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THE MANKAYAN MINERAL DISTRICT, LUZON, PHILIPPINES

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Abstract - The Mankayan Mineral District in northern Luzon, Philippines host three (3) world class copper and gold orebodies, all of which lie within the LCMC property. These are the Enargite-Gold deposit, the Far Southeast Porphyry Copper deposit and the newly discovered Victoria Gold deposit. There are other copper and gold prospects identified in the district making the area attractive for potential exploration.

The enargite-luzonite-gold deposit is a high sulphidation vein and unconformity replacement type of mineralization. It is hosted by andesitic and dacitic rocks. The principal ore minerals are enargite and luzonite, with significant presence of tennantite-tetrahedrite, base metals, electrum and tellurides.

The FSE porphyry copper deposit is a deep-seated bell-shaped deposit hosted by volcaniclastics. It has strong zonation features both in alteration and sulfide mineralization. It is centred on a quartz diorite intrusive complex characterised by the presence of a mineralised dark coloured and a relatively barren light coloured facies. The deposit is truncated by a north trending hydrothermal breccia pipe, which in itself is also mineralised with copper and gold.

The newly discovered Victoria gold deposit has the signatures of a low sulphidation, quartz-gold vein deposit, hosted by dacitic rocks and volcaniclastics. About 80% of the ore minerals are made up of sphalerite, galena and chalcopyrite. Steeply dipping, 2 to 8 meter wide vein systems, with up to 600 meter strike lengths have been developed so far.

The gold deposit could have some genetic associations with the Enargite deposit and probably indirectly with the FSE porphyry system. It is relatively apparent that the Victoria quartz-gold-base metal veins could have occurred similarly as the quartz-gold roots overprinting the enargite mineralization. This overprinting signifies the waning stages of the entire hydrothermal system.

