000477

CURRAGH RESOURCES INC

INTER-OFFICE MEMORANDUM

FARO OFFICE

DATE: November 27, 1990

TO: WM. W. DUNN
CHIEF ENGINEER

FROM: DAVE TENNEY
CHIEF GEOLOGIST

SUBJECT: GEOSTATISTICAL PREDICTION OF MILL HEADS FROM BLASTHOLE GRADES

Attached is a copy of my memo dated October 10th, 1990, with the suggestion that we (temporarily) use a regression formula to convert mill head grade calculated from blasthole data to actual mill head grade. Also attached is Dr. Dagbert's reply to this memo.

You will see that he calculates two regression lines, for blastholes grading above 4% combined PB+Zn, one for lead, and one zinc. He also notes that these two metals exhibit different statistical behaviours. However, there appears to be a systematic overvaluation of lead only. Accordingly, as an interim measure we should use the following regression formula (for lead only! Dagbert Page 3) when making short term predictions of head grade from blasthole grades: $Y = 0.538x + 1.32$

Y = mill head % Pb X = blasthole calculated % Pb

The cut off limits for ore blocks should be determined as they are currently.

The far better solution, Kriging of blasthole grades, (Dagbert Page 5), will be possible when the new "Ore Control" system from Gemcom is put into operation early next year.

D. Tenney.

Dave Tenney
Chief Geologist

DT:cc

cc: E. Beaumont	J. Hendry	G.Jilson	D. Basso
L. Pigage	C. Reed	G. Wilson	J. Vandenbroeck
G. Vos	B. Pisony	M. Wasel	P. Ledwidge

D.T.

C U R R A G H   R E S O U R C E S   I N C

INTEROFFICE MEMORANDUM

FARO OFFICE

Date: October 10, 1990

TO: WM. W. DUNN
CHIEF ENGINEER

FROM: DAVE TENNEY
CHIEF GEOLOGIST

SUBJECT: **STATISTICAL ANALYSIS OF MILL HEAD GRADES AND BLASTHOLE PREDICTED CRUSHER FEED GRADE**

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Introduction:

Published Mill Head Grades for the period April 10 to July 6/90 were compared with blasthole grades for a similar period with a with a view to establishing a linear regression relationship between the two. However, the published blasthole estimate of the mill head grade is for feed to the primary crusher, and there will be a lag time before that grade gets to the end of grinding circuit where the head grade is measured by the mill (the lead rougher feed). This lag time must be established before any meaningful linear regression relationship can be established.

Method:

Six tables of data were set up each containing only two variables: the published lead rougher feed as a % Pb + Zn, and the blasthole estimated primary crusher feed also as a % Pb + Zn. The data for the mill head feed, from April 10 to July 6 inclusive, (88 values), were identical in all six tables. In Table I (zero lag time) blasthole predicted grade for April 10 was shown on the same record line as mill head grade for April 10, and so on until July 6 where again blast grade and mill grade were both those published for that same day. However, in Table #2 (not appended) blasthole grade for April 9 was shown in the same record line as mill heads from April 10 thus allowing for a one day lag time, and so on until July 6, where blast grade for July 5 is on the same record line as mill head for July 6.

In Table # 5, which allows for (a rather unreasonable) four days lag time, blasthole predicted head grade for April 6 appears on the same record line as mill head grade for April 10 at the top of the table. At the bottom of the table blasthole grade for July 6 appears on the same record line as mill head grade for July 10. The other 86 records in the table show blasthole grades displaced by four days in the same way. Similarly tables # 2,3, and 4 show lag times of 1, 2 and 3 days.

Table # 6 shows the logically ridiculous situation where feed to the primary crusher arrives at the first lead rougher cell the day before, for a lag time of minus one day. This is included so that the statistics for more reasonable situations can be compared with a situation which is patently impossible.

Linear regression analysis was run for all six tables to represent lag times from -1 to 4 days, in the hope that the correlation co-efficient for one of the days (a one day lag time seemed the obvious choice) would be significantly higher than the rest.

Results:

The attached table shows that in fact higher correlations were noted for both zero and one day lag times, no matter whether the regression line was forced through the origin or not. This suggests an actual lag time of about 1/2 day. This is in conformity with other observations which include the size and average content of the fine ore bins. The linear regression line which represents this situation the best would be the average of lag time zero and one day.

ie: y (mill head) = x (blasthole grade) * 0.476 + 4.163 (zero lag)
y = x * 0.428 + 4.575 (1 day lag)

y = x *0.451 + 4.369 (approx. 1/2 day lag)

This suggests that blasthole calculations overestimate grade if they are above 7.95% Pb + Zn. This is in fair agreement with Dagbert's correction of blasthole grade (P.45)

$$y = 0.56x + 3.2$$

based upon a geostatistical line of reasoning. The observed and the theoretical in this case seem to lend each other support.

