Ore Geology Reviews 38 (2010) 37–58

Contents lists available at ScienceDirect

Ore Geology Reviews

journal homepage: www.elsevier.com/locate/oregeorev

Geology, petrography and geochemistry of igneous rocks related to mineralized skarns in the NW Neuquén basin, Argentina: Implications for Cordilleran skarn exploration

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ARTICLE INFO

Article history:
Received 15 January 2010
Received in revised form 19 May 2010
Accepted 20 May 2010
Available online 27 May 2010

Keywords:
Igneous rocks
Mineralized Cu
Fe
Au skarns
NW Neuquén Basin
Argentina

ABSTRACT

Five mineralized Cu, Au, and Fe skarns and related igneous rocks of the Andes Cordillera of NW Neuquén (Paleogene Campana Mahuida, Caicayén and Cerro Nevazón) and SW Mendoza (Neogene Vegas Peladas and Hierro Indio) provinces of Argentina (34–38°S) are reviewed to demonstrate that geochemical signatures of igneous rocks can be used to predict the metal potential of skarn prospects of the Andes Cordillera of Argentina. These igneous rocks are calc-alkaline, metaluminous, and derived from a sub-arc mantle source without residual garnet. They were emplaced at shallow depths. The Vegas Peladas, Hierro Indio, and Cerro Nevazón igneous rocks have similar major and trace element contents, and are typical of primitive, I-type plutons associated with Fe skarns worldwide. The Vegas Peladas and Hierro Indio plutons are, however, less reduced and they have lower Ni concentration than the Cerro Nevazón rocks, whose skarns have higher Au concentrations. In the Caicayén district, small skarns with sub-economic Cu concentrations and abundant pyrite are associated with porphyry copper style alteration in igneous rocks that underwent amphibole fractionation. Their chemical compositions are intermediate between the most primitive plutons associated with Fe skarns and the most evolved plutons associated with Cu skarns, both with high fO_2. At Campana Mahuida a small porphyry copper deposit and associated Cu skarns are linked to andesite dikes and pluton with similar SiO_2 contents but richer in incompatible trace elements (K, Rb, Sr, Ba, La, Ce, and Th) than the Mendoza, Cerro Nevazón and Caicayén igneous rocks. This suggests that their parental magmas evolved in an open system and were contaminated with crustal material, thus resulting in the strongest fractionation of amphibole and accessories phases. These intrusions share many features with typical Cu skarns-related plutons.

1. Introduction

There are 28 mineralized skarns in the Andes segment between 34° and 38°S known as Cordillera Principal of SW Mendoza and NW Neuquén (Méndez et al., 1995; Franchini and Dawson, 1999; Franchini, 2005; Franchini et al., 2007a, b, Pons et al., 2009). They are related to Andean Cordillera plutons that are part of a magmatic belt of calc-alkaline rocks caused by eastward subduction of the Nazca (Farallon) plate beneath South America (Davison and Mpodozis, 1991; Franchini et al., 2003; Pons et al., 2007). Their ages decrease from Paleogene, between 36° and 38°S, in NW Neuquén to Neogene between 34 and 36°S, in SW Mendoza (Fig. 1; Franchini et al., 2003, 2007b; Pons et al., 2007).

Skarn size and economic importance range from outcrops with only exploratory trenching and sampling to small deposits (e.g., Hierro Indio and Vegas Peladas; Zanettini, 1999; Franchini and Dawson, 1999; Franchini et al., 2007a, 2007b; Pons et al., 2009) that have been mined for Fe and Cu in the early 1900s. Some of these mineralized skarns are related to porphyry copper deposits (e.g., Campana Mahuida; Sillitoe, 1977; Franchini and Malvicini, 1998; Chabert and Zanettini, 1999) or porphyry-style alteration and mineralization (Caicayén District; Casé and Malvicini, 1999; Franchini et al., 2000). Other examples are enriched in precious metals (e.g., Ag at Cerro La Virgen and Aguas Amarillas skarns; Angelelli, 1984; Franchini and Dawson, 1999, or Au at Cerro Nevazón; Franchini et al., 1999).