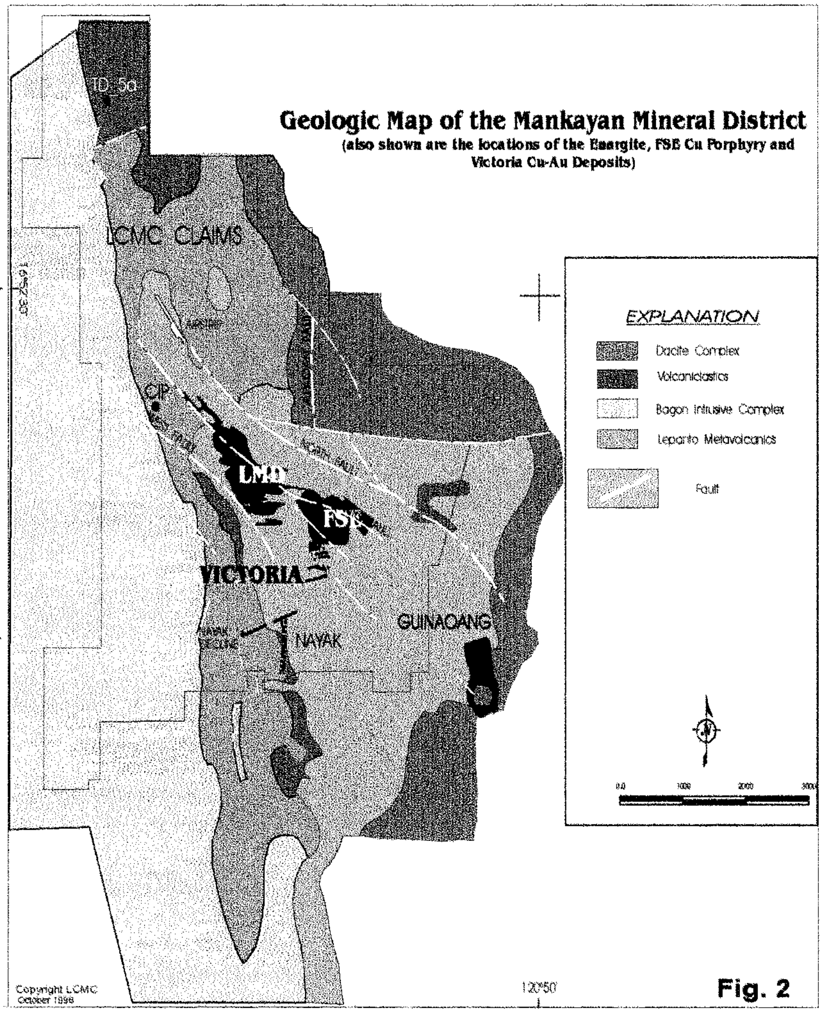


Fig. 2

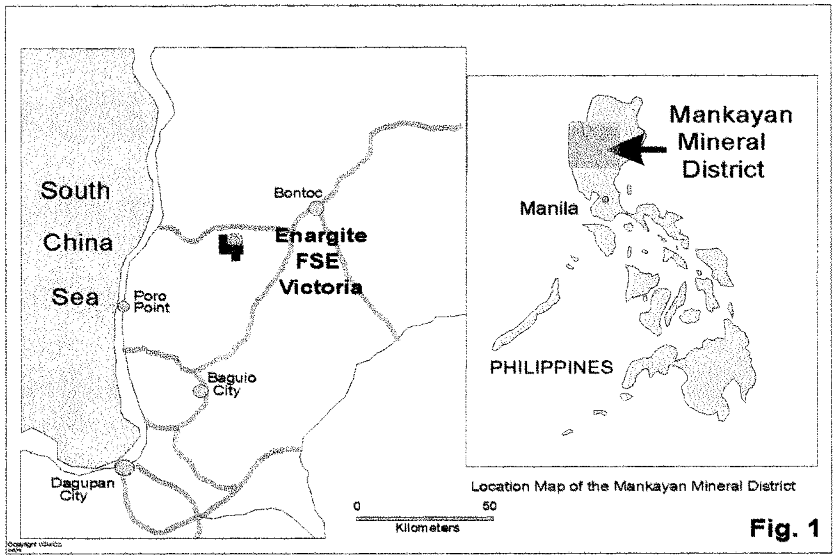
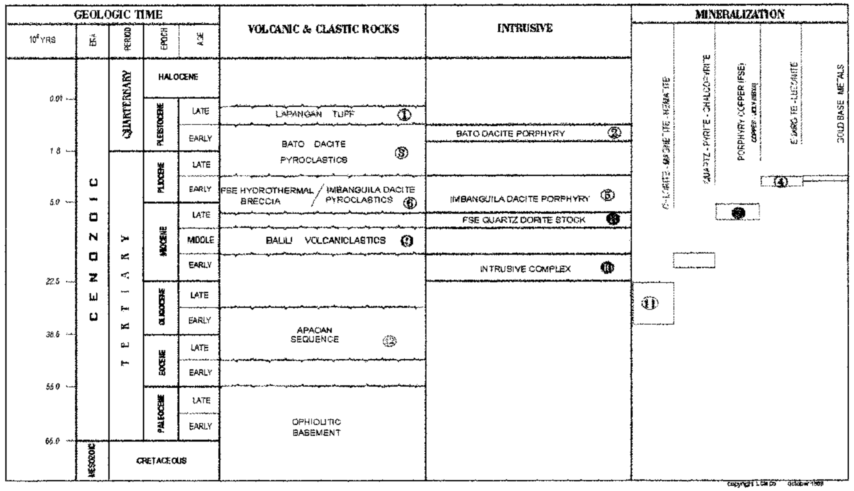


Fig. 1



STRATIGRAPHIC - CHRONOLOGIC SECTION OF THE MANKAYAN MINERAL DISTRICT

(FROM CONCEPCION & CINCO, 1989 ; GARCIA & BONGOLAN,1989)

Fig. 3

Introduction

The Mankayan Mineral District is one of the better-known Cu-Au districts in Northern, Luzon, Philippines. It is where the Lepanto enargite mine, the Far SouthEast copper-gold deposit and the Victoria gold mine are located. There are other porphyry copper type deposits and prospects in the area, and these are the Guinaoang deposit, the Palidan, the Pacda-Buaki, and the Bulalacao prospects. There are also epithermal quartz-gold vein deposits and these are the Suyoc and Nayak gold deposits

The Lepanto enargite mine is situated in Barangay Paco, Municipality of Mankayan, Benguet (*Figure 1*). The topography of the area is rugged with elevations reaching up to about 1000 to 1500 meters. Mankayan is about 250 aerial kilometers north of Manila and about 90-95 kilometers north of Baguio, the closest city, with access through Halsema road, which is the main artery of the Cordillera provinces.

