CHROME-ORE IN INDIA : ITS STRATEGIC IMPORTANCE, DOMESTIC RESOURCES & GAPS, LONG-TERM PROJECTIONS AND FUTURE OUTLOOK*

by O. P. VARMA *and* A. M. JAIPURIAR, *Indian School of Mines, Dhanbad*

(Communicated by Prof. S. C. Chatterjee, FNA)

(*Received 24 December 1974*; *after revision 15 April 1976*)

From present reckoning India seems to be favourably placed in regard to domestic resources of chromite—one of the key minerals of strategic importance, chiefly required for steel manufacture, besides having small applications in refractory and chemical industries.

This report contains results of detailed and continued independent study of the domestic chromite mineral industry, giving, for the first time, a complete synthesis of known reserves, pattern of consumption, and trade, *vis-a-vis*, anticipated needs, long-term projections and future outlook.

Proved reserves of various grades of chromite in the country stand at 4.14 million tons. With the present rate of production and expanded requirements of the future, they may be exhausted within 10–12 years. Even if other categories of ore reserves are taken into account, domestic resources of chromite may not last beyond the turn of the present century.

Methodology of projecting future requirements is discussed. The study shows that at the end of three decades, commencing from the year 1970, annual needs of the country in respect of chromite will be of the order of 222,500; 355,000; 500,000 tons—the latter against the anticipated steel production of about 40 million tons. Until then, internal supplies can be augmented to satisfy the needs, if efforts are made to prove the existence of possible and inferred reserves. However, beyond 2000 A.D. the situation may become alarming as the nation may have to depend on imports even for the domestic needs of this ore.

Wide swings in demand and depletion of the internal reserves will create serious problems for the future chromite industry. Their implications are discussed, one-by-one, and some suggestions, validated by facts and figures, are made as possible solution for the more imminent difficulties bound to be created by the continuing unscrupulous exploitation of this mineral.

INTRODUCTION

The mineral chromite, the only source of chromium metal, is essential for the manufacture of stainless steel and high temperature alloys. In addition, it has important refractory and chemical uses. Since chromium-alloys find application in defence armaments, chromite is not only industrially useful but also of strategic importance.

---

*This paper was read at the Symposium on "*Strategic Minerals of India*" held at the School of Studies in Geology, Vikram University, Ujjain, M.P., during April 20–22, 1973 convened by Prof. S. C. Chatterjee, FNA.

Although expansion and development of domestic steel industry has, since independence, been quite significant, it has not been commensurate with the vast domestic resources of high-grade iron-ore and other raw materials necessary for the growth of this basic industry. Despite its unsatisfactory and sluggish rate of expansion in the past, steel production is bound to be funadamental to our future national economy to which chromite is destined to play a big role. To sustain the present level of production proved domestic resources of chromite may barely suffice for the next decade. The country, therefore, is bound to face critical shortages of this mineral beyond the end of the present century, if advance measures are not taken for augmenting its reserves and conservation. Various technical and industrial problems related to these aspects are examined in this paper.

Uses and Specifications

Commercially, chrome-ore can be divided into three categories: (1) high-grade containing above 48 per cent Cr_2O_3, (2) medium-grade with Cr_2O_3 more than 40 per cent, and (3) low-grade containing less than 40 per cent Cr_2O_3. The latter is not exportable under the present trade conditions.

Industrial uses of chromite can be broadly grouped under three main headings—metallurgical, refractory and chemical—stated in order of their importance, each requiring chrome-ore of definite specifications as summarised in Table I, and also separately discussed in the following pages:

Table I

Specifications of chromite for principal industrial uses

METALLURGICAL: Ferrochrome		
Size : Hard and lumpy ore at about 150 mm size with not more than 10–15 per cent of 12 mm size.		
Cr_2O_3	...	48% (Min)
Al_2O_3 + MgO	...	25% (Max)
SiO_2	...	5% (Max)
Sulphur	...	0.5% (Max)
Cr : Fe ratio	...	2.8 : 1 (Min)
CHEMICALS: Chromium Chemicals		
Cr_2O_3	...	44% (Min)
Al_2O_3	...	15% (Max)
FeO	...	20% (Max)
REFRACTORY: Chrome bricks and Chrome cement		
Cr_2O_3	...	36–38%
FeO	...	15–20%
SiO_2	...	6% (Max)

Minor Uses: Tiles and bricks and painting yellow lines on roads—No rigid specifications.

Metallurgical—The most important application of chromite is in the manufacture of ferro-alloys used in making chromium steels. Metallic chromium is also utilised for similar purposes but to a lesser extent. These steels possess high tensile strength, toughness, resistance to wear, chemical corrosion and oxidation, and high electrical resistance.

Binary and ternary alloys of chromium are manufactured with varying quantities of chromium, carbon and silicon with sulphur not more than 0.3 per cent. But the most important ingredient of chromium steels is ferrochrome containing about 70 per cent of chromium. There are two varieties of ferrochrome—(1) high-carbon ferrochrome, and (2) low-carbon ferrochrome, containing 3–8 per cent and less than 2 per cent carbon respectively. Low-carbon ferrochrome is more costly than high-carbon ferrochrome and is used for producing chromium steels in which the presence of carbon is detrimental.

Apart from the broad specifications for metallurgical industry, cited in Table I, for the manufacture of carbon-free ferrochrome the ore should contain over 50 per cent Cr_2O_3, less than 1.5 per cent SiO_2, no injurious material and only traces of S and P. In war time, however, ore containing as little as 40 per cent Cr_2O_3 with Cr-Fe ratio 2.6:1 has been employed. Ore having Cr-Fe ratio less than 3 : 1 may, however, be utilised for producing low-carbon ferrochrome, which is the most economical between 2.8 : 1 and 3 : 1. Fines and concentrates can be utilised after sintering.

Ferrochrome plant at Garividi (A.P.), owned by M/s Ferro Alloys Corporation Ltd., is utilising chrome-ore of the following specifications for the production of low-carbon ferrochrome, ferro-silicon, and high-carbon ferrochrome:

Type of ferrochrome	Type of chromite	Constituents		Cr : Fe
		Cr_2O_3	FeO	
Low-carbon	Powdery	50–52%	...	3 : 1 (minimum)
Ferro-silicon	Lumpy	42% (minimum)	...	2.7 : 1 (minimum)
High-carbon	Lumpy high grade	40–50%	13–14%	

Refractory—Both chemical composition and physical characteristics are defined for the chrome-ore to be accepted by refractory makers. While lumpy ore over 12-mesh size with a minimum of fissures and cracks is desired, chemical specifications vary with different manufacturers. In general, presence of high silica, free iron and magnesium silicates is considered undesirable. The ore has to be high in Cr_2O_3 plus Al_2O_3, and low in iron. Although Cr-Fe ratio is of no importance, FeO should be less than 16 per cent, Cr_2O_3 more than 30 per cent and silica less than 6 per cent—higher quantities of silica than this are regarded most deleterious as it would cause the bricks to flex at a lower temperature.

