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Mineralizing Events of the World-Class Volta Grande Gold Deposit, Southeastern Amazonian Craton, Brazil †

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Abstract: The southeastern region of the Amazonian Craton has been the target of several metallogenetic surveys, which recently led to the identification of the world-class Volta Grande gold deposit with gold reserves of ~3.8 Moz at 1.02 g/t. This deposit is located ~60 km southeast of Altamira city, Pará state, and is hosted by the Três Palmeiras intrusive greenstone belt that is located in the northern Bacajá tectonic domain (2.24–2.0 Ga). The mineralization is hosted by a high-level intrusive and mylonitized suite. Local kinematic indicators suggest dip-slip movement in which the greenstone moves up relative to the intrusive rocks. Native gold mostly occurs as isolated grains in centimeter-wide quartz veins and veinlets associated with pervasive carbonate alteration that was synchronous with dynamic metamorphism. Part of the gold is also associated with disseminated sulfides in this generally low-sulfide mineralization. These relationships are compatible with orogenic lode-type gold systems elsewhere. New petrographic studies from core samples along a stratigraphic profile reveal the presence of lava flows and dykes of rhyodacite, rhyolite, and plutonic rocks such as quartz monzonite, granodiorite, monzodiorite, and subordinate microgranite crosscutting an earlier style of mineralization. These rocks are characterized by potassic, propylitic, intermediate argillic, and/or carbonate hydrothermal alterations in selective, pervasive, or fracture-controlled styles. Within the hydrothermal volcano-plutonic sequence, gold occurs as disseminated isolated grains or replacing sulfides. Both native gold and sulfides are also present in centimetric quartz veinlets. Such features of the deposit are similar to those from porphyry-type and low- to intermediate-sulfidation epithermal systems already identified in the Amazonian Craton. The Volta Grande deposit data suggest a second mineralizing event, common in large-tonnage gold deposits, and can represent a new exploration guide.

Keywords: hydrothermal alteration; lode-type; Volcano-plutonism; Porphyry-epithermal gold

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1. Introduction

The Volta Grande gold deposit, located in the southeasternmost region of the Amazonian Craton, represents the future for gold mining in northern Brazil (Figure 1). Economic feasibility studies revealed 3.8 Moz of proven resources at 1.02 g/t Au [1].

The deposit encompasses a mainly Proterozoic granite-greenstone terrain reworked during the Transamazonian Cycle (2.01–2.26 Ga) and the Bacajá domain [2]. It is north of the Carajás mineral province [3]. Several sequences form a lithostratigraphic diversity, such as metamorphic granitoid suites representative of the Archean basement, granitoids of magmatic arcs, and charnockites and granulites related to the final stages of the continental Rhyacian collision and high-grade metamorphic rocks [4].

The Volta Grande gold deposit is hosted in the WNW-ESSE-trending metavolcano-sedimentary Três Palmeiras greenstone belt (2.36 Ga). The Três Palmeiras greenstone belt comprises the Itatá amphibolite and Bacajá mica schist units, which usually show carbonate hydrothermal alteration [5]. Previous studies in this region suggested that gold mineralization closer to the Xingu River occurs near the boundary between the Três Palmeiras greenstone belt and collisional granitoids. Gold mineralization is restricted to regional shear zones and displays similarities to orogenic lode-type gold systems [4,6].

