MacGregor, D.P., The Application of Mining Rock Mass Rating (MRMR) to the design of open stoping layouts on BCL, Selebi-Phikwe.
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The Application of Mining Rock Mass Rating (MRMR) to the design of open stoping layouts on BCL, Selebi-Phikwe.

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The 3M section of the mine utilises an open stoping method of mining. Crush pillars are spaced 15.0m apart on dip and strike. The mine uses pillars and rock bolts as the in-stope support. Drilling into the hanging wall to obtain core samples is done to allow rock mass ratings to be calculated. An adjusted MRMR is then obtained and plotted against the hydraulic radius. This allows the span between the pillars to be adjusted.

Introduction

BCL Limited is a nickel and copper mining and smelting operation in the east of Botswana. The operation consists of a smelter at the main site with three mines providing ore. Additionally the smelter toll treats ore from other sources. The No 3 shaft is split into two sections, namely the Phikwe Central and South East Extension. The Selebi North mine is located 8km from the main site and the Selebi mine is 15 km away. The various mining methods are shown in table 1.

Mining Method	Type	Location	Dip Degrees	Thick-ness	Primary Support
Cut and fill	Massive	Phikwe	0 to 75	6 m to 100m	Using fill and 3m post pillars
Open stoping Breast Mining	Tabular	Phikwe	0 to 20	3m to 6m	Using 3m and 5m pillars
Open stoping	Tabular	South East Extension	30	2m to 4m	Using 3m rib pillars
Sub-level open stoping	Vein	Selebi North	75 to 90	2m to 20m	Using a moving cone method
Open stoping	Massive	Selebi	40 to 60	3m to 15m	Using 5m pillars

Figure 1. Mining methods used

Geology

Location

Selebi Phikwe is an unique metallogenic district where large Ni-Cu sulphide deposits are preserved in late Archaean granulite facies grade rocks in the Limpopo Belt, eastern Botswana (Figure 1). Metal zonation is extremely variable, and preservation of any large-scale variation is vague within the massive mineralisation of each deposit. The increased tenor of Ni and Cu from base to hangingwall can be inferred to reflect repeated injections of magma that allowed crystallisation after sulphur saturation. (Hoffmann, 2002).

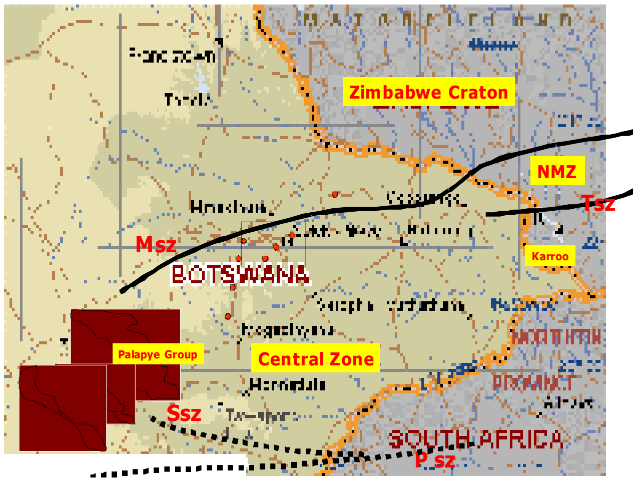

Figure 1. Regional Geological setting

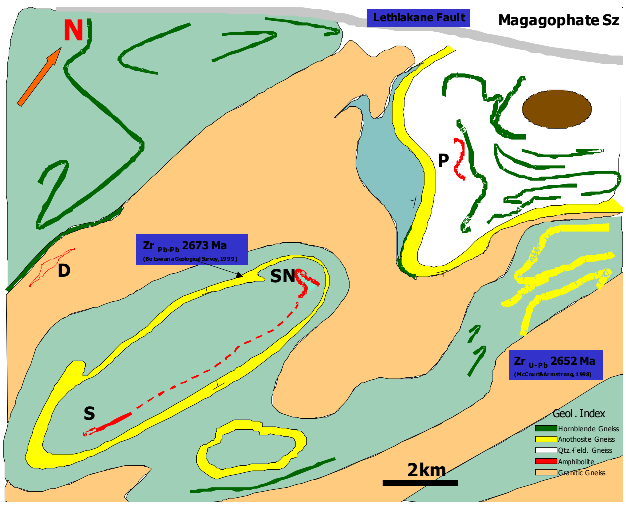

Figure 2. Position of ore bodies and surface geology.

