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IRON ORE PROCESSING IN INDIA WITH PARTICULAR REFERENCE
TO THE BOKARO STEEL LTD.*

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513

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Iron bearing feed material is one of the major inputs for steel production. The iron bearing materials used range from scrap to various types of oxide feeds (calibrated ore, sinter and pellets). Iron and steel industries consume about 98 per cent of iron ore produced and the balance 2 per cent is used in the manufacture of other commodities, such as cement, heavy media materials, iron oxide pigments, ferrites etc. This paper briefly reviews the iron ore resources of the world, iron ore deposits in India, technologies adopted for iron ore processing in India with particular reference to the captive iron ore mines of Bokaro Steel Ltd (BSL).

Iron Ore Resources Of The World

Iron ore occurs in all the continents and it constitutes five per cent by weight of the earth's crust. An estimate of the iron ore resources of the world was published by the United Nations in their 'Survey of World Iron Ore Resources' in 1970. In this survey, the total world resources of iron ore have been indicated as 782,500 million tons including potential resources of 531,200 million tons. In this estimate, various types and grades of ores were included and the resources were classified under measured, indicated and inferred.

However, according to a system of classification of mineral deposits developed jointly by U.S. Bureau of Mines and U.S. Geological Survey, the deposits have been placed under 'Reserves' and 'Reserve Base'. The estimate of 'Reserve Base' does not include inferred resources, while the resources which can be economically exploited have been classified as 'Reserves'. According to this system of classification, the world iron ore reserves work out to only 20 per cent of the identified resources, which appears to be more realistic. The world iron ore 'Reserves' and 'Reserve Base' have been presented in Table 1 on the next page.

It will be seen from the table that India ranks fourth in respect of reserves based on iron content.

Iron Ore Deposits In India

India is endowed with reserves of high grade hematite ores, distributed all over the country. However, the rich deposits occur mainly in Singhbhum district of Bihar, in Sundergarh, Mayurbhanj and Keonjhar districts of Orissa, in Bastar and Durg districts of Madhya Pradesh, in Bellary district of Karnataka, in Chanda district of Maharashtra and in Goa as shown in Figure 1.

Iron ore formation occurring in India belongs to Dharwar System of the Pre-Cambrian Age and generally exhibits the same characteristics in respect of lithological sequence, mineralogy, physical and chemical characteristics in all the deposits.

Mineralogy of the ores: The iron-ore minerals which generally occur in Indian iron ores are hematite (Fe_2O_3), magnetite (Fe_3O_4), martite (Fe_2O_3), siderite ($FeCO_3$), limonite ($2 Fe_2O_3, 3 H_2O$), and goethite (Fe_2O_3, H_2O). Most of the iron ores mined at present in the country is hematite of different types. However, in the ores mined, certain percentage of goethite/limonite is also present.

Character of the ores: The hematite ores range from a massive steel-grey type, through a porous laminated type to a fine soft powder. There exists no definite line of division between different types of hematite ore and one type passes gradually into the other type. The hematite ores are normally grouped under the following categories:

TABLE 1 - WORLD IRON ORE RESERVES AND RESERVE BASE[1]

		Crude ore (mill. long tons)		Iron content (mill. short tons)	
		Reserves	Reserve base	Reserves	Reserve base
North America:					
United States	..	15,800	24,800	3,700	5,900
Canada	..	11,700	25,100	4,500	9,800
Mexico	..	400	400(2)	200	200
Total	..	27,900	50,300	8,400	15,900
South America:					
Brazil	..	15,600	15,600(2)	10,800	10,800
Venezuela	..	2,000	2,000(2)	1,200	1,200
Other	..	900	1,800	500	1,000
Total	..	18,500	19,400	12,500	13,000
Europe:					
France	..	2,200	2,200(2)	900	900
Sweden	..	3,000	4,600	1,600	2,400
U.S.S.R.	..	59,000	59,000(2)	25,000	25,000
Other	..	1,900	4,500	800	1,800
Total		66,100	70,300	28,300	30,100
Africa:					
Liberia	..	900	1,600	500	800
South Africa, Rep. of	..	4,000	9,300	2,900	6,600
Other	..	1,000	3,700	500	2,100
Total	..	5,900	14,600	3,900	9,500
Asia:					
China	..	9,000	9,000(2)	3,500	3,500
India	..	7,100	7,100(2)	4,800	4,800
Other	..	900	1,600	400	800
Total	..	17,000	17,000	8,700	9,100
Oceania:					
Australia	..	15,000	33,000	10,100	20,200
Other	..	500	1,000	300	600
Total	..	15,500	34,000	10,400	20,800
World total(3)	..	151,000	206,000	72,000	98,000

NOTES:

(1) Estimated as of January 1, 1984.

(2) Available data not adequate to define or estimate marginal economic or subeconomic components of reserve base; therefore, reserve base is tentatively assumed to be equal to reserves.

(3) Rounded figures.

Source: United States Dept. of the Interior - Bureau of Mines, Bulletin 675.

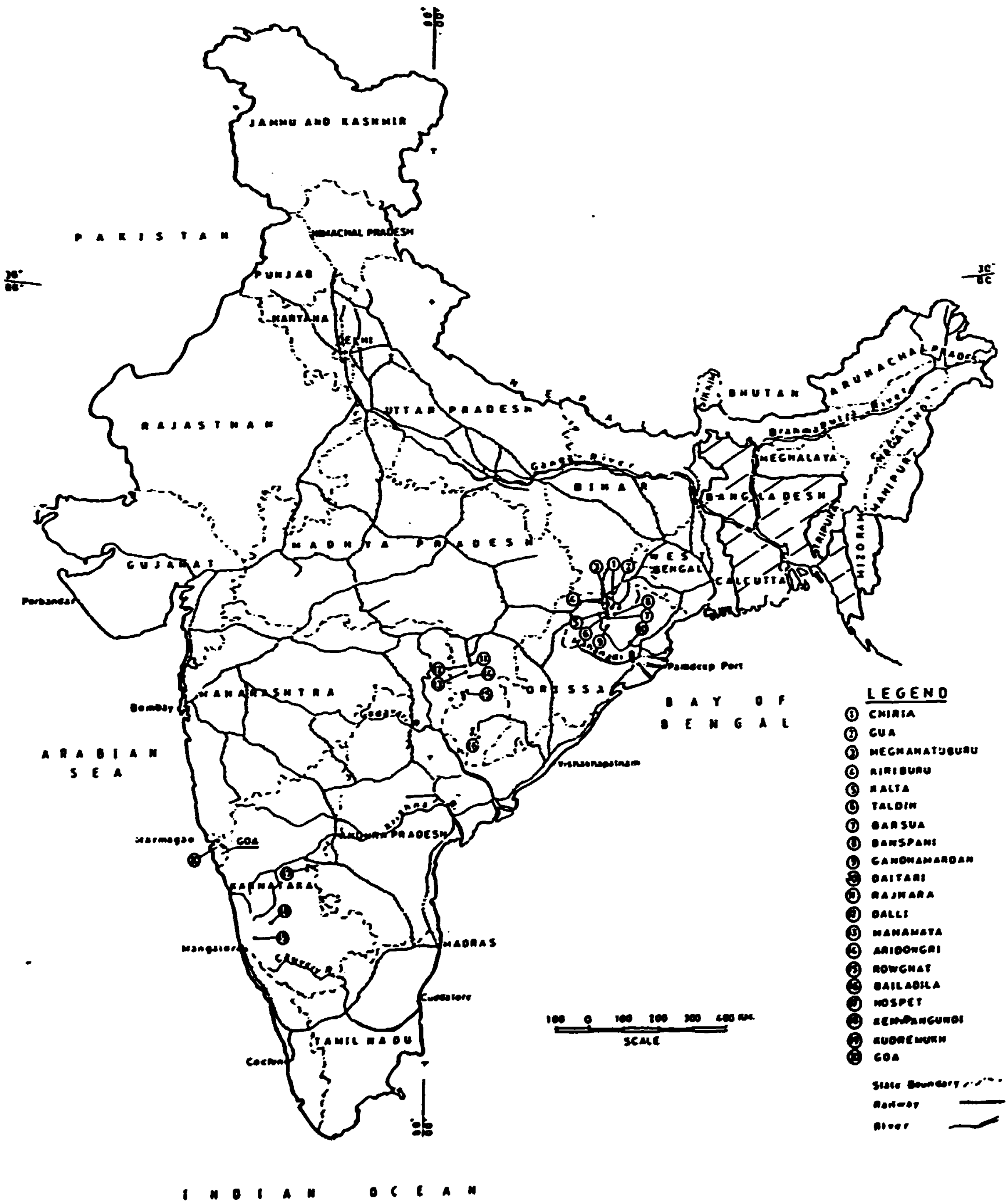

FIGURE-1 MAJOR IRON ORE DEPOSITS IN INDIA

a) Massive hematite - steel-grey in colour
b) Laminated hematite - reddish to grey in colour
c) Lateritic hematite - brown in colour
d) Powder hematite - dark blue-grey in colour

Quality of the ores: The iron content in the massive and hard laminated ores varies from 64 to 69 per cent and 57 to 67 per cent respectively, in soft laminated ores from 57 to 66 per cent, in powder ores (blue dust) from 65 to 69 per cent and in lateritic ores from 59 to 62 per cent. Chemical analyses of different ore types are given in Table 2.

