BMM
Burundi mining metallurgy

A Bankable Feasibility Study of the Musongati Nickel Laterite Project, Republic of Burundi

BMM International Limited

EXECUTIVE SUMMARY

Introduction

Nickel laterites were discovered in the Musongati area of Burundi in 1972, during an exploration program conducted by the Government of Burundi and the United Nations Development Program (UNDP) (1975). The discovery encouraged further exploration for nickel laterites throughout the 1970s and 1980s.

This feasibility study relates to the permit area held by BMM International Ltd (BMM) on the Musongati nickel laterite deposit and has been commissioned by BMM. It reviews the geology and mineralisation of the Musongati Permit Area and describes historical and recent exploration programs conducted in the area.

Two mineralised lateritic ore horizons have been identified at Musongati, an iron-rich ferralite horizon and a more magnesium-rich saprolite horizon. Nickel and cobalt mineralisation occurs in both horizons but is generally at a higher grade in the saprolite. Platinum, palladium and gold have also been reported in the ferralite horizon and the overlying canga also hosts precious metals. Historical mineral resources for nickel and cobalt for both ferralite and saprolite were declared in the 1970s and 1980s but these resource statements are not considered to comply with modern codes of practice for the reporting of mineral resources. Recent exploration activity has therefore been directed at upgrading previous work so as to develop JORC-compliant mineral resources. This report includes a discussion of the nature of the ore body and a code-compliant statement of recently estimated Indicated and Inferred mineral resources for nickel and cobalt, and also platinum, palladium and gold. Recommendations for further work include further infill drilling to upgrade the status of some of the resources to the Measured category.

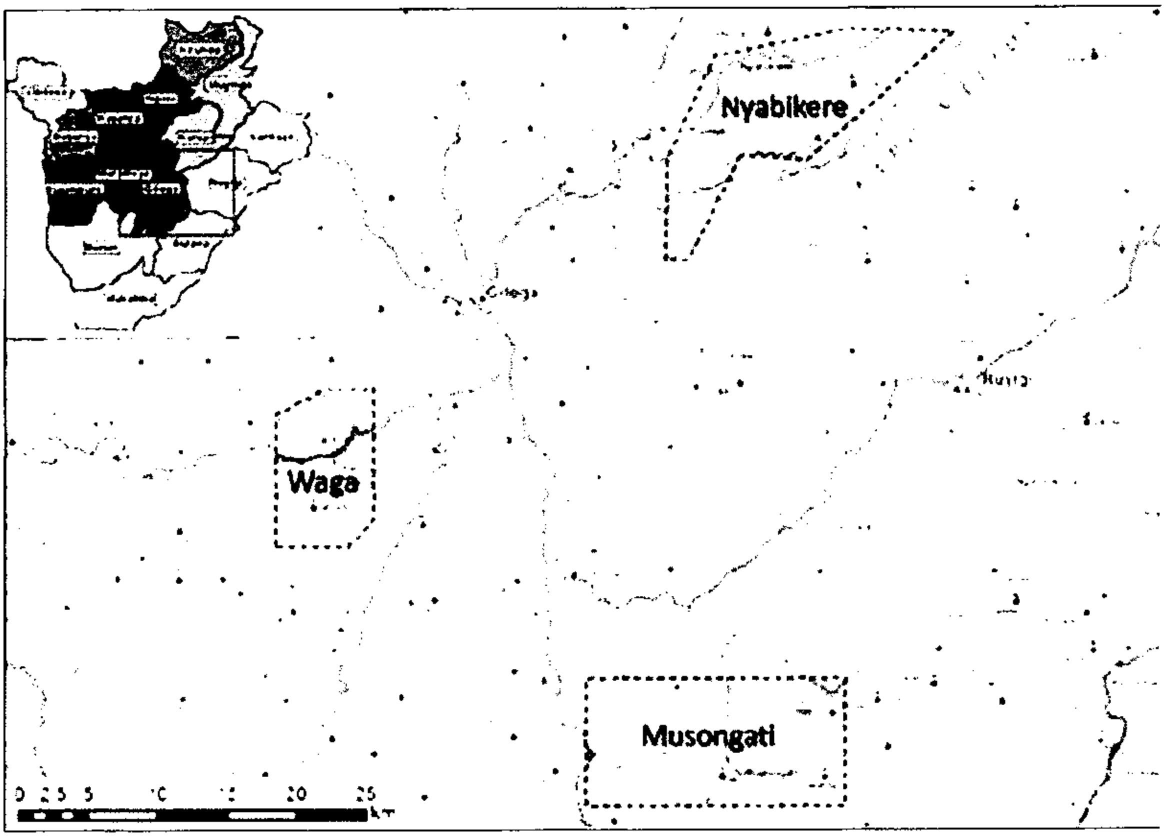
Planning for the future exploitation of the mineral resources at Musongati is discussed in this study: sections refer to the development of a mining methodology and mine plans, the preparation of ore feedstock and processing options, and the safe containment and disposal of tailings and waste products. Several processing options are under consideration and further metallurgical test work has been proposed in order to establish the optimal processing methodology/ies for both the ferralite and saprolite resources. A high-level Environmental Impact Assessment also forms part of this feasibility study.

Substantial development of infrastructure in Burundi, notably power generation, will be required prior to exploitation of the deposit. This is the subject of ongoing discussion between BMM and the Government of Burundi. Preliminary capital and operating expenditure (capex, opex) have been estimated for the potential exploitation of the Musongati resources, and a financial valuation of the project has been developed. An analysis of the world nickel market permits the resources and value of the Musongati project to be seen in the context of competing nickel deposits.

Mineral Tenure

BMM holds an exploration permit covering the Musongati nickel deposit, and also deposits at Waga and Nyabikere. The location of BMM's permit areas is shown in Figure 1.

Figure 1
Map showing the location of the BMM Musongati, Waga and Nyabikere Permit Areas in Burundi (Mineral Corporation, 2009)



A summary of the documents relating to BMM's licence holdings in Burundi, together with the historical timeline associated with the issuing of these documents, is presented in Table 1. The documents themselves are provided as Appendix 3.

The Musongati, Waga and Nyabikere permit areas are held by BMM under the terms of a Presidential Decree (*Décret*), no. 100/197 of 2008, and associated Agreement (*Convention*). The Agreement was signed on 15 September 2008 and forms an annexure to the Decree which was signed on 23 December 2008. The exploration permits are valid from the date of signature of the Presidential Decree, viz. 23 December 2008.

The Presidential Decree grants a 'Type A Permis de Recherches', an exploration licence, in favour of the company Samancor Ni (HK) Limited in respect of nickel, cobalt, copper and platinum-group metals on the Musongati, Waga and Nyabikere deposits. According to the Mining Act of the Republic of Burundi (1976: Article 39), a Type A permit covers areas of an irregular polygonal shape having at least one side oriented north–south.

Table 1
Documents relating to BMM's exploration permits in Burundi

Document	Description	Main Signatories	Date of commencement	Expiry date
Agreement (*Convention*) and annexures	Sets out terms and obligations; annexe A defines permit areas of Musongati, Waga and Nyabikere	Government of Burundi, Minister of Water, Energy and Mines; Samancor HK Ltd	15 September 2008	23 December 2011
Presidential Decree (*Décret*) No. 100/197 of 2008	Issue of Type A Exploration Permit (*Permis de Recherches*)	Samancor Ni (HK) Limited	23 December 2008	23 December 2011
Name change of company in Hong Kong, (Certificate no. 1196119)	Samancor (HK) Limited to Samancor Ni (HK) Limited	Registrar of Companies in Hong Kong (Certificate no. 1196119)	16 March 2009	
Name change of company in Hong Kong, (Certificate no. 1196119)	Samancor Ni (HK) Limited to BMM International Limited	Registrar of Companies in Hong Kong (Certificate no. 1196119)	10 August 2009	
Name change of company in Burundi	Samancor (HK) Limited to BMM International Limited	Office Notarial de Bujumbura, Acte. No. M/188/2010	10 January 2010	
Name change of company in Burundi	Samancor Ni (HK) Limited to BMM International Limited	Letter from BMM to the Minister of Energy and Mines	1 February 2010	

The Agreement is an exploration agreement between the Government of the Republic of Burundi, represented by the Minister of Water, Energy and Mines, and the company Samancor (HK) Limited. The registered address of Samancor Ni (HK) Limited is given as:

Unit 3A
20/F Far East Consortium Building
121 Des Voeux Road
Central, Hong Kong
Republic of China.

The name of the company Samancor (HK) Limited was changed in Hong Kong by special resolution to Samancor Ni (HK) Limited on 16 March 2009. On 10 August 2009 the name Samancor Ni (HK) Limited was changed to BMM International Limited. Both changes were certified by the Registrar of Companies in Hong Kong. In Burundi, the name change from Samancor (HK) Limited to BMM International Limited was certified through the Office Notarial de Bujumbura, Acte. no. M/188/2010, signed on 10 January 2010. The change from Samancor

Ni (HK) Limited to BMM International Limited was notified by letter from BMM to the Minister of Energy and Mines dated 1 February 2010.

The Presidential Decree (no. 100/197 of 2008) refers to the Agreement which was annexed to the Decree, specifically to indicate that the perimeters of the permit areas are contained therein. The Decree also indicates that Samancor Ni (HK) Limited is liable for all obligations specified in the Agreement. The Minister of Water, Energy and Mines is charged with the execution of the Decree which comes into force on the day of signature. According to the Decree, the exploration permit is issued to BMM for a single period of three years with the objective of completing a feasibility study on the Musongati Nickel Project and pre-feasibility studies on the Waga and Nyabikere deposits (translated from the original French).

Geological Setting

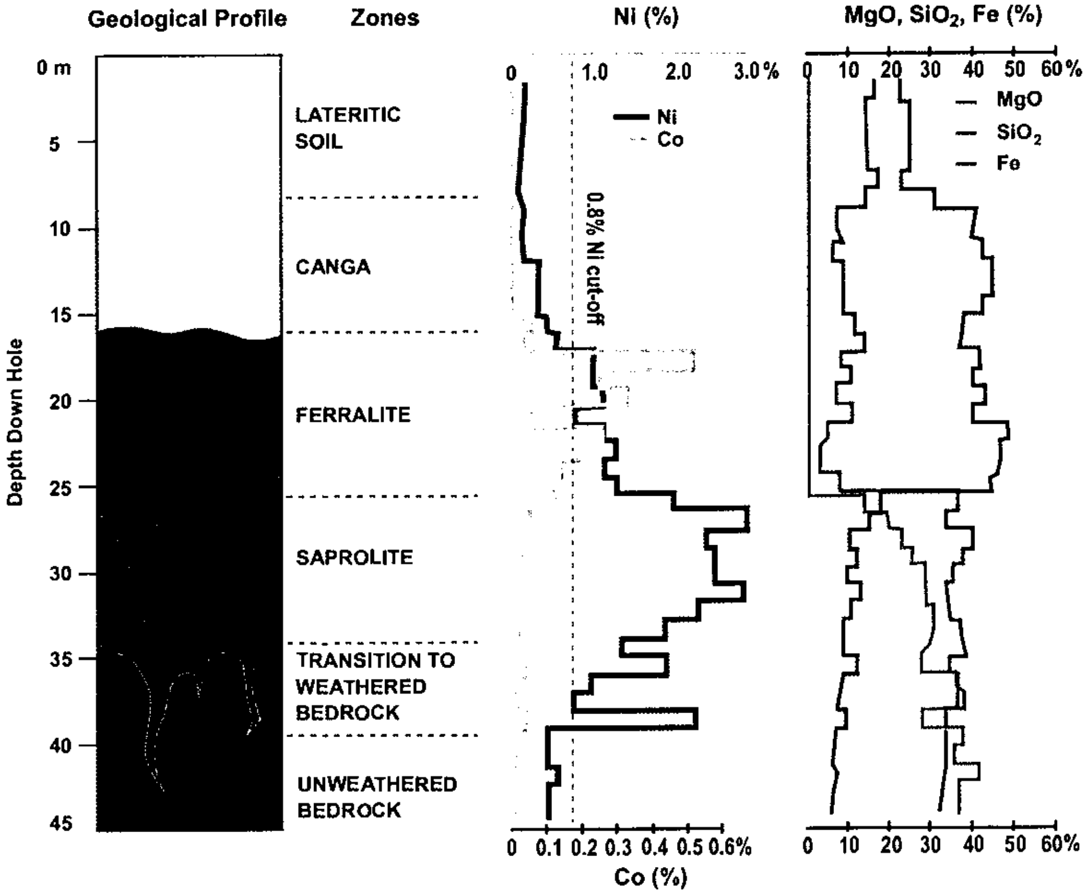
Geologically, Musongati is one of a series of layered ultramafic to mafic intrusions or 'complexes' occurring within the Kabanga–Musongati Belt of Central Africa. The Musongati complex is hosted by the 'lower series' of clastic sedimentary rocks of the Burundi Supergroup, and has an elongated trough- or keel-shaped geometry which steepens in a westerly direction, with dips varying between 20° and 60°.

The ultramafic units in the eastern part of the Musongati complex are associated with a strongly lateritised and mineralised plateau, dissected by a north–south drainage system. In this region BMM's permit area contains three mineralised plateaus identified, from east to west as Buhinda, Rubara and Geyuka. The western part of the Musongati complex, to the west of the Geyuka plateau, is underlain by norite, gabbronorite and quartz-norite over which no nickel-rich lateritic profile has developed.

The Buhinda Plateau covers an area of approximately 6 km^2 and is underlain mainly by dunite and in the northwest by peridotite. The Buhinda Plateau is divided into a high-grade (HG) zone and remaining extent (RE). Rubara covers an area of about 11 km^2 and is underlain by lherzolitic peridotite. Geyuka in the west covers an area of 11.5 km^2 and is underlain by feldspathic peridotite and pyroxenite. The laterite profile on these plateaus is similar to that found elsewhere in humid tropical environments and shows a strong vertical zonation which reflects the transition from unweathered host rock at the base to highly lateritised residues at the surface. Unlike many nickel laterites which are developed over ophiolites, the Musongati laterites overlie a layered ultramafic-mafic complex and display different chemical properties.

Nickel, copper, cobalt, gold and platinum-group element (PGE) enrichment occurs within sections of the Musongati laterite profile. The profile comprises, from top to bottom, soil, canga/cuirasse (a hard crust), ferralite, saprolite and weathered bedrock (Figure 2).

Figure 2
Schematic representation of laterite and metal zonation



Two main zones of mineralisation can be distinguished within the lateritic profile: the ferralite zone and the saprolite zone. The ferralite is a soft reddish/yellowish clayey horizon characterised by high iron and low magnesium and silica relative to saprolite, and low chromium relative to canga, because most of the major elements and silicate minerals have been leached from this zone. Nickel content increases with depth, ranging from 0.6% to 1.0% Ni in the reddish haematite-rich upper portion to between 1.2% and 1.4% Ni in the lower, yellowish-brown limonitic portion. Cobalt and copper have their highest concentrations in the ferralite, averaging 0.13% Co and >0.5% Cu. Precious metal concentrations of 0.5 ppm to 2 ppm (Pd > Pt >> Au) are typically associated with ferralite and the lower part of the overlying canga unit.

Below the ferralite, the saprolite zone is grey to grey-green, soft and friable. Clay minerals predominate, most commonly smectite and garnierite. The highest nickel concentrations are found in the saprolite, with values in excess of 2% Ni. The saprolite grades downwards into weathered, serpentinised bedrock or saprock, where the dominant Ni-bearing phase is generally serpentine. The transition to bedrock occurs over several metres and is characterised by a drop-off in nickel values to below 1% Ni, though isolated nickel values exceeding 1%, or even 2% Ni, are not uncommon.

Exploration

Exploratory percussion and diamond drilling, supplemented by trenching and metallurgical bulk sampling, was carried out by the UNDP over Buhinda, Rubara and Geyuka. Nine shafts were sunk to depths between 36 m and 55 m over previously drilled holes on Buhinda and Rubara. A pre-feasibility study was produced by The Ralph M Parsons Company (1978) for Buhinda. During the period 1979–1982 additional metallurgical test work was conducted and a new pre-feasibility study was prepared by the Swiss company Sulzer Frères Société Anonyme (1980). Thereafter, work was restricted to the 1.2 km^2 Buhinda HG zone. After 1985 there was no further exploration in the area until the commencement of BMM's tenure of the licence area. The Mineral Corporation (2009), on behalf of BMM, undertook a detailed review of all past work. Historical data were reported by The Mineral Corporation (2009) as being only partially complete.

Field exploration conducted by BMM commenced in 2009. A Versatile Time Domain Electromagnetic (VTEM) survey of the Musongati Permit Area was carried out by Geotech Airborne Limited in June 2009. Electromagnetic, magnetic and digital terrain model data were collected during the heliborne survey. A drilling program on all three plateaus commenced in late 2009 under the supervision of The MSA Group (MSA) and work continued until April 2011. The drilling campaign to date comprises 87 diamond drillholes for a total of 6 705.74 m drilled. Twelve holes were drilled on the Buhinda High Grade Zone, 37 on Buhinda Remaining Extent, 24 on Rubara and 14 on Geyuka.

The aim of the BMM drilling program was to permit the determination of JORC code-compliant resources over the Musongati Permit Area. This involved verification of UNDP data by twinning representative drillholes and comparing sample assay data, and the reduction of historical borehole spacing through infill drilling. The drilling program comprised:

- 8 twin drillholes on the Buhinda HG Zone. Drillhole spacing on the Buhinda HG zone was generally 100 m; but a small area in the centre was drilled to 50 m spacing
- 4 drillholes on the Buhinda HG Zone to investigate the PGE potential of the nickel laterite. Results from these holes were included in the nickel laterite resource estimation
- 37 infill drillholes on Buhinda RE to reduce the drill spacing from 400 m to 200 m
- 24 infill drillholes on Rubara to reduce the drill spacing of mostly 400 m to 200 m
- 14 drillholes at a 200 m spacing on Geyuka.

Sampling

In the ferralite and saprolite zones samples for geochemical analyses were collected over one-metre intervals; the sample width was increased to two metres in soil, canga and weathered bedrock. Sampling did not cross the logged lithological boundaries. All samples submitted for chemical analyses consisted of half of the core split along its long axis. An appropriate quality control program following industry best practice was put in place and involved the use of certified reference materials, field and laboratory duplicates, blanks, and check samples analysed at an independent laboratory.

Core samples were submitted to a sample preparation laboratory located in the Musongati Camp and managed by RC Inspection BV, an analytical services company with ISO 9001: 2008 certification. The homogenised pulp of each sample was stored in a labelled, sealable plastic cup and a sub-sample pressed into a pellet for on-site analysis by energy dispersive X-ray fluorescence analysis (EDX). This analytical method reports major element oxide concentrations (Fe_2O_3, SiO_2, MgO, Al_2O_3, CaO, K_2O, MnO, Cr_2O_3, TiO_2 and S), as well as various base metal concentrations (Ni, Cu, Co and Zn). These data were used to verify the geological logging and assisted in an accurate lithological classification.

A subset of the pulverised sample material was selected for Ni, Cu and Co analyses by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) at Set Point, an ISO 17025 accredited laboratory in Johannesburg, South Africa. Set Point performed multi-acid digestion and ICP-OES analyses reporting Ni, Cu, Co and Cr concentrations. Only these results were used in the resource calculations.

A subset of the stored pulverised sample material was selected for platinum (Pt), palladium (Pd) and gold (Au) ("3E") analysis by fire assay with ICP finish at Set Point. These results, together with the UNDP Pt, Pd and Au data from Phase 3 drilling (1984–1984), were used in the precious metal resource calculations. The following samples which were also analysed for Ni-Cu-Co by ICP were submitted for 3E fire assay analysis from the BMM boreholes:

- Every third sample from the saprolite, ferralite and canga units
- The transition from canga to ferralite was sampled continuously as this is recognised as the most prospective zone for precious metal mineralisation
- One sample from the soil unit
- One or two samples from the weathered bedrock, depending on the degree and type of weathering/alteration.

Initially, all samples reporting >1 ppm 3E were analysed for rhodium (Rh), but after it was realised that Rh concentrations are very low, generally below 50 ppb, the practice of analysing for rhodium was abandoned.

Mineral Resource Estimates

On behalf of BMM, MSA has conducted a review of previous exploration programs and existing sample preparation methodology and is of the opinion that the current data spacing at Buhinda, Rubara and Geyuka areas is adequate for declaration of updated, Code-compliant resources. The planning and execution of the most recent drilling and sampling programs and surveys was conducted in a professional manner and MSA is of the opinion that the resulting data are adequate for use in resource estimation.

Historical mineral resource estimates for Musongati modelled the ferralite and saprolite zones separately. These historical resource estimates do not comply with modern international reporting codes. Specifically, the lack of appropriate modern quality assurance and quality control (QAQC) programs undermines confidence in the resource estimates.

A revised mineral resource estimate has been completed by MSA, incorporating the data from the 2009–2011 campaign as well as the UNDP data. The distinction between ferralite and saprolite was retained in the recent mineral resource estimation process. The combined input database contains 7 148 samples from 323 drillholes (18 654.39 m) from Buhinda High Grade Zone, Buhinda Remaining Extent, Rubara and Geyuka. The new JORC-compliant mineral resource estimates for ferralite- and saprolite-hosted ore using a 0.8% Ni cut-off are presented below in Table 2 and Table 3 respectively. The location of the resources is shown in Figure 3. No geological losses have been applied at this stage, in the absence of data for such features. It is envisaged that geological losses will be better defined once more data are acquired relating to, *inter alia*, the basal contact morphologies of the saprolite zone.

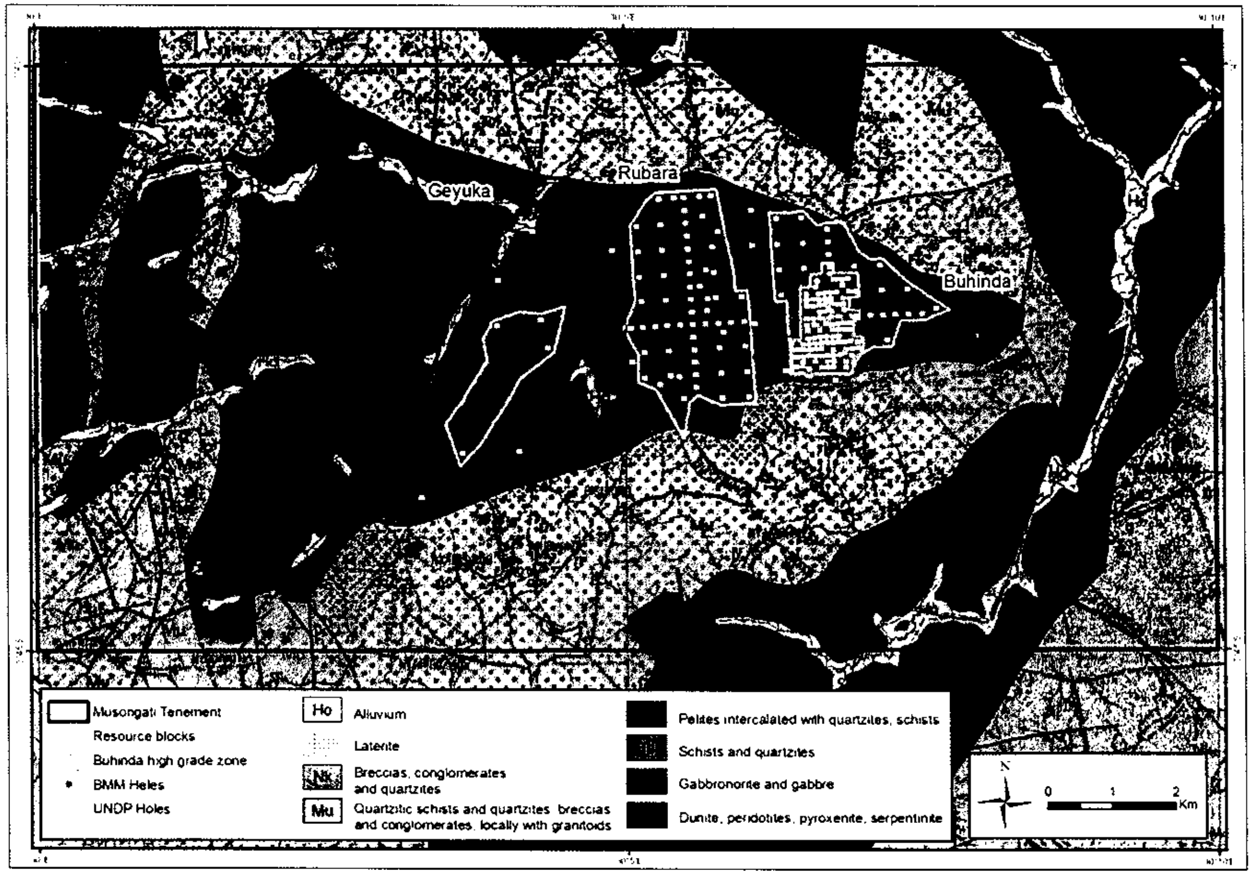
Table 2
In-situ Mineral Resources for the Combined Ferralite Resources, Musongati Permit Area, at a 0.8% Ni cut-off

Ferralite	Million Tonnes	Density	%Ni	Ni million lbs	%Co	%Cu	%Fe_2O_3	%SiO_2	%MgO	3E ppm	3E Koz	Pt ppb	Pd ppb	Au ppb
INDICATED														
Buhinda HG	15.77	1.02	1.18	409	0.16	0.36	63.0	10.1	1.8	1.36	689	438	820	100
Buhinda RE	10.89	0.98	1.05	253	0.17	0.33	61.8	9.1	1.2	1.15	402	331	717	101
Total/Average	**26.66**	**1.01**	**1.13**	**662**	**0.17**	**0.35**	**62.5**	**9.7**	**1.5**	**1.27**	**1091**	**394**	**778**	**100**
INFERRED														
Buhinda HG	0.71	0.97	1.20	19	0.15	0.30	57.2	15.0	4.0	1.20	28	496	606	103
Buhinda RE	8.45	1.02	1.03	193	0.17	0.32	60.8	10.4	1.3	1.25	339	356	792	102
Rubara	14.66	1.05	1.00	322	0.14	0.20	59.4	15.1	2.2	-		-		-
Geyuka	3.50	1.05	0.95	73	0.11	0.20	53.0	12.4	1.4	-		-		-
Total/Average	**27.32**	**1.04**	**0.99**	**607**	**0.14**	**0.24**	**59.0**	**13.3**	**1.9**		**367**			

Table 3
In-situ Mineral Resources for the Combined Saprolite Resources, Musongati Permit Area, at a 0.8% Ni cut-off

Saprolite	Million Tonnes	Density	%Ni	Ni million lbs	%Co	%Cu	%Fe_2O_3	%SiO_2	%MgO	3E ppm	3E Koz	Pt ppb	Pd ppb	Au ppb
INDICATED														
Buhinda HG	13.91	1.32	2.34	716	0.06	0.20	21.1	36.2	23.0	0.56	249	197	323	37
Buhinda RE	6.27	1.35	1.87	259	0.06	0.22	26.8	35.8	15.8	Inferred in the Nickel envelope				
Total/Average	**20.18**	**1.33**	**2.19**	**975**	**0.06**	**0.21**	**22.8**	**36.1**	**20.8**		**249**			
INFERRED														
Buhinda HG	3.30	1.36	1.94	141	0.05	0.19	22.1	35.9	22.1	0.54	58	191	306	45
Buhinda RE	15.94	1.36	1.77	622	0.06	0.20	25.0	36.7	17.7	0.51	261	145	317	47
Rubara	41.30	1.33	1.31	1195	0.05	0.13	31.5	34.2	14.9	-		-	-	-
Geyuka	15.48	1.33	1.00	340	0.06	0.14	34.7	26.6	11.3	-		-	-	-
Total/Average	**76.02**	**1.34**	**1.26**	**2298**	**0.05**	**0.15**	**30.4**	**33.2**	**15.1**		**319**			

Figure 3
Location of the four mineralised zones, Buhinda HG and Buhinda RE, Rubara and Geyuka, in the eastern part of the Musongati Complex. The distribution of drillholes is also shown, underlain by the published geology map



Mining, ore feed preparation and utilities

The nickel resource within the Musongati Permit Area is considered to be of sufficient size to support an operation producing 30 000 tonnes per annum of nickel for well in excess of 25 years.

