

*Bill + Dave
I think we
have to start with
responsibility for
so I would
get set up
can do
ASAP*

005044

CORRAGH RESOURCES INC
INTEROFFICE MEMORANDUM
FARO YUKON

DATE: March 28, 1990

TO: *[Signature]* BILL DUNN
CHIEF ENGINEER

FROM: DAVE TENNEY
CHIEF GEOLOGIST

SUBJECT: DEFINING ACCURACY OF ORE RESERVE GRADE ESTIMATES
=====

The current methods used to calculate the ore reserves at Faro are empirical to the extent that their accuracy cannot be guaranteed except with reference to prior blasthole production. This, as far as I am aware, is true of all ore reserve calculations except those using geostatistical methods ("Kriging"). Geostatistics not only provides an ore reserve tonnage and grade but can also give an estimate of the likely error contained in the estimates. If a particular degree of confidence is needed in the ore reserve estimate either on a local or global basis, then the required pattern and density of sampling can be determined. This would be of particular importance in the current drilling programme at the Vangorda Pit, but would also be of great value in any of the deposits.

Since Kriging, the branch of geostatistics in most common use, is a complex subject, I suggest we investigate the possibility of hiring a consultant geostatistician. The names of Michel David and Michel Dagbert of Geostat in Montreal come to mind immediately, but there are others. Their mandate would be to place some confidence limits on the ore reserve estimate (both globally and locally) and suggest a drill hole pattern and density which will give us the level of confidence we require. I understand from Jim Hendry that this is $\pm 5\%$.

This study is probably better handled through Gregg Jilson's office in Whitehorse, where facilities for this type of work are better and production work will not be an impediment.

D. Tenney

Dave Tenney

Chief Geologist

DT:cc

cc: M. Pelley

Gregg Jilson

~~R. Weymark~~

J. Hendry

Bill Dunbar

I know these people and they are the best in the business (geostatiticians)

Define a scope of work with Dave, review the info available on Vancouver. Discuss both of the above with these people to see what they could offer or do or require. A proposal.

"Involve Whitehorse"

[Signature]

Bill Dunn



FACSIMILE TRANSMISSION

TO: Mr. Dave Tenney, Chief geologist, Curragh Resources, Faro, Yukon

FROM: Mr. Michel Dagbert, Geostat Systems International Inc., Montreal, Quebec

DATE: 09/10/1990

Number of pages including this one:1

Subject/Message: Dear Dave,

We are couriering to you a second draft of the report with the validation of the long term error prediction and the correction of block estimates for proportion of blast holes in block. We think that this correction is particularly useful. In a test zone around the blast holes of benches 3490 to 3450, we found that if we apply the cut-offs on the straight block estimates derived from D.H. composites, we can get overestimation of tonnage of as much as 30% in 20/30 and 14% in 50/70 and underestimation of grade of up to 17% in 20/30 and 7% in 50/70. With the proposed "lognormal" shortcut correction, these numbers are down to 8%, 3%, 5% and 2% respectively. The correction can easily be implemented once you get the block estimate file.

I am still working on the last two items of the study i.e. the testing of the "geological framework" of the model as well as the processing of B.H. data for grade control. I am leaving for Africa but I have my portable with me and I will finish the work there. Final sections of the report will be sent to Montreal and forwarded to you. In the meantime, if you have any question, send a fax to Montreal and it will be relayed to me.

Regards,

GEOSTAT SYSTEMS INTERNATIONAL INC.

Michel Dagbert, for
Michel Dagbert, Manager



Montreal, September 10th 1990

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

Dear Dave,

Please find herewith a second draft of the report on the geostatistical analysis of Faro drill hole and blast hole data. The validation of the long term error prediction and the correction of block estimates for proportion of blast holes in block have been added to the text. Still to come is the testing of the "geological framework" and the B.H. data processing for grade control.

I am leaving for Africa but I have my portable with me and I will finish the work there. Final sections of the report will be sent to Montreal, and forwarded to you. If you have any question, send a fax at our Montreal office to my attention and it will be relayed to me the same day.

Yours sincerely,

GEOSTAT SYSTEMS INTERNATIONAL INC.

Michel Dagbert, Manager

Encl.

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 krig 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 than 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) than 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 some kind 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 than 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 10).

