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SKOURIES PORPHYRY COPPER-GOLD DEPOSIT CHALKIDIKI, GREECE: SETTING, MINERALIZATION AND RESOURCES

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Abstract: The Skouries syenite porphyry Cu-Au deposit, related to a belt of gneiss dome complexes, contains more than 500 Mt @ 0.47 g/t Au, 0.37% Cu. At depth a core of high grade Cu and Au is associated with late hypogene oxidation.

Introduction

The Skouries Porphyry Cu-Au deposit is part of the Kassandra Mining District in the province of Chalkidiki, northern Greece which was acquired by TVX Gold Inc. in a public auction in 1994. This world class district is comprised of several large polymetallic replacement deposits and somewhat younger porphyry deposits as well as numerous prospects.

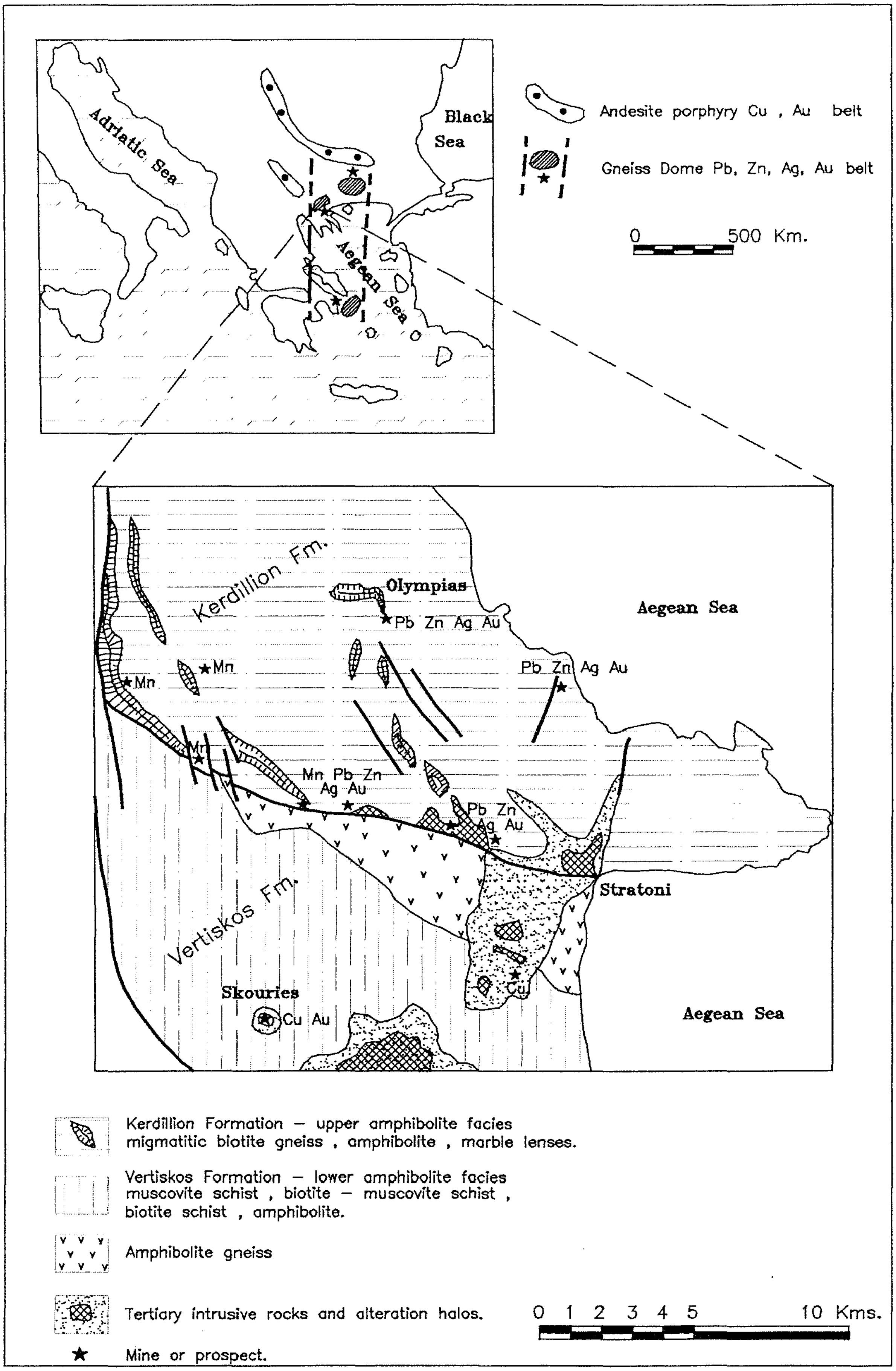
Setting

Regionally this portion of the Tethyan belt (Figure 1) is composed of NW-SE oriented fault bounded tectono-magmatic strips of variable metamorphic grade. The strips are oriented perpendicular to the closure direction of western Tethys in response to the compressional processes of subduction, accretion and collision which began at least as early as Jurassic and continued through to the end of the Eocene.

The porphyry copper deposits of the andesitic volcanic arcs through central Bulgaria and Yugoslavia are believed to be related to the subduction along both north and south facing zones flanking the Serbomacedonian–Rhodopean crustal block.

The collisional tectonism also appears to have led to a thickening of the crust in the region facing the Rhodopean Highland. During the ensuing late Tertiary relaxation phase tectonism, isostatic rebound and crustal thinning by diapiric uprise of gneiss dome complexes accompanied by tectonic denudation and extensional block faulting took place in a NNE-SSW belt from the Rhodope to the present Aegean arc. The related thermal perturbations led to the formation of Pb-Zn-Ag-Au replacement deposits and ultimately to lower crustal partial melting and the formation of the Au-Cu porphyry system at Skouries.

The Kassandra District has been the site of extensional tectonics involving detachment faults with N-S transport and later or coeval high angle block faulting since the early Oligocene. The polymetallic deposits are disposed around an upper amphibolite facies core (Kerdillion Fm) which is centred on a pronounced magnetic low. The central part of the gneiss dome is


