A common hydrothermal magmatic system generates different styles of gold mineralization at Algamarca and Shahuindo, Northern Peru

Renzo Galdos[1], Jean Vallance[1], Patrice Baby[2], Gleb S. Pokrovski[2]

[1] Facultad de ciencias e ingeniería, Especialidad Ingeniería Geológica, Pontificia Universidad Católica del Perú Av. Universitaria 1801, San Miguel, Lima 15088, Perú. E-mail: rgaldosp@pucp.edu.pe
[2] Groupe Métallogénie Expérimentale, Géosciences Environnement Toulouse (GET), UMR 5563, Observatoire Midi-Pyrénées, Université de Toulouse, Centre National de la Recherche Scientifique (CNRS), Institut de Recherche pour le Développement (IRD), 14, Avenue Edouard Belin, F-31400 Toulouse, France

1 Abstract

Algamarca and Shahuindo are two neighboring intermediate-sulfidation Au-Ag epithermal deposits of Miocene age located in the Marañon fold and thrust belt in the north of Peru, hosted in sedimentary sequences rich in carbonaceous matter of the Goyllarisquizga Group. These two deposits show strongly different styles of mineralization. At Algamarca, mineralization is expressed by up to 2 m-thick veins of quartz and sulfide minerals, with native gold content, traces of gold telluride minerals and possibly invisible gold in arsenical pyrite. In contrast, at Shahuindo, disseminated and replacement sulfide mineralization dominates, with gold exclusively present as invisible gold in arsenical pyrite and arsenopyrite. Algamarca and Shahuindo deposits show, however, similarities in age and paragenetic sequences that strongly suggest they were formed at the same time and were part of the same magmatic-hydrothermal system.
KEYWORDS: Arsenical pyrite; Invisible gold; Native gold; Intermediate-sulfidation deposit.

2 Resumen

Un mismo sistema magmático hidrotermal generó distintos estilos de mineralización aurífera en Algamarca y Shahuindo, Norte de Perú
Algamarca y Shahuindo son depósitos contiguos de oro y plata, de sulfuración intermedia, del Mioceno, están ubicados en la faja corrida y plegada del Marañón al norte de Perú y están hospedados en las secuencias sedimentarias, ricas en materia orgánica, del grupo Goyllarisquizga. Estos dos depósitos muestran diferentes estilos de mineralización, Algamarca consiste en vetas de cuarzo y sulfuros de hasta 2m de potencia, donde el oro se presenta bajo la forma de oro nativo, teluros de oro a nivel de trazas y además se infiere la presencia de oro en pirita arsenical; mientras que en Shahuindo, la mineralización se encuentra como sulfuros diseminados o de remplazamiento y el oro se presenta únicamente como oro invisible en pirita arsenical y arsenopirita. Sin embargo, Algamarca y Shahuindo muestran similitud en edad y en sus características mineralógicas y paragenéticas, indicando que se formaron coetáneamente y son probablemente parte de un mismo sistema magmático hidrotermal.

3 Introduction

The Marañon fold and thrust belt of Northern Peru hosts various porphyry-to epithermal-style gold deposits of Miocene age. Some of these deposits (e.g., La Arena, Lagunas Norte, Fig. 1), hosted by sedimentary sequences rich in organic matter of the Goyllarisquizga Group, are known as the metallogenic belt XXIA (Acosta et al., 2009). Algamarca and Shahuindo are two intermediate-sulfidation epithermal deposits that are part of this belt and are just ~2 km one from another (Fig. 1).
At Algamarca, mining has started since the colonial period (Defilippi et al, 2012) and continued more recently, between 1940 and 1989, with 1.5 million tons of ore grading 2.0% Cu and 680 g Ag/t with “some gold” extracted (Saucier and Poulin, 2004). Mineralization consists of veins of 0.1 to 2 m filling NE-SW to E-W strike faults, cutting the Chimu bedded quartzite of the NW-SE Algamarca anticline. The veins are filled mainly by quartz, chalcopyrite, tetrahedrite-tennantite, and pyrite