We must consider whether these regression lines may be used to correct blasthole data to predict mill heads on a routine basis. This approach should be checked with Michel Dagbert before it is implemented, as he will almost certainly have some comments on its statistical validity.

D. Tenney.

Dave Tenney
Chief Geologist

DT:cc
cc: Gregg Jilson, Lee Pigage, M. Dagbert, C. Reed, M. Wasel, D. Basso, B. Sanden, B. Pisony, J. Vandenbroeck

LINEAR REGRESSION - MILL HEAD GRADE -vs- BLASTHOLE PREDICTED CRUSHER FEED GRADE
WITH LAG TIMES OF -1 TO +4 DAYS
D. TENNEY - OCT. 2/90

	REGRESSION NOT FORCED THRU ORIGIN				REGRESSION FORCED THRU ORIGIN			
LAG TIME	CONSTANT	X-COEFF	CORR	MEAN HEADS	MEAN BLAST	CONSTANT	X-COEFF	CORR
- 1	6.12	.236	.234	8.046	8.164	0	.9804	.9946
0	4.163	.476	.464	8.046	8.156	0	.9831	.9963
1	4.575	.426	.413	8.046	8.140	0	.9847	.9959
2	5.594	.301	.292	8.046	8.136	0	.9845	.9952
3	4.891	.265	.255	8.046	8.142	0	.9835	.9949
4	7.442	.0743	.071	8.046	8.138	0	.9828	.9937

SYSTÈMES GEOSTAT INTERNATIONAL INC.

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FACSIMILE TRANSMISSION

TRANSMISSION DE FAX

To: Curragh Resources Inc, Faro Operation (Attention): MR. DAVE TENNEY

From: G.S.I.I, Mr. Michel Dagbert Date: NOV. 22ND, 1990

No. of pages (including this one): 8

* IF YOU DO NOT RECEIVE ALL THE PAGES, PLEASE TELEPHONE IMMEDIATELY.

Subject / Message: As per attached

GEOSTAT

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 (% Pb + Zn)	Corrected BH average (% 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 average 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	Expected grade of block around
(% Pb + Zn)	(% 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.

Comparison of blast hole estimates at a cut-off.

In fact, if we repeat our comparison of nearest neighbor BH estimate and real BH % Pb + Zn grade but now only for estimates above 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 (wo) 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.

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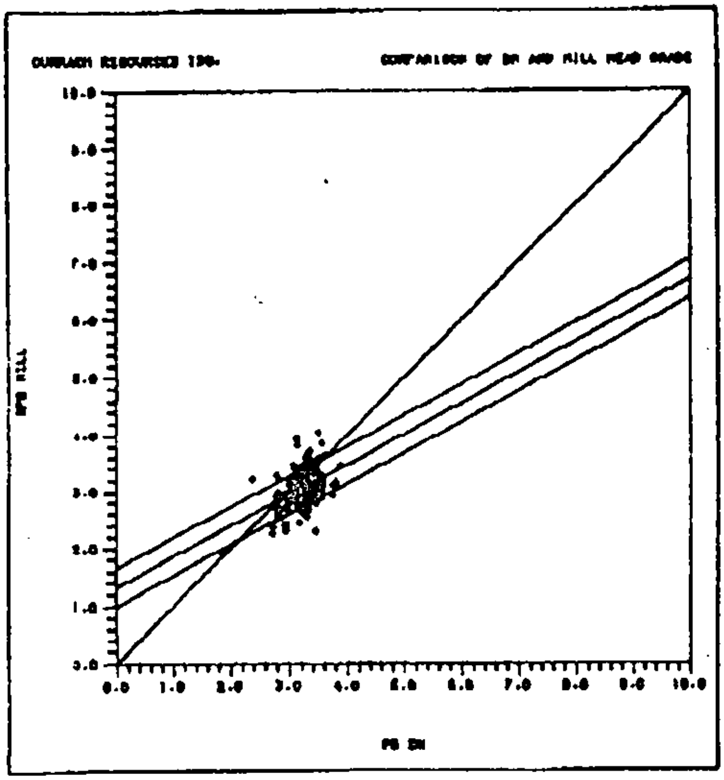
At any rate we think that a true blast hole kriging is preferable to an overall correction of individual blast hole values based on a regression of mill head grades on BH predicted grades before a cut-off is applied to those individual blast hole values. The overall correction does not take into account 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