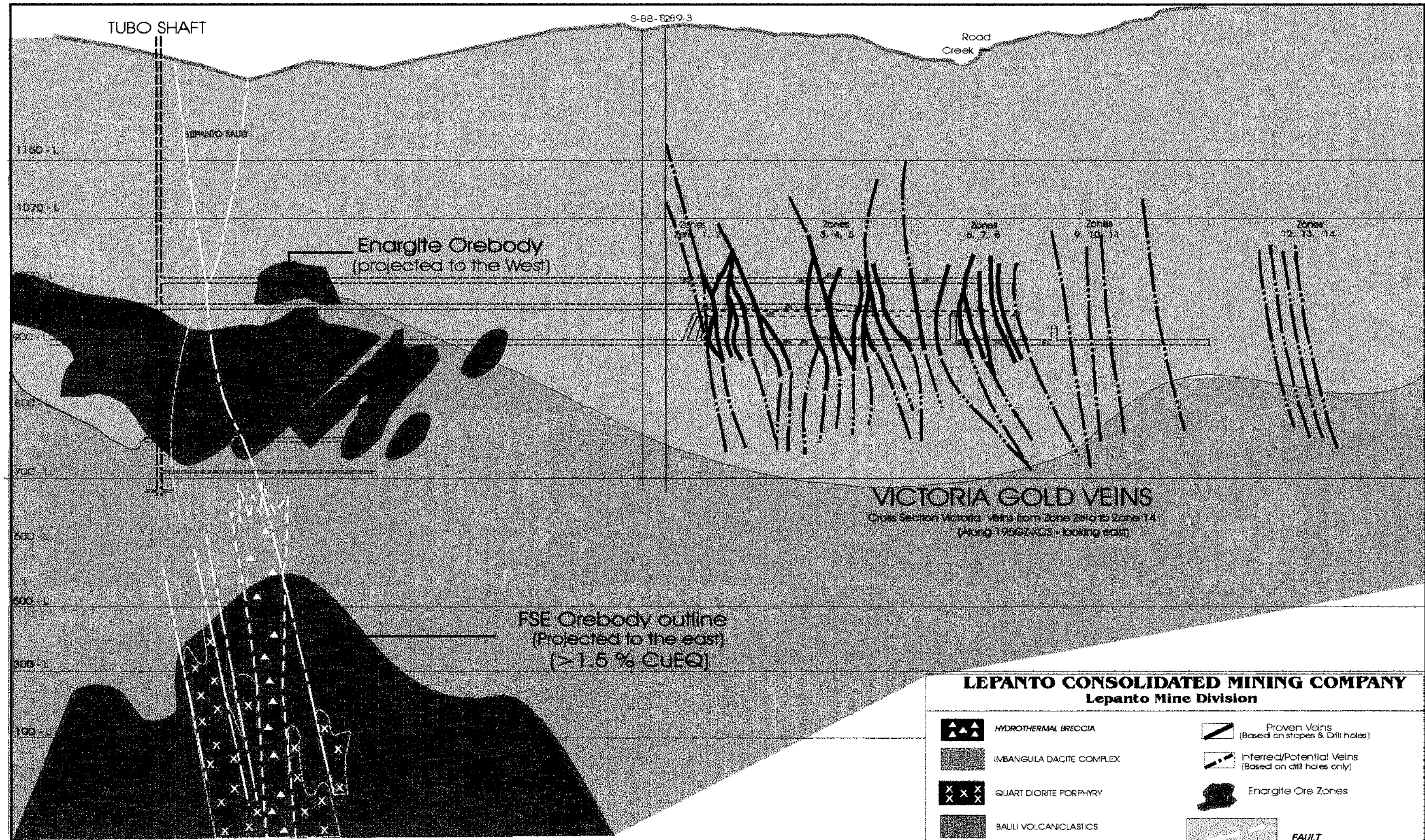
Regional Stratigraphy, Structure and Mineralization

The Mankayan Mineral District lies within a 150-kilometer long mineralized belt in the Central Cordillera. Like other Cu-Au belts (in the Philippines), the district is apparently related to the occurrences of calc-alkaline intrusives and to structures associated with the Philippine Fault system.

The distribution of the different lithologies underlying the Mankayan Mineral District is shown in *Figure 2*. A stratigraphic column (*Figure 3*) is also presented to show the relative ages of the different rock units (and mineralization). The oldest exposed lithological unit in the district is the Lepanto metavolcanics. Later tectonic events probably related to major movements along the Philippine Fault resulted to the emplacement of the Bagon Intrusive Complex. The deposition of sedimentary and volcaniclastic rocks followed, unconformably overlying the andesitic basement. The later intrusions of diorite complexes have brought about the high level emplacements of some porphyry copper-gold deposits. Much later volcanic events formed the dacite complex. The Imbanguila dacites are host to Enargite, FSE and Victoria mineralization. Bato dacites are however barren of any mineralization (being post-mineralization dacites).

