PILLAR STABILITY ANALYSIS AND ITS BEARING ON THE DESIGN OF UNDERGROUND MINING SYSTEMS FOR TWO SKARN-TYPE COPPER DEPOSITS OF THE COQUIMBO REGION, CHILE.

TOPUK DUYARLILIK ANAÜZÎ VE ONUN ŞİLİ'DE COQUÎMBO BÖLGESİNDE ÎKÎ ADET SKARN TÎPÎ BAKIR YATAKLARINDAKÎ YERALTI MADEN METODU TASARIMINA ETKÎSÎ

Federico E. **Brunner** *
Jorge Oyarzûn **

Keywords : Pillar Stability, Design of Underground Mining Systems.

ÖZET

Oda topuk yönetimi, Şili'de orta-küçük ölçekli bakır madenciliğinde yaygın olarak kullanılır. Bu metod, düşük eğimli volkanik- sedimanter tabakalar içerisinde yer alan tabaka "Monto" ve Skarn mineralleşmesi tipi yatakların işletilmesi için iyi bir seçenek sağlar. Bu yöntemin hem teknik hem de ekonomik olarak en kritik tarafı, kabul edilebilir bir cevher kazanımı ve ocağın duyarlılığını sağlayacak bir topuk tasarımıdır. Bu bildiri, Şili'de Coquimbo bölgesinde iki adet skam tipi bakır yatağı için; topuk dayanımı ve kazı boşluklarının duraylılığına önem vererek ocakların jeolojik ve kaya mekaniği özelliklerini vermektedir.

ABSTRACT

Room and pillar mining is extensively used by small to medium scale copper mining in Chile. This method provides a good alternative for stratiform/stratabound "monto" type deposits and skarn mineralisation emplace in gentle dipping volcanic-sedimentary strata. A critical aspect for this method-in both technical and economical terms-is the pillars design in order to obtain a good stability and an acceptable mineral recovery. The present paper describes the geological and rock mechanics properties of two skarn-type copper deposits of the Coquimbo Region, Chile, with emphasis in strength of the pillars and the stabilities of the chambers excavations.

*** Ingéniera Civil de Minas M.Sc., Depto. de Ingenieria en Minas. Universidad de La Serena. Casilla 554. La Serena - Chile.**

**** Geôlogo, Ph. D. Depto. de Ingenieria de Minas. Universidad de La Serena. Casilla 554. La Serena Chile**

1. INTRODUCTION

Pillars are defined as the "in situ" rock that remain between two or more underground openings. Considering the job that perform in the ground, they are classified according to the following main categories.

1.Support pillars 2.Protective pillars 3.Control pillars

In order to examine the mechanism of action of the pillars, three aspects must be considered:

1. The load applied to the pillar.
2. The strength of the pillar, considering the severals modes of failures.
3. The reaction of the pillar with respect to the floor and roof of the seam.

The stress acting in pillars can be cuantified applying either the tributary area load approach, or the theory of elastic deflection Coates (1966). The elastic solution proposed by Coates (1966), results in average stresses in the pillars that are 40% lower that the values submited by the tributary area load theory. Experimental and model studies Oravecz (1977) support this findings. However, in spite of this agreement between theory and ground measurements, the tributary area load is used in practical mining applications due its simplicity and comparative results.

The strength of mining pillars depends of the followings factors:

a) The strength of the rock mass of the material of pillar.
b) The size or volume effect (strength reduction of samples from laboratory to ground pillars): Concept of the "critical size".
c) The effect of pillar geometry (shape effect).
d) Structurais models, and their influence in pillar stability.

2. GEOTECHNICAL CONSIDERATIONS FOR PILLARS DESIGN.

2.1 Structural models

A distinction must be made between major and minor discontinuities. The terms major and minor are related to the size of either a pillar, pit or other mining structure. Major discontinuities are those which continue across pillars, or several benches in a pit.

Single minor discontinuities have limited influence on general stability problems. However due to their repetition in the field and systematic orientation as joint fracture sets, such minor discontinuities could have influence on the stability of mining structures.

Both types of discontinuities can be mapped using the detail line method Call (1976), Brunner (1986); which is a systematic spot sampling in situ technique.