Adriatic Sea
Black Sea
Aegean Sea
Andesite porphyry Cu , Au belt
Gneiss Dome Pb, Zn, Ag, Au belt
0 500 Km.
Kerdillion Fm.
Olympias
Pb Zn Ag Au
Aegean Sea
Mn
Mn
Pb Zn Ag Au
Mn
Mn Pb Zn Ag Au
Pb Zn Ag Au
Stratoni
Vertiskos Fm.
Cu
Skouries
Cu Au
Aegean Sea
Kerdillion Formation — upper amphibolite facies migmatitic biotite gneiss , amphibolite , marble lenses.
Vertiskos Formation — lower amphibolite facies muscovite schist , biotite — muscovite schist , biotite schist , amphibolite.
Amphibolite gneiss
Tertiary intrusive rocks and alteration halos.
0 1 2 3 4 5 10 Kms.
Mine or prospect.
Figure 1

cut by a series of aplite-pegmatite dikes and sills ranging in age from Eocene to Oligocene. These metaluminous igneous bodies contain minor ilmenite, garnet and allanite and represent the anatectic melts formed from the biotite-plagioclase gneisses of the Kerdillion Formation.

Aeromagnetic data clearly show a magnetic high axis on the south edge of the district which corresponds to an intrusive arch composed of subalkaline diorite to trachyte stocks and hypabyssal bodies. The Skouries Au-Cu porphyry deposit and other porphyry prospects are situated along the flank of that larger intrusive arch.

The Skouries deposit is centered on and around a series of small plugs and dikes of syenitic composition intruded in the early Miocene. The magmas were highly oxidized, were enriched in thorium and uranium and contained accessory uranothorite and allanite. There was a lack of contemporary volcanism, and the small size, quenched character, blind nature of some phases and presence of some breccia zones indicate hypabyssal emplacement.

History and Exploration

The timing of the original discovery of Skouries is unknown but ancient mining took place and some washing of eluvial material is also indicated. After early mining the district lay dormant until the latter half of this century and its modern history has been one of constant rediscovery and definition in a series of campaigns of which TVX's was the seventh. The failure of these efforts to result in a mining venture was always a combination of political and economic factors.

