

## **AN ASSESSMENT OF PENTLANDITE OCCURRENCE IN THE RUN OF MINE ORE FROM BCL MINE (BOTSWANA) AND ITS IMPACT ON THE FLOTATION YIELD.**

Antoine F. Mulaba – Bafubiandi<sup>1</sup> and Oaitse Medupe<sup>2</sup>.

*1: Mineral Processing and technology Research Group, Department of Extraction Metallurgy, Faculty of  
Engineering and the Built Environment, University of Johannesburg, POBox526 Wits 2050, South Africa.  
[amulaba@uj.ac.za](mailto:amulaba@uj.ac.za)*

*2: BCL Mining and Smelting. Concentrate Preparation Department, PO Box 3 S/Phikwe, Botswana  
[omedupe@bcl.bw](mailto:omedupe@bcl.bw)*

### **Abstract**

The feed to the BCL concentrator is made of the ore from Phikwe No3 shaft, Selebi shaft and Selebi North shaft. The receiving bin of the concentrator has daily throughput of 7869mt live capacity of ore with feed grade from underground operation of 0.70%Ni, 0.75% Cu and 0.05% Co. The valuable minerals in the ore are Pentlandite, Chalcopyrite. Cobalt is present mainly in the solid solution in pentlandite. The common non-sulphides minerals are Amphibolites, quartz, micas, and Feldspar while pyrite and pyrrhotite are the major gangue sulphides. Pyrrhotite contains between 0.1% and 1% Ni in solid solution. From the mineralogical investigation, it was found that approximately 65% of the pentlandite in the ore occurs as exsolutions in the pyrrhotite and the grain sizes ranges from 8 to 38µm. about 25% of the nickel bearing pentlandite is medium grained and subhedral. This kind of pentlandite occurs along the cracks of pyrrhotite or as inclusions in pyrrhotite. The rest of pentlandite present is disseminated in the gangue matrix. Because of the fine occurrence of pentlandite, fine grinding was conducted in order to improve the recovery as well as the concentrate quality. A series of subsequent flotation test were performed in order to evaluate grinds of 35, 40, 45, 50, 60 and 80% passing 75µm. It was observed that

- The mass pull increased together with increasing fineness of grind
- Similar nickel recoveries were obtained at 35 and 40% passing 75µm but from 50% and 60% the grind was seen to adversely affect the nickel recovery. At 80% passing 75µm the recovery increased by small amount.
- Flotation kinetics showed higher initial nickel recoveries but these did not translate into higher final recoveries.
- Grinding finer than 80% passing 75µm yield very high grades of the concentrate in the first minute of the flotation test, and the grade is dramatically reduced in the fifth minute of the test.

It was concluded that the current grind of approximately 48% passing 75µm is close to the optimum and no significant benefit were found to be associated with finer primary grinds. The inconsistency of the grade and recovery as well as the pentlandite losses will be discussed.

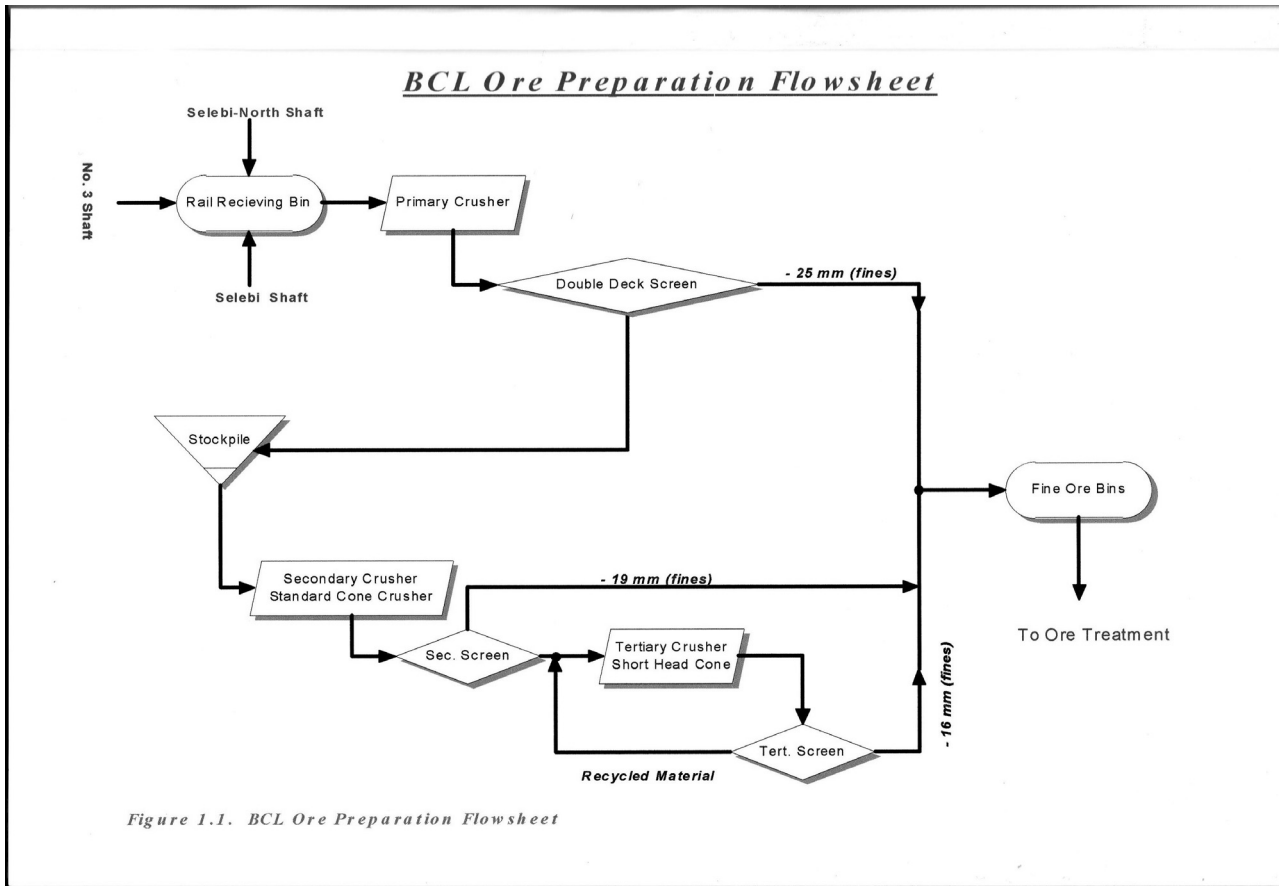
**Keywords:** *Pentlandite, Nickel losses, Grain size, Flotation*

