The Late Miocene Middle Cauca Au-Cu Porphyry Belt, Colombia: Time-Space Distribution of Magmatism and Controls on Au Mineralization

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Abstract. The Middle Cauca Belt in west-central Colombia contains a number of porphyry (e.g. Titribí, Nuevo Chaquiro) and low to intermediate-sulfidation epithermal deposits (e.g. Marmato, Zancudo), ranging in age from ~ 9 to 5.6 Ma. The deposits are hosted in the Romeral melange, a tectonized basement complex containing Mesozoic oceanic and older metamorphic rocks, overlain by Oligocene siliciclastic and middle to upper Miocene arc-volcanic rocks. The porphyry deposits are generally gold-rich although Nuevo Chaquiro is copper-rich. The igneous rocks related to porphyries are largely calc-alkalic and oxidized but at Titiribí they are distinctly more alkalic. The current topography together with the volcanic stratigraphy and igneous geochemistry suggest that the gold-rich nature of the porphyries can largely be attributed to shallow emplacement and, in the case of Titirbí to the alkalic character of the intrusions rather than a reduced oxidation state of the intrusions. The latter is likely the case at the 28.5 Moz La Colosa gold porphyry deposit, emplaced in early Paleozoic carbonaceous schists of the Cajamarca-Valdivia terrane to the S and E of the MCB.

1 Introduction

High gold content and Au/Cu ratios in porphyry deposits may be due to shallow-crustal emplacement (e.g. Murakami et al. 2010), alkalic nature of parental intrusions (e.g. Lang et al. 1995, Bissig and Cooke 2014) or the reduced character of basement and intrusive suites (e.g. Hart 2007). The Middle Cauca belt (MCB) in Colombia (Fig. 1) contains several gold-rich porphyry systems with associated low-sulfidation epithermal deposits. In this paper we summarize the geologic and petrochemical characteristics of key districts located in the MCB and adjacent areas and discuss these deposits in the context of the models outlined above.

2 The Middle Cauca belt

2.1 Geology

The Middle Cauca Belt is defined as a belt of late Miocene porphyry and related deposits hosted in the Romeral melange (Cediel et al. 2003; Shaw et al. 2011) of west-Central Colombia (Fig. 1). It is separated from the early

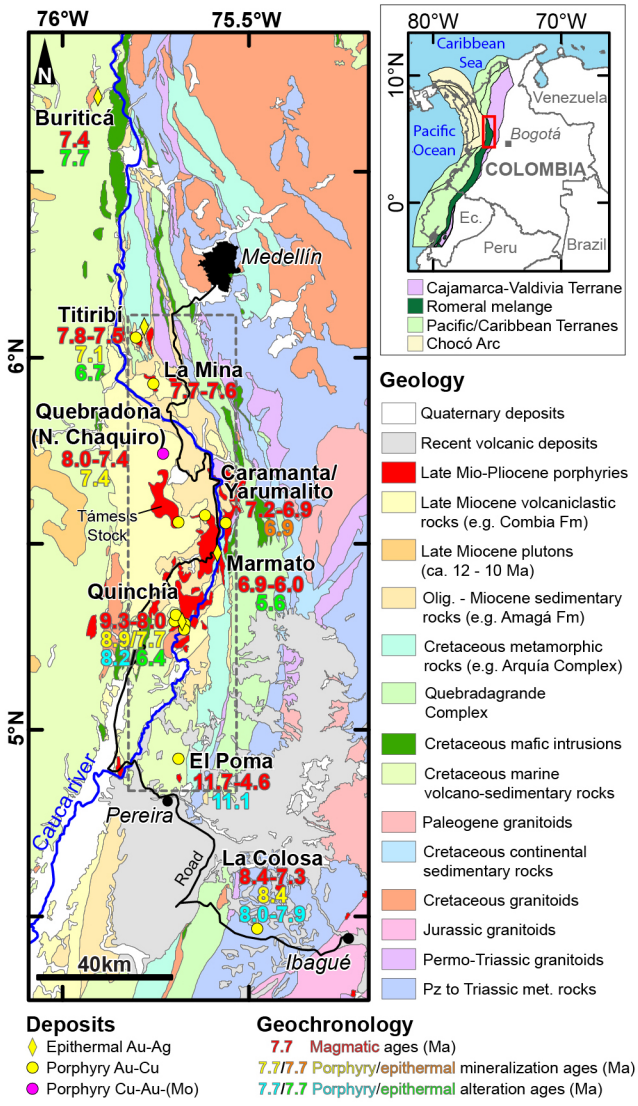

Figure 1. Geology, mineral deposits and geochronology of the Middle Cauca Belt (MCB) porphyries and associated deposits. Grey dashed outline shows the extent of the MCB