TABLE 2 - CHEMICAL ANALYSES OF DIFFERENT ORE TYPES

Sl. No.	Type of ore	Fe %	SiO_2 %	Al_2O_3 %	P %
1.	Massive ore	64.2 to 69.0	0.34 to 4.19	0.50 to 3.66	0.013 to 0.180
2.	Hard laminated ore	56.8 to 66.6	0.81 to 5.73	1.00 to 7.14	0.032 to 0.172
3.	Soft laminated ore	57.0 to 65.5	1.20 to 8.60	1.10 to 11.00	0.028 to 0.308
4.	Lateritic ore	58.8 to 61.5	1.00 to 6.88	3.72 to 8.85	0.088 to 0.320
5.	Blue dust	65.0 to 69.0	0.64 to 2.12	0.35 to 2.49	0.048 to 0.228

It will be seen from the table that the phosphorus content in Indian ores is generally high compared to similar types of ore available in other countries. Further, gangue content (Al_2O_3 + SiO_2) is high in certain ore types, namely hard laminated ore, soft laminated ore and lateritic ore.

Iron and gangue contents in blue dust are the highest and lowest respectively compared to other types of hematite ore but it cannot be directly used as feed material for production of hot metal in blast furnace due to its fineness. It can be considered as feed material only after agglomeration.

Reserves of iron ore: It was earlier believed that the iron ore reserves of India were about 27,720 million tons of all grades. However, on the basis of recent detailed exploration work comprising contour surveying, geological mapping, diamond drilling, sinking of shallow and deep pits, trenching, aditting, sampling, chemical analyses of core, pit, trench and adit samples, by the Geological Survey of India, the reserves of hematite ore containing 55 per cent Fe and above have been estimated at about 11,469 million tons and those of magnetite containing 35 per cent Fe at about 6,103 million tons. The distribution and reserves of iron ores in different states of India are shown in Table 3 on the next page. It will be seen from the table that the reserves of hematite and magnetite iron ores are the highest in the states of Bihar and Orissa, and Karnataka respectively.

The Kiriburu and Meghahatuburu iron ore deposits have been briefly discussed below since they are the captive iron ore sources of BSL.

Kiriburu Iron Ore Deposit

The Kiriburu iron ore deposit was developed as an open cast mechanised mine for exporting lump ore to Japan. The development of the mine was started in 1959-60 and completed in August, 1963. However, after the construction of Bailadila Iron Mine, the Government of India declared Kiriburu Iron Mine (KIM) as the captive mine to BSL.

TABLE 3 - DISTRIBUTION AND RESERVES OF IRON ORES IN DIFFERENT STATES OF INDIA
(million tons)

Type of ore	State	Distribution (districtwise)	Measured	Indicated	Inferred	Total
Hematite	Bihar and Orissa	Singhbhum, Keonjhar, Mayurbhanj and Sundergarh.	2787	2506	1403	6696
	M.P. and Maharashtra	Bastar, Durg, East Niwar, Gwalior, Jabalpur of M.P. and Chanda and Ratnagiri of Maharashtra.	1197	576	922	2695
	Karnataka	Bellary, Shimoga, Chickmagalur, Tumkur and Chitradurga.	429	438	299	1166
	Goa	Goa	239	604	41	884
	Andhra Pradesh and Rajasthan	-	-	11	17	28
		Total:	4652	4135	2682	11469
Magnetite	Karnataka	Chickmagalur, Shimoga, Dakshin Kannad and Uttar Kannad.	683	2344	2143	5170
	Tamil Nadu	Salem, North Arcot, South Arcot and Dharmapuri.	107	62	362	531
	Kerala	Kozhikode and Malappuram.	-	64	25	89
	Andhra Pradesh, Assam, Bihar, Haryana, Nagaland and Rajasthan	-	-	3	310	313
		Total:	790	2473	2840	6103

Source: Indian Minerals Yearbook, 1983, Indian Bureau of Mines, Nagpur

Location: The Kiriburu iron ore deposit forms a part of of the well-known Bonai Iron-Ore Range and is located in the Singhbhum District, Bihar, about 18 km by road from Barbil town in Orissa.

Geology: Geologically, the rock types occurring in the area belong to the Iron Ore Series of the Dharwar System. Iron ores occurring in the deposit are believed to have originated from tropical weathering of banded hematite-jasper. The banded hematite-jasper occurs in between two horizons of phyllites and shales. Laterite occurs as capping of the iron ore formation and lateritisation also extends to depths in some places.

Geological investigations: The detail geological investigations comprising geological mapping, sinking of trial pits, driving of an adit, core drilling, sampling and chemical analyses of core, pit and adit samples were carried out partly by the Indian Bureau of Mines (IBM) and mostly by the National Mineral Development Corporation Limited (NMDC).

The exploration work carried out on Kiriburu iron ore deposit is given below:

i)	Core drilling, m	..	16,530
ii)	Average depth of bore holes, m	..	70
iii)	Length of adit, m	..	270
iv)	Trial pits, m	..	932

Reserves and dimensions of ore body: On the basis of above exploration work, the ore reserves have been estimated at about 112 million tons and the dimensions of the ore body have been determined as given below:

i)	Strike length, m	..	2,000
ii)	Maximum width, m	..	500
iii)	Average width, m	..	320
iv)	Maximum depth, m	..	150
v)	Average depth, m	..	120

Ore types: The geological investigations indicate the occurrence of different ore types, namely massive laminated ore, porous laminated ore, blue dust etc. The type-wise incidence, physical and chemical characteristics of ores are given in Table 4.

TABLE 4 - TYPE-WISE INCIDENCE, PHYSICAL AND CHEMICAL CHARACTERISTICS OF ORES

Ore type	Type-wise incidence %	Physical and chemical characteristics				
		Sp. gravity	Hardness	Fe %	SiO2 %	Al2O3 %
Massive laminated ore	13.0	4.5	Hard	65.8	0.47	2.94
Laminated ore	26.0	3.7	Medium soft	65.41	0.93	1.82
Porous laminated ore	30.0	3.4	Medium soft	63.24	1.79	2.20
Blue dust	16.0	3.3	Soft	65.76	3.10	2.40
Laterite	15.0	2.3	Hard	53.98	3.92	7.83

Meghahatuburu Iron Ore Deposit

The Meghahatuburu iron ore deposit has been developed to meet the iron ore requirements of BSL after its expansion from 2.5 million tons to 4 million tons per year.

Location: The Meghahatuburu iron ore deposit like Kiriburu forms a part of the Bonai Iron-Ore Range and is located to the north of KIM at a distance of about 3 km.

Geology: The Meghahatuburu ore body occurs in a synclinal trough and is bounded on both sides by shales with intercalated bands of banded hematite-quartzite and banded hematite-jasper.

Geological investigations: The detail geological investigations comprising geological mapping and topographical surveying, sinking of deep and shallow trial pits, driving of two adits, diamond drilling, sampling and chemical analysis of core, pits and adit samples were carried out mostly by NMDC. A total of 4,500 m of diamond drilling was carried out. A total of 49 deep pits ranging in depth between 9 m and 12 m and also a large number of shallow pits have been sunk. Two cross-cut adits of about 150 m length each were driven.

Reserves and dimensions of ore body: On the basis of the above exploration work, the ore reserves have been estimated at about 122 million tons and the dimensions of the ore body have been determined as given below:

i)	Strike length, m	..	960
ii)	Maximum width, m	..	600
iii)	Average width, m	..	450
iv)	Maximum depth, m	..	130
v)	Average depth, m	..	70

Ore types: The geological investigations have identified four main ore types in the deposit, namely lateritic/limonitic ore, medium hard laminated ore, soft laminated-cum-powdery ore and blue dust. Type-wise incidence and chemical analyses of the ores are given in Table 5 on the next page.

Installation of Integrated Steel Plants and Development of Mechanised Mines

The first pig iron plant in India was put up in 1889 at Kulti, West Bengal and the ore fed to the plant was ironstone shale analysing 35 to 40 per cent Fe. In 1911, an integrated steel plant

TABLE 5 - TYPE-WISE INCIDENCE AND CHEMICAL ANALYSES OF ORES

Ore type	Type-wise incidence %	Chemical analyses Fe %	SiO_2 %	Al_2O_3 %
Lateritic/Limonitic ore	8.8	58.02	3.29	6.22
Medium hard laminated ore	4.0	62.90	1.84	2.92
Soft laminated-cum-powdery ore				
i) Aluminous ore	16.6	61.95	1.61	4.11
ii) Siliceous ore	68.2	64.26	2.58	1.86
Blue dust	2.4	65.20	2.05	1.36

was installed at Jamshedpur, Bihar and another small one was set up in Mysore in 1923. The production of steel from these three plants upto 1947 was only about one and a half million tons per year. Almost the entire requirements of 3 million tons of iron ore per year were met from float ore lying scattered on the gentler slopes and foot of the hills.

However, with the setting up of the new steel plants and the expansion of the existing ones for increasing the steel production from 2 million tons to 7 million tons per year during India's Second Five Year Plan (1956-61) and also with the expanding export market for iron ore, the demand for iron ore increased manifold and rose to about 18 to 20 million tons per year. The production of such large tonnages without large scale mechanisation was not possible, because in manual mining, the output per man-shift was about 1 ton only.

