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A STATISTICAL METHOD TO EVALUATE POTENTIALLY SIMILAR ZONES OF GROUNDWATER DISCHARGE AT THE BUNKER HILL MINE NEAR KELLOGG, IDAHO

by
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ABSTRACT

The Bunker Hill Mine is a large underground lead-zinc mine located in north Idaho's Coeur d'Alene Mining District near the town of Kellogg, Idaho (Figure 1). The mine is faced with waste water treatment responsibilities that stem from the discharge of acid mine drainage. The delineation of waterproducing zones through underground field observations and statistical analysis provides insight into the flow of groundwater through the fractured rock mass. The statistical analysis of rock fracture data collected in this study suggests that: 1) observed fault structures impede horizontal groundwater flow, 2) the faults appear to act as nearly vertical drainage structures, 3) head levels measured in previous studies are compatible with relative discharge noted at different mapping sites in this study, and 4) the faults probably constitute boundaries of hydrostratigraphic units that may constitute representative elemental volumes.

INTRODUCTION

The area of this study includes all underground mapping sites that are accessible and amenable to conventional mapping procedures on Five Level of the Bunker Hill Mine (Figure 2). The Five Level ranges from 400 feet to 800 feet below ground surface. Mining in this portion of the mine is inactive. All of Five Level is located below the water table and it is in equilibrium with long-term recharge. The individual mapping sites were grouped into mapping zones. The proportions of water-bearing discontinuities in each zone are listed in Table 1. The term "proportion" means the number of waterproducing discontinuities in a mapping zone divided by the total number of discontinuities in that zone. Water discharge from each fracture was observed and assigned a value of 0 if completely dry and a value of 1 if actually discharging water. More refined measurements are not feasible in the drift walls for low discharge rates. Discontinuities that exhibited visible, relatively high rates of discharge were encountered only rarely.

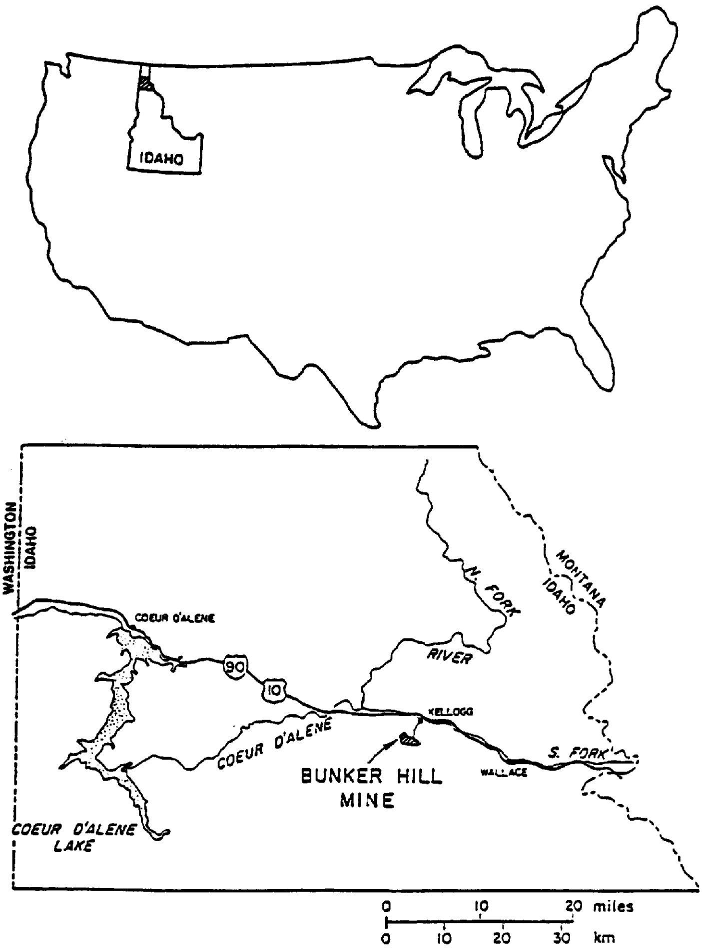

Figure 1. Bunker Hill Mine, Coeur d'Alene Mining District, Idaho, USA.