## **INTRODUCTION**

### **BCL concentrator operation**

The ore from Phikwe No3 shaft, Selebi Shaft and Selebi North shaft is transported by rail to a 1500mt receiving bin ahead of the primary crusher. The receiving bin has a daily throughput of 7869tons of ore with feed grade from underground operation of 0.70% Ni, 0.75% Cu and 0.05% Co. custom feed are also processed. The valuable minerals in the ore are pentlandite, chalcopyrite. Cobalt is present mainly in solid solutions in pentlandite. The common non-sulphides minerals are amphibolites, quartz, micas, and feldspar while pyrite and pyrrhotite are the major gangue sulphides. The pyrrhotite contains between 0.1% Ni and 1% Ni in solid solution.

The copper/nickel ore are crushed into three stage dry crushing plant and then ground in separate circuits. Concentration by flotation and magnetic separation produces a concentrate assaying approximately 3.5% Ni and 4.75% Cu. The concentrate then pumped in slurry form to the BCL smelter. Figure 1.1 and figure 1.2 shows the ore preparation flow sheet and the ore treatment flow sheet respectively.



**Figure 1.1:** BCL ore preparation flowsheet



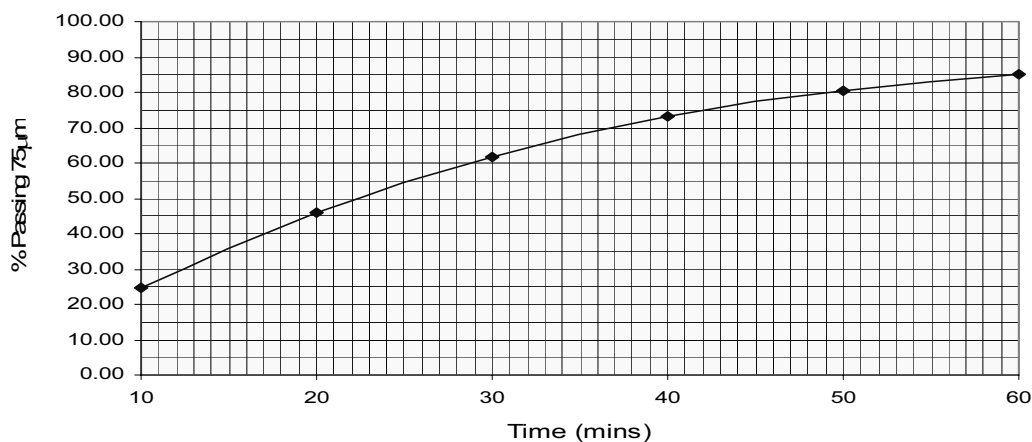
BCL concentrator sends the tailings to the tails dam at a nickel grade of 0.13%, of late the tailings grade has been found to be inconsistent. This increase in grade shows some nickel losses to the tailings. The inconsistent nature of the tailings grade results in lack of consistency in the nickel recovery as well. This problem may be attributed to a number of things such as: Incomplete liberation of the nickel bearing minerals, lack of blending facility, availability of fines, and wrong dosages. A number of projects have been carried out in order to investigate the above-mentioned possible problems.

Because incomplete liberation is a function of particle size and the mineral occurrence, the project was aimed at investigating the occurrence of pentlandite and its grain size in the ROM ore of BCL mine, as well as optimizing their flotation yield.

## EXPERIMENTAL

### Sample material and methods

Samples of primary crusher feed were taken from the rail bin on shift basis in order to get a representative sample from the entire three BCL shaft. The bulk of the samples were subjected to cone and quartering in order to reduce the mass to 150kg. The 150kg sample was packed in sealed matte bags and then sent to the University of Johannesburg. In order to prepare the sample for the test, it was crushed to -5mm using the laboratory jaw crusher, cone crusher and the roll crusher respectively. The crushed ore was then subjected to mass reduction using the Jones riffler and the rotary splitter where 1000g sample was used to establish a milling curve for this material in a laboratory ball mill at 60% solids. Figure 2 below shows the milling curve (expressed as percentage passing



**Figure 2:** Milling curve expressed as percentage passing 75µm versus milling time.



**(b) Disseminated ore: 40 to 70% sulphides.** The distinction between disseminated ore and type (a) is not abrupt, the massive ore grading into disseminated ore with increasing amounts of gangue. Pyrrhotite again is usually the dominant sulphides although disseminated chalcopyrite ore are common. Sulphides grain size is usually finer in the disseminated ore type, the sulphides being interstitial to the gangue minerals which may attain a size of several centimeters.