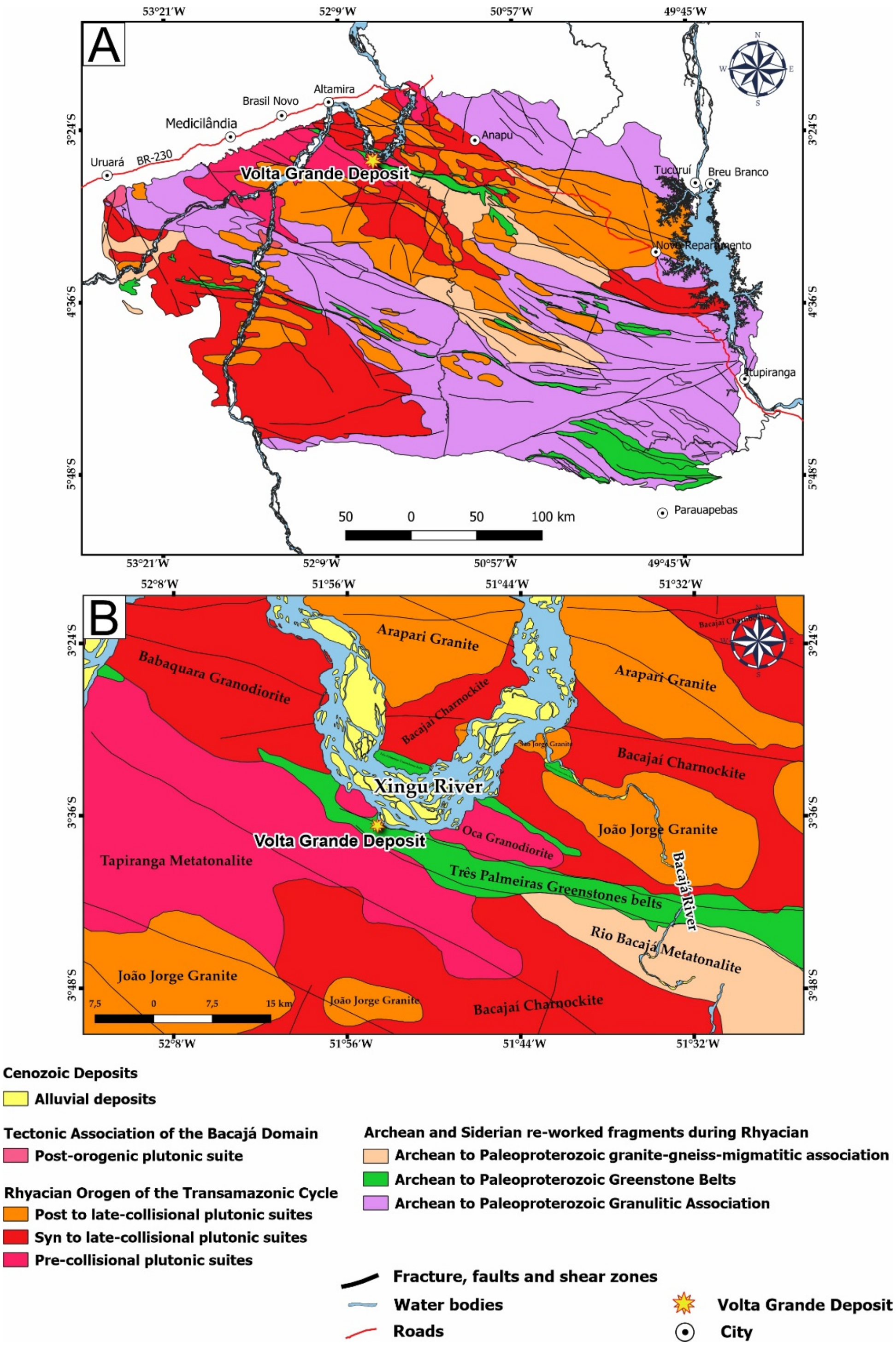

Figure 1. (**A**) Regional geological map of the Bacajá domain. (**B**) Detailed geological map of the Volta Grande gold deposit [1].

Our core logging, macroscopic petrographic textural description, and ore microscopy documented the existence of a younger isotropic intermediate to felsic volcano-plutonic sequence of unknown age. These younger rocks host disseminated gold in several types and styles of hydrothermal alterations as well as in veins and veinlets of quartz and carbonate (± sulfides). In this manuscript we present new geologic, stratigraphic, and petrographic data for the Volta Grande gold deposit aiming to contribute to a better understanding of its genesis. The volcano-plutonic lithotypes in association with the genetically related gold-bearing hydrothermal alteration resemble those in precious and base metal-bearing epithermal and porphyry-type mineralizing systems described elsewhere in the Amazonian Craton [7].

2. Materials and Methods

Core samples used in this research are part of the Belo Sun Mining Corp. portfolio. Samples were collected from five drilling holes and represent the promising exploitation targets. We sampled representative lithological features (such as those metamorphosed and not metamorphosed and hydrothermally altered) and gold-bearing quartz and carbonate veins. Macroscopic description guided the microscopic investigation. The classification of the plutonic and volcanic rocks followed the IUGS recommendations [8]. Thin-section analyses utilized a conventional optical microscope.