To meet these commitments, the work on the construction of the first large scale mechanised mine of 2.4 million tons annual capacity was started in 1954 at Gua, Bihar by Indian Iron and Steel Co Ltd for supply to their Burnpur Steelworks and was completed by 1957. The number of mechanised iron ore mines increased to four in 1961, six in 1964, ten in 1968, twelve in 1977 and fifteen in 1985 including Kudremukh Project.

The iron ore mines comprising small manual mines, medium-sized semi-mechanised and highly mechanised large mines are concentrated in four areas, namely the Barbil-Barajamda area in Bihar and Orissa; the Bellary-Hospet area in Karnataka; the Dalli-Rajhara-Bailadila area in Madhya Pradesh; and in Goa. The chemical analyses of sized ores supplied to the integrated steel plants during 1982-83 to 1986-87 by the captive mines are furnished in Table 6 on the next page. It will be seen from the table that the quality of sized ore obtained by TISCO from their captive mines at Noamundi and Joda is the best.

At present, there are about one hundred and fifty small and large operating iron ore mines in the country and about 75 to 80 per cent of present annual production of about 44 million tons are contributed by the highly mechanised large mines. India has already established a production capacity of about 70 million tons per year. At present, about 25 million tons of iron ore per year are being exported and it is planned to export about 40 million tons by end of this decade. At present, about 15 million tons of iron ore per year are being consumed by the integrated steel plants, the crude steel productions of which during 1984-85 to 1986-87 are given in Table 7.

TABLE 7 - CRUDE STEEL PRODUCTIONS OF INTEGRATED STEEL PLANTS DURING 1984-85 TO 1986-87
(million tons)

Name of the integrated steel plant	1984-85	1985-86	1986-87
BSL	1.925	2.003	2.056
BSP	1.998	2.319	2.176
RSP	1.119	1.177	1.100
DSP	0.760	0.876	0.922
IISCO	0.444	0.565	0.528
TISCO	2.049	2.094	2.250
Total:	8.295	9.034	9.032

TABLE 6 - CHEMICAL ANALYSES OF SIZED ORES SUPPLIED TO THE INTEGRATED STEEL PLANTS DURING 1984-85 AND 1986-87 BY THE CAPTIVE MINES

Name of integrated steel plants	Name of captive mines	Chemical analyses								
		1984-85			1985-86			1986-87		
		Fe %	SiO_2 %	Al_2O_3 %	Fe %	SiO_2 %	Al_2O_3 %	Fe %	SiO_2 %	Al_2O_3 %
Bokaro Steel Ltd (BSL)	Kiriburu and Meghahatuburu	61.96	1.91	3.40	61.53	2.09	3.71	63.40	1.25	2.83
Bhilai Steel Plant (BSP)	Rajahra and Dalli	63.30	2.80	2.96	64.72	2.15	2.34	66.20	1.83	2.04
Durgapur Steel Plant (DSP)	Bolani	62.40	NA	NA	61.00	NA	NA	61.80	NA	NA
Rourkela Steel Plant (RSP)	Barsua and Kalta	62.00	2.30	3.80	62.00	2.30	4.00	62.30	2.20	3.70
Indian Iron & Steel Co Ltd (IISCO)	Gua and Chiria	61.32	2.30	5.54	61.30	2.60	4.10	61.10	2.40	4.30
Tata Iron & Steel Co Ltd (TISCO)	Noamundi and Joda	66.89	0.73	1.98	66.94	0.79	1.93	66.81	0.79	1.99

Iron Ore Processing

In view of the growing demand for richer ores by the iron and steel industry resulting from the rising prices of coking coal, higher cost of energy, beneficial effects of improved technology on the economics of blast furnace operation, and the changing pattern in the type of iron ore requirements of iron and steel industry, systematic iron ore processing/preparation is gaining more and more importance in the iron ore producing countries including India.

All operations carried out on iron ore after mining and before smelting, to make it suitable for use in blast furnace, are covered under iron ore processing. These operations depend on the type and characteristics of the ores, and also on the method and scale of smelting operations. The ores used for iron production vary from rich hematites and magnetites containing over 65 per cent Fe to ferruginous quartzite with only about 30 per cent Fe. Accordingly, as the situation warrants, the ore processing/ preparation methods may vary from simple sizing to thermal pre-treatment.

Ore preparation aims at ensuring a consistent supply of properly sized homogenous iron bearing feed material to the smelting furnace. The processing/preparation techniques include crushing, screening, blending, be ficiation which covers concentration and agglomeration, and pre-reduction operations. Any single plant may adopt one or more of these operations depending on the ores used.

Sizing

Ore preparation starts with crushing and screening which are the most extensively adopted processing/preparation techniques generally denoted by the term 'sizing'. Sizing aims at limiting as far as practicable the maximum and minimum sizes of the ore charged at pre-determined levels. Crushing increases the ratio of the surface area to the volume, thereby promoting indirect reduction by gases. The removal of fines increases the permeability of the charge material and brings about an even upward flow of gases, ensuring better utilisation of the thermal and chemical power of gases, both of which help in reducing coke consumption. The maximum permissible size of the ore depends mainly on reducibility. In recent years, the general trend has been towards crushing to smaller sizes, which has undoubtedly been beneficial. In general, the ores are crushed below 75/50 mm. However, at present, the top size of ores generally ranges between 75 mm and 25/30 mm and the lower size-limit ranges between 10 and 8 mm. The improvement in productivity and reduction in coke rate achieved by using closely calibrated ore in the blast furnace feed are quite significant and encouraging as can be seen from the results presented in Table 8.

TABLE 8 - EFFECT OF USE OF CLOSELY CALIBRATED ORE AS BLAST FURNACE FEED ON PRODUCTIVITY AND COKE CONSUMPTION IN SOME SELECTED STEEL PLANTS

Name of steel plants	Feed size (mm)		Increase in productivity	Decrease in coke consumption
	Past	Present	%	%
Fontana Plant, Kaiser Steel Corpn., U.S.A.	-38	-25	14.0	14.0
Tobata Works, Yawata Steel, Japan	40-8	30-8	3.6	5.5
Higashida Plant, Yawata Steel, Japan	40-10	30-8	10.0	3.0
Hirohata Plant, Fuji Steel, Japan	50-10	25-10	3.0	8.0

Iron ore sizing practice in India has undergone significant changes over the last two decades, generally speaking from 10/12-100/150 mm to 10-40/50 mm. In most Indian steel plants, iron ore used in blast furnaces has a size range of 10 to 50 mm with +50 mm fraction in the ore often averaging 5 to 10 per cent. Since sized ore constitutes 55 to 60 per cent of blast furnace burden, use of closely calibrated ore in the blast furnace burden is absolutely necessary. Further, the fines (-10 mm) content in the sized ore should be reduced to the maximum extent possible because the Indian iron ores generally disintegrate more as they are rich and relatively more reducible.

The sizing plants installed in the large open-cast mechanised mines are essentially similar, consisting of ore hoppers for dumping blasted ore transported from the mines by rear-dump trucks, apron/plate feeders for feeding the ore from the hoppers to the primary crushers (jaw or gyratory crusher) preferably over stationary grizzlies, belt/apron feeders for feeding primary crushed ore to the secondary crushers (short-head gyratory or standard cone crusher) with intermediary scalping screens, surge bins or stockpiles, and feeders for delivering secondary crushed ore to conveyor belt systems for onward transmission to the screening units (dry or wet) and sized ore and fines to the stockpiles/ rail road bins. However, some plants are equipped with tertiary crushers as for example, Kiriburu ore processing plant. Typical flow-sheets of sizing and beneficiation plants in India are given in Figures 2 to 7.

The experience with closer sizing of iron ore, has been encouraging. For example at BSP, reducing the oversize (+50 mm) from about 33 per cent to 3 per cent and undersize (-12 mm) from about 18 per cent to 13 per cent resulted in a coke saving of 21 kg (3 per cent) together with a 7 per cent increase in production.

This improvement in its entirety may not perhaps be attributed solely to improved sizing, because simultaneously there was some improvement in the ore chemistry (about 1 per cent increase in Fe content). At other plants also, there have been savings in coke rates with closer sizing of ore, but the effect on productivity has varied due to various factors, a major one being the increase in the proportion of undersize.

TISCO carried out trial runs in one of their blast furnaces with lump ore of 10 to 30 mm size and were able to increase hot metal production by about 115 tons per day and reduce coke consumption by about 36 kg per ton of hot metal, compared to those obtained from feed material of 10 to 50 mm size. Results of trials are presented in Table 9.

TABLE 9 - RESULTS OF TRIAL CARRIED OUT BY TISCO AT ONE OF THEIR BLAST FURNACES FEEDING LUMP ORE OF 10 TO 30 MM SIZE

		Trial	Base practice
Duration	..	One month	One month
Lump ore in feed, %	..	40	39
Sinter, %	..	60	61
Feed size, mm	..	10 to 30	10 to 50
Production, tons/day	..	933	818
Productivity, tons/m^3/day	..	1.04	0.95
Coke rate, kg/ton of hot metal	..	771	807
Slag rate, kg/ton of hot metal	..	590	610

On the basis of the results obtained from the trial runs, TISCO have installed facilities in their ore processing plant at Noamundi to effect supply of 10 to 30 mm sized ore to their steel plant at Jamshedpur. Similarly, sizing facilities have been provided in the raw material handling yard of Visakhapatnam Steel Project (VSP) under construction, to produce blast furnace feed of 10 to 25 mm size. In the Modernisation Scheme of BSP under implementation, it is planned to provide sizing facilities in the proposed bedding and blending yard at Rourkela, to produce 10 to 30/40 mm sized ore.