Chemical—All chromium chemicals, such as chromates, dichromates, chromic acids, chromium acetate and chlorite, chrome alum, etc., are produced from chromite. Chromium compounds find great application in the manufacture of pigments, tanning of leather, mordanting, external therapy, chromium platting, etc. Of late, chrome colours have been widely adopted in advanced countries for painting yellow lines on roads. This application is likely to multiply both for new lines and for painting existing ones.

Domestic Resources and Reserves

Although chromite in India is known to occur in the States of Orissa, Karnataka. Andhra Pradesh, Maharashtra, Bihar, Tamil Nadu, Jammu & Kashmir and the Union Territory of Andaman & Nicobar Islands (Fig. 1), only the deposits of Orissa supply bulk of the present domestic output of chromite, whereas the regions of Karnataka, Maharashtra and Bihar are small contributors, producing only about 6 per cent of the total production. Known occurrences of chromite are listed in Table II.

During the last 20 years reserves of chromite have significantly improved from 1.32 million tons in 1955 to 4.8 million tons in 1960. Latest reserves index of domestic chromite, known from different sources, indicates varying estimates. According to the re-assessment by the Geological Survey of India in 1969 (GSI 1969) the combined reserves of all categories in Orissa and Karnatka stood at 7.22 million tons

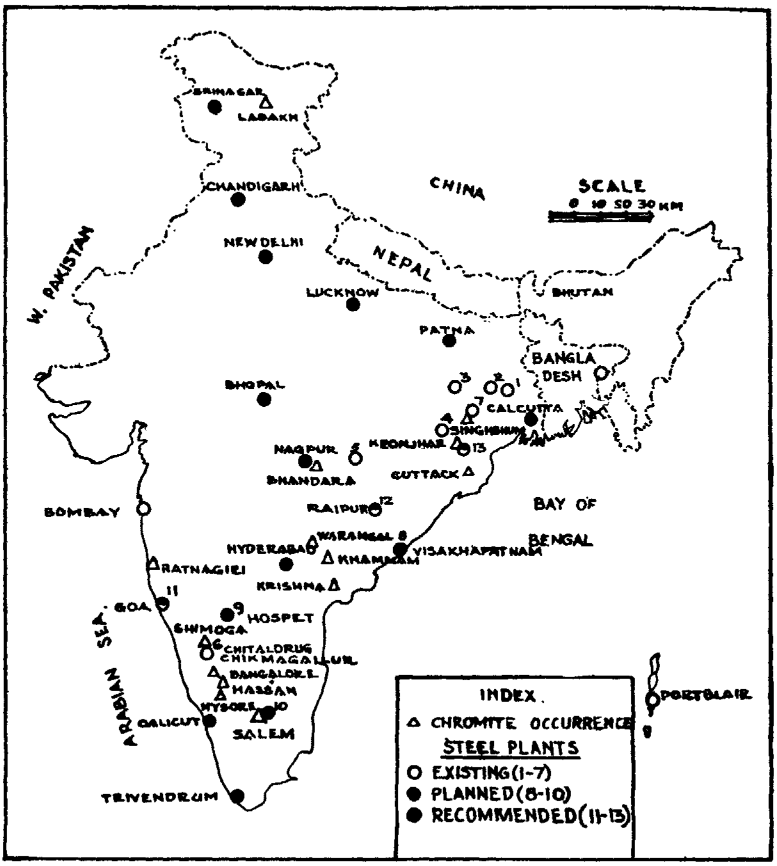

FIG. 1. Occurrences of chromite and sites of steel plants—existing, planned and recommended in India.

TABLE II

Occurrences of chromite in India

State	District	Locality	Grade (% Cr_2O_3)	Remarks
1. Andhra Pradesh	(i) Krishna (1)*	Kondapalle	39–55.6	The deposits are abandoned since 1967.
	(ii) Warrangal (2)	—	—	
	(iii) Khammam (3)	—	—	
2. Bihar	Singhbhum (4)	(i) Jojohatu	53.4	Mining stopped in 1966. A small production has, however, been reported in 1970.
		(ii) Kusmita	—	
3. Tamil Nadu	Salem (5)	(i) South-west base of Shevaroy Hill	35.6 – 44.5	Workability remains to be tested.
		(ii) Sittampundi	17.96 – 31.44	Amenable to beneficiation to yield refractory grade.
4. Maharashtra	(i) Bhandara (6)	Pauni	39.9 – 52.5	Spread over a small area with chances of fresh discoveries.
	(ii) Ratnagiri (7)	(i) Vagda	36.92 – 37.5	Amenable to beneficiation but high iron has to be reduced for metallurgical purposes.
		(ii) Kankauli	36.49 – 33.03	
5. Karnataka	(i) Chitaldrug (8)	Heddari-Devangire-Nuggihalli schist belt contains half a dozen localities, including Byrapur	Variable from place to place. 48–50 (Byrapur ore).	Thorough investigations are recommended. Those of Byrapur contain the best and the largest quantity of chromite.
	(ii) Hassan (9)			
	(iii) Kadur (10)	Chikmagalur and a few others	—	
	(iv) Mysore (11)	Shinduvalli and a few other localities	50.0	
	(v) Shimoga (12)	—	—	Commercially unimportant.
6. Orissa	(i) Cuttack (13)	Sukinda Chromite Belt	Metallurgical to Refractory.	Largest and the best reserves of the country are localized in this belt; contains 80% of the Indian reserves.
	(ii) Keonjhar (14)	Nausahi-Boula	All grades	Exploration has not been commensurate with the promise of the deposits; contains 6% of the domestic reserves.
	(iii) Dhenkanal (15)	Moulabhanj and a few other scattered occurrences	Inferior.	Thorough prospecting recommended.
7. Jammu & Kashmir	Ladakh (16)	Dras and Tashgam	—	Expected to yield good reserves. Their exploitation awaits development of means of communication.
8. Andaman & Nicobar	Portblair (17)	Chakrea	—	Only indications are, so far, reported.

*The figure in parenthesis indicates the number of the chromite district shown in Fig. 1.

including nearly 3 million tons of proved category. In his presidential address before the Section of Geology and Geography at the Sixtieth Session of the Indian Science Congress, Chandigarh—1973, M. S. Balasundaram states, "*The total reserves of chromite ore are of the order of* 13.86 *million tons located in Orissa, Karnataka, Tamil Nadu and Bihar. Of this* 4 *million tons, proved during the last decade, come entirely from Orissa. The reserves in the measured category are of the order of* 4.04 *million tons—indicated category* 2.52 *million tons, and inferred reserves of the order of* 7.3 *million tons, and fines* 1.59 *million tons*". Table III lists reserves of chromite as on December 1970 (Yousef 1973).

TABLE III

Estimated reserves of chromite, December, 1970 (In million tons)

Grade	Reserves			Grand Total
	Measured	Indicated	Inferred	
1. *Metallurgical*				
Lumps	0.317	0.0146	—	0.3316
Fines	1.615	1.516	—	3.131
2. *Other grades*				
Lumps	0.735	0.293	7.305	8.331
Fines	1.478	0.108	—	1.586
3. *Unclassified*				
(Lump-fine ratio not known)		0.297	—	0.297
TOTAL	4.145	2.2286	7.305	13.6766

In the absence of standardized exploratory practices, it is difficult to rely on the above-stated reserve data on chromite, collected from the official writings, or reports, on the exploration results arrived at much earlier. The calculated reserves are also not tied up with important parameters of depth, grade, time, etc. Proving of reserves of irregular, discontinuous, en echelon, ore bodies, such as of chromite, normally involves detailed study of structure and extensions of ore deposits. Therefore, unless an acceptable methodology and parameters are adopted for the exploration, exercises on future planning on minerals, as this one, should serve only a very limited purpose.