Most of the faults found in the district form a conjugate fracture pattern dominated by north and northwest trending shears, east-west trending extensional fractures and few north-south trending fissures.

There are three types of mineralization in the Mankayan Mineral District, the porphyry coppers (e.g FSE deposit, Bulalacao prospect, Guinaoang deposit, Buaki-Palidan prospects), the enargite-luzonite vein and unconformity replacements (e.g. Lepanto Enargite deposit), and the quartz-gold-base metal veins (e.g. Suyoc deposit, Nayak-Palidan prospects, quartz-gold zones in enargite, Victoria gold deposit). The location of the major deposits is shown in *Figure 2*. The spatial relationship of the Enargite and the Victoria deposits to the FSE deposit, in a schematic longitudinal section, is shown in *Figure 4*.



Schematic Cross Section Showing the Spatial Relationship between the Enargite, FSE Porphyry Cu and Victoria Cu-Au Deposits

Fig. 4

The Enargite-Gold Deposit

The Cantabro-Filipino Company was the first to do large-scale mining on the enargite deposit in 1865, producing at least 1,100 tonnes copper during the 10-year operation. Lepanto Consolidated Mining Company was formed on September 1936 and took over the mine until the start of World War II. The Japanese, under Mitsui Company, operated the mine during the war period and were able to produce 11,000 tonnes of copper. After the war, LCMC rehabilitated the mine and resumed production in 1948. Post-World War II mining operations with continuous expansion (from 1948 to 1996) extracted a total of 36.3 million tonnes of ore at 2.9% Cu and 3.4 g/t Au, producing 743,395 tonnes Cu, 92 tonnes Au and 390 tonnes Ag.

The Lepanto Cu-Au (enargite) deposit is a classic example of an acid-sulfate or high sulfidation type of epithermal mineralization. The ore body, which has a 2.5-km strike length, is made up of essentially the main breccia ore and the footwall - hanging wall branch veins. The breccia zone varies from 10 to 50 meters in width and is approximately 100 meters in height. Most of the ore occur as tensional fracture infillings where banding, crustification and breccia structures, with pervasive replacement features, are very common. Other enargite occurrences are the Easterlies, the northwest ore and the bonanza stratiform and stratabound ore zones.

The host rocks to enargite-gold mineralization are the metavolcanics, volcaniclastics and the Imbanguila dacites. The unconformable contact between the metavolcanics and dacite pyroclastics is the zone where ore tends to widen (Gonzales, 1959). The enargite-luzonite mineralization is located along the Lepanto fault, which is a major dilational structure. The presence of a dilational fault system has created permeabilities (as ideal channel ways) where lateral outflows of solutions take place. Ore deposition is more evident along receptive zones brought about by profuse brecciation and "horsetailing" along the fault.

Distinguishable alteration zonation patterns are observed. Silicification (and residual silica) is observed adjacent to the veins and grades into advance argillic alteration. Intermediate argillic-sericitic alteration forms an outer contiguous zone to advance argillic alteration. The propylitic alteration constitutes the farthest alteration zone. The development of the high sulfidation alteration in the enargite deposit could have been brought about by the interaction of predominantly magmatic vapor with meteoric waters. The varying intensity of fluid-rock interaction, taking into consideration the pH of the fluids would form the alteration zonation (Claveria, 1997).

Mineralization occurs in the form of enargite and luzonite (a dimorph of enargite with similar composition). Associated minerals such as tennantite-tetrahedrite, chalcopyrite and covellite are found in minor amounts. Gold (and silver) occurs as electrum and tellurides (Gonzales, 1959; Claveria and Hedenquist, 1994). Gangue minerals are quartz, kaolinite or dickite, alunite, barite and anhydrite. In a paragenetic study made by Claveria (1997) on the sulfides, a consistent sulfide evolution is observed, and this is from an enargite-luzonite-pyrite stage, to a tennantite-chalcopyrite-sphalerite stage then to a late gold-telluride stage.

Quartz-gold epithermal veins are found to occur in the enargite mineralization. They occur in zones made up of auriferous pyrite-quartz stringers. Garcia (1991) observed localized occurrences of these gold veins in the enargite mineralization, (1) as zones occurring below or peripheral to the main enargite ore body, (2) as steeply dipping zones crosscutting the enargite body, (3) as roots of branch veins, and (4) as zones crosscutting enargite related alteration. These epithermal veins commonly have an assemblage of pyrite-galena-sphalerite-gold. The formation of the quartz-gold epithermal veins could be attributed to the apparent waning stages of the hydrothermal system manifested by changes in the composition of the fluids from magmatic to meteoric, resulting to the formation of near-neutral pH conditions.

