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THE CHROMIUM RESOURCES OF ZIMBABWE

By D. SLATTER

A paper presented to the
International Economic Resources Conference on Zimbabwe
held in Salisbury, Zimbabwe from 1st-5th September, 1980

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Introduction

The potential of the chromium resources of Zimbabwe
is governed by the uses and world demand for this
metal. The main use for chromium ores is the production
of ferrochromium alloys which supply chromium to
the steel industry for chromium alloy steels and
stainless steels. The use of chromium ores for
refractories and for the production of chromium
chemicals is a far smaller market. In 1976, for
example, approximately 70% of the chromium requirement
in the United States was used in the steel industry,
approximately 18% in the chemical and 13% in the
refractory industries[1].

There is no known substitute for chromium in stainless
steel. Although there are a wide variety of industrial
materials which can substitute for stainless steel,
there are generally limitations to these concerning
either cost, performance or customer appeal. In
some alloy steels, chromium may be replaced by metals
such as Ni, Co, Cu, V and Mo, but the use of these
is generally more costly and may also lower performance
standards.

Thus the future of chromium is bound to the growth
of the steel industry and particularly to the stainless
steel industry which consumes 72% of the industry's
chromium requirements. Predictions concerning the
growth in world demand for stainless steel will,
therefore, reflect very largely the potential
demand for chromium. INCO reported that World
production of stainless steel increased from 1,6
million tonnes in 1955 to 6,7 million tonnes in 1974,
an annual growth rate of 7,7%[2]. The annual growth
rate for steel over the same period was 5.5%[3].
This growth rate has not been maintained over the past

few years due to general world recessionary problems, and the present trend in the world steel industry and thus the ferrochromium industry is rather bleak. Nevertheless, it is reasonable to predict an average growth rate of 4,0% per annum for stainless steel, in which case by 1985 world consumption would be approximately 10 million tonnes and more than 18 million tonnes by 2000 A.D., Fig. 1[4]. This growth rate may be considered pessimistic. For example, Winship[5] proposed a world growth rate of 8,2% for stainless steel, and Way[6] proposed 10,4% per annum. Admittedly these were made when the industry was booming in 1974/75 but even the more pessimistic prediction gives three times the 1974 consumption of stainless steel by the year 2000 and this has important implications for chromium ore and ferrochromium production.

In order to be used by the steel industry, chromium ores are converted into various ferrochromium alloys, and these are summarised in Table 1.

