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Montreal, July 27, 1990

Mr. Dave Tenney
Chief Geologist
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P.O. Box 1000
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Dear Dave,

Please find herewith my report for the Phase 1 geostatistical study of the Faro pit drill hole and blast hole data. It follows my visit of last week to Faro. As indicated in the original proposal, this report does not provide any definite answers to your questions about the accuracy of grade and tonnage estimates derived from drill holes or blast holes. It rather lists a series of points which must be checked with real data in the phase 2 study.

After this evaluation, we are now in a better position to evaluate the amount of time and efforts for that second phase. Our time and cost estimate is:

Senior geostatistician : 5 days at $830/day	= $4,150
Engineer : 10 days at $510/day	= $5,100
Expenses (courier, long distance)	= $ 500
TOTAL	= $9,750

Based on those projections, we estimate that we could produce the Phase 2 report 3 weeks after receiving your go-ahead. Since we have all the data and they are in good shape, we can start anytime you wish. Please keep in mind however that I am in Africa for 6 weeks starting at the beginning of September hence it would better to start on or before August 13

Don't hesitate to contact me if you have questions or suggestions about the Phase 1 report and the proposed work for Phase 2. I wish to thank you for your warm hospitality in Faro.

Yours sincerely

GEOSTAT SYSTEMS INTERNATIONAL INC.

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GEOSTATISTICAL ANALYSIS OF FARO DRILL HOLE AND BLAST HOLE DATA

PART 1 : PRELIMINARY EVALUATION

Respectfully submitted to Curragh Resources Inc.
by Geostat Systems International Inc.
Montreal, July 27,1990

FOREWORD

This study has been initiated by a letter of April 25 , 1990 , from Dave Tenney , chief geologist of the Faro operations for Curragh Resources Inc. to Geostat . This letter stated the three main objectives of the contemplated geostatistical analysis i.e. 1) estimate the likely error (global and local) of current computer-generated inverse distance (ID) grade and tonnage estimates , 2) determine the necessary spacing between holes to achieve a given confidence on the same estimates (in later discussions , it was mentioned that management objectives are a maximum +/-5% deviation for monthly grade and tonnage estimates and +/-2% deviation for annual estimates) ,3) using blast hole data , compare the ID estimates with truly geostatistical estimates (kriging) for the same blocks .

In its answer letter of April 30 , Geostat proposed to conduct a two phases study : Phase 1 would include a visit of Faro operations by a Geostat's representative (M. Dagbert) for gathering the necessary information and preparing a detailed scope of work . Phase 2 would be the analytical work itself conducted in Montreal .

Phase 1 was accepted by Curragh Resources on June 12 . The site visit was conducted by M. Dagbert in the week of July 16 and this is the report for that phase of the study .

INTRODUCTION

Curragh Resources Inc. is currently mining lead-zinc-silver sulphide ore from the Faro open pit northeast of Whitehorse in the Yukon . The mine is mostly a standard truck and shovel operation with some underground mining from a ramp at the bottom of the pit . Shovels are 12 yd3 and trucks 150-170 tons . Bench height is 20 ft . Ore production is about 450,000 tonnes/month or 15,000 tonnes/day . Mining in the pit is now restricted to the S (south) and E (east) phases . The central (A phase) is now completed . An estimated 6 M2 tonnes above 5 % Pb+Zn is left to be mined .

Initial exploration of the deposit was done on NE-SW sections at 140 ft intervals . Holes were mostly vertical and spacing between holes on the sections was also about 140 ft . In the recent years , in-fill drilling on about a 70x70 ft grid has been conducted in the remaining E and S parts of the pit. These new holes are generally vertical but some of them are dipping to the NE or SW . Drill hole assay intervals are generally 2.5 to 5 ft long . Each interval is assigned a lithological code (see below). Assay values are %Pb,%Zn,g/t Ag and g/t Au . A pulp specific gravity is also available for most intervals .

The Faro deposit is considered as a polydeformed stratiform deposit .Several different rock and ore types can be identified . Main ore types are from the outside into the core of the deposit :

2A Graphitic quartzite ore (code 20)
2BCD Pyritic quartzite ore (code 30)
2EC Pyritic semi-massive sulphide ore (code 40)
2E/F Pyritic massive sulphide ore (code 50)
2G Barytic massive sulphide ore (code 60)
2H Pyrrhotitic massive sulphide ore (code 70)

The quartzite ore types (20 and 30) form the outside "shell" of the deposit . The massive and semi-massive sulphide ore types (40 to 70) form the core of the deposit . Most of the ore left to be mined in the S and E phase of the pit is mostly of types 20,30,40 and 50

Main waste rocks are the FW and HW phyllites (codes 100-120) , a calc-silicate breccia cap to the east (code 170) and dike material (codes 180-190) .

The stratiform deposit has been subjected to intense folding and faulting . Isoclinal folds subparallel to schistosity can be recognized . Low angle thrust faults as well as post-metamorphic extensional faults with displacement of up to several hundred feet have been interpreted on sections and plans .

Grade control uses blast hole assay data (%Pb,%Zn and %Fe) . A specific gravity is derived from grade values using a multiple linear regression formula derived from pulp SG values in drill core samples . Lithological codes of material found in each blast hole are also recorded . Blast holes are on a square grid with side from 20 to 25 ft . Blast holes are classified according to %Pb+%Zn grade limits : 3-5% is low grade (3-4 is LLG and 4-5 is LGA or LGC),5-6% is medium grade and above 6% is high grade . A first calculation of ore in the blast is done after classifying each blast hole and assigning a tonnage from the volume of influence of the blast hole (generally the blast hole grid cell) and the inferred density of the blast hole material . A second classification is done after grouping neighbor blast holes with similar grades and lithology . Limits of that second classification are used to flag ore in the blast .

LONG TERM PREDICTION FROM DRILL HOLE DATA

Current modelling technique :

Current estimation of ore reserves from drill hole data is done through a regular block model and the PC-EXPLOR/PC-MINE software package . The block grid is parallel to the NW strike of the deposit (N of grid) as well as the NE direction of drill hole sections (E of grid) . Block size is 25 ft E-W x 35.35 ft N-S x 20 ft vertical (from 1300 to 2400 tonnes depending of density) . Of course , the block reserve grid is using the same benches as the mining operation . Maximum number of columns and rows in the grid is 128 . Maximum number of benches is 50 .

In a first step , a "geological" block model is defined . This means that a single lithological code is assigned to the block . This is done by digitizing the interpreted limits of lithological units on the cross-sections . Traces of section lithological intercepts are then drawn on bench plans (mid-bench elevation) and a new interpretation of lithological limits is then done on each bench plan . It is from this interpretation that the block geology assignment is made : lithological code of the block is that of its center on the interpreted bench plan .

The next step is the interpolation of average grades (%Pb, %Zn , g/t Ag and g/t Au) and specific gravity (SG) of each block from surrounding drill hole samples . Original drill hole assay intervals are grouped into 20 ft bench composites . Composite grades are SG weighted averages of portion of drill hole assay intervals in the composites . In the latest models (F8910 and F9003) , the highest assay values (above 95th percentile of the distribution) are clipped before compositing . Important too is the lithological assignment of the composite from the lithology of intervals in the composite . It looks like the rule used is majority one i.e. the code of composite is the code of intervals with the longest cumulated length in the composite (although the internal company report describing the comparison between drill hole predictions and blast hole values mentions a different rule : code of composite is code of its mid-point i.e. a rule similar to that used for blocks) .

The selection of composites used to interpolate a block is done according to lithological code and maximum distance to block center . In the latest block models (F8908 , F8910 and F9003) blocks of quartzite ore (codes 20 and 30) are interpolated from composites of the same type and blocks of semi-massive and massive sulphide ore (40 to 70) are interpolated from composites of the same type . Hence , there are only two categories of ore for block grade interpolation . Maximum distance from block center is defined with a search ellipsoid centered on the block : long axis of the ellipsoid is always along strike (NW-SE) with a search distance between 120 and 300 ft ; intermediate axis is across strike (NE-SW) , horizontal or dipping 12 deg. or 20 deg. to the SW depending of the part of the deposit where the block is located - search distance along that axis varies from 70 to 200 ft ; short axis is along vertical (or nearly vertical) with a search distance from 14 to 37.5 ft . Block interpolation is done in two or three passes with an increasing search ellipsoid in each pass . Hence , in the first pass , only blocks close to drill holes are interpolated and the block values are very much dependent of those drill hole values . This similarity is also achieved in the latest model (F9003) by restricting the interpolation to the six closest composites (of the right lithological code) in the search ellipsoid .

Finally , once the neighbor composites are selected , the interpolation method is an inverse distance one : the final block estimate is a weighted average of selected composite values with weights inversely proportional to some power of the distance between block and composite centers . Early models used a power 2 ($1/D^2$) . Latest model (F9003) uses power 1 (1/D) and 2 ($1/D^2$) i.e. inverse distance and inverse squared distance.

Validation of modelling technique

Verification of the long term reserve model is done periodically by comparing blast hole values with estimated block values within the same limit (one year production or any particular bench in a one year production) . In Table 1 , we are reproducing the results of that comparison for the latest model F9003 which uses the latest in-fill drill hole data on the 70 x 70 ft grid in the S and E parts of the pit and both 1/D and $1/D^2$ weightings . Other parameters of that most recent model are :

- assay data and SG clipped to 95th percentile before bench compositing
- 2% reduction of SG (to allow for porosity) before compositing
- blocks of 20/30 estimated by composites of 20/30 . Blocks of 40-70 estimated with composites of 40-70 .
- search radii for first pass : 120 x 70 x 19 ft
- search radii for second pass : 240 x 140 x 19 ft
- minimum number of composites : 2
- maximum number of composites : 6

The model appears to do a very good job in 1989 but it is too much conservative in the three previous years where both grade and tonnage are underestimated . This discrepancy is more pronounced at 5% (15% underestimation of metal) than 4% cut-off (12% underestimation of metal) . It can be argued that the better performance of the model in 1989 comes from the simple fact that the additional in-fill drilling used by the model was precisely in the area mined during that year .

If we compare the 1/D and 1/D^2 weighting , as a general rule the metal quantities come very close but we find less tonnes and an higher grade with the 1/D^2: this is to be expected since the higher the power of inverse distance , the less smooth is the distribution of grade estimates .

In 1989 , with both weighting methods and at the two cut-offs , there is still an underestimation of metal by about 2% . This might come from the clipping of high grade sample values : cutting or clipping high grade is fine for local (block) estimates close to those high grade samples but overall it generates a reduction of the estimated metal quantity .

Alltogether , even if metal quantities estimates are very close , the 1/D weighting seems to give slightly better results than the 1/D^2 (tonnage and grade estimates are closer to those indicated by blast holes)

If we do a similar comparison on a bench-by-bench basis for that year 1989 (Table 2 - 1/D weighting only) , we see much more variation between predicted reserves and reserves indicated by blast holes . Benches have been ordered according to tonnage above 4% cut-off indicated by blast holes with only those benches with more than 100 Ktonnes retained . We can see two benches with major discrepancies : 3430 and 3630 . In the first case there is an overestimation of tonnes and grade at the same time . In the second case , this is an underestimation . In both cases the difference on metal is around 12,000 tonnes . In most of the other benches , there is a compensation of errors : grade is overestimated and tonnage is underestimated or vice-versa . Hence metal is generally well predicted . There are also benches like 3410 , 3610 or 3550 where the prediction of both grade and tonnage are right .

Comparison area	Blast hole	F9003(1/D)	F9003($1/D^2$)
86-87 All (+4%)	5,978 Kt	5,875 Kt	5,669 Kt
	7.87%	7.07%	7.31%
	471 Kt	416 Kt	414 Kt
86-87 All (+5%)	5,291 Kt	4,970 Kt	4,860 Kt
	8.29%	7.54%	7.77%
	438 Kt	374 Kt	377 Kt
88 All (+4%)	4,579 Kt	4,429 Kt	4,382 Kt
	8.92%	8.11%	8.26%
	408 Kt	359 Kt	362 Kt
88 All (+5%)	4,284 Kt	3,860 Kt	3,786 Kt
	9.19%	8.63%	8.86%
	394 Kt	333 Kt	335 Kt
89 All (+4%)	5,066 Kt	5,028 Kt	4,904 Kt
	7.38%	7.32%	7.51%
	374 Kt	368 Kt	368 Kt
89 All (+5%)	4,309 Kt	4,181 Kt	4,148 Kt
	7.90%	7.88%	8.05%
	340 Kt	330 Kt	334 Kt

Table 1 Comparison of blast hole indicated reserves and drill hole predicted reserves in the latest block model for various production periods and two cut-offs .

Bench	Blast hole Ktonnes	%Pb+Zn	Metal	Block model Ktonnes	%Pb+Zn	Metal
3430	696	7.07	49	759	8.09	61
3410	688	7.23	50	680	7.30	50
3390	468	7.03	33	538	6.48	35
3370	442	7.29	32	331	7.44	25
3590	428	7.89	34	368	9.22	34
3610	388	8.38	32	388	8.17	32
3630	312	7.25	23	239	5.14	12
3570	309	7.64	24	277	8.25	23
3350	238	6.67	16	225	7.49	17
3550	228	6.97	16	235	7.06	17
3650	192	8.18	16	199	6.15	12
3530	184	7.13	13	144	6.87	10
3670	145	8.20	12	208	6.56	14
3690	108	6.92	7	151	6.91	10
TOTAL	5,066	7.38	374	5,028	7.31	368

Table 2 Comparison of blast indicated reserves and drill hole predicted reserves in the latest model (F9003 with 1/D) at a 4% Pb+Zn cut-off for year 1989

Discussion :

When we estimate the average grade of a block with a weighted average of grades of bench composites nearby , there is an inference error the magnitude of which is a function of the natural difference between the grade of those composites and the grade of bench intercepts inside the block . Obviously this difference increases with the distance between the samples and the block . A way to characterize this increase of the difference between bench intercepts as a function of the distance between the intercepts is by calculating variograms of bench composites grade values . To stick to the rules of the current modelling method , we would compute and model variograms of bench composites of type 20-30 and of type 40-70 separately . Then we would use those variograms to infer the likely error for block grade estimates , in each of the two lithological groups , and using a inverse distance weighting method from composites in drill holes on various grid : 140 x 140 ft , 140 x 70 ft , 70 x 70 ft ...... The "likely error" is measured by a standard deviation of the possible errors . This "standard error" can be converted into confidence intervals for grade estimates after assuming a normal distribution for the possible errors : for example , the 95% confidence interval is +/- 2 standard errors . With the variograms of 20/30 and 40/70 bench composites , it is possible to get the standard error with any distance weighted method and obviously find out , in the two lithological groups , which power of the inverse distance gives the least error (this "optimal" weighting would give results very close to true kriging of block grades from composite grades) .

Also from the variograms of bench composite grades in the two lithological groups , it will be possible to get the standard error for the grade estimate of groups of blocks (which is less than for a single block and not a straight combination of standard errors for blocks in the group) . We can look at groups representing a month , 3 months and a year production with various proportions of 20-30 / 40-70 blocks and various drilling grids . As a result of that study , we could derive the drilling grids necessary to get less than 5% relative deviation on monthly estimates and 2% on yearly estimates (at a 95% confidence level) .

Results from the variogram study are fairly theoretical and it would be good to check them against real data . We have two sets of real data that we can use : the drill hole bench composites themselves and the blast hole data . In both cases , we estimate the grade of bench composites or blast holes from bench composites around and in the same lithological type with various distance weighting methods (including kriging) . We then check that the distribution of experimental error has a standard deviation similar to that predicted from the variogram .

The variogram study described above is fine to get the precision of block grade estimates from various interpolation methods using the same composite data . However , the ultimate comparison of those block values is with the grade distribution of blast holes inside the same blocks . Now we know by experience that blocks do not have the same variability as samples , hence , even if we had perfect block values , we would not get the same proportion and average grade of blocks and samples above a given cut-off : at a low cut-off compared to the mean of all values , we expect more tonnes and less grade for blocks ; at a high cut-off , we expect less tonnes and less grade for blocks . In fact , what we should estimate in each block so that we have a fair comparison in the end , is the likely proportion and average grade of bench intercepts (= blast holes) with a grade above the cut-off . Several methods can give this answer . We can examine two of them : 1-(log)normal shortcut : we assume that the distribution of BH grades in a block has a simple shape (normal or lognormal) , the mean of the distribution is the regular block estimate and its variance is a combination of the estimation variance (takes into account oversmoothing from uncertainty) and the expected variability of BH grades in a block 2) indicator estimation : we directly estimate the quantiles of the BH grade distribution in blocks from the surrounding bench composites . Like before , we have to validate those different estimation methods : best is to use blast hole data available . In the area where we have those blast holes we will 1) estimate blocks from bench composites with the regular distance weighting (1/D) procedure 2) do a (log)normal correction on top of those block estimates 3) run a direct indicator interpolation of the blast hole grade distribution in the blocks . We will then compare the results of the 3 methods at different cut-offs with what we get when we apply the same cut-offs directly on the blast hole data .

The two exercices that we just described do not question the "geological" framework of the long term prediction model . Basically we say that a block is 50 (massive sulfide) because its center is interpreted to be in a 50 lens and even if 30 or 40 % of the block might be in a 20 or 30 zone . Also , we say that a composite is 50 because it is mostly made of 50 intervals and even if 30 or 40% of the composite is made of intervals with a 20 or 30 rock type . So we may end up estimating blocks with a significant fraction of low grade ore with composites entirely in high grade . On the other hand , blocks entirely in high grade ore might be interpolated from composites with a significant fraction in low grade . These oddities may happen a few times after considering that most contacts between ore types are subhorizontal and they do not coincide with bench limits . To get around this approximation of the existing geological interpretation in the long term prediction model , it will be necessary to estimate partial blocks i.e. find which different ore types there are in each block and infer the grade of each ore type fraction in the block from the surrounding samples (no longer bench composites) in the same ore type . Practically , this involves the estimation of smaller blocks (e.g. 5 ft cubes) from smaller composites (e.g. 5ft) in the drill holes and the recombining of all the small block estimates in the 20 ft high block . We can test that method on the drill hole bench composites themselves : first we reestimate the grade of those composites using composites of the same type in neighbor holes ; second , we estimate the grade of each different ore type fraction of composites using values of intervals of the same type in the neighbor holes and we recombine these composite fraction estimates to get a full composite grade estimate . We then look at which estimates are closer to the real composite values .

Another approximation of the geological interpretation is the "loose" matching of ore types . With the current model , a massive sulfide block (50) might be interpolated with some semi-massive (40) composites and vice-versa . A strict matching might give better results . Again this can be checked on real data : in that case , we could use blast hole data as the reference values . We reestimate blast hole grades from bench composites with 1) loose matching 2) strict matching and determine which prediction is best . We can also compare the statistics of composite grade values in lithological types grouped together in the estimation of blocks .

A last approximation of the geological interpretation is that it forgets about faults between a block and a composite in the same ore type i.e. two composites 50 ft from a block will have the same influence on the block estimate even if one of them is separated from the block by a fault and the other is not . However taking individual faults into account in the estimation of blocks might just be the limit of block reserve models with distance weighted grade interpolation method . The alternative is a sectional model with a large number of small "geological" blocks interpreted on sections . There is no internal variation of grade in each block : grade estimate is the plain average of drill hole intervals in the block . "Geological" block estimates can be recombined into any kind of 20 ft high "mining" blocks . This method is the one commonly used in highly folded and faulted stratiform deposits with strong geological controls like the iron ore deposits of Labrador or Western Australia . However building and testing such a detailed sectional model is beyond the scope of this study but it would be worth to, internally, test it on a few sections.

Tasks to be accomplished :

A-Grade interpolation of blocks (or groups of blocks):errors with various methods and drilling grids:

- conduct a statistical study of %Pb , %Zn and %Pb+Zn values of bench composites in units 20-30 and 40-70 (histograms,statistics and correlation)
- calculate and model a 3D variogram of %Pb , %Zn and %Pb+Zn values of bench composites in units 20-30 and 40-70 .
- use variogram models to get standard errors for block estimates of %Pb,%Zn and %Pb+Zn in the two lithological units and with various drilling grids and distance weighting methods (including kriging).
- use variogram models to get standard errors for estimates of average %Pb,%Zn and %Pb+Zn of groups of blocks representing a month , 3 months and a year production .
- validate standard error prediction by estimating bench composites and blast holes from nearby bench composites of the same lithological type . Compare standard deviation of experimental errors with predicted standard errors from variograms .

B-Correction of block estimates for proportion and grade of blast holes in blocks :

- recognize all blocks in the area where we have blast holes with coordinates (benches 3530 to 3570) . Determine the lithological type of those blocks (from bench map or BH lithology)
- perform a regular 1/D grade interpolation of those blocks using bench composites around (20-30 and 40-70 estimated separately) . Get tonnes and grades above various cut-offs (3%,4%,5% and 6%) directly from block estimates .
- perform a (log)normal correction on top of block estimates . Recalculate tonnes and grades at various cut-offs now using the block corrected values (fraction and grade of blocks with BH above cut-offs)
- do an indicator estimation of the BH grade distribution in each block . Calculate a third set of tonnes and grades from those estimated distributions .
- finally , compare the 3 sets of estimates with results obtained after applying cut-offs directly to blast hole data .

C-Testing the "geological framework" of the long term model :

- reestimate bench composite grades from composites in neighbor holes using 1) full composites 2) separate ore type fractions in composites . Determine if composite grade estimates are significantly better in the second case .
- compare statistics, histograms and correlation features of bench composites grades in ore types which are merged together in the estimation (20 and 30 , 40 and 50 and 60 and 70) .
- estimate blast hole grades from nearby bench composites with 1) loose matching 2) strict matching of ore types .

SHORT TERM PREDICTION FROM BLAST HOLE DATA

Current modelling technique :

As explained above , the processing of blast hole data to define the limits of the different ore types in a blast is fairly straightforward : blast hole assays (%Pb , % Zn and % Fe) as well as lithology are put on bench maps . Each blast hole is assigned a volume of influence corresponding to the blast hole grid (from 20 x 20 ft to 25 x 25 ft) . Volume is transformed into tonnage using a specific gravity derived from blast hole grades from a multiple linear regession formula . Then the grade control geologist manually groups neighbor blast holes with similar grades and lithology . Tonnage and grades of material in each ore category (low , medium and high grade) in the blast are then derived from those groupings .

Validation of modelling technique :

The way to validate the prediction of the short term model is to compare them with mill results over the same period of time . Unfortunately , in the case of Faro , this comparison is difficult because of the large stockpiles of the different ore types . One can never be sure of which time the ore currently milled has been mined . Hence when grade control says that , in that blast , there is 60,000 tonnes of high grade at 8.45% Pb+Zn , tonnage is fine because it is exactly what is sent to the high grade pile but grade might less than 8% or more than 9% .

Discussion :

Formally , the current short term prediction model is also a block model with a distance weighting grade interpolation method : blocks are the 20 x 20 ft or 25 x 25 ft volumes of influence of a blast hole and the interpolation method is nearest-neighbor (or polygon) i.e. the grade estimate for a block is the grade of the single sample in the middle . Like for the long term prediction model from drill holes , it is possible to assess the standard error of single blast-block grade estimate or a group of them . We just need compute and model variograms of blast hole grade . Such variograms have already been computed and they seem to be quite interpretable .

The variograms may also indicate that a better blast-block interpolation method than polygon could be used . Those calculated so far tend to show a significant nugget effect (1/3 of total variation is random , probably blast hole sampling error) . In that case , any distance weighting method using several neighbor blast holes around the blast-block to estimate would do better than nearest-neighbor . Obviously , this blast-block grade interpolation method must take into account the various lithologies of the blast holes (BH in dike should not be used to interpolate nearby blast-block around BH in massive sulphide) . Like for long term prediction model from drill hole , the foreseen advantages of this alternative short term prediction model must be checked on the blast holes themselves .

Tasks to be accomplished :

- conduct a statistical study of %Pb , %Zn and %Pb+Zn of the available blast holes in units 20-30 and 40-70 (histograms , statistics , correlation)
- calculate and model 2D (3D?) variograms for those blast holes . Try and relate nugget effect to available check sampling results conducted on blast holes .
- from the variograms , determine the standard error for the grade estimate of a blast-block derived from the blast hole in its center . Also determine the standard error for groups of blast holes .
- define a new blast-block grade interpolation method more consistent with the variograms Illustrate the results of the two methods on a bench .
- cross-validate the two grade interpolation methods on the blast holes themselves

DATA GATHERED

During our visit to Faro , we have gathered all the data necessary to conduct the geostatistical analysis study described here . Data files have been checked on our system and they are usable . We basically have 3 data files :

- drill hole data file : we have lithology and assay data (%Pb , % Zn) for 429 holes from the early 66 ones up to 90-F-93 . We have 3287 lithology intervals (codes 20,30,...) and 10899 assay intervals .
- drill hole bench composite file : we have mid-point coordinates , assigned lithology and calculated %Pb and %Zn as well as SG of a maximum of 7333 20ft D.H. bench composites (5733 with calculated assays)
- blast hole data file : we have coordinates , lithology and assay data (%Pb , %Zn and %Fe) of 1607 blast holes in benches 3530,3550 and 3570 . This is of course just a fraction of all blast holes but they are the only ones with digitized coordinates .

We also have interpreted lithological limits on 3 cross-sections (with drill hole traces) and 4 benches (with location of D.H. bench composites and their values) ; 3 of those benches are those where we have the blast holes (3530-3570) .

SYSTÈMES
GEOSTAT
INTERNATIONAL INC.

Montreal October 1st, 1990

Mr. Dave Tenney
Chief Geologist
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Dear Dave,

Please find herewith a final version of the report on the geostatistical analysis of Faro drill hole and blast hole data. Our conclusions and recommendations are at the very beginning of the report. Basically we have identified 3 sources of differences between estimates and true values:

+ spatial inference errors: they can only be reduced with more drill holes - numbers are in the report - kriging does not improve estimates that much over inverse distance.

+ oversmoothing of block estimates: a simple "lognormal shortcut" correction of the regular block estimate can reduce this type of error very significantly.

+ uncertainties of the geological model: we found many inconsistencies between the ore type classification of drill hole samples and blast holes specially in types 20 and 30. We can see room for much improvement in a better geological model.

We also show that it is worth implementing a fairly simple (absolute variograms with ordinary kriging) blast hole kriging plan in order to improve recoveries at various cut-offs. In the example that we ran, we have found a 12% increase of recovered tonnage at the 6% cut-off with estimated grade right on target.

I hope that this study can help you improve ore reserve estimation at Faro and its related deposit. I will of course answer any question that you may have or any clarification that you may need.

Yours sincerely,

GEOSTAT SYSTEMS INTERNATIONAL INC.
for
Michel Dagbert, Manager

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GEOSTATISTICAL ANALYSIS OF FARO DRILL HOLE AND BLAST HOLE DATA

PART 2 : ANALYSIS

Respectfully submitted to Curragh Resources Inc.
by Geostat Systems International Inc.
Montreal , October 3rd, 1990

FOREWORD

This is the second part of the geostatistical analysis of Faro drill hole and blast hole data. First part of the study was presented in a report of July 27th, 1990. It defined the objective of that second part of the study namely 1) determine the magnitude of estimation errors for various block sizes and drilling grids 2) determine ways to reduce those estimation errors 3) evaluate other alternatives for processing blast hole data to categorize ore in blasts. This work is covered by the P.O.# D-129004 of August 10th, 1990, from Curragh Resources Inc., to Geostat Systems Int'l Inc.

CONCLUSIONS AND RECOMMENDATIONS

1- In the calculation of tonnes and grade above cut-off, we have identified 3 major sources of differences between estimates derived from D.H. data and values derived from B.H. data in the same area: spatial interpolation errors, oversmoothing of distance weighted estimates and uncertainty of the geological model.

2- **The spatial interpolation errors** can be quantified by means of variograms calculated on drill hole bench composite values in the various ore types. If we stick to the current segregation of the quartzite ores (20, 30) and sulfide ores (40 - 70), then the average precision of 25' x 35' x 20' block % Pb + Zn grade estimates at a 95% confidence level are: ± 67% in 20-30 and ± 50% in 40-70 from drill holes on a 140' grid, ± 47% in 20-30 and ± 37% in 40-70 from drill holes on a 70' grid.

3- The above confidence intervals are quite large but they apply to rather small blocks. If we now consider groups of blocks which may represent a month, a quarter or a year production, we have the following average precision (still at a 95% confidence level) for tonnage and %Pb + Zn grade estimates above cut-offs : for a month and with the 140' grid: from ± 44% for tonnage above 6% cut-off to ± 14% for grade above 6% - for a month but with the 70' grid: from ± 22% to ± 7% - for a year with the 140' grid: from ± 13% to ± 4% - for a year with the 70' grid: from ± 6% to ± 2%. Previous figures assume a production made 50% from 20-30 and 50% from 40-70.

4- Precision of estimates for large volumes depends of drilling grid, ore type and cut-off. Uncertainty on tonnage above cut-off increases with cut-off and, at the 6% cut-off, is higher in 20-30 than in 40-70. Uncertainty on % Pb + Zn grade above cut-off is not as bad. It now decreases with cut-off and is less in 20-30 than in 40-70. Also, to get a ± 5% precision on all monthly estimates, we need a drilling grid between 35' and 40' at 3% cut-off and between 15' and 20' at 6% cut-off. The ± 2% yearly precision is easier to achieve: we can get it with just a 50' grid at the 3% cut-off but we need a 25' grid at the 6% cut-off.

5- The above quantification of spatial interpolation errors rests on variograms of D.H. bench composite grades in the two groups of ore types. With close to a thousand data points in each group, those variograms are well defined : relative nugget effects range from 35% (40-70) to 50% (20-30) of total variation; in 40-70, horizontal variations are isotropic with a maximum range of 600'; in 20-30, range along N-S (400') is much longer than along E-W (150'); in both groups, there is a strong vertical anisotropy with vertical range not exceeding 60' in 20-30 and 180' in 40-70. Variogram features and the resulting assessment of the magnitude of spatial interpolation errors are confirmed by a D.H. bench composite reuse study. For example, in 20-30, out of 719 reestimated composites, 480 (67%) have an estimation error less than the predicted standard error and 683 (95%) have an estimation error less than twice the predicted standard error: this is an almost perfect fit of estimated and actual errors.

6- Variograms of D.H. bench composites also indicate only minor differences between kriged estimates and inverse distance estimates for the same blocks. The power of inverse distance which gives results closer to kriging is between 1.0 and 1.5 and between 1.5 and 2. DEPENDING ON ROCK TYPE

7- The <u>oversmoothing of distance weighted block estimates</u> is quite noticeable in the Faro long term block model: if you apply a cut-off on block estimates derived from D.H. bench composites, you always find more tonnes and a lower grade than what is indicated by the distribution of blast holes in the same area. In 20-30, tonnage differences are as much as 30% (5% cut-off) and grade differences reach 17%. In 50-70, maximum tonnage and grade differences are respectively 14% and 7%.

8- A way to overcome the oversmoothing of straight block estimates is to infer the likely proportion and grade of blast holes above the cut-offs in each block. A simple correction of block estimates dubbed "lognormal" short-cut reduces maximum tonnage differences to 8% in 20-30 and 3% in 50-70. With that correction, maximum grade differences are only 5% in 20-30 and 2% in 50-70.

9- All the above conclusions assume that the <u>"geological model"</u> is correct e.g. when we assign a code 20 to a block (and thus, we infer its grade from just 20-30 D.H. bench composites around), the type of ore in that block is actually 20 (or 30). To validate that assumption, we have compared the ore type of a D.H. bench composite to the ore type of the nearest B.H. (in the same bench and at a distance of less than 20'). We found that the classification of the predominantly high grade types 50 + 60 + 70 is consistent from drill holes to blast holes since nearly 70% of the D.H. composites of that type have a B.H. of the same type next to them. However, we have more problems with types 20 and 30: in that case, more than 50% of the D.H. composites of those types have a B.H. of type 50-70 nearby. We suggest that the criteria used to classify D.H. samples and B.H. of type 20-30 be revised so that we have more consistency in the classification of the two types of samples.

10- Another suggestion related to the geological model is to separate type 40 from types 50, 60 and 70 in the estimation of blocks even if they all refer to sulfide ore. Statistics of type 40 D.H. composite grade values indicate that they are much lower than for the other categories of sulfide ores. As a result, there is a danger to underestimate a type 50-70 block with a type 40 composite next to it and overestimate a type 40 block with a type 50-70 composite nearby. In fact, in the comparison of block estimates with B.H. values in those blocks, better results were achieved after isolating type 40 composites (and type 55 blast holes).

11- This geostatistical analysis of D.H. bench composites data can be extended to blast holes. The idea here is to see whether there is a better procedure to delineate ore limits in blasts than just contour individual blast hole grades. From the test data set of about 2000 blast holes in the south part of benches 3450, 3470 and 3490, we found that:

+ if we krige the grade of blast blocks from blast holes and then apply the cut-off on those blast block estimates, the actual grade of the material that we recover is the estimated grade.

+ if we contour individual blast hole values, the actual grade is less than the expected grade (in the example that we ran we noticed a 8.5% shortfall at the 6% cut-off). Moreover, we get less tonnes than if we do the selection on kriged estimates (12% in our example).

+ recovery based on kriged blast blocks estimates is even better if we process blast holes of type 20-30, 50-60-70 and 40-55 separately.

+ blast block kriging can easily be implemented with blast hole variogram models. Horizontal variograms of groups of a few hundred of blast holes around a blast are quite interpretable. They generally show the same features as the corresponding variograms of D.H. bench composites. In particular, their nugget effect is the same hence it looks like the sampling precision of blast holes is as good as that of drill holes.

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1-LONG TERM PREDICTION FROM DRILL HOLE DATA

1-1 Statistical analysis of D.H. bench composite data

The current file of DH 20 ft bench composite data that we received from Curragh Resources Inc. has values for 7333 composites from 419 drill holes (from 65-53 to 90F93). For each composite, we have the 3 coordinates of the center point of the composite, its principal rock type (from 20 to 190 - 1608 composites have an undefined rock type of -1), the calculated grades for %Pb, %Zn and %Pb+Zn and the calculated specific gravity (with some undefined values of -1.0 too).

Out of this total, only 1730 composites are in the "mineralized" rock types i.e. 20,30,40,50,60,and 70 (3783 composites are in rock type 100 i.e. the top and bottom phyllites - 407 of them have a non-zero Pb+Zn value - surprisingly,31 composites in this supposedly "waste" rock type have a Pb+Zn grade above 6% with an overall maximum of 9.07 %) - In the current long term model, mineralized composites are grouped in two categories : "quartzite" ore (20+30) and semi-massive and massive sulfide ore (40+50+60+70) - Figure 1 is a map of those mineralized composites in one of the bottom bench of the pit, bench 3450, between elevations 3450 and 3470 '. On this map, we can see the 140' drilling grid in the center and north part of the pit (now mined-out) and the 70' drilling grid in the south part (now being mined). We see also that, as a general rule, the quartzite ore (20 = circles and 30 = triangles) is around the deposit whereas the sulfide ore (40 = plus, 50 = cross ,60 = diamond and 70 = arrow) is in the center. After producing this map from the composite file , we noticed many discrepancies between the rock type of composites in the file and the interpreted limits of the different ore types on the same bench as shown on a map received from the company. Staff at Curragh has been notified of these discrepancies (our fax of Aug. 21).

We can calculate summary statistics of composite values in the different mineralized rock types. They are shown on Table 1 for quartzite composites and table 2 for sulphide composites. Typical histograms of %Pb+Zn are on figures 2 (type 40 - skewed distribution) and 3 (type 50 - normal distribution). Our conclusions :

- distributions of Pb+Zn,Zn and Pb values are positively skewed and lognormal like in the low grade rock type 40 (Figure 2). Distributions are symmetric and normal like in the rather high grades rock types 50 , 60 and 70 (Figure 3). Distributions of values are slightly skewed in 20 but rather normal in 30 .

- except for the difference in shape described above, parameters of the distributions in 20 and 30 are fairly similar (there is a little more lead in 30) and it makes sense to group those two ore types in the estimation of blocks .

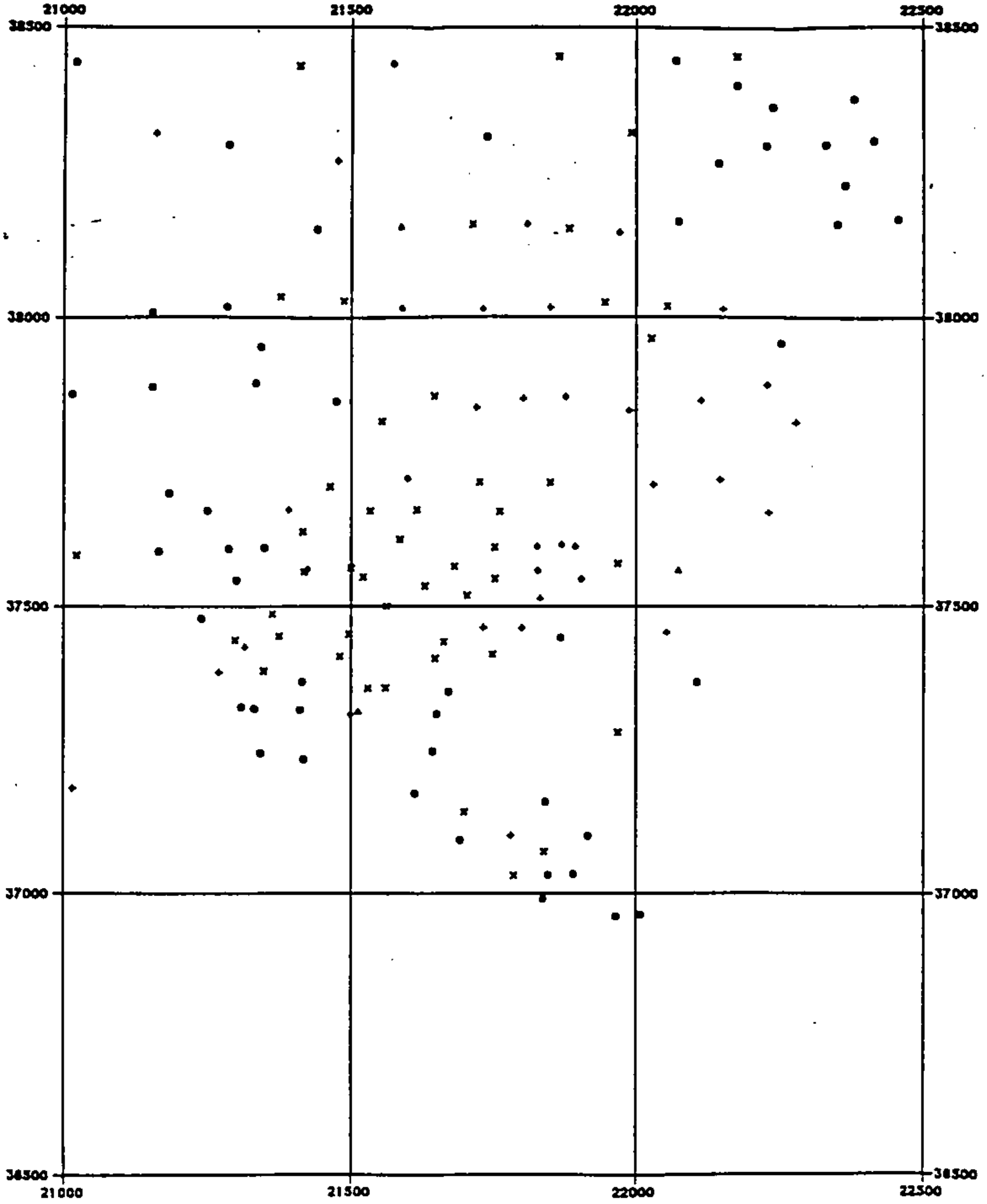
- on the other hand, the distributions of values in 40 are quite different from those in 50 , 60 and 70 and it does not seem logical to put all those composites in the same group . 40 has the lowest values of all ore types whereas 50 , 60 and 70 have the highest values . With this scheme , we may have potential problems when a high grade block 50 is estimated with a low grade composite 40 nearby and vice-versa

- the highest relative dispersions (coefficients of variation above 60 %) are in the low grade 40 . Then we have about the same dispersion in 20 and 30 (coefficients of variation between 55 and 60 %) . The lowest dispersion is in the high grades 50 , 60 and 70 (coefficients of dispersion between 30 and 40 %) . Hence , for the same drilling grid , precision of block estimates is expected to be better in high grade ore (50+60+70) than low grade ore (20+30) .

- production Pb+Zn cut-off grades (3,4,5 and 6%) are quite high compared to mean values of Pb+Zn in some ore types . The high grade cut-off of 6% is above the median of distributions in 40 , 20 and 30 . Then we can expect more difficulties in locating the high grade ore in those ore types .

There is a high degree of correlation between %Zn and %Pb in all ore types . Correlation coefficients range from 0.75 in 50 (Figure 4) to 0.86 in 20 (Figure 5) . Type 20 is also the ore type where the average ratio %Zn/%Pb is the highest (2.0 vs 1.3 to 1.6 in the other ore types) .

Figure 1 Map of "mineralized" DH composites in bench 3450 . (20 = circle , 30 = triangle, 40 = plus , 50 = cross , 60 = diamond , 70 = arrow)



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SYSTEMES GEOSTAT INTERNATIONAL
CURRAGH RESOURCES INC.
D.H. COMPOSITES IN BENCH 3450

Figure 2 Histogram of Pb+Zn grades of composites in type 40

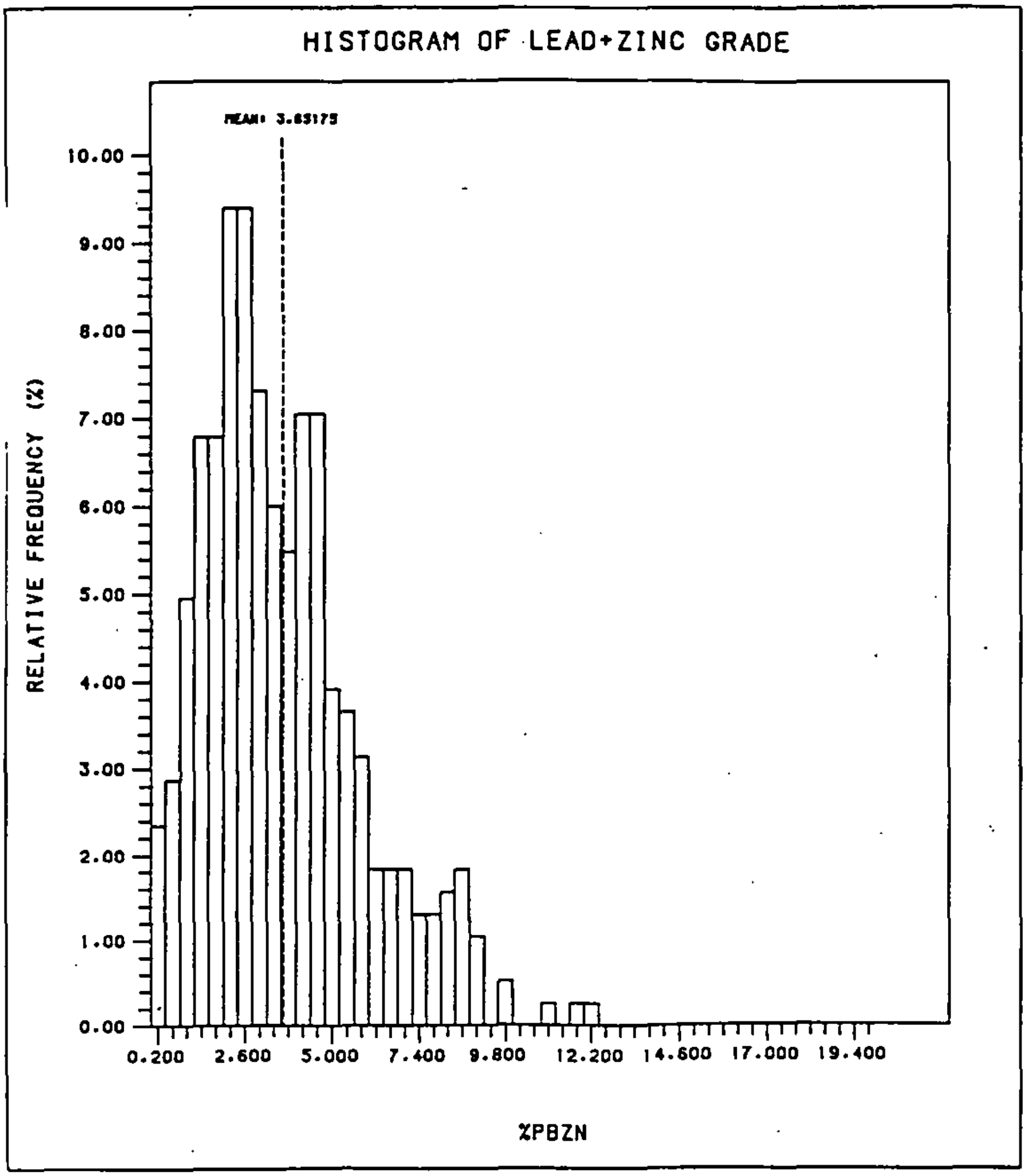


Figure 3 Histogram of Pb+Zn grades of composites in type 50

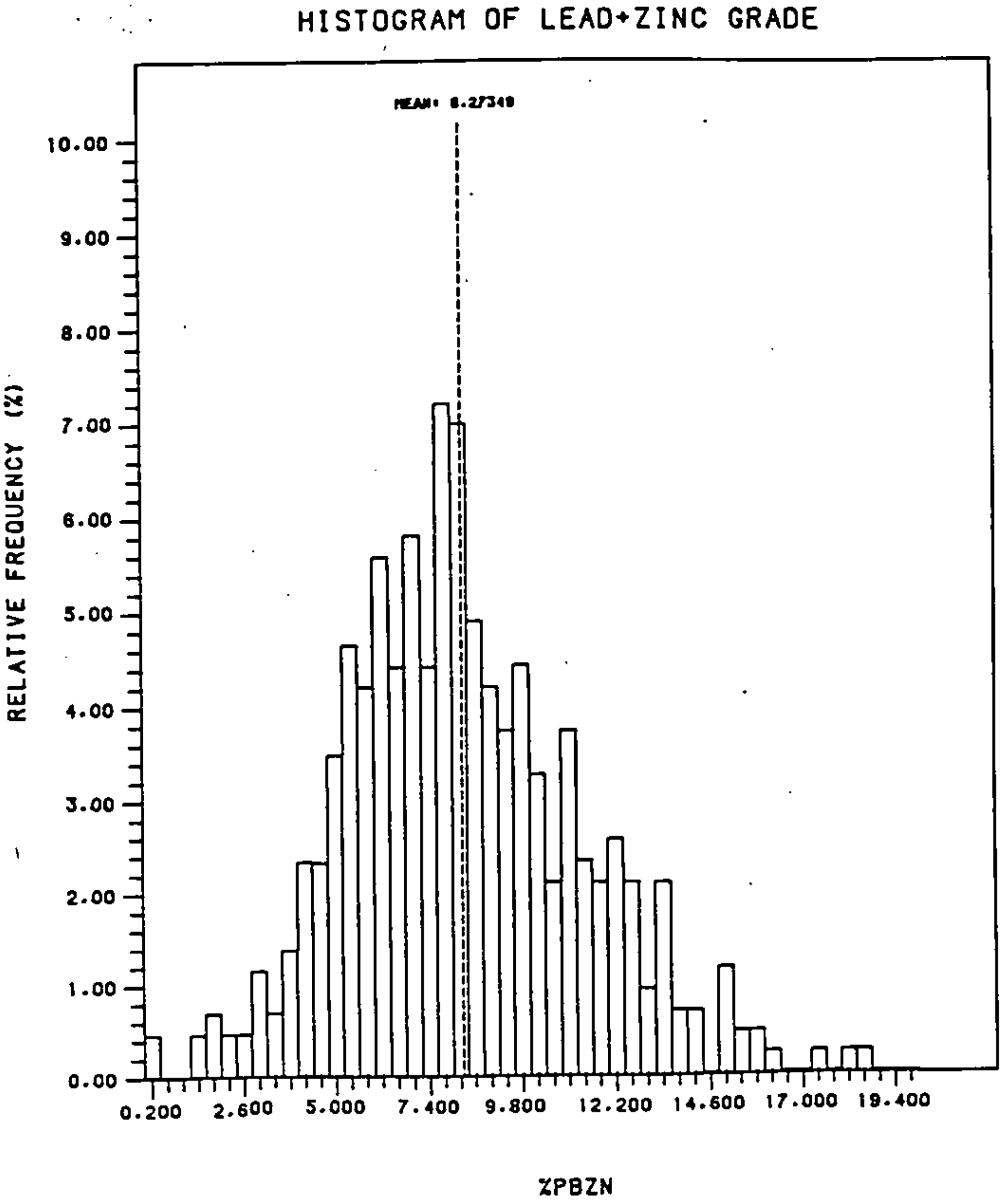


Table 1 Statistics of %Pb+Zn composite data

	20	30	20+30	40	50	60	70	40-70
Number	639	103	742	383	430	109	66	988
Minimum	0.0	0.0	0.0	0.0	0.0	3.0	1.84	0.0
Percentile 5%	1.12	1.36	1.04	0.77	3.84	4.75	3.64	1.32
Percentile 16%	2.40	2.19	2.38	1.56	5.42	6.40	5.75	2.62
Percentile 50%	4.73	5.33	4.81	3.22	7.98	9.40	9.33	6.47
Percentile 84%	7.84	8.62	7.96	5.71	11.45	12.06	12.37	10.40
Percentile 95%	10.12	11.09	10.23	8.17	13.48	14.70	14.39	13.12
Maximum	16.10	12.97	16.10	12.34	18.64	17.49	15.63	18.64
Mean	5.10	5.55	5.16	3.65	8.27	9.44	9.12	6.67
Standard deviation	2.81	3.17	2.87	2.22	3.04	2.98	3.11	3.67
Coefficient of variation	55	57	55	61	37	31	34	55

Table 2 Statistics of %Zn composite data

	20	30	20+30	40	50	60	70	40-70
Number	639	103	742	383	430	109	66	988
Minimum	0.0	0.0	0.0	0.0	0.0	1.77	1.23	0.0
Percentile 5%	0.68	0.09	0.58	0.36	2.00	2.29	1.85	0.82
Percentile 16%	1.59	1.26	1.57	0.99	3.13	3.52	3.30	1.63
Percentile 50%	3.16	3.19	3.16	2.00	4.97	5.41	5.57	3.90
Percentile 84%	5.15	5.66	5.21	3.48	7.26	6.77	7.02	6.30
Percentile 95%	7.01	6.92	7.00	5.14	8.57	8.25	8.76	8.17
Maximum	10.27	9.03	10.27	7.56	12.04	10.40	9.38	12.04
Mean	3.40	3.40	3.40	2.25	5.10	5.33	5.42	4.04
Standard deviation	1.90	2.03	1.92	1.39	2.03	1.79	1.88	2.27
Coefficient of variation	56	59	56	62	40	33	34	56

Table 3 Statistics of %Pb composite data

	20	30	20+30	40	50	60	70	40-70
Number	639	103	742	383	430	109	66	988
Minimum	0.0	0.06	0.0	0.0	0.0	1.07	0.61	0.0
Percentile 5%	0.36	0.79	0.33	0.21	1.35	2.07	1.23	0.34
Percentile 16%	0.74	1.26	0.74	0.42	2.06	2.79	2.36	0.95
Percentile 50%	1.50	2.09	1.56	1.23	3.05	3.95	3.70	2.57
Percentile 84%	2.65	3.31	2.80	2.38	4.33	5.50	5.18	4.11
Percentile 95%	3.55	4.07	3.69	3.14	5.32	6.71	5.78	5.32
Maximum	5.83	5.96	5.96	4.78	7.35	7.59	7.11	7.59
Mean	1.69	2.15	1.76	1.40	3.17	4.11	3.70	2.63
Standard deviation	1.00	1.29	1.05	0.96	1.21	1.38	1.40	1.54
Coefficient of variation	59	60	60	68	38	33	38	58

