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CYPRUS ANVIL MINE GEOTECHNICAL EVALUATION  
JUNE, 1984 FIELD TRIP

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BERZINS, B.

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## 1.0 INTRODUCTION

A field examination of geotechnical and environmental concerns related to groundwater flow into the CAMC pits was undertaken from June 13 to 16, 1984.

Activities which were undertaken at this time included:

- (1) identification and documentation of seepage and surface flows in the vicinity of the Zone 3 pit;
- (2) examination of existing failures and slumps;
- (3) review of water within the blast-hole grid on the 3870 and 3910 benches;
- (4) groundwater sampling of surface and subsurface flow.

These activities were supplemented by discussions with nine staff where possible.

## 2.0 EXAMINATION OF GROUNDWATER FLOW

### 2.1 Seepage Into Zone 1 Pit

A traverse of the Zone 1 pit walls was completed, and an inventory of visible seepages prepared. Conservatively, the estimated surface and near surface flow into this pit totals 30 to 40 l/s (400-550 IGPM), and originates from the sources documented in Appendix A. These sources are listed below in Table 2.1.

TABLE 1 - Groundwater Flow into Zone 1 Pit

SOURCE	ESTIMATED FLOW		REFERENCE PHOTO NO.
	l/s	IGPM	
Seepage from SW corner of pit	5	66	P1
Seepage from W wall of pit	1.5	20	P1
Faro Creek Valley seepage	25	330	P1
Seepage from S-SE corner	1	13	

At the time of the site visit, water was being pumped from the Zone 1 pit and discharged in the vicinity of the old adit. Although difficult to estimate, the pumped discharge seemed to be approximately 40 to 50 l/sec, perhaps equal to the visible inflow into the pit itself. It is highly likely that the pit is experiencing considerable inflow below the pond water surface; however, without monitoring of pit water levels and pump rates, the magnitude of this flow would be difficult to assess.

## 2.2 Seepage at Zone 3 Working Face

The groundwater flow in this area appears to be associated with:

- (1) near-surface flow within the overburden originating within the catchment area upslope from the pit,
- (2) seepage within joint sets/faults which transect the Big Indian Fault, and
- (3) seepage from the Diversion ditch.

As the Big Indian Fault itself contains a significant amount of gouge, it represents an impermeable barrier to subsurface flow. Blast hole data on the degree of hole "wetness" also indicates that holes on the hanging wall side of the Big Indian are noticeably wetter than on the footwall side.

An estimate of total groundwater flow into this area is difficult, particularly in the absence of borehole data on water levels. Based upon calculations described in Appendix C, approximately  $1.5 \text{ M}^3/\text{sec}$  of flow was observed at points upstream and downstream of the Zone 3 face. The implication of this "flow in equals flow out" relationship can be stated in simple terms.

$$\begin{array}{rcl} \text{upstream flow} & = & \text{downstream flow} \\ + & & + \\ \text{inflow from catchment area} & & \text{leakage into face} \end{array}$$

High rates of flow upslope of the diversion ditch are evidenced in Photo 26. Seepage from the ditch is illustrated in Figure 1, and Photos 8 and the pan view opposite Photo 12.

Seepage within the overburden and bedrock outcrop are currently collected in ditches which have been established at several levels along the wall. Flows within these ditches were approximately  $5 \text{ l}/\text{sec}$  in total. Perhaps the most significant concern related to these collection ditches is that they encourage ponding along tension cracks associated with overburden slumping. The consequences of this ponding on slope stability will be illustrated in Section 3.2.

### 2.3 Seepage at 3910 Bench

At the time of the site visit, two blasthole grids were being developed on the 3910 bench. Water levels were taken and a short-duration pump test was performed. Water level measurements are presented in Appendix B, along with the pump test data.

The lack of definite trends in water levels and the variability of levels in adjacent holes is consistent with the observation that groundwater flow through the waste rock is structurally-dominated (by joints and faults or alteration along dykes). As illustrated in Figure B2, water levels within 3 to 9 metres of the slope were still relatively high, even though blasting had taken place at least 48 hours before. These levels would seem to indicate a low

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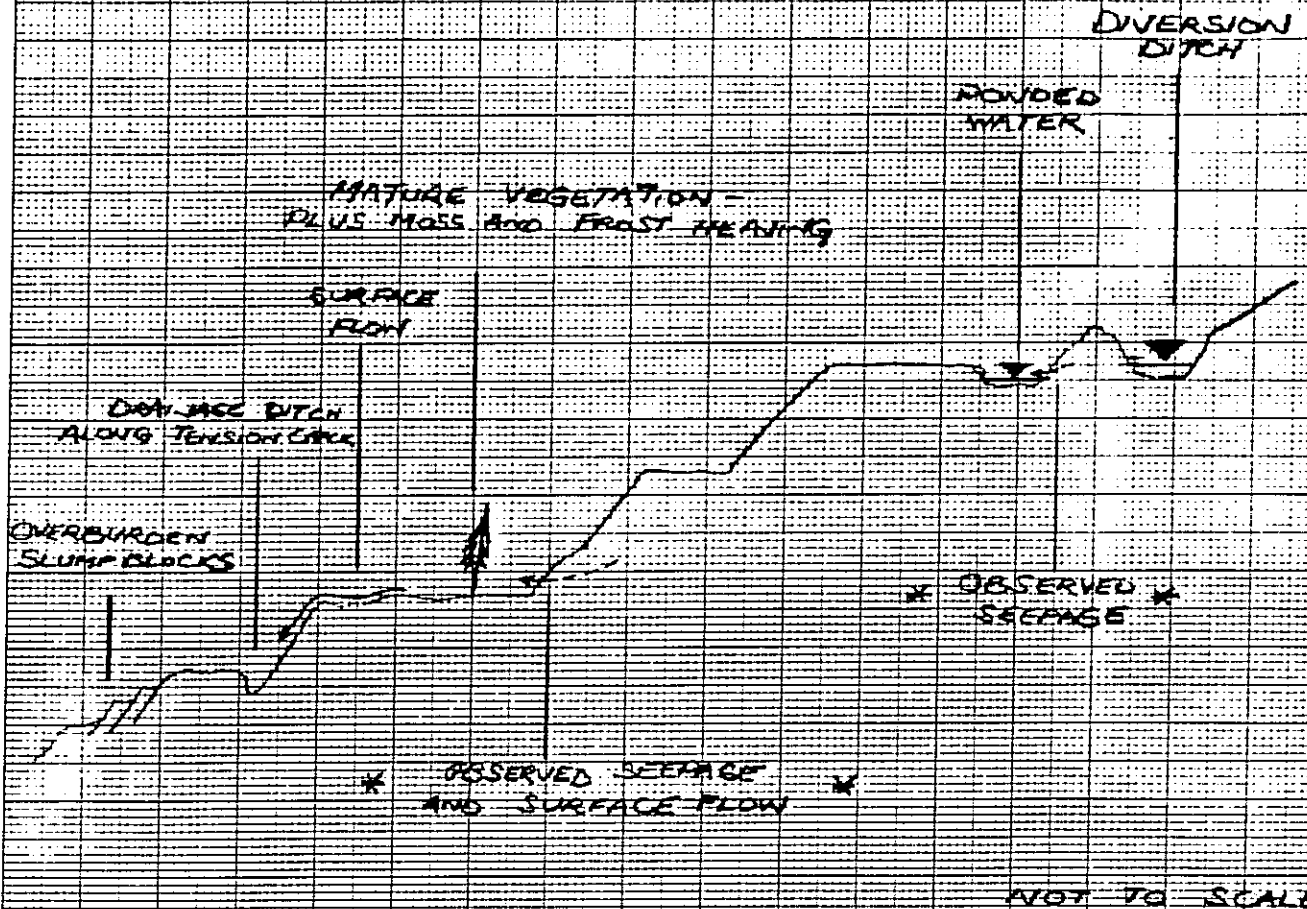