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

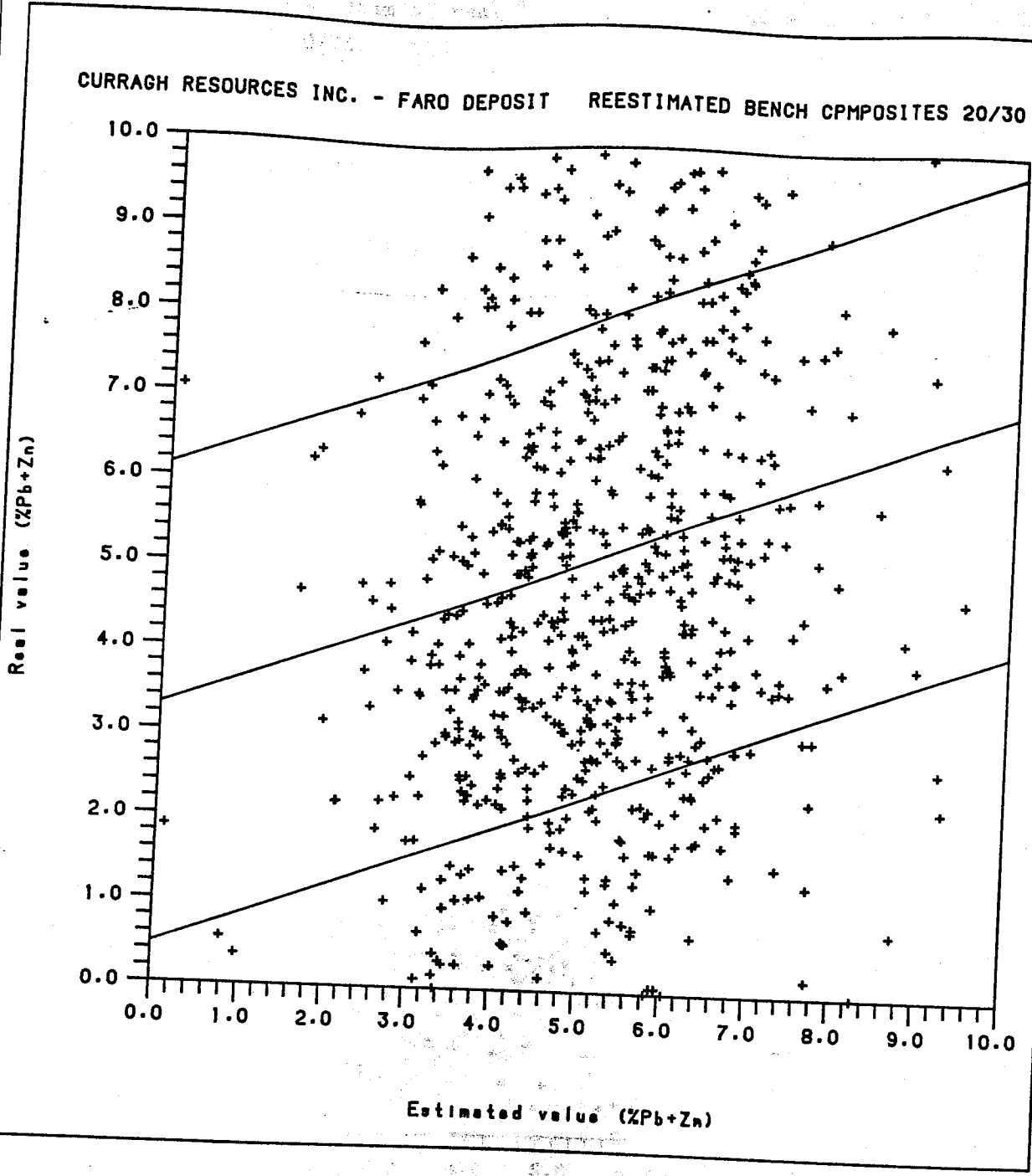


Figure 18: Scattergram of real % Pb + Zn value and estimated % Pb + Zn value in 40/70.

