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GEOLOGY OF THE FLORENCIA GOLD – TELLURIDE DEPOSIT (CAMAGÜEY, CUBA) AND SOME METALLURGICAL CONSIDERATIONS

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ABSTRACT

This paper describes the results from a study of the Florencia gold-telluride deposit in Central Cuba, including mineralogical, petrographical, microprobe and chemical analysis.
Valuable information is provided for the exploration, mining and processing of gold ores from other nearby deposits with similar characteristics.
Results highlight changes in the mineralogical composition of the ores between the north and south sectors of the deposit, as reflected in metallurgical concentrates after beneficiation and flotation of samples from these sectors.
It is shown that gold deposits of the Cretaceous Volcanic Arc of Cuba largely consist of native gold, telluride and pyrite, where arsenopyrite is almost absent. Traces of lead, zinc and cadmium are present in the periphery of the main ore zones.

Key Words: Volcanic arch, Cretaceous, Mineralogy, Electronic microprobe, Petrography, Gold, Telluride, Florencia, Cuba.

INTRODUCTION

Despite the long history of mining of auriferous resources in Cuba, the technique-productive and technological information was not conserved for different reasons. During several centuries the Spanish settlers, and later on the small companies, developed underground or rudimentary mining in the Holguín, Guaimaro-Jobabo, Placetas and Isla de la Juventud areas, which were interrupted by different economical and historical factors.
The Florencia deposit is located in the E area of the country, in the Guaimaro municipality, Camagüey. It is known from the last century as a gold mine district and there are several reports from that period describing its mining and infrastructure.

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In the nineties, the International Economic Association MacDonald Mines Ltd and GeoMinera S.A. carried out an intense exploration program in Florencia and in the surroundings of Jobabo area (fig. 1), including Maclama and Golden Hill located to the south. This exploration program led to a pre-feasibility study. Works were stopped and no inversion took place because of low prices of gold.

The results exposed in this paper include the underground explorations that were developed during the years 70-80 as a cooperation program between the Cuban and U.S.S.R government. This information was taken from field works such as drillings and gallery samples, as well as available literature of the Florencia district. It was also obtained important laboratory information such as petrographical, microprobe and chemical analysis.
The principle aim of this study was to determine the mineral assemblage of gold ore deposits and the way in which precious gold and silver elements occur.
The mining of these deposits may cause potentially adverse environmental impacts and some corrective measures are presented in order to mitigate them.

MATERIALS AND METHODS

Data were provided by the Oficina Nacional de Recursos Minerales from important areas with manifestations of gold located in the Cretaceous Volcanic Arch and information published by foreign companies that carried out works of geological prospecting in different areas of the country. 15 thin sections, 35 polished sections, and 10 fire-essay analysis were also analysed.

The results highlight the mineralogical differences between the products of the technological samples obtained in the North and South areas. The presence of minerals of the telluride group and the arsenopyrite absence in the ores, playing the pyrite an important part, is a characteristic feature of the auriferous sites located in the volcanic Cretaceous arch.

GEOLOGICAL SETTING

The Cuban tectonic zonation is very distinctive. A continental scarp extends along the northern margin of the Island and the narrow ophiolitic belt belonging to the ancient oceanic crust located to the South. The volcanic – sedimentary deposits complex, which represents the formation of an island arc, is developed along the central and southern parts of the territory. Metamorphic rocks from the continental mass are well know in western and south-eastern Cuba.

During the Aptian to Campanian, a geodynamic volcanic island arc regime was established in the Caribbean. Outcrops can be observed along the Camagüey province. In the central region of the country, the Los Pasos Formation contains several deposits and prospects of the VMS (Kuroko) type with appreciable contents of Cu, Zn, and subordinated Ag, Au, Cd and Pb.

