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Petrogenetic tools as tracers of ore-forming processes: An appraisal of recent approaches

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A global supply shortage of a number of key metals is forecast over the next few decades. Demand is set to outstrip production, while the rates of discovery of significant new mineral deposits continue to fall. Efforts to improve exploration success have driven the development of new concepts that regard the genesis of ore deposits as expressions of regional-scale earth processes governing both source and transport of metals. Determination of measureable geological phenomena sensitive to these processes could have considerable potential as tracers of ore-forming systems, with application to deep cover and to greenfields exploration.

Granite-hosted mineral deposits are major global sources for Cu, Mo, Sn, W, Li, U and Au. Much work has focused on late-stage fluid-driven mineralization processes. However, magma genesis and evolution exert a primary control on the propensity of granites to be metal fertile. A revolution in our understanding of crustal growth and differentiation processes has been forged through a range of mineral-based geochemical tracers, driven by the development of in-situ analytical techniques. As a consequence, there is considerable interest in whether these monitors of petrogenetic processes can be usefully applied to metallogenic problems. Key to this is conceptually linking the petrological record to mineralization processes, and at appropriate scales.

Factors which have been interpreted to exert a control over granite metal fertility, and which can now be monitored, are (a) the nature of source; (b) geodynamic setting; (c) the redox state of the magma; (d) evolution and fractionation; and (e) processes of mineralization. Source controls both metal endowment and intensive factors of the magma. Geochemical heritage describes whether a fertile magma requires a source region inherently more metal endowed than average crustal compositions, or whether an inherent composition promotes metal availability, for example the Al content of feldspars has been linked to Cu enrichment. The role of geodynamic setting and the input of mantle-sourced material, and of subduction versus intraplate setting, can be determined through isotope analysis. A routine isotope tracer is Hf-O in zircon, however, workers are now pursuing other isotope systematics in mineral inclusions within zircon.

Source also imposes a hereditary control on the redox state of the magma, with implications for metal availability. Sulphur speciation (S^{2-}/SO_4^{2-}) controls its solubility, and the ability of a magma to transport chalcophile metals. For incompatible metals (e.g., Sn, U), their redox state determines whether they are sequestered within crystallizing silicate minerals, or available in the magma to be further concentrated. It has been suggested that redox state can be monitored through rare earth element anomalies within zircons (Ce and Eu), and through Mn content in apatite.

The processes of fractionation during magmatic evolution leads to a concentration of incompatible metals, and ultimately the formation of ore minerals. Is there a fractionation threshold over which a significant economic concentrations can be developed? Recent work has suggested fractionation extent can be monitored within the trace elements of zircons; of apatite inclusions (Sr); and within whole rock element ratios (Nb/Ta).

These developments all point towards fresh ways of monitoring ore-forming processes through the igneous record. It is argued that a key to future research is conceptually linking the petrological record to mineralization processes coupled with the further development and calibration of existing and new tools to appropriate geochemical traits that promote metal fertility.