Age of the Cerro Quema Au-Cu deposit (Azuero Peninsula, Panama): Insights from biostratigraphy and Ar/Ar geochronology

Edad del depósito de Oro-Cobre de Cerro Quema (Península de Azuero, Panama): Evidencias bioestratigraficas y geocronologicas (Ar/Ar)

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Abstract: Cerro Quema is a high sulfidation epithermal Au-Cu deposit located in the Azuero Peninsula, SW Panama. It is hosted by a dacite dome complex intruded into fore-arc basin materials (Río Quema Formation). In this study we present new biostratigraphical and geochronological data in order to discuss the age, origin and evolution of the Cerro Quema deposit. Geological understanding of the deposit is a key tool to find new gold-bearing prospects in similar terrains. Biostratigraphy based in planctonic foraminifera and radiolarians, suggest an Upper Campanian-Maastrichtian age for the Río Quema Formation. Geochronological data indicates two stages of volcanism and magmatism in the Azuero Peninsula. The first ranges from 67.9±1.3Ma to 65.6±1.3Ma (i. e. Maastrichtian) while the second ranges from 54.8±1.2Ma to 49.5±0.2Ma (i. e. Early Eocene). Age of the Cerro Quema Au-Cu deposit is Early Eocene and it is related to the second stage of magmatism and volcanism of the Azuero Peninsula. Future gold exploration in the Azuero Peninsula should focus in areas were the Late Cretaceous volcanic arc materials are affected by the Early Eocene magmatism.

Key words: Cerro Quema Au-Cu deposit, Panama, Río Quema Formation, Ar-Ar geochronology, biostratigraphy.

Resumen: *Cerro Quema es un yacimiento epitermal de alta sulfuración de oro-cobre situado en la Península de Azuero, SO Panamá. Cerro Quema se encaja en un complejo de domos dacíticos intrusivos en materiales de cuenca de ante-arco (Formación Río Quema). Éste estudio presenta datos bioestratigráficos y geocronológicos a fin de discutir la edad, el origen y la evolución del yacimiento de Cerro Quema. El entendimiento de la geología del yacimiento es la clave para encontrar nuevos prospectos de oro en zonas geológicamente similares. Los datos bioestratigráficos basados en foraminíferos planctónicos y radiolarios sugieren una edad de Campaniense Superior-Maastrichtiano para la Formación Río Quema. Por otra parte, los datos geocronológicos sugieren dos etapas de volcanismo y magmatismo en la Peninsula de Azuero. La primera etapa está comprendida entre 67.9±1.3Ma y 65.6±1.3Ma (Maastrichtiense) y la segunda etapa se extiende desde 54.8±1.2Ma hasta 49.5±0.2Ma (Eoceno Inferior). La edad del yacimiento de Cerro Quema es Eoceno Inferior, asociado a la segunda etapa de magmatismo y volcanismo de la Península de Azuero. Futuras exploraciones de oro en la Península de Azuero deben centrarse en áreas donde los materiales del arco Cretácico Superior estén afectados por el magmatismo y volcanismo del Eoceno Inferior.*

Palabras clave: *Yacimiento de Cerro Quema (Au-Cu), Panamá, Formación Río Quema, geocronología Ar-Ar, bioestratigrafía.*

INTRODUCTION

The Cerro Quema Au-Cu deposit is located in the Azuero Peninsula, SW Panama (Fig. 1). The gold-copper deposit is a structurally controlled high sulfidation epithermal deposit, hosted by a dacite dome complex intruded into fore-arc basin materials. The Cerro Quema deposit is constituted by several mineable bodies, named (from East to West) Cerro Quema, Cerro Quemita and La Pava. Estimated total resources are 10 Mt with an average gold grade of 1.26g/t (Torrey and Keenan, 1994). The Cerro Quema deposit is one of the most promising gold-bearing prospects in Panama, and its geologic understanding could be the key to find new gold prospects in similar geologic terrains. In this paper we document the main geologic features of the high sulfidation epithermal Au-Cu mineralization at Cerro Quema deposit, and discuss the age, origin and its evolution.

GEOLOGIC SETTING

Panama microplate is situated in South Central America (Fig. 1), during Late Cretaceous up to present day this region is characterized by the subduction of the Farallon plate (nowadays Cocos and Nazca plates) beneath the Caribbean plate. Subsequently arc magmatism developed on the Caribbean plate.