The first modern effort was some short air hammer holes drilled by the Greek government around 1958, followed by a program by Nippon Mining in 1960 with the definition of 7 Mt of oxide copper ore amenable to open pit extraction. Placer International followed from 1962 through 1968 with a program involving about 11,000 meters of drilling that resulted in the delineation of 34 M tonnes @ .72% Cu and 1.1 g/t Au including 7.5 Mt of higher grade deep material. Following that, Penaroya took a brief look at the deposit in 1976 and drilled 2 short holes, one of which was in the southwestern MoS_2 bearing zone. In 1981 Billiton recalculated the resource based on revised economic criteria and arrived at a total probable of 72 M tonnes @ .5% Cu and .7 g/t Au. In 1986 the Greek company, Kassandra Mines, drilled 6 deep core holes. Most were in the known zone but Sk-2 expanded the area at depth to the southwest.

This previous work provided the basis for TVX, and beginning in 1996, after recognizing the increasing grade with depth in the southwest sector, and the nature of the biotitic alteration of the biotite schists, a nearly continuous drilling campaign was initiated which now after more than 73,000 meters has provided the data base for a new understanding of the porphyry system.

Model and Evolution

Outcrops at Skouries are mainly restricted to the ancient pit and along roads and drill platforms. Figure 2 - a) through e), shows the relationship of the presently known mineral deposit outline (+.25% Cu at 0 level projected to surface) to geology, soil geochemistry, and geophysical response.

The Skouries porphyry syenite system is represented at the surface by a small (180 x 250 meter) elliptical, composite intrusive pipe emplaced into the Vertiskos Formation; and by

