Ore Geology Reviews 65 (2015) 327–364

Contents lists available at ScienceDirect

Ore Geology Reviews

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

Review

Physiographic and tectonic settings of high-sulfidation epithermal gold–silver deposits of the Andes and their controls on mineralizing processes

Thomas Bissig [a,*], Alan H. Clark [b], Amelia Rainbow [b], Allan Montgomery [c]

[a] Mineral Deposit Research Unit, University of British Columbia, 2020-2207 Main Mall, Vancouver, BC V6T 1Z4, Canada
[b] Queen's University, Bruce Wing/Miller Hall, Kingston, ON K7L 3N6, Canada
[c] Riverside Resources Suite 1110, 1111 West Georgia Street, Vancouver, BC V6E 4M3, Canada

ARTICLE INFO

Article history:
Received 6 July 2014
Received in revised form 10 September 2014
Accepted 17 September 2014
Available online 28 September 2014

Keywords:
High-sulfidation
Epithermal
Andes
Landscape evolution
Erosion
Uplift
Flat subduction
Neogene

ABSTRACT

Gold and silver ores in the vast majority of Andean high-sulfidation epithermal Au–Ag deposits occur at high present day elevations and typically 200–500 m below low relief landforms situated at 3500 to 5200 m a.s.l. Most deposits are middle Miocene and younger and include, El Indio, Tambo, Pascua–Lama, Veladero (El Indio belt, Chile/Argentina), Cerro de Pasco (Central Peru), Pierina, Lagunas Norte, Yanacocha (northern Peru), Quimsacocha (Ecuador), and the California–Vetas mining district (Santander, Colombia), jointly accounting for >130 Moz Au resources. Slightly older examples are only preserved in the Atacama Desert and include the middle Eocene El Guanaco and El Hueso and the late Oligocene/early Miocene La Coipa deposits. The absence of Paleocene and older high-sulfidation epithermal deposits can be explained by limited preservation potential imposed by transpressional tectonics within overall contractile episodes and surface uplift. These conditions prevailed predominantly in segments of shallow-angle subduction of the Nazca or Caribbean plate below the South American continent, a tectonic setting also common for porphyry-style Cu (–Au, Mo) deposits. Stratovolcanoes are uncommon ore hosts and volcanic rocks coincident with mineralization are in most cases volumetrically restricted or absent, recording the terminal stages of local arc magmatism. However, dacitic domes are important at, e.g., Yanacocha and La Coipa. At Lagunas Norte, a small stratovolcano largely pre-dating but temporally overlapping with mineralization occurs immediately east of the deposit and volcanic sector collapse may have occurred during hydrothermal activity.

Mineralization is typically located near the backscarp of pediments or the heads of valleys incising now high-elevation, low-relief surfaces. In the California–Vetas Mining District and El Indio belt, hydrothermal alunite ages become generally younger upstream along the incising valleys, indicating that hydrothermal activity and, by inference, ore deposition were facilitated by erosion. The lowering of the water table and reduction of hydrostatic and lithostatic pressure at these sites of high local relief are believed to have enhanced both boiling and mixing of magmatic with meteoric fluids, ultimately enhancing ore deposition.

The host rock composition, permeability and location of the water table control the distribution of alteration zones and ore. Intermediate volcanic rocks are the most common ore-hosts but they typically pre-date mineralization by several Ma. However, high-sulfidation epithermal mineralization can be hosted in any conceivable rock type including high grade metamorphic rocks (California–Vetas mining district), significantly older plutonic rocks (Pascua–Lama) or quartzites (Lagunas Norte). Large vuggy quartz alteration zones and commonly oxidized low-grade large-tonnage mineralization are best developed in relatively permeable volcaniclastic rocks or hydrothermal breccia bodies, whereas coherent volcanic, plutonic, or metamorphic rocks may host fault- and breccia-controlled ores. The near-surface steam-heated zone can attain a thickness of several hundred meters in dry climates (e.g. Veladero, Pascua–Lama, Tambo) but is typically poorly developed and less than 20 m thick in humid climatic zones.

