

HOLE EFFECTS IN DIAMOND CORES FROM PALABORA

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1 ABSTRACT.

Palabora Mining Company has mined a large, low grade copper open pit in the Transvaal Province RSA for more than 25 years. The ore-body lies within an alkaline complex of intrusive pegmatoids. Residual fluids from more than one injection of carbonatite magmas exploited fractures and veins in the host rocks to deposit minerals of economic interest.

Initial geostatistical work on diamond cores indicated an interesting potential application of the "Hole-Effect" model. This is most significant in the horizontal direction and appears "damped" towards the vertical. The hole-effects have been highlighted by the application of multiple indicator cut-off grades; when samples from each of the major host rocks were isolated, hole-effects with different cycle lengths were apparent on application of different indicators; these may be signatures from the individual copper mineral deposition "regimes".

Subsequent comprehensive analysis of historical blastholes has led to the zonation of the ore-body by anisotropy and grade. There is confidence that these models will be applicable at depth because of the remarkable vertical continuity of the lithology and mineralisation.

2 INTRODUCTION.

Palabora Mine is sited 500 Km north-east of Johannesburg, RSA (see Figure 1) and is amongst the largest copper open pits and processing facilities in the world. Palabora produces a host of other bi-products and is the site of the world's largest vermiculite reserves. Copper pit reserves are projected to the year 2001 and underground feasibility studies to extend mine life are in progress. Prior to the current study, the application of geostatistics to Palabora was very limited.

3 THE DEPOSIT AND THE SAMPLING DATA

3.1 Geological Summary.

The Palabora Igneous Complex shown in Figure 2, is the result of multiple alkaline intrusions (in order pyroxenite, syenite and ultrabasic pegmatoids) into Archean gneiss country rock. The age of the complex is generally assumed to be greater than 2060 million years.

Pyroxenite intruded first in a kidney-shaped stock 6,4 Km N-S by 2,6 Km E-W. A peripheral corona of feldspathic pyroxenite was formed by interaction with the gneiss. Numerous syenite plugs were forcibly injected into the gneiss surrounding the main pyroxenite. This was followed by an extended period of non-violent and partly metasomatic activity, forming vertically disposed pegmatoid pipes at three sites within the pyroxenite and causing fenitization of the gneiss at the external contacts.

At the central site only ("Loolekop" see Figure 3), a dunite plug with some interstitial carbonatite was emplaced and then altered to foskorite. Banded carbonatite was then intruded at the centre and in concentric bands, bearing some copper sulphides. Subsequent fracturing of the entire infilling of the pipe and renewed igneous activity led to the intrusion of a dyke-like body of transgressive carbonatite at the intersection of two prominent zones of weakness. A divergent stockwork of transgressive veins cutting across all the older rocks was also developed. The bulk of the copper mineralisation accompanied this phase. Intensive post-carbonatite fracturing provided further channels for residual sulphide-rich fluids to permeate the transgressive carbonatite and, to a lesser extent, the older rocks. Shearing, brecciation, plastic flow and recrystallization occurred as the mass cooled. Some sulphides were remobilised and redeposited as valleriite at low temperatures.

Much later, the entire complex was invaded by barren dolerite dykes.

3.2 Lithologies and Ore Genesis.

Foskorite is composed of olivine, magnetite, apatite and phlogopite in variable proportions. Patches of calcite occur in addition to the carbonatite veining from later intrusives. Apatite and baddeleyite are abundant and economic but the magnetite is too high in titanium to be saleable.

Banded carbonatite is a magnetite-rich (20%) dolomitic sovite characterised by crude alignment of the magnetite in rudimentary layers concordant with the general concentric structure. Early, low-grade copper mineralisation accompanied this rock with bomite as the dominant phase. Transgressive carbonatite is similar without the crude banding. It is clearly cross-cutting and intrusive to the other rocks. It contains low-Ti magnetite, the bulk of the copper minerals (chalcopyrite, bomite, chalcocite and cubanite are dominant) and urano-thorianite.

The Palabora carbonatites are unusual and geochemically different from others, especially the high copper content. The sulphide textures are indicative of exsolution during cooling combined with reaction with late-stage fluids. The magnetite precedes the sulphides and its formation probably reduced the oxygen fugacity of the system, triggering sulphide precipitation. The sulphide deposition is estimated to have started at a temperature of 600 C, falling to 200 C for the valleriite.