3. Results

3.1. Três Palmeiras Greenstone Belt

3.1.1. Mylonitic Granodiorite

The mylonitic granodiorite is a light to dark gray, slightly greenish granitoid with a mylonitized texture. This rock is the product of dynamic recrystallization that happens mostly in gneissic protoliths along ductile shear zones under medium-grade, amphibolite-facie conditions (Figures 2a and 3A). The mylonitic granodiorite has a dominant granoblastic texture with porphyroclasts of plagioclase, quartz, and K-feldspar. Biotite and amphibole are equi-dimensional, polygonized to lenticular, and define the mylonitic flattening foliation. A porphyroclastic texture with the foliation and rotation of feldspar and recrystallization of quartz is common.

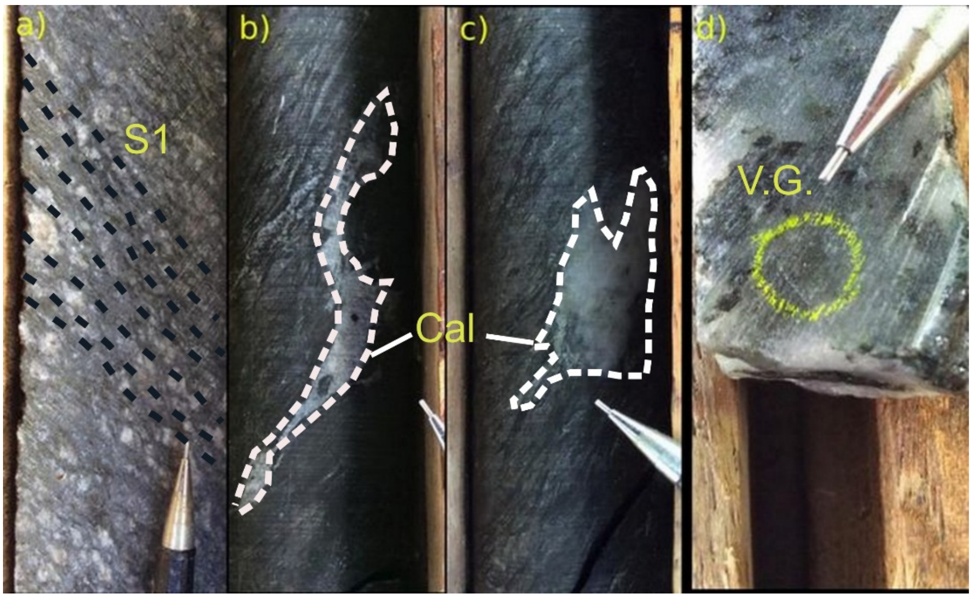

Figure 2. Representative core samples of the metamorphic lithotypes. (**a**) Mylonitic granodiorite and S1 foliation. (**b**,**c**) Calcite (Cal) within fractures and pods related to S1 foliation of the meta-andesite. (**d**) Visible gold (V.G.) particle and minor sulfides in quartz vein within mylonitic granodiorite.