**(c) Stringer ore:** this consists of veins and vein lets of sulphides varying from 1mm to 5cm in the thickness traversing and anastomosing in matrix of gangue. It forms much-localized patches in the ore body, usually close to or at the ore contacts. The sulphides consist of the usual assemblage of pyrrhotite-chalcopyrite.

### Mineral constituents of the ore

#### Minerals

#### Chemical formula

Pyrrhotite	$Fe_{1-x}S$
Chalcopyrite	$CuFeS_2$
Pentlandite	$(FeNi)_9S_8$
Pyrite	$FeS_2$
Bravoite	$(FeNi)S_2$
Magnetite	$Fe_3O_4$
Ilmenite	$FeTiO_3$
Cuprite	$Cu_2O$
Goethite	$HFeO_2$

#### Gangue

The gangue is composed of : Hornblende, Biotite, Quartz, Feldspar, Chlorite, Sericite, Garnets, Anthophyllite, and Tremolite.

### MINERAL DESCRIPTIONS:

#### Pyrrhotite

The pyrrhotite is typically a pale yellow with a distinct pink tint. It is faintly bireflent and anisotropic in greenish greys. Hardness is medium and reflectivity ranges from 30.5% to 32.5%. Grain size varies from 0.1mm to 5mm with the mean of about 1.0mm. Individual grains are anhedral to subhedral.

In the massive ore, pyrrhotite forms a matrix including all other sulphides and gangue minerals. Where gangue is more abundant the texture is typically xenoblastic, the pyrrhotite having smooth boundaries with gangue minerals. However, in contact with

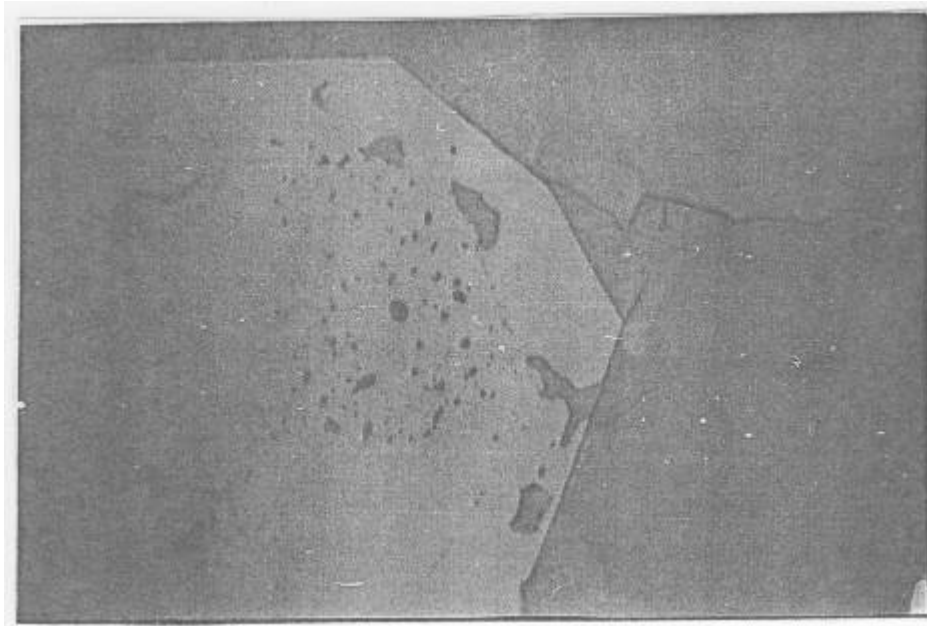
porphyroblasts of hornblende, pyrrhotite occasionally shows a denticulate or strongly penetrative margin. In some cases, where pyrrhotite is very much the dominant mineral and the texture can be described as being coarsely granoblastic.

Pyrrhotite occurs filling the cracks in gangue, as inclusions in gangue and other sulphides. Individual grains and whole masses of pyrrhotite frequently show oriented fracture which are bent in continuous feature throughout the specimen. These fractures are added advantage as far as crushing is concerned because during crushing it will break along these cracks very easily with less energy. Inclusions in pyrrhotite consist of pentlandite, chalcopyrite, and magnetite. Bravoite and gangue.

### **Chalcopyrite**

It is greenish yellow, anisotropic (weakly), very much softer than pyrrhotite with a reflectivity varying from 38% to 40%. It occurs as irregular masses of extremely variable size from few microns to centimeters across and is invariably anhedral and xenoblastic. Frequently it occurs rimming gangue and magnetite and occasionally pyrrhotite although more usually it is interstitial between pyrrhotite grains.

