

Review

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Review

# Gold Deposits Related to the Island Arc Formations and Ophiolitic Complexes of Eastern Cuba: A Review

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**Abstract:** The gold deposits of the eastern region of Cuba are genetically related to the lithological formations of the island arc and the ophiolitic complex, which have been studied and exploited since the time of the Spanish colonization in the mid-sixteenth century. These deposits are part of the so-called Aguas Claras-Guajabales mineral field, in the Holguín Province (Cuba) and lie in an extensive elongated strip of approximately 15 km in length. The object of this work is to make an orderly, detailed, and chronological review of the geological and mining work carried out in this region as well as to highlight the degree of study achieved in each of the stages of research. To facilitate this work, an extensive bibliographic review of all available materials was planned and carried out, such as reports, manuals, monographs, and articles. The results obtained from this study highlight that gold mineralization is closely linked to metasomatic processes produced by the circulation of hydrothermal fluids that affected different lithologies of both the volcanic island arc and the ophiolitic complex, it is noteworthy that the highest gold contents are mainly where the lithologies contact each other. This highlights the fact that the presence of alterations such as serpentinization, listvenitization, rodingitization and propylitization have played a primary role in the deposition of gold during mineralization processes. This work could be a very useful guide for future research in this region, as it is an orderly, concrete, and practical compilation of the characteristics of the mineralization and alterations, as well as a precise indication of the spatial position, thicknesses, and contents of the gold horizons.

**Keywords:** ophiolites; island arc; serpentinization; listvenitization; rodingitization; propylitization; gold; sulfides

## 1. Introduction

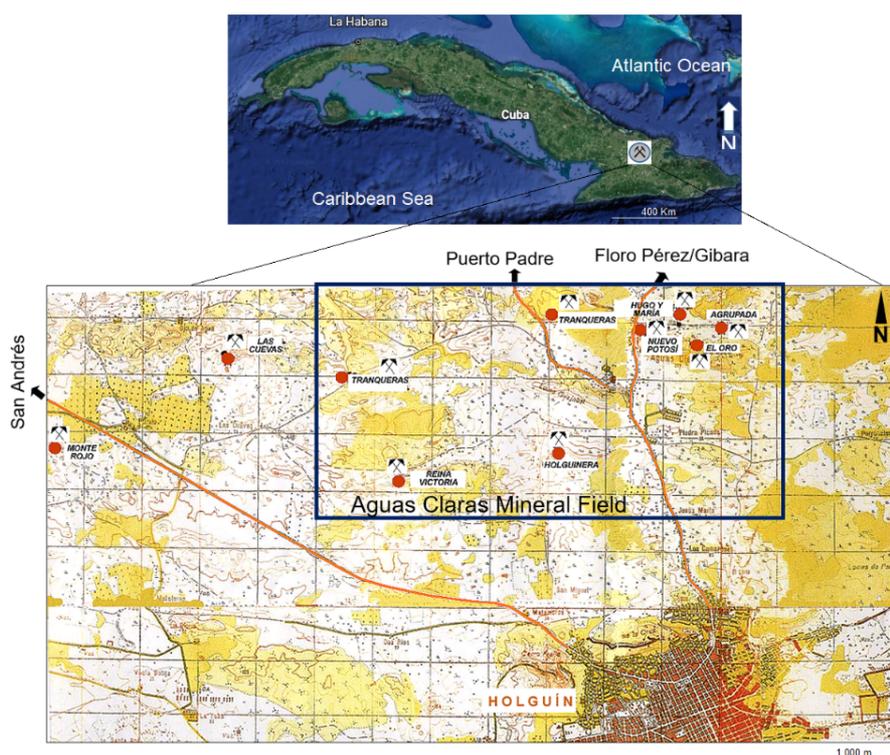
The deposits mentioned in this study have belonged for many years to the Aguas Claras mineral field, which includes a series of deposits known as Reina Victoria, Holguinera, Nuevo Potosí and Agrupada. These are the main ones; there are also small fields such as Hugo y María, El Oro, Santiago, Milagro, Casualidad, Nene, among others (Figure 1).

Although mining in the eastern region of Cuba began in the sixteenth century, it was not until the eighteenth century that it was documented [1–3]. López de Quintana [4] researched endogenous and alluvial deposits in the area of Guajabales and subsequently extracted ores with a content of 3.5 g/t Au. The Holguin-Santiago Mine Co. extracted 98.6 kg of Au between 1907 and 1910 [3]. Another mining company, the Santiago Mining Co., mined 512.8 kg of gold between 1904 and 1907 [1]. The mining work carried out by Abelspies [5] between 1929–1930 at the Santiago mine, found mineralized horizons with average grades of 17.8 and 88.8 g/t Au, respectively. In 1937, Schmeling [6] located gold-enriched ores with a grade of 14.2 g/t Au at the Reina Victoria deposit. Between 1942 and 1945, Biscuccia [7] extracted around 559.8 kg/Au from the Nuevo Potosí, Reina Victoria and Agrupada

deposits. Morón [8] in 1958 constructed two mine shafts at the Milagro mine where they found mineralized horizons with contents of 9.8 g/t Au. From 1963 to 1965, Chalyi et al. [9] carried out gold prospecting and exploration work gathering all the information obtained in preceding investigation. It was this research that quite possibly started the most challenging and in-depth of all studies compared to those carried out previously. In 1971 Bizet and García [10] drilled several wells at the Nuevo Potosí mine that intersected gold mineralized horizons with an average grade of 1.45 g/t Au. Between 1974 and 1976, Kazakov and Tabachkov [11] carried out gold prospecting work in the areas of Tranqueras I, II and III, Monte Rojo, La Ventura and La Fortuna, where they found gold ores of up to 3 g/t Au. In 1983, an extensive geological survey was carried out on a scale of 1:50,000 in this region by Hungarian and Cuban geologists [12]. The activities consisted of prospecting and exploration of gold, copper, chromium, among others. In 1988 the Santiago de Cuba Mining Company calculated the reserves in categories  $C_1 + C_2$  for the Aguas Claras deposits, estimating some 84,969 tons of gold ores and 424.90 kg of gold metal, with an average grade equivalent to 5.0 g/t Au. Costafreda and Velázquez [13] carried out geological and mining prospecting work at the Holguin deposit, which included geochemical and mining in the Holguinera deposit, as well as geochemical and geophysical campaigns, sampling, mapping, and drilling. In 1989 Csillag et al. [14] performed a metallurgical assay on a volumetric sample of gold ores with a weight equivalent to 111.5 kg and a grade of 4.0 g/t Au, which were extracted from the Reina Victoria and Nuevo Potosí deposits, with the following metallurgical recovery results: separation (70%), flotation (57%) and cyanidation (91%). From 1989 to 1994, Costafreda et al. [15] carried out new exploration works in the Reina Victoria, Holguinera, Nuevo Potosí and Agrupada deposits, which included the calculation of reserves in categories  $C_1 + C_2$  and forecast resources in  $P_1$ ,  $P_2$  and  $P_3$ . In July 1994, Rhodes Victoria S.A. was founded in Holguín, an International Economic Association with the purpose to continue studies in the Reina Victoria, Holguinera, Nuevo Potosí, Agrupada, Hugo y María, El Oro, Milagro, Santiago, and Monte Rojo deposits, which covered a total area of 120 km<sup>2</sup> [16]. The works that were done in this stage were geological prospecting with mapping, geophysics, geochemistry and well drilling. Since then, no new works of relevance have been recorded in the region.

The object of this work is to highlight the main results obtained during the most modern stages of geological and mining research in the Aguas Claras mineral field, dating back to the 1960s, in order to gather information on the location of the deposits, characteristics of the minerals and their relationship with the host rocks, according to the relevance of the information, thickness of mineralized horizons, gold contents, and the role of metasomatic alterations. With all this information, this study could be considered a practical guide to facilitate the work of potential investors and mining companies in the future, which would have a positive impact on the geological and mining industry of this region.

