

3D OREBODY MODELLING AND RESOURCE ESTIMATION OF THE JUCARO DEPOSIT, PINAR DEL RIO, CUBA

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ABSTRACT

The Jucaro deposit is an operating mine located in the NE part of Pinar del Rio province, 16 km from Bahia Honda town. The mine has a beneficiation plant with annual capacity of 150 000 t of ore. The deposit is hosted by the basaltic complex of the Encrucijada formation. The mineralization (pyrite and chalcopyrite) occurs as sulphides lenses dipping to the NW at the angle of 20°-70°. Two main orebodies form the deposit: Orebody I and Orebody III, the former is already mined out while the latter, which is the main subject of this research, contains almost all of the known resources. The total resources of the deposit were previously estimated as 2.6 Mt grading 1.98 % Cu and 20.91 % S, using manual calculation methods.

The primary aim of this research was to model the Jucaro deposit and reevaluate its resources by taking into account the spatial variability of the mineralization and by complementing the existing geological, drilling and underground data with a computerized 3d model.

The Jucaro deposit data, consisting of 116 surface drillholes and 66 underground drillholes, were stored in a relational database. The statistical analysis revealed the existence of a complex statistical population, which was split into two more or less homogeneous sub-populations: the mineralized zone and the hydrothermal alteration zone. Further analysis of the mineralized zone indicated that both sulphur and copper approximately conform to lognormal distributions. The variography revealed no spatial structure in the plane of the deposit. This confirmed the observed high variability of copper and sulphur grades in the Jucaro mine.

The deposit was geometrically modelled using the perimeter and surface methods. The geological model provided a good 3d representation of the complex morphology of the mineralized zone and was used to apply geological control to the resource estimation. Based on the lenticular shape of the deposit the grid model was selected to calculate the mineral resources. Copper and sulphur grades were estimated using the inverse power of distance weighting technique.

The total ore resource of the Jucaro deposit obtained from the grid resource model is 2.5 Mt grading 1.98 % Cu and 17.78 % S. The bulk of the Jucaro deposit ore tonnage (80%) is located in Orebody III. These results are slightly lower than the resource calculated by the conventional manual sectional methods.

It is concluded that 2D/3D GIS techniques are suitable for the geometric and volumetric modelling of the VMS deposits of Bahia Honda zone.

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1 CHAPTER 1 INTRODUCTION

1.1 Background

The mining industry, along with the sugar industry and tourism plays an important role in Cuba's economy. In 1993 and 1995 a new mining and the foreign investment laws were promulgated directed at both a radical restructuring and a controlled opening of the Cuban economy to foreign investment. Since then, Cuba's mining potential has attracted numerous foreign mining companies who are participating in production, development and exploration joint ventures throughout the country. The country has a large geologic database (partly digital) as a resource to explorers, as well as a substantial nickel mining industry. The principal exploration targets are nickel-cobalt, gold and base metal deposits.

In Pinar del Rio province (western Cuba) large concession areas have been acquired by foreign mining companies while others are being negotiated. The Bahia Honda region (eastern part of Pinar del Rio province) is a potential zone to host volcanogenic copper (with gold) deposits, lateritic nickel, bauxite and manganese deposits. There are several known mineral deposits and mineral occurrences in the region.

The region includes the Jucaro copper mine, which is a volcanogenic massive sulphide deposit (VMS), and beneficiation plant, with annual capacity of 150 000 t of ore. The plant could process copper resources mined from the area and in addition the bulk of the resources of the Jucaro deposit are still in the ground. Thus it is likely that the deposit and processing plant will enter in to a joint venture agreement.

Considering these facts the National Office of Natural Resources and Mine Management Board have deemed it necessary to reestimate the resource, which was manually calculated, using a computer assisted method. This will provide more reliable and updated results in tune with the western companies' requirements.

1.2 Geography of the study area

The Jucaro deposit is located in the NE part of Pinar del Rio province, 16 km from Bahia Honda town (fig1.1). The deposit is easily accessed by a 3.5 km asphalt road, which runs from the mine site to the first class La Palma - Bahia Honda road. The study area is bounded by the following Lambert coordinates: Easting - 269 400, Northing - 338 400 and Easting - 270 100, Northing - 339 000.

The climate is typically tropical with average temperatures ranging from 17.2° (February) to 32.1° (August). There are two well-defined seasons, dry from November to March and rainy from April to October. The annual rainfall is in the range of 1600-1900 mm. The drainage system is composed of small intermittent streams, which are dry in the dry season, and the San Miguel River, 2 km east from the mine site, which keeps continuously flowing over the entire year.

The land is covered by grass while palms are very abundant. The region is primarily used for sugar cane cultivation, coffee plantations, forestry and the small-scale livestock. The mining activity also has an important contribution to the economy of the region.

The study area is located near the northern flank of Sierra del Rosario. The relief of the study area is characterized by the presence of low elevations ranging from 30m to 100m above sea level. In the past the gossan coincided with top of an elongated elevation bearing SW- NE, which stands higher than the surrounding area, but nowadays it is caved in as the result of mining of Orebody I.

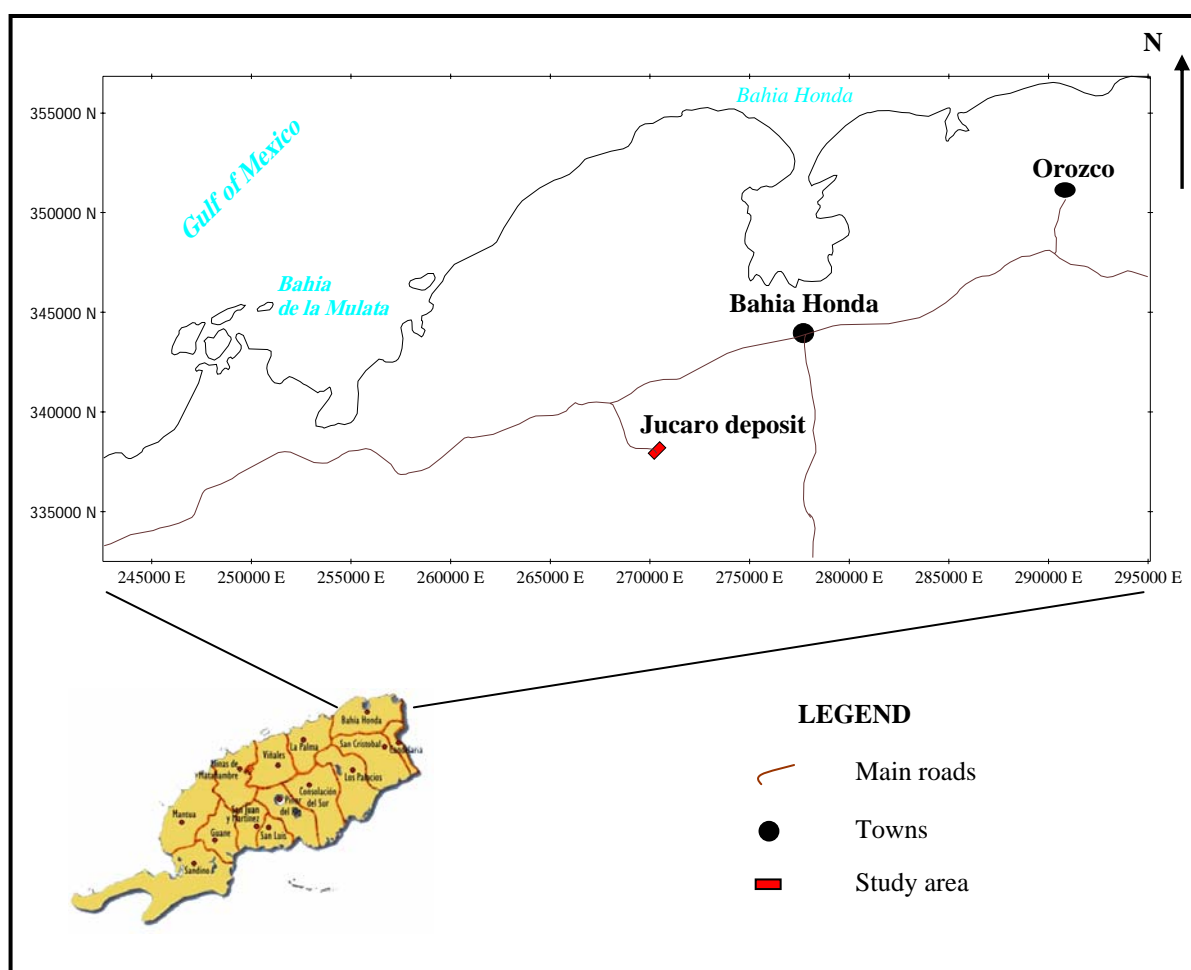


Figure 1.1 Location of the study area in western Cuba.

1.3 Previous work

The Jucaro mineral deposit (originally a mineral showing) was discovered during a prospecting and exploration campaign (1963-1965) executed in the Bahia Honda region on the basis of two trenches excavated in the gossan, which revealed the mineralization. Jucaro showing was deemed a prospective target.

From 1965 to 1966, during detailed prospecting of the deposit, R. N. Volodin drilled 8 holes, 7 of which intersected the mineralization. The resources were estimated as 0.5 Mt grading 1.5% Cu. In February 1967 E. S. Ansiferov started the preliminary exploration of the deposit. He revealed the existence of 3 orebodies, namely:

Orebody I; Orebody II; and Orebody III. Resources totaled 0.4 Mt at average grade of 2.59 % Cu and 11.09 % S.

Further exploration was carried out by P. Zamianov and A. Kulikov from 1968 to 1969, during which they evaluated Orebody III and revealed a new orebody (Orebody IV). The total estimated resources for these two orebodies were 1.6 Mt. Since 1971, E. Escobar continued the exploration of the deposit, aimed at evaluating the new-discovered Orebody IV and reinterpreting the geological structure of the deposit. It was concluded that Orebody III and IV encompassed just one body (Orebody III).

The total resources were by then evaluated as follows:

• Orebody I (cupriferous)	397 000 t at 2.62 % Cu and 10.75 % S
• Orebody II (cupriferous)	32 190 t at 2.70 % Cu and 17.27 % S
• Orebody III (cupriferous)	1 961 347 t at 2.03 % Cu and 20.91 % S
• Orebody III (pyritic)	215 831 t at 0.25 % Cu and 40.12 % S
Total	2 606 368 at 1.98 % Cu and 20.91 % S

Nowadays Orebody II is considered to be part of Orebody I. The deposit was brought into production in 1979 by the government owned Mining Western Enterprise.

1.4 Objectives of the research

The main objectives of the research are to model the Jucaro deposit, reestimate its resources so as to achieve a more reliable and updated assessment of the resources by taking into account the spatial variability of the grades and the complex geometry of the deposit. The objectives are attained through the following steps:

- Generation of a digital database of the deposit
- Statistical and spatial analysis of copper and sulphur grades
- 3D orebody modeling
- Estimation of resources by complementing existing geological, drilling and underground data with a computerized 3d model

As Orebody I is completely mined out, more emphasis is placed in the modelling and estimation of Orebody III, which also hosts the bulk of Cu resources.

2 CHAPTER 2 GEOLOGICAL BACKGROUND

2.1 Introduction

The Cuban archipelago is extremely complex from the geological point of view; particularly since many aspects of its geology remain unknown. Cuba contains Precambrian rocks (900 Ma metamorphic rocks in Santa Clara province) and an extensive series of continental margin, sedimentary rocks of Jurassic to Cretaceous age. It is structurally characterized by large nappe structures and thrusts.

Cuba can be divided into two broad geological provinces:

1. Western and central Cuba constitute a complexly deformed orogen resulting from the collision of a mid to late Cretaceous island arc with the late Jurassic to late Cretaceous sedimentary rocks of Florida Bahamas platform.
2. Eastern Cuba is characterized by a Cenozoic (Paleocene –Middle Eocene) volcanic plutonic arc complex of the Sierra Maestra. North and east of Sierra Maestra ophiolitic and arc island rocks of the Mesozoic orogen occur, overlain by Paleogene sedimentary rocks and tuffs.

Western Cuba (Pinar del Rio province) consists of three structural facies zones namely the Guaniguanico, San Diego and Bahia Honda zones (Mormil et al., 1980). The study area is located within the Bahia Honda zone (fig 2.1). The Bahia Honda zone is the northernmost one and is formed by ophiolitic rocks overlying a sequence rich in carbonate sedimentary rocks. The structurally lowermost unit of the zone consists of mafic and intermediate lavas, siliceous slates and well-laminated limestones, possibly in an island arc association. The uppermost ophiolite unit consists of basalts, gabbro and ultramafic rocks.

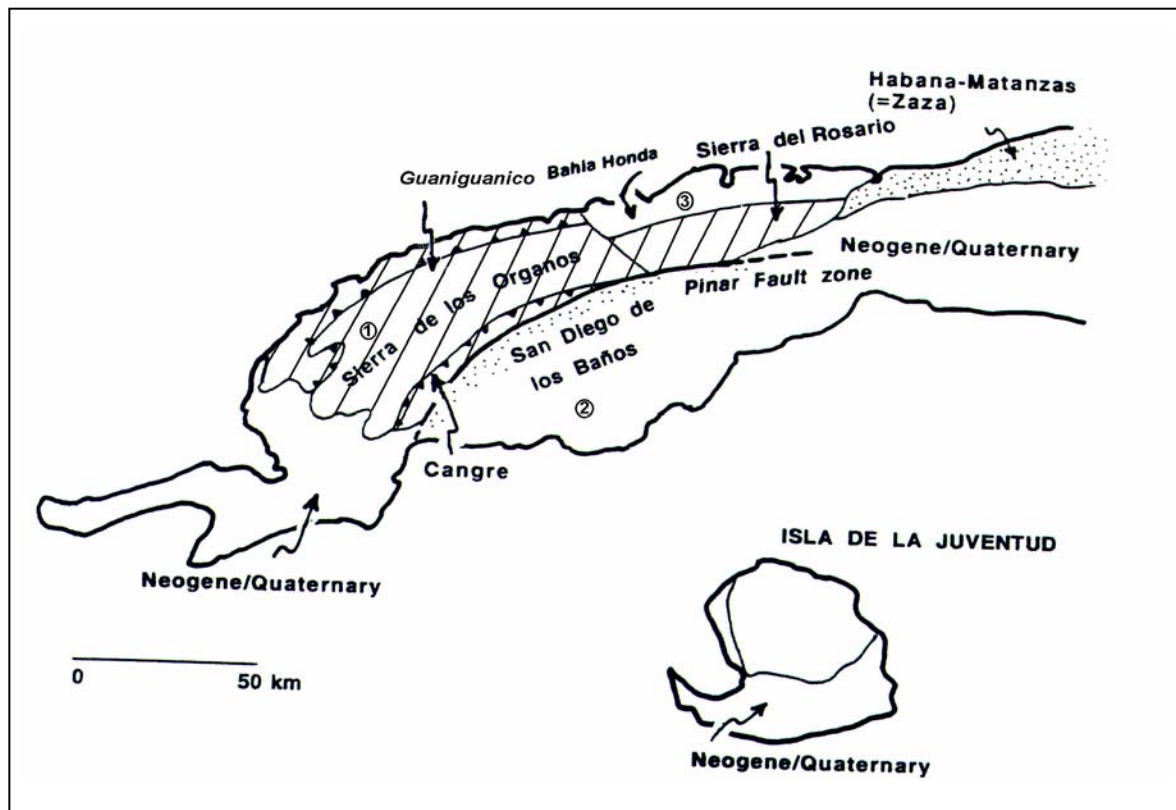


Figure 2.1 Structural facies zones of the Pinar del Rio province (1-Guaniguanico zone, 2-San Diego de los Baños zone and 3- Bahia Honda zone)

2.2 Geological setting of the region

The region is characterized by the profuse abundance of Cretaceous, Paleogene and Quaternary formations (fig 2.2). The geological structure is complex and dominated by nappe tectonics. The area has been interpreted from different points of view. The rocks in the region are grouped in three sequences:

- Quaternary sequences
- Rocks of the Upper Cretaceous Paleogene superimposed basin
- Rocks of Cretaceous back arc basin

Figure 2.2 Geological map of the region

Quaternary sequence

In the area the Quaternary sequence is well developed, being composed of sand, clay and weathered material derived from the underlying rocks, which form elluvial and diluvial mantles that cover the primary rock. These deposits are also found throughout the area filling up the riverbeds and floodplains.

Rocks of the Upper Cretaceous Paleogene superimposed basin

These rocks are grouped in 3 geological formations, 2 of which belong to Mariel group.

1. Via Blanca Formation is a flysch type sequence, composed of rhythmical interbedding of sandstones, ranging from polymictic to volcanomictic composition, with siltstones, claystones and conglomerates. The thickness is quite variable due to subsequent erosion, reaching a maximum of 550 m in some places.

Mariel Group is comprised of four geological formations namely Mercedes Fm., Apolo Fm., Madruga Fm. and Capdevila Fm. but only the last two are exposed in the area.

2. Capdevila Formation is composed of polymictic sandstone alternating with siltstone and conglomerate of different composition, subordinate tuffite and marls are also present.
3. Madruga Formation consists of sandstones, siltstones, shales and greywackes intercalated with conglomerates. Thickness does not exceed 100m

Rocks of Cretaceous back arc basin

These units occur in the form of tectonic sheets, evidencing the same style described in other parts of the province. This group is by far the most economically important as all the sulphide mineralization in the area is hosted by these rocks. It consists of three main formations:

1. The Orozco Formation is formed by tuff of basic to acidic composition, sedimentary rocks and minor amount of basalts associated with the lower part of the sequence, the thickness of this formation is about 400-500 m.
2. The Quiñones Formation, outcropping to the south of the Encrucijada Fm. consists of interbedded fine-grained sandstones, siltstones, shales and cherts. The thickness of the intercalations range from a few centimeters to 20-30 cm. Lenses of basalt, limestone and conglomerate are also described within this sequence.
3. The Encrucijada Formation is composed of tholeiitic basalts and pyroclastic sedimentary rocks (tuffs, silicites, siltstones, shale and limestone). Almost half of the volume of these rocks is of basic composition.

2.3 Magmatism

The magmatic activity in the region is characterized by the presence of the ophiolite assemblage, which is represented by its four members.

- Metamorphosed ultramafic
- Gabbro and cumulative
- Diabasic
- Basaltic with sediments

The rocks of the ultramafic member crop out in Cajalbana massif and in a narrow 50 km long band forming a serpentinitic melange. The composition of the rocks corresponds to a mixture of apoharzburgites serpentines, included in a groundmass of lherzolites, dunites and pyroxenites, with different degrees of serpentinization.

The second member of the complex is associated with the serpentinitic melange and the area where the Orozco formation outcrops. The contact between the gabbro and the effusive rocks of the Orozco Fm. is tectonic.

The third member, which is not abundant in the area, crops out in the western part of Cajalbana Massif where sheeted diabase dykes cut across the amphibolized gabbros of the previous member. The upper part of the section is intensely tectonized, being included within the serpentinitic melange.

The fourth member (basalts with sediments) is related especially to the ultramafites and forms a narrow E-W trending belt (1- 2.5 Km), located to the north and south of the serpentinitic melange. The northern belt is composed mainly of dolerites, basalts, tuff and tuffites, and the southern belt of aphyric and porphyric basalts, intercalated with sediments, including those of Quiñones formation.

2.4 Tectonic setting

The main tectonic unconformity observed in the area is at the same time manifested in the rest of Cuba. This is of lower Campanian age, and is located between the sequences of volcanic – sedimentary rocks and those of the cover.

In the structure of the Bahia Honda zone the presence of the serpentinitic melange, stretching from Cajalbana massif to the East of Encrucijada, is very conspicuous and indicates the importance of overthrusting in the geology of the area. Generally the melange appears bordered to the south and to the north by the association of gabbros and diabbases. Pszczolkowski and Albear (1979) describe two large units of nappes: one to the south of the melange zone (southern tectonic unit) and the other, structurally higher (northern tectonic unit). The first is mainly composed of Cretaceous rocks of Encrucijada and Quiñones Formations whereas the second one consists of Via Blanca, Orozco Formations ending with the rocks of Paleocene – Middle Eocene sequences and also including a large part of serpentinized ultramafites and gabbro – diabbases members that constitute fragments of the oceanic crust.

Both units have a complex internal structure. It is considered that the southern unit is composed of allochthonous nappes included in ophiolite or sandy – clayey melanges (Mediakov and Furrázola-Bermúdez, 1979).

The thrusting event corresponding to the eastern part of Pinar del Rio province took place during the lower to middle Eocene (Pszczolkowski et al., 1982), with additional displacement between the lower and the upper tectonic units later on.

2.5 Mineral deposits

The Bahia Honda zone is well endowed with mineral deposit and mineral showings. The most important commodities are those of iron, asphaltites, bitumens and cupriferous pyrites which are by far of the most economic importance. The pyritic Cu deposits are hosted by tholeiitic basalts of Encrucijada Fm. The most important deposits are Jucaro (2.6 Mt @ 1.98 % Cu), Buena Vista (0.2 Mt @ 1.7% Cu), Cacarajicara (0.6 Mt @ 1.10% Cu), Yagruma (0.6 Mt @ 1.25% Cu). In addition there are several sectors where hypothetical resources have been calculated on the basis of geochemical and geophysical anomalies, the existence of outcropping sulphide mineralization and drilling cores (table 2.1).

Table 2.1 Main sectors with calculated hypothetical resources in the study area

Sector	Contained copper (t)	Location
Blanca Arena	30 640	20 km east of Jucaro deposit
La Caoba	4 702	20 km northeast of Jucaro deposit
La Mulata	20 000	20 Km west of Jucaro deposit
Sundo-Francisco	6 527	2 Km west of Buena Vista deposit

These deposits and mineral occurrences are grouped in the Encrucijada metallogenic subzone described by Mormil et al. (1980) in the region of Bahia Honda. The deposits are characterized by the following features (Simon et al., 1986):

- They constitute massive stratiform sulphide accumulations.
- Stratigraphic control: The majority are located in the volcanic- sedimentary sequence of Encrucijada Formation of Aptian – Albian age.
- Lithological control: the mineralization is hosted by diabases, and aphyric chloritized basalts, frequently amygdaloid, interlayered with tuff, tuffaceous siltstones and limestones.


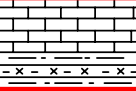

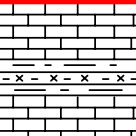
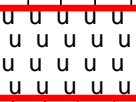
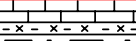
- The host basalts have undergone intensive hydrothermal alteration e.g. chloritization sericitization, silicification etc.
- The volcanism of mafic rocks presents a pronounced MORB character.
- The mineralogical composition: the main minerals are pyrite and chalcopyrite meanwhile hematite, magnetite, pyrrhotite and sphalerite being the most common accessories.
- Geochemical association: The Co/Ni ratio attains very high values.