Figure 4 : Scattergram of Zn and Pb composite values in ore type 50

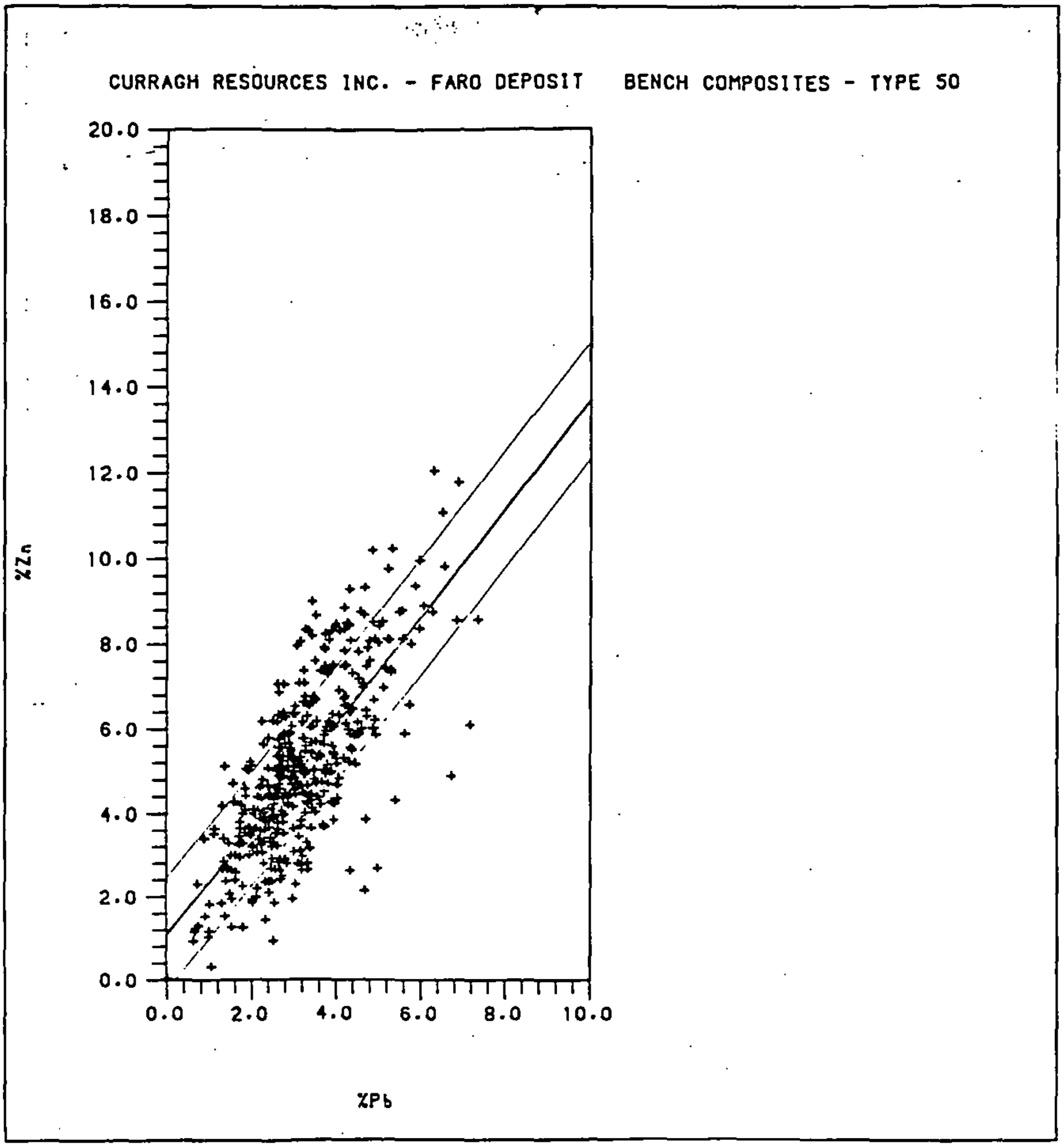
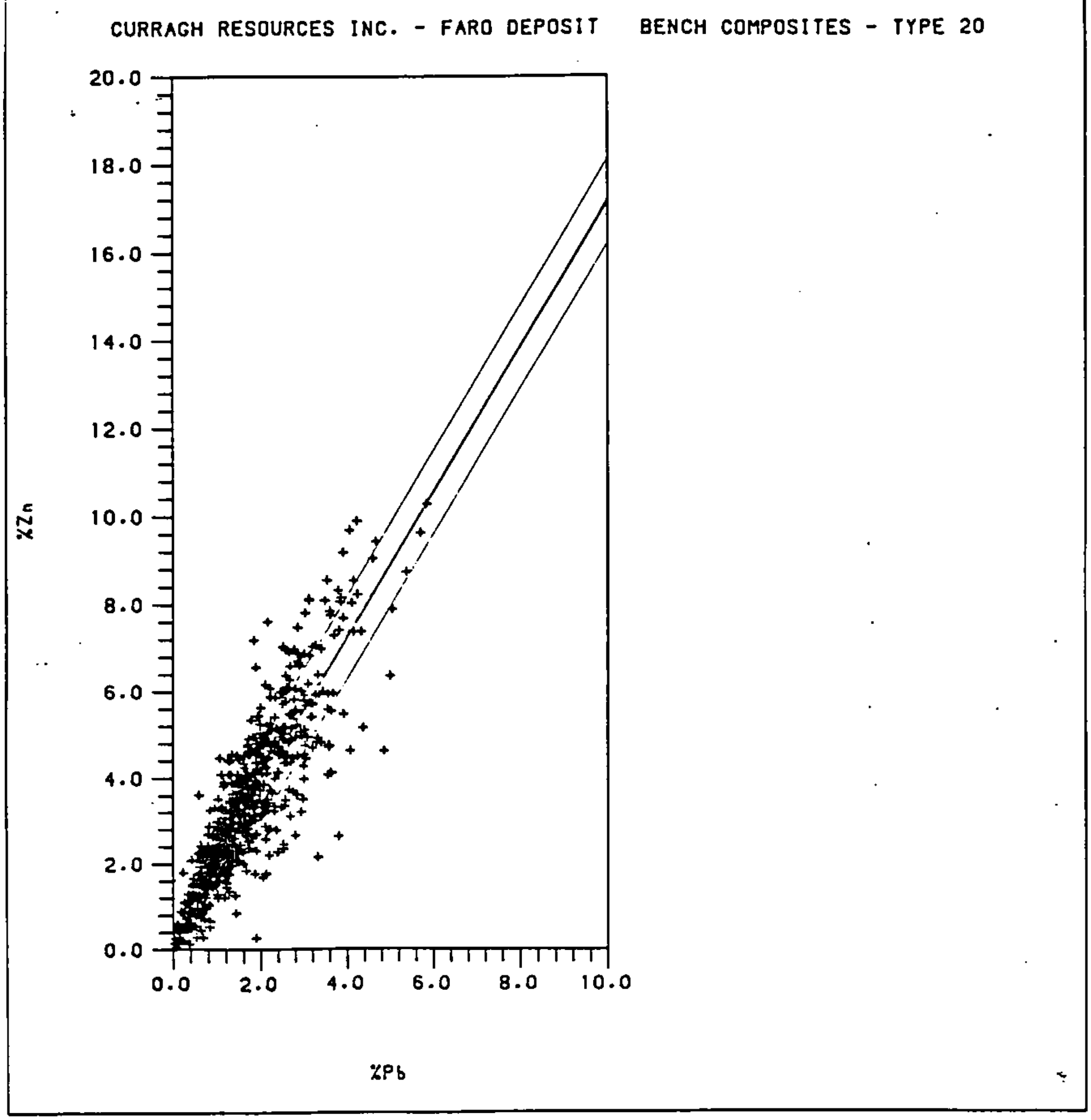


Figure 5 : Scattergram of Zn and Pb composite values in ore type 20



1-2 Variogram analysis of D.H. bench composite data

Variograms are diagrams showing the average difference between sample values as a function of the distance between samples . Variograms are computed along specific directions since the rate of increase of differences with distance may not be the same in all directions . Variograms are helpful in 1) assessing the magnitude of errors in the estimation of blocks 2) determining the most suitable estimation method for the blocks (e.g. choosing between 1/d or $1/d^2$) .

To keep consistent with the estimation method currently used at Faro , we have computed variograms of the grades and SG of bench composites in ore types 20-30 and 40-70 separately . Note that there is not enough composites in types 30, 60 and 70 to derive meaningful 3D variograms specifically in those ore types . However , it is quite feasible to have specific variograms for type 40 (and others for types 50,60 and 70 together) .

In both cases , variograms are computed along the vertical direction of most D.H. (angular tolerance 10 degrees - step for distances 20 ') and the four principal directions of the horizontal benches i.e. E,NE,N and NW (tolerance 45 degrees - step for distances 75 ') . In addition the omnidirectional variogram (tolerance 180 degrees) and an average horizontal variogram are computed . Variograms are of the absolute type with no transformation of raw data nor clipping of some high values .

Figure 6 shows the vertical variogram of %Pb+Zn together with the omnidirectional variogram in ore type 20-30 . We can notice an apparent nugget effect of about 4 (50% of overall variation) and higher differences along vertical than average (anisotropy) . Vertical range does not seem to exceed 60' . On figure 7 , we have the horizontal variograms of the same data : nugget effect is still very much apparent as well as some anisotropy . In this case , for short distances , the lowest curve (best continuity) is along N-S and the highest one (worst continuity) is along E-W . Also , NE is below average and NW is above average . A suitable model for the variogram of %Pb+Zn in 20-30 would be the sum of a nugget effect of 4 and a spherical function of sill 4.2 , long range 400' along N-15°-E , intermediate range of 150 ' along E-15°-S and short range of 60' along vertical . Variograms for the %Zn and %Pb grades in 20-30 are of the same type (Table 4) : the only noticeable difference is for %Pb with a truly N-S long range of 500'.

In 40-70 , the vertical variogram of %Pb+Zn is also above the omnidirectional variogram (Figure 8) . Apparent nugget effect is less than in 20-30 (35 % of overall variation) and vertical range is longer (180 ') . Along horizontal directions of the benches (Figire 9), variograms are almost linear with no apparent anisotropy . Model used is the sum of a nugget effect of 4 , a short range spherical function (60' horizontal and 40 ' vertical) and a long range spherical function (600' horizontal and 180 ' vertical) . Models for %Pb and %Zn are very much similar (Table 4) .

In conclusion , for both groups of ore types , it is feasible to define meaningful variograms for DH bench composite data . Horizontal ranges are generally several times the drill hole spacing . The only exception is with 20-30 where the E-W range is of the same order of magnitude as the original spacing between holes . Hence for this type of ore , additional holes at 70' distance on E-W section lines is quite an improvement . Also relative nugget effects are higher in 20-30 than in 40-70 which means that grade interpolation is more difficult in this type of ore (in other words , for the same drilling grid and block size , relative errors are likely to be higher)

Figure 6 Vertical and omnidirectional variogram of %Pb+Zn in type 20-30

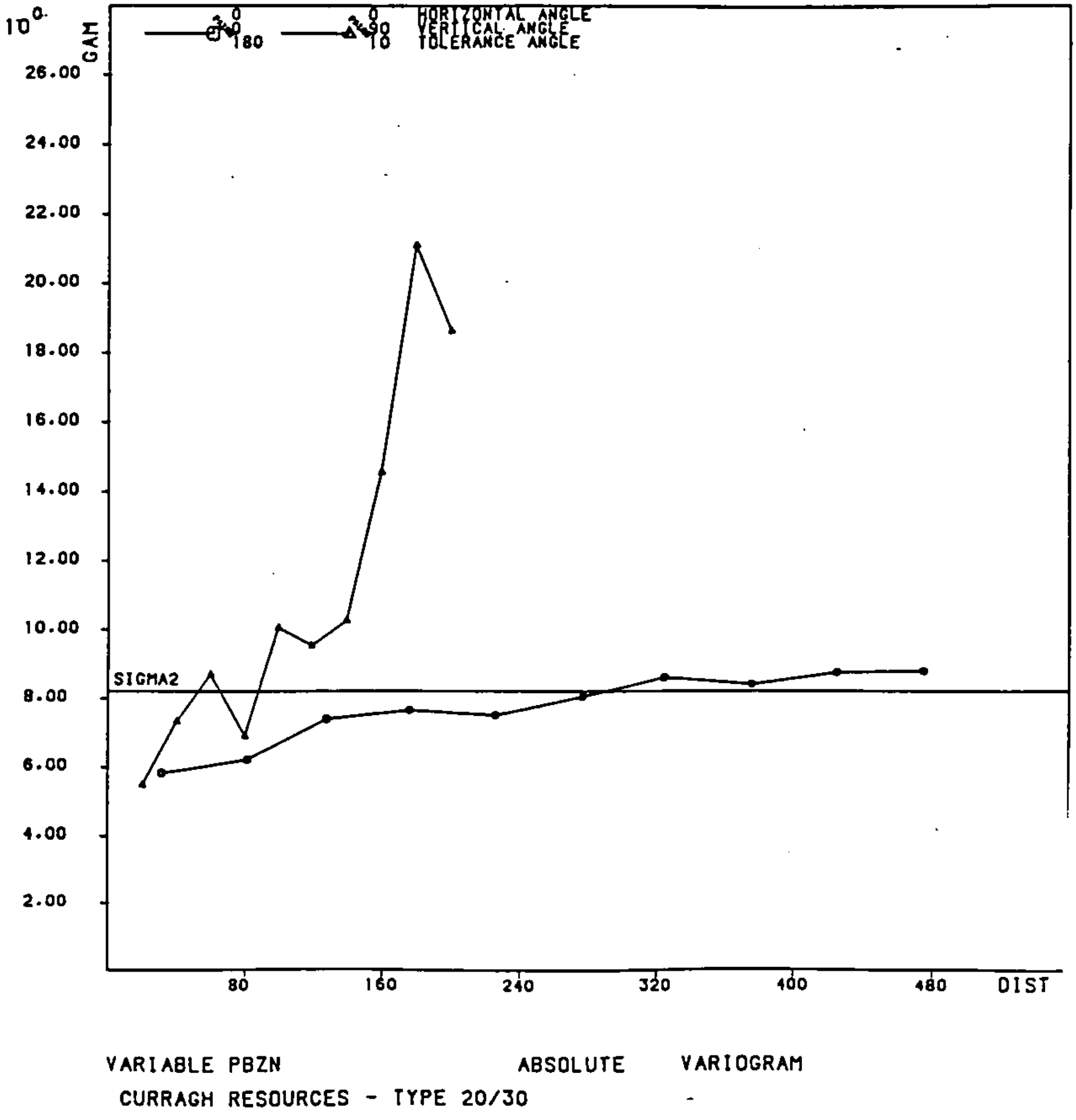


Figure 7 Horizontal variograms of %Pb+Zn in type 20-30

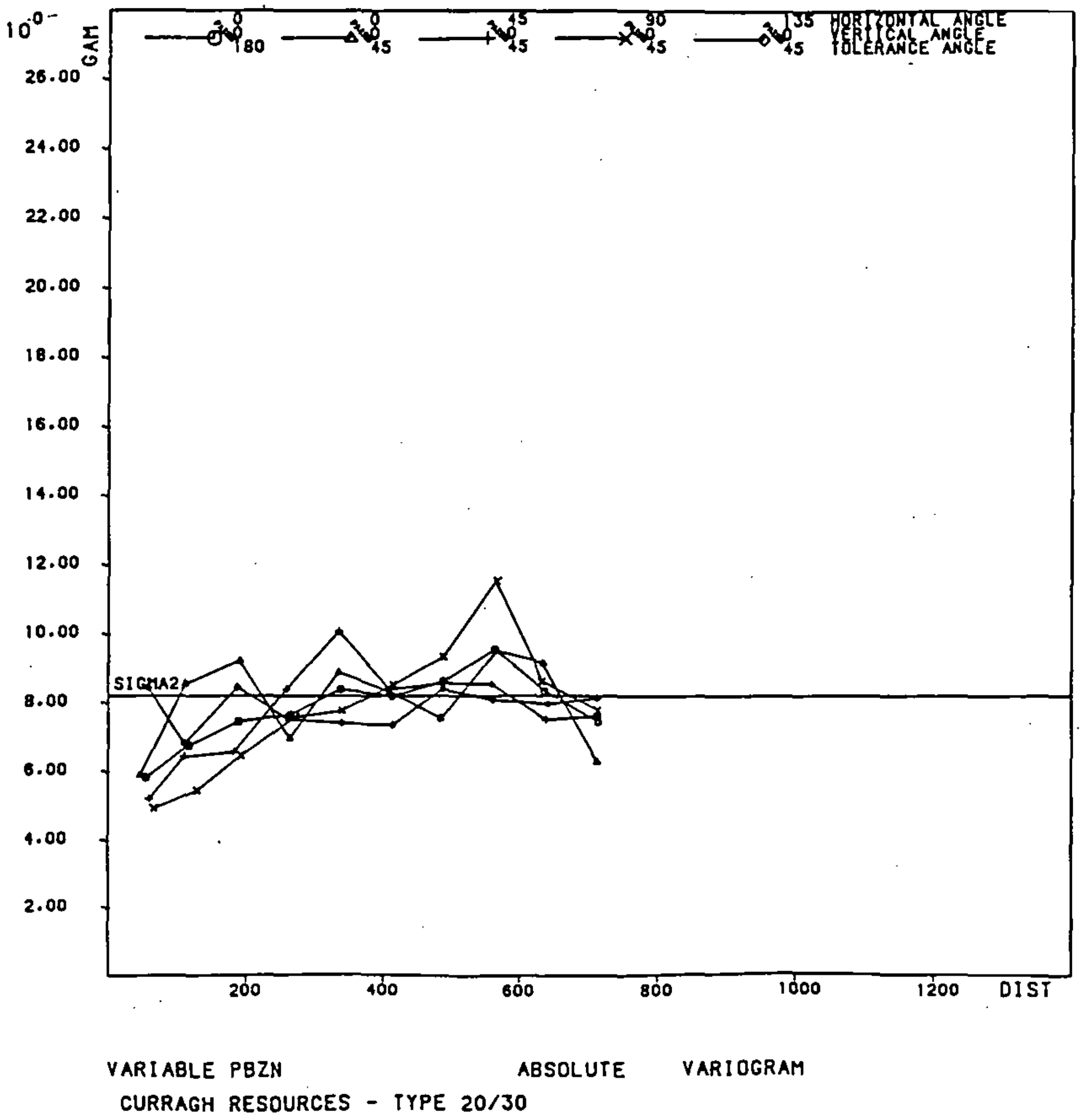


Figure 8 Vertical and omnidirectional variogram of %Pb+Zn in type 40-70

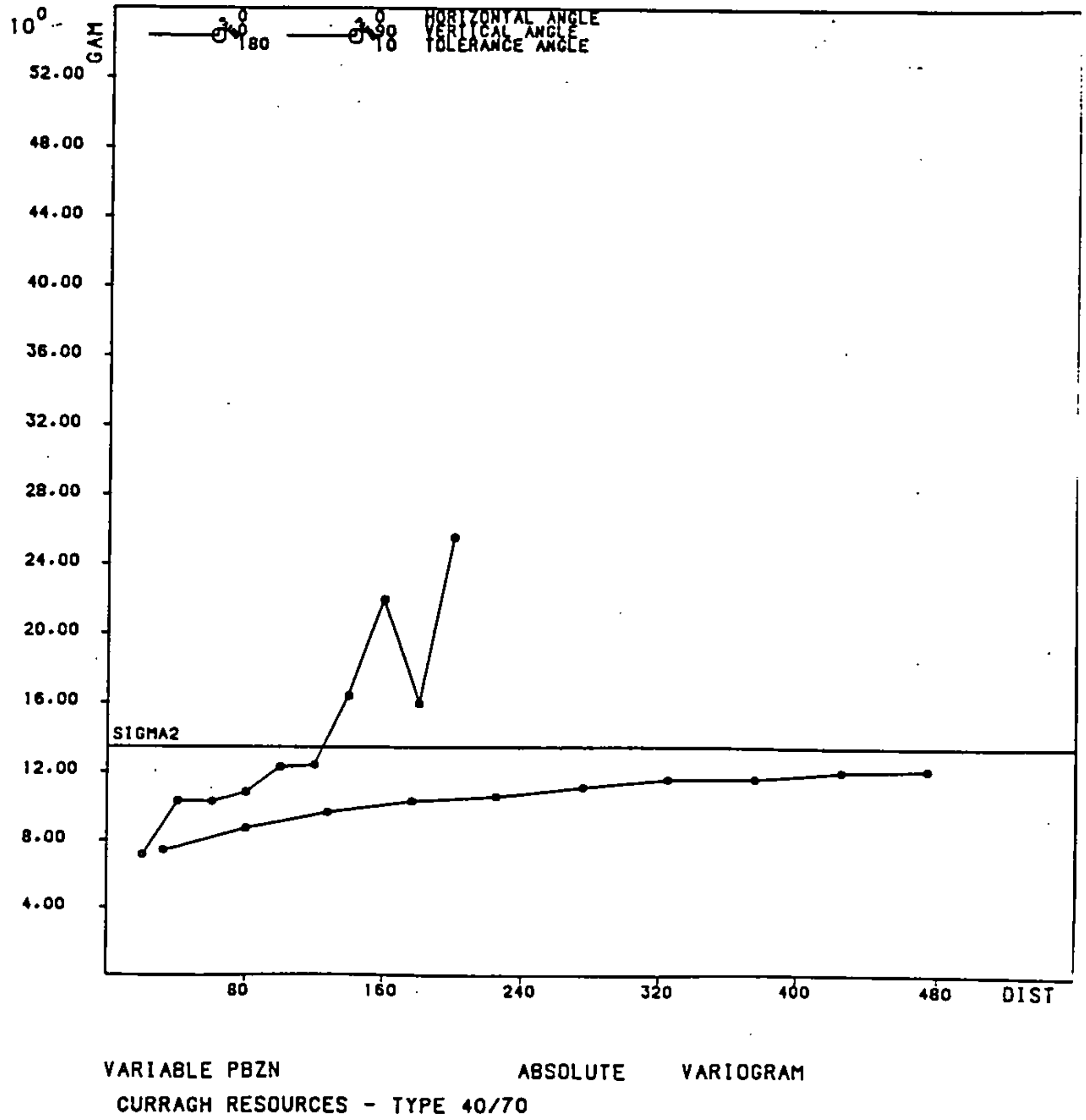
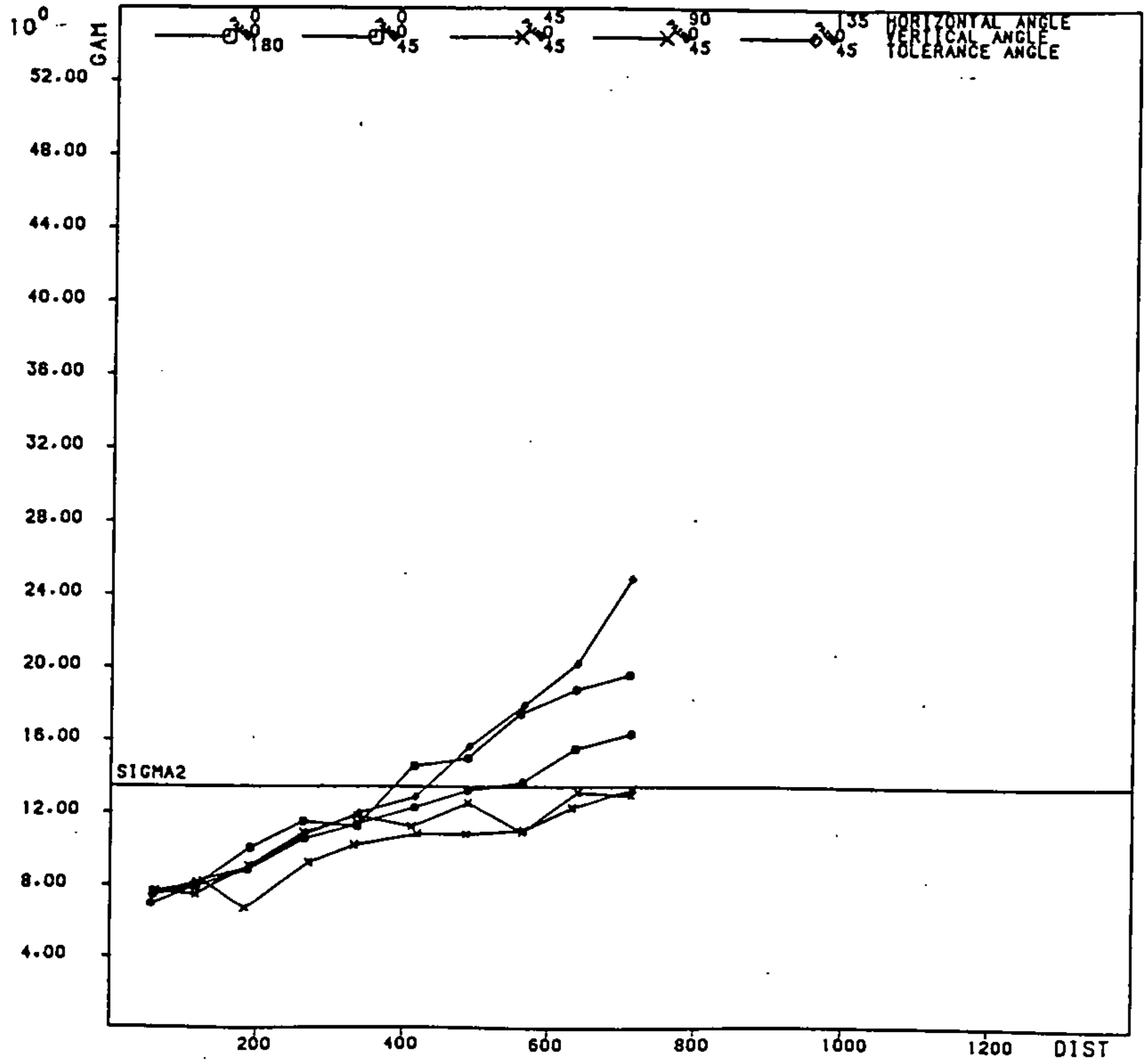


Figure 9 Horizontal variograms of %Pb+Zn in type 40-70



VARIABLE PBZN ABSOLUTE VARIOGRAM
CURRAGH RESOURCES - TYPE 40/70

Table 4 Variogram model parameters

Ore type	20-30			40-70		
Parameter	%Pb+Zn	%Pb	%Zn	%Pb+Zn	%Pb	%Zn
Nugget effect	4.0	0.5	1.5	4.0	0.8	1.3
Spherical 1						
Sill	4.2	0.6	2.2	2.0	1.6	1.5
Long range	400'	500'	400'	60'	600'	120'
Int. range	150'	150'	150'	60'	600'	120'
Short range	60'	60'	60'	40'	200'	80'
Spherical 2						
Sill				2.5		2.4
Long range				600'		600'
Int. range				600'		600'
Short range				40'		80'
Spherical 3						
Sill				5.0		
Long range				600'		
Int. range				600'		
Short range				180'		
Total sill	8.2	1.1	3.7	13.5	2.4	5.2

1-3 Standard errors for block estimates from D.H. composites

In the current block estimation method , the average grades and SG of 25' x 35.35' x 20' blocks are estimated by inverse distance using the bench composites of the similar ore type around the block . As explained above , matching of block and composite ore types is done with only two categories : 20+30 and 40+50+60+70 .

With the variogram models of bench composite data in the two categories , it is possible to quantify the precision of such block estimates . The common practice is to measure precision by a standard error . If the block estimate is 7.53 %Pb+Zn and the standard error is 1.40% Pb+Zn , then :

- there is a 68% probability that the true block grade lies somewhere between 7.53 - 1.40 = 6.13 %Pb+Zn and 7.53 + 1.40 = 8.93 %Pb+Zn
- there is a 95% probability that the true block grade lies somewhere between 7.53 - 2x1.40 = 4.73 %Pb+Zn and 7.53 + 2x1.40 = 10.33%Pb+Zn

Probabilities of 68% (+/- 1 standard error) and 95% (+/- 2 standard errors) are derived from a normal model applied to the distribution of errors . In that case , we could say that the precision of the estimate at a 68% confidence level is 1.40/7.53 = 18.5% and the precision at a 95% confidence level is 2x1.40/7.53 = 37% .

If we do the kriging of the average Pb+Zn grade of the blocks using the variogram models described in the previous section , we get the following standard errors :

-if the drilling grid is 70' x 70' , standard errors vary from 0.80%Pb+Zn (block centered on a drill hole) to 1.20%Pb+Zn (block in between drill holes) in types 20-30 and from 1.13%Pb+Zn to 1.25%Pb+Zn in types 40-70 .

-if the drilling grid is 140' x 140' , standard errors vary from 1.17%Pb+Zn (block centered on a drill hole) to 1.73%Pb+Zn (block in between drill holes) in types 20-30 and from 1.36%Pb+Zn to 1.68%Pb+Zn in types 40-70 .

In type 20-30 , because of the horizontal anisotropy of variograms , blocks between two holes on a N-S line are better estimated than blocks between two holes on an E-W line (standard errors of 1.06% and 1.18% respectively for the 70' grid and 1.28% and 1.73% for the 140' grid).

If we just keep the worst case block to get a single precision attached to a given drill hole grid , we have the following <u>95% confidence precisions :</u>

- in type 20-30 : 67% precision for 140' grid and 47% precision for 70' grid .
- in type 40-70 : 50% precision for 140' grid and 37% precision for 70' grid .

In order to illustrate the distribution of standard errors in blocks , we have kriged the %Pb+Zn grade of blocks in two test zones of bench 3450. . First , we plotted all the composites 20-30 and 40-70 in the bench and we defined approximate envelopes around each type of composite (Figure 10) . We filled those envelopes with the 25' x 35.35' blocks and we kriged the average %Pb+Zn grade of each block using composites of the same type around . The search ellipsoid used in each case is defined from the anisotropy of variograms : in 20-30 , the long radius is 400' along N-15-E , the intermediate radius is 150' along E-15-S and the short radius is 60' along vertical . In 40-70 , the long radius is 300' along any horizontal direction and 90' along vertical . Figure 11 is a map of block estimates . Figure 12 is a map of block standard errors . The average standard error is 1.59 %Pb+Zn in 20-30 and 1.73 %Pb+Zn in 40-70 . Those numbers confirm the precision values given above .

We can also use the same test zones to compare I.D. (inverse-distance) and kriged estimates . We have reestimated the %Pb+Zn of block in each ore category by inverse distance methods using various powers of the inverse distance composite-block . Each time we compared our I.D. estimates with kriged estimates for the same blocks and we can compute the average absolute difference for all blocks (Table 5) . We see that the average difference is minimal for a power between 1 and 1.5 in type 20-30 (average difference = 0.37%) and for a power between 1.5 and 2 in type 40-70 (average difference = 0.48 %) . We can also compare reserves above various cut-offs with the two methods (Table 6) .

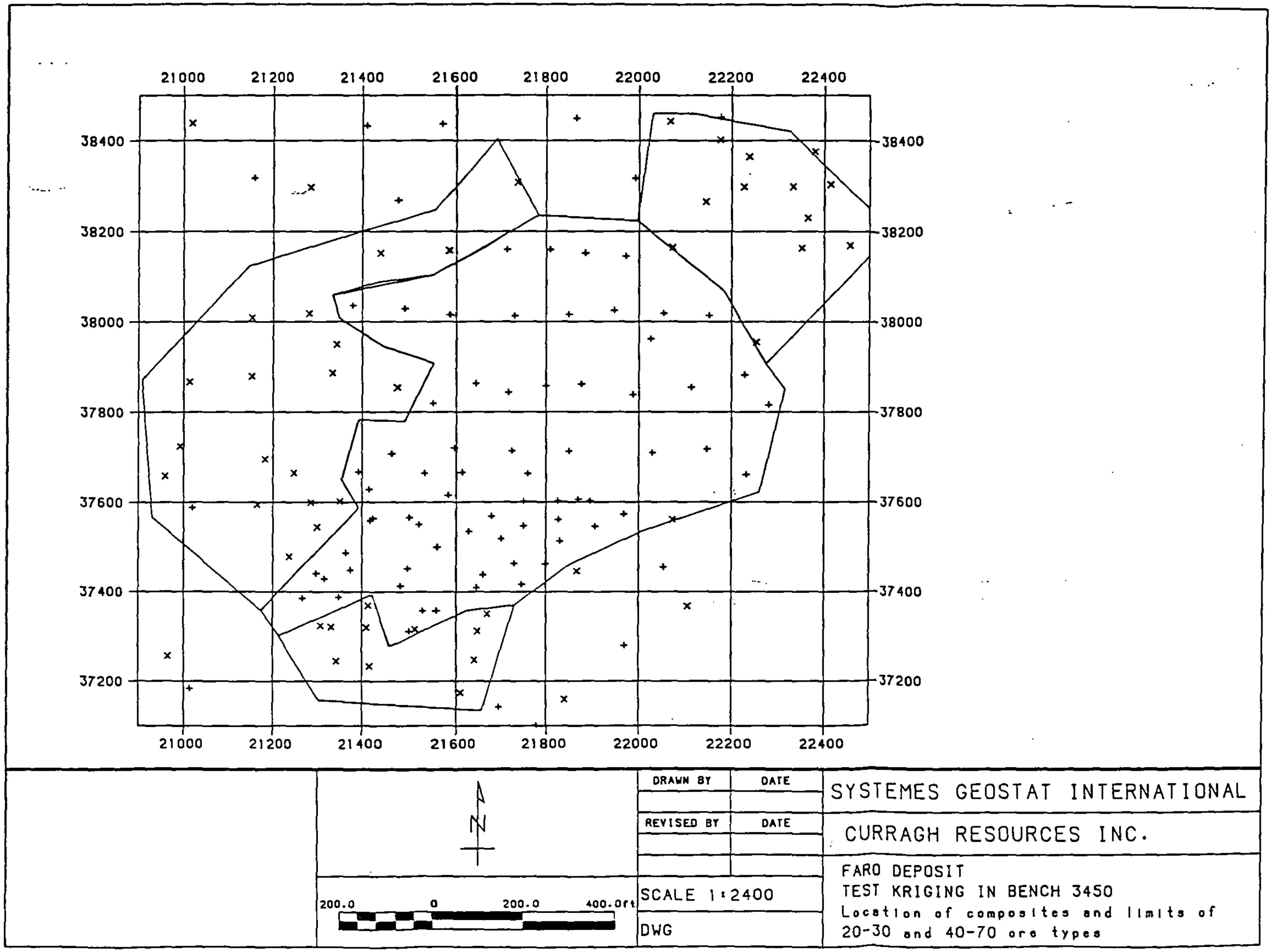


Figure 10 Test kriging in bench 3450: map of 20-30 (cross) and 40-70 (plus) composites with limits of test zones for each type

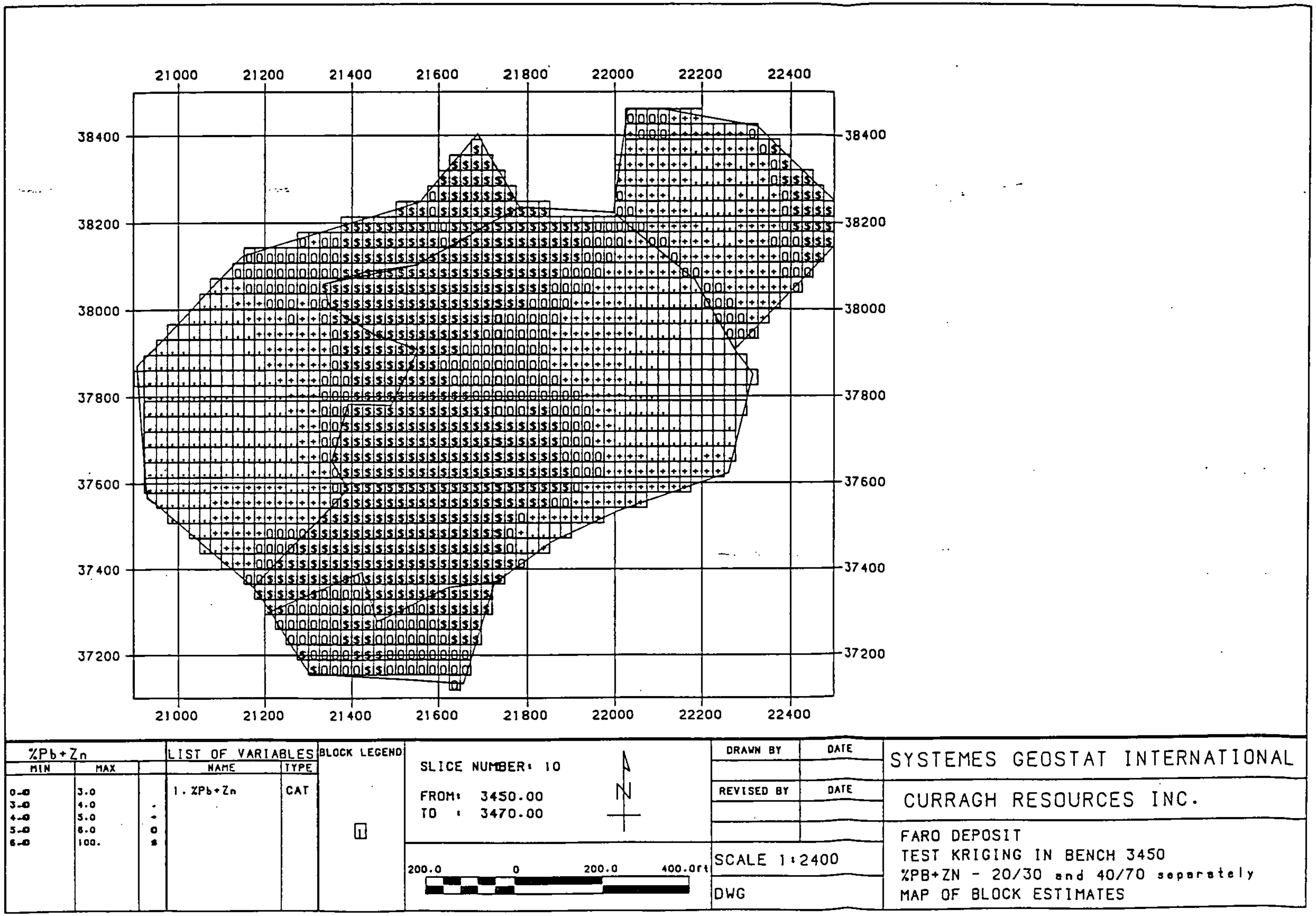


Figure 11 Test kriging in bench 3450 : map of block kriged estimates of %Pb+Zn (see legend for explanation of symbols)

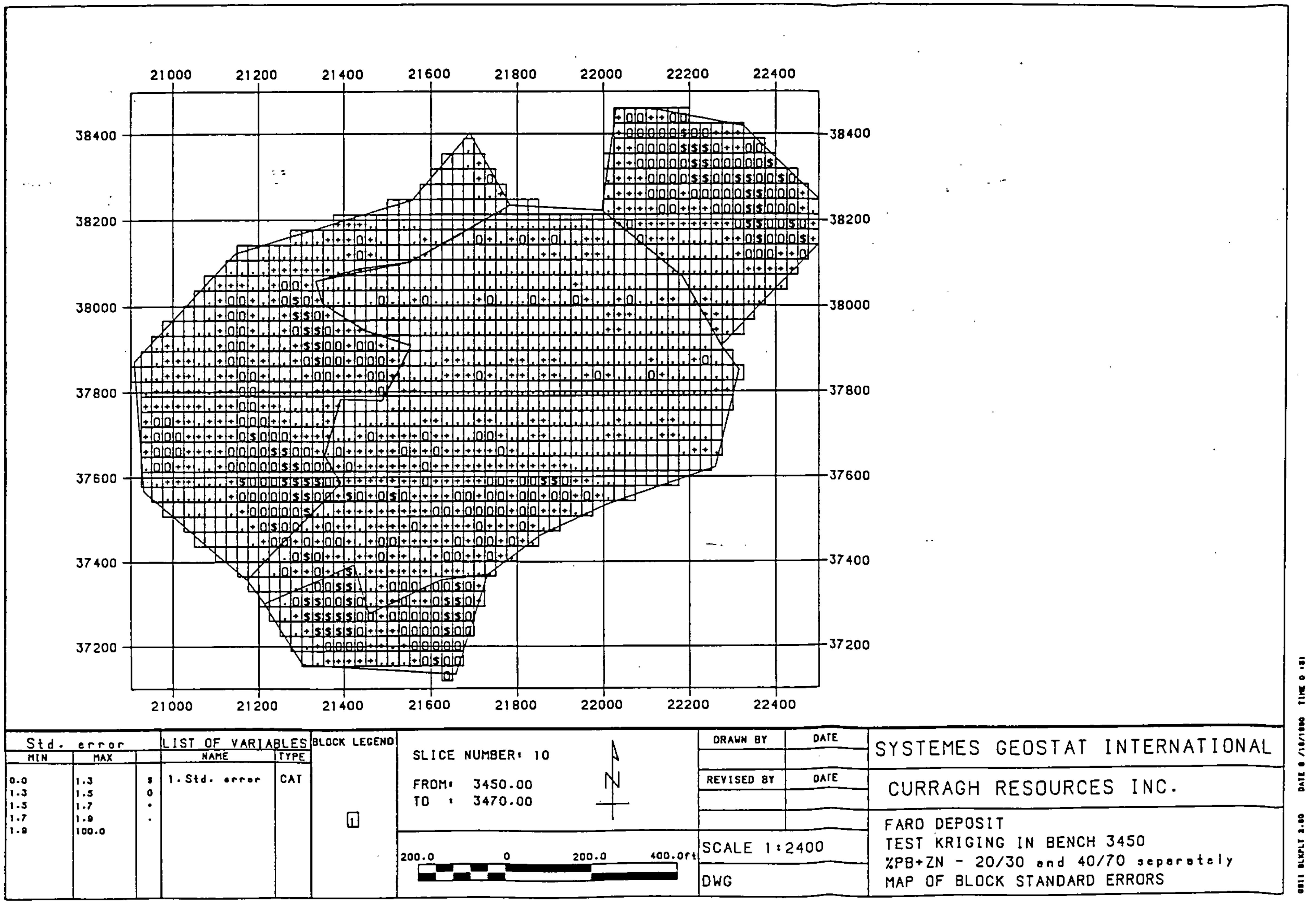


Figure 12 Test kriging in bench 3450 : map of block kriging standard error for estimates of %Pb+Zn (see legend for explanation of symbols)

Table 5 Average absolute difference between kriging and I.D. with various powers of inverse distance for block estimates of %Pb+Zn in the two ore types

Power	0.5	1.0	1.5	2.0	2.5
20-30	0.45	0.38	0.37	0.41	0.47
40-70	0.58	0.52	0.48	0.48	0.52

Table 6 Number of blocks above cut-offs with kriging and I.D. with various powers of inverse distance for block estimates of %Pb+Zn (Type 20-30 : total 699 blocks)

Estimate Cut-off	Kriging	I.D. 0.51.0	1.5	2.0	2.5	
3%Pb+Zn	675	695	687	675	667	654
4%Pb+Zn	517	565	553	523	503	491
5%Pb+Zn	324	333	350	359	359	350
6%Pb+Zn	144	122	132	140	149	164

Table 6 Number of blocks above cut-offs with kriging and I.D. with various powers of inverse distance for block estimates of %Pb+Zn (Type 40-70 : total 699 blocks)

Estimate Cut-off	Kriging	I.D. 0.51.0	1.5	2.0	2.5	
3%Pb+Zn	668	662	659	657	651	648
4%Pb+Zn	598	576	578	575	577	579
5%Pb+Zn	485	486	485	487	483	476
6%Pb+Zn	387	408	412	412	409	407

1-4 Standard errors for monthly , quarterly and yearly production estimates

From variograms , it is also possible to get the magnitude of errors for large block estimates i.e. volumes corresponding to one month , three months or one year production .

The technique used to derive those standard errors is a little bit different than the one used before to get errors of small blocks estimates . We can't combine estimation errors of small blocks in a big block to get the estimation error of the big block since those estimation errors are not independent . We can however combine extension errors i.e. errors produced when the small blocks correspond to the drilling grid cell and the estimation of those small blocks is done with only the sample in their center (polygonal estimation) . In that case the estimation variance for the big block is :

$$V^2=v^2/n$$

where v^2 is the extension variance of one composite to its cell of influence (derived from variograms) and n is the number of drilling grid cells in the big block

At Faro , the big blocks that we have investigated correspond to the average monthly , quarterly and yearly production . To get those volumes , we have considered the production figures for the first four months of 1990 . Depending of cut-off , the flagged-in-pit volume of ore varies from 671,000 bcys at 3% Pb+Zn cut-off to 468,000 bcys at 6% Pb+Zn cut-off. Hence , the "ore bench surface" mined in a month is 226,460 ft2 at 3% and 157,950 ft2 at 6% . For a quarter it is 3 times as much and for a year , 12 times .

To determine the number of drilling grid cells of ore mined in a month , a quarter and a year , we have considered two basic drilling grids : 140' and 70' . Hence , at a 3% cut-off , there are 226,460/(140x140)=12 ore composites on a 140 ft grid in a month volume and 46 composites on a 70 ft grid . At 6% cut-off , number of composites are respectively 8 and 32 .

First uncertainty is on the estimated surface (or volume) of ore above cut-off . This uncertainty depends of the degree of "connectivity" (amount of connection between ore lenses above the cut-off) of the ore above the cut-off and the overall proportion of ore above that cut-off in the ore type being mined . Obviously , we can be more confident on the estimate of volume of ore above cut-off if 80% of the samples are above that cut-off instead of just 20% . More precisely , the "relative" error (or precision) is likely to be higher in the second case . Then we can anticipate that the errors on volumes at 3% are less than at 6% and that we should do better in 40-70 than 20-30 because there is a higher proportion of composites above the usual cut-offs in this ore type . The connectivity of sample values above a cut-off can be measured through a variogram of indicator at that cut-off . The indicator value of a composite is 1 if the grade of the composite is above the cut-off and 0 otherwise . Figure 13 shows horizontal variograms of indicator at 3% Pb+Zn cut-off in 20-30 . Figure 14 has the same type of variograms but for cut-off 6% in 40-70 . As a general rule , indicator variograms have about the same features as the corresponding grade variograms . Once indicator variograms are modelled , we can determine v , the extension standard error

Where p is the overall proportion of composites above the cut-off . This formula has been implemented in ore types 20-30 and 40-70 , at 3% and 6% Pb+Zn cut-offs , and for 70' and 140' drilling grids . Results are given in Table 7 . We can see that :

+ monthly standard errors vary from 4.6% (70 ft grid - 3% cut-off - 20/30) to 26.6% (140 ft grid - 6% cut-off - 20/30)
+ yearly standard errors vary from 1.3% (id) to 7.7% (id)
+ as expected , standard errors are increasing with cut-off .
+ as expected , at the 6% cut-off , standard errors in 20-30 are higher than in 40-70 because the proportion of values above that cut-off is less (34% vs 54%)
+ at the 3% cut-off , standard errors in 20-30 are slightly less than standard errors in 40-70 because of the better connectivity of data above that cut-off in that ore type .

As indicated in the previous section , the above standard errors correspond to a 68% confidence . For a 95% confidence , all numbers must be doubled .

The error on tonnage above cut-off is a combination of the error on volume and the error on the estimated average specific gravity above the cut-off . Relative variations of specific gravity are rather limited : in 20-30 , average SG of composites at 3% cut-off is 3.25 with a standard deviation of 0.35 . At 6% cut-off , average is 3.39 and standard deviation is 0.34 . In 40-70 , average SG varies from 4.14 to 4.17 whereas standard deviation stays at 0.42 with cut-off from 3% to 6% . Based on these statistics , we can determine that the relative standard error of estimated SG above cut-off are : 1.3% (70ft grid) and 2.5 % (140 ft grid) for monthly blocks , 0.3 % (70 ft grid) and 0.7 % (140 ft grid) for yearly blocks , at both cut-offs and in the two ore types . Theoretically , the relative error variance of tonnage would be the sum of the relative error variance of volume and the relative error variance of SG . Now there is some negative correlation between volume and SG above cut-off : if we underestimate the volume , we probably overestimate the SG . As a result of this negative correlation , we think that the relative standard errors for tonnage above cut-off should not exceed the relative standard errors for volume above cut-off in Table 7 .

The error on estimated average grade (Pb+Zn) above cut-off can be derived from the general formula . In that case , v^2 is the extension variance of the Pb+Zn grade of a composite above cut-off to its cell of influence . It is derived from a variogram of composite grades above cut-off . Figure 15 presents horizontal variograms of %Pb+Zn above 3% in 20-30 . On figure 16 , we have the same type of variograms for %Pb+Zn above 6% in 40-70 . It is interesting to note that , as we increase the cut-off , the dispersion of grade values is decreasing : in 20-30 , at a 3% cut-off , mean and standard deviation of %Pb+Zn values are respectively 6.21% and 2.45% ; at 6% cut-off , they are 8.39% and 1.96% . In 40-70 , as cut-off goes from 3% to 6% , mean %Pb+Zn above cut-off goes from 7.84% to 9.44% and standard deviation goes from 3.09% to 2.46% . Hence , for average grade , magnitude of estimation errors decreases with cut-off . Relative standard errors for grade are detailed in Table 8. Conclusions are :

+ monthly standard errors vary from 3.3 % (20/30 - 70' grid - 6% cut-off) to 8.7% (40/70 - 140' grid - 3% cut-off).
+ yearly standard errors vary from 1.0 % (id.) to 2.5% (id.)
+ as expected , relative standard errors decrease with cut-off
+ standard errors are slightly better in 20-30 than 40-70 at all cut-offs .

All the above errors are given for ore types 20-30 and 40-70 separately . If production in a given period is made of a mixture of the two ore types , the relative standard error is a weighted average of standard errors of each ore type in the same proportions . If production is made of 50% 20-30 and 50% 40-70 , we get the 95% confidence precision of Table 9. From that table it appears that relative errors are higher for tonnage than grade . Additional calculations show that :

+ in order to get 95% relative standard errors of less than 5% on monthly estimates , we need a drilling grid between 35' and 40' at 3% cut-off and between 15' and 20' at 6% cut-off

+ in order to get 95% relative standard errors of less than 2% on yearly estimates , we need a drilling grid of about 50' at 3% cut-off and 25' at 6% cut-off .