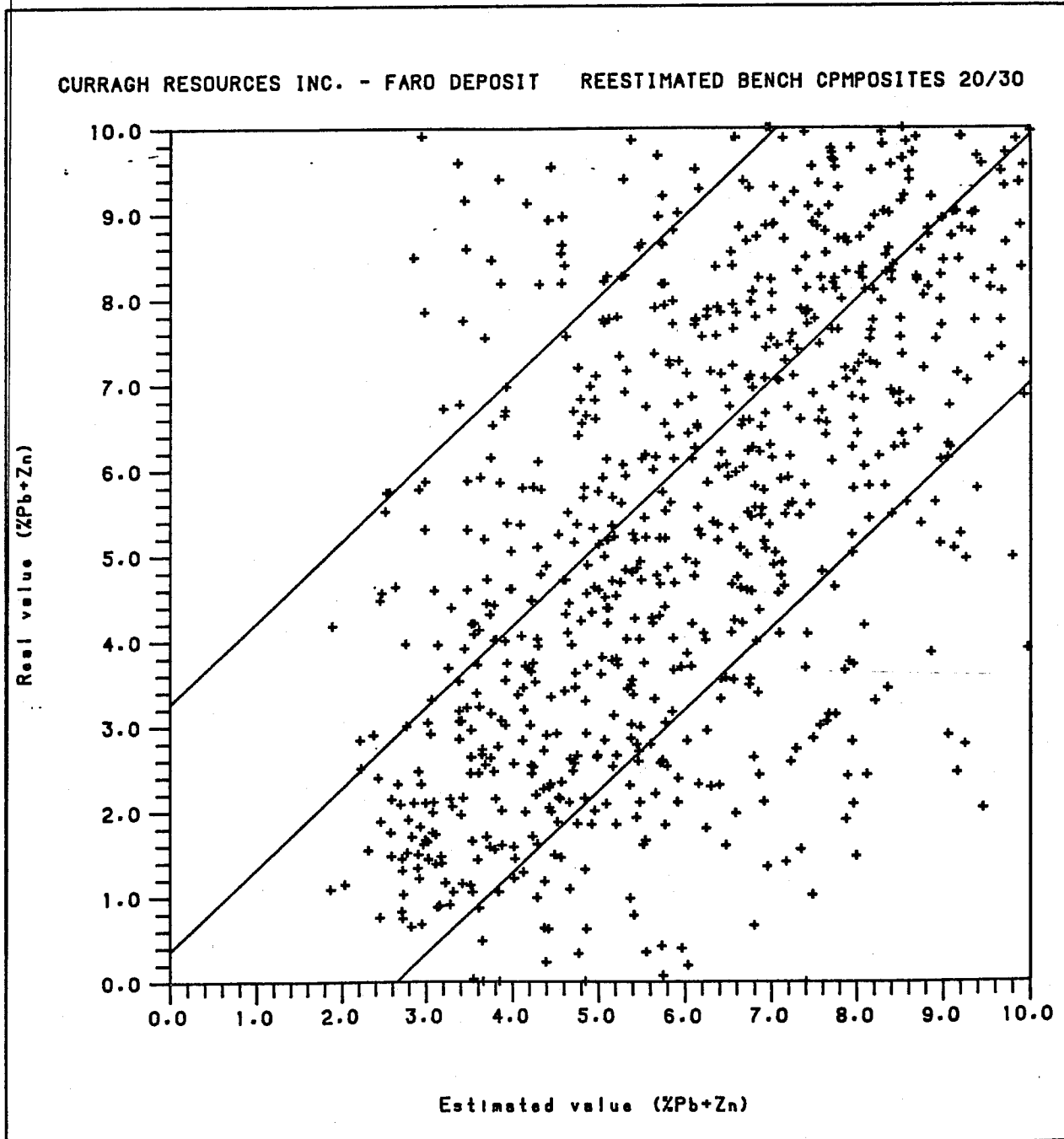


Figure 18

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

Cut-off (% Pb + Zn)	20/30		40/70	
	Actual	Estimated	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		40/70	
	Actual	Estimated	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) mean 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 from 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 (o 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 oversmoothing of kriged block values: 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, if we apply the usual cut-offs to the kriged block values, tonnages are too high and grade too low (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 krig 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 BHs 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 to estimate the likely proportion and grade of blast holes above the cut-off in each block.

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 13.

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 % Pb + Zn	Kriged D.H. values		B.H. values	
	% 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

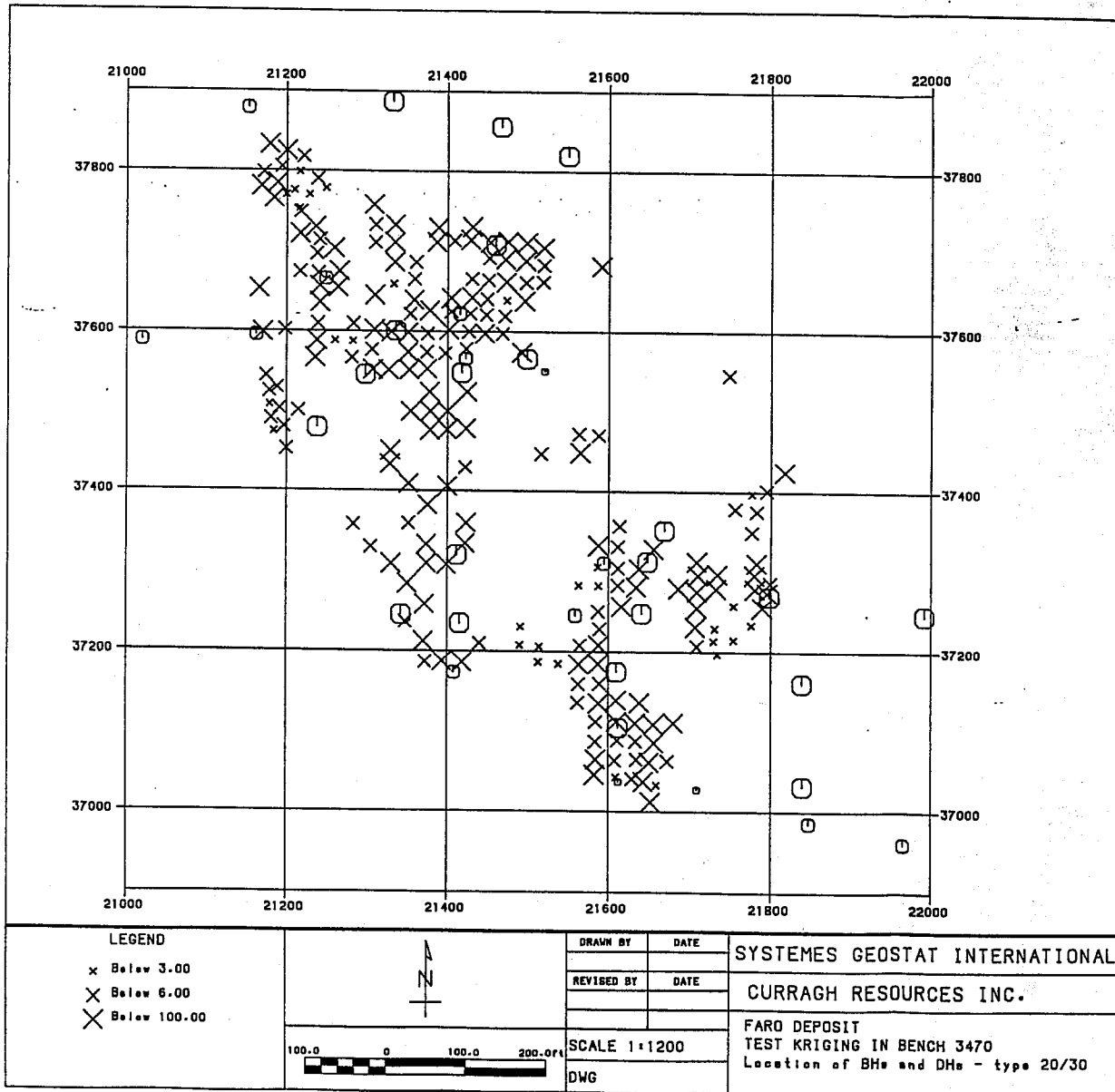
Table 14: Resources above cut-off from D.H. kriged block estimates and blast holes in those blocks. Type 50/70 (excluding 55) - 765 blocks.