2.6 Geology of Jucaro deposit

The Jucaro deposit is hosted by the basaltic complex of Encrucijada Fm (fig 2.3). From the point of view of the location of the mineralization, the whole sequence is divided into three parts (Izquierdo, 1980) (from bottom to top):

- (a) Footwall part consists of tuff with different grain size, calcareous tuff interlayered with porphyric basalt, limestone and siliceous rocks (pyroclastic –sedimentary complex).
- (b) Middle part is composed of basalts of different structures, with which the mineralization is associated. The mineralized bodies are situated between these rocks and the pyroclastic –sedimentary complex.
- (c) Hangingwall part is formed by carbonate rocks, shale and silty tuff.

The deposit is formed by two main orebodies (I and III) with minor bodies scattered around them (fig 2.4). The bodies are lenticular in shape, the strike length is around 300-350 m, the thickness ranges from 1 to 40m, averaging 10m. The strike of the deposit area is NE (40°-60°) with a dip to the NW at the angle of 20°-70°. The deposit is tectonized by postmineral faulting that complicates the overall structure and morphology of the deposit.

SYSTEM	SERIES	STAGE	Fm.	LITHOLOGY	THICK., m	DESCRIPTION
CRETACEOUS	LOWER	APTIAN-ALBIAN	ENCRUCIJADA		360m	Basalts of porphyric and aphyric textures, often amygdaloidal
					80m	Pyroclastic - sedimentary sequence: lime-stones, cherts, tuff and tuffites.
					310m	Basalts of aphyric, porphyric and amygdaloidal textures, the sulphide mineralization is hosted by this sequence, rocks close to the orebodies and within it are hydrothermally altered.
					95m	Pyroclastic - sedimentary sequence: lime-stones, cherts, tuff and tuffites.
					75m	Pillow basalts
					40m	Pyroclastic - sedimentary sequence

 Tectonic contact

Figure 2.3 Stratigraphic column of Jucaro deposit

Generally the shear zones predominate in the contact of the mineralized zone and the country rocks owing to different mechanical properties of rocks involved.

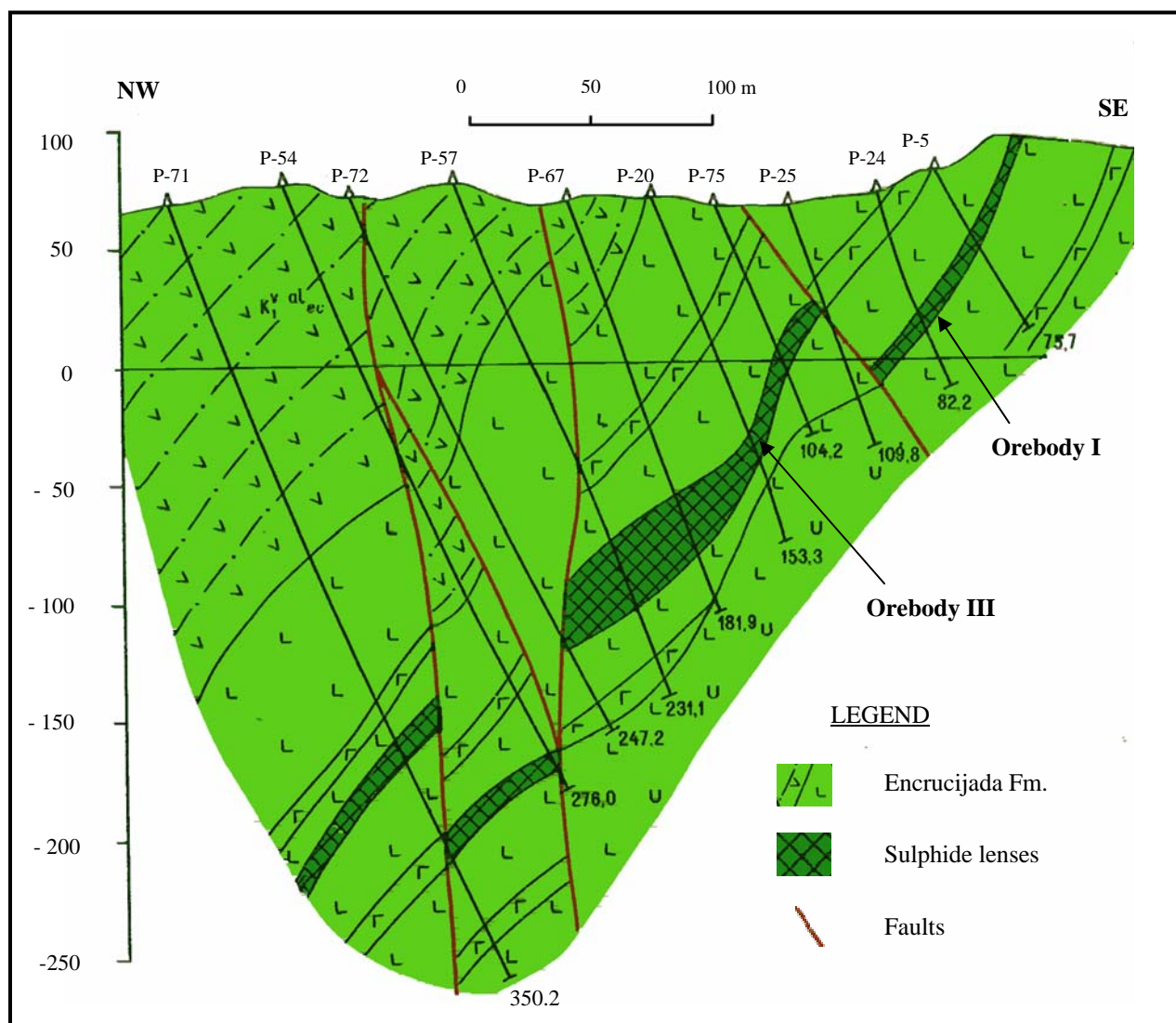


Figure 2.4 Geological section showing the orebodies that form the Jucaro deposit

The main ore minerals present are pyrite, chalcopyrite, magnetite, hematite, marcasite, galena, arsenopyrite, sphalerite. Quartz, Fe -rich chlorite, carbonates, sericite, and others are also associated with the mineralization. In the oxidized zone the following secondary minerals are also found: chalcocite, covellite, bornite, native copper and iron hydroxides

The country rocks are strongly altered, the predominant alterations are chloritization, hematization, sericitization and silicification.

Silicification is related to mineralized basalts, resulting in light colors, high strength and consistency. This process is frequently associated with chloritization and sericitization.

Chloritization is one of the commonest types of alteration in the deposit and occurs in the footwall formations related to the contact between the basalts and the pyroclastic – sedimentary sequence.

Three different type of ores have been described in the deposit: massive, disseminated and veinlet-disseminated, the last two being the most abundant. The massive ore is represented by chalcopyrite and occasionally by pyrite.

The disseminated ore is rarely found and is confined to hangingwall and footwall formations of the orebodies. On the other hand the veinlet-disseminated ore appears bordering the massive ore mainly in those places where the deposit is very narrow.

It is strongly believed that the Jucaro mineralization was formed by the discharge of hydrothermal solutions onto the seafloor of marginal back arc basin with basaltic tholeiitic volcanism.

The Jucaro deposit has many things in common with Cyprus type deposits. The main similarities are described below:

- The deposit comprises 2 main lenses (orebodies) of massive pyrite and chalcopyrite hosted by mafic volcanic rock.
- The mafic volcanic rocks (Encrucijada Fm.) belong to an ophiolitic complex formed at a back arc spreading center; possibly within a marginal basin.
- Sulphide lenses are in tholeiitic pillow basalts near a transition with carbonate rocks, shale and silty tuff.
- Three different ore type are present: massive (chalcopyrite and fine grained pyrite), disseminated and veinlet -disseminated
- Pyrite and chalcopyrite are the principal ore minerals while, magnetite, hematite, marcasite, galena, arsenopyrite, sphalerite are in subordinate amount.

- Quartz, chlorite, sericite and carbonates are the main gangue minerals
- The age of mineralization is Cretaceous
- Chloritization, hematization, sericitization and silicification are the main hydrothermal alteration phenomena.

Both the grade (1.98% Cu) and tonnage (2.6 Mt) of Jucaro deposit are higher than the average grade (1.7% Cu) and tonnage (1.6 Mt) of this type of mineral deposit all over the world (Cox and Singer, 1986) therefore it can be considered as a medium size deposit (fig 2.5)

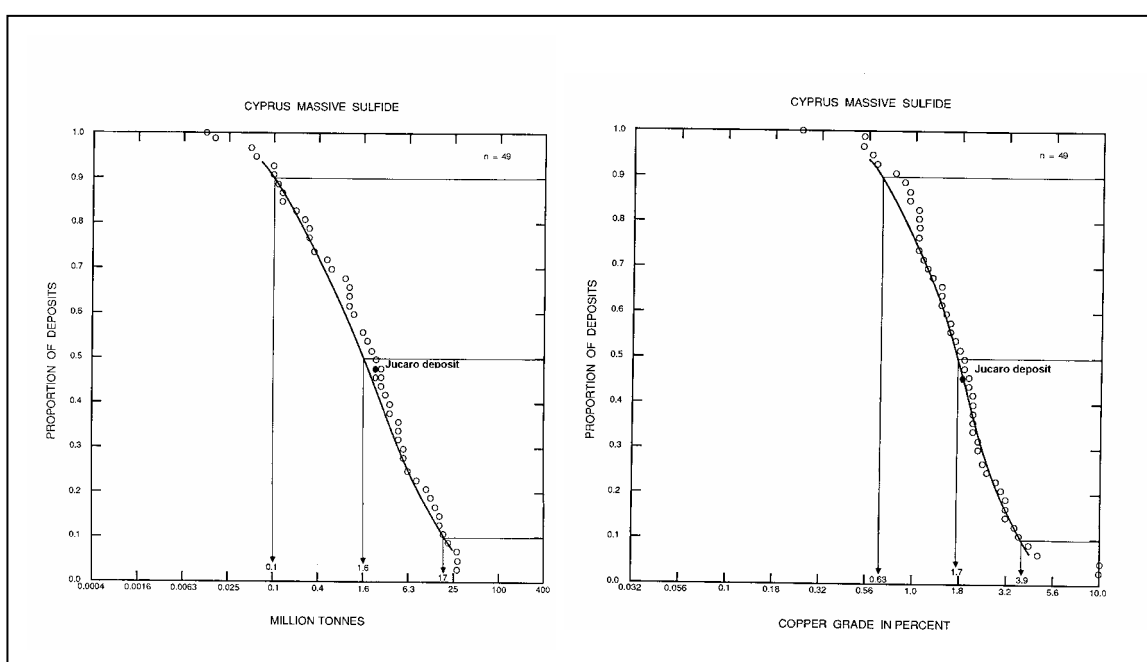


Figure 2.5 Showing the approximate position of Jucaro deposit in the grade - tonnage models (Cox and Singer, 1986)

However, the lack of stringer ore underlying the sulphide lenses and the very low grades of Pb, Zn and Ag, which have no economic importance are the major differences with respect to Cyprus type deposits located in other parts of the world.

3 CHAPTER 3 METHODOLOGY

3.1 Research Resources

The data used in this work consist of the material gathered during the exploration and exploitation of the Jucaro deposit.

The research material includes:

- Surface and underground drillhole data including collar coordinates, survey data, assay data, geological logs
- Channel samples from crosscuts
- Geological map of the region (1:50 000)
- Geological maps of levels and sublevels
- Total of 11 geological sections (1: 1000)
- Mine longitudinal and cross sections (1:200)

3.1.1 Drill hole data

The Jucaro dataset comprises 116 surface drillholes (40 of them intercept Orebody III) and 66 underground drillholes (41 intercept Orebody III). The main sections are at 50 m regularly spaced and the drillhole spacing along sections is 50m. The underground drillholes were bored from the second mine level (-25m) and were designed to evaluate the resource between the second and the third levels. This means that they characterize only the upper part of Orebody III. The average core recovery is 75%. A total of 1564 samples were collected from the 81 holes. The sample interval is approximately 1m. The number of samples gathered in each drillhole is variable and depends on the thickness of the mineralized zone.

3.1.2 Channel samples

Channel samples were taken along 6 crosscuts that intercept the upper part of the Orebody III on the second level. In the mineralized zone samples were taken over 1m. A total of 60 samples were collected and analyzed for Cu and S.

3.2 Methodology

The methodology for this research was selected taking into account the aim of this work, the characteristics of the Jucaro deposit database and the availability of software packages. A flow chart of the thesis is presented in fig 3.1 and a general description of the steps involved is given in the following text. The bulk of research was carried out using the capabilities of the 3D GIS mining software “MICROLYNX 2.2” for Windows. However other packages like GEOSOFT (map making), Access (Database generation), Microsoft Word and Excel were also used.

3.2.1 Data input

Both numeric data and map data were converted into digital format for the research. The numeric data were entered at the keyboard and the map data were digitized or scanned. The research requires the production of a relational database where all the information is brought into a suitable form for the Microlynx software. A database is a collection of information that is related to a particular topic or purpose. Database management systems are based on either a hierarchical, network or relational models.

In the relational database the information is stored in tables (two-dimensional structure) consisting of rows (records) and columns (attributes). This allows efficient and nonredundant data storage and retrieval. Searches of related attributes that are located in different tables can be done by linking two or more tables using any attribute they share in common (keyfield).

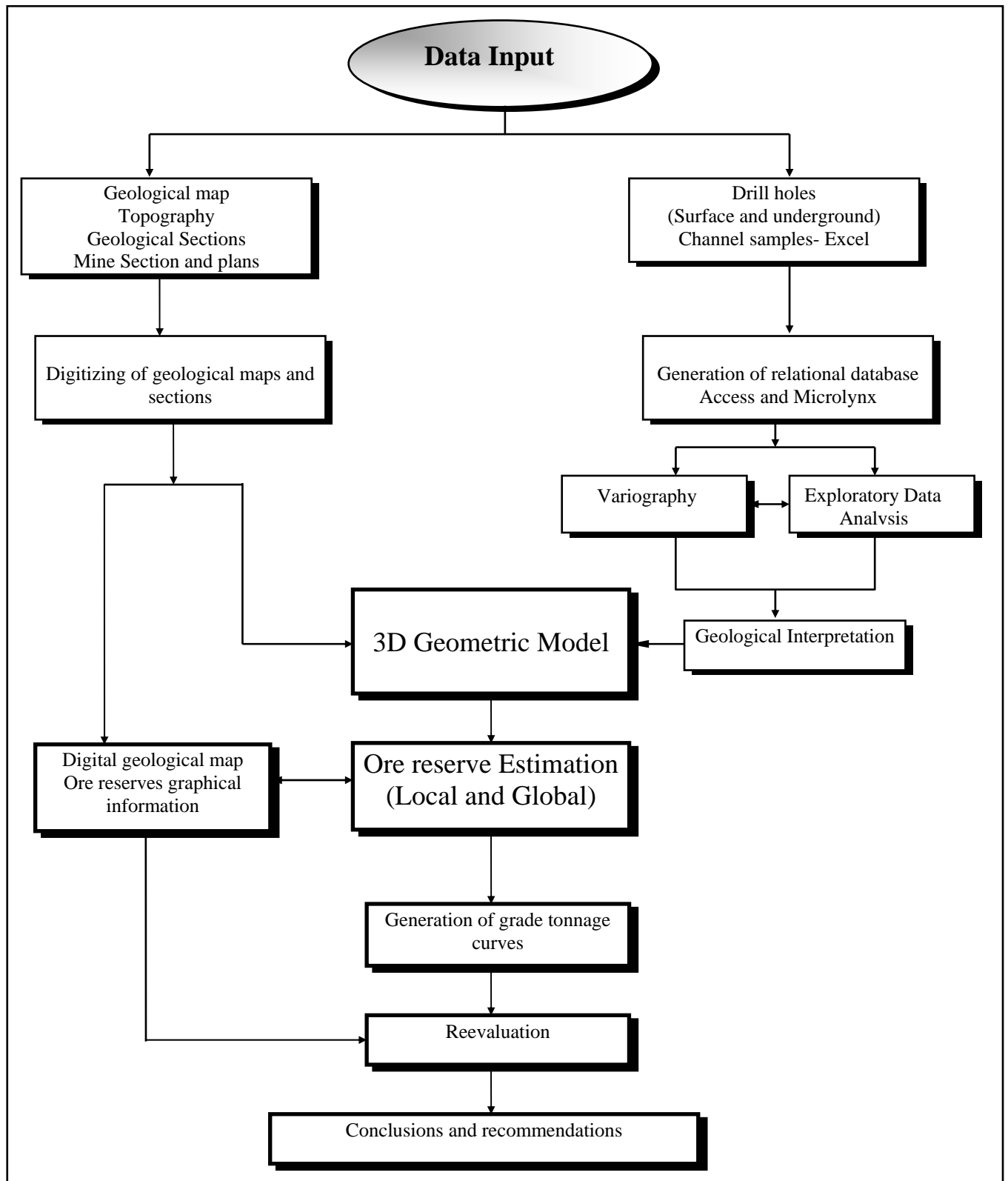


Figure 3.1 Flowchart of the methodology used in the research

The original Jucaro dataset was entered in Excel and subsequently imported into Access using the capabilities of Microlynx. The relational structure of the Jucaro database is shown in fig. 3.2. The information was organized in three different related tables Dcollar, Dsurvey and Dsample. Dcollar table records coordinates of collar and end of hole depth. The Dsurvey table contains the down hole survey (azimuth and dip information) and finally Dsample table stores assay results and lithological and geological codes.

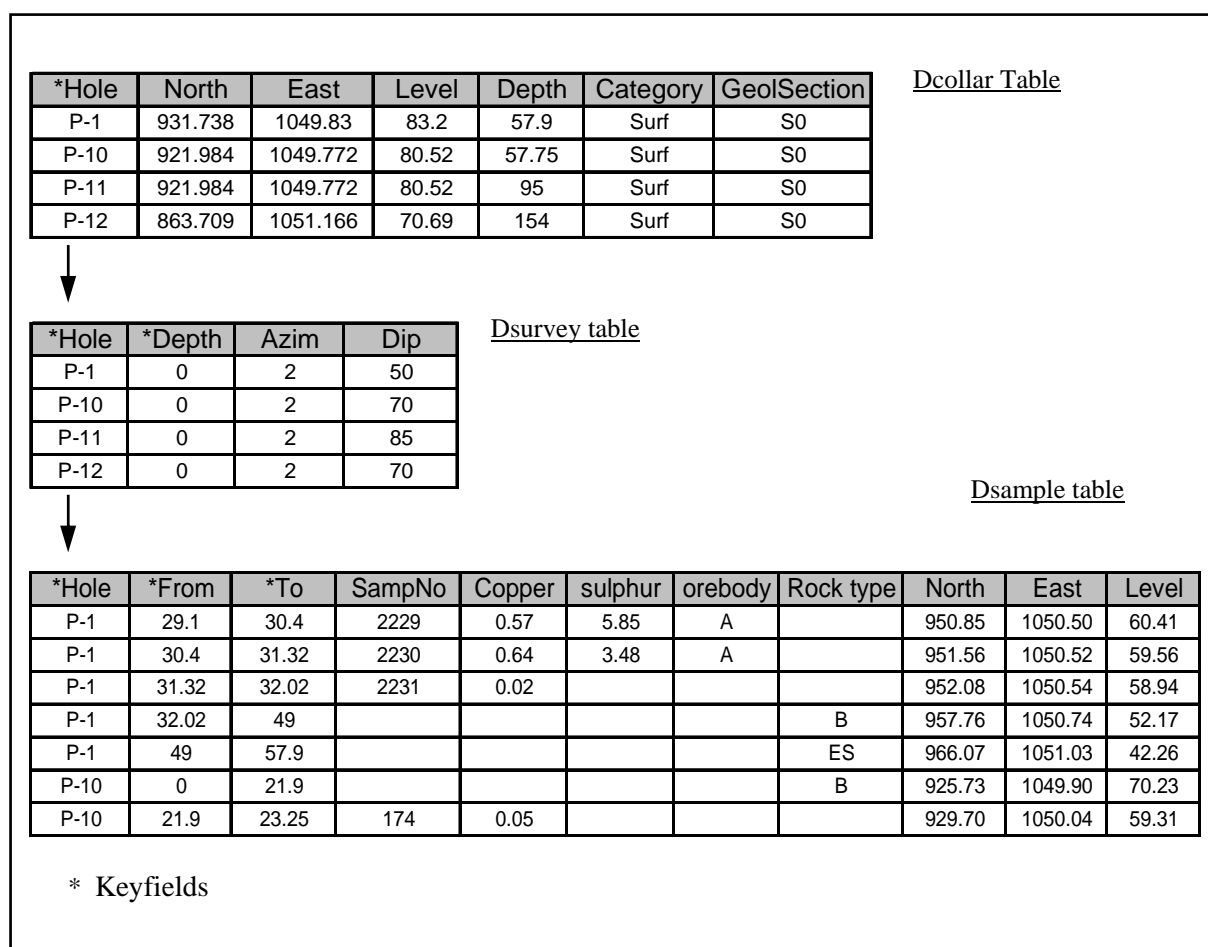


Figure 3.2 Relational structure of Jucaro database.

Subsequently tables are converted into delimited files and then transferred into Microlynx for further analysis, modelling and reserve estimation.

The geological map of the region where the deposit is located, was digitized (using ILWIS 1.4) and subsequently imported into GEOSOFT for the generation of the digital map. The location map and the map of the main tectonic units of the region were scanned.

The nineteen cross sections (11 main sections and 8 intermediate sections) of the Jucaro deposit were digitized under Microlynx. Each geological unit (e.g. Orebody III) was digitized as closed polygon (perimeters). The perimeters are then used in the geological modelling of the deposit.