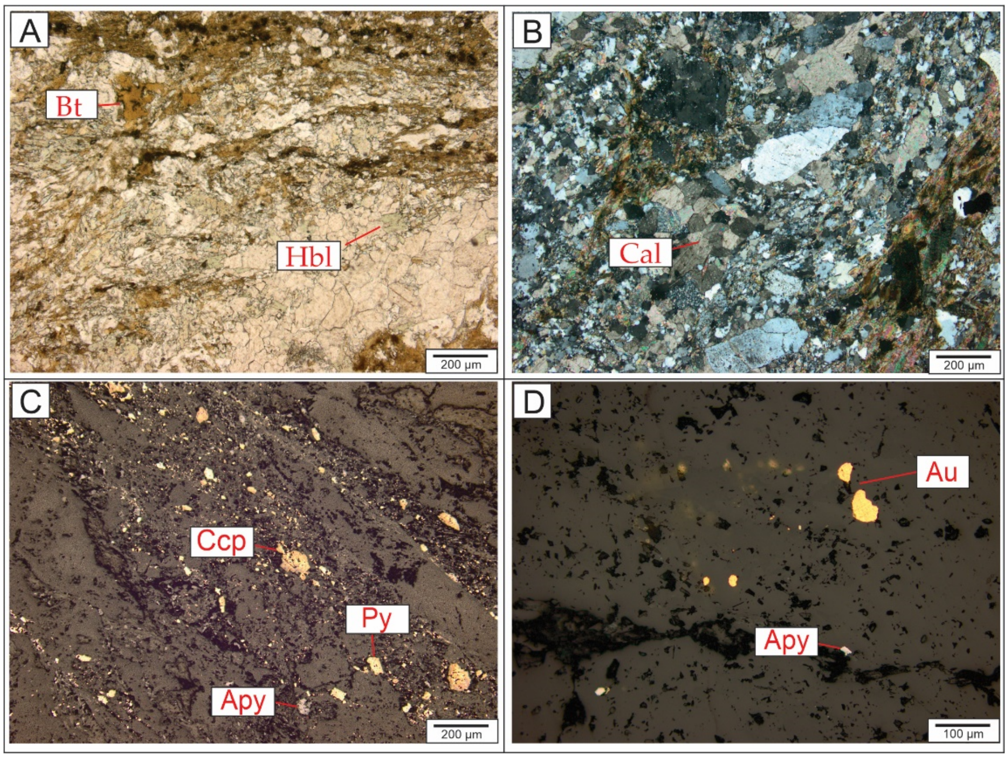

Figure 3. Representative microscopic features of the mineralized mylonitic granodiorite. (**A**) Metamorphic foliation related to mafic minerals, hydrothermal biotite (Bt) and magmatic amphibole (Hbl). (**B**) Pervasive carbonate (Cal–Calcite) alteration controlled by metamorphic foliation. (**C**) Disseminated sulfides throughout metamorphic foliation, chalcopyrite (Ccp), arsenopyrite (Apy), and pyrite (Py). (**D**) Gold (Au) and arsenopyrite (Apy) particles in quartz vein.

3.1.2. Mafic Rocks

The mafic rocks consist of dark gray meta-andesite (Figure 2a,c) and amphibolite with greenish tones, fine- to medium-grained, with a nematoblastic texture, locally glomeroporphyritic with biotite and actinolite aggregates. It contains plagioclase, hornblende, biotite, and actinolite lamellae. Chlorite, calcite, sericite, quartz, feldspar, and oxide minerals are the main secondary phases.

3.1.3. Hydrothermal Alteration

The mylonitic granodiorite and minor gneiss are mainly propylitic altered with epidote + carbonate + chlorite in porphyroclasts and groundmass. It also displays pre- and post-metamorphism fracture-controlled silicification and fracture-controlled and pervasive carbonate alteration that follows the mylonitic foliation. Locally, selective chloritic alteration affects biotite. Selective intermediate argillic alteration occurs mainly in plagioclase and microcline porphyroclasts, and twinning is obliterated by minor sericite. In the mafic rocks there is also a fracture-controlled carbonate alteration developed in veinlets and pods that are usually discordant to the foliation or associated with disseminated opaque minerals, including subhedral pyrite (0.3 mm).

3.1.4. Mineralization

The highest concentration of gold mineralization, determined by assay, occurs in centimetric quartz veins and veinlets (Figure 2d). This high-grade gold occurs in restricted contact zones with mylonite and along with sulfides (such as pyrite, chalcopyrite, and arsenopyrite; Figure 3C) and pervasive carbonate alteration. Rounded to subangular gold, particles are fine-grained and usually are included and/or fill open spaces in quartz within the veins (Figure 3D) or are disseminated in the host rock groundmass. Pyrite occurs as anhedral to subhedral submillimetric (0.1–0.5 mm) grains. Arsenopyrite (0.7–0.1 mm) is subhedral to anhedral and occurs associated with other sulfides (Figure 3C) or in monomineralic aggregates (Figure 3D). Chalcopyrite (0.1–0.5 mm) is subhedral and rounded. In the mafic rocks of the greenstone belt sequence, centimetric quartz veins and veinlets are the most important location of gold and sulfides.

3.2. Felsic to Intermediate Isotropic Volcano-Plutonic Sequence

3.2.1. Volcanic Rocks

The volcanic rocks are hypocrystalline, light gray, black, or dark red lava flows of rhyolitic to rhyodacitic compositions. They have a predominantly porphyritic texture and are aphyric on a smaller scale (Figure 4a,d). The phenocrysts are plagioclase, amphibole (hornblende altered to actinolite), biotite, and subordinate K-feldspar and quartz. The phenocrysts are hosted by a microlitic groundmass consisting of fine tabular crystals of plagioclase and quartz or in a felsic groundmass related to the intergrowth of K-feldspar and quartz.