Figure 13 Horizontal indicator variograms (3% Pb+Zn cut-off) in 20-30

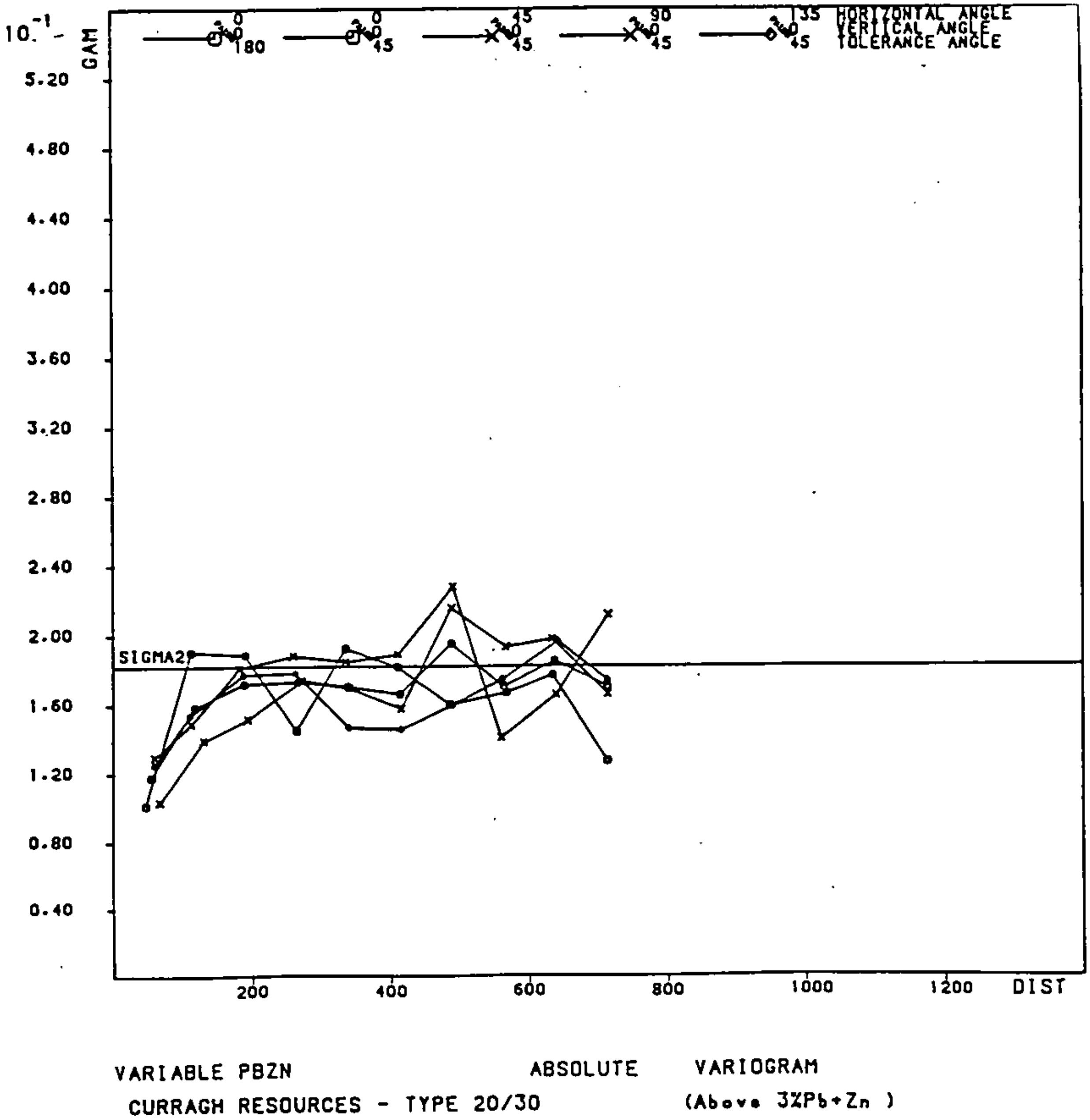


Figure 14 Horizontal indicator variograms (6% Pb+Zn cut-off) in 40-70

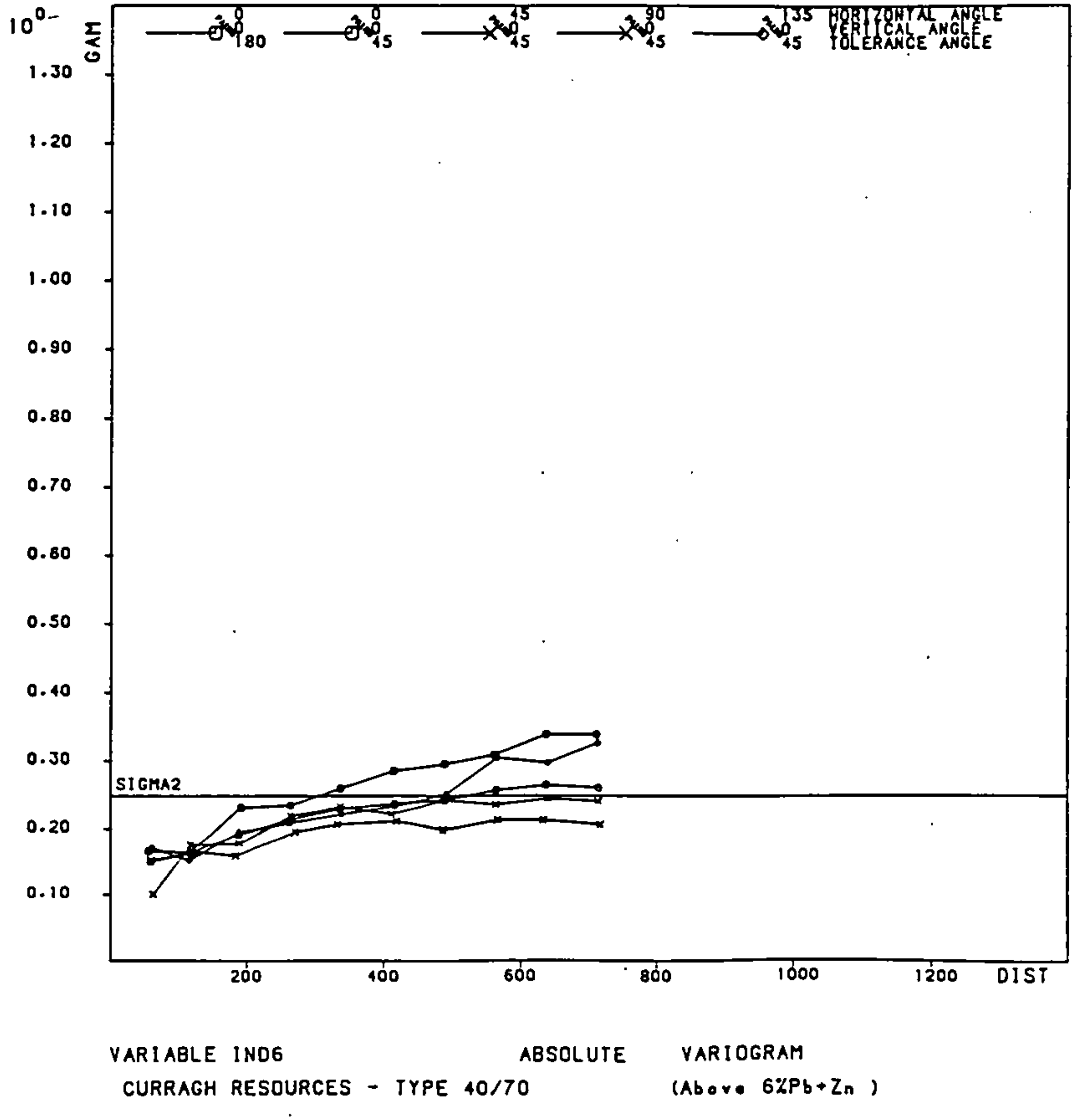


Table 7 Relative standard errors (%) on estimated surface (volume) above cut-off. @ 68% confidence level - double for 95% confidence !

Cut-off	3%Pb+Zn		6%Pb+Zn	
Ore type	20-30	40-70	20-30	40-70
Proportion of composites above cut-off (p)	0.76	0.80	0.34	0.54
Extension standard error (v)				
70' grid	0.27	0.31	0.44	0.36
140' grid	0.30	0.32	0.44	0.37
Monthly standard error (V %)				
70' grid	4.6	5.1	13.2	8.6
140' grid	10.1	10.5	26.6	17.7
Quarterly standard error (V %)				
70' grid	2.6	3.0	7.6	5.0
140' grid	5.8	6.0	15.4	10.2
Yearly standard error (V %)				
70' grid	1.3	1.5	3.8	2.5
140' grid	2.9	3.0	7.7	5.1

Figure 15 Horizontal variograms of %Pb+Zn above 3% cut-off in 20-30

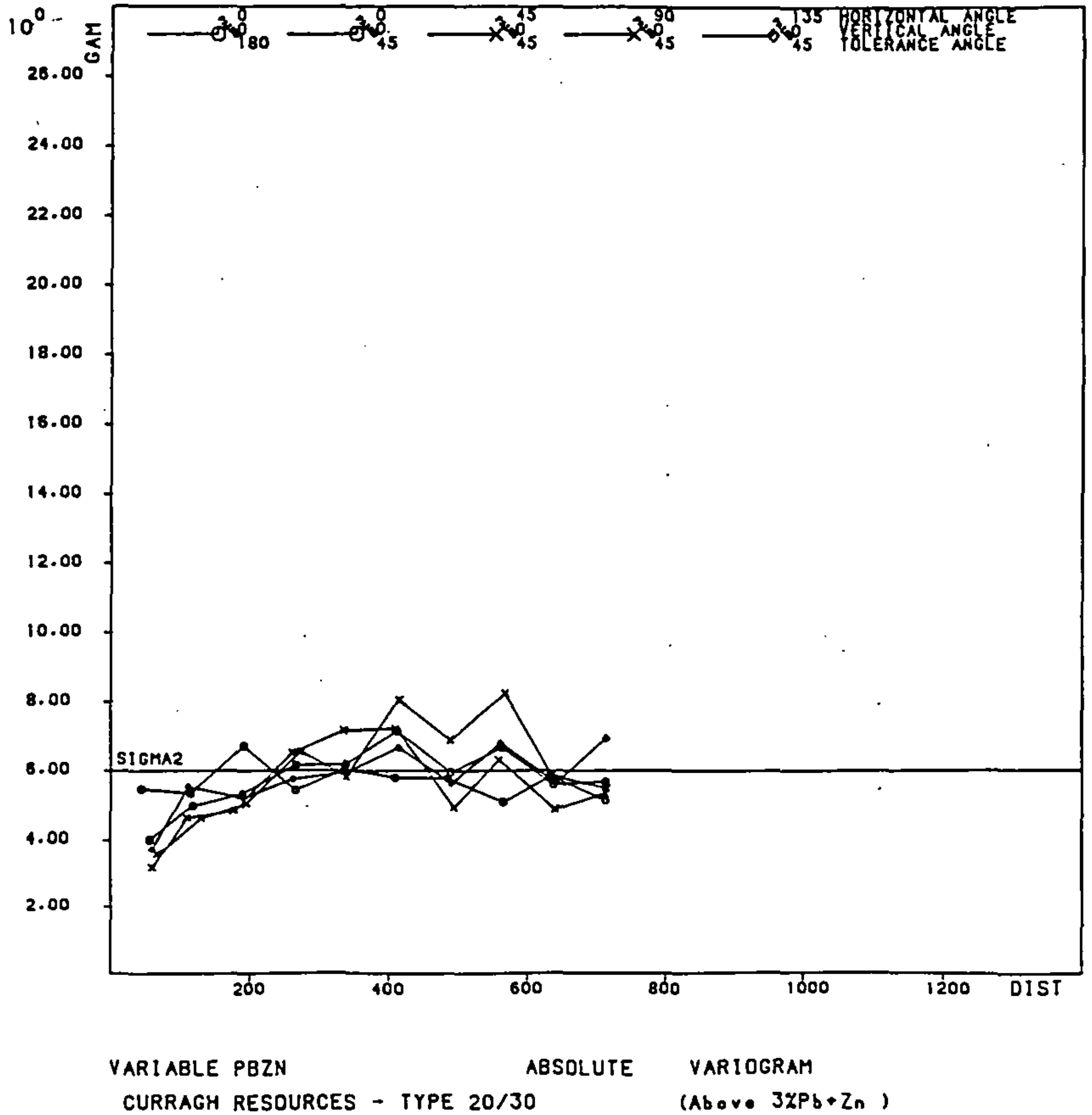


Figure 16 *Horizontal variograms of %Pb+Zn above 6% cut-off in 40-70*

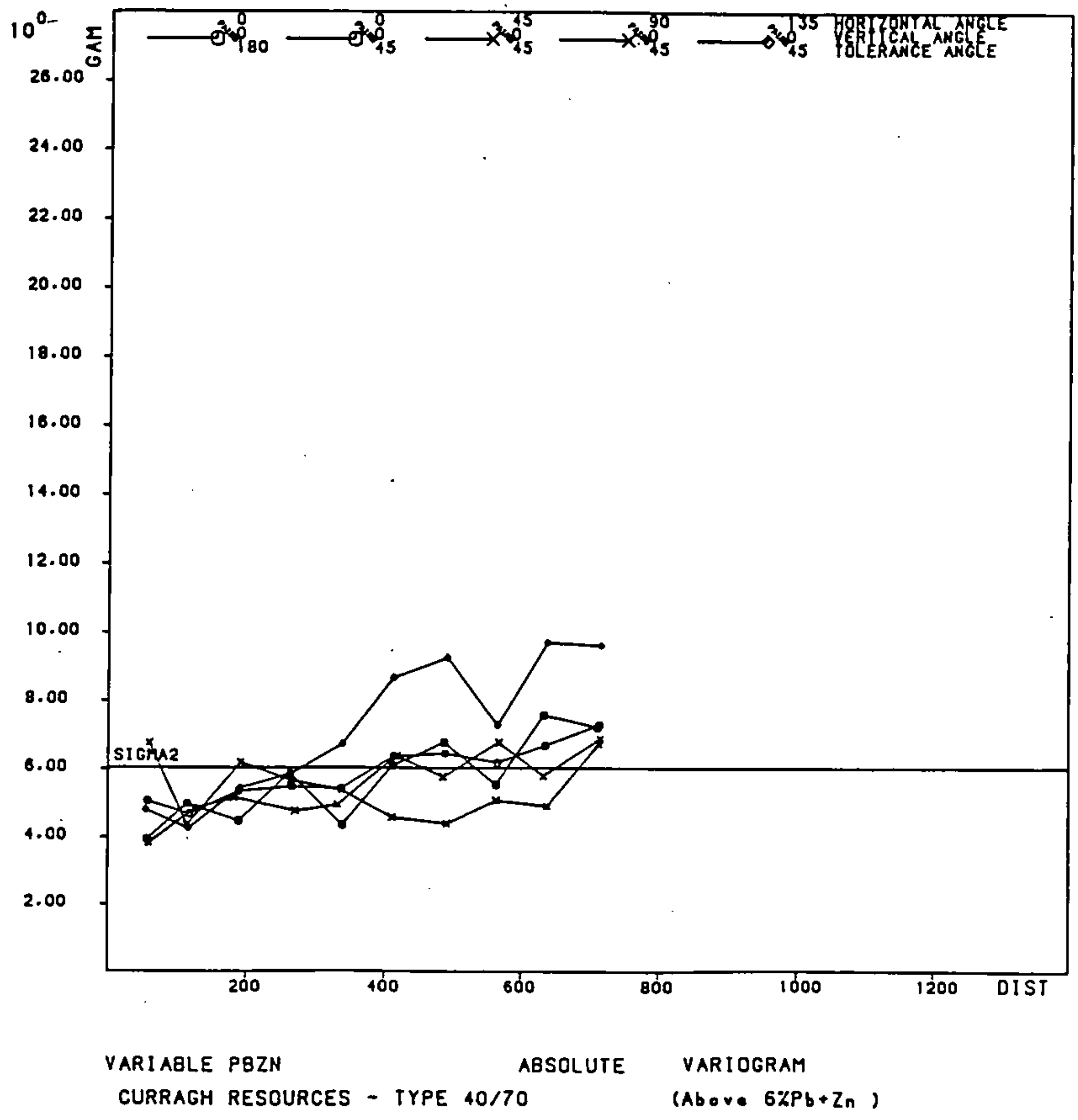


Table 8 Relative standard errors (%) on estimated %Pb+Zn grade above cut-off

Cut-off	3%Pb+Zn		6%Pb+Zn	
Ore type	20-30	40-70	20-30	40-70
Average grade above above cut-off (%Pb+Zn)	6.21	7.84	8.39	9.44
Extension standard error (v)				
70' grid	1.56	2.28	1.58	2.03
140' grid	1.70	2.32	1.61	2.06
Monthly standard error (V %)				
70' grid	3.7	4.3	3.3	3.8
140' grid	8.1	8.7	6.8	7.7
Quarterly standard error (V %)				
70' grid	2.1	2.5	1.9	2.2
140' grid	4.6	5.0	3.9	4.4
Yearly standard error (V %)				
70' grid	1.1	1.2	1.0	1.1
140' grid	2.3	2.5	2.0	2.2

Table 9 Average 95% confidence precisions (50% 20-30 + 50% 40-70)

Period	Month		Year	
Drilling grid	70'	140'	70'	140'
Tonnage				
3% cut-off	9.7	20.6	2.8	5.9
6% cut-off	21.8	44.3	6.3	12.8
Pb+Zn grade				
3% cut-off	8.0	16.8	2.3	4.8
6% cut-off	7.1	14.5	2.0	4.2

1-5 VALIDATION OF VARIOGRAMS AND ERROR PREDICTION

One way to check the validity of the prediction model is to reestimate samples from samples around. Estimates are compared to true values and actual errors with predicted errors.

For example, if we take the 742 bench composites of type 20 and 30, we can krige the % Pb + Zn grade of each of them using % Pb + Zn values of neighbor composites of the same type but in different holes. With the standard 400' x 150' x 60'search ellipsoid, we can reestimate 719 composites. Average estimate is 5.19% Pb + Zn which compares well with the mean value of the 719 data (5.18% Pb + Zn) i.e. the average error is virtually zero. The average absolute error is 2.35% Pb + Zn and the average squared error is 8.79 i.e. a standard deviation of 2.96% Pb + Zn. In other words, the average experimental uncertainty in the reestimation of samples from nearby samples is 2.96/5.18 = 57%. The average kriging variance is 8.02 or a standard deviation of 2.83% Pb + Zn, very close to the experimental value (individual standard errors vary from 2.35 to 4.05% Pb + Zn). These standard errors of about 2.9% Pb + Zn in the reestimation of composites at distances from 70' to 140' are consistent with the predicted standard errors of 1.20% to 1.73% Pb + Zn in the estimation of 25' x 35' blocks at about half those distances.

The same method can be used to test various features of the variogram model =

+ if we do the reestimation using a variogram model with no horizontal anisotropy (horizontal range = 300' in all directions), the absolute error is 2.34% Pb + Zn, the experimental error variance is 8.84 but the average kriging variance is only 7.50. Hence this model is giving estimates as good as the anisotropic model but the predicted error is too low.

+ if we do the reestimation with a model with no nugget effect, absolute error is 2.44% Pb + Zn, experimental error variance is 9.63 but average kriging variance is only 6.45. Hence a nugget effect gives better estimates and a more realistic predicted error.

+ if we do the reestimation using only the nearest composite in the 400' x 150' x 60' search ellipsoid, the average absolute error is 2.96% Pb + Zn hence distance weighting interpolation methods like kriging are preferable to polygon.

Back to the original prediction model, another way of checking the validity of error prediction with the sample reuse method is to count the number of times when the actual error is less than the predicted standard error or less than twice the predicted standard error. According to a normal model for the distribution of errors, we should have 68% of the errors less than the standard errors and 95% of them less them two standard errors. Actual numbers are 480 out of 719 i.e. 67% and 683 out of 719 i.e. 95%.

Even if the prediction of errors is correct, the estimates of composites are not that good as indicated by the correlation plot of figure 17. Correlation coefficient of estimated and true values is in fact only 0.18. What we can notice on this diagram is that estimates are smoother (less dispersed) then actual values. In fact the standard deviation of estimates is only 1.41% Pb + Zn whereas that of true values is 2.88% Pb + Zn.

A direct consequence of too smooth estimates is an overestimation of the proportion of values (tonnage) above a low cut-off and the underestimation of the proportion of values above a high cut-off (Table 10). Estimated grades above cut-off are always underestimated. Hence somekind of correction is necessary to "unsmooth" the distance weighted estimates. This would be considered in the next section.

In 40/70, the reestimation of composites is giving similar results: with the current variogram model, out of 985 reestimated samples, the average error is 0.07% Pb + Zn (mean of true values is 6.65% Pb + Zn, mean of estimates is 6.57% Pb + Zn), the average absolute error is 2.22% Pb + Zn, the experimental error variance is 8.43 (standard error: 2.90% Pb + Zn) and the average kriging variance is 8.89 (standard error 2.98% Pb + Zn). Also 73% of the actual errors are less than the predicted standard error and 95% of them are less then two standard errors. Correlation of estimates and true values is much better than in 20/30 (figure 18). Correlation coefficient is now 0.61. Oversmoothing of estimates is still present. As a result, since now all cut-offs are less than the mean grade, all the proportion of values above cut-off are overestimated and all grades above cut-off are underestimated (Table 11).

Figure 17: Scattergram of real % Pb + Zn value and estimated % Pb + Zn value in 20/30.

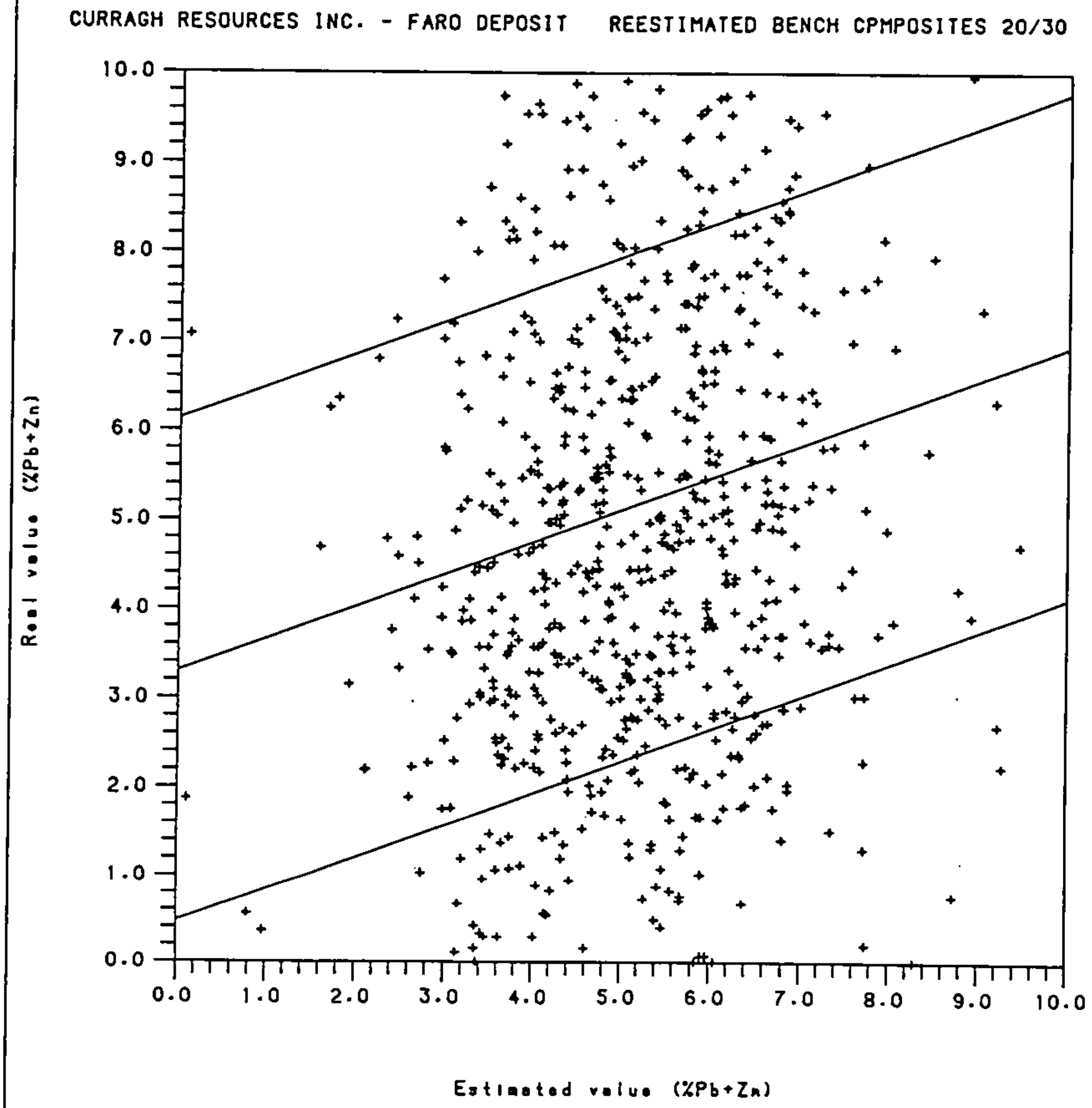


Figure 18: Scattergram of real % Pb + Zn value and estimated % Pb + Zn value in 40/70.

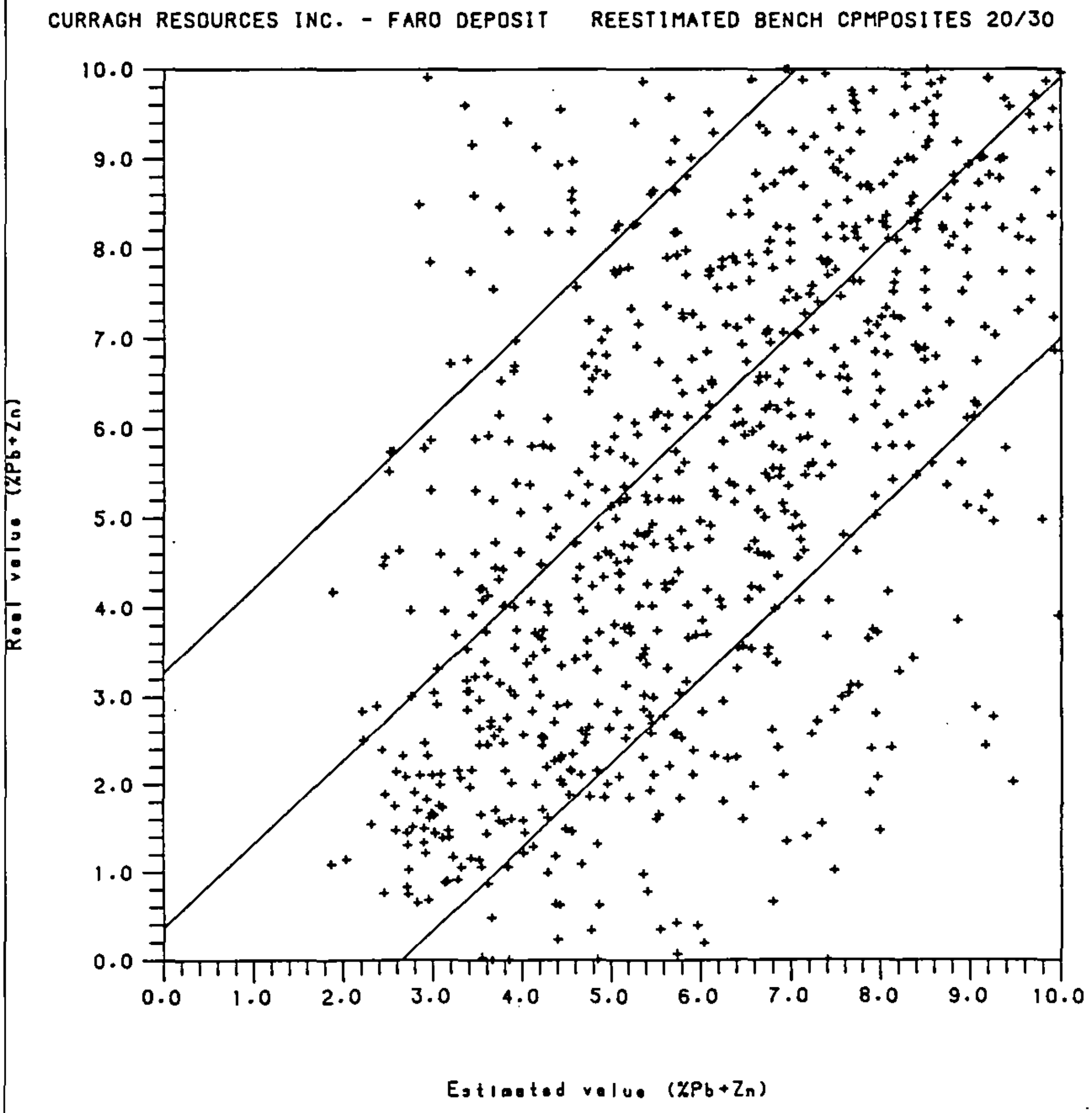


Figure 18

Table 10: Reestimation of composite % Pb + Zn grades. Proportion of actual and estimated values above cut-offs (% values).

Cut-off (% Pb + Zn)	20/30 Actual	 Estimated	40/70 Actual	 Estimated
3	76	95	80	95
4	61	79	73	84
5	48	55	63	72
6	34	27	54	57

Table 11: Reestimation of composite % Pb + Zn grades. Mean % Pb + Zn grade (no SG weighted) above cut-off: actual and estimated.

Cut-off (% Pb + Zn)	20/30 Actual	 Estimated	40/70 Actual	 Estimated
3	6.24	5.32	7.83	6.78
4	6.93	5.68	8.28	7.19
5	7.58	6.79	8.83	7.63
6	8.41	6.88	9.42	8.21

1-6 CORRECTION OF BLOCK ESTIMATES FOR PROPORTION OF BLAST HOLES IN BLOCKS

Another way to validate the long term prediction of block values from drill hole bench intercepts is to compare block estimates derived from those intercepts and blast hole grades in the same blocks.

We have % Pb, % Zn, % Pb + Zn as well as coordinates from 2083 BHs in benches 3490, 3470 and 3450 in the south phase of the pit. Table 12 lists some statistics of those blast hole values according to rock code. We can see that most of the blast holes that we have are in rock type 50. We have a significant group of "55" that we did not have before and which seems to have the same (low) means grades as type 40 in DHs. With the exception of 70, all mean B.H. grades in that zone are higher than the overall D.H. mean grades (Table 1-3), hence it is a relatively rich zone.

If we just consider the quartzite types, 20 and 30, we have 568 blast holes with % Pb + Zn values ranging form 0.10% to 14.83%, a mean of 6.39% and a standard deviation of 2.80%. Figure 19 is a map of those blast holes (x with size proportional to % Pb + Zn) in bench 3470. On the same map, we have the 20/30 D.H. composites in the same bench(0 also with size proportional to % Pb + Zn). We can notice that, overall, there is a good agreement between ore type characterization of D.H. composites and blast holes. There are however a few 20/30 D.H. composites which are more than 25' away from the closest 20/30 B.H., hence there are almost coincident with a B.H. which is not classified in type 20/30.

We can find all the blocks of the 25' x 35' model which contain a blast hole of type 20/30 and do the interpolation of the % Pb + Zn grade of those blocks from the drill hole composites (Figure 20). All together there are 413 blocks but since the blast hole grid is about 20', most of the time, there is only one blast hole in a block. The interpolation method that we use is kriging with the variogram model of % Pb + Zn for 20/30 D.H. composites (Table 4) and the 400' x 150' x 60' search ellipsoid.

If we compare the mean kriged grade of the 413 blocks with the mean grade of the 568 blast holes in those blocks, they are reasonably close: 6.24% Pb + Zn vs 6.38% Pb + Zn. The difference of 0.14% Pb + Zn (or relative difference of 2.2%) is consistent with the monthly and quarterly precision figures of % Pb + Zn estimates in 20/30 of table 10 (413 blocks represents about 1.5 months of production.

Even if means are close, the correlation between kriged D.H. grade of a block and mean B.H. grade of that block is not that great (Figure 21): correlation coefficient is only 0.11. The main reason for that poor correlation is the <u>oversmoothing of kriged block values:</u> kriged values range from 3.31 to 9.59% (standard deviation: 1.02%) whereas B.H. values range from 0.10 to 14.83% (standard deviation of 2.68%).

As a direct consequence of that oversmoothing, <u>if we apply the usual cut-offs to the kriged block values, tonnages are too high and grade too low</u> (Table 13). Tonnage difference is as much as 30% (5% cut-off) and grade difference as much as 17%.

compared with?

If we repeat the same exercise in 40-70 (excluding 55), we end up with 795 blocks that contain at least one blast hole of either 40, 50, 60 or 70 type. Mean of kriged values for those blocks is 8.16% Pb + Zn whereas the mean of blast holes in these blocks is 8.84%. This almost 10% difference is more than what can be expected. A closer look at the location of blast holes with type 55 indicates that they are in regions with D.H. composites of type 40 (Figure 22). Hence it seems more reasonable to krige all blocks that contain blast holes of type 40, 50, 60, 70 and 55 with the 40/70 D.H. composites. In that case, we end up with a mean of 909 blocks equal to 7.75% Pb + Zn whereas the mean of the BHs in those blocks is 8.12% Pb + Zn.

Difference is less than before but still fairly high. It shows that when a few low grade D.H. composites of type 40 are used in the estimation of mostly high grade 40-70 blocks, there is some overall underestimation of grade.

If we restrict ourselves to types 50-60-70, we have 1148 blast holes with % Pb + Zn values ranging from 3.13% to 18.21%, a mean of 9.07% and a standard deviation of 2.73%. Map of those blast holes in bench 3470 (together with the D.H. composites in the same bench) is on figure 23. In that case, we see that all D.H. composites are surrounded by BHs of the same type. However, we can see extensive zones of blast holes 50/70 with no 50/70 D.H. composites around = D.H. composites in those zones have probably been assigned a different rock type.

There are now 765 blocks with 50/70 BHx in them (Figure 24). The average kriged % Pb + Zn of those blocks is 9.02% which compares well with the mean B.H. of 9.07% Pb + Zn.

However, like in 20/30, correlation of D.H. estimate with B.H. value is not good (Figure 25). Correlation coefficient is a mere 0.31. Like before, this poor correlation is derived from the oversmoothing of block estimates: kriged values range from 5.70 to 10.94% (standard deviation: 1.11%) whereas B.H. values go from 3.13% to 18.21% (standard deviation: 2.52%). Again, because of that oversmoothing, if we apply a cut-off to the kriged block values, tonnages are too high and grades are too low (Table 14). Tonnage difference is as much as 14% (6% cut-off) and grade difference, 7% (same cut-off).

A way to overcome the oversmoothing of straight block estimates is <u>to estimate the likely proportion and grade of blast holes above the cut-off in each block.</u>

We can take the kriged estimate as the mean of that distribution. Its variance can be derived from the variogram of D.H. composites: it is simply the average value of the horizontal variogram in a rectangle 25' x 35'. It is 4.41 in 20/30 and 4.53 in 40/70. The shape of the distribution can be assumed to be a simple model, normal or lognormal (considering the histograms of D.H. bench composites, the best assumption is probably lognormal in 20/30 and normal in 40/70).

We have tried a "lognormal short cut" correction of the kriged block values in both 20/30 and 50/70 with the above variances. This means for example that if we have a kriged block estimate of 5.54% in a 20/30 block, we estimate that:

6.8% of the BHs in that block are below 3% with a grade of 2.58% Pb + Zn.

17.2% of the BHs are between 3 and 4% with a grade of 3.54% Pb + Zn.

22.1% of the BHs are between 4 and 5% with a grade of 4.50% Pb + Zn.

19.5% of the BHs are between 5 and 6% with a grade of 5.48% Pb + Zn.

34.4% of the BHs are above 6% with a grade of 7.82% Pb + Zn.

This is far different from the answer that you get if you apply the cut-off directly on the block estimate. In that case the estimated proportions for the same grade categories are simply:

0, 0, 0, 100% and 0. If we sum all the estimated proportions and grades above cut-off in each block, we get the results of Table 15.

We can see that the correction is achieving its goal: reduce tonnage and increase grade. Maximum tonnage difference is now 8% in 20/30 (6% cut-off) and 3 % in 50/70 (6% cut-off maximum grade difference is 5.4% in 20/30 (3% cut-off) and 2.4% in 50/70 (6% cut-off).

Table 12: Summary statistics of B.H. data available.

Rock type	Number of BHs	Mean % Pb	Mean % Zn	Mean% Pb + Zn
0	37	1.09	1.03	2.12
10	12	1.56	2.47	4.03
20	398	2.16	3.75	5.92
30	170	2.85	4.65	7.50
40	55	2.21	3.35	5.56
50	1061	3.46	5.60	9.05
55	263	1.66	1.99	3.65
60	6	4.61	7.33	11.96
70	81	3.75	5.25	9.00
20 + 30	568	2.37	4.02	6.39
40 + 50 60 + 70	1203	3.42	5.49	8.91
40 + 50 60 + 70 + 55	1466	3.11	4.86	7.96
50 + 60 + 70	1148	3.48	5.59	9.07
All	2083	2.86	4.55	7.41

Table 13: Resources above cut-off from D.H. kriged block estimates and blast holes in those blocks. Type 20/30 - 413 blocks.

Cut-off	Kriged D.H. values		B.H. values	
% Pb + Zn	% above	% Pb + Zn above	% above	% Pb + Zn above
3%	100	6.24	91	6.81
4%	98	6.28	82	7.17
5%	91	6.42	70	7.63
6%	59	6.86	53	8.33

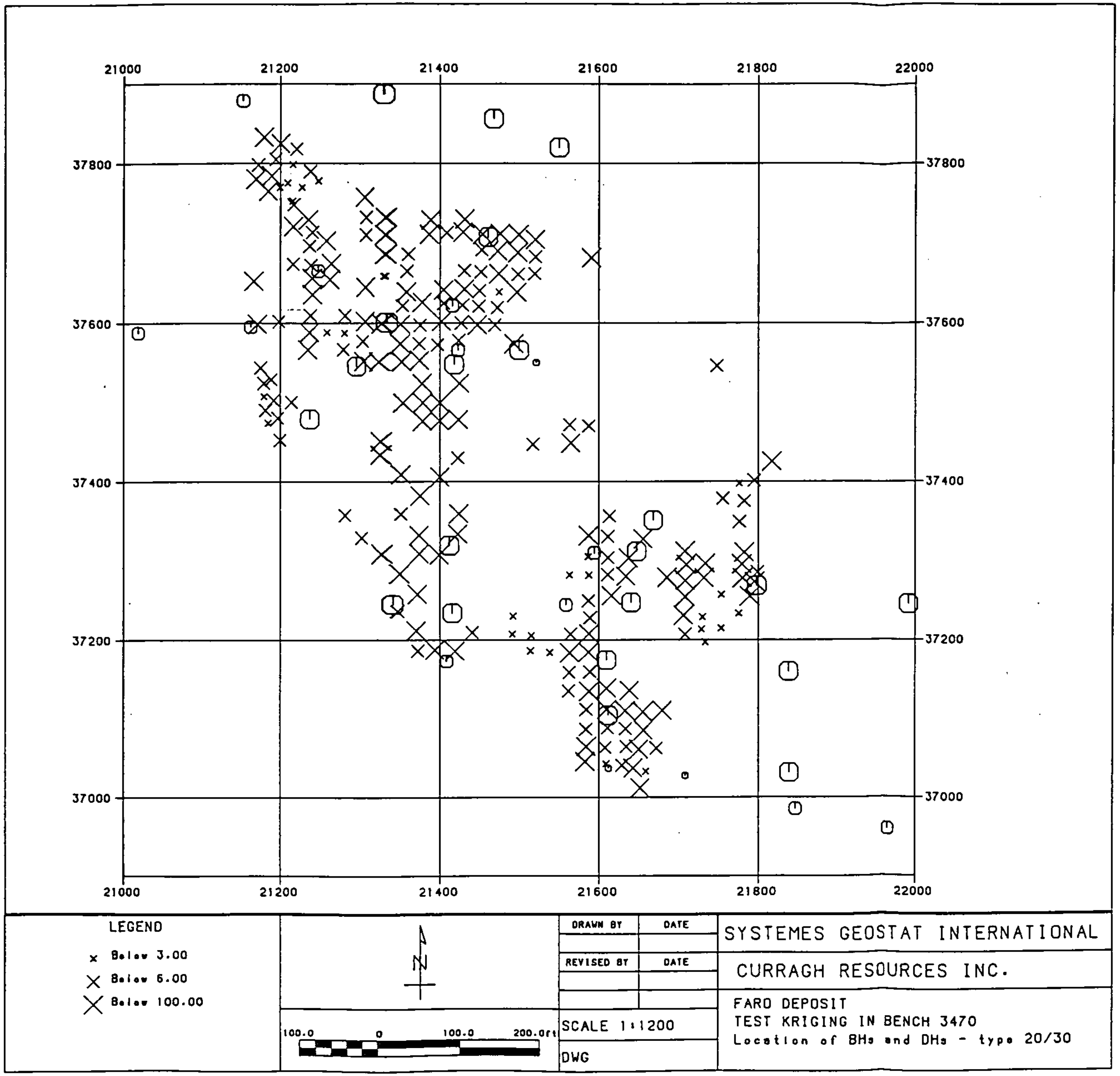
Table 14: Resources above cut-off from D.H. kriged block estimates and blast holes in those blocks. Type 50/70 (excluding 55) - 765 blocks.

Cut-off	Kriged D.H. values		B.H. values	
% Pb + Zn	% above	% Pb + Zn above	% above	% Pb +Zn above
3%	100	8.90	100	9.02
4%	100	8.90	99	9.07
5%	100	8.90	97	9.18
6%	100	8.90	87	9.56

Table 15: Resources above cut-off after correction of oversmoothing by lognormal short-cut (dispersion variances of 4.41 and 4.53 in 20/30 and 50/70 respectively).

Cut-off	Type 20/30		Type 50/70	
% Pb + Zn	% above	% Pb + Zn above	% above	% Pb + Zn above
3%	95	6.44	100	8.90
4%	84	6.81	99	8.94
5%	67	7.38	96	9.06
6%	49	8.09	90	9.33

Figure 19: Map of 20/30 DHs and BHs in bench 3470.



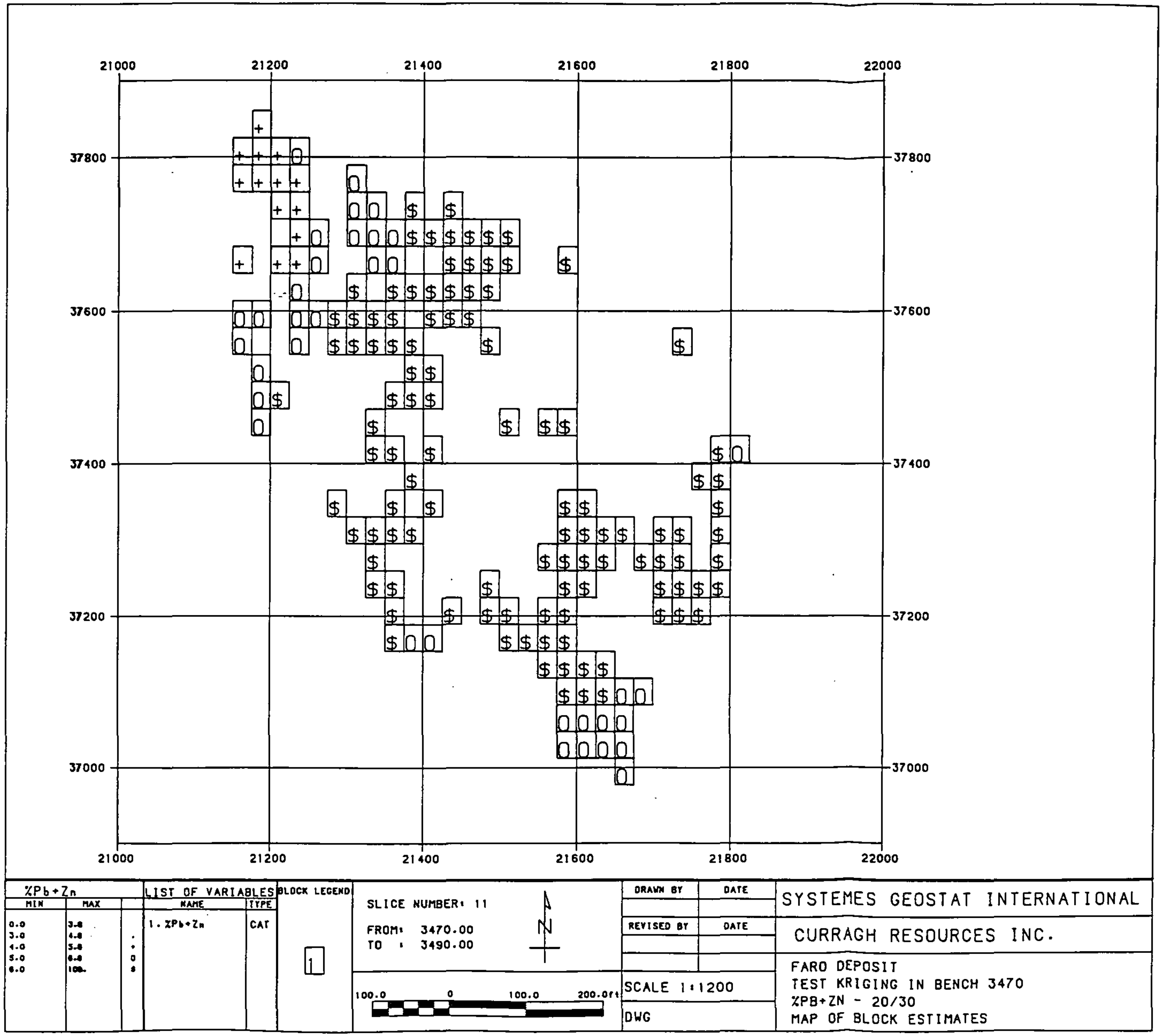


Figure 20: Map of estimated 20/30 blocks i
bench 3470.

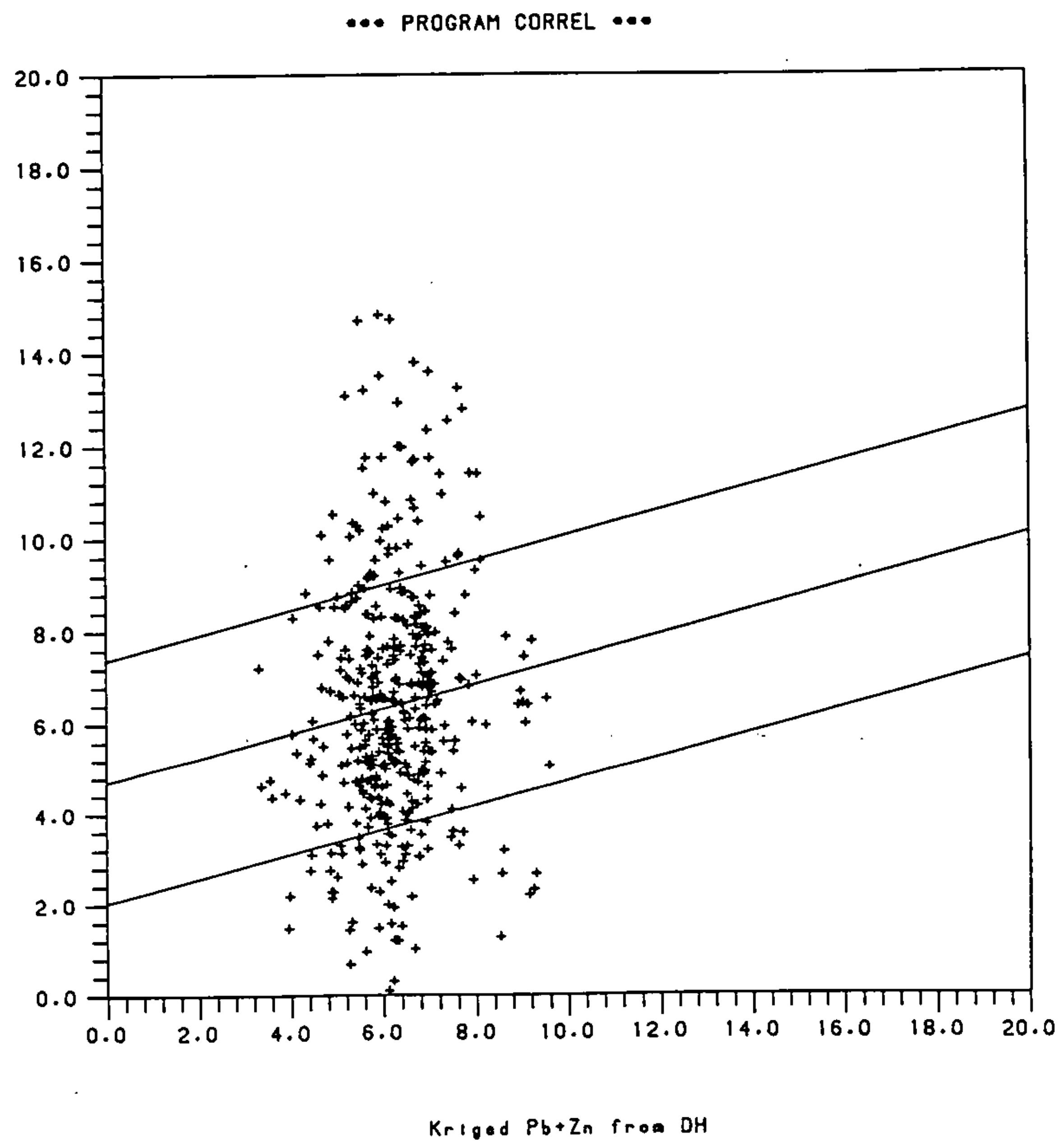


Figure 21: Correlation of kriged DH block and mean BH % Pb + Zn in 20/30.