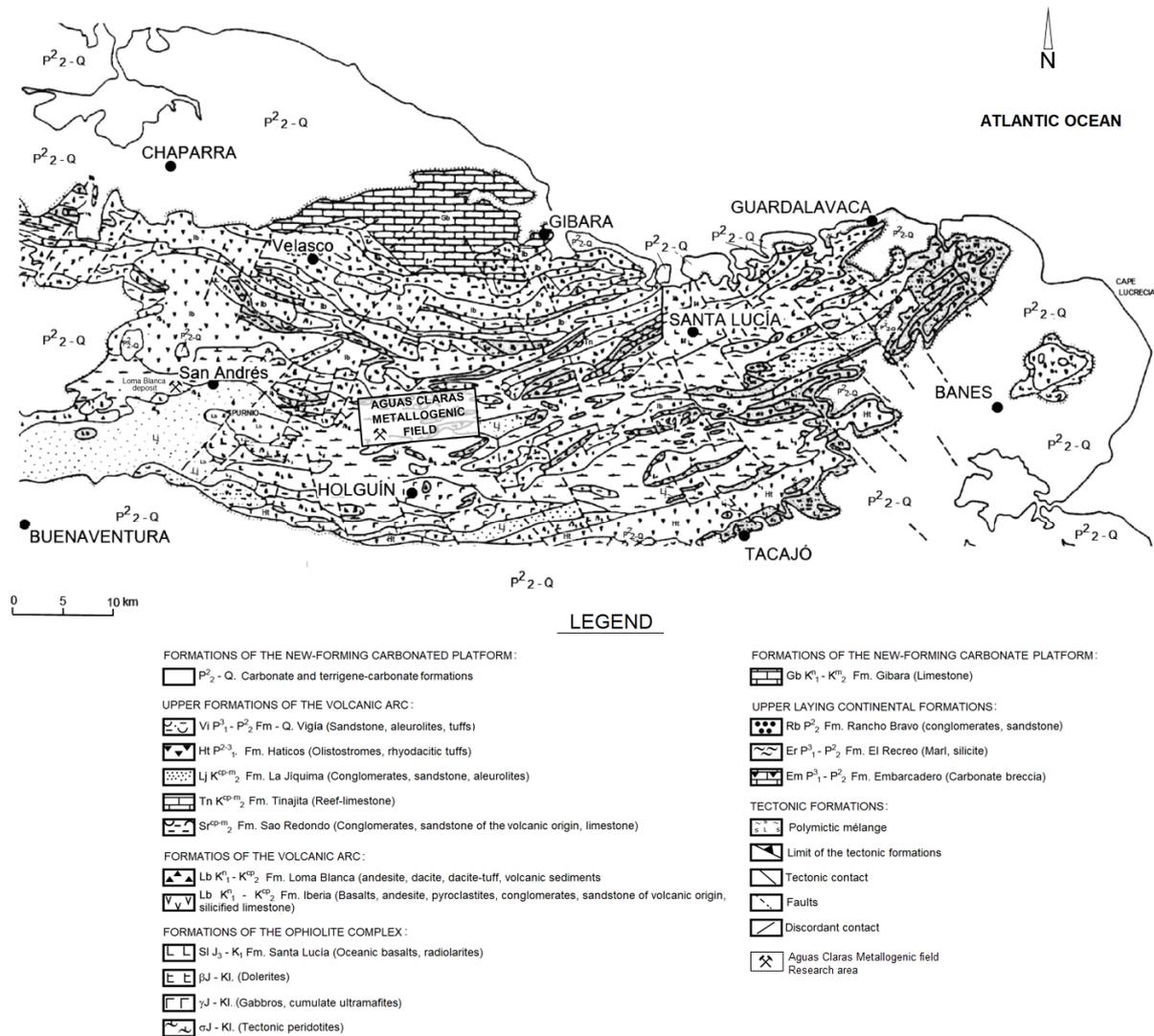
This work has been structured in several phases: first of all, there is a description of the regional geological framework; next, a geological description on a local scale of the main deposits (Reina Victoria, Holguinera, Nuevo Potosí and Agrupada); and then a description of the geological make up, the characteristics and potential of the minerals, types of alterations, calculated reserves and hypotheses about the origin of these deposits. Finally, there is a discussion about the aspects that have not been considered in the previous stages of research, such as the role of metasomatic alterations.



**Figure 1.** Map of the geographical location of the Aguas Claras mineral field, in the province of Holguín (Cuba) [16,17].

## 2. Geological Setting

The main geological feature of the region is the alternation of rock units from the ophiolitic complex and the Cretaceous island arc (Figure 2), which form strips facing east-northeast to west-southwest, with layer structures and imbricated mantles. There are also sediments from the Late Cretaceous-Paleogene, which originated due to the erosion of the arch-insular and ophiolitic formations, which are highly folded [18–20]. These formations have been called Structural-Facial Zones (SFZ), the main ones are Remedios, Placetas and Auras. The first of these units is made up of a carbonate sequence of several thousand meters and is part of the North American continental margin. On its southern edge, in an allochthonous position, and bounded by the Auras SFZ, are the formations of the Superimposed Basins [18,20].



**Figure 2.** Regional geological map including the research area [18].

The Structural-Facial Subzone Placetás (SFSP) is a place where the materials of the Auras SFZ have been installed due to thrust fault, these materials are part of the North American continental edge, and are inserted within the so-called La Palma Formation, where the age is Paleozoic to Mesozoic. It is made up of strongly tectonized orthogneiss of granitic and granodioritic origin, aleurolites and weakly carbonated pelites of euxinic facies, black schists, clayey-calcareous schists, and gray limestone, partly silicified [21–24].

The Auras SFZ is made up of lithologies from the ophiolitic complex, the formations of the volcanic arc and the cover formed during the Upper Cretaceous and Middle Eocene (Figure 2). These formations completely cover the continental slope and the southern part of the Bahamas Shelf [18,25,26].

After the Cuban Phase, the Remedios and Auras Structural-Facial Zones, were covered by terrigenous-carbonate deposits of the neoplataformic phase, through a process that began in the Upper Middle Eocene until present day [18].

#### Rocks of the Ophiolitic Complex:

The rocks of the ophiolitic complex represent between 30 and 60% of the formations of the outcrops in the area [18,20] (Figure 2), despite being an incomplete series, where the middle and upper levels are absent [27,28]. Andó [29] performed a geological and structural palinspastic reconstruction of the ophiolitic association of this region as a complete system, in which he highlights five main complexes: 1) Complex of the level of rhythmic construction, 2) Complex of tectonic

peridotites, 3) Cumulative complex, 4) Complex of parallel and subvolcanic bodies, and 5) Effusive or basalt complex.

The first two complexes, belonging to the tectonic level, which includes tectonic and transitional peridotites. Tectonic peridotites consist of harzburgites, chromitites, lherzolites and dunites; whereas the transitional ones are made up by harzburgites and dunites.

The cumulative complex encompasses ultramaphytes, the products originating in the transition from these and gabbros, tonalites and trondjemites. Within this complex there are two well-defined series: the banded and the isotropic. The banded series represent lithological species such as dunites, lherzolites-wehrlites and pyroxenites (ultramafic series). They also contain normal and amphibolic gabbro olivine, hornblendites, troctolites, websterites, clinopyroxenites and chromitites. On the other hand, the isotropic series include lithological species such as tonalites, trondjemites, diorites, gabbro, amphibolic and amphibolized micro-gabbro.

The lithologies that form the parallel dikes and subvolcanic bodies consist mostly of dolerites, micro-gabbro and spilites.

The basalts of the effusive complex are made up of several related lithologies, such as basalt-dolerites, spilites, as well as aphyric and tholeiitic varieties.

The sedimentary level is rich in siliceous and carbonate series, where sequences of jaspers, radiolarites, aleurolites and limestones have been formed.

#### Rocks of the Volcanic Island Arc:

The rocks of the volcanic island arc in the region are part of two large units: the Iberia Formation and the Loma Blanca Formation [22]. The Iberia Formation (Ib.  $K_1^a - K_2^{cp}$ ) is made up of lavas, basaltic and andesite-basaltic lava-breccias, tuffs and tuffites of the same chemical composition, volcanomictic sediments, silicites and limestones. The main lavas are basaltic, andesite-basaltic, and andesitic. Basalts lie in the lower part of volcanic complexes, while basaltic andesites outcrop in the upper parts. Several varieties of basalt are common, among which there are aphyric, porphyry, pyroxenic, olivine, and those that are usually rich in feldspars.

The Loma Blanca Formation (Lb.  $K_1^a - K_2^{cp}$ ) is made up of tuffs, zeolitic tuffs, tuffites, marls, lenticular limestones, tuffitic aleurolites and carbonate volcanomictic sandstones. This stratovolcanic sequence is cut by magmatites, mainly diorites, andesites, dacites and calc-alkaline and potassium rhyolites, which are relatively enriched with sodium. The final series consists of andesites, pearlized basalts, dacites and rhyolites.

#### Rocks from the Folded Formations of the Cretaceous Cover:

Are made up by limestones from the Tinajita Formation, conglomerates, sandstones, and aleurolites from the La Jíquima and Sao Redondo formations [20]. The conglomerates are of fluvio-marine facies, while the sandstones and aleurolites are either neritic facies or from more distal environments. The La Jíquima Formation (Lj.  $K_2^{cp-m}$ ) is made up of fine- to medium-grained, superficially oxidized stratified sandstones that are brownish-gray and yellowish-brown in color. The thickness of the strata varies, from a few centimeters to two meters, generally showing gradational stratification, which is interlayered with stratified aleurolites and argillites, which are often carbonated, with decimetric thickness. The thickness of this formation can be up to three hundred meters [20], with an abundance of foraminifera and nannoplankton.