FIGURE 1 - CROSS SECTION VIEW ABOVE  
ZONE 2 AREA

transmissivity (Figure 2). This low transmissivity, however, may only be directional, in that the cut faces may be parallel to permeable joint sets. In addition, vertical boreholes may not necessarily intersect steeply-dipping structural features, thereby leading to uncertainty in the interpretation of response during pumping.

#### 2.4 Seepage at 3870 Bench

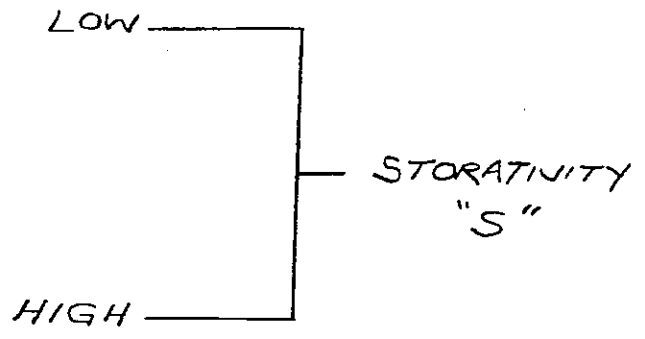
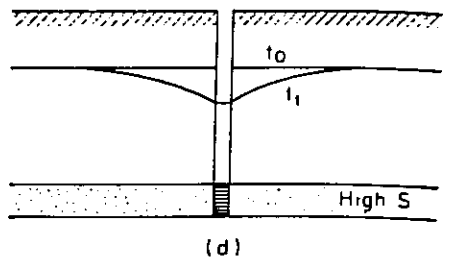
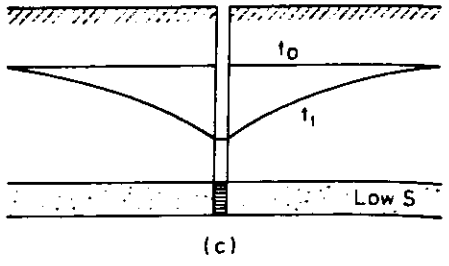
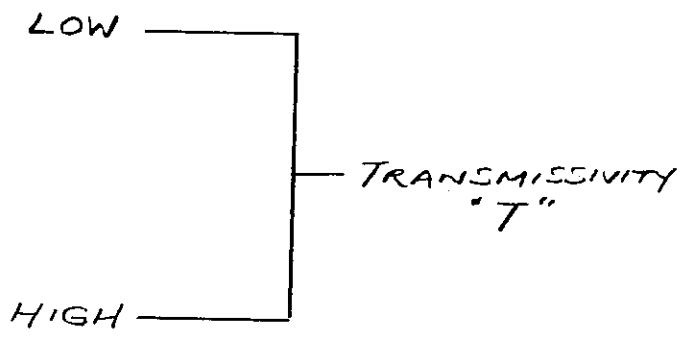
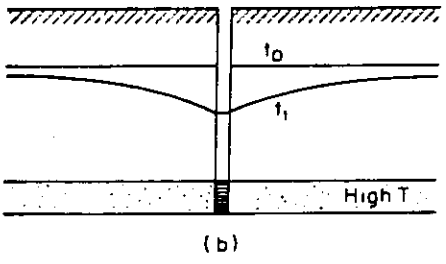
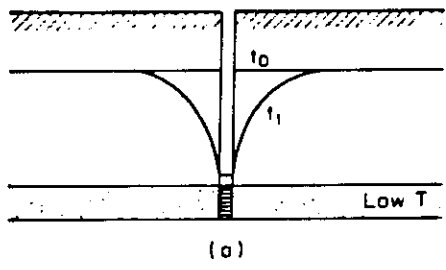
High water levels in blast holes on the 3870 bench (at the head of the ramp exit from Zone 1) appear to be the result of surface discharge of Zone 1 and 3 waters in the vicinity. The water is probably seeping back through the bedrock to cause problems in this area. Short duration pump tests were completed at two locations, one of which produced high steady state yields of several gallons (2-5 per minute) with limited transmissivity.

#### 2.5 Groundwater Quality

The primary objective of the sampling programme was to establish baseline levels of zinc contamination in waters entering and leaving the Anvil pit area. Samples were obtained at the locations illustrated in Figure 3. The results of analyses on selected samples are presented in Table 2.

The primary conclusions which can be drawn from the water quality sampling are:

- (1) surface and near-surface water flow associated with the Faro Valley contains Zn levels of less than .1 ppm (SBB 11 & 12);
- (2) groundwater percolating into the Zone 1 pit (through mineralized zones) exhibits high Zn levels of between 20 to 40 ppm;
- (3) groundwater from Faro Valley which flows beneath the waste piles at the head of the valley exhibits high Zn values (84 ppm), despite what should be a short residence time;