Several high anomaly areas have been described with presence of auriferous mineralization of epithermal type in the rocks of the Cretaceous Volcanic Arch of the eastern part in the country, forming the Ciego de Avila - Camagüey - Las Tunas and Holguín belt (López *et al*., 1990; Primelles *et al*., 1998; Primelles *et al*., 2003; Simon *et al*. (1999; Capote, 2004). The Camagüey region, is the most important because of its vast number of deposits, and constitutes a district of epithermal deposits. According to Díaz de Villalvilla *et al*. (2003), the nature of the rocks of the volcanic arc in Camagüey allows to correlate them with those of The Dominican Republic (Fig. 1).

There are several types of mineral deposits in Central Cuba including high sulphide (Golden Hill) and low sulphide systems (Beatriz, Florencia), Cu-Mo-Au porphyry (Palo Seco y La Purísima) and Au-Ag-Zn Skarns (La Purísima) deposits (Primelles *et al*., 1998; Primelles *et al*., 2003; Simon *et al*., 1999). These authors considered the gold mineralization in the territory as an intrusive-related model with intrusive rocks and other representatives of the rocks of the Arch, and state that epithermal deposits of the Camagüey district are not related genetically with the plutonic bodies of the Cretaceous

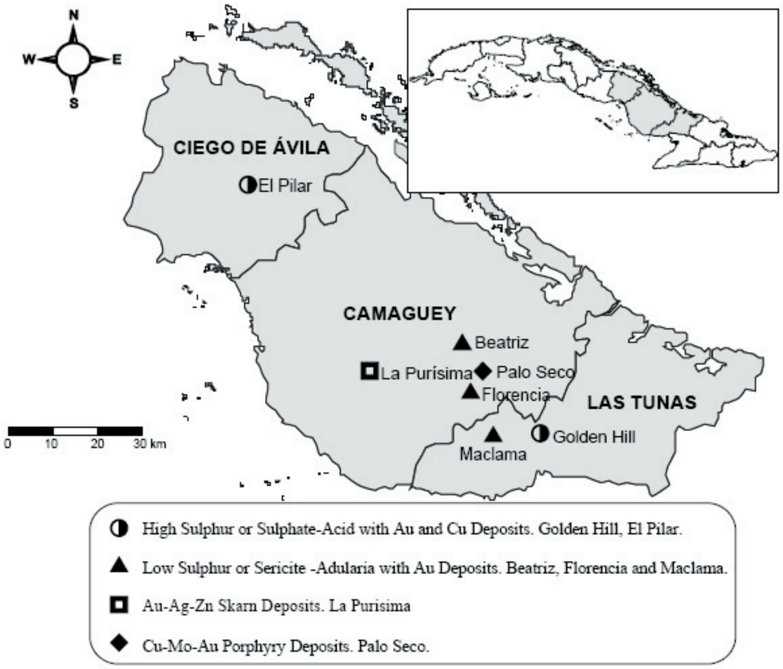

Fig. 1. Central Cuba deposit location.

Volcanic Arch. Simon *et al*. (1999) suggest that there is a relationship between the mineralization and the rhyolites of the Sierra Formation.

This paper underlines the mineralogical characteristics of these deposits by pyrite presence as the main mineral, either disseminated or as sulphur; the absence of arsenopyrite and the occurrence of a variety of minerals such as gold, silver, lead, bismuth and nickel of the telluride's group: Petzite, Calaverite, Silvanite, Hessite, Bolinskite, Shtiutzite, Melonite, and altaite, as well as the presence of gold of high purity and electrum (Torres *et al*., 2005; López, 1988; López *et al*., 1998; Bortnikov *et al*., 1988). The geochemistry of halos of Cu, Ag, Pb, Zn and Mo are characteristic for this type of location.

El Pilar epithermal prospect is located in the western part of Cuba (Fig.1), about 24 Kms from Ciego de Avila City. Beatriz is the better-studied deposit, located to the north of the Guaimaro area (Simon *et al*., 1999). The second in importance is Florencia located also in the Guaimaro area.
Golden Hill is located to the south of Las Tunas, and it is representative of sulphate, exposing an area of oxidation. The Jobabo municipality area exhibits several groups of small auriferous manifestations such as Georgina, Iron Hill, and Maclama.

