

AUTOMATED MAPPING OF METEORITE THIN SECTIONS USING IMAGE PROCESSING SOFTWARE. T. L. Hicks¹, G. J. Taylor¹, T. J. Fagan², A. N. Krot¹, and K. Keil¹, ¹Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, Honolulu, HI 96822, hicks@hipg.hawaii.edu ²Department of Earth and Planetary Sciences, Tokyo Institute of Technology, Tokyo 152-8551, Japan.

Introduction: The determination of mineral abundances in thin section is an essential diagnostic tool, for thorough petrographic description and interpretation of petrogenesis in rocks. Mineral modes have traditionally been acquired using a point counting routine, where a petrographic microscope is used to visually classify each mineral present. Drawbacks to this method include the relatively small number of points analyzed ($\sim 10^3$), the amount of time required to physically determine the minerals present, and the difficulty in identifying fine-grained minerals.

An alternative method of mineral modal determination involves the integration of X-ray element maps (obtained from an electron microprobe), and visualization software. Elemental x-ray mapping provides a very efficient and informative method for determining the distribution of elements in a thin section. These maps can qualitatively show relationships among minerals within the section, detect clustering in mineral groups, highlight minerals difficult to see visually, provide information on zoned minerals, and supply a field guide for future high precision quantitative analysis and Scanning Electron Microscope work. This automated process also allows for a more objective method of investigation, permits retention of spatial information throughout the investigation, and yields 2 to 3 orders of magnitude more points analyzed. This high density of counts obtained is valuable for estimating concentrations of minerals that are fine-grained and occur in minor abundance.

Technique: Semi quantitative X-ray elemental maps of polished thin sections were produced using a Cameca SX-50 electron microprobe. To create x-ray elemental maps, a focused electron beam was aimed at a position on the thin section and held there for a predetermined length of time. The Cameca SX-50 is capable of acquiring five Wavelength Dispersive Spectroscopy images from its x-ray spectrometers. Each spectrometer is set up for a specific element and measures the resulting emitted x-ray intensity. This value then defines the relative grayscale value at that point, or pixel, seen on a resulting element map. When 10 elements were required for analysis, this process was immediately repeated, using the same analysis points on the thin section. Probe conditions vary for each of these maps, depending on the size of section to map, and to optimize mapping time. Most maps were 1024 x 1024 pixels, were generated with currents of 50 or 100 nA,

had step sizes between 9 and 16 microns, and had dwell times of 11-17ms/pixel. All images were saved as uncompressed .tiff files, in order to maintain information acquired for all pixels.

The imaging program that was used in this study is named ENVI (Environment for Visualizing Images), which is a digital imaging software package normally used for terrestrial remote sensing. When imported into this program, each x-ray elemental map becomes one layer in a multi-layer image file (Figure 1). In this program, each element analyzed corresponds to a specific "band". Each pixel on an image then has a characteristic elemental profile, corresponding to the total counts recorded for each element analyzed (Figure 2). One advantage of using an image processing system for analysis is that it is possible to correct for any drift that may occur between sets of map collecting, before any processing starts.

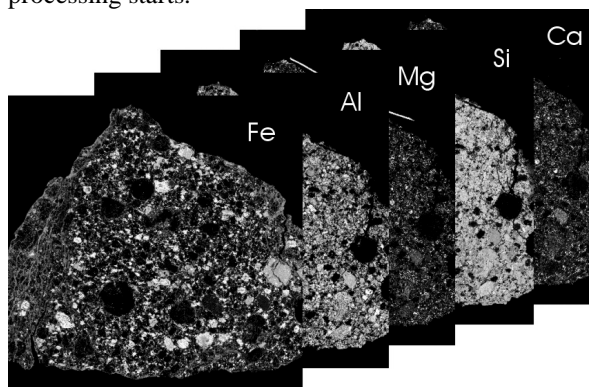


Figure 1: X-ray element maps were banded together to create a single image file, allowing each pixel to have abundance information for all ten elements studied. Five of the ten element maps for EH3 meteorite ALHA81189 are shown above.

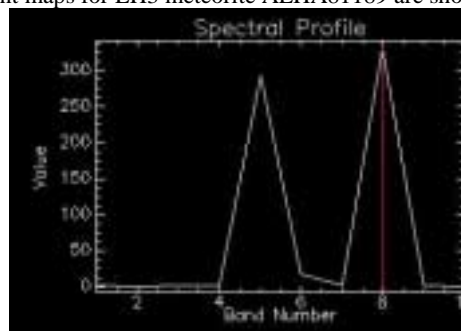


Figure 2: Representative compositional profile forsterite. Band numbers correspond to the elements as follows: Band 1=Ca, 2=P, 3=Al, 4=Si, 5=Si, 6=Fe, 7=K, 8=Mg, 9=Ti, 10=Na. Y-axis represents total number of counts on $K\alpha$ for each element at the selected pixel.

Mineral determination is accomplished by identifying sets of pixels that represent each of the minerals present, and then using a classification routine to cluster all remaining pixels into one of these mineral groups. Modal percentages for each of the mineral groups can be obtained by running a Post Classification routine. Options available for post classification include basic statistics such as the number of pixels in each group, and the minimum, maximum, mean and standard deviation for each element within each mineral group.

