ALKALINE PORPHYRY COPPER DEPOSITS AND IOCG – WHAT IS THE LINK?

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ABSTRACT

The geotectonic setting (cratonic or back-arc) of IOCG deposits, and the nature of their associated magmas is not consensual. Alkaline porphyry deposits and IOCG's show the same high temperature Na-Ca alteration and both occur in extensional tectonic settings. These two similarities contribute to the definition of the IOCG's source magmas. Magmas and volatiles extracted from the asthenosphere are able to metasomatise and fertilize the SCLM (Sub-continental Lithosphere Mantle) at specific depths (metasome). The metasomes are mantle portions enriched in Fe^{+3}, Ti, K, Nb, C, H, Cl, F, Cu, Ni, P, LREE, U, Th, Na and LIL. The metasomatism in the mantle occurs when the C-O-H peridotite solidus curve intercepts the cratonic geotherm. The IOCG deposits result directly from extensional periods in the SCLM (rifting), associated with partial melting of the metasome and the production of alkaline magmas rich in volatiles (O-H-C-S-CL-F). These melts are rich in compatible and incompatible elements and rarely reach the upper portions of the crust. In general the copper porphyry and IOCG deposits have more differences than similarities.

INTRODUCTION

Iron Oxide Copper Gold (IOCG) deposits are responsible for a significant portion of the World's Cu, Au and U production. Although these deposits present some similarities with skarns and magnetite-hematite-group deposits they are distinguished as an unique deposit type mainly by the following two features: i) high contents of compatible (Fe, Ni, Mg, Cu, Cr, Co) and incompatible elements (Na, K, F, Cl and REE) and ii) lack of a direct spatial association with igneous rocks. Some IOCG's deposits are considered to be related to back-arc magmatism (Sillitoe 2003; Richards and Mumin 2013), while *bona fide* IOCG formed in an intracratonic or anorogenic setting (Groves *et al.* 2010). Teixeira *et al.* (2009) proposed that the Carajás' IOCG deposits were formed during the evolution of an Archean rift in the SCLM. They argue that the evolution of the underlying cratonic keel provided the ingredients for generating precursor alkaline magmas of IOCG mineralizing fluids, even though no alkaline rocks have been spatially related to mineralization so far. In contrast, Groves *et al.* (2010) proposed that the enrichment of the SCLM was due to previously subducted oceanic slabs. We consider that the IOCG deposits are totally different from Cu±Au±Mo magmatic-hydrothermal systems. On the other hand, IOCG's and alkaline porphyry deposits have similar alteration styles (Ca-Na enrichment) and both are positioned in extensional tectonic settings. We use these two similarities not to highlight that IOCG's occur in the same geotectonic settings as alkaline porphyries, but to further constrain the link between IOCG's and alkaline magmatism. We argue that IOCG's are a result of magmatic and metasomatic processes related to thick and cold lithospheric keel.

IOCG AND PORPHYRY SYSTEMS

Richard and Mumin (2013) argued that the greatest overlap between porphyries and MH-IOCG deposits occurs in postsubduction Au-rich porphyry systems, whose mildly alkaline magmas are generated by partial melting of hydrous amphibole-rich residues of earlier arc magmatism. Such magmas would be S-poor relative to arc magmas because the flux of new sulfur from the subduction zone is no longer present. For authors such differences can be explained primarily by a difference in magmatic sulfur content, specifically the oxidized sulfur (SO_4^{2-}). We consider that the differences between porphyries and IOCG deposits are much more profound resulting from several different characteristics in: i) the geotectonic settings (subduction *versus* intracratonic); ii) the magma's chemical composition (calk-alkaline or mildly alkaline *versus* MMM mantellic-metasomatic-magmas, Mitchell 1995) and migration dynamics of the parental magma (shallow *versus* deep); iii) the alteration zones geometry (centered intrusion versus dilatational jogs); iv) the composition of the mineralization (Cu-Au-Mo *versus* Cu-Ni-Au-U); and finally v) the relation between mineralization and magmatic body (proximal *versus* distal). Such differences are not as evident when comparing the IOCG deposit with alkaline porphyries (**Figure 1**). There is a clear similarity between the mineralogy and the alteration zones geometry of these two deposit types. These suggest some similarities in tectonic setting and magmatic source for both. They are generated in extension tectonic regimes: back-arc setting in the case of alkaline porphyry and rift setting for the IOCG. Both deposit type present hydrothermal fluids exsolved from alkaline rocks. Nonetheless, it must be pointed out that alkaline rocks and their associated hydrothermal fluids generated in lithospheric edges are different from those generated in thick cratonic lithosphere.