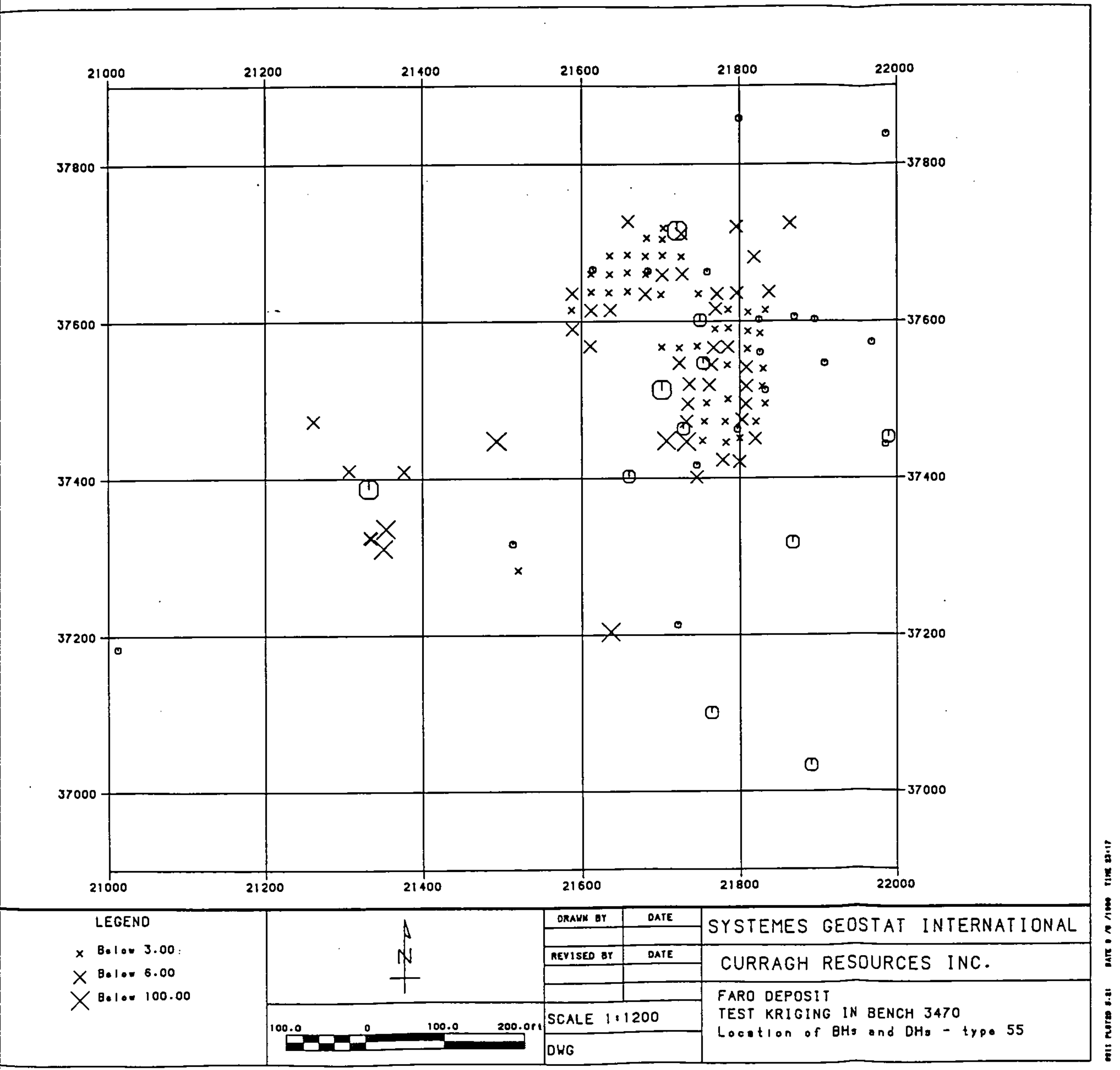


Figure 22: Map of 40 DHs and 55 BHs in bench 3470

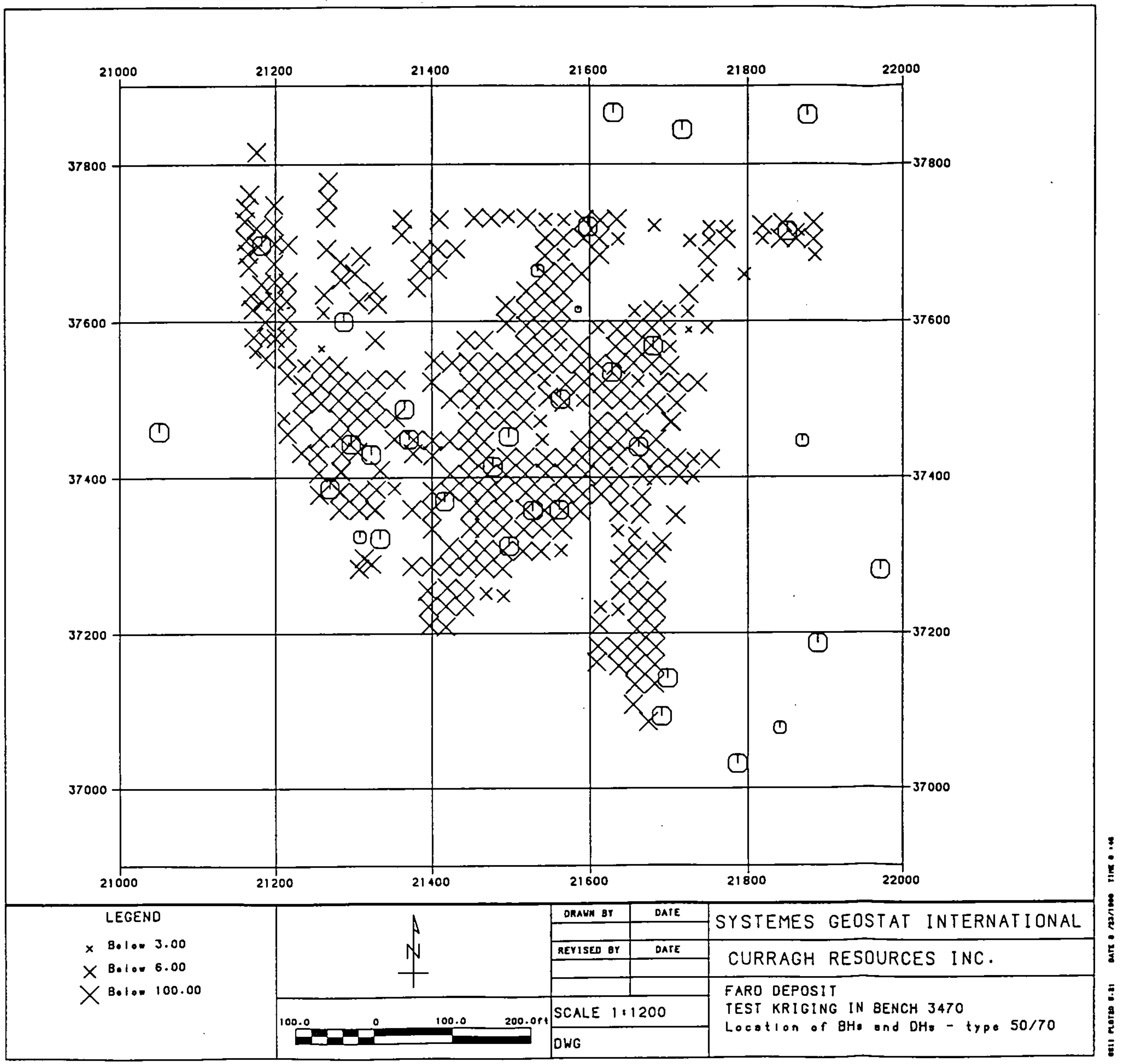


Figure 23: Map of 50/70 DHs and BHs in bench 3470

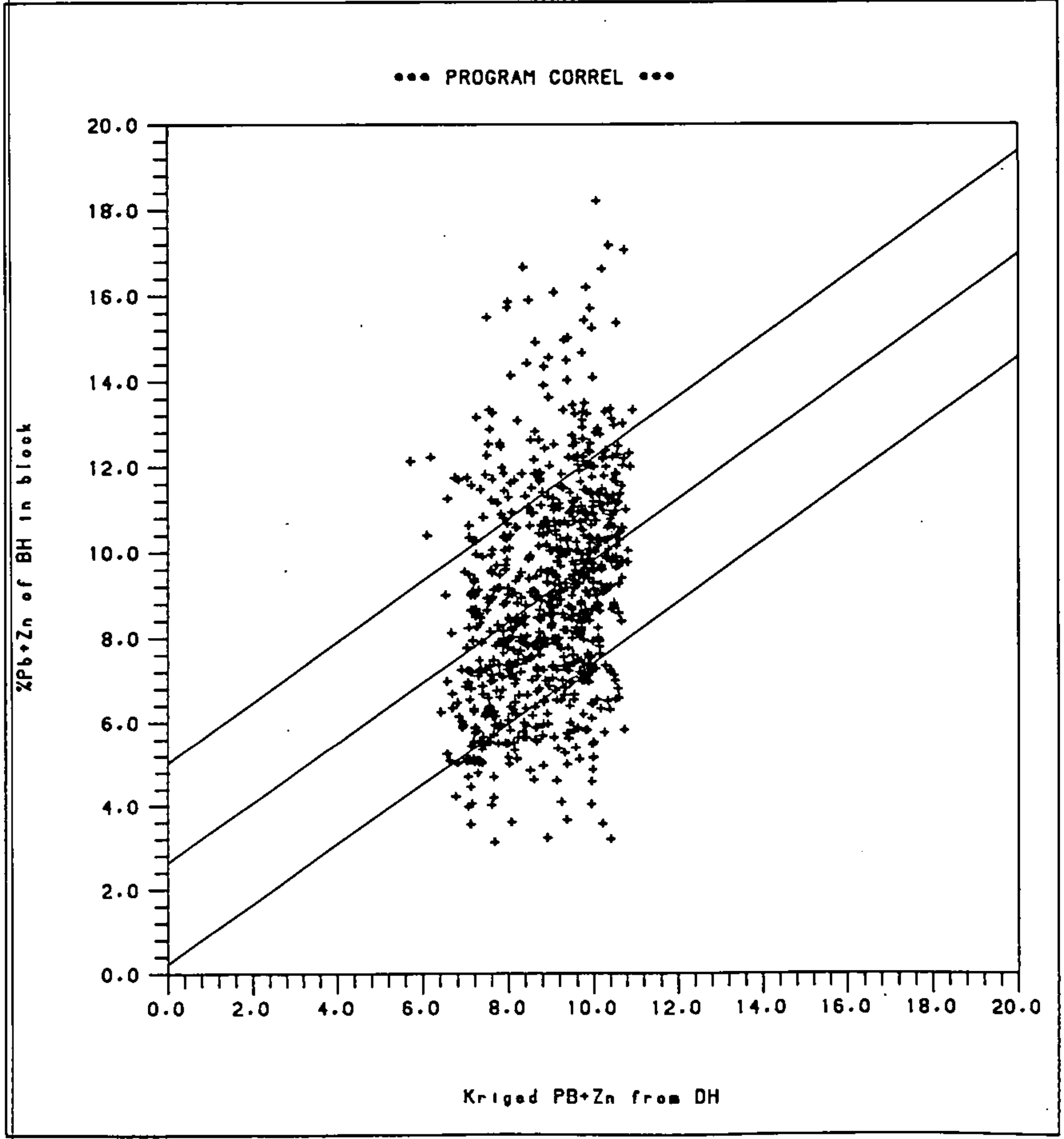


Figure 25: Correlation of kriged DH block and mean BH block % Pb + Zn in 50/70.

1.7 VALIDATION OF THE GEOLOGICAL MODEL

In the current long term prediction model, blocks are first classified according to their ore type, then their average grade is derived from drill hole bench composites of the same ore type around the block. In addition to the grade inference error which has been covered in the previous section, another source of error might be a wrong ore type assignment for the block. To get an idea of the degree of misclassification of blocks according to their ore type, we have checked the assignment of the ore code of drill hole bench composites against the assignment of the same ore types to blast holes nearby (assuming that the categorization of blast holes is more precise than that of drill hole bench composites since we can map ore type limits in a blast). In that part of the study, we have looked at the ore type of the nearest blast hole (within a 20' distance) to each drill hole composite in the test benches 3490, 3470 and 3450. Results are summarized on Table 16. Our comments are:

- more than 50% of the drill hole bench composites of type 20 + 30 (Total: 55) have a blast hole of type 50 + 60 + 70 nearby.

- more than 50% of the drill hole bench composites of type 40 (Total: 26) have a blast hole of type 55 nearby.

- about 70% of the drill hole bench composites of type 50 + 60 + 70 (Total: 96) have a blast hole of the same type nearby.

Hence it appears that the classification of the predominantly high grade types 50 + 60 + 70 is consistent from drill holes to blast holes.

Also, if we pool together the mostly low grade types 40 and 55, classification of these types is also adequate. We have more problems with types 20 and 30 : most of the drill hole bench composites of those types are surrounded by generally higher grade blast holes of type 50 , 60 or 70. In fact, out of the total 177 pairs of D.H./B.H., 55 (31%) involve a D.H. composite of type 20 + 30 whereas only 37 (21%) involve a B.H. of the same type. Hence types 20 and 30 seem to be underrepresented in drill hole composites compared to blast holes.

Table 16: Ore type of the nearest blast hole (within a 20' distance) to drill hole bench composites of various types.

Ore type of D.H.	Ore type of nearest B.H.									
	0	**10**	**20**	**30**	**40**	**50**	**55**	**60**	**70**	Total
20	0	0	17	5	1	24	1	0	1	49
30	1	0	1	1	0	3	0	0	0	6
40	1	0	1	0	1	8	14	0	1	26
50	0	0	4	3	1	56	9	0	2	75
60	2	0	0	0	3	3	2	0	0	10
70	0	0	4	1	0	6	0	0	0	11
Total	**4**	**0**	**27**	**10**	**6**	**100**	**26**	**0**	**4**	**177**

2 SHORT TERM PREDICTION FROM BLAST HOLE DATA

We have already introduced the reference blast hole data set in section 1-6 with summary statistics of their % Pb + Zn data on Table 12. Those blast holes are categorized according to the predominant ore type. Since some of the ore types are mostly low grade (55) and others are high grade (50-70), the distribution of all their % Pb + Zn values is rather heterogeneous. Histogram is a "fat" bell shaped curve with its peak at about 7.30 % Pb + Zn and large quantities of low and high grades (Figure 26). There is also a tail of very high grade data (above 15%). The coefficient of variation, 45% is fairly high considering that data come from a fairly restricted zone. If we look at distributions of values according to ore types, we also see some heterogeneities within each group:

x Distribution of the 37 %Pb + Zn values in type "0" is positively skewed with most values below 2% and other values up to 7%.

x Out of the 12 blast holes classified as "10", 2 are above 12% whereas the balance is 5% or less. As a result, the coefficient of variation for the 12 %Pb + Zn values in that group is 89%.

x Most of the 398 values classified in type 20 are within the range 2-10%. However, maximum reaches 17.68%. Coefficient of variation is similar to that for overall data 46%.

x The 170 data in type 30 are more homogeneous. Most values are within the interval 3 - 14%. Coefficient of variation is only 35%.

x In type 40, we just have 55 values ranging from 2 to 12%. Coefficient of variation is the same as overall (45%).

x Like in 30, the 1061 data in 50 are more concentrated: 90% of the values lie in the interval 5 - 14%. There are a few high outliers up to 20%. Coefficient of variation is a mere 30%.

x The 263 values in type 55 have the typical distribution of low grade material: lots of low values (median is just about 2%) and a few scattered high values (up to 13%). As a result, the coefficient of variation is pretty high: 62%.

x There is not much to say about the 6 blast holes classified in type 60. Values range from 6 to 16%. Coefficient of variation is 25%.

x Distribution of the 81 values in type 70 is well homogeneous with values from 5 to 13% and a coefficient of variation of 25%.

Formally, the current short term prediction model is also a block model with a distance weighting grade interpolation method: blocks are the 25 x 25 ft volume of influence of a blast hole and the interpolation method is nearest neighbor (or polygon). In other words, the grade estimate for a blast block is the grade of the single blast hole sample in the middle of the block. Like for the long term prediction model from drill holes, it is possible to assess the standard error a single blast-block grade estimate or a group of them. We just need compute and model variograms of blast hole grade.

At this point, we can calculate a) a global variogram of all the 2083 B.H. data available whatever their rock type assignment b) variograms in each rock type or combination of rock types.

Blast hole variograms are well defined provided they are computed on a few hundred data points. We have just computed horizontal variograms: with only data from 3 benches, we don't have that much information on B.H. grade variations through benches. Also, if we were to implement a blast hole distance weighting grade interpolation procedure (some form of blast hole kriging) we would tend to limit ourselves to blast holes on the same bench as the blast-block to estimate.

An example of blast hole variogram is given on Figure 27. It is for the % Pb + Zn of all available blast holes. In addition to the average variogram (circles), we have directional variograms along E-W (triangles) N-S (X) NE (+) and NW (diamond). Step to classify distances is 25' along E-W and N-S and 36' along NE and NW. All variogram points are defined from a large number of samples. There is no restriction on sample data. Those variograms show:

+ a well defined nugget effect of about 4 $(\%)^2$ i.e. about 35% of the variance of 11.5. Note that this is exactly the same as the nugget effect of % Pb + Zn of bench composite in both 20 + 30 and 40 + 70 ore types. Hence it looks like the sampling precision of blast holes is as good as that of drill holes.

+ a short range structure of about 100' (average variogram). For short distances, less than 100', we can detect some anisotropy pattern on directional variograms which is similar to the one observed on the bench composite variograms of type 20-30: top variogram (least continuity) is E-W and bottom variogram (best continuity) is N-S.

+ a long range structure of about 350' i.e. similar to what we had for the D.H. bench composites variograms.

Blast hole variogram models for various combinations of ore types are given on Table 17. We can see that:

+ the strong E-W/N-S anisotropy that we had for D.H. composites in 20/30 is still visible in the blast hole grades of the some ore type.

+ likewise, the variograms of blast holes in 50-60-70 is isotropic.

+ low grades 40 and 55 have been pooled together for variogram computation. The variograms show a strong trend at long distances due to the presence of isolated high grade blast holes categorized in those ore types. The model used does not take that trend into account.

To check the performance of various blast hole grade interpolation methods, we can use the same sample reuse method that we had for D.H. bench composites. The idea is to reestimate each of the 2083 B.H. % Pb + Zn grades from blast holes around using various interpolation methods and segregation of blast holes by ore type. Results are in Tables 18 and 19.

For example, if we do the reestimation with no segregation at all, we get a pretty good correlation between original and reestimated B.H. grade if we use kriging (r = 0.70 - Figures 28). It is not so good if we just use the nearest neighbor method (r = 0.56 - Figure 29) even if the dispersion of estimates perfectly matches that of the original data (see table 28). In fact, even if kriged estimates are smoother than real values, we can see one advantage of kriging over nearest-neighbor: the regression line of real on estimate is almost an y = x line. This means that if we mine all blast holes with an estimate of 6% the true average of these blast holes is 6% : we mine what we anticipate. There is no shortfall of grade above cut-off. On the other hand, if we use the nearest-neighbor approach, the regression line is like y = 0.56 x + 3.2. If we enter estimates (x) of more than 3.2/(1.0 - 0.56) = 7.27% Pb + Zn in this equation, the corresponding mean true value (y) is less than the estimate. Hence we overestimate high grade. For example, if we apply a cut-off of 6% Pb + Zn to the nearest-neighbor estimates, we get 1367 blast holes (66%) with an average estimated grade of 9.37% Pb + Zn but an average true grade of 8.57%. If we apply the same cut-off to the kriged estimates, we get 1560 blast holes (75%) with an average estimated grade of 8.46% Pb + Zn and an average true grade of 8.52%. Hence with kriging, we recover more tonnes (12%) at the expected grade. With nearest neighbor we have a grade shortfall of 8.5%.

We get even better results if we do the kriging of blast holes independently in 20-30, 50-60-70 and all the low grades 55-40-00-10 together. Correlation coefficient of real data and estimates is now 0.74 (Figure 30), regression line of real on estimate is virtually y = x. As a result, if we apply the 6% Pb + Zn cut-off on the estimates, we recover 1519 data (73%) with an average estimated value of 8.65% Pb + Zn and an average real value of 8.64%. We get a little less tonnage than in the case when we use all blast holes together but with a higher recovered grade. Our selectivity has improved.

Figure 26: Histogram of all B.H. % Pb + Zn available.

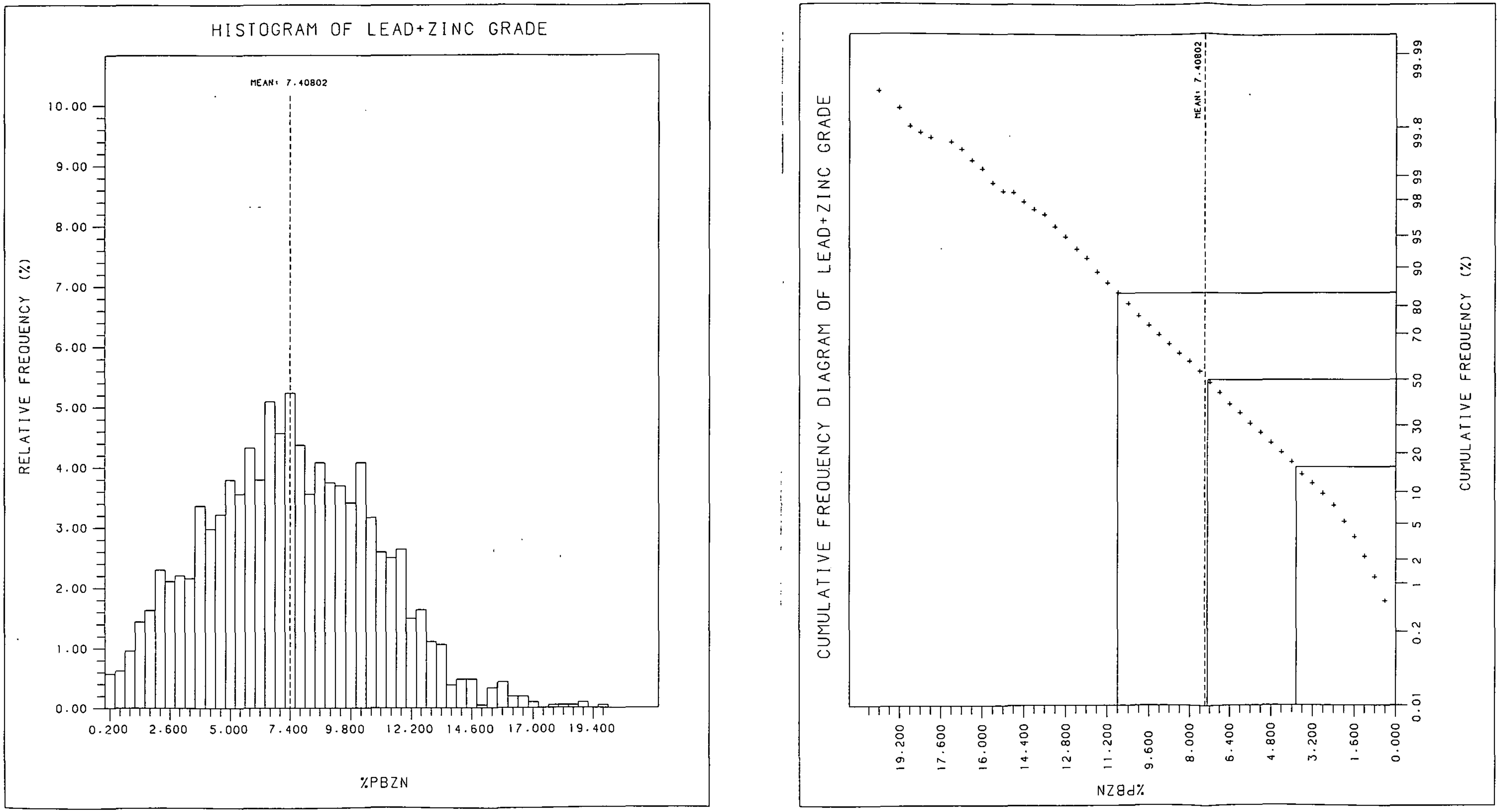


Figure 27: Horizontal variograms of all B.H. % Pb + Zn available.

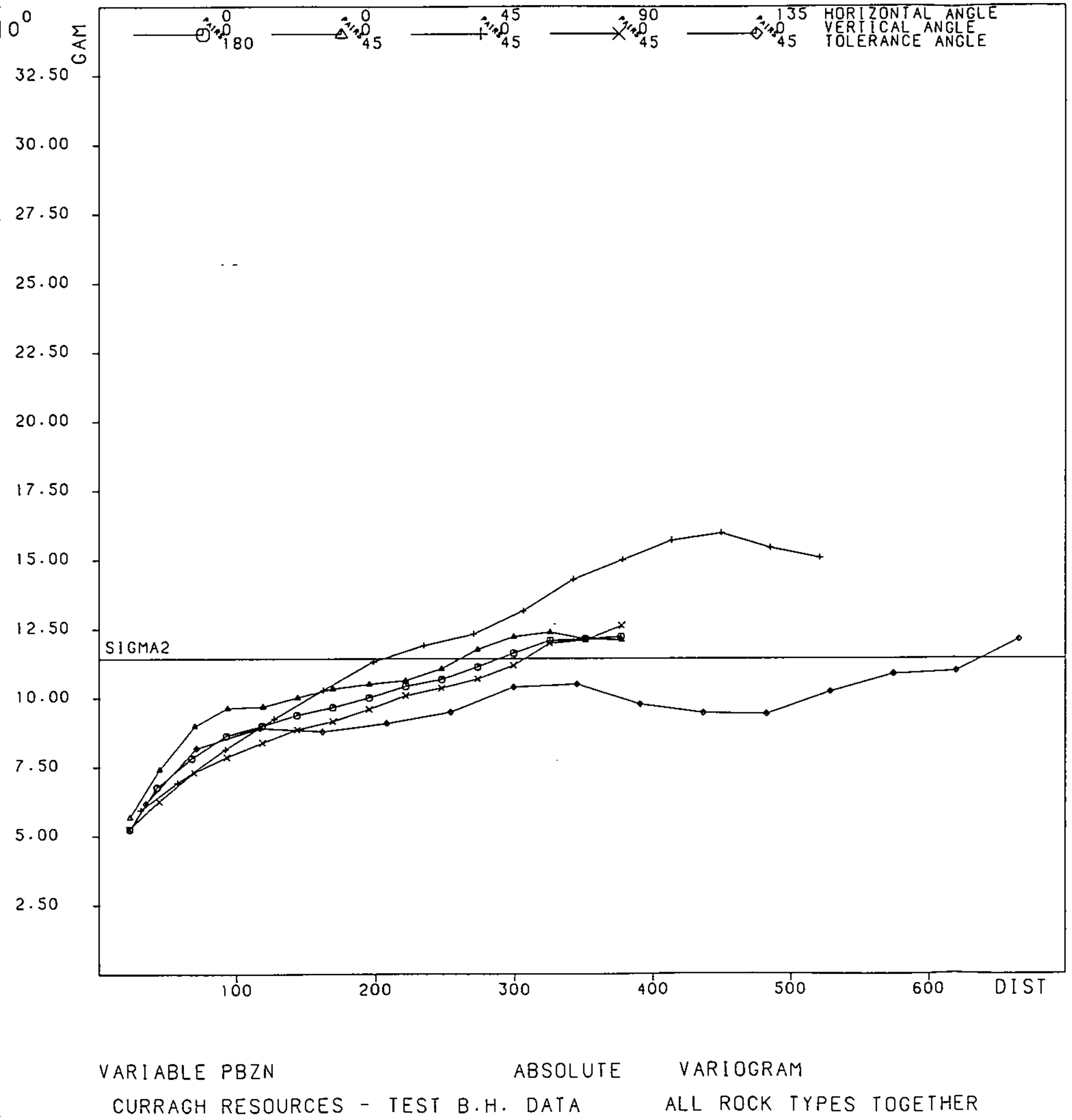


Figure 28: Correlation plot of real vs reestimated B.H. % Pb + Zn kriging. All B.H.s together.

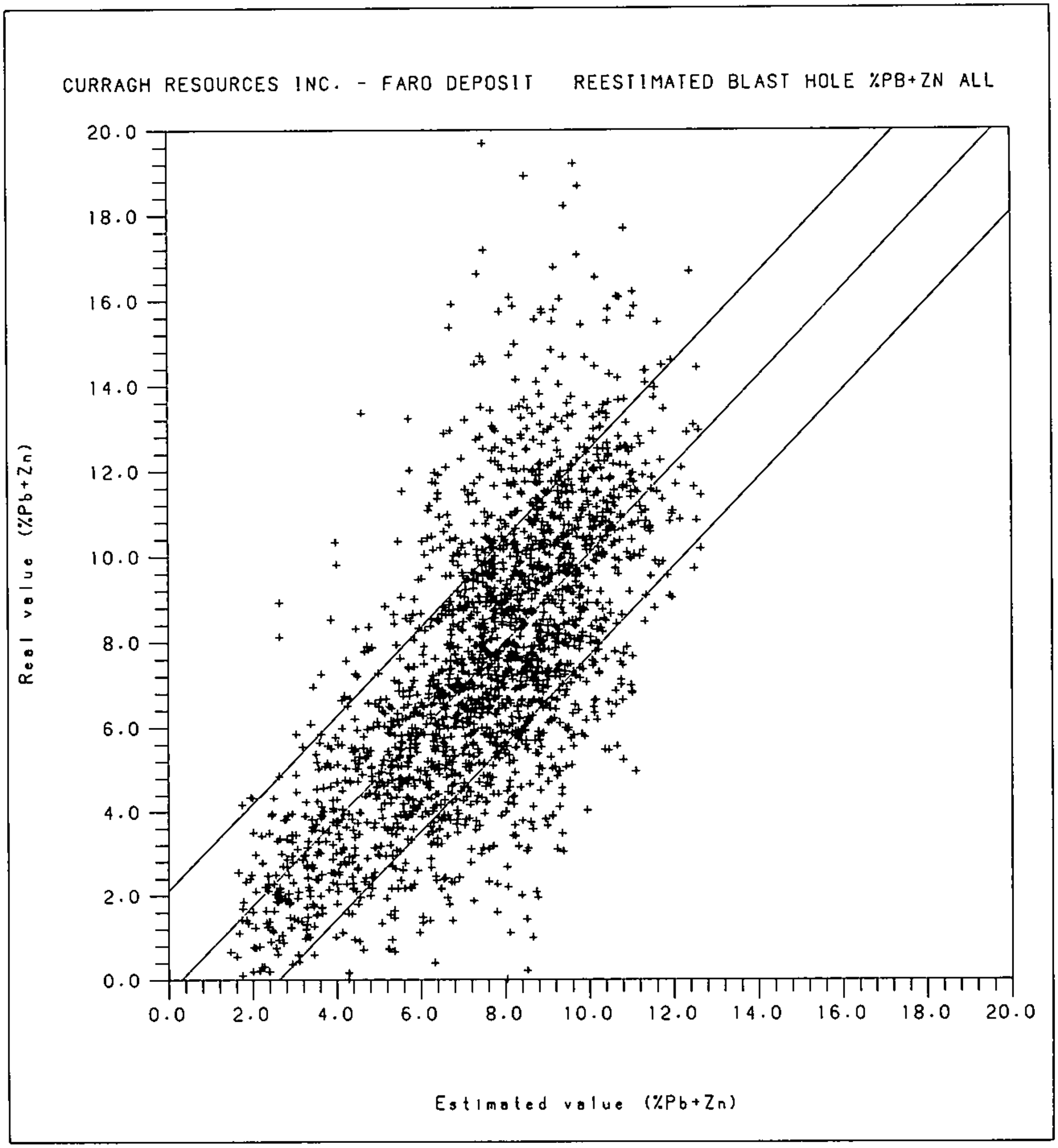


Figure 29: Correlation plot of real vs reestimated B.H. % Pb + Zn nearest neighbor. All B.H.s together.

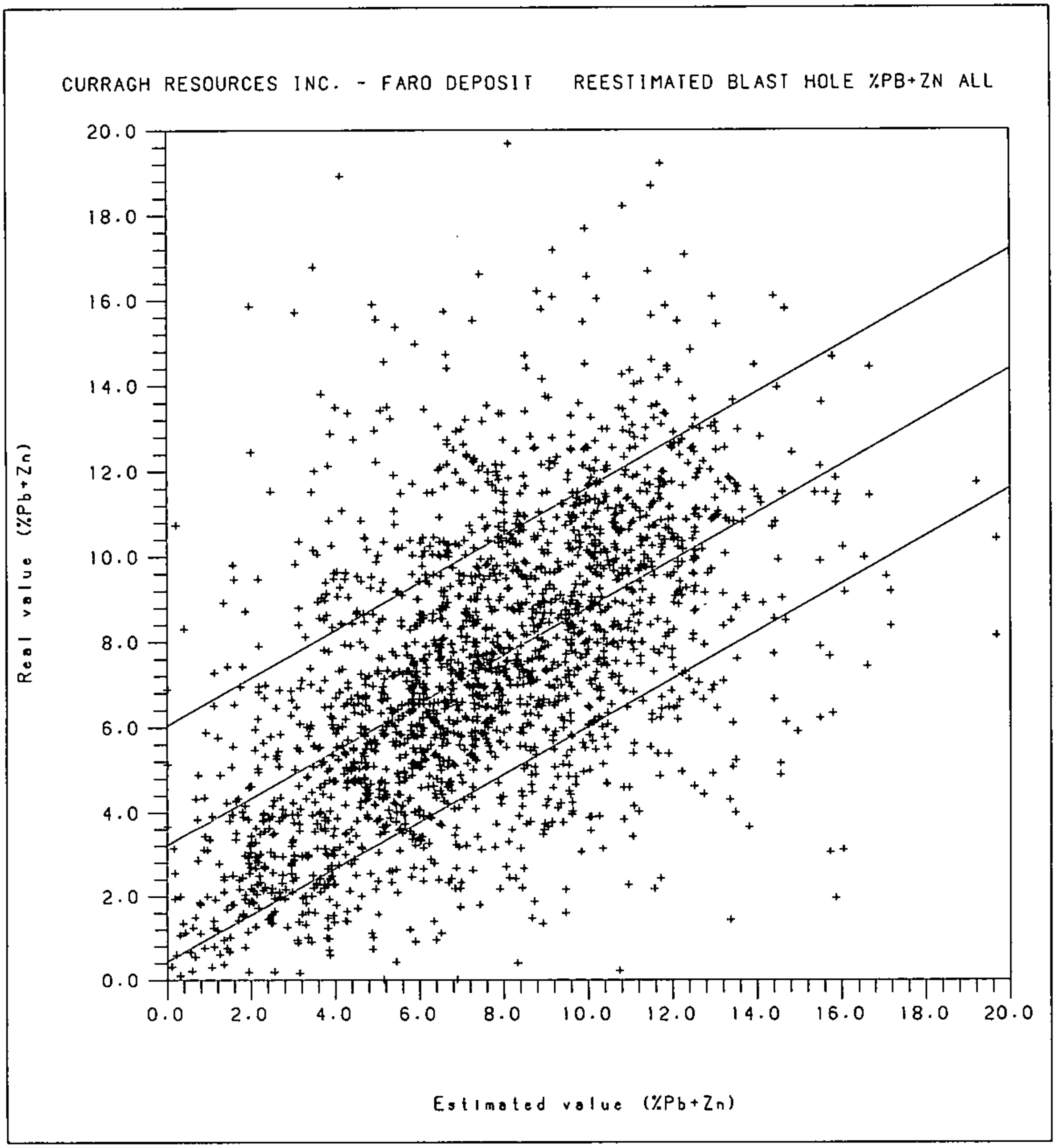


Figure 30: Correlation plot of real vs reestimated B.H. % Pb + Zn kriging. 3 separate ore types.

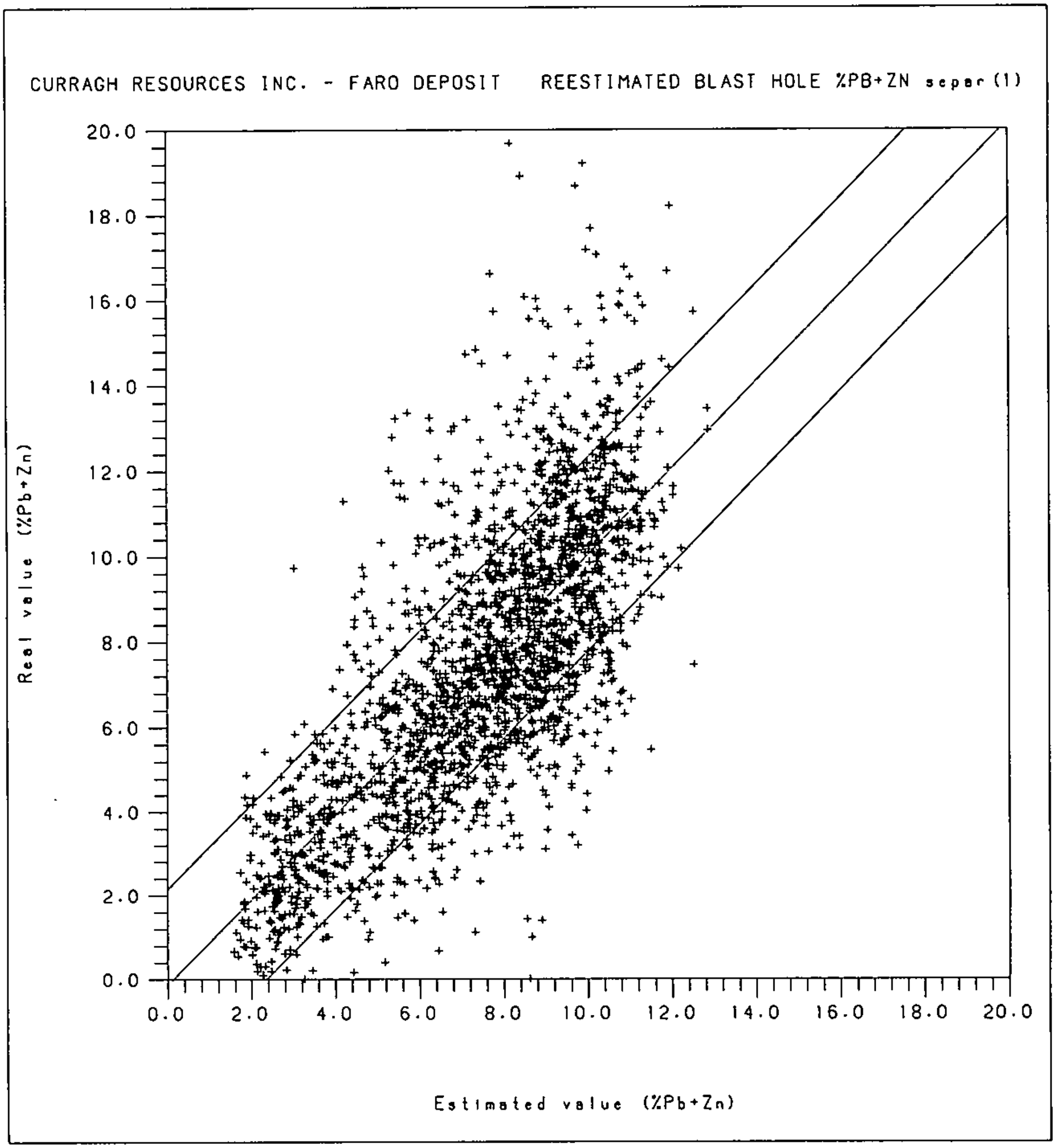


Table 17: Models of % Pb + Zn horizontal variograms for blast holes.

Blast holes	Nugget Effect $(\%)^2$	Sill $(\%)^2$	Spherical 1 Ranges (ft)	Sill $(\%)^2$	Spherical 2 Ranges (ft)	Sill $(\%)^2$	Spherical 3 Ranges (ft)	Total Sill (%)
All (N = 2083)	4	3.5	100	4.0	350	-	-	11.5
20 + 30 (N = 568)	3.5	2.0	50	2.5	75 (E-W) 500 (N-S)	-	-	8
50-60-70 (N = 1148)	4.0	0.5	50	3.0	300	-	-	7.5
40 + 55 (N = 318)	1.5	0.5	50	1.0	250	-	-	3.0

Table 18: Statistics of errors in the reestimation of % Pb + Zn grade of B.H.s for B.H.s around (on the same bench).

B.H. grouping	Interpolation method	Number of reestimations	Error (%)	Average Absolute error (%)	Experimental error variance $(\%)^2$	Theoretical error variance $(\%)^2$
All	Kriging	2078	-0.017	1.84	5.83	6.07
All	Nearest Neighbor	2078	-0.071	2.34	10.04	9.43
20-30 50-60-70 00-10-40-55	Kriging	2078	0.00	1.72	5.12	4.95

Table 19: Correlation of estimates and real values in the reestimation of % Pb + Zn grade of B.H.s from B.H.s around (on the same bench).

B.H. grouping	Interpolation method	Standard deviations Real	Standard deviations Estimates	Correlation coefficient	Regression real = f (estimates)
All	Kriging	3.37	2.26	0.70	y = 1.04 x - 0.3
All	Nearest Neighbor	3.37	3.36	0.56	y = 0.56 x + 3.2
20-30 50-60-70 00-10-40-55	Kriging	3.37	2.46	0.74	y = 1.015 x - 0.11

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October 22, 1990

Dr. Michel Dagbert
Geostat System International
4385 rue St. Hubert, Suite 1,
Montreal, Quebec

Dear Michel:

Thank you for the final version of the Phase II report. Attached is a list of questions which also cover the "Preliminary Evaluation". Many of them result from my incomplete geostatistical education, and some concern what are obviously typos. I very much enjoyed reading your conclusions and recommendations, and am very interested in implementing Kriging as a means of predicting mill feed grades (and tonnages) from blasthole data. We will also have to review our method for calculating computer generated ore reserves.

It looks as though you were able to do a good job of answering nearly all our questions, and we are now in a potentially much better position to estimate grade and tonnage from the Faro Pit than we were previously. The question of evaluating the impact of incorrectly interpretated geology remains a problem which, as you pointed out, will not likely be solved by block modelling.

I am recommending we continue this geostatistical work with a study of the Grum Deposit.

If you like you can send me any updated pages and I will replace those now in the original.

Yours truly,
CURRAGH RESOURCES INC.

Dave.

Dave Tenney
Chief Geologist

DT:cc

attmts.

LIST OF QUESTIONS

1 - 9	-	PRELIMINARY EVALUATION
10 - 22	-	FINAL PHASE II REPORT

1) Figs: 4,5,17,18,21,25 - show three parallel straight lines. What do they represent. (regression line ± one S.D.?)

Preliminary Evaluation:

2) Page 2 - (Bottom) - correction -

- 2EC - pyritic semi-massive sulphide ore (40)
- 2E/F - massive pyritic ore (50)

3) Page 3 - correction - 2nd line paragraph # 2

- ....multiple regression ......(not linear)

4) Page 4 - correction - Bottom 2nd paragraph

- " Latest model (F 9003) uses power 1 (1/D) and 2 "

- Could you explain the ... and 2?

5) Page 5 - Paragraph # 4 -

" ....1/D weighting seems to give better results than $1/D^2$

Results in Table # 1 suggests both 1/D and $1/D^2$ are close to blasthole results.

6) Page 7 - Bottom Paragraph

"...... we don´t compare block estimates with block true values: we rather compare the distribution of block estimates with the distribution of bench intercept values in the same area."

Are you saying we should do the latter rather than the former? What is the practical value of this statement?

7) Page 8 - Bottom line / Top Page 9

Are you recommending a block model with "Geological" block estimates? Does the complexity of geology at Faro really compare well to iron ore deposits in Labrador and Western Australia?

8) Page 10 - Paragraph # 1

".... linear regression...."

Should read "multiple regression".

9) Page 11 - 2nd Paragraph from bottom should read:

".... but they are the only ones with digitized coordinates"

Phase II Report:

10) Page 19 - Top Paragraph

"Enveloppes" should read "envelopes" on both line 3 and 4.

11) Page 19 -

Could I interpret results in Table # 5 to get an inverse distance power of 1.2 or 1.3 instead of 1.4 in rock types 20 - 30?

12) Page 24 - Bottom Paragraph

Does "connectivity" mean "continuity" in a geological sense or in a statistic sense?

13) Page 24 - Bottom Paragraph

When you do indicator Kriging, is the variogram constructed from the indicator values "0" or "1" (zero or one)? I assume that the indicators ("0" and "1") are assigned to model blocks based upon the Kriged grade of those blocks.

14) Page 26 - Bottom Paragraph

I assume relative standard errors of monthly and yearly estimates referred to are grade estimates not metal content estimates. Am I correct?
Also is there any significance to the use of "relative"? (Note that Table 9 refers to tonnage and grade separately).

15) Fax transmission dated 09/10/90 - Page 1 of 1

You state grade is underestimated by up to 17% in 20/30 rock types and up to 7% in 50/70 rock types. This suggests (as currently blasthole grades are in excess of mill heads) that dilution is greater than we had supposed.

16) Same fax sheet as above - lines 2/3 of message -

"correction of block estimates for proportion of blast holes in block"

Does this mean the correction of grade and tonnage in ore reserve blocks derived from the computer block model using the statistically determined distribution of blasthole tonnages and grades within the reserve block?.

17) (Page 38 2nd line from bottom) -

"tonnages are to high and grade too low" - compared with what? (BM S?). On a later page 55 you show Kriged BH assays give better results than polygonal (nearest neighbour) estimates of block grades, which seems in apparent contradiction with above statement - my understanding may be at fault here.

18) Is "lognormal short cut" (Page 39) an empirical method or is there a logical mathematical basis for using it which would apply to our situation at Faro?

Could you easily prepare comparison for several blocks showing polygonal (nearest neighbour), Kriged and Kriged + Lognormal short cut estimates of block grades?

Are you suggesting (based on P. 55) that we should Krige our blasthole grades to obtain a block grade or should a lognormal short cut correction be applied to Kriged grade as you did to diamond drill hole composite block grades (P. 39/40)?

19) Page 40 - Last Paragraph

"the correction is achieving its goal: reduce tonnage and increase grade."

Why is this a goal. If this correction in fact gives a better indication of "in situ" grade and tonnage then we must reevaluate dilution. (See question 15)

20) Page 55 - 2nd paragraph from bottom - 10th line

Formula should be: 3.2 / (1.0 -0.56)

21) Page 55 - Bottom Paragraph Line 5

By "true" do you mean "real" as in Line 2 of same paragraph.

22) Page 55 - Bottom Line -

If our selectivity has improved this must imply our dilution is higher than we thought.

23) P. ii Conclusions 4 - Line 4 -

Uncertainty about lead and zinc grade is <u>more</u> in rock types 20 - 30?

SYSTÈMES
GEOSTAT
INTERNATIONAL INC.

Montreal, November 16th 1990

Mr. Dave Tenney
Curragh Resources Inc.
P.O. Box 1000
Faro, Yukon
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Dear Dave,

Thank you for your letter of October 22. Please find herewith the corrected pages for the first and second reports as well as a few pages of answers to your list of questions.

Don't hesitate to communicate with me if you need additional clarifications.

Yours sincerely,

GEOSTAT SYSTEMS INTERNATIONAL INC.

Michel Dagbert, Manager

Encl.

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Geostatistical Analysis of Faro
Drill hole and Blast hole Data

CORRECTIONS AND CLARIFICATIONS

1- You are correct. The three parallel lines on the correlation plots of figures 4, 5, 17, 18, 21 and 25 are the regression line of y (vertical axis) on x (horizontal axis) in the middle and the ± one standard deviation lines on both sides. Assuming normal distributions for x and y values (lognormal distributions if we use log scale), the regression line gives an estimate of y given x and the two surrounding lines give the limits of 68% confidence interval for that estimate. For example, if we take the scattergram of % Zn vs % Pb for the composites in ore type 50 on Figure 4, given a composite with a 4% Pb, the best value of % Zn that we can predict for that composite is 6.2% but the 68% confidence for this predicted value is quite large from 4.8% to 7.6%.

2- Corrected page 2 attached

3- Both terminologies are correct. The density formula is a multiple regression since it involves several variables (% Pb, % Zn and % Fe) but it is also linear since it is a linear function of these variables. The exact terminology should then be: "multiple linear regression". Corrected page 3 attached.

4- "and 2" means the inverse of the power 2 (square) of distances. Corrected page 4 attached.

5- I agree that both weighting (1/D and 1/D^2) give results very similar to BH values specially for metal quantities. However if we look at grade and tonnage estimates, 1/D is marginally better than 1/D^2. Corrected page 5 attached.

6- The statement is misleading and I decided to suppress it completely. The rest of the text explains more clearly the problem of comparing block values above cut-offs and blast hole values above the same cut-offs in the same area. Basically, we mean that, even if we had exact 25' x 35' x 20' block values and blast holes in the same zone, the proportion and grade of those blocks above a cut-off, say 4% Pb + Zn, is not the same as the proportion and grade of blast holes above the same cut-off. If the overall grade in the zone is more then 4%, we have more tonnes in the blocks above the cut-off and at a lower grade. This comes from the lower variability of block values compared to sample values. Corrected page 7 attached.

7- Yes, I would suggest that, at least on a few sections, a purely geological block reserve estimation using the standard section method be attempted and results compared to 1) the inverse-distance regular block model on the same sections. 2) blast hole data in the same area. Of course the geological structure of Faro is not the same as that of the sedimentary iron ore deposits of Labrador or Western Australia specially the magnitude and layering. However, like in those deposits, we have at Faro:

1- a strong original statigraphic control.

2- intensive deformation of the original sedimentary structure.

8- Multiple linear regression. Corrected page 11 attached.

9- Corrected page 12 attached.

10- Corrected page 19 attached.

11- Yes. Table 15 indicates that in fact any power of inverse distance between 1.0 and 1.5 might give good results in ore type 20-30. In ore type 40-70, it would be any power between 1.5 and 2.0. Corrected on page 19 and conclusions.

12- Connectivity is used here in a geometrical sense. If ore lenses above a given cut-off are well connected and not scattered throughout the deposit in small patches, there is a good "connectivity" of ore above the cut-off. Additional explanations on page 24.

13- The indicator variograms are not used here to do indicator kriging (i.e. estimate the percentage of bench intercepts above a cut-off in a block) but rather to derive the estimation variance for the average value of the indicator (hence the proportion of ore above cut-off) over a large zone. Anyway it is right that it is computed after assigning a 1 to composites above the cut-off and 0 to composites below the cut-off.

14- Relative standard errors of 5% on monthly estimates and 2% on yearly estimate refer to tonnage estimates above cut-off. Error is slightly less for grade estimates (see table 9). Error on metal content estimates is even lower because of the negative correlation between tonnage and grade (if tonnage is overestimated, grade would tend to be underestimated).

Relative error means that error is not expressed in absolute terms (i.e. % Pb + Zn) but in relative terms: the error is divided by the estimate. Sometimes this is called a "precision".

15- If we take 413 blocks of 20/30 and the 568 blast holes in those blocks, we find that 59% of the blocks have an estimated grade (derived from D.H. bench composites of 20/30 around) above the 6% cut-off at an average grade of 6.86% whereas 53% of the blast holes are above the same cut-off with an average grade of 8.33% (Table 13) hence a difference of 17% on grade. If blast hole grades are in excess of mill heads, then mill heads are closer to the block estimates.

Now we are not too much surprised to hear that mill heads are less than blast hole grades. In fact, on page 55 of our report, when we analyze the continuity of blast hole grades, we come to the conclusion that, with the current processing of blast hole values (nearest neighbour), we overestimate high grade. We give an example for 6% cut-off: estimated grade is 9.37% but real grade is 8.57%, a 9% difference. There is a dilution when going from blast holes to block estimates but it is somewhat compensated by a dilution when going from blast holes to mill heads.

16- Yes this is exactly it: the original block grade estimate is taken as the mean of the distribution of blast hole grades in the block and the cut-off is applied to that distribution (not to the mean).

17- This is what we explain in #15. Block estimates derived from D.H. do not compare well to blast holes when you apply a cut-off because of the natural dilution when going from blast hole to blocks. This dilution is somewhat compensated by the fact that you don't mine individual blast holes but blocks around them.

18- The "lognormal short cut" is an empirical method that just consists in assuming that the distribution of blast hole grades in a block is lognormal with a mean equal to the block grade estimate and a variance derived from the variogram. In the case of Faro, it would be more appropriate to use a "normal shortcut" but the only thing that we had programmed at the time of the study was the lognormal model (now when variances are small, normal and lognormal are not that different).

The lognormal shortcut is designed to provide block reserves above cut-off directly comparable to individual blast holes in the same blocks. Now since block mined are not individual blast holes and there is some dilution here, it is a good idea to compare block estimates without lognormal correction, block estimates with lognormal correction, blast holes and kriged blast holes in the same zone.

Anyway, at the time of mining, when all decisions are taken from blast holes, it is definitely better to do the delineation of ore zones above a cut-off with kriged blast holes rather then individual blast holes. At this time, there is no need for a lognormal correction of the kriged blast holes grades (since you actually mine blocks and not individual blast holes).

19- Again the goal is to have block grades derived from DHs closer to those of blast holes in the same zone.

20- Corrected page 55 attached.

21- "True grade" is in fact "real grade". On the corrected page 55.

22- In the test zone, if we apply a 6% cut-off on the kriged blast holes with no segregation between ore types, we get 1560 B.H.s with an expected grade of 8.46% and a real grade of 8.52%. If we krige blast holes in separate ore types, we get 1519 BHs above 6% with an expected grade of 8.65% and a real grade of 8.64%. Selectivity has improved because 1) we get less discrepancy between expected grade and real grade 2) real grade above cut-off is higher. By all means, this is much better than applying the cut-off on individual blast holes: then we get 1367 BHs with an expected grade of 9.37% but a real grade of 8.57%.

23- No, as indicated by table 8, the uncertainty about lead and zinc grade is less in type 20-30 than in type 40-70. Although continuity is better in 40-70, variability of grade above cut-offs is less in 20-30 (standard deviations of composites grades above 3% and 6% cut-offs are 2.45% and 1.96% respectively in 20/30 and 3.09% and 2.46% respectively in 40/70).

GEOSTAT SYSTEMS INTERNATIONAL INC.

Michel Dagbert, Manager
11/16/90

MEMORANDUM

To:	Dave Tenney, Chief Geologist, Faro Operations, Curragh Resources Inc.
From:	Michel Dagbert, Geostat Systems International Inc., Montréal
Subject:	Comparison of mill head grades and blast hole predicted crusher feed grade.
Date:	November 22nd, 1990

Introduction

We have read your memo of October 10th showing the comparison of daily averages of mill head grades and blast hole grades for the period from April 10 to July 6. First you find that the best correlations are achieved with a zero (0.464) and one day (0.413) lag time between mine and mill and second that the regression of mill head % Pb + Zn grade on BH % Pb + Zn grade is of the form: $y = 0.451\,x + 4.369$

This suggests that high blast hole averages above 7.95% should be decreased (but at the same time, blast hole values below that same limit should be increased). To illustrate that correction:

Actual BH average	Corrected BH average
(% Pb + Zn)	(% Pb + Zn)
6	7.08
7	7.53
8	7.98
9	8.43
10	8.88

Note that this correction 1) relates to average blast hole values over a day (and not individual blast holes) 2) relates to BH values above a certain cut-off (say 4%) and not all BH values.

You relate that correction to the regression of real BH % Pb + Zn grades on their nearest neighbor estimate in our phase 2 geostatistical report of October 3rd: $y = 0.56\,x + 3.2$

This regression formula can be interpreted as the <u>average</u> relationship between the grade of a blast hole and the grade of the block (25 x 25) surrounding that blast hole. To illustrate that relationship:

BH grade (% Pb + Zn)	Expected grade of block around (% Pb + Zn)
2	4.32
4	5.44
6	6.56
8	7.68
10	8.80
12	9.92
14	11.04
16	12.16

Formally, it looks very similar to the first correction formula (corrected values in the range 6-10% are about the same - values above 7.3% are decreased - values below 7.3% are increased). However we must keep in mind that the second correction function 1) deals with individual blast hole values 2) at no cut-off.

If we assume that mill head grades are averages of blocks grades around blast holes, then the second relationship could represent the relationship between mill heads and blast holes provided that 1) it is limited to blast holes above the cut-off 2) it is based on the comparison of mean blast hole values and mean block values around those blast holes.

