA-ICPMS on portions of polished interior rock surfaces [4]. In contrast the abundances of major elements and many lithophile trace elements (including rare earth elements) are not measurably affected by typical metallic cutting tools. One obvious note of caution is to avoid the incorporation of weathering rinds, fusion crust or impact melt in the process of cutting meteorite specimens.

**Results**: The elemental data reported here (Table 1) were obtained at the University of Houston mostly on homogeneous re-ground powders that were microwave digested in HF-$HNO_3$, converted to HCl solutions, and then analyzed by ICP-OES and QQQ-ICP-MS (using Agilent Technologies instruments). $SiO_2$ was estimated here by difference, but will later be determined quantitatively.

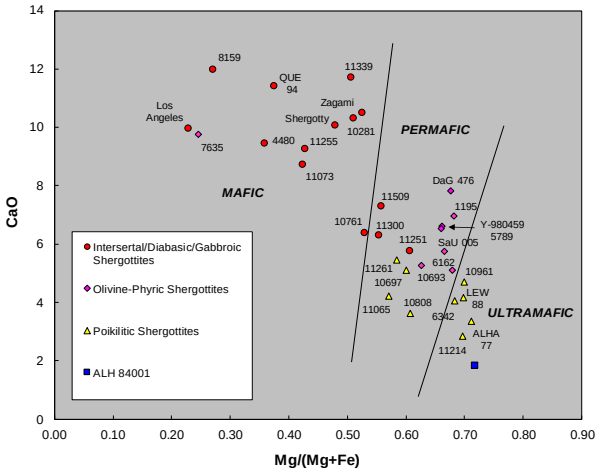


**Figure 1**. *Variation of mg with CaO for selected bulk shergottites and those analyzed in this study (after [5]).*

***Table 1. Whole Rock Elemental Abundances for Shergottites***

| **NWA** | **10281** | **10693** | **10697** | **10761** | **10808** | **11065** | **11073** | **11214** | **11251** | **11255** | **11261** | **11300** | **11339** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tool | Cu | Cu | Cu | Cu | Cu | Ni wire | Cu | Cu | Cu | Ni wire | agate[$] | Cu | none[#] |
| ***ITE cat**** | *E* | *D* | *I* | *I* | *E* | *I* | *E* | *I* | *E* | *E* | *I* | *I* | *E* |
| $SiO_2$[¶] | (59) | (57) | (54) | (66) | (62) | (49) | (60) | (59) | (51) | (61) | (53) | (62) | (54) |
| $TiO_2$ | 0.49 | 0.35 | 0.59 | 0.69 | 0.44 | 0.92 | 0.61 | 0.32 | 0.78 | 0.96 | 0.35 | 0.76 | 0.44 |
| $Al_2O_3$ | 6.69 | 4.32 | 3.67 | 3.51 | 3.64 | 2.71 | 6.49 | 2.20 | 4.61 | 5.96 | 2.44 | 4.09 | 5.88 |
| $Cr_2O_3$ | 0.16 | 0.53 | 0.61 | 0.35 | 0.43 | 0.74 | 0.09 | 0.68 | 0.40 | 0.11 | 0.64 | 0.38 | 0.18 |
| FeO | 13.58 | 16.28 | 18.86 | 13.21 | 14.99 | 23.57 | 15.87 | 14.91 | 18.97 | 14.82 | 20.83 | 14.86 | 16.68 |
| MnO | 0.38 | 0.37 | 0.43 | 0.38 | 0.38 | 0.47 | 0.43 | 0.36 | 0.34 | 0.46 | 0.34 | 0.40 | 0.30 |
| MgO | 7.96 | 15.37 | 15.85 | 8.36 | 13.02 | 17.61 | 6.55 | 19.27 | 16.47 | 6.24 | 16.46 | 10.35 | 9.61 |
| CaO | 10.31 | 5.27 | 5.09 | 6.36 | 3.63 | 4.21 | 8.72 | 2.83 | 5.78 | 9.25 | 5.44 | 6.28 | 11.69 |
| $Na_2O$ | 0.57 | 0.37 | 0.53 | 0.45 | 0.40 | 0.20 | 0.77 | 0.14 | 0.62 | 0.65 | 0.38 | 0.39 | 0.72 |
| $K_2O$ | 0.05 | 0.01 | 0.04 | 0.04 | 0.05 | 0.02 | 0.07 | 0.02 | 0.04 | 0.08 | 0.05 | 0.03 | 0.03 |
| $P_2O_5$ | 0.47 | 0.27 | 0.65 | 0.69 | 0.48 | 0.65 | 0.62 | 0.37 | 0.40 | 0.76 | 0.38 | 0.72 | 0.40 |
| SUM | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| *mg* | 0.511 | 0.627 | 0.600 | 0.530 | 0.607 | 0.571 | 0.424 | 0.697 | 0.607 | 0.429 | 0.585 | 0.554 | 0.507 |
| V | 263 | 148 | 185 | 183 | 143 | 171 | 251 | 115 | 141 | 247 | 118 | 174 | 227 |
| Zn | 56 | 55 | 58 | 54 | 55 | 60 | 68 | 57 | 44 | 70 | 44 | 60 | 36 |
| Rb | 2.8 | 0.3 | 1.3 | 1.8 | 3.0 | 0.8 | 4.6 | 1.1 | 3.1 | 3.7 | 0.7 | 2.0 | 3.3 |
| Sr | 60 | 21 | 20 | 36 | 30 | 60 | 51 | 14.2 | 29 | 47 | 35 | 37 | 35 |