Table 1 : Types of ferrochromium alloys produced from chromium ores

|	composition.	production and remarks
on omium	basis 60% Cr (65-70% Cr); 4-8% C; 1,5% Si max.	submerged arc smelting of high Cr ore. (Cr:Fe $>$ 2,7) C content depends largely on ore quality.
rome	50-55% Cr; ≈ 8% C $>$ 2% Si	submerged arc smelting of high-Fe ores (low Cr:Fe)
on omium	65-75% Cr; 0,05-2,0% C; 1,5 % Si	Perrin Process or similar exothermic reaction between Fe Cr Si and lime/chrome ore melt
rome	37-39% Cr ; 40-47% Si	submerged arc smelting of chrome ore and quartz
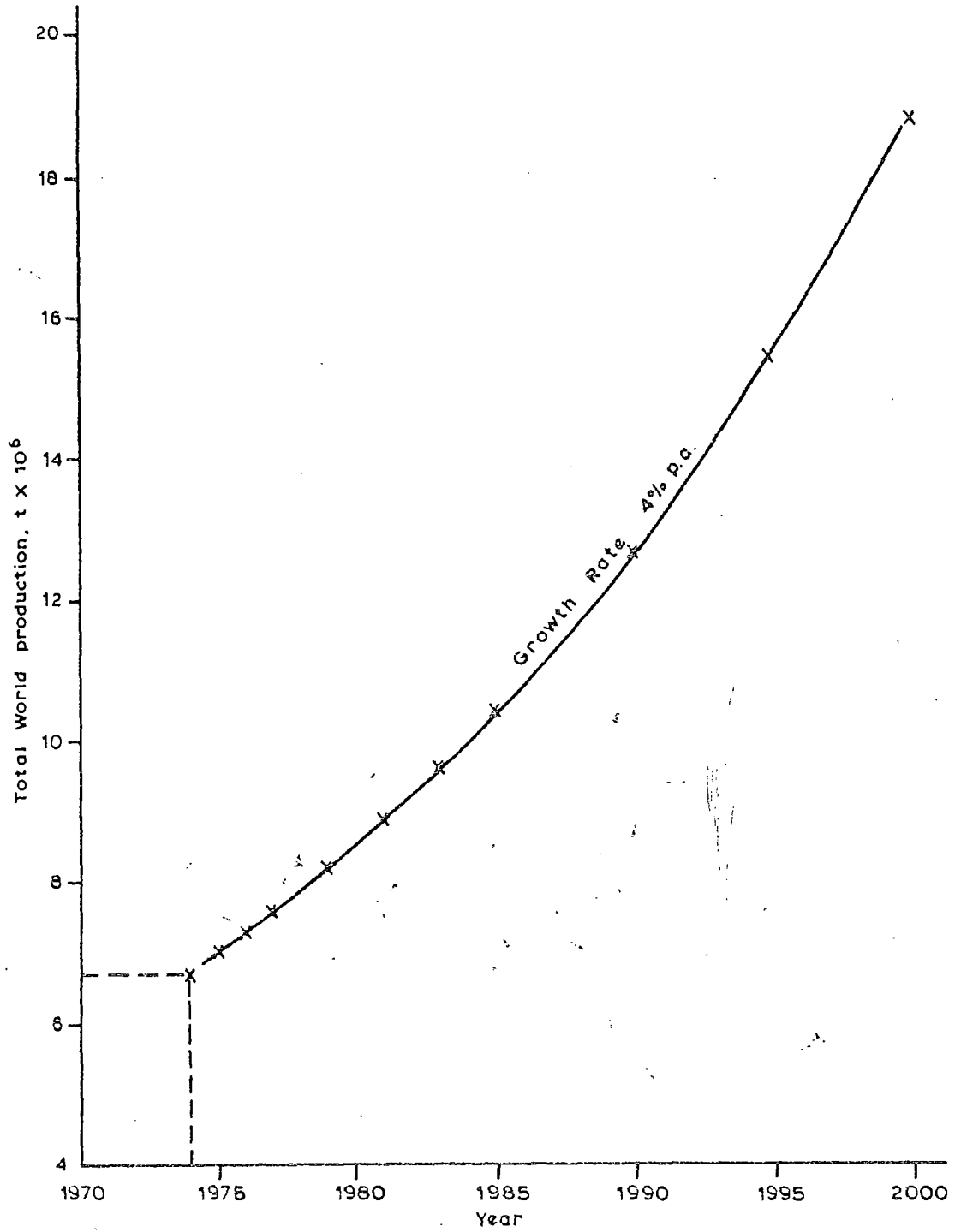
Fig.1: Projected growth of stainless-steel production.

Up until the early 1970's, the main industrial demand
was for low-carbon ferrochromium due to the low
carbon content required in stainless steel and to the
fact that excess carbon could not be removed from the
stainless steel melt without incurring large losses
of chromium. However, the advent of the AOD process
(argon-oxygen decarburising) radically changed the
technology of stainless steel production by making it
possible to remove carbon from the melt without losing
chromium. Thus the stainless steel producers switched
their demand to the less costly high-carbon alloys.
Demand for high-carbon ferrochromium increased from
35% of total ferrochromium consumption in 1970 to 85%
in 1978. In addition, the ability to remove carbon
made the Cr:C ratio of the alloy less important,
thus accounting for the advent of the so-called
charge chrome alloys produced from ores with low Cr:
Fe ratios. The strategic importance of the high
Cr:Fe ratio metallurgical grade Zimbabwean ores was,
therefore, lessened. There is still a distinct
advantage in supplying ferrochromium with a high
content of chromium but the price structure is now
more competitive.

As a result of the changes in technology which enable
the use of ferrochromium produced from ores not
classified as metallurgical grade, it is approporate
to reclassify chromium ores on a different system,
Table 2[7].