Golden Hill (Little Golden Hill, Three Hill and Big Golden Hill sectors), Florencia and Maclama are located close to the Guaimaro village. They are located in a smooth relief and the presence of an oxidation zone makes them feasible for open pit mining using the Heap Leaching method or using small facilities as Vat Leaching.
Regardless of beneficiation-mining process used, it is necessary to be cautious because toxic elements are present, and there are water reservoirs and rivers crossing the region.

MINERALIZATION

The mineralization studied in the Florencia deposit has a structural control that extends the body laterally up to 1 Km, with thickness of 30-40 m. The well-known mineral bodies are four: three in the North area and one in the South. They have forms of long narrow veins, with at least three quartz generations. The quartz types

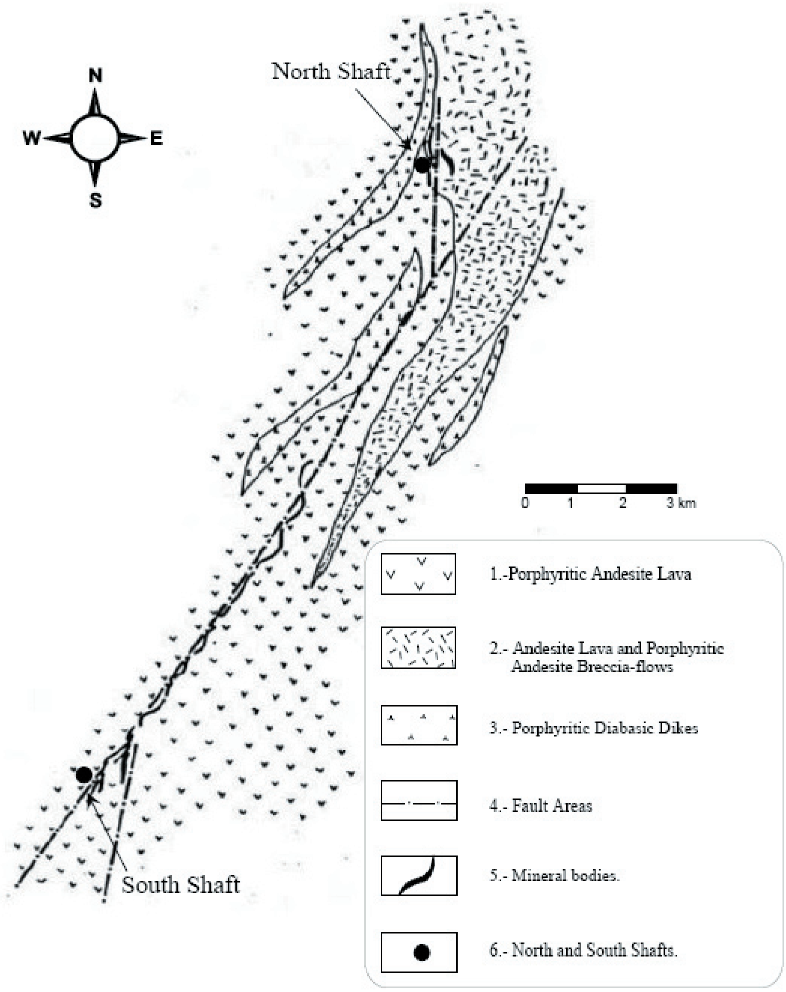

Fig. 2. Florencia's mineral bodies' district map (Shestokanova, 1967).

are sterile milk-like quartz, darker quartz -where mineralization is founded- and typical quartz filled open veins with calcite carbonates. Gas – liquid inclusions were studied by Bortnikov *et al*. (1988), paded mainly for quartz and carbonates (Fig.2).

