

South African Chrome Ore for the Production of Charge Chrome

M. Sciarone

CMI Ltd., South Africa

ABSTRACT

South African chrome ore will become the dominant source for ferrochrome production.

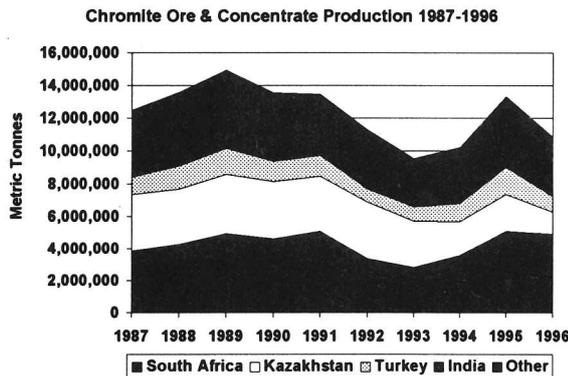
Factors such as geology, mining methods, beneficiation and chemistry of the ore are discussed.

The effect of chrome/iron ratio on the cost of ferrochrome production is analysed in detail.

1. Introduction

The production of chrome ore peaked in 1989 at 15 million tonne. Current per annum production is estimated at 11m tonne per annum (figure 1). This major decline is attributable to the rationalisation of the mining in Kazakhstan, Albania and Philippines.

Figure 1 :



It is estimated that approx. 3 million tonne of ore are traded of which about half is destined for metallurgical use as opposed to refractory, foundry and chemical applications. Forty percent of the 3 million tonnes of traded ore originate in South Africa and 60% from other sources, mainly Turkey, India and Middle East (including Iran) with small quantities from Brazil, Madagascar, Pakistan, Sudan, etc.

On the assumption that the chrome ores from non-South African sources have a limited potential of increased production and since more than 50% of all ore is expected to be mined in South Africa, the effect of South African ore on the efficiency of ferrochrome smelting is important (figure 2a and 2b).

Figure 2(a) World Chrome Ore Production

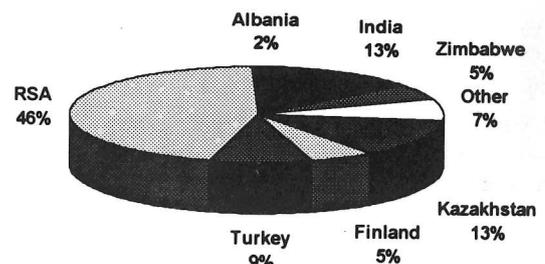
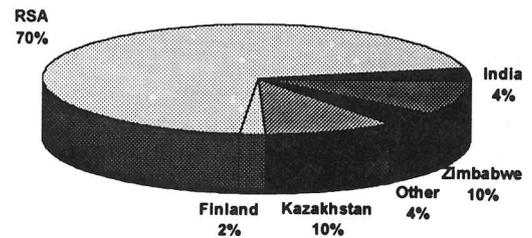


Figure 2(b) World Economic Chromium Reserves



2. Geology Of Chromite

The major economic chromite deposits are either of the stratiform or of the podiform type. Stratiform type chromite deposits occur as parallel zones or seams in large, layered igneous-rock complexes. The layering is regular and lateral continuity is considerable. Examples are Bushveld Ingenious Complex (South Africa) Great Dyke (Zimbabwe) and Kemi intrusion (Finland). Podiform-type chromite deposits occur in irregular shapes like pods and lenses. The distribution within a mineralised zone is erratic and unpredictable. Significant podiform deposits are found in Turkey, Albania, Greece, Zimbabwe and Kazakhstan.

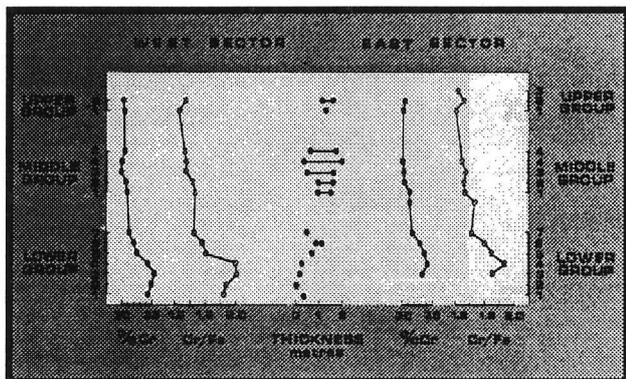
Some stratiform deposits have been disrupted by deformation such as the deposits in Orissa (India) and Campo Formosi (Brazil). In these cases exploration poses similar problems to those encountered in podiform deposits.