The mining method employed was the traditional cut and fill producing a daily tonnage of 4000 tonnes. The mine operated on 13 levels with the lowest mining elevation at level 670. Ore is hoisted from the lower levels to the main haulage at level 900 going to the mill. The mill was a 3-stage crushing, rod mill/ ball mill combination, and standard flotation roughing-cleaning circuit. Copper concentrates, with high gold contents were delivered to the Lepanto Roaster for partial roasting, to remove the arsenic and antimony, prior to delivery to the Philippine Smelter (PASAR).

The Far South East Porphyry Copper Deposit

The discovery of the Far Southeast ore body, contrary to earlier published reports, was the result of efforts pursued after establishing an exploration philosophy to search for porphyry copper deposits within the vicinity of Lepanto's operation. The initial prospect target, in 1977, was the 80-hectare Mankayan Communal Forest, a forest reserve located southeast of the company mining claims. Structural analyses show that the junction between the Lepanto and Pusdo Faults was a very prospective area and would likely be a target for exploration. In 1978, the company secured an endorsement for a prospecting permit from the Mankayan municipal government. The following year, 1979, the necessary government permits from the Bureau of Mines were obtained enabling the company to conduct an Induced Polarization survey in the area. The Communal Forest was awarded in 1980 to the company through Presidential Decree 1676.

Later in April 1980, a deep surface drill hole, using the IP survey results as guide, gave negative results. In October 1980, a second surface hole was drilled to a depth of 1100 meters. A low-grade (0.16% Cu and 0.305 g/t Au) leucocratic quartz diorite porphyry stock was intersected within the bottom 200 meters. Earlier in March 1980, a review of an underground inclined drill hole (U-74-1A) drilled in 1974 at 900 level gave an indication of porphyry copper mineralization, with the highest assay value of 1.4% Cu and .70 g/t Au. This was the initial hole that identified the porphyry copper mineralization. This information gave the company confidence to rehabilitate the 1.5-kilometer long 900 level access drift to reach the U-74-1A drill hole location. The rehabilitation was completed in November 1980 and a new hole adjacent to U-74-1A was collared in December 1980. This hole, U-80-23, became the second and confirming "discovery hole". It intersected open-ended copper-gold rich portions averaging 0.46% Cu and 0.410 g/t Au and notably increasing in values towards the bottom. Drilling was accelerated up to 1986 in grid pattern of roughly 75 meters by 100 meters.

Seventy-five (75) holes were completed with a drilled aggregate of 45 kilometers. Resource calculations and preliminary feasibility studies were done during the period 1986-1989. The FSEGRI (Far Southeast Gold Resources Inc.) was formed in 1989 to develop and exploit the orebody. It is a corporation 60% owned by Lepanto and 40% owned by Rio Tinto.

The previous works of Concepcion and Cinco (1989) and Garcia (1991) have described in detail the geology and mineralization of the FSE deposit. The FSE is a blind deposit located at the southeastern portions of the Lepanto mine area. The deposit is west-northwest trending with a longitudinal bell-shaped morphology and is deep seated with the top of the deposit lying 650 meters below the surface. It has a vertical extent of at least 1000 meters. At –100 meter elevation (below sea level), the dimensions of the ore body is 1000 meters long and 500 meters wide. It is genetically centered at the quartz diorite porphyry stock, inferred to have intruded the Balili volcaniclastics. It is noted that the deposit does not extend to the younger overlying dacites. The quartz diorite complex is composed of melanocratic and leucocratic porphyries. It is observed that the melanocratic or darker type is more hospitable to mineralization than the leucocratic or lighter type. The light colored variety is interpreted to be an intra-mineral phase following closely the major mineralizing event associated with the dark colored phase. Truncating the deposit at the center is a north trending hydrothermal breccia pipe, which contains clasts of the main copper porphyry deposit. The breccia pipe is destructive to the porphyry copper mineralization, but in itself occurs as host to breccia filling copper-gold mineralization. The occurrence of the breccia pipe is interpreted to be following closely the emplacement of the dacitic diatreme during the waning stages of the volcanic event.

A potassic core which grade outwards to a chlorite-illite zone and to an outer propylitic zone defines alteration zonation. These zones are capped by advance argillic alteration. In the hydrothermal breccia pipe, two (2) distinct zones are observed. Sericite-illite-tourmaline-chlorite occurs as matrix alteration at depth and grades upward to a chlorite-deficient advance argillic alteration.