The Florencia host rocks are traquibasalts and cretaceous (Albian-Turonian) andesite basalts. The volcanic rocks are cut by the granodiorite Stock and quartz-diorites belonging to the Guaimaro Stock, and also by a few younger diorites and granodiorites dikes. In the limits of the mineral field, there are two isolated areas denominated North and South, which differ in their mineralogical composition. They are represented mainly by vein – disseminated sulphurous mineralizations.

The North area is divided in three bodies with some ramifications, and the dominant mineralization is pyrite-chalcopyrite (Fig 3). The South area is lens-shaped with Pb-Zn-Ag-Cu poly-metallic mineralization, being better developed the Pb-Zn-Ag poly-metallic mineralization.

The mineral bodies of the north and south area have been explored using perforation wells up to 170 m depth and 300 m of strike, and underground mining.

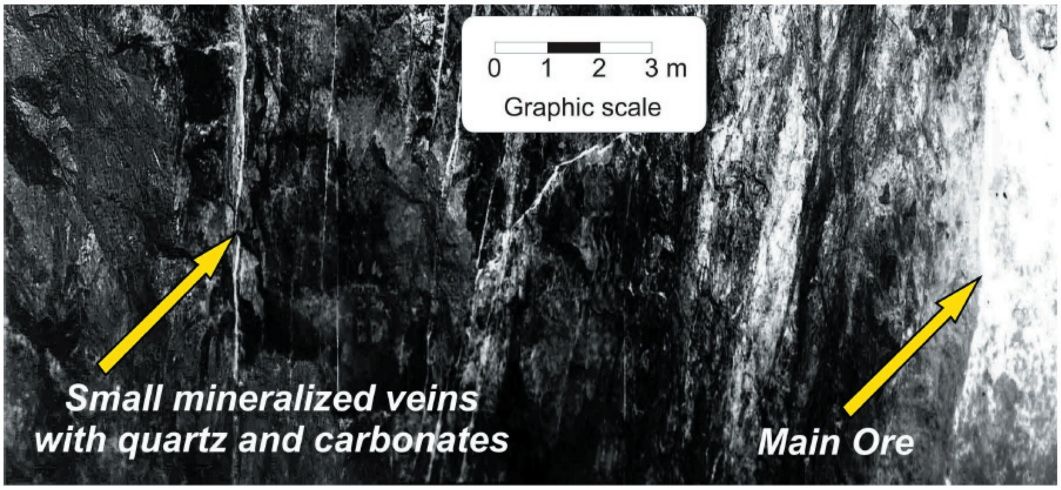

Fig. 3. Small vein located in the second level of the south wall. The main ore is also indicated in the right part of the photo.

MINERALOGICAL CHARACTERISTICS

Near 30 minerals are recognized in the veins at the Florencia deposit. By-product minerals include different quartz types and textures such as crustiform, banded and cockade with different colours, in occasions grey with open cavities, typical of crack fills. Starting from the thermodynamic analysis of the mineral associations in the system Au-Ag-Te (Bortnikov *et al*., 1989), the formation temperatures of the deposit varied between 70 and 280 °C.

The main economic components of some veins are gold and silver. The native gold is the major metallic mineral in the ores. It is observed in polished sections in grains of different sizes. Table I shows the results obtained by the author related to the count of the grains of gold with different sizes observed in 100 polished sections.

In Table II, the study of the mineral composition of the ores demonstrated that the finest gold of high purity is present, as well as gold and silver in form of telluride's Calaverite ($AuTe_{2)}$, Silvanite (Au Ag $Te_{4)}$, Petzite ($AgAuTe_2$), Hessite (AgTe), Shtiutzite and Bolinskite ($AgBiTe_2$).