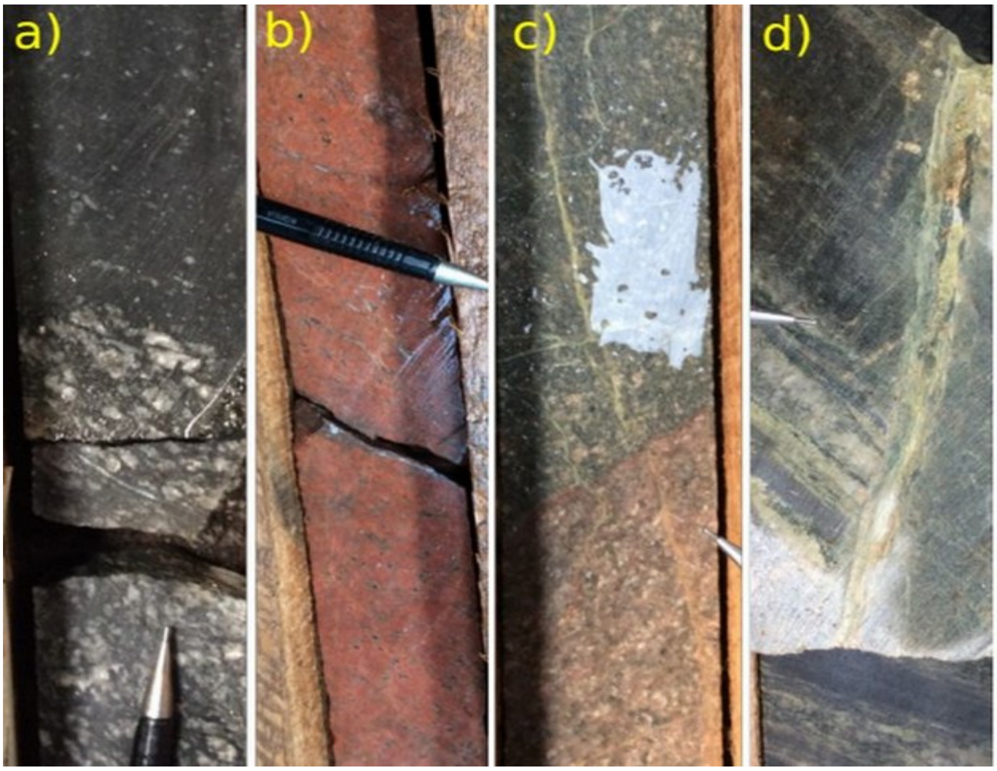

Figure 4. Representative core samples of the volcano-plutonic sequence. (**a**) Porphyritic rhyodacite (upside) in contact with mylonitic granodiorite (downside). (**b**) Strong pervasive potassic alteration in reddish porphyritic rhyolite. (**c**) Porphyritic rhyodacite (upside) with selective potassic alteration in contact with microgranite with moderate potassic alteration (downside). Fracture-controlled argillic and propylitic alteration also occur in this lithology. (**d**) Porphyritic rhyodacite with selective potassic and fracture-controlled propylitic alteration.

3.2.2. Plutonic Rocks

The granitoids range from medium- to coarse-grained and are dark gray in color with reddish or greenish portions that vary throughout the profiles (Figure 5) and are the most prospective for gold throughout the district. The following holocrystalline lithotypes were compositionally recognized (Figure 5): granodiorite, quartz monzodiorite, quartz monzonite, monzodiorite, and minor microgranite. These plutonic rocks have varying amounts of hornblende (2.9–29.4%) and biotite (0.2–9.0%).