Mining is planned to commence in the central southern portion of the Buhinda High Grade Zone and to progress northwards. Removal of both overburden and ore will be by free dig. The mining operation will consist of a pre-strip to expose saprolite ore and then conventional bench mining of soil, canga, ferralite and saprolite. In the course of the pre-strip significant quantities of ferralite will be mined and this ore will be stockpiled against future processing requirements. The overburden comprising soil and canga will be stockpiled separately and used for backfilling and rehabilitation. Ferralite and saprolite will be mined in a ratio of approximately 54 : 46. The ores will be mined separately and delivered to two separate stockpiles at the metallurgical processing plant. Plant personnel will blend the ore from the stockpiles to achieve the required feed grade and tonnage. A mining plan for the first six year of operation is presented in Table 4 and production and cash flow for the same period in Table 5.

Table 4
Mining plan for the first six years of operation

ORE EXPORT		Years					
		1	2	3	4	5	6
Pre strip							
Soil	M^3	5 323 097	5 323 097	1 774 366	1 774 366	1 774 366	
Canga	M^3	1 929 529	1 929 529	643 176	643 176	643 176	
Overburden							
Soil	M^3			355 193	532 789	710 386	781 424
Canga	M^3			241 024	361 536	482 048	530 252
Ore							
Ferralite	tonnes		2 540 518	607 485	760 006	912 528	671 093
Saprolite	tonnes		146 030	400 000	600 000	800 000	880 000
Ferralite Ore Management							
	stockpile		2 400 682	2 625 135	2 810 591	2 957 053	2 785 473
	withdrawn		139 836	383 033	574 550	766 066	842 673
Total Tonnes Ore			**285 865**	**783 033**	**1 174 550**	**1 566 066**	**1 722 673**

Table 5
Production and cash flow for the first six years of operation

COSTS		**Years**					
		1	2	3	4	5	6
Mined, including moisture							
30%	soil	6 920 026	6 920 026	2 768 427	2 999 302	3 230 177	1 015 852
	canga	2 508 388	2 508 388	1 149 460	1 306 125	1 462 791	689 328
35%	ferralite	0	3 429 699	820 105	1 026 009	1 231 912	905 976
	saprolite	0	197 140	540 000	810 000	1 080 000	1 188 000
	US$ / t	Costs (US$)					
waste	2.07	19 516 816	19 516 816	8 110 025	8 912 234	9 714 444	3 529 722
ore	3.03	0	10 989 323	4 121 119	5 563 106	7 005 094	6 344 746
crushing and drying	8.00	0	21 492 382	8 059 883	10 880 052	13 700 221	12 408 745
admin			2 200 000	2 200 000	2 200 000	2 200 000	2 200 000
Total on mine costs		***19 516 816***	***54 198 521***	***22 491 026***	***27 555 392***	***32 619 759***	***24 483 213***
Unit cost per tonne sold			***189.59***	***28.72***	***23.46***	***20.83***	***14.21***
Recovery							
Contained Ni	80%	0	3 965	10 861	16 292	21 722	23 894
Unit cost			***6.20***	***0.94***	***0.77***	***0.68***	***0.46***
Transport							
Road	15						
Rail	127.16						
Total	***142.16***		***40 638 602***	***111 315 988***	***166 973 983***	***222 631 977***	***244 895 174***
Total costs		19 516 816	94 837 123	133 807 014	194 529 375	255 251 736	269 378 387
Unit cost per tonne			**331.75**	**170.88**	**165.62**	**162.99**	**156.37**

Mined ore will be dried to <5% moisture and then crushed and sized using a co-current rotary dryer. The dried ore will then be conveyed to a closed circuit crushing system which includes a jaw crusher, a granulator and an autogenous rotary crusher. Feed for an onsite processing plant can be tailored to requirements.

Processing

Ausenco Vector undertook a venture analysis of the Musongati project in order to evaluate potential processing options for the treatment of nickel laterite ore. The study included processing, process services, process-related infrastructure, and major environmental issues.

Several options were evaluated and costed:

- Heap leaching of blended ferralite/saprolite ore or of saprolite ore only
- Atmospheric leaching of saprolite ore
- Ferro-nickel matte smelting of saprolite ore.

In each of the above options different annual tonnages of nickel production were modelled. Processing of an intermediate ore product from any of the three processes by Chemical Vapour Metal Refining (CVMR) technology was also considered.

The following key technical issues were considered during the evaluation:

1. Capacity to treat the ore
2. Capital and operating costs
3. Power requirements
4. Environmental issues associated with solid and liquid effluent disposal
5. Operability issues associated with a process plant located in a remote area.

The details of each of the above options, together with estimated capital and operating costs, are shown in Table 6. Heap leaching of ferralite appears technically difficult and likely to generate substantial quantities of residue. Atmospheric leaching of saprolite is expensive due to the high acid demand, and is likely to entail significant environmental issues in effluent disposal. Recent bottle roll test work data yielded low nickel recoveries from ferralite, which were directly associated with iron extraction. This indicated that nickel is likely to be fully associated with goethite, and, if so, would make heap leaching of the ferralite difficult as the bulk of the iron would need to be dissolved in order to obtain high nickel recoveries. Bottle roll data indicated that saprolite should be amenable to heap leaching. Atmospheric leaching of saprolite is expensive due to the high acid demand, and would be likely to entail significant environmental issues in effluent disposal. A further option which should be investigated is high pressure acid leaching (HPAL) of ferralite coupled with atmospheric leaching of saprolite. This presents itself as the only potential option for treating high-grade ferralite and is likely to have a relatively low acid usage (but low availability and higher complexity due to the operation of an autoclave).

Based on the venture analysis the following process routes were shortlisted:

- Heap leaching of saprolite
- Crude ferro-nickel smelting
- CVMR processing of a mixed hydroxide product from heap leaching or crude ferro-nickel.

Further metallurgical test work on Musongati ores, together with a review of capex and opex and environmental issues for each option, will be required before a final decision can be made.

Table 6
Overview of Processing Options for Musongati

Potential Treatment Technology	Nickel Production (kt/a)	Power Usage (MW)	Power Generation (MW)	Capital Cost (USD million)[1]	Capital Cost (USD/lb Ni)	Operating Cost (USD/lb Ni)[2]	Environmental Issues	Operability Issues	Potentially Fatal Issues
Heap Leaching (Option 1)							• Solids residue disposed of to dry stack tailings. • Liquid effluent recycled in process	• Low complexity equipment	• May not be able to treat ferralite based on initial bottle roll data.
Case 1A: Blend Feed	10	11.2	13.0	394.7	17.8	5.10			
Case 1B: Saprolite Feed	10	11.0	9.7	371.1	16.7	4.76			
Case 1C: Saprolite feed	20	18.4	19.5	544.2	12.2	4.31			
Atmospheric Leaching (Option 2)							• Solids residue to tailings storage facility • Excess sulphate containing effluent disposed of to evaporation pond	• Low complexity equipment • Substantial evaporation pond required which may be problematic	• Sulphate containing effluent may not be managed by evaporation ponds during the wet season. The cost of full magnesium sulphate neutralization is prohibitive (lime usage increases to 135 t/h). • Saprolite slurry is difficult to settle hence tailings disposal is an issue in an inland project location.
Case 2A: Saprolite Feed	10	10.4	17.3	423.2	19.0	4.54			
Case 2B: Saprolite Feed	20	22.4	34.7	628.8	14.1	3.99			
Pyrometallurgical Treatment (Option 3)							• Inert slag produced which is readily disposed of	• RKEF or matte production requires considerable expertise in operations • Matte smelting can tolerate wider feed range than RKEF • Iron in FeNi alloy could not be processed and reduced further due to high converter temperatures needed for a low iron FeNi. • PGM's would not be recovered using FeNi alloy production but is recoverable in matte smelting process.	• Need to supply 100 MW of power • FeNi cannot be sold due to high copper content.
Case 3A: FeNi Matte Production	25	101	N/A	931.1	17.1	3.56			
Case 3B: FeNi Alloy Production	25	105	N/A	964.5	17.6	3.60			
CVRM Intermediate Processing							• HSE issues due to high toxicity of nickel carbonyl, but CVRM have strong HSE track record (Section 7.5)	• High degree of complexity but CVRM plant need not be located in Burundi	
Case 4A: Carbonyl plant treating MHP	10	23	-	64		1.37			
Case 4B: Carbonyl Plant treating FeNi	22	21	-	338		1.22[3]			
High Pressure Acid Leaching						Likely to be lower than Heap or Atmospheric Leach due to lower acid usage.	• Similar residue issues to Atmospheric Leaching but smaller quantities. Effluent disposal issue could be alleviated by full neutralization of discharge liquor.	• Technically complex with high maintenance requirement and relatively low availability (83% max). • Could be only technical option capable of treating high grade limonite from Buhinda HG deposit.	

[1] Capital costs exclude tailings disposal and other major off-site infrastructure
[2] Based on nickel only. Cobalt credits excluded
[3] Based on nickel and iron powder operating costs reduce to US$ 0.44/lb

Tailings and Effluent Disposal

The extraction of nickel from the laterite deposit at Musongati will necessitate the disposal of tailings products and also plant effluent. Depending on the process option chosen, barren heap leach material, leach slimes or slag will be produced. The disposal of waste products will involve the construction and operation of the following facilities, depending on the process route chosen:

- tailings dams to dispose of the bhlm or tailings from atmospheric leach
- a waste dump to dispose of the slag from smelting
- effluent and evaporation ponds to dispose of plant effluent.

A conceptual design for the tailings and effluent disposal facilities is included in this feasibility study.

Tailings dams will allow for maximum water recovery for reuse at the plant so as to reduce the costs of water purchase. A slag dump would ensure that all polluted water is evaporated or returned to the plant for reuse and further nickel recovery. The effluent and evaporation ponds will store the hazardous plant effluent whilst allowing water to evaporate.

All facilities are intended to be of a temporary nature with deposition taking place into the mined void once sufficient space has been created, likely to be in year 5 of production.

Environmental Impact Assessment

A baseline study of the Musongati Permit Area and a high-level Environmental Impact Assessment (EIA) have been prepared but, until the processing options have been selected, the document cannot be finalised. Inclusion in this report of a high-level overview of the project meets current requirements in terms of Article 6 of the Decree no.100/22 of 7 October 2010.

Until the process has been determined the EIA is not able to provide definitive guidance on the nature of the associated impacts, nor on measures to be put in place for their mitigation. In the meantime, the three most favoured processing options are discussed in this report in terms of their respective impacts and mitigatory measures. As required by Burundian legislation, the applicable laws of Burundi are listed in the text and the level of public consultation to date is discussed.

An Environmental Management Plan (EMP) is presented within the report at a systems level which will allow its updating with specific impacts and mitigatory measures when the processing option is determined. This EMP sets out the responsibilities and methods for managing the various environmental aspects by mine personnel assuming the project goes ahead.

Infrastructure, Power and Communications

A brief study of regional and national infrastructure has been made, particularly in so far as it may affect the development of the Musongati project.

Internal transport within Burundi is dependent on the country's road network as there is no domestic railway system and very little scope for internal air traffic. Road transport is also the most important form of international freight transport for Burundi, and will be important for the supply of inputs to and export of product from Musongati, given the high cost of air traffic and the current unreliability of the Tanzanian rail link to Kigoma.

Burundi is served by three land corridors through neighbouring countries:

- The Northern Corridor which links Mombasa to Kampala, along which freight can travel either by road or rail to Burundi and thence Rwanda
- The Central Corridor road that runs from Dar es Salaam to Kigali, parts of which can be impassable during the rainy season
- The third corridor, the rail service from Dar es Salaam to Kigoma via Tabora, was until recently of particular importance to Burundi. At the port of Kigoma, cargo is transferred to vessels and shipped via Lake Tanganyika to the Port of Bujumbura.

A Master Plan prepared for the East African Community (EAC) proposes two possible rail extensions from Tanzania into Burundi. One is an offshoot from the proposed main line from Isaka to Kigali in Rwanda. The extension into Burundi from Keza would run through to Gitega, and on to the Musongati mining area. The other option is an extension from Uvinza in Tanzania to Bujumbura, with a possible extension to Musongati. In either case the Tanzanian section would require upgrading.

Given the potentially long lead-in to any construction work, a mining and processing operation at Musongati would need to rely, initially at least, on road transport. BMM would need to liaise with the governments of Burundi and Tanzania, and also the EAC, regarding the upgrade and ongoing maintenance of the route from Dar es Salaam to Musongati.

An adequate power supply is also required to be available at Musongati before a mining operation can be undertaken. Burundi's available electricity generation capacity is at present severely constrained. The supply deficit currently varies between 13 MW during the wet season and 23 MW during the dry season when the country's main hydropower plants are running at reduced capacity. The distribution network within Burundi is in poor condition, with much of the essential switch gear beyond repair. There is no grid power at Musongati and the exploration camp has relied on its own generators. The Burundian Government has a strategic plan to increase the power supply by the commissioning of several new power plants in the period up until 2030.

The proposed Musongati operation will use a maximum of 110 MW of electrical power to produce 50 000 t of nickel per annum at full production; approximately 30 MW of this will be co-generated, which means that the project will require an additional 80 MW of power which it is anticipated will be generated from the new hydropower sources. Estimated power requirements at each development phase are

- 10 000 t of nickel per annum: 17.5 MW
- 30 000 t of nickel per annum: 80 MW

- 50 000 t of nickel per annum: 110 MW.

The total installed power of selected power generation sites is 95.8 MW but as they are remote from the Musongati site there are likely to be transmission losses.

The provision of power and transportation is critical to the viability of the Musongati project. BMM has entered into a separate agreement with the Burundian Government to develop various hydropower projects which are expected to generate sufficient power to allow project development. Alternatively, it may be possible to establish a peat fired power station using local peat resources.

East African countries, including Burundi, have long had to rely on satellites and Very Small Aperture Terminal (VSAT) earth stations for most of their connectivity. However, the East African Submarine Cable System (EASSy) was completed in 2010 and comprises an 8 840 km long submarine fibre optic cable connecting countries from South Africa to Sudan. The backhaul connection from this cable to Burundi is expected to be completed in 2011.

Capital and Operating Costs

Five options have been identified and evaluated for the processing of the nickel ore. A sixth option is that of exporting the crushed and screened ore without further processing. The options are:

1. Export of Ore (24 000 tpa contained nickel from blended ore)
2. Heap Leach Blend (10 000 tpa contained nickel from blended ore)
3. Heap Leach Saprolite (20 000 tpa contained nickel from saprolite only)
4. Atmospheric Leach Saprolite (20 000 tpa contained nickel from saprolite only)
5. Smelt Matte Saprolite (24 600 tpa contained nickel from saprolite only)
6. Smelter Fe Ni Saprolite (24 900 tpa contained nickel from saprolite only)

Costings for each option include site establishment costs, the crushing, drying and screening plant, and process plant appropriate to the option selected.

Prior to these costs being incurred it will be necessary to upgrade the access roads to site at an estimated cost of US$ 10 million and, if appropriate, the construction of a rail siding at about US$ 50 million.

Additional capital costs will be the establishment of housing, site roads, offices and associated infrastructure amounting to about US$ 27 million. On-going test work and the feasibility study will generate additional costs estimated to cost US$ 35 million.

The estimated capital and operating costs for each option are summarised below in Table 13-1 and Table 8 respectively.

Table 7
Summary of Capital Costs

Capital	Export of Ore (24ktpa contained nickel from blended ore)	Heap Leach Blend (10ktpa contained nickel from blended ore)	Heap Leach Saprolite (20ktpa contained nickel from saprolite only)	Atmospheric Leach Saprolite (20ktpa contained nickel from saprolite only)	Smelter Matte Saprolite (24.6ktpa contained nickel from saprolite only)	Smelt Fe Ni Saprolite (24.9ktpa contained nickel from saprolite only)
Pre production	***$62,000,000***	***$55,761,600***	***$61,040,000***	***$61,040,000***	**$61,040,000**	**$61,040,000**
Earth works	$2,000,000	$337,600	$500,000	$500,000	$500,000	$500,000
Roads	$3,000,000	$844,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Housing	$20,000,000	$16,880,000	$21,840,000	$21,840,000	$21,840,000	$21,840,000
Associated Infrastructure	$2,000,000	$2,700,000	$2,700,000	$2,700,000	$2,700,000	$2,700,000
Testwork and Feasibility Study	$35,000,000	$35,000,000	$35,000,000	$35,000,000	$35,000,000	$35,000,000
Contractor site establishment	***$10,000,000***	***$5,000,000***	***$5,000,000***	***$5,000,000***	**$5,000,000**	**$5,000,000**
Crushing and screening	***$2,087,700***	***$2,087,700***	***$2,087,700***	***$2,087,700***	**$2,087,700**	**$2,087,700**
Plant	$1,637,700	$1,637,700	$1,637,700	$1,637,700	$1,637,700	$1,637,700
Services	$450,000	$450,000	$450,000	$450,000	$450,000	$450,000
Infrastructure	**$51,500,000**	**$61,500,000**	**$61,500,000**	**$89,500,000**	**$141,000,000**	**$141,000,000**
Tailings Dam				$18,000,000		
Slag handling					$5,000,000	$5,000,000
Offsite infrastructure incl power	$10,000,000	$10,000,000	$10,000,000	$20,000,000	$84,500,000	$84,500,000
Rail siding	$40,000,000	$50,000,000	$50,000,000	$50,000,000	$50,000,000	$50,000,000
General	$1,500,000	$1,500,000	$1,500,000	$1,500,000	$1,500,000	$1,500,000
Process Plant		***$399,000,000***	***$548,200,000***	***$639,500,000***	***$931,100,000***	***$964,500,000***
Total Capital Expenditure (Real)	**$125,587,700**	**$523,349,300**	**$677,827,700**	**$797,127,700**	**$1,140,227,700**	**$1,173,627,700**

Table 8
Summary of Operating Costs

Operating Cost Estimates (Real Terms)		Export of Ore (24ktpa contained nickel from blended ore)	Heap Leach Blend (10ktpa contained nickel from blended ore)	Heap Leach Saprolite (20ktpa contained nickel from saprolite only)	Atmospheric Leach Saprolite (20ktpa contained nickel from saprolite only)	Smelter Matte Saprolite (24.6ktpa contained nickel from saprolite only)	Smelt Fe Ni Saprolite (24.9ktpa contained nickel from saprolite only)
Cost Area	**Unit**	**US$**	**US$**	**US$**	**US$**	**US$**	**US$**
Waste	**/t mined**	*$2.07*	*$2.07*	*$2.07*	*$2.07*	*$2.07*	*$2.07*
Ore	**/t ore mined**	*$3.03*	*$3.03*	*$3.03*	*$3.03*	*$3.03*	*$3.03*
Crushing & Drying	**/t ore**	*$8.00*	*$3.00*	*$5.00*	*$5.00*	*$5.00*	*$5.00*
Road transport	**/t ore sold**	*$15.00*	-	-	-	-	-
Rail transport	**/t ore sold**	*$127.16*	-	-	-	-	-
Unit Cost	**/t ore sold**	*$157.73*	-	-	-	-	-
Tailings Dam	**/t processed**	-	-	-	*$0.20*	-	-
Slag	**/t processed**	-	-	-	-	*$0.05*	*$0.05*
Mining Costs	/t processed	-	*$9.81*	*$17.04*	*$17.24*	*$16.82*	*$16.81*
Processing Costs	/t processed	-	*$154.83*	*$182.93*	*$174.28*	*$160.23*	*$158.87*
Total Operating Costs	/t processed	-	*$164.64*	*$199.97*	*$191.52*	*$177.05*	*$175.68*
Mining Costs	/lb Ni	*$5.16*	*$0.32*	*$0.43*	*$0.43*	*$0.40*	*$0.40*
Processing Costs	/lb Ni	-	*$5.09*	*$4.58*	*$4.37*	*$3.78*	*$3.75*
Total Operating Costs	/lb Ni	*$5.16*	*$5.41*	*$5.01*	*$4.80*	*$4.18*	*$4.14*

Financial Valuation of the Project

The financial valuation has been performed using the escalate / de-escalate methodology, whereby all cash inflows and outflows are escalated by an appropriate index, then subsequently de-escalated at the inflation rate to determine NPV and IRR. The base date for escalation, NPV, and IRR calculations for the financial model is 1 July 2011. All production, costs, and revenues are based on calendar fiscal years and all cash inflows and outflows assumed to occur in the middle of each year, i.e. June of each year.

In total, six models were reviewed by MSA:

1. Export of Ore (24 000 tpa contained nickel from blended ore)
2. Heap Leach Blend (10 000 tpa contained nickel from blended ore)
3. Heap Leach Saprolite (20 000 tpa contained nickel from saprolite only)
4. Atmospheric Leach Saprolite (20 000 tpa contained nickel from saprolite only)
5. Smelt Matte Saprolite (24 600 tpa contained nickel from saprolite only)
6. Smelter Fe Ni Saprolite (24 900 tpa contained nickel from saprolite only).

Table 9 below summarises the IRR and NPV for each option. The export of ore option is not viable having no IRR and no positive NPV, indicating negative cash flows for the life of the project. The atmospheric leach option has the lowest IRR of 6.3% and the smelter Fe Ni option the highest at 10.8%. The provision of power, water and transport requirements is critical to the viability of the project; all these factors pose substantial risks to the project and hence a high hurdle rate would be required. Under these circumstances a hurdle rate around 20% would be appropriate.

Table 9
Net Present Value and IRR Summary

OPTION:		Export of Ore (24ktpa contained nickel from blended ore)	Heap Leach Blend (10ktpa contained nickel from blended ore)	Heap Leach Saprolite (20ktpa contained nickel from saprolite only)	Atmospheric Leach Saprolite (20ktpa contained nickel from saprolite only)	Smelter Matte Saprolite (24.6ktpa contained nickel from saprolite only)	Smelt Fe Ni Saprolite (24.9ktpa contained nickel from saprolite only)
	Disc Rate	**US$ '000s**	**US$ '000s**	**US$ '000s**	**US$ '000s**	**US$ '000s**	**US$ '000s**
NPV	0.0%	-$231,185	$874,659	$1,422,846	$1,393,869	$2,493,721	$3,753,693
	5.0%	-$213,712	$225,714	$320,921	$170,337	$578,821	$1,158,760
	7.5%	-$206,217	$58,484	$45,832	-$121,025	$113,187	$523,030
	10.0%	-$199,358	-$54,653	-$135,584	-$306,894	-$189,613	$106,502
	12.0%	-$194,266	-$119,405	-$236,602	-$406,892	-$356,290	-$124,920
	15.0%	-$187,198	-$188,055	-$340,014	-$504,891	-$525,052	-$362,427
	30.0%	-$159,428	-$256,020	-$435,499	-$587,430	-$678,570	-$585,411
	IRR=	**No IRR**	**8.7%**	**8.0%**	**6.3%**	**8.3%**	**10.8%**

Risk Assessment

Risks potentially affecting the viability and execution of a mining and processing operation at Musongati have been assessed and recorded. A risk matrix summarises the nature of the perceived risks, their impact and proposed mitigatory measures. Each of the risks was ranked according to the likelihood of its occurrence and the potential severity if it should occur. The product of these two figures indicates the overall score of each risk.

Many of the more significant (higher ranked) risks identified relate to the processing of the ore, in terms of the selection of the most appropriate methodology for the varied nature of the Musongati ore, the cost of inputs, the safe and controlled implementation of the selected process method, and the marketability of intermediate ore products. Environmental risks resulting from chemical spillage, road traffic accidents involving trucks transporting inputs, and leaks from plant or effluent disposal facilities leading to land and water pollution are also significant. A serious risk to the overall viability of the project relates to the timely supply of power to the site.

