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Quantitative EPMA Compositional Mapping and Cluster Analysis Applied to Meteorites

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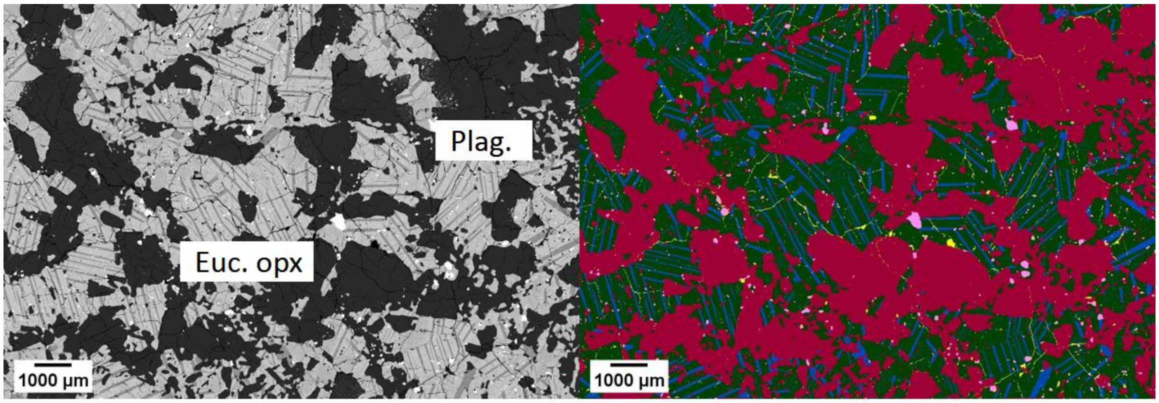
Meteorites represent important samples of planetary materials, and electron-probe microanalysis (EPMA) is fundamental to their characterization, classification, and petrologic interpretation. The classification and analysis of meteorites requires mineralogical inventory and analysis of composition and texture. Large-scale backscattered-electron and X-ray stage maps are important for use as base maps and for location of analytical areas of interest. These maps are used for detection of important phases, measurement of phase chemistry, calculation of area fraction, and determination of phase weight percent in modal recombination analysis. Important microanalysis issues include background correction and detection limit considerations, pixel size sampling related to mineralogy, recognition of single phase vs. multiphase pixels, and collating of analytical data to represent individual minerals in the meteorite. We continue recent developments in EPMA stage mapping using wavelength-dispersive (WDS) spectrometry coupled with downstream processing for applications to meteorite samples [1].

Here we report compositional mapping and k-means cluster analysis of two meteorite samples, an unbrecciated eucrite which is used to evaluate the accuracy of unsupervised cluster analysis, and a polymict diogenite which is used to demonstrate the classification of mineral and lithic clasts using supervised cluster analysis. These meteorites are classified based on composition of low-Ca and Ca pyroxene, plagioclase, and olivine (among other factors). Diogenites are characterized by coarse-grained low-Ca pyroxene typically lacking exsolution lamellae, whereas in eucrites pervasive exsolution is observed. The degree of mineral re-equilibration and identification of differing lithologies is evaluated by EPMA spot analysis and benefits from compositional mapping as both clasts and matrix represent aspects of source material. Petrographic thin sections of both meteorites were mapped at 1 – 15 mm pixel resolution using dwell times of 20 – 50 msec at a probe current of 100 nA. WDS quantitative analysis was made using Probe for EPMA and CalcImage, including a mean atomic number background correction, with full $\Phi(\rho z)$ correction at each pixel, with results directly comparable to EPMA spot analyses**.** Data files and 32-bit tiff images were used for cluster analysis.

Fig. 1 shows the results for unsupervised k-means cluster analysis of the unbrecciated eucrite using the Fiji Xlib plugin [2]. The compositions of low-Ca pyroxene (opx), Ca-pyroxene, and plagioclase are well discriminated using this method, which requires no knowledge of the mineral chemistry. Table 1 compares the EPMA spot analyses and cluster results, which show very good agreement. These compositions can be used as input for subsequent refinements using supervised cluster analysis. Fig. 2 shows the results for supervised k-means cluster analysis of the polymict diogenite using ENVI [3]. This sample presents challenges for cluster analysis because the exsolution lamellae are thinner, and there is a range of Mg/Fe for the low-Ca pyroxene coupled with a finer grain size of the matrix. The result is a blurring of the cluster population which causes unsupervised clustering to merge mineral compositions into a common set of clusters. In this case, the EPMA spot analyses were used as the library references for cluster analysis which dramatically improves the results.