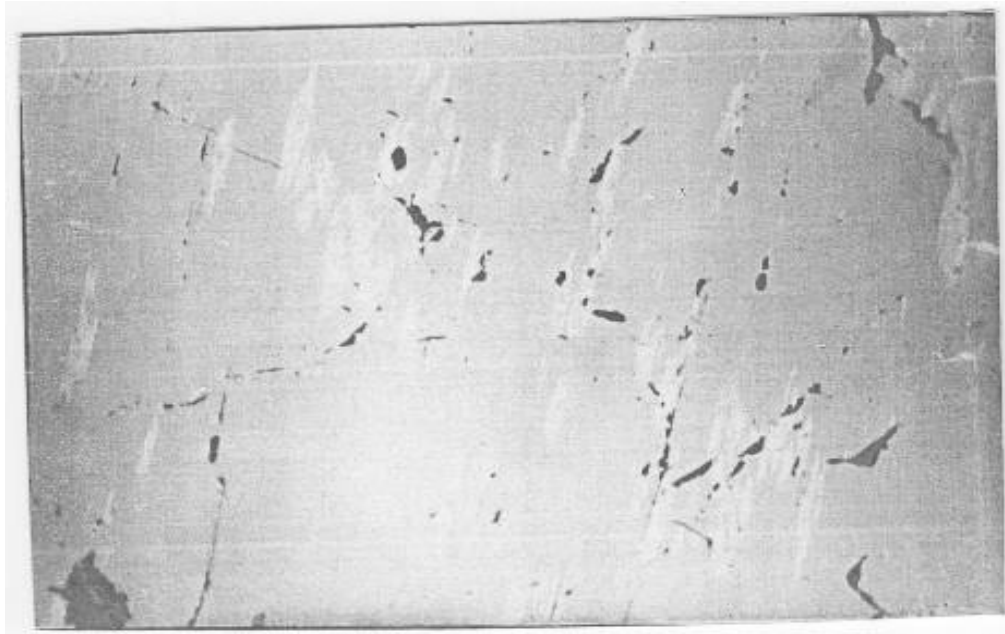
In disseminated ore, chalcopyrite may be the dominant sulphides occurring as interstitial sulphides in the gangue. It is abundant as irregular, bleb like or spherical inclusions in gangue and magnetite and occasionally in pyrrhotite. Chalcopyrite occur as large as (up to 2cm) masses replacing pyrrhotite in which relict grains of pyrrhotite are visible, the boundaries of which are outlined by irregular veinlets of pentlandite and irregular lines of inclusions of pyrrhotite and gangue within chalcopyrite. Unreplaced lamellae of exsolved pentlandite are occasionally visible and infrequently islets of unreplaced pyrrhotite occur. In some cases, chalcopyrite can be seen replacing pyrrhotite but leaving pentlandite lamellae, which had exsolved along the boundaries of the pyrrhotite grains. Chalcopyrite is relatively free of inclusions except where it can be seen replacing the pyrrhotite.



**Figure 3:** Euhedral Pyrite in pyrrhotite with inclusions of chalcopyrite

### **Pentlandite**

Pentlandite is a pale creamy yellow, isotropic (occasionally anomalously anisotropic) softer than pyrrhotite, harder than chalcopyrite, with reflectivity of 49%-52%. It characteristically occurs as flame like lamellae inclusions in pyrrhotite and as interstitial, equigranular, subhedral veinlets in pyrrhotite. The lamellae vary from a few microns to 1mm in length and up to 0.1mm wide. Pentlandite grains in the veinlets may be up to 1mm across

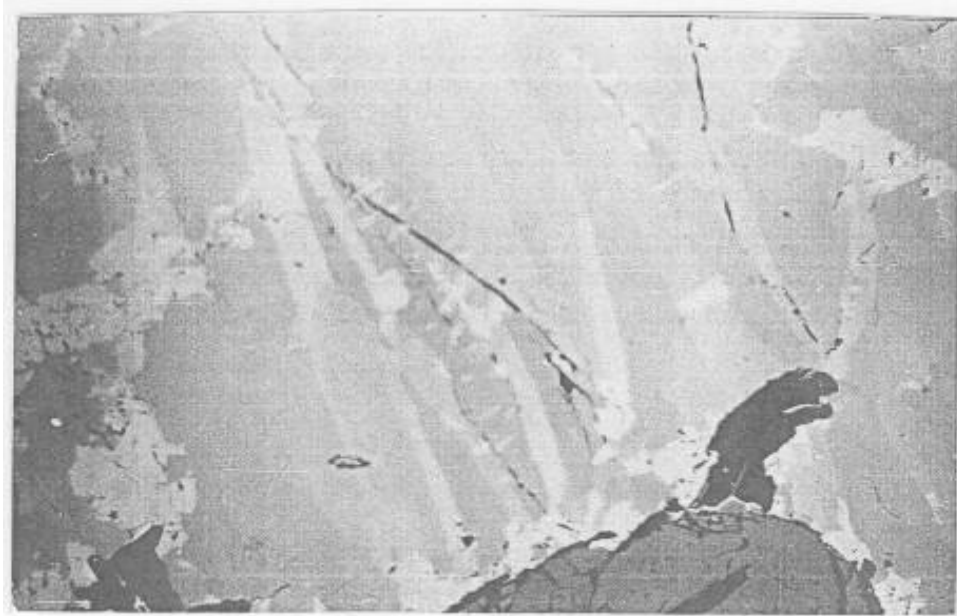


**Figure 4:** Flame like pentlandite exsolutions lamellae in pyrrhotite

Under high magnification the lamellae can be seen to consist of an oriented intergrowth of pyrrhotite and pentlandite, the orientation being related to the crystallographic directions of pyrrhotite.