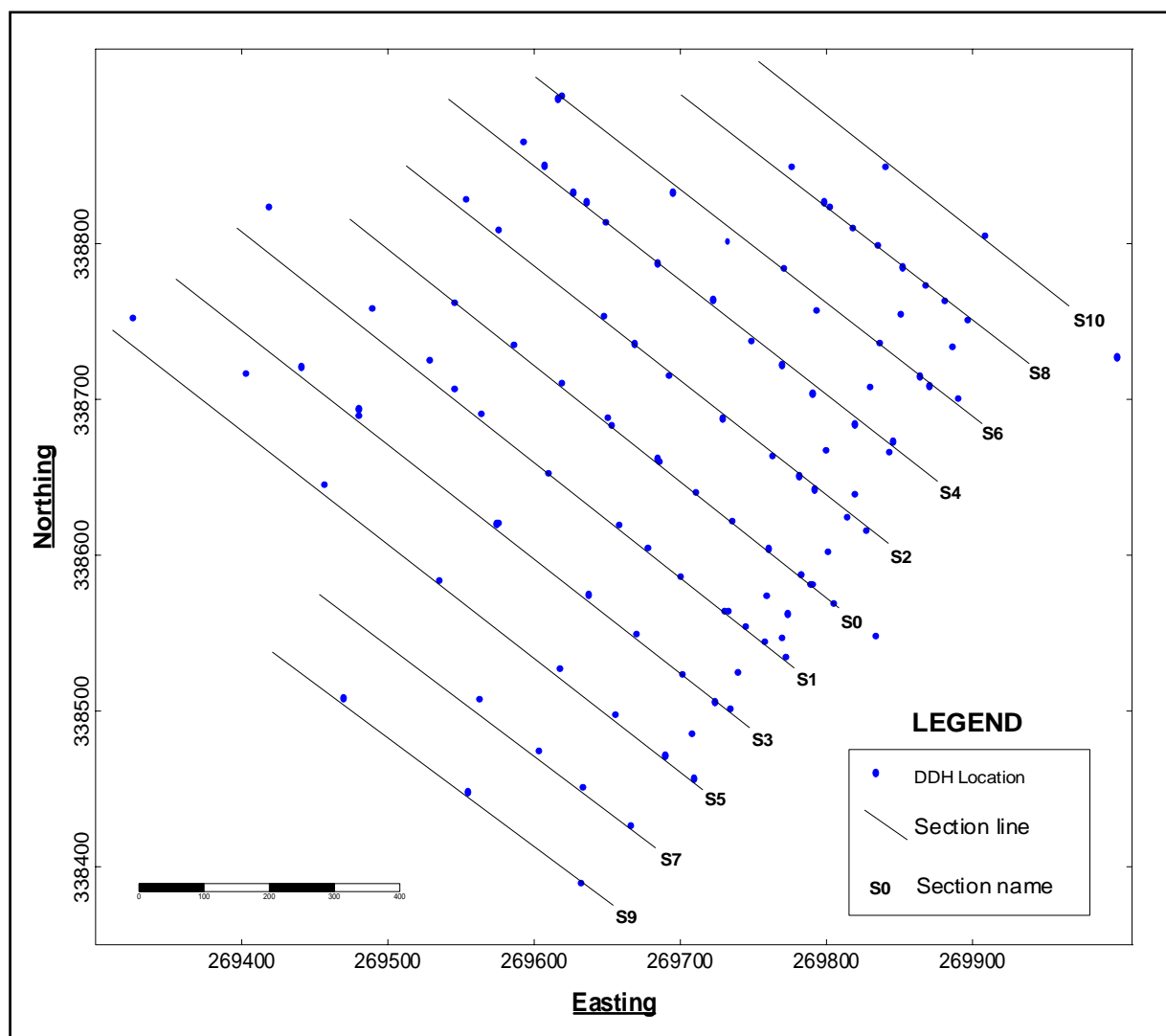


Figure 3.3 General layout of the main geological cross sections

The cross sections are oriented normal to the strike of the deposit (NE 40°-60°) therefore they are oblique to the coordinate system (fig 3.3). To facilitate the generation of section plots, geological and resource modelling, the coordinate system was transformed into a new system so that the new north is parallel to the direction of cross sections (SE 128°).

The steps involved in the coordinate transformation and the cross sections layout in the transformed coordinates system are shown in appendix 1.

3.2.2 Statistical and Geostatistical Analysis

This step is carried out in order to establish the characteristics and spatial relations of the dataset. The statistical analysis includes the calculation of summary statistics, production of histograms of the raw and composite data and the examination of normality. The analysis was performed in Microlynx and Excel.

The variography aims at investigating the spatial behavior and the continuity of the mineralization. The study rests on the calculation and modeling of variograms. The variograms for Cu and S were calculated in three directions: downhole, horizontal NS (across the strike) and horizontal EW (along the strike). The anisotropy of the mineralization was analyzed comparing the variograms estimated in different directions.

3.2.3 Geological modelling

The aim of this step is to create a 3d geometric model of the Jucaro deposit which represents the position and shape of a geological unit, e.g., Orebody III. This model was used to control the resource modeling.

Microlynx supports the following two methods of modelling geology.

- The linked-slice method, which is based on series of parallel equally spaced sections. The perimeters are digitized over the orebody, then the perimeters in adjoining section are linked together into a solid interpretation of each zone by defining manual links at the points of inflection. This is followed by the wireframe model to build a full 3D model from the digitized sections.
- The surface method is based on the generation of two surfaces containing the geological unit being modeled. Surfaces (hangingwall and footwall) are triangulated from known data points.

Both methods were used for 3d modelling of Orebody III.

3.2.4 Resource Modelling and grade estimation

In the resource modelling the grade, the tonnage and the contained metals are estimated on the basis of the previous 3D-orebody model and estimation techniques. Two main methods are offered within Microlynx for resource modelling: block modelling and grid modelling. The selection of the resource modelling type depends on the morphology, geometry and grade distribution of the orebody.

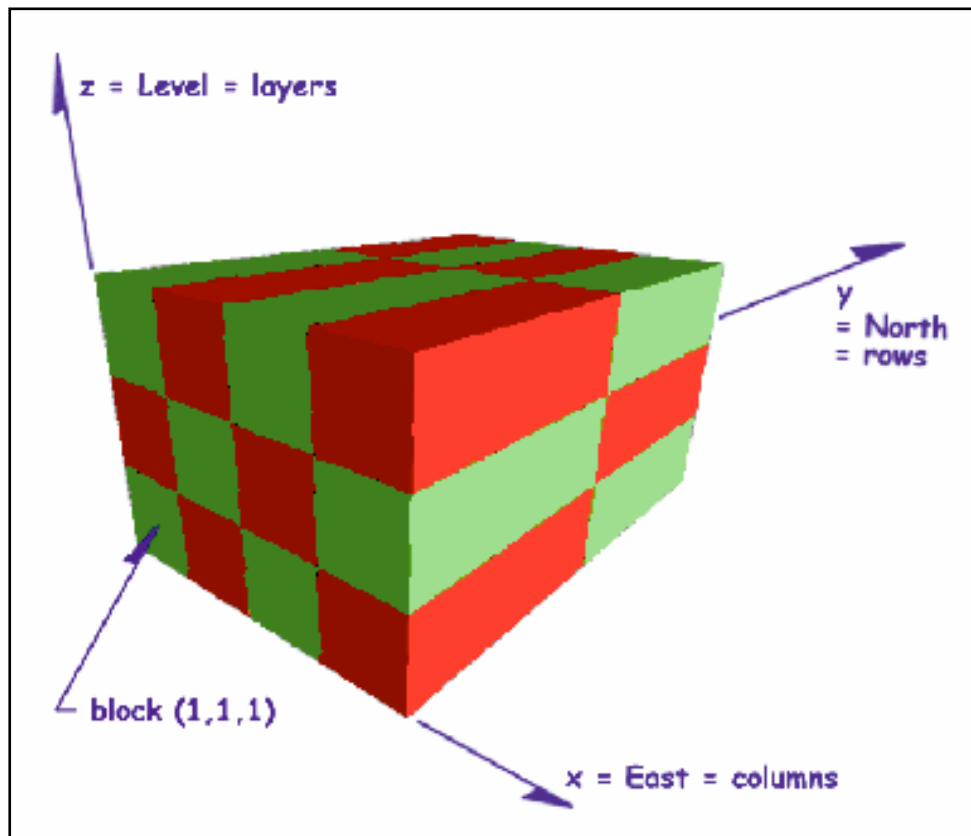


Figure 3.4 Showing a simple block model having 2 rows, 4 columns, and 3 layers of blocks

The block model consists of a series of regular cuboidal cells, stacked contiguously in three dimensions to encompass a volume in space (fig 3.4).

The block size should reflect the selective mining unit to be used and should also be small enough to allow accurate definition of the shape of the orebody. This model is suitable for massive and disseminated deposits.

The grid model is very similar to the block model, in that it consists of a series of cuboidal cells, which have regular sizes in two dimensions and are stacked contiguously in those two dimensions. The third dimension of each cell is variable in both position and extent. Together, the cells describe a volume in space. The model is illustrated in figure 3.5.

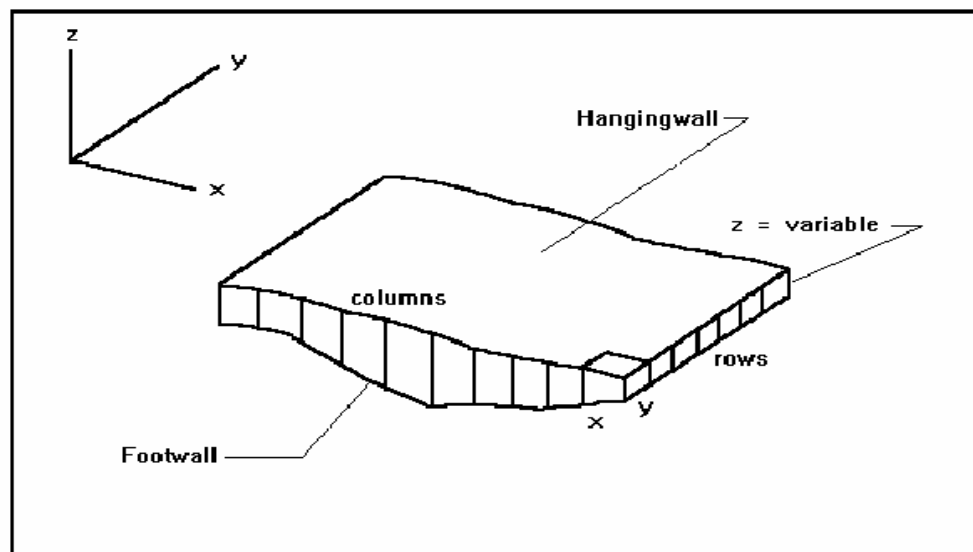


Figure 3.5 Showing the grid model (MicroLYNX98)

The grid model is most suited to a tabular deposit where the transverse dimension of the orebody is small compared to its lateral extents and the variation of grade across the deposit is either unimportant or not able to be determined. In this research the grid model was used to estimate the reserves of Orebody III regarding the lenticular shape of Jucaro deposit.

Finally the grade values within each grid cell are estimated using the techniques available in Microlynx namely: triangulation, inverse distance weighting and kriging. The estimated resource results can be tabulated in standard format and displayed in 2d planes and 3d space.

3.2.5 Generation of grade – tonnage curves

These curves are very important because they can tell at glance exactly how much ore exists above a certain cutoff grade and how the change of cutoff grade affects the tonnage and the contained metal. The curves were generated in Excel and the procedure is thoroughly explained in chapter 6.

4 CHAPTER 4 STATISTICAL AND STRUCTURAL ANALYSIS

4.1 General

A sound exploratory data analysis, aimed at revealing the characteristics and relations between data, is the necessary first step in any evaluation exercise. It includes the calculation of descriptive statistics, the construction of histograms and cumulative frequency curves, which give illumination into the type of the statistical distribution of data, the identification of the presence of complex populations, which may represent different geological zones, and the identification of outliers.

On the other hand, the structural analysis is a useful technique to characterize the spatial variability inherent in most mineralization and to identify the principal directions of continuity (anisotropy). The variography comprises the estimation, modelling and interpretation of the variograms.

Both raw data and composite data of copper and sulphur were used for the statistical analysis. The structural analysis was carried out using only the composite data of the two elements.

4.2 Raw data

In order to take into consideration the geology of Jucaro deposit the statistical analysis was undertaken separately for the two orebodies. The deposit (Orebodies I and III) was also statistically characterized since it is generally accepted that initially both bodies formed a single orebody disrupted by later tectonism. In addition, so as not to mix data with different support, the drillhole data and the channel data were also treated individually. The results obtained are summary statistics, histograms, probability plots and scatter plots.

4.2.1 Univariate statistics

The univariate statistics of the whole database are summarized in tables 4.1 and 4.2

Table 4.1 Descriptive statistics for copper and sulphur based on drillhole data.

	Jucaro Deposit		Orebody I		Orebody III	
	Cu(%)	S(%)	Cu(%)	S(%)	Cu(%)	S(%)
No of samples	2556	2350	1134	872	1422	1478
Minimum	0.01	0.01	0.01	0.01	0.01	0.01
Maximum	24.88	55.78	21.45	41.92	24.88	55.78
Mean	1.08	10.20	1.08	8.18	1.08	10.68
Variance	5.10	105.24	4.86	55.70	5.29	130.69
St. error of mean	0.05	0.21	0.07	0.25	0.06	0.30
Skewness	4.30	1.61	3.83	1.67	4.63	1.41
Kurtosis	24.33	2.28	18.53	3.24	28.22	1.29
Coef. of Variaton	2.08	1.00	2.03	0.91	2.12	1.00
Geom. Mean	0.28	5.47	0.27	4.99	0.29	5.77
Log variance	2.87	1.85	2.96	1.36	2.79	2.14
Log estim. of mean	1.19	13.81	1.20	9.87	1.18	16.78

Table 4.2 Descriptive statistics for copper and sulphur based on channel data.

	Orebody III	
	Cu(%)	S(%)
N° of samples	103	97
Minimum	0.08	0.80
Maximum	14.64	45.59
Mean	2.15	13.68
Variance	6.99	127.57
St. error of mean	0.26	1.15
Skewness	2.20	1.23
Kurtosis	5.49	0.67
Coef. of Variation	1.23	0.83
Geom. Mean	1.13	9.67
Log variance	1.38	0.78
Log estim. of mean	2.28	14.25

The summary statistics provide measures of location, shape and symmetry of the distribution of the data values. It is obvious from the tables above that the distributions of both elements for the different subsets are positively skewed, having a long tail of high values. The positive skewness and the coefficient of variation (c.v.)

support this point, in addition the fact that c.v. is greater than 1 also indicates the presence of erratic high values (potential outliers), which may have some impact on the production of variograms and the final resource estimation. Often positively skewed data reflect the mixing of populations or grade classes; therefore all subsets are to be checked for potential multi modality.

The average grade and the variance of copper for both orebodies are very similar (table 4.1) but sulphur is more abundant and variable in Orebody III. Similarly the channel data subset presents higher average copper grades and much low sulphur grade than the corresponding drillhole data.

4.2.2 Histograms and probability plots

The frequency histograms and probability plots graphically illustrate how the data are distributed in the deposit and allow testing of whether sample populations in the data set conform to normal or lognormal distributions. The histograms were constructed for the original and transformed (natural logarithm) data. Histograms and probability plots for Cu and S in the whole deposit (Orebodies III and I) and in each orebody are presented in figures 4.1, 4.2, and 4.3.

The histograms of untransformed Cu and S grades illustrate that the data are strongly skewed. The histograms and probability plots of the transformed data are rather symmetric although the marked changes from one class to another, and the presence of inflexion points (breaks) in the cumulative frequency curves, indicate the mixing of several populations (multimodality).

A detailed study of the cumulative frequency curves of Ln (Cu) for each subset is presented in the Appendix 2. The break of the distributions at 0.3% Cu (Jucaro deposit and Orebody I) and 0.5 % Cu (Orebody III) gives ground for the subdivision of the data into two more or less homogeneous populations; in addition 0.3% and 0.5% Cu are two of the cutoff grades used in the mine to outline the outer limits of the deposit. In our case 0.32 % Cu is used to delimit the extension of mineralization. The first population (Cu >0.32%) comprises the mineralized zone and the second one is

the hydrothermal alteration zone that surrounds the high-grade zone. Consequently the further analysis is focused only on the mineralized zone.

The histograms and the probability plots of the mineralized zone itself are shown in figs 4.4-4.6 and the summary statistics are presented in Appendix 3. These figures depict more symmetric histograms of the transformed data and the cumulative frequency curves approximate a straight line, although some inflection points are again present. The existence of different types of ore (disseminated, massive, etc) within the deposit may explain the breaks in the probability plot. However these probable subpopulations do not prove to be spatially coherent, are mixed in many places and are not easily separable. Therefore it was decided not to split further the mineralized zone.

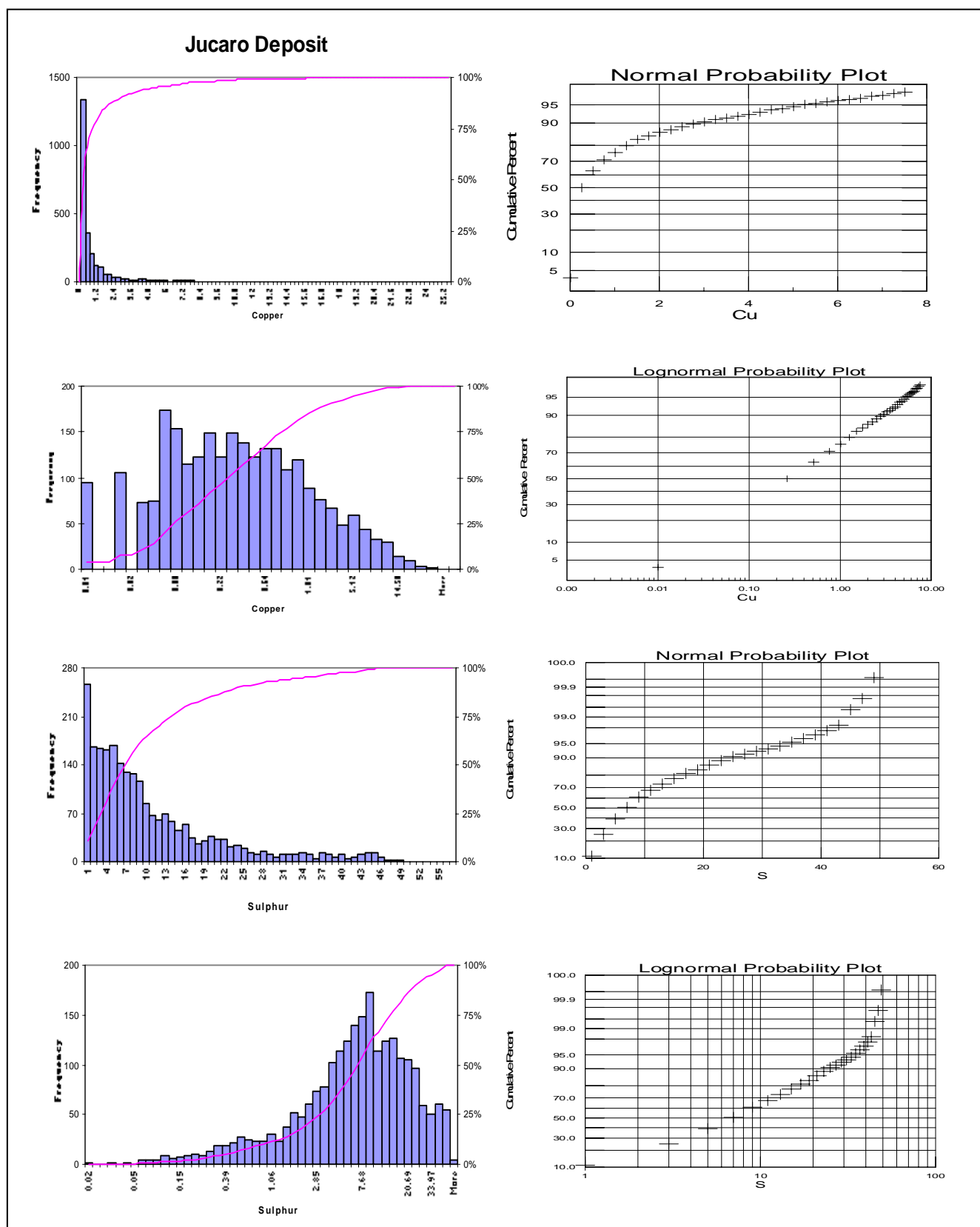


Figure 4.1 Histograms and probability plots of Cu (%), \ln (Cu), S (%) and \ln (S) of the whole Jucaro deposit

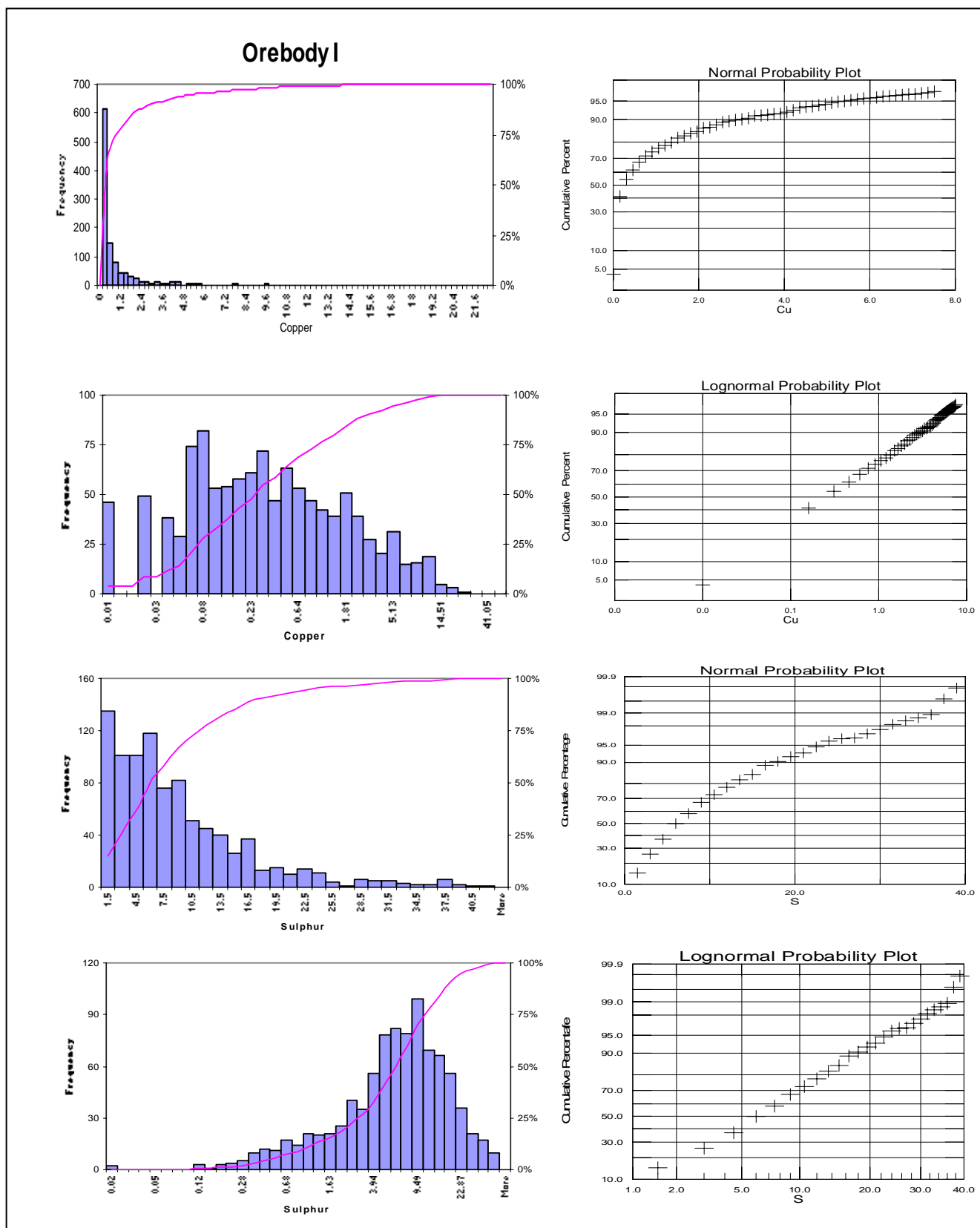


Figure 4.2 Histograms and probability plots of Cu (%), $\ln(Cu)$, S (%) and $\ln(S)$ of Orebody I