Copper grades average 0.5% in the open pit and minimum mining units can exceed 1% Cu. Individual assays of diamond cores or blast-holes can record up to 10% Cu.

3.3. Sampling and Ore Reserves.

A total of 137 surface diamond drill holes were drilled between 1956 and 1976 intersecting the ore-body at depths up to 1.2 Km below surface. These holes indicate a remarkable vertical continuity of lithology, mineralogy and grade as shown in Figure 4. These cores were logged for structure, lithology and assayed in 5 feet (later 1.5 metres) sections for copper. Composites were assayed for subsidiary minerals.

The long term ore reserves were constructed by traditional methods from the diamond cores. Annual tonnage and grade experience factors are applied for long term planning. The chippings from production blast-holes in the open pit are sampled and assayed. The position and grade of every hole (250 000+) were recently captured on computer and this is now routine. The blast-hole assays are utilised for grade control and short-term mine planning. Blast-hole geological maps are produced of each bench, but carbonatites cannot be distinguished in chippings. A further 36 diamond holes (20 Km) are currently being drilled from an exploration shaft within the open pit as part of the underground feasibility studies.

All this information has recently been utilised for the development of experimental geostatistical models. These models, in conjunction with a comprehensive geological block model, will be used for the construction of future ore reserves.

4 GEOSTATISTICAL STUDIES OF DIAMOND CORES.

4.1 Down-the-Hole Semi-Variograms.

The diamond cores were initially studied by constructing down-the-hole semivariograms. It was apparent from an early stage that the copper is closely associated with the carbonatite lithologies and that segmentation of the core by logged rock-type would be necessary. The rocks are interfingered and mixed throughout the deposit and therefore only continuous cores of 50m or longer were selected. This selection yielded about one hundred relatively uncontaminated lengths of the three main copper-bearing rocks, foskorite (FK), banded carbonatite (BC) and transgressive carbonatite(TC).

A semi-variogram of a length of transgressive carbonatite (LK016TCI) is shown in Figure 5a. The Nugget Effect is typically high, 0.6 of the total variance. The experimental model fitted is a HoleEffect with a cycle period of 32 metres, with evidence of a second hole at 64 metres. As the holes are not as deep as the N.E., the model has been decayed to fit the data up to 40 metres.

Figures 5b to 5f are Indicator Semi-Variograms of the same length of core.

Figure 5b (0.2% Cu) shows a smoothly rising semi-variogram broken sharply at lags of 7, 20 and 45-50 metres. This type of semi-variogram is common for low and high indicator values.

Figure 5c (0.6% Cu) shows well-developed holes at 32 and 64 metres (this cycle length corresponds to that of Figure 5a).

Figure 5d (0.8 % Cu) clearly exhibits a different cycle period of 15 metres. Figure 5e (1.4% Cu) shows a generally rising but rather confused picture.

Figure 5f (2.7% Cu) shows remnants of a smoothly rising graph but is broken more frequently than in 5b.

An example of banded carbonatite (LK122BCI) is shown in Figure 6a. The experimental model fitted is a Hole-Effect with a cycle period of 15 metres. In this case the holes are deep and the model has not been decayed. This graph is somewhat confused between lags of 20 and 40 metres.

Figures 6b to 6e are Indicator Semi-Variograms of the same length of core.

Figure 6b (0.2% Cu) exhibits a cycle period of 15 metres whereas Figure 6c (0.8% Cu) clearly shows a cycle period of 19-20 metres.

Figure 6d (1.4% Cu) clearly exhibits a cycle period of 14 metres. Figure 6e (1.6% Cu) shows evidence of a smoothly rising graph broken into "segments" of roughly 10 metres.

Similar examples can be found in the foskorite cores.

All the above cycle distances are along apparent dips and should be converted to the horizontal using the dips of the individual holes.

For each of the major rock types, three and sometimes more indicators have been found which yield cyclic indicator semi-variograms of different periodic lengths. The interpretation is that these spacings are signatures of the different phases of mineralisation. The infilling of the pipe was fractured by intermittent activity of varying intensity. The major joints so-formed were exploited by mineralised residual fluids, depositing copper and other minerals in the planes of weakness. Where later joints encountered copper deposited by a previous phase, remobilisation may have occurred, giving rise to some of the small-scale textures described by previous authors. The sharp breaks seen especially in the low and high grade indicator semivariograms may be a measure of late stage fracture spacing.

