820 CD
DOI: 10.1017/S1431927606066505

Microsc Microanal 12(Supp 2), 2006

# Crystal Chemistry Inspired Element Ratio Mapping Improves the Understanding of Petrogenesis: Martian Meteorite Examples

C.S. Schwandt*

*Jacobs Sverdrup/ESCG, P.O. Box 58447, JE23, Houston, TX 77258-8447

The passion of some is to drive technological improvements, while the passion of others is to answer questions using these new technologies. Art Chodos utilized available technology to extricate clues about the genesis of numerous rock types. Rocks obtained not just worldwide, but from the Moon as well. When barriers, such as a lack of appropriate standards, arose, he implemented corrective actions, such commissioning the creation of standard reference materials [1]. I strive to emulate such tenacity and devotion while investigating meteorites and synthetic meteorite analogs. With this in mind, a short overview of the improvements in elemental X-ray mapping capabilities and new interpretation methods are addressed using the petrogenesis of Martian meteorites as an example.

Prior to the present generation of electron microprobes, the collection of elemental X-ray maps, that is the acquisition of a X-ray wavelength for a single element relative to the surface geography of a sample, was achieved using a piece of Polaroid film. The film was wonderful piece of technology at the time. Two drawbacks to film however were that acquisition was not digital and the Polaroid film's sensitivity for the collection of X-rays was limited. About twelve years ago, stage control, data acquisition, and computer hardware and software improvements made transitional leaps which permitted routine collection of digital elemental X-ray maps. Computer acquired data was thus immediately ready for further manipulation. Even so, further improvements have continued, such as the capability of applying the same quantification routine to each voxel.

Meteorites are unique samples in many ways. They are material from other parts of our solar system. However, they represent a biased sampling, are subject to alteration, and their planetary body of origin must be inferred after investigation. They offer an intriguing forensic investigation. Therefore one of the first applications of the improved mapping technology was the ability to easily determine the percentages of the phases within a thin section, and then using the quantitative chemistry of the phases calculate a bulk composition for the meteorite [2]. One of the advantages of using the digital X-ray maps is that one can use hundreds of thousands or millions of sample points instead of a few hundred. Handling such large data sets initially posed a slight problem, however, a programming language, the Interactive Data Language (IDL), specifically designed to rapidly handle large hyper-spectral image arrays has proven very useful. Using IDL it is easy to examine the three dimensional chemical arrays using a crystal chemistry methodology. In addition to phase identification and modal determination of the phases, the methodology allows testing and validation of crystal development and growth models [3]. Importantly, the validation is quantitative rather than simply qualitative. This approach illuminates the petrogenetic clues present in the minerals as a product of their formation.

The majority of meteorites from Mars are mafic (Mg, Fe rich) rocks of fine grain size. Roughly a third of the known Martian meteorites have grain sizes of 1mm and smaller and would be classified by most terrestrial geologists as basalts (shallowly emplaced or surface extruded lava rocks of mafic composition)[4,5]. Some are slightly more coarse, such as the clinopyroxenites (predominantly monoclinic pyroxene), but even these have a similarly small grain size of only a couple millimeters. The olivine-bearing clinopyroxenites are referred to as Nakhlites after the first “type” meteorite, Nakhla. The Nakhlites have pyroxenes with extremely complex compositional zoning which is an expression of growth conditions during crystallization. Concurrent to the investigation of meteorite samples synthetic analogs are grown in the laboratory to provide comparative examples and thereby strengthen our understanding of formation conditions for the meteorites on their original parent body. Examining the amount of Al in pyroxenes of Nakhlites, it is evident there is a large range of incorporation (Fig. 1). Al is a minor element relative to the crystal chemistry of pyroxene. It also affects the incorporation of trace elements into pyroxene. Therefore mapping the distribution of aluminum in the meteorites is especially informative about their crystal growth environment.

As more Nakhlites are discovered and investigated, it is evident the Nakhlites are sector-zoned with respect to Al. The amount of sector zoning of Al and abundance of Al also varies. Nakhlites with more Al demonstrate more sector zoning. The presence of sector zoning is an indicator that the bulk composition of the rock reflects the composition of the magma (melt) at the time of pyroxene nucleation [6]. X-ray mapping of synthetic pyroxene sector zoning suggests that the incorporation of higher concentrations of Al and other charge compensating impurity elements results from larger amounts of supercooling during initial crystal growth and with rapid growth [7]. This is not necessarily an indication of rapid cooling, only the presence of supercooling. Using the crystal chemical methodology with fully quantified chemical -voxel maps to construct, interpret, and test various coupled substitution models that correspond to different growth models, allows us to: 1) Explain the variation in Al content. 2) Describe the type of crystallization history of the meteorites. 3) And infer a relative emplacement depth for the various Nakhlite melts.

References

[1] P. Carpenter et al., J. Res. Natl. Inst. Stand. Technol. 107, (2002) 703-718.
[2] C. Schwandt et al., Lunar and Planetary Science XXXII, Abstract # 1913, (2001) Lunar and Planetary Institute, Houston (CD-ROM).
[3] C. Schwandt and G. McKay, Microsc. Microanal. 11 (Suppl. 2) (2005) 1300.
[4] C. Meyer, Mars Meteorite Compendium, http://curator.jsc.nasa.gov/antmet/mmc/index.cfm.
[5] A. Treiman, Chemie der Erde Geochemistry, 65 (2005) 203-296.
[6] L. Hollister and R. Hargraves, Apollo 11 Lunar Science Conf. 1 (1970) 541-550.
[7] C. Schwandt and G. McKay, Am. Mineral. (in final revision) (2006).

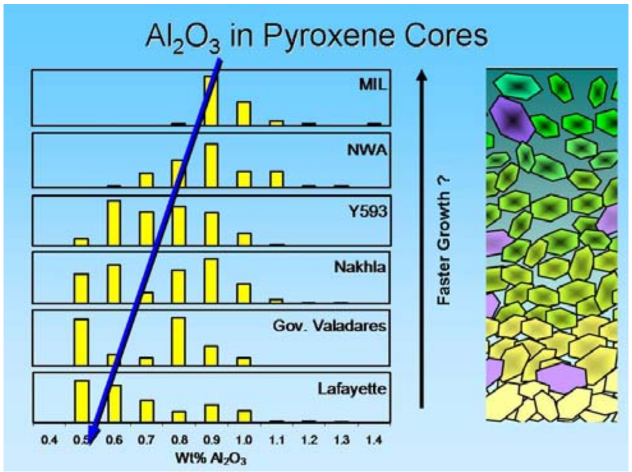

Fig. 1: Concentration of alumina in the pyroxenes of six Nakhlite meteorites.