CCSM stability graph and time evaluation of open stope stability

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ABSTRACT: The main purpose of this study is to assess footwall and hangingwall stability of Copper Cliff South Mine (CCSM) stope walls using Mathew's Stability Graph Method. The secondary purpose of this study is to determine whether time influences the footwall and hangingwall stability. This work is a continuation of a previous study at Copper Cliff North Mine. Nineteen stopes are evaluated to test the hypothesis and none of these stopes are located adjacent to major geological features. A specific CCSM Stability Graph is developed using the guidelines of the Mathew's Stability Method. As well, a Dilution Plot is developed using a revised approached of overbreak dilution in three classes: (1) less than 10% "Stable", (2) 10 to 20% "Stable With Support" and (3) greater than 20% "Unstable". This graph is developed to estimate the amount of dilution from walls of open stopes. Geology joint mapping and diamond drill core logs provide the largest source of data. Factors A, B and C are calculated using GDA (Geomechnical Design Analysis) software. Likewise, σ_1 wall stresses at specific elevations and distances in the stopes are calculated using MAP3D. The numerical modelling reveals that the assumption of Factor A of unity is not correct in most cases. It was noticed, based on intuition, that opening time has an effect on opening stability. This study found a rudimentary correlation based on the data of 18 stopes whereas an improved correlation was found when 6 high dilution stopes were removed from the data set.

1 INTRODUCTION

There is a need to better understand rockmass behaviour with respect to open stope size so operations can maximize mining cycle while maximizing production and all the while controlling dilution.

This study utilizes the Stope Stability Graph (Mathews et al., 1981) approach to evaluate the stope stability of nineteen stope walls at Vale Inco's Copper Cliff South Mine (CCSM) in Canada. The time component associated with footwall and hangingwall stability is also investigated.

Currently, Copper Cliff South Mine produces ore from five orebodies (790, 800, 850, 865 and 880). The ore lies along a north-south striking quartz diorite dyke. The dyke extends approximately 3-kilometres south of the Sudbury Basin.

The following points highlight some unique features of the study:

1.) Previous work was based on traditional Equivalent Linear Overbreak and Sloughage (ELOS) measurement to quantify dilution and assess stability. This new study uses a mark of 10% external dilution (Figure 1) from a stope face to measure stability. There are two types of dilution, internal (planned) and external. Internal dilution is rock that is blasted during mining of the ore. External dilution is rock that is not part of the planned stope boundary, i.e. it is extended beyond the planned stope outline, as shown in Figure 1. In this study, ≧ 10% unplanned (i.e. external) dilution is set as the marker to indicate instability of a stope.

2.) Rockmass quality, in particular RQD, was assessed for an area surrounding each of the studied stopes.

3.) Rays, 10 m long, were extended from the walls of the completed Cavity Monitor Survey (CMS) surface, joined with strings in Mine2-4D and these strings are linked to make wireframes for analysis of RQD. In this fashion, the rock mass quality assessment is considered stope specific.

4.) MAP3D numerical modeling was undertaken to assess stope wall stress estimates taking geometry and excavation sequence into account. In this fashion, values of Rock Stress Factor A are obtained.

5.) Factor B (Joint Orientation Factor) and Gravity Adjustment Factor C, are calculated using a software program called GDA (Geomechanical Design Analysis).

6.) Horizontal slicing for overbreak calculations is used in this study.

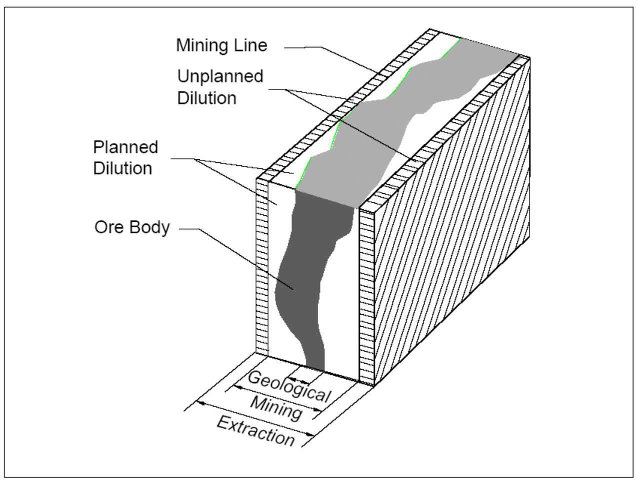

Figure 1. Illustration of planned and unplanned dilution, (after Wang, 2004)

2 PROCEDURES AND DATA COLLECTION

2.1 *Mapping*

Geologists use computers and AutoCAD©2000 to record joint information for all development headings. Ore heading dip and dip direction data, not located near major structures, are exported via an in-house macro routine to an ASCII text file. This file is subsequently imported into a spreadsheet. Underground mapping allowed first-hand assessment of rockmass conditions at Copper Cliff South Mine. In development headings, it was observed that the Q system rating of J_a (joint alteration variable) is equal to 2. The joint roughness variable, J_r, was assessed at 1.0 in most headings in the 865 O.B. and 880 O.B. For stope stability evaluations, it was found that J_r = 1 could lead to a conservative assessment for the rockmass conditions on the scale of stope wall excavations. Therefore J_r was set to 1.0 to 1.5 depending on the orebody (Cai, 2008). The joint number, J_n, was determined from geology mapping of joint sets, obtained in DIPS by importing data from spreadsheets. Joint sets were evaluated for each zone. Planar data (dip/dip direction) was evaluated in this program to assign appropriate number and orientation for joint sets. Rockmass Quality Designation (RQD) was determined by exporting Diamond Drill Hole (DDH) data in a torus surrounding the stope wall from Mine2-4D into a spreadsheet on a stope-by-stope basis. The torus is a volume between the CMS stope wall and a 30-foot offset wall.