The main concentrations of gold are found in native gold and Petzite, broadly distributed among tellurides, and in silver concentrates, mixed with native gold, Hessite, and Petzite. These data show how gold and silver are represented in the ores, being the tellurides important in their composition. Comparing North and South ore sectors, it is observed a smaller development of the sphalerite and galena in the North. Here the Pyrite contains inclusions of native gold

Table. I. Grains of Gold Counting

Sizes mm	Number of grains
0, 00 n – 0,015	16
0,020 – 0,040	6
0, 040 – 0,080	4
0,080 – 0,160	2

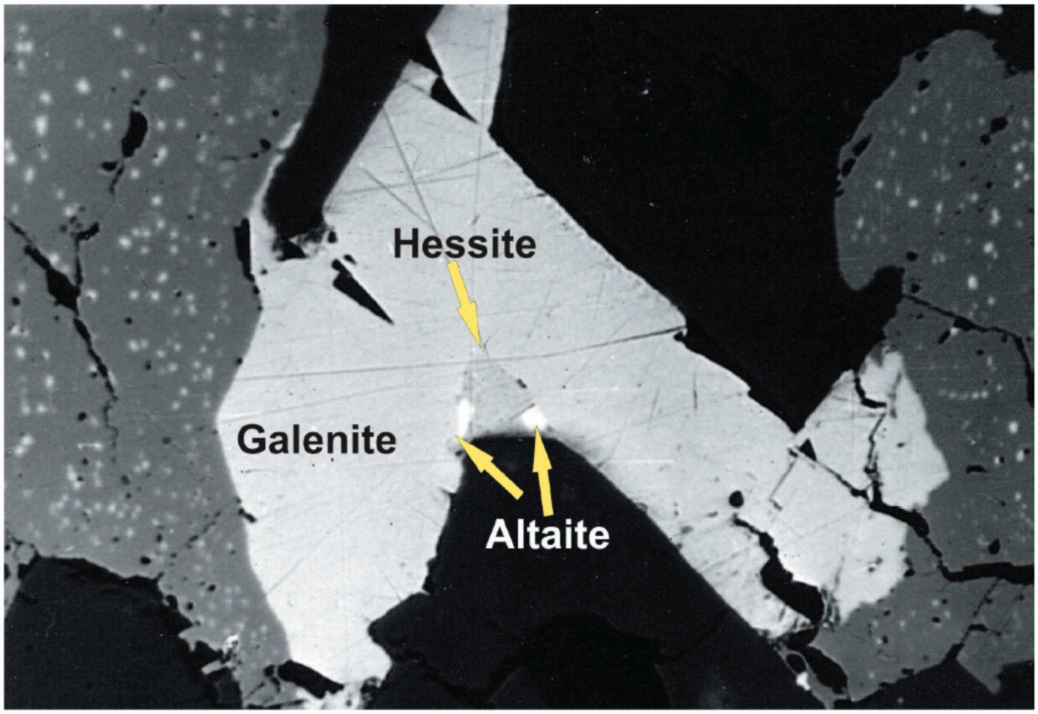

Fig. 4. Hessite and altaite in galenite. Increase 200 X.