Beneficiation

The beneficiation of the ores may be defined as the method of upgrading and enriching the useful mineral content of the ores, by removing the undesirable and deleterious components. The processes adopted depend on the physical and chemical characteristics of the ores, to take advantage of properties like specific gravity, magnetism, surface characteristics etc. The beneficiation processes normally employed are washing, gravity separation, magnetic separation and flotation. The selection of the most appropriate beneficiation process and the determination of the optimum degree of beneficiation for each type of ore are fairly complex technical and economic tasks.

The higher the iron content of the ore, the more economical is blast furnace smelting, provided other conditions are the same It is generally accepted that every 1 per cent increase in the Fe content of ores containing 50 to 60 per cent Fe will bring about 1.25 per cent to 2.50 per cent decrease in coke rate, depending on the type of gangue material. Beneficiation processes adopted in India for upgrading of iron ores are presented in Figures 2 to 7 and briefly described below.

The captive mines of TISCO, RSP, BSP and BSL at Noamundi, Barsua, Dalli and Kiriburu respectively are equipped with beneficiation facilities comprising scrubbing, wet screening, classifying and the one at Barsua is also provided with jigging facilities to upgrade primarily the ore fines. In actual operation of the beneficiation plants, it has been found that more silica than alumina is carried in the slime/tailings; but the net effect achieved from washing is the increase in iron content in the ore, enabling reduction of slag volume as well as coke and flux consumption in the blast furnace. In the beneficiation plants at Bailadila, Daitari, Donimalai and Meghahataburu wet screening and classifying facilities have been provided to upgrade fines by rejecting the classifier overflow, to reduce fines content in the sized ore as well as to ensure the screenability and smooth flow of the ores which become wet and sticky during the monsoon months.

Since the beneficiation plant at Barsua Iron Mine of RSP is equipped with jigging facility, it is briefly described below.

The beneficiation plant located at Barsua was commissioned in October, 1968 and consists of the washing and jigging sections which are connected by two parallel lines of launders. The washing section, which is designed to handle 800 tons of crushed r.o.m. ore per hour consists of two parallel circuits comprising drum scrubbers and wet screens.

The jigging section, which processes only ore fines (400 tons per hour) consists of two parallel circuits up to the jigs. The major process equipment in this section are double-deck wet screens, spiral classifiers, Remer jigs, cyclones, thickener etc. Typical chemical analyses of r.o.m. ore, sized ore and ore fines are given in Table 10.

TABLE 10 - TYPICAL CHEMICAL ANALYSES OF BARSUA R.O.M. ORE, SIZED ORE AND ORE FINES

		Fe %	SiO_2 %	Al_2O_3 %
R.O.M. ore	..	58.20	2.50	8.20
Sized ore	..	61.20	1.50	5.70
Ore fines	..	60.80	1.40	5.70

Kiriburu Iron Ore Processing Plant

The Kiriburu iron ore processing plant is discussed below since it is the captive mine of BSL. The Kiriburu Iron Mine (KIM) was initially developed to produce 3.3 million tons of r.o.m. ore per year to export 2 million tons of lump ore of 12 to 200 mm size to Japan. Subsequent to the development of Bailadila Iron Mine, Kiriburu was attached to BSL as their captive mine which was expanded/modified to supply about 1.30 million tons of lump ore of 10 to 40 mm size and about 2.95 million tons of minus 10 mm ore fines per year by processing annually about 5 million tons of r.o.m. ore.

The existing facilities comprising iron ore sizing, washing, stockpiling and wagon loading, are briefly described hereunder and a flowsheet for the same is presented in Figure 2.

Primary crushing section: The primary crushing section is equipped with two parallel crushing circuits, which reduce the r.o.m. ore to minus 200 mm size. The blasted r.o.m. ore is transported from the mine to a r.c.c. hopper by rear-dump trucks. The ore from the hopper is drawn out by a 2200 mm x 6500 mm heavy duty apron feeder and fed at a predetermined rate to a 1520 mm x 2130 mm double toggle jaw crusher through a stationary bar grizzly of 2000 mm x 4700 mm size. It scalps out minus 200 mm material from the feed to the crusher. The crushed ore, together with the undersize of the grizzly, is delivered to the secondary crushing section by a 1830 mm belt conveyor. This belt conveyor is equipped with an electromagnet and a metal detector to remove tramp iron from the crushed ore before the same is fed to the secondary crusher.

Secondary crushing section: The secondary crushing section consists of two parallel circuits for reducing the minus 200 mm sized ore to minus 40 mm size.

KIRIBURU IRON MINE

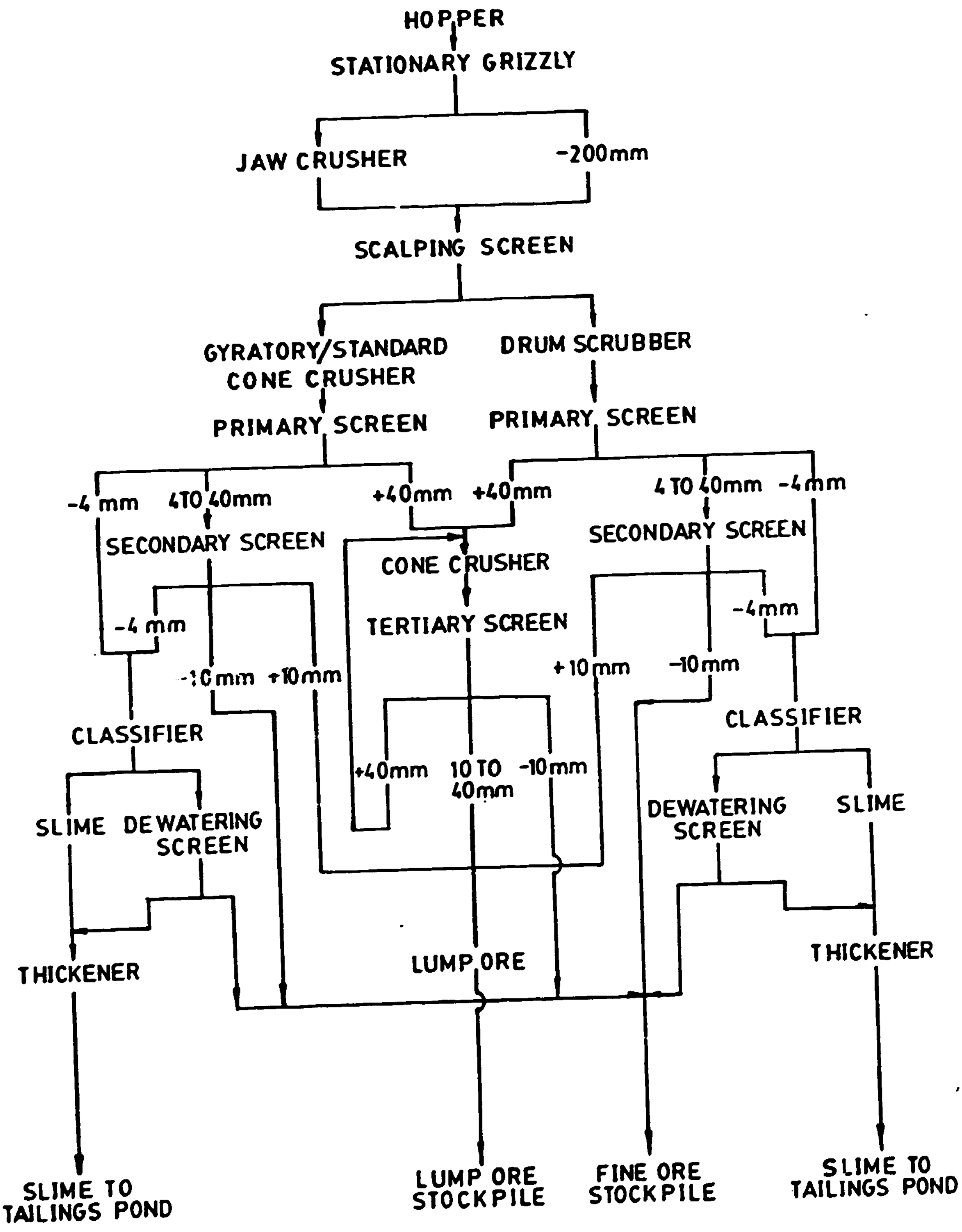

FIGURE-2

The primary crushed ore is delivered to a 1830 mm x 3660 mm single-deck scalping screen which scalps out minus 70 mm material from the feed to the secondary crusher. The oversize of the scalping screen is fed to a 610 mm x 1680 mm secondary gyratory crusher/2200 mm standard cone crusher by a rail-mounted feed conveyor. This feeding arrangement permits operation of secondary crusher from either of the primary crushers. The crushed ore is delivered to the washing section by a 1050 mm belt conveyor.