(Tumialan, 2003). Sphalerite, galena, bornite, and enargite were also reported (Reyes, 1980; Sánchez, 2012; Defilippi et al., 2016). The underground mine is currently worked by small-scale miners. The main mineralized structure is known as the Descubridora vein where punctual values of 8.4 g/t Au, 2058 g/t Ag, and 13.3% Cu were reported (Defilippi et al., 2016). A K-Ar age of 15.5±0.4 Ma was reported by Noble and McKee (1999) from hydrothermal muscovite bordering a polymetallic vein.
At Shahuindo, exploration started in the 1980s and the gold production started in 2016. Proven plus probable reserves are of ~55 t Au (1,763 koz Au) at 0.46 g/t (Cesar Alvarez, 2019 pers. comm.). The mineralization is expressed as disseminations and replacements in the Carhuaz and Farrat sandstone to siltstone Formations and, to a lesser extent, within andesitic to dacitic intrusives and as massive pyrite bodies at the intrusive contacts. Pyrite is the most abundant sulfide mineral and occurs together with lesser amounts of chalcopyrite, arsenopyrite, pyrrhotite, sphalerite, galena, tetrahedrite-tennantite and enargite, white mica is the main gangue mineral with scarce carbonate and quartz. Pre-ore andesitic to dacitic intrusives were dated to 26 and 16 Ma, respectively, using the U-Pb method on zircon (although no error margins reported; Bussey and Nelson, 2011). These similar ages suggest that the two deposits formed at ca. 15.5 Ma similarly to other intermediate-sulfidation deposits of the same belt like Quiruvilca from 15.18± 0.08 to 15.41± 0.13 Ma or Las Princesas 15.69 ± 0.07 Ma, estimated using $^{39}Ar/^{40}Ar$ data from hydrothermal minerals (Montgomery, 2012).

4 Sampling and methods

Twenty polished sections were studied: 7 samples from Algamarca, from dumps and ore load of underground mining works in Alisos and San Blas veins, and 13 samples from Shahuindo, from drill cores. A detailed mineralogical study has been performed using optical microscopy combined with Scanning Electron Microscope (SEM) at PUCP University, Lima. Quantitative analyses, Electron Probe Microanalyses (EPMA) of pyrite, arsenopyrite, marcasite, sphalerite, chalcopyrite, tennantite-tetrahedrite and enargite were performed by CAMECA SXFive instrument at the Centre of Microcaractérisation R. Castaing (Toulouse, France).

5 Results

Petrography

At Algamarca, veins show crustiform banding and breccias, textures of open space precipitation, with abundant, up
to 4-mm-size, euhedral quartz intergrown with pyrite (Py-C) of the same size; grains of native gold up to 20 µm across were identified in 3 polished sections. They mainly fill micro fractures in tetrahedrite, or at the contact between chalcopyrite and tetrahedrite grains. At Shahuindo, ore is mainly present as sulfides with replacement textures or as disseminations, the host rock permeability controls the gold mineralization, presents scarce quartz up to 250 µm in size. Native gold or electrum have not been observed. Based on the analytical data obtained, the paragenetic sequences of Algamarca and Shahuindo have been established (Fig. 1). Both show several generations of pyrite, 3 at Algamarca (Py-A, Py-B, and Py-C) and 4 at Shahuindo (Py-I, Py-II, Py-III, and Py-IV) where the most recent generations overgrowed or replaced earlier ones. Diagenetic pyrite was only observed at Shahuindo (Py-I). Both sequences exhibit an As-rich pyrite stage, Py-B at Algamarca and Py-III at Shahuindo, the main gold carrier mineral in this deposit (Vallance et al., 2019). Followed by a Cu-Ag stage dominated by chalcopyrite and tetrahedrite. Late minerals like sphalerite and enargite previously reported at Algamarca (Reyes 1980, Sanchez 2012 and Defilippi et al 2016) and identified at Shahuindo were not found in our Algamarca's samples.

Compositional data

Native gold at Algamarca contains 13.9 wt% Ag (on average). The generations of pyrite with highest As concentrations are Py-B at Algamarca with a mean value of 2.3 wt%, and Py-III at Shahuindo with a mean value of 1.8 wt%. At Algamarca and Shahuindo, all tetrahedrite is systematically Fe-rich with values from 1.1 to 2.2 apfu, with tetrahedrite at Shahuindo being more enriched in Zn and Ag than at Algamarca. Ag was not detected in enargite and tennantite (detection limit 0.2 wt%), while in tetrahedrite the values reached 1.6 and 5.9 wt% at Algamarca and Shahuindo, respectively.