Lower ranked risks include a possible delay to the commencement of the operation due to poor transport infrastructure, the ore tonnage being lower than estimated, and a lack of material for backfilling of the mined void.

Recommendations for Further Work

It is recommended that the identified Mineral Resources be upgraded through infill drilling to achieve Indicated or better status resources. A lack of defined grade continuity exists at the current drillhole spacing. In MSA's opinion the most prospective zones are the Buhinda High Grade Zone and Remaining Extent, where there is potential to upgrade resources to the Measured category. Other resource blocks where higher nickel grade has been identified also merit further investigation. A program to obtain bulk density data through a series of measurements including pitting and volume-weight exercises, is also desirable.

Migration of the current customised exploration database to Datashed software is recommended, to enable enhanced data management, validation checks and QAQC analysis and reporting.

A variety of geotechnical work will be required to inform the mine planning process. In particular, compressive strength tests and slope stability tests need to be carried out. Drying tests, hardness and shear strength tests need to be performed on the ore to facilitate the design of the crushing facility. Screening tests are also required to determine the most appropriate screen sizes.

Further metallurgical test work on the Musongati ore as outlined in Section 9 above needs to be carried out in order to define the preferred processing methodology.

In order to conform to international best practice and prior to a final decision being made on exploitation methodologies, a fauna survey will need to be conducted by local specialists supported, as required, by international experts. This will comprise a desktop component to identify the species presumed to exist within the area and a local trapping survey to verify the actual presence of each species. In the event that any species listed as threatened or endangered are identified, specific initiatives will need to be planned to capture as many individuals as possible for release at a potentially protected location elsewhere.

Similarly, the project will also need to conduct a flora survey to identify any indigenous, potentially threatened plant species within the site area. Due to the continued human presence, this is expected to be limited to small populations of individuals, if any. This survey should, in addition, establish the presence of plants used for medicinal or other purposes by local inhabitants. Any such species should be harvested prior to the disturbance of the land and their propagation for future rehabilitation or as seed material should be investigated.

As part of the public consultation process, a social baseline census should be taken, both for the purposes of compensation, as required under Burundian law, but also to ensure that the mine management has access to objective data regarding the local socio-economic context.

Ongoing negotiation and discussion between BMM and representatives of the governments of Burundi and Tanzania and international bodies will be required to facilitate the upgrade of transport infrastructure and the provision of power to the Musongati site.

Table of Contents

List of Tables

List of Figures

List of Appendices

1 INTRODUCTION

1.1 Scope of Work

The MSA Group (MSA) was asked by BMM International Limited (BMM) to prepare a feasibility study on the nickel laterite deposit in their Musongati Permit Area in central Burundi. The study is to be presented to the Government of the Republic of Burundi in compliance with the terms of their exploration licence.

An exploration program over the permit area was carried out during the 1970s and 1980s under the auspices of the United Nations Development Program and the Government of Burundi and mineral resources (not JORC Code compliant) were reported. Since 2009 MSA has carried out further exploration work on behalf of BMM, as a result of which a Competent Person's Report and Mineral Resource Estimates have been prepared. The recently declared Mineral Resources are JORC-compliant. Sections of the Competent Person's Report and Mineral Resource Estimates are summarised in this document and the full report is appended.

The newly declared resources are used as the basis for mine planning and ore preparation and processing studies. Several processing methods are under consideration and are the subject of on-going research. A review of infrastructure is also presented. A high-level Environmental Impact Assessment has been undertaken with respect to the exploitation and on-site beneficiation and processing. Capital and operating cost estimates have beer included for several possible financial models. A financial valuation considers options for marketing ore or a beneficiated product.

An analysis of risks associated with all aspects of the project and recommendations for further work, including infill drilling, are also included. A brief study of the world nickel market helps contextualise the nickel resources of the Musongati Permit Area within the global nickel market.

1.2 Principal Sources of Information

The content of this study has been informed by material provided by BMM regarding their Exploration Agreement with the Burundian Government, by historical information summarised in the report of The Mineral Corporation (2009), by a range of academic sources, and by the results of fieldwork and resource modelling conducted by MSA. A number of specialists have contributed their expertise to the study.

2 THE WORLD NICKEL MARKET

2.1 Introduction

The purpose of this section is to describe and assess the international market for nickel (Ni) in the context of likely production from the Musongati deposits. It will, therefore focus, where there is differentiation, on the market for nickel derived from lateritic deposits, while recognising that a sulphide-derived component is likely to materialise in due course.

This section of the study is based on a proprietary report compiled by Roskill Information Services Ltd entitled *Nickel: Market Outlook to 2014* (Twelfth Edition, 2010), that had been purchased by the client and which was made available to MSA for this study. This in turn made extensive use of data acquired from the International Nickel Study Group (INSG). The Roskill report covers not only the nickel market, but also the nature, geology, extraction, beneficiation and uses of nickel, in considerable detail. However, the report was published in January 2010, using information available prior to that time – in some cases as much as a year earlier. At the time of compiling the present study, therefore, some of the Roskill information may as much as two years out of date: a critical factor in a market as characteristically dynamic and volatile as that for nickel.

This study is an attempt both to summarise and to update the market component of the Roskill material – and to include aspects, such as the key role played by cobalt, and the rise of nickel pig iron (NPI), that the Roskill report rather surprisingly failed to address in any detail. However, its scope does not extend to a discussion of those aspects of the Roskill report that are peripheral to market dynamics and which have not changed materially in the interim.

The most recent information available on the nickel industry that is essentially in the public domain (i.e. not subject to subscription payments) was presented in sessions of the 4th New Caledonia Nickel Conference held in Noumea, New Caledonia, in November 2010, an event widely regarded as the industry bellwether. The current study has drawn on two presentations in particular: those of Jim Lennon of Macquarie Securities (*The Nickel Supply/Demand Outlook*); and Vanessa Davidson of CRU (*Nickel Pig Iron Overview*). In addition, use has been made of data from the latest – though still dated – commodity publications of the US Geological Survey; the INSG; and various corporate presentations and on-line trading brokers.

2.2 Nickel Ore Types

Economic concentrations of nickel occur in one of two types of ore:

- **Sulphide ore,** predominantly as pentlandite ($[Ni,Fe]_9S_8$) in association with pyrrhotite (Fe_xS_{x+1}, e.g. Fe_7S_8) and chalcopyrite ($CuFeS_2$) in both disseminated and massive ores. Deposits occur as replacement, dissemination or fracture fills in lenticular, sheet-like or elongate bodies near the base of ultramafic intrusions (greenstones).

Nickel grades vary widely, ranging from <0.2% Ni in the Bushveld Complex of South Africa to >2% Ni in some Brazilian ores; the global weighted average is around 1% Ni. Copper (Cu) and cobalt (Co) mineralisation frequently occur with nickel, often in recoverable concentrations. Most sulphide deposits are ultimately mined by underground methods, although exploitation may commence as an open pit on deposits that are not severely oxidised or leached.

- **Lateritic ore**, either as oxide-rich (limonitic) or silicate-rich (saprolitic) material, or as a continuum from the one to the other, with the limonitic ore being closest to surface.

  Laterites are formed by surficial weathering of nickel-rich ultramafic host rocks (e.g. serpentinites, peridotites) to create upper zones of nickel-rich iron oxides and clays (limonites); and below them, zones of nickel-magnesium silicates like garnierite ($[Ni,Mg]_6Si_4O_{10}[OH]_8$) that lie immediately above the unweathered host rock (saprolites). Lateritic weathering causes dissolution of magnesia, nickel and silica and their percolation downwards, to be precipitated in zones of great enrichment (up to 20 times the concentration in the unweathered host rock).

  Laterites formed under tropical humid conditions ('wet' laterites) contain less clays and are more amenable to hydrometallurgical processing than those formed under arid conditions ('dry' laterites).

Upper, limonitic laterite ores have nickel grades typically in the range 0.8–1.5% Ni, whereas lower, saprolitic laterite ores are enriched to as much as 3.5% Ni. Limonitic ores are the most common type (e.g. in Cuba, Philippines, Indonesia) and reserves have an average grade of approximately 1.8% Ni. Saprolitic (or garnierite, or silicate) ores constitute the majority of ore mined in Brazil and New Caledonia and generally have slightly higher grades (approximately 2.0% Ni) than the limonitic ores. By definition, laterite ores are relatively close to surface, with the result that most laterite deposits are amenable to extraction by relatively inexpensive opencast mining methods.

About 70% of remaining global resources of nickel are estimated to be contained in lateritic ores, which are becoming of increasing commercial importance as new processing technologies are developed to extract the metal from the ore.

2.3 Nickel Processing and Refining

2.3.1 Processing

Processing consists of the extraction and transformation of the nickel content in the ore to a highly concentrated form, with a nickel content of up to 80%. Whereas sulphide ores require a first stage, that of producing a finely ground metal concentrate, laterite ores omit this stage. Both ore types are then processed using either pyrometallurgical or hydrometallurgical technology.

2.3.1.1 Pyrometallurgical route

Sulphide concentrates are roasted and smelted to produce a matte containing up to 80% Ni, with other metals. Most sulphides are processed this way, using one of a variety of related technologies, of which the Outokumpu flash smelting option is probably the most widely used.

Laterite ores processed by pyrometallurgical means are usually transformed into ferro-nickel (FeNi), by passing a mixture of ore and coal down a rotary kiln through which a counter-directional flow of hot gases (about 1 000 °C) is driven. The partially-reduced ore is transferred to an electric furnace where, in the presence of further coal or coke, the Ni/Fe oxides are completely reduced and melted, to yield a FeNi product containing approximately 25% Ni. Sulphur is removed from the crude FeNi by the addition of alkali; other impurities are removed by air, and the resulting fine FeNi is either granulated or cast into ingots for sale.

South African mining company Exxaro has developed a new alloy manufacturing process called AlloyStream® which is currently being commercialised for iron–manganese (FeMn) production in a joint venture with Assmang. The technology is versatile regarding reductant feedstock and has greatly reduced electricity consumption. Pilot plant tests suggest that the process has even greater application for FeNi production using lateritic ore, than for FeMn and Exxaro is understood to pursuing this option too.

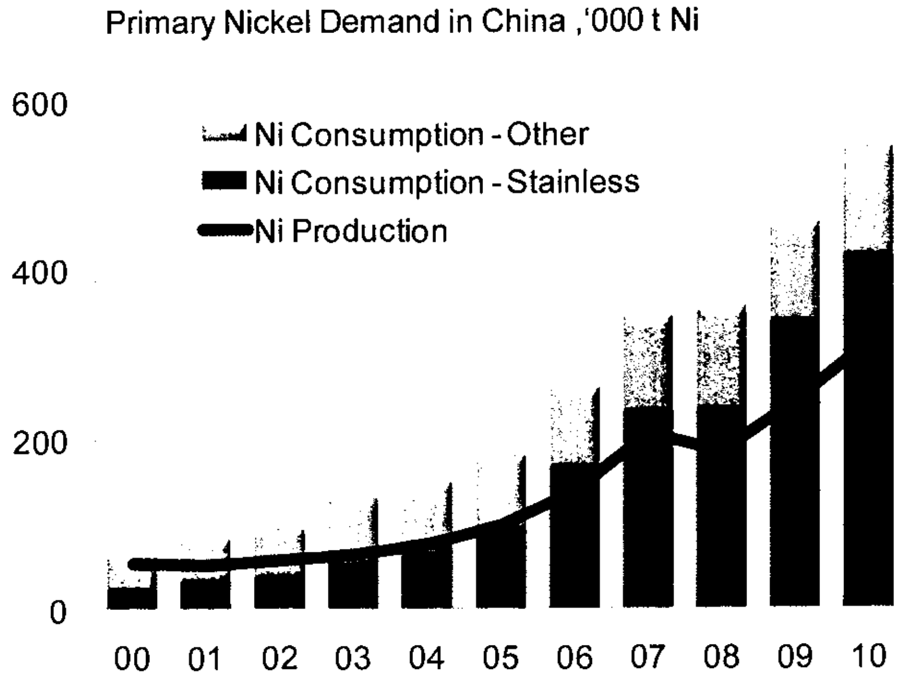
The production of matte from lateritic ore is achieved by the addition of sulphur or pyrite into the kiln, to result in a matte of 30–35% Ni.

Nickel Pig Iron (NPI) is a product developed exclusively in China during the last seven years to alleviate the country's growing shortage of nickel, when even conventional imports have failed to meet domestic demand for the metal (Figure 2-1).

NPI is a raw, low purity form of FeNi, containing 1–15% Ni (vs 15–80% Ni in conventional FeNi) and higher contaminant contents. It is derived from low-grade limonitic ore or medium- to low-grade saprolitic ore – all of which is currently sourced from Indonesia or the Philippines – which is blended with iron ore, smelted, sintered and cast as 10–25 kg ingots. Most NPI is smelted in electric arc furnaces and is of relatively higher grade (6–15% Ni) than the product emanating from old, re-commissioned blast furnaces (1–6% Ni). All current production of NPI is in China.

Because of its impurities, NPI needs to be blended with purer forms of nickel prior to use in steel mills, in the approximate ratio 1 t NPI : 2.5 t pure nickel. This effectively limits NPI consumption in China to approximately 30% of total nickel demand. The process is also a large energy consumer, making it more expensive than other sources of nickel. Its production rate is therefore closely linked to the prevailing nickel price: higher nickel prices (greater demand) make increased production of NPI both necessary and viable; but NPI effectively acts as a dampener on peaking nickel prices.

Figure 2-1
Primary nickel production and consumption in China (Davidson, 2010)



Data: CRU Analysis

2.3.1.2 Hydrometallurgical route

Several hydrometallurgical processes have been developed for the treatment of nickel sulphide ore, but to date only the *Sherritt Gordon ammoniacal pressure leaching process* has been used commercially. However, it is unable to recover any valuable platinum-group metals that may be present in the ore and its use is therefore largely confined to the treatment of nickel matte.

Numerous hydrometallurgical processes have been developed for the processing of *laterite* ores – especially limonitic laterite – although their sustainable commercial viability has not yet been proven conclusively. The two principal processes in operation (of which others are essentially variations) are the *Caron roast ammoniacal leach process*; and the *Moa Bay high temperature pressurised acid leach (PAL) process*.

In the *Caron* process, dried and blended limonitic ore is roasted to reduce the Ni and Co (but not the Fe) to metallic state; and the resulting material is leached with ammoniacal ammonium carbonate. Cobalt is removed from the pregnant leach solution (PLS) with hydrogen sulphide and recovered in a separate circuit; and the residual PLS is cleaned, stripped of ammonia, thickened, reduced with hydrogen in a furnace and finally sintered with nitrogen to produce saleable nickel oxide. The Caron process is attractive in that it selects for nickel and cobalt and does not consume reagents, but its energy consumption is high and recoveries are generally disappointing. It is used mainly to treat high-iron limonitic laterite ores in Cuba.

The *Moa Bay* process is used to treat low magnesium (Mg) ores by direct leaching with sulphuric acid in autoclaves at high pressure and temperature. Selective dissolution of Ni and Co, but little Fe occurs; the PLS is flash-reduced, followed by decanting, neutralisation, pre-heating with steam and then by precipitation with hydrogen sulphide and further flash-reduction. The resultant solution is further thickened to yield a Ni–Co matte containing about 50% Ni, which is then refined. A variation of the Moa Bay process, in which PAL takes place at room temperature, has been used at the major Australian dry laterite mines of Murrin Murrin, Bulong and Cawse. The latter two operations also use solvent-extraction / electro-winning (SX/EW) to recover the nickel from the PLS matte.

Atmospheric Heap Leaching is a process applicable to oxide-rich laterite ore types in which the clay content is low enough (i.e. preferably 'wet' laterite ores) to permit the percolation of acid solutions through an unconsolidated heap of ore. Ore is ground and agglomerated and, if its clay content is too high, mixed with coarser, clay-poor material in order to improve permeability. The ore is then stacked on thick, impermeable plastic sheets (membranes) and acid is percolated over the heap for a prolonged period (several months). In due course, up to 70% of the contained Ni/Co is taken into the acidic solution, which is drained off and neutralised with limestone. The resulting Ni–Co hydroxide intermediate product can then be sent to a smelter for refining. The process has the advantage of being much cheaper than those described above, because its capital investment costs are low; and in operation, it requires no energy or pressure. Its disadvantages are that it is slow; extraction is incomplete; it is a consumer of acid; and it is limited in terms of ore types for which it is suited.

2.3.2 Refining

Ni and Ni/Cu mattes are refined to the constituent metals by either pyrometallurgical or hydrometallurgical processes.

2.3.2.1 Pyrometallurgical Refining

In the *slow-cooling, magnetic-matte-separation and chlorination* process, slow cooling of the matte allows Cu and Ni sulphides to form separate crystals. The crystalline matte is then crushed and subjected to magnetic separation to remove any precious metal component; and floated selectively to separate Cu from Ni mattes. The Ni-rich matte is then roasted in a fluidised bed (FB) to yield an impure nickel oxide, which is chlorinated in a second FB reactor to volatilise impurities, and finally reduced by hydrogen in a third FB reactor to produce a pure, metallised nickel oxide for sale.

An alternative *carbonyl matte* refining process is intended for the production of high purity nickel powders and pellets. Nickel matte is converted in a top-blown rotary convertor at 1 650°C to nickel metal, which is then granulated and reacted with CO in a pressure reactor to produce a crude Ni carbonyl gas and a residue containing Cu, Co and precious metals. The Ni carbonyl gas is then purified by condensation and fractional distillation to yield a vapour that is finally decomposed to pellets or powder.

2.3.2.2 Hydrometallurgical Refining

In the *Eramet* process, Ni matte is leached with chlorine and ferric chloride; sulphur is removed by filtration and Fe and Co by SX from the resulting PLS, with further purification being achieved through hydrolysis and selective electrolysis. Nickel is recovered as either nickel chloride or as electrolytic nickel.

Elsewhere, (e.g. in South Africa) a sulphate-leach process is adopted: a continuously circulating PLS and electrolyte is subjected to two stages of atmospheric leaching and one of pressure leaching with sulphuric acid. A nickel-enriched liquor is tapped off to produce Ni cathode.

2.3.3 Nickel Products

Depending on the process/refining route adopted and the application requirement, nickel can be produced in a range of end-products.

Cast ingots or granules of FeNi containing 25-30 % Ni are the most common, as they are best suited to further alloying. NPI is a low grade variant of this product type.

Ni cathode, the end-product of matte electrolysis or electro-winning (EW), is the most common form in which nickel is recovered from purified leach solutions. The cathode sheets, typically about 1 cm in thickness, are cut into small squares (e.g. 2.5 cm^2) and used mainly in stainless steel and other alloys.

Ni powder is either used directly in batteries and chemicals, or compressed into small briquettes for use in alloying.

Ni oxide sinter contains 85–90% Ni and finds application in alloys, in chemicals and in vitreous enamelling.

Utility Ni ('shot') contains approximately 97% Ni and is used as an additive in cast iron.

2.4 Nickel Consumption (Demand) Trends

Nickel production can be measured either as 'Mined Ni', which refers to the recoverable nickel content of sulphide concentrates and laterite ores; or as 'Primary Ni', which refers to the nickel content of nickel end-products sold to consumers. The latter is generally about 8–10% less than the former, due to processing losses, plant efficiencies and (to a small extent), stockpiling. Figures in this section refer to primary Ni.

Global primary Ni production in 2010 is expected to have reached 1.4 Mt again, having peaked in 2007 at 1.423 Mt before declining to 1.378 Mt and 1.329 Mt in 2008 and 2009 respectively. Consumption of primary Ni in 2009 was down at 1.241 Mt, having declined from a peak of 1.401 Mt in 2006. Some stocks of nickel that accumulated during 2008 and 2009 are now in the process of being worked down.

Stainless steel currently accounts for about two thirds of global primary nickel consumption (0.8–0.9 Mt/a), followed by nickel alloys (about 0.2 Mt/a), nickel plating (0.1 Mt/a), and alloy steels (0.07 Mt/a). Other end-uses are in batteries, catalysts, chemicals and cast iron.

2.4.1 Stainless Steel

Stainless steel is a generic term for corrosion-resistant alloy steels containing 10.5% or more of chromium (Cr). The corrosion resistance of stainless steel is due to the formation, in an oxidising environment, of a tightly adherent, continuous, impervious Cr-rich oxide layer on the surface, which prevents further oxidation.

Global crude stainless steel production surged to a new record of 30.7 Mt in 2010, having slumped to 24.6 Mt in 2009 from a historical peak of 27.8 Mt in 2007; and resumed its steady growth path from 19 Mt in 2000. Global production capacity is currently around 39 Mt/a, distributed across 23 countries, although the largest producers currently are China (11.3 Mt/a), Japan (3.9), India (2.5), USA (1.9), South Korea (1.7) and Italy (1.7). Capacity growth of about 4.5 Mt/a is scheduled for India and China alone by 2015.

Global consumption of finished stainless steel declined to 20.6 Mt in 2008 from its peak of 22.7 Mt in 2006 – compared with only 15.8 Mt in 2000 – but has since recovered to 22 Mt. Virtually all the growth over the last decade has occurred in China, and to a lesser extent, India: Chinese consumption grew from 1.6 Mt in 2000 to 5.1 Mt in 2008; and India's from 0.48 Mt to 0.96 Mt in the same period. Both China and (especially) India still have a per capita utilisation of stainless steel (known as 'intensity of use') that is a small fraction of that enjoyed by OECD countries and South Korea – and Africa's stainless steel intensity of use is negligible. There is, therefore enormous potential for increased use of stainless steel globally, especially as societies become urbanised.

Nickel is added to stainless steel to improve its ductility. Steels containing 4–22% Ni (average about 8%) are termed 'austenitic' and until recently, accounted for as much as 75% of total stainless steel production – and for the bulk of global nickel consumption. Recent higher nickel prices, however, especially relative to the total cost of stainless steel production, have led to the increased production of stainless steels lower in nickel content, and a fall in the proportion of the austenitic variety currently to only about 60% worldwide, although it is still higher in the West (Figure 2-2).

This trend is also evident in the move from high-Ni austenitic steels (the so-called 300 series) to those with a lower Ni content (200 series), as shown in Figure 2-3 a and b. Ferritic stainless steel (400 series), which contains *no* nickel, is also gaining in importance.

Figure 2-2
Western world austenitic (nickel) steel proportion of total stainless steel
(Lennon, 2010)

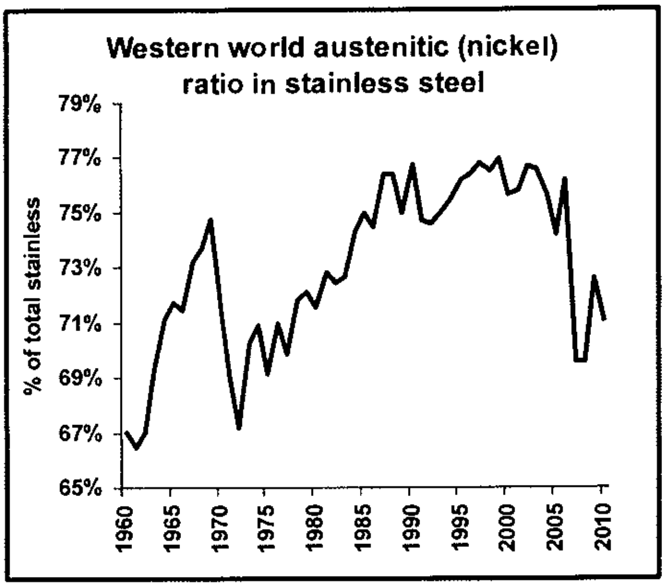
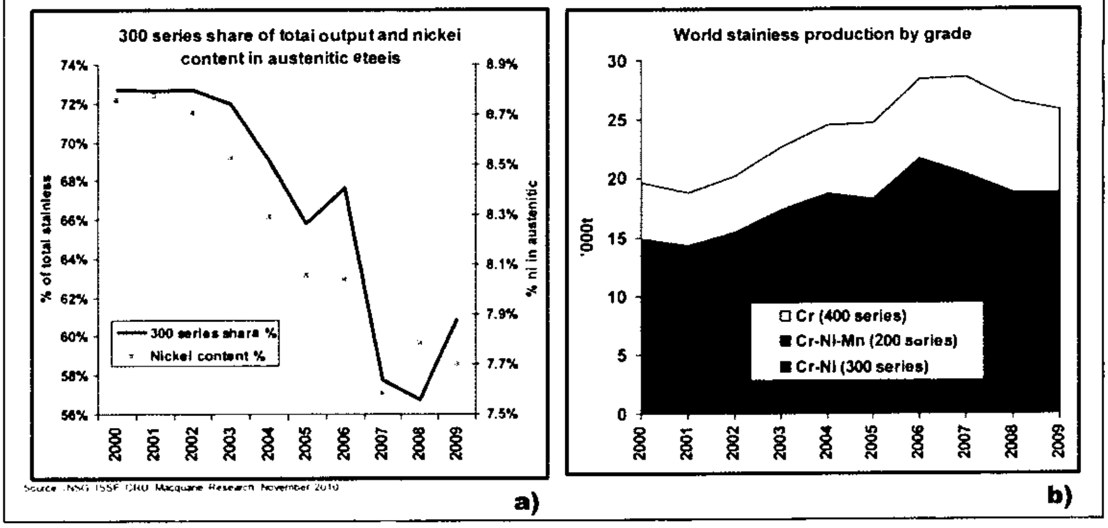


Figure 2-3
The trend from high Ni austenitic steels to those with lower Ni content
(Lennon, 2010)



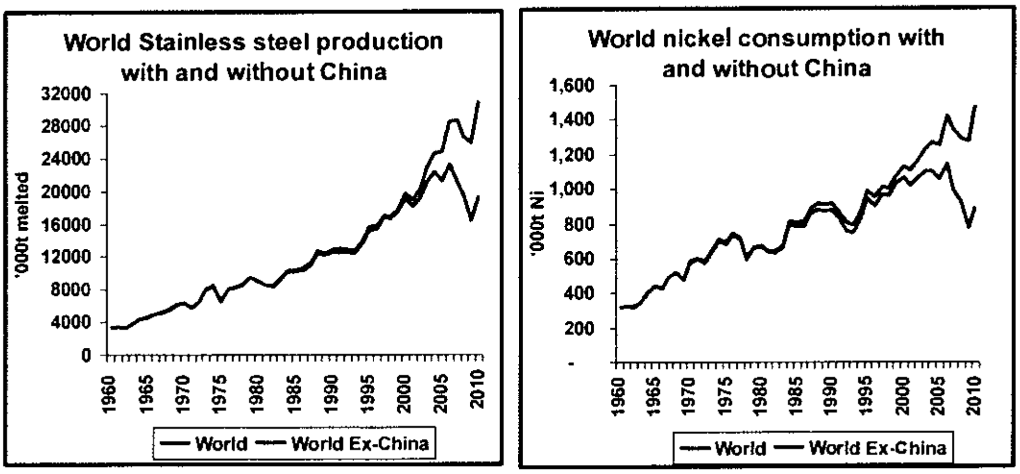
Source: INSG, ISSF, CRU, Macquarie Research, November 2010

a)

b)

The lower (200 series) grades of austenitic stainless steel are being produced mainly in India and China, especially for the rapidly growing kitchen and catering markets, where ultra-hygienic and sterile environments are less critical than in other applications. As in other commodities, the growth in stainless steel (and nickel) consumption has been driven mainly by China over the last decade – even during the financial crisis of 2008–2010 (Figure 2-4 a and b), when Western production of stainless steel and nickel consumption plunged to levels of a decade earlier. Most Chinese domestic consumption of stainless and other steels has up until now been concentrated in the eastern part of the country; however, attention is now turning to western China, which has remained largely rural and unindustrialised.