Point plots and contoured percent plots are used for defining the joint sets measured along each detail line. The contoured pole diagram is a necessary aid in the analysis of mining structures such as pillars, pits, etc.

The best application of this approach in the stability analysis, is obtained using the modal orientations of dip and dip direction angles' as input design parameters.

If a point plot is used for the treatment of the measurements öf joint orientations in a cluster, the mean orientation and the value of dispersion about this mean can be obtained as follows t

a) Determination of a 'joint set based on engineering judgment.
b) Determination of mean orientation in each cluster. In this Step, the joint orientation values in the joint set are modelled as vectors.
c) Determination of the dispersion from the mean value.

The point plot method is preferable for the treatment of joint orientation« in the cluster, because once the joint sets have been determined, the various characteristics from all the fractures falling within the joint set can be combined to form mathematical distributions.

2.2 Distribution of joint set characteristics

Each joint has a dip, a length, spacing and a waviness angle. ' Class intervals are chosen and histograms of each characteristies and for each set of similarly oriented joinA are constructed. Then, the curve that best fits the data distribution is determined.

2.3 Analysis of joint fracture sets in a design sector.

A design sector is formed by a finite number of detail lines. Correlations within and between join sets in the different design sectors are necessary for obtaining the joint fracture sets for design within a structural domain.

The analysis for obtaining the joint fracture sets is performed as follows:

1) The mean vector of each joint set is plotted in a Schmidt equal- area projection.
2) Adjacent mean vectors are compared with the Fisher distribution.
3) The F test is then compared to the ratio obtained from the mean vectors tested to the theoretical frequency distribution with the same degree of freedom, and inspected for closeness of fit for a certain risk value.

This process is repeated within and between sectors of design in a structural domain. Then, the joint fracture sets of design are determined and the structural domains are optimized.

2.4 Influence of discontinuities on pillar stability.

Weakness planes reduce the pillars strength because they provide less strength to sliding (shear fracture). Sliding can occur if one or more planes transect the horizontal transverse section of a pillar. This can happen for a single plane Figure 1, and in this case, the movement occurs it will be along the plane. Also, the movement can occur in the directions of the lines of intersections if two or more weakness planes are present Figure 2.

The study and analysis of the stability for both modes of fractures can be performed using the methodologies developped by Tousell (1977), and Miller et al (1979).

2.5 Multiple openings in competent massive elastic rock.

The design techniques for multiple openings require a knowledge of the change in stress concentration around a single opening that results when additional nearby openings are created. Thus for multiple openings, it is the final stress distrxbution around the system of openings that is used for design purposes (Obert and Duvall, 1967). The results from photoelastic model studies of rows of various shaped holes in plates has established that the rate of increase of the maximun stress with the ratio ^~ (width opening/width pillar) is less than the rate of increase of the average stress in the rib pillar. Consequently, for larger values of Wo/Wp the average stress approaches the maximun stress concentration and the stress distribution in the rib pillar becomes more uniform. Because of this fact, the design of pillar support for romm- and pillar mining is generally based on the average stress in the pillar as determined by tributary theory.

An application of this theory for analyzing the stability of irregular pillars, irregularly spaced in a romm and pillar mining method is as follow:

$$\sigma p = \sigma v \frac{At}{Ap} \qquad (1)$$

$$Ra = 1 - \frac{\sigma v}{\sigma p} \qquad (2)$$

Where:

op : Average pillar stress
ov : Vertical applied stress before mining
Ap : Area of the pillar
Ra : Areal extraction ratio

Equation 2, can be rewritten as a design equation for IIa by replacing op by Cp/F, thus

$$Ra = 1 - \frac{F\sigma v}{Cp} \qquad (3)$$

$$Cp = C_1 \left[0.778 + 0{,}222 \frac{Wp}{Hp} \right. \qquad (4)$$

Where

Cp : Compressive strength of pillar.
C : Compressive strength of cubical specimen.
F : Safety factor usually between 2 to 4. Furthermore this paramenter consider the size effect.
Ao : Area of the stope

The design equation for random irregular pillars is sketched as follow.

$$\frac{Ap}{Ao} = \frac{F\sigma v}{Cp - F\sigma v} \qquad (5)$$

3 ANALÎSIS OF PILLARS STABILITÏ IN THE HAINHINES OF THE SAN ANTONIO MINING DISTRICT, (COQUIMBO REGION)

3.1 Geology:

The San Antonio copper district Ardila et al, (1991 a,b) is 24 km NW from La Serena. It includes several stratabound copper and iron (magnetite) skarn deposits. Some 200.000 t of copper ore (1.5-2.2 % Cu; 1-2 g/t au) have been mined but new drillings are necessary in order to retake production.Figure 3.