Figure 2 denotes a transparent wireframe to illustrate RQD point data for a typical stope. The green "wireframe links" represent the 30-foot torus. (Note: North direction set at top of page for figures 2 and 3.)

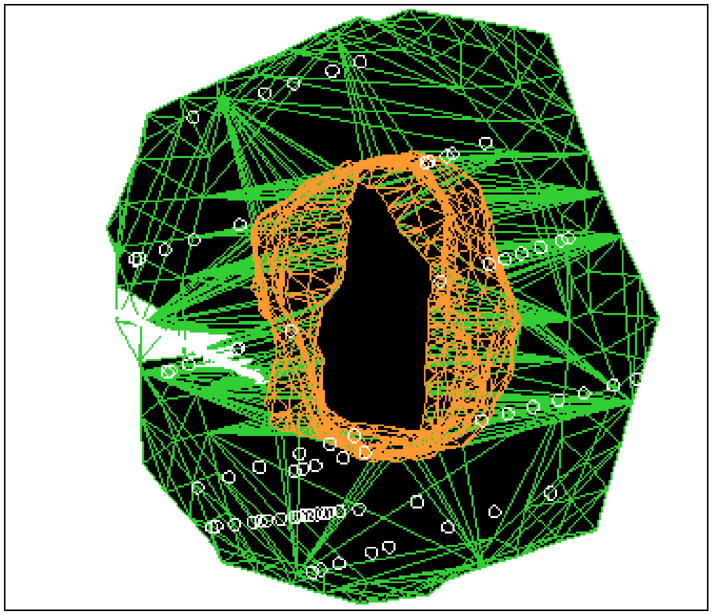

Figure 2. Plan view of transparent wireframe to illustrate RQD point data (white circles) in diamond drill holes

2.2 *Dilution Slicing*

Dilution is calculated by slicing the stope boundary (blast design) and CMS wireframes of a given stope in AutoCAD©2000. An in-house routine in AutoCAD©2000 can slice wireframe 3D faces at desired intervals horizontally, vertically or on inclined planes. Typical practice at the operation assesses the hangingwall and footwall overbreak by slicing wireframes vertically on 10-ft intervals. The previous Copper Cliff North Mine study used a horizontal slicing technique to evaluate the four walls of each stope simultaneously (Kalenchuk, 2003 & Ouchi, 2004). This technique was used in the Copper Cliff South Mine study. Overbreak is defined as the difference between the blast volume and CMS volume. Blast volume is calculated by measuring and recording average length along strike and width (across strike) from footwall to hangingwall. Figure 3 shows a typical "slice" with hatched area representing external dilution overbreak on North face.

2.3 *Numerical Modelling using MAP3D*

Since Mine2-4D© wireframes could not be exported directly to MAP3D, a four-step procedure was employed to create loops (strings) at proper elevations in MAP3D and connected to make solids (wireframes). The walls of adjoining stopes were aligned such that no gaps were present to aid efficiency in MAP3D computing time.

A minimum horizontal distance of two stope lengths was used for model limits. For instance, a 60-foot long stope for which wall stresses are to be calculated included any stopes and geological structures within a 120-ft zone. More often a larger distance was used. In the vertical direction, any stopes or geological structures within one stoping block above and one below a given area were included in the model. Grid point elevations were set by dividing the stope wall into 4 equal segments and then picking the mid-point and next point above and below where segments joined. The grid points were also set at a pre-determined distance from the stope wall. For example, a 60-ft stope length and a corresponding wall with 10% dilution used a grid point set 60-ft x 10% = 6ft from the stope wall as shown in Figure 4.