<u>Comparison of blast hole estimates at a cut-off.</u>

In fact, if we repeat our comparison of nearest neighbor BH estimate and real BH % Pb + Zn grade but <u>now only for estimates above</u> 4% Pb + Zn, we expect an average grade of 8.48% Pb + Zn (out of 1728 blast holes) but the real average grade of those blast hole is only 8.07% Pb + Zn. The regression formula for that restricted set of blast holes estimated above the cut-off of 4% is now: $y = 0.47\ x + 4.10$ with a correlation coefficient of 0.42.

This is now very close to the type of differences that we can experimentally observe between BH predicted and mill head grades.

It is interesting to note that if we do a comparison between real blast hole grade and kriged blast hole grade from neighbors at the same cut-off of 4%, we get the same good results as we had at no cut-off: 1875 blast holes have an estimate above cut-off (a 8% gain in tonnage compared to nearest-neighbor). The expected average grade is 7.90% % Pb + Zn and the real average grade is also 7.90%. The regression of real on kriged grade is : $y = 1.04\ x - 0.3$ (correlation coefficient = 0.60) i.e. almost the perfect $y = x$ relationship.

Analysis of daily mill head and BH values

We have received a fax copy of the daily values used to derive the first regression equation. For each day, from April 1 to July 31 1990, we have tonnes, % Pb, % Zn and % Pb + Zn as mined that day from BH data and tonnes, % Pb, % Zn and % Pb + Zn as milled that day.

If we sum all the tonnages for the 122 days, we get 1,595,605 tonnes mined and 1,601,957 tonnes milled, i.e. only a difference of 6,352 tonnes or less than 0.4%.

If we calculate the tonnes-weighted average grades for % Pb, % Zn and % Pb + Zn we get:

- from mine (BH) : 3.21% Pb, 5.14% Zn, 8.36% Pb + Zn
- from mill : 3.05% Pb, 5.02% Zn, 8.08% Pb + Zn

There is one extremely high value of % Zn mined for July 3: 14% (next highest is only 6%) which of course generates another high value for % Pb + Zn: 17.12% (next highest is only 9.73%). If we eliminate that suspicious data, we have average mined grades of : 3.21% Pb, 5.06% Zn and 8.28% Pb + Zn. Hence without that addity, the difference between the two lead values stays high but there is now almost no difference for zinc (5.06% vs 5.03% hence less than 1% relative difference).

Assuming a zero lag time between mine and mill, if we look at the correlation plots of % Pb and % Zn (Figure 1 without zero values and odd zinc value) we can see that:

x there is some kind of systematic difference between the two series of lead values: for that metal, we have only 38 days (out of 118) when mill is above mine. A simple non-parametric sign test indicates that this discrepancy is highly significant. The regression equation of lead of mill on lead of mine is: $y = 0.538\ x + 1.32$ with a 0.39 correlation coefficient.

x there is no real systematic difference between the tow series of zinc values: we now have 57 days (out of 117) when zinc of mill is more than zinc of mine. This is not a significant difference. Of course, like in any comparison where the correlation is passable, low mine values correspond to higher mill values and high mine values correspond to lower mill values. Thus the regression of mill on mine is: $y = 0.422\ x + 2.88$ with a 0.47 correlation coefficient.

x for % Pb + Zn, we find almost the same regression as yours: $y = 0.347\,x + 5.20$ with a 0.36 correlation. We have 50 days (out of 117) when mill is higher than mine, a non significant difference at a 90% confidence level. Of course the slight mine-mill unbalance that we observe for % Pb + Zn is mostly generated by the unbalance of lead values.

To illustrate the different behaviour of lead and zinc, we have plotted the weekly fluctuations of mine and mill values (Figure 2). For each day, a weekly value is calculated by averaging (using daily tonnages as weights) the values of that day, the 3 days before and the 3 days after.

As we average grades into more directly comparable tonnages, we clearly see the systematic lead difference and the more random difference for zinc.

Discussion

First we have seen that a comparison of BH predicted and mill head % Pb + Zn daily grades points to a correlation which is very much similar to the correlation between estimated BH % Pb + Zn grade by the nearest neighbor method and real BH % Pb + Zn grade above a cut-off of 4%. Hence it looked at first like the differences that were observed between mill and mine could be explained by the estimation errors of a blast-block grade form the single blast hole in its centre.

After looking at the mine-mill differences in more details, we found that we tend to have a systematic overestimation of lead mill head grades whereas zinc differences appear more random.

Now it may be that, because of a more erratic behaviour, the estimation of the lead grade of blast blocks by just the blast hole in the middle has more serious impact on the recovery of lead than zinc. To test that hypothesis, we have redone the comparison of blast hole estimates and blast hole real grades but now separately for lead and zinc. Then we have looked at the differences, for each element, and only for blast hole estimates above 4% Pb + Zn. Like before we have 1728 blast holes in this case = their average estimated lead grade is 3.22% and the average real grade is 3.09% (very close to the mine-mill statistics of lead). For zinc, the average estimated grade is 5.26% and the average real grade is 4.98% i.e. a similar type of difference that we don't observe in the mine-mill reconciliation.

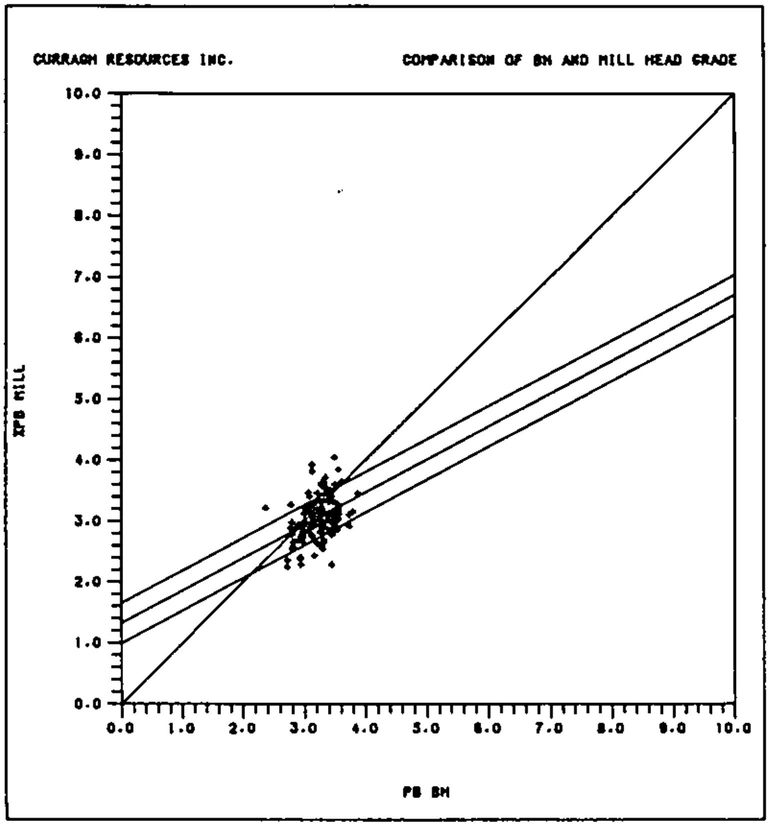
Altogether, it looks like the mine-mill difference that we see for lead can be explained by the way BH data are handled in the grade control procedure whereas we don't have any readily explanation for the good coincidence between zinc BH predicted and mill head grade.

At any rate we think that a true blast hole kriging is preferable to an overall correction of individual blast hole values based on a regression of mill head grades on BH predicted grades before a cut-off is applied to those individual blast hole values. The overall correction does not take into account the local configuration of data (i.e. zones with blast holes of systematic high or low grade where obviously no correction is needed vs zones with blast holes of rapidly changing grades) whereas blast hole kriging does it. Also, the overall correction is not applicable to blast hole data below economic cut-offs (say 4%): in fact, according to that formula, any blast hole would have a corrected value above the cut-off ($x = 0$, $y = 4.369\%$ Pb + Zn).

GEOSTAT SYSTEMS INTERNATIONAL INC.

Michel Dagbert, Manager

Figure: 1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COMPARISON OF BH AND MILL HEAD GRADE
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PB BH
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2.0
3.0
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7.0
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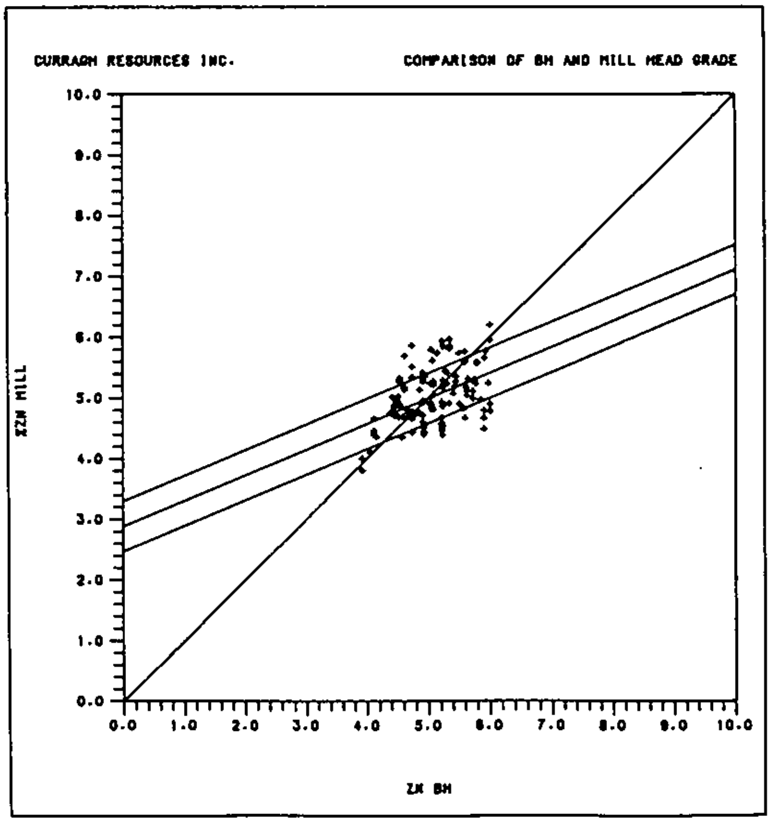
10.0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COMPARISON OF BH AND MILL HEAD GRADE
%ZN MILL
ZN BH
0.0
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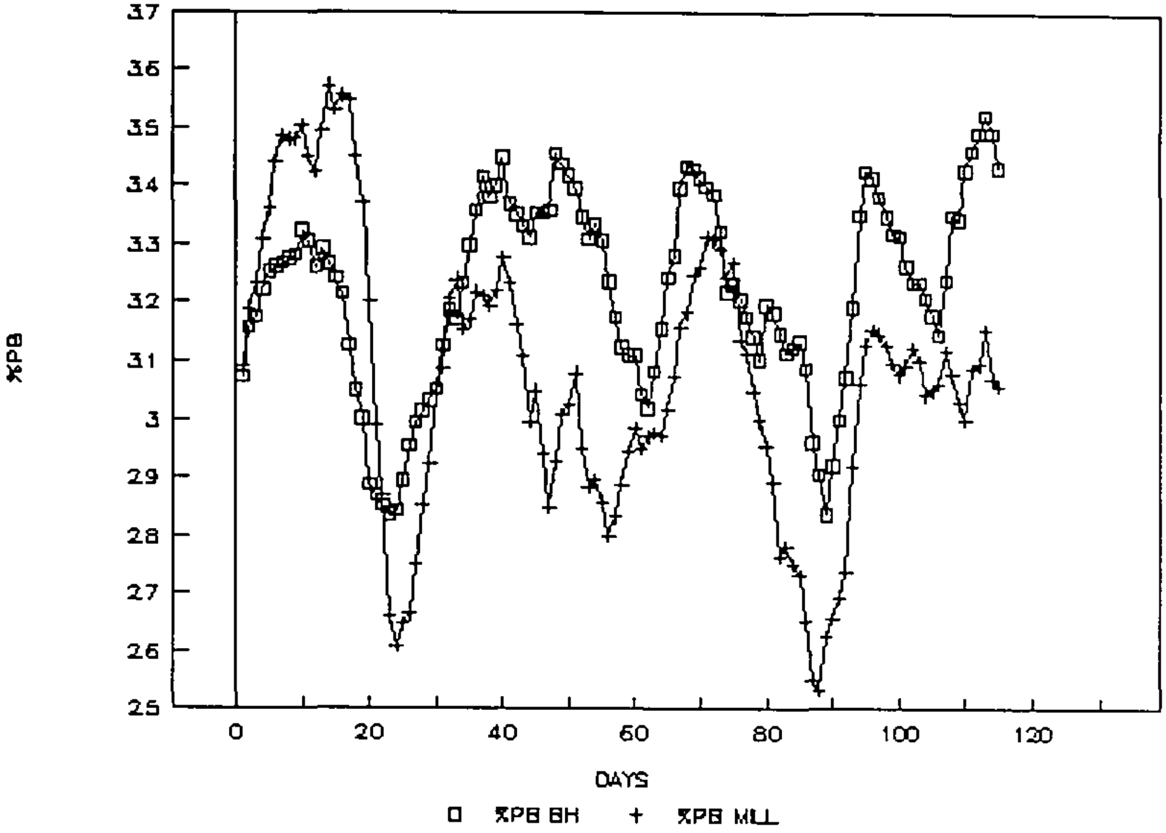
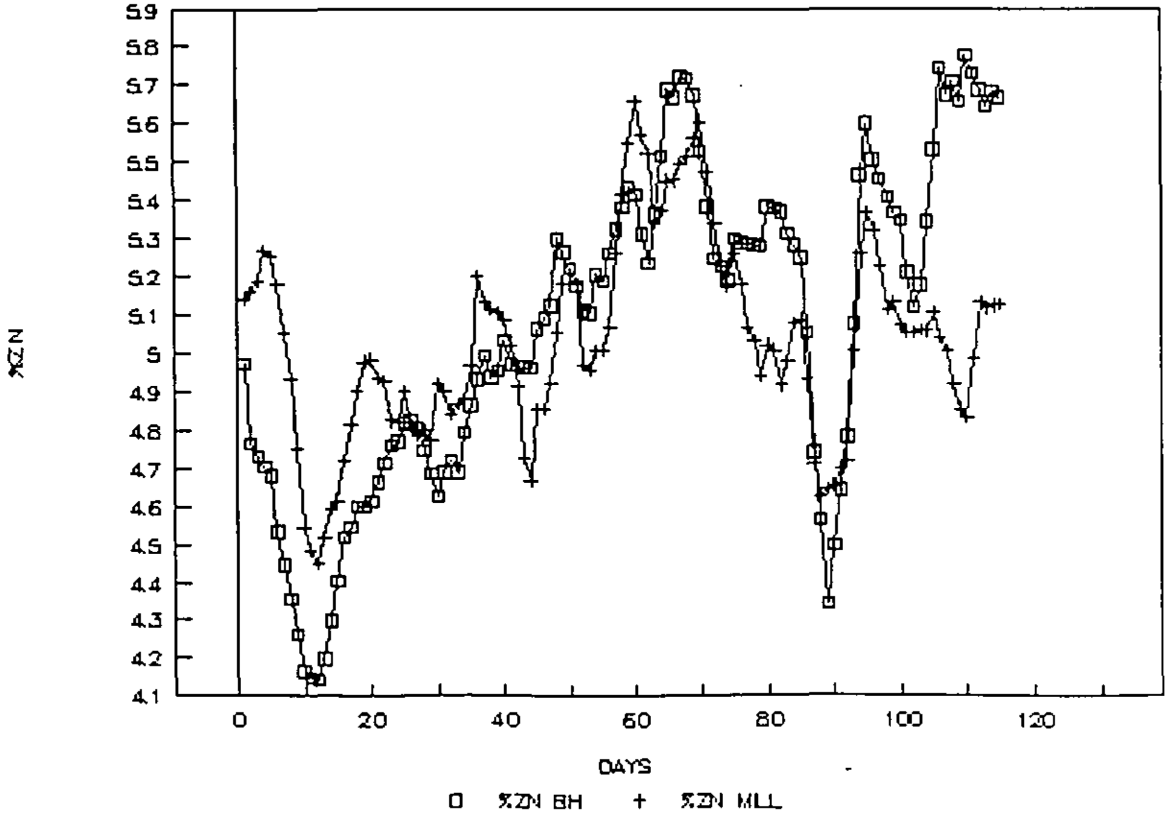
7 DAYS MOVING AVERAGES FOR %PB

Figure: 2



7 DAYS MOVING AVERAGES FOR %ZN



SYSTÈMES
GEOSTAT
INTERNATIONAL INC.

Montreal October 1st, 1990

Mr. Dave Tenney
Chief Geologist
Curragh Resources Inc.
P.O. Box 1000
Faro, Yukon
Y0B 1K0

Dear Dave,

Please find herewith a final version of the report on the geostatistical analysis of Faro drill hole and blast hole data. Our conclusions and recommendations are at the very beginning of the report. Basically we have identified 3 sources of differences between estimates and true values:

- spatial inference errors: they can only be reduced with more drill holes - numbers are in the report - kriging does not improve estimates that much over inverse distance.
- oversmoothing of block estimates: a simple "lognormal shortcut" correction of the regular block estimate can reduce this type of error very significantly.
- uncertainties of the geological model: we found many inconsistencies between the ore type classification of drill hole samples and blast holes specially in types 20 and 30. We can see room for much improvement in a better geological model.

We also show that it is worth implementing a fairly simple (absolute variograms with ordinary kriging) blast hole kriging plan in order to improve recoveries at various cut-offs. In the example that we ran, we have found a 12% increase of recovered tonnage at the 6% cut-off with estimated grade right on target.

I hope that this study can help you improve ore reserve estimation at Faro and its related deposit. I will of course answer any question that you may have or any clarification that you may need.

Yours sincerely,

GEOSTAT SYSTEMS INTERNATIONAL INC.
for
Michel Dagbert, Manager

Encl.

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GEOSTATISTICAL ANALYSIS OF FARO DRILL HOLE AND BLAST HOLE DATA
PART 2 : ANALYSIS

Respectfully submitted to Curragh Resources Inc.
by Geostat Systems International Inc.
Montreal , October 3rd, 1990

FOREWORD

This is the second part of the geostatistical analysis of Faro drill hole and blast hole data. First part of the study was presented in a report of July 27th, 1990. It defined the objective of that second part of the study namely 1) determine the magnitude of estimation errors for various block sizes and drilling grids 2) determine ways to reduce those estimation errors 3) evaluate other alternatives for processing blast hole data to categorize ore in blasts. This work is covered by the P.O.# D-129004 of August 10th, 1990, from Curragh Resources Inc., to Geostat Systems Int'l Inc.

CONCLUSIONS AND RECOMMENDATIONS

1- In the calculation of tonnes and grade above cut-off, we have identified 3 major sources of differences between estimates derived from D.H. data and values derived from B.H. data in the same area: spatial interpolation errors, oversmoothing of distance weighted estimates and uncertainty of the geological model.

2- **The spatial interpolation errors** can be quantified means of variograms calculated on drill hole bench composite values in the various ore types. If we stick to the current segregation of the quartzite ores (20, 30) and sulfide ores (40 - 70), then the average precision of 25' x 35' x 20' block % Pb + Zn grade estimates at a 95% confidence level are: ± 67% in 20-30 and ± 50% in 40-70 from drill holes on a 140' grid, ~~± 47% in 20-30 and ± 37% in 40-70 from drill holes on a 70' grid.~~

3- The above confidence intervals are quite large but they apply to rather small blocks. If we now consider groups of blocks which may represent a month, a quarter or a year production, we have the following average precision (still at a 95% confidence level) for tonnage and %Pb + Zn grade estimates above cut-offs : for a month and with the 140' grid: from ± 44% for tonnage above 6% cut-off to ± 14% for grade above 6% - for a month but with the 70' grid: from ± 22% to ± 7% - for a year with the 140' grid: from ± 13% to ± 4% - for a year with the 70' grid: from ± 6% to ± 2%. Previous figures assume a production made 50% from 20-30 and 50% from 40-70.

4- Precision of estimates for large volumes depends of drilling grid, ore type and cut-off. ~~Uncertainty on tonnage above cut-off increases with cut-off and,~~ at the 6% cut-off, is higher in 20-30 than in 40-70. Uncertainty on % Pb + Zn grade above cut-off is not as bad. It now decreases with cut-off and is less in 20-30 than in 40-70. Also, to get a ± 5% precision on all monthly estimates, we need a drilling grid between 35' and 40' at 3% cut-off and between 15' and 20' at 6% cut-off. The ± 2% yearly precision is easier to achieve: we can get it with just a 50' grid at the 3% cut-off but we need a 25' grid at the 6% cut-off.

5- The above quantification of spatial interpolation errors rests on variograms of D.H. bench composite grades in the two groups of ore types. With close to a thousand data points in each group, those variograms are well defined : relative nugget effects range from 35% (40-70) to 50% (20-30) of total variation, in 40-70, horizontal variations are isotropic with a maximum range of 600'; in 20-30, range along N-S (400') is much longer than along E-W (150'); in both group, there is a strong vertical anisotropy with vertical range not exceeding 60' in 20-30 and 180' in 40-70. Variogram features and the resulting assessment of the magnitude of spatial interpolation errors are confirmed by a D.H. bench composite reuse study. For example, in 20-30, out of 719 reestimated composites, 480 (67%) have an estimation error less than the predicted standard error and 683 (95%) have an estimation error less than twice the predicted standard error: this is an almost perfect fit of estimated and actual errors.

6- Variograms of D.H. bench composites also indicate only minor differences between kriged estimates and inverse distance estimates for the same blocks. The power of inverse distance which gives results closer to kriging is 1.4 in 20-30 and 1.75 in 40-70.

7- The oversmoothing of distance weighted block estimates is quite noticeable in the Faro long term block model: if you apply a cut-off on block estimates derived from D.H. bench composites, you always find more tonnes and a lower grade then what is indicated by the distribution of blast holes in the same area. In 20-30, tonnage differences are as much as 30% (5% cut-off) and grade differences reach 17%. In 50-70, maximum tonnage and grade differences are respectively 14% and 7%.

8- A way to overcome the oversmoothing of straight block estimates is to infer the likely proportion and grade of blast holes above the cut-offs in each block. A simple correction of block estimates dubbed "lognormal" short-cut reduces maximum tonnage differences to 8% in 20-30 and 3% in 50-70. With that correction, maximum grade differences are only 5% in 20-30 and 2% in 50-70.

9- All the above conclusions assume that the "geological model" is correct e.g. when we assign a code 20 to a block (and thus, we infer its grade from just 20-30 D.H. bench composites around), the type of ore in that block is actually 20 (or 30). To validate that assumption, we have compared the ore type of a D.H. bench composite to the ore type of the nearest B.H. (in the same bench and at a distance of less than 20'). We found that the classification of the predominantly high grade types 50 + 60 + 70 is consistent from drill holes to blast holes since nearly 70% of the D.H. composites of that type have a B.H. of the same type next to them. However, we have more problems with types 20 and 30: in that case, more than 50% of the D.H. composites of those types have a B.H. of type 50-70 nearby. We suggest that the criteria used to classify D.H. samples and B.H. of type 20-30 be revised so that we have more consistency in the classification of the two types of samples.

10- Another suggestion related to the geological model is to separate type 40 from types 50, 60 and 70 in the estimation of blocks even if they all refer to sulfide ore. Statistics of type 40 D.H. composite grade values indicate that they are much lower than for the other categories of sulfide ores. As a result, there is a danger to underestimate a type 50-70 block with a type 40 composite next to it and overestimate a type 40 block with a type 50-70 composite nearby. In fact, in the comparison of block estimates with B.H. values in those blocks, better results were achieved after isolating type 40 composites (and type 55 blast holes).

11- This geostatistical analysis of D.H. bench composites data can be extended to blast holes. The idea here is to see whether there is a better procedure to delineate ore limits in blasts than just contour individual blast hole grades. From the test data set of about 2000 blast holes in the south part of benches 3450, 3470 and 3490, we found that:

+ if we krige the grade of blast blocks from blast holes and then apply the cut-off on those blast block estimates, the actual grade of the material that we recover is the estimated grades.

+ if we contour individual blast hole values, the actual grade is less than the expected grade (in the example that we ran we noticed a 8.5% shortfall at the .6% cut-off). Moreover, we get less tonnes than if we do the selection on kriged estimates (12% in our example).

+ recovery based on kriged blast blocks estimates is even better if we process blast holes of type 20-30, 50-60-70 and 40-55 separately.

+ blast block kriging can easily be implemented with blast hole variogram models. Horizontal variograms of groups of a few hundred of blast holes around a blast are quite interpretable. They generally show the same features as the corresponding variograms of D.H. bench composites. In particular, their nugget effect is the same hence it looks like the sampling precision of blast holes is as good as that of drill holes.

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1-LONG TERM PREDICTION FROM DRILL HOLE DATA

1-1 Statistical analysis of D.H. bench composite data

The current file of DH 20 ft bench composite data that we received from Curragh Resources Inc. has values for 7333 composites from 419 drill holes (from 65-53 to 90F93) . For each composite , we have the 3 coordinates of the center point of the composite , its principal rock type (from 20 to 190 - 1608 composites have an undefined rock type of -1) , the calculated grades for %Pb , %Zn and %Pb+Zn and the calculated specific gravity (with some undefined values of -1.0 too) .

Out of this total , only 1730 composites are in the "mineralized" rock types i.e. 20,30,40,50,60,and 70 (3783 composites are in rock type 100 i.e. the top and bottom phyllites - 407 of them have a non-zero Pb+Zn value - surprisingly,31 composites in this supposedly "waste" rock type have a Pb+Zn grade above 6% with an overall maximum of 9.07 %) - In the current long term model , mineralized composites are grouped in two categories : "quartzite" ore (20+30) and semi-massive and massive sulfide ore (40+50+60+70) - Figure 1 is a map of those mineralized composites in one of the bottom bench of the pit , bench 3450 , between elevations 3450 and 3470 ' . On this map , we can see the 140' drilling grid in the center and north part of the pit (now mined-out) and the 70' drilling grid in the south part (now being mined) . We see also that , as a general rule , the quartzite ore (20 = circles and 30 = triangles) is around the deposit whereas the sulfide ore (40 = plus , 50 = cross ,60 = diamond and 70 = arrow) is in the center . After producing this map from the composite file , we noticed many discrepancies between the rock type of composites in the file and the interpreted limits of the different ore types on the same bench as shown on a map received from the company. Staff at Curragh has been notified of these discrepancies (our fax of Aug. 21).

We can calculate summary statistics of composite values in the different mineralized rock types . They are shown on Table 1 for quartzite composites and table 2 for sulphide composites . Typical histograms of %Pb+Zn are on figures 2 (type 40 - skewed distribution) and 3 (type 50 - normal distribution) . Our conclusions :

- distributions of Pb+Zn,Zn and Pb values are positively skewed and lognormal like in the low grade rock type 40 (Figure 2) . Distributions are symmetric and normal like in the rather high grades rock types 50 , 60 and 70 (Figure 3) . Distributions of values are slightly skewed in 20 but rather normal in 30 .

- except for the difference in shape described above , parameters of the distributions in 20 and 30 are fairly similar (there is a little more lead in 30) and it makes sense to group those two ore types in the estimation of blocks .

- on the other hand , the distributions of values in 40 are quite different from those in 50 , 60 and 70 and it does not seem logical to put all those composites in the same group . 40 has the lowest values of all ore types whereas 50 , 60 and 70 have the highest values . With this scheme , we may have potential problems when a high grade block 50 is estimated with a low grade composite 40 nearby and vice-versa

- the highest relative dispersions (coefficients of variation above 60 %) are in the low grade 40 . Then we have about the same dispersion in 20 and 30 (coefficients of variation between 55 and 60 %) . The lowest dispersion is in the high grades 50 , 60 and 70 (coefficients of dispersion between 30 and 40 %) . Hence , for the same drilling grid , precision of block estimates is expected to be better in high grade ore (50+60+70) than low grade ore (20+30) .

- production Pb+Zn cut-off grades (3,4,5 and 6%) are quite high compared to mean values of Pb+Zn in some ore types . The high grade cut-off of 6% is above the median of distributions in 40 , 20 and 30 . Then we can expect more difficulties in locating the high grade ore in those ore types .

There is a high degree of correlation between %Zn and %Pb in all ore types . Correlation coefficients range from 0.75 in 50 (Figure 4) to 0.86 in 20 (Figure 5) . Type 20 is also the ore type where the average ratio %Zn/%Pb is the highest (2.0 vs 1.3 to 1.6 in the other ore types) .

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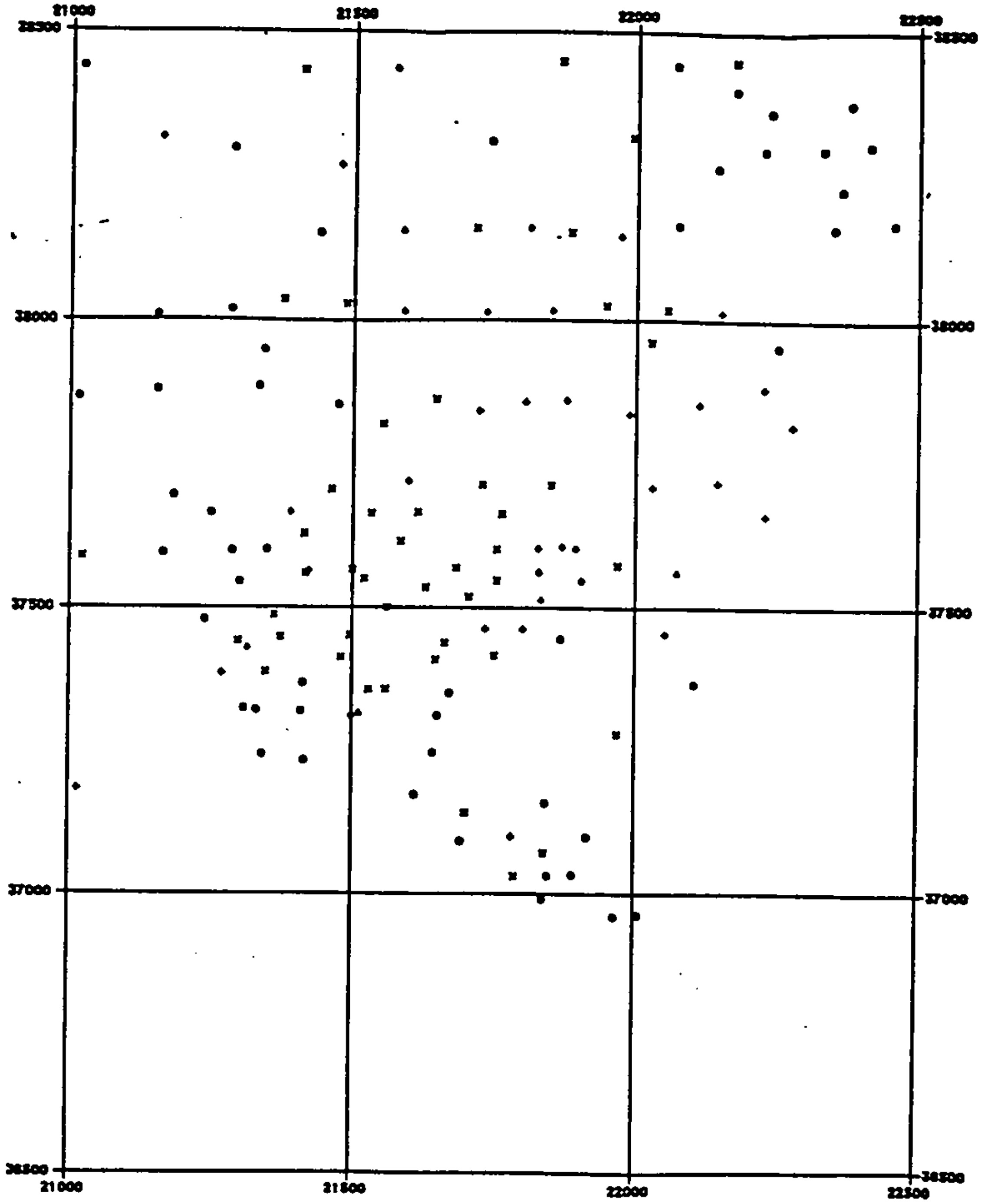
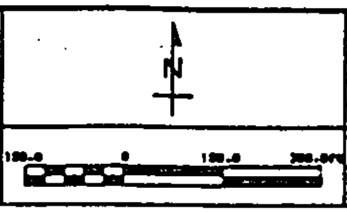
Figure 1 Map of "mineralized" DH composites in bench 3450. (20 = circle , 30 = triangle, 40 = plus , 50 = cross , 60 = diamond , 70 = arrow)





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CURRAGH RESOURCES INC.

D.H. COMPOSITES IN BENCH 3450

Figure 2 Histogram of Pb+Zn grades of composites in type 40

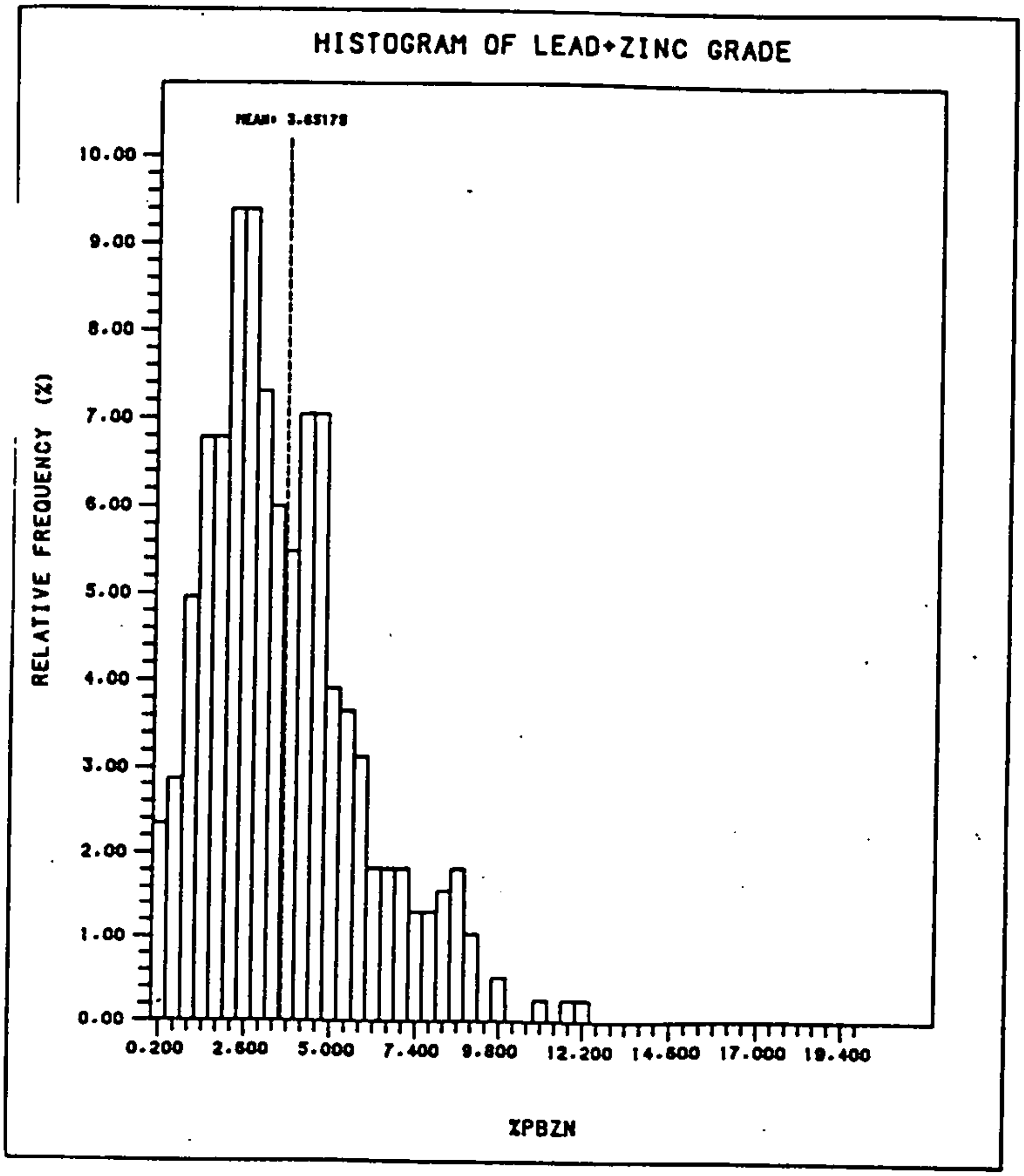


Figure 3 Histogram of Pb+Zn grades of composites in type 50

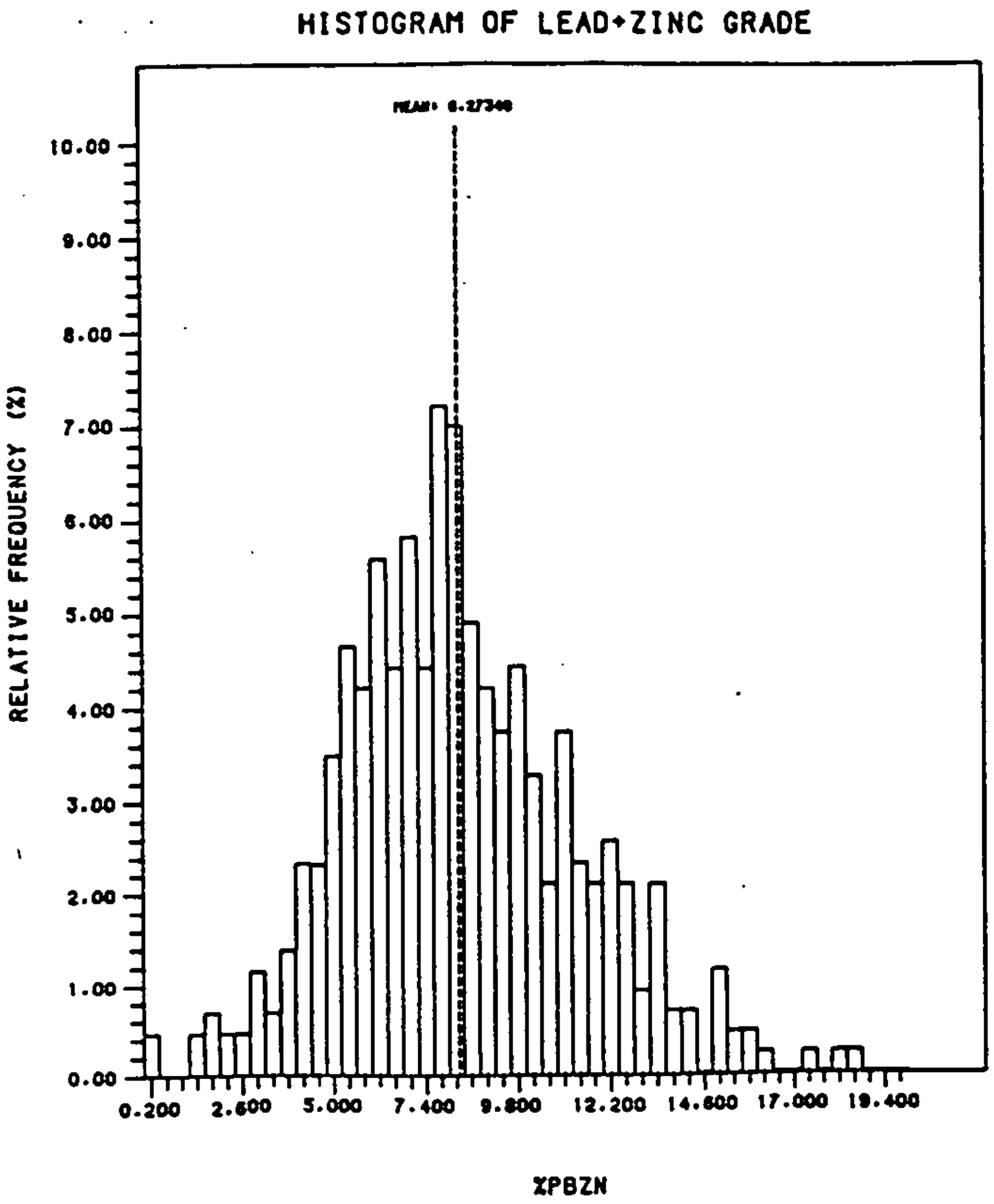


Table 1 Statistics of %Pb+Zn composite data

	20	30	20+30	40	50	60	70	40-70
Number	639	103	742	383	430	109	66	988
Minimum	0.0	0.0	0.0	0.0	0.0	3.0	1.84	0.0
Percentile 5%	1.12	1.36	1.04	0.77	3.84	4.75	3.64	1.32
Percentile 16%	2.40	2.19	2.38	1.56	5.42	6.40	5.75	2.62
Percentile 50%	4.73	5.33	4.81	3.22	7.98	9.40	9.33	6.47
Percentile 84%	7.84	8.62	7.96	5.71	11.45	12.06	12.37	10.40
Percentile 95%	10.12	11.09	10.23	8.17	13.48	14.70	14.39	13.12
Maximum	16.10	12.97	16.10	12.34	18.64	17.49	15.63	18.64
Mean	5.10	5.55	5.16	3.65	8.27	9.44	9.12	6.67
Standard deviation	2.81	3.17	2.87	2.22	3.04	2.98	3.11	3.67
Coefficient of variation	55	57	55	61	37	31	34	55

Table 2 Statistics of %Zn composite data

	20	30	20+30	40	50	60	70	40-70
Number	639	103	742	383	430	109	66	988
Minimum	0.0	0.0	0.0	0.0	0.0	1.77	1.23	0.0
Percentile 5%	0.68	0.09	0.58	0.36	2.00	2.29	1.85	0.82
Percentile 16%	1.59	1.26	1.57	0.99	3.13	3.52	3.30	1.63
Percentile 50%	3.16	3.19	3.16	2.00	4.97	5.41	5.57	3.90
Percentile 84%	5.15	5.66	5.21	3.48	7.26	6.77	7.02	6.30
Percentile 95%	7.01	6.92	7.00	5.14	8.57	8.25	8.76	8.17
Maximum	10.27	9.03	10.27	7.56	12.04	10.40	9.38	12.04
Mean	3.40	3.40	3.40	2.25	5.10	5.33	5.42	4.04
Standard deviation	1.90	2.03	1.92	1.39	2.03	1.79	1.88	2.27
Coefficient of variation	56	59	56	62	40	33	34	56

Table 3 Statistics of %Pb composite data

	20	30	20+30	40	50	60	70	40-70
Number	639	103	742	383	430	109	66	988
Minimum	0.0	0.06	0.0	0.0	0.0	1.07	0.61	0.0
Percentile 5%	0.36	0.79	0.33	0.21	1.35	2.07	1.23	0.34
Percentile 16%	0.74	1.26	0.74	0.42	2.06	2.79	2.36	0.95
Percentile 50%	1.50	2.09	1.56	1.23	3.05	3.95	3.70	2.57
Percentile 84%	2.65	3.31	2.80	2.38	4.33	5.50	5.18	4.11
Percentile 95%	3.55	4.07	3.69	3.14	5.32	6.71	5.78	5.32
Maximum	5.83	5.96	5.96	4.78	7.35	7.59	7.11	7.59
Mean	1.69	2.15	1.76	1.40	3.17	4.11	3.70	2.63
Standard deviation	1.00	1.29	1.05	0.96	1.21	1.38	1.40	1.54
Coefficient of variation	59	60	60	68	38	33	38	58

Figure 4 : Scattergram of Zn and Pb composite values in ore type 50

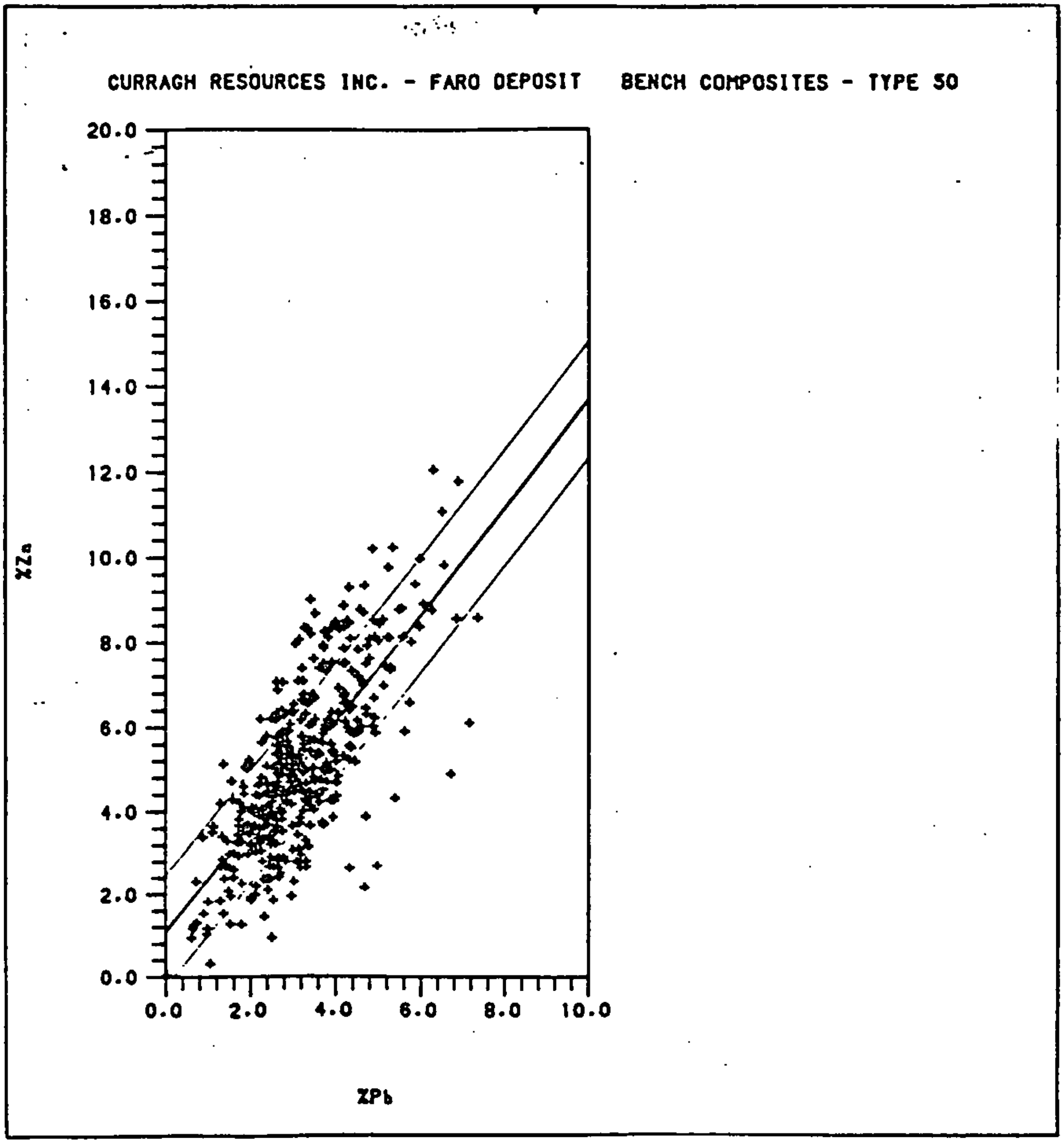
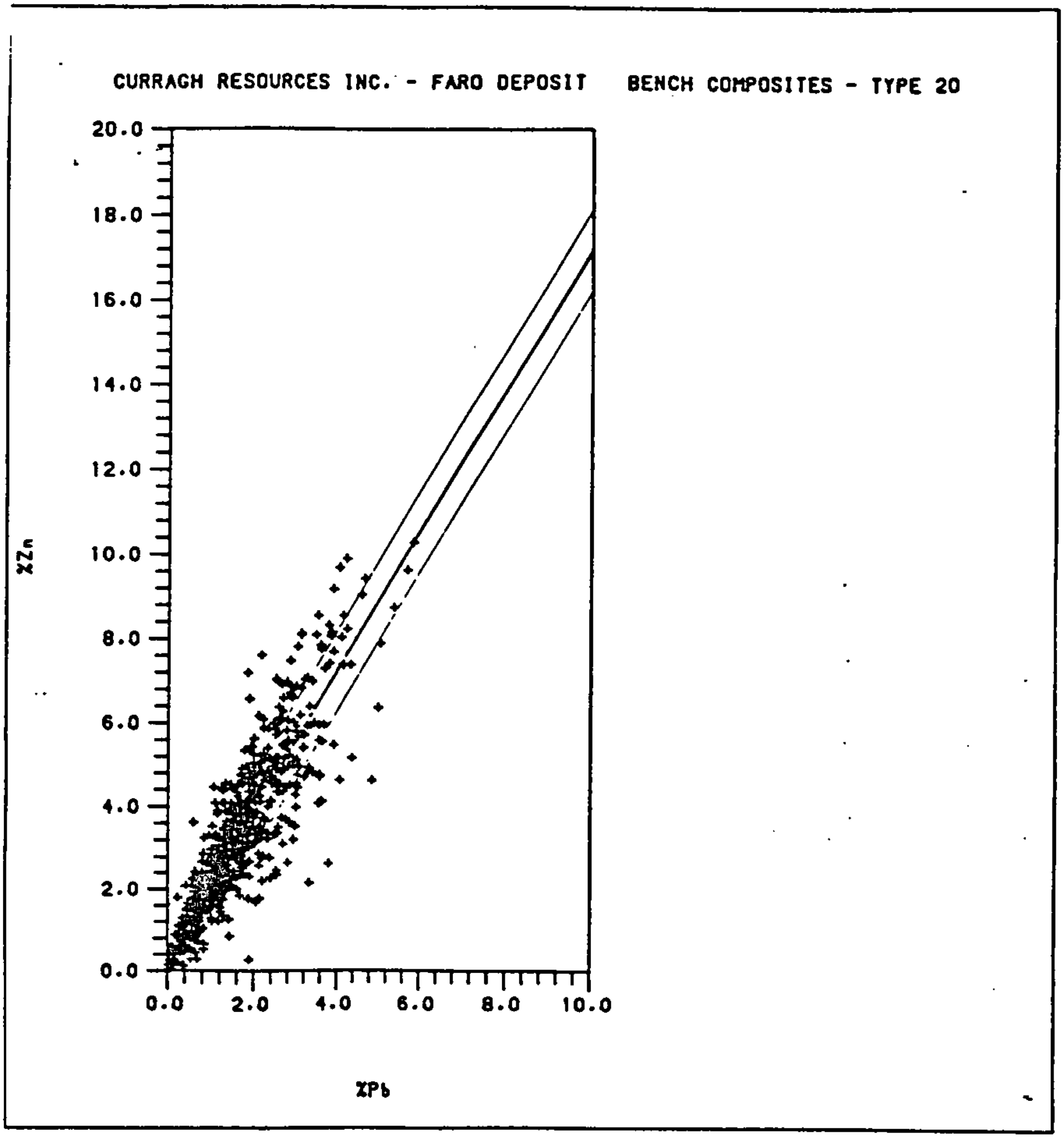


Figure 5 : Scattergram of Zn and Pb composite values in ore type 20



1-2 Variogram analysis of D.H. bench composite data

Variograms are diagrams showing the average difference between sample values as a function of the distance between samples . Variograms are computed along specific directions since the rate of increase of differences with distance may not be the same in all directions . Variograms are helpful in 1) assessing the magnitude of errors in the estimation of blocks 2) determining the most suitable estimation method for the blocks (e.g. choosing between $1/d$ or $1/d^2$) .

To keep consistent with the estimation method currently used at Faro , we have computed variograms of the grades and SG of bench composites in ore types 20-30 and 40-70 separately . Note that there is not enough composites in types 30, 60 and 70 to derive meaningful 3D variograms specifically in those ore types . However , it is quite feasible to have specific variograms for type 40 (and others for types 50,60 and 70 together) .

In both cases , variograms are computed along the vertical direction of most D.H. (angular tolerance 10 degrees - step for distances 20 ') and the four principal directions of the horizontal benches i.e. E,NE,N and NW (tolerance 45 degrees - step for distances 75 ') . In addition the omnidirectional variogram (tolerance 180 degrees) and an average horizontal variogram are computed . Variograms are of the absolute type with no transformation of raw data nor clipping of some high values .