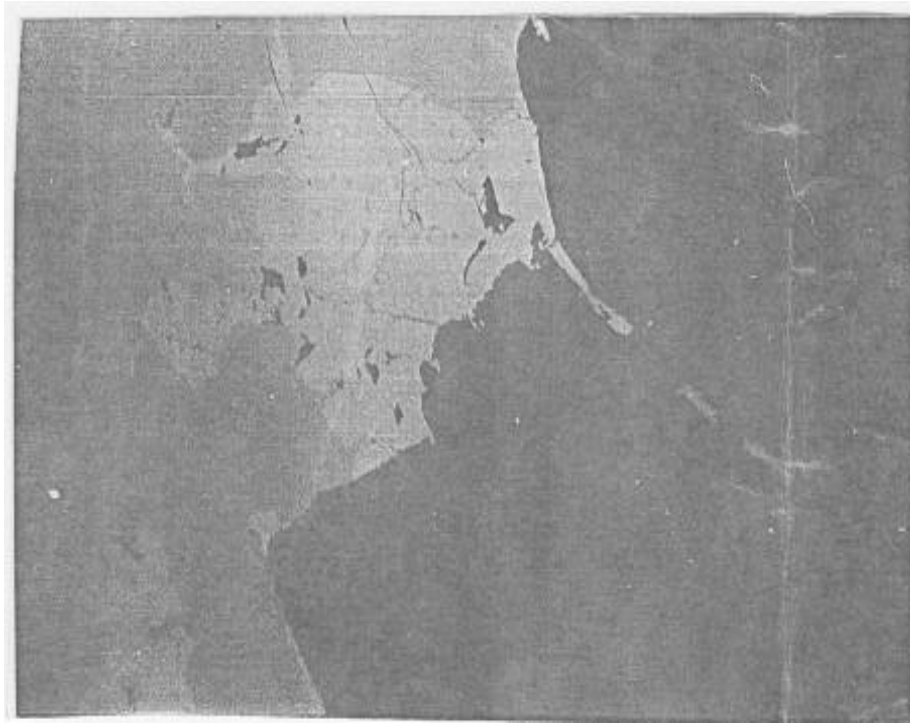
Granular pentlandite is usually restricted to pyrrhotite grain boundaries, where it appears to be interstitial, and rims around inclusions in the pyrrhotite. It occasionally bears interstitial chalcopyrite but also penetrates cracks in gangue and magnetite.

Frequently granular pentlandite appears to adopt a lamellar habit along contacts with pyrrhotite, individual grains of pentlandite passing into lamellar pyrrhotite at the pentlandite/pyrrhotite interface.



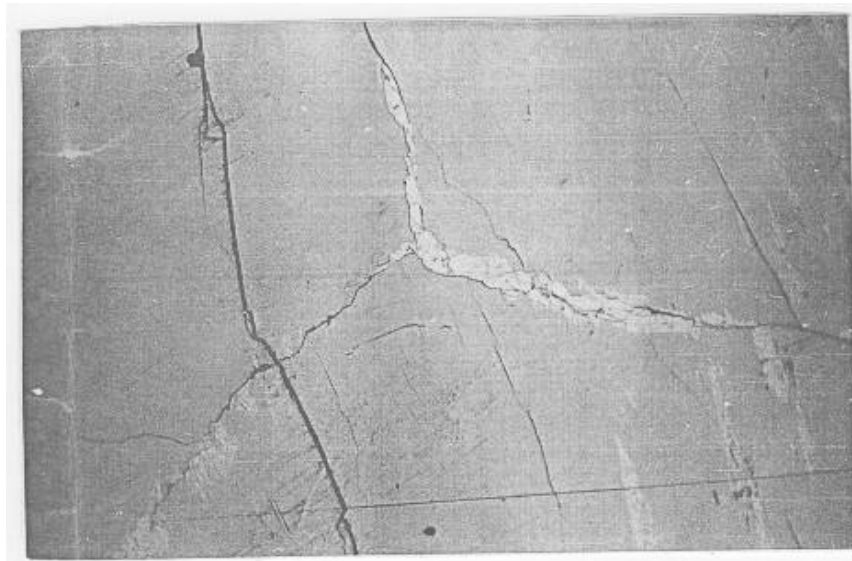
**Figure 5 :** Pyrrhotite (medium grey) showing twinning, subhedral pentlandite (light grey) and magnetite (dark grey)

In association with chalcopyrite, which has replaced pyrrhotite, pentlandite adopts a peculiar unoriented, very fine intergrowth with pyrrhotite that is only just resolvable under microscope. The pyrrhotite in this intergrowth is filled with radial shrinkage fractures.



**Figure 6:** Pentlandite (light grey) exsolved in the pressure shadow of a magnetite crystal.

In some cases pentlandite occurs along the cracks of pyrrhotite where it forms lamellae like exsolutions. As mentioned earlier fractures are points of weakness and the pyrrhotite breaks easily along these cracks and releasing pentlandite with less energy.