For more detailed geology, extensive publications exist (ref 1, 2, 3). Economic factors in the development are : the thickness of seams and depth of the deposit, its grade and location.

Slide 3 shows the typical values of the chromitite seams of the Bushveld gneous Complex (BIC) in South Africa. It is evident that the best Cr/Fe ratio ores are mainly in the lower group (LG) and that the LG-6 seam is the most significant seam. It is then no surprise that the mining of chromite in South Africa at present is mainly restricted to the LG-6 seams.

Figure 3 also shows the Cr/Fe ratio of the different seams of the BIC chromites.

Figure 3



The subdivision of the chromite layers into three groups, the variation in the Cr/Fe ratio with the stratigraphic elevation, and the thickness of the chromite layers. The variation in the Cr/Fe ratio is similar in the east and west sectors of the Complex. Greatest variation in layer thickness occurs in the Middle Group Chromites.

For LG-6 the combined average Cr₂O₃ content of lumps and concentrate after beneficiation, is 42% and the Cr/Fe ratio range is between 1,5 and 1,6.

In the upper group UG-2, a “waste” product from the platinum mining containing 42% Cr₂O₃, and the Cr/Fe ratio range is between 1,30 - 1,38.

3. Mining of Chromite

The mining techniques used depend on the ore body. Typically in South Africa, there are opencast, conventional scraper-winch mining (figure 4) and trackless mechanised mining with Load Haul Dumpers (LHD's) (figure 5).

Opencast reserves are usually limited in extent and are not cost effective, relative to other mining operations, at depths of over 30m.

Figure 4

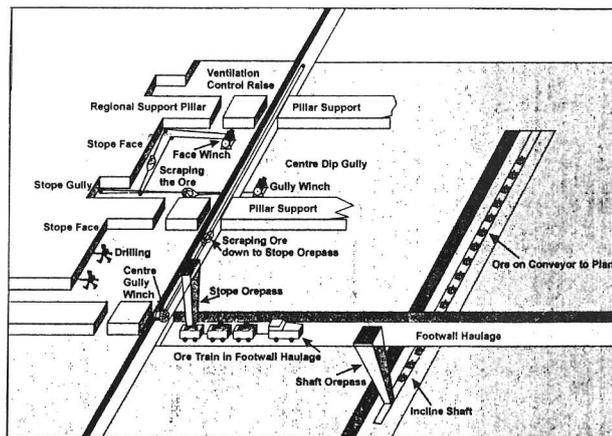
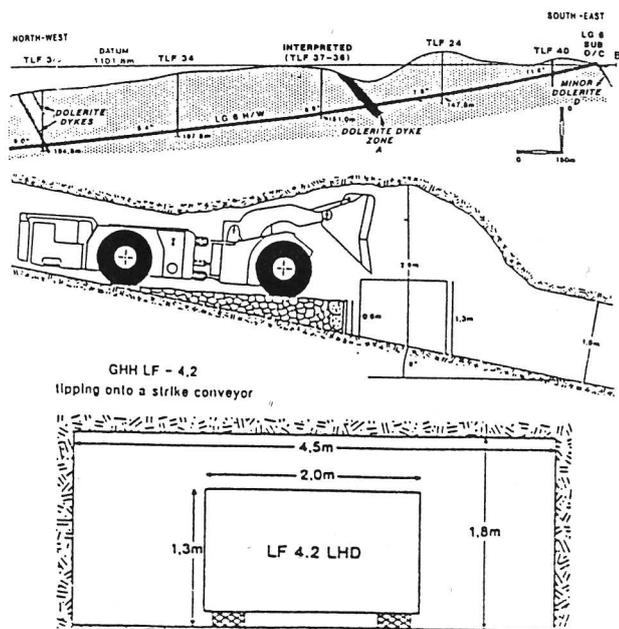