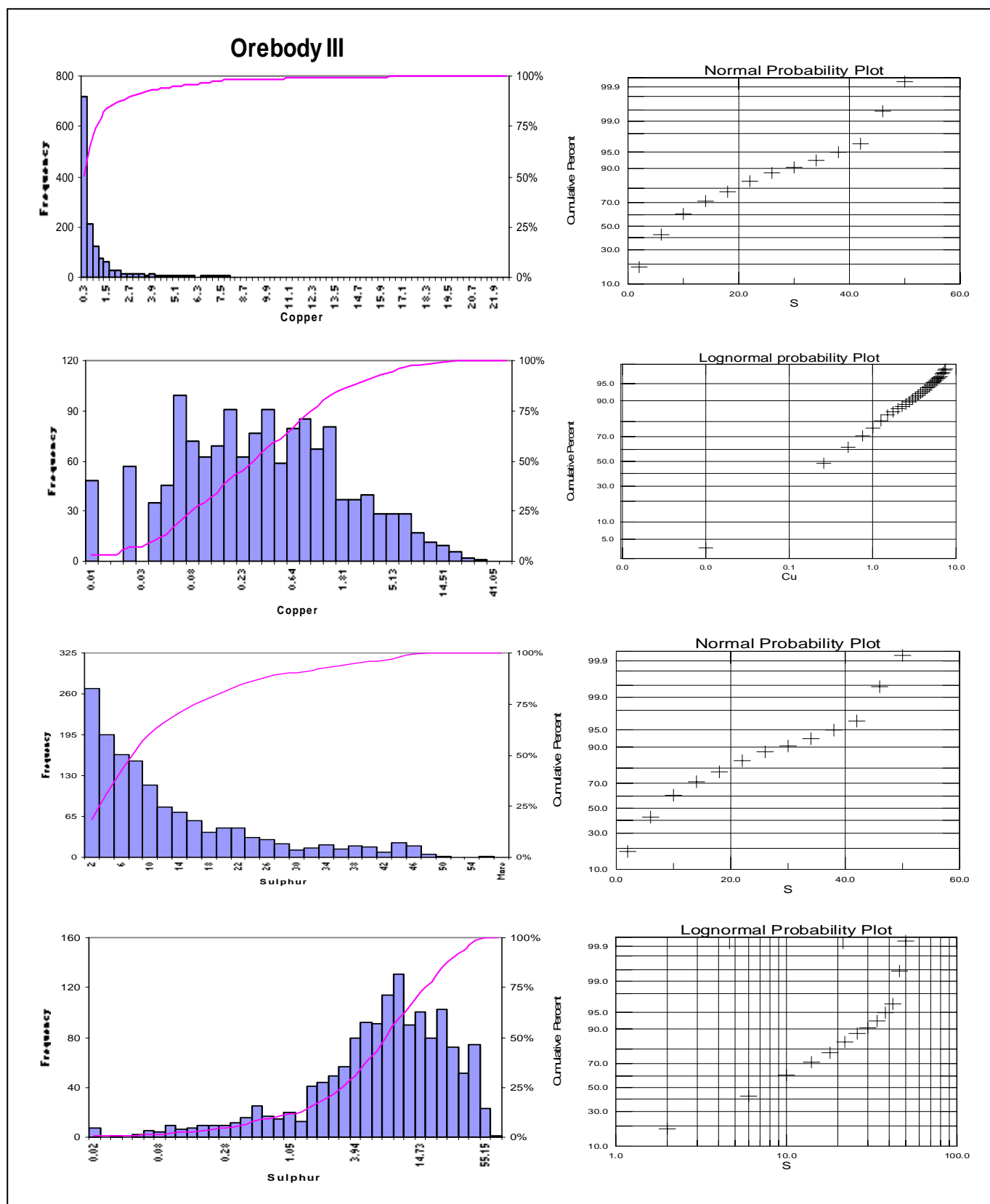


Figure 4.3 Histograms and probability plots of Cu (%), \ln (Cu), S (%) and \ln (S) of Orebody III.

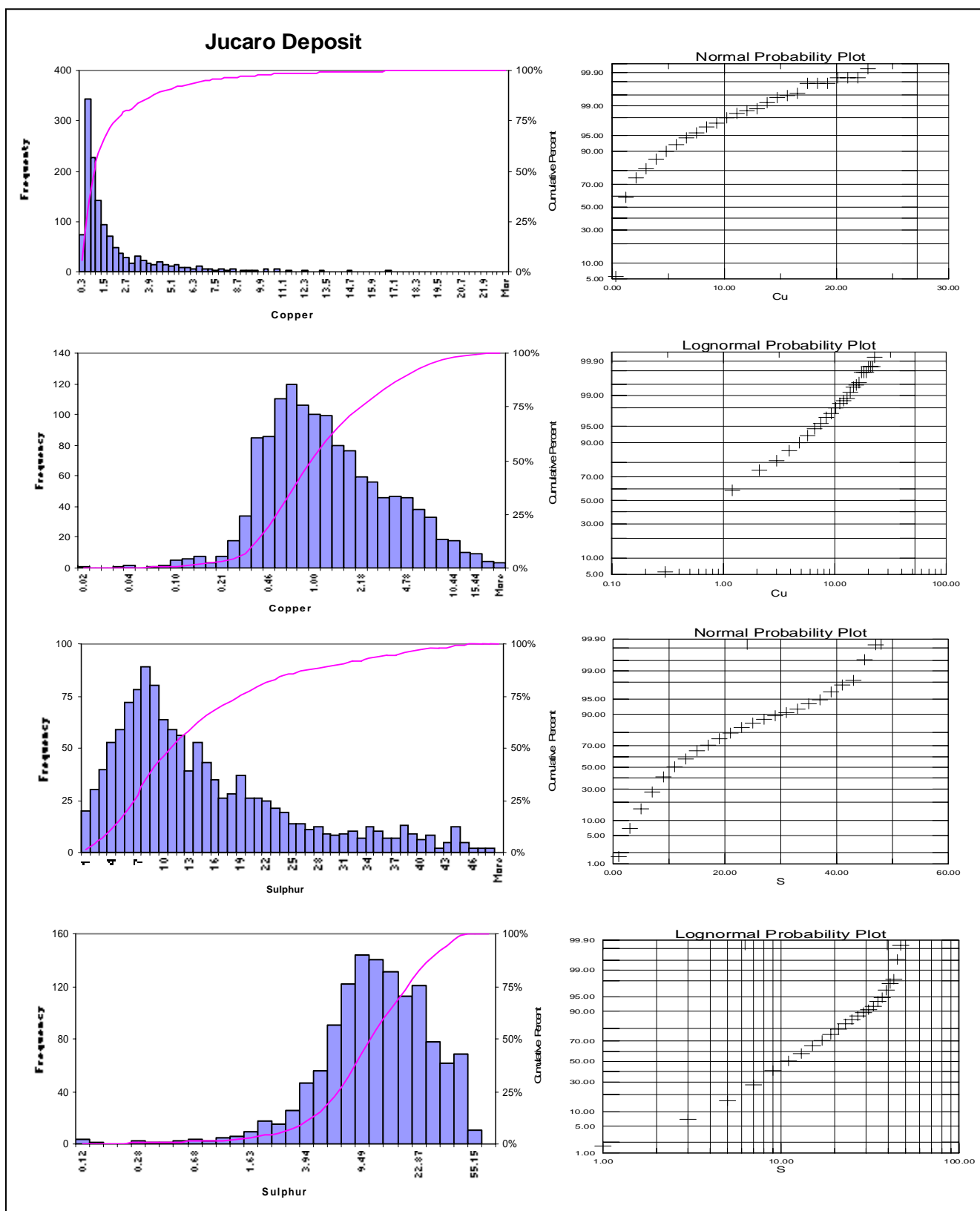


Figure 4.4 Histograms and probability plots of Cu (%), \ln (Cu), S (%) and \ln (S) of the whole Jucaro deposit (mineralized zone)

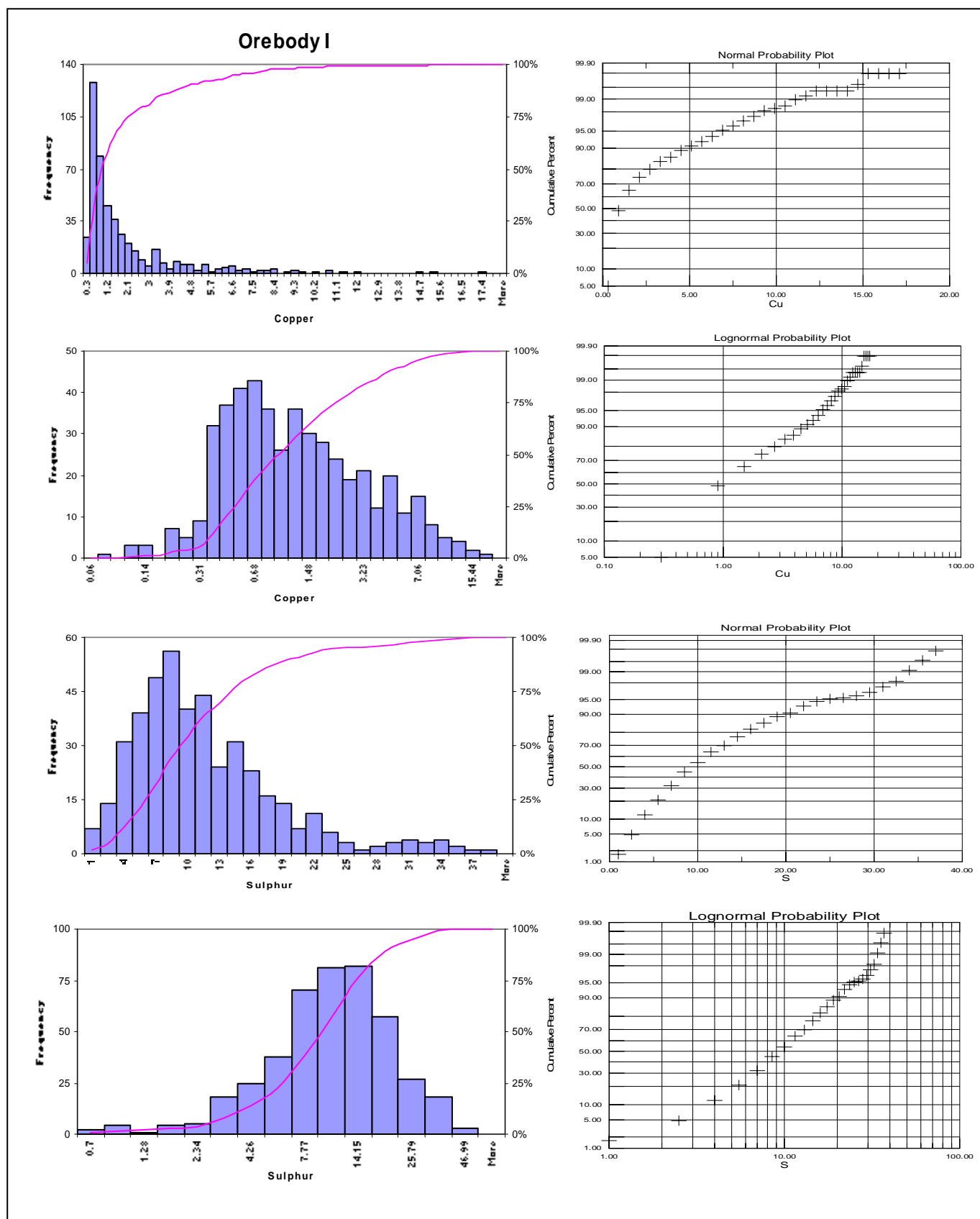


Figure 4.5 Histograms and probability plots of Cu (%), $\ln(Cu)$, S (%) and $\ln(S)$ of Orebody I (mineralized zone).

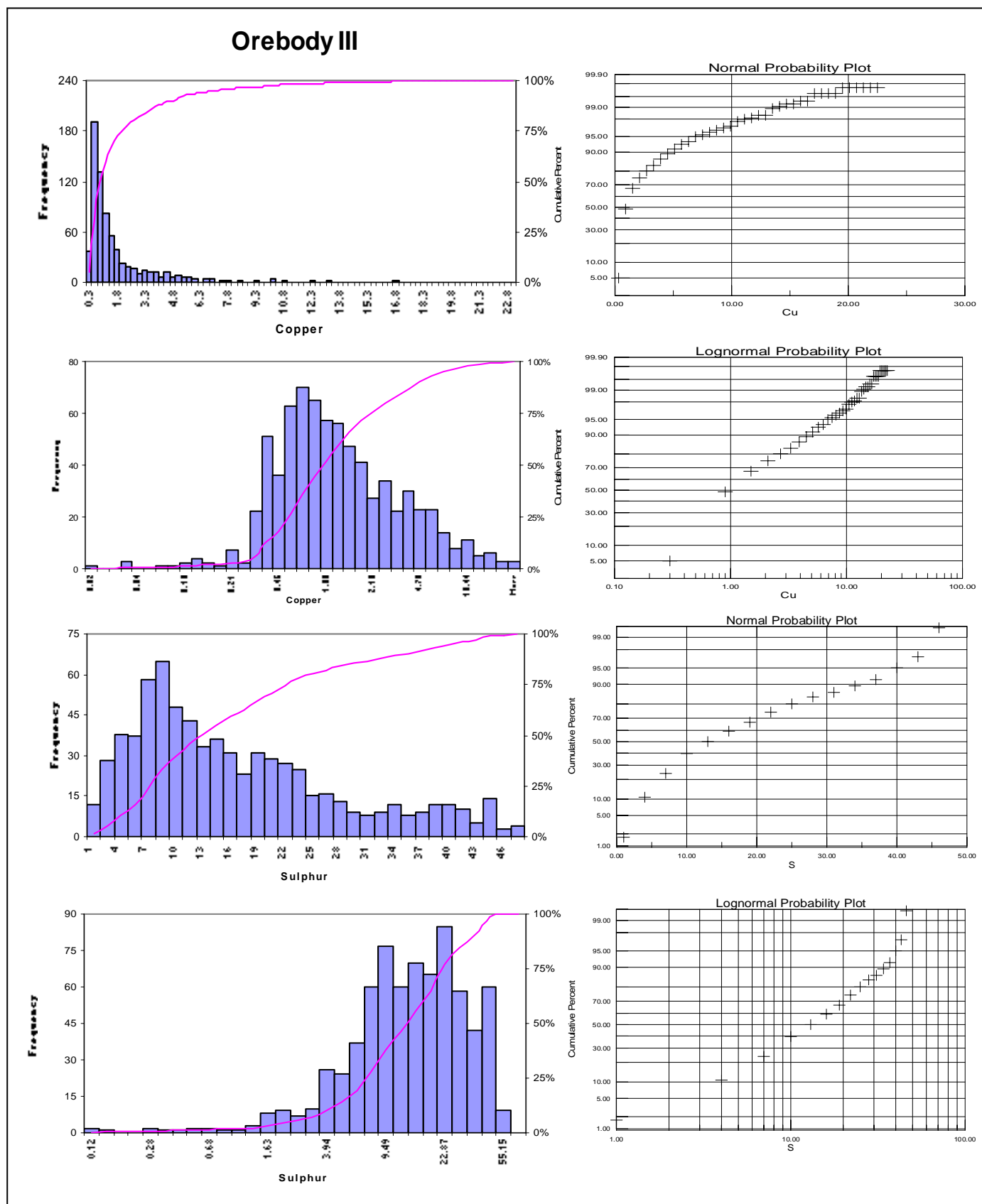


Figure 4.6 Histograms and probability plots of Cu (%), $\ln(Cu)$, S (%) and $\ln(S)$ of Orebody III (mineralized zone).

4.3 Drill hole composites

Sample compositing is a process whereby drillholes are divided into intervals that are different to the original field sample intervals. For each new interval, the numerical sample values are computed as the mean of the values of the original field sample intervals, weighted by their original length.

There are several different methods of sample compositing: downhole (collar), bench and geological.

- Downhole compositing – drillhole samples are combined into regular down hole intervals, starting at the hole collar.
- Bench compositing – drillhole samples are regularized into intervals that coincide with level bench elevations.
- Geological compositing – samples are combined in such a way that geological boundaries are preserved within the composites; applied in order to reflect geological or mining constraints.

For this project geological compositing was selected in order to restrict the regularization process within the mineralized zone. The composite interval (1m) was selected on the basis of average sample length (0.98m) and minimum mining thickness of 1m. The composite data are used for the volume modelling and structural analysis.

4.3.1 Univariate statistics

The univariate statistics of the drillhole composite data are summarized in table 4.3. The results are comparable to those of the raw data (see appendix 3) only the variances are different for all subsets, the 1m composite variances being lower than the raw ones. This is explained by the increase of the support size (smoothing effect).

The channel sample compositing is not presented here since the channel samples were taken exactly every 1m thus the statistics are the same as for the channel raw data.

Table 4.3 Descriptive statistics for copper and sulphur based on composite data from the mineralized zone.

	Jucaro Deposit		Orebody I		Orebody III	
	Cu(%)	S(%)	Cu(%)	S(%)	Cu(%)	S(%)
No of samples	1220	1159	479	436	741	723
Minimum	0.02	0.10	0.07	0.10	0.02	0.11
Maximum	22.82	47.59	17.40	38.00	22.83	47.59
Mean	1.92	14.06	1.87	10.89	1.95	15.97
Variance	6.71	105.66	5.46	48.72	7.54	130.37
St. error of mean	0.07	0.30	0.11	0.33	0.10	0.42
Skewness	3.34	1.18	2.78	1.31	3.52	0.90
Kurtosis	15.06	0.83	9.91	1.93	16.25	-0.05
Coef. of Variation	1.35	0.73	1.25	0.64	1.41	0.71
Geom. Mean	1.09	10.44	1.10	8.76	1.09	11.59
Log variance	1.04	0.76	1.00	0.54	1.08	0.86
Log estim. of mean	1.85	15.23	1.82	11.48	1.87	17.77

4.3.2 Histograms and probability plots

Histograms and probability plots of untransformed and transformed Cu and S data were drawn using the 1m composite data. The results indicate that both elements can be treated, as lognormal distributions (Figs 4.7-4.9) although some breaks are present in the cumulative frequency curves of Cu and S, which may indicate the presence of a complex population.

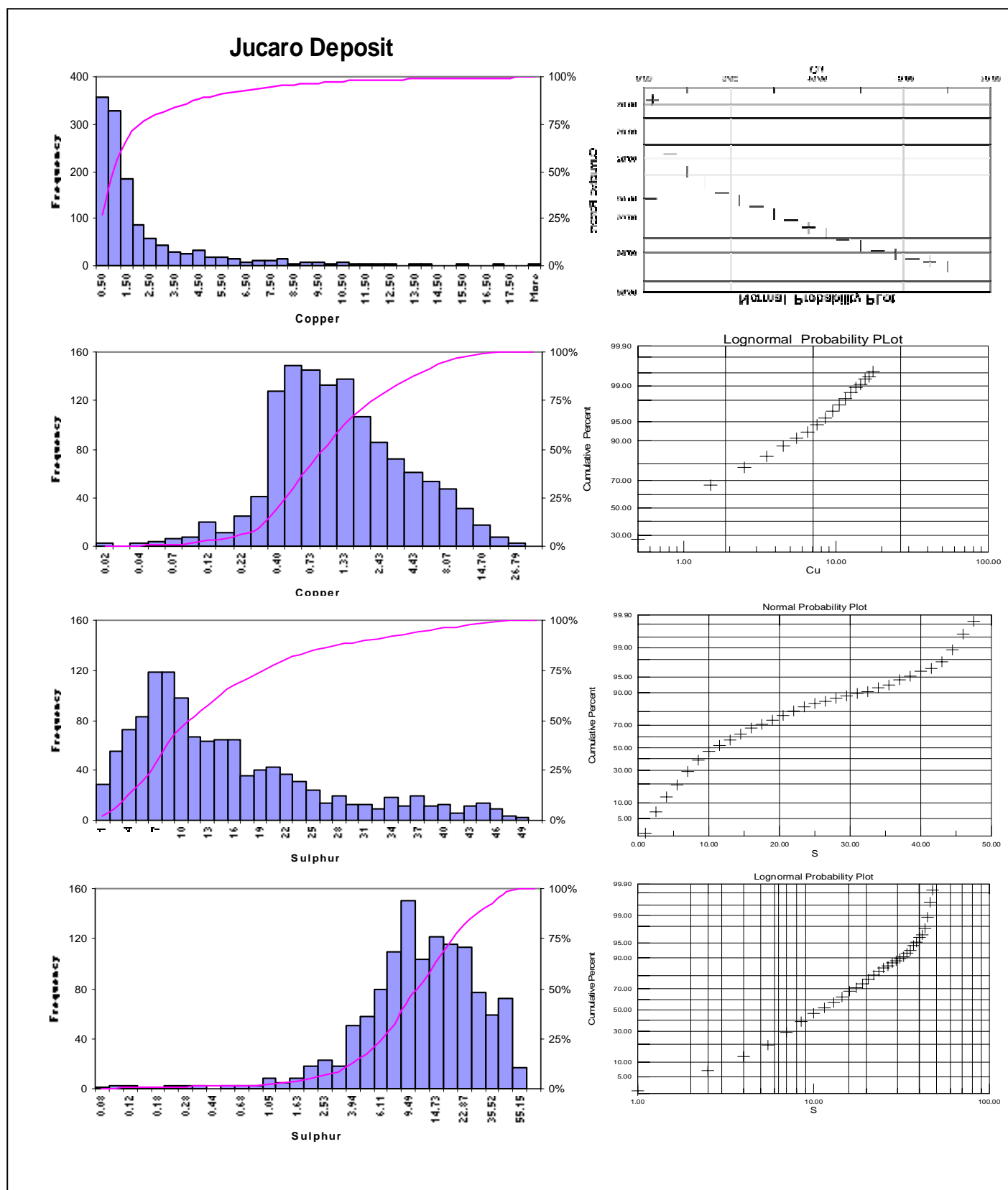


Figure 4.7 Histograms and probability plots of Cu (%), $\ln(Cu)$, S (%) and $\ln(S)$ of the whole Jucaro deposit (1m composite data from the mineralized zone).