Paleozoic Cajamarca-Valdivia terrane to the E by the NE to N-striking Romeral strike-slip fault system, and from the Pacific terranes and the Chocó Arc to the W by the Garrapatas-Dabeiba fault system (Cediel et al. 2003). The

basement of the Romeral melange comprises low-grade metamorphosed basaltic-gabbroic ocean floor assemblages interpreted as accreted remnants of a peri-cratonic continental margin basin (e.g. Quebradagrande complex; Nivia et al. 1996) containing local slivers and fragments of early Paleozoic and Permo-Triassic schists, gneisses and amphibolites (e.g. Arquía complex). Within the MCB, basement is overlain by upper Oligocene to lower Miocene siliciclastic rocks of the Amagá Formation and the mafic to felsic volcanic rocks of the middle to upper Miocene Combia formation.

2.2. Ore deposits

Key porphyry districts are briefly summarized from N to S below (Fig. 1).

The Titiribí Au-Cu porphyry cluster (4.6 Moz Au, ~0.3 Mt Cu), and overprinting low-sulfidation epithermal mineralization at Zancudo and Chisperos (Kantor and Cameron 2016), are located near the northern limit of the Romeral melange. Porphyry mineralization accompanies diorite stocks intruding the Amagá and Combia formations between 7.8 and 7.1 Ma. Sericite adjacent to epithermal mineralization at Chisperos is slightly younger (6.7 ± 0.1 Ma). Epithermal mineralization at Zancudo is hosted in Arquía Complex metamorphic rocks.

The Quebradona district contains five porphyry centers emplaced in the Combia Formation between 8.0 and 7.4 Ma. The 566 Mt @ 0.64% Cu, 0.31 g/t Au Nuevo Chaquiro Cu-Au-(Mo) porphyry, located at the center of the district, was discovered at a depth of 250 m below surface (Bartos et al. 2017). Minor intermediate-sulfidation epithermal Au mineralization crops out above the porphyry Cu mineralization.

Caramanta includes a cluster of porphyry Au-Cu prospects also intruding the Combia Formation, some 30 km SE of Nuevo Chaquiro. Mineralization is centered on granodiorite porphyries dated at 7.2 - 7.1 Ma, spatially and temporally related to the eastern margin of the Tamesis Stock (Fig. 1; 7.8 - 7.2 Ma). Intermediate-sulfidation epithermal mineralization associated with E-trending structures cutting the Tamesis Stock 500 m to the west, yielded an age of ~8.2 Ma.

About 2.3 Moz Au have been produced at Marmato making it the most important gold producer in the MCB. Published resources of 14.4 Moz Au and 90 Moz Ag are the largest within the MCB. The mineralization style is low- to intermediate-sulfidation epithermal, but Au-rich porphyry has also been identified at depth. 6.9 to 6.0 Ma diorite-granodiorite porphyries intruding the Arquía complex, host mineralization. Sericite related to epithermal mineralization yielded a K-Ar age of 5.6 Ma (Tassinari et al. 2008).

The Quinchía District includes several porphyry Au prospects including La Cumbre (2.5 Moz Au, 145 t Cu), Tesorito and Dosquebradas, as well as the Miraflores low-sulfidation epithermal breccia deposit (1.82 Moz Au). Age constraints range from 8.9 to 8.0 for granodiorite porphyries and 7.7 Ma for molybdenite at Dosquebradas. At Tesorito, a ~9.1 Ma early phenocrystic garnet-bearing granodiorite porphyry hosts mineralization (Bissig et al. 2017).

El Poma, a porphyry Au (-Cu) prospect, recently discovered 40km to the south of the Quinchía district, extends the southern end of the historically known Middle Cauca belt. Granodiorite porphyries at El Poma range in age from ~11.75 to 8.8 Ma, the latter likely representing the mineralization age. A post-mineral plagioclase porphyry dyke was dated at 4.65 ± 0.2 Ma. Extensive volcanic deposits associated with the presently active arc partially cover prospective rock units to the south of El Poma, indicating under cover exploration potential in the southern MCB.