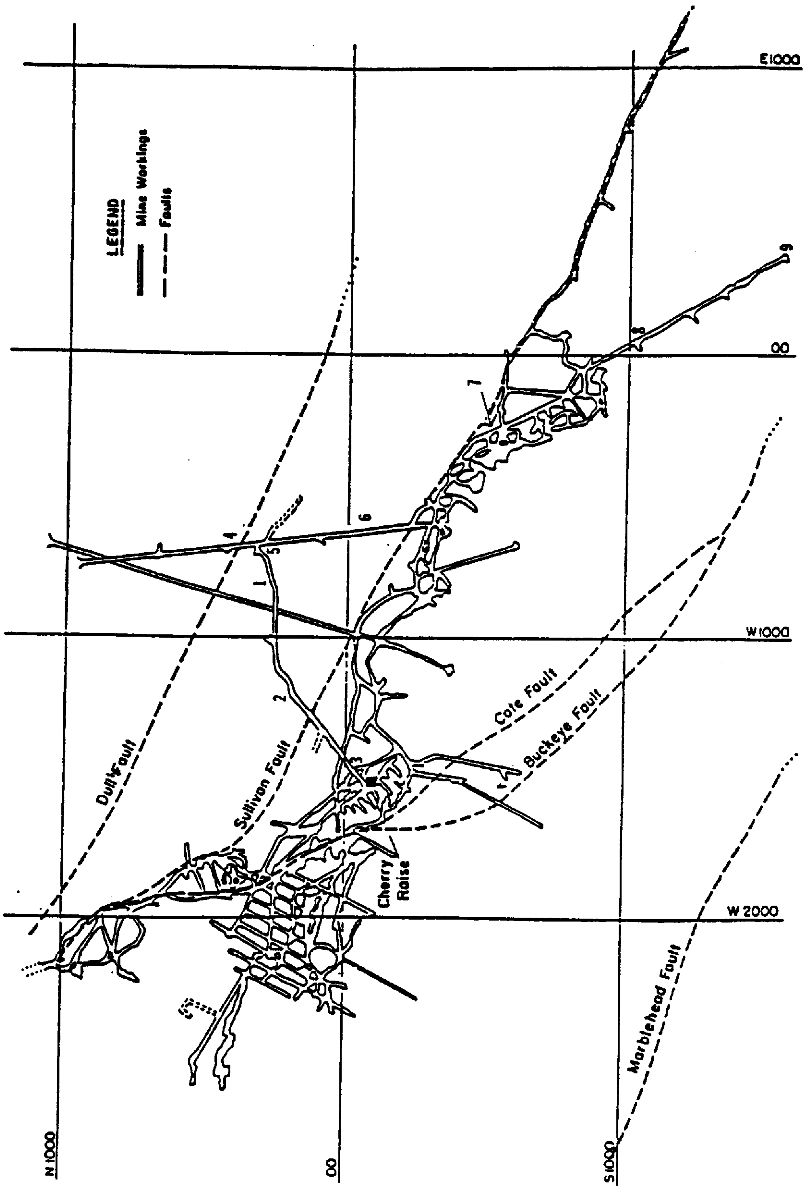

Figure 2. Five Level Map, Bunker Hill Mine.

The Bunker Hill Mine is located south of the Osburn Fault. Several other smaller faults lie subparallel to the Osburn Fault. These faults include the Dull, Sullivan and the Cate. Most of the ore was mined along the Cate Fault (Juras 1977). As shown in Figure 2 the Dull, Sullivan and Cate Faults are in the direct vicinity of this study area. These faults strike east-southeast and dip approximately 45° to 70° southwest. The Osburn Fault has been observed from Coeur d'Alene, Idaho, to Superior, Montana (Hobbs et al. 1965).