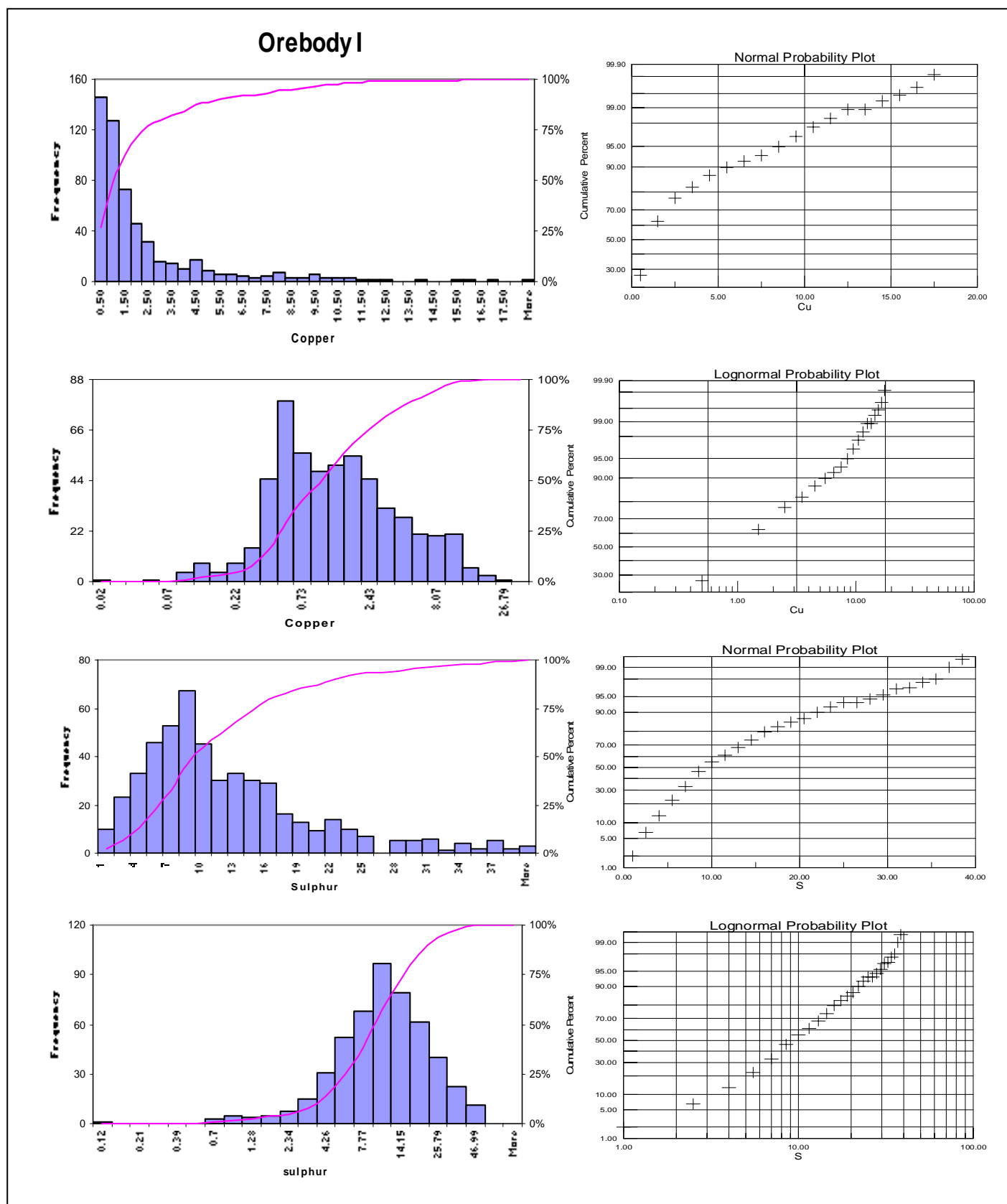


Figure 4.8 Histograms and probability plots of Cu (%), \ln (Cu), S (%) and \ln (S) of Orebody I (1m composite data from the mineralized zone).

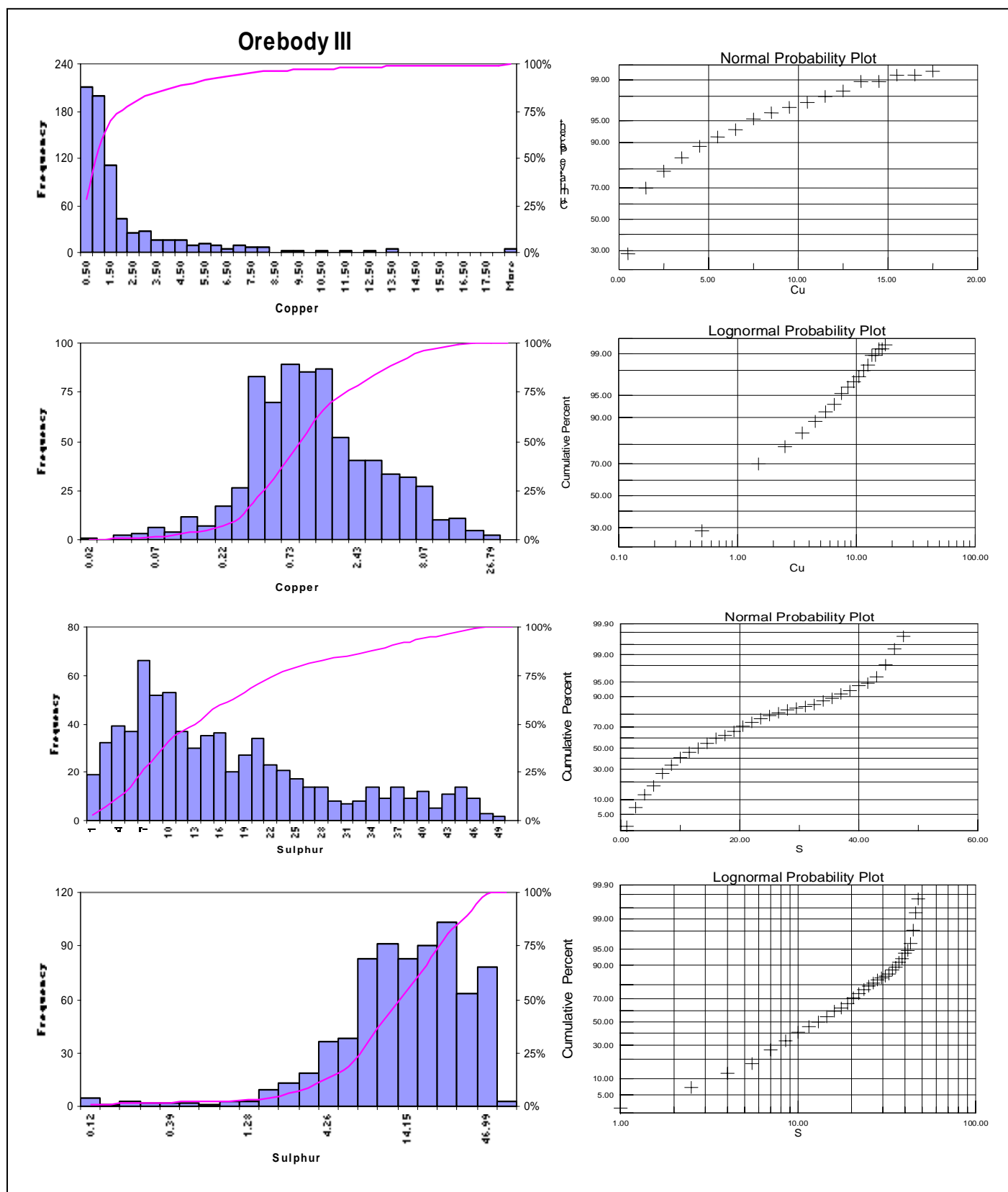


Figure 4.9 Histograms and probability plots of Cu (%), \ln (Cu), S (%) and \ln (S) of Orebody III (1m composite data from the mineralized zone).

4.4 Correlation analysis

The correlation analysis aims at identifying possible statistical relationships between two variables. The variables can be positively correlated, negatively correlated, or uncorrelated. The Pearson correlation coefficient (ρ) is the most commonly used statistic to summarize the linear relation between two variables. It ranges from -1 (negative correlation) to $+1$ (positive correlation); when ρ is close to zero variables are not related.

The raw data of the mineralized zone for the whole Jucaro deposit is used for the correlation analysis. As both Cu and S are lognormally distributed the log-transformed values were plotted to construct the scattergram.

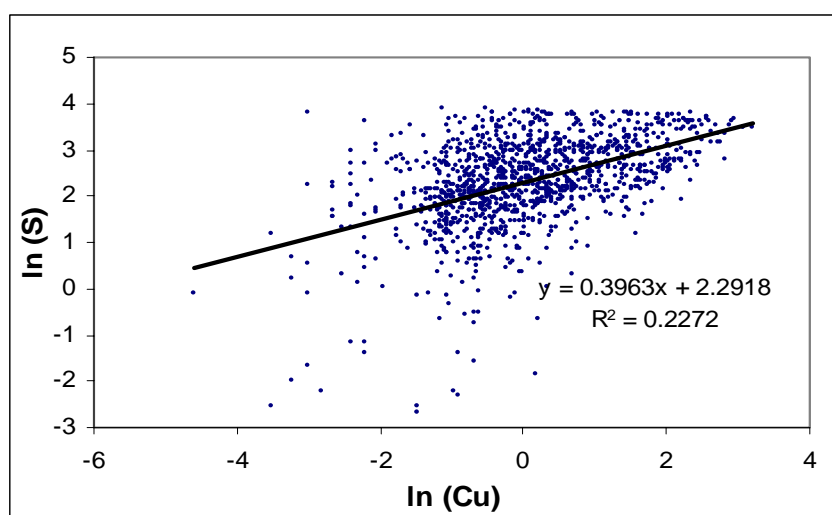


Figure 4.10 Scatterplot of ln S vs. ln Cu of the mineralized zone

The correlation coefficient is 0.48 (fig 4.10), indicating a very weak relationship between Cu grade and S grade. This is typical for Cyprus type deposits where pyrite is the most abundant mineral. The calculated coefficient is significant at 99 % confidence level. The scatterplot also shows an upper limit for sulphur grade (there is no sulphur grade greater than 55% S); this is interpreted as a mineralogical barrier.

4.5 Structural analysis

The aim of this study is to analyze and quantify the spatial variability of mineralization, and to identify the main directions of continuity through the production and modelling of variograms. A variogram is a graph describing the expected difference in values between pairs of samples with a given relative orientation (Clarke, 1982).

Since the data for geostatistical analysis should be drawn from a geologically homogeneous population, several attempts were made to split the mineralized zone into different single subpopulations on the basis of histograms and cumulative frequency curves. The entire attempt to separate the mineralized population at different cutoffs (1.5% and 4% Cu) failed, as the subpopulations do not prove to have any spatial integrity. In other words different ore types are mixed up all over the deposit and it is not possible to separate them at core sample scale.

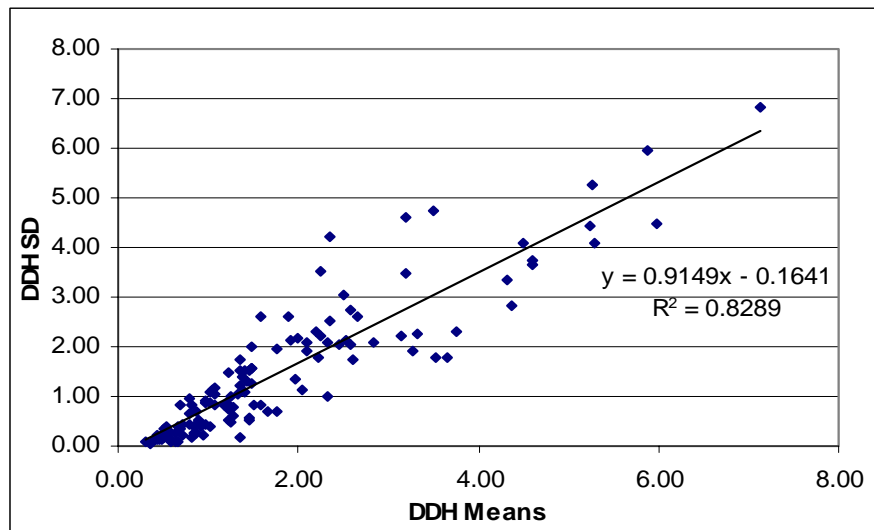


Figure 4.11 Scatterplot of local means vs. local standard deviations.

As the data are lognormally distributed, copper grade was checked for the presence of the proportional effect (relationship between the local mean and the local standard deviation). The scatterplot of the mean and the standard deviation for each drillhole

(fig 4.11) confirms that a proportional effect exists. The relationship is linear and the correlation coefficient is equal to 0.92. The relative variograms were used throughout this study in order to take account of the presence of the described effect.

Three directional variograms were calculated: N-S (Downdip-180⁰), E-W (along the strike-90⁰) and downhole. These directions refer to the transformed coordinate system. The analysis was carried out for the whole deposit and for each separate orebody. The lag spacing was selected on the basis of the average drillhole spacing (50m for the whole deposit and Orebody III and 25m for Orebody I); the downhole variogram was calculated using a lag of 1m (composite sample length) and an angular tolerance of 30⁰. The parameters of the calculated variograms are shown in table 4.4.

Table 4.4 Main parameters used in the calculation of directional variograms.

	Direction	Dip (degree)	Lag(m)
Orebody I	Downdip(180 ⁰)	50	25
	Along strike (90 ⁰)	50	25
	Downhole (0 ⁰)	70	1
Jucaro deposit and Orebody III	Downdip(180 ⁰)	40	50
	Along strike (90 ⁰)	40	50
	Downhole (0 ⁰)	70	25

The relative experimental variograms with fitted models for copper and sulphur grades in the Jucaro deposits are shown in figures 4.12 and 4.13. The downhole variograms for both elements revealed a clear spatial structure with a range of about 6m. On the other hand the variograms calculated in the plane of the orebody showed no spatial correlation. They behave as a pure nugget effect. The spatial structure on the plane of the deposit, if it exists, might have a range smaller than the drillhole spacing (25 m), so a spherical model with a range of 15m was chosen to model the empirical variograms. The results for Orebodies I and III are very similar to those of the whole deposit and are presented in Appendix 4; however, the variograms of Cu in Orebody I and S in Orebody III are very erratic and difficult to interpret.

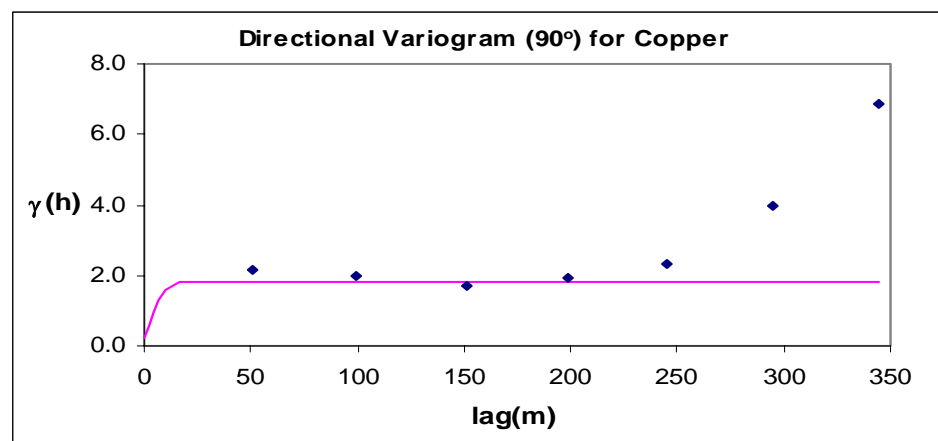
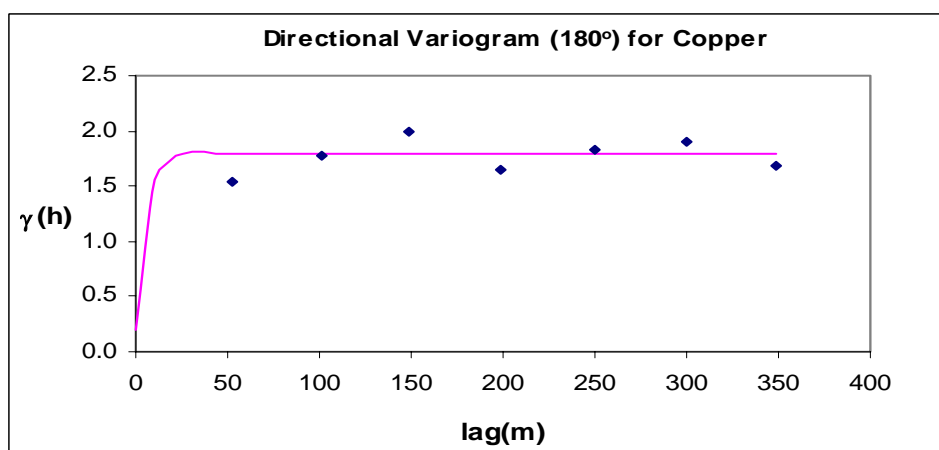
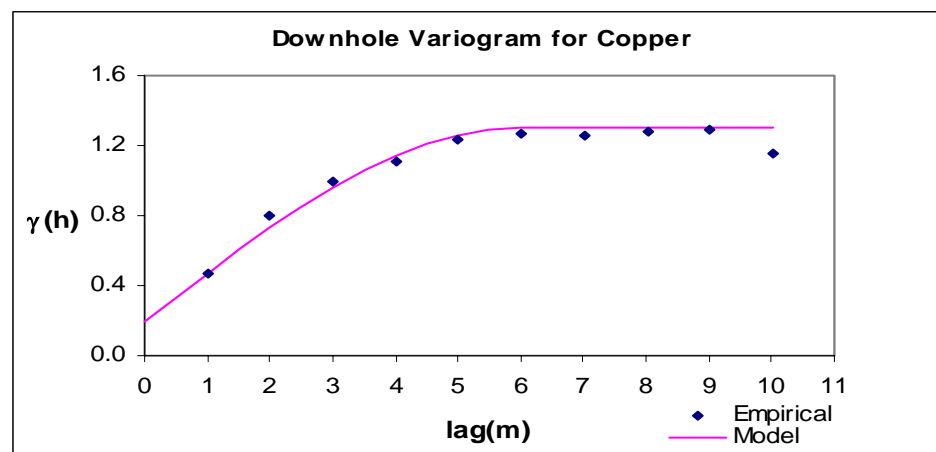


Figure 4.12 Relative variograms for copper in the Jucaro deposit

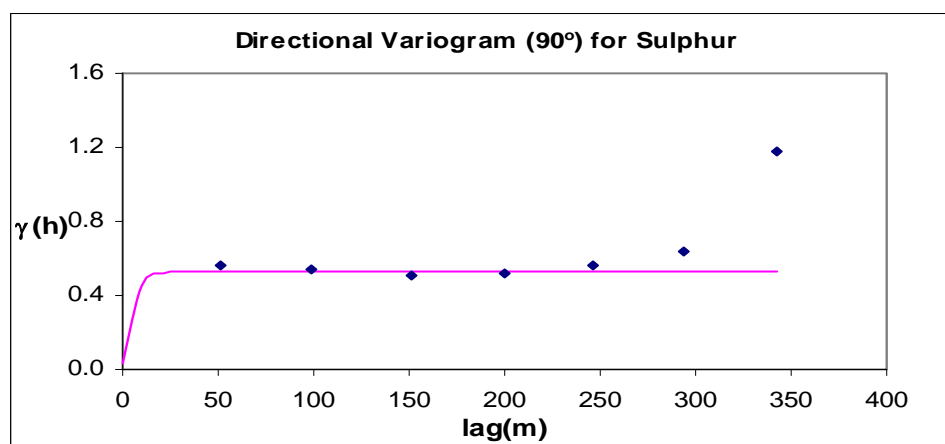
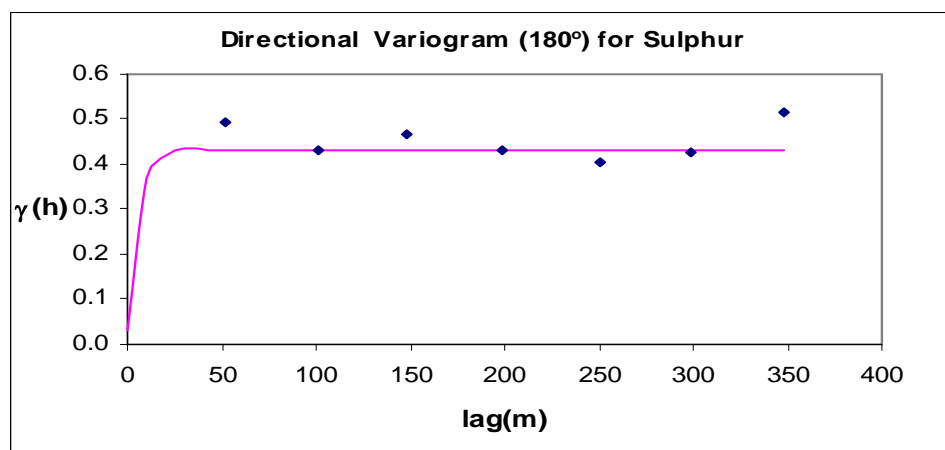
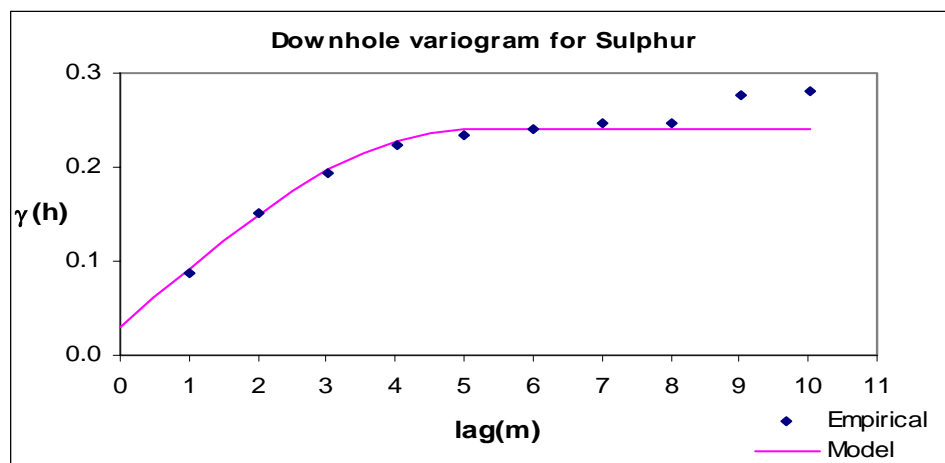


Figure 4.13 Relative variograms for sulphur in the Jucaro deposit

An indicator approach was used to enhance the existing spatial correlation and to deal with the erratic nature of the directional variograms in the deposit. The copper grade was transformed using an indicator function $i(x, z)$, which is based on the grade of a sample point $z(x)$ and on a selected indicator cutoff grade (COG).

$$i(x, z) = \begin{cases} 1, & \text{if } z(x) \geq \text{COG} \\ 0, & \text{if } z(x) < \text{COG} \end{cases}$$

Indicator COGs of 1.5 % and 4% copper were selected based on the analysis of the probability plots (Appendix 2). After several trials the 4% COG was discarded as it failed to produce any interpretable structure.