Figure 2-4
World stainless steel production: with and without China; world nickel consumption with and without China (Lennon, 2010)



Source INSG ISSF CRU Macquarie Research November 2010

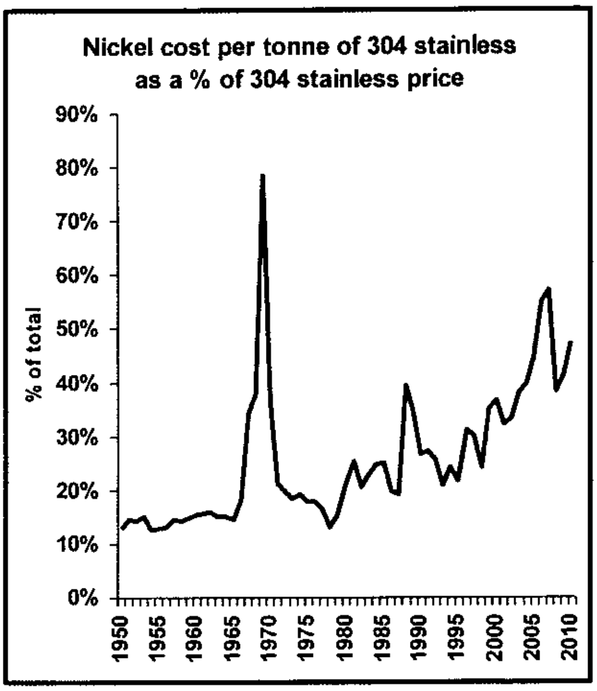
a) b)

Thus, despite the constraints of the last three years and the move towards stainless steels containing less or no nickel, the consumption of nickel in the sector continues to grow. However, these recent trends should be seen as a warning that the market is quite versatile with regard to nickel content; and that a return to the very high nickel prices of 2006–2007 will prompt further diversification away from nickel in stainless steel manufacture.

Currently, the cost of the nickel content in a 300 Series stainless steel amounts to almost 50% of the total cost per tonne of the steel, compared with only 25% in the 1980s, and little more than 10% in 1950 (Figure 2-5). Given that the stainless steel market also accounts for over 65% of *total* nickel consumption, the metal is particularly vulnerable to diversification and producers will need to take care not to price their commodity irreversibly out of its principal market.

Figure 2-5

Nickel cost per tonne of 304 stainless steel as a percentage of the 304 stainless steel price (Lennon, 2010)



Stainless steel *scrap* can be an important factor in determining the market for new nickel. In 2008, over 40% of nickel used globally in the production of austenitic stainless steel was obtained from stainless steel scrap, ranging from over 60% in the US to just over 30% in Asia. Advantages of scrap include that it is environmentally cleaner, has a shorter melting time, and that there fewer losses on treatment. The principal shortcoming can be its availability: typically, scrap supplies decline as production of new stainless steel increases; and become more readily available as fresh production falls. Thus, at the very time that demand for scrap rises (and with it, the nickel price), the supply tightens and scrap prices rise.

2.4.2 Nickel Alloys

A nickel alloy is a ferrous or non-ferrous alloy in which nickel is an important, though not necessarily a principal constituent. There are numerous such alloys, in which nickel is combined with metals such as copper, chromium, cobalt, iron, zinc and others. Annual production of this suite of alloys is estimated at approximately 0.3 Mt containing an average nickel grade of 50–55% Ni (14–15% of total Ni consumption). Most production takes place in Europe and the US, with China still being a small player in this sector (about 0.05 Mt/a). The alloys are used principally in the aerospace industry; in electronics and appliances; in the chemical processing industry; and in oil and gas. There are also numerous other smaller applications for nickel alloys of various types.

The outlook for Ni-alloys will depend largely on the fortunes of the aerospace, power generation and oil and gas industries. Projections for the aerospace industry are robust, with a continued increase in demand for lightweight, fuel-efficient aero-engines being expected. In the energy sector, demand growth for oil and gas has been forecast at an annual rate of approximately 1.5% for the next 20 years.

2.4.3 Nickel Plating

Plating accounts for about 7% of total global nickel consumption. Nickel is a versatile plating metal, combining decorative appearance with high resistance to wear and corrosion. Its best known application is as a base for decorative chrome plating, although it is widely used in industry for wear and corrosion protection and for the restoration or repair of worn or mis-machined parts.

Of several different plating methods available, electroplating is the best known and most widely used; nickel is the metal most used in this industry. Electroplating is a surface treatment in which material forming the cathode of an electrolytic cell (or bath) is coated by electro-deposition of metal from solution. The cell anode is made of the coating metal (e.g. Ni) and as an electric current is passed from the cathode to the anode, metal ions pass into solution at the anode and are deposited on the cathode.

Nickel plating is most extensively used in the automotive industry, where it is gradually being substituted by plastics and other coatings. Its outlook is therefore not promising, although the recent development of a new nickel-tungsten alloy, still in trials, might succeed as a replacement for chrome plating.

2.4.4 Others

About 5% of total nickel production is consumed in 'other alloy steels': those Ni-containing steels other than stainless and heat resisting steels, for example, bearing and tool steels, and for which demand growth is likely to be modest due to competition from other materials.

Nickel is also used in a range of new-generation storage batteries like the nickel-cadmium (Ni-Cd), nickel-metal hydride (NiMH), nickel-iron and sodium-nickel chloride batteries. Solid growth in the market for re-chargeable batteries can be expected, particularly for portable electronic equipment, hybrid electrical vehicles and for storage of renewable energy; however, NiMH batteries face increasing competition from lithium-ion cells in this market.

Nickel is also widely used, in association with other metals, as a catalyst, and, as its oxide, in enamelling of porcelain.

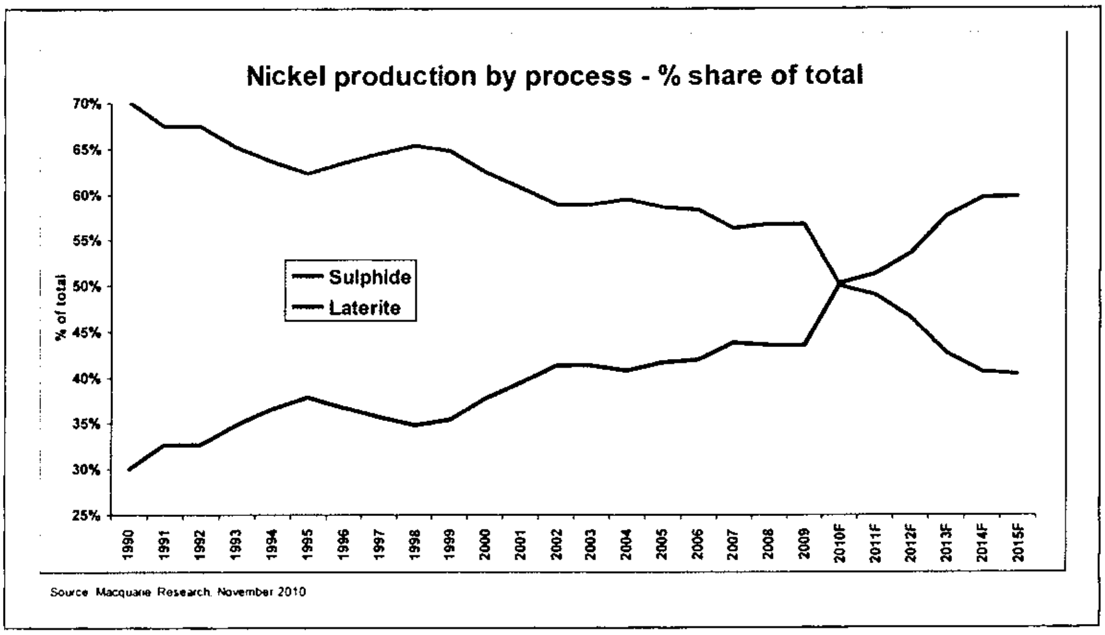
2.5 Nickel Production (Supply) Trends

Global mined nickel production in 2010 is expected to have reached approximately 1.58 Mt, close to the former peak of 1.6 Mt achieved in 2007, before the economic crisis of 2008/2009, when it fell to 1.47 Mt as mines around the world closed their highest cost operations. Jim Lennon of Macquarie (2010) forecasts that by 2015 production, having resumed its historical growth path, will deliver >2.1 Mt in that year.

Sources of nickel are widespread and in 2009 / 2010, mine production took place in at least 25 countries. Of these, the most important are Russia (0.29 Mt in 2008); Canada (0.26 Mt); Australia (0.2 Mt); Indonesia (0.18 Mt); New Caledonia (0.1 Mt); and Philippines (0.08 Mt).

Historically, by far the majority of nickel was extracted from sulphide ores, predominantly from underground mining operations. However, over the last 20 years, as large, low-cost sulphide deposits have been depleted and become harder to replace, the mainly opencast exploitation of lower grade, easy-to-mine but harder-to-process laterite nickel deposits has increased steadily. Lennon (2010) concluded that by 2010, laterite-sourced nickel for the first time exceeded the traditional source from sulphide ores (Figure 2-6). This trend is expected to continue, especially as processing technologies to extract nickel from oxide ores become more commercially viable.

Figure 2-6
Nickel production according to source (Lennon, 2010)



Source Macquarie Research, November 2010

Sulphide-Ni mining operations are concentrated in Russia, Canada, Australia and China; whereas the largest producers of nickel from laterites are Indonesia, New Caledonia, Philippines , Cuba, Australia and Colombia.

Over 50 companies worldwide are involved in mining nickel, the principal producing companies being MMC Norilsk Nickel (about 19% of global nickel production); Vale Inco (13%); BHP Billiton (9%); Xstrata (7%); and Jinchuan (6%). The top ten companies control over three quarters of global production.

This relative concentration of control enables the major producers to respond quickly to changes in the market: when nickel demand plummeted after the onset of the global financial crisis in 2008, they quickly closed down their highest-cost operations, taking a total of almost 350 000 t of contained Ni (about 23% of total output) out of the market within a few months, mainly in Canada and Australia. As the crisis eased and demand returned, so this production has gradually come on stream again. Nevertheless, the volatility inherent in the nickel market – due to the number of players, the large number of buyers and the high contribution of nickel to the cost of stainless steel – is such that even the efforts of the major producers were unable to prevent dramatic changes in the price of the metal during the recent crisis.

2.6 Nickel Production Costs

The Roskill report (2010) estimated the weighted average nickel industry total operating cash cost, after by-product credits, in 2009, to be US¢ 318/lb refined Ni. If by-product value is excluded, the cost estimate rises to US¢ 393/lb. Thus, by-product credits reduce costs by an average of about 19%.

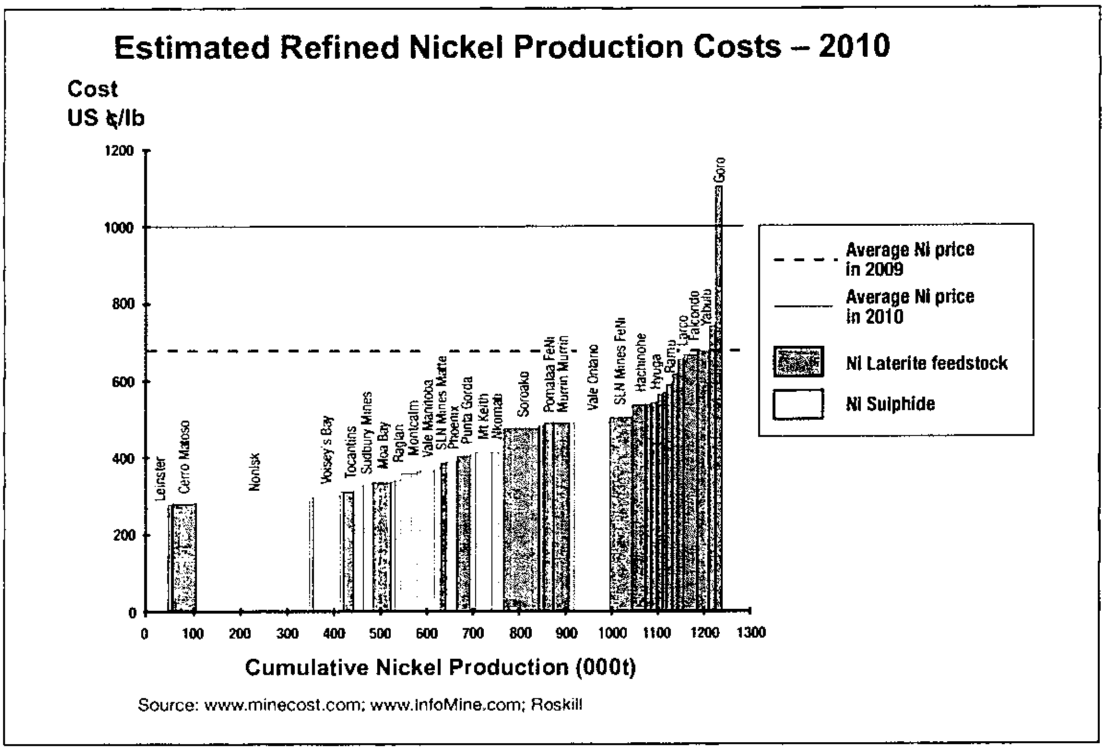
These estimates took into account the closure of highest cost operations in response to the financial crisis, as well as other cost-reduction measures implemented by companies to enable them to withstand it. However, it can be concluded that these steps are not sustainable in the long term, and that as the market recovers, and higher prices can again be tolerated, operating cash costs will return to higher levels, especially once higher-cost operations return to production.

The estimates of 2009 costs above are similar to those incurred in 2005; by 2008, costs had risen to about US¢ 470/lb and US¢ 550/lb with/without by-product credits respectively, as producers went on spending sprees and began to exploit lower grade, higher cost deposits, or parts of existing resources hitherto sub-economic. With more stringent cost control measures in place, it can be expected that comparable operating costs will be about US¢ 410/lb (US$ 9 000/tonne) and US¢ 500/lb (US$ 11 000/tonne) respectively in 2010/2011.

Figure 2-7 provides an indicative cumulative production cost curve (after by-product credits) for the nickel industry in 2010. The figure also shows the average prices realised for 2009 and 2010; the latter demonstrates that all but the highest-cost producers were profitable last year.

Another important feature shown in this figure is the concentration of laterite nickel producers towards the high end of the cost curve; only BHPB's Cerro Matoso operation in Colombia has consistently reported costs close to the bottom of the curve – its favourable position due in large part to the proximity of the mine to low-cost hydroelectric power and natural gas.

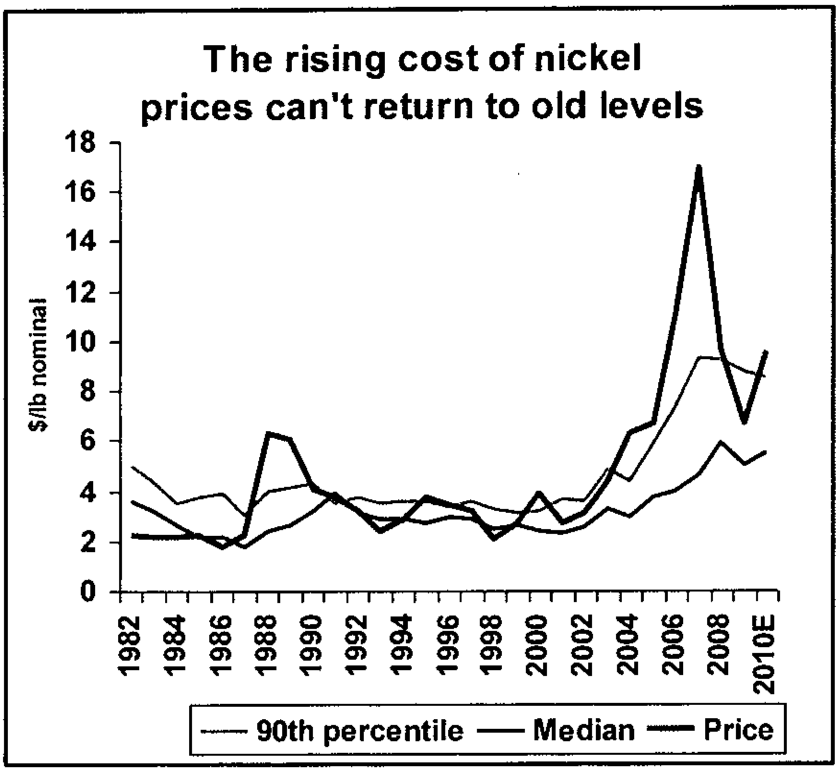
Figure 2-7
Cumulative production cost curve for 2010 (after Roskill, 2010)



Source: www.minecost.com; www.InfoMine.com; Roskill

As the proportion of nickel production from laterites increases, so it can be expected that there will be an inexorable rise in real average production costs; and in the absence of a comparable increase in nickel prices – which are driven more by the stainless steel market than by shortage of nickel supply – this is likely to translate into reduced profitability for most laterite nickel producers. However, as Jim Lennon pointed out in his paper given in November, 2010, the unavoidable increase in production costs, now that any excess has been stripped out, must lead to increases in future prices, as summarised in Figure 2-8.

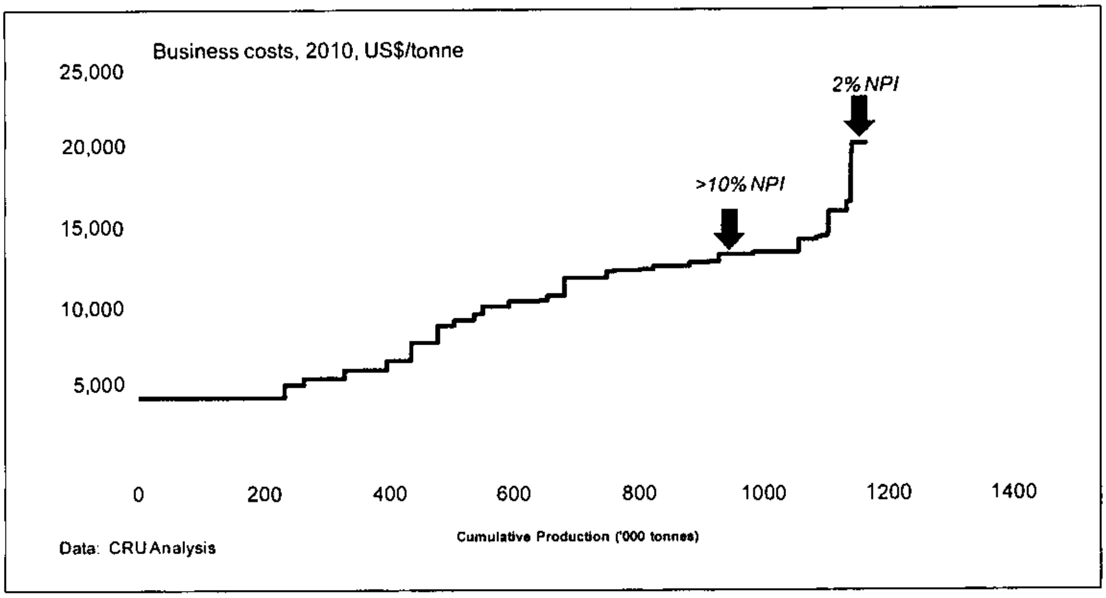
Figure 2-8
The rising cost of nickel (Lennon, 2010)



Source: Macquarie Research, November 2010

Nickel pig iron (NPI) has become an important component of the market, at least in China, which is the only country in which it currently plays a role. However, NPI is expensive relative to other sources of nickel and really operates as a swing supplier, coming into its own as the nickel price moves upward, especially in the period until conventional nickel supply responds to higher prices. Figure 2-9 shows the characteristic position of NPI on the nickel cost curve, emphasising its swing supply role.

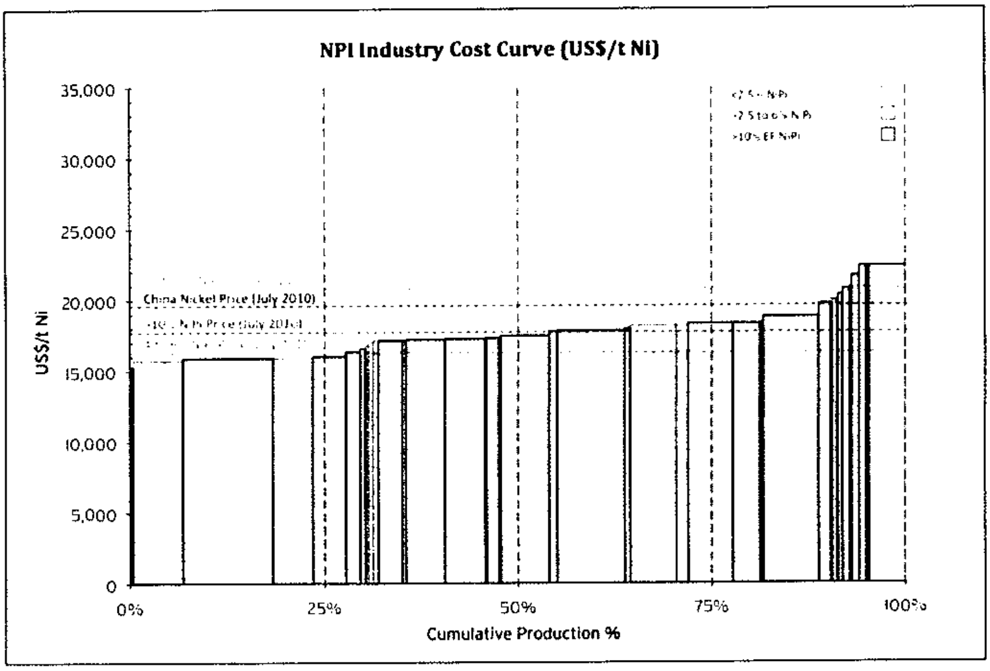
Figure 2-9
Low-grade NPI plants representing swing producers (Davidson, 2010)



Data: CRU Analysis

NPI production costs are remarkably similar across the spectrum of producers, averaging about US$ 17 000/tonne (US¢ 770/lb) of contained Ni (Figure 2-10). Lennon maintains that this cost will remain at this level for the next few years.

Figure 2-10
NPI production cost curve (Lennon, 2010)



Source Clark and Marron, November 2010

2.7 Nickel Supply / Demand Balance

The large numbers of players on both sides of the nickel market equation – over 50 producers, in over 20 countries, exploiting large resources; numerous toll refiners, often in countries other than where the nickel is mined; and many users, across a diversity of applications – ensure that equilibrium in the market is quickly restored following disruptions such as that of the recent global financial crisis; and that changes in end-consumer demand have an immediate impact on every element of the supply chain. There is no imminent shortage of nickel resources, just that remaining (mainly lateritic) resources will incur higher processing costs (but lower mining costs) in being turned to account; and that to some extent, at least, the market will accommodate these unavoidably higher costs. To the extent that there is a lag between changes in demand and the response of suppliers, this is increasingly being cushioned by the strategic role of NPI in the dominant market sector, China.

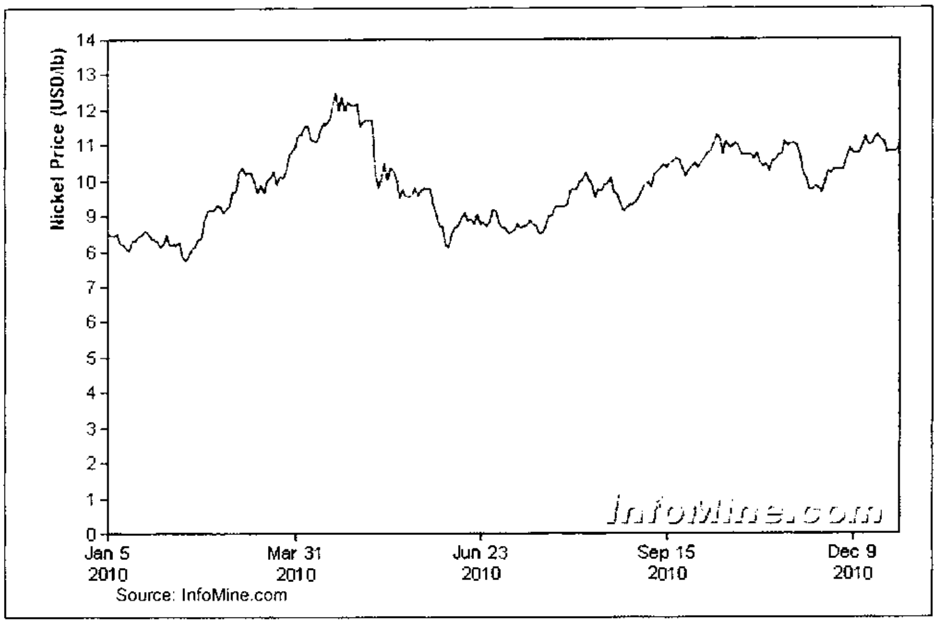
The conclusion to be drawn is that all players intending to participate in the long term in the nickel market need to build as much flexibility into their businesses as possible: to operate at as low a cost as possible in order to withstand the inherent price volatility of the metal; yet to maintain the ability to adjust production volumes according to demand.