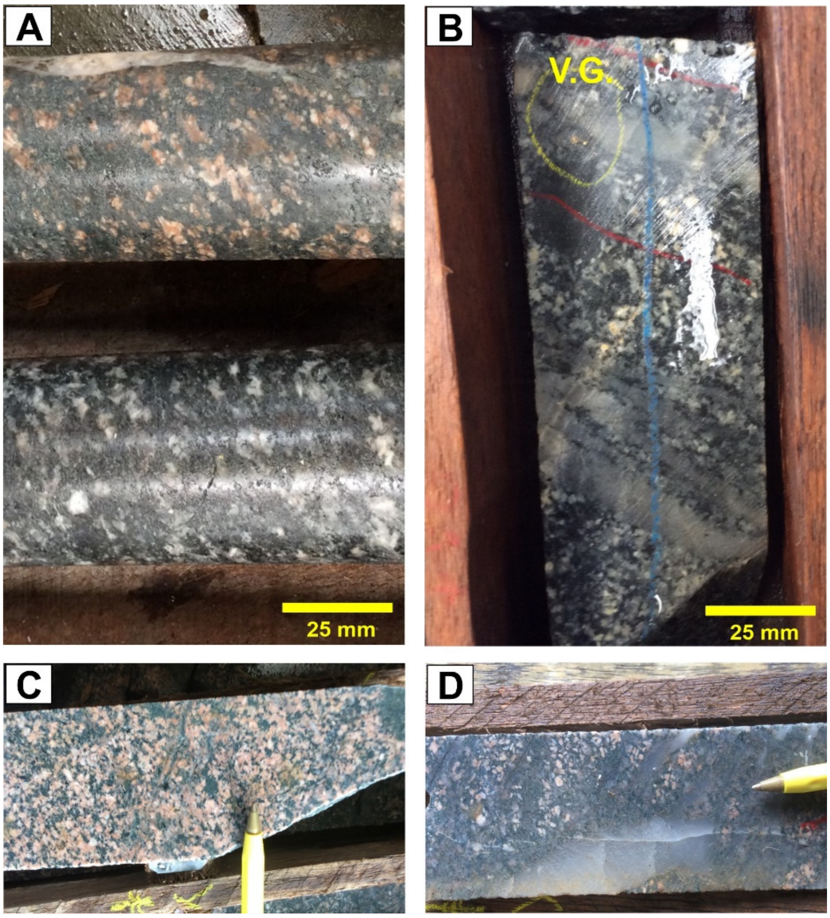

Figure 5. Representative core samples of the volcano-plutonic sequence. (**A**) Selective potassic alteration in granodiorite (upside) and preserved granodiorite (downside). (**B**) Visible Gold (V.G) within quartz vein in quartz monzodiorite. (**C**) Pervasive potassic alteration on quartz monzodiorite. (**D**) Microgranite with pervasive potassic alteration and associated quartz veins.

3.2.3. Hydrothermal Alteration

The hydrothermal alteration types in the volcanic rocks are potassic, propylitic, intermediate argillic, and silicic with moderate to strong intensity in selective and fracture-controlled styles (Figure 4). The plutonic rocks are characterized by potassic, propylitic, and silicic alterations. Among the plutonic rocks, the monzodiorite is more intensely altered, showing replacement of the magmatic plagioclase by secondary K-feldspar (e.g., microcline), and formation of hydrothermal biotite from primary biotite. Similarly, the potassic alteration of the volcanic rocks, results in the formation of secondary K-feldspar and biotite from plagioclase and primary biotite, respectively. Propylitic alteration of the monzodiorite is represented by actinolite, chlorite, and sericite replacing magmatic hornblende, biotite, and feldspars, respectively. Propylitic alteration is also characterized by calcite veinlets and the formation of hydrothermal epidote over feldspars. In the volcanic rocks, the propylitic alteration is evidenced by the replacement of magmatic biotite by chlorite and the replacement of magmatic hornblende by actinolite. Pervasive epidote crystals and calcite are controlled by a fracture system along the altered rocks. Silicification of plutonic and volcanic rocks is represented by fine-grained hydrothermal quartz that fill veins and veinlets.

3.2.4. Mineralization

Gold particles in volcanic and plutonic rocks are usually hosted by quartz veins (up to 1 cm wide) and veinlets and occur in association with chalcopyrite, pyrite, and arsenopyrite (Figure 6C). These minerals precipitate either isolated in hydrothermal quartz or as composite aggregates, although sulfides are also disseminated in calcite veinlets (Figure 6D). The habit of hydrothermal minerals varies from euhedral pyrite to anhedral or rounded millimeter-sized gold. Higher grade zones along the plutonic and volcanic rocks sequence are associated with silica-rich centimeter-sized fissures and fractures as well as by quartz stockworks. However, significant contents of gold are disseminated along centimetric intervals of propylitic alteration in porphyritic dacite.