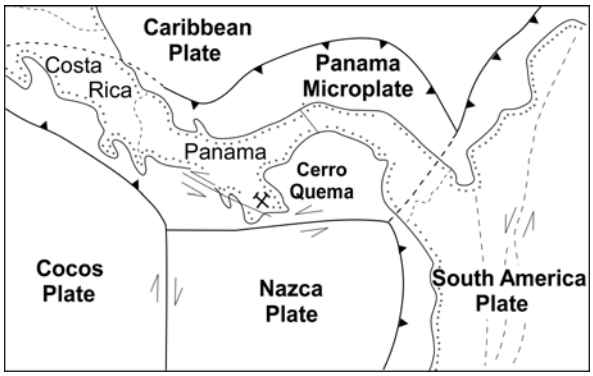

FIGURE 1. *Location of the Cerro Quema Au-Cu deposit, adapted from Corral et al., (2011).*

In the Azuero Peninsula, the initial stage of the volcanic arc is preserved, whose fore-arc basin hosts the Cerro Quema Au-Cu deposit (Corral et al., 2011). In the most simplistic terms, the Azuero Peninsula can be described as an igneous basement overlain by fore-arc sediments (Buchs et al., 2011).

Five distinct rock associations have been recognized in the Azuero Peninsula:

(1) The Azuero Igneous Basement (AIB), composed of basaltic sequences of Aptian - Early Santonian age. (Kolarsky et al., 1995; Buchs et al., 2011).
(2) The Azuero Primitive Volcanic Arc (APVA), non mapable arc-related igneous rock sequences of Late Campanian – Maastrichtian age (Buchs et al., 2011).
(3) The Azuero Arc Group (AAA), arc-related igneous and sedimentary rocks representing the Cretaceous and Paleogene volcanic arcs (Lissinna, 2005; Buchs et al., 2011, Wegner et al., 2011; Corral et al., 2011).
(4) The Tonosí formation, a sedimentary sequence of Middle Eocene-Early Miocene age, unconformably overlapping all the previous untis (Recchi and Miranda, 1977; Kolrasky et al., 1995).
(5) The Azuero Accretionary Complex (AAC), corresponding to Paleogene seamounts and oceanic plateaus accreted to the paleo-subduction trench (Buchs et al., 2011).

The Cerro Quema deposit is hosted by a dacite dome intrusions of the Río Quema Formation (RQF; Fig. 2). This formation is enclosed in the Azuero Arc Group, and represents the fore-arc and volcanic apron sequence of the Cretaceous volcanic arc.

Hydrothermal alteration at Cerro Quema is controlled by regional E-W trending faults and consists of an inner zone of nearly pure quartz (vuggy silica), locally presenting a quartz-alunite and pyrophyllite (advanced argillic alteration), enclosed by kaolinite, illite and illite/smectite (argillic alteration). A propyllitic alteration is only observable in some drill cores, surrounding the argillic alteration zone.

Gold occurs as disseminated submicroscopic grains and as “invisible gold” within the pyrite lattice (Corral et al., 2011). Higher gold grades are associated to the oxidized zones of the deposit. Copper is associated to Cu-bearing phases such as enargite-luzonite, bornite and tennantite as well as secondary copper sulfides such as covellite and chalcocite.

BIOSTRATIGRAPHY

The age of the Río Quema Formation is not well constrained despite the radiometric and biostratigraphic dating performed in the Azuero Peninsula. In order to constrain the age of the RQF and the Cerro Quema Au-Cu deposit, as well as to understand the Cretaceous and Paleogene arc dynamics, a biostratigraphical study was carried out. Sixteen thin sections of pelagic-hemipelagic limestones and mudstones from different depositional environments and localities of the Azuero Peninsula have been studied (Fig. 2).

Several planctonic foraminifera were found: *Globigerinelloides* cf. *prairiehillensis* Pessagno, *Heterohelix globulosa*, *Globotruncana* cf. *linneiana* and *Rugoglobigerina rugosa*, *as well as* radiolarians *Pseudoaulophacus lenticulatus*, *Archaeodictyomitra lamellicostata* and *Pseudoaulophacus* sp. Therefore, the age of the Río Quema Formation range from Late Campanian to Maastrichtian.

Ar/Ar GEOCHRONOLOGY

The $^{40}Ar/^{39}Ar$ method for determining the radiometric age of earth materials has gained widespread acceptance in the geological community and has been applied to a host of problems including sedimentary provenance studies, paleomagnetism, thermal histories of metamorphic terranes and mantle and atmospheric evolution.

The first geochronological data in the Azuero Peninsula were K/Ar ages of el Montuoso and Valle Rico batholiths (Del Giudice and Recchi, 1969; Kesler et al., 1977). Recent geochronological contributions of Lissina, (2005) and Wegner et al., (2011) reported the first Ar/Ar ages for some rocks of the Azuero Peninsula.