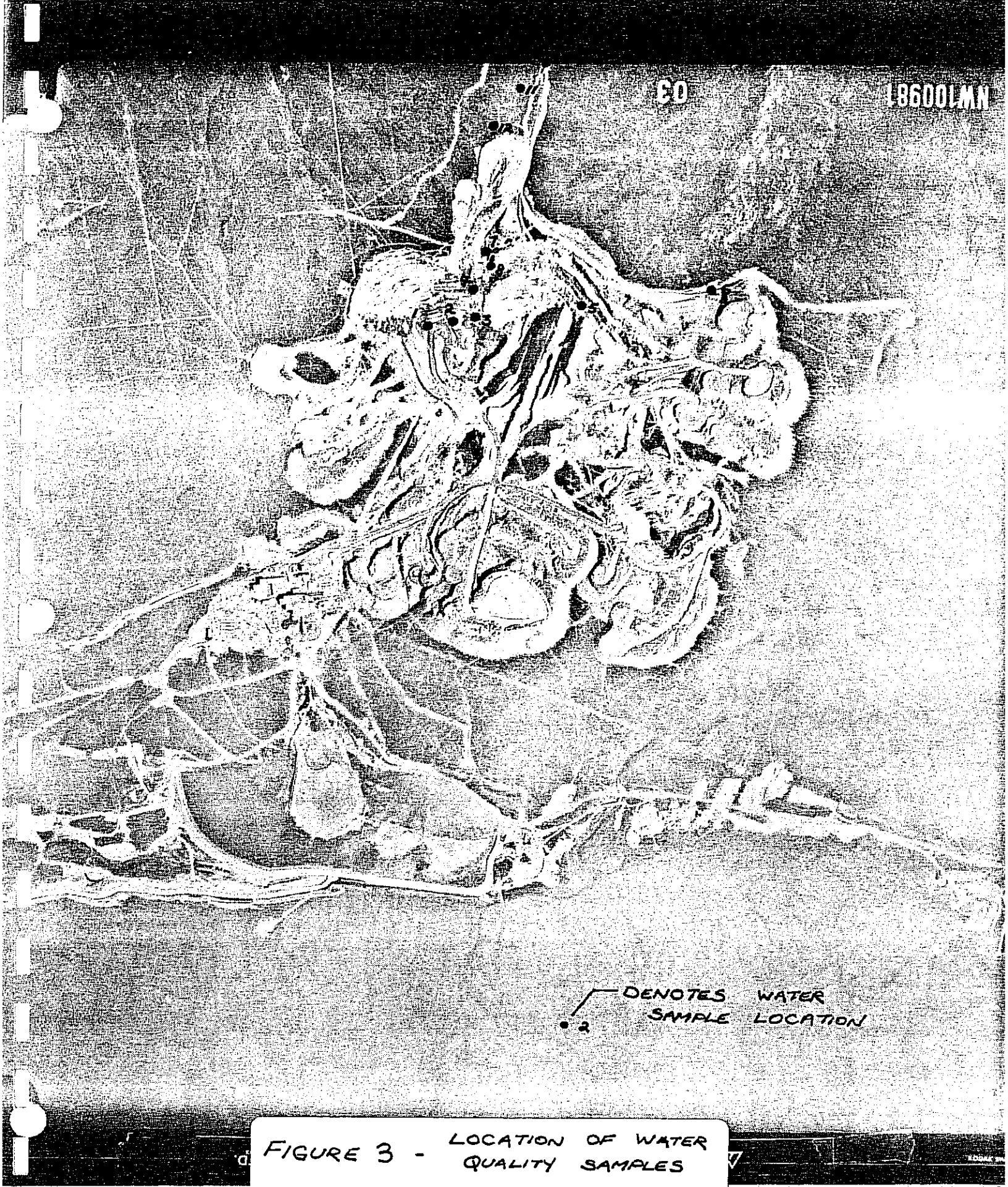


after Freeze and Cherry  
(1979)

FIGURE 2 - COMPARISON OF DRAWDOWN CONES FOR VARYING TRANSMISSIVITY AND STORATIVITY

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186001AN

An aerial photograph showing a coastal region with a complex network of roads and water bodies. A legend in the bottom right corner indicates that a specific symbol (a line with a dot) denotes water sample locations. The photograph is oriented vertically on the page.

• DENOTES WATER  
SAMPLE LOCATION

FIGURE 3 - LOCATION OF WATER  
QUALITY SAMPLES

Table 2 - Groundwater and Surface Water Quality

Sample No.	Pb	Zn	Fe	Cu	Mn	Mg	Ca	Na	pH	Colour	Turbidity	Sulphate	Conductivity	Alkalinity
SBB 1	.08	40.5	.21	.01	4.52	34.5	40	33	7.4	15	22	505.3	700	119.5
2	.08	29.8	.04	.01	4.12	32.3	47	7	7.6	0	2	593.8	740	83.0
3	.10	17.1	.11	.02	1.15	21.0	35	4	7.5	70	140	244.0	400	52.4
4	.08	44.0	.07	.03	2.83	27.0	38	27	7.0	0	4	443.6	600	100.8
5	.08	.05	.10	.01	0.43	51.6	38	25	8.1	5	3	224.3	590	223.3
6	.14	.06	.10	.01	0.41	2.1	1	1	6.6	30	7	11.5	30	9.9
7	.08	84.0	3.59	.79	5.51	32.0	33	5	5.2	70	75	609.0	660	4.9
8	.08	.11	.85	.01	.49	19.1	26	6	6.8	30	25	60.9	220	94.8
9	.07	.04	.01	.04	.41	11.5	22	2	7.1	0	5	68.3	150	54.3
10	.07	.05	.09	.02	.41	1.3	1	1	6.6	30	5	3.7	20	9.9
11	.08	.01	.14	.01	.41	1.1	1	1	5.6	60	6	4.1	20	5.9
12	.08	.07	.03	.01	.41	4.4	34	1	8.0	0	7	10.3	170	131.4

PPM

Mg/l      U Ohms      Mg/l

- (4) Zone 1 discharge exhibits high Zn levels (44 ppm) as a result of 2 and 3.

These findings are significant for a number of reasons. Firstly, all groundwater flow through mineralized zones exhibits high Zn levels; consequently, the quality of water which flows into the pit areas will be always affected by high Zn values. Secondly, it is very likely that high Zn values are to be expected in waters percolating through waste rock throughout the dumps located at the site. Finally, all surface water recovered from mineralized zones and working areas should be ultimately discharged within the tailings system, rather than allowed to flow directly into the natural streams in the area.

### 3.0 SLOPE STABILITY EVALUATIONS

Optimization of pit slopes in the overburden and bedrock require detailed analysis and stereonet characterizations of the most probable failure modes.

#### 3.1 Overburden Failures

Large failures in the overburden are evidenced above the Zone 3 working face (Photos 6, 12, 19, 22). Preliminary calculations (Appendix D) and mine site observations support the contention that failure is occurring at the overburden/bedrock contact, (R. Lopaschuk, pers comm).

To date, there is no evidence that the failure is deepseated, however, the presence of splay faults associated with the Big Indian Faults may be contributing to the development of a failure surface in an undetermined fashion. As shown in Appendix D, however, water within the tension crack at the headscarp of the slump block contributes to a significant reduction in the safety factor. Consequently, continued emphasis must be placed upon the control and reduction in surface water flows in the vicinity of the Zone 3 face.

### 3.2 Bedrock Instability

The pit slopes in the north and east blocks of the mine are characterized by numerous, small-scale wedge failures. A major driving force associated with these failures is again the presence of groundwater within the joint sets which define the wedge. It would be impractical to prevent the influx of surface water into shallow wedges which produce "cosmetic" failures. Emphasis should be placed on dewatering to eliminate large scale failures which may breach the pit slope benches, and to address possible concerns related to large scale block failures associated with the Big Indian Fault.