6 Discussion and conclusions

The spatial proximity, age and paragenetic sequence similarities, all indicate that both Algamarca and Shahuindo are related to the same magmatic-hydrothermal center. However, although they were generated from a common source, they do show strongly different mineralization styles. At Algamarca, ore occurs as veins with typical textures of open space precipitation, gold is present as native gold and as gold-telluride minerals. Arsenical pyrite occurs in a similar position as at Shahuindo and it is expected to host bound gold (LA-ICP-MS analysis are in progress to evaluate its gold content). The main and most common Au ore-bearing minerals in epithermal deposits are known to be electrum, native gold, and Au tellurides (White and Hedenquist, 1995; Simmons et al., 2005), but arsenical pyrite has also been recognized as an important gold carrier in many cases (e.g., Reich et al., 2005; Deditius et al., 2014; Morishita et al. 2018; Sykora et al., 2018; references therein). Efficient gold scavenging by pyrite and arsenopyrite may occur from low-concentrated fluids undersaturated with respect to metallic gold, whereas native gold precipitation requires much more Au-concentrated fluids. Thermodynamic modeling of fluid-rock interactions at Shahuindo indicates that carbonaceous matter favor gold transport in chemically reactive few competent carbonaceous-bearing rocks (Vallance et al., 2019). By contrast, we infer that in Algamarca in highly competent and less reactive rocks other gold transport and mechanisms (e.g. uptake of reduced sulfur from the fluid related to sulfide precipitation) lead to native gold precipitation. Our findings highlight the importance of further studies such as fluid inclusions, stable isotopes, geochronology and, most importantly, the true state of this bound gold in the mineral that can only be assessed by direct in situ techniques (synchrotron), coupled with the full range of more traditional microanalytical methods, to understand the respective gold transport, deposition, at Shahuindo and Algamarca. Our results show an example of different styles of gold epithermal mineralization present in a same hydrothermal-magmatic system; they thus offer important perspectives for improving exploration models for gold mineralization in Northern Peru.

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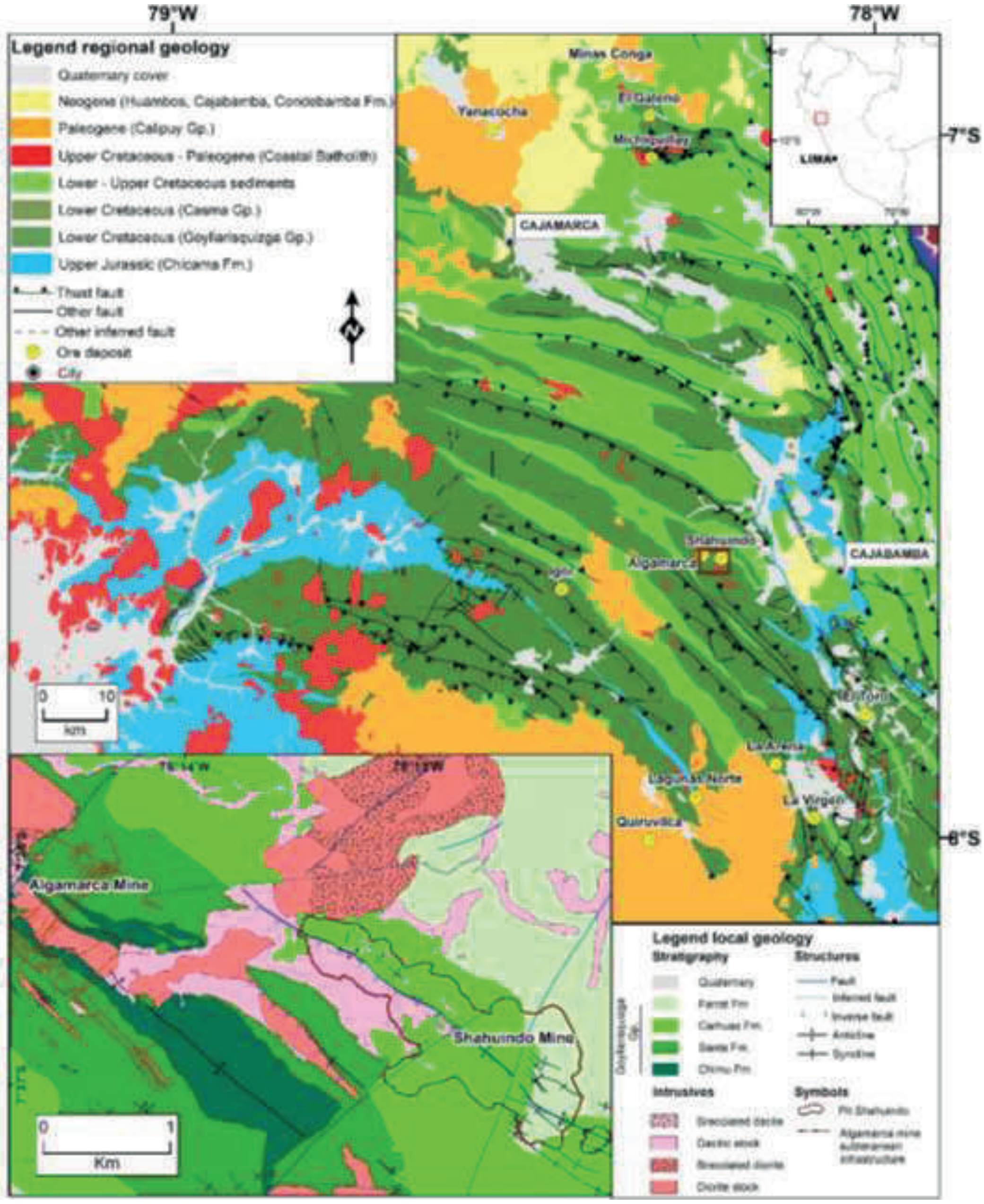