PRODUCTION TRENDS IN INDIA

Chromite mining in India began somewhere in 1903, initially with a very modest production, but in 1917 output reached a peak of 60,000 tons, and with minor fluctuations, this tempo of production continued to be maintained upto 1927. Thereafter, the production during pre-independence period ranged between 24,000 and

62,000 tons per annum with Karnataka State sharing 48 per cent, Baluchistan 36 per cent and Bihar 16 per cent.

Just before independence, India occupied 8th position among the chromite-producing countries, sharing approximately 4 per cent of the global output of chrome ore. This position did not appreciably change until 1951, inasmuch as internal production remained below 20,000 tons. However, in 1952 chromite production doubled, and again in the following year it went up by the same arithmetical ratio. The leap in chromite production in these years synchronised with the changed production trends in different States (Fig. 2). Karnataka, which continued to have the largest share, 65 per cent of India's total output of chromite, surrendered its leading position to Orissa in 1952, where the newly-discovered deposits in Keonjhar district shared 71 per cent against 18 per cent from Karnataka with Bihar trailing behind in the third position.

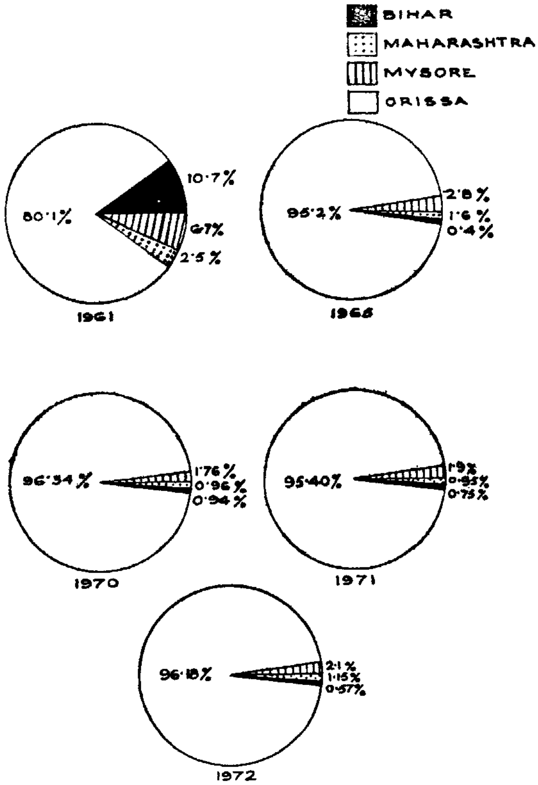

FIG. 2. States' share in domestic chrome-ore production

The decade 1950–60, although witnessed no regular rise in chromite output, the production reached a new high of 1,06, 896 tons in 1960 including a maiden production of 229 tons from Maharashtra. Chromite production in India during 1960-74, given in Table IV, indicates that for the last three years production-level has remained between 0.2 and 0.38 million tonnes. Of this, Orissa yielded 96.3–98.2 per cent, Karnataka 1.5–2.2 per cent, and Maharashtra 0.3–0.96 per cent. Bihar, which had stopped chromite production in 1966, produced only 0.94 per cent of the total output in 1970.

TABLE IV

Chrome ore production in India, 1960-1974

Year	Quantity (in Metric (Tons)	Value (in Thousand Rupees)	Name of the State Producing Chromite				
			Andhra Pradesh	Bihar	Maharashtra	Karnataka	Orissa**
1960	106,896	6,212	—	4,884	1,228	6,930	93,854
1961	48,785	2,899	—	5,210	1,289	3,187	39,099
1962	66,648	4.259	—	7,095	591	7,778	51,184
1963	69,013	4,425	—	7,078	3,006	7,618	51,311
1964	34,969	2,077	—	2,232	729	2,830	29,178
1965	59,685	3,723	—	233	999	1,650	56,803
1966	77,770	5,343	39	—	1,564	—	76,167
1967	113,868	8,022	—	—	237	—	113,631
1968	205,659	13,306	—	—	627	3,469	201,563
1969	226,568	12,024	—	—	2,415	5,018	219,135
1970	270,879	14,418	—	2,525	2,543	4,782	261,029
1971	273,135	26,969	—	2,023	2,587	5,211	263,239
1972	281,025	26,786	—	1,550	3,236	5,921	270,318
1973	290,000	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
1974	375,000	,,	,,	,,	,,	,,	,,

**Excludes production of 2,000 tonnes, 7309 tonnes and 8,479 tonnes recovered during the prospecting operations from the Kalrangi Mine of the Orissa Mining Corporation Ltd., during 1965, 1966, and Jan.–May 1967, respectively.

N.A. = Not available. (–) = Nil.

WORLD PRODUCTION

Global output of chromite varied slightly from 3.65 million tons in 1953 to 4.0 million tons in 1962. However, during the following two years, though production declined to 1953 level, it soon picked up in 1965, and, since then, it continued to go up by about 0.3 million tons in each year until 1969. In 1971, the world production reached a record figure of nearly 6.61 million tons.

Country-wise world production of chromite for the period 1967–71 is given in Table V. A perusal of the tabulated data will show that, excepting U.S.S.R., all the industrially advanced countries are nearly or totally dependent on imports for their needs of chromite. The major chromite-producing countries are U.S.S.R., Republic of South Africa, Philippines, Turkey, Southern Rhodesia, Albania, India and Iran (Fig. 3); during 1969 they shared nearly 87.9 per cent of the world's output. In

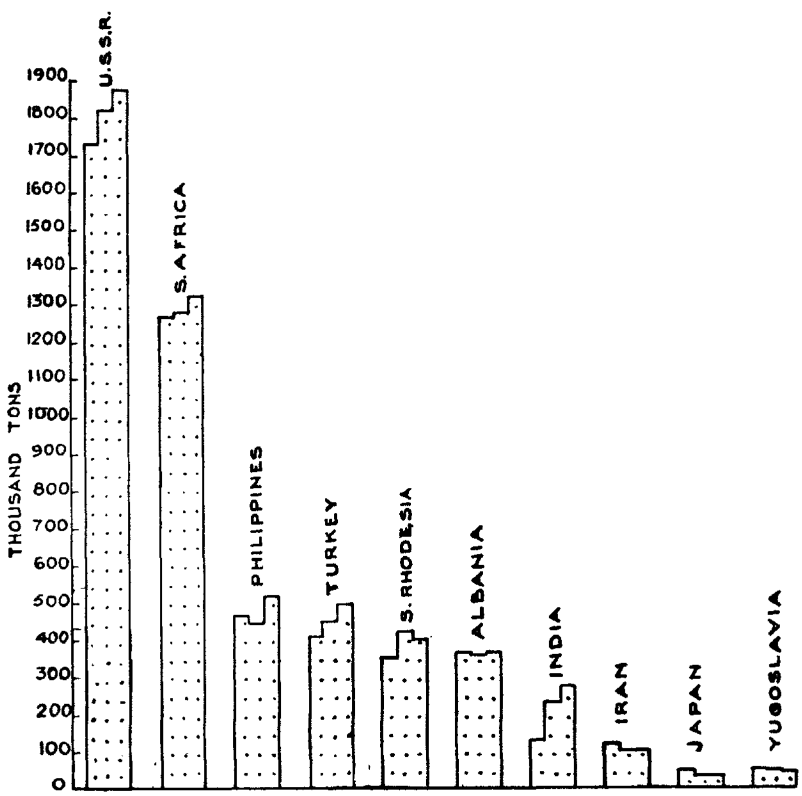

FIG. 3. Country-wise production of chrome-ore, 1967–69

1970, relative positions of chromite-producing nations changed, but slightly, with Albania having an edge over Southern Rhodesia and Malagasy Republic over Iran.