The mined orebodies are in two limestone beds of lower cretaceous volcano-sedimentary series (Arqueros Formation). The limestone beds are separated by porphyric flows of mafic andésites. The strata have a NO 40°- 60° W strike and dip 18° to 32° to the SW.

The lower mineralized limestone bed is 8 to 15 m thick, and enclose the Manto Siete and Union Mines, that have produced some 70.000 t of Cu ores, they are situated about 1500 m from the contact between the stratified rocks and a granodioritic batholite dated at 89- 98 M.y. (K-Ar; biotite), that is responsible for a 300 to 600 m wide metamorphic halo. The upper mineralized limestone bed, is 3 to 12 m thick. Its principal deposit correspond to the Fortuna Mine, located about 450 m from the batholite. This mine has produced some 60.000 t. of Cu ore.

The main orebodies have 75 to 120 m along the strike, are 20 to 80 m. wide and have a thickness of 3 to 6 m. their boundaries are rather irregular. Most abundant metallic mineral is magnetite. Pyrite and chalcopyrite are disseminated in bands parallel to the strata, as well as in veinlets. In the Fortuna mine, the host rock is skarn (garnet, epidote, amphibole and pyroxene). In the Manto Siete and Union Mines, that are at a greater distance from the batholite, the sulfides replace skarn minerals as well as magnetite, silicate of hydrothermal origin and limestone. However, the mineralization decreases in passing to the marble zone.

An important geological trait of the district is the

rvifi

presence of andesitec, dikes, some decimeters thick, that are N 35°- 75° W in strike and dip between 70° NE to 90°. they were emplaced before the metasomatic processes and are parallel to the elongation of the orebodies (and therefore, to their strike).

Two set of post-mineral faults are present. One of them includes high-angle normal fault, N 30°- 45° W in strike. The other one correspond to high angle thrust faults that are N- S to NNE in strike.

The orebodies are affected by supergene oxidation in the areas where they crop-out. Limonite, chrysocolla, malachite gypsum and jarosite are the main products of this process.

The host rocks are not affected by closely spaced fractures nor weakened by strong H^+ metasomatism. Instead, the skarn has produced a harder rock than the original limestone, a fact that is favourable for the pillar strenght and therefore, for the underground mining of the deposits.

3.2 Rock fabric elements of the mining district of San Antonio:

The collection of the geological information as much in surface as underground, was obtained from eight (8) random detail lines, located in the geological units of the mining district of San Antonio. Figure 3.

Figures 4 to 7, present examples of graphical representations of fracture sets of the detail lines, and major discontinuities from the report Proyecto Chile 28 (1971); in polar equal area projection (Schmidt). Furthermore we can see the most representatives modal concentrations in strike and dip of fracture sets, found with Poisson exponential binomial limit. Abel (1981).

Figures 8 to 10 and Table 1, present the mean orientations and the modal concentrations for strike and dip of the facture sets, obtained from underground, surface and surface-underground plots.

The analysis of the data indicates a good correlation between the principal fracture sets and the rock fabric. The following fracture sets for the San Antonio mining district were obtained:

Sı	N18E/73SE	5$_5$	N38E/88NW
5$_2$	N33E/73SE	S$_6$	N18E/83 NW
53	N38E/88SE	S$_7$	N48W/45H
5$_4$	N45W/88NE		

Five of these sets are sub parallel to the thrust faults system (Sı, S2, S3, S$_5$ and Se) and two of them, sub parallel to the normal faults systems and to the dikes (S4 and S7).

3.3 Analysis of pillar stability in function of the geological structure.

From the knowledge of the principal fracture sets of weakness, we proceeded to determine the influence that they should have on the stability of rooms and pillars, at the mines Fortuna and Union- Manto Siete.

