# Laser-ablation ICP-MS analysis of olivine phenocrysts, sulfides, and MORB glasses from the Central Indian Ridge, and the East Pacific and Mid Cayman Rises

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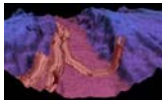
## INTRODUCTION:

Transition metals (Fe, Co ,Ni, Cu, Zn, Se, V, and Mn) are commonly concentrated in sulfide globules or disseminated sulfide grains in volcanic rocks. The presence of volatiles, such as sulfides, plays an important role in fractionating these elements during magmatic cooling (Ackermand, et al.) Thus, understanding the partitioning of the transition elements in the sulfides might allow us to constrain the crystallization history of the magma by measuring the transition metal concentrations in the glasses.

It is known that deep seated submarine eruptions prevent fast degassing of lavas; therefore the volatiles and associated late phases could accumulate at the glassy margins of the flows (Ackermand et al.) This project attempted to locate sulfides in three different regions of the globe by analyzing basalt glasses for the trace elements associated with sulfides. The concentration of trace elements among the glasses indicates the evolution of magma formation.

| ALVIN | Mg25(LR) | Si29(LR) | Ca43(LR) | Sc45(LR) | Ti49(LR) | V51(LR) | Cr53(LR) | Mn55(LR) | Fe57(LR) |
|---|---|---|---|---|---|---|---|---|---|
| line 1D | 0.699141 | 1 | 0.08657 | 0.015282 | 0.162112 | 0.105132 | 0.024605 | 0.413592 | 0.768448 |
| line 1E | 0.703965 | 1 | 0.087914 | 0.016513 | 0.171036 | 0.114852 | 0.029841 | 0.436145 | 0.798557 |
| line 1F | 0.691395 | 1 | 0.087252 | 0.015733 | 0.164137 | 0.104712 | 0.033426 | 0.414106 | 0.766166 |
| | 0.698167 | 1 | 0.087245 | 0.015843 | 0.165762 | 0.108232 | 0.029291 | 0.421281 | 0.77439 |
| | 1% | 0% | 1% | 4% | 3% | 5% | 15% | 3% | 2% |
| Knglassav | Mg25(LR) | Si29(LR) | Ca43(LR) | Sc45(LR) | Ti49(LR) | V51(LR) | Cr53(LR) | Mn55(LR) | Fe57(LR) |
| line 1 | 0.975449 | 1 | 0.193629 | 0.031217 | 0.213299 | 0.114926 | 0.037822 | 0.387887 | 0.6701 |
| 1Med. | 1.042841 | 1 | 0.232637 | 0.038313 | 0.208207 | 0.108465 | 0.039284 | 0.372657 | 0.625355 |
| 1small | 1.023585 | 1 | 0.262487 | 0.043329 | 0.198648 | 0.110346 | 0.038389 | 0.347421 | 0.55876 |
| average | 1.013958 | 1 | 0.229651 | 0.03762 | 0.206718 | 0.111246 | 0.038499 | 0.369322 | 0.618072 |
| stdev | 3% | 0% | 15% | 16% | 4% | 3% | 2% | 6% | 9% |
| MD3707-4 | Mg25(LR) | Si29(LR) | Ca43(LR) | Sc45(LR) | Ti49(LR) | V51(LR) | Cr53(LR) | Mn55(LR) | Fe57(LR) |
| line4 | 0.753575 | 1 | 0.080383 | 0.015471 | 0.147952 | 0.087893 | 0.02186 | 0.403354 | 0.641064 |
| line3 | 0.749898 | 1 | 0.083318 | 0.015209 | 0.146786 | 0.090838 | 0.01999 | 0.40323 | 0.707435 |
| line2 | 0.740701 | 1 | 0.078464 | 0.015328 | 0.147144 | 0.084997 | 0.018698 | 0.393405 | 0.653656 |
| average | 0.748058 | 1 | 0.080722 | 0.015336 | 0.147294 | 0.087909 | 0.020183 | 0.399996 | 0.667385 |
| stdev | 0.9% | 0.0% | 3.0% | 0.9% | 0.4% | 3.3% | 7.9% | 1.4% | 5.3% |