Table 1. Proportions of Visibly Wet Discontinuities

Mapping Zone	Number of Observations	Proportion of Wet Discontinuities
Zone 1	466	0.086
Zone 2	69	0.234
Zone 3	44	0.000
Zone 4	59	0.610
Zone 5	55	0.038
Zone 6	379	0.248
Zone 7	61	0.000
Zone 8	56	0.089
Zone 9	154	0.268

STATISTICAL PROCEDURE

An appropriate statistical test for the comparison of two binomial populations, such as the proportions presented in Table 1, can be used to determine whether statistically significant differences in water discharge from fractures exist among mapping zones. The underlying assumption of this test is that independent random samples are drawn from two binomial populations with unknown parameters (Ott 1984). Ostel and Malone (1988) noted that if large samples are tested (say, 30 or more observations) then a binomial distribution approximates a normal distribution, which provides the basis for the hypothesis testing. The samples in this study contained 44 to 466 observations per mapping zone.

The null hypothesis (H_0) is that the proportions of wet discontinuities in two mapping zones are equal. The alternative Hypothesis (H_a) is that the proportions are not equal. Rejection criterion of the null hypothesis is dependent on the calculated value of the standard normal variate, or Z value. If the calculated Z value exceeds the tabled value of $Z_{\alpha/2}$ then H_0 is rejected and H_a is accepted. The standard normal variate is calculated by the following (Ott 1984):

$$Z = \frac{(\frac{X_1}{n_1}) - (\frac{X_2}{n_2})}{(P(1-P)(\frac{1}{n_1} + \frac{1}{n_2}))^{\frac{1}{2}}} \qquad (1.1)$$

Where:

$$P = \frac{X_1 + X_2}{n_1 + n_2}$$

X_j = number of water-bearing discontinuities in the i-th population,
n_i = number of observations in the i-th population.

Results of hypothesis testing for the differences in proportions of waterbearing discontinuities among zones are presented in Table 2.

Table 2. Differences in proportions of water-bearing discontinuities between zones. (Zones 3 and 7 were excluded from the hypothesis testing because they contained no wet fractures.)

Zones	Calculated z value	Calculated α value	Conclusion
1 vs. 2	-03.654	0.0003	Reject H_o
1 vs. 4	-10.784	0.0000	Reject H_o
1 vs. 5	+01.217	0.2237	Fail to Reject H_o
1 vs. 6	-06.059	0.0000	Reject H_o
1 vs. 8	-00.087	0.9307	Fail to Reject H_o
1 vs. 9	-04.226	0.00002	Reject H_o
2 vs. 4	-04.226	0.00002	Reject H_o
2 vs. 5	+03.377	0.00007	Reject H_o
2 vs. 6	+00.648	0.517	Fail to Reject H_o
2 vs. 8	+02.128	0.0333	Reject H_o
2 vs. 9	+00.373	0.709	Fail to Reject H_o
4 vs. 5	+06.643	0.0000	Reject H_o
4 vs. 6	+06.671	0.0000	Reject H_o
4 vs. 9	+02.499	0.0125	Reject H_o
5 vs. 6	-03.212	0.0013	Reject H_o
8 vs. 4	-05.829	0.0000	Reject H_o
8 vs. 5	+01.611	0.1072	Fail to Reject H_o
8 vs. 6	-01.965	0.0494	Fail to Reject H_o
8 vs. 9	-02.046	0.0407	Reject H_o
9 vs. 5	+03.283	0.0010	Reject H_o
9 vs. 6	+00.327	0.7430	Fail to Reject H_o

The term α, which dictates the significance level of the hypothesis test, is the probability that the null hypothesis will be rejected when it is actually true (Brownlee 1960). The smaller the value of this probability the heavier the weight of the sample evidence for rejecting H_0 (Ott 1984). Alternatively, rather than selecting a particular level of significance for comparing mapping zones, α values can be calculated using a calculated Z value. In this context, α is not the level of significance but rather a measure of the rarity of the calculated Z value (Miller 1983). The calculation procedure for determining α values is presented in Miller (1983). Both perspectives for the role of α were considered in this analysis. The pre-chosen value of α for a rejection criterion was 0.05.