The Sao Redondo Formation (Sr.  $K_2^{cp-m}$ ) is a volcanomictic and carbonate sedimentary series, highly dismantled by tectonics and weathering. The lithology consists of greenish brown volcanomictic sandstones of indeterminate thickness and is heavily eroded. It has intercalations of redeposited and argillitized tuffites, of basic to medium composition, which are sometimes carbonate, with planar pelagic limestones, contaminated by fine volcanomictic sediments. The thickness of these limestones is of just a few meters [22].

### 3. Materials and Methods

#### 3.1. Materials

To carry out this research, 45 documents were compiled, catalogued, and studied in detail consisting of reports, maps, and articles available in the archives of the Ministry of Basic Industry, the National Office of Mineral Resources, the Eastern Geomining company, the Holguin Geominera (Cuba), as well as the company Rhodes Victoria. S.A. The work that was used the most was from the 1960s onwards.

### 3.2. *Methods*

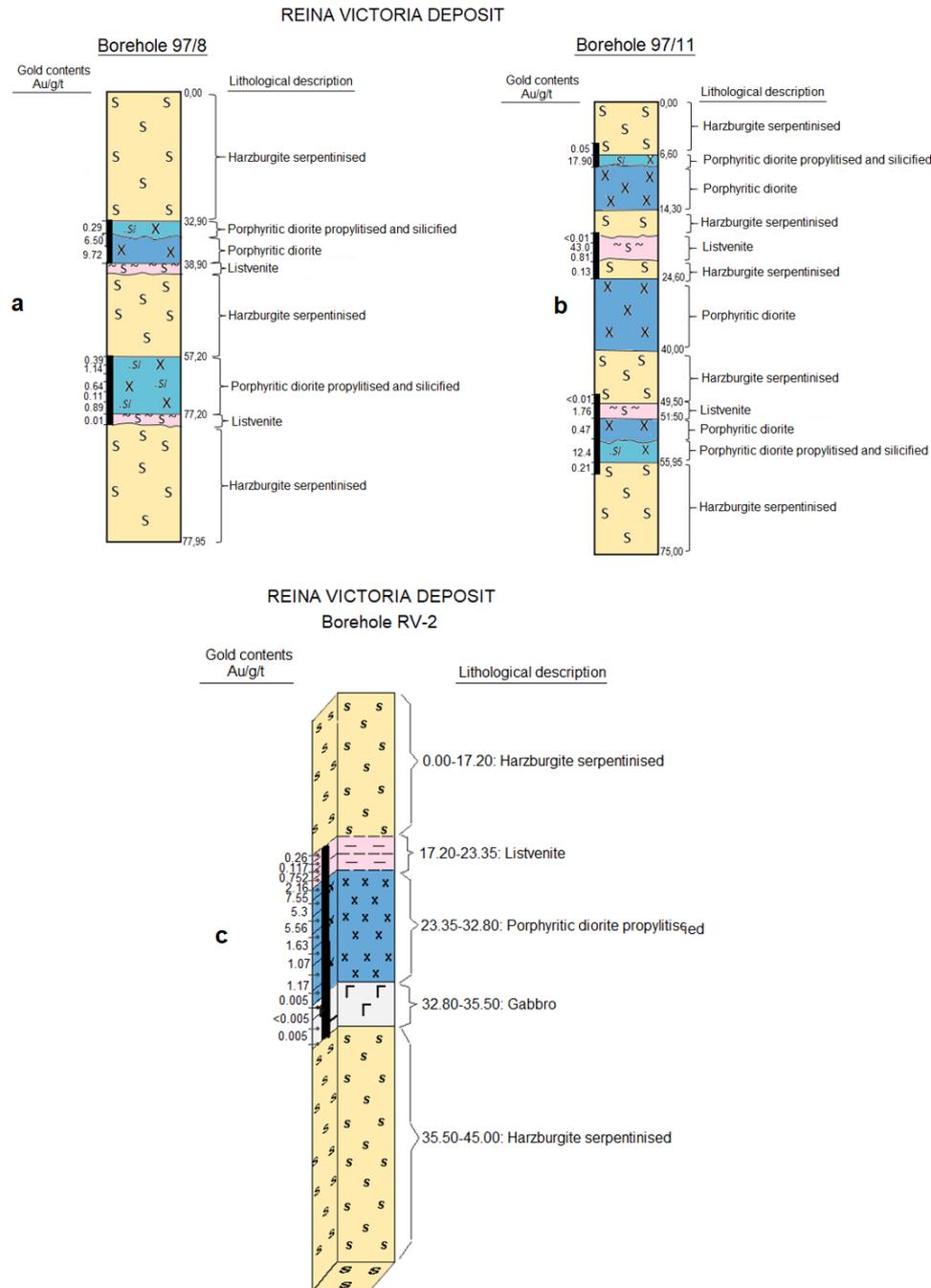
All available documents underwent a process of selection, sorting, cataloguing, studying, interpretation, and synthesis. The structure used for the presentation and discussion of the results consisted of summarizing the geological, petrological, mineralogical characteristics, the state of the reserves and resources, as well as making a hypothesis on the genesis of the gold mineralization of the main deposits, such as Reina Victoria, Holguinera, Nuevo Potosí and Agrupada.

## 4.- **Results**

### 4.1. *Reina Victoria Deposit*

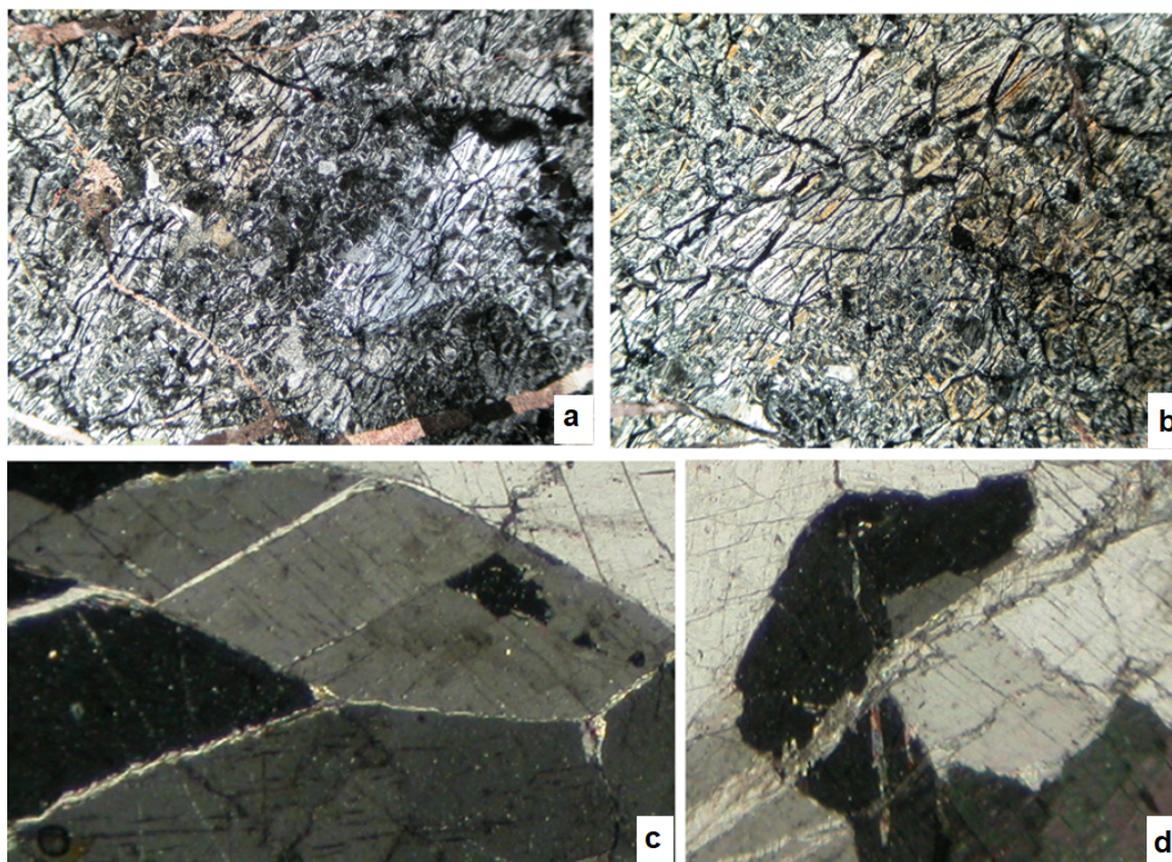
One of the main gold deposits of the Aguas Claras mineral field is Reina Victoria, which is in the westernmost part (Figure 1), specifically at the following coordinates: 26°56'2.56"N and 76°18'35.65" W [17]. The geological nature of the deposit is made up by rocks of the ophiolitic complex, such as serpentinitised harzburgite, dunite and gabbro, which are in close contact with strongly propylitized porphyrite diorite (Figure 3 a, b, c). Diorite forms elongated bodies parallel to each other, and extends in an east-northeast and west-southwest direction, and it always outcrops on the surface [10,13,16].