Figure 6 shows the vertical variogram of %Pb+Zn together with the omnidirectional variogram in ore type 20-30 . We can notice an apparent nugget effect of about 4 (50% of overall variation) and higher differences along vertical than average (anisotropy) . Vertical range does not seem to exceed 60' . On figure 7 , we have the horizontal variograms of the same data : nugget effect is still very much apparent as well as some anisotropy . In this case , for short distances , the lowest curve (best continuity) is along N-S and the highest one (worst continuity) is along E-W . Also , NE is below average and NW is above average . A suitable model for the variogram of %Pb+Zn in 20-30 would be the sum of a nugget effect of 4 and a spherical function of sill 4.2 , long range 400' along N-15°-E , intermediate range of 150 ' along E-15°-S and short range of 60' along vertical . Variograms for the %Zn and %Pb grades in 20-30 are of the same type (Table 4) : the only noticeable difference is for %Pb with a truly N-S long range of 500'.

In 40-70 , the vertical variogram of %Pb+Zn is also above the omnidirectional variogram (Figure 8) . Apparent nugget effect is less than in 20-30 (35 % of overall variation) and vertical range is longer (180 ') . Along horizontal directions of the benches (Figire 9), variograms are almost linear with no apparent anisotropy . Model used is the sum of a nugget effect of 4 , a short range spherical function (60' horizontal and 40 ' vertical) and a long range spherical function (600' horizontal and 180 ' vertical) . Models for %Pb and %Zn are very much similar (Table 4) .

In conclusion , for both groups of ore types , it is feasible to define meaningful variograms for DH bench composite data . Horizontal ranges are generally several times the drill hole spacing . The only exception is with 20-30 where the E-W range is of the same order of magnitude as the original spacing between holes . Hence for this type of ore , additional holes at 70' distance on E-W section lines is quite an improvement . Also relative nugget effects are higher in 20-30 than in 40-70 which means that grade interpolation is more difficult in this type of ore (in other words , for the same drilling grid and block size , relative errors are likely to be higher)

Figure 6 Vertical and omnidirectional variogram of %Pb+Zn in type 20-30

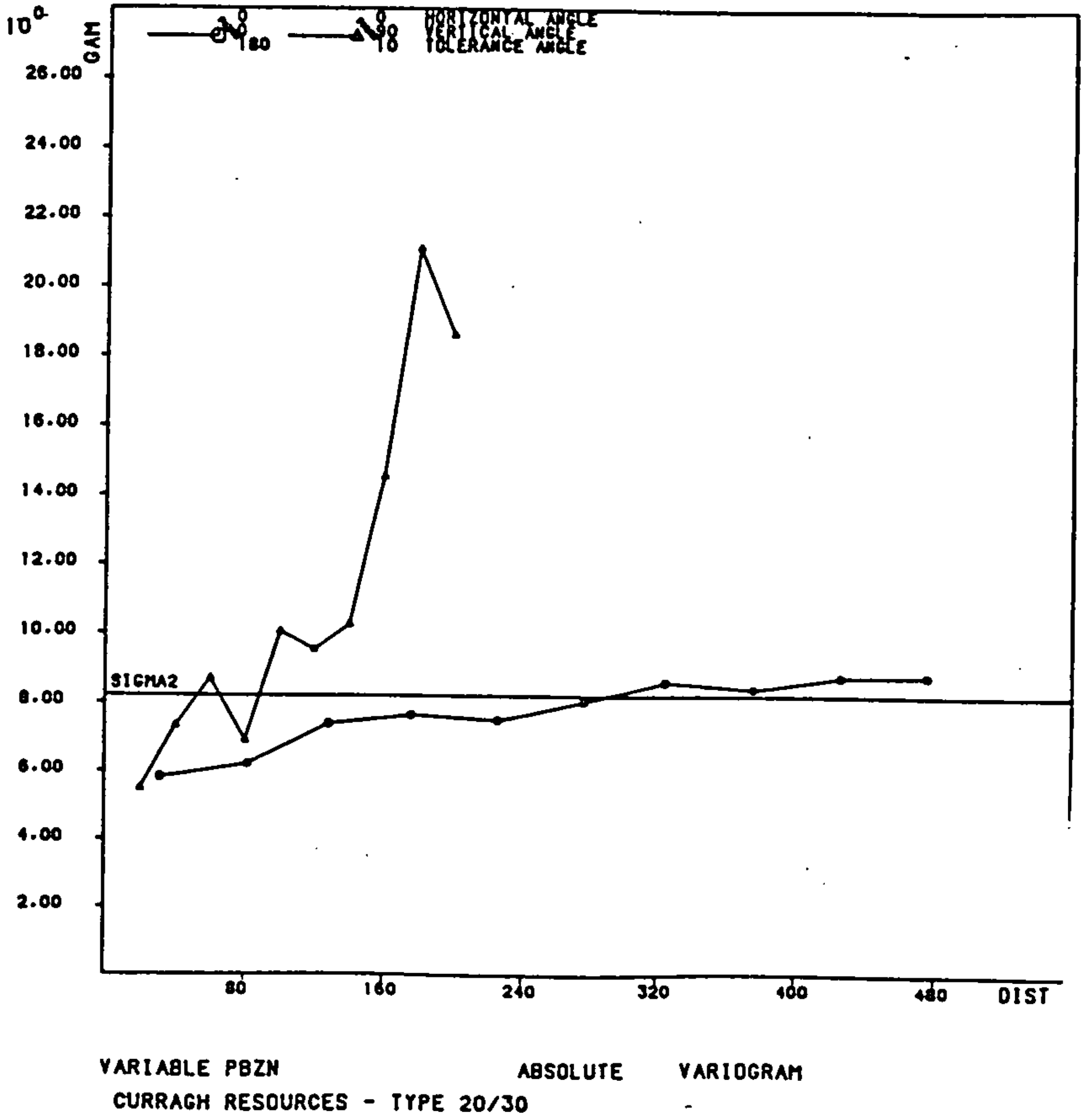
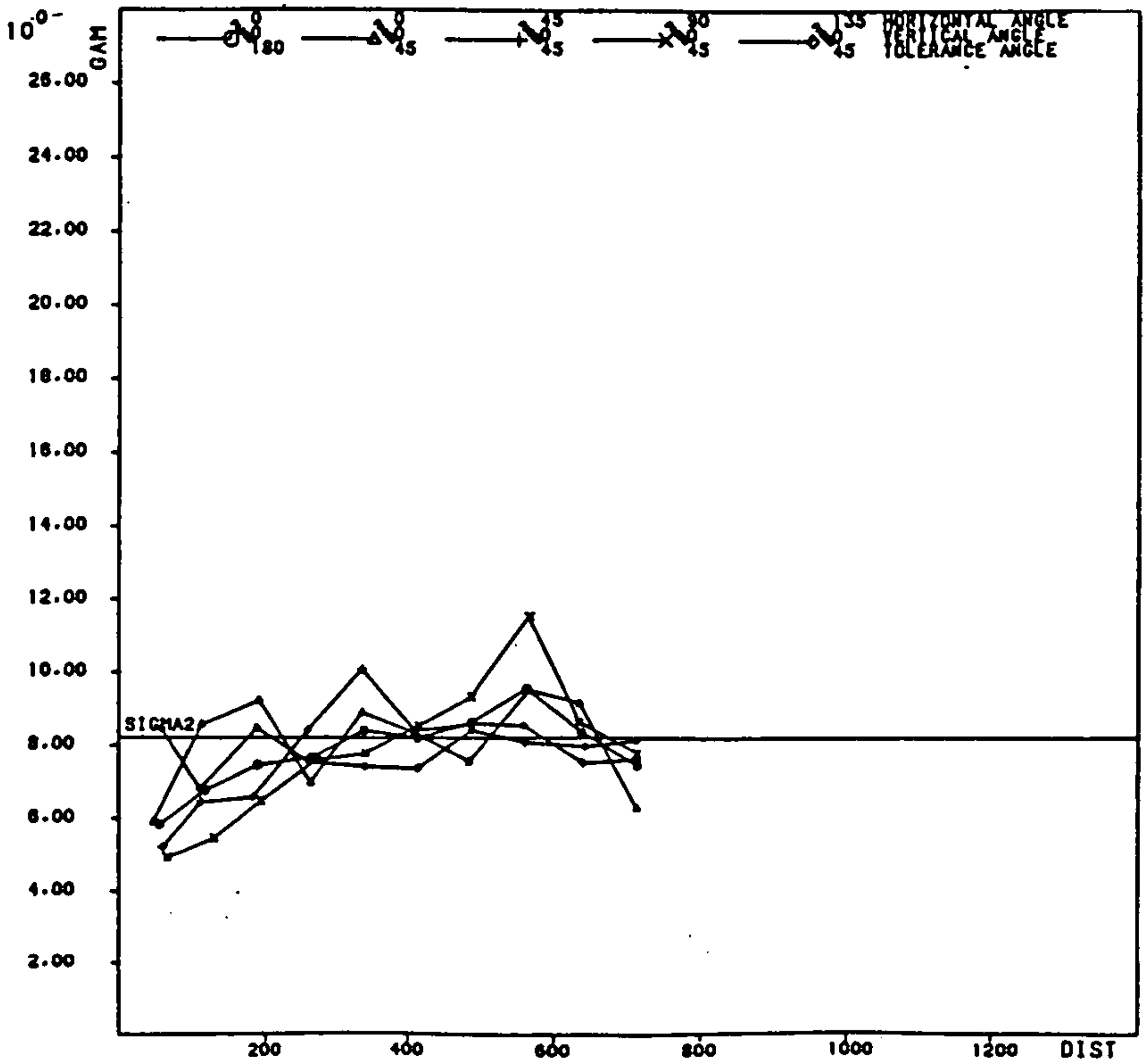


Figure 7 Horizontal variograms of %Pb+Zn in type 20-30



VARIABLE PBZN ABSOLUTE VARIOGRAM

CURRAGH RESOURCES - TYPE 20/30

Figure 8 Vertical and omnidirectional variogram of %Pb+Zn in type 40-70

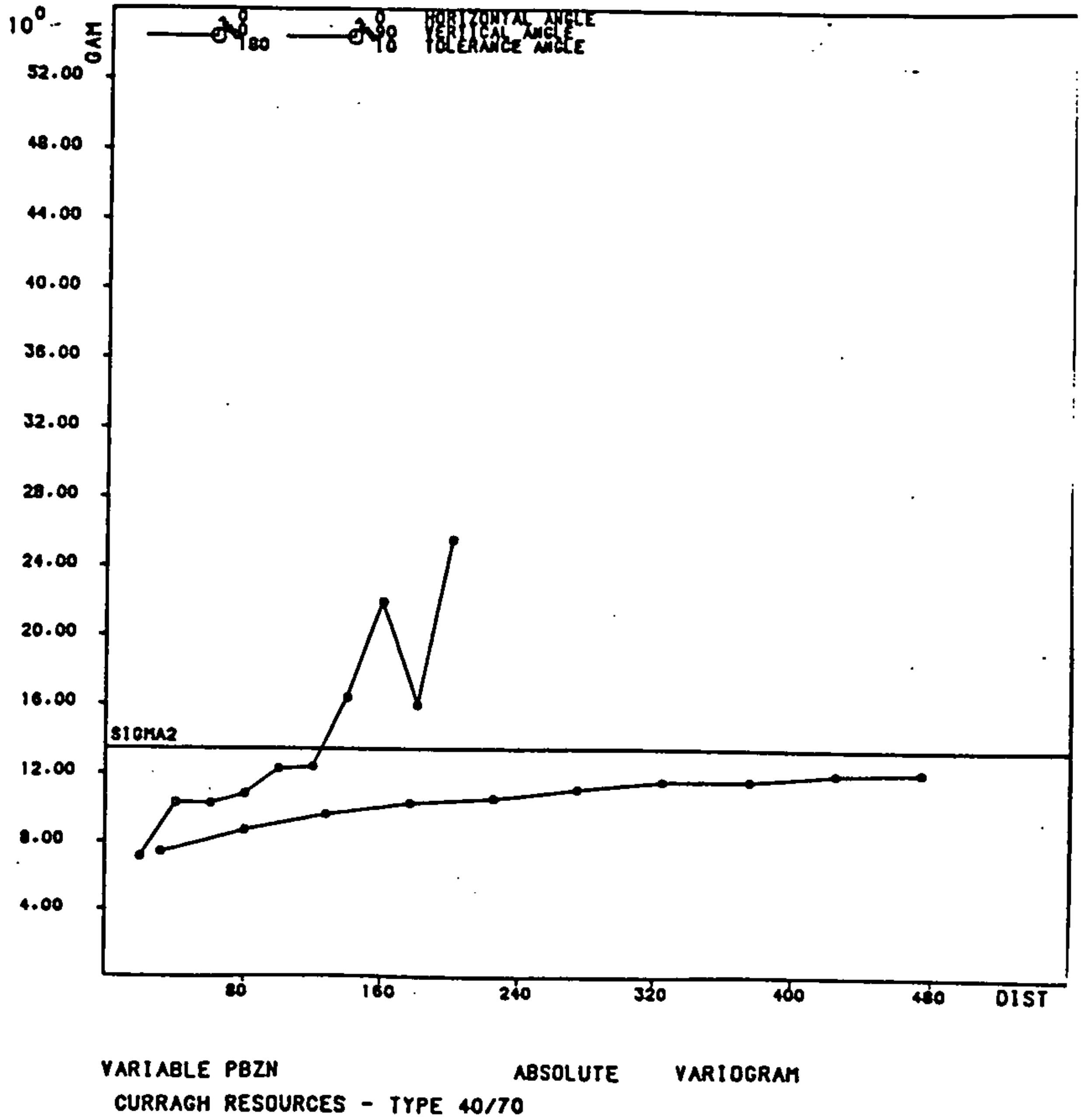


Figure 9 Horizontal variograms of %Pb+Zn in type 40-70

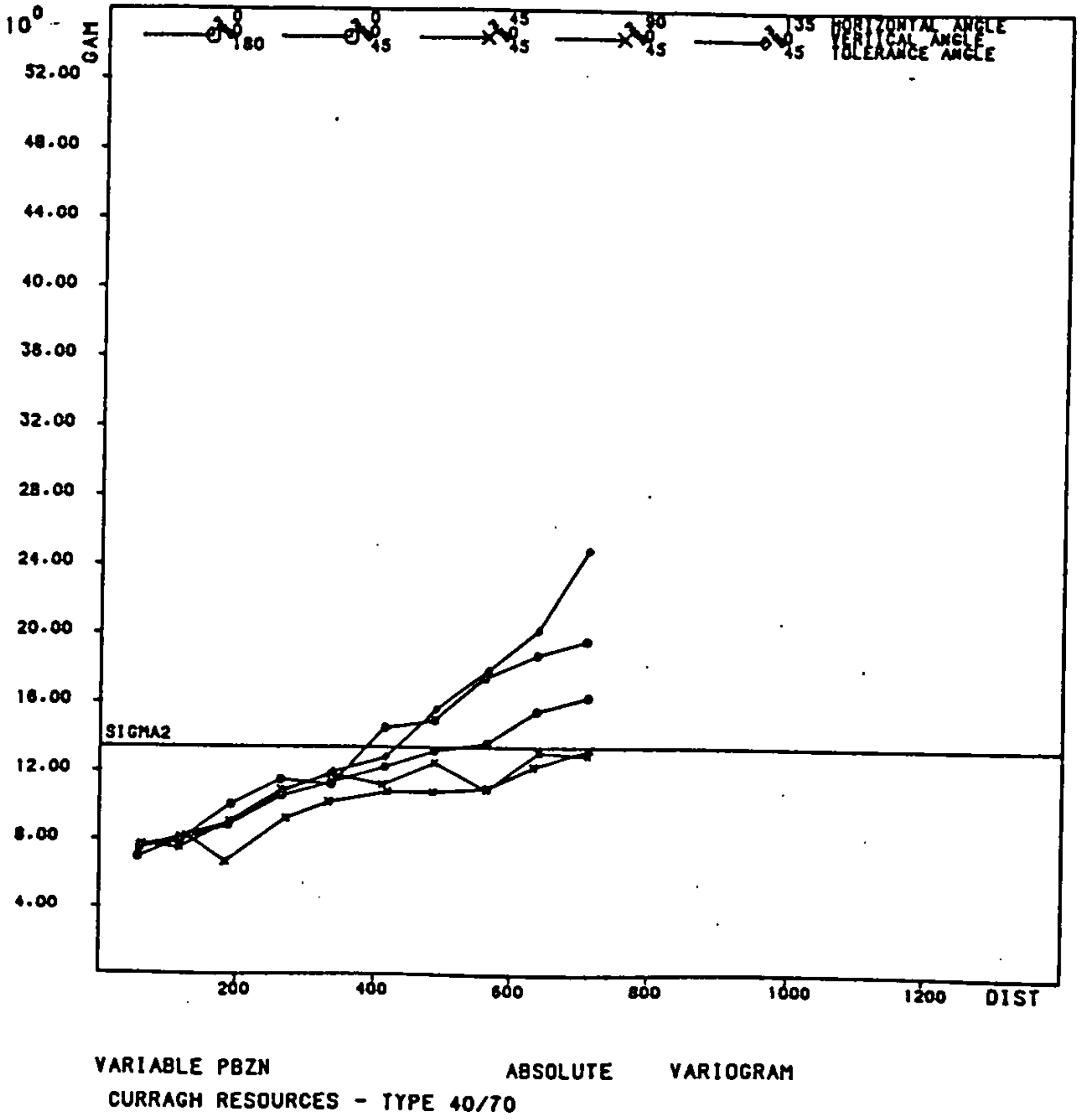


Table 4 Variogram model parameters

Ore type	20-30		40-70			
Parameter	%Pb+Zn	%Pb	%Zn	%Pb+Zn	%Pb	%Zn
Nugget effect	4.0	0.5	1.5	4.0	0.8	1.3
Spherical 1						
Sill	4.2	0.6	2.2	2.0	1.6	1.5
Long range	400'	500'	400'	60'	600'	120'
Int. range	150'	150'	150'	60'	600'	120'
Short range	60'	60'	60'	40'	200'	80'
Spherical 2						
Sill				2.5		2.4
Long range				600'		600'
Int. range				600'		600'
Short range				40'		80'
Spherical 3						
Sill				5.0		
Long range				600'		
Int. range				600'		
Short range				180'		
Total sill	8.2	1.1	3.7	13.5	2.4	5.2

1-3 Standard errors for block estimates from D.H. composites

In the current block estimation method, the average grades and SG of 25' x 35.35' x 20' blocks are estimated by inverse distance using the bench composites of the similar ore type around the block. As explained above, matching of block and composite ore types is done with only two categories : 20+30 and 40+50+60+70.

With the variogram models of bench composite data in the two categories, it is possible to quantify the precision of such block estimates. The common practice is to measure precision by a standard error. If the block estimate is 7.53 %Pb+Zn and the standard error is 1.40% Pb+Zn, then :

- there is a 68% probability that the true block grade lies somewhere between 7.53 - 1.40 = 6.13 %Pb+Zn and 7.53 + 1.40 = 8.93 %Pb+Zn
- there is a 95% probability that the true block grade lies somewhere between 7.53 - 2x1.40 = 4.73 %Pb+Zn and 7.53 + 2x1.40 = 10.33%Pb+Zn

Probabilities of 68% (+/- 1 standard error) and 95% (+/- 2 standard errors) are derived from a normal model applied to the distribution of errors. In that case, we could say that the precision of the estimate at a 68% confidence level is 1.40/7.53 = 18.5% and the precision at a 95% confidence level is 2x1.40/7.53 = 37%.

If we do the kriging of the average Pb+Zn grade of the blocks using the variogram models described in the previous section, we get the following standard errors :

- if the drilling grid is 70' x 70', standard errors vary from 0.80%Pb+Zn (block centered on a drill hole) to 1.20%Pb+Zn (block in between drill holes) in types 20-30 and from 1.13%Pb+Zn to 1.25%Pb+Zn in types 40-70.
- if the drilling grid is 140' x 140', standard errors vary from 1.17%Pb+Zn (block centered on a drill hole) to 1.73%Pb+Zn (block in between drill holes) in types 20-30 and from 1.36%Pb+Zn to 1.68%Pb+Zn in types 40-70.

In type 20-30, because of the horizontal anisotropy of variograms, blocks between two holes on a N-S line are better estimated than blocks between two holes on an E-W line (standard errors of 1.06% and 1.18% respectively for the 70' grid and 1.28% and 1.73% for the 140' grid).

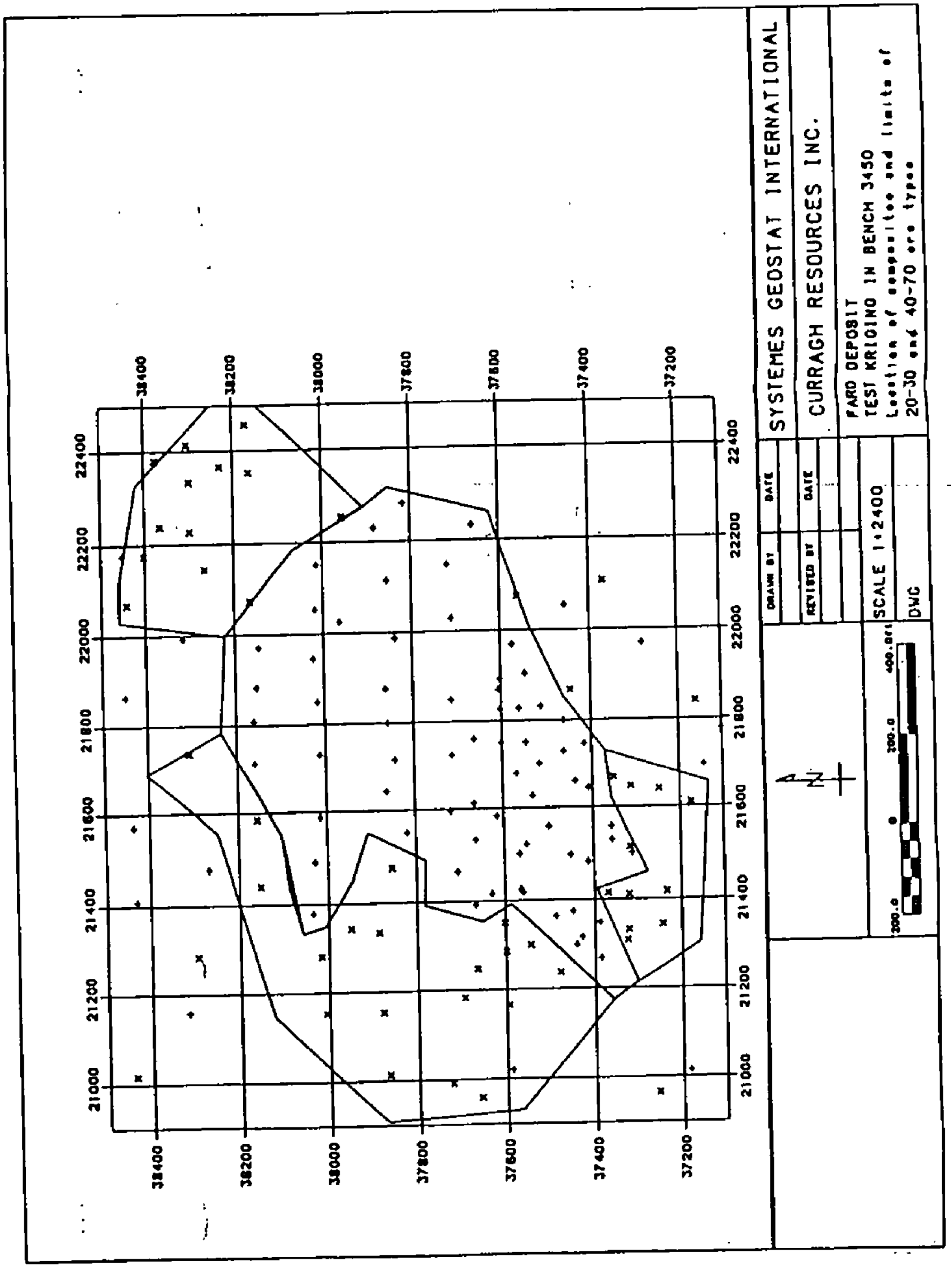
If we just keep the worst case block to get a single precision attached to a given drill hole grid, we have the following 95% confidence precisions :

- in type 20-30 : 67% precision for 140' grid and 47% precision for 70' grid.
- in type 40-70 : 50% precision for 140' grid and 37% precision for 70' grid.

In order to illustrate the distribution of standard errors in blocks , we have kriged the %Pb+Zn grade of blocks in two test zones of bench 3450 . First , we plotted all the composites 20-30 and 40-70 in the bench and we defined approximate enveloppes around each type of composite (Figure 10) . We filled those enveloppes with the 25' x 35.35' blocks and we kriged the average %Pb+Zn grade of each block using composites of the same type around . The search ellipsoid used in each case is defined from the anisotropy of variograms : in 20-30 , the long radius is 400' along N-15-E , the intermediate radius is 150' along E-15-S and the short radius is 60' along vertical . In 40-70 , the long radius is 300' along any horizontal direction and 90' along vertical . Figure 11 is a map of block estimates . Figure 12 is a map of block standard errors . The average standard error is 1.59 %Pb+Zn in 20-30 and 1.73 %Pb+Zn in 40-70 . Those numbers confirm the precision values given above .

We can also use the same test zones to compare I.D. (inverse-distance) and kriged estimates . We have reestimated the %Pb+Zn of block in each ore category by inverse distance methods using various powers of the inverse distance composite-block . Each time we compared our I.D. estimates with kriged estimates for the same blocks and we can compute the average absolute difference for all blocks (Table 5) . We see that the average difference is minimal for a power of about 1.4 in type 20-30 (average difference = 0.37%) and for a power of about 1.75 in type 40-70 (average difference = 0.48 %) . We can also compare reserves above various cut-offs with the two methods (Table 6) .

Figure 10 Test kriging in bench 3450 : map of 20-30 (cross) and 40-70 (plus) composites with limits of test zones for each type



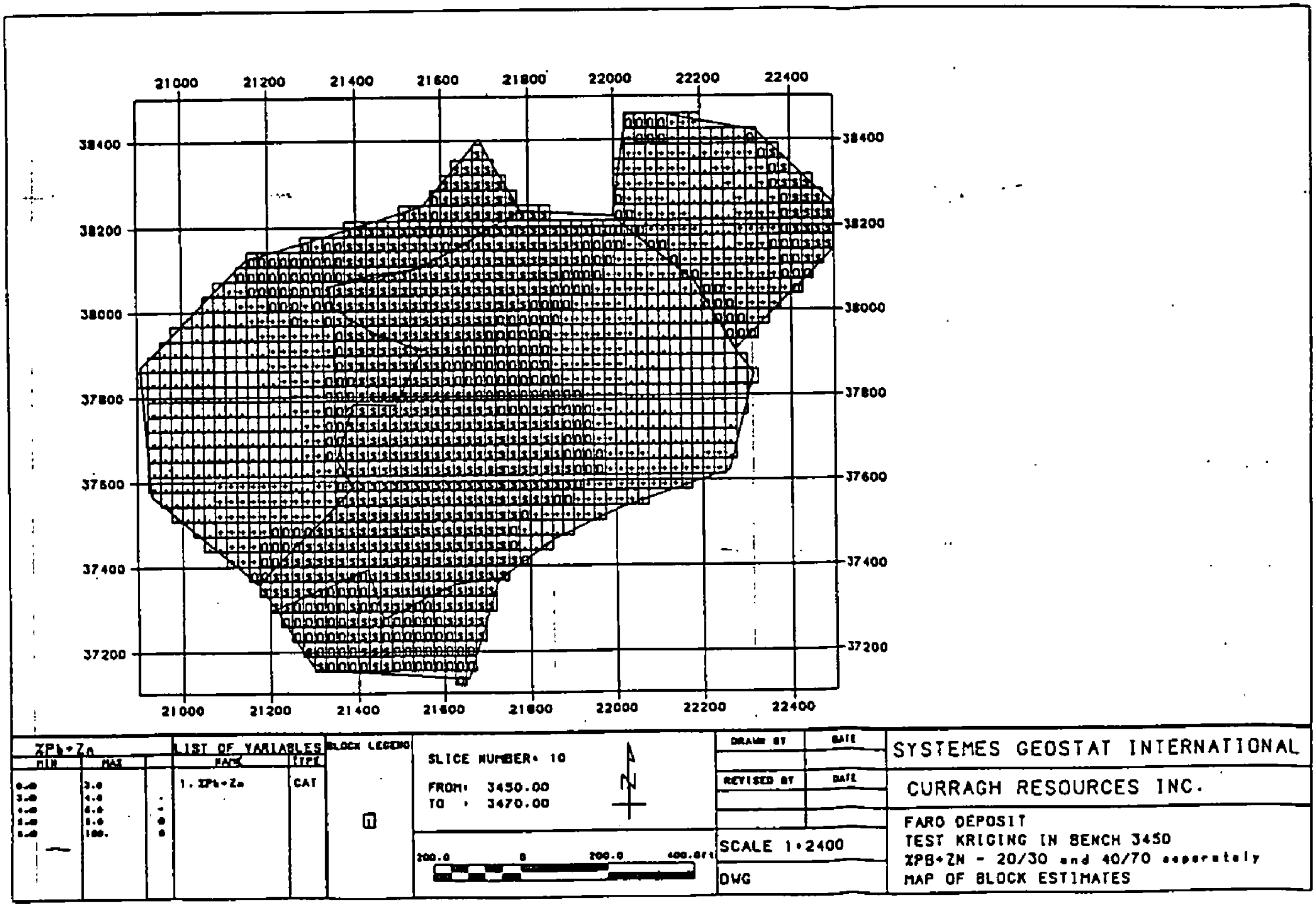


Figure 11 Test kriging in bench 3450: map of block kriged estimates of %Pb+Zn (see legend for explanation of symbols)

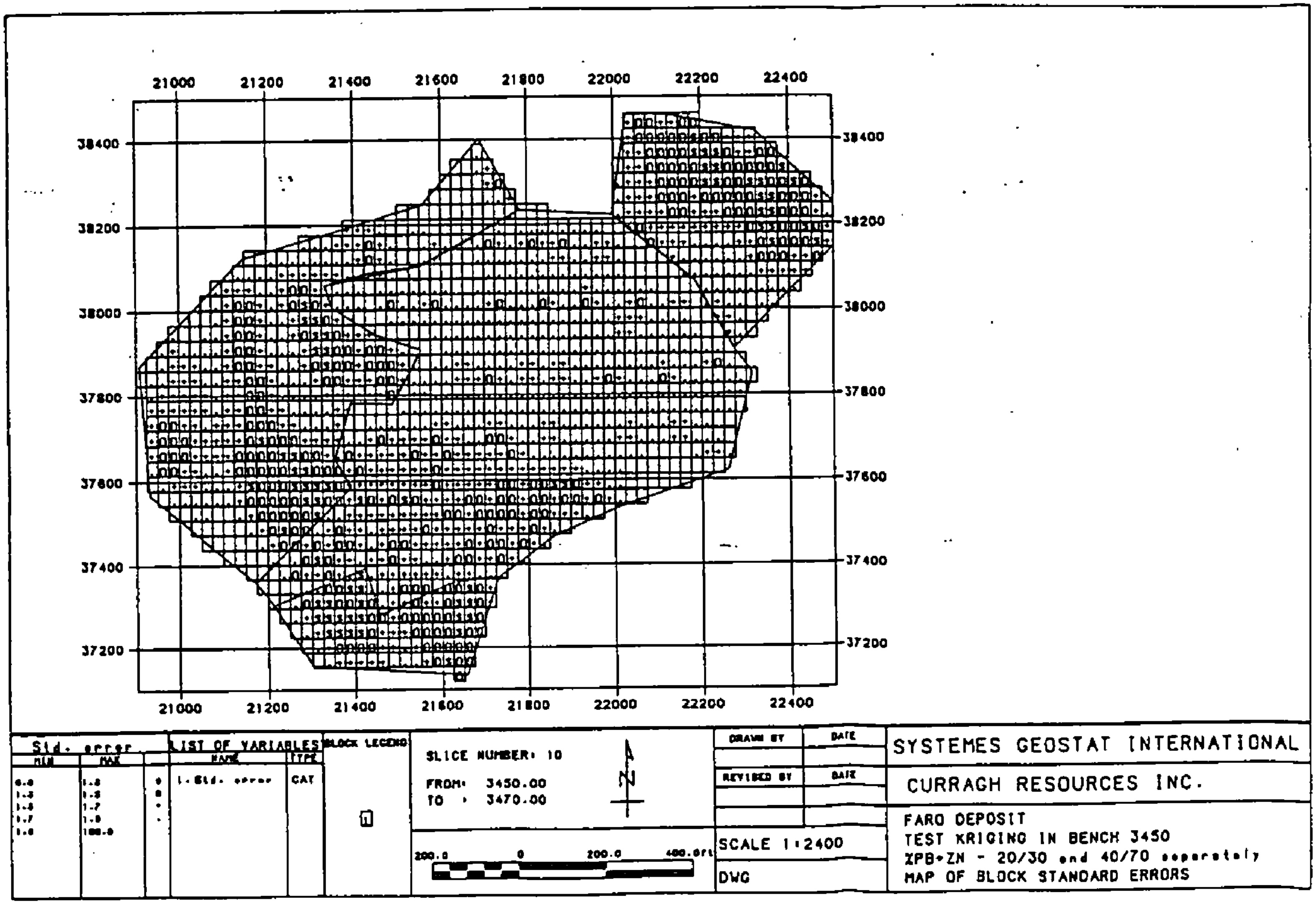


Figure 12:Test kriging in bench 3450 : map of block kriging standard error for estimates of %Pb+Zn (see legend for explanation of symbols)

Table 5 Average absolute difference between kriging and I.D. with various powers of inverse distance for block estimates of %Pb+Zn in the two ore types

Power	0.5	1.0	1.5	2.0	2.5
20-30	0.45	0.38	0.37	0.41	0.47
40-70	0.58	0.52	0.48	0.48	0.52

Table 6 Number of blocks above cut-offs with kriging and I.D. with various powers of inverse distance for block estimates of %Pb+Zn (Type 20-30 : total 699 blocks)

Estimate Cut-off	Kriging	I.D. 0.51.0	1.5	2.0	2.5	
3%Pb+Zn	675	695	687	675	667	654
4%Pb+Zn	517	565	553	523	503	491
5%Pb+Zn	324	333	350	359	359	350
6%Pb+Zn	144	122	132	140	149	164

Table 6 Number of blocks above cut-offs with kriging and I.D. with various powers of inverse distance for block estimates of %Pb+Zn (Type 40-70 : total 699 blocks)

Estimate Cut-off	Kriging	I.D. 0.51.0	1.5	2.0	2.5	
3%Pb+Zn	668	662	659	657	651	648
4%Pb+Zn	598	576	578	575	577	579
5%Pb+Zn	485	486	485	487	483	476
6%Pb+Zn	387	408	412	412	409	407

1-4 Standard errors for monthly , quarterly and yearly production estimates

From variograms , it is also possible to get the magnitude of errors for large block estimates i.e. volumes corresponding to one month , three months or one year production . The technique used to derive those standard errors is a little bit different than the one used before to get errors of small blocks estimates . We can't combine estimation errors of small blocks in a big block to get the estimation error of the big block since those estimation errors are not independent . We can however combine extension errors i.e. errors produced when the small blocks correspond to the drilling grid cell and the estimation of those small blocks is done with only the sample in their center (polygonal estimation) . In that case the estimation variance for the big block is :

$$V^2=v^2/n$$

where v^2 is the extension variance of one composite to its cell of influence (derived from variograms) and n is the number of drilling grid cells in the big block

At Faro , the big blocks that we have investigated correspond to the average monthly , quarterly and yearly production . To get those volumes , we have considered the production figures for the first four months of 1990 . Depending of cut-off , the flagged-in-pit volume of ore varies from 671,000 bcys at 3% Pb+Zn cut-off to 468,000 bcys at 6% Pb+Zn cut-off. Hence , the "ore bench surface" mined in a month is 226,460 ft2 at 3% and 157,950 ft2 at 6% . For a quarter it is 3 times as much and for a year , 12 times .

To determine the number of drilling grid cells of ore mined in a month , a quarter and a year , we have considered two basic drilling grids : 140' and 70' . Hence , at a 3% cut-off , there are 226,460/(140x140)=12 ore composites on a 140 ft grid in a month volume and 46 composites on a 70 ft grid . At 6% cut-off , number of composites are respectively 8 and 32 .

First uncertainty is on the estimated surface (or volume) of ore above cut-off . This uncertainty depends of the degree of "connectivity" of the ore above the cut-off and the overall proportion of ore above that cut-off in the ore type being mined . Obviously , we can be more confident on the estimate of volume of ore above cut-off if 80% of the samples are above that cut-off instead of just 20% . More precisely , the "relative" error (or precision) is likely to be higher in the second case . Then we can anticipate that the errors on volumes at 3% are less than at 6% and that we should do better in 40-70 than 20-30 because there is a higher proportion of composites above the usual cut-offs in this ore type . The connectivity of sample values above a cut-off can be measured through a variogram of indicator at that cut-off . The indicator value of a composite is 1 if the grade of the composite is above the cut-off and 0 otherwise . Figure 13 shows horizontal variograms of indicator at 3% Pb+Zn cut-off in 20-30 . Figure 14 has the same type of variograms but for cut-off 6% in 40-70 . As a general rule , indicator variograms have about the same features as the corresponding grade variograms . Once indicator variograms are modelled , we can determine v , the extension standard error of the indicator of a composite to its cell of influence . Then to get the relative standard error of the surface (or volume) above cut-off , we use a formula derived from the general one presented above :

$$V = v/(nxp)^{1/2}$$

Where p is the overall proportion of composites above the cut-off . This formula has been implemented in ore types 20-30 and 40-70 , at 3% and 6% Pb+Zn cut-offs , and for 70' and 140' drilling grids . Results are given in Table 7 . We can see that :

+ monthly standard errors vary from 4.6% (70 ft grid - 3% cut-off - 20/30) to 26.6% (140 ft grid - 6% cut-off - 20/30)
+ yearly standard errors vary from 1.3% (id) to 7.7% (id)
+ as expected , standard errors are increasing with cut-off .
+ as expected , at the 6% cut-off , standard errors in 20-30 are higher than in 40-70 because the proportion of values above that cut-off is less (34% vs 54%)
+ at the 3% cut-off , standard errors in 20-30 are slightly less than standard errors in 40-70 because of the better connectivity of data above that cut-off in that ore type .

As indicated in the previous section , the above standard errors correspond to a 68% confidence . For a 95% confidence , all numbers must be doubled .

The error on tonnage above cut-off is a combination of the error on volume and the error on the estimated average specific gravity above the cut-off . Relative variations of specific gravity are rather limited : in 20-30 , average SG of composites at 3% cut-off is 3.25 with a standard deviation of 0.35 . At 6% cut-off , average is 3.39 and standard deviation is 0.34 . In 40-70 , average SG varies from 4.14 to 4.17 whereas standard deviation stays at 0.42 with cut-off from 3% to 6% . Based on these statistics , we can determine that the relative standard error of estimated SG above cut-off are : 1.3% (70ft grid) and 2.5 % (140 ft grid) for monthly blocks , 0.3 % (70 ft grid) and 0.7 % (140 ft grid) for yearly blocks , at both cut-offs and in the two ore types . Theoretically , the relative error variance of tonnage would be the sum of the relative error variance of volume and the relative error variance of SG . Now there is some negative correlation between volume and SG above cut-off : if we underestimate the volume , we probably overestimate the SG . As a result of this negative correlation , we think that the relative standard errors for tonnage above cut-off should not exceed the relative standard errors for volume above cut-off in Table 7 .

The error on estimated average grade (Pb+Zn) above cut-off can be derived from the general formula . In that case , v^2 is the extension variance of the Pb+Zn grade of a composite above cut-off to its cell of influence . It is derived from a variogram of composite grades above cut-off . Figure 15 presents horizontal variograms of %Pb+Zn above 3% in 20-30 . On figure 16 , we have the same type of variograms for %Pb+Zn above 6% in 40-70 . It is interesting to note that , as we increase the cut-off , the dispersion of grade values is decreasing : in 20-30 , at a 3% cut-off , mean and standard deviation of %Pb+Zn values are respectively 6.21% and 2.45% ; at 6% cut-off , they are 8.39% and 1.96% . In 40-70 , as cut-off goes from 3% to 6% , mean %Pb+Zn above cut-off goes from 7.84% to 9.44% and standard deviation goes from 3.09% to 2.46% . Hence , for average grade , magnitude of estimation errors decreases with cut-off . Relative standard errors for grade are detailed in Table 8. Conclusions are :

+ monthly standard errors vary from 3.3 % (20/30 - 70' grid - 6% cut-off) to 8.7% (40/70 - 140' grid - 3% cut-off).
+ yearly standard errors vary from 1.0 % (id.) to 2.5% (id.)
+ as expected , relative standard errors decrease with cut-off
+ standard errors are slightly better in 20-30 than 40-70 at all cut-offs .

All the above errors are given for ore types 20-30 and 40-70 separately . If production in a given period is made of a mixture of the two ore types , the relative standard error is a weighted average of standard errors of each ore type in the same proportions . If production is made of 50% 20-30 and 50% 40-70 , we get the 95% confidence precision of Table 9. From that table it appears that relative errors are higher for tonnage than grade . Additional calculations show that :

+ in order to get 95% relative standard errors of less than 5% on monthly estimates , we need a drilling grid between 35' and 40' at 3% cut-off and between 15' and 20' at 6% cut-off

+ in order to get 95% relative standard errors of less than 2% on yearly estimates , we need a drilling grid of about 50' at 3% cut-off and 25' at 6% cut-off .

Figure 13 Horizontal indicator variograms (3% Pb+Zn cut-off) in 20-30

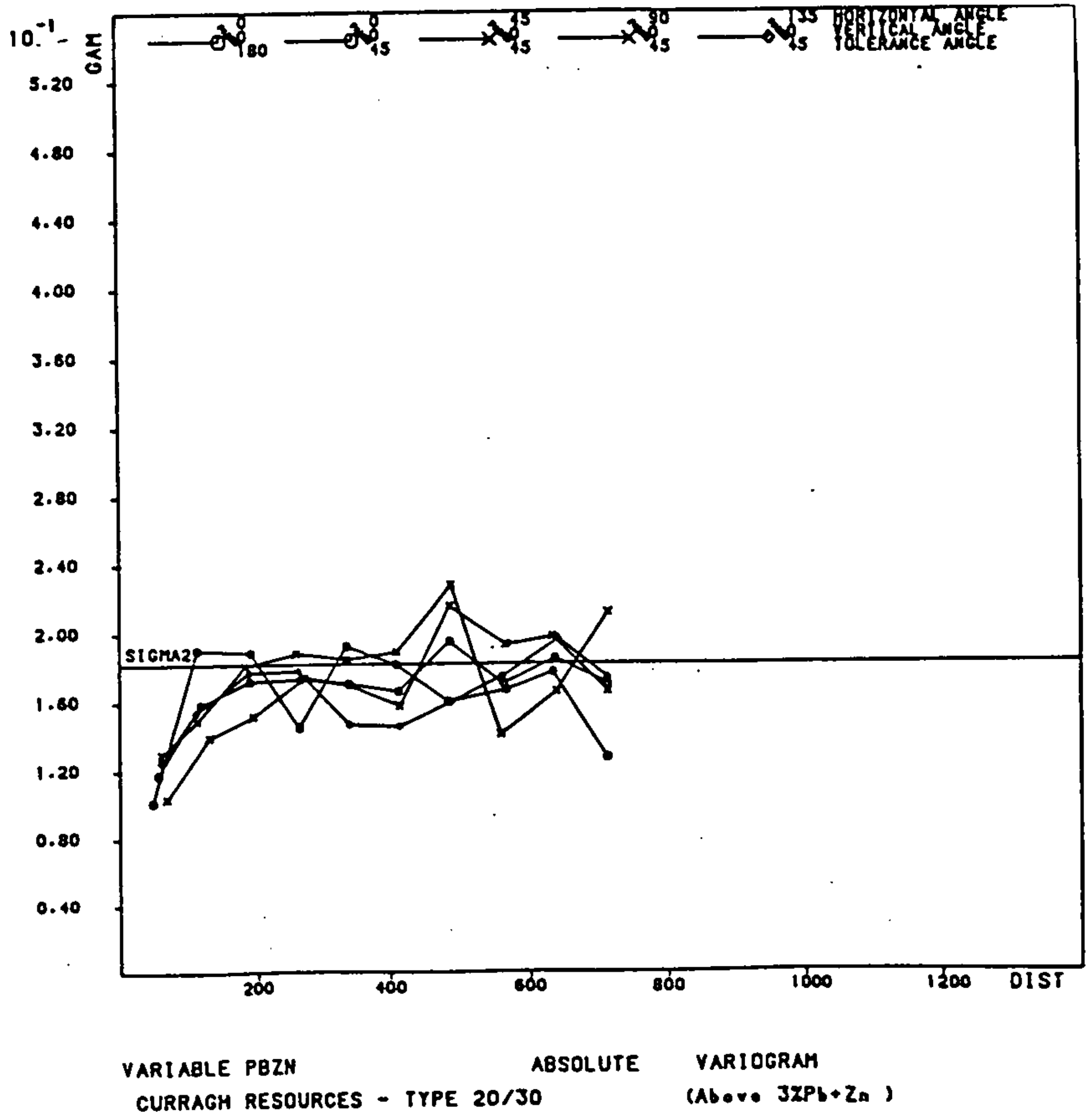


Figure 14 Horizontal indicator variograms (6% Pb+Zn cut-off) in 40-70

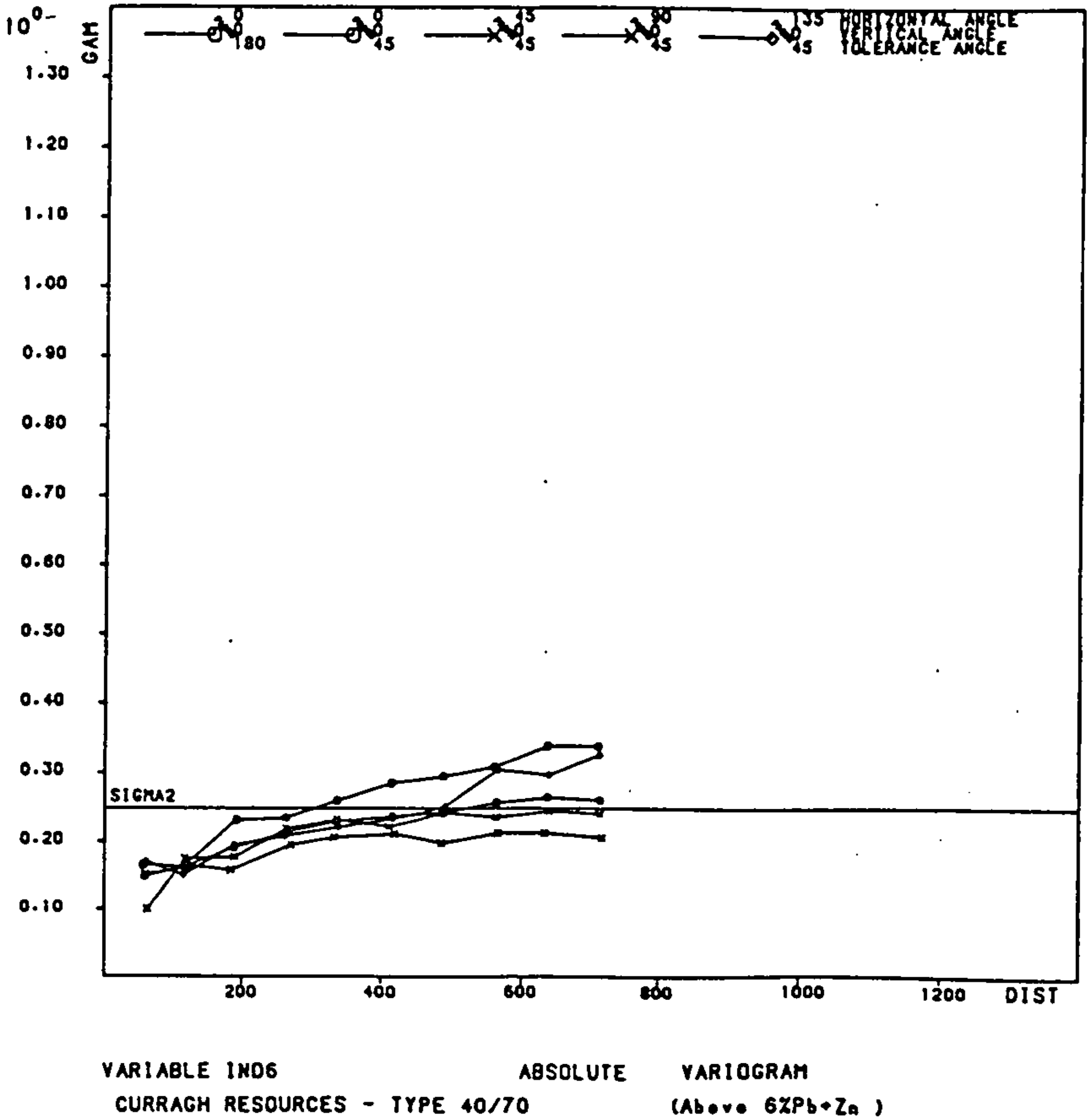


Table 7 Relative standard errors (%) on estimated surface (volume) above cut-off.