4.2 Global Diamond Core Semi-Variograms.

Nearly all the diamond drilling was aligned perpendicular to strike. Figure 7 is a plan view of the drilling pattern over the central high grade core and Figure 8 is a section viewed from the East.

After classification of the entire suite by rock type, global semi-variograms were run (Figures 9, 10 and 11 – the different symbols represent tolerances of 5, 10 and 15 degrees). These gave reasonable semi-variograms in the North-South (Figure 9) and Vertical (Figure 10) directions but there was an obvious lack of "infilling" in the EastWest direction (Figure 11). Holes are

evident at 80 & 160m North-South and the Vertical range is still to be established but exceeds 200m.

5 GEOSTATISTICAL STUDIES OF BLAST HOLES.

A comprehensive study of the blast-holes from the open pit has been done. The data was split into 100m by 100m cells containing about 3 000 holes each. It was found that local anisotropies exist which can be related to the geology. There is a generally concentric pattern following the banded carbonatites (see Figure 3), sharply broken by very strong radial anisotropies in the transgressive carbonatites. On the basis of anisotropy and grade it was possible to divide the deposit into geostatistical provinces.

Semi-variograms from the main E-W trending transgressive carbonatite area are shown in Figure 12. These semi-variograms do not display the Hole Effects seen previously in the cores as when large quantities of data are analysed, the Hole Effects "counteract" each other and are smoothed out towards Two-Component Sphericals.

6 DEFINITIVE MODELS FOR KRIGING.

The intention is to utilise both the blast-hole models (corrected for the difference in support) and the global diamond-core models to construct kriging systems. The blast-hole models will be particularly useful in deriving the E-W parameters because of the lack of diamond drilling in this direction (see Figure 11).

The underground reserves will be developed from the current exploration drilling, and several other deep holes which intersect the area below the projected bottom of the open pit.

7 CONCLUSIONS.

On a small scale, this copper deposit exhibits some extraordinary geostatistical behaviour. Almost every section of diamond core shows a Hole-Effect, sometimes dominant but often "recessive" within a Spherical- or Linear-type model.

As with most Hole-Effects, the behaviour disappears when large quantities of data are analysed simultaneously and Spherical Models have been fitted to the extensive blasthole records for the purposes of developing kriging systems.

Nevertheless, it is interesting that the rocks contain evidence of individual phases within a complex mineralisation process.

8 SELECTED REFERENCES.

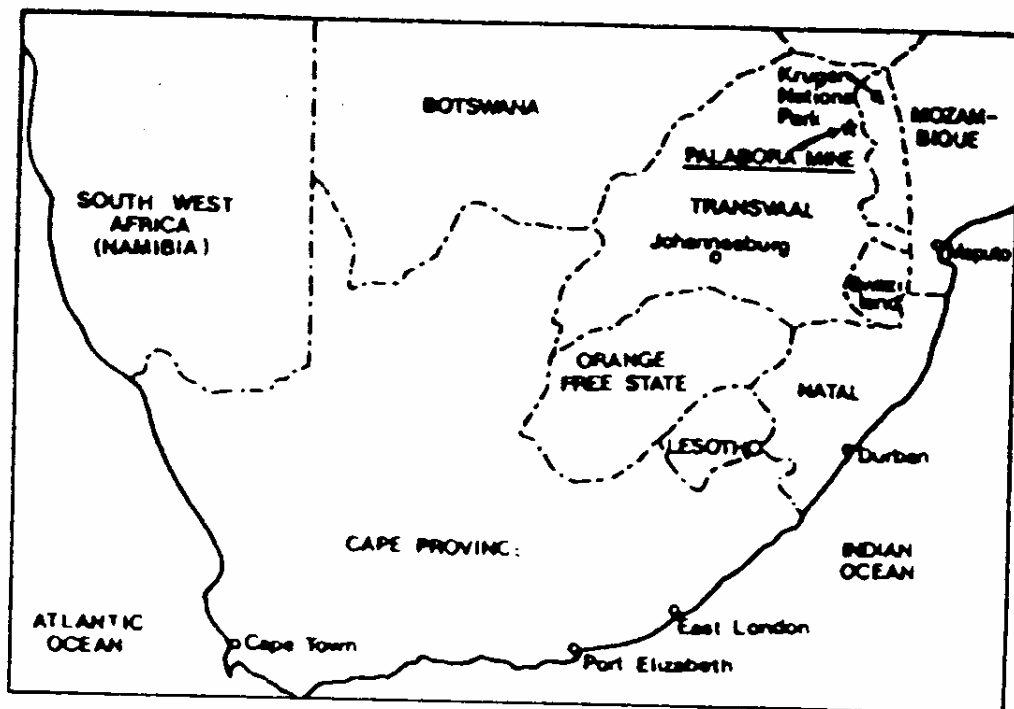
Aldous, R.T.H. Ore Genesis in Copper Bearing Carbonatites, Ph.D. Thesis, Imperial College of Science and Technology, University of London, 1980.