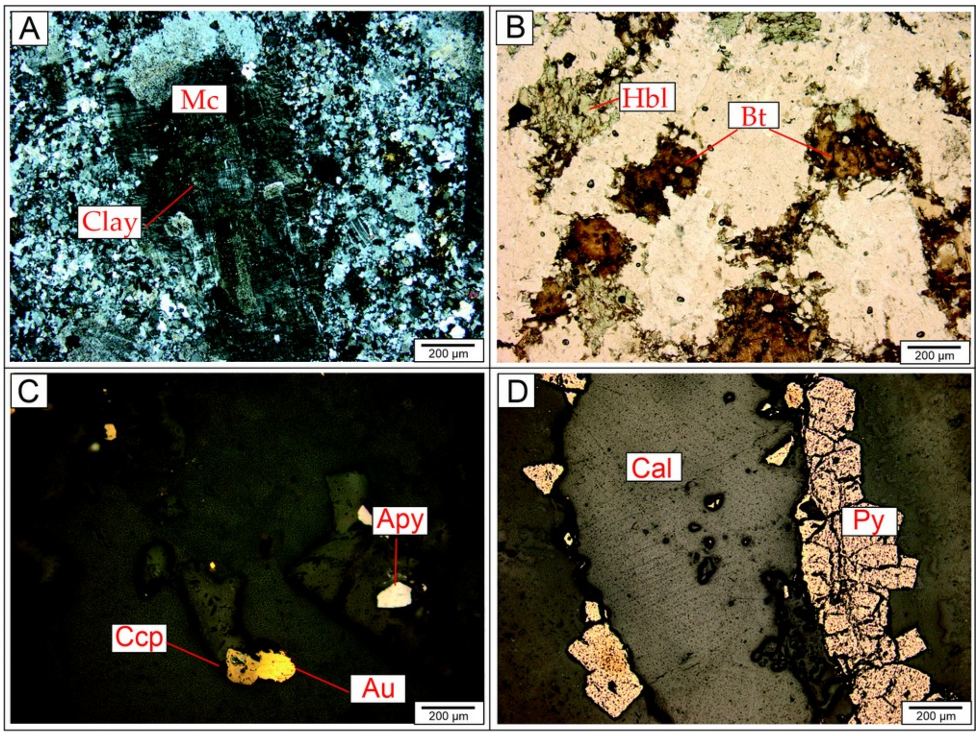

Figure 6. Representative microscopic features of the volcano-plutonic sequence. (**A**) Plagioclase pseudomorph replaced by hydrothermal K-feldspar (Mc) with overprinting of argillic alteration (clay) in a microlitic groundmass. (**B**) Hydrothermal biotite (Bt) and magmatic amphibole (Hbl) in microgranite. (**C**) Gold (Au), arsenopyrite (Apy), and chalcopyrite (Ccp) hosted in a quartz vein. (**D**) Aggregate of pyrite (Py) crystals hosted in calcite (Cal) veinlets.

4. Discussion

The overprinting of mineralizing events is commonly described in world-class deposits, such as the Dongyaozhuang gold deposit situated in Wutai Mountain (China). At Dongyaozhuang, mineralized and hydrothermally altered volcanic rocks are superimposed on an older mineralizing orogenic system [9]. Thus, our preliminary results of this research revealed a similar genetic model for the Volta Grande deposit (Figure 7).

The features that indicate superimposition of two distinct mineralizing events at the Volta Grande gold deposit can be summarized as follows: the oldest is represented by mylonitic and gneissic rocks with quartz veins and veinlets and pervasive carbonate alteration controlled by metamorphic foliation. This setting has been explored by Belo Sun Mining Corp. [10]. The younger described here is a mineralizing event that is genetically related to the volcano-plutonic sequence that hosts quartz veins and veinlets as part of a shallow brittle regime and is accompanied by moderate to intense hydrothermal alterations.