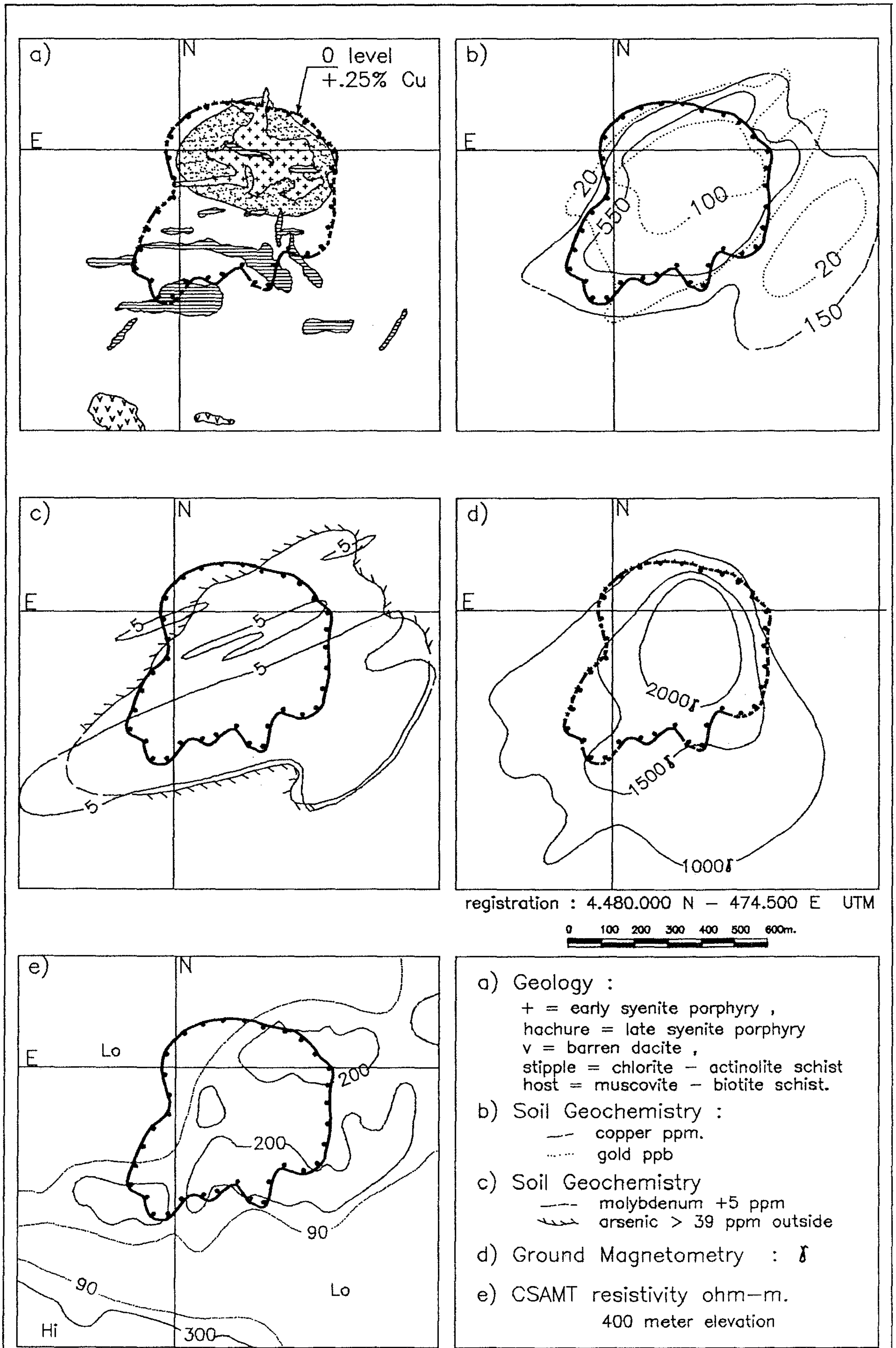

a)
N
E
0 level
+.25% Cu
b)
N
E
20
550
100
20
150
c)
N
E
5
5
5
5
5
d)
N
E
2000γ
1500γ
1000γ
registration : 4.480.000 N – 474.500 E UTM
0 100 200 300 400 500 600m.
e)
N
E
Lo
200
200
90
90
Lo
Hi
300
a) Geology :
+ = early syenite porphyry ,
hachure = late syenite porphyry
v = barren dacite ,
stipple = chlorite – actinolite schist
host = muscovite – biotite schist.
b) Soil Geochemistry :
copper ppm.
gold ppb
c) Soil Geochemistry
molybdenum +5 ppm
arsenic > 39 ppm outside
d) Ground Magnetometry : γ
e) CSAMT resistivity ohm–m.
400 meter elevation

Figure 2

several EW to NE trending dikes, of the same composition, in a zone extending to the south and southwest. These dikes are generally weakly mineralized and are observed cutting the main plug. The crosscutting relationships of dikes, textural variations, mineralogical assemblages and veining demonstrate the multiple intrusive pulses that have complicated the zoning patterns.

The porphyries are emplaced in fine grained schists of the Vertiskos Formation which are composed of muscovite, biotite, chlorite, actinolite, feldspar and quartz. The distribution of chlorite and actinolite is restricted to near the porphyry plug and therefore is regarded as an alteration phase.

Due to the extensive cultural modification of the surficial materials, ridgeline "C" horizon soil samples were augmented by drill hole 1st assay interval values in the geochemical study (Cardenas, 1998). The copper +550 ppm contour conforms closely to the +.25% Cu at depth and the +150 ppm contour conforms closely to +.1% Cu. Gold geochemical values are coincident but generally low with +.1 ppm in rock represented by +20 ppb in soil samples. Molybdenum is restricted to the south and southwest side of the system where, in fact, the porphyries contain high molybdenum as well as copper and gold. Of all the other elements tested only arsenic showed a consistent pattern with a depletion in the central porphyry area to values of less than 40 ppm in soil versus values to 100-150 ppm at more than 600 meters from the center of the system.

At present an exploration decline is being driven to the 350 meter level of the main porphyry and mapping in that tunnel shows the limited influence of the system on the host rocks. From outside toward the porphyry, at greater than 2.5 stock diameters there is <.5% pyrite in the unaltered schist. This increases gradually to 2% pyrite accompanied by calcite at 1.5 stock diameter where the first base metal bearing vein (5 cm quartz, calcite, sericite, pyrite, chalcopyrite, sphalerite, galena, marcasite) was encountered. Inward from one stock diameter is the first appearance of zones of biotitic alteration with +.15% Cu as chalcopyrite along with 2% magnetite, pyrite, and rare molybdenite.