Journel, A.G and Froidevaux, R. Anisotropic Hole-Effect Modelling, Proceedings of the 17th APCOM Symposium, 1982 pp 572-585.

Leroy, A.J. and Lill, J.W. Case Study of Palabora Mining Company Limited, Surface Mining Symposium 1989.

Figures

**FIGURE 1.
LOCATION OF PALABORA MINE**



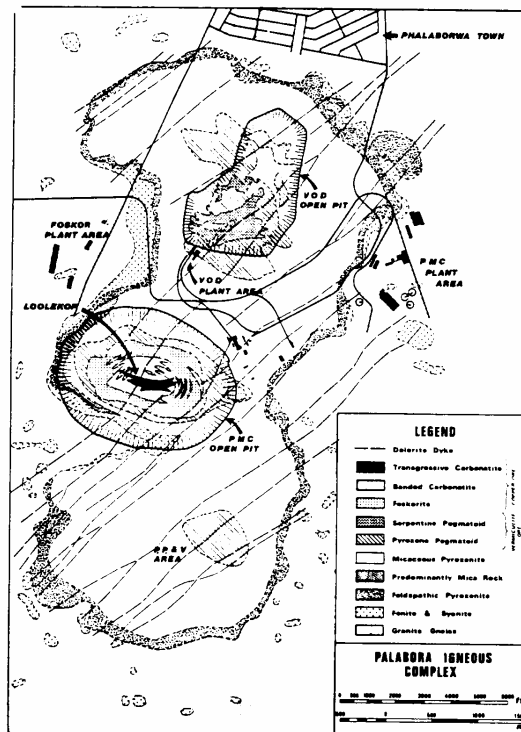


FIGURE 2. GENERAL GEOLOGY
OF THE PALABORA IGNEOUS COMPLEX