Cut-off % Pb + Zn	Kriged D.H. values		B.H. values	
	% 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).

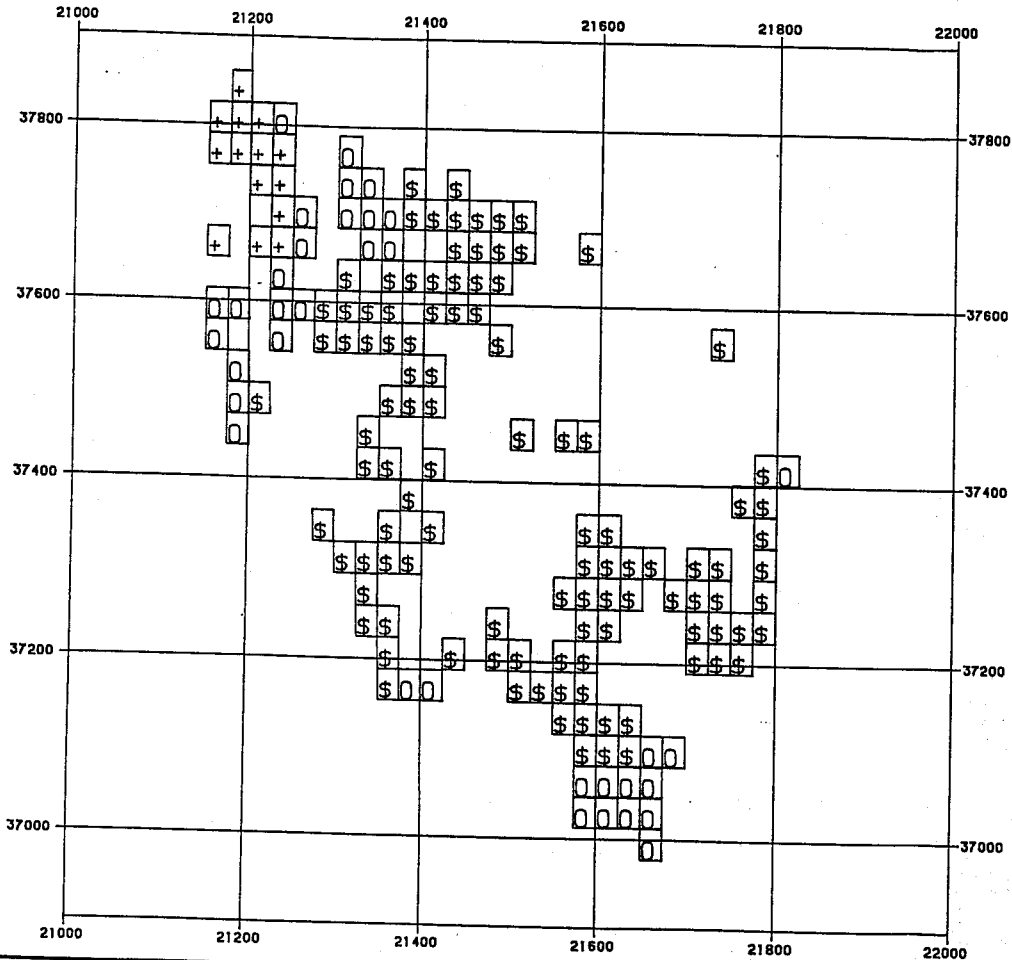
Cut-off % Pb + Zn	Type 20/30		Type 50/70	
	% above	% Pb + Zn above	% above	% Pb + Zn above
3%	95	6.44	100	8.90
4%	84	6.81	99	8.94
5%	67	7.38	96	9.06
6%	49	8.09	90	9.33



