COLLEGE OF
COMPUTER, MATHMATICAL, & NATURAL SCIENCES
DEPARTMENT OF GEOLOGY
The Plasma Mass Spectrometry Laboratory

Chemical Effects of Metamorphism on Enstatite Chondrites

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GEOL394 – Senior Thesis II: Research

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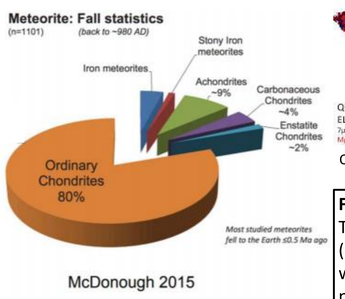
Introduction

Meteorites preserve the history of the universe; however, they have been metamorphosed and altered from their original form. Scientists study these changes in order to trace back the history of the meteorite and determine the initial conditions in which it formed. To best understand the history of meteorites, it is imperative that scientists can explain the degree of metamorphism, which varies in conjunction with different groups of meteorites. The types of meteorites that have been found on Earth are summarized in **Figure 1** below.

In this project, I will be examining chondrites, which are the most primitive and unaltered group of meteorites. The long-term goal for this project is to develop a metamorphic grade scale for enstatite chondrites. To assign a metamorphic grade, it is best to simultaneously use textural and chemical properties.

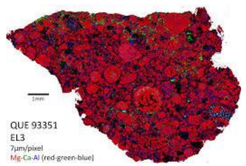
For example, in low grade ordinary chondrites, chondrules can be identified easily (**Figure 2**) and the variation of the Fe/Mg ratio between enstatite grains is large. The converse of this statement is also true.

Currently, the metamorphic grades for enstatite chondrites are texturally determined, no chemical method exists to assign metamorphic grades. Because enstatite chondrites contain a very small amount of oxidized iron, it would be difficult to assess variation utilizing an Fe/Mg ratio. Therefore, a new method must be developed to reliably assign a metamorphic grade for enstatite chondrites by chemical means.

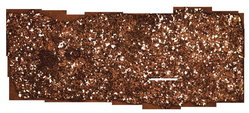


McDonough 2015

Figure 1: Meteorite Distribution. Ordinary chondrites are the most common meteorite found on Earth, while enstatite chondrites are the rarest.



QUE 933351 (EL3) – (Jacquet, 2018)



Pillistfer (EL6)

Figure 2: Low Grade vs High Grade Enstatite Chondrites. Two photomicrographs of a type 3 (low grade) and type 6 (high grade) enstatite chondrites. These metamorphic grades were assigned by textural properties, such as the presence/absence of chondrules. Chondrules are crystallized pieces of molten solar nebula, and they are usually spherical in shape. Notice how the quantity of chondrules in the low grade sample is much larger than the presence of chondrules in the high grade sample.

Hypothesis

Instead of relying on major element ratios (Fe/Mg), trace elements might be more useful instead for enstatite chondrites. **The variation in select trace element concentrations in enstatite grains observed in enstatite chondrites will decrease with increasing metamorphic grade.**

Metamorphism

- Chondrites are isochemically metamorphosed
  - Changes in pressure are negligible
  - No significant fluid flow
  - Duration of heating is most important
    - Heat is produced by radioactive decay of Al-26 (Taylor, 2004)
- Onion Shell Model (**Figure 3**)
  - Low grades are on the outside of the parent body, heat can escape easier
  - High grades are insulated on the inside of the parent body
- Metamorphism allows elements to diffuse and homogenize

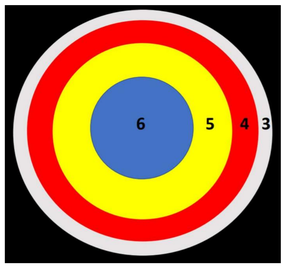


Figure 3: Onion Shell Model. The figure above is supposed to represent a parent body of a meteorite on a kilometer-long scale. The boundaries between metamorphic grades are approximate and not well defined.

Methods

To appropriate evaluate the hypothesis, this project will be performed in 3 phases.