This paper is a review of the geology, petrography and geochemistry of igneous rocks related to mineralized skarns in NW Neuquén (Campana Mahuida, Cerro Nevazón and Cerro Caicayén; Franchini et al. 2003; Franchini 2005; Franchini et al., 2007a; Table 1) and SW

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doi:10.1016/j.oregeorev.2010.05.006

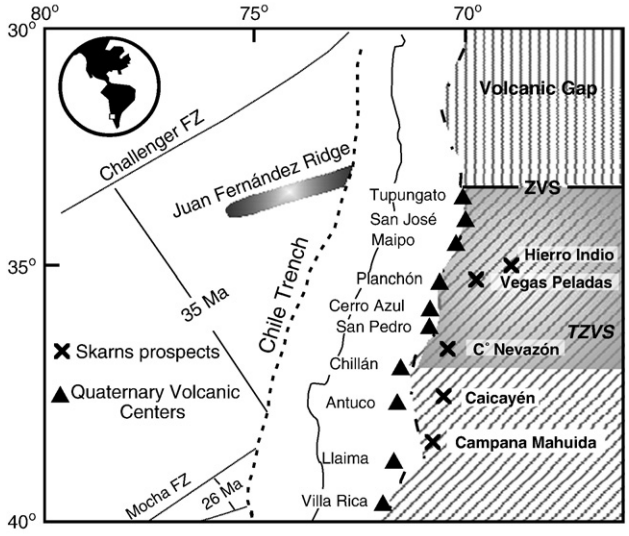

Fig. 1. Location map of the skarn prospects associated with Paleogene (Campana Mahuida, Cerro Nevazón and Caicayén) and Neogene (Vegas Peladas and Hierro Indio) igneous rocks and of other volcanic centers from the Southern Volcanic Zone segment (SVZ) and Transitional Southern Volcanic Zone (TSVZ, modified from López Escobar, 1984; Tormey et al., 1991; Franchini et al., 2003).

Mendoza (Vegas Peladas and Hierro Indio; Franchini et al., 2007b; Pons et al., 2007; Pons et al., 2009; Table 1), including the main characteristics of each deposit. The compositions of Neuquén and Mendoza igneous rocks (Appendices A-D) are compared to the subduction-related plutons associated with Fe, Au, Cu and Zn skarns in other parts of the world (Meinert, 1995) to address the relationship between pluton composition and the metal content of associated skarns. Interestingly, although the igneous rocks from NW Neuquén and SW Mendoza seem to have formed from similar mantle-generated magmas, differences in the evolutionary trends of these magmas correlate with the styles of alteration and mineralization in the resulting skarns. Thus, the geochemical signatures of igneous rocks can be useful in predicting the metal potential of the numerous skarn prospects of the Andes Cordillera of western Argentina, even where outcrops are limited.

2. Setting

The study areas are located in the Andes Cordillera, in the segment belonging to the actual Southern Volcanic Zone (Fig. 1; SVZ, 33°–46°S; Hildreth and Moorbath, 1988; Tormey et al., 1991; Ferguson et al., 1992) where the thickness of continental crust decrease from the north (Northern SVZ) between 33° and 34°30′S (65–60 km; Hildreth and Moorbath, 1988 and references therein) to the south (55 km; Transitional SVZ between 34.5° and 37°S) and Southern SVZ between 37° and 46° (42–35 km; López Escobar, 1984; Tormey et al., 1991; Ramos et al., 2004). In this region, Mesozoic and Cenozoic sedimentation and magmatism were superimposed on a Paleozoic basement of accreted continental and oceanic terranes (Mpodozis and Ramos, 1998). A significant feature is the NW-trending Cortaderas lineament, 220 km in length (36°S; Ramos and Kay, 2006), that correlates with a change in the structure of the underlying continental crust and mantle lithosphere (Ramos and Kay, 2006). This lineament separates two regions with differences in the geometry of the subducting slab and crustal rheology and marks the southern limit of a Miocene shallow subduction zone. North of the lineament, Neogene backarc magmatism changes from an early Miocene non-arc-like chemistry, to a late Miocene arc-like chemistry and then back to a Pliocene non-arc chemistry (Kay et al., 2006). South of the lineament, Neogene backarc magmatism is absent (Kay et al., 2006) and the region was characterized by a constant normal subduction with little fluctuations in the position of arc front from the Cretaceous to the Quaternary (Ramos and Kay 2006).