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



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



ZPb+Zn		LIST OF VARIABLES		BLOCK LEGEND 1	SLICE NUMBER: 11		DRAWN BY	DATE	SYSTEMES GEOSTAT INTERNATIONAL CURRAGH RESOURCES INC. FARO DEPOSIT TEST KRIGING IN BENCH 3470 ZPB+ZN - 20/30 MAP OF BLOCK ESTIMATES
MIN	MAX	NAME	TYPE		FROM: 3470.00	TO: 3490.00			
0.0	3.0	1. ZPb+Zn	CAT						
3.0	4.0							SCALE 1:1200	
4.0	5.0					DWG			
5.0	6.0								
6.0	100.								

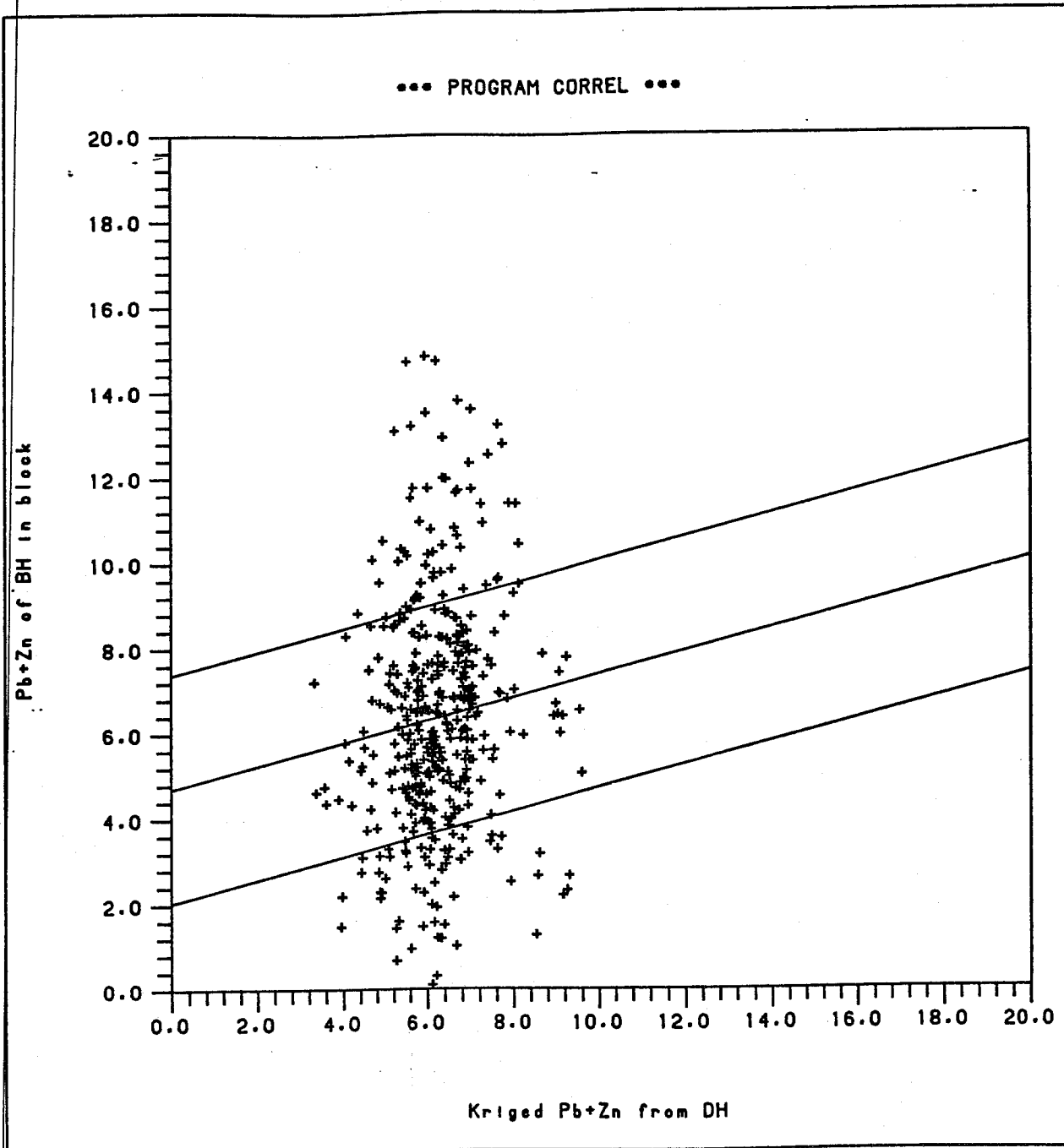
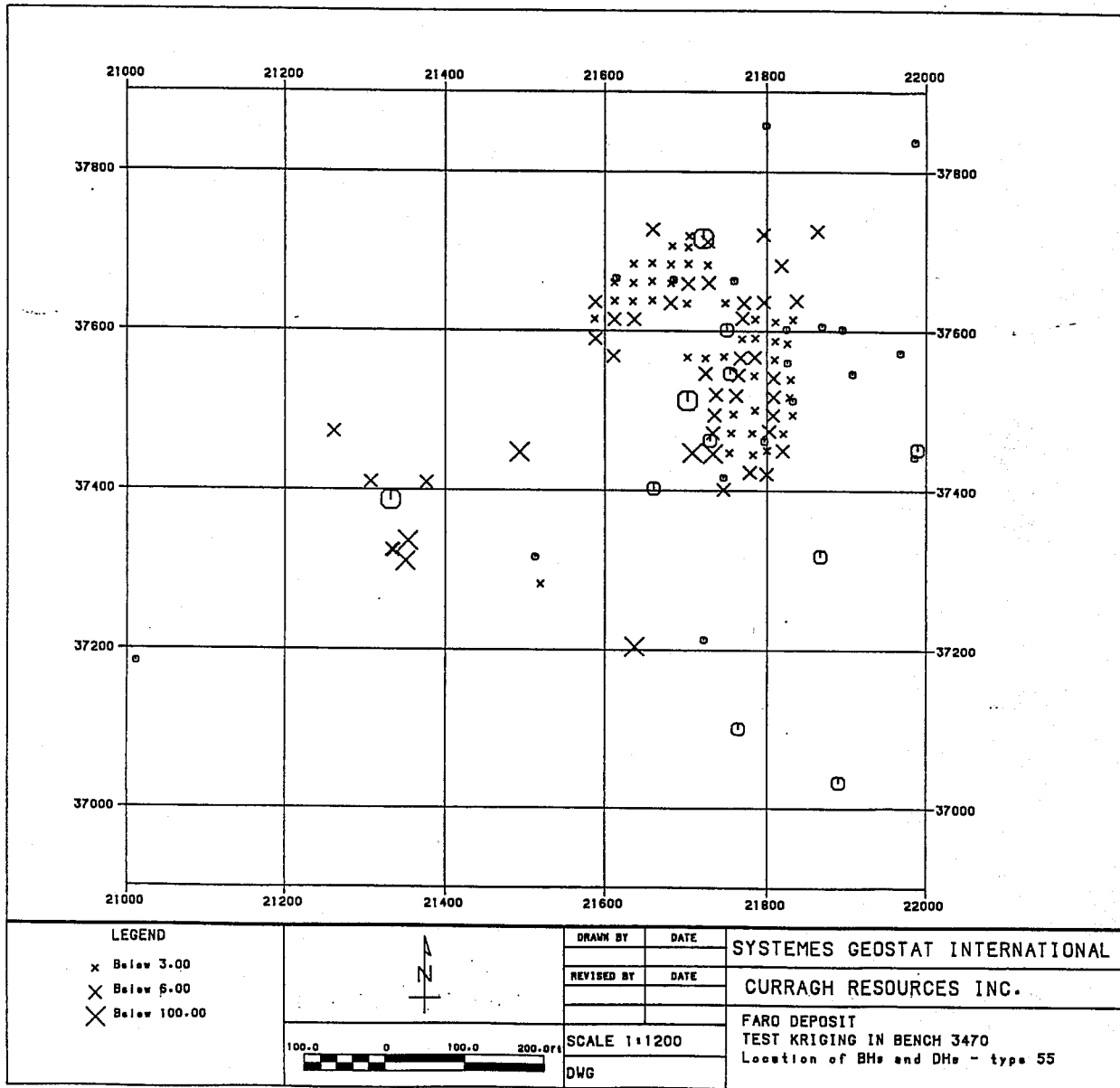