DOMESTIC CONSUMPTION

Domestic consumption of chromite in comparison to that of other countries, endowed with requisite raw materials for steel industry, is appalingly low (Fig. 4). Even, this low consumption has remained restricted for long years to refractory and chemical industries (Fig. 5b), mainly due to the indifferent attitude of the alien government in developing indigenous steel and allied industries. Chromium steel was first time produced in India in the late fifties. Later on, when steel plants at Durgapur, Bhilai, and Rourkela commenced producing chromium steel regularly from 1962, total requirement of ferrochrome continued to be satisfied by imports until 1965. However, regular production of ferrochrome in India began from 1966 with a small output of 637 tons, which came down to 69 tons in 1967.

India's present production capacity of ferrochrome is nearly 0.04 million tons, 80 per cent of which is shared by the plant of M/s. Ferroalloy Corporation Ltd., located at Garividi (A.P.), and the second unit of M/s. Industrial Development Corporation of Orissa, located at Jajpur Road (Orissa). The remaining production comes from other six small units (cf. Banerjee 1962, 1963). The plant at Garividi has

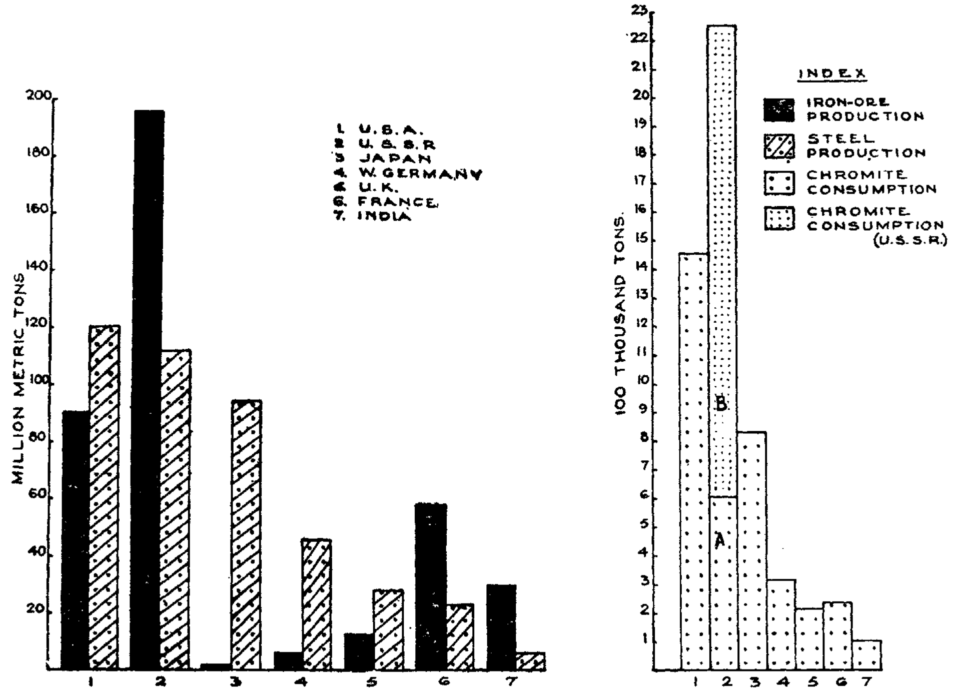

FIG. 4. Iron-ore and steel production and chromite consumption (1970) of advanced countries *vs*. India

installed capacity of 10,000 tons of low-carbon ferrochrome, 5,000 tons of high-carbon ferrochrome and 8,000 tons of silicon-chrome, whereas the plant at Jajpur Road has rated capacity of 10,000 tons of ferrochrome and 700 tonnes of ferro-silicon. The two plants in 1970 produced only 13,000 tons of various grades of ferrochrome, which is only 35 per cent of the built-in production capacity, and that has further declined by about 50 per cent in 1974.

India actually began making noteworthy utilization of chromite in metallurgical industry from 1965. Its yearly consumption in this industry during the period 1968-70 has been as follows:—

Year	*Consumption in metric tons*
1968	4,260
1969	15,600
1970	40,000

Internal consumption of chromite in refractory industry was about 3,500 tons per annum during 1950s. Rising trends, however, are noticed from 1956 onwards. This industry utilized 38,000 tons of chromite in 1968, and in 1970, its demand was of the order of 40,000 tons. It is anticipated that domestic needs of chromite in future