3. Geological framework of NW Neuquén and SW Mendoza

The Campana Mahuida, Nevazón and Caicayén districts are located in the Cordillera Principal of NW Neuquén, along the western boundary of the Thrust Belt segments of the Chos Malal and Agrio Fold Belts defined by Bracaccini (1970) and Ramos (1978) (Fig. 2). The region is characterized by a series of E-verging folds and related thrusts which developed a complex thrust front that is bounded to the east by an area of gentle folding. These fold belts are bordered on the NW and SE, respectively, by the Cordillera del Viento anticline and the Loncopué graben, an extensional structure filled with Plio-Pleistocene basalts (Ramos, 1999). The Agrio and Chos Malal Fold Belts consist of 7000 m of Jurassic and Cretaceous sedimentary rocks that unconformable overlie Permian–Triassic volcaniclastic basement (the Choiyoi Group; Fig. 2). The structures of the area have a N–S orientation and are dominated by folds with complex faults. This area was affected by Paleogene magmatism which cuts the fold and fault structures (e.g., Cerro Negro, Cerro Mayal, Cerro Caicayén, Collipilli, Franchini et al., 2003).

The Vegas Peladas and Hierro Indio prospects are located in the fold and thrust belt of Malargüe (34°–36°S; Kozlowski et al., 1993; Mingramm et al., 1993), in the central-south Andes segment known as Cordillera Principal of SW Mendoza province (Fig 2; Ramos, 1993). During the Late Triassic–Early Tertiary, this region located east of the arc–trench system, was characterized by a series of fault-bounded depressions, and the tectonic regime was dominated by extension and subsidence with local episodes of uplift, folding, and erosion (Gulisano and Gutiérrez-Pleimling, 1995). These basins were filled with more than 6000 m of Late Triassic to Paleocene marine and continental sedimentary rocks that unconformably overlie the Permian–Triassic volcaniclastic basement of the Choiyoi Group (Fig. 2). Compressional tectonics began in the Tertiary (Gulisano and Gutiérrez-Pleimling, 1995) forming the thick-skinned Malargüe fold and thrust Belt (Kozlowski et al., 1993). This compression was followed by widespread volcano-plutonic activity, represented in this segment by three magmatic cycles (Ramos and Nullo, 1993): the Late Eocene to Early Oligocene Molle Group (Haller et al., 1985; Nullo, 1985), the widespread Miocene Huincán Formation (Nullo, 1985; Bouza, 1991; Baldauf et al., 1992), and young Pleistocene volcanism (Ramos and Nullo, 1993). Typical Cordilleran I-type plutons were emplaced into the Mesozoic–Cenozoic sedimentary sequences along the main (N–S) thrust faults and folds (Ramos and Nullo, 1993).

4. General characteristics of mineralized skarns and associated igneous rocks

4.1. The Cerro Nevazón skarns

Three mineralized skarn bodies occur at the contact of the Paleogene (60.1 ± 1.6 to 56 ± 1.7 Ma) igneous rocks with the Jurassic micritic limestone siltstone and sandstone and Cretaceous black shale (Table 1). The skarns are similar to Au-rich skarn deposits elsewhere (Franchini et al., 1999; Table 1). The igneous rocks consist of three stocks and numerous sills and dikes and crop out along the eastern boundary of the Cordillera del Viento (Fig. 2), between Cajón del Medio and Cajón Grande creeks. The stocks intruded the core of an anticline and occur as three discontinuous outcrops with an elliptical shape, elongated in the N–S direction; these may be apices of a single