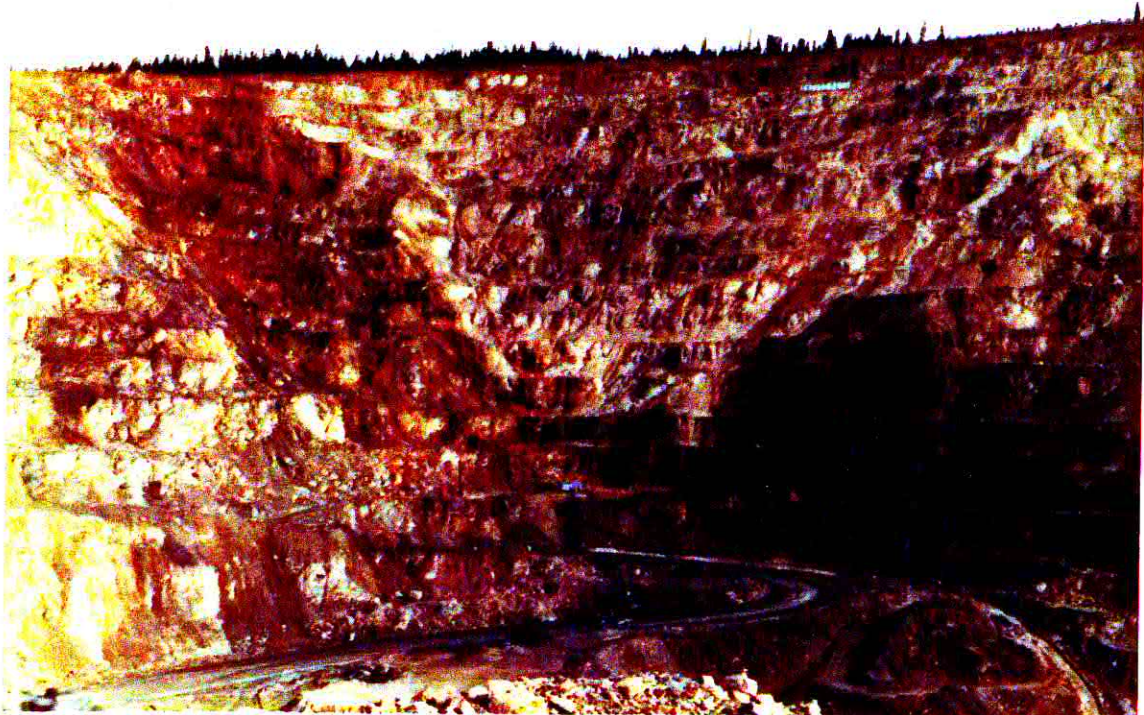
#### Recommendations

Further steps to optimize the data collected to date can be carried out quite economically. The following activities should be carried out immediately.

- (1) Redirect the discharge from Zone 1 and Zone 3 pit areas to a location where seepage into blast areas is eliminated.
- (2) Further grade the Zone 3 slope to eliminate ponding of water and flow into tension cracks.
- (3) Conduct studies into the correlation between historical blast-hole records and water problems.
- (4) Conduct aerial photography over the area to facilitate completion of up-to-date mapping of pit geometries and geotechnical features.

Activities necessary to complete item (3) have been initiated upon approval of R. Visagie.





**Photo 1**  
**Evidence of seepage into Zone 1 pit**



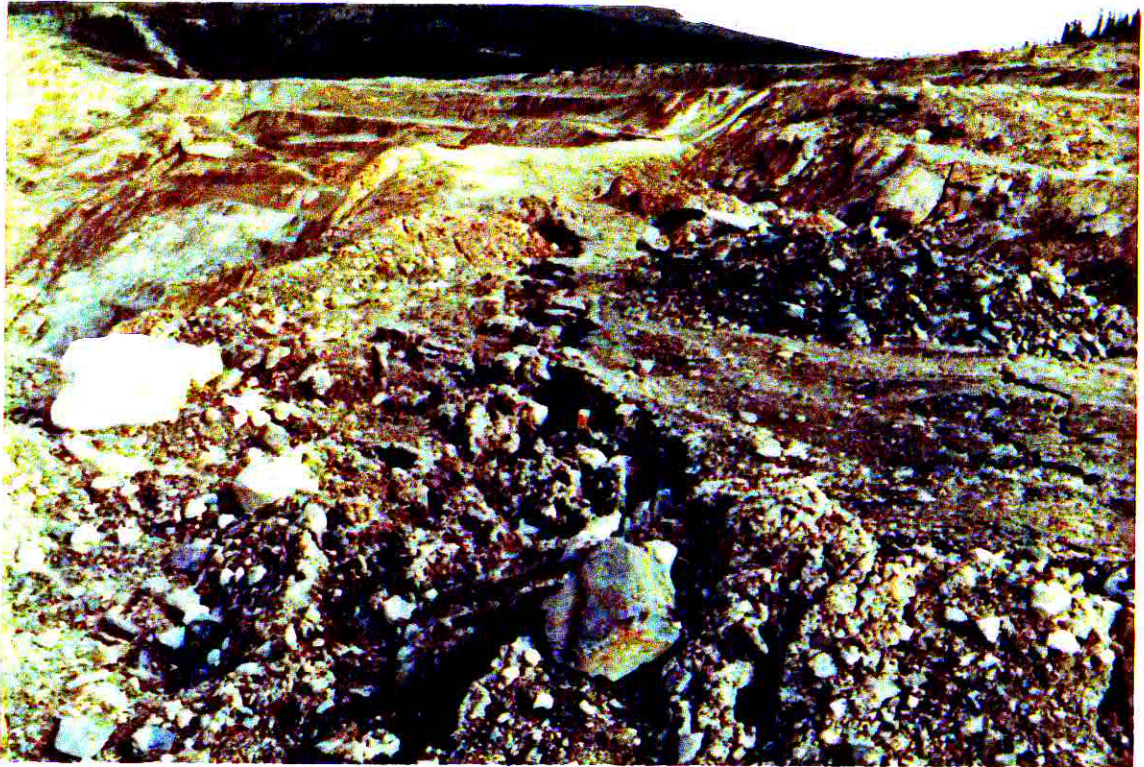
**Photo 3**  
**Lined ditches at edge of Zone 3 working area**