Sulfide zonation is characterised by bornite-chalcopyrite-magnetite in the potassic core, chalcopyrite-magnetite-hematite-pyrite-molybdenite in the chlorite-illite zones and chalcopyrite-pyrite-hematite in the propylitic zone. Gold occurs in native form and is intimately associated with chalcopyrite-bornite, and in most cases show positive correlation with copper and magnetite. In the hydrothermal breccia pipe, the related sulfide zonations are characterized by chalcopyrite-magnetite-pyrite-bornite-molybdenite in the deeper sericitic-illite zone of the breccia, and chalcopyrite-pyrite-hematite-enargite-covellite-molybdenite at the upper advance argillic zones of the breccia.

The current geologic resource from 350 level to –250 level is estimated at 650 million tonnes with 0.65% Cu and 1.33 g/t Au using a 0.7% copper equivalent cut-off grade.

The FSE deposit is recognized as one of the largest deep-seated porphyry copper orebody. Since the deposit has a high temperature gradient, successful mining would require sophisticated refrigeration. Additional studies on the project are now being reviewed to address this issue as well as the mining method.

The Victoria Gold Deposit

In early 1991,a shallow drilling programme within the Nayak area, where surface mining is being done by locals, blocked 0.3 million tonnes of 3 g/t gold ore, which was not economical. In 1995, the exploration was shifted to probe the Tabbac area, northeast of Nayak, and test the parallel quartz gold zone model. A surface hole, drill in May 1995, intersected a 21.6 meter wide mineralized zone with a grade of 3.7 g/t Au. A subsequent underground hole,

Plan View of the Pinch and Swell Structural Patterns Observed In the Zone 4 Gold Veins at Haulage level

Fig. 5

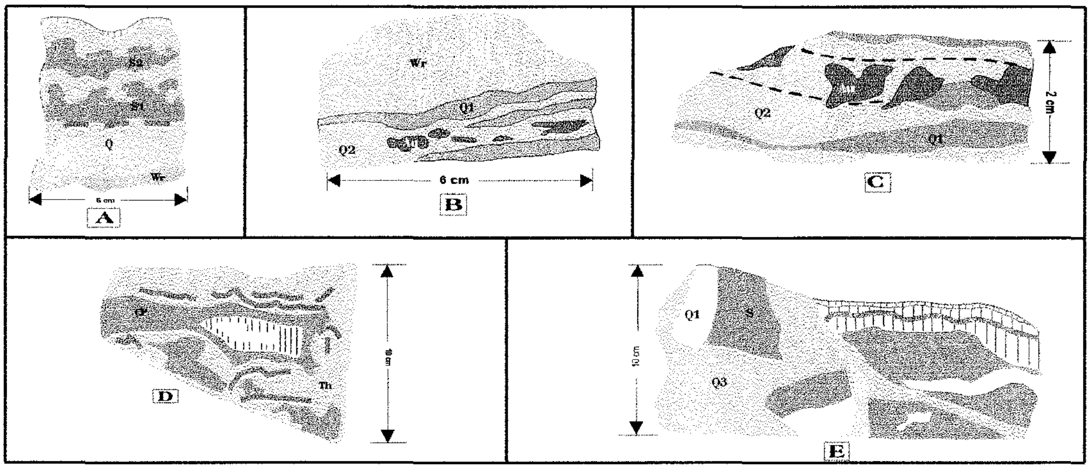


Fig. 6

Depositional Structures and Paragenesis

A) The characteristic open space in filling and banding structures exhibited by gangue and sulfide minerals (Q - quartz, S1 - chalcopyrite, S2 - galena/sphalerite

B) & C) The different occurrences of gold grains associated with dark sulfide rich quartz (Q1) and light colored translucent quartz (Q2) (Au - gold, Wr - Wallrock)

D) The open space in filling and replacement features of chalcopyrite (CP) and tetrahedrite (th) in the veins