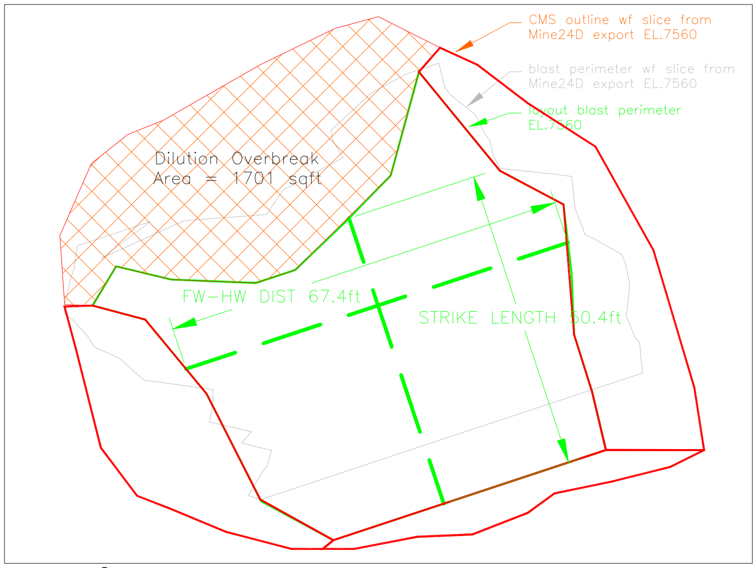

Figure 3. AutoCAD2000® horizontal slice

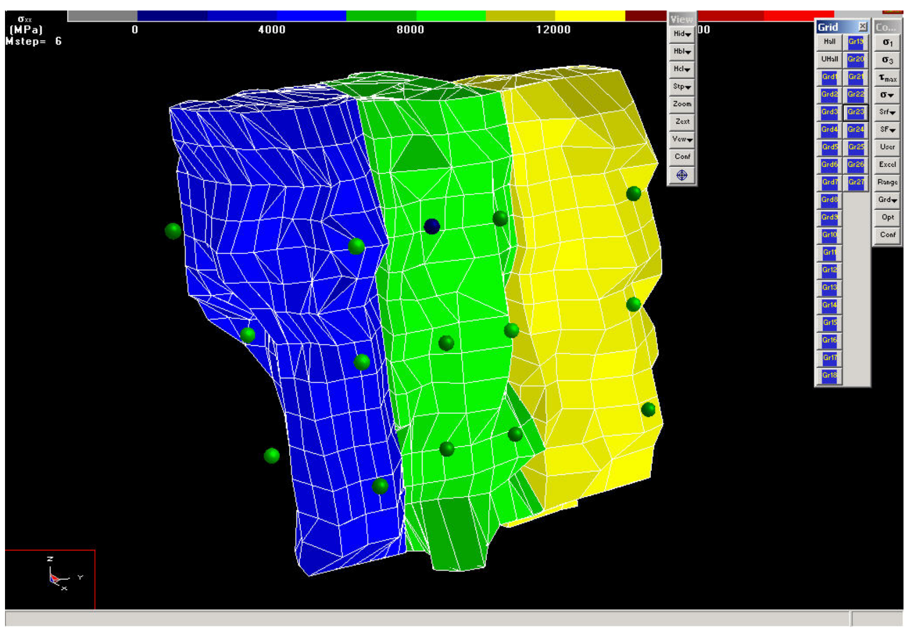

Figure 4. MAP3D stope model with data grid points (green dots) for upper, mid and lower elevations

3 DATABASE

All geological mapping and logging data are used to create a database. Having excluded walls composed of backfill, the remaining walls were assigned rockmass classification numbers according to the Q system. In the stope stability graph method, the modified Q' is used.

RQD ranges from 80 to 95, with most data greater than 85. The joint set number, J_n, ranges from 6 to 9 in the quartz diorite dyke (ore host). In the metasediments, J_n is 12. The joint roughness, J_r, is typically 1 based on mapping data on a relatively small scale (e.g. drifts). It was found that J_r = 1 could lead to a conservative assessment for the rockmass conditions on the scale of stope wall excavations (Cai, 2008) so this value is increased to 1.5, except in the 865 ore zone where joint roughness was assigned a value of 1. Joint alteration number J_a was set at 2 for all areas. Table 1 and Table 2 summarize stope height (Ht), stope face length (Lgth), RQD, J_n, J_r, Q', and Factors A, B, C and Modified Stope Stability Number N' for stope faces in the study. Height and length units are metres.

Table 1. Database Statistics 790 & 800 Orebodies

Stope	Wall	Ht*	Lgth	HR	RQD	J_n	J_r	Q'	A	B	C	N'
790 O.B. 4130 Level												
6805	North	48	13	5.2	89	9	1.5	7.3	0.19	0.42	7.31	4.12
6805	East		12	5.1	89	9	1.5	7.3	0.35	0.20	6.21	3.20
6805	South		13	5.2	89	9	1.5	7.3	0.19	0.42	7.31	4.16
6805	West		12	5.1	89	9	1.5	7.3	0.41	0.20	6.51	3.85
6865	North	48	15	5.9	90	9	1.5	7.3	0.29	0.78	8.00	13.23
6865	East		13	5.4	90	9	1.5	7.3	1.00	0.20	7.75	11.24
6865	West		13	5.9	90	9	1.5	7.3	0.31	0.20	7.75	3.48
6925	North	47	11	4.8	90	9	1.5	7.3	0.42	0.53	7.93	12.99
6925	East		17	6.4	90	9	1.5	7.3	0.42	0.20	7.94	4.91
6925	West		17	6.4	90	9	1.5	7.3	0.42	0.20	7.94	4.91
800 O.B. 3540 Level												
7656	North	63	8.5	5.3	85	9	1.5	7.3	0.31	0.24	7.85	4.29
7656	East		19	7.9	85	9	1.5	7.3	1.00	0.20	6.78	9.90
7656	West		19	5.3	85	9	1.5	7.3	0.10	0.20	6.87	1.00
7476	East	65	18	7.9	87	9	1.5	7.3	0.10	0.20	6.91	1.01
7476	South		16	7.0	87	9	1.5	7.3	0.82	0.24	7.87	11.22
7476	West		18	7.9	87	9	1.5	7.3	0.10	0.20	6.90	1.01
7470	North	65	27	10.9	87	9	1.5	7.3	0.21	0.24	7.93	2.94
7470	South		27	9.5	87	9	1.5	7.3	0.11	0.22	7.80	1.36
7470	West		23	10.9	87	9	1.5	7.3	0.21	0.26	7.94	3.19
800 O.B. 4130 Level												
7534	North	51	12	5.3	88	9	1.5	7.3	1.00	0.23	7.90	13.32
	East		15	7.0	88	9	1.5	7.3	0.39	0.25	7.59	5.41
	South		12	5.3	88	9	1.5	7.3	0.20	0.24	7.90	2.77
	West		15	7.0	88	9	1.5	7.3	0.27	0.26	7.76	3.99
7536	East	50	17	6.6	89	9	1.5	7.3	0.20	0.26	7.90	3.04
	South		8.8	3.9	89	9	1.5	7.3	1.00	0.24	7.98	14.22
	West		17	6.6	89	9	1.5	7.3	0.10	0.25	7.74	1.42
7656	North	49	15	6.6	91	9	1.5	7.3	0.74	0.23	7.98	9.93
	East		18	6.6	91	9	1.5	7.3	0.15	0.23	7.74	2.15
	West		18	6.6	91	9	1.5	7.3	0.16	0.26	7.91	2.35
7474	East	50	15	6.1	88	9	1.5	7.3	**	~~0.24~~	~~7.54~~	**
	South		8.5	4.3	88	9	1.5	7.3	1.00	0.23	7.96	13.35
	West		15	6.1	88	9	1.5	7.3	0.23	0.21	7.11	2.54