RESULTS

The results of the hypothesis testing indicate a trend in the discharge characteristics of the rock mass on Five Level. This trend seems to be dependent on the positions of mapping sites relative to the large fault structures mentioned previously. Greater proportions of dry discontinuities are present immediately south of these major faults. The proportions of wet discontinuities increases in the southwest direction as the distance from the faults increases until another fault structure is encountered. The pattern then appears to be repeated as the south-westerly distance from the next successive fault increases. This interpretation coincides with field observations made in the mine workings.

It is not apparent that the orientation of a drift has a significant effect on the proportions of wet or dry discontinuities. For example, Zones 3 and 7 are nearly parallel and exhibit a perfect correlation. Zones 3 and 5, on the other hand, are nearly perpendicular but also exhibit a very high degree of correlation. This apparent lack of an orientational control seems to prevail over the entire study area.

CONCLUSIONS

It appears from this analysis that the major fault structures exhibit significant control on the groundwater flow regime in this area. Discontinuities seem to exhibit varying levels of discharge in the pattern described above. This pattern may indicate that the faults act as barriers to horizontal flow in the study area. Concomitantly they may constitute boundaries for hydrostratigraphic units or representative elemental volumes characterized by distinctive patterns of water discharge. The area under study is recharged by precipitation and stream flow in the Milo Creek Basin which overlies the Dull, Sullivan and Cate Faults (Figure 3). The faults may retard horizontal groundwater flow in the southwest to northeast direction at their boundaries.

The faults appear to be acting as diversion structures rather than barriers. In the vertical direction, it appears that they act as drains. This interpretation explains the large proportions of dry discontinuities immediately to the southwest (upgradient) of these structures. This direction is on the down-dip side of the fault structures but on the upgradient side of the flow system as supported by the findings of Erickson (1985). In his study, Erickson monitored shutin pressures of exploratory underground drill holes in the New East Reed drift. The potentiometric levels calculated are shown in Figure 4. It is apparent from Erickson's study that head levels increase in a southwesterly direction and as the distance from the Sullivan Fault increases. If Darcy's law is considered valid for the fractured rock mass and if the hydraulic conductivity of the rock mass is considered to be constant, then higher heads would result in higher discharge rates to the northeast. This is apparently the case on Five Level. Therefore, if the faults are acting as drains, head levels should be similar to those shown in Figure 4. All present evidence leads to this conclusion.

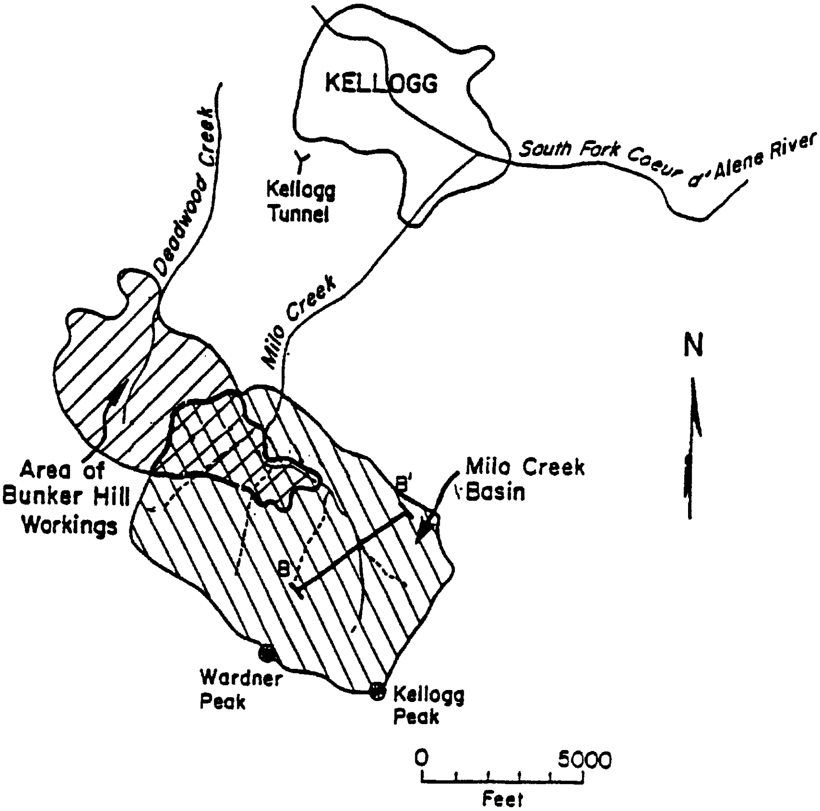

Figure 3. Milo Creek Basin, groundwater recharge area (Trexler, 1975).