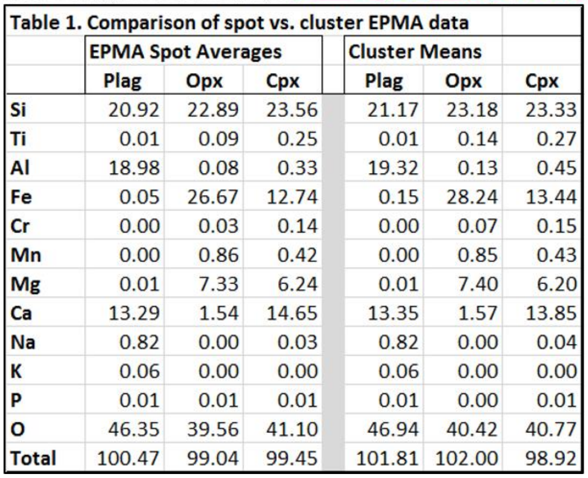


Table 1. Comparison of spot vs. cluster EPMA data						
	EPMA Spot Averages			Cluster Means		
	Plag	Opx	Cpx	Plag	Opx	Cpx
Si	20.92	22.89	23.56	21.17	23.18	23.33
Ti	0.01	0.09	0.25	0.01	0.14	0.27
Al	18.98	0.08	0.33	19.32	0.13	0.45
Fe	0.05	26.67	12.74	0.15	28.24	13.44
Cr	0.00	0.03	0.14	0.00	0.07	0.15
Mn	0.00	0.86	0.42	0.00	0.85	0.43
Mg	0.01	7.33	6.24	0.01	7.40	6.20
Ca	13.29	1.54	14.65	13.35	1.57	13.85
Na	0.82	0.00	0.03	0.82	0.00	0.04
K	0.06	0.00	0.00	0.06	0.00	0.00
P	0.01	0.01	0.01	0.01	0.00	0.01
O	46.35	39.56	41.10	46.94	40.42	40.77
Total	100.47	99.04	99.45	101.81	102.00	98.92

Figure 1. Unbrecciated eucrite sample. Left: BSE stage map with low-Ca pyroxene hosts with exsolved Ca pyroxene and plagioclase (dark). Right: Unsupervised k-means cluster map with low-Ca hosts in forest green, Ca pyroxene lamellae in blue, plagioclase in red. Table 1. Comparison of EPMA spot analyses and cluster means on plagioclase, low-Ca pyroxene, and Ca-pyroxene.

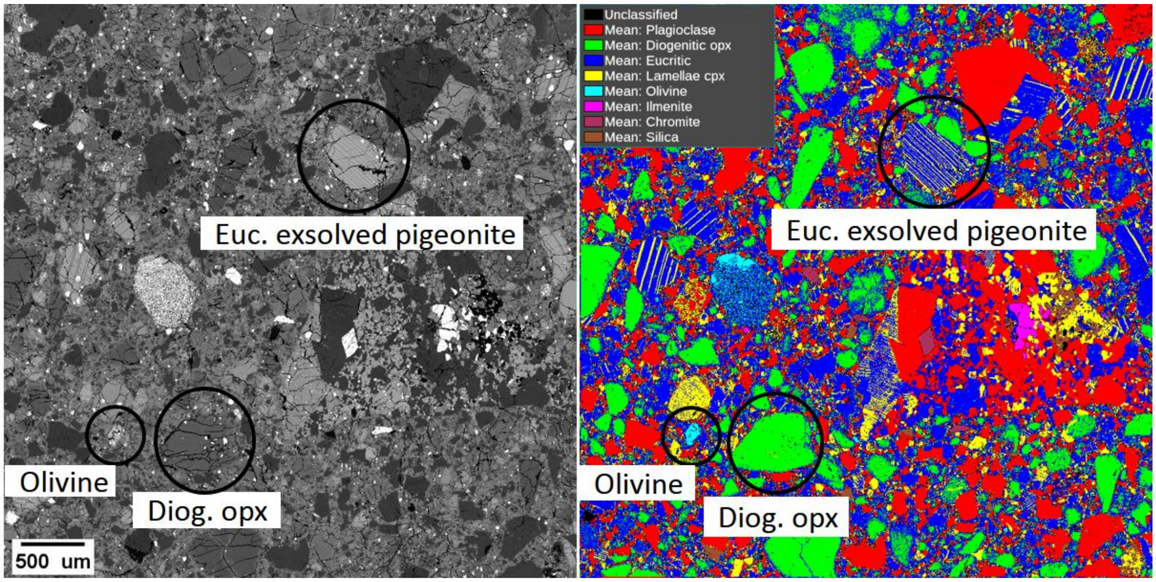


Figure 2. Left: Stage BSE image of polymict diogenite sample. Right: Supervised k-means cluster analysis classification map showing discrimination of diogenitic low-Ca pyroxene, eucritic pyroxene, and olivine.

References

[1] C.J.-K Yen et al. *LPS LI* Abstract # 2804, 2020.
[2] Fiji Xlib plug-in, http://imagej.net/Xlib
[3] ENVI software, http://www.harrisgeospatial.com