**Figure 7:** Pentlandite exsolutions along pyrrhotite cracks

The granular pentlandite frequently contains abundant inclusions of gangue in contrast to the lamellar pentlandite which is completely free of inclusions

### SUMMARY OF THE PENTLANDITE OCCURRENCE IN THE ORE

Approximately 65% of the pentlandite in the ore occur as flame like exsolutions in pyrrhotite, and the grain sizes ranges from 8 to 38 $\mu$ m. about 25% of the nickel bearing pentlandite is medium grained and subhedral. This kind of pentlandite occurs along the cracks of pyrrhotite or as inclusion in pyrrhotite. The rest of pentlandite present is disseminated in the gangue matrix. The table below shows the distribution of nickel in each screen size. It should be appreciated that, nickel percentage increases with decreasing particle size.

Fine grinding is required in order to liberate pentlandite.

**Table 1:** BCL rougher feed PSD and Ni distribution

Size ( $\mu$ m)	Mass retained (%)	Mass passing %	%Ni	Ni distribution
212	24.6	75.4	0.20	8.30
150	12.6	62.8	0.38	8.05
106	13.3	49.6	0.51	11.39
75	10.6	38.9	0.68	12.17
53	8.6	30.4	0.82	11.87
38	7.4	22.9	0.92	11.53
-38	22.9	0.0	0.95	36.70
total	100		0.59	100

The P<sub>80</sub> grind size of the feed is above 212 $\mu$ m. this is very coarse compared to the mean pentlandite grain size (8 to 38 $\mu$ m). The mean chalcopyrite grain size ranged from 11 to 55 $\mu$ m. 60% of the feed is coarser than 40 $\mu$ m and pentlandite is poorly liberated in these size fraction of the feed. The liberation of chalcopyrite in the feed is reasonably good.

### FINE GRINDING RISK ASSESSMENT

It has been established that the presence of very fine slimes in the pulp causes deterioration in flotation, lowering the recovery, the grade of the concentrate and the rate of flotation. Flotation of sulphides minerals are very strongly affected by even small amounts of them. The upper size limit of deleterious fine particle varies for different ores and reagents additions from 10 to 3 $\mu$ m. in a number of cases, fine particle of gangue minerals impoverish the froth product. In other cases, the main losses of floatable minerals to the tailings are in fine sizes. Very often, these cause sharp deterioration in the floatability of larger particle, which float readily after desliming.

A finer grind size will increase the reactivity of the material and change the material handling characteristics of the solids. This may affect the solid/liquid separation, storage and material handling equipment. It could also lead to; greater dust losses in the smelter, increased risk of dust fire and increased risk of dry storage bins blocking. Very fine particles leads to high specific surface that would cause; high pulp viscosity, adsorption of large quantity of reagents, rigidity of the froth, high dissolution rare in water, and covers large area of the surface of the particle and bubbles.

## **RESULTS AND DISCUSSION**

### **Sample Material**

The average back calculated head grade for the entire test performed is presented in table 2 and compared with typical BCL head grade figures.

**Table 2:** Average head grade of Flotation Feed Sample Tested

<i>Elements</i>	<i>Grade</i>	<i>Typical Grade</i>
Ni	0.74	0.72
Cu	1.00	0.75
Co	0.04	0.07
Fe	20.6	19.9
S	8.9	8.6

The copper grade appeared to be slightly high and the cobalt slightly low but the other assays suggest that the sample taken for testing is representative of typical BCL material.

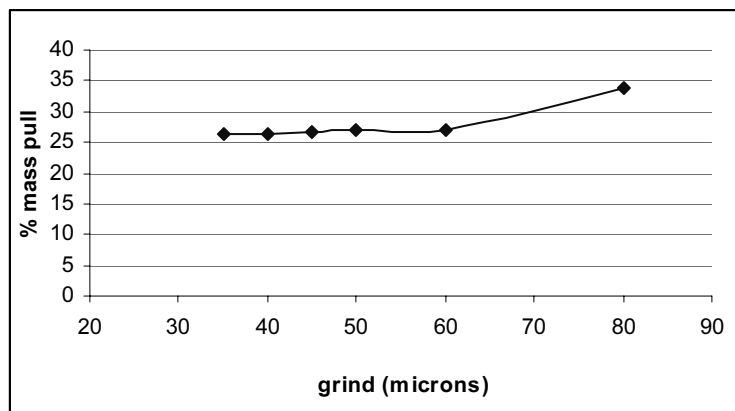
### **Primary Grind Optimization Tests**

The flotation tests were performed at grinds of 35, 40, 45, 50, 60, and 80% passing 75µm in order to evaluate the effect of grind over quite a wide range.

The result has been evaluated focusing on nickel as may be seen in table 3 and figures 8 through 10.

**Table 3:** Effects of grind on Ni Concentrate Grade and Recovery.

<b>Grind (% -75µm)</b>	<b>Mass Pull (%)</b>	<b>Ni Grade (%)</b>	<b>Ni Rec (%)</b>
35	26.4	2.49	93.7
40	26.52	2.52	94.79
45	27.63	2.58	93.04
50	27.1	2.7	93.49
60	27.47	2.59	92.45
80	33.9	2.14	97.34



**Figure 8:** Effect of Grind on Mass Pull

The mass pull to concentrate is seen to consistently increasing by small amount between 35 and 60 grinds and a dramatic increase with fineness at 80 % passing 75µm. This could suggest either higher recovery or increased entrainment of fines. Examining the nickel grade and recovery trends presented as figure 9 and 10 suggests that the optimum primary grind would lie in the ranges of 40 and 45% passing 75µm. Once the grind reaches the 50 to 60% passing 75µm range the Ni recovery is seen clearly to be adversely affected. At 80% passing 75µm the grade is dramatically reduced, this could mean high fine entrainment that reduces the purity of the concentrate.