The indicator variograms for copper in the deposit are depicted in fig. 4.14. The same spatial relationship is expressed by the downhole variogram; the other two directional variograms did not produce any improvement in this study. The indicator variograms for Orebody I and III (Appendix 5) fail to reveal any spatial autocorrelation in the plane of the orebodies; however they are more stable and amenable to interpretation. The indicator approach confirmed the absence of a spatial relation between samples in both the dip and strike directions.

The results of the variography are consistent with the observed high variability of copper and sulphur grades in the Jucaro mine, which is caused by the complex tectonic distortion of the deposit. It is believed that the original spatial continuity of the mineralization was destroyed by the postmineralization faulting.

4.6 Conclusions of the statistical and geostatistical analysis

The following conclusions were drawn from the interpretation of the above results.

- In the mineralized zone both sulphur and copper approximately conform to a lognormal distribution

- There is a weak linear correlation between sulphur and copper grades in the deposit
- The spatial structure of copper and sulphur grades have a range shorter than the drill spacing; that is why they are not revealed by the directional variograms calculated in the plane of the deposit

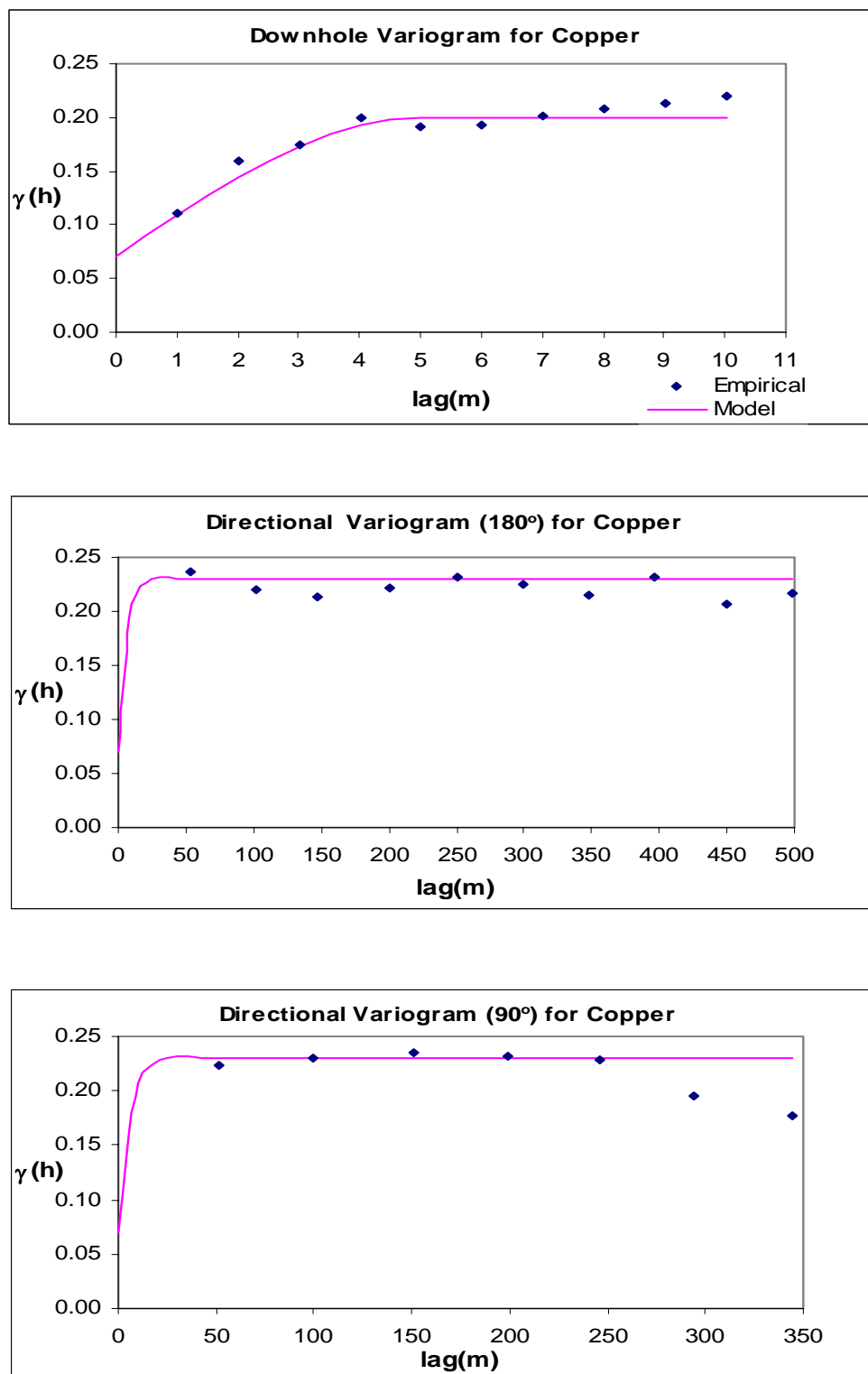


Figure 4.14 Indicator variograms for copper in the Jucaro deposit

5 CHAPTER 5 GEOLOGICAL AND RESOURCE MODELLING

5.1 General

This chapter deals with the creation of geometric and resource (volumetric) models of the Jucaro deposit. The geometric model represents the spatial location and the morphology of the orebodies and is then used to control the resource modelling. Several different methods are described in literature for the 3D geological characterization of mineralized bodies (Sides, 1997). In this case the automatic boundary-fitting methods (surface method) and manual boundary-fitting methods (perimeters method) were used for the modelling.

The surface method is a surface based approach where the geological surfaces (hanging wall and footwall) are automatically derived from a set of points representing intersection of drillholes with the limits of mineralization. Surfaces are initially represented as a series of non-overlapping triangles joining the known data points (triangulated irregular network). A triangulated volume model that matches the dimensions of the surface triangles is then generated between the surfaces.

The perimeters methods is a section based approach where the outline of mineralization (perimeters) is digitized on a series of parallel transverse geological sections and subsequently linked between sections in order to obtain a 3d model of geology.

5.2 Geological modelling

The modelling procedure used can be divided into the following steps:

- Geological sections arrangement
- Creation of geological and grade pattern tables
- Hangingwall and footwall surface model creation
- Perimeter digitizing and creation of solid model
- Hangingwall and footwall surface model creation
- Visualization (2d representation and 3d rendering of the created model)

5.2.1 Geological section arrangement

The primary source of information for the interpretation of the deposit outline is the drillhole data observations. These are displayed in an appropriate format on a set of transverse parallel geological sections that coincide with the original exploration drilling sections (fig 3.3). A total of nineteen cross sections (11 main sections and 8 intermediate sections) was arranged perpendicular to the strike of the deposit, which trends NE (40°-60°). The sections are looking east (east orientation) and the spacing is 25m. The geological cross section arrangement used for the interpretation is depicted in table 5.1 and Appendix 1.

Table 5.1 Cross section arrangement of Jucaro deposit

<u>Section No</u>	<u>Orientation</u>	<u>Z coord</u>	<u>Width +</u>	<u>Width -</u>
Section 10	E	800	12.5	12.5
Section 8	E	850	12.5	12.5
Section 68	E	875	12.5	12.5
Section 6	E	900	12.5	12.5
Section 46	E	925	12.5	12.5
Section 4	E	950	12.5	12.5
Section 24	E	975	12.5	12.5
Section 2	E	1000	12.5	12.5
Section 02	E	1025	12.5	12.5
Section 0	E	1050	12.5	12.5
Section 01	E	1075	12.5	12.5
Section 1	E	1100	12.5	12.5
Section 13	E	1125	12.5	12.5
Section 3	E	1150	12.5	12.5
Section 35	E	1175	12.5	12.5
Section 5	E	1200	12.5	12.5
Section 57	E	1225	12.5	12.5
Section 7	E	1250	12.5	12.5
Section 9	E	1300	12.5	12.5

5.2.2 Geological and grade pattern tables

Before starting the modelling process the geological units (orebodies) to be modelled have to be defined in the system lookup table. The geological unit table consists of a meaningful unit code, followed by a description, density and display color information. A density of 3.49 t/m³ was used, which is the same value as used in previous studies. The color information controls the visualization and plotting of the different units. In this research a geological code was assigned to each orebody that forms the deposit (table 5.2).

Table 5.2 Geological table used in this project










System Table Edit - GEOLOGY					
Text based colour code pattern		GEOLOGY			
LValue	Description	Nib	Hatch	SG	Example
C	OREBODY III	12	1	3.49	
D	OREBODY IIIA	9	1	3.49	
A	OREBODY I	10	1	3.49	
B	OREBODY IA	13	1	3.49	
<div> <div>Insert</div> <div>Delete</div> <div>Export</div> <div>Save</div> <div>Close</div> </div>					

Table 5.3 Grade pattern table used for copper in this project

System Table Edit - COPPER

Numeric based colour code pattern

COPPER

LValue	Description	Nib	Hatch	Example
0	... <= 0	7	1	
0.3	>0.0 ... <=0.3	10	1	
1.5	>0.3 ... <=1.5	11	1	
4	>1.5 ... <=4.0	9	1	
10	>4	12	1	

Insert

Delete

Export

Save

Close

The project also requires a grade pattern table to facilitate the display and interpretation of the interpolated resources. The grade intervals for the two elements modelled (copper and sulphur) were selected based on the cumulative frequency plots (Appendix 2). The grade pattern used for copper in the resource modelling is shown in table 5.3

5.2.3 Hangingwall and footwall surface model creation

After having created the geological and grade pattern tables the next stage of modelling was the generation of a simple geological model using a surface based approach. This first step required some editing of the database in order to simplify the interpretation so as to eliminate the bifurcation of the mineralization (fig 5.1). These bifurcations cause serious problems during the automatic extraction of the hangingwall and the footwall. Those branches that are large enough in terms of ore reserves were treated as a different orebodies (e.g. Orebody 1a) and new names and codes were assigned to them.

Subsequently the automatic extraction of the hangingwall and footwall was undertaken by using **Create surface from sample** function. This function creates a string file containing points, which reside on a specified surface, from the intersection points of the surfaces with the drillholes. In the case of Orebody III the hangingwall and the footwall are defined respectively as the surfaces above and below code C. This code tags the samples belonging to the mineralized zone in Orebody III. The hangingwall and footwall surfaces, represented by points alone, are triangulated within the survey manager thus fully defining the surface. To ensure that string data passed on to the triangulation are suitable and error free the string file is checked for gremlins (e.g. inconsistencies such as duplicates points, segments which cross themselves etc). All the gremlins found were carefully rectified.

The topography of the deposit was represented using the same approach, the only difference being that the spot heights were derived directly from the drillhole collars and then triangulated to model the topographical surface.

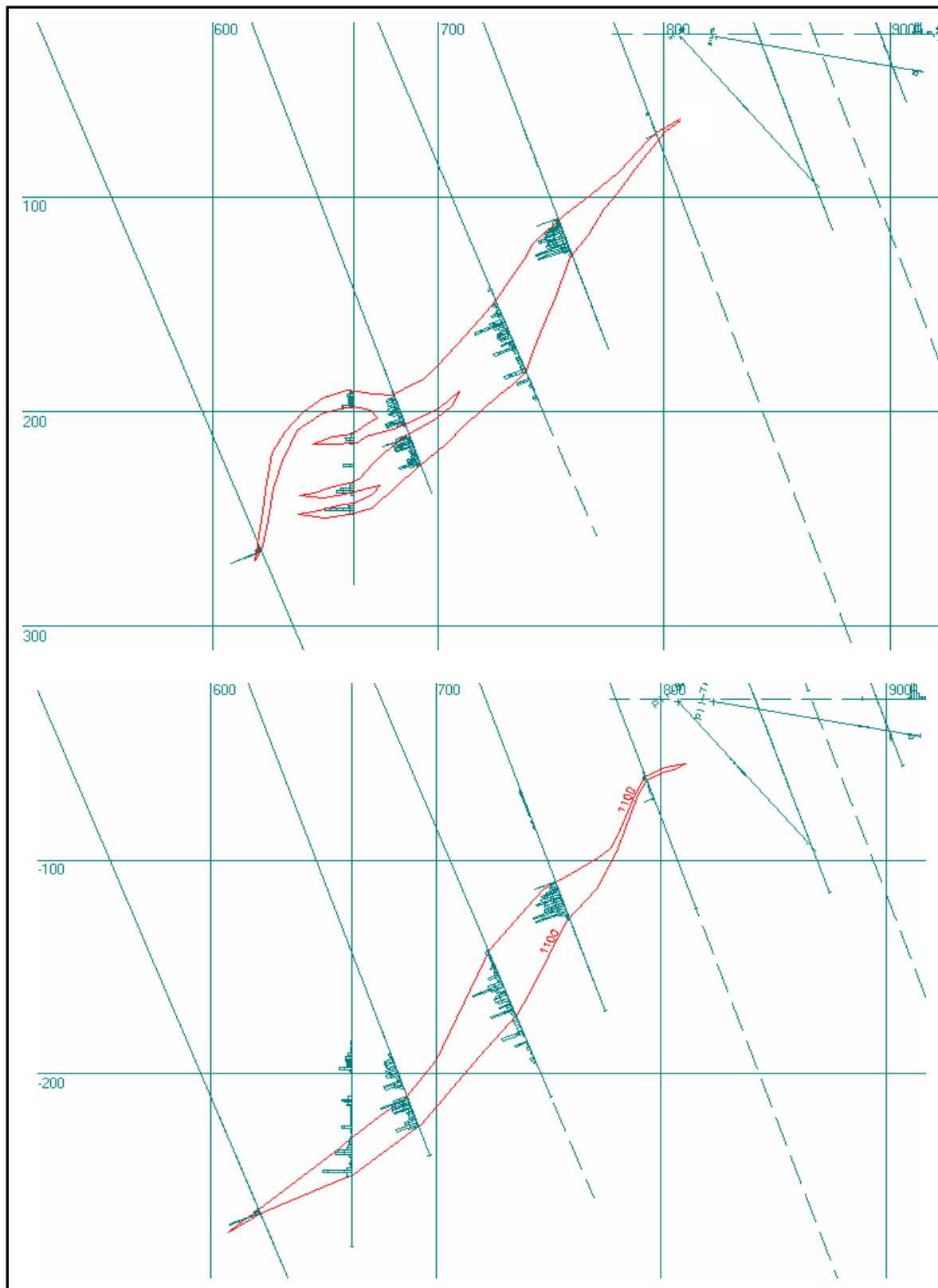


Figure 5.1 Showing the simplification of the morphology of Orebody III by eliminating bifurcations (section 1).

The triangulated hangingwall and footwall were cut by a series of parallel cross sections (25m apart) allowing the calculation of the volume contained between them. The result of this operation is a perimeter [per] file containing the outlines of the orebodies on each section. As the generated sections are not a perfect representation of the mineralization they are only used as a guide in the next step.

5.2.4 Perimeter digitizing and solid model

In this stage the geology of the deposit is interactively interpreted on the screen of the computer. The procedure used is as follows. First one of the geological sections is displayed on the background and the corresponding section with the outline of the orebody is also added to it. Then the limit (0.32 % Cu) of the ore zone is digitized in such a way as to enclose as much high grade as possible. Although sometimes it was also necessary to include some low-grade areas in order to ensure the continuity of the orebody. Each orebody present in the geological section is digitized as a separate perimeter, which is assigned a name, a code (representing the geological unit to which the polygon belongs) and the z-plane coordinate. This step is repeated for all the geological sections through the deposit.

Once all the perimeters have been digitized, they are merged with the samples in the database (**assign geology to sample** function) in such a way that all samples that fall within a geological perimeter, are tagged with the geological code of the perimeter defined in the geological table. In addition some attributes such as copper and sulphur are written from samples to perimeters in order to report areas, volumes, tonnage and grades within perimeters contained in a geological model (tables 5.4 and 5.5). This simple resource estimation is based on the average of all samples falling within the perimeter limits within the specified projection distance from the section (table 5.1) and gives a rough idea about the resource of the deposit.

The primary use of this approach is to apply geological control to the grade interpolation so that the grade of any model element is estimated using only samples pertaining to the same orebody.

Table 5.4 Resource summary of Orebody III based on perimeter (section) based method.

<u>Section</u>	<u>Z coord.</u>	<u>SG</u>	<u>Area</u>	<u>Volume</u>	<u>Tonnage</u>	<u>Copper(%)</u>	<u>Sulphur(%)</u>	<u>Cu(t)</u>	<u>S(t)</u>
875	875	3.49	152	3792	13234	4.34	13.71	574	1814
900	900	3.49	498	12453	43462	2.52	11.90	1095	5172
925	925	3.49	945	23631	82473	2.16	15.97	1781	13171
950	950	3.49	2873	71812	250624	2.48	16.60	6215	41604
975	975	3.49	1409	35234	122968	2.27	17.18	2791	21126
1000	1000	3.49	1280	31999	111677	1.39	15.74	1552	17578
1025	1025	3.49	1434	35857	125141	1.91	10.56	2390	13215
1050	1050	3.49	1113	27820	97092	0.89	34.35	864	33351
1075	1075	3.49	2295	57374	200233	5.89	6.69	11794	13391
1100	1100	3.49	3629	90723	316622	2.00	19.31	6332	61140
1125	1125	3.49	2590	64740	225944	1.68	5.30	3796	11975
1150	1150	3.49	2000	49999	174498	0.95	18.74	1658	32701
1175	1175	3.49	599	14984	52295	0.52	6.65	272	3478
1200	1200	3.49	90	2238	7809	0.09	4.54	7	355
Total			20906	522657	1824073	2.26	14.81	41123	270074

Table 5.5 Resource summary of Orebody I based on perimeter (section) based method.

<u>Section</u>	<u>Z coord.</u>	<u>SG</u>	<u>Area</u>	<u>Volume</u>	<u>Tonnage</u>	<u>Copper(%)</u>	<u>Sulphur(%)</u>	<u>Cu (t)</u>	<u>S (t)</u>
875	875	3.49	98	2451	8555	1.47	13.79	126	1180
900	900	3.49	451	11283	39378	2.30	11.47	906	4517
925	925	3.49	402	10058	35101	1.23	15.75	432	5528
950	950	3.49	240	6009	20973	0.68	8.15	143	1709
975	975	3.49	392	9791	34170	0.45	8.08	154	2761
1000	1000	3.49	704	17598	61416	1.91	11.85	1173	7278
1025	1025	3.49	461	11517	40192	0.70	6.03	281	2424
1050	1050	3.49	512	12811	44709	1.95	11.81	872	5280
1075	1075	3.49	1184	29605	103323	2.11	12.24	2180	12647
1100	1100	3.49	1087	27185	94875	3.40	11.95	3226	11338
1125	1125	3.49	811	20279	70775	1.91	5.66	1352	4006
1150	1150	3.49	787	19674	68663	1.46	8.25	1002	5664
1175	1175	3.49	441	11028	38487	0.89	11.00	343	4234
1200	1200	3.49	23	580	2023	0.50	9.19	10	186
Total			7595	189869	662641	1.84	10.37	12199	68751

The next stage is the generation of a 3D solid model of the deposit from the previously digitized sections through wireframing. The wireframing process involves creating a series of triangles that link perimeters from section to section. This can be interactively controlled by manually digitizing corresponding strategic points (inflection points) in successive sections. The wireframes of Orebodies I and III (fig 5.1 and Appendix 6) show the complex morphology of the Jucaro deposit. The 3D

solid model can then be used to control the resource estimation under the resource manager.

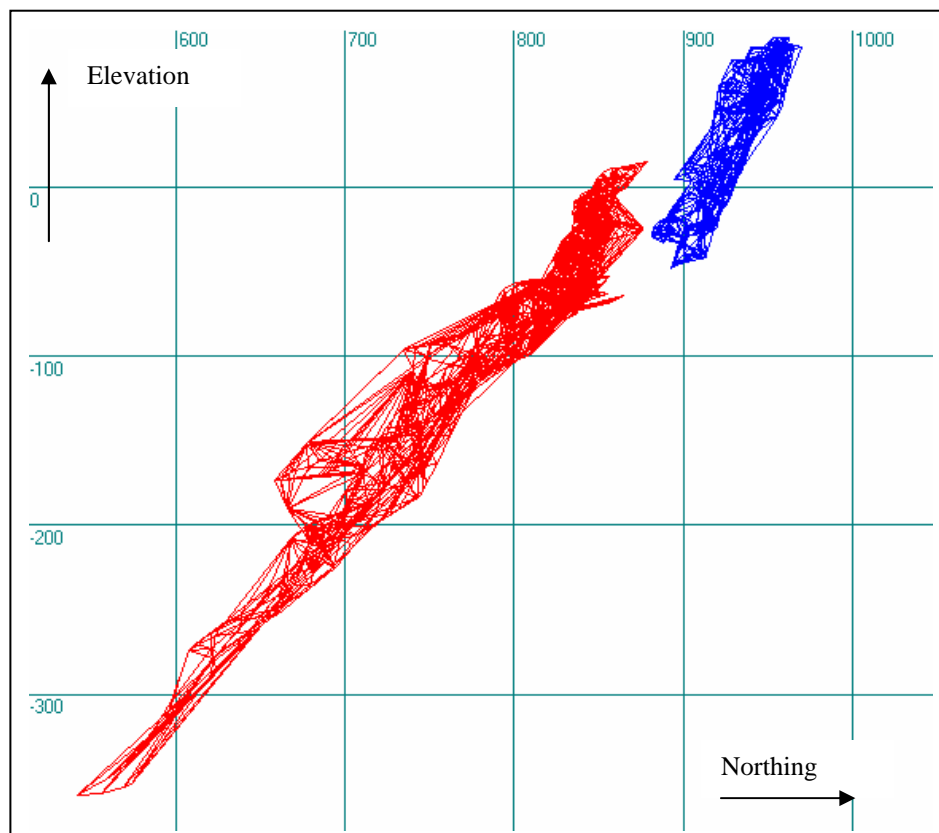


Figure 5.2 Wireframe model of Jucaro deposit on vertical section normal to strike.