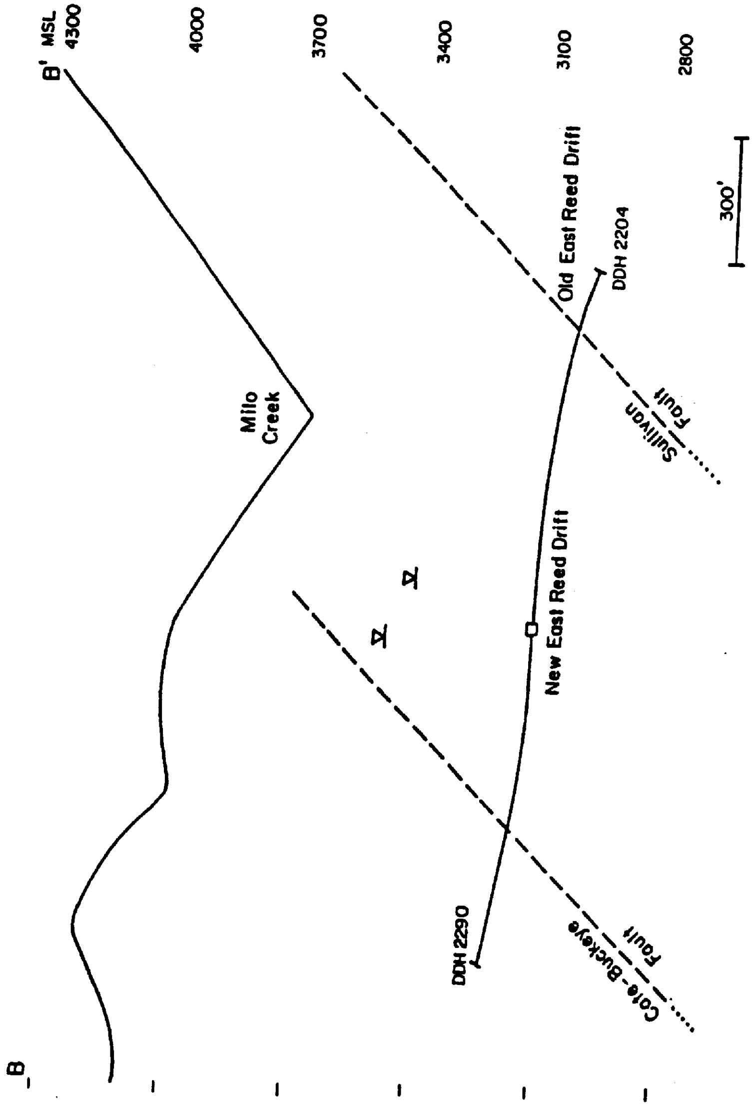

Figure 4. Hydraulic Head Levels Calculated Using Shut-in Diamond Drill Hole Pressures (Erickson, 1985)

The fault structures encountered during field observations, both major and minor, contain fault gouge filling. This filling is most likely of low enough hydraulic conductivity to support the supposition that the faults allow groundwater to flow primarily in a vertical direction only. Also, the pattern of wet and dry discontinuities discussed previously seems to indicate that a high hydraulic conductivity rock material may exist along the hanging wall side of the fault structures which could explain the water discharge patterns observed. This supposition is substantiated to a degree by field observations. If indeed these conclusions are valid, then remedial efforts toward acid-mine drainage abatement should be concerned with containing flow along those structural features that facilitate vertical drainage.

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