Table 2 : Former classification and new classification
of chromium ores

former classification	composition of ore	new classification
metallurgical grade	$> 46\%$ Cr_2O_3; Cr: Fe $> 2:1$	high-chromium
chemical grade	$40-46\%$ Cr_2O_3; Cr: Fe $< 2:1$	high-iron
refractory grade	$> 20\%$ Al_2O_3; $> 60\%$ $Al_2O_3 + Cr_2O_3$	high-aluminium

Reserves of Zimbabwean ores and production

Zimbabwe is the largest known source in the World of the
high-chromium ores with officially published figures
giving reserves of 560 million tonnes and a similar
additonal amount as potential further reserves. Reserves
of high-chromium ores for the remainder of the World,
including South Africa and the USSR, have been estimated
at approximately 90 million tonnes with a potential of
a further 87 million tonnes, Table 3[7]. Thus on these
estimates Zimbabwe holds 85% of the World's known high-
chromium ores. It should be emphasized, however,
that estimates concerning the ore reserves of the USSR
are very speculative and probably very conservative.

Estimated World reserves of the high-iron ores is 1200
million tonnes of which South Africa holds 1100 million
tonnes and Zimbabwe 56 million tonnes, Table 3.

Table 3   Official world reserves of chromium ores[7]

ore type	reserves (tonnes x 10^6)		
	Zimbabwe	South Africa	remainder
high-Cr	560	----------90----------	
high-Fe	56	1100	44

Thus 97% of the presently identified World reserves of
chromium ores are in the Southern Africa sub-continent.

Reserves of the podiform ores in Zimbabwe are much less
than the Great Dyke reserves, probably only 10-15 million
tonnes, but confidential information indicates that the
reserves of both high-chromium and high-iron ores on the
Great Dyke are very much greater than the official estimates
and may amount to more than 3000 million tonnes. The
official estimates are based upon reserves calculated to
an inclined depth of 200 metres only.

In 1977, cumulative primary chromium requirements for the
World up to the year 2000 were estimated to be 89 million
tonnes[7]. This corresponds to approximately 270 million
tonnes of ore and as the non-Southern African reserves
are estimated at 120 million tonnes there is a potential
shortfall of approximately 150 million tonnes which will
have to be met from either Zimbabwe or South Africa unless
further substantial reserves are discovered elsewhere.

In this regard it is of interest that a recent publication,
Mining Week of August 6, 1980, states "According to all
indications, the reserves of other major producers like
the Philippines, Yugoslavia and Albania are slowly
starting to run out and possibly only non-viable reserves
will be left in between five and ten years' time".

