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Promising Fertility Indicators of Magmatic Systems: An Integrated Study of Zircon Geochemistry and Multilayer Perception

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Recent studies have increasingly shown that some minerals (e.g., apatite, zircon, rutile, magnetite, epidote) are potential indicators for magma fertility. Among those, zircon is a common accessory mineral in intermediate to felsic intrusions that hosts a variety of trace elements and is typically resistant to physical and chemical weathering. As such, zircon may serve as an ideal petrogenetic indicator, oxygen fugacity proxy, and mineral indicator for source rock fertility and consequently mineral exploration. For example, Ce anomalies, Eu anomalies, and several trace element ratios (e.g., 10,000*(Eu/Eu*)/Y, (Ce/Nd)/Y, and Dy/Yb) of zircons have been proposed as diagnostic indicator for porphyry Cu (±Mo ±Au) productive magmas. However, the generality, reliability, and robustness of those parameters remain undetermined or need to be tested in various localities because the data used to formulate those parameters are not sufficiently representative. Meanwhile, few similar attempts have been made to discriminate unmineralized from mineralized intrusions with respect to other metals. In this study, we compile 18,000 zircon trace element analyses of rock samples from a large variety of deposits (Au, Cu series covering Cu, Cu-Au, Cu-Mo, Cu-Mo-Au, Cu-Mo-W, Cu-Pb-Zn, Mo, Fe, Sn, W, W-Sn, W-Mo, W-Cu-Mo) and unmineralized intrusions in various localities. Discriminant analysis in various violin plot shows that zircons from Cu-series deposits statistically have high values of Ce anomalies, Ce^{4+}/Ce^{3+} ratios, Eu anomalies, 10,000*(Eu/Eu*)/Y, (Ce/Nd)/Y, and low Dy/Yb ratios, confirming previous studies. However, all those parameters fall in a large range with considerable overlaps between unmineralized and mineralized intrusions in terms of Cu series. This misclassification may reflect the fact that metal enrichment and ore formation is a function of numerous factors affected by prolonged, complex magmatic-hydrothermal processes. An additional implication is that when a data set is sufficiently large, the discrimination for Cu fertility of magmatic rocks may be problematic. As such, large data sets and new methods of discriminant analysis are needed to evaluate magma fertility more accurately. The results further show that those indicators, even they are effective when discriminating Cu-mineralized and unmineralized rocks in some cases, cannot be used for separating fertile and barren intrusions with respect to other metals. As an alternative attempt, we employ multilayer perception (MLP) to develop discriminative indicators for metal fertility. This attempt is based on the consideration that machine learning is particularly suitable for data classification in multidimension feature space. Because variable in MLP function cannot be null, 6,000 out of the 18,000 samples are screened, with the remaining 12,000 used for the data classification. The classification yields an overall accuracy of 82% in discriminating mineralized and unmineralized rocks with respect to the metals mentioned above. Results from this study highlight that MLP-based data classification of zircon trace element compositions can be a more promising and reliable approach to evaluate magma fertility.