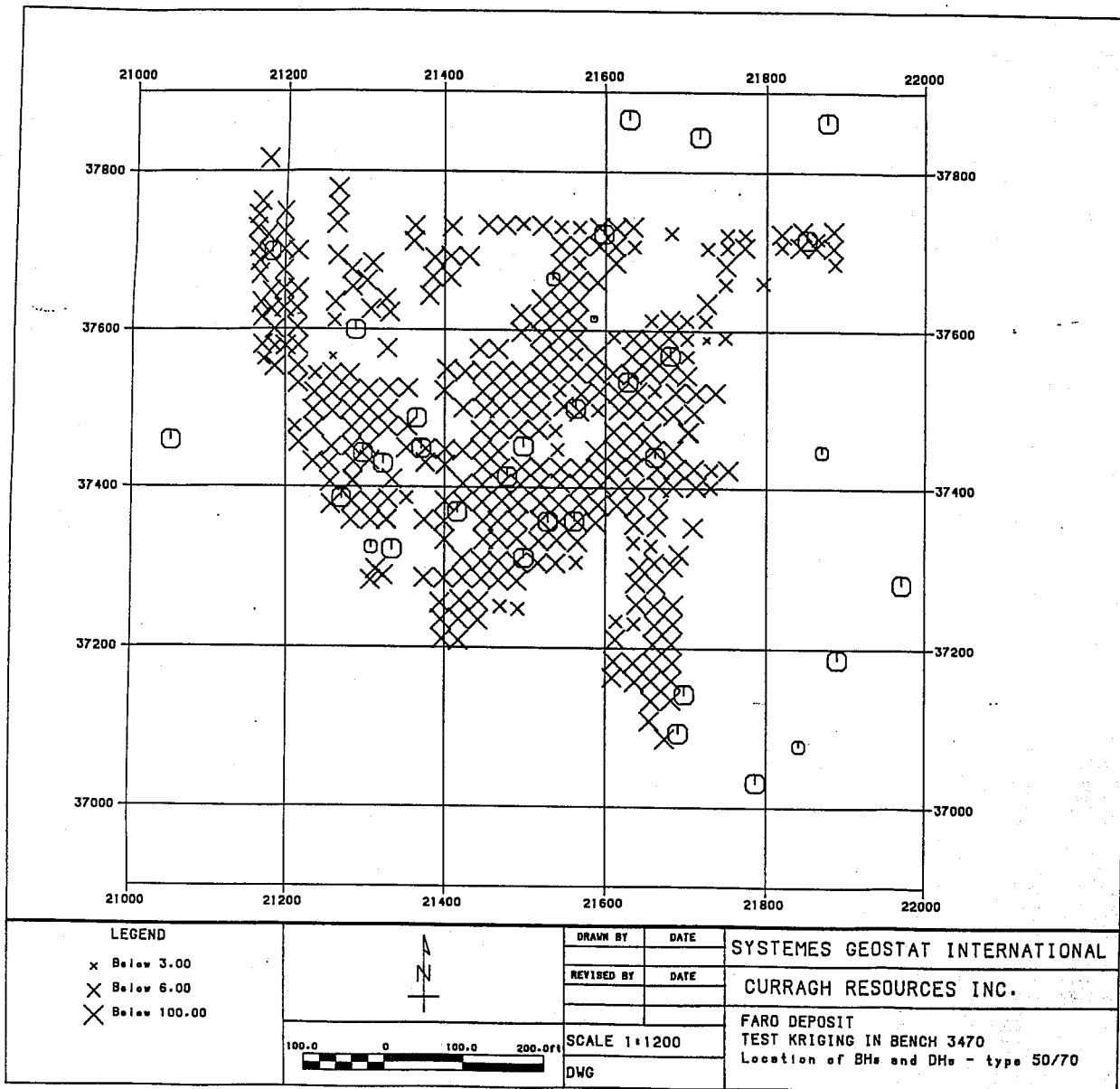
Figure 21: Correlation of kriged DH block and mean BH % Pb + Zn in 20/30.