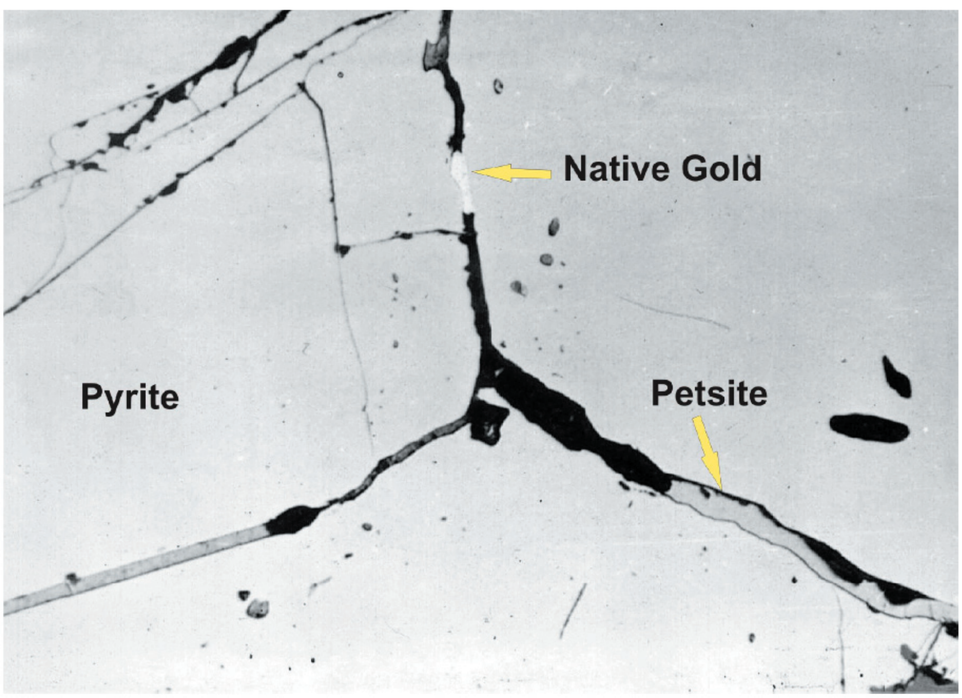

Fig. 5. Vein of native gold and petsite in pyrite II. Increase 200 X.

Table. 2. Electron Microprobe Analyses (Mass. %)

No.	Mineral	Au	Ag	Pb	Bi	Te	S	Total
1	Petzite	24.80	41.62	-	-	33.43	-	100.05
2	Petzite	25.95	40.36	-	-	32.61	-	98.92
3	Petzite		49.36	-	-	34.62	-	102.38
4	Petzite	11.07	51.72	-	-	33.22	-	98.01
5	Hessite	10.01	54.12	-	-	36.66	-	100.79
6	Hessite	1.43	59.10	0.45	-	39.40	-	100.38
7	Hessite	0.60	59.70	0.44	0.27	39.16	-	100.17
8	Hessite	0.12	59.81	1.41	0.10	38.34	-	99.78
9	Hessite	-	60.00	0.90	-	38.58	-	99.48
10	Hessite	1.54	60.54	0.37	-	36.25	-	100.70
11	Shtiutzite	-	54.70	0.20	-	42.47	-	97.39
12	Calaverite	41.18	0.47	-	-	57.27	-	98.92
13	Calaverite	43.21	-	-	-	56.86	-	102.09
14	Bolinskite	-	16.67	0.36	36.02	42.59	0.83	98.71
15	Bolinskite	-	13.39	0.10	37.57	43.57	1.13	98.79
16	Bolinskite	-	18.31	-	35.16	46.14	-	99.61
17	Tsumoite	-	-	-	61.65	37.31	-	98.66
18	Raklidzite	-	1.61	14.33	37.53	45.52	0.16	99.45
19	Altaite	0.18	0.90	57.65	1.23	39.25	-	98.21
20	Altaite	-	0.60	58.26	1.15	38.92	-	98.93
21	Altaite	0.24	1.09	58.66	0.32	37.03	-	97.34

and segregation of gold tellurides (Calaverite and Petzite) (Fig 3, 4, and 5).The analyses of the pyrite mono-fractions with high contents of gold (64 up to 450 g/t), underline the significant role of the pyrite as concentrator of gold in this sector.

In the South sector, the galena and the sphalerite are diffused, the native gold prevails in form of small inclusions in the pyrite; and inside the group of tellurides, the Altaite and silver tellurides are diffused.

RESULTS.

There are two mineral forms present in Florencia deposit ores: gold and silver. The presence of high purity gold and silver tellurides, evidences that a quantitative balance of the interrelations between these two types of ores is needed.

During exploration works in 1990, the Camagüey Geology Company took two technological samples of 4 tons each one: Technological Sample-3 (MT-3) in the North sector and Technological Sample-4 (MT-4) in the South sector. The analyses were carried out by the Centre of Investigations for the Mining Metallurgic Industry executing the investigations for beneficiation by flotation and gravitation enrichment methods.