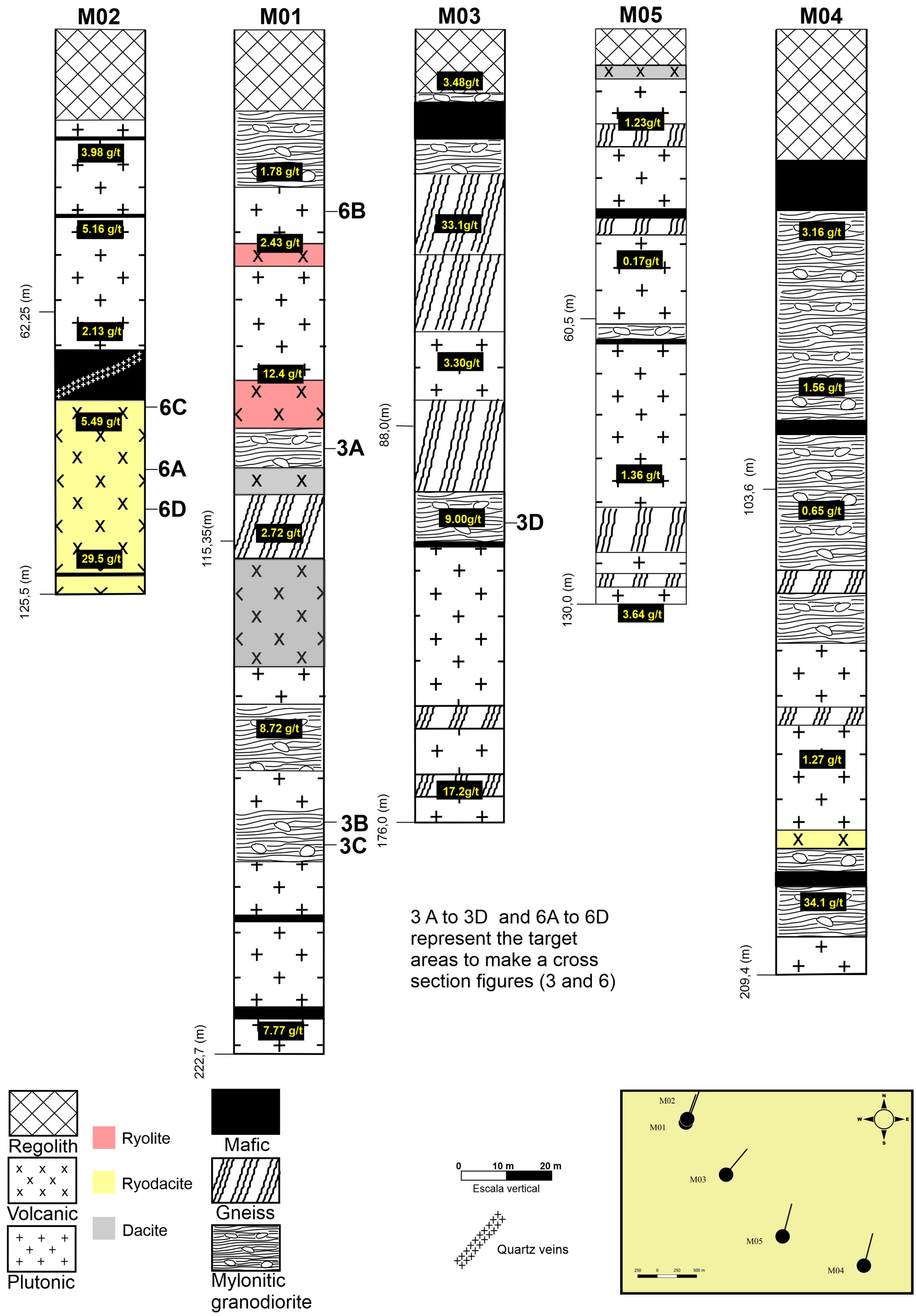

Figure 7. Sketch of the stratigraphic profile of the studied core samples and the bore holes relationships. Ore grades are shown for reference.

5. Conclusions

Our data from the Volta Grande gold deposit reveal potential for a new gold exploration model in the Bacajá domain. The hydrothermal alteration types associated with the volcano-plutonic system of this deposit are similar to those of Proterozoic low- to intermediate-sulfidation epithermal deposits genetically associated with a porphyry-type mineralizing system, as described in the Amazonian Craton [7]. Geochemical rock data, qualitative and quantitative mineral analyses, geochronology, and fluid inclusions will be needed to test this interpretation.

Economic gold concentration occurs in quartz veins and veinlets related to metamorphic fluid evolution. A later hydrothermal system, genetically related to the volcano-plutonic sequence, introduces gold in quartz stockworks and as disseminated grains in the surrounding wall rock.

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Conflicts of Interest: The authors declare no conflict of interest.

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