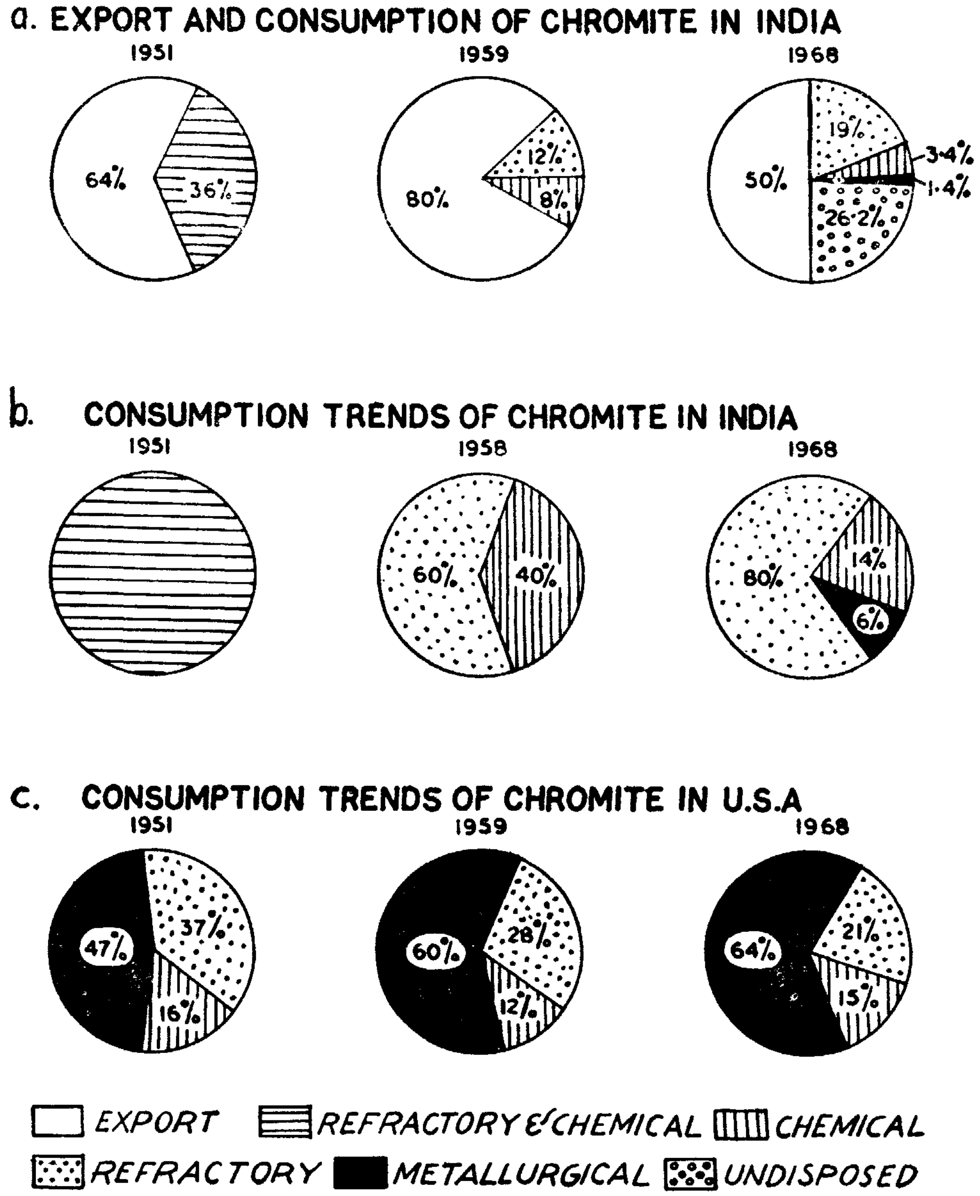

FIG. 5.

for refractory purposes will go up because of the fact that, barring Rourkela, other steel plants produce steel by open-hearth furnaces.

Chemical industry has not consumed more than 10,000 tons of chromite per year uptil 1961; that went up to 14,000 tons during 1962. But during the subsequent years consumption declined and this industry did not use more than 9,000 tons of chromite per year until 1970. In spite of this transitional set-back, it is expected that yearly requirement of chromite for chemical industry may be of the order of 24,000 tons by 1975. Since the indigenous automobile industry is the biggest consumer of dichromates, the demand for chrome chemicals at home must rise in future.

Overseas Trade

India has been exporting chromite from the very beginning of its exploitation in this country. During 1950s our exports varied from 60–80 per cent of the internal production, but the exports declined sharply to 25 per cent and 15 per cent in 1962 and 1963, respectively (Table VI). The ore shipments, however, picked up again in

Table V

World production of chromite (in short tons)

Countries	1967	1968	1969	1970	1971
South America					
Brazil	16,562	18,774	18,000	50,442	—
Europe					
Albania	360,342	360,000	360,000	500,000	600,000
Finland	7,037	39,899	78,623	132,838	139,400
Greece	13,200	14,000	33,000	58,710	53,131
U.S.S.R.	1,731,000	1,820,000	1,874,000	1,929,000	1,800,000
Yugoslavia	51,987	49,891	43,468	44,715	49,000
Africa					
Malagasy Republic	...	...	88,000	155,000	292,000
Southern Rhodesia	350,000	420,000	400,000	400,000	400,000
Republic of South Africa	1,266,615	1,270,667	1,320,203	1,573,000	1,700,000
Sudan	27,600	24,300	28,895	29,393	
Asia					
Cyprus	24,037	27,672	25,951	36,165	41,268
India	120,740	226,698	237,000	270,879	273,135
Iran	120,000	99,000	154,000	132,000	130,000
Japan	49,859	30,745	32,829	12,007	13,000
Pakistan	29,071	28,683	29,000	39,412	
Philippines	462,694	446,282	517,709	635,000	560,000
Turkey	409,108	459,000	492,000	526,200	530,000
Oceania					
Australia	154	...	...	...	
New Caledonia	1,365	...	...	...	
World Total	5,041,371	5,335,611	5,635,138	6,527,000	6,610,000

Note : The figures will not exactly add to the total due to rounding off in many cases.

TABLE VI

Export and industry-wise consumption of chromite in India (1951-1970)

(Tons)

Year	Export	Refractory	Chemical	Metallurgy	Total domestic consumption
1951	8123				5000 tons
1952	7543	Total consumption			per annum
1953	15353	was on an average			
1954	23353	5000 tons per annum			
1955	48274				
1956	41,865	8,000	6,600	—	14,600
1957	41,823	10,000	7,000	—	17,000
1958	49,401	N.A.	N.A.	—	N.A.
1959	81,684	12,200	8,630	—	20,830
1960	41,195	N.A.	N.A.	—	N.A.
1961	41,195	15,000	10,000	—	25,000
1962	16,543	25,500	14,000	254	40,754
1963	10,334	N.A.	N.A.	N.A.	33,737
1964	31,066	N.A.	N.A.	N.A.	36,167
1965	33,362	21,193	7,058	4,123	32,378
1966	43,736	25,512	7,598	1,911	34,362
1967	77,211	26,512	6,972	168	33,652
1968	1,08,222	38,000	N.A.	4,260	42,260*
1969	1,11,620	N.A.	N.A.	15,600	65,000
1970	1,30,874	40,000 (app)	10,000 (app)	40,050	90,050

*Excluding consumption in chemical industry.

the following year during which export reached 80 per cent of its internal output. Since then, export has been near about 50 per cent of the domestic output.

Contrary to our favourable export position for chromite, domestic requirements of ferrochrome until the year 1969 continued to be met partially by imports. But in the year 1970, India, first time, shipped 4,000 tons of high-carbon ferrochrome from indigenous production, fetching foreign exchange equivalent to one crore of rupees. The exercise, given in Table VII, based on the available relevant data, is intended to show the large losses we are undergoing in exporting raw chromite instead of ferrochrome.

The calculations show that by switching over to the export of ferrochrome from that of chromite, the annual profit from this trade will increase by Rs. 5.78—19.37 crores at the 1974 level of chromite export at 2,57,000 tons.

WORLD CONSUMPTION

Chromite consumption against iron ore and steel production of some countries is shown in Fig. 4. Data on U.S.S.R. from two sources, plotted separately, are at variance. Quantity shown by 'A' is from U.S.B.M.'s Mineral Year Book (U.S.B.M. 1967), while that represented by 'A+B' is noted from the Mining Journal (Indian

TABLE VII

Export of chromite versus ferrochrome

Commodity	Description	Approximate value per tonne
1. Chromite	(a) Production cost inclusive of royality	Rs. 90–110/-
	(b) Total cost, f.o.b. Paradip port	Rs. 150/-
	(c) Export price, f.o.b. Paradip port	Rs. 500/-
	(d) Profit earned by export	Rs. 350/-
2. High Carbon Ferrochrome**	(a) Production cost	Rs. 2,000/-
	(b) Total cost, f.o.b. Paradip port	Rs. 2,100/-
	(c) Export price, f.o.b. Paradip port	Rs. 3,250/-
	(d) Profit earned by export	Rs. 1,150/-
	(e) Extra profit from H.C. Ferrochrome export in terms of per tonne of chromite	Rs. 225/-
3. Low-Carbon Ferrochrome***	(a) Production cost at factory	Rs. 5,000/-
	(b) Export price, f.o.b. Paradip port	Rs. 7,860/-
	(c) Profit earned by export	Rs. 2,760/-
	(d) Extra profit from export of L.C. Ferrochrome in terms of per tonne of chromite	Rs. 754/-

**Two tonnes of chromite are consumed in the manufacture of one tonne of H.C. Ferrochrome.
***2½ tonnes of chromite are consumed in the manufacture of one tonne of L.C. Ferrochrome.