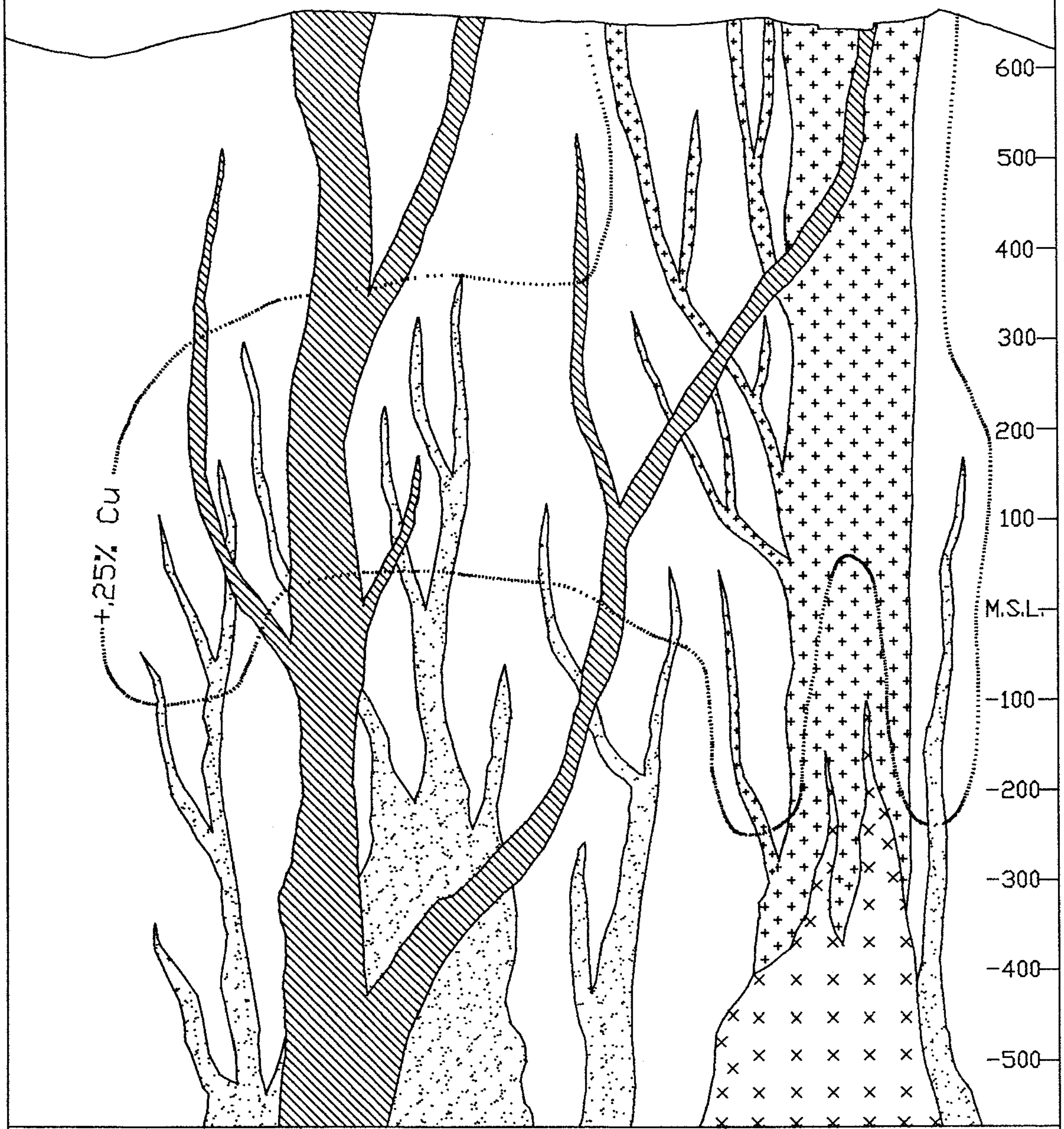
The magnetic survey data show a very good correlation with copper grade (+.25 Cu = 1500 gammas over regional). The resistivity profiling data (CSAMT) also show a close correlation of moderately resistive zones and altered mineralized intrusive rocks (Flores, 1998). The unaltered dacite porphyry to the south of the deposit is represented by high resistivity.