Samples: Meteorite thin sections analyzed using this method include several enstatite chondrites (ALHA81189, ALHA77295, ALH 88070, Kota Kota, Qingzhen, Sahara 97092, Indarch, and St. Marks), lunar meteorite NWA 773, Martian meteorite Shergotty, as well as a number of CAI's in the reduced CV chondrites Efremovka and Leoville.

Results: Mineral modes were obtained for all samples listed above. An example of this method is shown with the Martian meteorite Shergotty. The colored mineral map (Figure 3) shows the abundance and distribution of minerals within the section. Zoning within the pyroxene grains can be visualized by creating separate mineral groups for the Fe-rich and Mg-rich pyroxene. Calculated mineral abundances are shown below, compared with results from other studies.

	A	B	C	D	E
Pyroxene	67.8	70.5 / 69.1	68.9	70	67
Plagioclase	25.1	23.9 / 22.7	24.0	20	24
Mesostasis	2.3	2.8 / 5.2		3	3
Magnetite	1.1	2.0 / 2.5	2.3	2	2
Ilmenite	0.3	0.5 / 0.3	1.8	0.5	0.2
Pyrrhotite	0.5	0.3 / 0.2	--		0.4
Phosphate	2.0	tr / tr	1.3	1	2
Silica	1.0				0.5

A- This study; B- Stolper & McSween, 1979 [1]; C- Duke, 1968 [2]; D- Smith & Hervig, 1979 [3]; E- Stoffer et al., 1986 [4]

Finer grained sections and CAI's prove more complicated due to the larger number of pixels that fall on a grain boundary. Pixels that contain signatures for more than one mineral are classified as a "mixed pixel". For classification purposes, mixed pixels are directed to the mineral group that most closely suits it's elemental spectrum. It is important to ensure that only material within the CAI is calculated in the final mode. To do this the CAI is first 'cut out' of the surrounding meteorite image. This is done after layering all the element bands together, but before any analysis begins. To do this a mask is produced to cover the portion of the image containing the CAI. Any part of the image not covered by the mask is then subtracted out. This leaves pixels within the CAI with their original values, while pixels that fall outside of the mask are set to zero.

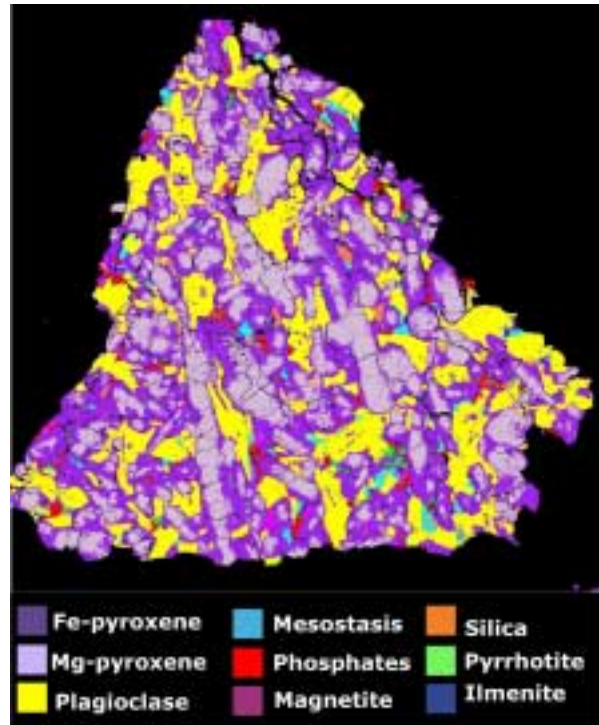


Figure 3: Final Shergotty mineral map.

For CAI L3535-5 (Figure 4), mineral mapping highlights the distinction between the pyroxene-rich mantle and anorthite-rich core. The forsterite that surrounds the CAI is an accretionary rim.

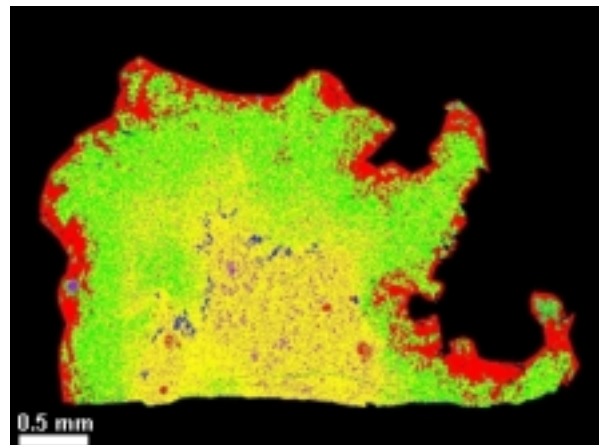


Figure 4: Color-coded mineral map of CAI L3535-5 from Leoville. Red=Forsterite, Green=Ca-pyroxene, Yellow=Anorthite, Blue=Nepheline, Purple=Spinel.

References: [1] Stolper E. M. and McSween H. Y., Jr. (1979) *GCA*, 43, 1475-14984. [2] Duke M. B. (1968) In *Shock Metamorphism of Natural Materials*, 612-621. [3] Smith J. V. and Hervig R. L. (1979) *Meteoritics*, 14, 121-142. [4] Stoffer D. et al. (1986) *GCA*, 50, 889-913.