- P – Phikwe
- SN – Selebi North
- S – Selebi
- D - Dikoloti

In Selebi Phikwe, three Ni-Cu base metal sulphide deposits (Phikwe, Selebi and Selebi North) occur along the northern margin of the Limpopo Belt's Central Zone and rank's as a major Ni district on the continent (figure 2). The strata-bound sulphide mineralisation is hosted within an amphibolite derived from a mafic magma which intruded in response to a collisional tectonic regime. Intense deformation events have resulted in modification of the regional trending east-west fabric, and structural control on the Ni-Cu ore-shoots is evident.

Stratigraphy

A generalised stratigraphic column (figure 3) and an orebody stratigraphic column (figure 4) together illustrate the geological succession of the mine.

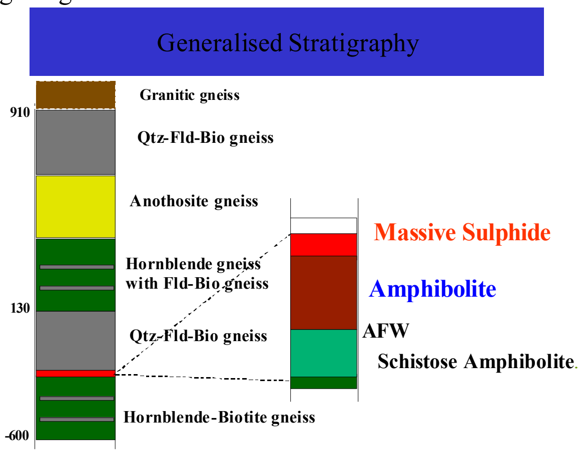

Figure 3. Generalized stratigraphic column

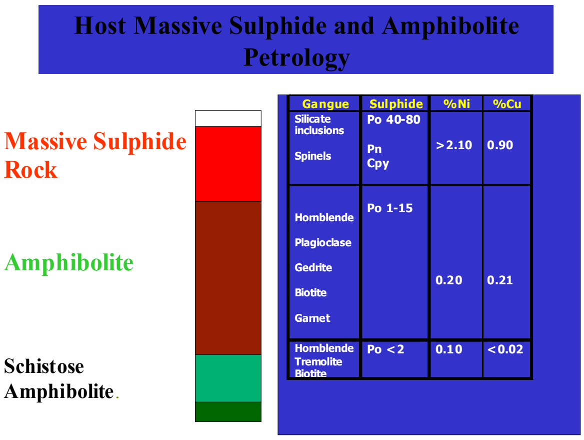

Figure 4. Orebody

Structure

The Selebi Phikwe metallogenic district can be divided into an earlier (ca. 2700 Ma) banded sequence of hornblende-, quartz-biotite- and feldspar-rich banded gneisses and a later granitic gneiss (U-Pb zircon age 2652 Ma). The stratabound-mineralised horizon at each deposit occurs at a similar stratigaphic horizon, conformable with respect to hornblende-rich footwall gneiss and quartz-biotite rich hangingwall gneiss. These late Archaean granulite facies grade rocks of the Central Zone are separated from the Northern and Southern zones by the Magogaphate and Palala shears, respectively, and are considered as major discontinuities in the tectonic-genetic models for the Limpopo belt. Two prominent macro structures, the Selebi Synformal Basin and the Phikwe Antiform, host and control the location of the deposits in tight and open folds.

The orebody-thickness at each deposit varies significantly in the strike and dip directions, and are attenuated (0.2-0.5 metres-thick) at the margins by late D_2 shears that trend ENE at Phikwe and Selebi. Thickening of the orebody at Phikwe 20-60 metres can be considered in terms of tectonic duplication related to syn-F_2 thrusting. The broad 'Thick Zone' at Phikwe trends sub-parallel with the major ENE shears. Prominent ore shoots at Selebi and Selebi North are sub-parallel with the trace of major F_1, F_2 and F_3 fold structures, respectively.

The gneisses forming the country rock of the Selebi-Phikwe orebodies can be divided into two main groups. The first is a suite of well-banded hornblende gneiss, grey quartzo-feldspathic gneiss, anorthosite, minor magnetite quartzite and marble, and the second a group of granitic gneisses.