In this study eight hornblende phenocrysts from four different rock samples have been selected for laser step-heating $^{40}Ar/^{39}Ar$ analysis at the USGS, to

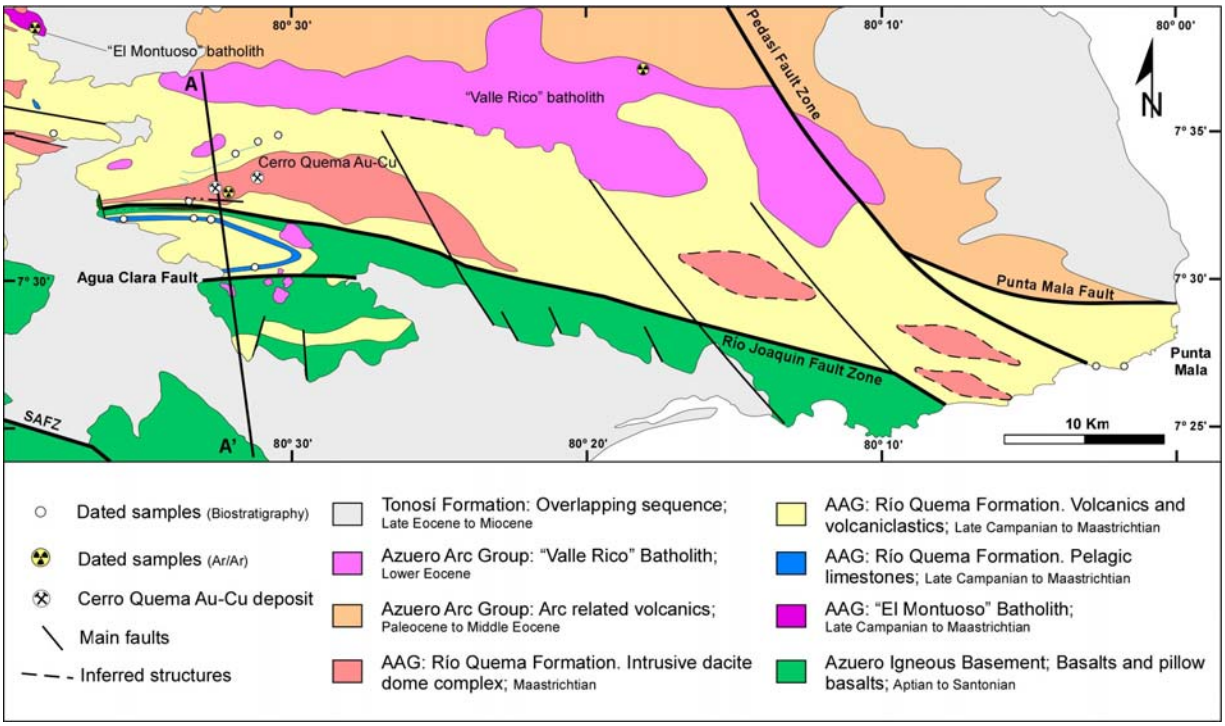

FIGURE 2. *Geologic map of the Central and Southeastern Azuero Peninsula showing the main units and the location of the Cerro Quema Au-Cu deposit. SAFZ: Soná-Azuero Fault Zone. AAG: Azuero Arc Group. A-A': geological cross section*

determine the age of different rocks related with the Cerro Quema Au-Cu deposit. Our data are the first geochronological ages completely integrated within the geologic framework of the Azuero Peninsula. Dated samples represent the arc-related volcanic and arc-related intrusive rocks of the Azuero Arc Group (Fig. 2). This allows the evolution reconstruction of the Azuero Peninsula geology as well as the age constrain of the Cerro Quema Au-Cu deposit.

Two hornbledes from the "El Montuoso" batholith gave a plateau age of 65.7±1.4Ma and integrated age of 65.5±0.7Ma, in strong agreement with the plateau age. One hornblende from the "Valle Rico" batholith gave an integrated age of 54.8±1.2Ma. Obtained plateau ages of hornbledes from the dacite dome complex of the Río Quema Formation were: 67.9±1.3Ma, 66.0±1.1Ma and 65.6±1.3Ma. Finally an attempt to date the volcaniclastic sediments of the RQF was made in order to obtain the age of all the volcanic, volcaniclastic and plutonic rocks of the Azuero Arc Group. Unfortunately no plateau ages could be obtained and integrated ages had no geologic sense within the geologic framework of the Azuero Peninsula.