The mineralization of gold and other accompanying minerals lies in zones of metasomatic alteration caused by the irruption and diffusion of hydrothermal solutions during the processes of obduction, thrust and emplacement of the ophiolitic complex [27–29]. These fluids simultaneously altered both the ophiolitic lithologies and the arch-island rocks in proximal contact, so that when diffusing through serpentinitised harzburgite and dunite, it caused listvenitization (Figure 3 a, b, c), while crossing gabbro sequences caused rodingitization [30–32]. When diffusion took place in insular arc rocks, such as porphyritic diorite, these were altered to propylite [30].



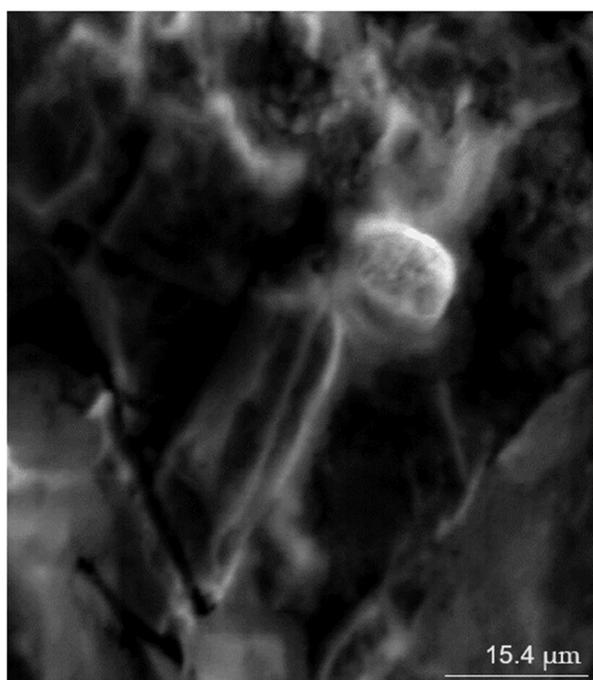
**Figure 3.** Lithological columns from the central part of the Reina Victoria deposit (a and b), as well as from the eastern flank (c) showing the distribution of gold contents and its relationship to different lithologies [32–37].

In Figure 4 (a and b), there are veins filled with carbonate and serpentine material with listvenite; in addition, both olivine and pyroxene are replaced by tremolite and serpophyte [36]. Figure 4 (c and d) shows fine veins filled with tiny grains of gold, which developed along the contact between the edges of altered amphiboles; also note how in Figure 4 (c) the veins can be seen in the entire visual field.



**Figure 4.** Microphotographs of thin sections (a, b) taken with crossed nicols (Nx-crossed nicols. Obj. 0.5x) from a sample of serpentinitised harzburgite that lies at about 15.60 m deep on the eastern flank of the Reina Victoria deposit. The c and d are microphotographs of a doubly polished diorite sample taken at 30.90 m, strongly propylitized [36,37].

Figure 5 shows by scanning electron microscopy the presence of native gold detected in a sample of porphyry diorite strongly propylitized that lies in the eastern part of the Reina Victoria deposit. Gold shows different textures such as spherical, laminar, hooked, and filamentous, and is found with other mineral phases such as pyrite and sphalerite.



**Figure 5.** Microphotograph obtained by scanning electron microscopy, showing the presence of native gold grains and sheets embedded in a diorite sample extracted at 25 m depth (Borehole RV-2), on the eastern flank of the Reina Victoria deposit [32,36].

Costafreda et al. [30] classified the bodies and mineralized zones of the Reina Victoria deposit into four main groups, in accordance with their morphology and structure, taking into account their shapes and dimensions, the relationship of the mineralization to its host rocks, as well as the petrological and tectonic characteristics. Namely:

- Veins, veinlets, streaks, and disseminations.
- Large diameter ore bodies.
- Lenticular mineral zones.
- Mineral zones in friable materials of clayey, mylonitic and cataclastic nature.

In all cases, gold ores are always closely linked to the zones of metasomatic alteration and are made of pyrite, native copper, malachite, iron oxides and hydroxides, covellite, arsenopyrite, pyrrhotite, sphalerite, chalcopyrite, galena, chromite, magnetite, titanates, quartz, carbonates, and native gold. Mineralized zones can extend over an area from 10 to more than 20 m [30].

The gold morphology is dendritic, hooked, elongated, cylindrical and sometimes with clear needle-like finishes on the crystals. Occasionally at the extremes, there is a change in coloration which indicates a variation in its composition. It is often spherical shaped and has small plates. The color changes based on the shape and composition of the crystals; that is, for those cases where the structure is dendritic and/or hooked, the color turns coppery yellow, showing a significant amount of iron and copper. On the other hand, a light-yellow color persists in the presence of crystals with spherical or plate structures, which shows a higher content of silver (electrum). Native gold can be found in the form of independent aggregates within carbonate mass; it can also be found in intergrowth with chalcopyrite or forming irregular aggregates with galena. The size of the grains varies between 2-10  $\mu\text{m}$  and 30-150  $\mu\text{m}$  [38].

The latest calculation of reserves made at this deposit was 2,200,739 tons of ore and 3,657 kilograms of gold metal, with an average content of 1.66 g/t Au [3].

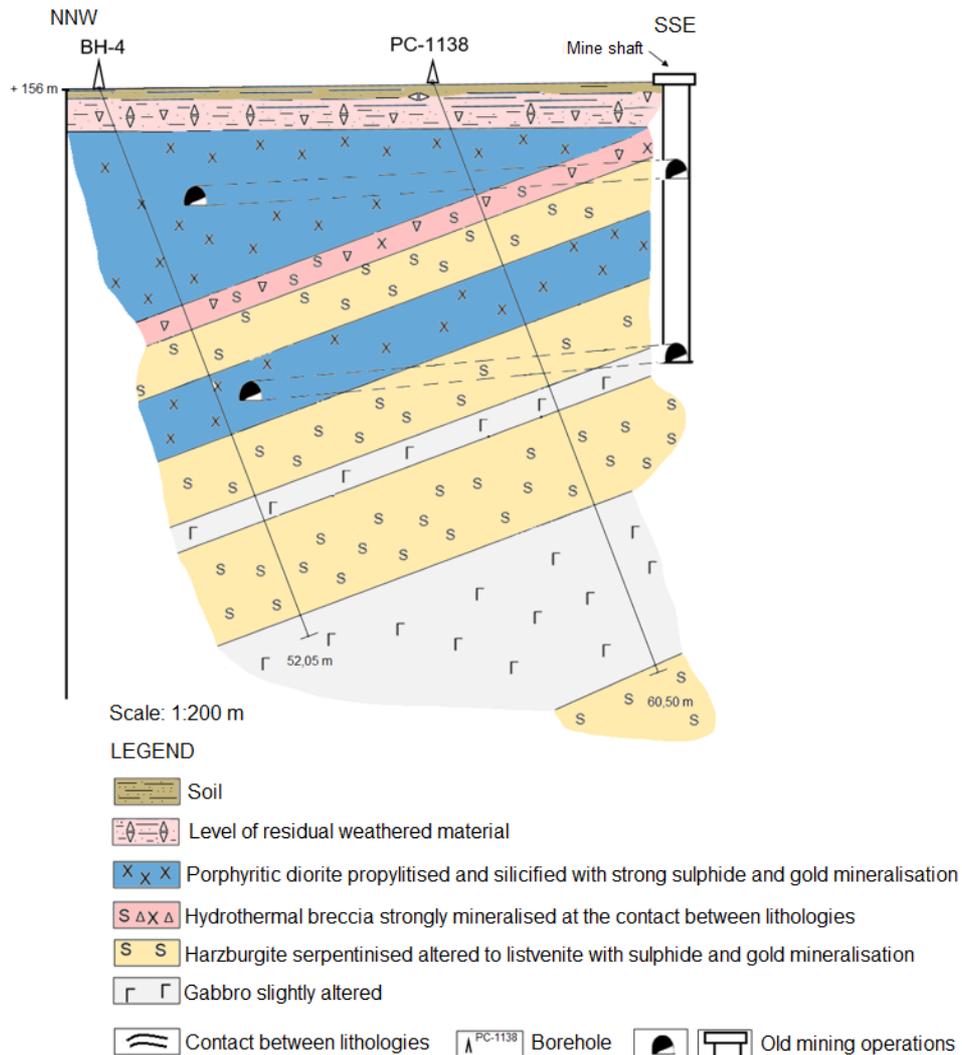
#### 4.2. Holguinera Deposit

This deposit is located 4 km east of the Reina Victoria deposit, at the following geographical coordinates 20°56'18.81"N and 76°16'59.18"W (Figure 1). This deposit is one of the oldest in this region. The surface of the reservoir is covered by complex geochemical anomalies of Au-Cu-Zn, and contrasting anomalies of Au-Ba, with high values of induced polarization and radiometry [13,30].