* stope height measured from bottomsill floor elevation to topsill floor elevation
** no grid point set in MAP3D

Q' values were calculated for each ore zone using GDA, and the values obtained are mostly between 6.1 and 7.3, with minimum and maximum values of 4.2 and 8.3 respectively.

Except for the 865 O.B. stopes from 3015 – 3135 Level and the 880 O.B. stopes, σ_1, the maximum principal stress in the wall, was calculated at each stage in the mining of the stopes by numerical modeling and the resulting Factor A was calculated. When $\sigma_c:\sigma_1 \geq 10$, where σ_c is the uniaxial compressive strength of the rock, we have A = 1.

The calculated value for Factor B ranges from 0.2 to 0.8 with 48% of the values falling between 0.2 and 0.4 and 41% between 0.4 and 0.6.

Footwall dip was measured for each stope. Fourteen out of nineteen stopes had a footwall dip greater than 80 degrees. For the given joint orientations, all footwalls tend to have a potential slabbing failure mode. Only in the 865 O.B. there was a case to set the north wall as a sliding type failure mode, resulting in lower C value. 19% of the calculated Factor C values are between 6.0 and 7.0 with 70% of the values greater than 7.0.

The resulting Modified Stability Numbers (N') are between 0.8 and 22.0. The low value corresponds to the west wall (HW) of 2650 1401 Stope in the 865 O.B. that had a high σ_1 stress of 140 MPa due to adjacent filled stopes and a thin crown (15.2 metres) overhead between 2400 and 2450 Levels. The high σ_1 results in a low σ_c:σ_1 ratio, thereby reducing Factor A drastically (magnitude = 0.1). High stress is reasonable as this area is in its final mining stage. That is, with the completion of the adjacent 1402 stope, there remains only the crown to be mined. The greatest magnitude for N' was found in 3135 0950 VRM. In conjunction with sub-perpendicular joint orientation (Factor B = 0.48) as well as slabbing failure mode (C = 7.51), this results in a high value of N'.

N' values for 38% of the walls are between 0.1 and 5.0 as shown in Figure 5.

Table 2. Database Statistics 865 & 880 Orebodies

Stope	Wall	Ht*	Lgth	HR	RQD	J_n	J_r	Q'	A	B	C	N'
865 O.B. 2650 Level												
1401	East	58	14	5.6	90	9	1.0	6.3	0.10	0.20	6.47	0.79
	West		14	5.6	90	9	1.0	6.3	0.10	0.32	5.67	1.11
1402	West	59	19	7.1	87	9	1.0	6.0	1.0	0.20	7.74	9.43
865 O.B. 3135 Level												
0950	North	32	5.2	2.2	82	9	1.0	4.6	1.0	0.46	2.50	7.01
	East		15	5.1	82	9	1.0	4.6	1.0	0.20	7.94	6.98
	South		5.2	2.2	82	9	1.0	4.6	1.0	0.48	7.54	22.06
	West		15	5.1	82	9	1.0	4.9	1.0	0.20	7.91	9.64
1050	North	32	8.2	3.3	89	9	1.0	4.9	1.0	0.48	2.50	7.31
	East		21	6.4	89	9	1.0	4.9	1.0	0.20	8.00	9.75
	West		21	3.3	89	9	1.0	4.9	1.0	0.20	7.96	9.70
1150	North	31	9.1	3.5	87	9	1.0	4.8	1.0	0.20	2.50	3.05
	East		28	7.4	87	9	1.0	4.8	1.0	0.20	7.72	9.42
	West		28	3.5	87	9	1.0	4.8	1.0	0.20	7.69	9.39
880 O.B. 0870 Level												
2500	North	46	9.1	4.6	91	9	1.3	6.3	1.0	0.23	7.46	11.84
	East		25	7.3	91	9	1.3	6.3	1.0	0.20	6.07	8.38
	South		9.1	4.6	91	9	1.3	6.3	1.0	0.20	7.43	10.26
	West		25	7.3	91	9	1.3	6.3	1.0	0.20	6.16	8.50
2400	East	46	25	5.8	88	12	1.3	4.6	1.0	0.20	5.28	4.46
	South		6.4	4.5	88	9	1.3	6.1	1.0	0.27	7.71	14.38
	West		25	5.8	88	9	1.3	6.1	1.0	0.20	5.38	7.43
880 O.B. 0690 Level												
2500	North	56	10	4.1	82	9	1.3	5.7	1.0	0.20	7.16	10.44
	East		19	8.5	82	9	1.3	5.7	1.0	0.20	6.19	9.03
	South		10	4.1	82	9	1.3	5.7	1.0	0.20	6.74	9.83
	West		19	8.5	82	9	1.3	5.7	1.0	0.20	5.90	8.60
2400	East	53	20	8.5	81	12	1.3	4.2	1.0	0.24	7.18	7.90
	South		8.8	4.0	81	9	1.3	5.6	1.0	0.23	7.93	1.33
	West		20	8.5	81	9	1.3	5.6	1.0	0.24	7.10	12.45