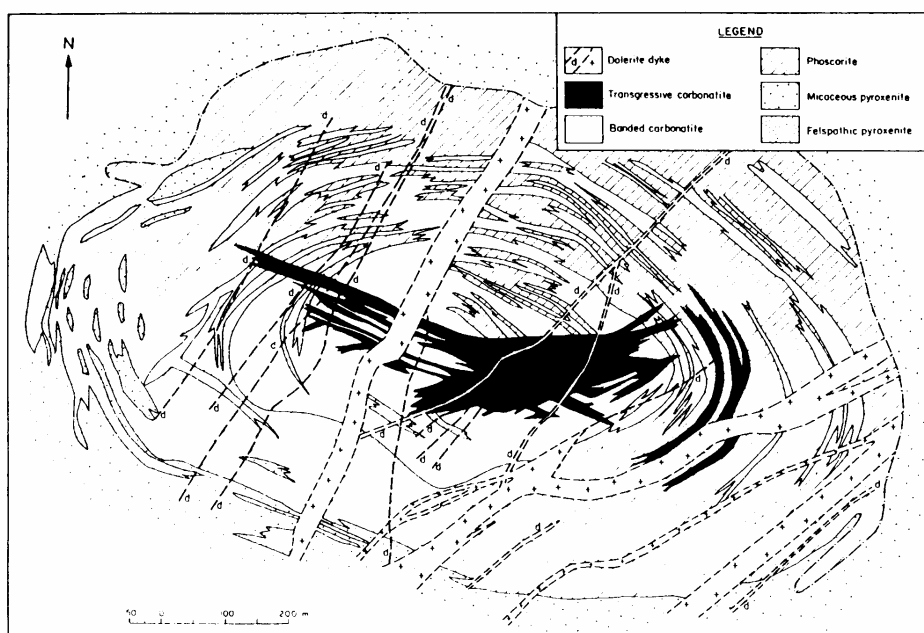


FIGURE 3. LITHOLOGY OF THE LOOLEKOP DEPOSIT

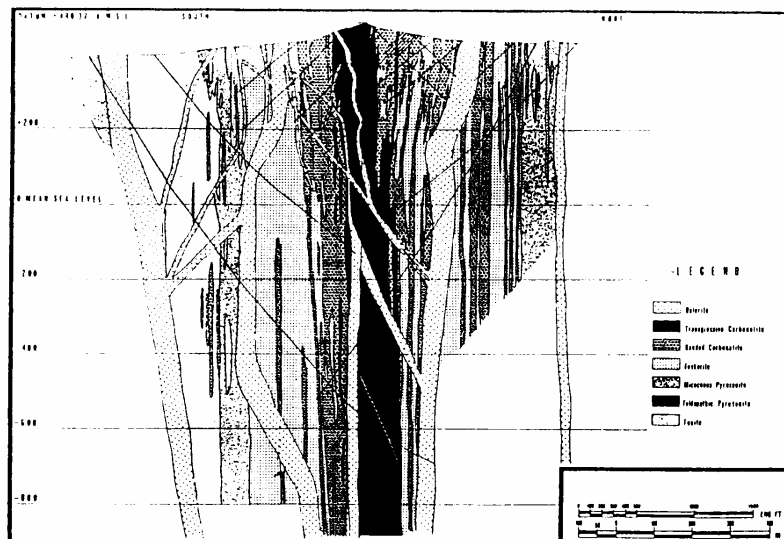


FIGURE 4. TYPICAL SECTION THROUGH LOOLEKOP DEPOSIT

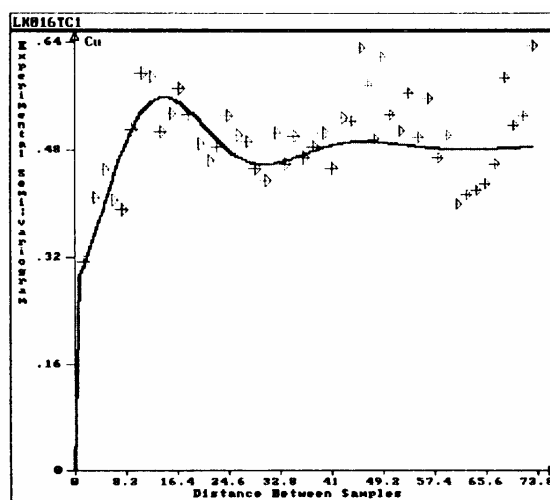


FIGURE 5a.
LK016TC1 DOWN-THE-HOLE
SEMI-VARIOGRAM

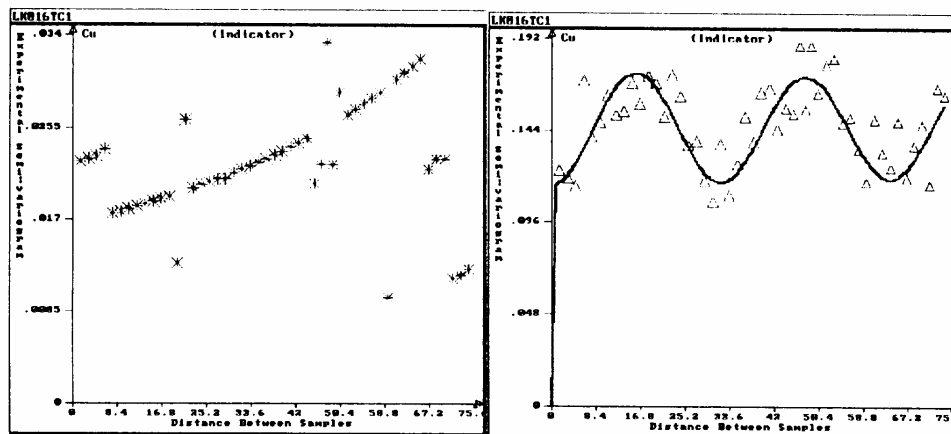


FIGURE 5b & c. LK016TC1 INDICATOR SEMI-VARIOGRAMS 0.2% & 0.6% Cu.