Bur. Min. 1965); the latter appearing more reasonable in the light of this country's steel production. In major steel producing countries, metallurgical industry accounts for the bulk of internal chromite consumption. For example, in U.S.A. this industry used 65 per cent of the total chromite consumed internally in 1969 against 50 per cent in 1950 (Fig. 5C). Inasmuch as chromite application in metallurgical industry in the U.S.A. has steadily grown during the last three decades, consumption of metallurgical grade chromite has been commensurate with the indigenous stainless steel production, which stood at 0.83 million tons in 1970 but chemical grade chrome-ore demand has not shown any appreciable change since 1950 in terms of percentage of the total consumption. It is significant to note that during 1969, 20 per cent of the world production was utilized in refractory, 15 per cent in chemical, primarily for sodium dichromate manufacture, and the rest in metallurgical industry.

STEEL *vs.* CHROMITE

From the discussions in the preceding sections, it is evident that consumption of chromite is largely dependent on steel industry. It is, therefore, mandatory that for a real and meaningful study of chromite some relevant aspects of the domestic steel industry are discussed ahead of other things.

Today, iron constitutes over 90 per cent of the metals produced in the world and in the foreseeable future it is destined to continue to be the most desired metal. The major steel producing countries, barring Japan, are largely self-sufficient in iron-ore reserves. India, in iron-ore resources, with reserves of about 29,000 million tonnes, ranks seventh among the world countries. But, an enquiry into the growth history of the domestic iron and steel industry shows that although the post-independence period has witnessed considerable advancement in this sphere, over-all expansion and development of this key industry at home has been appallingly low by any international standards. After commissioning of the first three public sector steel plants, the domestic iron and steel output which would have gone to nearly 9.0 million tonnes, has almost been stagnant at the level of 6.0 million tons, roughly 67 per cent of the rated capacity. Even this rate of production has declined to 50 per cent of the built-in capacity during 1967–68, but for the last few years, again, some improvement has been noted.

India's fourth public sector plant at Bokaro went into production in October, 1972. Due to this, current year's production may be raised to 7.3 million tons. Plans are ready for the erection of three more steel plants during the Fifth and Sixth Plan periods—one in the Fifth Plan and the two in the Sixth Plan periods. If the plan proposals are timely executed, steel output may be raised to 19.0 million tons by the end of the Fifth Plan (1978–79).

A study of the growth-rate of steel industry in Japan shows that this nation with meagre mineral raw-material resources has doubled its iron and steel production after every ten years since the end of World War II. Normally, India should have also advanced its production to nearly 80 million tonnes by the end of the present century, but—achievement of this production target seems to be a Herculean task in the Indian context. However, a moderate turnout of 40 million tonnes of steel by that time may be quite possible.

LONG-TERM PROJECTIONS

To work out future requirement of ferrochrome in relation to the steel production in India, data of developed countries like Japan, U.S.S.R., U.S.A., etc., are made use of in this study. These countries, on an average, consume 1.9–3.2 kg. ferrochrome per ton of steel. Assuming that India's need may be about 2.5 kg. ferrochrome per ton of steel in the later part of this century against the present figure of 1.25 kg/tonne, indigenous requirements for ferrochrome may be expected to be nearabout 0.1 million tonnes against 40 million tonnes of steel by 2000 A.D.

On the basis of the above ferrochrome-steel consumption ratio, internal requirement of ferrochrome may be around 30,000 tons against the steel output of 12.25 million tonnes by 1975, and with the estimated steel production of 19 million tonnes by 1980, its need may increase to about 47,500 tonnes. Accepting that the envisaged targets of 30 and 40 million tonnes of steel production by 1990 and 2000 are achieved, corresponding requirements of ferrochrome in that event will be of the order of 0.075 and 0.1 million tons respectively, excluding export commitments. That would mean approximately 0.3 million tonnes per annum of chromite for domestic steel industry by 2000 A.D. (one tonne of ferrochrome manufacture needs nearly three tons

TABLE VIII

Industiry-wise projected needs of chromite (Tonnes)

Year	Metallurgy	Refractory	Chemical	Total
1975	91,800	45,000	15,000	1,51,800
1980	142,500	60,000	20,000	2,22,500
1990	225,000	90,000	40,000	3,55,000
2000	300,000	120,000	80,000	5,00,000

of chromite). Projected demands of chromite by various industries from 1975–2000, worked out by the authors, are presented in Table VIII.

Listed data in Table VIII will show that annual domestic consumption of chromite may reach a figure of 0.5 million tonnes per year by 2000 A.D., nearly 60 per cent of this for the metallurgical industry, and 24 per cent and 16 per cent for refractory and chemical industries, respectively.

Whereas total embargo on the export of raw chromite may be in the best interest of the country, the Government may be in the necessity of exporting this commodity at least at the present level of about 0.13 million tonnes per annum. We may, therefore, have to mine chromite at about 0.63 million tonnes yearly by the end of the 20th century.

According to the Planning Commission estimates, chromite requirement in the year 1983-84 will be about 330,000 tonnes for an envisaged production of 1,10,000 tons of ferrochrome. In addition, requirements of refractory and chemical industries will be of the order of 1,20,000 tonnes and 30,000 tonnes respectively, and if export of chromite at the current level is maintained, an extra quantity of 1,50,000 tonnes will have also to be produced. These targets seem to be much on the higher side and extremely difficult, if not impossible, to achieve considering the present level of ferrochrome output only at 13,000 tonnes a year.

RESOURCES AND GAPS

Even at the present rate of chromite production at 0.28 million tonnes per year, our proved reserves of 4.14 million tonnes of chrome-ore may exhaust by 1986, or perhaps earlier owing to larger demands. Notwithstanding this, chromite production has to rise, as shown in Table VIII, from 1975 by approximately 14,000 tonnes each year until 2000 A.D. to satisfy the growing needs. In addition, our export of ferrochrome may also be raised from the present level of 4,000 tonnes to about 10,000 tonnes per annum by 1980. Assuming that the present ferrochrome output, which is only 35 per cent of the rated capacity, will pick up to 75 per cent of the installed capacity, that is, 40,000 tonnes per annum, additional 20,000 tonnes of chrome-ore per year will have to be made available by 1984. It is, therefore, imperative that advance measures are adopted to prove another 6 million tonnes of this ore to fulfil the national demand for the period ending 2000 A.D.