Cut-off	3%Pb+Zn		6%Pb+Zn	
Ore type	20-30	40-70	20-30	40-70
Proportion of composites above cut-off (p)	0.76	0.80	0.34	0.54
Extension standard error (v)				
70' grid	0.27	0.31	0.44	0.36
140' grid	0.30	0.32	0.44	0.37
Monthly standard error (V %)				
70' grid	4.6	5.1	13.2	8.6
140' grid	10.1	10.5	26.6	17.7
Quarterly standard error (V %)				
70' grid	2.6	3.0	7.6	5.0
140' grid	5.8	6.0	15.4	10.2
Yearly standard error (V %)				
70' grid	1.3	1.5	3.8	2.5
140' grid	2.9	3.0	7.7	5.1

Figure 15 Horizontal variograms of %Pb+Zn above 3% cut-off in 20-30

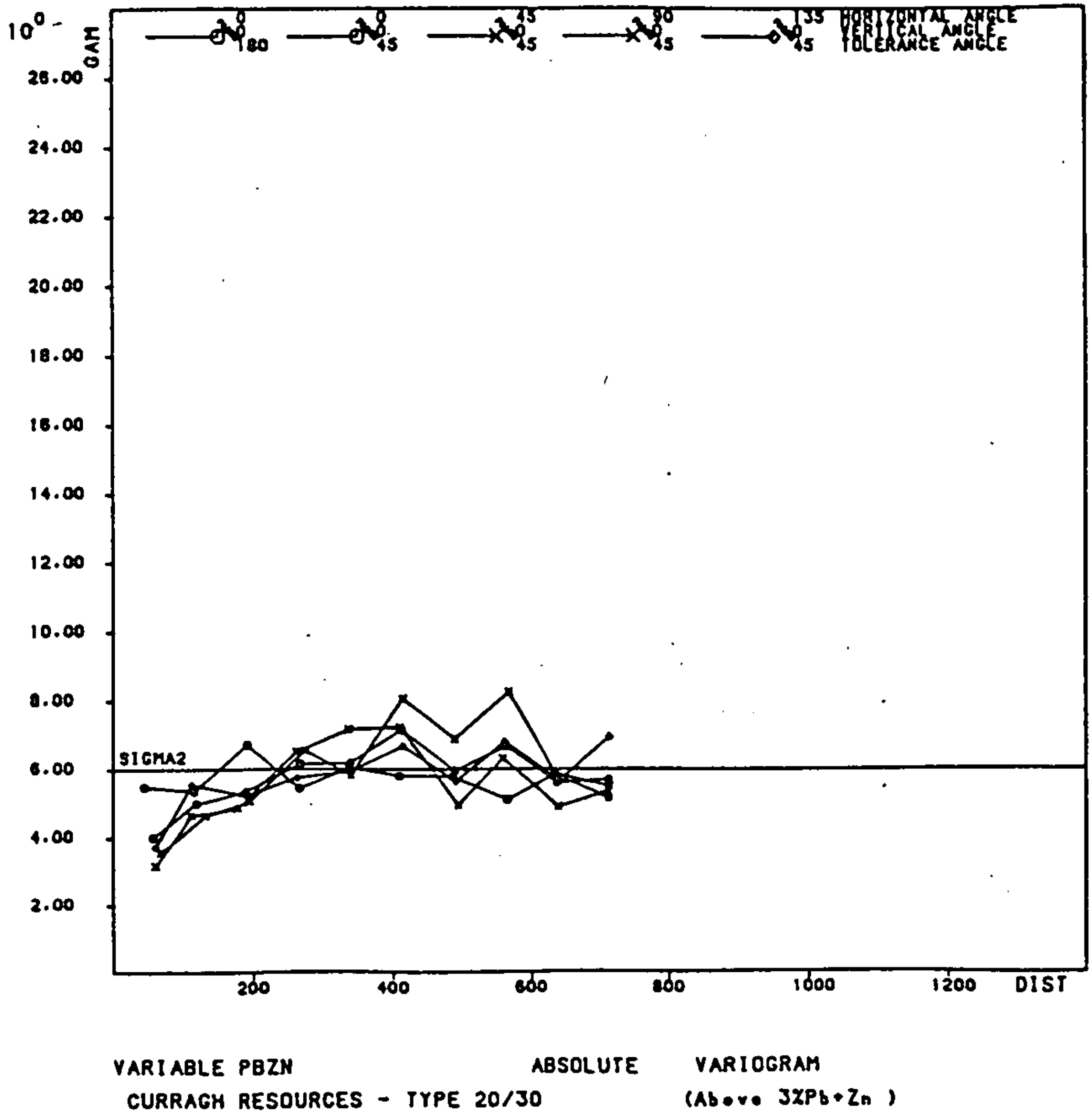


Figure 16 *Horizontal variograms of %Pb+Zn above 6% cut-off in 40-70*

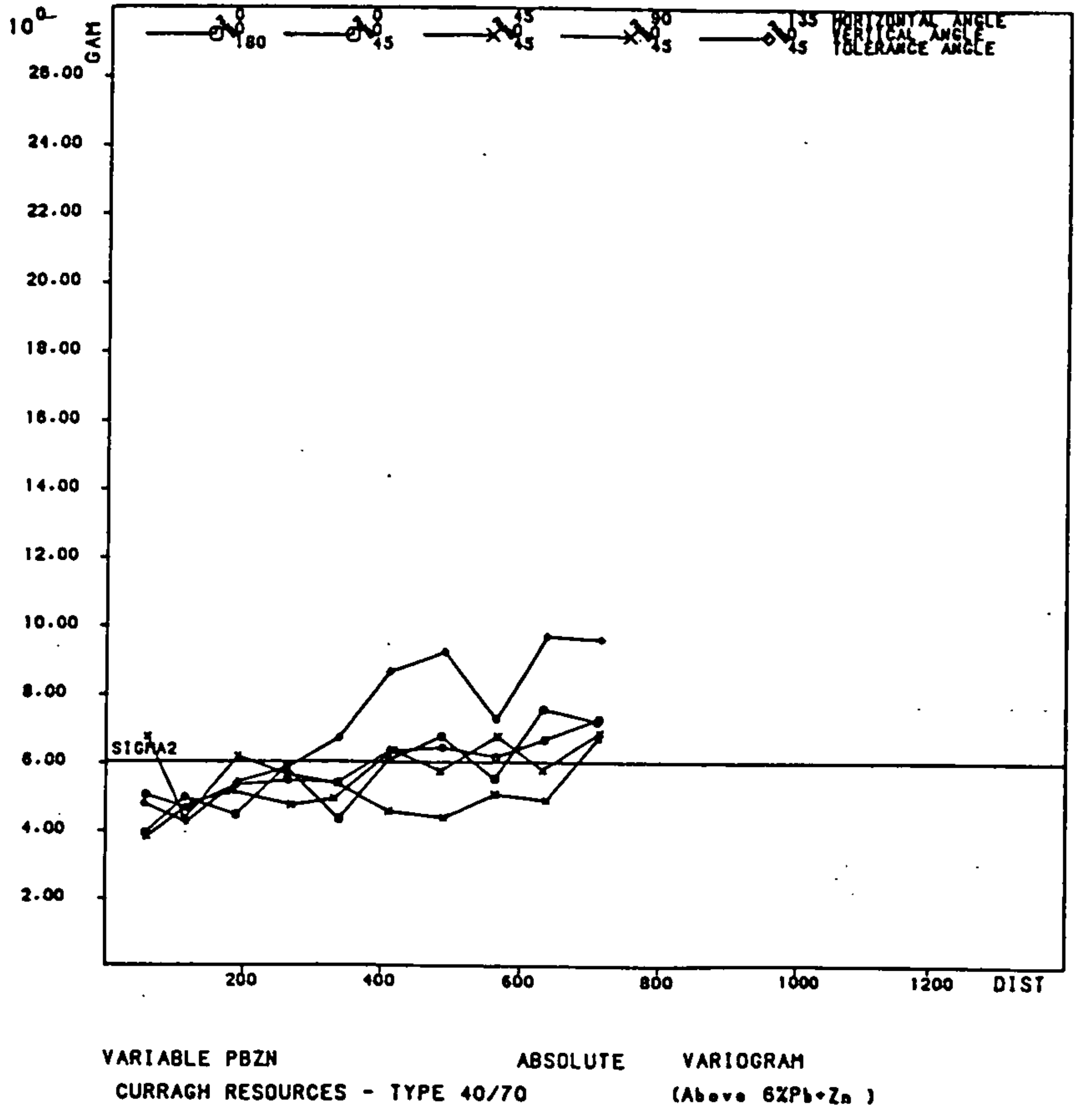


Table 8 Relative standard errors (%) on estimated %Pb+Zn grade above cut-off

Cut-off	3%Pb+Zn		6%Pb+Zn	
Ore type	20-30	40-70	20-30	40-70
Average grade above above cut-off (%Pb+Zn)	6.21	7.84	8.39	9.44
Extension standard error (v)				
70' grid	1.56	2.28	1.58	2.03
140' grid	1.70	2.32	1.61	2.06
Monthly standard error (V %)				
70' grid	3.7	4.3	3.3	3.8
140' grid	8.1	8.7	6.8	7.7
Quarterly standard error (V %)				
70' grid	2.1	2.5	1.9	2.2
140' grid	4.6	5.0	3.9	4.4
Yearly standard error (V %)				
70' grid	1.1	1.2	1.0	1.1
140' grid	2.3	2.5	2.0	2.2

Table 9 Average 95% confidence precisions (50% 20-30 + 50% 40-70)

Period	Month		Year	
Drilling grid	70'	140'	70'	140'
Tonnage				
3% cut-off	9.7	20.6	2.8	5.9
6% cut-off	21.8	44.3	6.3	12.8
Pb+Zn grade				
3% cut-off	8.0	16.8	2.3	4.8
6% cut-off	7.1	14.5	2.0	4.2

1-5 VALIDATION OF VARIOGRAMS AND ERROR PREDICTION

One way to check the validity of the prediction model is to reestimate samples from samples around. Estimates are compared to true values and actual errors with predicted errors.

For example, if we take the 742 bench composites of type 20 and 30, we can krige the % Pb + Zn grade of each of them using % Pb + Zn values of neighbor composites of the same type but in different holes. With the standard 400' x 150' x 60'search ellipsoid, we can reestimate 719 composites. Average estimate is 5.19% Pb + Zn which compares well with the mean value of the 719 data (5.18% Pb + Zn) i.e. the average error is virtually zero. The average absolute error is 2.35% Pb + Zn and the average squared error is 8.79 i.e. a standard deviation of 2.96% Pb + Zn. In other words, the average <u>experimental</u> uncertainty in the reestimation of samples from nearby samples is 2.96/5.18 = 57%. The average kriging variance is 8.02 or a standard deviation of 2.83% Pb + Zn, very close to the experimental value (individual standard errors vary from 2.35 to 4.05% Pb + Zn). These standard errors of about 2.9% Pb + Zn in the reestimation of composites at distances from 70' to 140' are consistent with the predicted standard errors of 1.20% to 1.73% Pb + Zn in the estimation of 25' x 35' blocks at about half those distances.

The same method can be used to test various features of the variogram model =

+ if we do the reestimation using a variogram model with no horizontal anisotropy (horizontal range = 300' in all directions), the absolute error is 2.34% Pb + Zn, the experimental error variance is 8.84 but the average kriging variance is only 7.50. Hence this model is giving estimates as good as the anisotropic model but the predicted error is too low.

+ if we do the reestimation with a model with no nugget effect, absolute error is 2.44% Pb + Zn, experimental error variance is 9.63 but average kriging variance is only 6.45. Hence a nugget effect gives better estimates and a more realistic predicted error.

+ if we do the reestimation using only the nearest composite in the 400' x 150' x 60' search ellipsoid, the average absolute error is 2.96% Pb + Zn hence distance weighting interpolation methods like kriging are preferable to polygon.

Back to the original prediction model, another way of checking the validity of error prediction with the sample reuse method is to count the number of times when the actual error is less than the predicted standard error or less than twice the predicted standard error. According to a normal model for the distribution of errors, we should have 68% of the errors less than the standard errors and 95% of them less them two standard errors. Actual numbers are 480 out of 719 i.e. 67% and 683 out of 719 i.e. 95%.

Even if the prediction of errors is correct, the estimates of composites are not that good as indicated by the correlation plot of figure 17. Correlation coefficient of estimated and true values is in fact only 0.18. What we can notice on this diagram is that estimates are smoother (less dispersed) then actual values. In fact the standard deviation of estimates is only 1.41% Pb + Zn whereas that of true values is 2.88% Pb + Zn.
A direct consequence of too smooth estimates is an overestimation of the proportion of values (tonnage) above a low cut-off and the underestimation of the proportion of values above a high cut-off (Table 10). Estimated grades above cut-off are always underestimated. Hence somekind of correction is necessary to "unsmooth" the distance weighted estimates. This would be considered in the next section.

In 40/70, the reestimation of composites is giving similar results: with the current variogram model, out of 985 reestimated samples, the average error is 0.07% Pb + Zn (mean of true values is 6.65% Pb + Zn, mean of estimates is 6.57% Pb + Zn), the average absolute error is 2.22% Pb + Zn, the experimental error variance is 8.43 (standard error: 2.90% Pb + Zn) and the average kriging variance is 8.89 (standard error 2.98% Pb + Zn). Also 73% of the actual errors are less than the predicted standard error and 95% of them are less then two standard errors. Correlation of estimates and true values is much better than in 20/30 (figure 18). Correlation coefficient is now 0.61. Oversmoothing of estimates is still present. As a result, since now all cut-offs are less than the mean grade, all the proportion of values above cut-off are overestimated and all grades above cut-off are underestimated (Table 11).

Figure 17: Scattergram of real % Pb + Zn value and estimated value in 20/30.

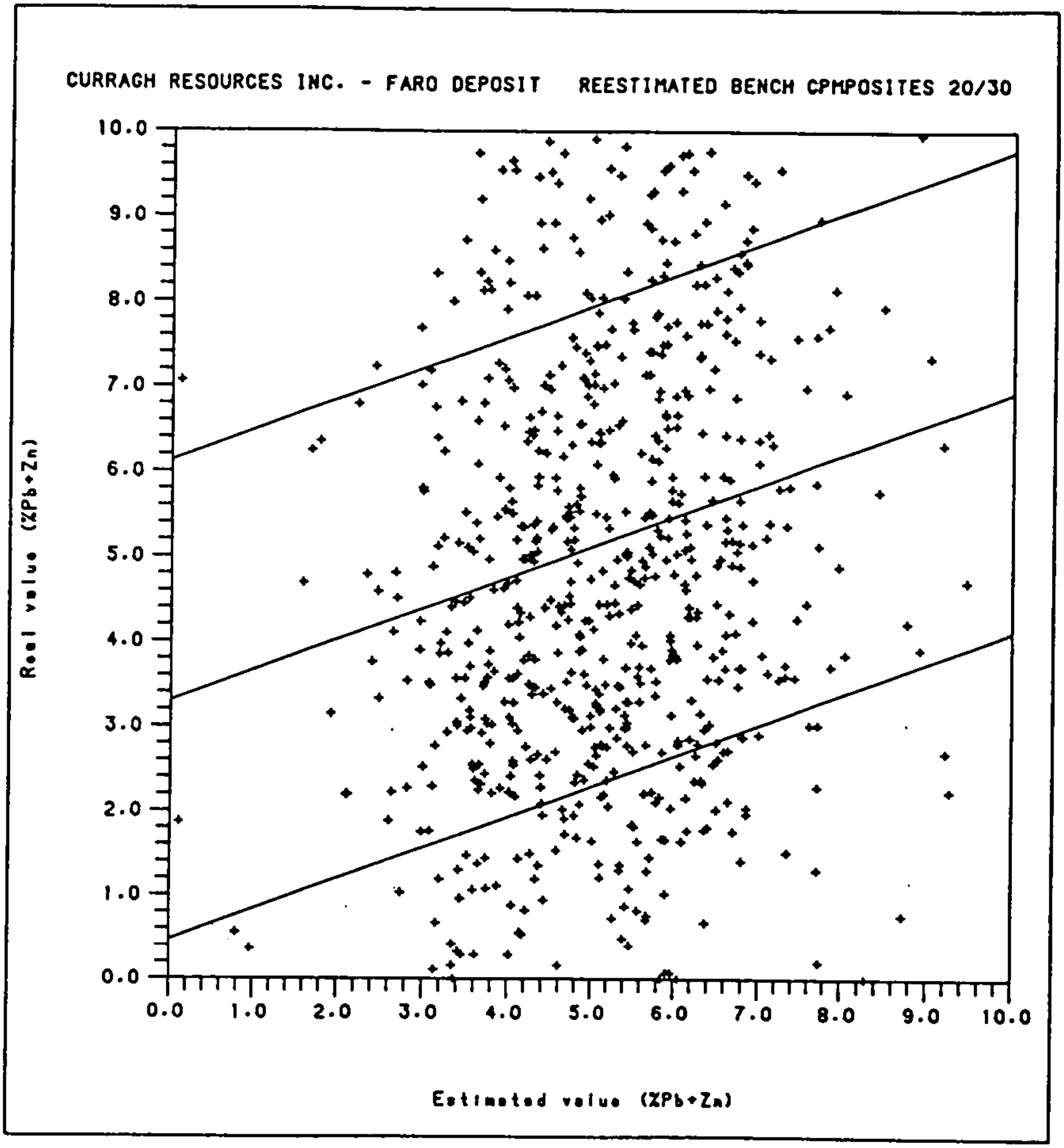


Figure 18: Scattergram of real % Pb + Zn value and estimated % Pb + Zn value in 40/70.

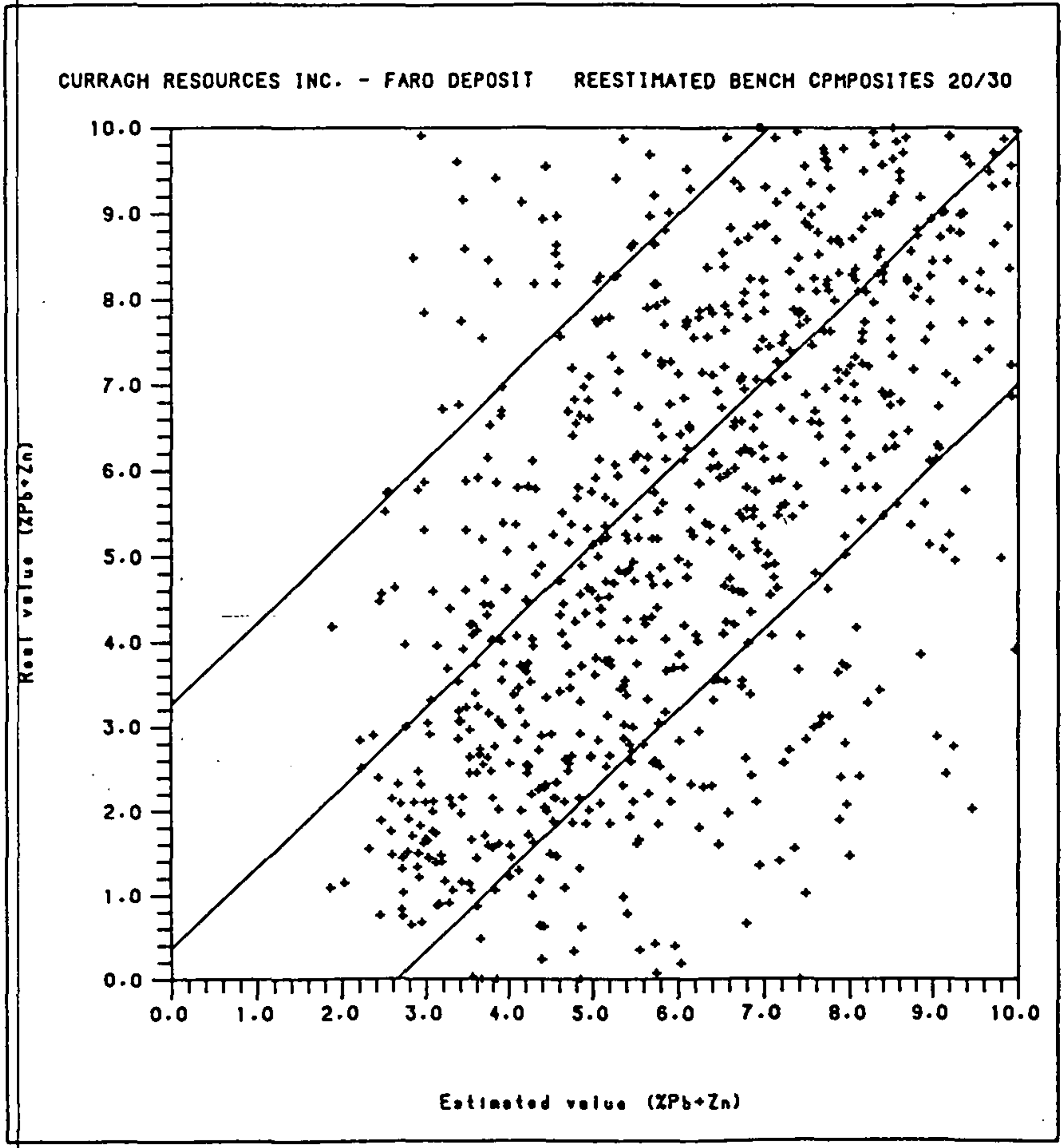


Figure 18

Table 10: Reestimation of composite % Pb + Zn grades. Proportion of actual and estimated values above cut-offs (% values).

Cut-off (% Pb + Zn)	20/30 Actual	 Estimated	40/70 Actual	 Estimated
3	76	95	80	95
4	61	79	73	84
5	48	55	63	72
6	34	27	54	57

Table 11: Reestimation of composite % Pb + Zn grades. Mean % Pb + Zn grade (no SG weighted) above cut-off: actual and estimated.

Cut-off (% Pb + Zn)	20/30 Actual	 Estimated	40/70 Actual	 Estimated
3	6.24	5.32	7.83	6.78
4	6.93	5.68	8.28	7.19
5	7.58	6.79	8.83	7.63
6	8.41	6.88	9.42	8.21

1-6 CORRECTION OF BLOCK ESTIMATES FOR PROPORTION OF BLAST HOLES IN BLOCKS

Another way to validate the long term prediction of block values from drill hole bench intercepts is to compare block estimates derived from those intercepts and blast hole grades in the same blocks.

We have % Pb, % Zn, % Pb + Zn as well as coordinates from 2083 BHs in benches 3490, 3470 and 3450 in the south phase of the pit. Table 12 lists some statistics of those blast hole values according to rock code. We can see that most of the blast holes that we have are in rock type 50. We have a significant group of "55" that we did not have before and which seems to have the same (low) means grades as type 40 in DHs. With the exception of 70, all mean B.H. grades in that zone are higher than the overall D.H. mean grades (Table 1-3), hence it is a relatively rich zone.

If we just consider the quartzite types, 20 and 30, we have 568 blast holes with % Pb + Zn values ranging form 0.10% to 14.83%, a mean of 6.39% and a standard deviation of 2.80%. Figure 19 is a map of those blast holes (x with size proportional to % Pb + Zn) in bench 3470. On the same map, we have the 20/30 D.H. composites in the same bench(0 also with size proportional to % Pb + Zn). We can notice that, overall, there is a good agreement between ore type characterization of D.H. composites and blast holes. There are however a few 20/30 D.H. composites which are more than 25' away from the closest 20/30 B.H., hence there are almost coincident with a B.H. which is not classified in type 20/30.

We can find all the blocks of the 25' x 35' model which contain a blast hole of type 20/30 and do the interpolation of the % Pb + Zn grade of those blocks from the drill hole composites (Figure 20). All together there are 413 blocks but since the blast hole grid is about 20', most of the time, there is only one blast hole in a block. The interpolation method that we use is kriging with the variogram model of % Pb + Zn for 20/30 D.H. composites (Table 4) and the 400' x 150' x 60' search ellipsoid.

If we compare the mean kriged grade of the 413 blocks with the mean grade of the 568 blast holes in those blocks, they are reasonably close: 6.24% Pb + Zn vs 6.38% Pb + Zn. The difference of 0.14% Pb + Zn (or relative difference of 2.2%) is consistent with the monthly and quarterly precision figures of % Pb + Zn estimates in 20/30 of table 10 (413 blocks represents about 1.5 months of production.

Even if means are close, the correlation between kriged D.H. grade of a block and mean B.H. grade of that block is not that great (Figure 21): correlation coefficient is only 0.11. The main reason for that poor correlation is the <u>oversmoothing of kriged block values;</u> kriged values range from 3.31 to 9.59% (standard deviation: 1.02%) whereas B.H. values range from 0.10 to 14.83% (standard deviation of 2.68%).

As a direct consequence of that oversmoothing, <u>if we apply the usual cut-offs to the kriged block values, tonnages are too high and grade too low</u> (Table 13). Tonnage difference is as much as 30% (5% cut-off) and grade difference as much as 17%.

If we repeat the same exercise in 40-70 (excluding 55), we end up with 795 blocks that contain at least one blast hole of either 40, 50, 60 or 70 type. Mean of kriged values for those blocks is 8.16% Pb + Zn whereas the mean of blast holes in these blocks is 8.84%. This almost 10% difference is more than what can be expected. A closer look at the location of blast holes with type 55 indicates that they are in regions with D.H. composites of type 40 (Figure 22). Hence it seems more reasonable to krige all blocks that contain blast holes of type 40, 50, 60, 70 and 55 with the 40/70 D.H. composites. In that case, we end up with a mean of 909 blocks equal to 7.75% Pb + Zn whereas the mean of the BHs in those blocks is 8.12% Pb + Zn.

Difference is less than before but still fairly high. It shows that when a few low grade D.H. composites of type 40 are used in the estimation of mostly high grade 40-70 blocks, there is some overall underestimation of grade.

If we restrict ourselves to types 50-60-70, we have 1148 blast holes with % Pb + Zn values ranging from 3.13% to 18.21%, a mean of 9.07% and a standard deviation of 2.73%. Map of those blast holes in bench 3470 (together with the D.H. composites in the same bench) is on figure 23. In that case, we see that all D.H. composites are surrounded by BHs of the same type. However, we can see extensive zones of blast holes 50/70 with no 50/70 D.H. composites around = D.H. composites in those zones have probably been assigned a different rock type.

There are now 765 blocks with 50/70 BHx in them (Figure 24). The average kriged % Pb + Zn of those blocks is 9.02% which compares well with the mean B.H. of 9.07% Pb + Zn.

However, like in 20/30, correlation of D.H. estimate with B.H. value is not good (Figure 25). Correlation coefficient is a mere 0.31. Like before, this poor correlation is derived from the oversmoothing of block estimates: kriged values range from 5.70 to 10.94% (standard deviation: 1.11%) whereas B.H. values go from 3.13% to 18.21% (standard deviation: 2.52%). Again, because of that oversmoothing, if we apply a cut-off to the kriged block values, tonnages are too high and grades are too low (Table 14). Tonnage difference is as much as 14% (6% cut-off) and grade difference, 7% (same cut-off).

A way to overcome the oversmoothing of straight block estimates is <u>to estimate the likely proportion and grade of blast holes above the cut-off in each block.</u>

We can take the kriged estimate as the mean of that distribution. Its variance can be derived from the variogram of D.H. composites: it is simply the average value of the horizontal variogram in a rectangle 25' x 35'. It is 4.41 in 20/30 and 4.53 in 40/70. The shape of the distribution can be assumed to be a simple model, normal or lognormal (considering the histograms of D.H. bench composites, the best assumption is probably lognormal in 20/30 and normal in 40/70).

We have tried a "lognormal short cut" correction of the kriged block values in both 20/30 and 50/70 with the above variances. This means for example that if we have a kriged block estimate of 5.54% in a 20/30 block, we estimate that:

6.8% of the BHs in that block are below 3% with a grade of 2.58% Pb + Zn.

17.2% of the BHs are between 3 and 4% with a grade of 3.54% Pb + Zn.

22.1% of the BHs are between 4 and 5% with a grade of 4.50% Pb + Zn.

19.5% of the BHs are between 5 and 6% with a grade of 5.48% Pb + Zn.

34.4% of the BHs are above 6% with a grade of 7.82% Pb + Zn.

This is far different from the answer that you get if you apply the cut-off directly on the block estimate. In that case the estimated proportions for the same grade categories are simply:

0, 0, 0, 100% and 0. If we sum all the estimated proportions and grades above cut-off in each block, we get the results of Table 15.

We can see that the correction is achieving its goal: reduce tonnage and increase grade. Maximum tonnage difference is now 8% in 20/30 (6% cut-off) and 3 % in 50/70 (6% cut-off maximum grade difference is 5.4% in 20/30 (3% cut-off) and 2.4% in 50/70 (6% cut-off).

Table 12: Summary statistics of B.H. data available.

Rock type	Number of BHs	Mean % Pb	Mean % Zn	Mean% Pb + Zn
0	37	1.09	1.03	2.12
10	12	1.56	2.47	4.03
20	398	2.16	3.75	5.92
30	170	2.85	4.65	7.50
40	55	2.21	3.35	5.56
50	1061	3.46	5.60	9.05
55	263	1.66	1.99	3.65
60	6	4.61	7.33	11.96
70	81	3.75	5.25	9.00
20 + 30	568	2.37	4.02	6.39
40 + 50 60 + 70	1203	3.42	5.49	8.91
40 + 50 60 + 70 + 55	1466	3.11	4.86	7.96
50 + 60 + 70	1148	3.48	5.59	9.07
All	2083	2.86	4.55	7.41

Table 13: Resources above cut-off from D.H. kriged block estimates and blast holes in those blocks. Type 20/30 - 413 blocks.

Cut-off	Kriged D.H. values		B.H. values	
% Pb + Zn	% above	% Pb + Zn above	% above	% Pb + Zn above
3%	100	6.24	91	6.81
4%	98	6.28	82	7.17
5%	91	6.42	70	7.63
6%	59	6.86	53	8.33

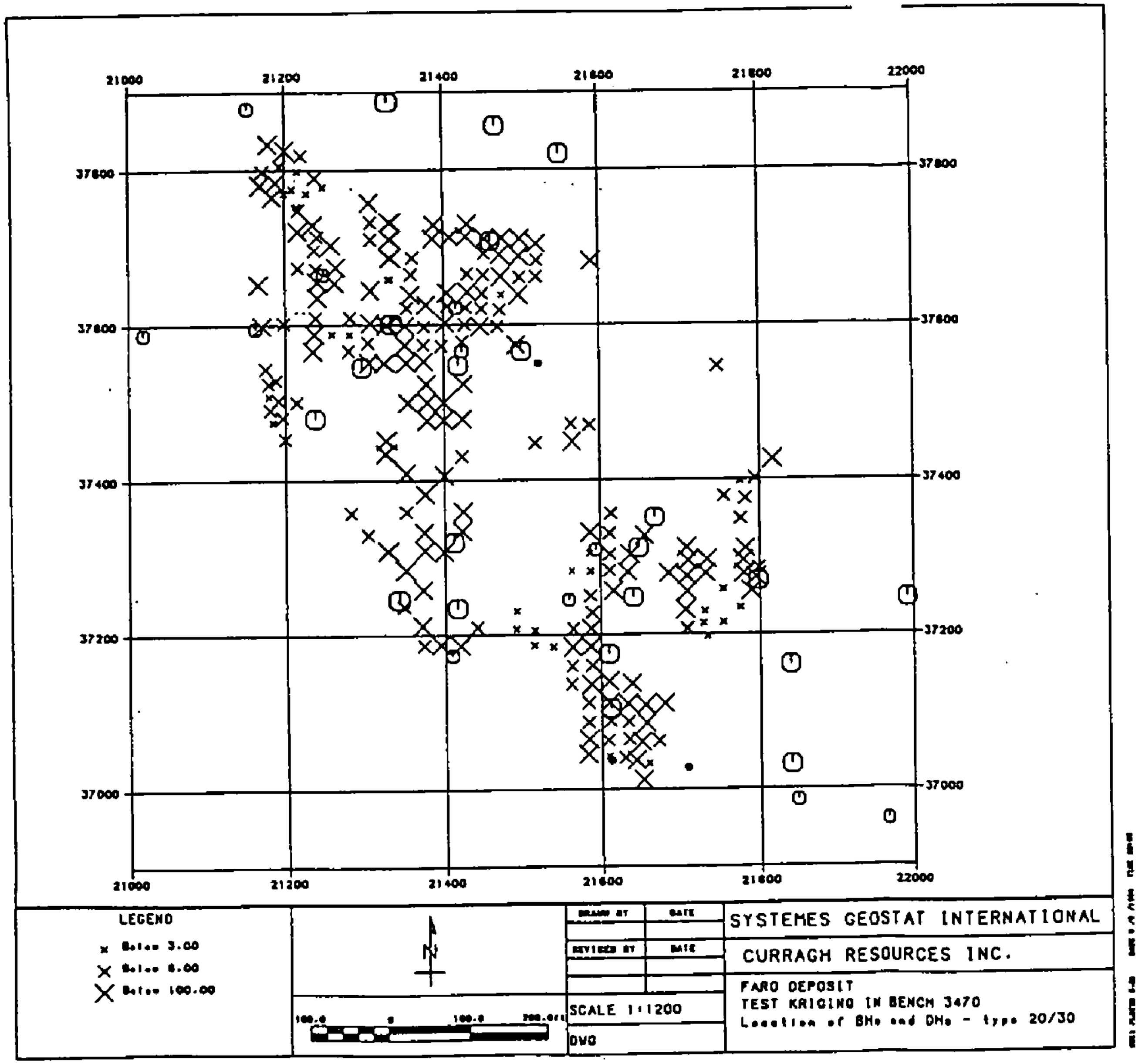
Table 14: Resources above cut-off from D.H. kriged block estimates and blast holes in those blocks. Type 50/70 (excluding 55) - 765 blocks.

Cut-off	Kriged D.H. values		B.H. values	
% Pb + Zn	% above	% Pb + Zn above	% above	% Pb +Zn above
3%	100	8.90	100	9.02
4%	100	8.90	99	9.07
5%	100	8.90	97	9.18
6%	100	8.90	87	9.56

Table 15: Resources above cut-off after correction of oversmoothing by lognormal shortcut (dispersion variances of 4.41 and 4.53 in 20/30 and 50/70 respectively).

Cut-off	Type 20/30		Type 50/70	
% Pb + Zn	% above	% Pb + Zn above	% above	% Pb + Zn above
3%	95	6.44	100	8.90
4%	84	6.81	99	8.94
5%	67	7.38	96	9.06
6%	49	8.09	90	9.33

Figure 19: Map of 20/30 DHs and BHs in bench 3470.



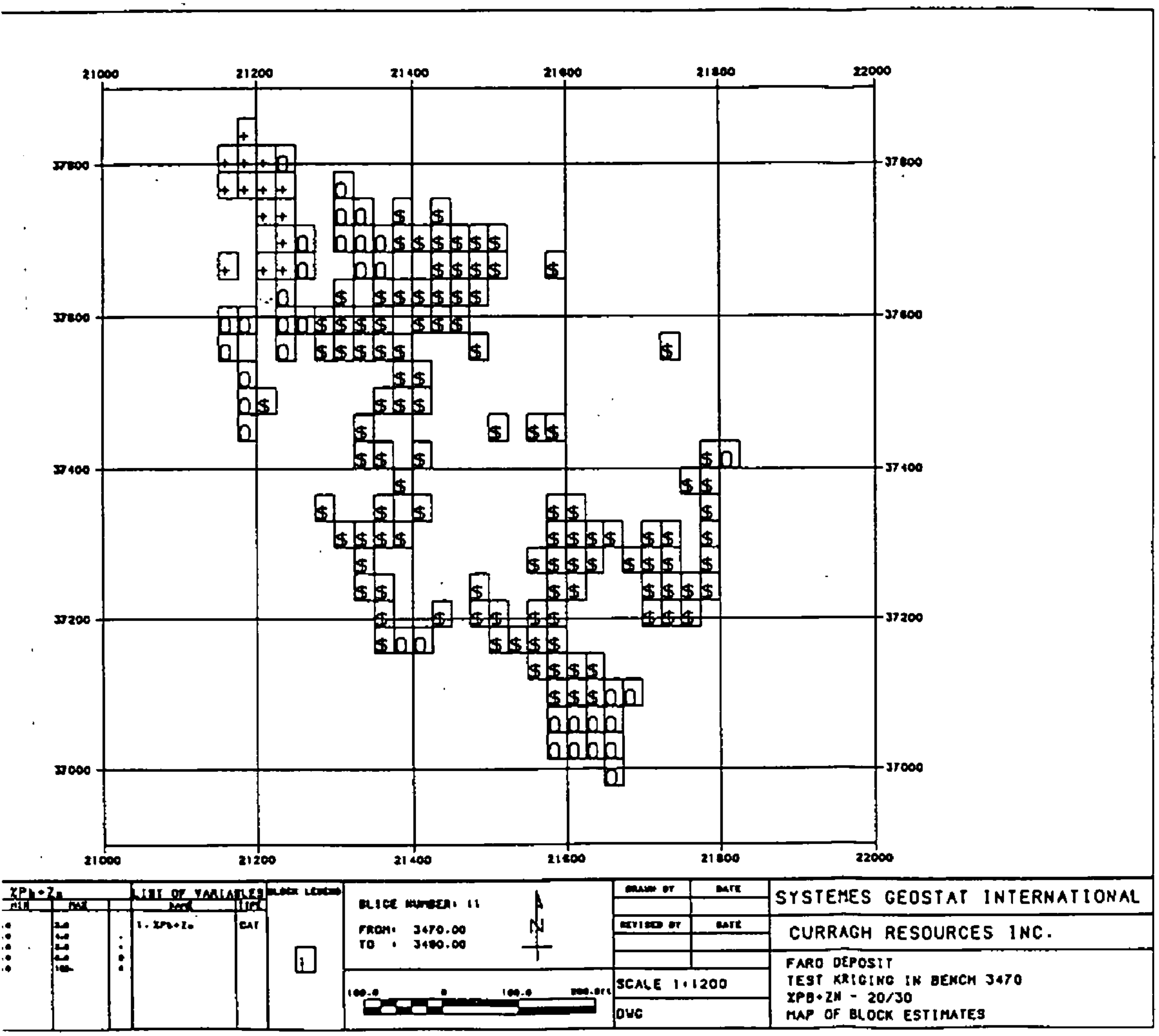


Figure 20: Map of estimated 20/30 blocks in bench 3470.

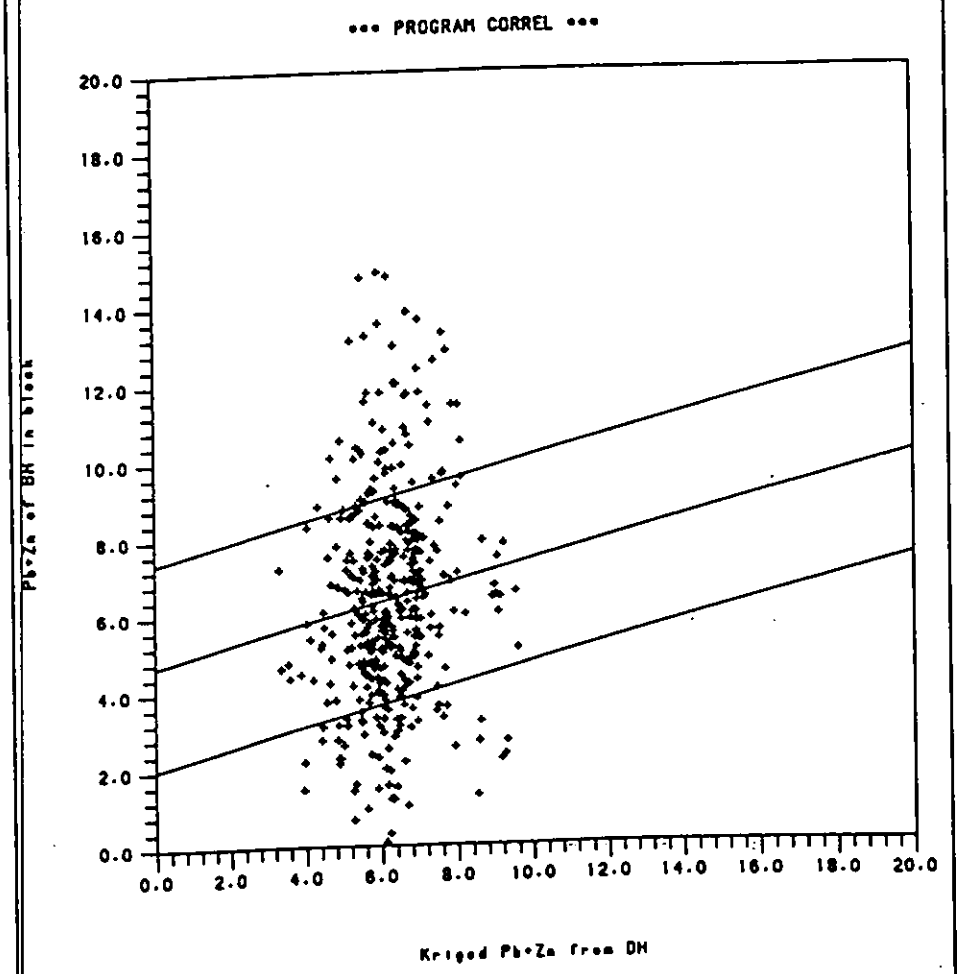


Figure 21: Correlation of kriged DH block and mean BH % Pb + Zn in 20/30.

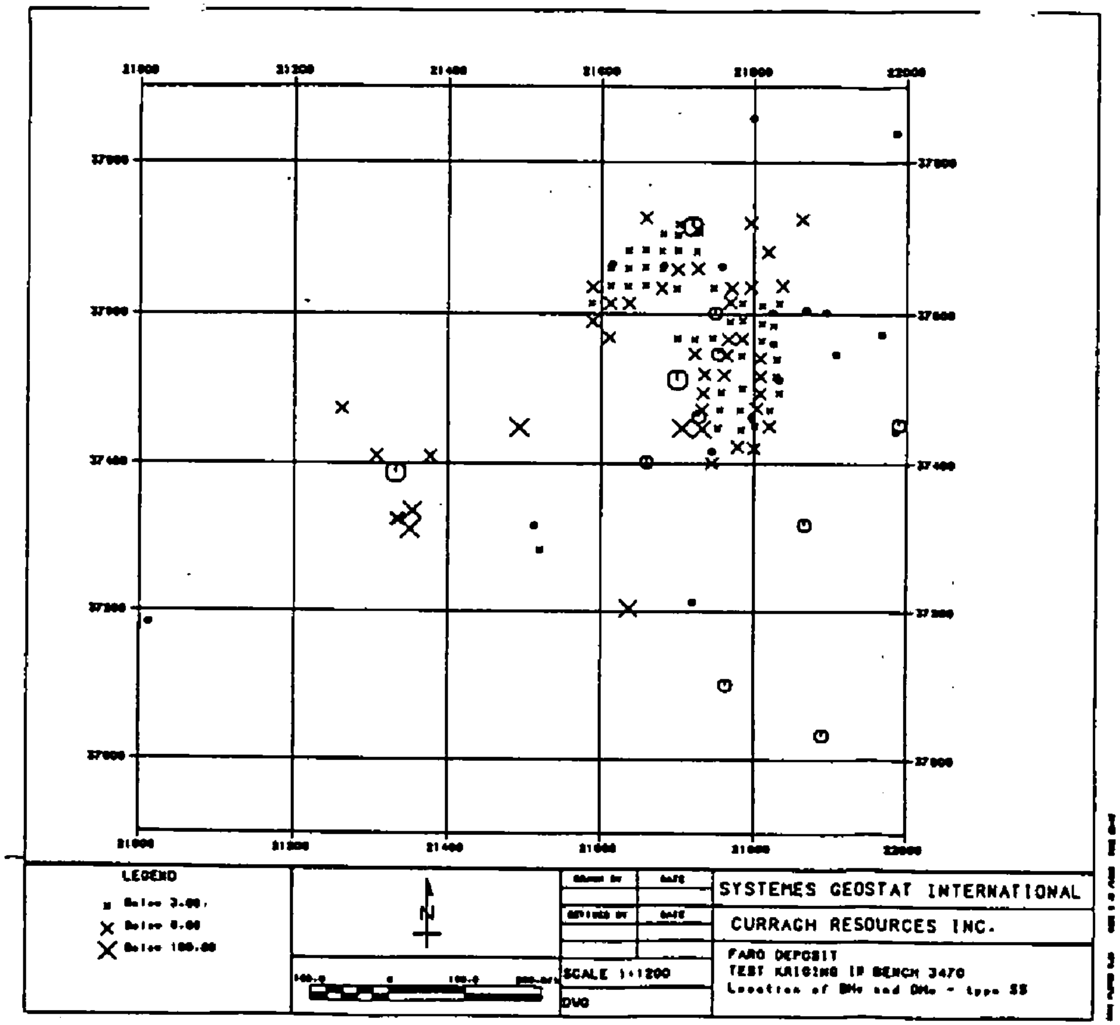


Figure 22: Map of 40 DHs and 55 BHs in b
3470

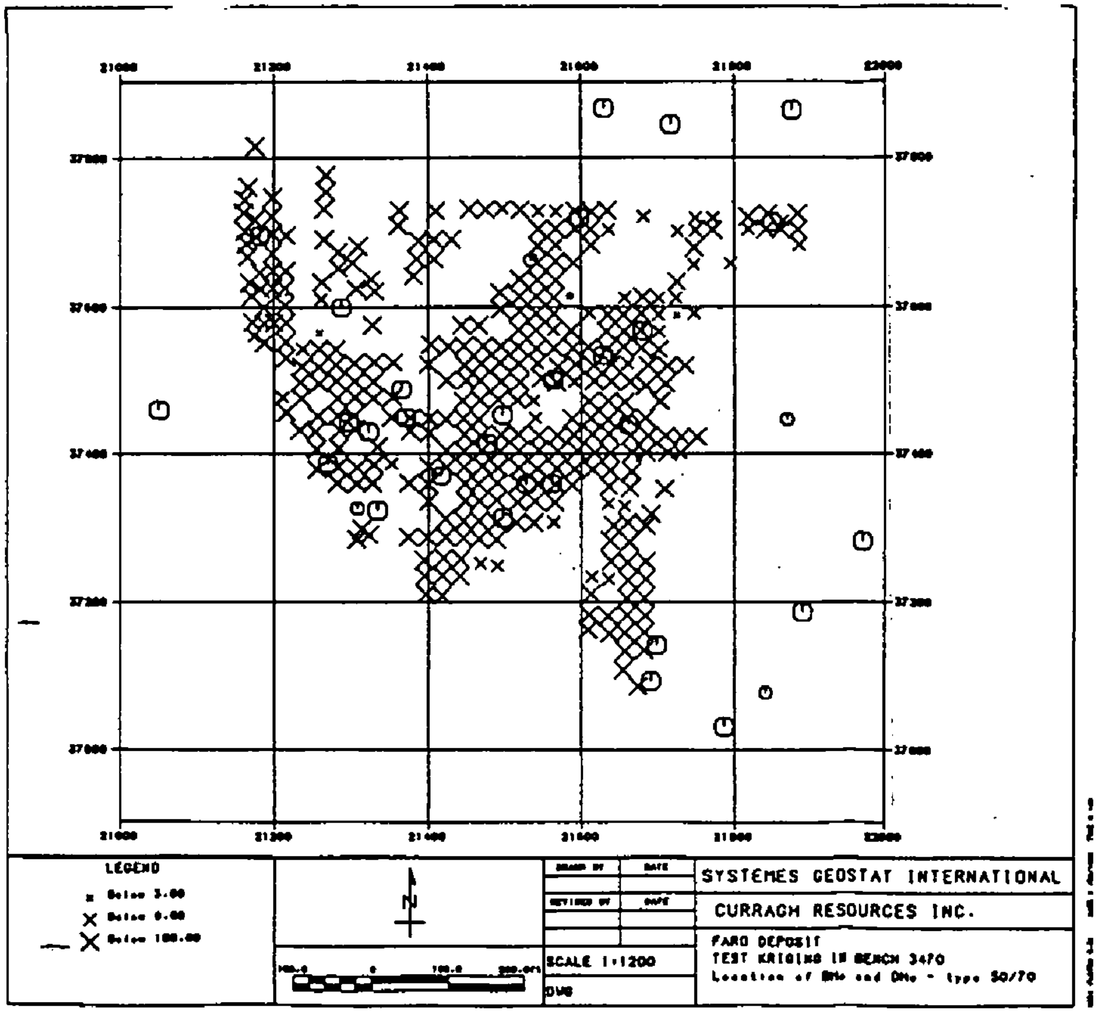


Figure 23: Map of 50/70 DHs and BHs in bench 3470

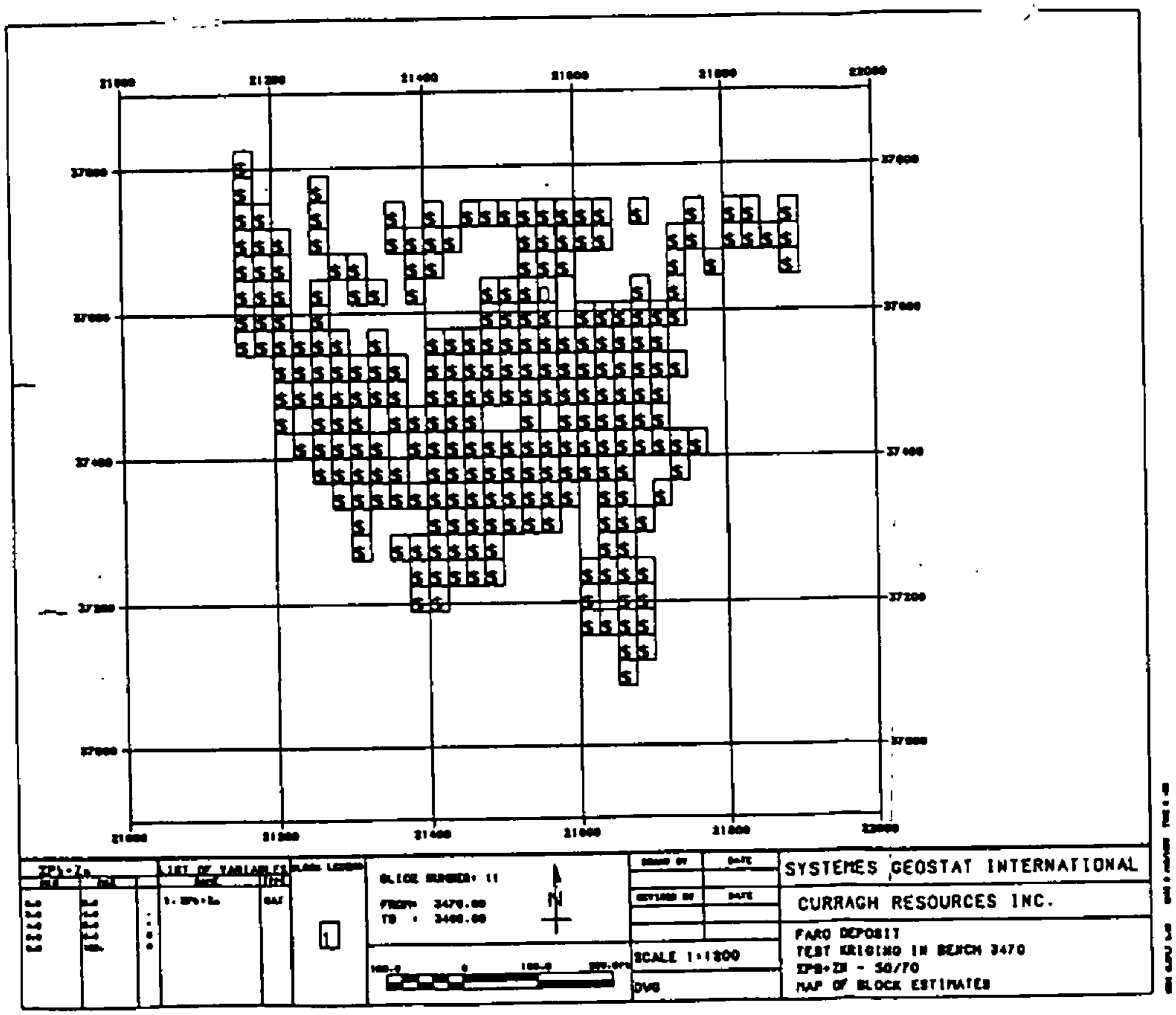


Figure 24: Map of estimated 50/70 blocks in bench 3470

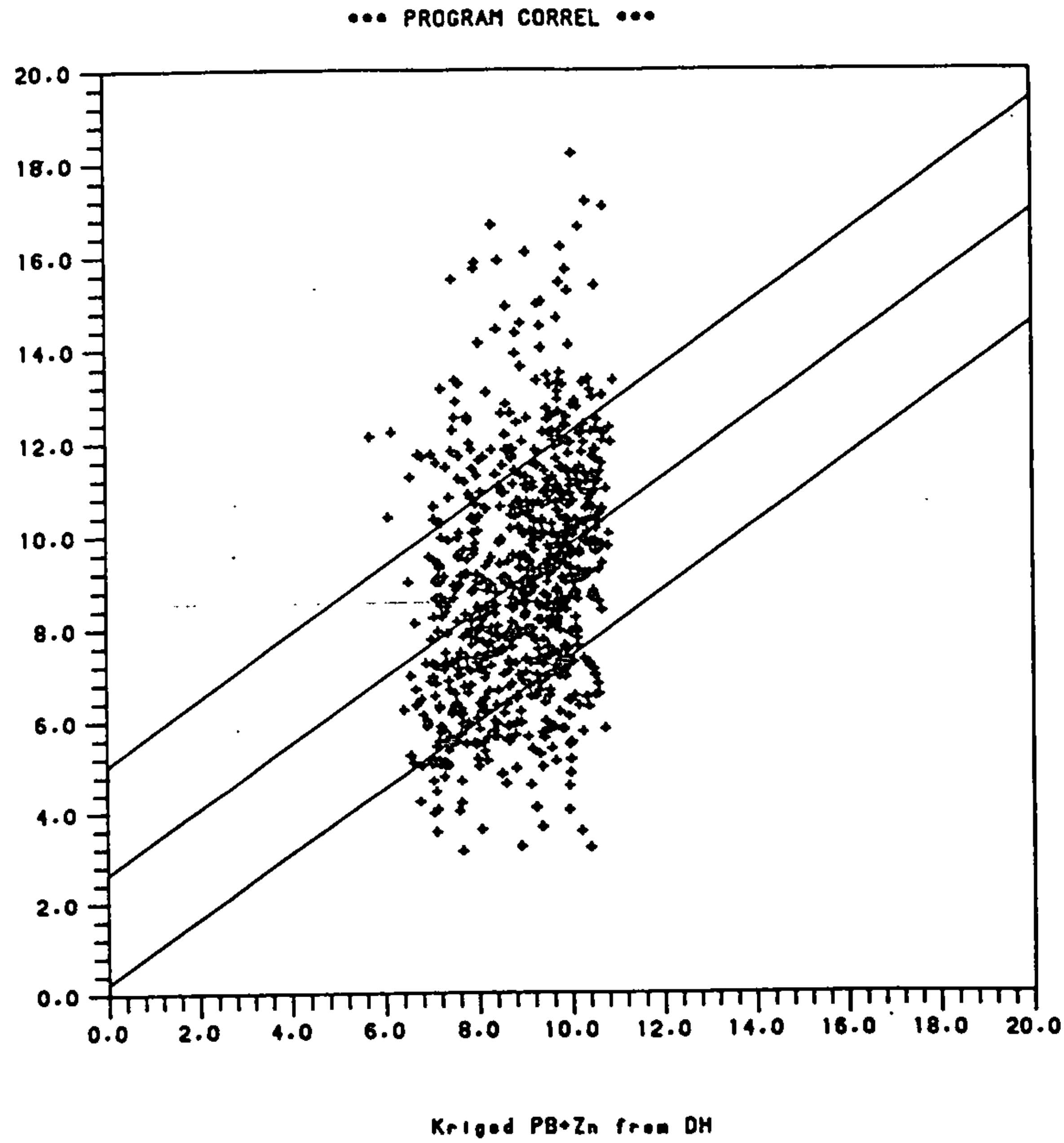


Figure 25: Correlation of kriged DH block and mean BH block % Pb + Zn in 50/70.

