Spatial and genetic links between magnetite-(apatite) and IOCG systems

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Magnetite-(apatite) (MtAp) and iron oxide copper gold (IOCG) systems include a complex mélange of ore deposits with diffuse limits and poorly known genetic relationships. At a worldwide scale, MtAp districts are fairly abundant but only locally are spatially related with IOCG mineralization. Conversely, major IOCG districts not always related spatially or temporally with MtAp mineralization. Geology and geochemistry suggest that MtAp rocks are formed by crystallization of ultrabasic iron-rich melts more akin to carbonatites and other silica-depleted alkaline melts, than to silicate-rich magmas (Tornos et al., 2023). The unusual diopside/actinolite and apatite-rich but quartz-depleted composition of these rocks is difficult to explain if they are related to magmatic-hydrothermal systems formed during the crystallization of mafic to felsic water-rich intrusive rocks. More likely, evolved MtAp systems behave as natural analogues of blast furnaces with separation of a deep and dominant layer of massive magnetite capped by a complex assemblage of apatite and Ca-Mg silicates that is chemically and physically similar to that of slag. Fractional crystallization of these late rocks produces a wide variety of coexisting immiscible melts that are not fully understood. Local presence of hematite and abundant anhydrite suggest that these melts were highly oxidized and transported little reduced sulfur. The crystallization of large amounts of magnetite induced water supersaturation of aqueous fluids and the release of vast amounts of aqueous fluids that form large aureoles of alkali-calcic-iron alteration with local replacive magnetite mineralization (≈skarn). In subaerial systems, the formation of the magnetite-slag zonation is inhibited and the violent release of large amounts of aqueous vapor produces large maar-diatreme complexes with crater lakes infilled with breccias. The ultimate origin of these iron-rich melts seems to be related with the contamination of silicate melts by continental to shallow marine sediments, many times evaporite-rich, that underlie most MtAp districts. Melt contamination can be traced through radiogenic and stable isotopes and melt inclusion data. $^{87}Sr/^{86}Sr$ and triple oxygen isotope data (Peters et al. 2021) as well as by the abundance of melt inclusions enriched in different salts, including, carbonates, sulfates and chlorides (Bain et al. 2020). MtAp systems can be the host of, IOCG systems characterized by the hydrothermal precipitation of magnetite and chalcopyrite associated with an actinolite-feldspar hydrothermal alteration. The most likely reason of this association is that magnetite, whatever the origin, is an excellent trap due to its brittle behavior and its capability of buffering both redox and pH at intermediate to low fluid/rock ratios. This is observable in several deposits in northern Sweden where the "IOCG" mineralization postdates and cross cuts earlier MtAp mineralization (e.g. Malmberget, Bauer et al, 2018). However, IOCG-like systems can also form away from ironstones, as veins or stratabound replacements ("periskarn") of permeable volcanoclastic andesite. The ultimate origin of the ore forming aqueous fluids is unknown but could be related with the crystallization of mafic silicate melts or fluids released from an underlying MtAp system.

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