ORE PREPARATIONS & BENEFICIATION

Fast depleting limited resources and present projections for chromite, specially for the imminent large-scale expansion of domestic steel industry, should render necessary to adopt stringent measures for chrome-ore conservation, beneficiation, and ore-preparation. As stated earlier, country's latest estimated all-category-reserves of lumpy ore are only about one million tonnes. Against this, our present annual requirement of this ore is about 60,000 tonnes, which in all probability be raised to 0.1 million tonnes per annum by 1980. On the other hand, our proved reserves of friable and sandy chrome-ore of all categories are appreciably large and they can be looked at as an alternative source for our long-term requirements of metallurgical industry, provided suitable measures for their beneficiation and agglomeration are adopted. Affluent nations have already started utilising chrome-ore sands and friables for this purpose. This step, among other things, will enable India to erect larger ferrochrome furnaces, that cannot tolerate an excessive proportion of fines as they are apt to cause heavy blows and eruptions (Selmer-Olsen 1971).

The possible agglomeration processes are briquetting, sintering, and pelletising, but the latter is more in vogue. Japan has already built up ferrochrome metallurgy based on the use of pre-reduced pellets of friable chromite (Selmer-Olsen 1971). Finland is also reported to have successfully produced pellets from such type of ore (USBM 1963). In India, too, repeated attempts have been made by various State Departments of Geology, especially by Indian Bureau of Mines and National Metallurgical Laboratory to beneficiate and agglomerate Indian chrome-ore. Although these attempts have been successful in several ways, results have not yet found any industrial application (Chopra *et al.* 1969; Mathur 1969; GSI 1971; and Indian Bur. Min. 1962, 1963). This may be due to the fact that agglomeration adds extra cost to the chrome-ore, and it may be prohibitive under Indian conditions. Notwithstanding this, extra cost can be offset by upgrading the ore and pre-reducing the pellets as to effect saving in electric power, which is at present very costly in India.

Detailed discussion on the methods of ore beneficiation recommended by different agencies is beyond the scope of this paper. Yet, it is appropriate to point out that the obtained concentrates of chromite by gravity methods, magnetic separation, and floatation have been low in Cr-Fe ratio; that could not further be appreciably improved by simple methods of reduction roasting and acid leaching. However, in certain overseas countries iron reduction from chromite structure has been possible by chlorinating chromium-bearing minerals. Hussain (1971) in his paper has given a detailed description of the technique practised. Iron and chromium were separated as chlorides by chlorinating chromite with CCl_4 at temperatures between 700–800°C, and found that 80 per cent of the iron and 30 per cent of the chromium could be chlorinated within two hours to improve Cr-Fe ratio from 2.9 to 10.6. Low-grade Barramyia chrome-ore from Egypt has recently been beneficiated by tabling and magnetic separation (Yousef 1970) followed by chlorination. In this effort, ore containing 36–38 per cent Cr_2O_3 with Cr-Fe ratio 1.3–1.9 : 1 has been upgraded to contain Cr_2O_3 47–55 per cent with Cr-Fe ratio 2.5–3.5 : 1. A magnetic separator, developed in U.S.A. (Yousef 1966), has successfully enriched low-grade chromite operating on low magnetic susceptible grains suspended in water.

In Indian ores low Cr-Fe ratio may be improved by chlorination to bring it to the desired specifications. As chrome-ore in India is characterised by varying composition and gangue association, no single method may possibly prove effective for commercial ore recoveries. More vigorous researches will have to be conducted to find out suitable ore dressing flow-sheets for the ores of different characteristics.

OUTLOOK

Chromium content in different chrome-steels varies from a small fraction to 25 per cent according to the nature of commercial steel. Inasmuch as, iron and steel constitute 95 per cent of the metal produced in the world, bulk of the chromite output goes to, and will continue to be despatched for the metallurgical indurtry. Moreover, in the modern technology about 70 per cent of chrome refractory bricks are used by steel industry (Banerjee 1973); hence, its consumption as refractory material is bound to grow in the years to come.

Of late, there has been a major break-through in the chromium-material technology. A new series of straight chromium-steels, comparable to nickel-chromium steel in corrosion resistance, have been developed in the U.S.A. (USBM 1963). Japan has also developed a chromium-plated steel (Allen 1970) to substitute for tin-coated steel for containers, particularly for bear and carbonated waters. Success has also been achieved in electroplating to impart a few colours, including chromium-plated gold colour, to metallic surfaces (USBM 1966). In the field of refractory, manufacture of high performance basic chromium refractory bricks superior to the prevailing ones has been achieved in the U.S.A. (USBM 1966). Moreover, yellow paint containing chromium is now being used increasingly for lines on roads in developed countries, and in India, too, this application of chromium is sure to expand considerably. More and more internal demand of chromite than hitherto can, therefore, be expected in future.

India is fortunate to possess relatively large deposits of chromite. Of these, sizable reserves of low-grade chrome-ore can be put to potent use, if researches are pursued along useful lines to upgrade the ore. In regard to metallurgical grade chrome-ore, internal supplies are restricted but our resources should be large enough for satisfying the current and prospective demands of chemical and refractory industries for many years to come. In all likelyhood, future exploration would enhance the national reserve index of this ore because of the favourable geological setting of the Indian terrain with wide-spread occurrences of ultramafites, that are true abode of chromite concentrations in nature.

PROBLEMS AND SUGGESTIONS

Some of the problems confronting the chromite mining are similar to those facing the national mining and mineral industry as a whole. Hereunder are presented only the problems and suggestions relevant to the chromite industry:—

1. *Problems related to mining*—These problems have emerged mainly as a result of wrong and short-sighted policies of the Government based on political and

other narrow considerations in granting mining rights of chromite on small areas to parties having little or no resource even for the minimal investment on their development and exploitation. As a result of this, today, one finds scores of under-developed and poorly-managed mines under different ownerships even with a single chromite district of one geologic continuity. These units have been mining the ore from these areas for more than two decades but have scarcely shown any initiative for improving infra-structural facilities like roads, warehousing, and electricity and water supply. Barring one, these companies' sole motive has been profit, excessively earned by them over the years in almost complete disregard to conservation and development of the deposits. On their properties rarely any exploration plans have been drawn and executed. If ever, it had been only little and vague, just to satisfy the pressing statutory regulations and requirements. Surprisingly, unabated reckless and unscrupulous mining still continues primarily for export trade neglecting the dire national necessities of conservation of these resources, so vital for our prospective steel industry.

As capital investment on mechanization and development is directly proportional to mineable reserves of the property, it is necessary for planned and large-scale mine development to integrate small deposits to constitute economically viable bigger mines with larger reserves. Implementation of this suggestion, which is the most relevant in case of chromite mining industry, is already much over due.

2. *Problems related to the utilization of off-grade ores*—Although chromite mining in India is about 70 years old having yielded huge ore tonnage and mighty profits, no commensurate efforts to conserve and utilize low-grade ores seem to have yet been made even by the public sector undertakings. The Government of India has also not shown, so far, its serious concern to this problem. As such only piece-meal and unconcerted ore beneficiation exercises on low grade chrome ore have been pursued at one or two centres, and the results achieved through these pursuits have not made any notable impact on chromite mining industry in India. Notwithstanding these attempts, several kinds of off-grade chromite ores still remain untreated and unidentified in regard to their amenability to beneficiation. A techno-economic study of the low grade ores must, therefore, be started as early as possible.