<u>Washing section</u>: The washing section consists of parallel circuits comprising drum scrubbers and double-deck wet screens. The undersize of the scalping screen ahead of the secondary crusher is delivered to a 2400 mm x 7000 mm drum scrubber for washing of minus 70 mm sized lump ore.

The scrubbed material is delivered to a 2130 mm x 6000 mm double-deck primary screen for separating the ore into three fractions, namely plus 40 mm, 4 to 40 mm and minus 4 mm.

The 4 to 40 mm fraction is delivered to a 1830 mm x 3660 mm double-deck secondary screen for further wet screening and sizing into three fractions 10 to 40 mm, 10 to 4 mm and minus 4 mm.

The lump and fine ores of 10 to 40 mm and minus 10 mm sizes respectively are conveyed to the sized ore and ore fines stockpiles by 1050 mm downhill belt conveyor systems.

The undersize of the bottom deck of the primary and secondary screens, is fed to a rake/spiral classifier for removal of slime of minus 100 mesh size. The slime is delivered to a thickener for recovery of water.

The rake/spiral classifier delivers washed and cleaned minus 10 mm classifier fines to a 1830 mm x 4200 mm dewatering screen. The dewatered classifier fines are conveyed to the stockpile of ore fines.

<u>Tertiary crushing section</u>: The oversize of plus 40 mm from the top deck of the 2130 mm x 6000 mm primary screen is delivered to the tertiary crusher section by a 1050 mm belt conveyor. The tertiary crusher section consists of 2200 mm short head cone crushers working in closed circuit with 2100 mm x 6000 mm double-deck screens. The crushed product of 10 to 40 mm size and minus 10 mm are delivered to the lump ore and ore fines stockpiles by 1050 mm downhill conveyor systems.

<u>Stockpiling and wagon loading section</u>: The sized ore is stockpiled by a tripper conveyor and reclaimed by a system of vibrating feeders and a tunnel conveyor. The reclaimed sized ore is delivered to overhead rail road bins by a 1050 mm belt conveyor system for loading into railway wagons.

The ore fines are stockpiled by a stacker and reclaimed by a bucket wheel reclaimer. The reclaimed ore fines are loaded into wagons by a 1050 mm belt conveyor system and wagon loader.

The sized ore and ore fines reclaiming conveyors are equipped with belt scales for automatic recording of the weights of the individual materials being conveyed.

For the collection of samples, an automatic sampler is provided in each of the conveyor belts carrying sized ore and ore fines.

The chemical analyses of r.o.m. ore and products as well as the recoveries achieved at Kiriburu during 1980-81 to 1985-86 are presented in Table 11 on the next page. It will be seen from the table that the iron content in sized ore and ore fines is more or less same. Ore processing facilities at Meghahatuburu are not discussed since they are identical to Kiriburu.

<u>Blending</u>

The ores in their natural state are generally non-uniform, and it becomes often desirable to blend various grades and types of ores together to obtain an uniform feed for the blast furnace. A properly conceived blending system ensures an end product of

TABLE 11 - CHEMICAL ANALYSES OF R.O.M. ORE AND PRODUCTS AS WELL AS THE RECOVERIES ACHIEVED AT KIRIBURU DURING 1980-81 TO 1985-86

Year	Chemical analyses: R.O.M. ore Fe %	SiO_2 %	Al_2O_3 %	Sized ore Fe %	SiO_2 %	Al_2O_3 %	Ore fines Fe %	SiO_2 %	Al_2O_3 %	Recoveries (%) Lump	Fines	Slime
1980-81	63.06	1.35	2.87	63.66	0.94	2.51	63.26	1.05	2.70	37.0	36.1	26.9
1981-82	62.91	1.59	2.69	63.78	1.01	2.10	63.64	1.18	2.45	37.6	37.1	25.3
1982-83	62.81	2.01	2.67	63.48	1.25	2.16	63.15	1.51	2.66	38.8	36.3	24.9
1983-84	62.58	2.13	3.08	63.35	1.29	2.46	62.76	1.75	3.10	41.9	35.5	22.6
1984-85	62.32	2.12	2.99	63.23	1.40	2.31	62.67	1.75	2.96	39.1	34.7	26.2
1985-86	61.69	2.10	3.67	62.72	1.42	2.82	61.82	1.79	3.65	38.6	34.9	26.5

uniform physical and chemical characteristics, which in turn helps in the production of consistent quality iron. It is, therefore, customary that plants based on locally purchased and/or imported ores from various sources adopt some sort of blending to obtain a more uniform feed material. Blending is also advantageous in the case of a steel plant which obtains its ore supplies from captive mines, to minimise the effects of possible fluctuations in the quality of ore received.

The blending system for the iron ores comprising bedding and reclaiming facilities has not been provided in any highly mechanised mine in India, as these are generally expected to be provided in the steel plants themselves. In India, however, only in three steel plants, namely at DSP, BSP and BSL, blending facilities have been installed. DSP is equipped with Robins Messiter stacker and reclaimer and BSP utilises ore bridge cranes for blending. BSL has been equipped with stackers and barrel type reclaimers for blending of both sized ore and ore fines.

Some blending facilities do exist at some of the captive mines, but these are inadequate. For instance, at the Barsua Iron Mine, the blending of ore fines is carried out by bedding the ore fines with a twin-boom stacker and then loading the fines into railway wagons by a shovel. At the Bailadila Iron Mine, the blending of lump ore is

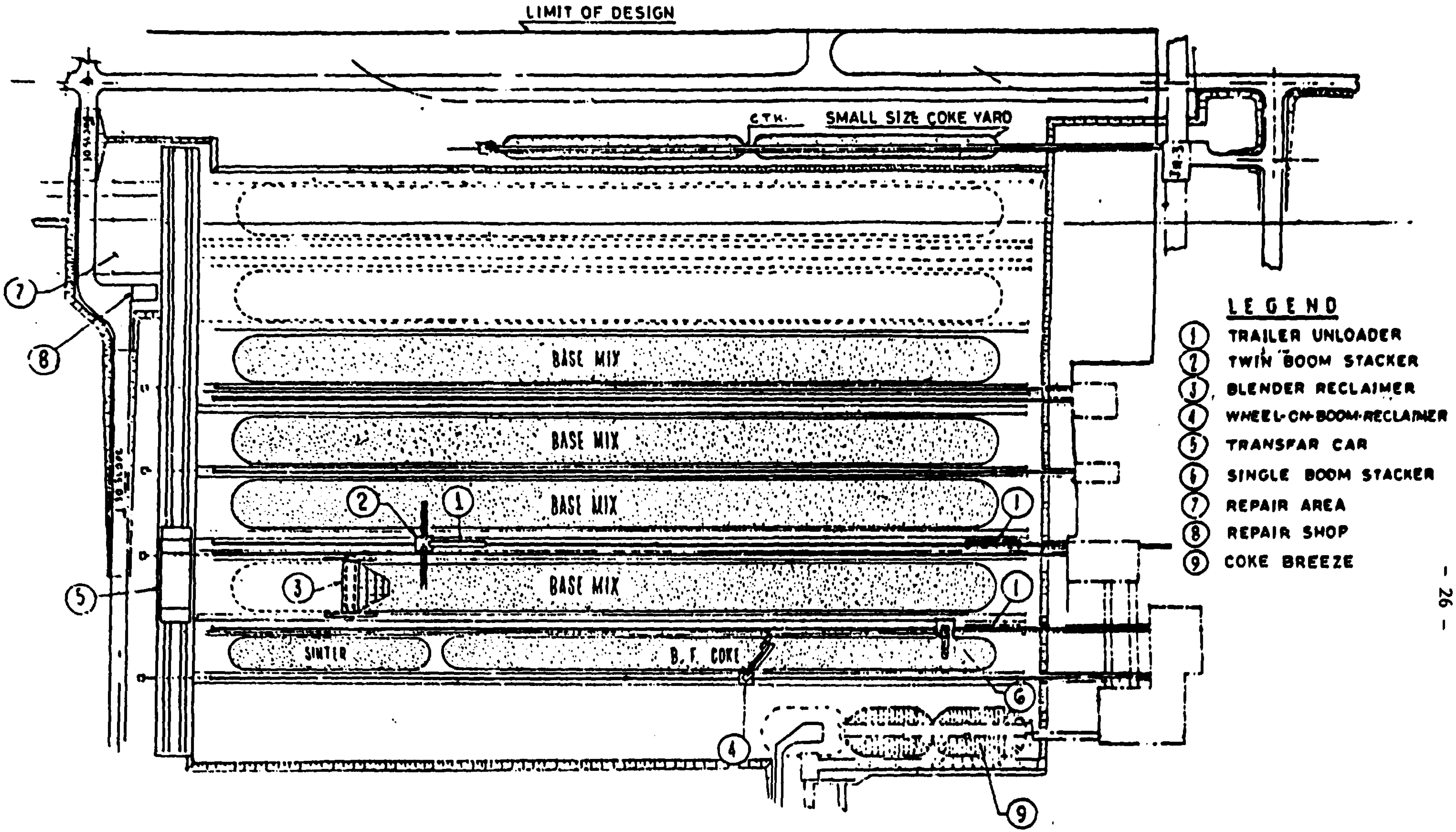
LIMIT OF DESIGN
C.T.K.
SMALL SIZE COKE YARD
BASE MIX
BASE MIX
BASE MIX
BASE MIX
SINTER
B. F. COKE
LEGEND
1 TRAILER UNLOADER
2 TWIN BOOM STACKER
3 BLENDER RECLAIMER
4 WHEEL-ON-BOOM-RECLAIMER
5 TRANSFAR CAR
6 SINGLE BOOM STACKER
7 REPAIR AREA
8 REPAIR SHOP
9 COKE BREEZE

FIGURE-8

carried out by a combination of a stacker and tunnel reclamation system. The facilities provided at Barsua and Bailadila are not adequate to deliver an end product similar to that from a fully equipped blending system, however, these can, to some extent, minimise the day-to-day fluctuations in ore quality.