**Photo 4**  
**Surface flow on overburden into drainage ditches**



**Photo 5**  
**Ponding in vicinity of 3910 bench**



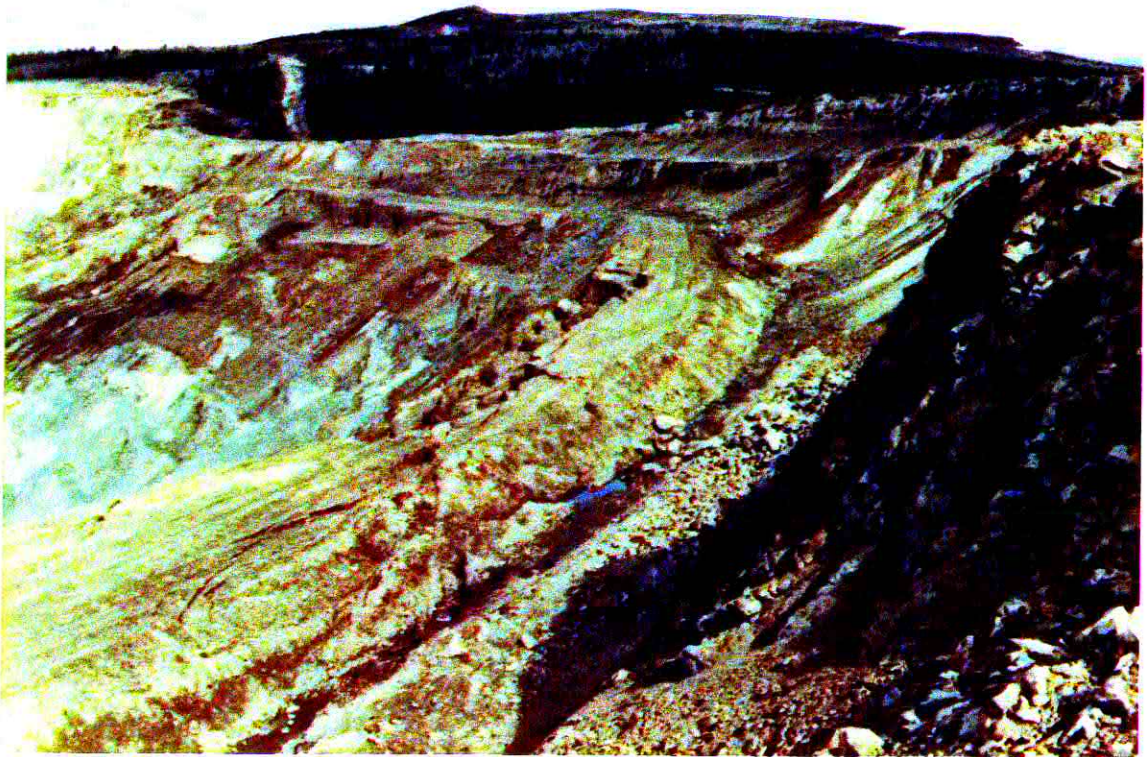
**Photo 6**  
**Slumping in overburden**



**Photo 8**  
**Evidence of seepage from diversion ditch**



**Pan view of section through diversion ditch**



**Photo 12**  
**Overburden slumps above Zone 3 pit area**  
**(away from the working face)**



**Photo 20**  
**Transecting joint system in bedrock outcrop**  
**above overburden slump**



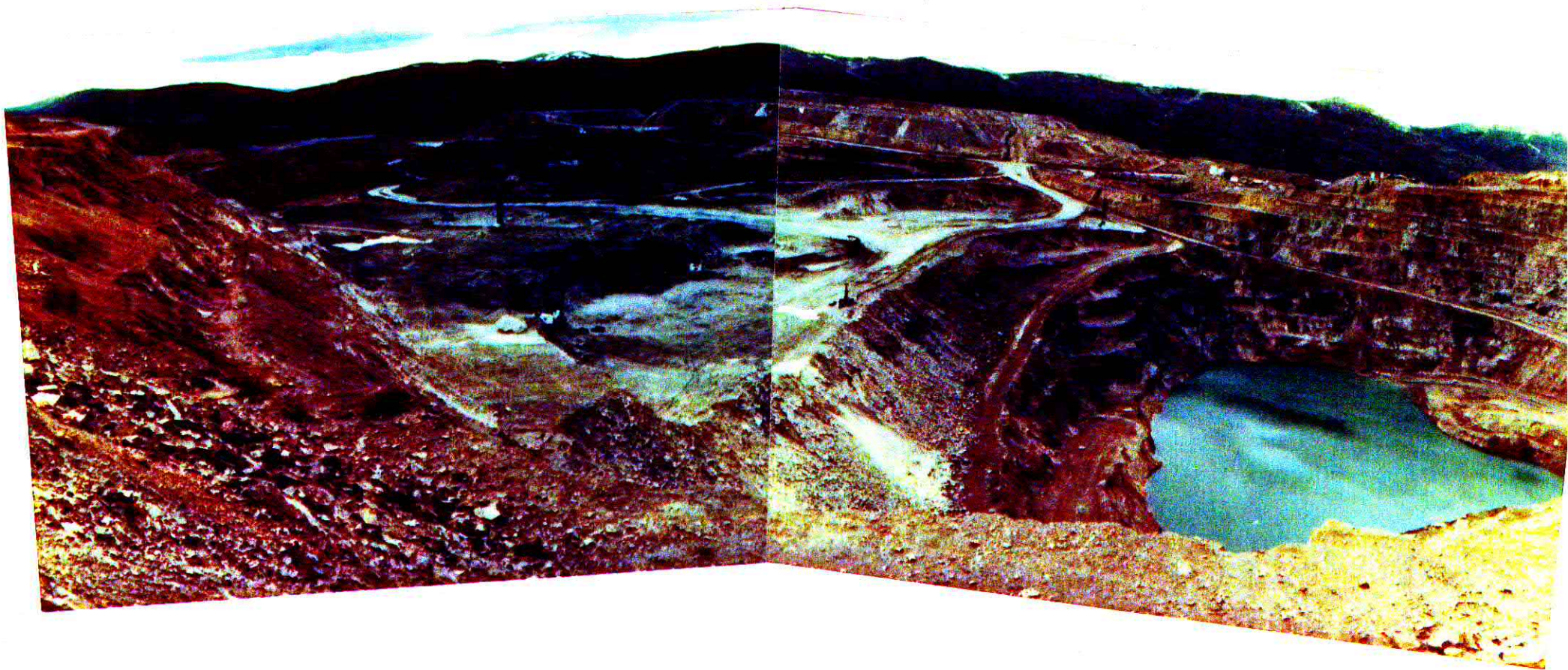
**Photo 21**  
**Transecting joints above overburden slump**



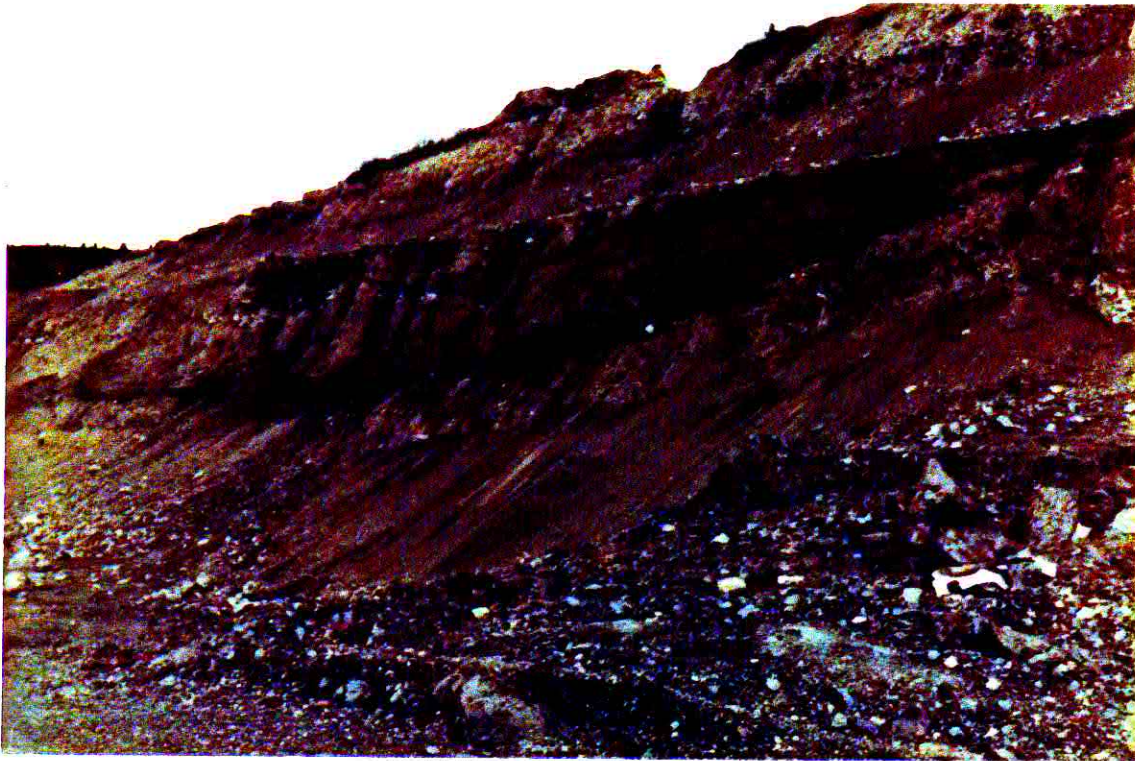
**Photo 22(a)**  
**Overburden slumping**