We selected two representatives zones in the orebodies (Figures 11 to 13), and performed a survey of the actual geometry of rooms and pillars (see Tables 2 and 3 respectively). Next, we elaborated the different stereo plots of the pillars, considering the structural information defined at the mining district of San Antonio.

The analysis concluded that the possible problem of inestabilities would be of the wedge type (example Figure 14a and b). However, in the analysis no problems were detected that could affect the stability. Tables 4 and 5.

Generally, it can be concluded that the actual pillars analyzed at the mines, or others that could be developped with the same geometrical characteristics in the future, would have no inestability problem for the fracture sets present at the mining district of San Antonio.

3.4 Pillars stability analysis1

Due to the irregular shape of pillars, beside the random spatial location of them (Figures 11 to 13); the methodology of analysis employed in the determination of pillar stability, considered the theoretical concepts developed in section 3.5.

Values used at the design variables are sketched as f0II0W8.

1. Uniaxial compressive strength. Values for this variable were obtained from Brunner (1991). Averages corrected

values taken for cubical samples in the beds were:
Mine Fortuna: 120 MPa
Mine Union- Manto Siete: 124 Mpa

2. Overburden in situ stress (uv). This parameter is variable for each pillar, and it is determined considering the different geological lithologies found in the zone.
3. Area of extraction (Ao), Area of Pillar (Ap) values were obtained from Figures 11 and 12 respectively.
4. Factor of safety (F). This value was calculated from ecquations 4 and 5. For full stability values from 2 to 4 should be used in the analysis. Duvall (1982).

Tables 6 to 8, present values of the safety factors for the pillars analysed. An analysis of the data indicate that pillars at La Fortuna mine would be safe in the long range. However, the analysis of the pillars situation in level 908 of Mine Union- Manto Siete, indicated a dangerous deterioration of them; beeing under the limits of stability required at present. Furthermore, several stopes show some type of slabbing failure at the roof.

4. PRÄLIMINAR! CONSIDERATIONS OF THE UNDERGROUND MINING SYSTEMS TO BE IMPLEMENTED AT THE MINES LA FORTUNA UNION- MANTO SIETE.

The analysis of the future exploitation for Cu-Fe orebodies, located in the iron skarn will be based at a hypothetical situation of ore reserves in a similar geotechnical surrounding. This approach will consider the feasibility to exploit the orebodies, in an economical and rational way to a small mining scale.

The geometrical characteristics for both orebodies are sketched as follows:

Mine Fortuna
Strike direction dimension : 70 m
Thickeness : 4 m
Strength of ore and country rock: Fair to strong

Mine Union- Manto Siete
Strike direction dimension : 60 m
Thickeness: 8 m
Dip : 25° - 27°
Strength of ore and country rock : Fair to strong.

According to the characteristics above mentioned, the feasible mining system possible to be implemented are:

Fortuna Mine

Full face room and pillar. Figures 15 ant 16 respectively.

Union- Manto Siete Mine

Full face and bottom single bench. Figures 17 and 18 respectively.

5. CONCLUSIONS

The analysis of the data indicates that pillars in the Fortuna mine would be safe in the long range. However, the analysis of the pillars situation in level 908 of mine Union-Manto Siete, reveals a dangerous deterioration of them; beeing under the limits of stability required at present. Furthermore, several stopes showed some type of slabbing failure at the roof.

According to these partial conclusions, the mining system recommended to be adopted in case of a reopening of the district, are full face room and pillar (Fortuna mine) and full face and bottom single bench (Union and Manto Siete Mine). For smaller orebodies, open stoping with random pillars could provide a satisfactory alternative method.

Whichever of the mining system to be developped, the geometrical dimensions in the stopes should be 8 m (Fortuna) and 7 m (Uniön-Manto Siete); with an arrangement of square pillars of 1.5 x 1.5 m (Fortuna), and 3 x 3 m (Union- Manto Siete) respectively and obtaining an extraction ratio around 80%.

In cases of employing a method of exploitation by open stoping with random pillars it is not advisable to mantain an area of ore extraction larger than 120 m^2 without structural support. Naturally, this conclusions could be extended to other deposits presenting similar geological and geomechanical conditions.