However, with the necessity of feeding the blast furnace with materials of uniform physical and chemical characteristics to obtain its maximum efficiency and to produce hot metal of uniform consistency, critical to modern oxygen steelmaking process, the importance of bedding and blending yards has been realised and the installation of the same in the existing steel plants has already been started.

TISCO have been presently installing a bedding and blending yard at their steel plant, while similar facilities have been provided in the Modernisation Scheme of RSP. Similarly, an elaborate bedding and blending system has been provided in the raw material handling yard of VSP, which is briefly discussed below since it is the first plant having base-mix yard as shown in Figure 8.

The bedding and blending yard at VSP has been provided with three storage yards - one for ore and flux, the second for base-mix blending for the sinter plant and the third for coking and steam coal for the power plant. The approximate areas covered by different storage yards are given in Table 12.

TABLE 12 - APPROXIMATE AREAS OF STORAGE YARDS

Storage yard		Approximate area m x m
Ore and flux	..	365 x 560
Base-mix blending (including BF coke, sinter and small size coke storage)	..	380 x 500
Coal	..	370 x 980

The stockpiles in the ore and flux yard, base-mix yard and coal yard will be arranged such that the storage capacity can be expanded to meet the requirements upto about 4.5 million tons capacity with minimum changes/modifications to the different raw material handling systems.

The stockpile sizes and capacities for major raw materials are given in Table 13.

TABLE 13 - STOCKPILE SIZES AND CAPACITIES

Raw material		Number of stockpiles and approx. sizes m	Storage capacity days	Stock quantity tons	Stock quantity cu m
Sized iron ore	..	2 - 170x30x11.7	44	133,907	54,656
Ore fines and blue dust	..	3 - 325x30x11.7	32	343,543	163,592
Limestone:					
Sintering	..	2 - 90x30x10.9	40	39,613	24,758
Calcining	..	2 - 200x30x10.9	47	97,165	60,728
Dolomite:					
Sintering	..	2 - 140x30x10.9	40	65,773	41,108
Calcining (for brick)	..	1 - 40x30x10.9	46	6,733	4,208
Calcining (for flux)	..	1 - 90x30x10.9	48	19,806	12,379
Base-mix	..	4 - 450x30x11.7	32	550,570	305,872
BF coke	..	1 - 323x20x7.2	1.6	10,156	22,570
Sinter	..	1 - 117x20x7.2	1.1	13,900	7,738

Stacking and Reclaiming System

Stackers and reclaimers will be used for stacking and reclaiming of ore and flux, coal and the base-mix for sinter. The number of stackers and reclaimers including their capacities is given in Table 14.

TABLE 14 - REQUIREMENTS OF STACKERS AND RECLAIMERS

Item	Number	Capacity tph	Location
Twin-boom stacker	4	1,400	Ore and flux storage yard
Blender reclaimer	3	1,200	
Wheel-on-boom reclaimer	3	450	
Twin-boom stacker	2	1,200	Base-mix yard
Blender reclaimer	2	1,200	
Fixed single-boom stacker	1	800	
Wheel-on-boom reclaimer	1	800	
Single-boom slewing stacker	3	850	Coal storage yard
Wheel-on-boom reclaimer	3	550	
Stacker-cum-reclaimer	1	850/550	

Sized iron ore for blast furnace, mixed iron ore fines, limestone for calcining and base-mix will be reclaimed by blender reclaimers and all other materials will be reclaimed by wheel-on-boom type reclaimers.

The fluctuations in the quality of sized ore and ore fines to be supplied to the blast furnaces will be within the following limits:

		%
Fe	..	± 0.50
SiO_2	..	± 0.25
Al_2O_3	..	± 0.30

Agglomeration

The total mechanisation of mining operation, closer sizing of iron ore and the adoption of ore beneficiation processes result in the generation of large quantities of ore fines. These ore fines are not acceptable for direct use in the smelting processes as well as in many of the direct reduction processes. These have to be agglomerated before use. The two agglomeration processes which are in commercial operation, are sintering and pelletising. The selection of the appropriate process of agglomeration depends on the size of the ore fines/concentrates. Generally, the sinter feed is of -10 mm size, with 100 mesh fraction as low as possible, preferably not exceeding 20 per cent. Pelletising is usually adopted for very fine materials of about -200 mesh size.

Pelletising: Pelletising process was developed for treating concentrates/natural ore fines which are too fine-grained to be sintered. Pelletising is adopted for all types of ore fines such as hematite, magnetite etc. Normally, the pellets for export are not highly fluxed. The beneficial characteristics of pellets as blast furnace feed material such as size uniformity, high strength, and uniform micro porosity which ensures good gas permeability and reducibility, have resulted in the rapid development of pelletising. As in the case of use of sinter, the main advantages of using pellets in the blast furnace are reduced coke rate, increased output and improved operations. In addition to their suitability for smelting process, pellets have found wide acceptance for the production of sponge iron.

Sintering: Sintering is the most widely adopted agglomeration process at present for ironmaking. The utilisation of fluxed sinter in large proportions has brought about significant reduction in the coke rate and increase in the production. In addition to these economic advantages, the sintering plant also acts as a scavanger in the steel plant, because it permits the utilisation of by-products like flue dust, mill scale, coke breeze, flux fines etc, which would have been wasted otherwise. The sintering process also helps in eliminating deleterious impurities like sulphur, arsenic, zinc and volatile alkalis.

Sintering of ore fines in India was adopted first in 1955 by TISCO and use of pellets in blast furnace was started in 1972 also by TISCO. However, the use of pellets was discontinued because of high cost of production of pellets in their captive plant located at Noamundi.

All the steel plants in India except IISCO are provided with sintering facilities. The number and size of sinter strands as well as the rated capacity of sinter plants installed/being installed/ proposed to be installed in the steel plants of India are presented in Table 15 on the next page.

The non-installation of sintering facilities at IISCO has resulted in a huge accumulation of ore fines amounting to about 30 million tons at their captive mine at Gua which might result in

TABLE 15 - INFORMATION ON SINTER PLANTS INSTALLED/BEING INSTALLED/PROPOSED TO BE INSTALLED IN THE STEEL PLANTS OF INDIA

Name of the steel plants	Number of sinter strand	Size of sinter strand m^2	Rated capacity mill tons/year	Remarks
BSP	4	50	4.29	
	3	75		
BSL	3	252/312	6.40	
DSP	2	140	1.50	
RSP	2	125	1.50	
	1	162	1.27	Proposed to be installed under Modernisation Scheme to increase sinter in the blast furnace burden from the present level of 40 per cent to 80 per cent.
TISCO	2	75	1.50	
	1	192	1.61	Under construction, after commissioning sinter in the feed will go up from 40 per cent to about 65 per cent.
VSP	2	312	5.3	Erection completed, to be commissioned in near future.

closure of the mine, unless necessary arrangements for the off-take of fines are made at an early date. In view of this, IISCO are seriously considering the installation of a sintering unit at their Burnpur Works.

In the initial years of operation, acid sinter was produced at Jamshedpur Works of TISCO, but subsequently the plant switched over to fluxed sinter. However, the sinter plants at BSP, RSP, DSP and BSL commenced with the production of fluxed sinters.

Typical chemical analyses of the sinters produced in the integrated steel plants in India during 1984-85 to 1986-87 are given in Table 16 on the next page.

With regard to sintering, the most significant development has been the increase in the basicity, which has enabled reduction in the raw limestone and dolomite charged with the burden and thereby helping in the reduction of the coke rate, besides resulting in other benefits.

Another advantage of utilising sinter has been the replacement of a certain portion of quartz/quartzite by sand. The use of lump quartz/quartzite in the burden tends to rob the furnace of heat at the tyuere zone, thus resulting in a somewhat lower hot metal temperature - a major handicap in the Indian blast furnace practice. The fullest advantage of replacing quartz/quartzite in the Indian steel plants can only be taken with the use of higher proportions of sinter in the burden.

In view of the foregoing, the usage of sinter has substantially changed during 1965 to 1985 as can be seen from the figures given in page 30.