Figures have now been released by the Zimbabwean Central
Statistical Office for the annual production of chromium
ore in Zimbabwe from 1964 to the present, thus covering
the period when these details were kept secret for political
reasons, Fig. 2[8]. Annual production of chromium ore
increased from 447000 tonnes in 1964 to a peak of 876000
tonnes in 1975. Production then decreased to 478000 tonnes
in 1978 but showed a slight increase again to 542000
tonnes in 1979. The decrease in production was due probably
to the effect of both the repeal of the Byrd Amendment
in the United States and to the general decrease in demand
for ferrochromium following the downturn in the World's
steel industries. Although the tonnage for 1978 was very
similar to that of 1964, the value of the production
increased from approximately $4,5 million in 1964 to
$13,5 million in 1978 reflecting increases in the price
of the ore from approximately $10/tonne in 1964 to
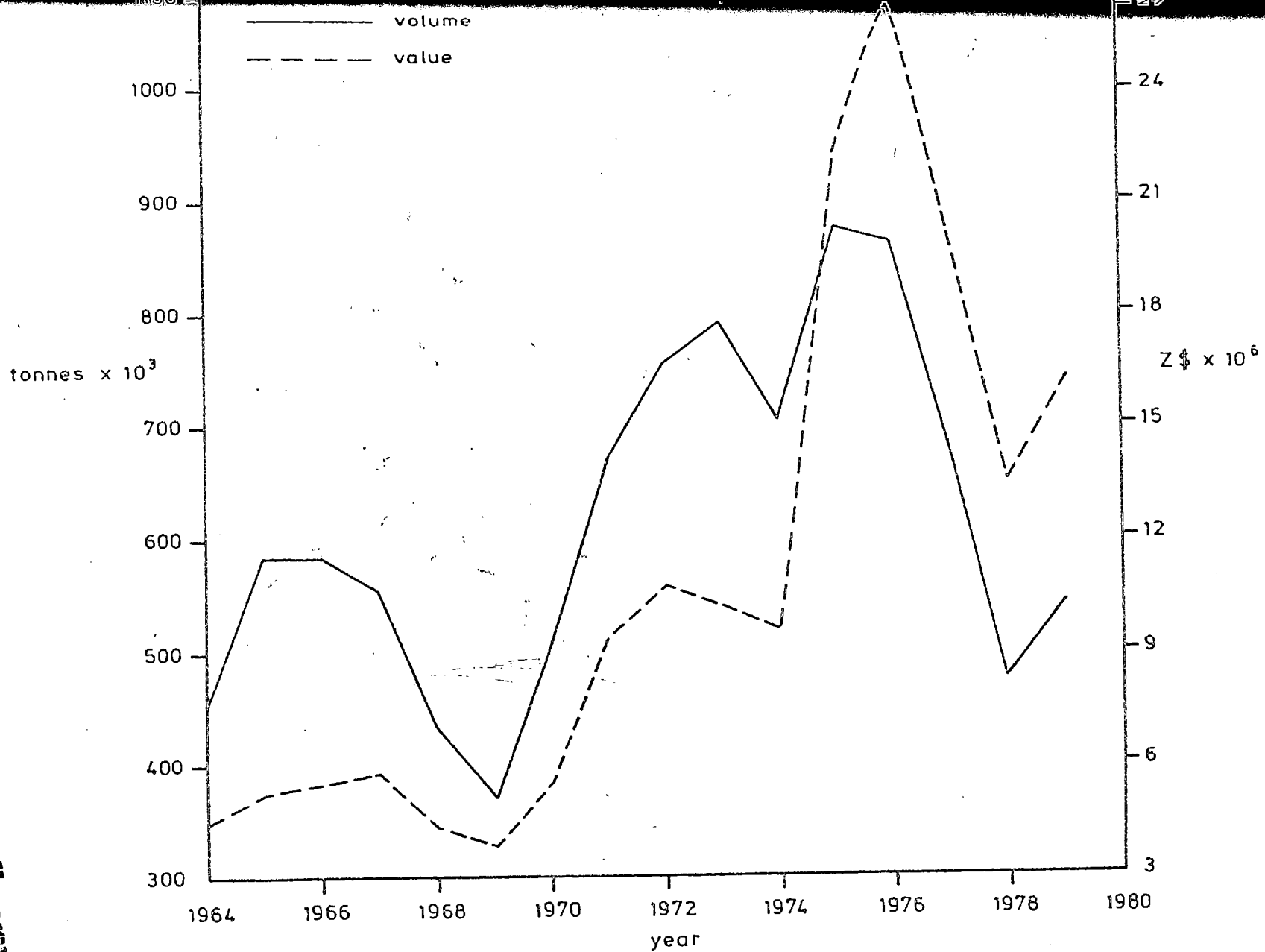approximately $30/tonne from 1976 onwards.

Fig 2 : Chromium ore production and value in Zimbabwe from 1964 to 1979.

A very large proportion of the chromium ore produced in
Zimbabwe is processed into ferrochromium alloys, mainly
high-carbon ferrochromium and ferrochromium silicon,
with some low-carbon ferrochromium. There are two large
producers at present in Zimbabwe, Rhodall belonging
to Anglo American, and Rhomet belonging to Union Carbide,
with fairly similar outputs in terms of total tonnage
and a combined total output of approximately 235 000
tonnes/annum.

Total consumption of ore to produce this quantity of
alloy is estimated to be approximately 517 000 tonnes.
A total of 542 000 tonnes of ore was produced in 1979
and thus approximately 95% of Zimbabwe's ore production
was converted into ferrochromium alloys and only 5%
exported as the ores.