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



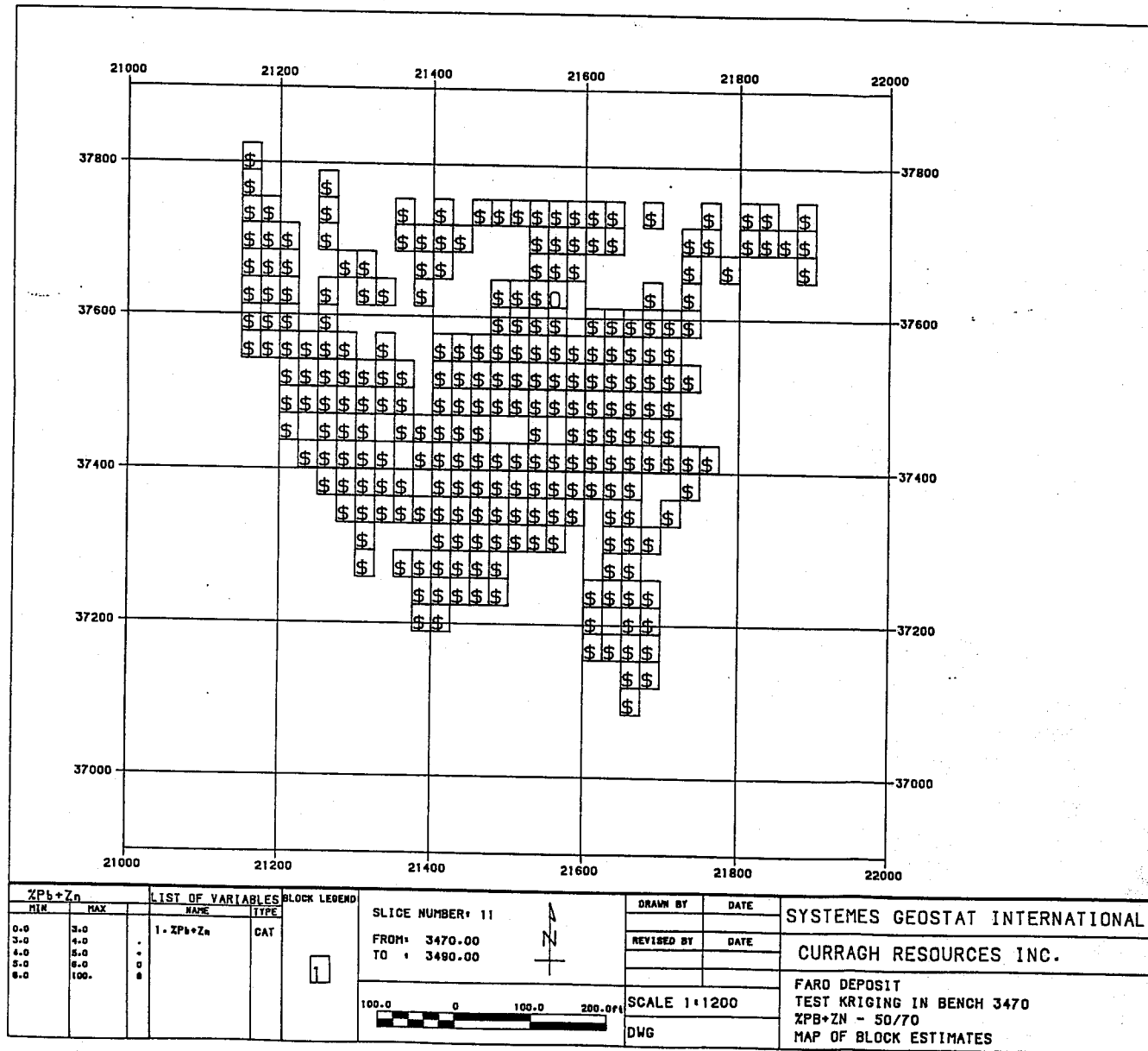
UNIT PLATES 5-81 DATE 9/29/1990 TIME 0517