The Holguinera deposit is made up on the surface of a powerful soil that developed from the decomposition of the residual material from the weathering of porphyry diorite (Figure 6). The rock is strongly propylitized, silicified, and limonited, and exhibits abundant sulfide mineralization accompanied by gold. In general, its contact with serpentinitised harzburgite is usually very breccious and mineralized.

Harzburgite is highly serpentinitised and listvenitized, and exhibits marked mineralization of sulfide, gold, quartz, carbonate, and talc.

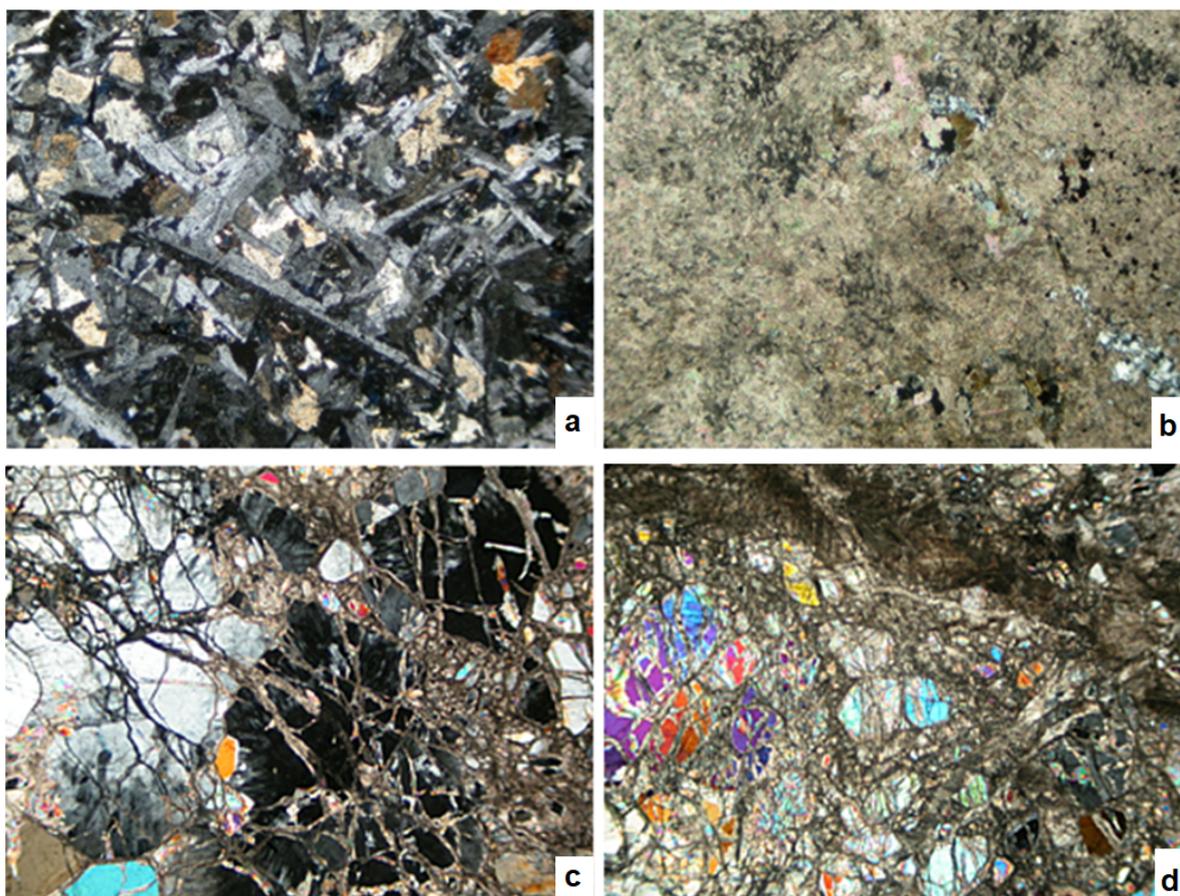
The gabbro forms thin bodies and usually shows a moderate alteration to rodingite.



**Figure 6.** Lithological column of the central part of the Holguinera deposit [30,32].

Macroscopically, diorite is gray in color, with visible greenish and bluish hues, which are indications of a deeply penetrating metasomatic hydrothermal alteration, with the presence of sericite, quartz, epidote, and chlorite. The textures are porphyry and felted (Figure 7 a), although in some cases these could be completely erased by the sericitization process (Figure 7 b).

Serpentinised harzburgite exhibits micaceous and crystalline textures, and consists mainly of olivine, talc, serpentine, asbestos, carbonate, dolomite, and small amounts of quartz and opaque minerals (Figure 7 c and d). The alteration of the harzburgite is also hydrothermal, of low to medium temperature, with the formation of listvenite as a product of contact metamorphism [13,30,39].



**Figure 7.** Petrographic thin-section microphotographs taken with crossed nicols (Nx-crossed nicols. Obj. 0.5x) show a felted texture in a sample of porphyry diorite (a) where plagioclase microliths stand out on a matrix visibly affected by incipient sericitization. In (b) a diorite is observed totally altered by the metasomatic processes of contact where the protominerals have been almost completely erased. Figure 7 (c and d) shows microphotographs of a serpentinised harzburgite altered by hydrothermal processes, very close to the contact with diorite [35,36].

The ores of the Holguinera deposit are mainly sulfide, sulfide-polymetallic, sulfide with iron, pyrite and chromitic, located in veins or in a dispersed form (Figure 8 a-b). Costafreda et al. [30] and Reyes et al. [40] suggest the existence of three different types of mineral paragenesis for this deposit: sulfurous, sulfurous-polymetallic, made of the pyrite-chalcopyrite-sphalerite-arsenopyrite-galena-pyrrhotine association, and the chromite-ilmenite-magnetite association. The latter may indicate a stage of magmatic formation in the levels and sublevels of cumulative complexes and tectonic-transitional peridotites [27], to which gold mineralization is not genetically linked; however, gold is preferentially associated with polymetallic sulfurous paragenesis.

Gold mineralization consists of native gold and electrum with associated acanthite. It forms grains between 10 and 30  $\mu\text{m}$  in size and is preferably located in hypogenic primary pyrite crystals or intergrown with arsenopyrite. The most similar mineralogical association to locate gold in this deposit is: arsenopyrite-chalcopyrite-galena-sphalerite-cuprite-bornite-native gold [30].



Földessy [3] estimated the gold ore resources in the Holguinera deposit at around 1,062,000 tons and about 1,494 kg of gold metal, with a content of 1.0 - 4 g/t Au.

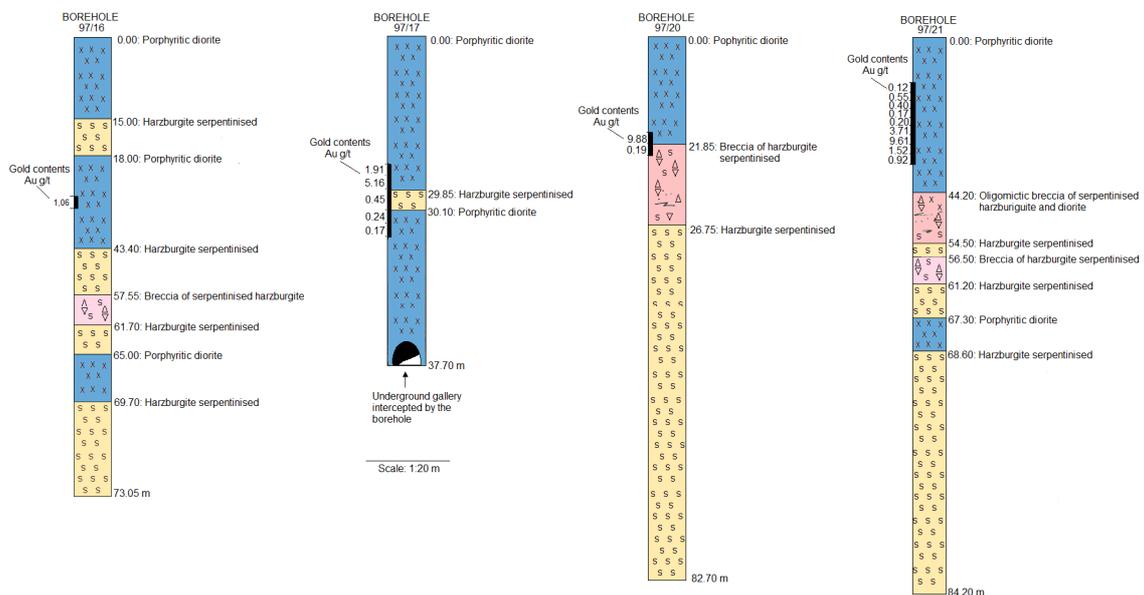
### 4.3. Nuevo Potosí Deposit

The Nuevo Potosí deposit is located about 7.33 km east-northeast of the Reina Victoria deposit and about 5 km north-northeast of the Holguinera deposit, at coordinates 20°57'29"N and 76°15'59"W (Figure 10).