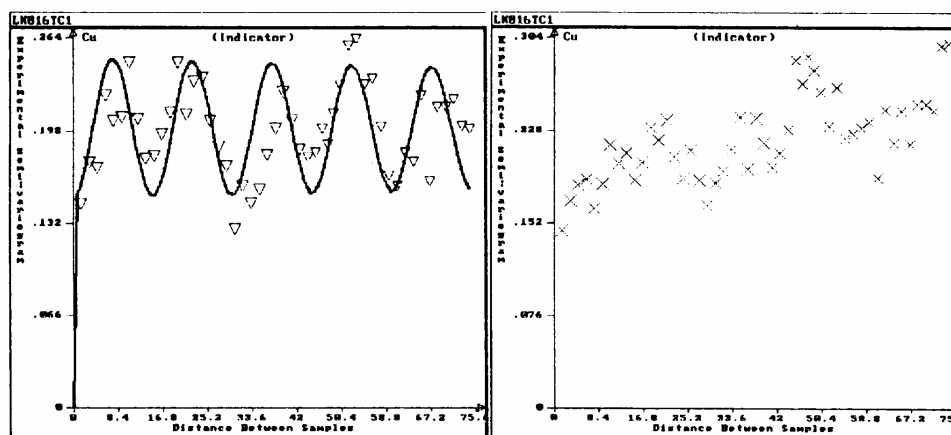


FIGURE 5d & e. LK016TC1 INDICATOR SEMI-VARIOGRAMS 0.8% & 1.4% Cu.

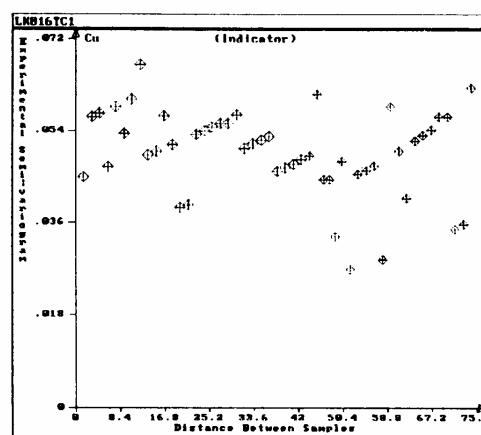


FIGURE 5f. LK016TC1 INDICATOR SEMI-VARIOGRAM 2.7% Cu.