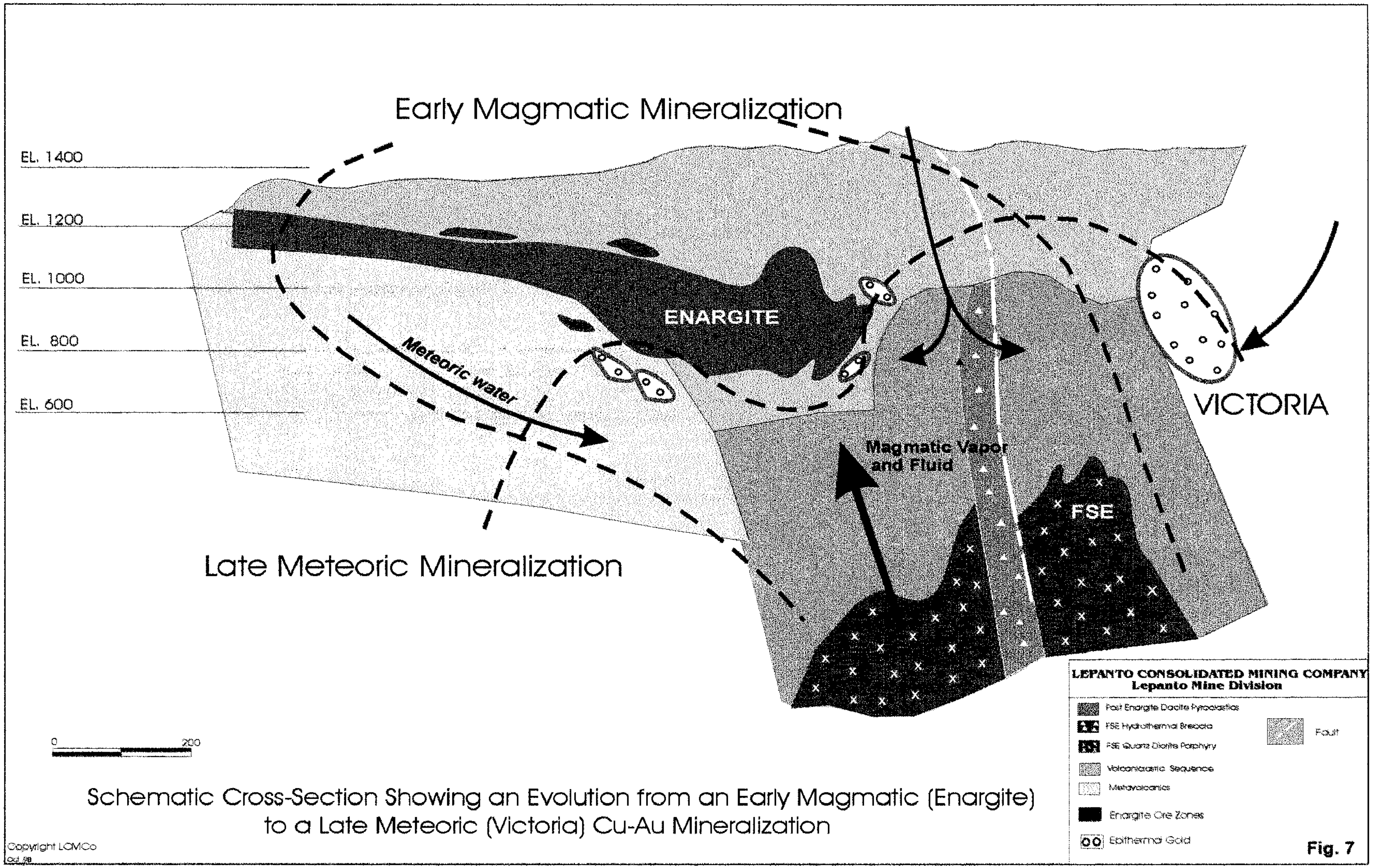
E) The occurrence of 2 quartz stages: an early dark sulfide rich quartz (Q1) and late white sulfide poor quartz (Q3). (S - Sulfides) drilled in September 1995, intersected 8 mineralized zones with grades ranging from 1.3 to 193 g/t Au making these 2 holes the discovery holes of the Victoria deposit. A crosscut was developed 50 meters below the underground hole to check the downward extensions of these veins. The results were encouraging and led to full scale underground and installation of a 2500 t/d CIP plant, which became operational in March 1997. Victoria took 18 months from discovery to operation.

The late Miocene-early Pliocene Imbanguila dacite pyroclastics and porphyries predominantly host the major veins of the Victoria gold deposit. There are few narrow veins hosted by the middle Miocene Balili volcaniclastics and the pre-Eocene Lepanto metavolcanics. The Victoria vein systems are divided into zones based on continuity. Fourteen (14) zones have been identified to date. Each zone can consist of a set of major veins and associated splits or a single vein. Up to 600 meters lateral and 300 meters vertical dimensions have been exposed in some of the veins currently being mined. The vein widths vary from 2 to 8 meters. The veins generally trend east-northeast with 75-80^{o} dips towards the south. Pinch and swell vein patterns are clearly observed (*Figure 5*). Exemplified by the presence of cymoid loops and ladder type veins, the defined pinch and swell features are noted both laterally and vertically. Continuity may both have regularity along the vein and complexity due to displacements by younger faults. The development of these vein patterns has been recognized and will be the guide in the mining operations.