Provision for ore concentrators based on well-established techniques for small mines will be an advance step to help utilization of low-grade ores. Since small deposits cannot sustain capital expenditure, it is suggested that Government should provide common custom concentrators to the small units until the small mines are integrated to form large and economically viable enterprise. Custom milling facility for small operators exist in several overseas mining regions. For example, in the tin mining area of Bolivia, some gold fields in Australia, copper areas in Chile, and silver mines in Mexico custom concentrators are provided by the local governments.

3. *Problems related to ore preparations*—Allied to the beneficiation of low-grade ores is the problem of utilization of concentrates and naturally occurring sandy chromite for ore preparations, which, as noted earlier, are being increasingly put to use in several steel producing countries. Recently, a process to manufacture 'cold pellets' from friable chrome ores has been developed at Regional Research Labo-

ratory, Bhubaneshwar (Yousef 1973). This step involves an extra-cost to the tune of Rs. 100/- per tonne of ore but it may be off-set, at least in part, by increased efficiency and cheaper supply of electric power.

There are other problems, too, arising from our lack of expertise and know-how in matters of extractive metallurgy. It is learnt that ferrochrome manufactured in India does not find ready acceptance in foreign markets, whereas raw chromite is readily marketable. Long -term overseas trade agreements for chromite are, however, not in the national interest. For good and all, this trade should be replaced, as quickly as possible, by semi-finished products, such as ferrochrome, indigenous quality of which should be improved to conform to the international specifications.

In addition to the difficulties stated above, chromite mining industry faces a few more challenges due to non-standardization of exploration norms and lack of experience on the part of explorers for deep drilling for chrome ore in alpine type of serpentinous belts, that have, uptil now, been found to contain all the known chromite resources of this country. We would do well to compel the industry to set aside certain percentage of the profit for development and exploration activities. Setting up of a working group to advise the Government in matters of policy, and technical service to the exploiting agencies should not only be an appropriate step to safeguard wasteful mining but also to ensure the most efficient conservation and exploitation of the dwindling resources of this valuable commodity.

Conclusions

Our resources of chromite should be adequate to fulfil the national needs for the immediate future. To satisfy long-term demand, specially of the steel industry, upgrading of ore and ore-preparation techniques will have to be adopted in a big way. The Indian terrain affords fair chances for fresh discoveries of chromite concentrations. Presence of some more favourable areas for chromite has already been indicated by preliminary prospecting and mapping. Intensification of exploration in systematic and planned manner will have to be done to locate potential reserves both in known and virgin areas. Utilisation of low-grade chromite for ferrochrome manufacture (Udy's process) and used chrome-bricks for preparation of chromium compounds may also considerably reduce the anticipated gap between demand and supply.

Acknowledgement

The authors are thankful to Shri G. S. Marwaha, Director, Indian School of Mines, and the University Grants Commission for providing travelling facilities to present this paper at this symposium.

References

Allen, James, E. (1970). Tin line conversion to chrome. *Iron & Steel Engng.*, **47**, No. 5, p. 88.

Balasundaram, M. S. (1970). Major mineral development in Eastern India. *The Eastern Metal Rev.*, Annual No., pp. 31–33.

Chopra, M. S., Mathur, G. P., and Narayanan, P.I.A. (1969). Beneficiation of low-grade ores from Madhya Pradesh and Maharashtra. *Min. & Engng. J.*, **8**, 6, 187–189.

Das, Ratnakar (1972). Ferrochrome—The symbol of progress. *Souvenir,* Rotary Club of Jajpur Road, Orissa.

Hussein, M. Kamal, and El-Barawi, M. (1971). Study of the chlorination and beneficiation of Egyptian Chromite Ores. *Trans. Inst. Min. Metal.*, **80**; Bull. No. 772, pp. 7–11 (C).

Krishnan, M.S. (1953). Chromite. *Bull. geol. Surv. India,* Series A; *Econ. Geol.,* No. **7**, pp. 1–45.

Mani, K.S., Murty, M.G.K., and Das, K.S.(1972). Mines & Minerals, Sukhinda Valley. *Souvenir,* Rotary Club of Jajpur Road, Orissa.

Marwar, S. A., and Joshi, A. B. (1969). Beneficiation and other related tests on ores and minerals from Maharashtra. *Indian min. engng. J.,* **8**, 6, 173–179 (S).

Mathur, V. N. (1969). Role of pilot plants in industrial research with special reference to mineral beneficiation. *Indian min. Engng. J.,* **8**, 6, 173–179.

Neely, J. E., Boyer, W. H., and Martenek (Jr), C. A. (1970). Sintered magnesia chrome grains for new type of refractory. *J. Am. ceram. Soc.,* **49**, 8, 710–713.

Sarin, K.K., and Ghosh, T.K.(1971). Development of ferro-alloy Industry in India. *The Eastern Metal Rev.,* Annual No., pp. 55–56.

Selmer-Olsen, S. (1971). Trends in ferro-alloy production. *J. South Af. Inst. min. Metal.,* **71**, 10, 213–214.

Yousef, A.A.(1970). Concentration of low grade chromite ore for metallurgical and chemical purposes. *J. Min., Metal. Fuel.,* **18**, 1, 12–17.

Yousef, A.A.(1966). Magnetic separator for minerals of low magnetic susceptibility. *Indian Miner.,* **20**, 4, 370–371.

——————(1973). Pelletisation of chrome-ore fines possible. *Indian Ceramics,* **17**, No. 1, p. 82.

Banerjee, J. C. (1973). Changing pattern in refractories technology and development in India. *Indian Ceramics,* **17**, 1, p. 40.

GSI (1971). *G. S. I. News,* Vol. **2**, 12, p. 5.

Eastern Econ. (1972). Records & Statistics—1969–72: *Eastern Econ.*, p. 1155.

GSI (1950). Raw Materials: The Wealth of India, **II**, 134–142.

Indian Bur. Min. (1951). *Indian Mineral Year Book*

——————(1959). *Indian Mineral Year Book.*, pp. 100–105.

——————(1962). *Indian Mineral Year Book.*, pp. 227–237.

——————(1963). *Indian Mineral Year Book.*, pp. 282–289.

——————(1965). *Indian Mineral Year Book.*, pp. 61 & 308–309.

——————(1967). *Indian Mineral Year Book.*, pp. 21 & 246–255.

——————(1969). *Indian Mineral Year Book.*, pp. 332–339.

USBM (1934). *Mineral Year Book.*, pp. 465–475.

——————(1945). *Mineral Year Book.*, pp. 607–617.

——————(1951). *Mineral Year Book.*, pp. 274–286.

——————(1959). *Mineral Year Book.*, pp. 319–329.

——————(1963). *Mineral Year Book.*, pp. 186–191.

——————(1966). *Mineral Year Book.*, pp. 277–286.

——————(1969). *Mineral Year Book.*, pp. 295–304.

——————(1970). *Mineral Year Book.*, p. 29.

Indian Bur. Min. (1965). Annual General Review. *Min. J.*, **99**, 1, pp. 75–76.