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



WELL PLATES L&L DATE 8/22/1988 TIME 8:14

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



DATE: 8/25/1990 TIME: 8:10P

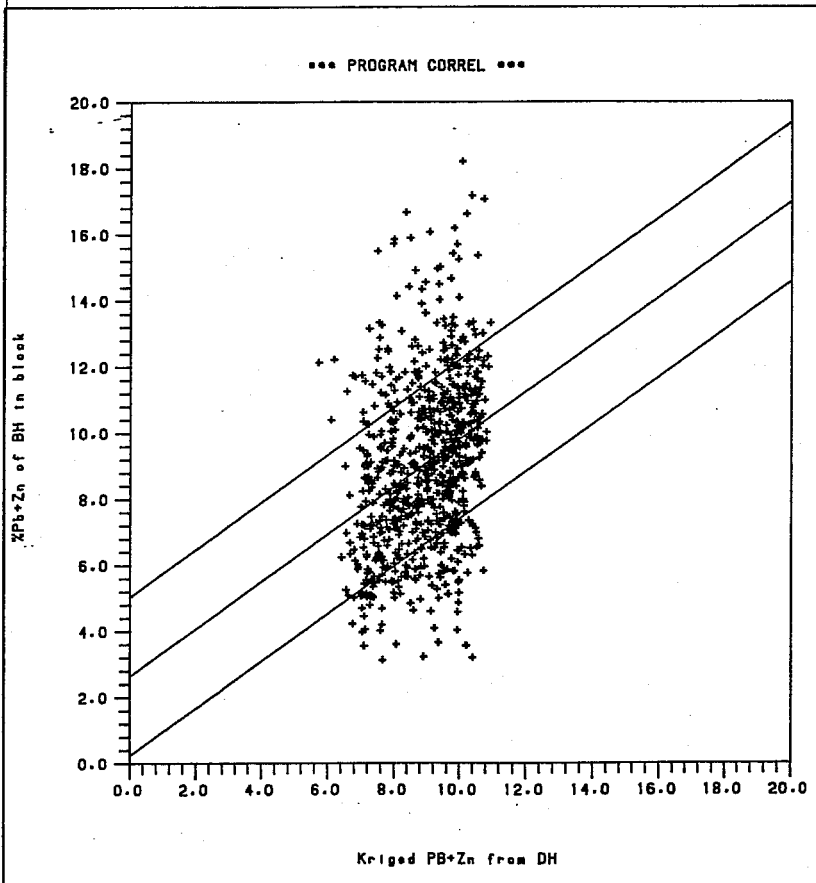


Figure 25: Correlation of kriged DH block and mean BH block % Pb + Zn in 50/70.



Bill Dunn

MESSAGE PAR TELECOPIEUR/FAX MESSAGE

A/TO: Télécopieur/Fax No.: _____
Nom/Name: Mr. Dave Tenney
Compagnie/Company: Curragh Resources Inc.

DE/FROM: Nom/Name: Geostat Systems International Inc.

DATE: September 20th, 1990 Nombre de pages/Number of pages: 7

Message/Subject: Continuation of Geostat report on Faro received from Mr. Michel Dagbert in Abidjan. Figures and additional text still to come.

Regards.

Lise Mayville, sec.

En cas de difficulté/If any problems: (514) 521-7544

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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 10. 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 a). 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 b. 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 a. 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 same 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 b and c.

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 c). It is not so good if we just use the nearest neighbor method ($r = 0.56$ - Figure d) even if the dispersion of estimates perfectly matches that of the original data (see table c). 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 $y = 0.56x + 3.2$. 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 e), 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.

Table a: Model 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 (%)
AI (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 b: 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 c: 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	$y = 1.015 x - 0.11$