IOCG AND MANTLE-DERIVED MAGMAS

The production of magmas in the SCLM occurs when the peridotite solidus curve intercept the cratonic geotherm due to high H_2O, CO_2 activity or to an increase in the temperature (*e.g.* plume). Wyllie (1980) considers that the irreversible ascent of deep magmas is interrupted by physical discontinuities (*e.g.* the bottom of the lithosphere and the base of the crust) and intersection with the thermal maxima in the C-O-H peridotite solidus. The metasome is a mantle region where volatile loss from aborted melts metasomatise the mantle (Haggerty 1986). According to this author the metasome is the source of alkalic, high-redox state melts and incompatible element-rich silicates in kimberlites, lamproites and related alkali-rich rocks. The cratonic keels with cold geotherm would trigger the formation of two metasomatized horizons and one of which capable of yielding MMM magmas (carbonatites, ultramafic lamprophyres, kamafugites) which could be the precursors of mineralizing IOCG fluids.

MANTLE METASSOMATISM: SUBDUCTION-DRIVEN VS. PLUME-DRIVEN

It is well know that convergent settings are the sites of significant mass exchange between the Earth's surface and its interior. They play a significant role in the depletion and enrichment history of the Earth's mantle (Widom *et al.* 2003). Crustal material that escapes fluxing into the mantle wedge overlying subducting slabs may be an important component of geochemically enriched mantle plumes, particularly the LREE budget (Tatsumi 2005). Richards and Munin (2013) suggest that release of sulfate-bearing fluids during prograde metamorphism of subducted oceanic crust is thought to contribute the bulk of sulfur to the metasomatised mantle source of Phanerozoic arc magmas. However, Haggerty (1989) based on studies of mantle xenoliths in cratonic regions have petrologically demonstrated that enrichment in incompatible elements and LREE, forming the classical MARID mineralogy, could be attained by plume interaction. This lithospheric metasomes at 100-60 km depth would partially melt by the rapidly rising of asthenosphere protomelts at the intersection of the dry-peritotite solidus curve, yielding alkaline volatile-rich fluids and melts. Recently, Giuliani *et al.* (2013) provided the first evidence for the occurrence of sulfate-dominated fluids in the Earth's mantle. Therefore, mantle sulfides may have originated from immiscible sulfide melts that separated from silicate and/or carbonatite melts at mantle depths, from S-bearing C–O–H fluids (Giuliani *et al.*, 2013). Consequently, enrichment in LREE and incompatible elements present in all IOCG deposits can be also a result of plume interaction in cratonic lithosphere rather than enrichment by slab components in sub-arc environments.

CONCLUSION

The typical IOCG deposits show no spatial relationships with magmatic bodies of any kind. On the other hand, because these deposits are part of the evolution of a SCLM rift setting, they occur simultaneously with bimodal magmatism and A- type granites. The similarities between alkaline porphyries and IOCG suggest that the IOCG mineralizing fluids can be provided by alkaline magmas generated at the mantelic metosome. Extensional events (*i.e.* rifting) in the SCLM may induce the production of small melting fractions of alkalic nature rich in incompatible and compatilble elements. This is the link between alkaline porphyry gold deposits and IOCG deposits. IOCG and mildly alkaline porphyry deposits show similar Ca-Na hydrothermal alteration establishing a genetic link between them.