**Photo 22(b)**  
**Overburden slump blocks**



**Pan view of pit**



**Photo 25**  
**Erosion due to subsurface flow in overburden**



**Photo 26**  
**Evidence of subsurface flow in  
catchment area above Zone 3 pit**



**Photo 27**  
**Jointed bedrock daylighting in Faro Creek diversion ditch**



**Photo 28**  
**Pump test on 3870 bench**



**Photo 29**  
**Pump test on 3910 bench**



**Photo 32**  
**Evidence of seepage loss from culvert**



**Photo 33(a)**  
**View of Zone 3 working face**



**Photo 33(b)**  
**Detail of seepage noted on P-33 (a)**



**Photo 34**  
**Groundwater seepage on west slope of Faro Creek Valley**



**Pan view of catchment area above Zone 3**



**Pan view of overburden failure**



ANALYSIS OF PUMP TEST DATA

CAMC - 3870 Bench

Pump at:   H8  

Initial Water Depth:   1.90 m  

Date:   840615  

Final Water Depth:                     

Time (Seconds)	Pump Rate *		Observation Wells				
	IGPM	l/sec	H7	G7	G8	G9	H9
0	0	-	2.65	2.86	2.30	2.05	1.85
300	60		2.70	2.85	2.30	2.05	1.85
540	30		-	-	-	-	-
600	10		2.80	2.90	2.30	2.03	1.90
720	10		-	-	-	-	-
1020	5		-	-	-	-	-
1200	5		2.87	2.91	2.35	2.01	1.94
1800	5		2.90	2.95	2.36	2.01	1.94

Comments:

- Holes spaced at 23'.
- High flow from fractures noticed at 2 to 5 m depth.
- Pump capacity approximately 60 IGPM.

\* Estimated by operator - accuracy + 20%.

ANALYSIS OF PUMP TEST DATA

CAMC - 3870 Bench

Pump at:   E8  

Initial Water Depth:   2.30 m  

Date:   840615  

Time (Seconds)	Pump Rate * IGPM	1/sec	Observation Wells			
			E7	D8	E9	F9
0	60		3.30	3.71	2.44	2.50
210	5			PUMP WELL EMPTY		
300	2		3.31	3.73	2.50	2.50
600	1		3.32	3.76	2.54	2.51

Comments:

- Holes spacing at 23'.
- Small inflow from joints observed near surface.
- Test terminated due to low flow rates.

\* Estimated by operator - accuracy + 20%.

ANALYSIS OF PUMP TEST DATA

CAMC - 3910 Bench

Pump at:     D18    

Initial Water Depth:     1.40 m    

Date:     840615    

Time (Seconds)	Pump Rate * IGPM	1/sec	Observation Wells			
			E18	D19	C18	D17
0	60		1.85	2.84	2.85	3.40
120	10					
240	2					
300	0		1.94	2.89	2.58	3.40
PUMP SHUT OFF TO PREVENT DAMAGE						
600	2 METRES OF INFLOW OCCURRED DURING SHUTDOWN					
660			1.84	2.85	2.58	3.38

Comments:

- Well spacing at 7 m.
- Hole depths 43' (average).
- Hole was dry at 300 seconds.
- Hole would be designated as a "liner" hole when entered into blasting records.

\* Estimated by operator - accuracy + 20%.