The alteration halos around veins are relatively narrow. In an outward sequence, the silicic alteration occurs very near the veins, followed by sericitic-argillic alteration, then to propylitic zones. It is also common to observe veins bounded by propylitic alteration.

The mineralization observed in Victoria is an epithermal quartz-gold-base metal vein deposit. The veins occur along tensional structures and it is common to observe crustiform, banded and breccia infilling textures with few gradational features and partial replacements among the sulfides and gangue minerals (*Figure 6a*). The predominant base metals present are sphalerite, galena and chalcopyrite. Gold, in most cases, is associated with quartz. It occurs in clusters or peppered randomly in quartz (*Figures 6b and 6c*). Sphalerite is abundant in some gold rich samples. There appears to be an apparent lateral and vertical continuity of copper occurrences, and would also be appropriately to classify Victoria as a "copper rich gold deposit". The massive appearance of chalcopyrite, tetrahedrite and pyrite with few occurrences of bornite and chalcocite identified copper rich veins (*Figure 6d*). The predominant gangue minerals are quartz, carbonates and gypsum. In general there are two (2) stages of quartz formation (*Figure 6e*). The first stage quartz is associated (and inter-banded) with sulfides, and the second stage quartz is characteristically barren and whitish in color. Rhodochrosite is the predominant carbonate gangue. There are few sulfides found in the carbonates. Rhodonite apparently occurs with rhodochrosite. Gypsum (anhydrite) is found cross cutting early mineralization. It carries very few sulfides. Preliminary paragenetic studies show apparent three stages of mineralization, the early quartz (-gold) stage followed by a carbonate stage and a late gypsum stage. The abundance of base metals relatively decreases towards the gypsum stage.

Initial fluid inclusion studies made by MGB-Petrolab (1996) indicated that the temperatures for quartz formation cover a wide range from 180 to 218^{o}C, and that sphalerite (and consequently the copper mineralization) could have been deposited from hydrothermal fluids at similar temperatures.



Schematic Cross-Section Showing an Evolution from an Early Magmatic (Enargite) to a Late Meteoric (Victoria) Cu-Au Mineralization

Fig. 7

The current mineral resource has been estimated at 11 million tonnes at 7.3 g/t Au. On-going drilling and exploration development continue to increase this resource at a rate of approximately 3 million tonnes/year. The overall potential is expected to be in the range of 5 to 10 million ounces.

The mining method currently being used is a mechanized drift and fill, and this is adaptable for 2 to 8 meter wide veins. Mining progresses in every 2 to 3 meter vertical cuts. The haulage level is at 900 level where ore is transported to the CIP milling plant by rail for a distance of 3.5 kilometers. Ramp mining is now being tested in Zone 0 and has shown better productivity. Eventually more zones will utilize this mining method upon completion of the ramps driven from level to level. A new project, consisting of a twin decline and internal shaft, is being constructed south of Victoria to provide ventilation new access and better service for back filling. This project is due to be completed by September 1999.

Discussions on Ore Genesis

The Victoria gold deposit lies within the Lepanto property, with a 2.0 sq. km. area, which also bounds the two well known Cu-Au deposits, the Enargite epithermal copper (+ gold) and the Far Southeast (FSE) porphyry copper (+gold) deposits. The proximity of the three deposits would give an impression that they could be related together in a single hydrothermal system.

Close spatial and temporal relationships between the enargite and the FSE deposits exist and such association suggests a strong genetic link between the two deposits (Hedenquist et.al., 1998). The contemporaneous formation of the FSE porphyry and the epithermal enargite implies that the two deposits were formed from a single evolving magmatic-hydrothermal system. Magmatic vapor was responsible for the advance argillic alteration related to the enargite mineralization. A change from magmatic vapor and hypersaline fluid dominated environment to a meteoric water dominated hydrothermal system would be responsible for the enargite deposition.

The Victoria gold deposit could have some genetic associations with the quartz-gold-base metal mineralization overprinting the Enargite deposit. They exhibit very similar ore mineralogy and textures. The overprinting implies a continuous change in the composition of the mineralizing fluids from an early acidic (enargite mineralization) to a late neutral pH (quartz-gold-base metal mineralization). The influx of meteoric water into deeper levels and the dilution of the mineralizing fluids, indicating the waning stages of an evolving hydrothermal system, would be responsible to the deposition of the Victoria gold veins (*Figure 7*).

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