The physiographic and tectonic settings of high-sulfidation epithermal deposits are distinct from low-sulfidation epithermal districts such as those of Patagonia, El Peñón (Chile) or Fruta del Norte (Ecuador). The latter range to significantly older ages (Jurassic to early Eocene) occur at mainly lower elevations and were emplaced in extensional settings. A temporal coincidence between uplift, erosion and mineralizing processes as well as a spatial and temporal association with porphyry style mineralization is not evident for these low-sulfidation districts.

---

* Corresponding author.
E-mail address: tbissig@eos.ubc.ca (T. Bissig).

http://dx.doi.org/10.1016/j.oregeorev.2014.09.027
0169-1368/

Contents

1. Introduction

The Andes are the world's most endowed region with respect to giant magmatic-hydrothermal ore deposits (Cooke et al., 2005). They host the largest-known porphyry copper deposits (e.g., Rio Blanco–Los Bronces–Los Sulfatos, El Teniente, Chuquicamata) as well as many of the world's largest epithermal Au–Ag deposits (e.g., Yanacocha, Lagunas Norte, Pascua–Lama, Veladero: Sillitoe, 2008). The vast majority of Andean epithermal deposits containing >10 Moz Au are of high-sulfidation type. These deposits have a close link to a magmatic source for fluids, volatiles and metals (e.g., Deyell et al., 2004; Rye, 1993) but form at depths of typically less than 1 km (e.g. Sillitoe, 2010) and consequently mineralizing processes are influenced by the near-surface physicochemical environment. The main focus of this review is on deposits and districts where the bulk of the precious metal is contained in the epithermal environment, i.e., the shallow part of magmatic-hydrothermal systems, and concentrates on the physiographic environment of epithermal mineralization. This paper does not discuss major porphyry Cu deposits in detail, although the shallow portions of many of these have been overprinted by epithermal mineralization or alteration (e.g., Masterman et al., 2004; Ossandón et al., 2001). Similarly, the deposits hosting Sn, W, Ag and Au ores in the eastern Cordillera of Bolivia and Peru are not discussed. Following a general summary of epithermal deposit types and their terminology, this article presents a comprehensive overview of the major high-sulfidation epithermal districts and mineral belts of the Andes. It focuses on the links between landscape evolution, climatic setting, volcanology and tectonics, and discusses the influence these factors can have on both mineralizing processes and the preservation of the deposits.

2. Epithermal deposits

Epithermal deposits are usually classified into sub-types based on either ore sulfide assemblage or characteristic associated alteration; both schemes have inherent limitations. Some of the most widely referenced review papers on the topic (Hedenquist et al., 2000; Sillitoe and Hedenquist, 2003; Simmons et al., 2005) prefer a classification into high, low and intermediate-sulfidation types. This classification scheme can, however, be problematic, because sulfide assemblages may be difficult to classify in a field exploration setting, particularly if the deposit has been oxidized. Moreover, sulfide assemblages within a single deposit may represent precipitation over the entire breadth of sulfidation state, from high to intermediate and low-sulfidation, depending on fluid–wall rock interaction (e.g., El Indio: Heather et al., 2003a, 2003b; Cerro de Pasco: Baumgartner et al., 2008; Lagunas Norte: Cerpa et al., 2013). Alternative classification is based on dominant alteration and gangue assemblages and includes quartz–adularia–sericite and quartz–alunite or acid sulfate type epithermal deposits (Heald et al. 1987, Tosdal et al., 2009), the former typically including low to intermediate-sulfidation sulfide assemblages and the latter associated with high-sulfidation deposits. The limitation of this classification scheme is that, particularly in high-sulfidation deposits, alteration may pre-date and may not be directly related to mineralization (see below).