6. REFERENCES

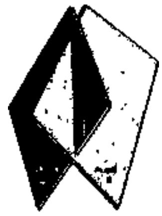
-Abel, J.F. 1981, Unpublished Lectures Notes Course Design of Underground Excavation. Mining Engineering Department. Colorado School of Mines. Golden Colorado, 80401. U.S.A.

- Ardila R., Carrascal, E.f Canchaya, S, Canut de Bon, C y Collao R. 1991; Geologia de los skarns cupriferos del distrito de San Antonio, Region de Coquimbo, Chile. 60 Congreso Geolögico Chileno V 1 p 253-255.
- Ardila, R., Carrascal, E y Oryarzûn J. 1991; Proposiciôn de un modelo genético para los yacimientos cupriferos tipo skarn de San Antonio y Panulcillo, Region de Coquimbo, Chile. 6Q Congreso Geolögico Chileno, V 1 p 256-260.
- Brunner, F.E., 1986. Estabilidad de taludes. 378 Convenciön Instituto de Ingenieros de Minas de Chile. Copiapö. Chile.
- Brunner, F.E., 1991. Propiedades fisicomecânicas del distrito minero de San Antonio de la franja de Lambert IV Region. Proyecto Naciones Unidas Santiago Chile. 31 paginas.
- Call, R.D. and others, 1976, Estimation of joint set characteristics from surface mapping data. 17 th Symposium of rock mechanics. Utah, U.S.A.
- Coates, D.F. 1965-1966, Pillar Loading Part I: "Littérature Survey and new hypothesis" R 168, 1965; Part II: "Model studies" R 170, 1965; Parte III: "Field Measurements" R 180, 1966; Part IV: "Inclined workings" R 192, 1966; Mines Branch (CANMET) Research reports, Queen's Printer, Ottawa.
- Duvall, W.I, 1982, Non caving systems. Design of noncaving mine openings, p 1472-1478. Underground mining methods handbook. W.A. Hustrulid. Editor Society of Mining Engineers of AIME, U.S.A.
- Miller, D.R. and Barrett, J.R. 1979. Jointed rockmass characteristics and their influence on slender pillars. In proceedings 20 th symposium on rock mechanics, Austin Texas, 1979. Pages 199- 208.
- Naciones Unidas, 1971, Distrito minero de San Antonio. Proyecto Chile 28 NU-ENAMI. Chile.
- Obert, L. and Duvall, W.I., 1967, Rock mechanics and the design of structures in rock. J. Wiley and Soons Inc. U.S.A.

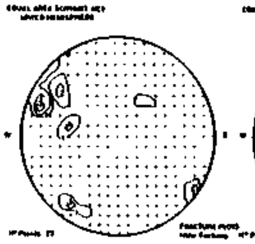
Oravecz, K. 1977, Analogue modelling of stresses and displacements in board and pillar workings in mines. International journal of rock mechanics and mining sciences. Vol. 14 NQ 1. p. 7-23.

Touseull, J.A. 1977, Stereographic method of determining whether planes of weakness transect pillars. Bureau of mines report of investigations RI 8232 U.S.A.

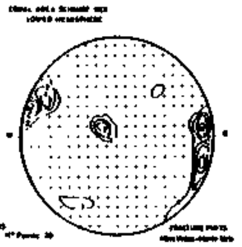
FIS. I PILLAR CUT 6 , 0 PLANE OFFRACTURE