| Ba | 185 | 10 | 16 | 132 | 76 | 38 | 27 | 87 | 76 | 98 | 261 | 22 | 23 |
| La | 1.50 | 0.15 | 0.83 | 0.98 | 1.41 | 0.47 | 1.66 | 1.18 | 1.45 | 1.75 | 0.44 | 1.12 | 1.45 |
| Ce | 3.88 | 0.41 | 1.88 | 2.56 | 3.47 | 1.16 | 3.97 | 3.22 | 3.56 | 4.25 | 0.98 | 2.93 | 3.54 |
| Pr | 0.50 | 0.07 | 0.27 | 0.40 | 0.48 | 0.17 | 0.56 | 0.37 | 0.50 | 0.59 | 0.16 | 0.44 | 0.51 |
| Nd | 2.48 | 0.50 | 1.48 | 2.30 | 2.37 | 0.98 | 2.75 | 1.68 | 2.46 | 2.96 | 0.96 | 2.58 | |
| Sm | 0.98 | 0.40 | 0.85 | 1.13 | 0.88 | 0.58 | 1.08 | 0.62 | 0.94 | 1.16 | 0.56 | 1.19 | |
| Eu | 0.46 | 0.21 | 0.36 | 0.48 | 0.34 | 0.25 | 0.47 | 0.25 | 0.36 | 0.48 | 0.27 | 0.48 | 0.39 |
| Gd | 1.59 | 0.92 | 1.58 | 1.78 | 1.43 | 1.12 | 1.82 | 0.97 | 1.52 | 1.89 | 1.10 | 1.92 | 1.66 |
| Tb | 0.28 | 0.19 | 0.29 | 0.30 | 0.26 | 0.20 | 0.33 | 0.17 | 0.27 | 0.34 | 0.21 | 0.32 | 0.31 |
| Dy | 2.02 | 1.38 | 2.05 | 1.94 | 1.78 | 1.42 | 2.31 | 1.14 | 1.88 | 2.35 | 1.42 | 2.09 | 2.13 |
| Ho | 0.43 | 0.31 | 0.42 | 0.38 | 0.37 | 0.30 | 0.50 | 0.23 | 0.40 | 0.49 | 0.29 | 0.41 | 0.45 |
| Er | 1.21 | 0.88 | 1.18 | 1.03 | 1.05 | 0.80 | 1.37 | 0.64 | 1.13 | 1.37 | 0.81 | 1.13 | 1.29 |
| Tm | 0.17 | 0.12 | 0.16 | 0.13 | 0.14 | 0.11 | 0.20 | 0.08 | 0.16 | 0.19 | 0.11 | 0.15 | 0.18 |
| Yb | 1.09 | 0.82 | 1.00 | 0.84 | 0.94 | 0.70 | 1.28 | 0.55 | 1.00 | 1.28 | 0.68 | 0.91 | 1.14 |
| Lu | 0.15 | 0.11 | 0.14 | 0.11 | 0.13 | 0.10 | 0.18 | 0.07 | 0.14 | 0.17 | 0.10 | 0.12 | 0.221 |
| Y | 10.0 | 7.1 | 10.1 | 9.3 | 9.2 | 6.9 | 11.8 | 5.9 | 16.5 | 12.3 | 6.8 | 9.9 | 9.8 |
| Zr | 32 | 9.4 | 28 | 34 | 16 | 29 | 49 | 17.6 | 66 | 45 | 18 | 37 | 35 |
| Hf | 1.0 | 0.4 | 1.2 | 1.2 | 1.1 | 1.1 | 1.6 | 0.59 | 1.4 | 1.4 | 0.7 | 1.4 | 1.608 |
| Th | 0.3 | 0.03 | 0.2 | 0.15 | 0.3 | 0.1 | 0.4 | 0.22 | 0.4 | 0.3 | 0.1 | 0.2 | 0.3 |
| U | 0.1 | 0.02 | 0.04 | 0.1 | 0.06 | 0.03 | 0.1 | 0.04 | 0.1 | 0.04 | 0.04 | 0.05 | 0.07 |

[¶]Estimated by difference [$]Interior slice ground in agate mortar [#]Clean interior rock fragment

*__Incompatible trace element categories__: *E = enriched, I = intermediate, D = depleted*

**Discussion**: The Mg/(Mg+Fe) and CaO contents for the newly analyzed shergottite specimens (see Figure 1) span the range of compositions previously measured for 75 out of a total of 94 known shergottite specimens including NWA 11509 [5-7]. Intermediate gabbroic shergottites NWA 10761 and NWA 11300 constitute a variety not previously recognized. Although the elevated Ba abundances in NWA 10281, NWA 10761 and NWA 11261 probably imply the presence of minor secondary terrestrial barite in the analyzed powders, we believe that the other reported abundances accurately reflect those of the parent shergottite magmas.

**References**: [1] Chappell B. and White A. (1974) *Pacific Geology* **8**, 173-174 [2] Brandon A. et al. (2012) *GCA* **76**, 206-235 [3] Tait K. et al. (2015) *LPS* **XLVI**, #2138 [4] Yang S. et al. (2015) *MaPS* 50, 691-714 [5] Irving A. et al. (2010) *LPS* **XLI**, #1547 [6] Irving A. et al. (2017) *LPS* **XLVIII**, #2068 [7] Irving A. et al. (2018) *LPS* **XLIX**, *this conference*.