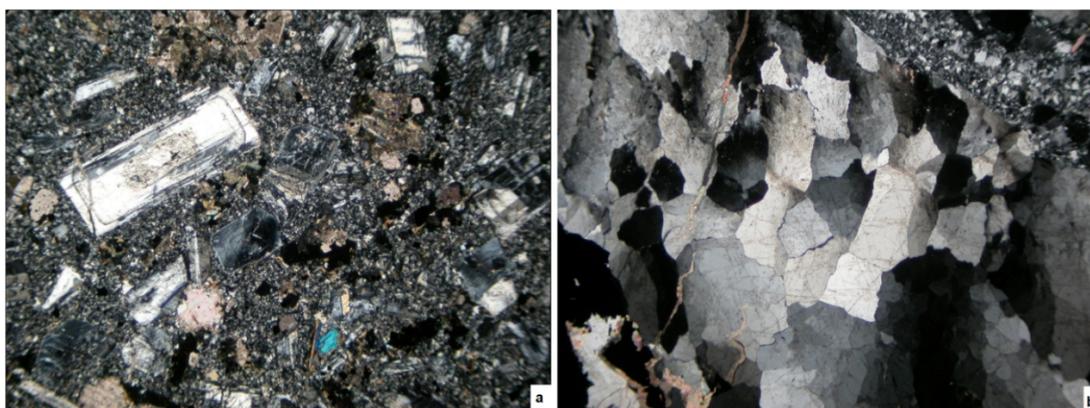
Figure 10. Location of the Nuevo Potosí deposit [17].

The geological make up of the Nuevo Potosí deposit is like that described in the Reina Victoria and Holguinera deposits, and consists basically of porphyry diorite, serpentinised harzburgite and gabbro, to which a mineralization of hydrothermal genesis is spatially linked (Figure 11).



**Figure 11.** Lithological columns from the Nuevo Potosí deposit [30,32,41].

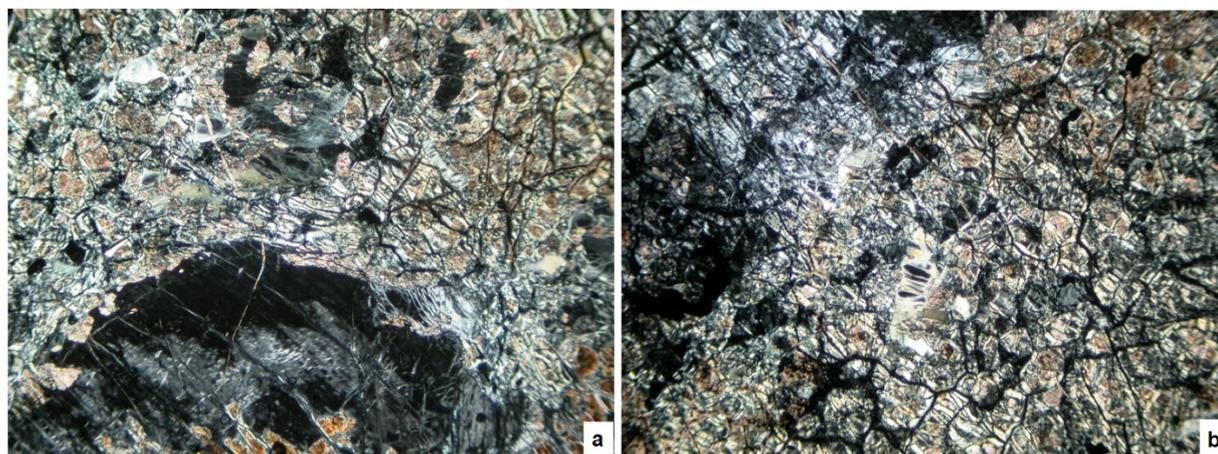
Diorite has a gray color, ranging from light to dark, with green, light brown, pink, and bluish tones. In general, it has a uniform, massive, very consistent, hard, compact structure, sometimes with a certain porous and tonsillar appearance, perhaps by hydrothermal leaching, but it usually alternates with friable, fragmented, and brecciated parts. The texture (Figure 12 a-b) is variable, holocrystalline, medium to coarse-grained phaneritic, equigranular, panidiomorphic, and saccharoidal; even, hypidiomorphic and allotriomorphic. It is mainly made up of plagioclase, amphibole and, to a lesser extent, pyroxene phenocrysts.



**Figure 12.** Thin-section microphotography with crossed nicols (Nx-crossed nicols. Obj. 0.5x) from a porphyry diorite sample taken at the Nuevo Potosí deposit, at a depth of 21.50 m [32].

The features to be highlighted are the strong predominant sericitization, the generalized alteration of both amphibole and pyroxene, and the low presence of quartz, which may be masked by sericite. Large phenocrysts of plagioclase show signs of reaction with the paste. Opaque minerals, mainly pyrite, predominate (Figure 12 a). In Figure 12 b there is a clear predominance of xenomorphic quartz and saccharoidal in a section of a vein in which metallic mineralization is also located (lower left). The presence of calcite veins that bisect the quartz indicates that it corresponds to a later mineralizing pulse [35].

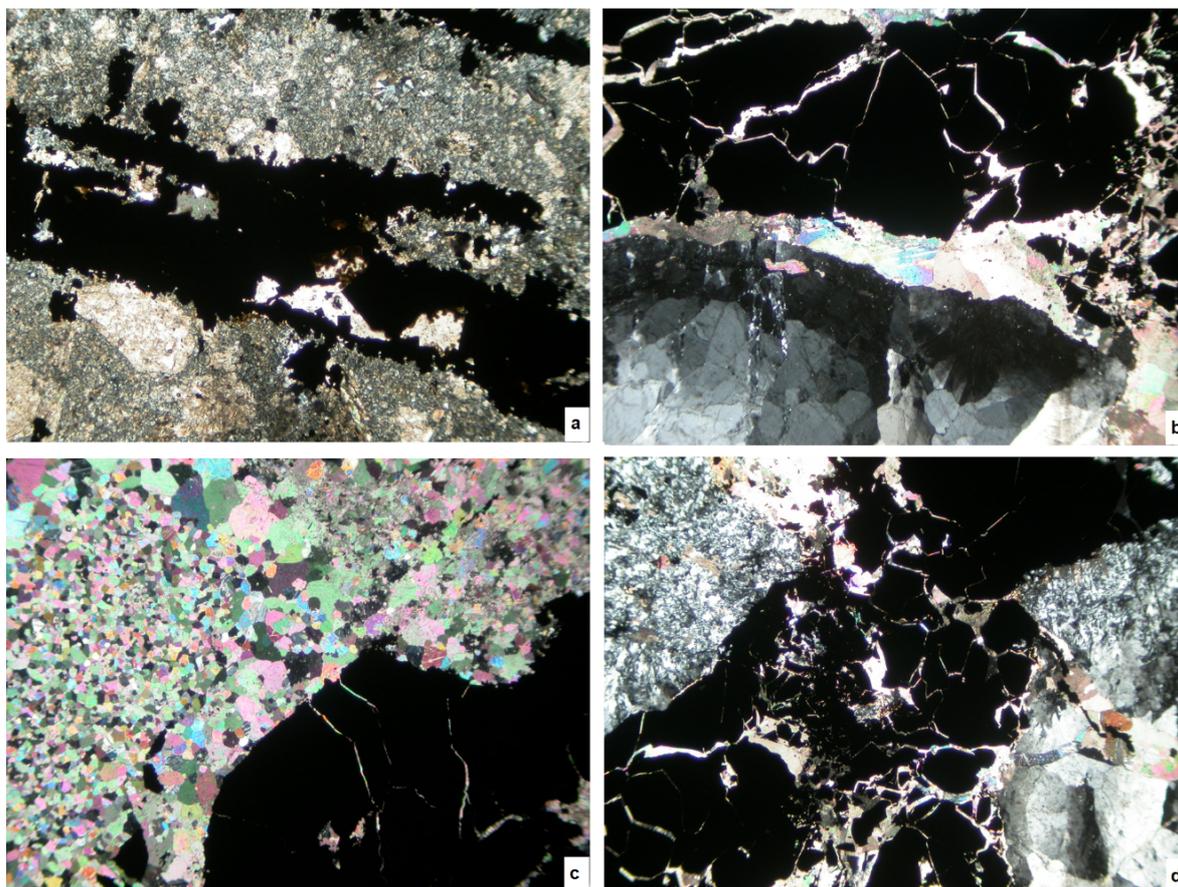
The serpentinised harzburgite has colors ranging from dark green to black, with reddish, brown, bluish, and yellowish hues, with a strong banded appearance (Figure 13 a-b). Its structure is massive, uniform, virtually compact, hard, and coherent, although it frequently becomes a breccious, cataclastic, mylonitic and clayey structure. The texture is coarsely granular, phaneritic and panidiomorphic granular, where the olivine crystals appear very tight and completely altered to serpentine and magnesite. The texture can also be poikilitic when olivine phenocrysts contain chromite and pyrite spinel inclusions. Pyroxene crystals appear strongly altered to chrysotile asbestos.