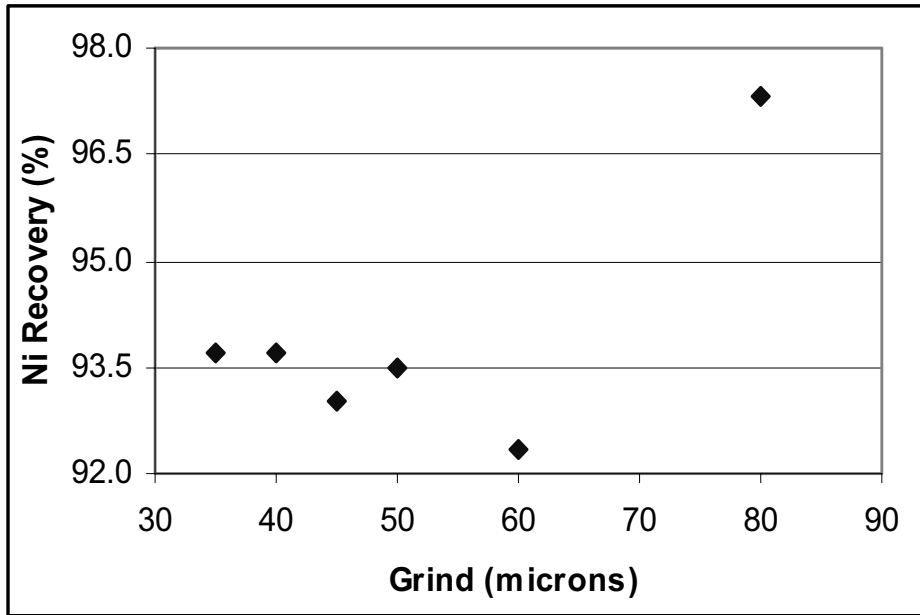


Figure 9: Effect of grind on Nickel Recovery

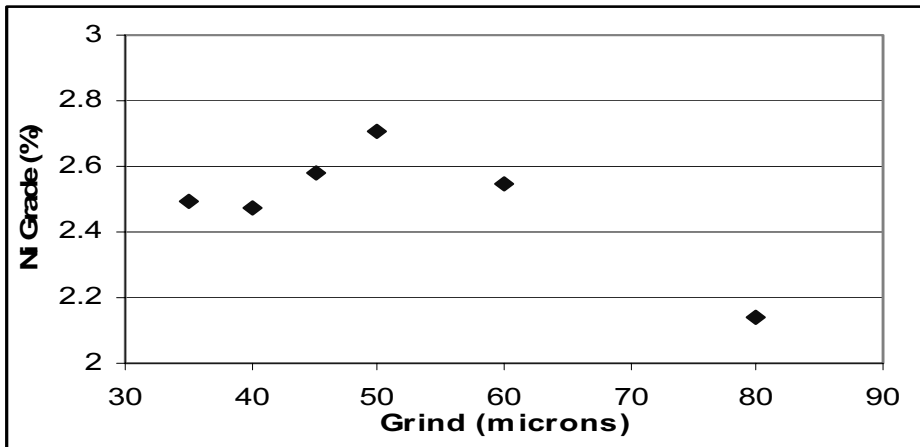


Figure 10: Effect of grind on concentrate Ni Grade

The cumulative grade recovery curves established from the kinetics data collected during the rougher rate floats (figure 11) once again show that finer grinds do not translate into higher nickel recoveries at the completion of the float. There are significant advantages associated with finer grind during the initial stages of the float (both higher grades and recoveries) but this effect is reduced as the float progresses. At most there appear to be a slight concentrate grade benefit associated with finer grinds.

No optimization of the rougher flotation reagent suite has been performed during this test program. It is possible that higher initial collector dosages or the use of stronger collectors could produce even higher nickel recoveries to rougher concentrate than have been observed here.

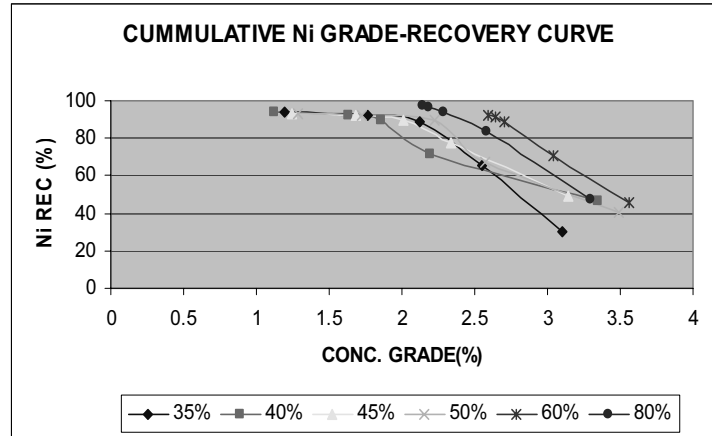


Figure 11 : cumulative rougher Ni grade-Recovery curves

Fine grinding gives high nickel grade in the first minute of flotation test, medium sized particles of the most actively floating pentlandite are transferred to the froth. With time, flotation of other particle size takes place including those of the gangue. These come about as a result of fine particle coating and agglomerating into floatable particles and hence affecting the quality of the concentrate as the flotation continues. These is illustrated in figure 12 and figure 13