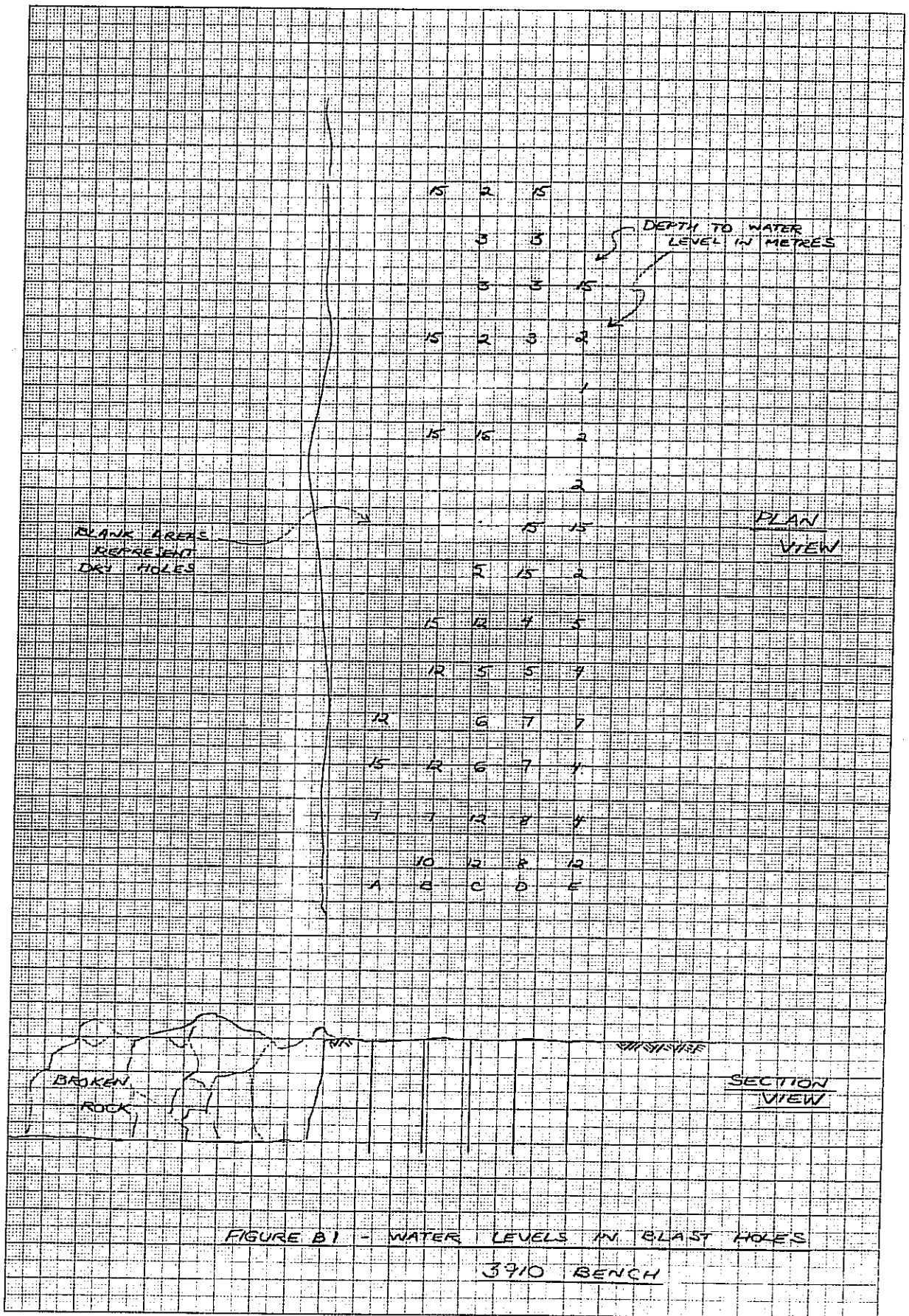
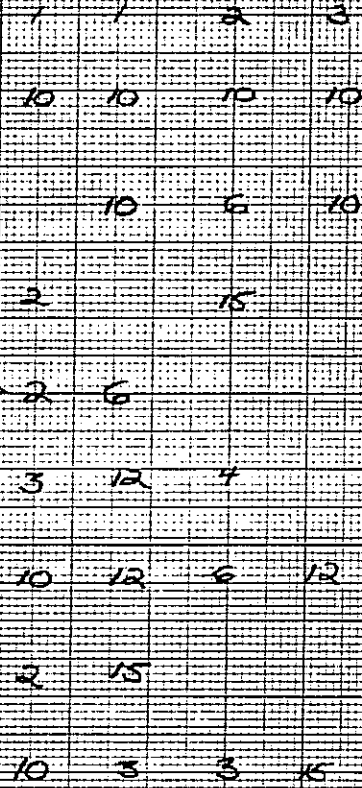


FIGURE B1 - WATER LEVELS IN BLAST HOLES  
3910 BENCH

DEPTH TO WATER  
LEVEL IN  
METRES



PLAN VIEW



SECTION VIEW

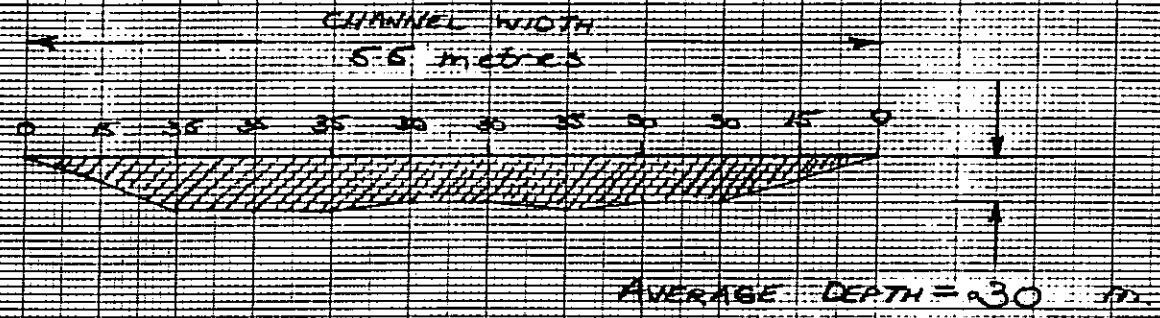
FIGURE B2 - WATER LEVELS IN BLAST HOLES

3910 BENCH



UPSTREAM FLOW ESTIMATE - FARD CREEK DIVERSION

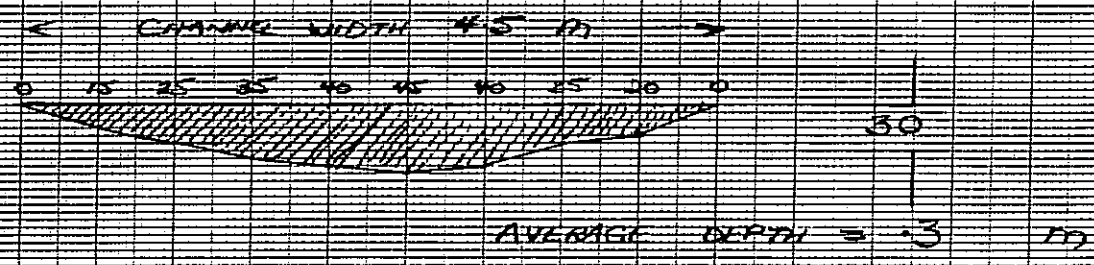
CROSS SECTIONAL VIEW



UPSTREAM FLOW =  $(5.5 \text{ m})(.3 \text{ m})(1 \text{ m/s}) = 165 \text{ m}^3/\text{sec}$

DOWNSTREAM FLOW ESTIMATE - FARD CREEK DIVERSION

CROSS SECTIONAL VIEW



DOWNSTREAM FLOW =  $(4.5 \text{ m})(.3 \text{ m})(1.1 \text{ m/s}) = 1485 \text{ m}^3/\text{sec}$

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10 X 10 TO THE CENTIMETER  
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CAMC - SLOPE STABILITY EVALUATION

ANALYSIS OF PLANE FAILURES IN OVERBURDEN

Ref: Hoek & Bray (1977)

$$F = \frac{(2^c/\gamma H)P + [Q \cot \psi_p - R(P + S)] \tan \phi}{Q + RS \cot \psi_p} \dots \dots \dots (1)$$

$$Q + RS \cot \psi_p$$

$$P = \frac{(1-Z)}{H} \operatorname{Cosec} \psi_p \dots \dots \dots (2)$$

$$Q = \left( \left(1 - \frac{Z^2}{H^2}\right) \cot \psi_p - \cot \psi_f \right) \sin \psi_p \dots \dots \dots (3)$$

$$R = \frac{(\gamma w)}{\gamma} \frac{(Zw)}{H} \frac{(Z)}{H} \dots \dots \dots (4)$$