Geotechnical parameters

State of stress

The in situ stresses were determined by the CSIR (Janssen-Schmidt,1992) and rotation of them done by Genmin Rock Engineering Department (Spencer, 1993). These have been converted to a rate of MPa per metre of depth.

		Depth	Vertical (Z)	Strike (X)	Dip (Y)
RM1	3#	810	0.0448	0.0278	0.025
RM2	3#	750	0.0438	0.049	0.035
RM3	Selebi	650	0.0456	0.011	0.021
	Average		0.045	0.029	0.027

Table 2. Stress Measurements

Rock strength

Various tests have been done on the main rock formations on the mines and are summarised in the draft code of practice (Macgregor and Hogan, 2003).

Rock Type	Density kg/m³	Young's Modulus GPa	Poisson's Ratio Median	UCS Min-Max Mpa
Hanging wall gneiss	2769	78	0.19	101 – 233
Massive Sulphide	2730	81	0.23	119 – 200
Amphibolite	3053	89	0.2	127 – 155
Footwall gneiss	2787	91	0.19	96 – 176
Dyke	2945	98	0.27	272

Table 3. Mechanical rock properties

Previous Work

Cut and fill stopes

Coggan et al (1992) used the MRMR to assist with the design of the post pillar cut and fill stopes in the Phikwe area (table 4). This resulted in a span of 15m being adopted which was applied to the adjacent open stoping in the 3M section.

Rock type	RMR	MRMR	RMS	DRMS	Mining span (m)	Hydraulic Radius
Hanging wall gneiss	72	52	81	58	25	12
Massive Sulphide	63	41	53	35	20	8
Host Amphibolite	55	33	41	25	15	6
Micaeceous Amphibolite	41	24	27	16	9	3
Footwall gneiss	70	50	74	50	25	12

Table 4. Ratings obtained by Coggan

Support strategies

For the past thirty years the main primary support on the mine has been pillars and 2m re-bar. The pillars have changed from non-yield pillars to yield pillars as the mine has progressed deeper. Re-bar is installed with Ordinary Portland cement and spaced 1m apart in dip and strike directions. Wedge and dome failures are the biggest ground control problems. A classification of the cut and fill stopes determines whether additional 10m (38 ton) cable bolts need to be installed. In the cut and fill stopes after the initial cut, systematic cable bolting is possible.

Figure 5. Drilling of cable bolts in cut and fill stopes

Open stoping mining

Layout

Twin raises are developed either side of a central 5m rib pillar. A modified bord and pillar method of extraction is used. Fifteen metre panels are mined from the raises leaving 5m by 5m pillars between stopes (figure 6).

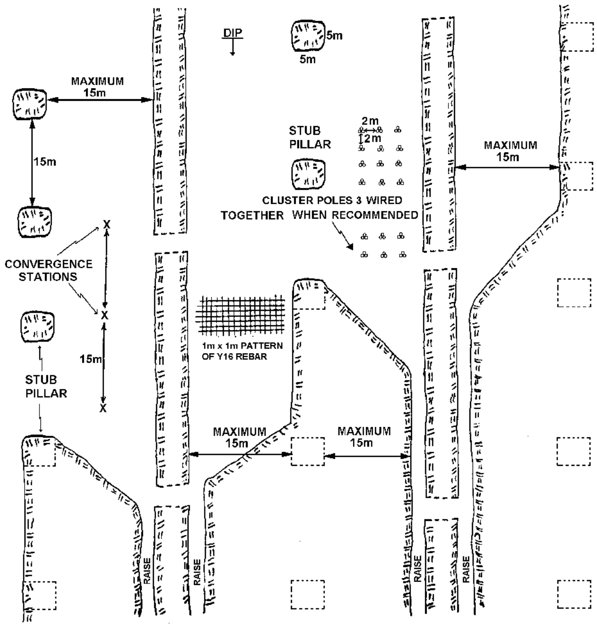

Figure 6. Open stoping mining method

Stability

Wedge and dome failures have occurred in this section. In the cut and fill stopes the roof of the stope mainly consists of the orebody. This means that doing a rock mass classification of the sidewalls will be representative of the roof conditions. In the open stoping area the roof of the excavation is hangingwall gneiss. Classifying the exposed roof does not give a representative rating, since the weak overlying parting planes are not assessed.