2.8 Nickel Pricing

In an efficient market such as that for nickel, the price of the metal almost immediately reflects changes in market conditions – hence its characteristic volatility. Having said that, however, it is interesting to note the almost static price that has characterised nickel prices over the last year; throughout 2010, the price remained very close to US$ 10/lb, with only a very cautious upward trend (Figure 2-11).

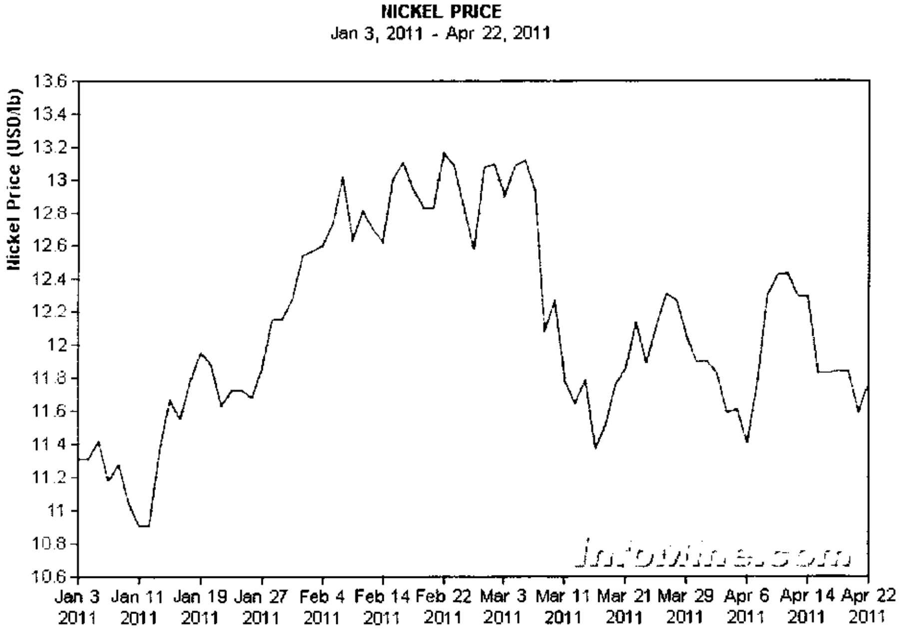
Since the beginning of 2011, the Ni price continued to strengthen gradually, reaching US$ 13/lb Ni in late February, before falling back to under US$ 12/lb by mid-March, since when it has oscillated between US$ 11.50 and US$ 12.50/lb (Figure 2-12).

Figure 2-11
Nickel price trend, 5 January – 30 December 2010 (InfoMine)



Source: InfoMine.com

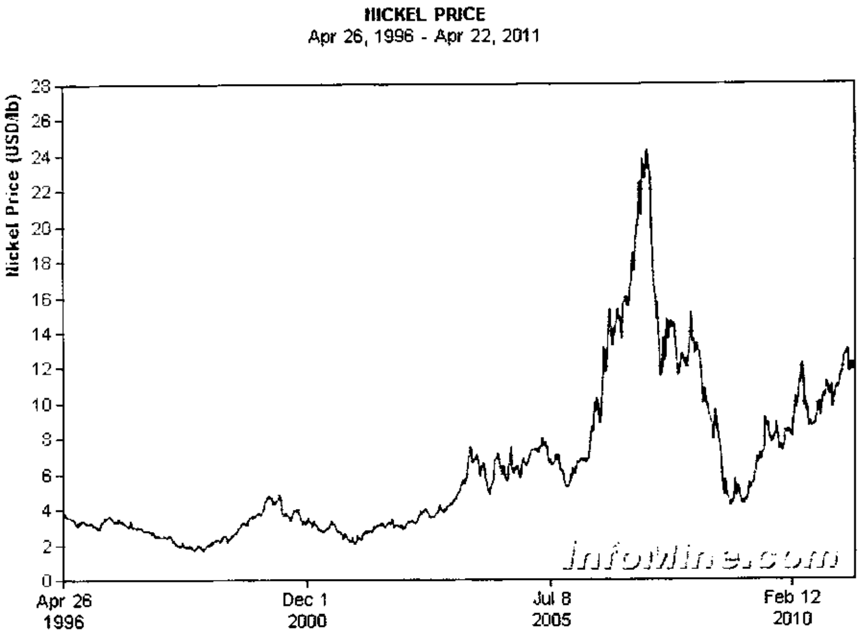
Figure 2-12
Nickel price trend, 3 January 2011 – 22 April 2011 (InfoMine)



Source: InfoMine.com

Over the last 15 years – even excluding the aberration of 2006–2007 – the nickel price has been quite volatile in nominal terms, despite improving from US$ 2–4/lb to its present levels (Figure 2-13).

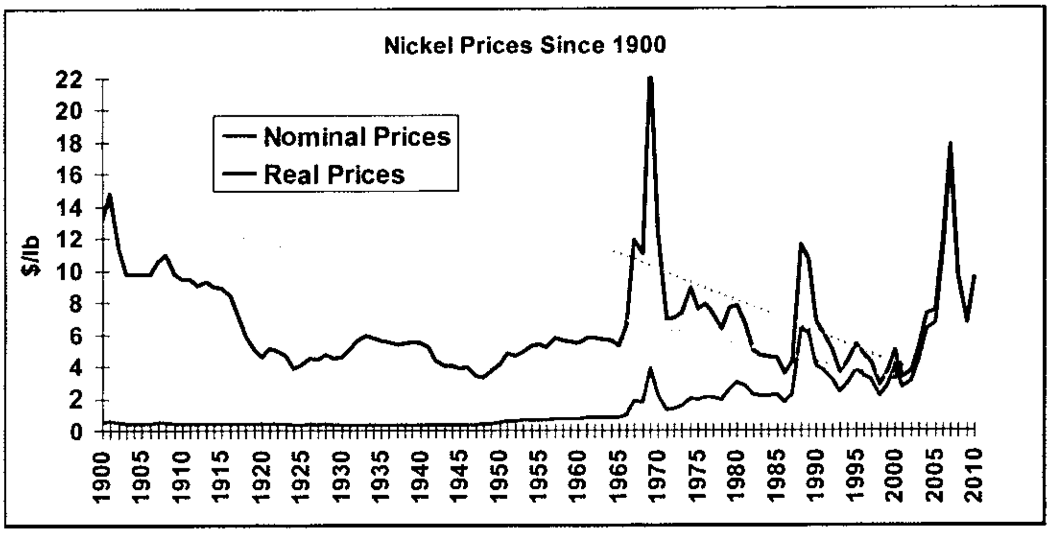
Figure 2-13
Nickel price trend, 26 April 1996 – 22 April 2011 (InfoMine)



Source: InfoMine.com

In real money terms, however, the trend over the last century has been generally downwards, as indicated by Lennon (Figure 2-14), until the last five years, since when there has been a sustained upward shift in prices – linked, as would be expected, to the increased production cost level shown earlier in Figure 2-8. Given the potential for supply/demand equilibrium in the nickel market, it can be expected that the outlook for nickel prices will again begin to reflect a real-term decline from the newly established base level of US$ 9–11/lb, meaning that prices of the day will increase approximately in line with prevailing US inflation. This is not to imply that short-term volatility in nickel prices is something of the past: the very nature of the market ensures that it responds rapidly to events affecting it; but that it also moves quickly to correct over-reaction.

Figure 2-14
Nickel price trend, 1900–2010 (Lennon, 2010)



Source USGS LME Macquarie Research November 2010

2.9 The Role of Cobalt

Cobalt (and copper) occurs commonly with both sulphide and laterite ores of nickel, and is more often than not present in sufficient concentrations to warrant recovery. In some cases, the value of cobalt (Co) and copper (Cu) credits can be great enough to determine the viability of the nickel mining operation.

The reason why cobalt, rather than copper, is the focus of this discussion is that the very small global market for cobalt, and the potential for production from the Democratic Republic of the Congo (DRC) to saturate this market, renders the nickel mining business particularly susceptible to changes in the value of cobalt.

According to the 2008 Yearbook of the United States Geological Survey (USGS) (published in April 2010), cobalt is a metal used in a diversity of commercial, industrial, and military applications, many of which are considered strategic and critical. Its leading use globally is in rechargeable battery electrodes. Superalloys, which are used to make parts for gas turbine engines, are another major – and growing – use. Cobalt is also used to make airbags for automobiles; catalysts for the petroleum and chemical industries; cemented carbides (also called hardmetals) and diamond tools; corrosion- and wear-resistant alloys; drying agents for paints, varnishes, and inks; dyes and pigments; ground coats for porcelain enamels; high-speed steels; magnetic recording media; magnets; and steel-belted radial tyres.

Cobalt does not always occur together with nickel; but in those deposits for which grade information is available, it is typically present in concentrations of about 5–10%

of that of the associated Ni, usually in somewhat higher concentrations in laterite ores than in sulphide ores.

According to the USGS and Cobalt Development Institute, global mined production of cobalt reached a record of approximately 88 000 t in 2010, a 22% increase on the previous year and 46% greater than the figure of 60 300 t in 2004. In 2010, by far the largest producer of cobalt was the DRC with 45 000 t or slightly over 50% of total global production; it was followed by Zambia (11 000 t), China (6 200 t), Russia (6 100 t), Australia (4 600 t), and Canada (2 500 t).

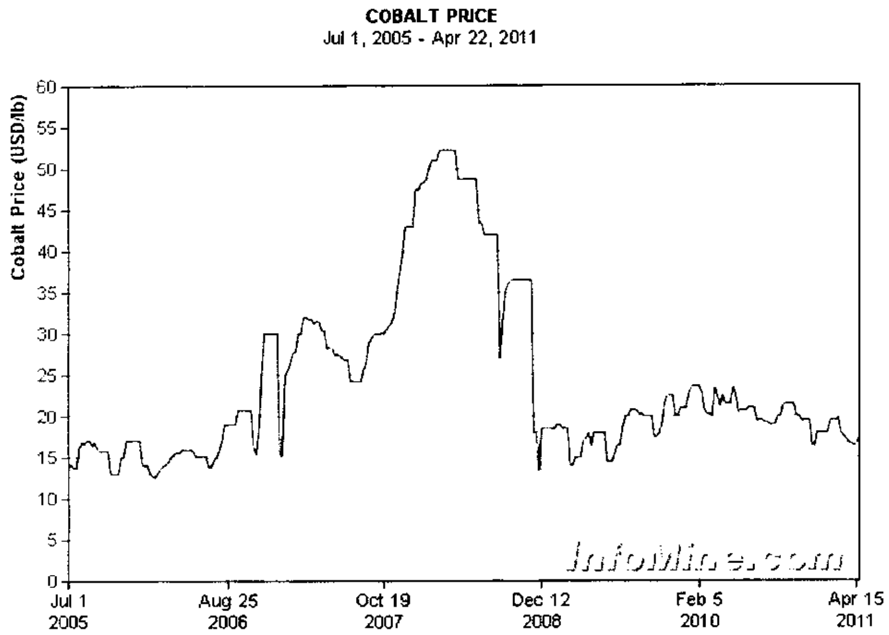
In its report for 2008, the USGS tabulated potential new cobalt projects that might come on stream up until 2013; if all came to fruition, they would bring a total of 191 000 t of new Co production into the market: 79 000 t of it from the DRC, 27 000 t from Zambia and 24 000 t from China. Of course, it is most unlikely that every planned project is realised; but it is instructive to note that DRC production increased by 14 000 t between 2008 and 2010; and that of Zambia by 4 100t in the same period.

Refinery (or 'primary') Co output in 2010 was about 65 000 t, vs only 48 500 t in 2004. Global refinery capacity was given as 86 500 t (China 30 kt; Finland 10 kt; Zambia 8.2 kt; Russia 6 kt; Canada 6 kt; Australia 5.7 kt; Norway 5.2 kt).

From the figures provided above, it is clear that there is already a significant over-supply of Co into the market, mainly due to dramatic increases in by-product Co from the DRC and Zambia, where the principal metal mined is copper. Surprisingly, this continuing over-supply has not yet been fully reflected in the price of the metal, which although declining, is still at levels enjoyed for the last three years (Figure 2-15 and Figure 2-16). Figure 2-15 shows the Co price performance since 2005; and indicates that prices have returned to virtually the same level as they were before the commodity 'bubble' of 2006/2007. Figure 2-16 shows the price trend for the last year in more detail: here it becomes apparent that there is a steady, if gradual decline in the price of Co from over US$ 23/lb in April 2010 to its current level of about US$ 16–18/lb – a decline of approximately 25%.

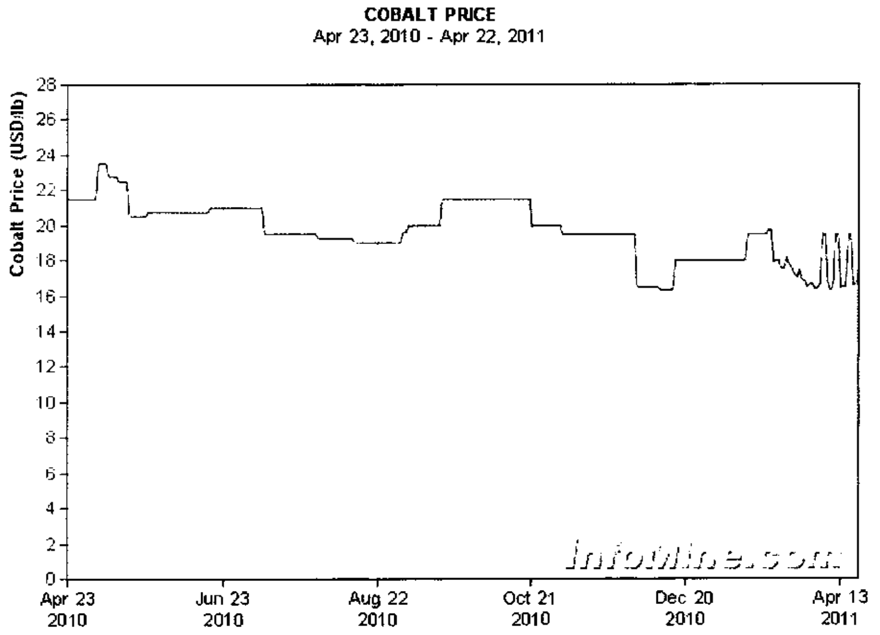
Note that the price of cobalt is approximately double that of nickel; thus, if its typical concentration in nickel ores is about one tenth that of Ni, it can be said that, as a guideline, the typical Co content of nickel ore currently has a value 15–20% that of Ni. This can be sufficient to determine the viability of a high cost operation; and many Ni-Co operations – unlike most major Cu-Co mines – depend on the contribution from Co for their sustainability. The big Cu-Co producers of the DRC and Zambia base their viability on the Cu price; most could tolerate a far lower price for cobalt than their nickel-producing counterparts. Given planned increases in Cu-Co production in the DRC and Zambia and new Ni-Co refineries in China, a major downward shift in Co prices can be expected within the next year or two, once requisite sovereign strategic stockpiles have been accumulated. This in turn is likely to create new commercial applications for lower cost Co; but will jeopardise some existing Ni-Co production.

Figure 2-15
Cobalt price trend, 1 July 2005 – 22 April 2011 (InfoMine)



Source: InfoMine.com

Figure 2-16
Cobalt Price, 23 April 2010 – 22 April 2011 (InfoMine)



Source: InfoMine.com

2.10 Nickel Market Outlook to 2015

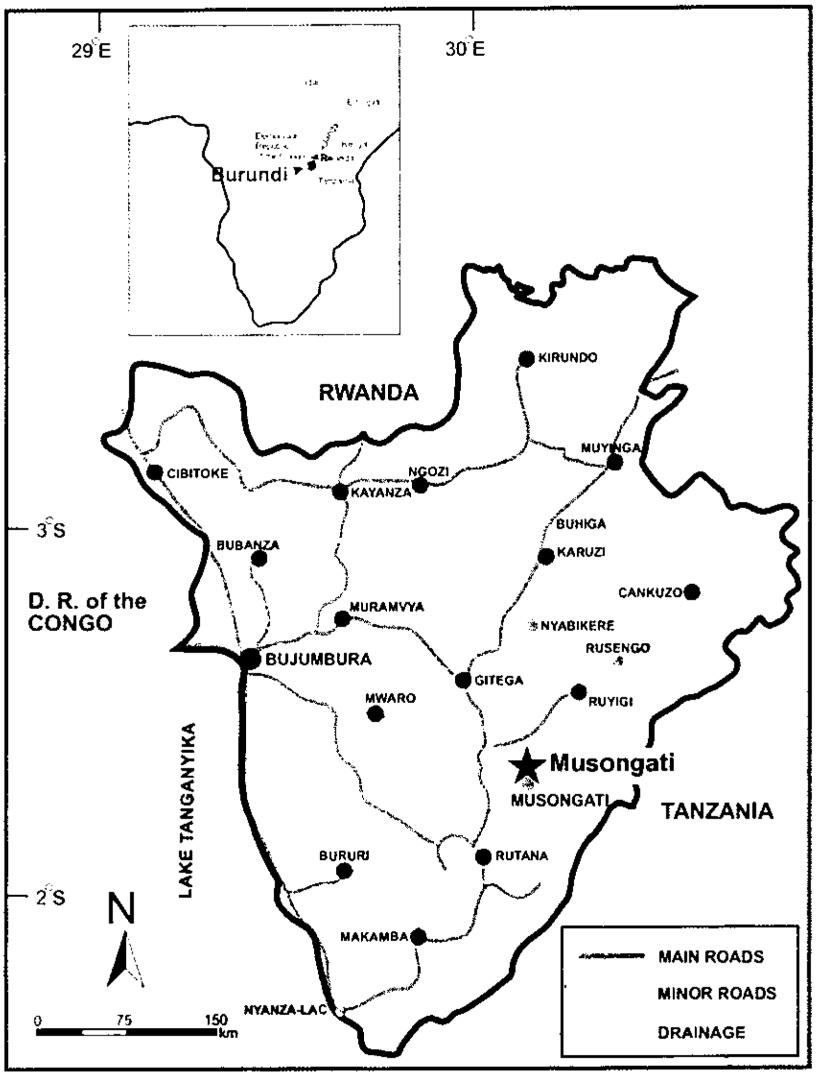
The following points summarise the key factors that are likely to define the nickel market during the next five years at least (assuming no extraordinary economic or political events):

- Over two thirds of nickel consumption is in the manufacture of stainless steel, the global demand for which is likely to continue to show strong growth, especially in China, India and, eventually, Africa.
- However, recent high nickel prices have incentivised stainless steel producers to develop products that consume less nickel, with the result that Ni content in austenitic steels has fallen from about 75% towards 60% in recent years, almost negating the benefit of increased steel consumption.
- Similarly, automotive manufacturers have begun moving away from nickel-plated parts to plastic, because of both weight and cost considerations.
- Nickel's other strong market sectors are in alloys and batteries; both have reasonable growth potential, but both are vulnerable to substitution.
- Chinese end-users responded to high nickel prices by developing Nickel Pig Iron (NPI), a low quality Fe-Ni, which can be blended with higher grade material. Although NPI is costly to produce and cannot constitute more than about 30% of steel plant feed, it will contribute to setting a cap on future nickel prices.
- The inexorable shift towards the exploitation of laterite ores will continue; although they are generally cheaper to mine, processing costs of current technologies are higher, leading to an overall increase in cost. Unless / until these costs can be contained, the profit margin for laterite-nickel producers in particular will continue to be eroded, because of upward inflexibility of prices.
- Reliance on Co by-product credits to maintain viability is fraught with risk, because cobalt prices are set to fall substantially in the face of greatly increased production from Cu-Co producers in central Africa.
- Although characterised by short-term volatility, the nickel market is close to being an efficient market, with many producers, refiners and users. This means it quickly regains equilibrium following economic disruption.
- Producers who are able to maintain production costs below the 50th percentile without being dependent on Co credits should remain profitable under virtually all market conditions.

3 LOCATION OF MUSONGATI PERMIT AREA

BMM's Musongati Permit Area is situated in southeast Burundi, some 85 km east-southeast of Bujumbura, the capital, and 60 km south-southeast of Gitega, the second largest town in the country (Figure 3-1). Access is by a 12 km long section of gravel road leading off the tarred road, the RN8, which connects Bujumbura with Gitega. The project area lies at an elevation of approximately 1 700 m above mean sea level in the tropical highlands and about 1 000 m above Lake Tanganyika which forms the south-western boundary of Burundi.

Figure 3-1
Location of Burundi and the Musongati Permit Area



The Musongati Permit Area covers an area of 17 176.35 hectares (approximately 170 km^2) and is bounded by the coordinates shown in Table 3–1, as contained in the Exploration Agreement (2008). Demarcation of corner points by means of concrete beacons is not required under the Burundi Mining and Petroleum Code (1976).

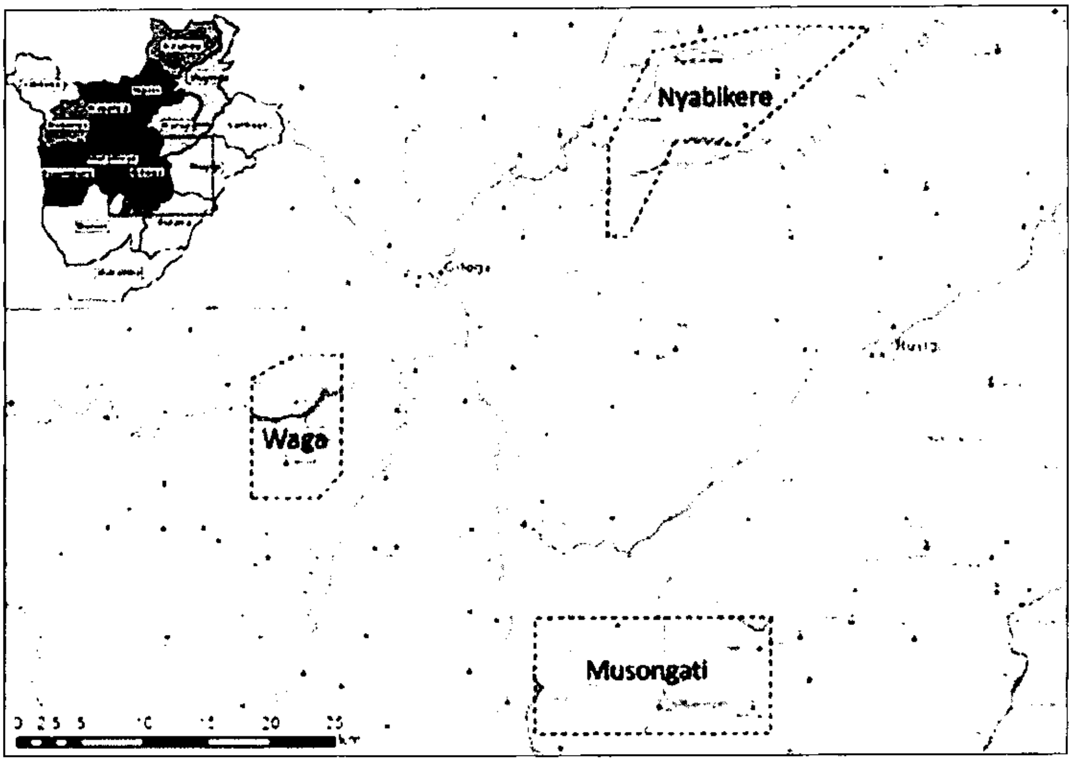
Table 3–1
Geographic Coordinates of the Musongati Permit Area

Polygon Apex	Latitude South	Longitude East
A	3°40'	30°00'
B	3°40'	30°10'
C	3°45'	30°10'
D	3°45'	30°00'

4 MINERAL TENURE

Nickel laterites were discovered in the Musongati area in 1972, during an exploration program conducted by the Government of Burundi and the United Nations Development Program (1975). The discovery encouraged further exploration throughout the 1970s and 1980s. BMM now holds an exploration permit covering both the Musongati deposit and also deposits at Waga and Nyabikere (Figure 4-1).

Figure 4-1
Map showing the location of the BMM Musongati, Waga and Nyabikere Permit Areas in Burundi (Mineral Corporation, 2009)



A summary of the documents relating to BMM's licence holdings in Burundi, together with the historical timeline associated with the issuing of these documents, is presented in Table 4–1. The documents themselves are provided as Appendix 3.

Table 4–1

Documents relating to BMM's exploration permits in Burundi

Document	Description	Main Signatories	Date of commencement	Expiry date
Agreement (*Convention*) and annexures	Sets out terms and obligations; annexe A defines permit areas of Musongati, Waga and Nyabikere	Government of Burundi, Minister of Water, Energy and Mines; Samancor HK Ltd	15 September 2008	23 December 2011
Presidential Decree (*Décret*) No. 100/197 of 2008	Issue of Type A Exploration Permit (*Permis de Recherches*)	Samancor Ni (HK) Limited	23 December 2008	23 December 2011
Name change of company in Hong Kong, (Certificate no. 1196119)	Samancor (HK) Limited to Samancor Ni (HK) Limited	Registrar of Companies in Hong Kong (Certificate no. 1196119)	16 March 2009	
Name change of company in Hong Kong, (Certificate no. 1196119)	Samancor Ni (HK) Limited to BMM International Limited	Registrar of Companies in Hong Kong (Certificate no. 1196119)	10 August 2009	
Name change of company in Burundi	Samancor (HK) Limited to BMM International Limited	Office Notarial de Bujumbura, Acte. No. M/188/2010	10 January 2010	
Name change of company in Burundi	Samancor Ni (HK) Limited to BMM International Limited	Letter from BMM to the Minister of Energy and Mines	1 February 2010	

The Musongati, Waga and Nyabikere permit areas are held by BMM under the terms of a Presidential Decree (Décret), no. 100/197 of 2008, and associated Agreement (*Convention*). The Agreement was signed on 15 September 2008 and forms an annexure to the Decree which was signed on 23 December 2008. The permits are valid from the date of signature of the Presidential Decree, viz. 23 December 2008.