* stope height measured from bottomsill floor elevation to topsill floor elevation

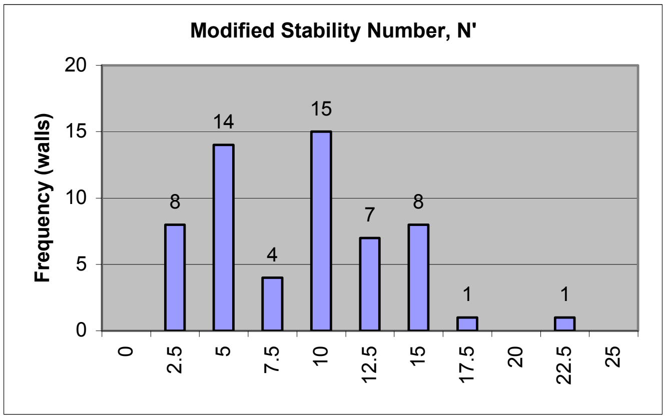

Figure 5. Distribution of the number of Stope Walls vs N' Value

Most stope lengths (hangingwall and footwall correspond to east or west) are between 50 to 60 feet in length as shown in Table 1. The stope widths (north and south walls) vary between 17 and 90 feet, with approximately 80% between 20 and 70 feet. The large widths correspond to two faces (north and south) of 3350 – 3540 7470 VRM in the 800 orebody "Crossover" zone. Stope heights range from 103 to 213 feet with two-thirds of the stopes being between 125 and 200 feet. Nine of the nineteen stopes have a width to height ratio of 0.3, in a range of 0.14 to 0.54.

The Hydraulic Radii for 118 walls (planned and CMS) are 7.2 to 35.7-ft (2.2 to 10.9 m). More than three quarters of the walls have hydraulic radii of 20 to 35-ft. 18% of the faces have hydraulic radii less than 20-ft (6.1 m) and only 4% are more than 30-ft (9.1 m).

4 RESULTS & DISCUSSION

4.1 *Modified Mathews Stability Graphs and Dilution Plots*

In this study, outliers were identified as any data point that plots in an inappropriate region on the Modified Stability Chart. For example, the two failure points in the stable region in Figure 6 are termed failure outliers. Similarly, the stable points that plot in the caving zone are termed stable outliers. These outliers are caused by an incorrect assessment of the stope geometry and the Modified Stability number N'. However, there is an opportunity to produce plots that are meaningful by using dilution lines. Outliers denote the limitation of an empirical method whereby other unaccounted factors likely influence the modified stability number (N') and hydraulic radius. Factors include: unrecognized weakness zones, caving during blasting or mucking, seismicity, blasting of holes near the ore contact (i.e. where blasting gasses break beyond the ore/rock contact) etc. All these factors are difficult to quantify for inclusion in the N' calculations.

4.1.1 *790 Orebody*

Table 3 ranks the data points based on three dilution classes, i.e. less than 10% ("Stable"), 10 – 20% ("Stable With Support") and greater than 20% ("Unstable") for the 790 O.B.

The 4130 6865 north wall had a high value for Factor B (0.78, $\xi = 59°$, ξ is difference (angle) between critical joint and slope surface measured in degrees) resulting in a high N' value compared to other walls (0.2 for west and east, $10° \leq \xi \leq 30°$). On the 4130 6865 east wall, numerical modeling returned a low σ_1 (-23 MPa) at the mid-point elevation of the stope. Assigning a low value of 2.0 MPa for σ_1 resulted in Factor A = 1.0 which led to a high N' value.