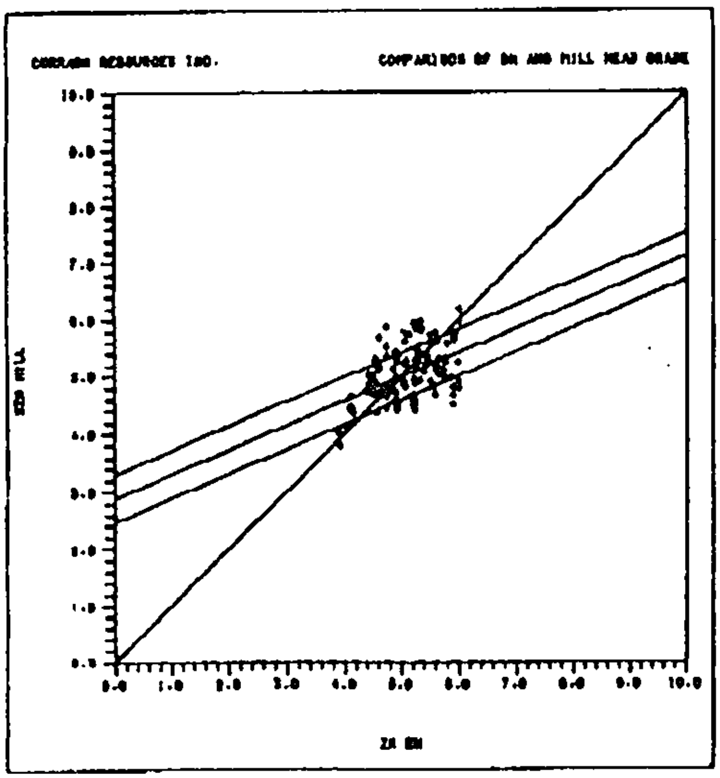
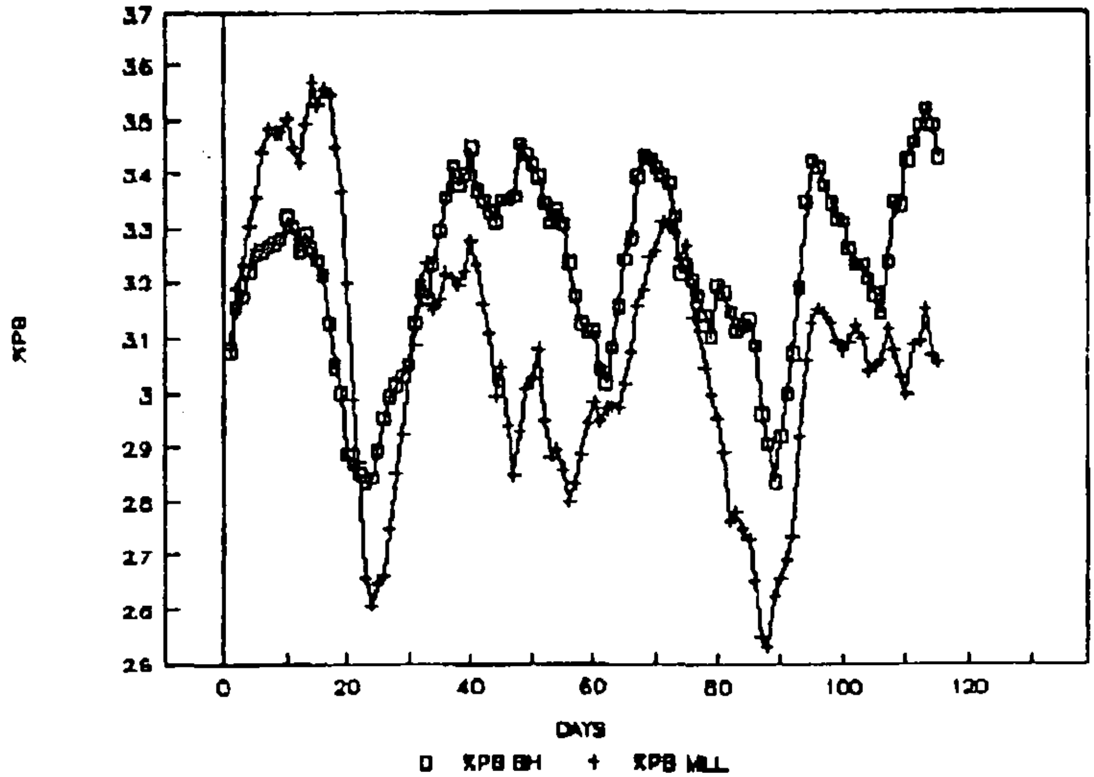


Figure: 2

7 DAYS MOVING AVERAGES FOR %PB



7 DAYS MOVING AVERAGES FOR %ZN