Figure 5

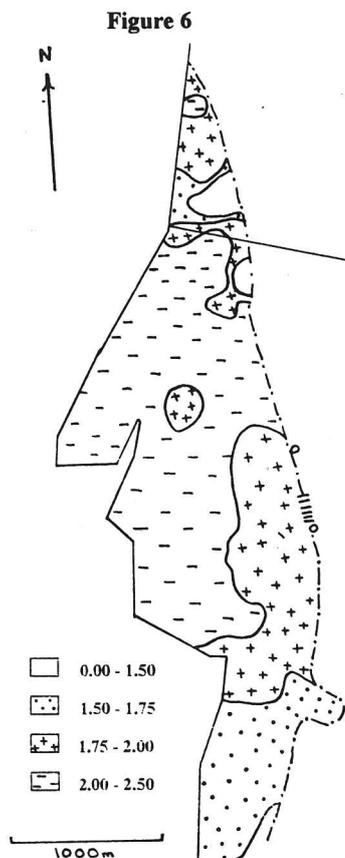


Conventional scraper mining is used to mine narrow seams. The main disadvantages are high labour cost and high initial development cost. Mechanised mining is generally applied where the stoping width is greater than 1,6m. The advantages of the latter are high recovery and high labour efficiency. This mining method uses less than half the workforce per run of mine (ROM) tonne in comparison to the scraper method. In older mines of the BIC, most mining is done by the scraper method.

Lately, with the LG-6 and LG-6A being mined together with the waste parting, mechanised trackless mining becomes possible. At present, this is undoubtedly the more economic method. To change existing operations from scraper mining to trackless is not easy and rather expensive, if not impossible, if seams as thin at 0.9m re mined.

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At the eastern side of the BIC the LG-6 layers are mostly between 1 and 1,2m thick and until recently only conventional scraper mining had been applied. Recent exploration has shown that at the eastern side also a very substantial LG-6 seam in excess of 1,8m thick occurs, such as at Thorncliffe (figure 6).



This deposit is now mined underground by CMI from a vertical depth of 30m at an incline of 8° after an initial phase of opencast mining from the outcrop. It has all the ingredients of a low cost operation.

Beneficiation Of Chromite

Traditionally in South Africa, the run-of-mine ore would be screened. The lump fraction was upgraded, the fines fraction was beneficiated, and the problematic middle size fraction was stockpiled.

The rather low dilution of the run-of-mine ore with waste rock, low labour rates, and low capital investment made this beneficiation system the most economical method for quite some time.

With the increase in the cost of mining in general and especially the cost of labour it is now standard practice to beneficiate the coarse fractions in dense medium circuits and the fines on spirals. This resulted in a more homogeneous product of a good yield and at higher efficiency.

Typically the following grade results are achieved in South African mining with the following yields :

WESTERN SIDE (SEAM WITH WASTE PARTING)

	Chrome grade	Cr/Fe	
ROM	34% Cr ₂ O ₃ average		
Product	39% Cr ₂ O ₃ lump	1,49	Overall Yield 70%
	45% Cr ₂ O ₃ concentrate	1,55	

EASTERN SIDE (SOLID THICK SEAMS)

	Chrome grade	Cr/Fe	
ROM	37% Cr ₂ O ₃ average		
Product	39% Cr ₂ O ₃ lumps	1,51	Overall Yield 85%
Product	45% Cr ₂ O ₃ concentrate	1,57	

The platinum mines waste UG-2 can be upgraded to the following typical analysis :

	Chrome grade	Cr/Fe
Concentrate	Product	42% Cr ₂ O ₃ 1,38

Smelting of Chromite

The production of high carbon ferrochrome is carried out by reducing the chromite ore with a carbonaceous reductant in a submerged electric arc furnace. Conventional smelting in South Africa is smelting ore without any agglomeration of the ore. This necessitates a furnace burden which contains a high percentage of ore fines, generally in the order of 50% of the ore charged. Such a burden results in a rather rough furnace operation that needs stoking, hence most furnaces in South Africa are of the semi-closed type to allow such stoking to take place.

A tonne of alloy requires 2,6 tonne LG-6 ore or 2,5 tonne of UG-2 ore. In both cases the electrical energy will be the same per tonne of alloy. The chromium yield is typically 70%.

The economic comparison between LG-6 and UG-2 is very interesting. The extreme fineness of UG-2 requires agglomeration for a conventional smelting operation. It is assumed that pelletising UG-2 ore costs \$15 per tonne of ore.

The low Cr/Fe ratio of UG-2 reduces the overall chrome unit production by nearly 8% (ie 52% Cr to 48%Cr). This amounts to a loss of revenue of \$40 per tonne alloy, given a sales price of \$500/ton or ±50 US\$/lb of chrome contained.