| Co59(LR) | Ni60(LR) | Cu63(LR) | Zn66(LR) | Sr88(LR) | Y89(LR) | Zr90(LR) | Nb93(LR) | Ba137(LR) | La139(LR) | Ce140(LR) | Nd146(LR) | Sm147(LR | Gd158(LR | Dy163(LR) | Er167(LR) | Yb172(LR) | Hf178(LR) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.766827 | 0.043748 | 0.102214 | 0.00684 | 0.186995 | 0.014469 | 0.023848 | 0.001373 | 0.006811 | 0.002391 | 0.005661 | 0.001427 | 0.000679 | 0.000851 | 0.001941 | 0.000638 | 0.000712 | 0.000595 |
| 3.777689 | 0.041917 | 0.102751 | 0.007269 | 0.18902 | 0.01587 | 0.022636 | 0.001179 | 0.006406 | 0.002469 | 0.006374 | 0.001024 | 0.000622 | 0.000895 | 0.001904 | 0.000781 | 0.000716 | 0.000534 |
| 3.785197 | 0.044805 | 0.10362 | 0.007087 | 0.192446 | 0.014937 | 0.021839 | 0.001433 | 0.006654 | 0.002371 | 0.005876 | 0.001297 | 0.000633 | 0.001028 | 0.00194 | 0.000848 | 0.000655 | 0.000671 |
| 3.776571 | 0.04349 | 0.102862 | 0.007065 | 0.189487 | 0.015092 | 0.022775 | 0.001328 | 0.006624 | 0.00241 | 0.00597 | 0.001249 | 0.000645 | 0.000925 | 0.001928 | 0.000756 | 0.000694 | 0.0006 |
| 0% | 3% | 1% | 3% | 1% | 5% | 4% | 10% | 3% | 2% | 6% | 16% | 5% | 10% | 1% | 14% | 5% | 11% |
| Co59(LR) | Ni60(LR) | Cu63(LR) | Zn66(LR) | Sr88(LR) | Y89(LR) | Zr90(LR) | Nb93(LR) | Ba137(LR) | La139(LR) | Ce140(LR) | Nd146(LR) | Sm147(LR | Gd158(LR | Dy163(LR) | Er167(LR) | Yb172(LR) | Hf178(LR) |
| 6.336062 | 0.037427 | 0.15546 | 0.011585 | 0.192393 | 0.019433 | 0.04117 | 0.004252 | 0.008648 | 0.004076 | 0.012046 | 0.002081 | 0.000962 | 0.001051 | 0.002037 | 0.000907 | 0.000604 | 0.000941 |
| 6.483566 | 0.034645 | 0.158334 | 0.011406 | 0.184807 | 0.016817 | 0.039838 | 0.003683 | 0.008852 | 0.00465 | 0.011305 | 0.002063 | 0.000892 | 0.001125 | 0.001907 | 0.000883 | 0.000727 | 0.000978 |
| 6.500064 | 0.032568 | 0.161729 | 0.011028 | 0.187837 | 0.017143 | 0.038413 | 0.003463 | 0.008431 | 0.003902 | 0.011332 | 0.00202 | 0.000832 | 0.000994 | 0.001788 | 0.000711 | 0.000654 | 0.001168 |
| 6.439897 | 0.03488 | 0.158507 | 0.01134 | 0.188346 | 0.017798 | 0.039807 | 0.003799 | 0.008644 | 0.00421 | 0.011561 | 0.002055 | 0.000895 | 0.001057 | 0.001911 | 0.000833 | 0.000662 | 0.001029 |
| 1% | 7% | 2% | 3% | 2% | 8% | 3% | 11% | 2% | 9% | 4% | 2% | 7% | 6% | 7% | 13% | 9% | 12% |
| Co59(LR) | Ni60(LR) | Cu63(LR) | Zn66(LR) | Sr88(LR) | Y89(LR) | Zr90(LR) | Nb93(LR) | Ba137(LR) | La139(LR) | Ce140(LR) | Nd146(LR) | Sm147(LR | Gd158(LR | Dy163(LR) | Er167(LR) | Yb172(LR) | Hf178(LR) |
| 1.439291 | 0.025005 | 0.063941 | 0.006995 | 0.14318 | 0.014356 | 0.022048 | 0.00132 | 0.003737 | 0.00377 | 0.009528 | 0.00147 | 0.000472 | 0.000798 | 0.001427 | 0.000595 | 0.000649 | 0.000635 |
| 1.537275 | 0.027016 | 0.054792 | 0.0061 | 0.149133 | 0.014236 | 0.021404 | 0.0013 | 0.004222 | 0.002905 | 0.006286 | 0.001257 | 0.000377 | 0.000805 | 0.00147 | 0.00051 | 0.000525 | 0.000649 |
| 1.36652 | 0.024336 | 0.049162 | 0.005551 | 0.137548 | 0.014011 | 0.020768 | 0.001294 | 0.003699 | 0.002504 | 0.006222 | 0.001108 | 0.000446 | 0.000649 | 0.001348 | 0.000518 | 0.000561 | 0.000564 |
| 1.447695 | 0.025452 | 0.055965 | 0.006216 | 0.143287 | 0.014201 | 0.021407 | 0.001304 | 0.003886 | 0.00306 | 0.007345 | 0.001278 | 0.000431 | 0.000751 | 0.001415 | 0.000541 | 0.000579 | 0.000616 |
| 5.9% | 5.5% | 13.3% | 11.7% | 4.0% | 1.2% | 3.0% | 1.0% | 7.5% | 21.2% | 25.7% | 14.2% | 11.4% | 11.8% | 4.4% | 8.7% | 11.1% | 7.4% |

Central Indian Ridge

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National High Magnetic Field Laboratory

## METHOD:

10 Mid Ocean Ridge Basalt (MORB) samples from the Central Indian Ridge (MD,) Mid Cayman Rise (KN,) and East Pacific Rise (AL) were crushed, sieved and glasses picked under a binocular microscope. Approximately 300 milligrams of each sample were then mounted in epoxy and polished to 0.3mm using a Buehler Handimet 2 Roll Grinder and a Metaserv 2000 Grinder/Polisher with Beuhler alumina oxide slurries. Samples are sonicated between each level of polishing and optically scanned to reach a level of 50% exposure of grains.