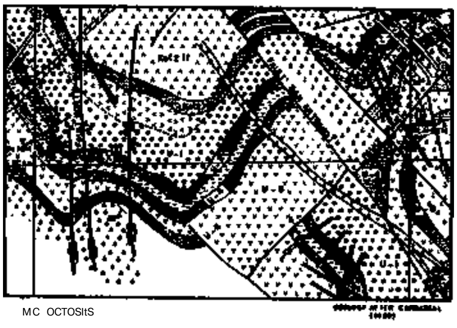
FI9.t ««MC OF INESTA8UTV



m* SCHMIDT PLOT MHC FORTUNA



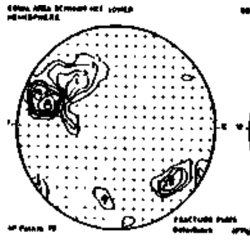
PH.S KNM0TPLOT MINEUNON-MAHTOSIETC



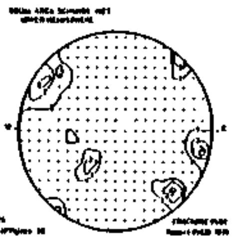
MC OCTOSltS

1 iHGtnliKi
I M1HI0 ilClt

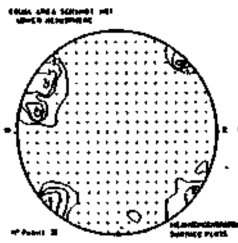
FIS 3 SCOLOSV OF MININS DISTRICT OF SAN ANTONIO



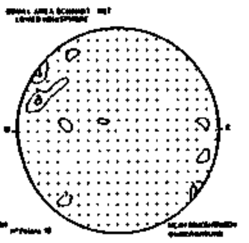
FIS. S SCHMIDT PLOT «TAK. LH*5



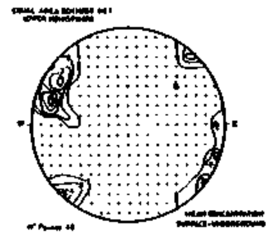
FiS. T SCHMıOT PLOT MINUS DISTRICT OF SAN ANTONIO



FIS. S MCAN CONCENTRATIONS SCHMIDT SURFACE PLOTS



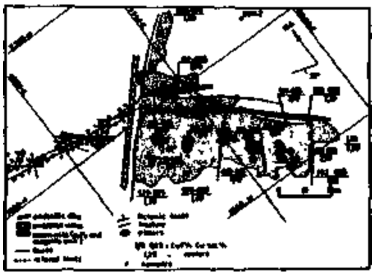
FIS. 9 MCANCONCCNTIIATIONS SCHMOT UND!RSR0UN0 PLOTS.



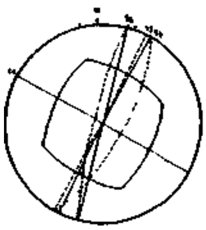
FIS. K) MCAN CONCENTRATIONS SCHMIDT UHWR9K0UÜO- SURFACE PLOTS

FW H PILLA«» CSNKMMO IN THf STtMLIT« «TUO» »T
UIM UNION - M»NTO »fTE

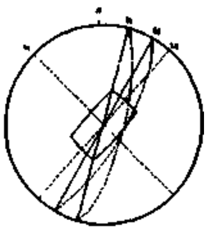
FM It PILLAR« CONSIDER«) »I THE «TAIILITV 9TUOT AT
MINE FORTUNA



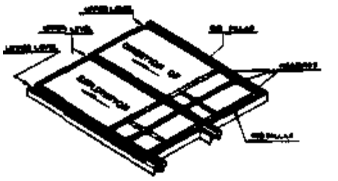
FM IS FULAR» CONMOERED IN THt STABILITY «TOO»
AT LEVEL SOS MINC MANTO SU T t IPHUO.-ISTIİ



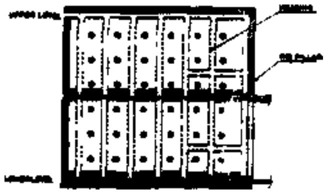
FM M« 1TERF.0 «JOT PLANES»!««)
«NTH INLLAR AT MM FORTUNA



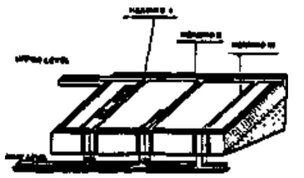
FM Mb STEREO FLOT PL»H€t»,>jl
WITH PS-LARS I-S AT
MM UMDN MANTO MITE



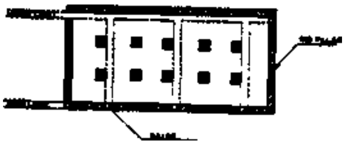
FA a PERSPECTIV« PANO. OF IXPLOTATIOH
AT MM LA FORTUNA