Additional ore deposits of similar age to those of the MCB, but located outside the geological limits of the Romeral melange, include La Colosa and Buriticá (Fig. 1).

The 28.5 Moz La Colosa porphyry Au deposit, located some 50 km SE of El Poma, contains the largest gold resource in Colombia. Mineralization was dated at 8.43 Ma (Re/Os, molybdenite; Leal-Mejía 2011). It is hosted by early Paleozoic carbonaceous schists of the Cajamarca-Valdivia terrane and is not considered part of the MCB.

Buriticá (3.7 Moz Au, 10.7 Moz Ag) is a high-grade intermediate-sulfidation epithermal Au deposit located some 75 km N of Titiribí. It is hosted by 7.41 ± 0.4 Ma granadiorite porphyry which intrudes early-mid Cretaceous Cañas Gordas terrane oceanic sedimentary and volcanic rocks. The age of hydrothermal sericite associated with mineralization is within error of the host-rock age (Lesage et al. 2013).

3 Temporal and Spatial trends

The oldest igneous rocks of the MCB (~12 - 11 Ma), are represented by felsic crystal tuffs of the Combia Formation and garnet-bearing granodiorite porphyries, both located in the south, at El Poma. Sericite, albeit of uncertain relationship to gold mineralization, was also dated at that age. Coeval 12 to 10 Ma plutons were documented in the Cañas Gordas terrane (Western Cordillera) 25 - 30 km W of the MCB (Leal-Mejía 2011). After 10 Ma, magmatism and porphyry mineralization migrated northward along the MCB to reach the Titiribí district by 7.5 Ma. After 7.3 Ma, magmatic activity and mineralization returned to the central part of the belt (e.g. Caramanta, Nuevo Chaquiro), and locally, an eastward-younging trend is recognized. The easterly-most deposit, Marmato, was emplaced after 6.8 Ma. Epithermal Au mineralization was formed shortly after porphyry mineralization in the Titiribí and Quinchía districts, but may be as old as, or older than, porphyry mineralization in the El Poma and Caramanta districts.

4 Igneous geochemistry

There is a general trend towards increasing SiO_2 content of porphyries and volcaniclastic rocks of the Combia Formation from N to S within the MCB (Fig. 2). Igneous