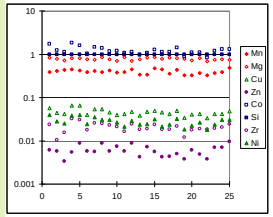
Pillow Basalt showing glassy margins

Polished glass grains mounted in epoxy

Laser-ablation ICP-MS was performed for 28 trace elements and the 8 elements of Mg, Si, Co, Cu, Zn, Zr, Ni, and Mn, were analyzed and normalized to the Si content of the MORB glasses. For each sample three MORB glasses were averaged to use as a baseline for comparison. The laser-ablation system, New Wave UP-213 nm Nd: YAG, coupled to the Finnegan ELEMENT-1 ICP-MS settings for data collection were: 40 micron lines or spots at 10 Hertz repetition rates, 65% energy level.

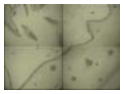
Standard glasses of known concentrations were measured to ensure the ICP-MS was calibrated properly. The laser ablation system vaporizes solid particles of basalt glass which are then introduced to the ICP-MS. The mass spectrometer uses a plasma to create ions from the material. The ions are accelerated into a magnetic field where ions of different masses take different paths through the field. The number of ions of each mass are counted by an electron multiplier and recorded as counts per second, thus the intensity of each element is recorded for each sample.

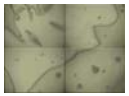
Graph 1



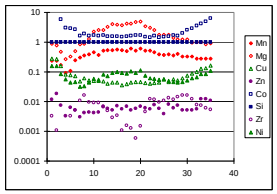

MORB Glass form Central Indian Ridge

Silica Normalized





Graph 2




Olivine Phenocryst showing increased intensities of Mg and Ni
Silica Normalized

## RESULTS and DISCUSSION:

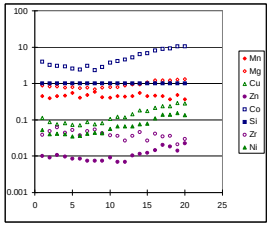
The three glasses chosen represent distinct area of the ocean floor with samples taken from a variety of depths: Mid- Cayman Rise KN series at 4300 m, Central Indian Ridge MD series at 3200m, and the East Pacific Rise Alvin series at 2500m. Along with depth come characteristics of the ocean floor and the samples. The greater the depth, the thinner the ocean crust, less melting has occurred, and the less chance of degassing and loss of sulfur. Magmas all originate in the mantle and initially start with roughly the same composition, however as can be seen in Table 1, each of the MORB glass averages from the three areas sampled contain significant differences among six elements: Mg, Ca, Co, Cu, Zn, and Ce.

Graph 1 shows a glass track from the MD samples where the trace elements of Si, Mg, Mn, Ni, Co, Cu, Zn, Zr remain relatively stable compared to one another. Olivine is one of the first minerals to crystallize from the magma and takes up Mg and Ni. Graph 2 shows the increased intensity of those to elements identifying that spot as an olivine phenocryst. Elements that are not taken up by olivine such as Ce, Cu, and Zn show lesser levels in the Alvin and MD series indicating that these glasses from shallower depths may have sulfides formed in them. The sulfide minerals occur, in general, in disseminated amounts (less than 1% volume) in the glassy margins of the flow (Ackermand et al.) They are difficult to find and do not occur in abundance. Graph 3 demonstrates the characteristics of a potential sulfide. The intensities of Ni, Co, and Cu are increasing while the Mg level remains constant. Further analysis would be necessary to make a definitive identification as a sulfide. Because sulfides are highly soluble in the magma, they are good indicators of the fractional crystallization process that occurs in the formation of new seafloor basalts.

## CONCLUSION:

The high Mg, Ni, and Ce for the KN samples and the deeper ridge depth indicates a larger degree of melting for this sample. The low Ce and low Ni, Co, Cu indicates a higher degree of melting and the crystallization of sulfides**.**

### Profile of Potential Sulfide




### Showing increased levels of Co,Cu,and Zn

**References:**

Ackermand, D., Hekinian, R., Stoffers, P. (2007). Minerology of magmatic sulfides and transition metal oxides from lavas of the Pitcairn Hotspot and the Pacific Antarctic Ridge. *N. Jb. Miner. Abh.* V184/1. p.77-94. Stuttgart, published online.

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