5.2.5 Hangingwall and footwall surface model creation

The next stage involves the creation of the hangingwall and footwall surface models. This step is very similar to the above-described one with the only difference being that the string files are derived directly from the digitized perimeters (**Perimeter to string** function) and are then triangulated to end up with the surface model (fig 5.2). Later these geometric models are used to constrain the mineralization in the grid model.

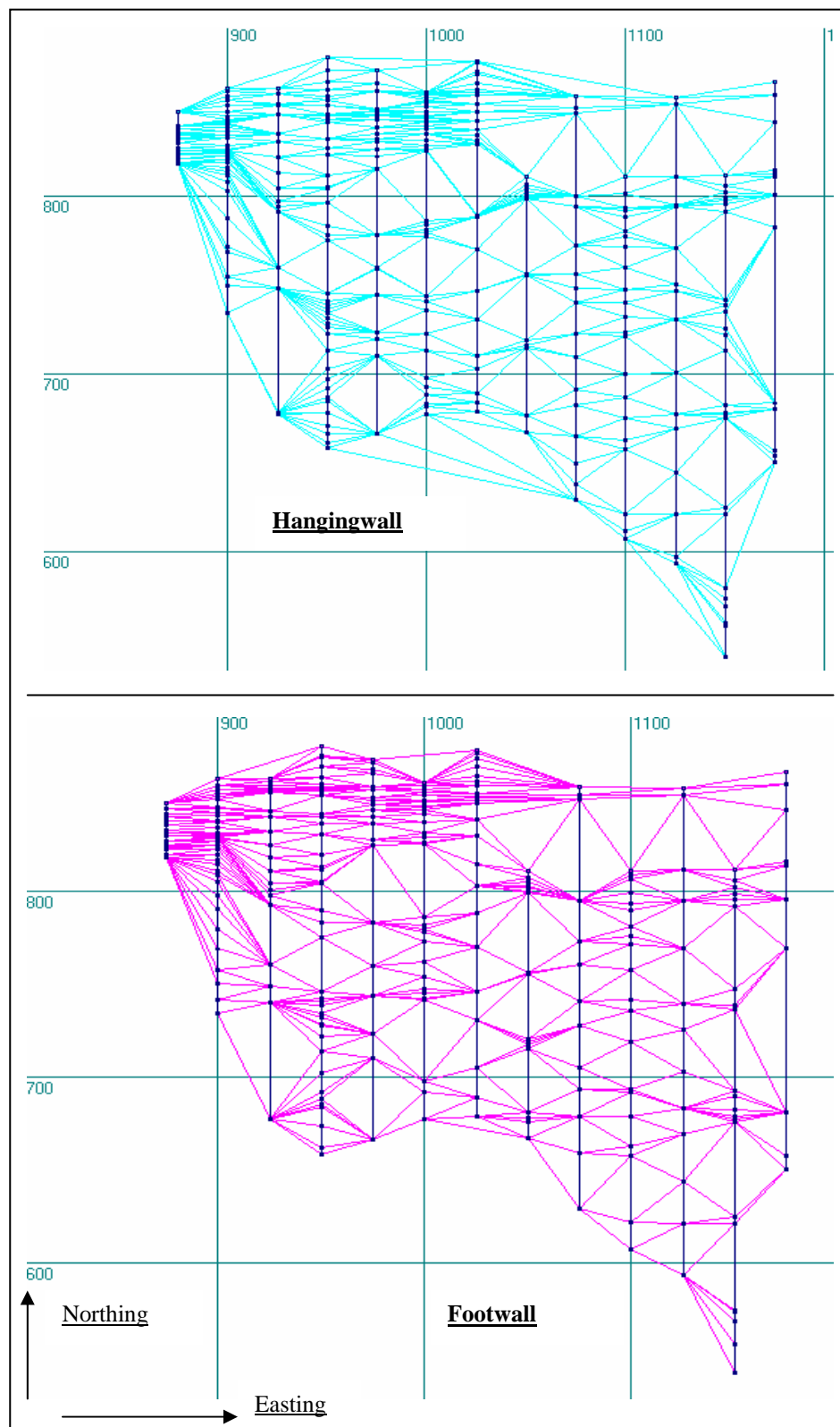


Figure 5.3 Triangulated hangingwall and footwall of surface model (Orebody III). Viewed on horizontal plane

5.3 Resource modelling

As explained in the chapter 3 the grid model was selected for the resource modelling of Jucaro deposit based on the lenticular shape of the mineralized lenses. The gridded seam model consists of cells, which are rectangular prisms with the same cross-sectional area but varying height. The cell size (Siz_N, Siz_E) was determined as 20 % of the average drillhole spacing and the heights (Siz_L) are calculated from the hangingwall and footwall elevations at the grid point.

The resource modelling involves 3 main steps:

- Creation of the database structure
- Creation of the defined cells
- Estimation of model cell values

5.3.1 Creation of the resource model database

At this stage the fields to be stored and the tables to be included in the database are defined. The resource model database is not relational in that it consists of independent tables for each regular grid used in the model. The database contains the fields to include in the resource estimation and the grid dimensions. The Jucaro resource database is composed of 3 main tables. A grid table, where the spatial location, cell size and the number of cells in each direction are defined and two model tables (one for each orebody) that store the information of every cell in the model (fig 5.3).

Each cell is characterized by a set of attributes or properties, some of which are automatically generated by the system once the database has been created, while others are defined by the user. The system required attributes are mandatory in order to create a grid model. All the attributes used in this study are described in table 5.6.

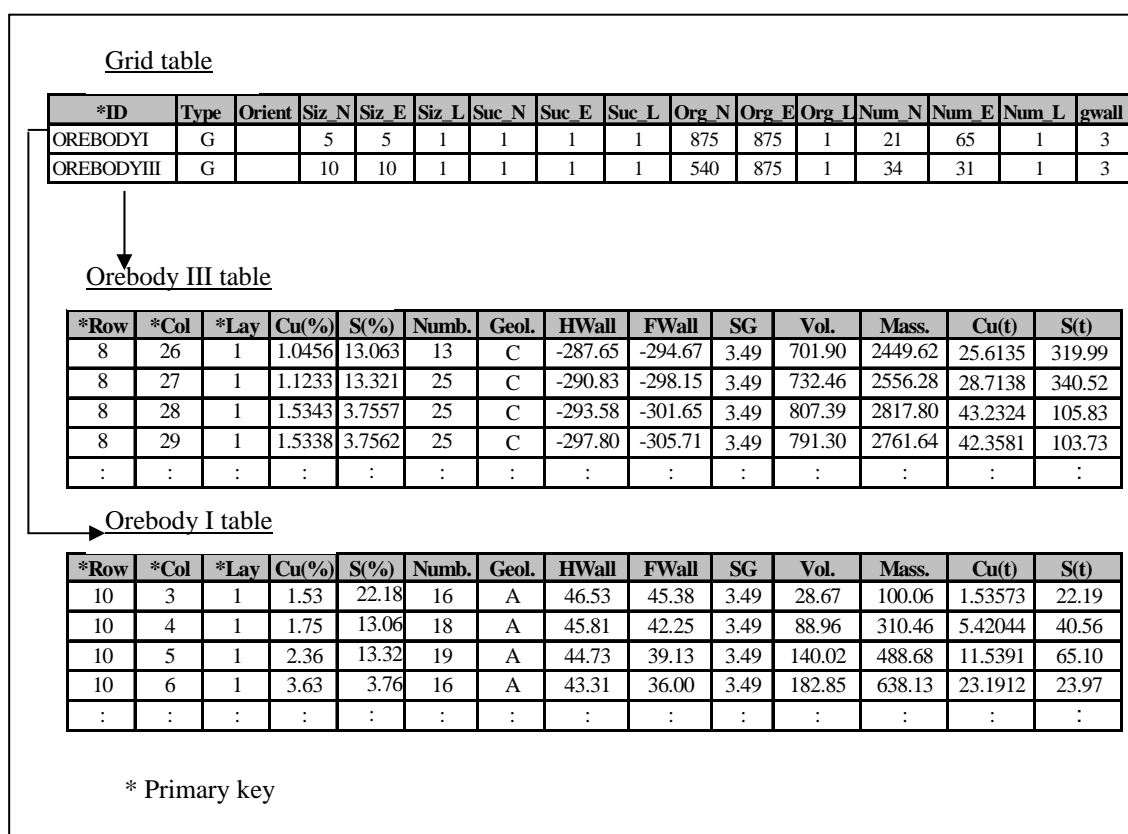


Figure 5.4 Structure of the Jucaro resource database.

After defining the structure of the database the next step involves the determination of the spatial parameters of the grid model. The parameters are defined as follow. The cell size for Orebody I was chosen as 5m in the northing and easting directions resulting in 65 rows and 21 columns of cells. The centroid of the cell (1,1,1) in the bottom left corner was located at 875 N and 875 E.

For Orebody III the cell dimensions were chosen as 10m in the northing direction and 10m in the easting direction. In this case 31 rows and 34 columns were obtained. The centroid of cell (1,1,1) was defined at 540N and 875 E.

Table 5.6 Defined field within the Jucaro model tables.

Field	Type	Description
<i>Required system variables stored in resource model</i>		
ID	Text	Model table Id
Type	Text	G= grid model
Siz_N,E,L	Single	Size of the model cell in the North, East and level directions
Suc_N,E,L	Integer	The number of subcells. Set to 1 for the grid model
Org_N,E,L	Double	The origin of the model. Location of the centroid of cell (1,1,1)
Num_N,E,L	Integer	The number of cell in each of the three directions. Set to 1 in the level direction for the grid model
gwall	Integer	Grid model orientation. Level =3
Row	Integer	The number of cells from the origin in the x direction
Col	Integer	The number of cells from the origin in the y direction
Lay	Integer	The number of cells from the origin in the z direction. Set to 1 for grid model
Hwall	Single	Elevation of the hangingwall estimated by surface interpolation
Fwall	Single	Elevation of the footwall estimated by surface interpolation
SG	Single	The density of a cell, here defined as a constant of 3.49 t/m ³
Vol.	Double	Cell volume (m ³)=Siz_N*Siz_E*(Hwall-Fwall)
Mass.	Double	Mass of each cell (tons) =Vol.x SG
<i>Optional user defined stored variables</i>		
Cu(%)	Single	Copper grade of the cell calculated by inverse distance weighting technique
S(%)	Single	Sulphur grade of the cell calculated by inverse distance weighting technique
Numb.	Single	Number of samples involved in the estimation
Geol.	Text	The orebody to which the cell belongs - a code type variable
<i>Optional relational variables derived from stored values</i>		
Cu(t)	Double	Contained copper (in tons) of the cell = Cu (%) x Mass.
S(t)	Double	Contained sulphur (in tons) of the cell = S (%) x Mass.

5.3.2 Creation of the defined cells

On initial creation of the database only the structure of the model is defined, all the tables are still empty. Therefore the next step is to create records defining the cells and to assign geology codes to them. This step sets up a geological and spatial control for subsequent estimation of the model cell variables. There are different methods for doing this namely:

- *Subdivide a block model*
- *Solid interpolation*
- *Surface interpolation*

In this study the **Surface interpolation** function is used to create the cells and to interpolate the elevations of the hangingwall and footwall of the orebodies at each cell of the grid model. As each table in the grid model describes a single orebody it is not necessary to tag each cell with a geological code. After that the density, volume and the tonnage of every cell is calculated by executing **Store system field** function.

5.3.3 Estimation of model cell values

At this stage the copper and sulphur grades are estimated for each cell using one of the interpolation tools available (e.g. Kriging, Inverse distance and triangulation). As the cupriferous mineralization in the Jucaro deposit has no spatial continuity it was decided to reject Kriging and to use inverse distance instead.

The inverse power of distance weighting technique applies a weighting factor, which is the inverse of the distance between each sample and the cell centroid, raised to the power 'n', where 'n' usually varies between 1 and 3. Only samples falling within a specified volume are used in the interpolation (Annels, 1991).

The following parameters were used to execute the interpolation process:

- Source of sample to be used. Since the grade estimation should be constrained by the geology, a database query containing only the composite data that intercept the orebody being modeled was created and then used in the estimation.
- Size and orientation of the search ellipsoid. As the structural analysis revealed no spatial correlation in the plane of the orebodies the search radii were selected intuitively on the basis of drillhole spacing. The x, y, z search radii are 60 m, 60m and 20m for Orebody III, and 30m, 30m, 20m were used for Orebody I. The search ellipsoid was rotated 40° around the east axis in such a way that the z search axis becomes normal to the plane of the orebody.
- Number of samples used. The minimum and maximum number of samples required for the estimation process were set as 2 and 10 respectively.
- Weighting the neighboring samples to estimate the grade for the cell. A value of 2 as power of inverse distance was selected.

5.3.4 Grid model resources report

The results of the resource modelling can be displayed in section and plan. A summary of the estimated values of copper and sulphur grades was produced in tabular format. It includes the ore tonnage, copper and sulphur grades and contained copper and sulphur. The tabulation was set up as rows (level), columns (sulphur) and pages (easting). The final resource figures are presented in the next chapter. The results of the model were also exported as a delimited text file for the generation of grade -tonnage curves.

6 CHAPTER 6 RESOURCE ESTIMATION RESULTS

6.1 General

In this chapter the final results of the resource modelling are summarized in a tabular format for easy interpretation. Detailed results are presented as sections and plans, showing the grade and total resource for individual cells in the resource model. In addition the grade - tonnage curve of Cu for the two orebodies and for the whole deposit are presented. Finally the grid model estimation results are compared with the manual resource estimates.

The estimation process covers the whole deposit although several small mineralized lenses, which are scattered around the main orebodies, were neglected as their contribution to the total resources is insignificant. Only those small mineralized lenses that are revealed in more than 2 main sections were modelled. The two main orebodies were modelled separately and only the data within the limits of mineralized bodies were used for the grade estimation. Subsequently the models were combined to end up with the final figures for the Jucaro deposit resources.

6.2 Global estimation

The resource results for copper and sulphur are summarized in a tabular format according to elevation (tables 6.1-6.2). The detailed report was set up to show the resources contained in blocks with dimensions of 50m wide along strike and 25 m high. A block comprises the ore located within two main sections and is named according to the number of the bounding sections (Appendix 7).

Total ore tonnages of 1.9 Mt at an average grade of 1.95 % Cu and 20.05 % S, and 0.6 Mt at average grade of 2.05 % Cu and 15.04 % S, are obtained for Orebody III and I respectively. The total ore resource of Jucaro deposit obtained from the grid resource model is 2.5 Mt grading 1.98 % Cu and 17.78 % S.

Table 6.1 Summary resource report of Orebody III

	Ore tonnage(t)	Cu(%)	S(%)	Cont. Cu(t)	Cont.S(t)
L 0, 25	16684	3.45	20.87	576	3482
L -25, 0	80596	2.79	16.13	2249	13000
L -50,-25	126806	1.74	10.01	2206	12693
L -75,-50	226346	2.53	12.38	5727	28022
L -100,-75	184547	1.49	15.88	2750	29306
L -125,-100	142914	2.68	20.84	3830	29783
L -150,-125	159839	2.03	23.25	3245	37162
L -175,-150	227883	1.67	24.56	3806	55968
L -200,-175	269474	1.78	29.49	4797	79468
L -225,-200	158646	2.34	28.81	3712	45706
L -250,-225	105719	1.37	13.85	1448	14642
L -275,-250	69565	1.68	14.52	1169	10101
L -300,-275	41846	1.4	19.53	586	8173
L -325,-300	30915	1.32	17.67	408	5463
L -350,-325	30100	1.04	13.32	313	4009
L -375,-350	18558	0.79	6.73	147	1249
Total	1890436	1.95	20.05	36967	378227

Table 6.2 Summary resource report of Jucaro Deposit

	Ore tonnage(t)	Cu(%)	S(%)	Cont. Cu(t)	Cont.S(t)
L 75, 100	871	0.7	9.3	6	81
L 50, 75	116163	1.44	9.74	1673	11314
L 25, 50	175605	2.42	9.9	4250	17385
L 0, 25	179952	2.33	12.74	4193	22926
L -25, 0	195496	2.25	12.87	4399	25160
L -50,-25	151642	1.75	9.89	2654	14997
L -75,-50	226346	2.53	12.38	5727	28022
L -100,-75	184547	1.49	15.88	2750	29306
L -125,-100	142914	2.68	20.84	3830	29783
L -150,-125	159839	2.03	23.25	3245	37162
L -175,-150	227883	1.67	24.56	3806	55968
L -200,-175	269474	1.78	29.49	4797	79468
L -225,-200	158646	2.34	28.81	3712	45706
L -250,-225	105719	1.37	13.85	1448	14642
L -275,-250	69565	1.68	14.52	1169	10101
L -300,-275	41846	1.4	19.53	586	8173
L -325,-300	30915	1.32	17.67	408	5463
L -350,-325	30100	1.04	13.32	313	4009
L -375,-350	18558	0.79	6.73	147	1249
Total	2486079	1.98	17.78	49110	440915

6.3 Ore tonnage and ore vertical thickness variations

The ore tonnage and the vertical thickness are irregularly distributed over the deposit and change abruptly from section to section. The bulk of the Jucaro deposit ore tonnage is located in Orebody III, which contains 80 % of the total resources. Meanwhile 51 % of the tonnage of the deposit is found between sections 0 and 3 (blocks 01 and 13). The same pattern is also observed in the Orebodies I and III (fig 6.1 and Appendix 8).

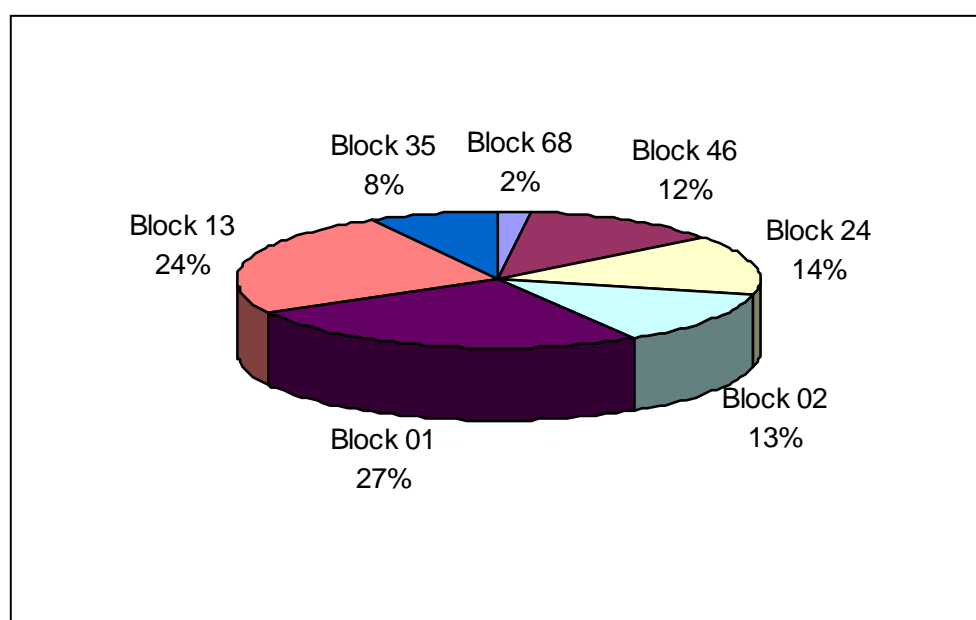


Figure 6.1 Distribution of the ore tonnage in the different mining blocks, Jucaro deposit

On the basis of copper grade the ore tonnage distribution in the deposit is not uniform either. Half of the tonnage (54%) has a copper grade varying between 0.3 % and 1.5 % at average of 0.9%. On the other hand only 8% of total resource has grade values above 4 % Cu averaging 6.26 % (Appendix 9).

The vertical ore thickness within individual grid cells is quite variable ranging from 0 in the fringes of the deposit to 44.66 m around sections 1, 3 and 4 with an average value of 8.08 m. The thicker parts of the orebody correspond with the blocks of higher tonnage in the deposit.

6.4 Copper and Sulphur grades distribution

The estimation results of copper and sulphur grades in each cell of the grid model are displayed in color-coded cross sections and longitudinal sections (fig 6.2-6.3 and 6.4 respectively). Four intervals were selected to show the spatial pattern of estimated grades within the deposit (Chapter 3). Figure 6.2 depicts the estimated copper grade of each cell in section S1 (1100E) and section S4 (950E), the copper grade changes irregularly in the horizontal direction with alternation of zones with different copper values. However in sections S3, S0 and S2 the grade is less variable and ranges from 0.3 to 1.5 % (Appendix 10). As the cross sections of the grid model do not give any information about the vertical variation of grades in the deposit, the estimated grade is displayed in a vertical longitudinal projection N 1000 (fig 6.4). It is clear that the richer areas are surrounded by zones of lower grade and are located in the fringes of orebodies

Appendix 8 shows the distribution of the Cu grades according to the levels and the mining blocks. The richer zones in the deposit fairly coincide with the blocks containing the higher tonnage. The higher average grade is found in Orebody I.

The distribution of sulphur grade among estimated cells of the grid model is shown in fig 6.3. The variation of the grade in the horizontal direction follows a similar pattern to Cu although the changes are more regular, particularly in Orebody III where sulphur grades between 10 and 30 % are predominant. Orebody I is poorer in sulphur with prevailing grades in the range of 1 to 10%. The richest zones, like those of Cu, are in the flanks of orebodies (fig 6.4).