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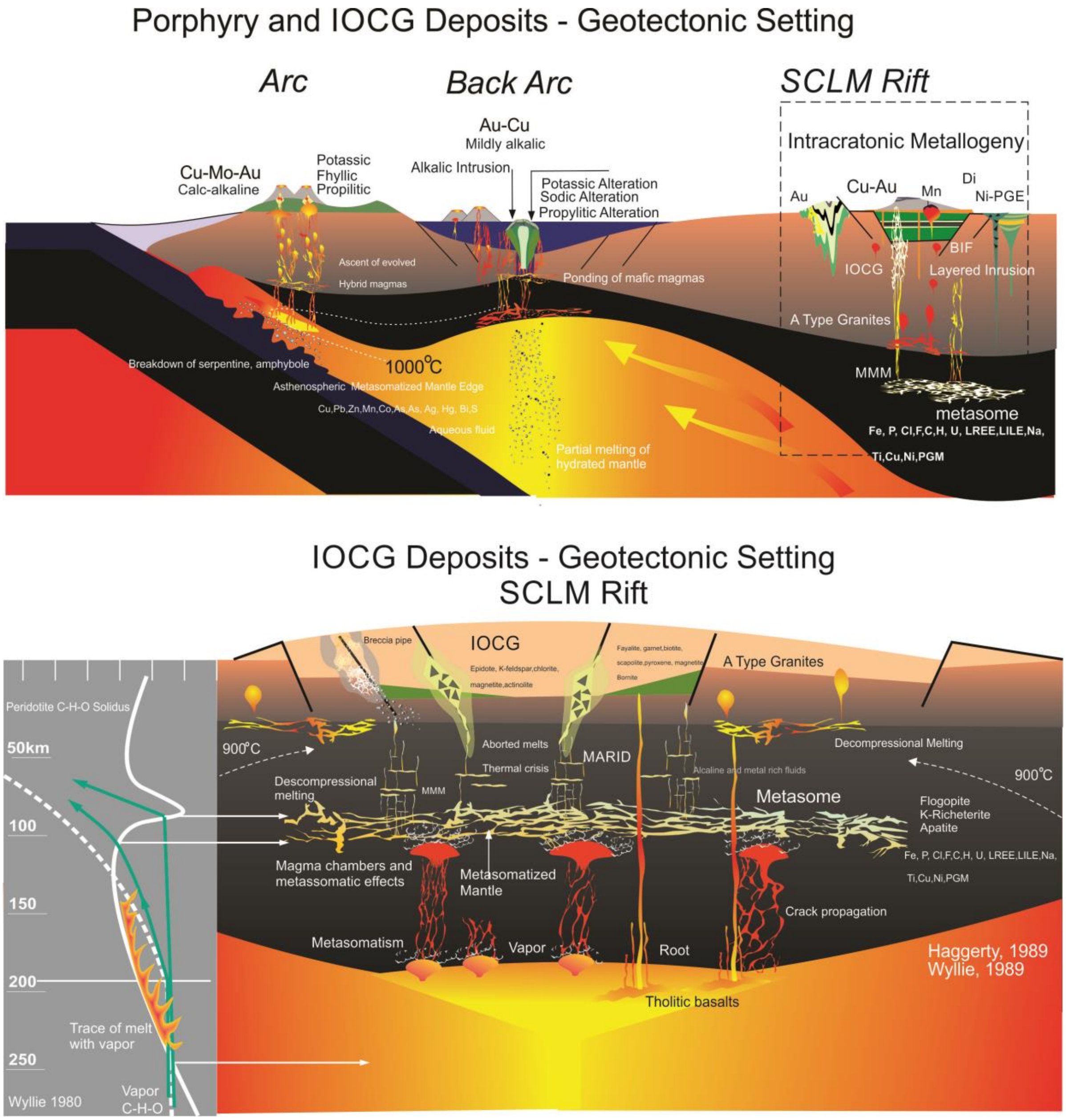

Figure 1: Geotectonic setting and metallogeny for porphyry and IOCG deposits at Arc, Back-arc and Intracratonic environment.