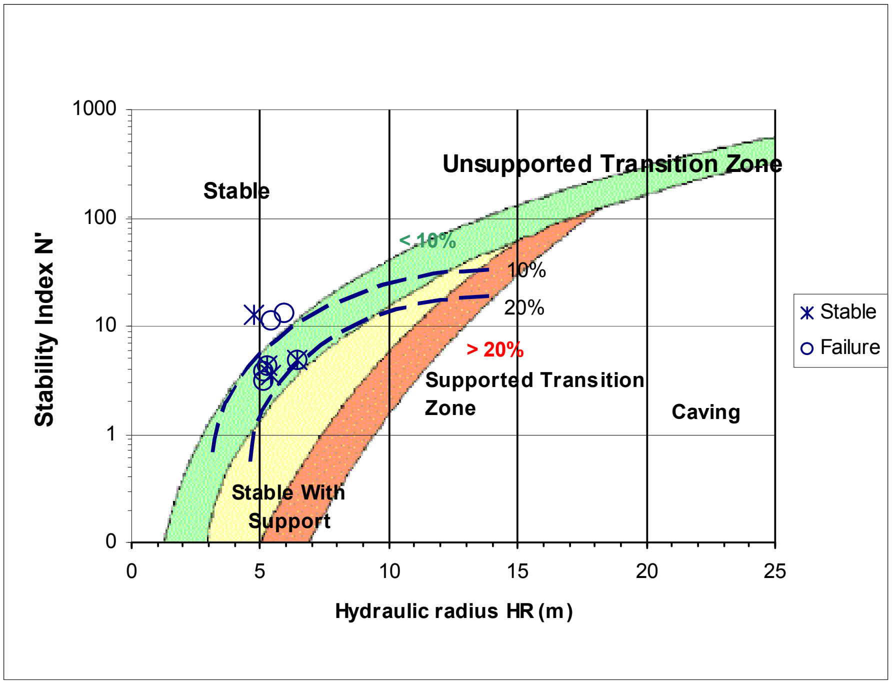

Figure 6. Combined Stability Chart/Dilution Plot 790 O.B. (after Hoek et al., (1995), Potvin (1988), Nickson (1992))

Table 3. 790 OB Overbreak by Dilution Class

STOPE Level/ WKPL	WALL	N’	HR (m)	Over-break Dilution (%)	Stable Outlier (%)	Failure Outlier (%)
Less than 10 per cent Dilution “Stable”						
4130 6925	North	13.0	4.8	5.8		
4130 6865	North	13.2	5.9			16.2
4130 6865	East	11.3	5.4			16.4
10% - 20 per cent Dilution “Stable With Support”						
4130 6805	North	4.24	5.2	2.2		
4130 6865	West	3.54	5.4	9.7		
4130 6805	West	3.80	5.1	19.1		
4130 6805	South	4.24	5.2	20.3		
4130 6805	East	3.19	5.2	21.2		
20+ per cent Dilution “Unstable”						
4130 6925	West	4.84	6.4		6.6	
4130 6925	East	4.84	6.4	22.8		

The west wall of 4130 6925 stope returned a low measured value of dilution whereas the east wall dilution is more appropriate, given the fact that Factors A, B and C as well as hydraulic radius are identical for these walls.

4.1.2 *800 Orebody*

Table 4 ranks external dilution by the three dilution classes, <10%, 10 – 20%, >20% for 3350 – 3540 Level and 3970 – 4130 Level stope walls in the 800 O.B.

i) It is worth noting that out of a total of 21 faces, 4 are considered “Stable” (less than 10% dilution) and one stable point is an outlier as it plots in the “Unstable” region. It is seen from the 800 O.B. stability chart that seventeen of twenty-one walls have more than 10% dilu-

tion, ranging from 11.6 to 146.4%, and are considered unstable. The high dilution values for this area, known as the 805 O.B. "Crossover Zone" are attributed to two facts:most stope sizes are too big for ground conditions, and
ii) geological conditions, in particular ore placement may influence stope stability.

Two faces, 4130 7536 East and West Walls, are failure outliers since they plot in the "<10% dilution" region. East and west walls of this stope represent hangingwall and footwall respectively. The MAP3D model returned negative wall stresses, indicating that the walls are in tension in this region. Choosing another elevation (e.g. B.R. topsill – 12.2m), we have a stress magnitude of σ_1 = 48.1 MPa, which yields a Factor A of 0.20, and the resulting N' value of 3.04 will translate the data point down to the "< 20% dilution" zone.

The stable outlier is 4130 – 7656 west wall (N'=2.37, HR=6.64 m) with 3.3% dilution. The N' number is the result of a Factor A of 0.16 (σ_1 = 56.1 MPa) at the mid-point elevation. The other point values for σ_1 are 39.3 and 68.2 MPa for the upper and lower grid points respectively. The 4130 – 7656 west wall has the largest magnitude of hydraulic radius compared to the other three stable points, but the value is comparable to the other walls of this stope. Its N' number is similar to that of the east wall. This would lead one to question the cavity monitor surveys results. Quite possibly, a shadow due to the position of the laser survey unit was thought to be a wall when in fact there was a void that the laser could not "see." Dust and dripping water can also be sources of CMS error but not usually a problem at this mine site.