The electrical energy per tonne of alloy will remain constant as the saving in energy, when chrome units are replaced by iron units, is compensated by the increase in slag volume caused by the chemical composition of UG-2.

A typical mass balance would be as follows :

	Cr/ Fe	Cr ₂ O ₃	FeO	Al ₂ O ₃	MgO	SiO ₂	Cr	Fe	Si	C
LG-6 ore *	1,52	42	24	14	10	7				
Slag		18	9	27	19	25				
Metal							52	35	4	6,5
UG-2 ore **	1,38	42	27	15	10	4				
Slag		18	9	28	19	25				
Metal							48	38	4	6,5

* average composition of lumpy and concentrate at 1:1 ratio
 ** composition after beneficiation and agglomeration

LG-6 ore is produced in South Africa at a cost between \$10 and \$20, depending on the quality of the deposit and the mining method. This ignores any differences in transport cost by assuming that the UG-2 is produced in close proximity to the FeCr smelter (which is not necessarily the case for UG-2, although increasingly the case for LG-6).

	LG-6	UG-2
Cost of ore	\$12,50	0 *
Beneficiation	2,50	2,50
Units per tonne alloy	2,7t	2,5t
Agglomeration cost	0	15
Total ore cost per tonne of FeCr	\$40,50	\$43,75
Loss in revenue	0	40,00
Ore "cost" per tonne alloy	\$40,50	\$83,75

* By-product or waste

Slide 10

Difference \$43,25

On this basis, UG-2 ore is not an attractive replacement for LG-6 ore. The issue is, however, more complex. LG-6 ore yields, after mining and beneficiating, lumpy ore, chips (small lumps) and concentrate fines in a typical ratio of 25-25-50.

For large furnaces, efficient smelting is not always achievable with a raw material burden containing 50% of the ore as concentrate fines. Thus the ratio of concentrate to be used is lowered and surplus concentrate is available for pelletisation (or selling as surplus).

Better operating results are obtainable when the ore burden for LG-6 ore consist of 50% lumps and chips; 30% concentrate, 20% pellets. For large furnaces, efficient smelting is not always achievable with a raw material burden containing 50% of the ore as concentrate fines, while all UG-2 ore needs to be pelletised.

	LG-6	UG-2
Cost of ore	\$12,50	0
Beneficiation	\$ 2,50	\$ 2,50
Units per tonne alloy	2,6t	2,5t
Agglomeration per tonne ore	\$15,00	\$15,00
Agglomeration per tonne alloy	\$ 7,80 (20%)	\$43,75 (100%)
Loss in revenue	0	\$40,00
	\$46,80	\$83,75

Difference \$ 36,95

This calculation shows clearly that as long as low cost LG-6 ore is available, UG-2 - in spite of its abundance as a "waste" product and, in the case above, available free of charge to the smelter - is not an attractive substitute for LG-6, or at least not until the cost of LG-6 rises by a sufficient rate to overcome the application cost gap, presently ± \$40 per tonne of FeCr or ± \$15/tonne of ore.

The comparison between high and low Cr/Fe ratio chromite ore is even better illustrated by a comparison between typical South African ore and standard export Turkish/Kazakhstan high ratio chromite. Typical high ratio ore contains 47% Cr₂O₃ minimum, and its Cr/Fe ratio will be 3,0 minimum. Typically the alloy produced from such an ore yields an alloy containing 63% chromium. If this ore is replaced by South African ore, the alloy will contain only 52% chromium, a drop of 17,5% in chromium content. At a market value of \$700 per tonne for high carbon ferrochromium, the loss in revenue will be \$120. This means that the high grade ore should carry a premium of about \$50/tonne of ore over South African ore.

Discussion

The above examples show the great advantage of the high Cr/Fe ratio for the economics and productivity of a ferrochrome smelter.

An annual growth of 5% in the ferrochrome production would require approximately 400 000 tonne additional ore.

High grade ore reserves are relatively small, frequently difficult and expensive to mine, and sometimes at a problematic location.

Low grade ores are available in South Africa and can be exploited efficiently in a short time span for local processing and conversion into charge chrome.

These economic realities will dictate that in spite of the profound effect of Cr/Fe ratio on the cost of production, the main growth of ferrochrome will be from low grade ores.

It is likely that in time the high ratio ore will increase substantially in cost, but the high chromium alloy will eventually create a niche market that may carry a premium.

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7. References

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