The Presidential Decree grants a 'Type A Permis de Recherches', an exploration licence, in favour of the company Samancor Ni (HK) Limited in respect of nickel, cobalt, copper and platinum-group metals on the Musongati, Waga and Nyabikere deposits. According to the Mining Act of the Republic of Burundi (1976: Article 39), a Type A permit covers areas of an irregular polygonal shape having at least one side oriented north–south.

The Agreement is an exploration agreement between the Government of the Republic of Burundi, represented by the Minister of Water, Energy and Mines, and the company

Samancor (HK) Limited. The registered address of Samancor Ni (HK) Limited is given as:

> Unit 3A
> 20/F Far East Consortium Building
> 121 Des Voeux Road
> Central, Hong Kong
> Republic of China.

The name of the company Samancor (HK) Limited was changed in Hong Kong by special resolution to Samancor Ni (HK) Limited on 16 March 2009. On 10 August 2009 the name Samancor Ni (HK) Limited was changed to BMM International Limited. Both changes were certified by the Registrar of Companies in Hong Kong. In Burundi, the name change from Samancor (HK) Limited to BMM International Limited was certified through the Office Notarial de Bujumbura, Acte. no. M/188/2010, signed on 10 January 2010. The change from Samancor Ni (HK) Limited to BMM International Limited was notified by letter from BMM to the Minister of Energy and Mines dated 1 February 2010.

The Presidential Decree (no. 100/197 of 2008) refers to the Agreement (*Convention*) which was annexed to the Decree, specifically to indicate that the perimeters of the permit areas are contained therein. The Decree also indicates that Samancor Ni (HK) Limited is liable for all obligations specified in the Agreement. The Minister of Water, Energy and Mines is charged with the execution of the decree which comes into force on the day of signature. According to the Decree, the exploration permit is issued to BMM:

> for a single period of three years with the objective of completing a feasibility study on the Musongati Nickel Project and pre-feasibility studies on the Waga and Nyabikere deposits (translated from the original French).

The Agreement sets out the respective commitments and obligations of Samancor (HK) Limited, now BMM, and the Government of the Republic of Burundi. In the Agreement Samancor (HK) Limited is said to have applied for a 'permis d'exploitation' (exploitation permit) for the Musongati, Waga and Nyabikere permit areas and requested rights and benefits in relation to ferrous, non-ferrous and precious metals and platinum-group metals. The Agreement grants a 'permis de recherches exclusifs' (an exclusive exploration permit) to Samancor (HK) Limited for the Musongati, Waga and Nyabikere areas. As reported above, the Presidential Decree states the exploration permit is for nickel, cobalt, copper and platinum-group metals and mentions neither ferrous nor precious metals.

5 GEOLOGICAL SETTING

The Musongati layered complex covers an area of approximately 56 km^2 and is genetically linked to a much larger intrusion referred to as the Mukanda-Buhoro-Musongati complex which covers an additional 62 km^2. The complex is hosted by the "lower series" of the Burundi Supergroup, and has an elongated trough- or keel-shaped geometry which thickens in a westerly direction, with dips of the magmatic layers varying between 20° and 60°to the west.

The western part of the complex is underlain by norite, gabbro-norite and quartz-norite without the development of a nickel-rich laterite profile. The ultramafic units in the eastern part of the Musongati igneous complex are associated with a strongly lateritised and mineralised plateau, dissected by a north-flowing drainage system. In this region the permit contains the three mineralised zones of Buhinda, Rubara and Geyuka. Buhinda is divided into a high-grade (HG) zone and remaining extent (RE).

Geyuka in the west covers an area of 11.5 km^2 and is underlain by feldspathic peridotite and pyroxenite. Rubara in the centre covers an area of about 11 km^2 and is underlain by lherzolitic peridotite. Buhinda in the east covers an area of approximately 6 km^2 and is underlain mainly by dunite and in the northwest and southeast by peridotite.

The laterite profile, similar to that elsewhere in humid tropical environments, shows a strong vertical zonation which reflects the transition from unweathered host rock at the base to highly-laterised residues at the surface. Unlike many nickel laterites which are developed over ophiolites, the Musongati laterites are developed over a layered ultramafic-mafic complex and thus display certain chemical peculiarities.

Nickel, copper, cobalt and precious metal enrichment occur within the laterite profile. The laterite profile comprises soil, canga/cuirasse, ferralite, saprolite and weathered bedrock. Most significantly, the Musongati laterites contain elevated concentrations of copper and precious metals (PGE and Au) and the average nickel content in the most enriched zone of the laterite profile, developed from olivine-rich dunite, can be higher than in comparable profiles of ophiolitic laterites.

A fuller account of the regional and deposit geology is given in the JORC Competent Person's Report for the Musongati Permit Area (Appendix 2).

6 PREVIOUS EXPLORATION AND HISTORICAL MINERAL RESOURCE ESTIMATES

6.1 Previous exploration

The nickeliferous laterite deposits at Musongati were first discovered and investigated by the Government of Burundi during 1972, in a cooperative project with the United Nations Development Program (UNDP) to evaluate the mineral potential of Burundi. The UNDP work was conducted in three phases between 1973–1974, 1976–1977 and 1983–1984, and managed by various international consultants. This work included soil geochemical and ground magnetic surveys followed by diamond drilling programs on each of the three areas, for a total of 237 diamond drillholes with a meterage of 12 684 m. Core recovery was generally in the range of 93%–95% in the mineralised zones. Full details of the UNDP work are included in the JORC Competent Person's Report for the Musongati Permit Area (Appendix 2).

Drilling was supplemented with trenching and pitting for metallurgical bulk sampling over the subareas. A total of nine shafts were sunk next to previously drilled holes on Buhinda and Rubara to depths between 36 m and 55 m.

Metallurgical testing and a pre-feasibility study produced by The Ralph M Parsons Company (RMP, 1978) covered only Buhinda. During the period 1979–1982, additional metallurgical work and another pre-feasibility study by the Swiss company Sulzer Frères Société Anonyme (Sulzer) were carried out. The last phase of work was restricted to the 1.2 km^2 Buhinda HG area.

The Mineral Corporation undertook a detailed review of all past work in 2009. Historical data were reported by The Mineral Corporation as being partially complete. All historical work and mineral resource estimates are documented in The Mineral Corporation report (2009). No further work was undertaken between 1985 and 2009.

6.2 Historical Mineral Resource Estimates

Two types of nickel lateritic nickel mineralisation are distinguished on the basis of iron and magnesium content. A saprolite zone is overlain by a ferralite zone, which is in turn overlain by a nickel-depleted overburden of canga and soil which will require stripping and possible stockpiling of canga. All of the historical mineral resource estimates have modelled the saprolite and ferralite zones separately.

Previous mineral resource estimates have been reported for Musongati and also include a quantitative assessment of the platinum and palladium metal contents for the Buhinda high-grade zone. These must be regarded as historical in nature and do not comply with modern international reporting codes. Specifically, the lack of appropriate modern quality assurance and quality control (QAQC) programs undermines confidence in the historical estimates. A summary of historical mineral resource estimates for Musongati is presented in Table 6–1 below. Further details are provided in the JORC Competent Person's Report for the Musongati Permit Area (Appendix 2).

Table 6–1
Musongati Historical Mineral Resource Estimates

Entity	Year	Methodology	Area	Mt	%Ni	%Co	%Cu	Cut-off % Ni	Comment
UNDP	1978	Cross-sectional polygons	Buhinda HG + RE	87.5	1.5			0.8	Ferralite and saprolite components
Sulzer	1980	Polygonal	Buhinda HG + RE	72.5	1.5			0.8	Review of UNDP estimate
Exploration und Bergbau	1985	Polygonal section	Buhinda HG	29.86	1.6			0.8	Buhinda HG Zone following a third drilling campaign
Sulzer	1980	Polygonal	Rubara	49.8	1.2			0.8	Ferralite and saprolite components
Argosy Minerals Inc	1999	Polygonal	Geyuka	63.18	1.1	0.05	0.14	0.8	Ferralite and saprolite, based on 10 UNDP Phase 1 drillholes
Mineral Corporation	2009	First principle estimation	Buhinda HG	29.9	1.6	0.12	0.31	0.8	Ferralite and saprolite
Mineral Corporation	2009	First principle estimation	Buhinda RE	42.6	1.4	0.09	0.26	0.8	Ferralite and saprolite
Mineral Corporation	2009	First principle estimation	Rubara	49.8	1.2	0.08	0.19	0.8	Ferralite and saprolite
Mineral Corporation	2009	First principle estimation	Geyuka	24.4	0.9			0.8	Ferralite and saprolite

7 RECENT EXPLORATION AND CURRENT MINERAL RESOURCE ESTIMATES

7.1 Recent exploration

BMM completed a further 87 holes for 6 706 m at Musongati between 2009 and 2011 with drilling carried out by South African-based drill contractor Geoserve using Longyear 44 rigs. The design and management of the drill program and the handling and sampling of drill core material at the core yard was conducted by MSA.

The additional drilling fulfilled the following purposes:

Eight twin drillholes in the Buhinda HG zone to validate the results obtained during the UNDP drilling campaigns. Drill spacing in the Buhinda HG zone is mostly 100 m; however, a small area in the centre was previously drilled by the UNDP to 50 m spacing.

- Four drillholes were drilled in the Buhinda HG zone to investigate PGE potential of the Ni-laterite. These four drillholes are included in the Ni-laterite resource estimation.
- 37 infill drillholes were drilled in Buhinda RE to reduce the drill spacing from 400 m to 200 m and to test two geophysical targets.
- 24 infill drillholes were drilled on Rubara to reduce the drill spacing of mostly 400 m to 200 m and to test three geophysical targets.
- 14 additional drillholes at a 200 m spacing on Geyuka including the testing of two geophysical targets.

An appropriate quality control program was in place throughout this campaign, and followed industry best practice through the use of certified reference materials, field and laboratory duplicates, blanks, and check samples analysed at an independent laboratory.

7.2 Current Mineral Resource Estimates

The MSA Group (MSA) has conducted a review of previous exploration programs and existing sample preparation methodology and is of the opinion that the current data spacing at Buhinda, Rubara and Geyuka areas is sufficient for declaration of updated nickel resources. The planning and execution of these most recent infill and step-out drilling programs and GPS surveys was conducted in a professional manner and MSA is of the opinion that the resulting data are adequate for use in resource estimation.

A revised in-situ JORC-compliant mineral resource estimate has been completed by MSA, using the data from the 2009–2011 campaign as well as the UNDP data. No geological losses have been applied at this stage. The combined input database contains 7 148 samples in 321 drillholes (18 654.39 m) from all four areas. The ferralite and saprolite horizons were modelled separately. As well as nickel, precious metals –

Pt, Pd and Au ("3E") – have been estimated within the ferralite and saprolite resource envelopes for those areas where adequate data are available.

The combined mineral resources for all four areas (Buhinda HG; Buhinda RE; Rubara and Geyuka) are summarised below in Table 7–1and Table 7–2, at a 0.8% Ni cut-off, and include Indicated and Inferred categories, according to the JORC Code (2004 edition). Detailed Mineral Resource Estimates are presented in the JORC Competent Person's Report for the Musongati Permit Area (Appendix 2). The location of the four mineralised zones is shown in Figure 7-1.

Table 7–1

In-Situ Mineral Resources for Ferralite at a 0.8% Ni Cut-Off, Musongati Permit

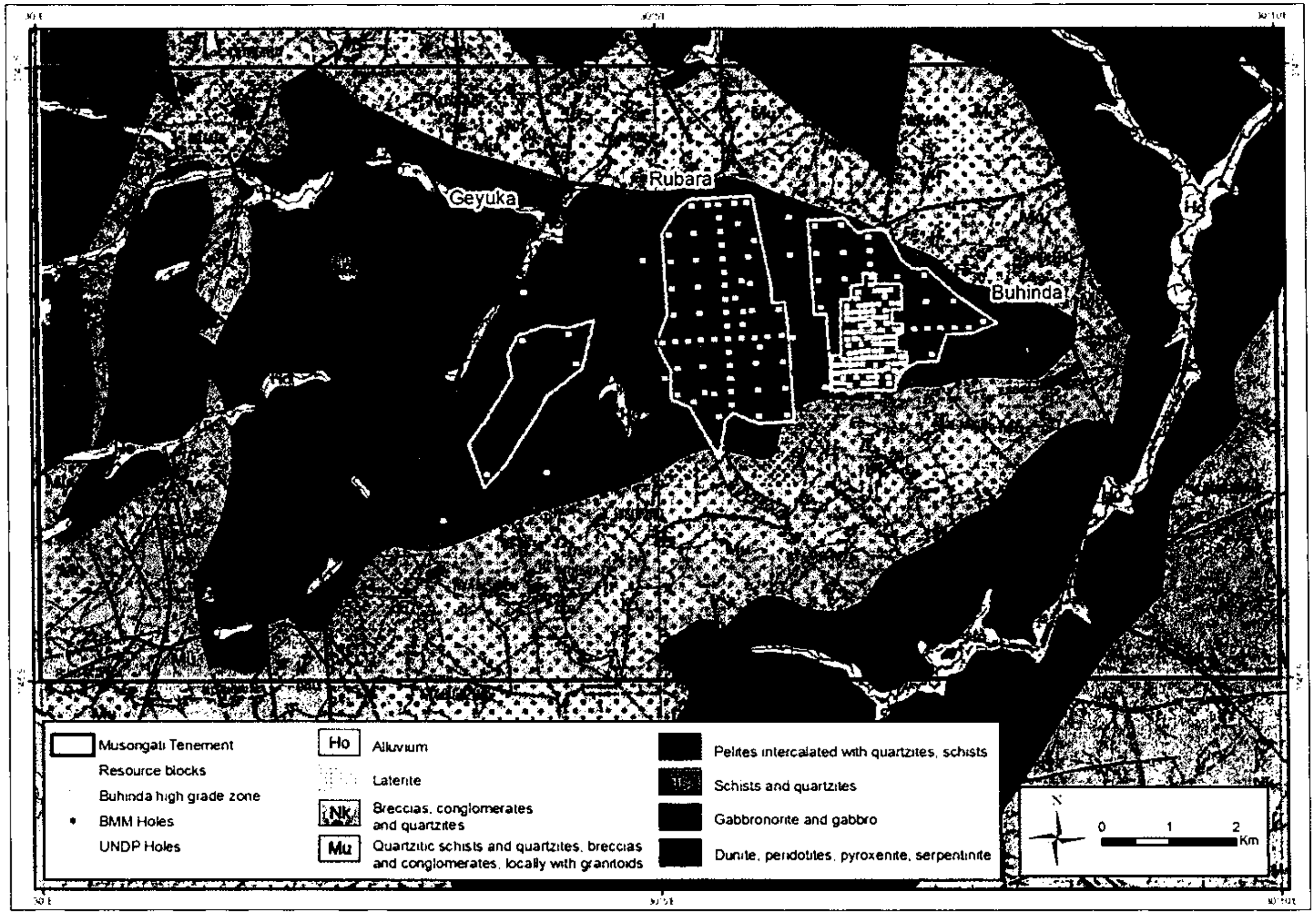
Ferralite	Million Tonnes	Density	%Ni	Ni million lbs	%Co	%Cu	%Fe_2O_3	%SiO_2	%MgO	3E ppm	3E Koz	Pt ppb	Pd ppb	Au ppb
INDICATED														
Buhinda HG	15.77	1.02	1.18	409	0.16	0.36	63.0	10.1	1.8	1.36	689	438	820	100
Buhinda RE	10.89	0.98	1.05	253	0.17	0.33	61.8	9.1	1.2	1.15	402	331	717	101
Total/Average	**26.66**	**1.01**	**1.13**	**662**	**0.17**	**0.35**	**62.5**	**9.7**	**1.5**	**1.27**	**1091**	**394**	**778**	**100**
INFERRED														
Buhinda HG	0.71	0.97	1.20	19	0.15	0.30	57.2	15.0	4.0	1.20	28	496	606	103
Buhinda RE	8.45	1.02	1.03	193	0.17	0.32	60.8	10.4	1.3	1.25	339	356	792	102
Rubara	14.66	1.05	1.00	322	0.14	0.20	59.4	15.1	2.2	-		-		-
Geyuka	3.50	1.05	0.95	73	0.11	0.20	53.0	12.4	1.4	-		-		-
Total/Average	**27.32**	**1.04**	**0.99**	**607**	**0.14**	**0.24**	**59.0**	**13.3**	**1.9**		**367**			

Table 7–2
In-Situ Mineral Resources for Saprolite at a 0.8% Ni Cut-Off, Musongati Permit

Saprolite	Million Tonnes	Density	%Ni	Ni million lbs	%Co	%Cu	$\%Fe_2O_3$	$\%SiO_2$	%MgO	3E ppm	3E Koz	Pt ppb	Pd ppb	Au ppb
INDICATED														
Buhinda HG	13.91	1.32	2.34	716	0.06	0.20	21.1	36.2	23.0	0.56	249	197	323	37
Buhinda RE	6.27	1.35	1.87	259	0.06	0.22	26.8	35.8	15.8	Inferred in the Nickel envelope				
Total/Average	**20.18**	**1.33**	**2.19**	**975**	**0.06**	**0.21**	**22.8**	**36.1**	**20.8**		**249**			
INFERRED														
Buhinda HG	3.30	1.36	1.94	141	0.05	0.19	22.1	35.9	22.1	0.54	58	191	306	45
Buhinda RE	15.94	1.36	1.77	622	0.06	0.20	25.0	36.7	17.7	0.51	261	145	317	47
Rubara	41.30	1.33	1.31	1195	0.05	0.13	31.5	34.2	14.9	-		-	-	-
Geyuka	15.48	1.33	1.00	340	0.06	0.14	34.7	26.6	11.3	-		-	-	-
Total/Average	**76.02**	**1.34**	**1.26**	**2298**	**0.05**	**0.15**	**30.4**	**33.2**	**15.1**		**319**			

Figure 7-1

Location of the four mineralised zones, Buhinda HG and Buhinda RE, Rubara and Geyuka, in the eastern part of the Musongati Complex. The distribution of drillholes is also shown, underlain by the geology



8 MINING METHODOLOGY AND MINE PLANNING, ORE BENEFICIATION AND UTILITIES

8.1 Introduction

The nickel resource within the Musongati Permit Area is of sufficient size to support an operation producing 30 000 tonnes per annum of nickel for well in excess of 25 years.

Mining is planned to commence in the central southern portion of the Buhinda High Grade Zone and to progress northwards once the 18 m thick overburden has been removed. This will be achieved by free dig by a suite of excavators and haulage trucks. The removal of the ore is also a free dig process, to be handled by a second suite of excavators and haulage trucks. The ore will be taken to stockpiles at the primary crushers and then fed into the ore processing system via front-end loaders. Further details of mining, ore beneficiation and utilities can be found in Appendix 4.

Depending on the final metallurgical process option selected, mining can be configured to supply any combination of feed material once the initial box cut excavation is complete.

8.2 Mining

The general surface layout of the proposed Musongati Mine is illustrated in Figure 8-1. The site footprint will include the mining operation, ore stockpiles and ore reprocessing, and, depending on the processing route chosen, heap leach pads, a beneficiation plant, kilns and smelters, auxiliary plant for water treatment, acid preparation, power and steam, and also waste dumps.

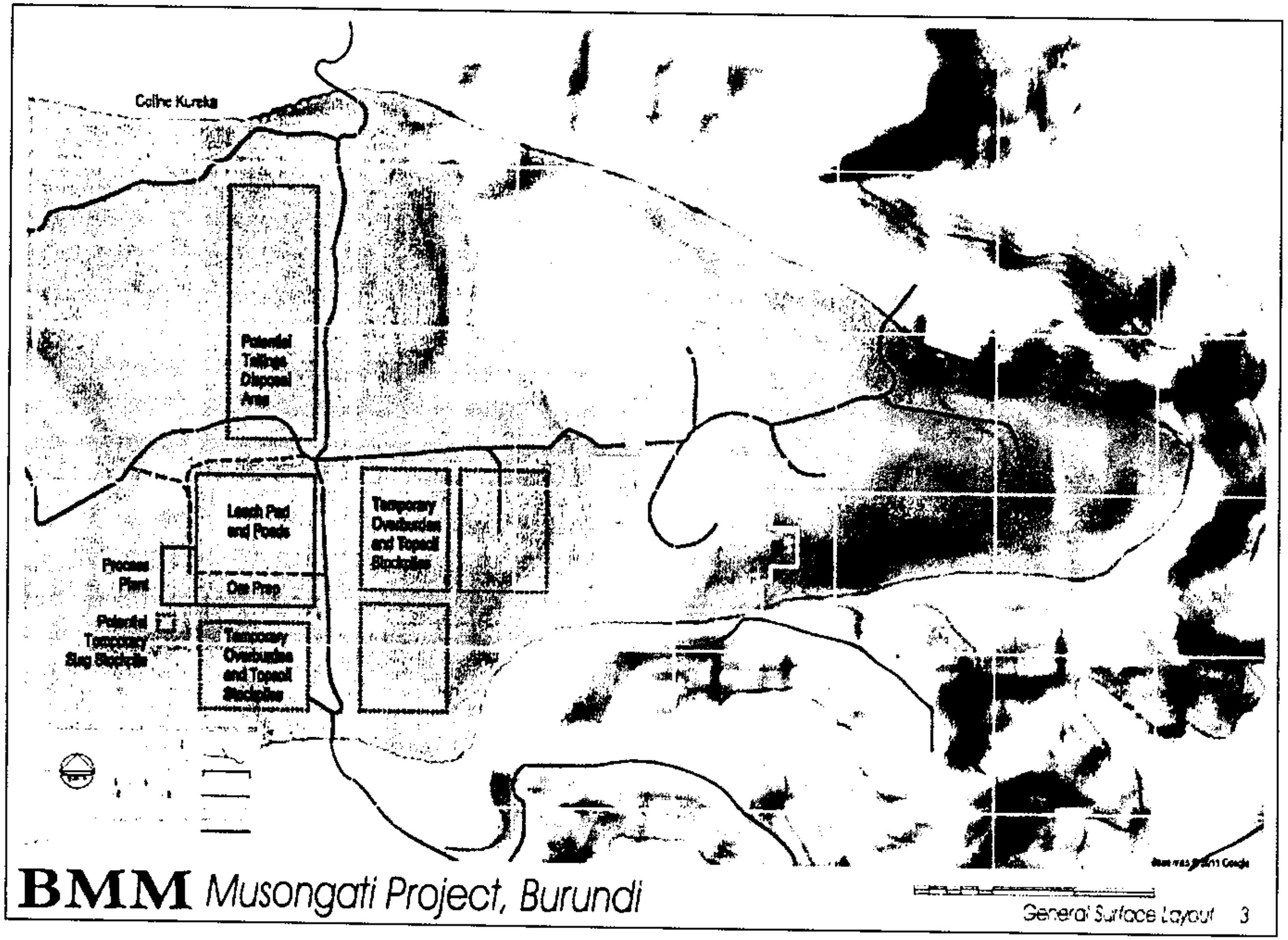
The Musongati nickel laterite deposit is covered by 18 m of overburden which overlies the ferralite and saprolite. A number of mining options exist and are dependent on the processing route chosen. Potentially both ferralite and saprolite ore are mined and sold; alternatively, a blend of ferralite and saprolite is fed to a metallurgical plant. A third option is that only saprolite ore is mined as it is higher grade than the ferralite ore.

The mining operation will be free dig, with no blasting required, and although the economic exercise is terminated at 25 years the deposit is expected to last in excess of 30 years. It is planned that a specialist mining contracting company is used to undertake the mining of the deposit. The effect of this will be to increase the mining cost but capital expenditure and direct staffing requirements will be reduced.

A key issue in respect of the Musongati deposit is the very high moisture content of the ferralite and saprolite. With the exception of the overlying canga, the material to be mined is uncompacted and friable. Intact rock strength (IRS) is low due to the uncompacted nature of the ore. In the open pit a series of consecutive benches will be cut and will constitute a stack. It is anticipated that the slope angle will be less than the natural angle of repose for the material due to the excessively high moisture content. Slope angles of 20° and 30° have been used for the soil and canga respectively. The bench height will match the width of the material as this varies from 8–10 m in both cases. In the ferralite and saprolite horizons grade control and dilution will be constrained by controlling the bench height and matching it to the excavator which would be the primary production tool. Based on the ore thickness, a bench height of 5 m will be used. The high moisture content will mean that no water will be used in the mining operation and that the pits will make water from the commencement of mining.

The mining operation will consist of a pre-strip to expose saprolite ore and then conventional bench mining of soil, canga, ferralite and saprolite. In the course of the pre-strip significant quantities of ferralite will be mined. This ore will be stockpiled against future processing requirements. The overburden comprising soil and canga will be stockpiled separately and used for backfilling and rehabilitation. Ferralite and saprolite will be mined in a ratio of approximately 54 : 46. The ores will be mined separately and delivered to two separate stockpiles at the metallurgical processing plant. Plant personnel will blend the ore from the stockpiles to achieve the feed grade and tonnage required by the processing plan.