Accepting even the conservative estimate of 560 million
tonnes of high-chromium ores in Zimbabwe, it is evident
that at the present rate of production the reserves are
sufficient for over 1000 years, 500 years if production
is doubled, or 100 years at ten times the production.
Thus the controlling factor in chromium ore or
ferrochromium production in Zimbabwe will be not the
reserves available but the world demand.

Properties of Zimbabwean ores for ferrochromium production

The chromium ores of Zimbabwe can be classified into
two main types; the seam deposits occurring in the Great
Dyke and comprising the major part of the known
reserves, and the alpine or podiform deposits which
occur as isolated occurrences in ultrabasic intrusions
not associated with the Great Dyke. Before considering
these ores in more detail it is useful to consider the
specific properties which make an ore most suitable for
smelting to high-carbon ferrochromium, for this is the most

important of the alloys. The properties of the ores
can be sub-divided into chemical and physical properties
and the most important of these for high-carbon ferrochromium
production are summarised in Table 4.

Table 4 : Properties required in chromium ores for
efficient production of high-carbon ferrochromium

property of ore	
chemical	physical
high Cr_2O_3 content high Cr:Fe ratio high refractory:non- refractory ratio	low friability low decrepitation high bulk density high gangue softening or melting temperature

The Cr_2O_3 content determines the grade of the ore and
thus the amount of chromium recovered per tonne of ore
smelted, whereas the Cr:Fe ratio determines the chromium
content of the alloy. The refractory:non-refractory
ratio is a ratio which has been investigated at the
Institute of Mining Research and it has been found to
correlate extremely closely with the chemical reducibility
of the ores. In general the more difficult the ore is
to reduce, the better it performs in a submerged arc
furnace producing high-carbon ferrochromium.

The friability of an ore is its tendancy to break or
disintegrate into small fragments under the applied and
abrasive loads encountered during mining of the ore,
during its transportation and within the smelting furnace
itself. If large quantities of fine material resulting
from the disintegration of a friable ore are added to,
or produced within, the furnace these can have a blanketing
effect in the charge. This prevents the steady escape of
the gases produced and can result in explosive release

of the gases with accompanying ejection of molten material.
Apart from the physical danger to personnel and equipment,
this condition results in erratic and thus unsatisfactory
furnace operation. Friable ores, therefore are not suitable
for submerged arc furnace smelting and such ores have to
be either fed in gradually with non-friable or lumpy
ores at a rate which will not disrupt operations, or if
present in large quantities, they must be agglomerated by
pelletising or briquetting.

The decrepitation of an ore is its tendancy to disintegrate
when subjected to thermal shock, such as encountered in
the furnace. Thus the effect of an ore which has a high
degree of decrepitation is similar to that of a friable
ore in producing excessive fines within the furnace.

The bulk density of the ore is controlled, not only by
the proportion of the heavy chromium and iron constituents
to the lighter gangue constituents, but also by its
physical condition, in particular its porosity. The
bulk density of the ore will to some extent determine
whether or not the ore descends deep within the furnace
before being reduced, a condition which results in
efficient smelting.

Similarly, the gangue softening temperature helps to
determine whether the ore will physically maintain its
form before being reduced deep within the furnace, or
whether the spinel crystals will be released from the
gangue at a relatively shallow depth in which case
the spinels tend to enter the slag, recovery of alloy
may be decreased and there may be problems with the slag
due to its increased content of Cr_2O_3.

Considering first the Great Dyke ores, these can be
sub-divided into two groups on the basis of the mean
composition of the seams, Table 5.

Table 5 : Chemical groupings of Great Dyke chromium
ores for smelting to ferrochromium alloys

mean composition or ratio	Group 1 Seams 1,2 and 3	Group 2 Seams 4-9 (10 and 11)
Cr_2O_3 (%)	43-46	47-51
FeO	17-19	13-17
Cr:Fe	1,9-2,5	2,6-3,5
R:non-R	2,3-3,5	2,8-5,0

R = refractory

The Group 2 ores are characterised by higher contents of
Cr_2O_3, higher Cr:Fe ratios and lower FeO contents than
the Group 1 ores. The ratio of the refractory:non-
refractory components also tends to be greater in the
Group 2 ores. These are true high-chromium ores whereas
the Group 1 ores are more closely related to the high-
iron ores of South Africa.