$$S = \frac{(Zw)}{Z} \frac{(Z)}{H} \sin \psi_p \dots \dots \dots (5)$$

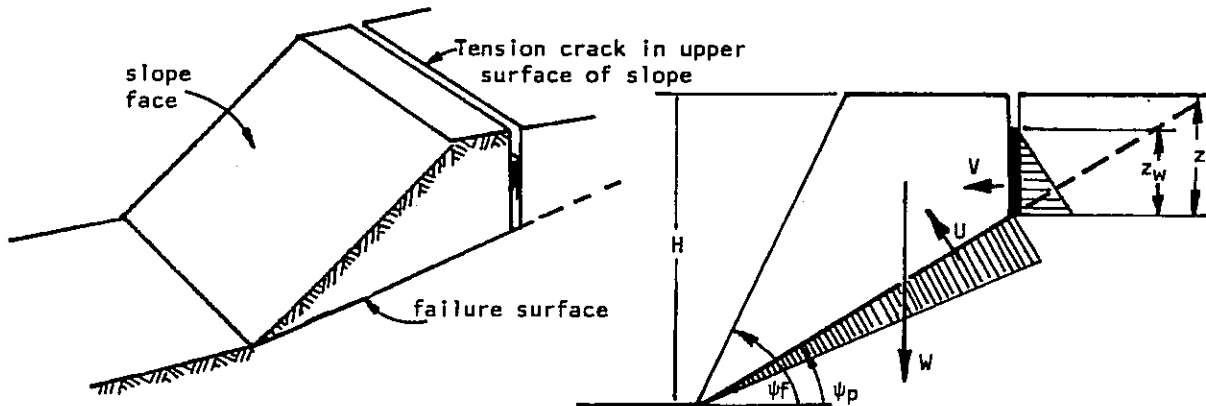


Figure 62a : Geometry of slope with tension crack in upper slope surface.

The following assumptions were made in solving equations (1) through (5):

$$H = 40 \text{ feet}$$

$$Z_w = Z = 10 \text{ feet}$$

$$w = 62.4 \text{ pcf}$$

$$\phi = 33^\circ = \text{average angle of repose of existing slopes}$$

$$\gamma = 120 \text{ pcf for till (assume dry)}$$

$$\psi_p = 45^\circ$$

$$\psi_f = 60^\circ$$

therefore:

$$\begin{aligned} (2) \quad P &= \frac{(1-Z)}{H} \operatorname{cosec} \psi_p = \frac{(1-10)}{40} \operatorname{cosec} 45^\circ \\ &= (.75) \operatorname{cosec} 45^\circ \\ &= 1.06 \end{aligned}$$

$$\begin{aligned} (3) \quad Q &= \left[ \frac{(1-(Z)^2)}{H} \operatorname{Cot} \psi_p - \operatorname{Cot} \psi_f \right] \operatorname{Sin} \psi_p \\ &= \left[ \frac{(1-(10)^2)}{40} \operatorname{Cot} 45^\circ - \operatorname{Cot} 60^\circ \right] \operatorname{Sin} 45^\circ \\ &= \left[ .94 \operatorname{Cot} 45 - \operatorname{Cot} 60 \right] \operatorname{Sin} 45 \\ &= \left[ .94 - (.58) \right] .71 \\ &= .26 \end{aligned}$$

$$\begin{aligned} (4) \quad R &= \frac{(\gamma w)}{\gamma} \frac{(Z_w)}{Z} \frac{(Z)}{H} = \frac{(62.4)}{120} (1) \frac{(10)}{40} \\ &= .13 \end{aligned}$$

$$\begin{aligned} (5) \quad S &= \frac{(Z_w)}{Z} \frac{(Z)}{H} \operatorname{Sin} \psi_p = (1) \frac{(10)}{40} \operatorname{Sin} 45^\circ \\ &= (.18) \end{aligned}$$

Therefore, solution of equation (1) yields;

$$F = \frac{2 \left( \frac{c}{\gamma H} \right) P + \left[ Q \cot \psi_p - R (P + S) \right] \tan \phi}{Q + RS \cot \psi_p}$$

$$= \frac{2 \left( \frac{c}{(120)(40)} \right) 1.06 + \left[ .26 \cot 45 - .13 (1.06 + .18) \right] \tan 33}{.26 + (.13)(.18) \cot 45}$$

$$= \frac{(4.42)(10^{-4})c + \left[ .25 - .16 \right] .65}{.28}$$

$$= (10^{-3})(1.58)c = .065$$

assuming the slope is marginally stable with a full tension crack,  $F \approx 1$ .

Therefore:

$$c = \frac{1 - 0.65}{(1.58)(10^{-3})} = 600 \text{ psf}$$

If dewatering is successful in reducing the water level  $Z_w$  to  $.5 Z$ , a new factor of safety can be calculated with new values for  $R$  and  $S$ :

$$R = 0.65 \text{ and } S = 0.9$$

$$\begin{aligned} \therefore F &= \frac{2 \left( \frac{600}{(120)(40)} \right) 1.06 + \left[ .26 - .065 (1.06 + .09) \right] .65}{.26 + (.065)(.09)} \\ &= \frac{.27 + .12}{.27} = 1.43 \end{aligned}$$

Therefore: partial dewatering or elimination of surface flow will increase the factor of safety to acceptable values.

no dewatering	$FS \approx 1$
partial dewatering	$FS \approx 1.4$

This assumes failure occurs at the bedrock/overburden interface.

Martin and Piteau (1976) reported on pit design on the north and east slopes, and assumed failure in the bedrock would occur along foliation planes dipping at 32 to 36°, which contain bands of clay gouge. They assumed  $\phi = 24^\circ$  and  $c = 2880$  psf (based upon shear tests), for the foliation planes.

If we assume failure occurs in the bedrock along foliation planes (and not at the bedrock/overburden interface), then equations (1) through (5) can be recalculated to yield a new safety factor for failure through the bedrock:

The assumptions must now be:

$$H = 40'$$

$$Z_w = Z = 10'$$

$$\gamma_w = 62.4$$

$$\phi = 24^\circ$$

$$\gamma = 120 \text{ pcf}$$

$$\psi_p = 36^\circ$$

$$\psi_f = 60$$

$$P = \frac{(1-Z)}{H} \operatorname{cosec} \psi_p = 1 - \frac{10}{40} (\operatorname{cosec} \psi_p) = 1.28$$

$$Q = \left[ \frac{(1-(Z)^2)}{H} \operatorname{Cot} \psi_p - \operatorname{Cot} \psi_f \right] \operatorname{Sin} \psi_p = \\ = \left[ (1 - .25^2) \operatorname{Cot} 36 - \operatorname{Cot} 60 \right] (\operatorname{Sin} 36) = .42$$

$$R = \frac{(\gamma_w)}{\gamma} \frac{(Z_w)}{Z} \frac{(Z)}{H} = \frac{(62.4)}{120} (1) (.25) = .13$$

$$S = \frac{(Z_w)}{Z} \frac{(Z)}{H} (\operatorname{Sin} \psi_p) = (1) (.25) (\operatorname{Sin} 36) = .15$$

$$\therefore F = \frac{1}{(120)(40)} (2)(2880)(1.28) + \frac{\left[ (.42) (\operatorname{Cot} 36) - (.13) (1.28 + .15) \right] \operatorname{Tan} 24^\circ}{.42 + (.13)(.15) \operatorname{Cot} 36^\circ} \\ = \frac{1.54 + .17}{.45} = 3.8$$

- ∴ failure along foliation planes is unlikely even with adverse groundwater conditions.