Table 4. 800 O.B. Overbreak by Dilution Class

STOPE Level/ WKPL	WALL	N'	HR (m)	Overbreak Dilution (%)	Stable Outlier (%)	Failure Outlier (%)
Less than 10 per cent Dilution "Stable"						
4130 7536	South	13.8	3.9	0.7		
4130 7534	North	13.2	5.3	8.0		
4130 7474	South	13.7	4.3	9.6		
4130 7536	East	15.2	6.6			11.6
4130 7536	West	14.2	6.6			28.3
10% - 20 per cent Dilution "Stable With Support"						
4130 7656	North	9.69	6.6	20.3		
4130 7534	South	2.81	5.3	28.1		
3540 7476	South	11.1	7.0	34.9		
3540 7656	East	9.95	7.9	38.5		
3540 7656	North	4.32	5.3	126		
20+ per cent Dilution "Unstable"						
4130 7656	West	2.37	6.6		3.3	
4130 7656	East	2.22	6.6	14.1		
4130 7474	West	2.63	6.1	28.3		
3540 7470	South	1.37	10.9	35.9		
3540 7656	West	1.00	7.9	40.4		
3540 7476	West	1.01	7.9	41.6		
4130 7534	West	3.93	7.0	46.8		
3540 7476	East	1.01	7.9	51.6		
4130 7534	East	3.93	7.0	53.8		
3540 7470	West	3.17	9.6	75.7		
3540 7470	North	2.90	10.9	146.4		

4.1.3 *865 Orebody*

Table 5 ranks faces for the 865 O.B.. This orebody has experienced a number instability problems. The 865 orebody has known weakness zones, e.g. Olivine Diabase Dyke, Creighton Fault and a shear along strike within the ore zone (quartz diorite dyke). For this orebody the west wall is hangingwall and the east wall is the footwall.

Table 5. 865 O.B. Overbreak by Dilution Class

STOPE Level/ WKPL	WALL	N'	HR (m)	Overbreak Dilution (%)	Stable Outlier (%)	Failure Outlier (%)
Less than 10% Dilution "Stable"						
3135 0950	North	6.99	2.7	0.2		
3135 0950	South	22.0	2.7	4.8		
3135 0950	East	9.68	5.3	9.8		
3135 0950	West	9.64	5.3			10.0
3135 1050	North	7.40	4.0			33.9
10% - 20 per cent Dilution "Stable With Support"						
3135 1150	East	9.41	7.6	28.3		
3135 1150	West	9.46	7.6	33.0		
3135 1050	East	9.66	6.9	41.6		
3135 1050	West	9.61	6.9	53.9		
3135 1150	North	3.05	4.9	71.8		
20+ per cent Dilution "Unstable"						
2650 1401	East	0.79	6.3	36.5		
2650 1401	West	1.51	6.3	38.0		
2650 1402	East	9.4*	8.0	39.2		

* MAP3D returned –42.6MPa mid-point elevation, σ_1 set to 1 MPa, other elevations also in tension.

Reviewing Table 5 the three "stable" faces belong to 3135 0950 VRM. This stope was stable due in part to its small strike length and width. Conversely, the three faces with dilution values greater than 20% are 2650 1401 East and West walls along with 2650 1402 West wall. These three faces which were modelled in MAP3D©, fall in the "Stable With Support" zone, reflecting actual conditions in these stopes. The ore zone extended further north than planned during ITH drilling of 1150 SS_RB resulting in extra length (92 feet average) for the stope. This hanging-wall (west wall) of 1150 stope did have extra material fall off as noted during two underground inspections by the author. There is an important point to remember – stopes between 3015 and 3135 Levels (0950, 1050 and 1150) were not modeled in MAP3D and therefore Factor A was set to unity and as result their N' magnitudes were most likely overestimated.

4.1.4 *880 Orebody*

Results for the 880 O.B. are given below in Table 6. None of the stope walls were modeled numerically for wall stress and this is reflected in the high values for N'.

Table 6: 880 O.B. Overbreak by Dilution Class

STOPE Level/ WKPL	WALL	N'	HR (m)	Ovbk Dil'n (%)	Stable Outlier (%)	Failure Outlier (%)
0690 2400	South	14.4	4.5	3.4		
0690 2500	North	12.3	4.6	4.8		
0870 2500	South	9.85	4.1	5.5		
0690 2500	South	11.3	4.6			15.8
0870 2500	North	10.4	4.1			37.5
0870 2400	South	15.2	4.1			66.0
0690 2400	West	7.90	5.8	4.1		
0690 2500	West	8.48	7.3	7.9		
0690 2400	East	7.70	5.8	8.9		
0690 2500	East	8.40	6.3	23.2		
0870 2400	East	15.3	8.5	34.6		
0870 2400	West	12.4	8.5	36.6		
0870 2500	East	9.10	8.5		6.8	
0870 2500	West	8.56	8.5	54.4		

For the first two failure outliers changes to any inputs to decrease N' would "translate" the points into the 10 – 20% dilution zone. For 0870 2400 South, changes to N' will not translate the point to its proper location at >20% dilution. The 0870 2500 East face stable outlier can only be translated into the <10% dilution class with a two-fold increase in N', not feasible with the given input data.

5 OPENING TIME AND DILUTION

For the 59 walls evaluated in this study, overbreak dilution ranges from a minimum of 0.3% to a maximum of 146%. Table 7 summarizes data for the 19 stopes.