Figure 3 is a schematic cross section (looking NW) from the main porphyry to the southwest Cu-Au-Mo center. The details of intrusion sequence are not known but based on incomplete data the following sequence of events is visualized:

1. Intrusion of pink syenite porphyry principally in the SW zone but extending as more isolated dikes to the north side of the main porphyry. This rock has undergone intense potassic alteration and the metamorphic rocks above and around these dikes have been strongly biotitized. Copper was introduced in several veining stages beginning from late magmatic. Miarolytic cavities in the dike contain small crystals of bornite, chalcopyrite, molybdenite, biotite, and quartz. The ratios of the ore elements are near crustal abundance ratios and metal content is quite uniform.

2. The second event is believed to be the intrusion of some of the main porphyry plug with the formation of a high grade ore shell containing abundant bornite and magnetite. This zone, which has been largely removed by erosion, was followed by

MODEL SECTION (VIEW 310)



Pink Syenite Porphyry – Chatoyant feldspars , abundant flecks of hematite, miarolytic cavities with biot.; qtz, cp, bn, mo, Cu : Au : Mo in crustal ratios.

Main Porphyries – variable texturally and mineralogically, aplitic phases, high matrix phases,; crowded phases, high magnetite, high sphene varieties; high silica–magnetite, cp>>bn>py ; high Cu , Au , low Mo.

Intra Mineral Syenite Porphyry – large phenocrysts of K-feldspar, chloritized biotite and rare hornblende , shreddy biotite and magnetite in groundmass, py>cp , .15 Cu , 25 ppm Mo , Cu : Au = 1

Late Oxidized Porphyry – strong chlorite , pyrite , specularite alteration ; sulfidation and redistribution of pre-existing mineralization, many textural phases with abundant aplite , some UST noted , subhorizontal (tangential) qtz – magnetite veining. Cu : Au < 1 , copper < .2 % , Mo mobilized into late veins.

Figure 3

renewed intrusion and development of another ore shell 300 – 400 meters below. Between the two shells is a zone with abundant aplite cut by feldspar stable pyrite veinlets (possibly the lower reaches of the upper zone).

3. The formation of these ore zones was followed by the intrusion of a weakly mineralized syenite porphyry, which shows propylitic alteration except where cut by later vein stages. At least part of this stage was earlier than the end of quartz magnetite veining, and was earlier than the majority of the subsequent stage of sulfide veins.

4. The final stage of mineralization was accompanied by strong chlorite, pyrite, specularite alteration and removal and remobilization of copper and gold to higher levels where the metals were redeposited in "S" veins (1 mm to 20 cm) of chalcopyrite-bornite ± quartz, carbonate and with formation of weak chlorite-Fe oxide alteration halos. Due to the strong alteration it has not been possible to decide what is the causative intrusion but the presence of abundant aplite with UST, micrographic intergrowths, vein dikes, and parting veins, are suggestive of final crystallization in the presence of an exsolved phase, and the subhorizontal (tangential) veining sequence may indicate a deeper level in the system.

The overall alteration mineralization patterns and types are consistent with those known in other deep seated porphyry systems, but in detail the patterns become complicated due to small size of intrusions. In general, hydrothermal alteration at Skouries occurs as a central silico-potassic zone (usually with very high magnetite content) and a propylitic zone which envelops and partially covers the previous zone.

The potassic alteration affects the syenite porphyries and the schists usually as potassium feldspar veinlets with lesser biotitic veinlets in intrusive rock and as pervasive biotite replacement in the schists. At very deep levels the biotitic schist has been partially replaced by porphyroblastic K-feldspar. Anhydrite is common at deep levels, below the strongest portion of the magnetite shell. Calcite is ubiquitous, in all veining stages, but becomes most common in the latest stage. Potassic alteration replaces a weak earlier actinolite-magnetite alteration zone around the central porphyry. This stage is mostly veinlet controlled and does not appear to have contributed much to the total metal, but does contain some chalcopyrite and bornite.