In smelting the ores to ferrochromium, those in Group 1
will be more easily reduced and thus less power intensive
than those in Group 2. However, the relatively low Cr:
Fe ratios will result in alloys containing 58%-64% Cr,
falling between the charge chrome of 50%-55% Cr produced
in South Africa and the high-carbon ferrochromium
containing 65%-70% Cr produced from the ores with higher
Cr:Fe ratios. The Group 1 ores can be smelted directly
to ferrochromium in the composition range indicated, but
they should preferably be blended with Group 2 ores in
the furnace charge in order to produce a better quality
alloy.

The chemical variations between the different podiform
ores are complex and they cannot be characterised as
simply as the seams on the Great Dyke. Although the
range in Cr_2O_3 content is very similar to that of the
Great Dyke ores, the mean of 44% Cr_2O_3 is slightly less
than the mean of 47% Cr_2O_3 for the Great Dyke ores. However,

The mean Cr : Fe ratio is some what greater at 2,9 (ranging
from 1,9 - 4,1), compared with 2,7 (ranging from 2,0 - 3,5)
for the Great Dyke ores. This is due to the generally
lower content of approximately 12% FeO in the
podiform ores compared with approximately 16% FeO in the
Great Dyke.

With only two exceptions, ores from the podiform deposits
have more favourable physical properties for smelting than
most of the Great Dyke ores. For example, the mean
friability of the podiform ores is 17%, ranging from
4,5% - 32% whereas mean friability for the Great Dyke ores
is 42% ranging from 10% - 92%[9].

Physico-chemical ratings of the ores for smelting.
A favourable combination of chemical and physical properties
in the ores results in the most effective production of
high-carbon ferrochromium, and thus a system of physico-
chemical ratings has been devised in order to assess the
individual ores or seams[10].   The ratings take into
account what are considered to be the important chemical
and physical properties required in the ore for submerged
arc smelting to high-carbon ferrochromium, most of which
have been described briefly in this paper.

Some examples of physico-chemical ratings applied to the
seams on the Great Dyke and to the best and the worst
of the podiform deposits are given in Table 6.

Table 6 : Examples of physico-chemical ratings applied to
the chromite seams on the Great Dyke and to the
podiform deposits

deposit or seam	physico-chemical rating (points)	percentage rating
max. rating	900	100
best podiform	769	85
No. 4 seam	662	74
No. 6 seam	613	68
No. 7 seam	530	61
worst podiform	548	61
No. 1 seam	546	61
No. 9 seam	533	59
No. 2 seam	530	59
No. 5 seam	525	58

It is evident that the best of the ores for high-carbon
ferrochromium is from a podiform deposit which achieves
a rating of 769 points, or 85% of the theoretical maximum.
Of the Great Dyke seams, No. 4 Seam is superior to the
remaining seams.

It is of interest that apart from No. 4 Seam and to an
extent No. 6 Seam, the remaining seams of the Great Dyke
achieve very similar ratings, although these may have
been achieved through different combinations of favourable
or unfavourable properties.

Areas for further exploration and development
From what has already been determined concerning the
smelting properties of Zimbabwean chromium ores, several
possible areas become evident for further investigation
and possible development by potential ferrochromium
producers. Foremost is No. 4 Seam which has the best
potential on the Great Dyke for high-carbon ferrochromium

production. This seam should be investigated far more extensively in order to determine whether its favourable properties are maintained over its entire length.

If, however, present developments in plasma smelting become commercially viable for the treatment of chromium ores, there may be a revolution in ferrochromium technology. The most significant potential advantage of plasma smelting is that it requires finely divided ores and thus the need for costly agglomeration of the friable ores, which comprise a very large proportion of the Zimbabwean reserves, will fall away. In a plasma smelting plant, the friable ores will come into their own and the suitability of an ore for high-carbon ferrochromium will depend mainly upon its chemical properties. The more friable seams such as No. 7 and No. 9 will then become more important sources for the ore.

Although the reserves of the podiform ores are small in comparison with the Great Dyke ores, their generally outstanding properties for present-day smelting practices should encourage exploration for further deposits not only in the areas in which deposits are known to occur but in new areas which may have potential for the discovery of further deposits.