Figure 8-1
General layout of mining areas and tailings deposition areas



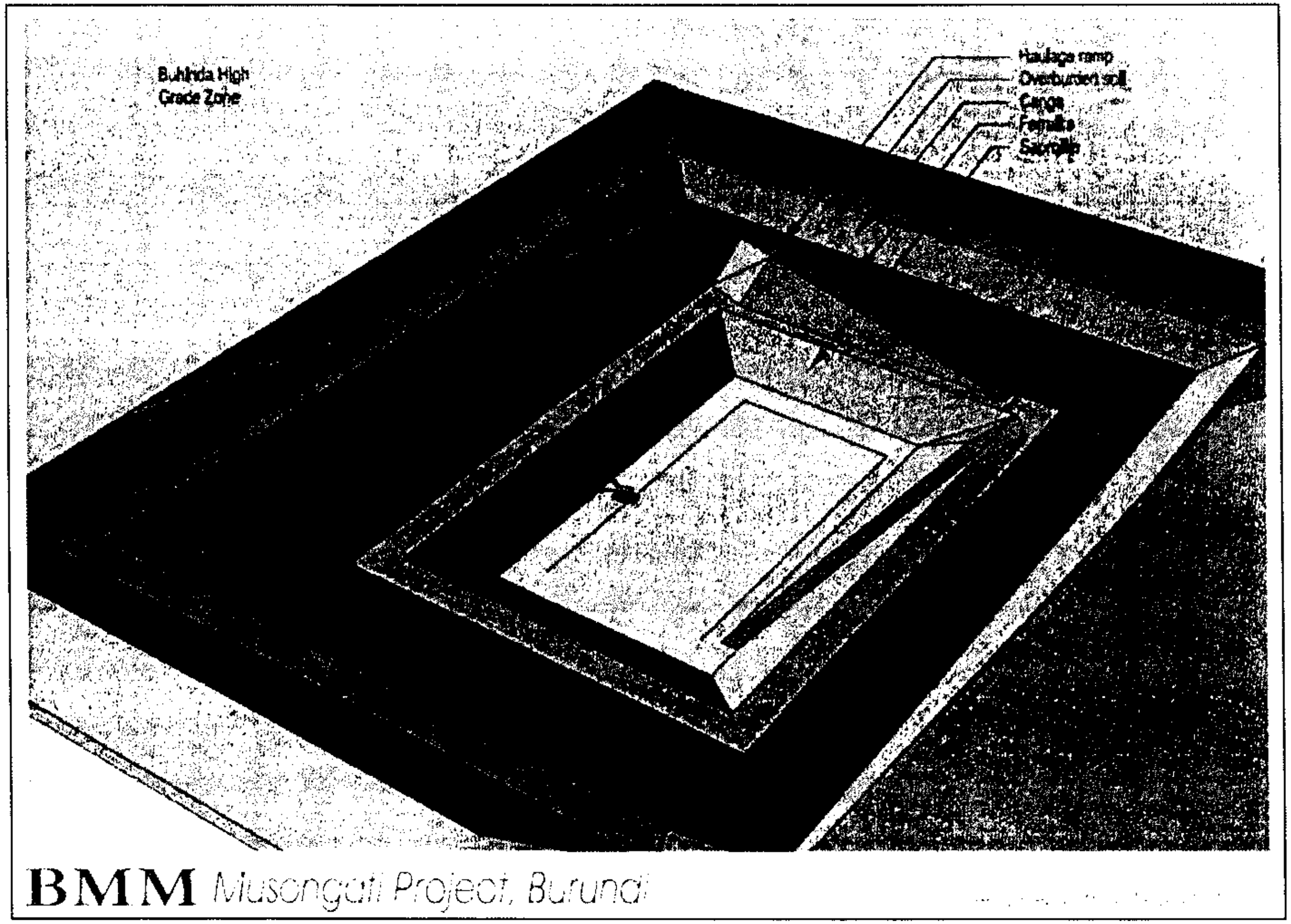
The soil pre-strip will comprise 10.6 Mt of soil in the first two years and a further 5.3 Mt in the following three years. The canga pre-strip will comprise about 3.85 Mt in the first two years and a further 1.9 Mt in the following three years. Ferralite will be mined in year 2 and in order to ensure enough saprolite is exposed this will amount to about 2.5 Mt (Table 8–1). Once a sufficient void has been created in the open pit, the waste will be back-filled into the void concurrently with the mining operation.

Table 8–1
Mining plan for the first six years of operation

ORE EXPORT		Years					
		1	**2**	**3**	**4**	**5**	**6**
Pre strip							
Soil	M^3	5 323 097	5 323 097	1 774 366	1 774 366	1 774 366	
Canga	M^3	1 929 529	1 929 529	643 176	643 176	643 176	
Overburden							
Soil	M^3			355 193	532 789	710 386	781 424
Canga	M^3			241 024	361 536	482 048	530 252
Ore							
Ferralite	tonnes		2 540 518	607 485	760 006	912 528	671 093
Saprolite	tonnes		146 030	400 000	600 000	800 000	880 000
Ferralite Ore Management							
	stockpile		2 400 682	2 625 135	2 810 591	2 957 053	2 785 473
	withdrawn		139 836	383 033	574 550	766 066	842 673
Total Tonnes Ore			**285 865**	**783 033**	**1 174 550**	**1 566 066**	**1 722 673**

Figure 8-2 shows the initial box cut and the different horizons exposed.

Figure 8-2
Aerial view of box cut from the east



8.3 Ore Preparation

Mined ore will need to be dried to <5% moisture and then crushed and sized before being either exported or processed. A co-current rotary dryer will dry the material and reduce the moisture level to about 1%. The hot gas generator uses a blast furnace as the main fuel and coke oven gas as start-up fuel. The dried ore will then be conveyed to a closed circuit crushing system which includes a Jaw crusher, a granulator and an autogenous rotary crusher. Ore feed for the export option will consist of a blend of the ferralitic fraction and the saprolitic fraction. Feed for an onsite processing plant can be tailored to requirements.

8.4 Utilities

The provision of power, water and transport is critical to the viability of the project. Although there is currently insufficient power available in Burundi for the development of the project BMM has, as indicated elsewhere, entered into a separate agreement with the Burundian Government to develop various hydropower projects which will generate sufficient power to allow project development. Alternatively, it is possible to establish a peat fired power station using local peat resources.

8.5 Mining costs

Capital mining costs are shown in Table 8–2 and associated costs and a cash flow during the first six years of production in Table 8–3.

Table 8–2

Mining and associated capital costs

Capital costs	**US$**	**US$**
Pre-production		
earthworks	2 000 000	
roads	3 000 000	
housing	20 000 000	
associated infrastructure	2 000 000	
Total pre-production		**27 000 000**
Contractor site establishment		**10 000 000**
Crushing and screening		
plant	1 637 700	
services	450 000	
Total crushing and screening		**2 087 700**
Infrastructure		
offsite infrastructure	10 000 000	
rail siding	40 000 000	
general	1 500 000	
Total infrastructure		**51 500 000**
Total capital costs		**90 587 700**

Table 8–3
Production and cash flow for the first six years of operation

COSTS		Years					
		1	2	3	4	5	6
Mined, including moisture							
30%	soil	6 920 026	6 920 026	2 768 427	2 999 302	3 230 177	1 015 852
	canga	2 508 388	2 508 388	1 149 460	1 306 125	1 462 791	689 328
35%	ferralite	0	3 429 699	820 105	1 026 009	1 231 912	905 976
	saprolite	0	197 140	540 000	810 000	1 080 000	1 188 000
	US$ / t	Costs (US$)					
waste	2.07	19 516 816	19 516 816	8 110 025	8 912 234	9 714 444	3 529 722
ore	3.03	0	10 989 323	4 121 119	5 563 106	7 005 094	6 344 746
crushing and drying	8.00	0	21 492 382	8 059 883	10 880 052	13 700 221	12 408 745
admin			2 200 000	2 200 000	2 200 000	2 200 000	2 200 000
Total on mine costs		***19 516 816***	***54 198 521***	***22 491 026***	***27 555 392***	***32 619 759***	***24 483 213***
Unit cost per tonne sold			***189.59***	***28.72***	***23.46***	***20.83***	***14.21***
Recovery							
Contained Ni	80%	0	3 965	10 861	16 292	21 722	23 894
Unit cost			***6.20***	***0.94***	***0.77***	***0.68***	***0.46***
Transport							
Road	15						
Rail	127.16						
Total	***142.16***		***40 638 602***	***111 315 988***	***166 973 983***	***222 631 977***	***244 895 174***
Total costs		19 516 816	94 837 123	133 807 014	194 529 375	255 251 736	269 378 387
Unit cost per tonne			**331.75**	**170.88**	**165.62**	**162.99**	**156.37**

9 PROCESSING OPTIONS

9.1 Introduction

BMM International Ltd. is currently undertaking a development program for the processing of nickel laterite ore produced from the Musongati nickel laterite deposit in Burundi. The Musongati resources are believed to contain around 150 Mt of ore at 1.32% Ni (0.8% Ni cut-off grade). The initial ore target for the project will be the global Buhinda resource (combined high grade and remainder). This area contains 75 Mt of laterite resources (combined indicated and inferred resources) at 0.8% Ni cut-off, which is suitable feedstock for a 10−20 ktpa Ni project.

A major factor in the development of the Musongati nickel laterite deposit is the selection of the most appropriate processing technology. Key issues impacting on this selection are:

- The deposit is geographically remote
- Power availability is limited
- The technical base in Burundi is low, therefore complex technologies will be more difficult to implement
- The ore contains substantial amounts of copper in addition to nickel and cobalt.

Based on the above, the following technologies were selected for evaluation:

Option 1 – Heap Leaching

Option 2 – Atmospheric Leaching

Option 3 – Matte Smelting

Option 4 – Processing of intermediate products using CVMR's carbonyl based vapour processing technology for the production of value-added nickel, iron and cobalt powder.

Ausenco Vector has been contracted to develop a Venture Analysis (Idea Phase) engineering design and cost evaluation of these processing options, aimed at providing a ±50% cost estimate for the project, and identifying the key business drivers. This report summarises the results of this investigation. The full report is presented as Appendix 5.

9.2 Scope of Work

The purpose of the Musongati Nickel Project Venture Analysis Study is to evaluate potential processing options for the treatment of nickel laterite ore from the Buhinda high grade resource at Musongati, and to identify processing and environmental issues. The study will include processing, process services, process-related infrastructure, and major environmental issues.

The Venture Analysis evaluates the following potential cases:

1. Heap Leaching of both blended ferralite (limonite) / saprolite ore (Case 1A) and saprolite only (Cases 1B and 1C), with nickel production as a mixed nickel/cobalt hydroxide (MHP). The nickel production was 10 kt/a for Cases 1A and 1B and 20 kt/a for Case 1C.

2. Atmospheric Leaching of saprolite ore at 10 kt/a nickel production (Case 2A) and 20 kt/a nickel production (Case 2B). The nickel product was again MHP.

3. Smelting of the high grade saprolite ore producing FeNi matte (Case 3A) and FeNi alloy (Case 3B) by standard Rotary Kiln – Electric Furnace (RKEF) industry practice. The ore throughput for this option is 1.2 Mdt/a, which produces 25 kt/a Ni in FeNi matte and FeNi alloy.

4. Processing of intermediate MHP or crude ferronickel using CVMR metal vapour refining technology leading to the production of nickel and iron powder. Two cases were evaluated, Case 4A where the feedstock was crude ferronickel containing 22 kt/a of nickel and Case 4B where the feedstock was MHP containing 10 kt/a of nickel.

The accuracy of the capital and operating cost estimates was ±50% (as defined by the Ausenco Vector Project Management Guidelines).

9.3 Resources and Location

The nickel laterite deposit and proposed process plant site are located approximately 50 km by road from the town of Gitega in Burundi and 85 km from the country's capital Bujumbura. The proposed plant site is adjacent to the Buhinda ore body, close to the village of Musongati. Main road access to the Musongati site is via Gitega. A route also links Musongati with the town of Kigoma in Tanzania (130 km). Kigoma has rail access to the major port at Dar es Salaam. It is proposed that Dar es Salaam will be the receiving port for sulphur, coal and other reagents for the process plant.

In early 2011 The MSA Group completed mineral resource estimates for the Musongati Permit Area, which includes the Buhinda, Rubara and Geyuka plateaus. Table 9-1 summarises the resources for the Musongati Permit Area at a 0.8% Ni cut-off grade.

Table 9-1
Mineral Resources of the Musongati Permit Area at a 0.8% Ni cut-off

Deposit	Type	Million Tonnes	Density t/m^2	Ni %	Co %	Cu %	Fe_2O_3 %	SiO_2 %	MgO %
INDICATED RESOURCES									
Buhinda HG	Ferralite	15.77	1.02	1.18	0.16	0.36	63.0	10.1	1.8
	Saprolite	13.91	1.32	2.34	0.06	0.20	21.1	36.2	23.0
Buhinda RE	Ferralite	10.89	0.98	1.05	0.17	0.33	61.8	9.1	1.2
	Saprolite	6.27	1.35	1.87	0.06	0.22	26.8	35.8	15.8
INFERRED RESOURCES									
Geyuka	Ferralite	3.50	1.05	0.95	0.11	0.20	53.0	12.4	1.4
	Saprolite	15.48	1.33	1.00	0.06	0.14	34.7	26.6	11.3
Rubara	Ferralite	14.66	1.05	1.00	0.14	0.20	59.4	15.1	2.2
	Saprolite	41.30	1.33	1.31	0.05	0.13	31.5	34.2	14.9
Buhinda HG	Ferralite	0.71	0.97	1.20	0.15	0.30	57.2	15.0	4.0
	Saprolite	3.30	1.36	1.94	0.05	0.19	22.1	35.9	22.1
Buhinda RE	Ferralite	8.45	1.02	1.03	0.17	0.32	60.8	10.4	1.3
	Saprolite	15.94	1.36	1.77	0.06	0.20	25.0	36.7	17.7

9.4 Conceptual Engineering Design – Heap Leaching (Option 1)

9.4.1 Description of Heap Leach Process Plant

The process plant would be designed to recover nickel and cobalt values from high-grade Buhinda ore based on heap leaching with sulphuric acid. The proposed downstream processing would produce a single mixed hydroxide product (MHP).

The proposed process plant comprises the following metallurgical unit operations:

- Ore preparation of run-of-mine (ROM) ore via two-stage crushing
- Agglomeration of crushed ore with sulphuric acid, followed by stacking onto a specially prepared heap
- Two-stage (counter-current) heap leaching of the stacked ore to recover nickel and cobalt. A dynamic on/off pad was employed in the current study
- Precipitation of dissolved iron and aluminium from the pregnant leach solution (PLS) generated from heap leaching using a two-stage impurity removal circuit
- Recovery of nickel and cobalt from impurity-free PLS as a mixed hydroxide product (MHP) via a two-stage mixed hydroxide precipitation circuit, the first stage producing the MHP product and the second for metals scavenging
- Neutralisation of MHP stage 2 barren liquor in a bleed neutralisation circuit, with recycle of neutralised liquor to the heap leach
- Disposal of neutralisation residue via dry stacking to a residue storage facility (RSF) in conjunction with spent ore from heap leaching.

Process packages include a sulphur-burning acid plant, a limestone slurrying plant, a lime kiln and slaking plant, and an MgO slurrying plant.

9.4.2 Design Basis

The proposed process plant design is based on process mass and energy balances which have been developed from process design criteria and the overall process diagram. A plant availability of 75% (6 570 hrs/yr) has been applied for ore crushing, agglomeration and stacking, and 90% (7 900 hrs/yr) for the rest of the plant (heap leaching, PLS processing, utilities and reagents).

Based on projected heap leach ramp-up, and an analysis of projects similar in complexity, the following ramp-up schedule has been applied:

Year 1: 43% of design nickel production (blended ore feed), 35% of design nickel production (saprolite ore feed)

Year 2: 100% of design nickel production

Year 3+: 100% of design nickel production.

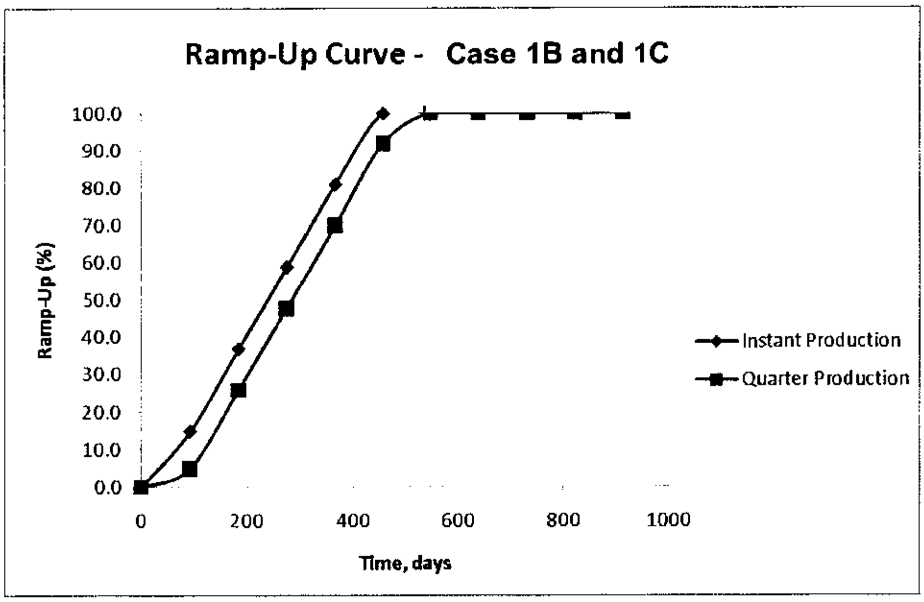
The key process data are shown in Table 9-2 based on the projected ore feed schedules.

Table 9-2
Key process data: Musongati Heap Leach Process Plant

Parameters	Units	Case 1A	Case 1B	Case 1C
Ore Feed to Plant				
Tonnage	Mdt/a	0.80	0.63	1.23
Ni	%	1.83	2.26	2.26
Co	%	0.10	0.06	0.06
Fe	%	26.60	14.90	14.90
Mg	%	8.70	13.80	13.80
Acid Consumption (HL)	kg/t ore	510	530	530
Acid Consumption (Total)	kg/t ore	560	570	570
Nickel Recovery				
Heap Leaching	%	75	75	75
Overall	%	70	70.6	70.6
Product				
Mixed Hydroxides	dt/a	31 200	27 300	54 700
Contained Nickel	t/a	10 000	10 100	20 200

The expected nickel production ramp-up for saprolite ore (Cases 1B and 1C) is given in Figure 9-1.

Figure 9-1
Expected nickel production ramp-up for saprolite ore feed



9.4.3 Infrastructure and Services

The Musongati Heap Leach Project requires substantial supporting infrastructure. The following main infrastructure facilities have been identified:

- Site works for the process plant, heap leach and other facilities
- The construction of a sulphur handling/storage facility for sulphur importation at Dar es Salaam with a capacity of 35 000 DWT (10 kt/a options – Case 1A, 1B and 2A) and 50 000 DWT (20 kt/a Options – Case 1C and 2B)
- Process plant internal roads and access to the adjacent residue storage facility (RSF)
- A power plant which will utilise excess steam from the acid plant to generate power for use in the process plant and associated infrastructure. Current preliminary estimates for Case 1A (blended ore) are for a power production of 13 MW of power with a consumption of 11 MW. For Case 1B (saprolite feed), the power production is 10 MW and the corresponding consumption 11 MW, indicating a deficiency of power. The 20 kt/a nickel production (Case 1C), has an overall slight power surplus, with a power production of 20 MW versus a consumption of 19 MW. These data assume that the acid plant also produces the low pressure steam requirement for the process plant.
- The additional power requirement will be supplied by power from external sources

- Power distribution facilities within both the process plant and heap leach area. A water treatment facility is required which supplies filtered water and demineralised water to the process plant and utilities
- Other utility services, including telecommunications, waste treatment and waste disposal
- A construction camp to accommodate the construction workforce
- Site buildings, including control rooms, product storage facilities, reagent preparation buildings and a product filter house
- Communications facilities to provide telephone, facsimile, UHF radio, mobile communications and computer data requirements to the process plant.

9.5 Conceptual Engineering Design – Atmospheric Leaching (Option 2)

9.5.1 Description of Atmospheric Leaching Plant

The atmospheric leach process plant comprises the following metallurgical unit operations:

- Ore preparation
- Two-stage (counter-current) atmospheric leaching to extract nickel and cobalt
- Counter-current decantation (CCD) to recover aqueous nickel and cobalt from leach residue solids
- Precipitation of dissolved iron and aluminium from the pregnant leach solution (PLS) using a two-stage impurity removal circuit
- Recovery of nickel and cobalt from impurity-free PLS as a mixed hydroxide product (MHP) via a two-stage mixed hydroxide precipitation circuit, the first stage producing the MHP product and the second for metals scavenging
- Two stage final neutralisation circuit, with recirculation of barren solution to the CCD circuit as wash liquor.

Process packages include a sulphur-burning acid plant, a limestone slurrying plant, a lime slaking plant, and an MgO slurrying plant. The estimates have been developed for a nickel production of 10 000 t/a (case 2A) and 20 000 t/a (Case 2B) Ni in MHP product for the cases investigated.

9.5.2 Design Basis

The proposed process plant design is based on process mass and energy balances which have been developed from process design criteria and the overall process diagram. A plant availability of 86% (7 500 hrs/yr) has been applied. Similar to heap leaching, a ramp-up schedule has been developed based on an analysis of projects similar in complexity, and has been estimated as:

Year 1: 70% of design nickel production

Year 2: 90% of design nickel production

Year 3+: 100% of design nickel production.

The key process data are shown in Table 9-3.

Table 9-3
Key process data: Musongati Atmospheric Leach Process Plant

Parameters	Unit	Case 2A	Case 2B
Ore Feed to Leach			
Tonnage	Mdt/a	0.50	1.00
Ni	%	2.34	2.34
Fe_2O_3	%	21.1	21.1
MgO	%	13.0	13.0
Acid Consumption (Leach)	kg/t ore	850	850
Acid Consumption (Total)	kg/t ore	870	870
Nickel Recovery			
Atmospheric Leaching	%	92.5	92.5
MHP	%	95.3	95.3
Overall	%	88.5	88.5
Products			
Mixed Hydroxides	dt/a	20 400	40 800
Contained Nickel	t/a	10 000	20 000

9.5.3 Supporting Infrastructure and Services

The supporting infrastructure and services required for an atmospheric leach based process plant will be similar to those of a heap leach based plant, with the following key differences:

- An excess of power will be produced from the process plant as a substantially larger acid plant is required. At 10 kt/a nickel production (Case 2A) the power generation has been estimated at 17 MW and the power demand 10 MW. At 20 kt/a nickel production (Case 2B) the power generation has been estimated at 35 MW and the power demand 18 MW
- The atmospheric leach plant will require a substantial tailings storage facility and an evaporation pond to evaporate excess process solution. A preliminary estimate of evaporation pond sizing indicates that three modules, each of size

1 000 m wide x 1 000 m long x 10 m high would be required for 20 kt/a nickel production.

9.6 Conceptual Engineering Design – FeNi Matte Smelting (Option 3)

9.6.1 Description of Ferronickel Matte Smelting Process Plant

The ferronickel matte process plant would be designed to produce a nickel/cobalt containing matte from Musongati saprolite ore, based on Rotary Kiln – Electric Furnace (RKEF) processing. The proposed product is ferronickel matte grading at 68% Ni.

The proposed process plant comprises the following metallurgical unit operations:

- Ore preparation of run-of-mine (ROM) ore via two-stage crushing
- Ore blending using a stacker-reclaimer system
- Drying of the blended ore using a rotary dryer (to 20% moisture)
- Calcination of the dried ore in rotary kilns at 900 °C to remove associated moisture, and to partially reduce nickel and iron using bituminous coal addition
- Electric furnaces where the calcine is melted using a combination of electric arc power and the slag bath power. Molten sulphur is added to sulphidise the calcine. The smelting products are slag and high iron ferronickel matte.
- •The matte tapped from the electric furnace is transferred to one of the two converters, where iron is oxidised from the crude matte, producing a low iron matte product
- Granulation of the molten slag with high pressure water, with storage of the slag in a temporary slag stockpile prior to back-filling of mined areas with granulated slag during mine rehabilitation
- Production of granulated ferronickel matte and ferronickel alloy product in a metal granulation plant.

Associated process packages include a coal preparation plant (producing both pulverised coal for kiln burners and crushed coal for reduction in the rotary kiln), cooling towers (for the electric furnace and general plant cooling), water treatment, and plant and instrument air packages.

9.6.2 Description of Ferronickel Alloy Smelting Process Plant

The ferronickel alloy based smelter is similar to the matte plant, but produces a 20% Ni ferronickel product grading at 25% Ni. The ferronickel process plant comprises the following metallurgical unit operations:

- Ore preparation, blending, drying and calcinations similar to matte production
- Electric furnaces where the calcine is melted using a combination of electric arc power and the slag bath power. The calcine smelting products are slag and crude ferronickel (FeNi)

- Granulation of the molten slag with high-pressure water, with storage of the slag in a temporary slag stockpile prior to back-filling of mined areas with granulated slag during mine rehabilitation
- Refining of the crude FeNi in a refinery to remove impurities such as sulphur, carbon, silicon and oxygen
- Production of granulated ferronickel product in a metal granulation plant
- Recovery of ferronickel from refinery slag in a slag metal recovery plant using a combination of screens and magnetic separators.

Associated process packages include a coal preparation plant (producing both pulverised coal for kiln burners and crushed coal for reduction in the rotary kiln), cooling towers (for the electric furnace and general plant cooling), water treatment, a nitrogen and oxygen plant (producing process gases for the refinery), and plant and instrument air packages.

9.6.3 Design Basis

The proposed process plant design is based on process mass and energy balances which have been developed from process design criteria and the overall process diagram. Plant availabilities for each process area have been based on industry experience. For example, the availability in the rotary kiln, electric furnace and refinery (converters) is 85%; within ore reclaiming and drying the availability is 80%.

Based on projected process plant ramp-up, and an analysis of projects similar in complexity, the following ramp-up schedule has been applied for the project:

Year 1: 65% of design nickel production

Year 2: 88% of design nickel production

Year 3: 98.5% of design nickel production

Year 4+: 100% of design nickel production.