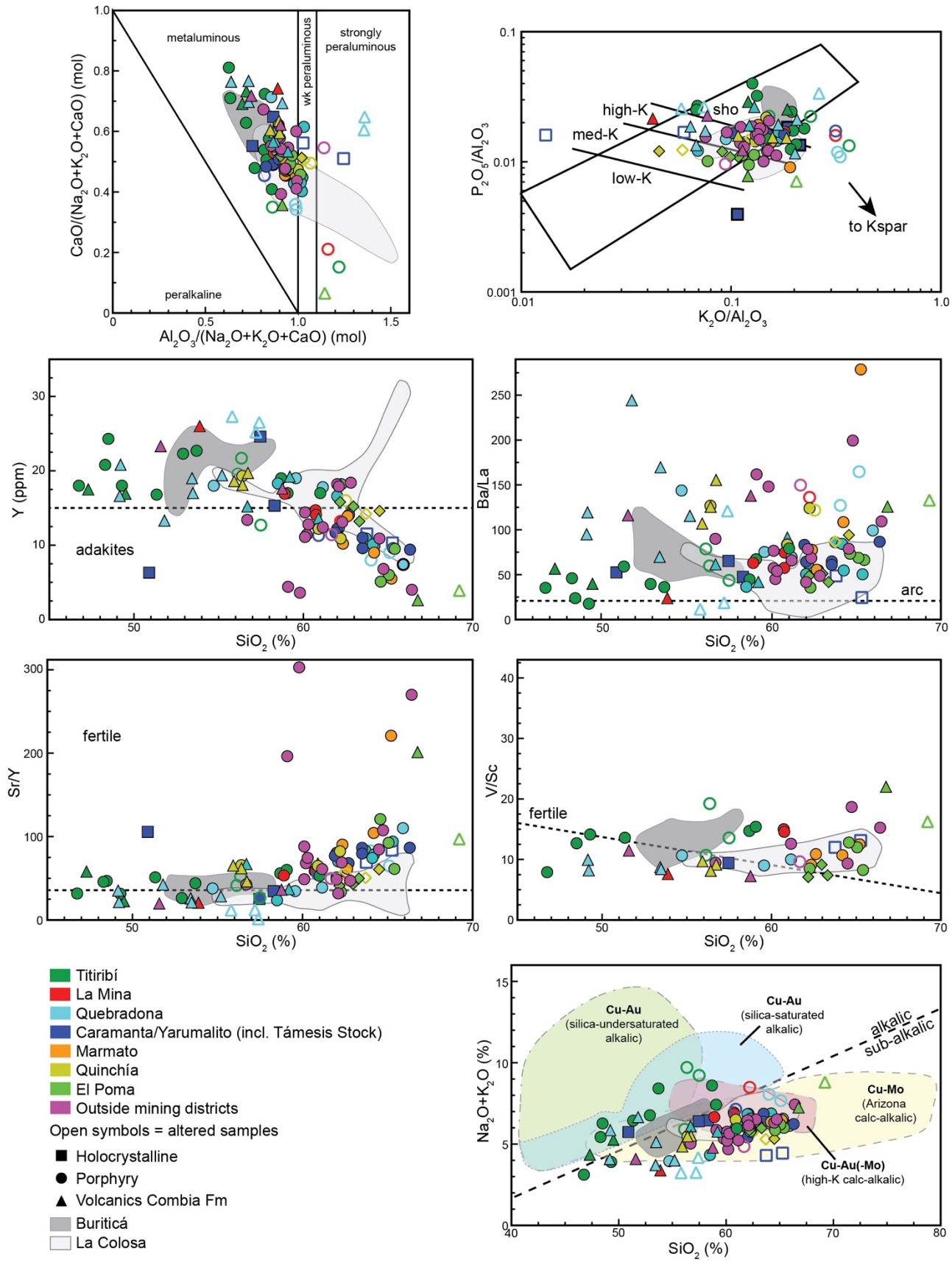

Figure 2. Lithogeochemistry of magmatic rocks of the Middle Cauca Belt. Abbreviations: *wk* weakly, *med* medium, *sho* shoshonite, *Kspar* K-feldspar.

rocks of most porphyry districts and age-equivalent porphyries unrelated to known mineralization exhibit "adakite-like" geochemical signatures and fall into the "porphyry fertile" compositions using Sr/Y and V/Sc diagrams (Loucks 2014). However, igneous rocks from Titiribí have a subtle but distinctly more alkaline character when compared to other districts to the South (Fig. 2). Igneous rocks from the Buriticá epithermal deposit, some 75 km N of Titiribí but located in the Cañas Gordas Terrane of the Chocó arc, have a similarly alkalic affinity. Unlike the other porphyry districts in the MCB, but similar to other alkalic porphyry deposits elsewhere (Bissig et al. 2014), many igneous rocks from Titiribí and Buriticá do not fall in the porphyry fertile fields.

5 Discussion

The MCB and nearby Miocene porphyry-related ore deposits are generally gold-rich. The high Au/Cu ratios are herein largely attributed to shallow emplacement of porphyry systems (cf. Murakami et al. 2010). This can be inferred from the temporal relationship of porphyry stocks with only slightly older host-volcanic rocks, as well as from the proximity and similar age of epithermal and porphyry mineralization. Comparatively high Cu content is only reported from the Nuevo Chaquiro deposit where 810m @ 1.65% Cu and 0.78g/t Au was intersected starting at 400 m depth (CHA-50 drillhole, AngloGold Ashanti 2014). Based on whole-rock geochemical and mineralogical characteristics (Bissig et al. 2017), mineralizing porphyries are water-rich and oxidized, and thus similar to other porphyry provinces around the world (Loucks 2014). A notable exception is the Titiribí district where the Au-rich nature of mineralization can potentially be attributed to the mildly alkalic nature of magmatism, as widely documented for other alkalic porphyry deposits (Lang et al. 1995; Bissig and Cooke 2014).