1.7 VALIDATION OF THE GEOLOGICAL MODEL

In the current long term prediction model, blocks are first classified according to their ore type, then their average grade is derived from drill hole bench composites of the same ore type around the block. In addition to the grade inference error which has been covered in the previous section, another source of error might be a wrong ore type assignment for the block. To get an idea of the degree of misclassification of blocks according to their ore type, we have checked the assignment of the ore code of drill hole bench composites against the assignment of the same ore types to blast holes nearby (assuming that the categorization of blast holes is more precise than that of drill hole bench composites since we can map ore type limits in a blast). In that part of the study, we have looked at the ore type of the nearest blast hole (within a 20' distance) to each drill hole composite in the test benches 3490, 3470 and 3450. Results are summarized on Table 16. Our comments are:

- more than 50% of the drill hole bench composites of type 20 + 30 (Total: 55) have a blast hole of type 50 + 60 + 70 nearby.

- more than 50% of the drill hole bench composites of type 40 (Total: 26) have a blast hole of type 55 nearby.

- about 70% of the drill hole bench composites of type 50 + 60 + 70 (Total: 96) have a blast hole of the same type nearby.

Hence it appears that the classification of the predominantly high grade types 50 + 60 + 70 is consistent from drill holes to blast holes.

Also, if we pool together the mostly low grade types 40 and 55, classification of these types is also adequate. We have more problems with types 20 and 30 : most of the drill hole bench composites of those types are surrounded by generally higher grade blast holes of type 50 , 60 or 70. In fact, out of the total 177 pairs of D.H./B.H., 55 (31%) involve a D.H. composite of type 20 + 30 whereas only 37 (21%) involve a B.H. of the same type. Hence types 20 and 30 seem to be underrepresented in drill hole composites compared to blast holes.

Table 16: Ore type of the nearest blast hole (within a 20' distance) to drill hole bench composites of various types.

Ore type of D.H.	Ore type of nearest B.H.									
	0	10	20	30	40	50	55	60	70	Total
20	0	0	17	5	1	24	1	0	1	49
30	1	0	1	1	0	3	0	0	0	6
40	1	0	1	0	1	8	14	0	1	26
50	0	0	4	3	1	56	9	0	2	75
60	2	0	0	0	3	3	2	0	0	10
70	0	0	4	1	0	6	0	0	0	11
Total	4	0	27	10	6	100	26	0	4	177

2 SHORT TERM PREDICTION FROM BLAST HOLE DATA

We have already introduced the reference blast hole data set in section 1-6 with summary statistics of their % Pb + Zn data on Table 12. Those blast holes are categorized according to the predominant ore type. Since some of the ore types are mostly low grade (55) and others are high grade (50-70), the distribution of all their % Pb + Zn values is rather heterogeneous. Histogram is a "fat" bell shaped curve with its peak at about 7.30 % Pb + Zn and large quantities of low and high grades (Figure 26). There is also a tail of very high grade data (above 15%). The coefficient of variation, 45% is fairly high considering that data come from a fairly restricted zone. If we look at distributions of values according to ore types, we also see some heterogeneities within each group:

x Distribution of the 37 %Pb + Zn values in type "0" is positively skewed with most values below 2% and other values up to 7%.

x Out of the 12 blast holes classified as "10", 2 are above 12% whereas the balance is 5% or less. As a result, the coefficient of variation for the 12 %Pb + Zn values in that group is 89%.

x Most of the 398 values classified in type 20 are within the range 2-10%. However, maximum reaches 17.68%. Coefficient of variation is similar to that for overall data 46%.

x The 170 data in type 30 are more homogeneous. Most values are within the interval 3 - 14%. Coefficient of variation is only 35%.

x In type 40, we just have 55 values ranging from 2 to 12%. Coefficient of variation is the same as overall (45%).

x Like in 30, the 1061 data in 50 are more concentrated: 90% of the values lie in the interval 5 - 14%. There are a few high outliers up to 20%. Coefficient of variation is a mere 30%.

x The 263 values in type 55 have the typical distribution of low grade material: lots of low values (median is just about 2%) and a few scattered high values (up to 13%). As a result, the coefficient of variation is pretty high: 62%.

x There is not much to say about the 6 blast holes classified in type 60. Values range from 6 to 16%. Coefficient of variation is 25%.

x Distribution of the 81 values in type 70 is well homogeneous with values from 5 to 13% and a coefficient of variation of 25%.

Formally, the current short term prediction model is also a block model with a distance weighting grade interpolation method: blocks are the 25 x 25 ft volume of influence of a blast hole and the interpolation method is nearest neighbor (or polygon). In other words, the grade estimate for a blast block is the grade of the single blast hole sample in the middle of the block. Like for the long term prediction model from drill holes, it is possible to assess the standard error a single blast-block grade estimate or a group of them. We just need compute and model variograms of blast hole grade.

At this point, we can calculate a) a global variogram of all the 2083 B.H. data available whatever their rock type assignment b) variograms in each rock type or combination of rock types.

Blast hole variograms are well defined provided they are computed on a few hundred data points. We have just computed <u>horizontal variograms</u>: with only data from 3 benches, we don't have that much information on B.H. grade variations through benches. Also, if we were to implement a blast hole distance weighting grade interpolation procedure (some form of blast hole kriging) we would tend to limit ourselves to blast holes on the same bench as the blast-block to estimate.

An example of blast hole variogram is given on Figure 27. It is for the % Pb + Zn of all available blast holes. In addition to the average variogram (circles), we have directional variograms along E-W (triangles) N-S (X) NE (+) and NW (diamond). Step to classify distances is 25' along E-W and N-S and 36' along NE and NW. All variogram points are defined from a large number of samples. There is no restriction on sample data. Those variograms show:

> + a well defined nugget effect of about 4 $(\%)^2$ i.e. about 35% of the variance of 11.5. Note that this is exactly the same as the nugget effect of % Pb + Zn of bench composite in both 20 + 30 and 40 + 70 ore types. <u>Hence it looks like the sampling precision of blast holes is as good as that of drill holes.</u>
>
> + a short range structure of about 100' (average variogram). For short distances, less than 100', we can detect some anisotropy pattern on directional variograms which is similar to the one observed on the bench composite variograms of type 20-30: top variogram (least continuity) is E-W and bottom variogram (best continuity) is N-S.
>
> + a long range structure of about 350' i.e. similar to what we had for the D.H. bench composites variograms.

Blast hole variogram models for various combinations of ore types are given on Table 17. We can see that:

> + the strong E-W/N-S anisotropy that we had for D.H. composites in 20/30 is still visible in the blast hole grades of the some ore type.
>
> + likewise, the variograms of blast holes in 50-60-70 is isotropic.

+ low grades 40 and 55 have been pooled together for variogram computation. The variograms show a strong trend at long distances due to the presence of isolated high grade blast holes categorized in those ore types. The model used does not take that trend into account.

To check the performance of various blast hole grade interpolation methods, we can use the same sample reuse method that we had for D.H. bench composites. The idea is to reestimate each of the 2083 B.H. % Pb + Zn grades from blast holes around using various interpolation methods and segregation of blast holes by ore type. Results are in Tables 18 and 19.

For example, if we do the reestimation with no segregation at all, we get a pretty good correlation between original and reestimated B.H. grade if we use kriging (r = 0.70 - Figures 28). It is not so good if we just use the nearest neighbor method (r = 0.56 - Figure 29) even if the dispersion of estimates perfectly matches that of the original data (see table 28). In fact, even if kriged estimates are smoother than real values, we can see one advantage of kriging over nearest-neighbor: the regression line of real on estimate is almost an y = x line. This means that if we mine all blast holes with an estimate of 6% the true average of these blast holes is 6% : we mine what we anticipate. There is no shortfall of grade above cut-off. On the other hand, if we use the nearest-neighbor approach, the regression line is like y = 0.56 x + 3.2. If we enter estimates (x) of more than 3.2/(1.056) = 7.27% Pb + Zn in this equation, the corresponding mean true value (y) is less than the estimate. Hence we overestimate high grade. For example, if we apply a cut-off of 6% Pb + Zn to the nearest-neighbor estimates, we get 1367 blast holes (66%) with an average estimated grade of 9.37% Pb + Zn but an average true grade of 8.57%. If we apply the same cut-off to the kriged estimates, we get 1560 blast holes (75%) with an average estimated grade of 8.46% Pb + Zn and an average true grade of 8.52%. Hence with kriging, we recover more tonnes (12%) at the expected grade. With nearest neighbor we have a grade shortfall of 8.5%.

We get even better results if we do the kriging of blast holes independently in 20-30, 50-60-70 and all the low grades 55-40-00-10 together. Correlation coefficient of real data and estimates is now 0.74 (Figure 30), regression line of real on estimate is virtually y = x. As a result, if we apply the 6% Pb + Zn cut-off on the estimates, we recover 1519 data (73%) with an average estimated value of 8.65% Pb + Zn and an average true value of 8.64%. We get a little less tonnage than in the case when we use all blast holes together but with a higher recovered grade. Our selectivity has improved.

Figure 26: Histogram of all B.H. % Pb + Zn available.

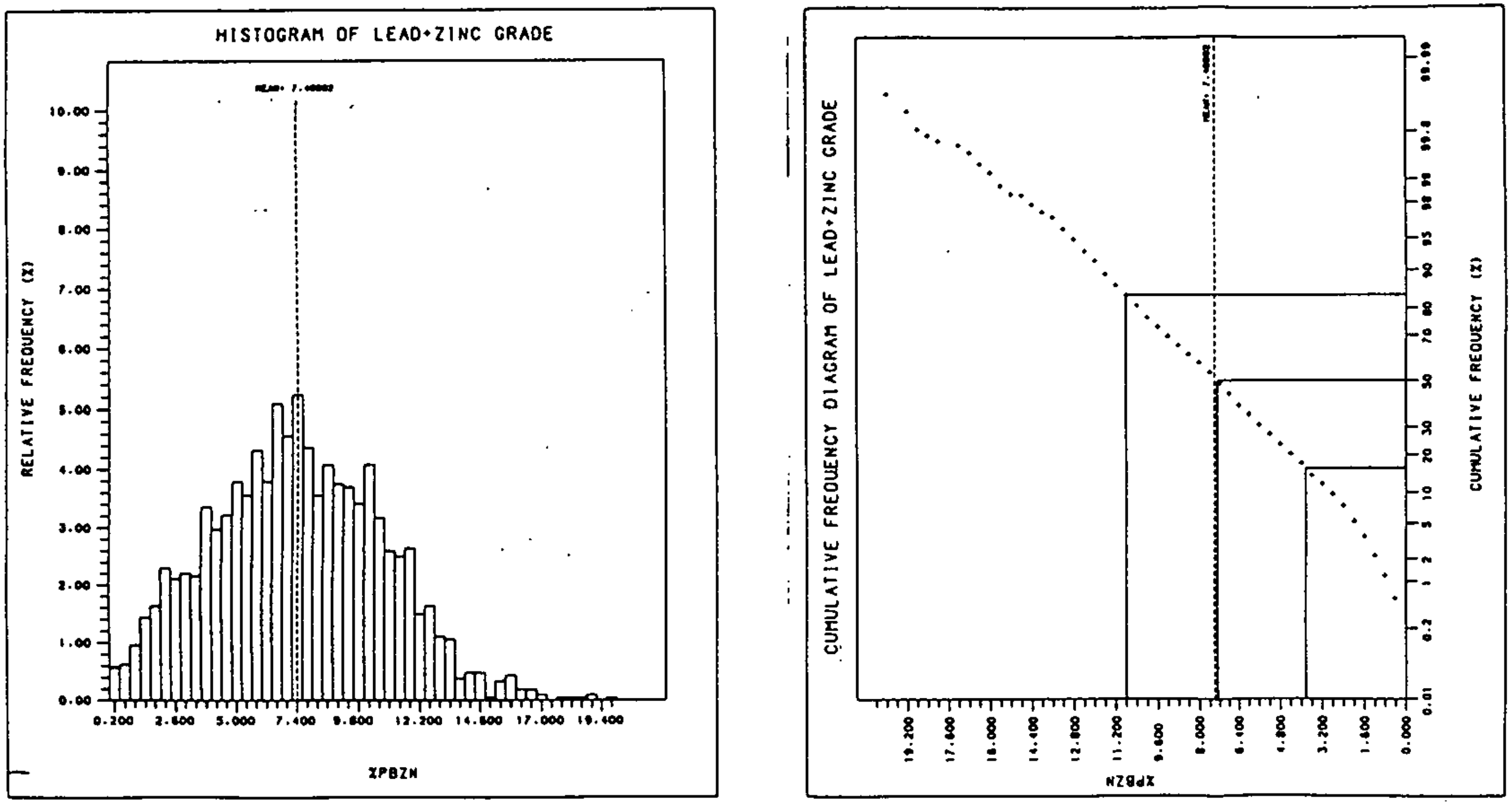


Figure 27: Horizontal variograms of all B.H.
% Pb + Zn available.

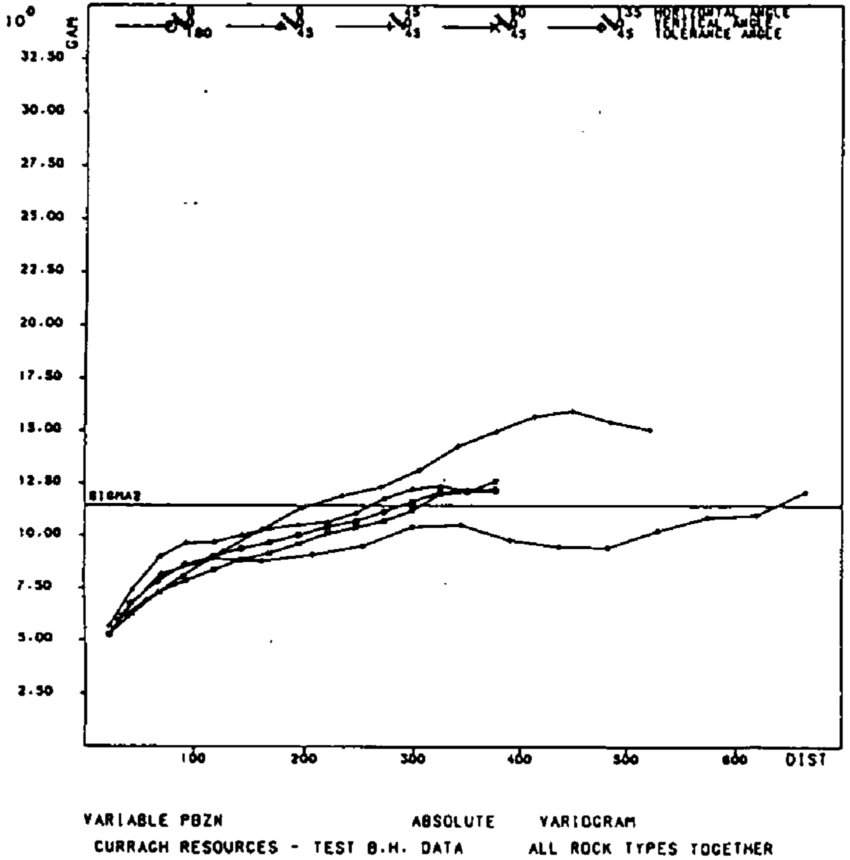


Figure 28: Correlation plot of real vs reestimated B.H. % Pb + Zn kriging. All B.H.s together.

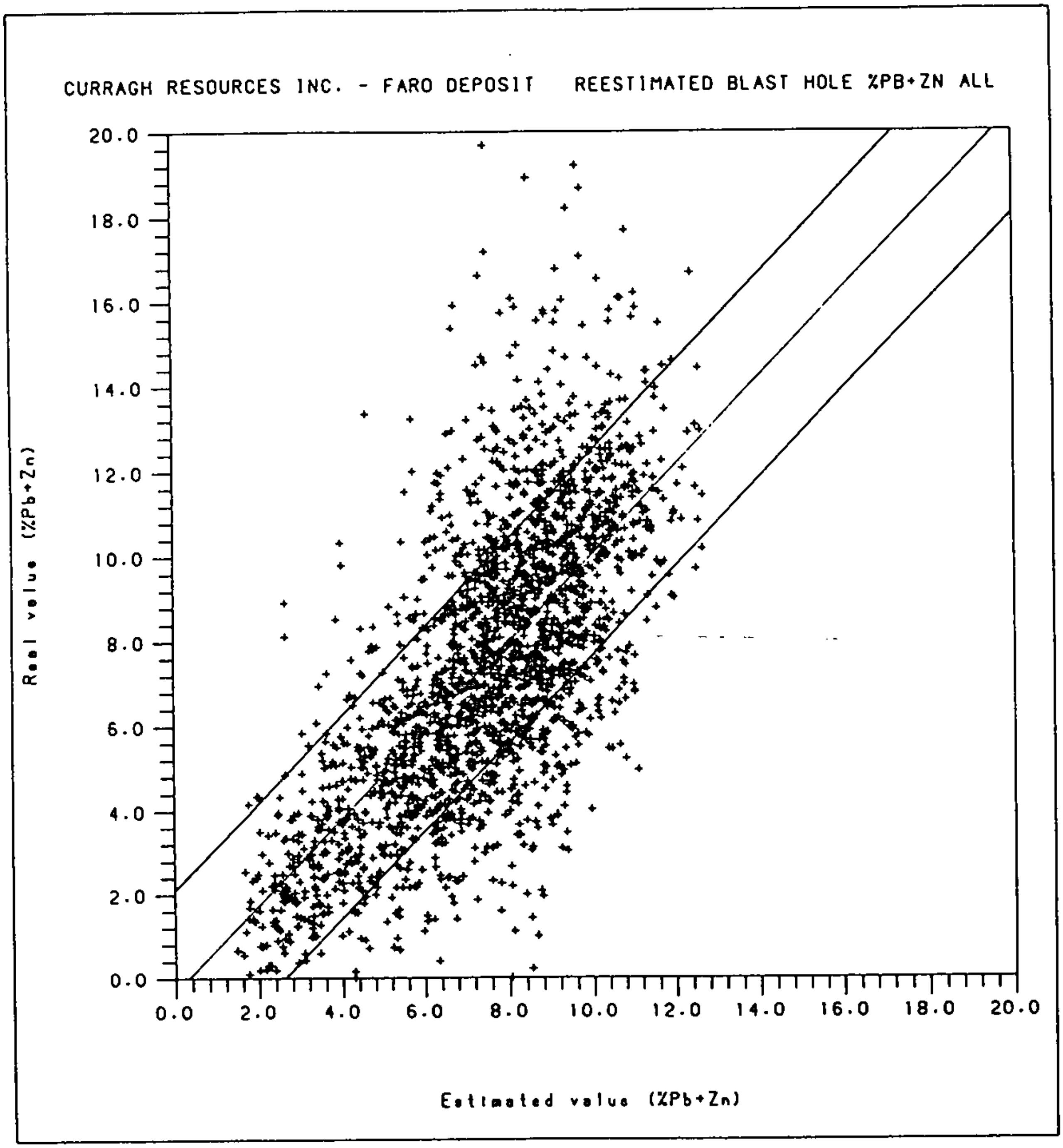


Figure 29: Correlation plot of real vs reestimated B.H. % Pb + Zn nearest neighbor. All B.H.s together.

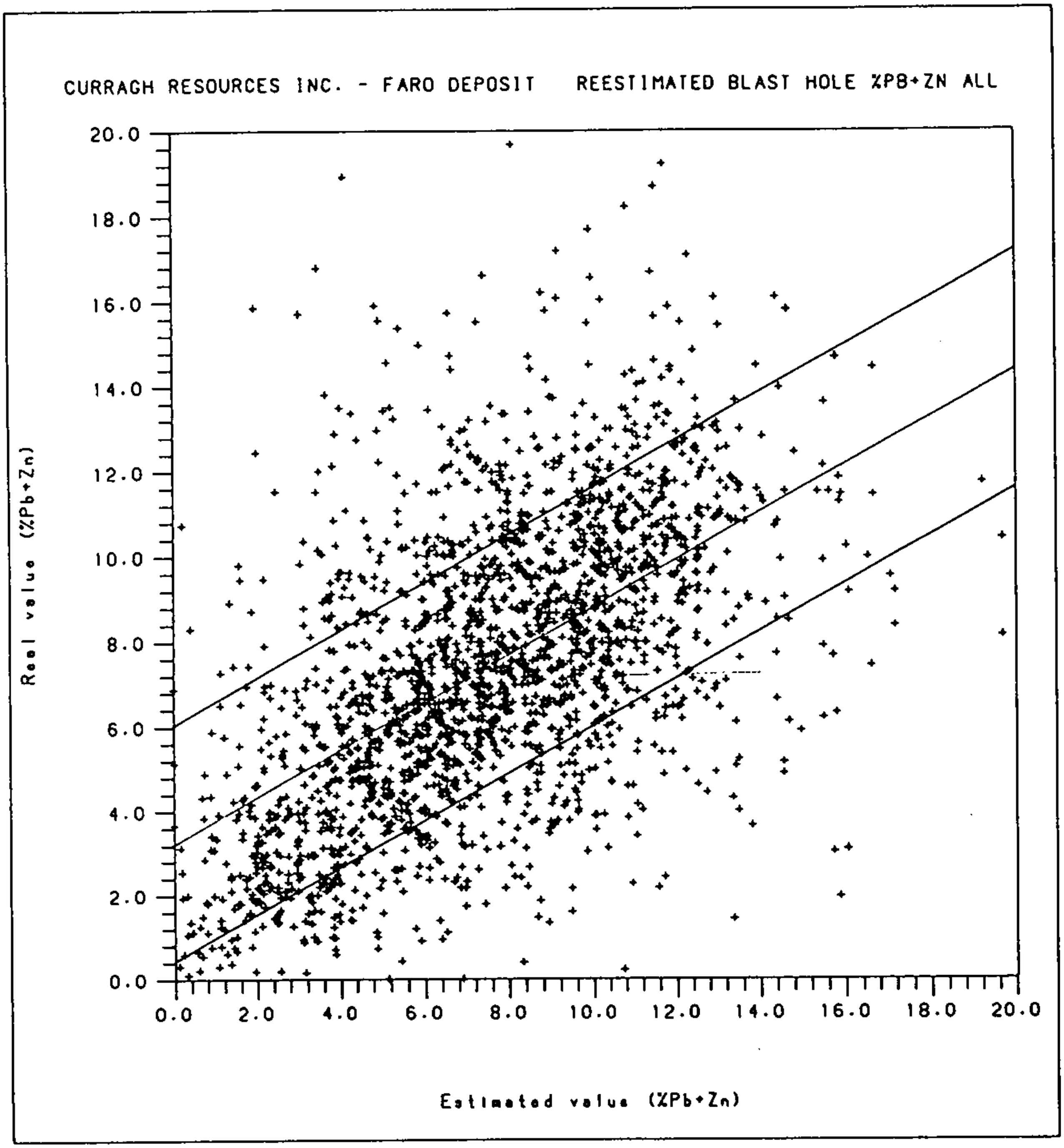


Figure 30: Correlation plot of real vs reestimated B.H. % Pb + Zn kriging. 3 separate ore types.

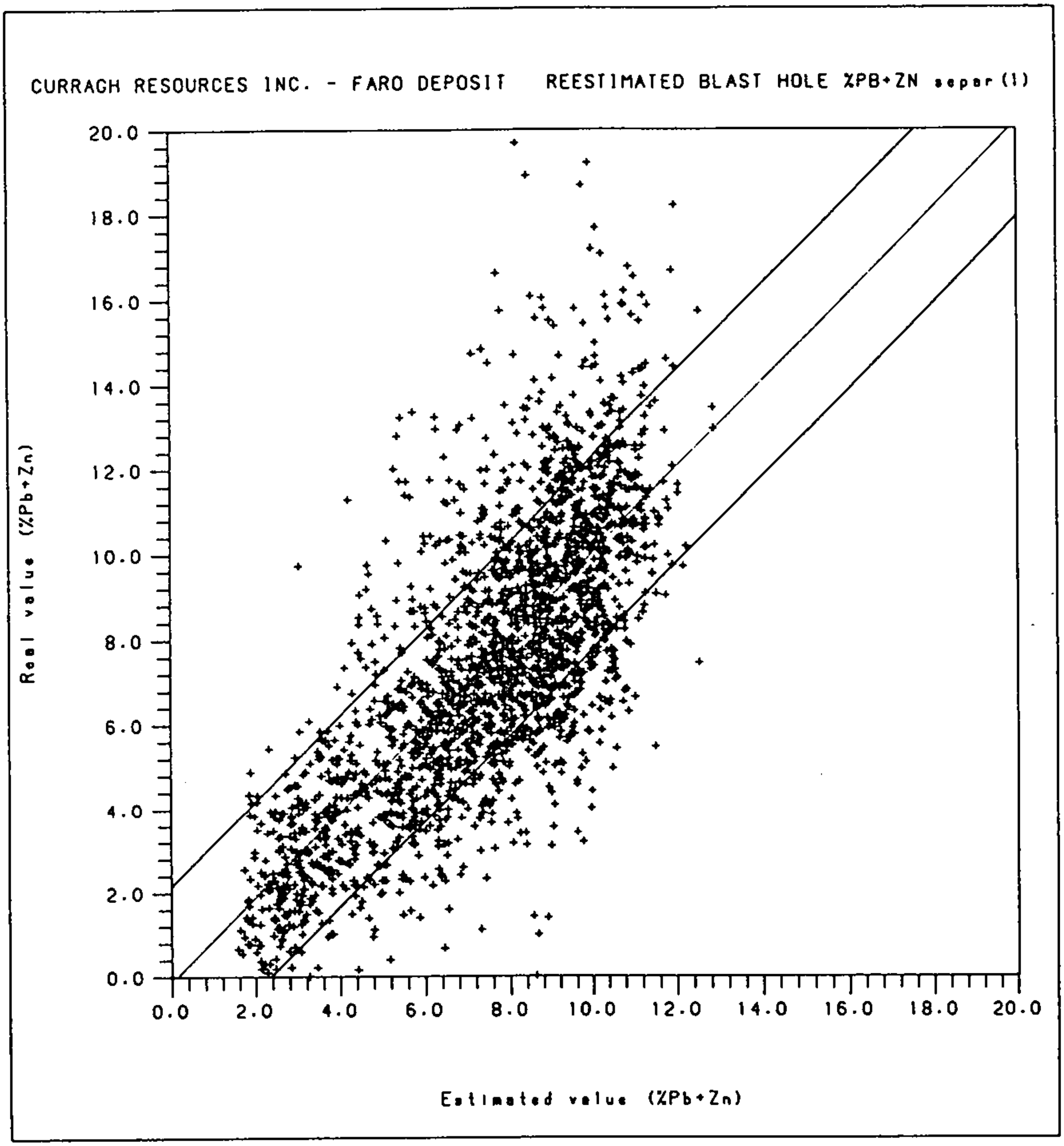


Table 17: **Models of % Pb + Zn horizontal variograms for blast holes.**

Blast holes	Nugget Effect $(\%)^2$	Sill $(\%)^2$	Spherical 1 Ranges (ft)	Sill $(\%)^2$	Spherical 2 Ranges (ft)	Sill $(\%)^2$	Spherical 3 Ranges (ft)
All (N = 2083)	4	3.5	100	4.0	350	-	-
20 + 30 (N = 568)	3.5	2.0	50	2.5	75 (E-W) 500 (N-S)	-	-
50-60-70 (N = 1148)	4.0	0.5	50	3.0	300	-	-
40 + 55 (N = 318)	1.5	0.5	50	1.0	250	-	-

Table 18: Statistics of errors in the reestimation of % Pb + Zn grade of B.H.s for B.H.s around (on the same bench).

B.H. grouping	Interpolation method	Number of reestimations	Error	Average		
				Absolute error	Experimental error variance	Theoretical error variance
			(%)	(%)	(%)^2	(%)^2
All	Kriging	2078	-0.017	1.84	5.83	6.07
All	Nearest Neighbor	2078	-0.071	2.34	10.04	9.43
20-30 50-60-70 00-10-40-55	Kriging	2078	0.00	1.72	5.12	4.95

Table 19: Correlation of estimates and real values in the reestimation of % Pb + Zn grade of B.H.s from B.H.s around (on the same bench).

B.H. grouping	Interpolation method	Standard deviations		Correlation coefficient	Regression real = f (estimates)
		Real	Estimates		
All	Kriging	3.37	2.26	0.70	y = 1.04 x - 0.3
All	Nearest Neighbor	3.37	3.36	0.56	y = 0.56 x + 3.2
20-30 50-60-70 00-10-40-55	Kriging	3.37	2.46	0.74	y = 1.015 x - 0.11

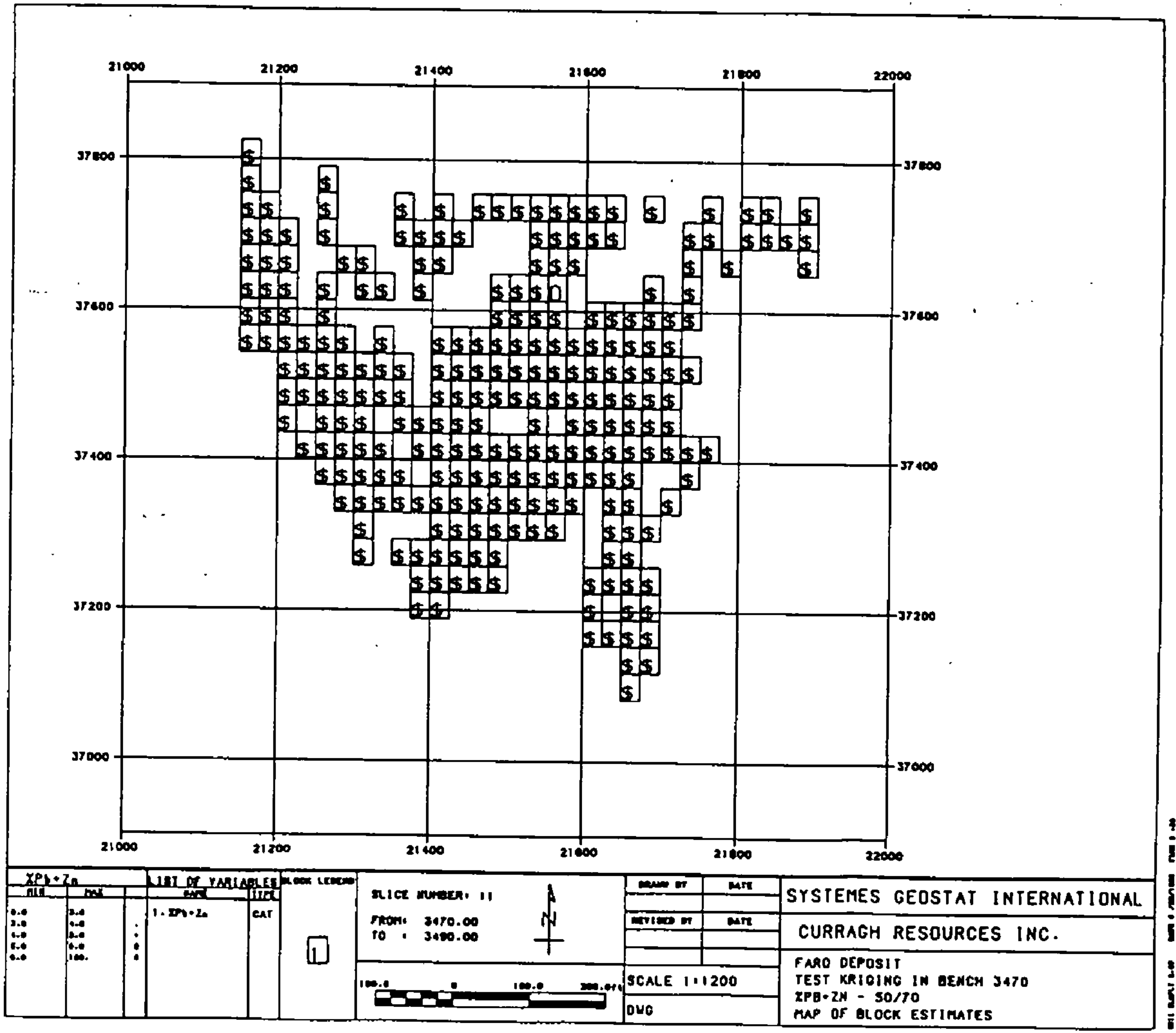


Figure 24: Map of estimated 50/70 blocks in bench 3470

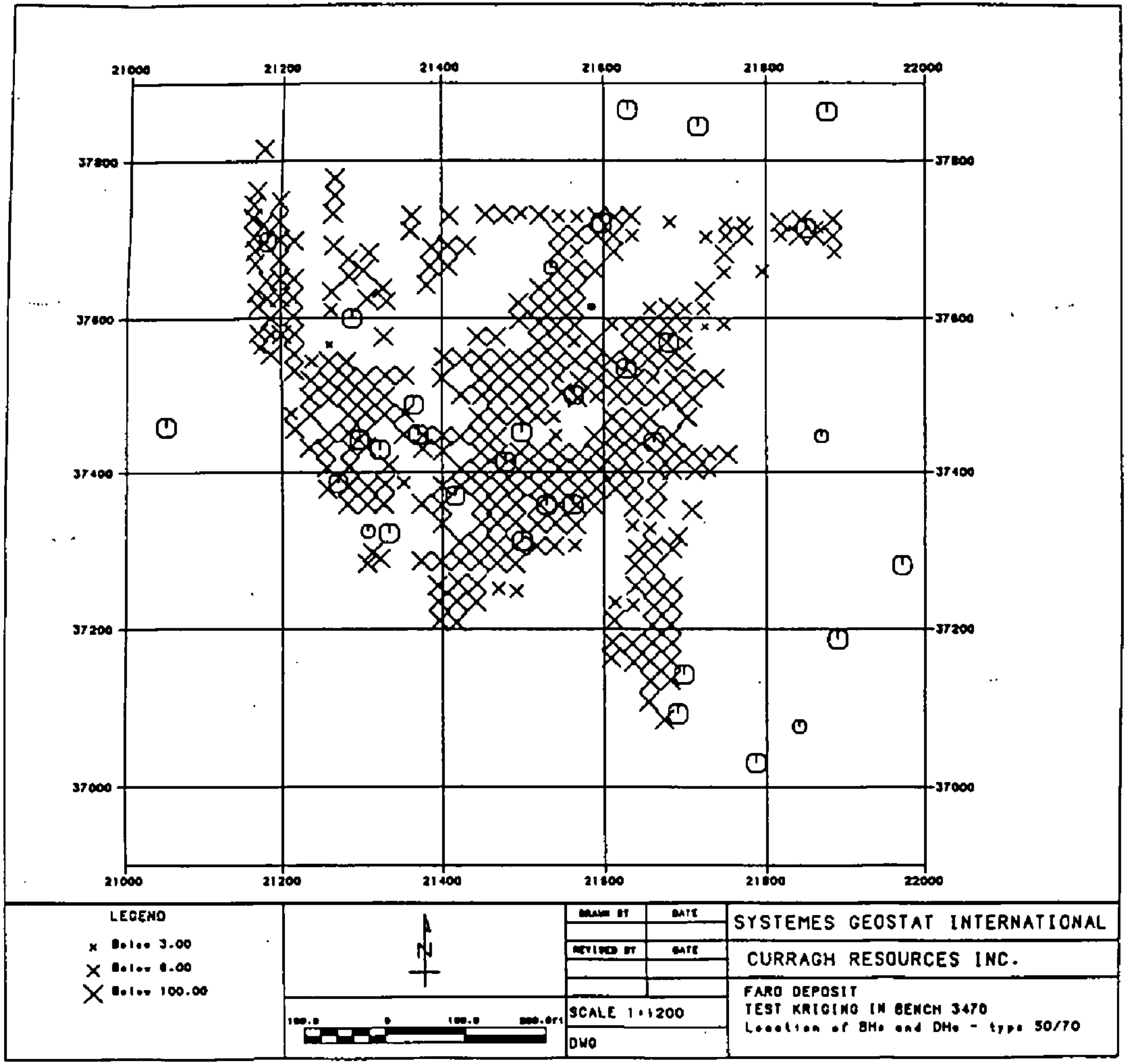


Figure 23: Map of 50/70 DHs and BHs in bench 3470

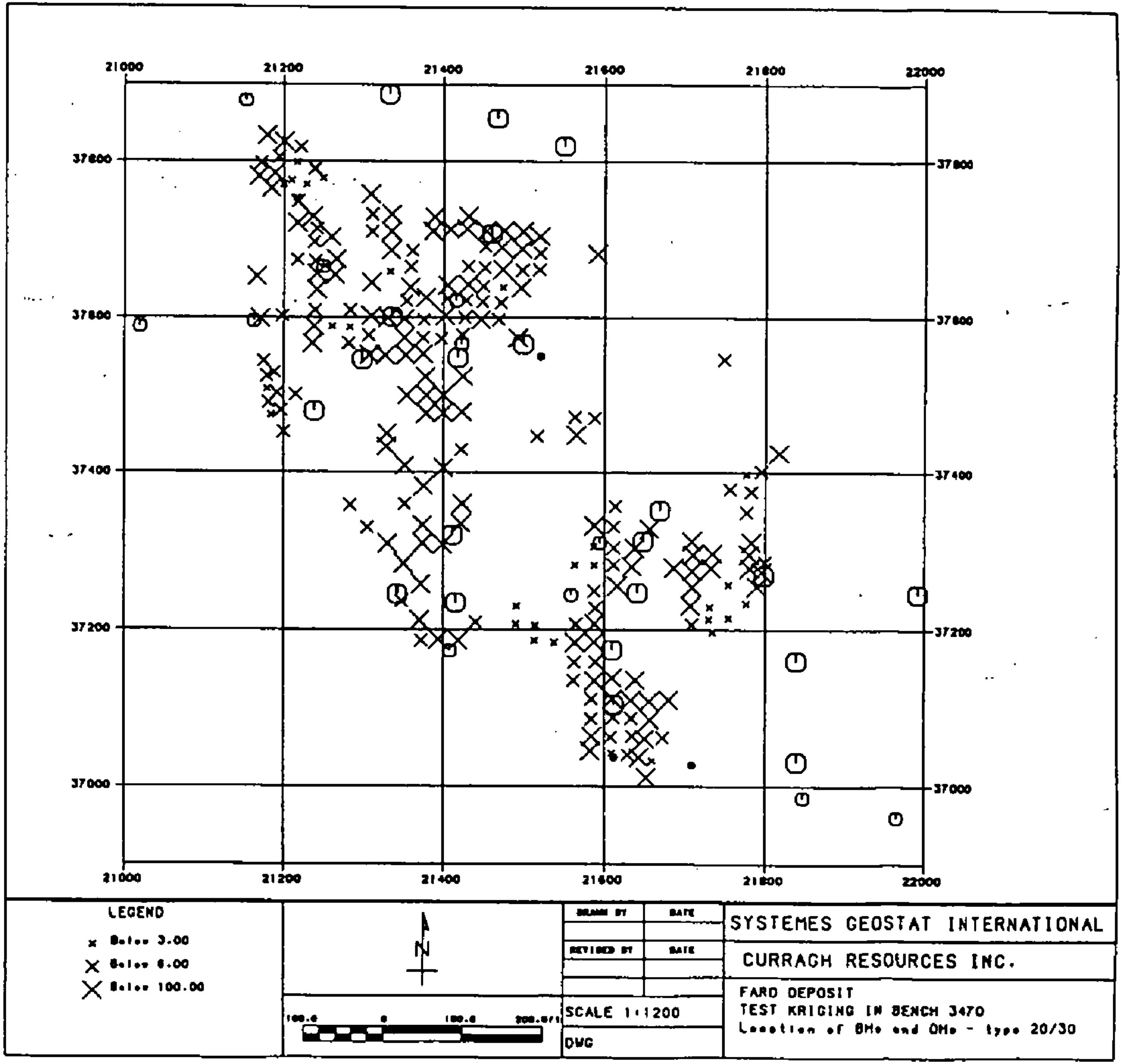


Figure 19: Map of 20/30 DHs and BHs in bench 3470.

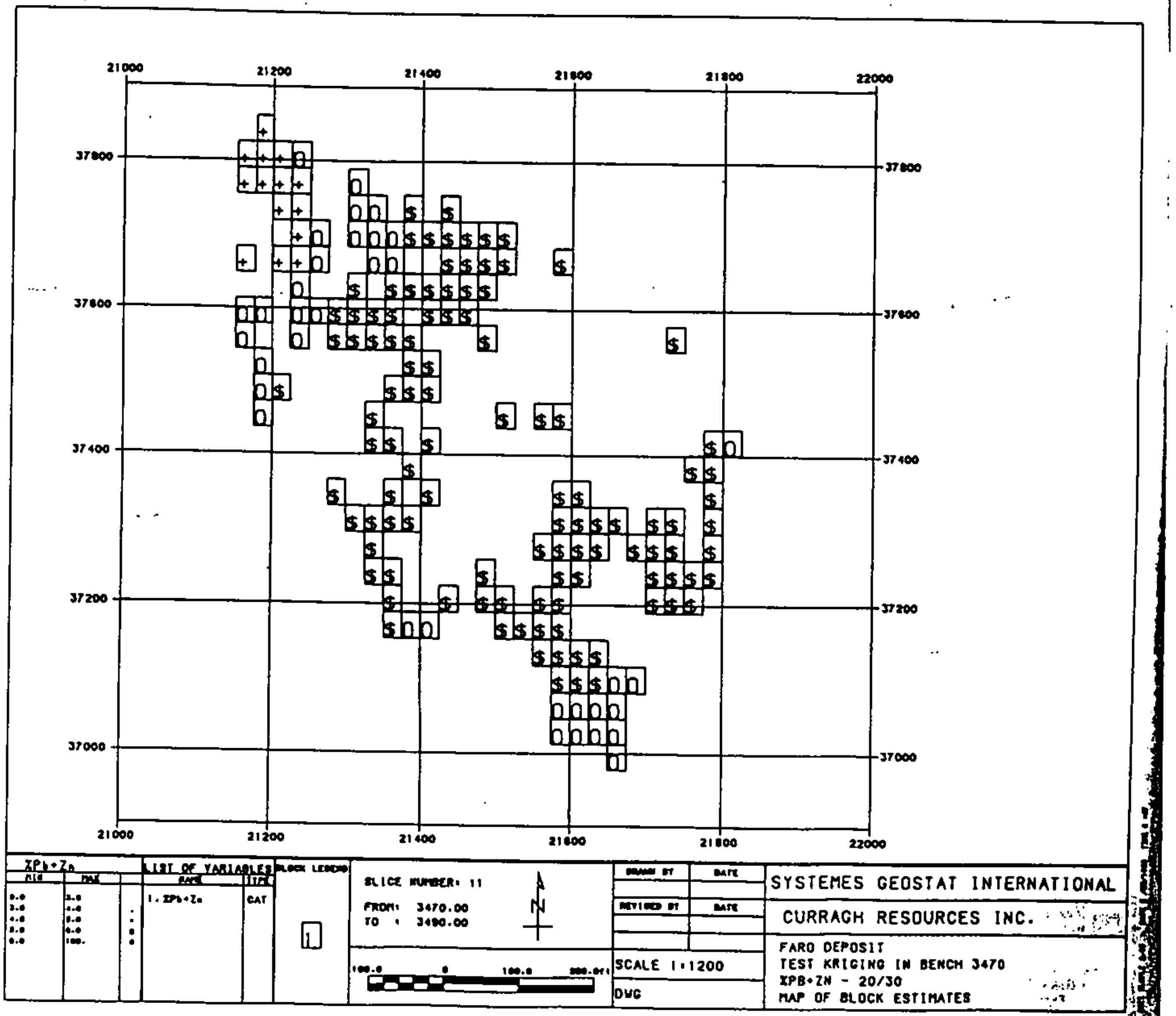


Figure 20: Map of estimated 20/30 blocks in bench 3470.

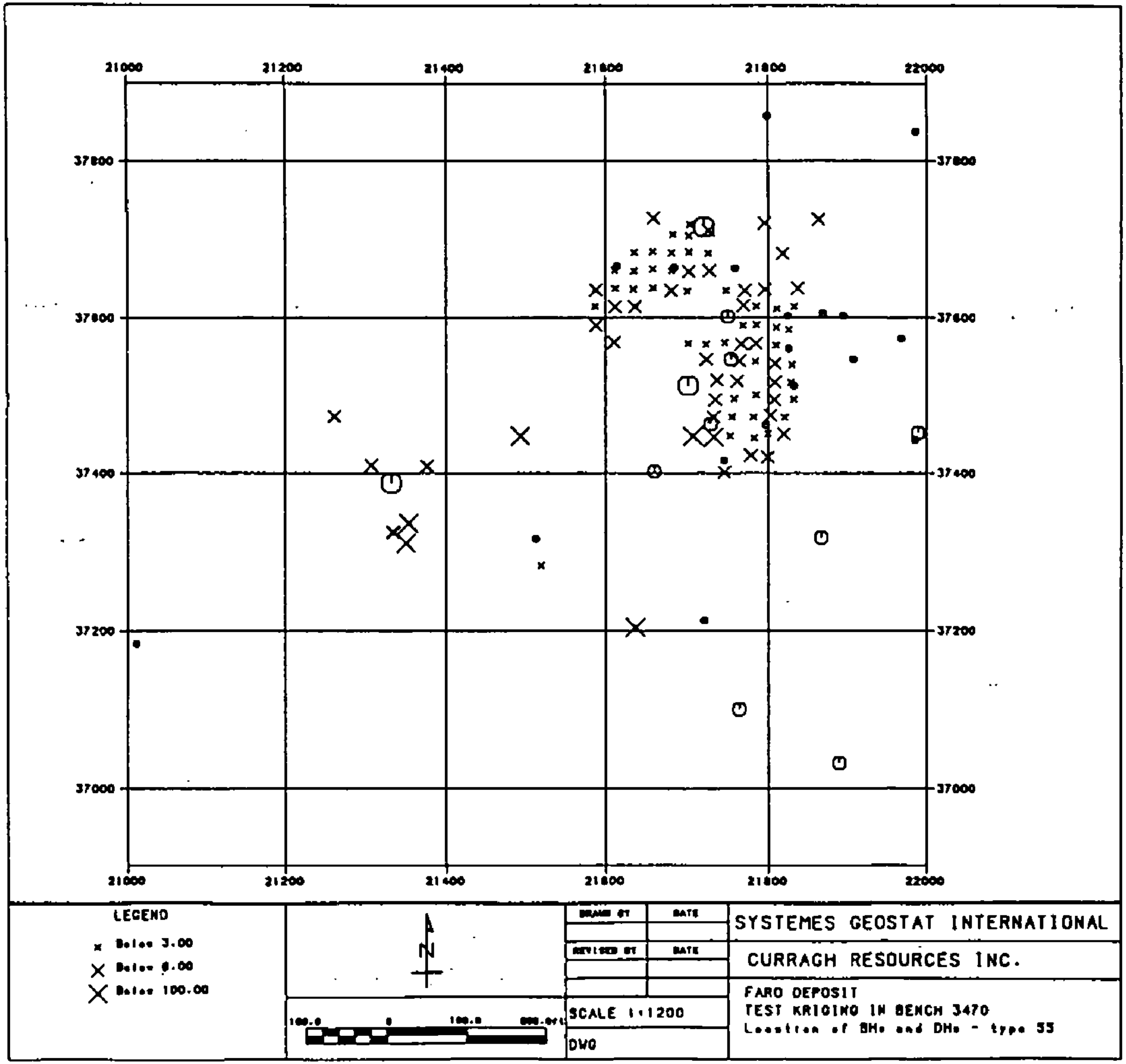


Figure 22: Map of 40 DHs and 55 BHs in ben
3470

RECEIVED JUL 17 1990

Collin Bowen, Jim Hart
Greg Jilson;
I support this
approach

CURRAGH RESOURCES INC.

Inter-Office Memorandum

TO:
Dave Tenney
Chief Geologist
Faro Minesite

FROM:
Gregg A. Jilson
Vice-President, Exploration
Whitehorse Office

cc:
Toronto Office
Marvin H. Pelley, Executive Vice-President, Mining
James W. Hendry, Vice-President, Engineering
Whitehorse Office
Lee C. Pigage, Senior Geologist
Cameron V. Reed, Geologist

RE: GEOSTATISTICAL STUDY

DATE: 05 29 1990

Apologies on the sluggish delay in getting back to you on geostatistics. I take it Mohan Shrivastava did not reply to the request for proposal, he has visited the site previously and already has some of the geology and data under his belt. His text book on geostatistics was recently published, by the way.

I am strongly supportive of this investigation. We carried out a similar review shortly after reopening the mine. At that time, the conclusion was that the geologic complexity of the deposits was the primary detriment in the reliability of tonnage and grade estimation and that geostatics could not help with that. Due to the unclustered nature of the data points (except Grum), it was felt that kriging would not necessarily help improve grade estimation on the basis of diamond drill hole data available at that time. ✓

determinant

The situation has changed dramatically now that the drill density has been increased, thus I feel that it is more likely that geostatistics and kriging will be of value. For one thing, the data is now clustered more at Faro. But mostly I suspect you now will be able to get a meaningful variogram from diamond drill hole data - this could not be done before. ✓

I believe the objectives outlined in Dagbert's letter are good ones but I would like to see consideration of the applications of geostatistics to grade control in the pit added to this list. ✓

...../2

I recommend some things be done before the selected geostatician arrives:

1. Compile blasthole data for several benches with XYZ coordinates - I suggest using the core data that we put into a PCXPLOR database some time ago;

2. get deep blasthole data (if available) and diamond drill hole composites for the same benches organized into files;

3. get the original geological interpretation on the bench and the final interpretation from pit mapping for the same benches - have this digitized and standing by;

4. select benches with good blasthole data, not 40' holes split into parts, etc., also preferably benches that were mined on grade; (these to limitations may not be possible to live within); and

5. do several contiguous benches, preferably the lowest four benches in the pit.

I feel very strongly that geostatistics offers us powerful capabilities in the grade control practices in the open pit. I doubt the current area of influence method really grades ore adequately. The concept that one blasthole in the centre of a 1,200 tonne block of ore adequately evaluates the grade of that block is naive at best.

Assuming that the grade could be representative, it is not likely that the variance of the sample of cuttings is the same as the 1,200 tonnes of sulphides - it is a virtual certainty that the variance will be different. I believe the blasthole, and it's neighbours, give us some idea of the probability that that block is ore or waste. It is that probability we should be estimating by kriging and establishing our pit operational decisions on a threshold probability that a block is ore. I believe the field here is called indicator kriging.

Please note that these applications of geostatistics in the pit can only be realized if the data is organized and the methodologies are streamlined. This can be done with our current tools but our staff are not sufficiently trained in the intricacies of their use and have neither the time nor hardware to get the plan done. Nonetheless, the data must be organized and spatially related - without this there will be no application of modern geostatistical technology possible in our ore control practice.

ORECONTROL, by GEMCOM is a tool currently available that is compatible with our other software, that will accomplish this spatial organization and relieve technicians of unproductive data entry digitizing and plotting. **Without the purchase of such a tool, there will be no possibility of realizing the benefits of modern geostatistical science at the Faro Mine.**

write AFE ~$20,000

I look forward to the results of this investigation. Please do not hesitate to contact me if our staff can help in the preparation and presentation of data and goelogic concepts to aid the investigation.

GAJ*geb
faro\geostat.dt