The key process data are shown in Table 9-4.

Table 9-4
Key process data: Musongati Matte Smelting Process Plant

	Unit	Case 3A	Case 3B
		FeNi Matte	FeNi Alloy
Ore Feed to Plant			
Saprolite	Mdt/a	1.2	1.2
Moisture	%	30	30
Nickel Content	%	2.26	2.26
Overall Recovery			
Nickel	%	91.0	92.0
Products			
Refined ferronickel matte	dt/a	35 600	123 200
Nickel Content	%	69.30	20.20
Nickel Production (in matte)	t/a	24 700	24 900

9.6.4 Supporting Infrastructure

A matte smelting process plant requires substantial supporting process plant infrastructure. The following main infrastructure facilities have been identified:

- Site works for the process plant, granulation pond, construction facilities and construction camp
- Surface water management
- Process plant roads
- Process plant buildings, including general buildings (such as offices, laboratory, canteen, medical centre, fire station, change houses, security and weighbridge), process plant operational buildings (such as control rooms) and service-related buildings (such as electrical substation buildings, reagent and consumable buildings, coal preparation and handling building, services buildings)
- A construction camp to accommodate the construction staff
- Process plant sub-stations and HV distribution to all process plant areas. The sub-stations involve a 150 kV GIS main sub-station and several area substations. The estimated overall process plant load is 100 MV
- Sewage treatment facilities for the process plant and temporary construction camp
- Fire protection systems

- Fuel storage facilities
- Communications facilities to provide telephone, facsimile, UHF radio, mobile communications and computer data requirements.

9.7 Conceptual Engineering Design – Intermediate Product Processing by CVMR

9.7.1 Description of CVMR Carbonyl Processing

In addition to primary ore processing options (Options 1 to 3), the processing of intermediate products by chemical metal vapour refining (CVMR) technology has been evaluated. Two intermediate nickel products were evaluated:

- Case 4A: crude ferronickel (containing 22 kt/a of nickel)
- Case 4B: MHP (containing 10 kt/a of nickel) produced from saprolite processing.

The CVMR technology involves the following processing stages:

- Drying and reduction of the feed (especially MHP) to produce a metalised feed to vapour phase processing
- The production of nickel, iron and cobalt powder utilising CVMR carbonyl processing (carbonylation using carbon monoxide, distillation of nickel and iron carbonyl gas, cobalt separation using nitrous oxide, decomposition of carbonyl gases at elevated temperature to produce nickel, iron and cobalt powder.

The key process data are shown in Table 9-5.

Table 9-5
Key process data: intermediate processing using CVMR Vapour Phase Processing Technology

	Units	Case 4A	Case 4B
CVMR Feed			
Tonnage to Heap Leach	dt/a	73 800	28 400
Ni	%	30.0	35.4
Co	%	0.7	1.2
Fe	%	66.7	2.7
CVMR Metal Extraction			
Ni	%	98	97
Co	%	75	75
Fe	%	92	
Overall Recovery to MHP			
Nickel	%	88.2	88.2
Cobalt	%	86.7	86.7
Nickel Powder Production			
Nickel	t/a	21 700	9 740
Cobalt	t/a	380	250
Iron	(t/a)	45 300	

9.7.2 Supporting Infrastructure

The intermediate product refinery need not be located at Musongati, but at a location which favours reagent supply and the marketing of products. Key supporting infrastructure for CVMR processing comprises:

- Carbon monoxide (CO) make-up supply which will be produced from a dedicated gas plant using methanol or LNG as the carbon source
- Power supply: the current power demand is 22 MW for crude ferronickel processing and 23 MW for MHP processing. About 90% of the MHP power demand is for drying and reduction, which could be supplied by an alternative fuel source.

9.8 Conceptual Capital Cost Estimates

9.8.1 Accuracy of Estimate

This estimate complies with the requirements of an Ausenco Vector Venture Analysis Study. The accuracy of the capital cost estimate is considered to be ±50%.

9.8.2 Estimate Summary

The scope of the cost estimate includes capital for the following:

Direct costs:

- Process plant, including heap leaching (Option 1) and PLS processing (Options 1 and 2) for hydrometallurgical options
- Major process packages, including the acid/power plant, limestone slurrying plant and lime kiln for hydrometallurgical options; and coal preparation and process gases for matte smelting
- Utilities and reagents, including water treatment, power sub-stations and distribution and mobile equipment
- Process plant infrastructure, including site preparation, process plant roads, sulphur unloading and storage facilities, and process plant buildings
- General infrastructure, including electronic data services and security.

Indirect costs:

- Construction camp and operation
- Construction equipment and fuel requirements
- Temporary construction facilities
- Mobilisation and demobilisation
- Pre-commissioning
- Health, Safety and Environment (HSE) and training requirements
- Engineering, Procurement and Construction Management (EPCM), vendor supervision, and commissioning assistance
- First fill and commissioning spares
- Contingency.

Process plant estimates were developed from those for similar areas in similar sized nickel projects and adjusted for flow or equipment capacity and currency movements. Acid plant costs were based on budget vendor pricing for a 1 100 metric tonnes/day (MTPD) acid plant (from SNC Lavalin-Fenco) and based on an EPCM based contract.

Costs for CVMR carbonyl processing were developed by CVMR based on feed specifications supplied by Ausenco Vector.

Heap Leach estimates were based on a similar nickel laterite heap leach project in South America which operates under high rainfall conditions.

Process and general infrastructure costs were also developed from similar nickel laterite projects and adjusted for area requirements and capacity as required.

The indirect costs were prepared on the basis of a project management team being retained to perform the services of engineering, procurement of major equipment and management of construction.

A contingency of 35% has been applied to direct and indirect costs. The contingency reflects the state of development of the project, and allows a margin for changes to the process and equipment selection and sizing where specific design criteria are not yet available.

Summaries of capital costs are shown in Table 9-6 (Heap Leaching Options), Table 9-7 (Atmospheric Leach Options), Table 9-8 (matte smelting) and Table 9-9 (CVMR processing of intermediates). Costs are presented in March 2011 United States Dollar (US$) values.

9.8.3 Exclusions

The following items are specifically excluded from the estimate:

- Mining related capital costs
- Residue storage facility (RSF) and tailings storage facility (TSF) estimates and deferred capital
- Major off-site infrastructure for a greenfields project such as the accommodation village and services, dedicated port facilities upgrade at Dar es Salaam, diesel storage at the port, air strip, mine access roads, access road upgrade from the Tanzanian border to the proposed plant site, etc.
- Duties and taxes
- Escalation
- Owner's costs
- Technology fees (if applicable)
- Engineering, Procurement, Construction Management (EPCM) assistance following introduction of feed to the plant, during commissioning and ramp up
- An estimate of working capital requirements.

Table 9-6
Musongati Nickel laterite Project: HL–MHP Capital Cost Estimates (Option 1)

Description	Capital Cost, Million US$		
	Case 1A	Case 1B	Case 1C
	Blend Feed 10 kt/a Ni	Saprolite Feed 10 kt/a Ni	Saprolite Feed 20 kt/a Ni
Ore Preparation and Stacking	29.4	27.7	36.2
Heap Leach Pad and Ponds	26.6	26.4	33.1
Nickel Recover	27.5	23.4	37.7
Bleed Neutralisation	5.5	9.4	13.8
Spent Ore and Residue Stacking	7.4	6.8	10.4
Sulphuric Acid / Power Plant	69.9	60.8	73.9
Lime Kiln and Slurrying Plant	8.2	11.5	17.5
Other Major Packages	10.1	8.1	28.9
Water Services and Utilities	20.0	18.9	25.6
Process Plant Infrastructure	27.0	23.6	37.8
General Infrastructure[1]	1.0	1.1	1.9
Subtotal Direct Cost	**232.4**	**217.8**	**316.8**
EPCM	20.6	19.8	30.9
Other Construction Services	42.6	40.4	58.4
Subtotal Indirect Cost	**63.2**	**60.2**	**89.3**
Direct + Indirect Cost	**295.5**	**278.0**	**406.1**
Contingency, 35%	103.4	97.3	142.1
Total Project Cost	**399.0**	**375.4**	**548.2**
Total Project Cost, US$/lb Ni	**18.0**	**16.9**	**12.3**

[1] Electronic data services and fencing costs only. Excludes major off-site infrastructure

Table 9-7
Musongati Nickel Laterite Project: AL–MHP Capital Cost Estimates (Option 2)

Description	Capital Cost, Million US$	
	Case 2A	Case 2B
	Saprolite Feed 10 kt/a Ni	Saprolite Feed 20 kt/a Ni
Ore Preparation	8.6	12.5
Nickel Recovery	73.9	103.0
Final Neutralisation	5.8	7.8
Sulphuric Acid / Power Plant	61.0	92. 9
Lime Kiln and Slurrying Plant	8.4	12.7
Other Major Packages	19.7	29.8
Water Services and Utilities	22.0	31.0
Process Plant Infrastructure[1]	56.2	90.6
General Infrastructure[2]	1.5	2.3
Other Direct Cost	2.9	4.3
Subtotal Direct Cost	**259.9**	**386.9**
EPCM	25.8	38.2
Other Construction Services	30.9	48.6
Subtotal Indirect Cost	**56.7**	**86.8**
Direct + Indirect Cost	**316.6**	**473.7**
Contingency, 35%	110.8	165.8
Total Project Cost	**427.4**	**639.5**
Total Project Cost, US$/lb Ni	**19.2**	**14.4**

[1] Includes 3 $MgSO_4$ evaporation ponds

[2] Electronic data services and fencing costs only. Excludes major off-site infrastructure

Table 9-8
Musongati Nickel Laterite Project: FeNi Matte and Alloy Capital Cost Estimates (Option 3)

Description	**Capital Cost, Million US$**	
	Case 3A	**Case 3B**
	FeNi Matte	FeNi Alloy
Ore Preparation and Blending	9.4	9.4
Ore Drying	17.6	17.6
Agglomeration	19.0	19.0
Calcining	37.4	37.4
Smelting	196.8	196.8
Refining (Converters)	10.5	20.5
Matte Granulation, Drying and Packing	7.3	6.2
Refinery Slag-Metal Recovery	0.0	9.1
Process Services	28.9	29.4
Process Plant Infrastructure	77.7	79.4
General Infrastructure[1]	2.0	2.0
Subtotal Direct Cost	**406.5**	**426.9**
EPCM	74.9	76.1
Other Construction Services	208.2	211.5
Subtotal Indirect Cost	**283.2**	**287.6**
Direct + Indirect Cost	**689.7**	**714.4**
Contingency, 35%	241.4	250.1
Total Project Cost	**931.1**	**964.5**
Total Project Cost, US$/lb Ni	**17.1**	**17.5**

[1] Electronic data services and fencing costs only. Excludes major off-site infrastructure

Table 9-9
Musongati Nickel Laterite Project: CVMR Refinery Capital Cost Estimates (Option 4)

Description	**Capital Cost, Million US$**	
	Case 4A 10 kt/a Ni Carbonyl Plant treating MHP	**Case 4B** 22 kt/a Ni Carbonyl Plant treating FeNi
Equipment Cost	28.2	161.5
Mechanical Installation	2.0	11.3
Skids	0.6	2.0
Insulation	0.1	0.3
Instrumentation	9.3	53.3
Heat Tracing	0.6	1.6
Piping and Ducting	2.1	11.7
Valves	2.0	3.7
Design and Engineering	2.0	11.3
Subtotal Direct Cost	**46.9**	**256.6**
Training and Certification	0.4	0.5
Manuals and Procedures	0.3	0.5
Commissioning and Start-up	1.0	1.5
Travel Expenses	0.8	0.8
Vendor's Representative	0.4	0.4
Freight and Insurance	0.7	0.9
Subtotal Indirect Cost	**3.4**	**4.4**
Direct + Indirect Cost	**50.3**	**261.01**
Contingency (direct cost only), 30%	14.1	77.0
Total Project Cost	**64.3**	**338.0**

9.9 Conceptual Operating Cost Estimates

9.9.1 Accuracy of Estimate

This estimate complies with the requirements of an Ausenco Vector Venture Analysis Study. The accuracy of the operating cost estimates is considered to be ±50%.

9.9.2 Operating Cost Summary

The operating cost estimates are based on the process design criteria, flowsheets and mass balances.

The operating costs include:

- Reagents and utilities
- Labour
- General expenses
- Maintenance consumables
- Contract expenses, including contract maintenance.

Pricing for all major reagents is based on budget pricing from South African suppliers or recent nickel project evaluations (especially sulphur and coal pricing). A price for crushed limestone of US $25/tonne was assumed based on a similar situation in a South American project (no local limestone available). Transport costs from the port of Dar es Salaam to site were based on freight data from The Minerals Corporation (2009) and taken at US$ 99/tonne.

Labour rates were based on an estimation of the required organisational structure, current African labour rates (Republic of Congo) and expatriate labour and on-costs from a nickel laterite project under construction in Africa. Expatriate costs were based on a Filipino workforce supplemented by key Western positions.

A contingency of 10% was applied to all operating costs.

Table 9-10 summarises operating costs at Year 3 for the hydrometallurgical options evaluated. The main operating costs were reagents (dominated by sulphur, limestone, MgO, and coal), maintenance materials and labour costs.

The operating costs for the FeNi matte and FeNi alloy smelting option (Option 3) for Year 4+ are presented in Table 9-11. As expected, the operating costs are dominated by coal and power costs which represent over 70% of variable costs.

The operating costs for CVMR processing of crude ferronickel and MHP are given in Table 9-12. Operating costs here are dominated by power, maintenance and labour. There is significant potential to reduce MHP processing costs by substituting a cheaper fuel source than electricity for drying and reduction, since 90% of the power demand is in this area. Costs are presented in February 2011 United States dollar (US$) values.

Table 9-10
Operating Cost Estimates for Hydrometallurgical Processing Options (Year 3+)

Expense Item	**Annual Operating Costs (Year 3+), US$ Million**				
	Case 1A 10 kt/a Ni HL-MHP Blend	**Case 1B** 10 kt/a Ni HLM-HP Saprolite	**Case 1C** 20 kt/a Ni HL-MHP Saprolite	**Case 2A** 10 kt/a Ni AL-MHP Saprolite	**Case 2B** 20 kt/a Ni AL-MHP Saprolite
Consumables	69.55	64.66	124.32	65.28	124.58
Labour	11.39	11.39	13.92	9.65	10.79
Maintenance Materials	6.39	6.26	9.17	6.13	9.00
Contract Expenses	13.59	12.44	23.34	9.24	15.33
Administration and General Expenses	1.50	1.50	3.70	1.61	1.95
Sub-total Operating Costs	**102.43**	**96.25**	**174.45**	**91.91**	**161.65**
Contingency, 10%	10.24	9.63	17.45	9.19	16.17
Total Operating Cost	**112.67**	**105.88**	**191.90**	**101.10**	**177.82**
Total Operating Cost, US$/lb Ni	**5.10**	**4.76**	**4.31**	**4.54**	**3.99**

Table 9-11
Musongati Nickel Laterite Project: FeNi Matte Option Year 4+ Operating Cost Estimate

Expense Item	Annual Operating Cost, Million US$	
	Case 3A FeNi Matte	**Case 3B** FeNi Alloy
Consumables	145.00	145.24
Maintenance Materials	7.46	7.80
Subtotal Variable Costs	**152.46**	**153.04**
Contract Maintenance	1.87	1.95
Power Maintenance	0.50	0.50
Labour	11.36	10.88
General Administration	10.14	13.33
Subtotal Fixed Costs	**23.87**	**26.66**
Subtotal Operating Costs	**176.33**	**179.70**
Contingency, 10%	17.63	17.97
Total Operating Cost	**193.96**	**197.66**
Total Operating Cost, US$/lb Ni	**3.56**	**3.60**

Table 9-12
Musongati Nickel Laterite Project: CVMR Refinery Operating Cost Estimates (Option 4)

Description	Annual Operating Cost, Million US$	
	Case 4A 10 kt/a Ni Carbonyl Plant treating MHP	**Case 4B** 22 kt/a Ni Carbonyl Plant treating FeNi
Supervision	1.02	4.32
Technical	1.16	5.72
Labour	2.01	8.55
Maintenance	1.25	8.90
General Operations Expense	0.23	0.72
Technical Service	0.51	3.56
Subtotal Fixed Costs	**6.18**	**31.77**
Carbon Monoxide	0.64	1.83
Nitrogen	0.15	0.71
Product Drums	0.21	1.50
Labels	0.02	0.12
Diesel	0.02	0.14
Others	0.25	1.78
Subtotal Variable Costs	**1.29**	**6.08**
Electricity[1]	20.04	18.30
Water	0.01	0.01
Subtotal Utilities Costs	**20.05**	**18.31**
Subtotal Operating Costs	**27.52**	**56.16**
Contingency, 10%	2.75	5.62
Total Project Cost	**30.27**	**61.78**
Total Project Cost, US$/lb Ni	**1.37**	**1.22**

9.9.3 Estimate Exclusions

The following items have not been included in the operating cost estimates developed for the Musongati Venture Analysis options:

- Mining and ore haulage
- Operating costs for major infrastructure, such as port facilities, accommodation village, tailings dam / residue storage facilities, off-site roads, air strip, etc.
- Sustaining capital costs
- Marketing costs
- Corporate consultancies
- Duties, customs or other imposts
- Finance-related costs
- Government charges and royalties.

9.10 Metallurgical Development Program Overview

A metallurgical development program has been developed to provide the fundamental information needed to develop metallurgical design criteria at different stages of the Musongati nickel project.

The metallurgical development program will involve the following stages:

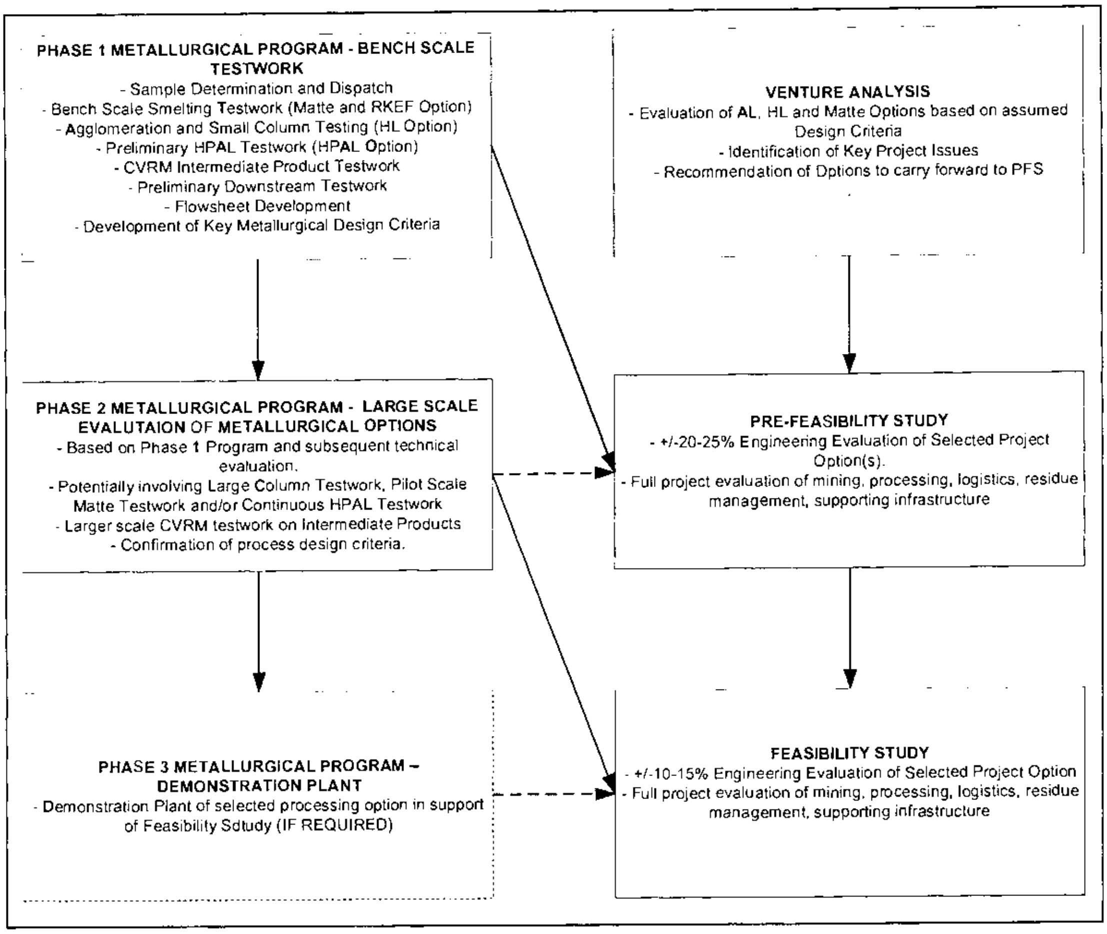
Phase 1: Bench scale test work on potential metallurgical options

Phase 2: Larger scale evaluation of short-listed metallurgical options

Phase 3: Potential demonstration plant.

Each of these stages will provide the key metallurgical data required for subsequent engineering studies, the Phase 1 bench scale test work being employed for a Pre-Feasibility Study, the Phase 2 larger scale test work (including pilot plant trials) as the basis for a Feasibility Study. Figure 9-2 presents the recommended test work program to provide key design criteria at each stage of the processing circuit.

Figure 9-2
Overview of a metallurgical development program for the Musongati Nickel Laterite Project



Based on the current Venture Analysis Study and the results of limited previous test work it is recommended that the Phase 1 metallurgical program evaluate the following processing options:

- Heap leaching of saprolite
- Smelting to a crude ferronickel product
- Preliminary high pressure acid leaching (HPAL) testing of an integrated pressure acid leach / atmospheric leach circuit
- Processing of intermediate products (MHP or crude ferronickel) to metal powder utilising CVMR metal vapour processing technology.

Scopes of work and laboratory responses have already been received for a heap leach / atmospheric leach hydrometallurgical test work program and a matte smelting test work program. These test work programs should be modified to incorporate the recommended process option changes.

9.11 Evaluation of Processing Options

An evaluation of the four processing options for high grade Buhinda ore was undertaken based on the following key technical issues:

1. Capacity to treat the ore
2. Capital and operating costs
3. Power requirements
4. Environmental issues associated with solid and liquid effluent disposal
5. Operability issues associated with a process plant located in a remote area.

The results of this analysis are summarised in Table 9-13. Based on this evaluation, the following process routes have been shortlisted for carrying forward in the project:

- Heap leaching of saprolite
- Crude ferronickel smelting
- CVMR processing of MHP or crude ferronickel.

Heap leaching of ferralite appears technically difficult and likely to generate substantial quantities of residue. Atmospheric leaching of saprolite is expensive due to the high acid demand, and likely to entail significant environmental issues in effluent disposal.

A further option which should be investigated is high pressure acid leaching (HPAL) of ferralite coupled with atmospheric leaching of saprolite. This presents itself as the only potential option for treating high-grade ferralite and is likely to have a relatively low acid usage (but low availability and higher complexity due to the operation of an autoclave).

Table 9-13
Overview of Processing Options for Musongati

Potential Treatment Technology	Nickel Production (kt/a)	Power Usage (MW)	Power Generation (MW)	Capital Cost (USD million)[1]	Capital Cost (USD/lb Ni)	Operating Cost (USD/lb Ni)[2]	Environmental Issues	Operability issues	Potentially Fatal Issues
Heap Leaching (Option 1)							• Solids residue disposed of to dry stack tailings. • Liquid effluent recycled in process	• Low complexity equipment	• May not be able to treat ferralite based on initial bottle roll data.
Case 1A: Blend Feed	10	11.2	13.0	394.7	17.8	5.10			
Case 18: Saprolite Feed	10	11.0	9.7	371.1	16.7	4.76			
Case 1C: Saprolite feed	20	18.4	19.5	544.2	12.2	4.31			
Atmospheric Leaching (Option 2)							• Solids residue to tailings storage facility • Excess sulphate containing effluent disposed of to evaporation pond	• Low complexity equipment • Substantial evaporation pond required which may be problematic	• Sulphate containing effluent may not be managed by evaporation ponds during the wet season. The cost of full magnesium sulphate neutralization is prohibitive (lime usage increases to 135 t/h). • Saprolite slurry is difficult to settle hence tailings disposal is an issue in an inland project location.
Case 2A: Saprolite Feed	10	10.4	17.3	423.2	19.0	4.54			
Case 2B: Saprolite Feed	20	22.4	34.7	628.8	14.1	3.99			
Pyrometallurgical Treatment (Option 3)							• Inert slag produced which is readily disposed of	• RKEF or matte production requires considerable expertise in operations • Matte smelting can tolerate wider feed range than RKEF • Iron in FeNi alloy could not be processed and reduced further due to high converter temperatures needed for a low iron FeNi. • PGM's would not be recovered using FeNi alloy production but is recoverable in matte smelting process.	• Need to supply 100 MW of power • FeNi cannot be sold due to high copper content.
Case 3A: FeNi Matte Production	25	101	N/A	931.1	17.1	3.56			
Case 3B: FeNi Alloy Production	25	105	N/A	964.5	17.6	3.60			
CVRM Intermediate Processing							• HSE issues due to high toxicity of nickel carbonyl, but CVRM have strong HSE track record (Section 7.5)	• High degree of complexity but CVRM plant need not be located in Burundi	
Case 4A: Carbonyl plant treating MHP	10	23	-	64		1.37			
Case 4B: Carbonyl Plant treating FeNi	22	21	-	338		1.22[3]			
High Pressure Acid Leaching						Likely to be lower than Heap or Atmospheric Leach due to lower acid usage.	• Similar residue issues to Atmospheric Leaching but smaller quantities. Effluent disposal issue could be alleviated by full neutralization of discharge liquor.	• Technically complex with high maintenance requirement and relatively low availability (83% max). • Could be only technical option capable of treating high grade limonite from Buhinda HG deposit.	

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[1] Capital costs exclude tailings disposal and other major off-site infrastructure

[2] Based on nickel only. Cobalt credits excluded

[3] Based on nickel and iron powder operating costs reduce to US$ 0.44/lb