Rock mass classification

In order to rate the hangingwall gneiss above the excavation, the Geology department drilled additional core holes in the roof. Eleven holes spaced 20m apart on dip (figure 7), were drilled at a depth of 835m.

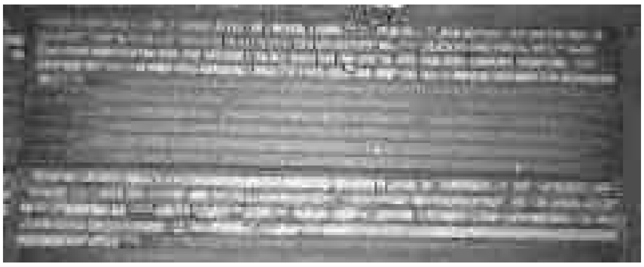

Figure 7. Cores drilled in hangingwall gneiss

Six metre holes were drilled in two adjacent raises and the cores rated (table 5). Laubscher's classification system was used for the MRMR's (Laubscher, 1990).

	Hole No	Length	Fractures	RQD	F/m	RMR	MRMR	RMS	DRMS
1	GT 11771	3.3	33	54	10.0	50	21	46	26
2	GT 11772	6	56	45	9.3	49	21	44	25
3	GT 11773	6	56	71	9.3	53	23	49	28
4	GT 11774	6	78	29	13.0	45	19	40	23
5	GT 11775	6	100	8	16.7	42	18	36	20
6	GT 11776	6	57	64	9.5	52	22	48	27
7	GT 11777	6	71	51	11.8	49	21	45	25
8	GT 11778	6	113	4	18.8	44	19	39	22
9	GT11770	6	108	3	18.0	41	17	35	20

10	GT 11769	6	76	56	12.7	46	19	40	23
11	GT 11768	6	54	58	9.0	51	22	47	27
Total/Average		63.3	802	40	12.7			Mpa	Mpa

Table 5. Rock mass ratings.

Spans and Hydraulic radii

Hydraulic radii for each mining method were calculated (table 6).

	Short span m	Long Span m	Area m²	Circumference m	Hydraulic Radius
Cut and fill	15	100	1500	230	6.5
Phikwe Open stopes	15	100	1500	230	6.5
South East Ext	20	200	4000	440	9.1
Selebi	20	100	2000	240	8.3
Selebi North	60	100	6000	320	18.8

Table 6. Hydraulic radius

The Adjusted MRMR's were plotted against the Hydraulic radii. These ratings were compared with other areas on the mine (figure 8).

By reducing the span in the open stope the hydraulic radius was reduced from 6.5m to 4.1m. This resulted in a shift towards the stable zone. With the decreased span and the installation of the normal 2m rebar, the potential for wedge and dome failures has been considerably reduced. Monitoring of these stopes continues and where instabilities are found additional support in the form of cable bolting is done. Should it be considered unsafe to install additional support, these areas are abandoned.

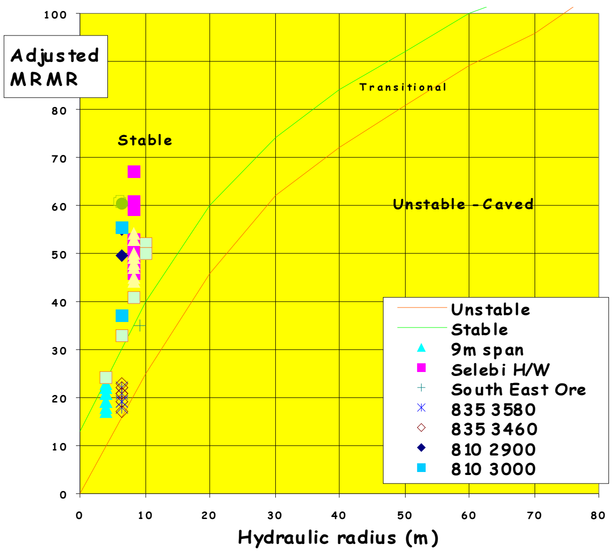

Figure 8. Adjusted MRMR vs Hydraulic radius.

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