**Figure 13.** Thin-section microphotography with crossed nicols (Nx-crossed nicols. Obj. 0.5x) from an altered harzburgite sample taken at a depth of 15.60 m, on the southern flank of the Nuevo Potosí deposit. Note the degree of serpentinization that olivine crystals have attained, and the presence of chrysotile asbestos formed by alteration of pyroxenes. There is reddish-brown hematite and hydrohematite confined to veins. Incipient asbestization can be observed at some points in the visual field [35].

In the Nuevo Potosí deposit, the metallic mineralization is composed of pyrite, marcasite, chalcopyrite, sphalerite, arsenopyrite, leucoxene, pyrrhotine, magnetite, chromiferous spinels and native gold, distributed in the form of disseminations of small grains throughout the rock, as well as inside the veins, where they form elongated, idiomorphic, hypidiomorphic and xenomorphic microcrystalline aggregates, yellow in color and marked metallic luster, emplaced as subparallel along the veins [34,42].

Figure 14 a shows black mineralized bands with a subparallel arrangement, as well as a strong propylitic alteration that affects the entire matrix, in which amphibole phenocrysts altered to carbonates persist. Figure 14 (b, c and d) shows, in black, the dominant presence of metallic mineralization confined to large vein systems in which calcite is almost always accompanied. The emplacement of mineralization, including calcite gangue, was produced by the action of hydrothermal solutions that ran through paleodivide developed in the host rock [35,36].



**Figure 14.** Microphotographs of double-polished sections (a, b, c and d) showing a strongly mineralized porphyrite diorite, taken at a depth of 27.40 m (Obj. 0.5x) [32].

Gold appears occluded in arsenopyrite crystals, in the form of particles with diameters between 0.002 mm and 0.08 mm, or as tiny irregular segregations. It is possible that the alteration of arsenopyrite contributed to the release of these fine gold particles. The original arsenopyrite was probably gold, present in the form of a solid solution that formed part of the structure of its crystal lattice. It is also often associated with calcite and quartz in the veins [33,34].

Földessy's reserve estimates indicate a volume equal to 128,529 tons of gold ore and 552.7 kg of gold metal, with a content of 5.67 g/t Au and a mineralized horizon thickness of 1.5 m [3].

#### 4.4. Agrupada Deposit

The Agrupada deposit lies the easternmost part of the Aguas Claras mineral field. It is located 2 km north-northeast of the Nuevo Potosí deposit, with the following coordinates: 20°57'49"N and 76°14'59"W (Figure 15).

This deposit has been one of the main mining enclaves in which enormous exploration and exploitation works have been carried out, since the time of Spanish colonization. However, the most outstanding works are focused on the decade of the 1960s [3,9,30,34,41,43].



**Figure 15.** Location of the Agrupada deposit [17].

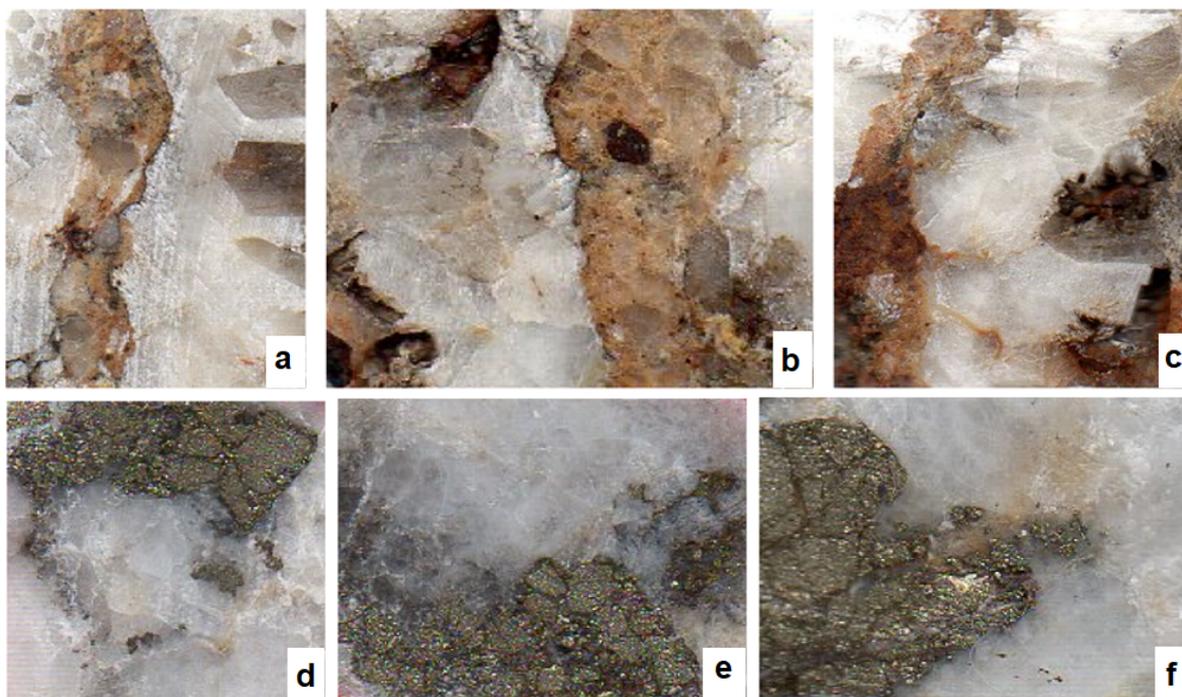
The lithological composition of the deposit is very similar to that of Reina Victoria, Holguinera and Nuevo Potosí, where there are rocks of ultrabasic, basic, and intermediate composition, represented by serpentinitised harzburgite, gabbro, dolerite, and porphyry diorite. The harzburgite commonly alters to listvenite, and is markedly cataclastized, mylonitized, and foliated due to the tectonic processes that caused the emplacement of the ophiolitic complex. Porphyritic diorite is highly propylitized (Figure 16) and forms dikes that dip southward at varying angles between 60° and 90°. They extend in an east-northeast direction for about 300 m, and the thickness reaches 30 m.

Gabbro, gabrodiorite and dolerite are remnants of the cumulative level and parallel dikes of the ophiolitic complex of the Holguín region, as confirmed by Andó [27] and Andó et al. [28].



**Figure 16.** Highly tectonized porphyrite diorite that outcrops in the central part of the Agrupada deposit [32].

Previous studies classify the Agrupada deposit as hydrothermal, with veins and stockwork systems as well as and phyllonian [9,30,44,45], and established the existence of a series of main mineral bodies known as: "Veta Abalo I", " Veta Abalo II", "Veta del Pozo de Mina 1" and the "Veta Emilito"; as well as an appreciable number of veins with contents of up to 2 g/t Au. These veins are filled with quartz, calcite, chlorite, epidote, and sulfides consisting of pyrite, chalcopyrite, galena, sphalerite, as well as gold, chromite, sphene-titanite, and leucoxene [9]. The veins have comb, crustiform, ridge, and breccia textures, in which other minerals of secondary alteration are found, such as hematite, limonite, chlorite, and epidote (Figure 17 a, b, c). Sulfurous ores play a key role in the veins; they form large compact aggregates and irregular masses made of tiny cubic crystals of pyrite with which gold is frequently associated (Figure 17 d, e, f) [30].



**Figure 17.** Images obtained from partially polished samples extracted at different points of the "Veta Emilito", at the Agrupada deposit [30].

Gold appears in the form of small grains scattered over sulfides, but also as a native element associated with silver, calcite, pyrite, and quartz. Its structure is usually irregular, with no apparent geometric habits or idiomorphism, with appearances of patches and intergranular fillings. The diameter of the gold particles can reach 0.3 mm.

