Pyrite Trace Element Behavior in IOCG Deposits: An Unsupervised Learning Approach for Vectoring and Ore Paragenesis

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Iron oxide copper-gold (IOCG) deposits are a class of mineral deposits that can contain significant quantities of strategic and critical minerals, essential for the renewable energy transition. However, the high degree of complexity and internal variability of IOCG deposits has inhibited the development of a robust genetic model. Over the last decade, trace elements in pyrite have been used successfully in ore deposit exploration as geochemical pathfinders to ores, including for some IOCG deposits. Here we present the results of a comparison of unsupervised learning methods applied to pyrite LA-ICP-MS trace element maps from three IOCG and affiliated provinces in Australia: Arthur Metamorphic Complex (Alpine prospect), TAS; Gawler Craton (Hillside deposit, Prominent Hill deposit, and Con Ryan prospect), SA; and Cloncurry District (Ernest Henry deposit, E1 prospect, and Starra prospect). We aim to cluster the pyrite LA-ICP-MS maps in order to assess the degree of compositional complexity among samples from different systems, and to test whether certain common elemental patterns could be defined. The LA-ICP-MS maps show elemental zoning, which represents variability in temperature and chemistry during pyrite crystal growth. For most samples, hierarchical clustering works better than K-means by highlighting elemental zoning in pyrite, while some K-means clustering results tended to emphasize noise. For sites like Ernest Henry, Hillside, and Prominent Hill, clusters from both methods indicate proximity to the orebody. However, some clusters appear only in specific deposits while other clusters are common across multiple deposits. Hillside and Prominent Hill, or Ernest Henry and E1 samples show similar clusters, suggesting geological and fluid composition similarities. This study provides critical insights for improving exploration strategy and resource estimation, as well as the conceptual development of ore genesis processes through a rapidly emerging tool.