In contrast to the MCB porphyries, the Cu-poor but Au-rich nature of the giant La Colosa porphyry deposit is best explained by the relatively reduced nature of the causative intrusive rocks. The latter are hosted in strongly reducing Paleozoic carbonaceous schists of the Cajamarca-Valdivia terrane. La Colosa can best be classified as a reduced, gold-rich porphyry system within the clan of reduced intrusion-related gold deposits (Rowins 2000, Hart 2007).

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References

AngloGold Ashanti (2014) Q2 2014 Exploration update report. http://www.anglogoldashanti.com/en/Media/Reports/Quarterly%20Reports/Q22014Exploration.pdf. Accessed 03 February 2017

Bartos PJ, García C, Gil J (2017) The Nuevo Chaquiro Cu-Au-(Mo) deposit, Middle Cauca Belt, Colombia: geology, alteration, mineralization. Economic Geology 112:275-294

Bissig T, Cooke DR (2014) Introduction to the special issue devoted to alkalic porphyry Cu-Au and epithermal Au deposits. Economic Geology 109:819-25

Bissig T, Del Real I, Vaca S (2014) Late Triassic to Early Jurassic basalts and intrusions related to alkalic and calc-alkalic porphyry Cu-Au deposits of the Quesnel Terrane, south-central British Columbia: petrochemistry, tectonics and metalllogeny. GSA Annual Meeting, Vancouver, British Columbia, paper 240-2

Bissig T, Leal-Mejía H, Stevens RB, Hart CJR (2017) High Sr/Y magma petrogenesis and the link to porphyry mineralization as revealed by garnet - bearing I - type granodiorite porphyries of the Middle Cauca Au - Cu belt, Colombia. Economic Geology 112:551-568

Cediel F, Shaw RP, Caceres C (2003) Tectonic assembly of the Northern Andean Block In: Bartolini C, Buffler RT and Blickwede J (eds) The circum-Gulf of Mexico and the Caribbean - hydrocarbon habitats, basin formation, and plate tectonics. AAPG Memoir 79:815–848

Hart CJR (2007) Reduced intrusion-related gold systems. Mineral Deposits of Canada: A synthesis of major deposit types, district metallogeny, the evolution of geological provinces, and exploration methods. Geological Association of Canada, Mineral Deposits Division, Special Publication pp 95-112

Kantor JA, Cameron RE (2016) Technical report on the Titiribí project, department of Antioquia, Colombia. NI-43-101 Report prepared by Behre, Dolbear and Co. for Brazil Resources Inc., p 179, available under the Brazil Resources Inc. SEDAR profile at www.sedar.com. Accessed 3 February 2017

Lang JR, Lueck B, Mortensen JK, Russell JK, Stanley CR, Thompson JF (1995) Triassic-Jurassic silica-undersaturated and silica-saturated alkalic intrusions in the Cordillera of British Columbia: Implications for arc magmatism. Geology 23:451-454.

Leal-Mejía H (2011) Phanerozoic gold metallogeny in the Colombian Andes: a tectono-magmatic approach. PhD thesis, University of Barcelona, 989 p

Lesage G, Richards JP, Muehlenbachs K, Spell TL (2013) Geochronology, geochemistry, and fluid characterization of the late Miocene Buriticá gold deposit, Antioquia Department, Colombia. Economic Geology 108:1067-1097

Loucks RR (2014) Distinctive composition of copper-ore-forming arc magmas. Australian Journal of Earth Sciences 61:5-16

Murakami H, Seo JH, Heinrich CA (2010) The relation between Cu/Au ratio and formation depth of porphyry-style Cu–Au±Mo deposits. Mineralium Deposita 45:11-21

Nivia A, Marriner G, Kerr A (1996) El Complejo Quebrada Grande: una posible cuenca marginal intracratónica del Cretáceo Inferior en la Cordillera Central de los Andes Colombianos. In: Abstracts of the VII Colombian Geological Congress, vol III, p 108–123

Rowins S (2000) Reduced porphyry copper-gold deposits: A new variation of an old theme. Geology 28:491-494

Shaw RP, Padilla R, Leal H (2011) Colombia's So-Called "Middle Cauca Porphyry Belt": towards an empirical definition. Abstract AME RoundUp 2011, Vancouver, 24-27 January 2011.

Tassinari CC, Pinzon FD, Ventura JB (2008) Age and sources of gold mineralization in the Marmato mining district, NW Colombia: a Miocene–Pliocene epizonal gold deposit. Ore Geology Reviews 33:505-518