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Geological Criteria for Porphyry Copper Exploration

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1 Introduction

Porphyry Cu deposits, containing ~80% of the world's Cu resources, continue to be prime exploration objectives. The geological model for porphyry Cu deposits has developed progressively over the past century and, when applied to exploration, it successfully integrates empirical features with elements of porphyry Cu genesis as well as providing a template for interpretation of geochemical and geophysical data.

This summary highlights some basic features of the porphyry Cu model that can be deployed at the area selection, prospect appraisal and detailed exploration stages, preparatory to considering methods that were critical to recent major discoveries. Sillitoe (2010) and references therein provide further geological details.

2 Area Selection Criteria

Porphyry Cu deposits form at convergent plate margins in both Cordilleran and island arc (including back arc and post-collisional) settings where they are related to calc-alkaline and, far less commonly, alkaline magmatism. Magmatic arcs constructed during contractional tectonism and, hence, deficient in volcanic products tend to host the largest and highest-grade deposits. Arcs characterised by chemically reduced crustal profiles, extension resulting in compositionally bimodal (basalt-rhyolite) magmatism or widespread ash-flow caldera development are not prospective. Arcs older than mid-Mesozoic also tend to be less prospective because of the greater likelihood of deposits having been eroded.

Porphyry Cu deposits form in commonly closely spaced, spatially and temporally restricted belts, some more productive than others (e.g. central Andes). Therefore isotopic dating of prospects offers a valid means of preliminarily assessing potential. Porphyry Cu deposits also tend to occur in groups, forming either apparently random clusters or well-defined alignments. This fact emphasises the importance of brownfields exploration in the vicinity of known deposits.

Development of high-grade hypogene ore in many porphyry Cu deposits appears to have been influenced by host-rock permeability and/or chemical composition. Massive carbonate sequences inhibit dissipation of the mineralizing fluids, thereby enhancing internal Cu precipitation, as well as inducing proximal skarn formation where permeability is adequate. Ferrous Fe-rich host rocks reduce the fluids, causing efficient Cu precipitation beyond the porphyry intrusions.

3 Prospect Appraisal Criteria

Porphyry Cu exploration commonly focuses on prominent colour anomalies produced by kaolinite and limonite resulting from supergene oxidation of pyritic rocks, most of them located either above or around the main Cu concentrations. However, deposits that are relatively deeply eroded and dominated by potassic alteration may lack appreciable peripheral pyrite and, hence, give rise to far subtler visual expressions.

During exploration, alteration zones related to porphyry Cu deposits need to be distinguished from those of different origins. The best criterion is the presence of EDM (halo)-, A-, B- and/or D-type veinlets, all of which withstand the effects of weathering. Increased veinlet intensity is an effective vector to ore.

Surface recognition of alteration zoning is also a good method of vectoring towards porphyry Cu ore. Centrally positioned potassic and overlying and/or overprinted chlorite-sericite or sericitic alteration can constitute ore, although the first two of these are unstable during weathering and may be at least partially masked by supergene kaolinisation. Widespread sodic-calcic alteration suggests that the roots of a system may be exposed and any orebody eroded.

Many visually and topographically prominent and, commonly, areally extensive advanced argillic alteration

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zones constitute the shallow portions of porphyry Cu systems; they may host high-sulphidation (HS) epithermal Au ± Ag orebodies of either disseminated or lode type. Since most of these advanced argillic lithocaps are erosional remnants, exploration should commence around their peripheries, in case porphyry Cu centre(s) have already been exhumed, before being tested at depth internally. Lithocap mineralogy can provide vectors to the underlying porphyry intrusions. Intermediate-sulphidation epithermal Au ± Ag orebodies can form on the margins of lithocaps, where they tend to be overshadowed by the prominence of the advanced argillic alteration.

The hydrothermal breccias common in porphyry Cu deposits need to be carefully distinguished. Magmatic-hydrothermal breccias that contained open space during sulphide introduction may have enhanced Cu tenors, whereas matrix-supported phreatomagmatic breccias filling diatreme vents are commonly barren and may even destroy pre-existing ore. Mineralized clasts in diatreme breccias may provide evidence for underlying porphyry Cu and associated mineralization.

The alteration zoning of porphyry Cu systems is reflected by their geochemical responses. Maximum Cu values, accompanied by Mo and/or Au, define potential ore zones and are surrounded by propylitic haloes containing Zn, Pb, Ag (± Au) and Mn.

4 Detailed Exploration Criteria

Copper and any accompanying Mo and/or Au mineralization in porphyry Cu deposits is normally heterogeneously distributed as a result of several factors, including relative intrusion age and sulphide zoning. This heterogeneity needs to be accurately defined for resource estimation purposes.

Porphyry Cu stocks or dykes are typically composite, comprising early, inter-mineral and late-mineral phases. Inter-mineral porphyries cut the already-mineralized early porphyry phases and, consequently, are lower in grade. Late-mineral phases are largely barren.

Upward and outward sulphide zoning, particularly increases in pyrite/chalcopyrite ratios, can provide a useful vector at the drilling stage. Within pyrite-poor, potassic core zones, bornite/chalcopyrite ratios may increase downwards, resulting in higher Cu ± Au tenors, whereas pyritic, HS assemblages, containing bornite, chalcocite, covellite and/or enargite, typify the shallow sericitic and advanced argillic zones. Where these zones overprint mineralized quartz veinlet stockworks, Cu contents can be increased (hypogene enrichment).

This sulphide zoning, which results in total sulphide contents ranging from 2-3 vol. % in the cores of deposits to 10-20 vol. % in their outer and upper parts, dictates interpretation of induced-polarisation (IP) chargeability responses. The presence of up to 10 vol. % of magnetite in the potassic zones of many Au-rich porphyry Cu deposits generates readily detectable magnetic anomalies. Properly interpreted IP and magnetic anomalies can assist with the efficient drill-out of porphyry Cu prospects.

5 Recent Discovery Methodologies

Discoveries of major porphyry Cu deposits are rare events, with only nine worldwide during the last decade. Six of them resulted from brownfields exploration programmes, and six were entirely concealed beneath post-mineral cover.

Vectoring based on alteration and/or sulphide mineralization observed in pre-existing drill core or reverse-circulation (RC) cuttings was influential in seven of the discoveries. In three of these, previous explorers had failed to make the key observations that led to eventual discovery.

Top-of-bedrock (beneath post-mineral cover) or drainage geochemistry was an important ingredient in the discovery of two deposits, and persistent drill testing of deep chargeability anomalies resulted in one of the brownfields discoveries. Geophysics was also successfully integrated with geological observations in three other discoveries.

Therefore detailed geological (re)appraisal of drill core or cuttings has been the key tool used in recent porphyry copper discoveries, albeit with significant contributions also being made by conventional geochemistry and prospect-scale IP or magnetic surveys.

Reference

Sillitoe, R.H., 2010. Economic Geology, 105: 3-41.