TABLE 16 - TYPICAL CHEMICAL ANALYSES OF SINTER PRODUCED IN THE INTEGRATED STEEL PLANTS DURING 1984-85 TO 1986-87

Name of integrated steel plants	Chemical analyses											
	1984-85				1985-86				1986-87			
	Fe %	FeO %	$SiO_2+Al_2O_3$ %	CaO+MgO %	Fe %	FeO %	$SiO_2+Al_2O_3$ %	CaO+MgO %	Fe %	FeO %	$SiO_2+Al_2O_3$ %	CaO+MgO %
BSL	51.71	11.52	10.52	15.72	52.45	10.71	10.52	15.27	53.0	9.79	10.48	14.67
BSP	46.3	8.23	11.84	22.22	48.68	6.06	10.67	19.85	49.63	7.03	10.37	19.10
DSP	55.3	10.3	10.0	11.4	55.4	9.2	10.3	11.4	56.0	9.2	10.0	10.7
RSP	45.5	9.4	12.0	21.5	47.6	8.6	10.5	20.3	48.0	8.0	10.3	19.9
TISCO	44.94	6.97	12.04	23.96	47.48	6.73	10.48	22.08	48.66	7.28	9.62	20.93

		1965-66		1975-76		1985-86	
		Ore %	Sinter %	Ore %	Sinter %	Ore %	Sinter %
BSP	..	71	29	59	41	42	58
DSP	..	100	-	80	20	71	29
RSP	..	83	17	65	35	63	37
TISCO	..	82	18	54	34	58	42
BSL	..	-	-	19	81	36	64

It will be noted from the table that use of sinter in the steel plants is more during 1985-86 compared to that of 1975-76, except in case of BSL where sinter use has gone down from 81 per cent to about 64 per cent.

Conclusion

The economic advantages of better preparation of blast furnace burden are well known. Some economic effects of improved burden preparation under Indian condition are quite encouraging and interesting. A recent study indicates that replacing 100 per cent ore practice by 80 per cent sinter and 20 per cent closely calibrated ore, the productivity may increase by about 40 per cent, the coke rate may reduce by about 22 per cent and the hot metal cost will be reduced by about 25 per cent.

In view of the foregoing and in consonance with the installation of more and more giant blast furnaces in India, whose burden specifications are extremely stringent, the use of prepared burden material obtained by adopting various iron ore processing technologies, such as closely calibrated sized ore, sinter and pellets is growing.