The propylitic alteration is composed of chlorite, epidote, albite, and calcite and is observed principally replacing minerals adjacent to fractures and veinlets. This alteration is not to be confused with the late chlorite-specularite alteration which contains some K-feldspar, biotite, and actinolite in veinlets (higher temperature?), and which contains, in open cavities, late zeolite (stilbite?).

Argillic alteration comprising illite, montomorillonite and sericite is observed around late calcite-pyrite veins (some with sphalerite and galena) as penetrative replacement halos. The argillic alteration does not affect grade unless sericite is involved, then an extensive pyritization is present, and pre-existing chalcopyrite and bornite are only preserved where locked in other minerals.

The overall mineralization pattern is also simple with central bornite-chalcopyrite followed outward by chalcopyrite and pyritic zones. The total content of pyrite is quite low at the surface and no leached cap or enriched zone was developed. There is a 30 – 40 meter oxide zone at the surface followed by chalcocite and covellite but the overall grade is not significantly enhanced.

The late "S" vein stage contains in addition to chalcopyrite and bornite, rare chalcocite, digenite and covellite with hematite. Galena is observed as a rare accessory in these veins, and coarse gold is often associated with bornite, digenite, and galena. Flourite occurs as a rare gangue mineral with this stage.

Gold mineralization occurs as native metal (>80 wt.% Au) from a few microns to +150 microns in size. The gold is usually associated with gangue minerals or with bornite. Interatomic gold is rare with contents in sulfide minerals usually not exceeding 3 ppm (Chryssoulis, 1997). The rare electrum that has been observed is related to the late oxidative stage of mineralization.

Resources

The TVX program, (Magri, et.al., 1998), involved the drilling of 73,000 meters, which have been mapped for geotechnical and geologic information. The geologic mapping was based on the El Salvador Anaconda method, recording information about lithology, hydrothermal alteration minerals (distribution and content), metallic mineralization and quartz veining (size, distribution, relative ages, and sulfide ratios) structures and other relevant geologic characteristics.

A geologic interpretation of the deposit was made working back and forth between plans on 100 meter separation, and perpendicular sets (NW and NE) of vertical sections separated by 50 meters. This interpretation involved lithology, hydrothermal alteration, vein density, isogrades of gold and copper, and structures.

The core was measured, photographed and sampled on 2 meter intervals. Core recovery for all categories averaged +91% for the drilling program. Specific gravity measurements were done on whole pieces of representative core (total 483). All samples were analyzed for Cu total and for gold (fire assay 50 g). One of every 10 samples was analyzed for Ag, Mo. The first meters of every hole were analyzed for soluble and leachable Cu in the oxide zone. Every 10^{th} sample was sent to a separate laboratory for assay check. A separate sample was prepared on every 10^{th} coarse reject to check sample preparation.

The gold check assays showed considerable scatter due to coarse gold (37% > 50 microns). All samples between 2.8 and 5 grams were reassayed using 100 grams of pulp and all samples above 5 grams/t were reassayed by screen fire assays using 500 grams pulp.

The sample data were made into 5 meter composites and were subjected to statistical analysis including declustering. Grade variograms were calculated and effective ranges were above 150 meters in both porphyry and schist for both Au and Cu. In preparing the block model a search radius of 150 meters was used except for gold grades in excess of 8 g/t where the search radius was reduced to 20 meters. Copper and gold were positively and strongly correlated in all rock types with an overall correlation coefficient of 0.8.

Block models were developed using ordinary kriging for total copper and gold. Kriging variances were chosen at .45 and .80 for measured/indicated and indicated/inferred. This gave a radius of influence for measured ore of 25 to 30 meters and for indicated ore to 85 – 90 meters. Below 500 M tonnes 80% of the resource base is in the measured + indicated category and below 150 M tonnes more than 90% of the resource is measured + indicated.

Grade tonnage relationships are presented on Figure 4. Since the last geological resource calculation in July, 1998, drilling continued in the southwest porphyry sector with the addition of approximately 40 M tonnes of 0.5% Cu, 0.5 g/t Au and 200 ppm Mo. Small increases may be expected in the future in this sector and also on the southeast side.