FM. M FLAN FAND. OF »FLOTATION MM FORTUNA



FW. IT PWSHLMW 1 PARC OF ««FLOTATION
AT NINE UNION- MANTO M T t



"*'* fi4"P*"B-0' KRLOTATION AT MKE
UNION-MANTO «ETI

Table 1 Fractures set mining district of San Antonio

Fracture set	Combined mean orientations (surface-under ground)		Mean orientations principal structures (report PMUD-71)	
A	N 18 E	73 SE	N 31 E	76 SE
B	N 33 E	73 SE	N 63 E	70 SE
C	N 38 E	88 SE	N 53 W	88 NE
D	N 45 W	88 NE	N 52 W	35 NE
E	N 38 E	88 NW	N 45 E	73 NW
F	N 18 E	83 NW	N 13 E	81 NW
G	N 48 W	84 SW	N 47 W	84 SW

Table 2. Geometrical characteristics of rooms and pillars at mine Union-Manto Siete

Pillar Nº	Pillar width (m)	Pillar length (m)	Strike of axial axis of pillar (°)	Strike of transverse axis of pillar (°)	Pillar height (m)	Stope width (m)	Pillars alignment (°)	A (°)	λ (°)
1	1.40	3.60	N45W	N45E	5.5	11.3	N70E (P1-P2)	75	63
2	3.8	4.10	N30E	N60W	7.8	9.6	N15W (P2-P3)	69	62
3	1.5	2.8	N70E	N20W	5.6	7.2	N30W (P3-P4)	75	70
4	1.0	1.8	N40E	N50W	5.3	7.2	---	79	71
5	1.2	1.7	N45W	N45E	4.7	8.0	N57W (P4-P5)	76	63

Table 3 Geometrical characteristics of rooms and pillar at mine Fortuna

Pillar Nº	Pillar width (m)	Pillar length (m)	Strike of axial axis of pillar (°)	Strike of transverse axis of pillar (°)	Pillar height (m)	Stope width (m)	Pillars alignment (°)	a (°)	A (°)
1	1.0	1.00	N45W	N45W	1.0	---	---	66	49
2	2.1	2.3	N60W	N30E	1.8	6.4	N42E (P1-P2)	66	44
3	1.6	2.2	N45E	N45W	4.8	10.3	N30W (P3-P2)	66	49
4	1.6	2.9	N40W	N50E	4.7	8.4	N52E (P4-P3)	64	45
5	1.7	4.6	N15W	N55E	2.2	14.2	N55E (P5-P4)	66	45
6	0.9	2.9	N50W	N40E	2.5	2.9	N2E (P6-P5)	71	42
7	1.2	3.7	N55W	N35E	3.5	7.7	N75E (P7-P6)	71	42
8	1.5	4.2	N50E	N40W	2.9	3.5	N8 (P8-P7)	66	49

Table 4 Determination of the geometric parameters of the wedges. Mine Fortuna

Pillars	Fractures system	Q_1 (°)	Q_2 (°)	Mar (°)	(°)	(°)	Q_{1m} (pillar) (°)	Q_{2m} (pillar) (°)	H_p (pillar) (m)	W_p (pillar) (m)	D_w (pillar) (m)	Z_p (pillar) (m)
1-3-8	S_2-S_5	12	4	31	64	24	14.7 1 9.0 3 15.1 8	22.0 1 18.5 3 31.7 8	1.80 1 4.08 3 2.85 8	1.9 1 1.60 3 1.5 8	0.87 1 2.34 3 1.30 8	2.34 1 6.82 3 4.05 8
2	S_2-S_5	4	1	14	43	83	12.5	10.2	1.8	2.10	1.92	8.29
2	S_1-S_4	12	4	31	43	98	50.2	49.4	1.8	2.10	1.93	2.03
2	S_3-S_5	6	1	19	42	80	26.6	16	1.8	2.1	2.0	4.33
4-5	S_2-S_5	4	1	18	44	105	7.30 4 21.4 5	7.9 4 21.8 5	4.7 4 2.3 5	1.6 4 1.70 5	4.9 4 2.3 5	12.83 4 5.6 5
4-5	S_3-S_5	6	1	18	44	105	2.30 4 21.4 5	7.9 4 21.8 5	4.7 4 2.2 5	1.6 4 1.70 5	4.9 4 2.3 5	12.83 4 5.6 5
4-5	S_1-S_5	12	4	31	44	121	17.2 4 50.6 5	18.8 4 37.1 5	4.7 4 2.2 5	1.6 4 1.7 5	4.9 4 2.2 5	9.4 4 2.5 5

TABLE 5. Determination of the geometric parameters of the wedges. Mine Union- Manto Siete.