Metallurgical problems in ferrochromium production in Zimbabwe
There are three main problems associated with the production of high-carbon ferrochromium in Zimbabwe and which are, or will be, common to every producer. These are:-
1) The carbon content of the alloy.
2) The sulphur content of the alloy.
3) The use of friable ores and ore fines.

Higher prices and a distinct market advantage are at present commanded by high carbon ferrochromium which contains less than 6% C, as opposed to the generally

encountered contents of 7%-8% C. Decreased carbon
contents in the alloys are achieved only by the use of
certain types of ores and the correct smelting conditions.
The suitable ores not only have to be what is known
as 'hard, lumpy', but they require other specific properties
which enable them to have a carbon-refining action on
the high-carbon ferrochromium. Such ores occur to a
limited extent only in Zimbabwe, and not at all in
South Africa, and their presently known reserves are
being depleted rapidly. However, the problem of reserves
of hard, lumpy refining ores is not peculiar to
Zimbabwe alone and already the economic distinction
between the high-carbon alloys on the basis of their
carbon content is less pronounced and it may disappear
totally in the near future.

The sulphur content of Wankie coke tends to be relatively
high and consequently the sulphur content of high-
carbon ferrochromium may tend to exceed the specified
maximum levels. In this case additional procedures
are necessary to remove the excess sulphur from the
ferrochromium, but these will incur extra costs. The
most satisfactory solution is to provide a reductant with
a low content of sulphur so that the problem does not
arise and one of the mining companies in Zimbabwe is
now carrying out investigations into a low-sulphur
coal deposit from which a char suitable for ferroalloy
production can be produced.

The question of friable ores and ore fines is a world-
wide problem which is becoming more prominent with the
depletion of the World's reserves of the hard, lumpy
ores. Greater proportions of friable ore are, of
necessity, being charged to submerged arc furnaces, and
thus agglomeration facilities, such as briquetting or

pelletising are becoming necessary, involving further
pre-treatment costs. Again this problem is not
peculiar to Zimbabwe and it is possible that the
potential developments in plasma metallurgy which
have been mentioned, will change the present physical
disadvantage of friable ores to an advantage.

Conclusion

The world is going to be increasingly dependent upon
Southern Africa for its supply of chromium. Whether
this comes from South Africa with its low grade ores
and low mining costs, or from Zimbabwe with high-grade
ores but higher mining costs, will depend not only
upon the relative economics of production and upon
the preference of the steel industries, but also upon
the different political climates in both these
countries and the degree to which the various Western
countries are prepared to rely upon one country only
as their main source of a strategically important
metal.

REFERENCES

1) National Materials Advisory Board. "Contingency
   plans for chromium utilisation". National Research
   Council, National Academy of Sciences, Washington
   D.C.; 1978.

2) International Nickel Company. Market Research
   Division. "World Stainless Steel Statistics".
   London. Metal Bulletin, 1975

3) Miller, J.R. "Iron and steelmaking metallics demand
   and supply : 1975-1985". Steel Furnace Mon. Vol. 9
   No. 12; 1974 pp. 775-792.

4) Ossin, D.I. and Fletcher,D "The production of
   stainless steel in South Africa" NIM Rep. No 1899;
   15th July 1977; p 38.

5) Winship, W.D. "Stainless steel and welding - a review
   and preview". S.A. Inst. of Welding, Symp. Proc.
   Johannesburg; Johannesburg 1975

6) Way, H.J.R. "Trends in the Ferrochromium Market
   of the Western World". Infacon '74; Glen, H.
   (ed); Johannesburg, South African Institute for
   Mining and Metallurgy; 1974; pp 281 - 292.

7) Morning, J.L. 'Chromium - 1977' U.S. Dept. of the
   Interior Bureau of Mines, MCP-1; 1977; 14 pp

8) Monthly Digest of Statistics, May 1980; Zimbabwe
   Central Statistical Office, Salisbury; pp 18-19.

9) Slatter, D. de L "The physical properties of Rhodesian
   chromium ores and their significance in ferrochromium
   production" IMR Rep No. 28 Aug 1978; 75 pp

10) Slatter, D. To be published.

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