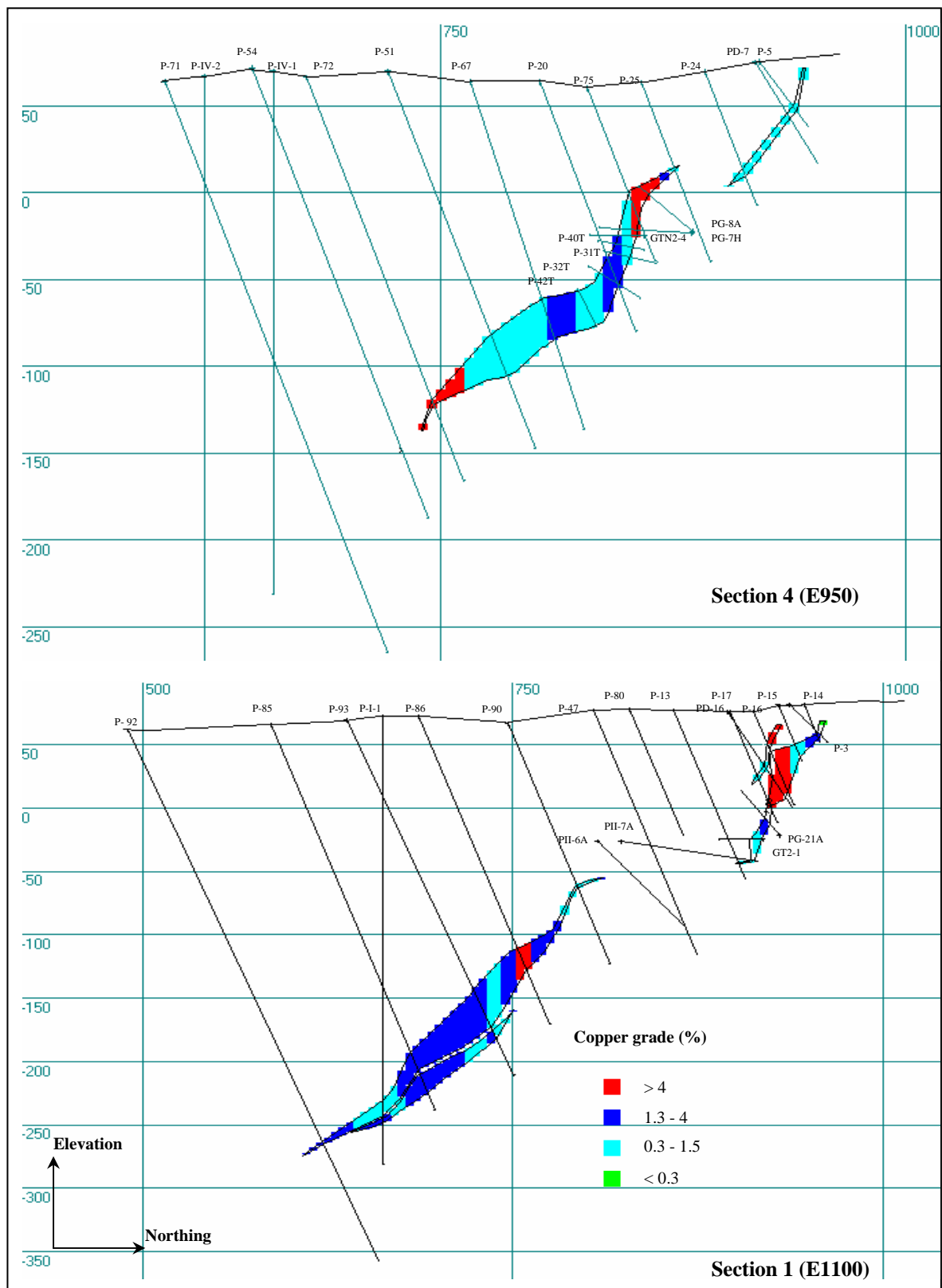


Figure 6.2 Color - coded cell estimated Cu (%) plotted on vertical cross sections

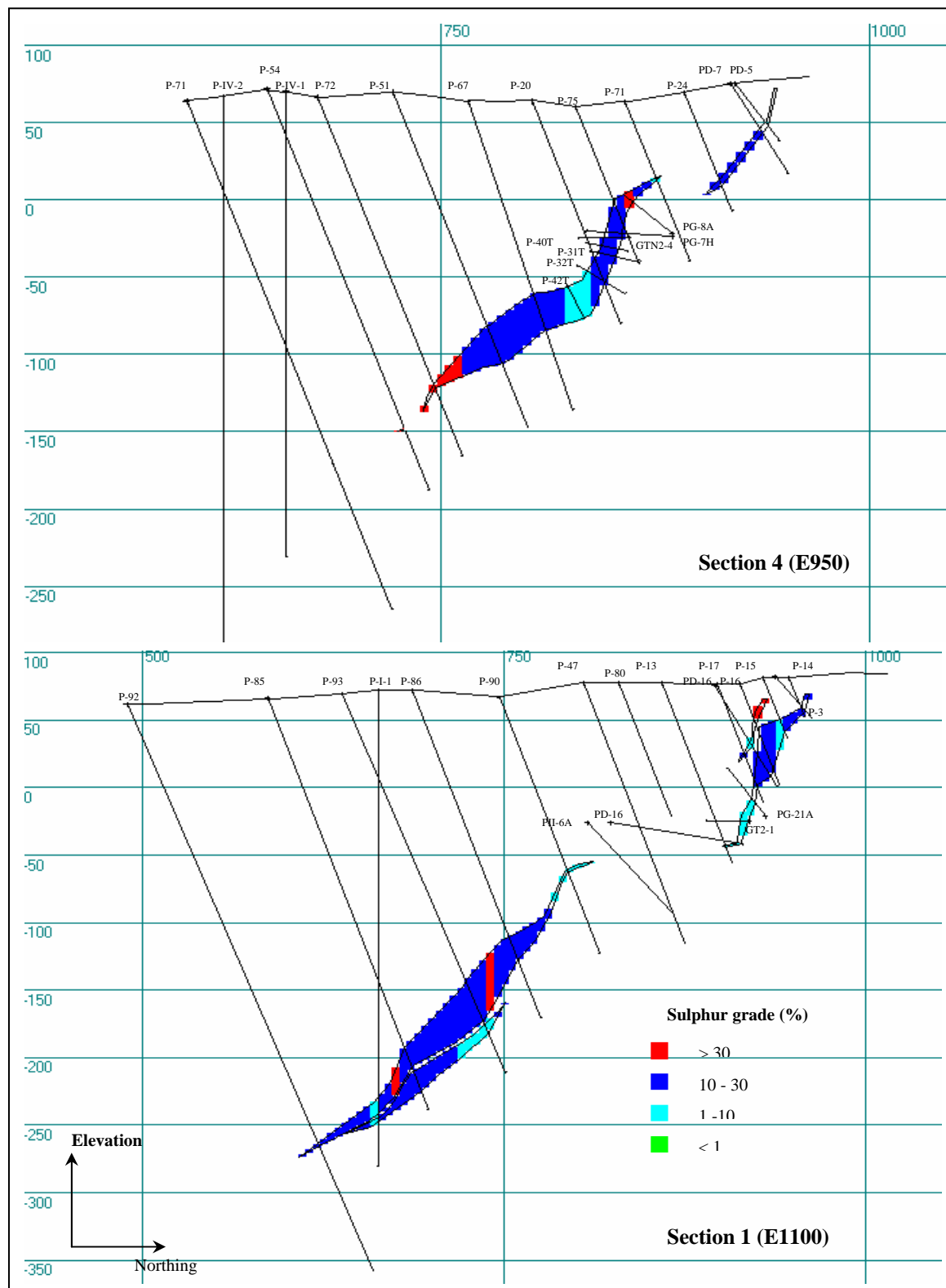


Figure 6.3 Color - coded cell estimated S (%) on vertical cross sections.

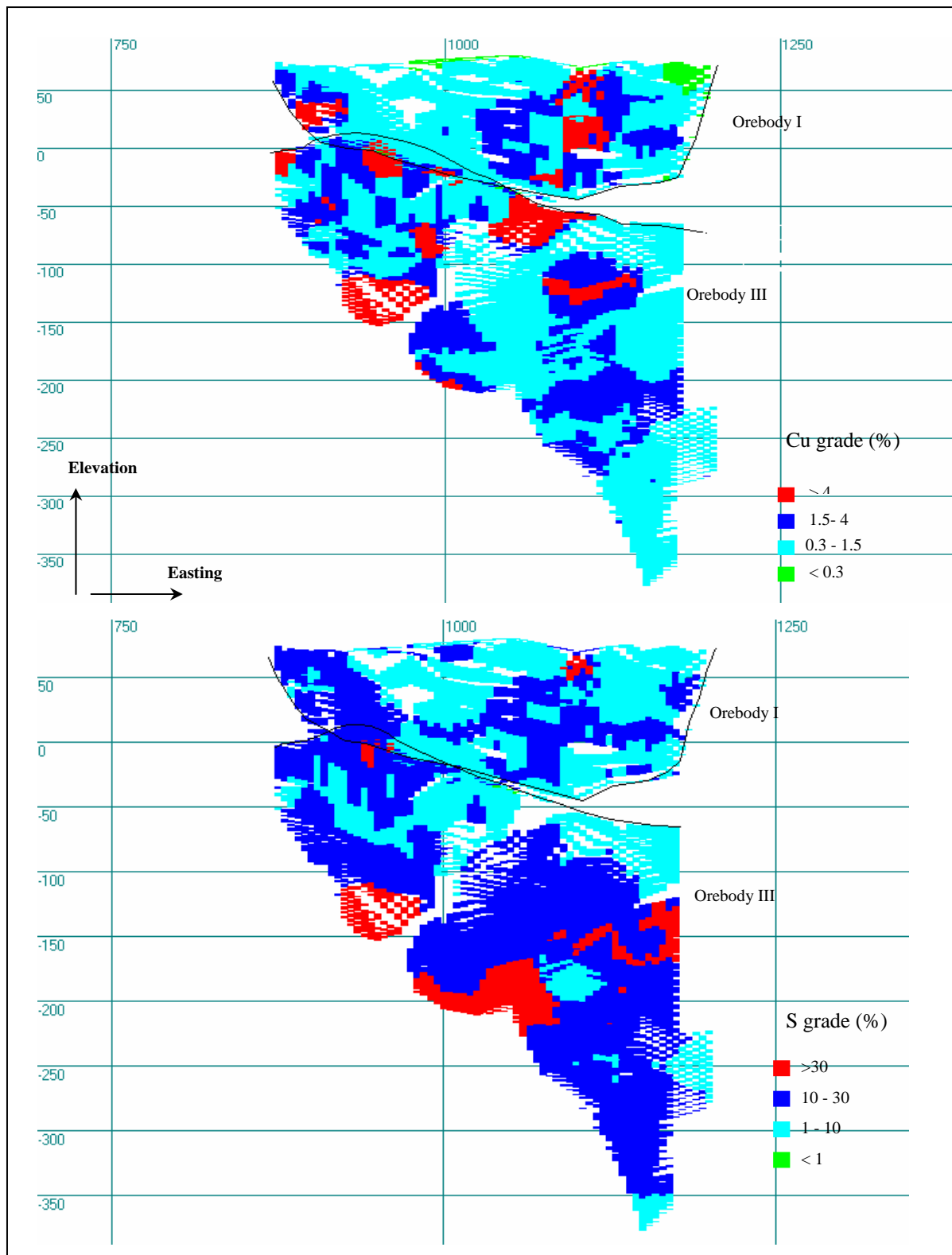


Figure 6.4 Spatial distribution of estimated Cu and S grades viewed in vertical longitudinal projection N1000.

6.5 Grade - tonnage curves

In evaluating the economic viability of a mining project, it must be possible to forecast the tonnage and value of the fraction of resources that can be mined as ore. The factors that determine the relative utilization of capacities in a mining system are the grade distribution of the material being mined and the cutoff grade, which is being applied to that mined material (Lane 1998). During the mine life the cutoff grade frequently changes in order to accommodate the mine to the current economic conditions. The general situation is that the cutoff grade can be decreased when the metal price increases and/or technical conditions are improved. The tool frequently used is the so-called grade - tonnage relation, which relates the tonnage of mineable ore to its average grade for a given set of economic conditions.

The plotting of grade- tonnage curves is a very important step in resource estimation as the curves depict at a glance exactly how much ore exists above a certain cutoff and how the change of cutoff grade affects the tonnage, the grade and the contained metal. In this study grade tonnage curves have been computed to help in the understanding and assessment of the results obtain from the grid model. A cutoff of 0.32% Cu was used to define the extension of mineralization thus the curves relate only to resources available at cutoffs grade above 0.32 % Cu.

In this project the procedure used to generate the grade tonnage curves is as described below.

- ◆ A database query containing the estimation results is created and subsequently exported to Excel;
- ◆ The Cu grade is sorted into decreasing order;
- ◆ Calculation of cumulative tonnage, cumulative contained metal and cumulative Cu grade;
- ◆ Assigning Cu grade to the x axis, cumulative tonnage to the y axis, and cumulative grade to the secondary y axis, of a scatterplot

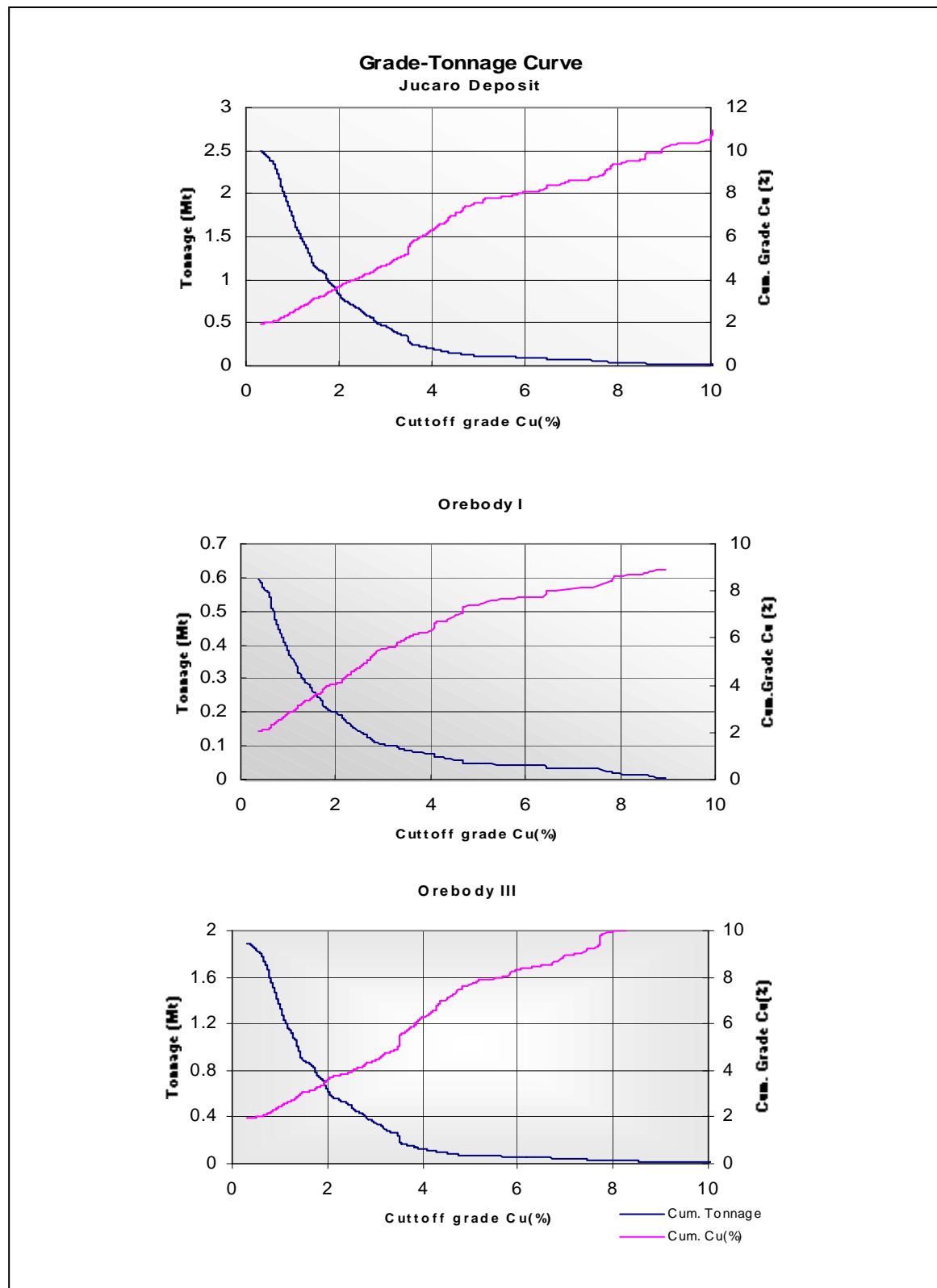


Figure 6.5 Grade - tonnage curves for Cu based on the results of the grid model.

The grade -tonnage curves for the whole Jucaro deposit and its individual bodies are presented in figure 6.5. Table 6.3 shows the variation of tonnage and the average Cu grade for Orebody III for different cutoff grades.

Table 6.3 Ore tonnage and Cu grade at various cutoff grades

<u>Cutoff</u>	<u>Tonnage (Mt)</u>	<u>Cu (%)</u>
0.32 %	1.9	1.95
0.5 %	1.8	1.99
0.7 %	1.7	2.1
1.0%	1.4	2.41

6.6 Comparison with manual resource estimates

The resources of Jucaro deposit were manually calculated using the conventional sectional method during the exploration campaign of Orebody III (Escobar, 1971). The deposit was outlined by employing a cutoff grade of 0.5 % Cu and a minimum mining thickness of 1m. In this study a cutoff grade of 0.32 % Cu and a minimum mining thickness of 1m were used for delimiting the extension of mineralization.

The resource results of the grid model are not completely comparable with manual ones. Firstly all the data generated during the underground exploration and exploitation of the deposit have been incorporated in the database, and therefore a larger database was used in this project. Secondly the morphology of the deposit was simplified in order to facilitate the automatic generation of the hangingwall and the footwall surfaces (chapter 4) and thirdly some small mineralized lenses, which also contribute to the total Jucaro deposit resource were neglected, as they are confined in one geological section. Table 6.4 compares the results obtained using the two different methods.

Table 6.4 Comparison of the grid model and manual resource results

Cutoff grades	<u>Grid model results</u>			<u>Sectional method results</u>		
	Tonnage (Mt)	Cu (%)	S (%)	Tonnage (Mt)	Cu (%)	S (%)
0.32 %	2 486 079	1.98	17.78			
0.5 %	2 409 223	2.02	17.96	2 606 368	1.98	20.91

The comparison of the results indicates that the total tonnage of the deposit is 8 % lower than the manual one. On the other hand the average sulphur grade obtained from the grid model is 14 % lower while the copper grade is slightly higher. The difference in tonnage may be explained by the simplification of the real shape of the deposit in order to meet the requirements of the software used.

6.7 General remarks concerning the geological and resource modelling

After having created the geometric and volumetric models of the cupriferous mineralization in Jucaro deposit the following remarks can be drawn.

6.7.1 Geological modelling

- ◆ Both the surface and perimeter methods were combined in order to geologically model the deposit.
- ◆ Each orebody was separately modeled and those lenses, which are not continuous along strike (confined to one geological section), were not represented. Although this is a simplification of reality it was done for the sake of simplicity of the geology model.
- ◆ The complex morphology of the deposit was simplified by eliminating the bifurcating lenses, while these constitute mineable resources, they only complicate the automatic extraction of the hangingwall and footwall. Where possible the branches were treated as independent mineralized lenses.

- ◆ As the Jucaro deposit is not aligned to any of the conventional planes (horizontal, north south and east - west section) a coordinate system transformation was carried out so that the new north becomes parallel to the direction of the geological sections. This step is necessary to overcome the limitation of the software in handling deposits striking obliquely with respect to the principal axes of the grid system used.

6.7.2 Resource modelling

- ◆ The grid model was selected to estimate the resource of Jucaro deposit on the basis of the thin lenticular shape of the orebodies forming the deposit
- ◆ A constant density of 3.49 t/m^3 was used to calculate the tonnage for the entire deposit. This also represents a simplification of reality because the density depends on the sulphur grade, which keeps changing from place to place. The constant value was chosen for making the grid model resource results comparable with the manual ones.
- ◆ The grid cell size was selected as 20% of average drillhole spacing (5m and 10m respectively for Orebody I and Orebody III).
- ◆ The size and shape of the search ellipsoid were defined intuitively since the variography failed to reveal any spatial continuity of the mineralization. Meanwhile the ellipsoid was oriented so as to take account of the fact that the deposit is dipping to the south (transformed coordinate system) at an angle of 20° - 70° .
- ◆ The total estimated resource obtained for the grid model amounts to 2.5 Mt at an average grade of 1.98 % Cu and 17.78 % S. These results are slightly lower than the resource calculated by the conventional sectional methods.

7 CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Several conclusions and recommendations can be drawn concerning the orebody modelling and ore resource estimation of the Jucaro deposit

1. In spite of the complex geometry and high spatial variability of mineralization the 2D/3D GIS modelling technique proved to be suitable for evaluation of the sulphide orebodies forming the Jucaro deposit
2. The statistical analysis shows that both copper and sulphur grades conform to lognormal populations in the mineralized zone although the cumulative probability plots give some evidence for statistically complex populations. On the basis of the statistical analysis, cutoff grades in the range of 0.3 -0.5% Cu seem to be the most appropriate in defining the extension of the mineralization in the deposit. The correlation analysis revealed a weak linear relationship between Cu and S.
3. The geology model of the deposit provided a good 3d representation of the morphology of the mineralized zone, which allowed the resource estimates to be constrained through the application of geological control.
4. The structural analysis indicates that the sulphide mineralization has no spatial continuity in the plane of the orebody, however a short-range spatial structure is revealed in the vertical direction. This is consistent with the observed high variability of sulphur and copper grades in the deposit.
5. Based on the above conclusion the geostatistical technique (kriging) is not suitable to estimate the Cu and S grades thus inverse power of distance weighting (IPDW) interpolation seems to be the most viable technique to deal with the characteristics of the mineralization.

6. A total in situ resource of 2.5 Mt averaging 1.98 % Cu and 17.78 % S was estimated for the Jucaro deposit. These results are slightly lower than the manually calculated resources. A summary showing the in situ resource of Jucaro deposit is presented in table 7.1

Table 7.1 Summary of estimated resources of Jucaro deposit by grid model

	Tonnage (Mt)	Average Cu(%)	Average S(%)
Jucaro Deposit	2.5	1.98	17.78
Orebody I	0.6	2.05	15.04
Orebody III	1.9	1.95	20.05

7.2 Recommendations

- I. Improvement of the capabilities of the Microlynx program in order to handle tabular deposits with any strike and dip is recommended. This should allow them to be projected on to vertical longitudinal projection (VLP), and the determination of horizontal thickness normal to the strike direction without the necessity for any coordinate transformation.
- II. Application of 2D/3D GIS for orebody modelling and ore reserve estimation of other VMS deposits of the area in order to ascertain the full potential of the region.
- III. Estimation of the resource of Jucaro deposit using a variable density, which is a function of the sulphur grade.
- IV. Performance of a reconciliation study using the production data of the Orebody I, which is already mined out, in order to check and validate the reserve estimation procedures used in this study.