Pillars	Fractures system	Q_1 (°)	Q_2 (°)	Mam (°)	(°)	(°)	Q_{1m} (pillar) (°)	Q_{2m} (pillar) (°)	H_p (pillar) (m)	W_p (pillar) (m)	b_p (pillar) (m)	Z_p (pillar) (m)
1-5	S_2-S_4	11	4	30	64	114	12.4 (1) 8 (5)	13.1 (1) 8.50 (5)	2.50 (1) 4.7 (5)	1.80 (1) 1.2 (5)	2.70 (1) 2.30 (5)	8.2 (1) 2.0 (5)
1-5	S_2-S_3	32	3	52	64	94	29.4 (1) 11.3 (5)	37.7 (1) [illegible] (5)	5.5 (1) [illegible] (5)	1.4 (1) [illegible] (5)	2.7 (1) [illegible] (5)	3.9 (1) [illegible] (5)
1-8	S_1-S_{10}	30	2	45	62	8	11.7 (1) 10.7 (8)	11.9 (1) 14.9 (8)	5.5 (1) 4.7 (8)	1.4 (1) 1.2 (8)	2.9 (1) 2.38 (8)	4.9 (1) 3.5 (8)
1-8	S_1-S_3	84	87	73	74	72	66.3 (1) 65.7 (8)	102.3 (1) 81.3 (8)	5.5 (1) 4.7 (8)	1.40 (1) 1.2 (8)	1.6 (1) 1.4 (8)	9.9 (1) 9.8 (8)
2	S_2-S_4	8	11	31	69	84	12.7	10.5	7.8	3.0	3.8	11.4
2	S_1-S_3	3	156	51	69	70	32	31	7.8	3.0	3.2	4.7
2	S_3-S_5	30	2	45	69	84	24	22.7	7.8	3.0	3.2	6.2
3	S_2-S_4	4	11	30	68	42	7.9	8.4	5.6	1.5	2.3	8.6
3	S_1-S_3	4	156	51	73	82	19.5	17.7	5.6	1.5	1.7	2.7
3	S_3-S_5	10	2	46	72	96	15.7	15.3	5.6	1.5	1.8	4.5
4	S_2-S_4	4	11	31	70	73	7.1	6.0	5.3	1.0	1.1	8.3
4	S_1-S_3	4	156	51	79	88	15.3	14.3	5.3	1.0	1.03	3.0
4	S_3-S_5	10	1	46	79	96	12.7	11.5	5.3	1.0	1.03	4.4

Table 6 Pillars stability at level 908. Mine Union- Manto Siete (1971)

Pillar Nº	Effective area of pillar (m^2)	Vertical stress (MPa)	Extraction area (m^2)	Factor of safety considering correction by size and shape
1	12.50	1.32	169	6.40
2	22.30	1.30	155	11.90
3	17.40	1.65	131	8.78
4	24.80	2.0	71	16.20
5	12.40	2.28	93	6.63

Table 7 Actual pillars stability at level 908. Mine Union-Manto Siete.

Pillar Nº	Effective area of pillar (m^2)	Vertical stress (MPa)	Extraction area (m^2)	Factor of safety considering correction by size and shape
1	7.20	1.32	174	3.20
2	9.80	1.30	168	4.35
3	3.00	1.65	118	1.32
4	2.72	2.04	93	1.46
5	2.50	2.20	103	1.14

Table 8 Actual pillars stability at mine Fortuna.

Pillar Nº	Effective area of pillar (m^2)	Vertical stress (MPa)	Extraction area (m^2)	Factor of safety of de pillar
1	1.30	0.58	52	4.5
2	2.10	0.73	85	4.8
3	2.90	0.75	194	3.70
4	3.70	0.53	83	8.0
5	4.25	0.33	101	13.7
6	2.80	0.25	56	22.5
7	3.85	0.28	49	27
8	3.50	0.23	66	17.6