The authors studied the flotation concentrate and gravitation of the MT-4 sample and flotation of the MT-3 sample. The analysis of the three concentrates of the technological MT-3 and MT-4 samples were carried out by the Moscow Institute of Geology and Geochemistry of the Minerals in order to know the contents of Au, Ag, Te and Bi.

Portions of the samples were dissolved in concentrated HNO_3 and heated for one hour, and the remaining product, was solved in regal water. The determination of Au, Ag, Te, and Bi was done in the concentrate samples and in the break-up samples (after the concentrated HNO_3 treatment) and later all samples were tested using atomic absorption spectroscopy methods. The analysis was carried out with the contents of

Table. III. Chemical analyses results of the concentrate phases, solutions, and break-up remains.

Concentrates	Analysis g/t				
	Element	*Au*	*Ag*	*Te*	*Bi*
MT–4 Gravitation	Concentrates	35	179	188	44
	Break-up	4.0	172	162	42
MT–4 Flotation	Break-up remains	32	7.2	18	5
	Concentrates	39	172	178	44
	Break-up	4.1	165	160	42
MT–3 Flotation	Break-up remains	35	5.0	15	5
	Concentrates	140	190	220	26
	Break-up	10	182	200	25
	Break-up remains	128	7.5	21	5

these elements in the levels from 1-10 g/t after their concentration.

The results are shown in the Table III highlighting the differences between the contents in the elements analysed in the MT-3 and MT-4 samples. The content of gold in MT-3 is four times the content in MT-4, as well as the silver and telluride concentrations, in both concentrates are similar but bigger than gold concentration. The relationship Ag/Au, in the concentrate MT-4 is 5.1 (gravitation) and 4.4 in flotation, and 1.35 in MT-3.

The most important quantitative evaluation of precious metals is obtained starting from the analysis of the minerals of the telluride groups in the concentrate and in the solutions after its treatment with HNO_3. The quantity of gold that passes to the solution used to find telluride forms in the ores is 10.4 - 11.5 -% for MT-4 and 7.1%. for MT-3 . The silver, contrary to the gold, is in telluride form in more than 95% .It passes to the breaks-up with the HNO_3 treatment of the concentrate.

It is important to highlight some differences in the composition of the concentrates obtained in MT-3 and MT-4 technological samples shown in the spectral analysis:

1. - The biggest Pb and Zn contents in MT-4 concentrate reflect relative bigger sphalerite and galena quantities in the ores of the south sector.

2. - The biggest quantities in sphalerite are related with biggest contents of Cadmium (0.15%) in the MT-4 flotation concentrate.

3. - It is important to note the Cobalt high contents in the concentrate (Table IV) and high Co/Ni relationship values (from 10 up to 20). The content of Cobalt increases twice in the MT-3 concentrate and it reaches up to 0.11%. This is conditioned by the quantities of pyrite in this concentrate and it is also confirmed by the pyrite mono-fraction results where the Cobalt content varies from 0.15% to 0.40%.

The data demonstrate that future technological research should take into account the presence of minerals from the telluride group in ores related to precious metals (Table V), the silver and the presence of small inclusions of native gold and gold telluride in pyrite.

GEOLOGICAL FACTORS WITH POTENTIAL ENVIRONMENTAL EFFECTS

Some epithermal gold deposits have been defined and studied in the volcanic Cretaceous arch (e.g., Little Golden Hill, Big Golden Hill, Three Hill, Florence, and Jacinto). There are other important such as El Pilar-San Nicolás, La Purisima, Tres Antenas, Corral de Rojas, and La Mina.

The presence of several types of mineral deposits genetically distinctive in these formations are characterized by pyrite presence as main mineral,

Table. IV. Results of the spectral quantitative analysis of the concentrate.