Fig.1. Geological map of the Marañon Fold and Thrust Belt in northern Peru with location of major deposit and projects, modified from Eude (2014). Inset: Geological map of the study area with location of the Shahuindo open pit and the former Algamarca mine (Pan American Silver, 2019).

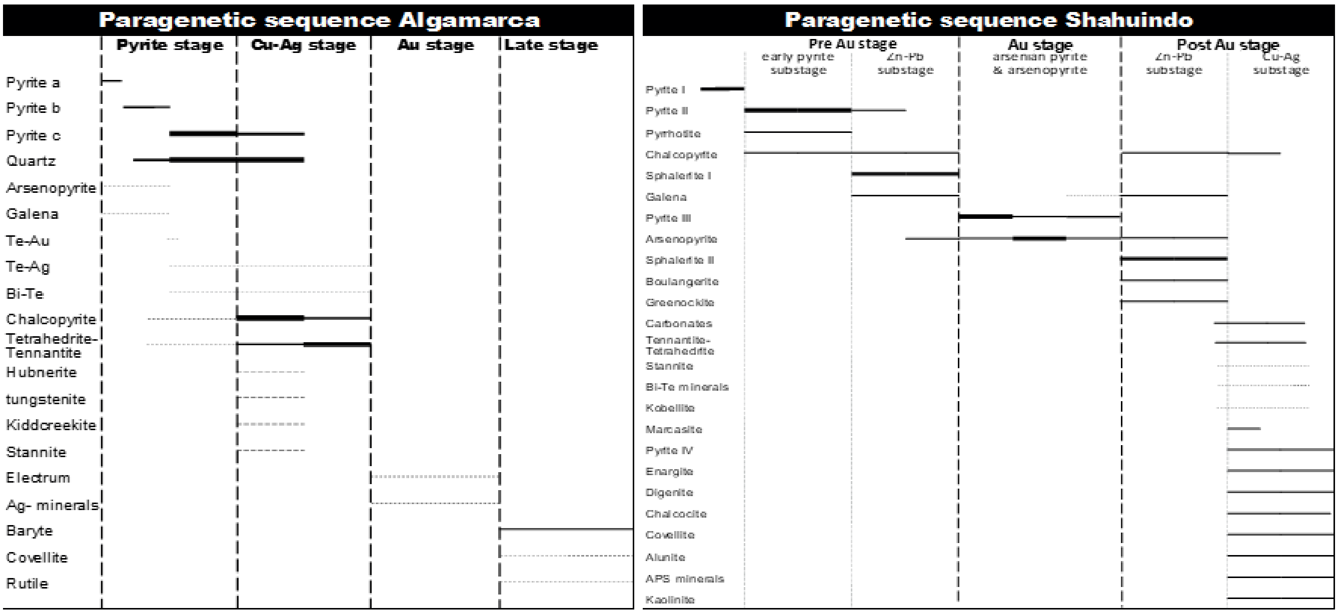

Fig. 2. Paragenetic sequences for Algamarca and Shahuindo.