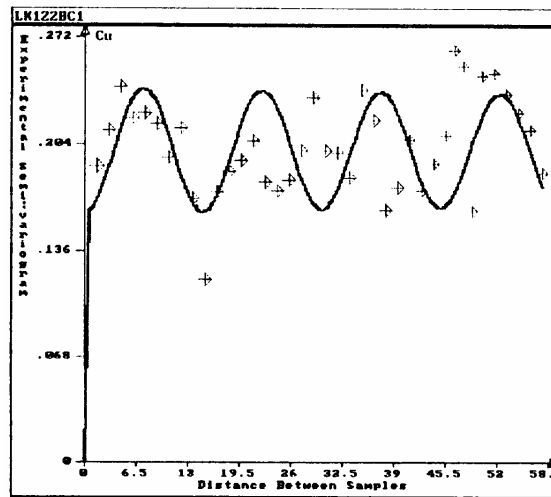


FIGURE 6a. LK122BC1 DOWN-THE-HOLE SEMI-VARIOGRAM

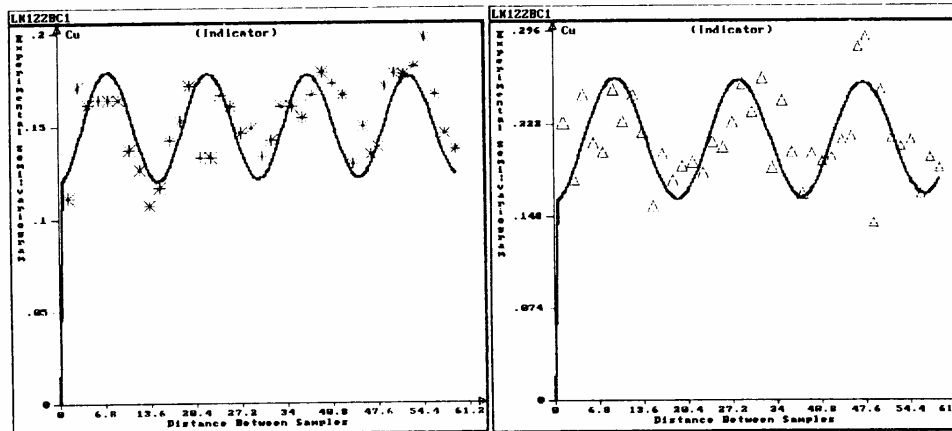


FIGURE 6b & c. LK122BC1 INDICATOR SEMI-VARIOGRAMS 0.2% & 0.8% Cu.

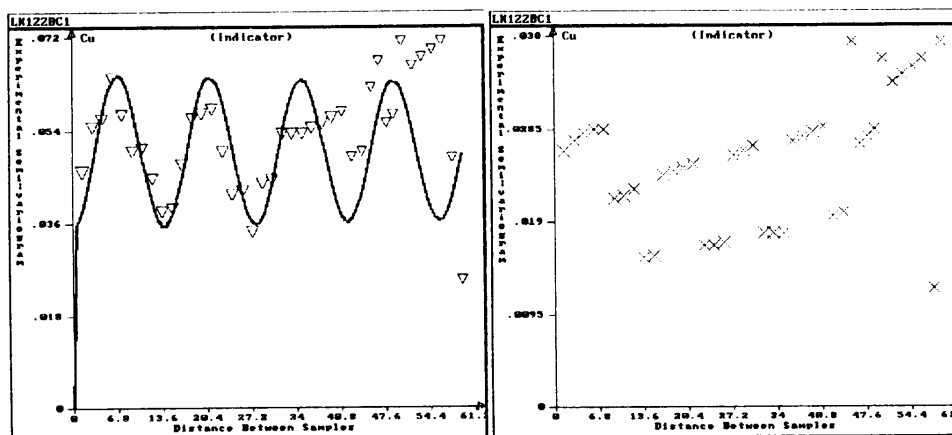


FIGURE 6d & e. LK122BC1 INDICATOR SEMI-VARIOGRAMS 1.4% & 1.6% Cu.

FIGURE 7.
PLAN VIEW OF
DRILLING PATTERN

(not to scale -
local coordinate
system)

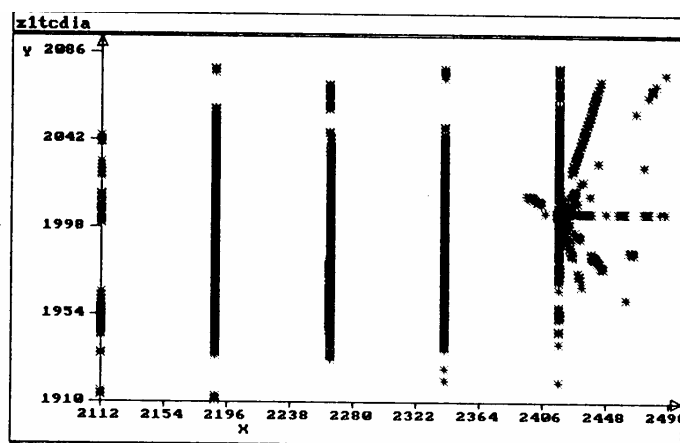


FIGURE 8.
SECTION VIEW OF
DRILLING PATTERN

(not to scale -
local coordinate
system)

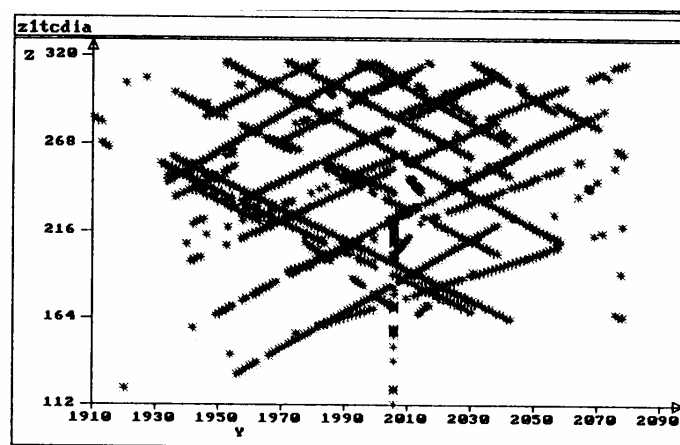


FIGURE 9.
NORTH-SOUTH
SEMI-VARIOGRAM
(TRANSGRESSIVE)

