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Interpretation of Pyrite LA-ICP-MS Maps from the Colosseum Au Mine, Southern California

Nelson Román[1], Daniel D. Gregory[1], Simon E. Jackson[2], Jean-Luc Pilote[3]
1. Department of Earth Sciences, University of Toronto, Toronto, ON, Canada, 2. Geological Survey of Canada, Ottawa, ON, Canada, 3. Geological Survey of Canada, Quebec, QC, Canada

Pyrite LA-ICP-MS mapping has become a common technique for the study of pyrite in ore deposits, since pyrite texture and trace element composition provide unique insights into the evolution of these systems. However, despite the advantages of the use of LA-ICP-MS maps, their interpretation is still challenging, especially when comparing pyrite generations from the same deposit that have similar textures or intricate paragenesis. In this study, we aim to develop a statistically robust approach to identifying chemical zones associated with different pyrite generations, such that, combined with detailed petrographic observations, they allow confident comparison of pyrite from different parts of a deposit, even when pyrite textures are similar and crosscutting relationships are absent.

For this purpose, we applied unsupervised clustering for the examination of pyrite LA-ICP-MS maps from the Colosseum Au mine, southern California. Gold mineralization here is closely associated with pyrite, providing an ideal framework for the study of the relationship of pyrite features with important mineralization events. We utilized five pyrite LA-ICP-MS maps, representative of the two main pyrite generations in the Colosseum mine, which are (1) early pyrite, characterized by coarse, euhedral crystals (>500 µm), frequently fractured, and (2) late pyrite, characterized by aggregates of finer-grained euhedral crystals (<150 µm).

The clustering techniques used were K-means, Clustering Large Applications (CLARA), Hierarchical clustering, Hierarchical K-means, and Gaussian Mixture Models (GMM). Results were validated using clustered maps and biplots of compositional data. The best clustering results were achieved by different methods in each map. Hierarchical clustering (Ward), CLARA, and GMM yielded the best results. In each map, four to five clusters were identified, which correctly differentiated between early pyrite, fractures in early pyrite, and late pyrite, matching petrographic observation.

Clustered maps reveal that early pyrite is characterized by compositional zoning, which occurs mostly as concentric zones. Conversely, late pyrite does not show intra-grain compositional zoning. Compositional transition from early to late pyrite is represented by a decrease of Co, Ni, and Te contents, coupled with an enrichment of Cu, Ag, Sb, Pb, and Tl contents from early to late pyrite. Late pyrite has consistently higher Au concentrations than early pyrite, with median Au concentrations of 1.1 and 0.06 ppm, respectively, emphasizing the association of late pyrite with economic mineralization. However, among the zones identified in early pyrite, a group shows higher As and Au concentrations, with medians higher than 2,000 and 0.7 ppm, respectively. Moreover, Au in fractures in early pyrite reach abundances over 100 ppm. This is consistent with the occurrence of anomalous, economic areas in the deposit not necessarily associated with late pyrite. The changes between early and late pyrite could be related to a shift in the physicochemical conditions during pyrite deposition, which also led to efficient Au mineralization. This aspect will be investigated in subsequent studies.

These results show that clustering techniques applied to pyrite compositional maps facilitate chemical zone identification in pyrite grains, allowing direct comparison between pyrite generations and the extraction of relevant information in a petrographic and paragenetic context.