Native gold, commonly associated with galena and calcite, can take on scaly and lamellar textures up to 0.3 mm in diameter. Its ore content varies from 30 to 50 g/t Au. According to Chalyi et al. [9], gold formation is syngenetic with calcite and postgenetic to sulfide mineralization and quartz. The average gold content reported at the Agrupada deposit ranges from 6.75 – 8.67 g/t Au, although specific values of up to 200 g/t Au have been reported.

The estimate of reserves made by Chalyi et al. [9] establishes about 36,308 tons of gold ore and about 191.37 kg of gold metal, with an average content of 5.27 g/t Au.

#### 4.5. Hypothesis on the Origin of Mineralization

The origin of the location of the mineralized bodies in the Aguas Claras mineral field is the object of numerous controversies that are still unresolved. Traditionally, it has been accepted that porphyry diorite is the main host rock that carries gold mineralization, from a morphological point of view it looks like dikes that intrude into the ultramaphytes [9]. It was established that porphyritic diorite has a genetic and spatial relationship with sulfide mineralization to which gold is associated, and that once the accompanying fluids were emplaced, they transmitted this mineralization not only to diorites, but also to the ultrabasite and basite rocks of the environment by direct diffusion, through interlithological contacts, fault and diacalse planes. These same fluids simultaneously altered the felsites, maphytes, and ultramaphytes due to contact metasomatism.

Pentelényi and Garcés [12], Andó [27,28], Kozák [22,23] and Földessy [3], have a new genetic approach, divided into three fundamental criteria that are summarized in the following paragraphs:

##### Genetic Approach Based on the Ophiolitic Environment:

Andó [12,27,28] states that mineralization is found in rocks of the ophiolitic complex (diorite, gabbro, harzburgites). Diorite is a differential of cumulative gabbro and not a product of island arc magmatism. The mineralization may have originated from a process of autometasomatism triggered during the obduction and subsequent overthrusting of the ophiolites, as well as by local anomalous accumulation of metals at the various levels of this complex. According to this author, mineralization has an allochthonous character.

##### Genetic Approach Based on the Cretaceous Island Arc Environment:

According to Kozák [12,22,23], the mineralization was deposited in subvolcanic rocks of the Cretaceous island arc. These rocks, consisting of porphyritic diorite mineralized by sulfides and gold, intruded levels of rocks of basic and ultrabasic chemism (serpentinised harzburgite, gabbro), their contacts being hot. Its location is autochthonous.

##### Genetic Approach Based on Mixed Geological Environments:

According to Földessy [3,12], mineralization does not belong to the main igneous activity of the Cretaceous island arc, since it is present not only in the ophiolitic lithologies, but also in the effusive and sediments that form the cover. Its position is para-autochthonous, as its emplacement, interlithological contacts, and original alteration haloes have been preserved, despite the regional thrusting and dismemberment experienced.

## 5. Discussion

After evaluating the results of the authors who have worked in the area, several aspects can be clarified that show that not all the work carried out prior to the 1960s was genuinely scientific in nature, and that its only objective was the empirical treatment of ores to carry out mining activities, focused very much on local exploitation of gold ores so as to obtain easy, direct profits in the shortest possible time, with a minimum expenditure of resources and investments. It has been established that the most serious work began in 1960.

The first thing to highlight in this discussion is the great unanimity of opinion that exists in seeing that the gold mineralization in the Aguas Claras mineral field is uniquely and strongly linked to some felsites (porphyritic diorite, granodiorite), as demonstrated by the work of Chalyi et al. [9].

Another of the key problems is the absolute thought that the genesis of these deposits, are considered to be hydrothermal typology in the traditional sense of classification, without considering the general geological context where the mineralizing solutions originated [43,44]. Attention is paid only to the characteristics of the areas of alterations, as well as the places where they are located and their link with areas of strong geophysical and geochemical anomalies outside the scope of direct contact of intrusive dikes with ultrabasic rocks.

The role of alterations was first studied in depth by Pentelény and Garcés [12] and Costafreda et al. [13,15,16,32,35,36], who carried out a great deal of research to establish the genetic and spatial relationship of metasomatic processes with an anomalous concentration of mineralization. In this way, several types of alterations were established in the Aguas Claras mineral field, of which the following are briefly mentioned:

*Serpentinization:* Andó [27] describes it as a regional allochemical process that, in addition to including the incorporation of water and the release of other chemical components, facilitates ion exchange, the decomposition of complex minerals, the synthesis of compounds and numerous oxidation-reduction reactions, depending on the affected rocks. In this process, reaction products such as serpentine, magnetite, chlorite, and brucite were originated. On the other hand, metal ions of copper, zinc, gold, and appreciable amounts of silica and calcium were released and deposited. The gold grades determined in serpentinitised ultramaphytes range from 0.2 to 3.0 g/t Au [32].

*Rodingitization:* Földessy and Costafreda [45] argue that this is a process that occurs when hydrothermal solutions affect cumulative gabbro, forming a metasomatic product known as rodingite, where its composition consists of zoisite, prehnite, diopside, actinolite, and chlorite, often accompanied by free gold. This zone of alteration is smaller consisting of a few centimeters up to 5 meters, starting from the conduits through which the hydrothermal fluids circulated. Gold content can be as high as 4 g/t Au.

*Listvenitization:* Pentelényi and Garcés [12], Costafreda and Velázquez [13] and Costafreda et al. [30] justify it as a process of metasomatic alteration that directly affects the ultrabasic rocks that are in direct contact with diorites, microdiorites and andesites, the reaction product being a listvenite, which is covered by a mineralization consisting of pyrite, chalcopyrite, native copper, pyrrhotine, arsenopyrite, sphalerite, galena, chromite, malachite, cuprite, bornite, magnetite, and marcasite, as well as associated titanates and native gold. In this zone, the gold content ranges from 0.4 to 10 g/t Au.

*Propylitization:* Costafreda et al. [32] and Földessy and Costafreda [45] agree that this is a process of metasomatic alteration that affects diorites and andesites, with the cenotype being a propylite. As a result of this process, secondary minerals such as chlorite, epidote, quartz, carbonate, and calcite are formed, accompanied by sulfides and gold. This process can extend over areas greater than 30 meters, and gold contents can reach values of up to 19.9 g/t Au.

In accordance with what has been discussed, it is established that the importance and economic potential of the deposits of the Aguas Claras mineral field lies not only in the presence of diorite dikes or their intrusion into the ultramaphytes, but also because of the typology and extension of the zones of metasomatic alteration developed in different lithologies. Therefore, these observations must be taken into account in the planning of future work.

In addition to alterations, interlithological contacts are observed to contribute to effectively control the mineralization. As observed in these deposits, the nature of the contacts can be of several types: first, tectonic contacts in which breccias, cataclasts and mylonites appear from the proximal lithologies, which due to their characteristics represent areas of high permeability, favorable for the diffusion of ion-charged solutions; on the other hand, these zones contribute to the abrupt depressurization and cooling of hydrothermal fluids, causing the precipitation of mineral ions, in such a way that they can act as true thermodynamic sieves. Secondly, there are direct contacts between lithologies without tectonic disturbance, but with a halo of varying dimensions produced by metasomatism; in this enclave, there is a bidirectional diffusion of ions that are exchanged between the affected rocks, causing an instability in the hydrothermal solutions and with it the ionic discharge, which is usually in the form of veins and disseminations. Thirdly, the presence of faults of different

typologies and diachas that cut all the lithologies of the Aguas Claras mineral field are contributing factors to the spatial control of mineralization.

Finally, the presence of carbonate on the one hand and silica on the other are two important signs to consider, since their presence indicates the character of the reactions of the fluids with the host rocks.

## 6. Conclusions

After the description, analysis and discussion of the results presented in this work, the following conclusions were established:

1. The Aguas Claras mineral field appears to have significant gold reserves, given the reported gold contents, the extent of the areas where the deposits are located, and the long period in which they have been exploited without depletion.
2. Geological and mining work has traditionally focused on mineral zones with anomalous gold enrichment, i.e., veins, veinlets, stockwork horizons and proximal areas of influence, but never beyond these limits.
3. As observed, zones of metasomatic alteration, such as listvenitization, rodingitization, propylitization and serpentinitization, are very important in the control of mineralization. These zones, of varying sizes, are often large areas within the Aguas Claras mineral field, which greatly increases the importance of this region.
4. On the other hand, knowledge of interlithological contacts, areas with development of breccias, cataclasites and mylonites, as well as faults and diachas would help to better understand the mechanisms of formation of gold ores in these geological environments.
5. The criteria set out in points 3 and 4 could be of great help in future research as both the zones of alteration and the interlithological contacts could be considered in the calculation of the reserves, thus contributing to a significant increase in geological resources.
6. Finally, this work could be used as a safe practical guide for new research projects carried out in this region, providing a more pragmatic, but essentially scientific, sense.

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