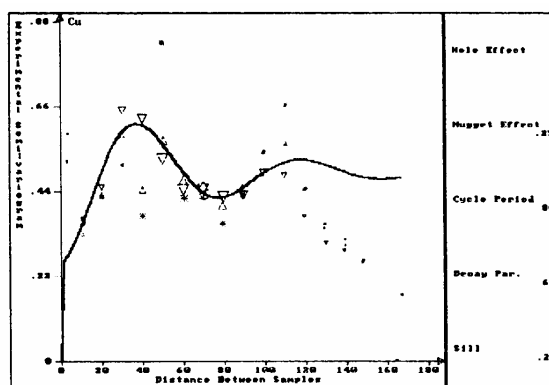


FIGURE 10.
VERTICAL
SEMI-VARIOGRAM
(TRANSGRESSIVE)

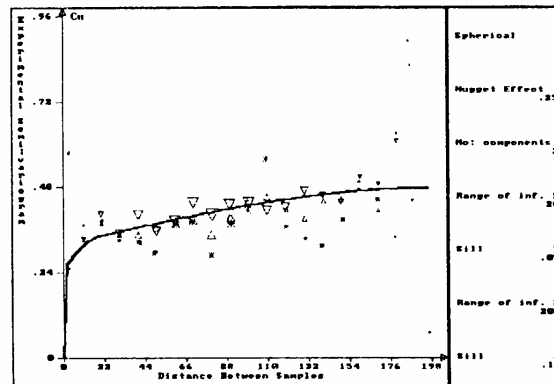


FIGURE 11.
EAST - WEST
SEMI-VARIOGRAM
(TRANSGRESSIVE)

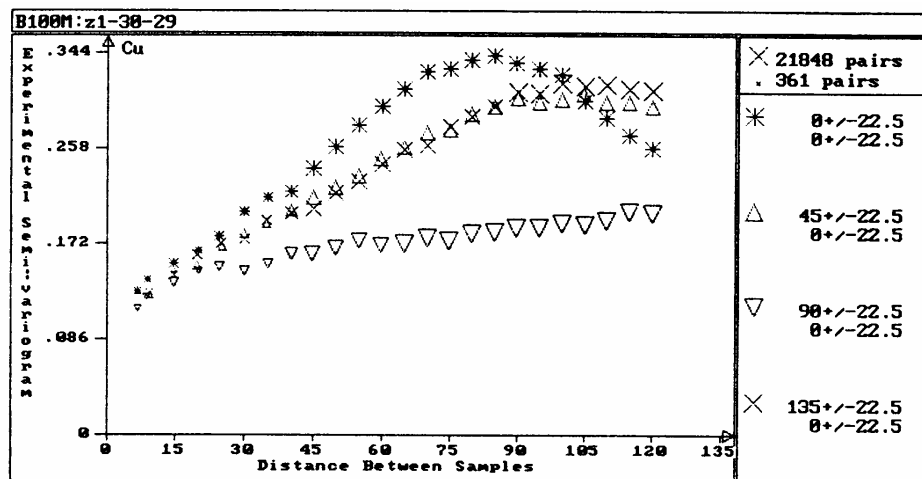
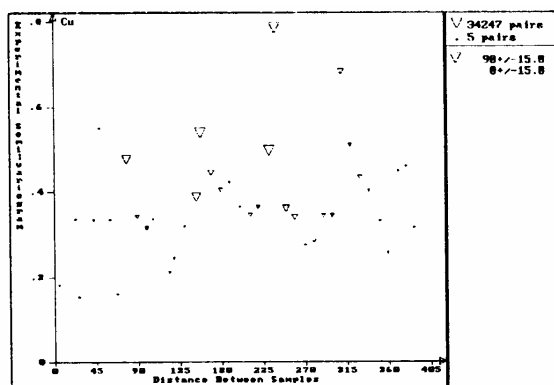


FIGURE 12. TYPICAL SEMI-VARIOGRAM OF BLAST-HOLES