Concentrates	ELEMENTS												
	Au* *g/t	***Ag* *g/t***	***Zn* *%***	***Cd* *%***	***Mn* *%***	***Pb* *%***	***Bi* *%***	***Cu* *%***	***Co* *%***	***Ni* *%***	***Sb* *%***	***As* *%***	***Sn* *%***
MT-4 Zone South Gravitation	39.8	100.0	1.9	0.055	0.031	1.0	0.007	0.32	0.047	0.0043	0.090	0.056	-
MT-4 Zone South Flotation	33.0	84.0	5.0	0.150	0.090	1.0	-	0.83	0.50	0.0050	0.040	0.050	0.005
MT-3 Zone North Flotation	122.0	90.0	1.2	0.012	0.027	0.058	-	1.50	0.110	0.0050	0.022	0.050	0.002

Table. V. Te determination in ores by hidruros generation methods (North area). Level 0.

Mineral body	# Samples	Content Te g/t
1	5	91
1	7	87.5
1	8	36.6
5	14	13.4
1	19	12.2
3	21	24
1	22	40.6
4	28	2.2

either disseminated or accompanied by quartz in veins. The almost absence of arsenopirite in the ores and the presence of a variety of minerals such as gold, silver, lead, bismuth and nickel belonging to the telluride group is an important common feature to keep in mind during future mining operations. The existence of at least three small deposits with advanced studies and the data presented here, as well as the high prices of gold and silver at present time, permitted to start the mining process in Golden Hill, Florencia and Beatriz, and defined the corresponding environmental studies in order to take the systematic measures to avoid or decrease damage as possible.

- Size of the Deposit: They are small and located near each other. They stand out as small elevations on the surface. Typical oxidation zones reach 10-20 m depth. Ores are formed by pyrite as the main mineral, quartz, carbonates, and mineral loamy product of the wall – rock alteration. The reserves are approximately 5 - 10 tons of gold. The veins usually have high gold contents and erratic distributions could be present. Small mining operations are needed to open pit facilities and benefit chord in the studied resources.
- The mobility of the metals and the acid drainage product of the water circulation and the pyrite presence during the mining activity (open pit), could be limited directly by the presence of carbonates in the mineral bodies and associated with the wall rocks.
- The oxidation of these sulphurs could generate acid drainage, which can potentially affect the superficial drainages of the area of influence in the mine and consequently enter in the food-chain. Some detailed studies are proposed about risks in the area (e.g., the use of some types of biotechnological barriers such as bacteria or mushrooms that neutralises the environmental contamination during the exploitation works in the area).

Du Bray (2004) recollected samples of stream sediment using the open-pit method and heap leaching showing results of < 5 to 12 silver ppm, 0.04 to 0.4 ppm of gold, < 5ppm cadmium, 18 to 81 ppm cooper, 1.4 to 4.2% of iron 200 to 2.020 ppm, Manganese, 7 to 197 ppm lead, and 70 to 1.131 ppm zinc.

The existence of at least 3 small deposits with advanced studies and the data presented here, as well as the high prices of gold and silver at present time, permitted to start the mining process in Golden Hill, Florencia and Beatriz, and defined the corresponding environmental studies in order to take the systematic measures to avoid or decrease damage as possible.

CONCLUSIONS.

1. The presence of telluride group minerals and the absence of arsenopyrite in the Cretaceous Volcanic Arch ores, being the pyrite the most significant, represent a characteristic feature for the auriferous locations.
2. The Florencia Ore Deposit has important mineralogical differences between the two main areas: North and south.
3. The highest Pb and Zn contents in the MT-4 concentrate reflect the relative bigger quantity of sphalerite and galena in a small part of the south sector.
4. The biggest quantities of sphalerite are related to the biggest contents of Cadmium (0.15%) in the MT-4 flotation concentrate.
5. The environmental impact caused by open pit and the pyrite presence (acid drainage mining), and the beneficiation methods used will give tellurides an inadequate final destination as residuals from the mining or during the mining processes.

RECOMMENDATIONS.

Optimal operation conditions should be studied more in detail at a proper scale for the industrial recovery of the gold and silver associated to tellurides, as well as the potentially environmental impacts for that process.

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