Table 7. Stope Open Time – ELOS – Overbreak Dilution – Regression Coefficients

STOPE Level/ WKPL	TIME OPEN (day)	ELOS Total (m)	Ovbk Dil'n (%)	R^2 *	R^2 *
4130 6925	38	1.07	35.2	0.88	790
4130 6865	61	1.29	42.3	for	O.B.
4130 6805	79	1.92	62.8	n=3	
3540 7476	34	5.3	128	0.83	800
3540 7656	41	6.5	205	for	O.B.
3540 7470	66	10.3	258	n=3	0.25
4130 7656	37	3.8	37.7	0.78	for
4130 7474	42	3.8	37.9	for	n=7
4130 7536	50	4.1	40.6	n=4	
4130 7534	62	13.6	136		
2650 1401	70	2.27	74.5		865
2650 1402	87	1.19	39.2		O.B.
3135 0950	23	0.76	24.9	1.00	0.29
3135 1050	73	3.94	129	for	for
3135 1150	76	4.06	133	n=3	n=5
0690 2500	37	1.58	51.7		880
0690 2400	~~477~~	~~0.50~~	~~16.3~~**		O.B.
0870 2500	22	3.18	104		0.012
0690 2400	42	4.18	137		n=3

* linear regression of form y= mx+b; n represents number of stopes
** 0690 2400 removed from data set

The stope face that has the least dilution is 4130 – 7474 East wall. The greatest dilution is found in the 3540 – 7656 North wall. Coincidentally, both stopes are situated in the 800 OB "Crossover" zone and both of these extreme stopes employed a raise bore slot-slash mining technique. More than half (59%) of the walls included in this study had dilution less than 30%. However, almost 25% of walls had dilution values greater than 50% (14 of 59 cases). Fifty-seven percent of the stopes (11 of 19) were open for 50 days or less. The remaining eight stopes were open from 70 to 90 days.

With the 19 stopes, the regression coefficient R^2 is 0.012 indicating no correlation between dilution and time. However, the 10 stopes with less than 100% overbreak dilution were grouped and tested for regression coefficient R^2 as shown in Figure 7. The regression coefficient is 0.34 indicating stope dilution is attributed partially to opening time.

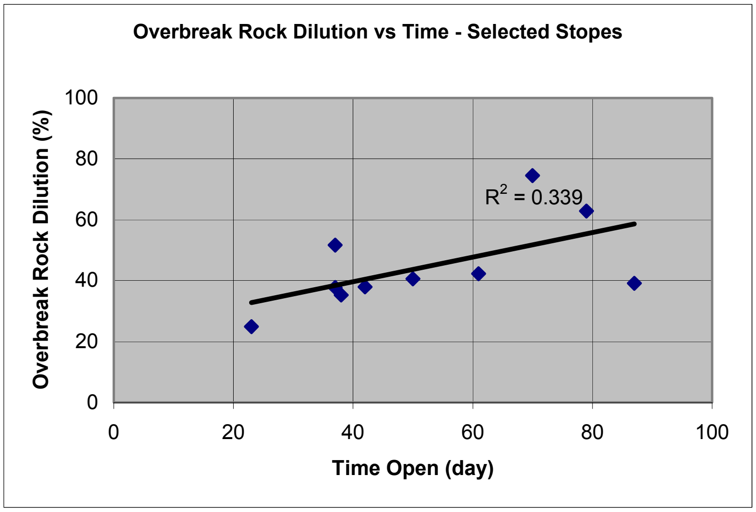

Figure 7: Selected Stopes Overbreak Dilution vs. Time Open

6 CONCLUSIONS

The CCSM Stability Graph has been developed following the guidelines of the Mathew's Stability Method. The Dilution Plot (ELOS) has been revised in this study to measure stability based on overbreak dilution in three classes: less than 10% "Stable"; 10 – 20% "Stable With Support" and greater than 20% "Unstable". This graph has been developed to estimate the amount of dilution from open stope walls.

The database for Copper Cliff South Mine is composed of 59 faces from 19 stopes in four orebodies, 790, 800, 865 and 880. N' values range from 0.79 to 22.02 and hydraulic radii from 2.26 to 10.90 metres.

Factors A, B and C were calculated using GDA software. The σ_1 wall stresses at specific elevations and distances were calculated using MAP3D. The numerical modelling revealed that the assumption of Factor A of unity is not correct in most cases.

Dilution ranged from 0.2 to 146.4% for 3135 Level 0950 north face (865 OB) and 3540 Level 7470 north face (800 OB) respectively.

Eleven of eighteen stopes were open for 50 days or less. The remaining seven stopes were filled within seventy to ninety days.

For the thirteen faces investigated in the 865 OB there were two failure outliers on the modified stability graph. On the new dilution plot, eleven points (faces/walls) plotted in the correct dilution class with two failure outliers. A small test was conducted for two stopes in the 865 OB by reducing the MAP3D σ_1 values such that Factor A was set to unity. This, in turn reduced the N' value and moved the points into the "Stable" zone of the dilution plot. This test served to confirm the validity of numerical modelling to determine wall stresses.

An improved correlation was found when six high dilution stopes were removed from the data set.

The developed site-specific database for Copper Cliff South Mine is useful for stope stability assessment at the mine site. The approach taken in this study to apply the Stability Graph Method can reduce significantly uncertainty related to the application of this method. In addition a methodology of relating stope stability to percent dilution has been created which permits such risk based evaluations to be made at the stope design stage.

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