DISCUSSIONS

Our biostratigraphycal study of the Río Quema Formation date the initial volcanic arc activity related to the Farallon plate subduction beneath the Caribbean plate at Late Campanian-Maastrichtian. This is in good agreement with previous works which suggested that the initial volcanic arc was at least Maastrichtian (~71Ma) and expanded up to Early Eocene (~40Ma) (e.g., Del Giudice and Recchi, 1969; Lissinna, 2005; Wegner et al., 2011). Biostratigraphical data is also consistent with the subduction onset age of 75-73Ma proposed by Buchs et al., (2011).

Geochronological Ar/Ar ages suggest a first magmatism and volcanism stage occurred at least from 67.9±1.3Ma to 65.6±1.3Ma (Maastrichtian) in the Azuero Peninsula. This magmatic event dates the initial volcanic arc developed in the western Caribbean plate. This is also in good agreement with the biostratigraphy dating.

Our Ar/Ar data suggest a second stage of magmatism and volcanism during Early Eocene time (54.8±1.2Ma). This coincides with previous ages of 53±3Ma to 49.5±0.2Ma reported by Del Giudice and Recchi, (1969) and Lissina, (2005).

The age of the Cerro Quema Au-Cu deposit must be Lower Eocene and related to the second stage of magmatism and volcanism. This stage produced quartz-diorite intrusions in the whole arc, from the fore-arc basin towards the arc (Fig 3). According to the classical model of high sulfidation epithermal deposits (e. g., Hedenquist and Lowenstern, 1994), such intrusions would produce the heat, the fluid and the water flow necessary to generate the Cerro Quema Au-Cu deposit.

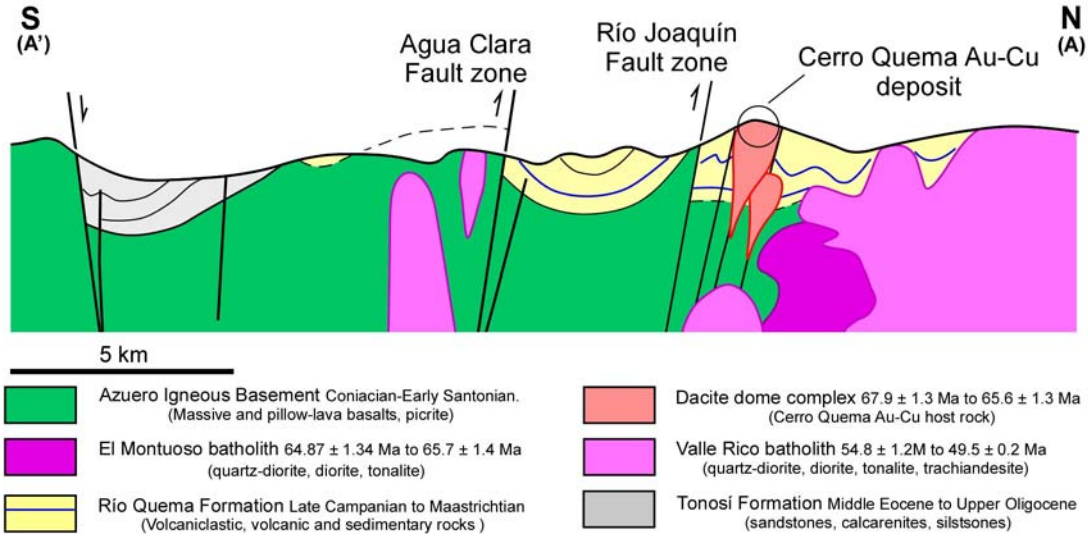

FIGURE 3. *Geologic cross section of the Cerro Quema Au-Cu deposit. showing the Upper Cretaceous and Lower Eocene volcanic arcs relationship.*

CONCLUSIONS

- Age of the Río Quema Formation is Upper Campanian-Maastrichtian.

- In the Azuero peninsula two stages of volcanism and magmatism were identified, the first one during Late Cretaceous and the second one during Early Eocene.

- Host rocks of the Cerro Quema Au-Cu deposit are the dacite dome complex intruded in the fore-arc basin of the Upper Cretaceous volcanic arc.

- Age of the Cerro Quema Au-Cu deposit is Lower Eocene, related to a series of quartz-diorite intrusion produced during the second stage of volcanism and magmatism developed in the Azuero Peninsula.

- Future gold exploration in the Azuero Peninsula must be addressed to zones were the Cretaceous Volcanic arc materials are affected by the Early Eocene magmatism stage.

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