- *Phase I:* Petrography – **Figure 2**
  - Purpose: Constructing a Map of our meteorite samples
- *Phase II:* Mineralogy, EPMA (Electron Probe Microanalyzer)
  - Purpose: Identify enstatite grains
- *Phase III:* Element Distributions, LA-ICP-MS (Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry)
  - Purpose: Determine the abundance for the trace elements of interest
- *Phase IV:* Calculations, Analysis of Data – **Figures 4, 5, and 6**
  - Estimate the variation for each trace element for each metamorphic grade for a given meteorite sample by calculating relative standard deviation, this reflects the range in the sample: $RSD = \frac{ST.DEV.}{Average} * 100\%$

Results

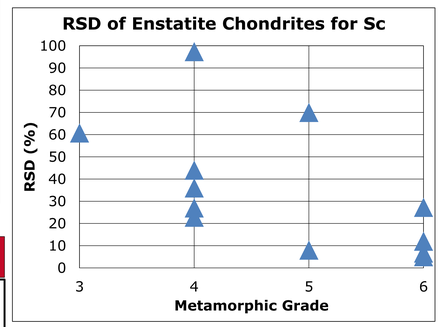


Figure 4: RSD for Sc for each meteorite. Each data point represents the RSD of Sc for a given meteorite sample that was analyzed.

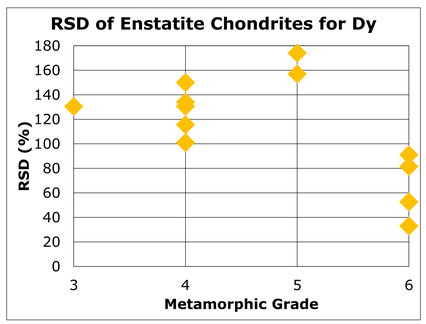


Figure 5: RSD for Dy. The calculation of RSD values for the lightest HREE, Dysprosium, was repeated with the same method as Figure 4.

Results (cont.)

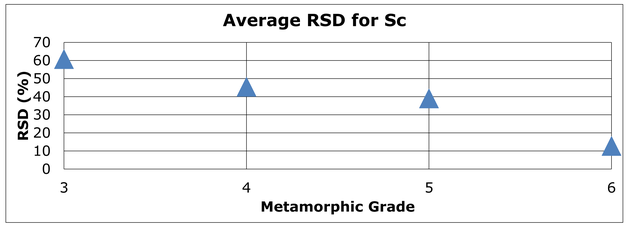


Figure 5: Average RSD for Scandium. This graph took all of the RSD values for Scandium (from Figure 4)and averaged them for each metamorphic grade. This decreasing trend supports the hypothesis.

Discussion, Conclusions, and Future Work

Discussion:

- RSD is a measure of the variation or range in the sample
  - RSD can be used for comparisons because it is a percent value
- The variation observed is much larger than the error in the analyses
- Trace elements that had higher abundance often had less error

Conclusions:

- The hypothesis is supported by the data that was collected for various trace elements. The most promising trace elements are Sc, Y, and HREE. For all of these trace elements, the overall trend of data indicates that there is a decreasing RSD, and thus a decreasing variation for an increasing metamorphic grade.
- Scandium was the best trace element that supported our hypothesis:
  - Sc was in high abundance, so it reduced measurement errors
  - Sc began with a large range in concentrations
  - Sc diffuses at a slow "Goldilocks" rate
- Because different elements diffuse at different rates, some trace elements will not support the hypothesis as effectively.
- For example, Dysprosium did not have as high abundance as Sc and while the overall trend is decreasing, Dy had higher RSD values for type 5 and type 6 than expected (Dy is one of the lighter HREE)

Future Work:

- Calculation of diffusion rates. A reliable diffusion rate can be used to best pinpoint the metamorphic grade that a particular sample belongs to.
- Perform analyses on a more samples (especially lower grade EC's)
  - Investigate brecciated samples
- Test this hypothesis on ordinary chondrites and compare results
- Model historical time and temperature regime, compare results with others

References and Acknowledgements

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