As a final note it should be mentioned that during the past 2 years, 6M oz of Au has been discovered at Skouries by 73,000 meters of drilling: 82 oz/meter.

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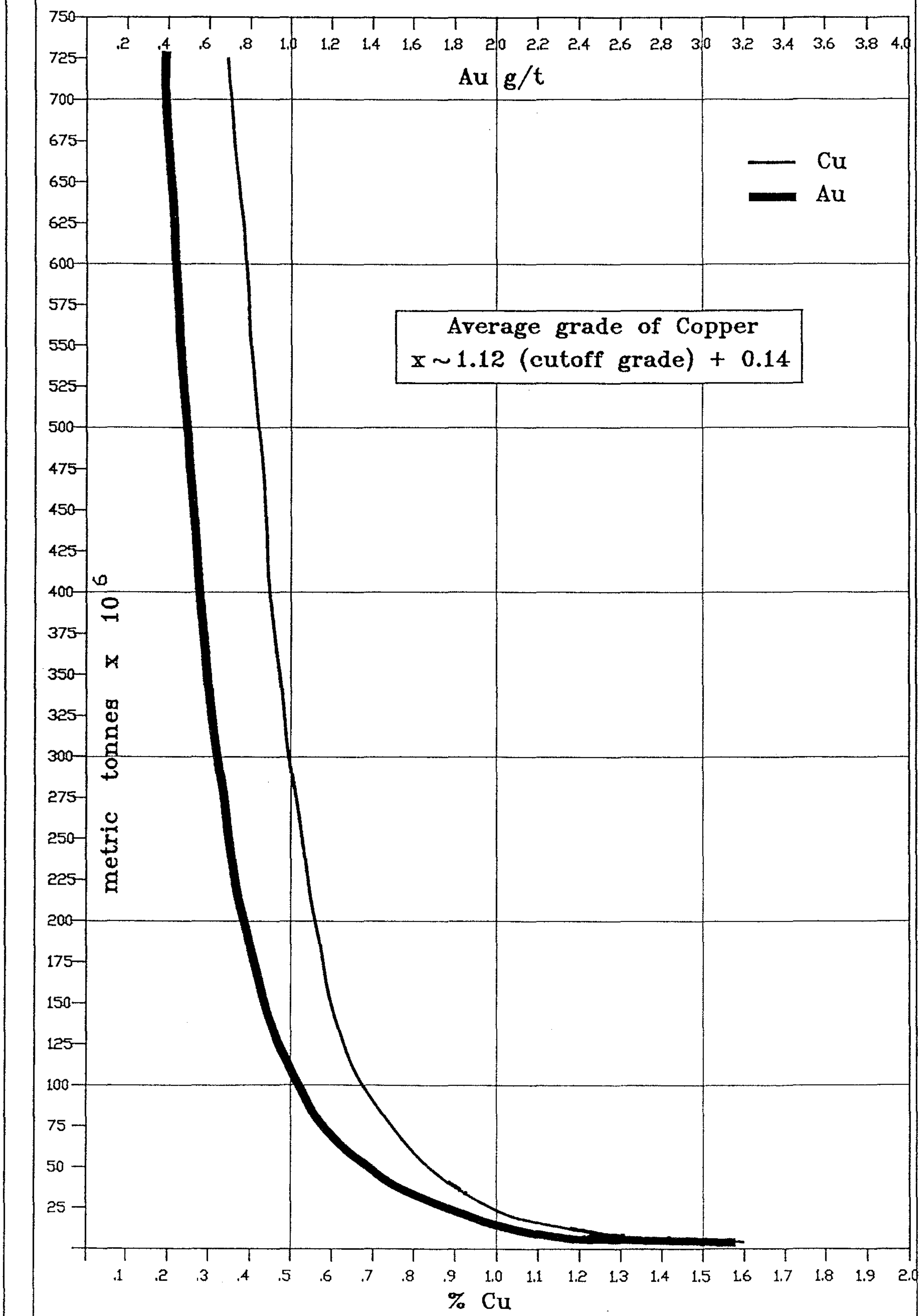

SKOURIES Cu – Au Porphyry
Grade – Tonnage Curve

Figure 4