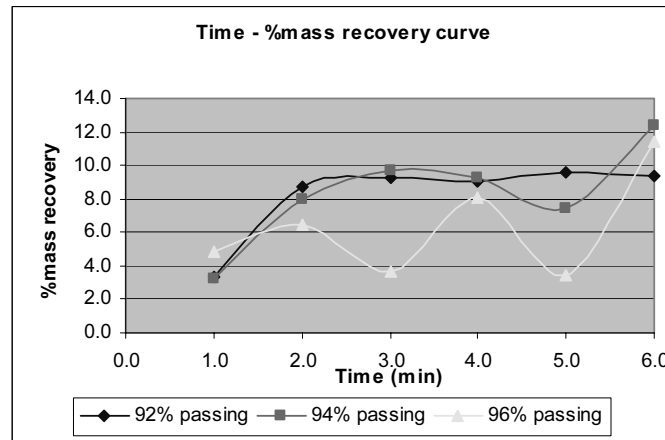
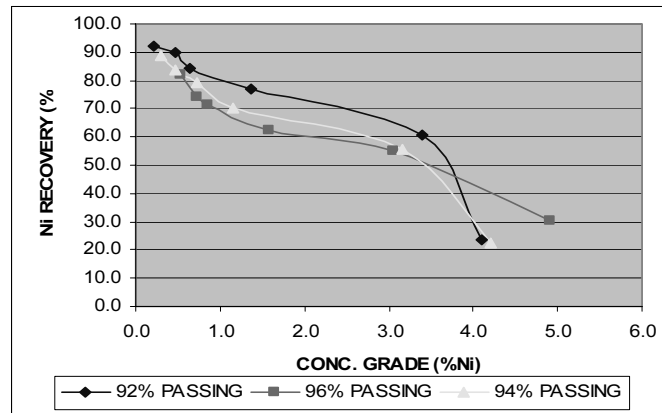
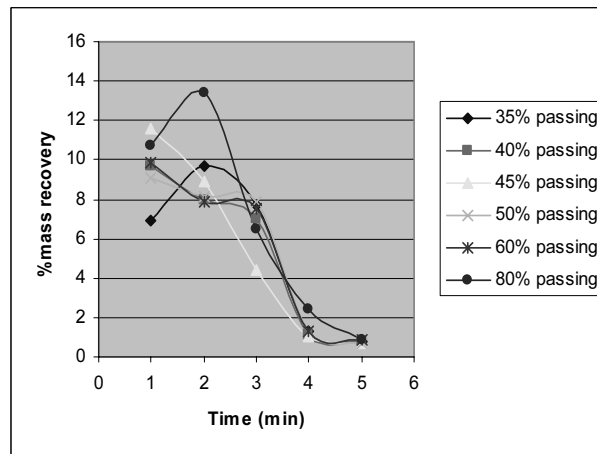


Figure 12: %mass recovery – time



**Figure 13:** cumulative grade –Ni recovery curve

As for the grinds 35 to 80% passing 75µm, it can be seen that higher mass recovery is experienced in the first minutes of flotation. It then decreases indicating that actively floating particles are being depleted as the flotation proceeds. Only less floating particles float towards the end of the test. This behavior is illustrated by figure 14



**Figure 14:** % mass recovery – time curve

### Conclusions and recommendations

- ❖ Finer grinding give very higher grade in the initial stages of the flotation test. The grade then decreases as the test continues due to the fine entrainment into the concentrate.

- ❖ The current grind of 48% passing 75 $\mu$ m used by BCL would appear to be close to the optimum. There does not appear to be any benefit associated with grinding finer.
- ❖ The losses to the final tailings is assumed to occur in the +38 $\mu$ m size fraction.
- ❖ Pentlandite losses occurs as poorly liberated grains in the pyrrhotite
- ❖ Their reporting to the final tails is therefore probably a function of particle size and slow kinetics of pyrrhotite.
- ❖ Further tests are to be carried out using dispersant in the finely ground ore.

### **Acknowledgements**

This work was conducted while one of the authors (O.M.) was graduate student at the University of Johannesburg. The authors wish to thank the management of BCL Mining and Smelting (Botswana) for the permission to present this paper.

### **Reference:**

- |  |   |
|--|---|
| <i>V.I Klassen and V. A Mokrousov</i>    | An Introduction To The Theory of flotation  |
| <i>N. L. Weiss, Editor</i>               | SME Mineral Processing Handbook Volume 1  |
| <i>B. A. Wills</i>                       | Mineral Processing Technology   |
| <i>A. M. Evans</i>                       | Ore Geology and Industrial Minerals   |
| <i>W. D. Nesse</i>                       | Introduction To Optical Mineralogy  |
| <i>J. F. Richardson and Coulson</i>      | Chemical Engineering (Particle technology and Separation processes) Volume 2        |
| <i>J. Lurie</i>                          | South African Geology For Mining, Metallurgical, Hydrological and Civil Engineering |
| <i>R. V. Dietrich and J. Skinner</i>     | Rocks and Rock minerals   |
| <i>Cochran and Willey</i>                | Sampling Techniques   |
| <i>D. M. Hausen and W. C. Park</i>       | Process Mineralogy For Extractive Metallurgy, Mineral Exploration, Energy Resources |
| <i>E. G. Kelly and D. J. Spottiswood</i> | Introduction to Mineral processing  |