MEGHAHATUBURU IRON MINE

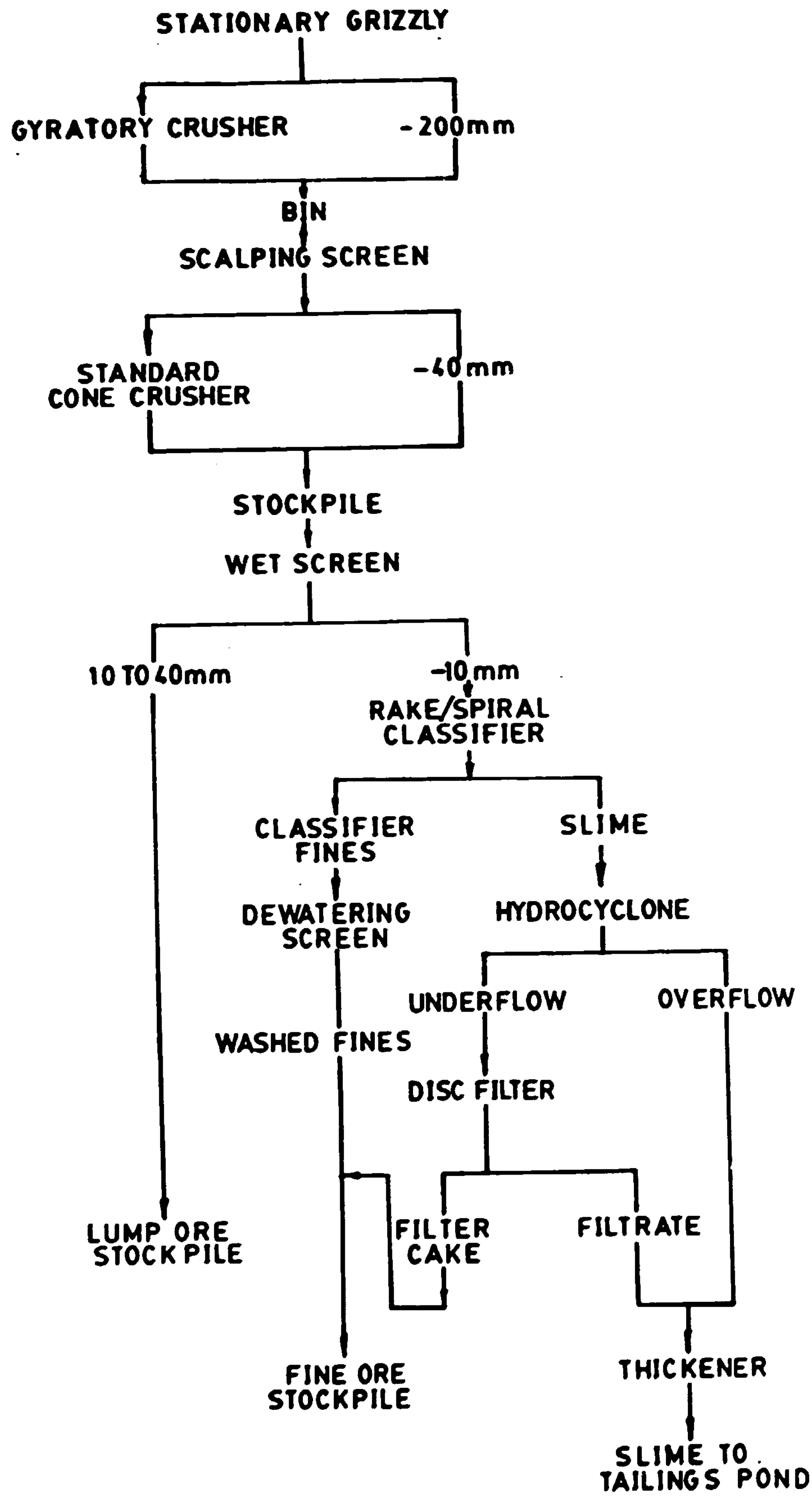

FIGURE-3

DALLI IRON MINE

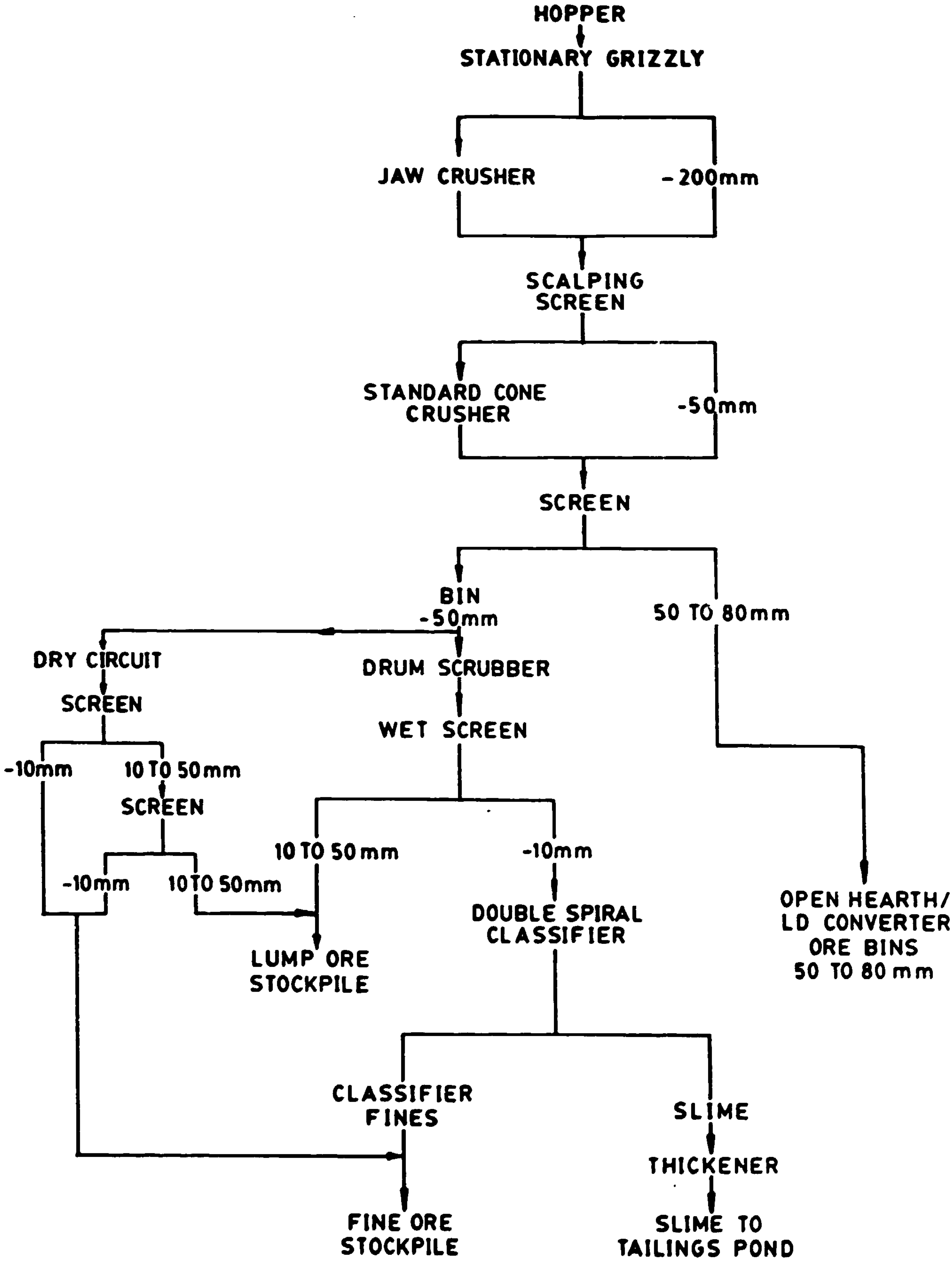

FIGURE-4

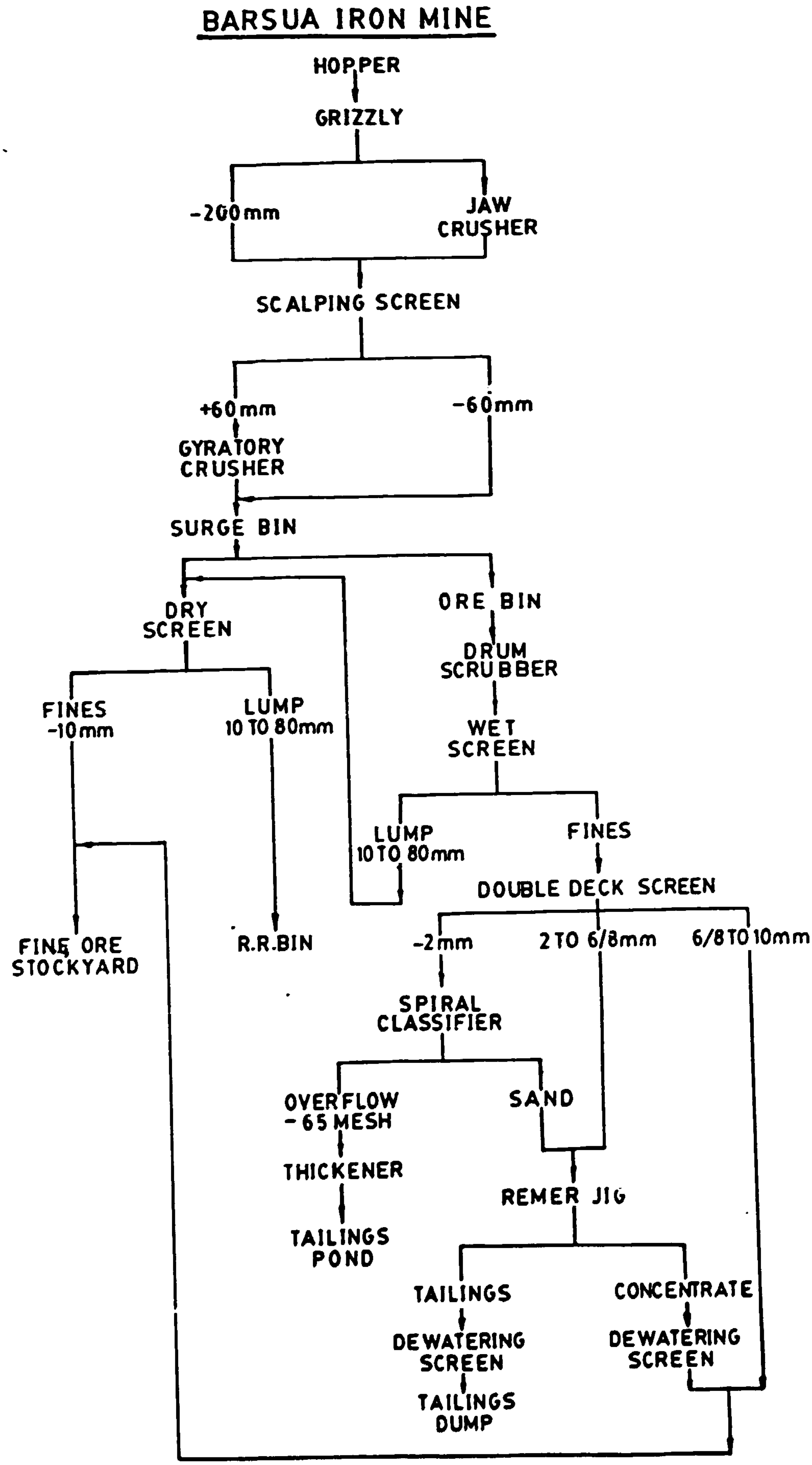
BARSUA IRON MINE
HOPPER
GRIZZLY
-200mm
JAW CRUSHER
SCALPING SCREEN
+60mm
-60mm
GYRATORY CRUSHER
SURGE BIN
DRY SCREEN
ORE BIN
DRUM SCRUBBER
FINES -10mm
LUMP 10 TO 80mm
WET SCREEN
LUMP 10 TO 80mm
FINES
DOUBLE DECK SCREEN
FINE ORE STOCKYARD
R.R.BIN
-2mm
2 TO 6/8mm
6/8 TO 10mm
SPIRAL CLASSIFIER
OVERFLOW -65 MESH
SAND
THICKENER
REMER JIG
TAILINGS POND
TAILINGS
CONCENTRATE
DEWATERING SCREEN
DEWATERING SCREEN
TAILINGS DUMP

FIGURE-5

G'\A IRON MINE

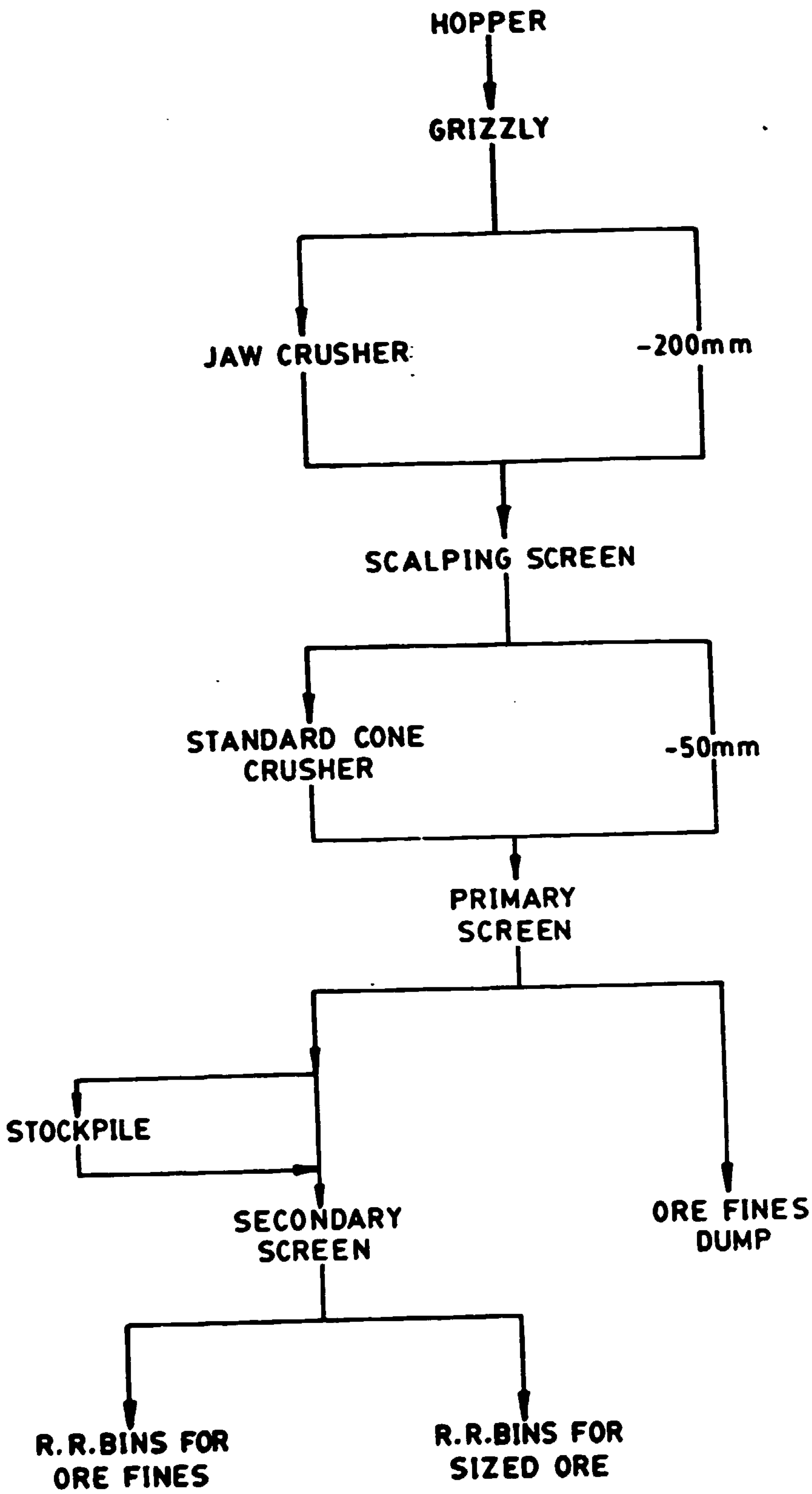

FIGURE-6

NOAMUNDI IRON MINE

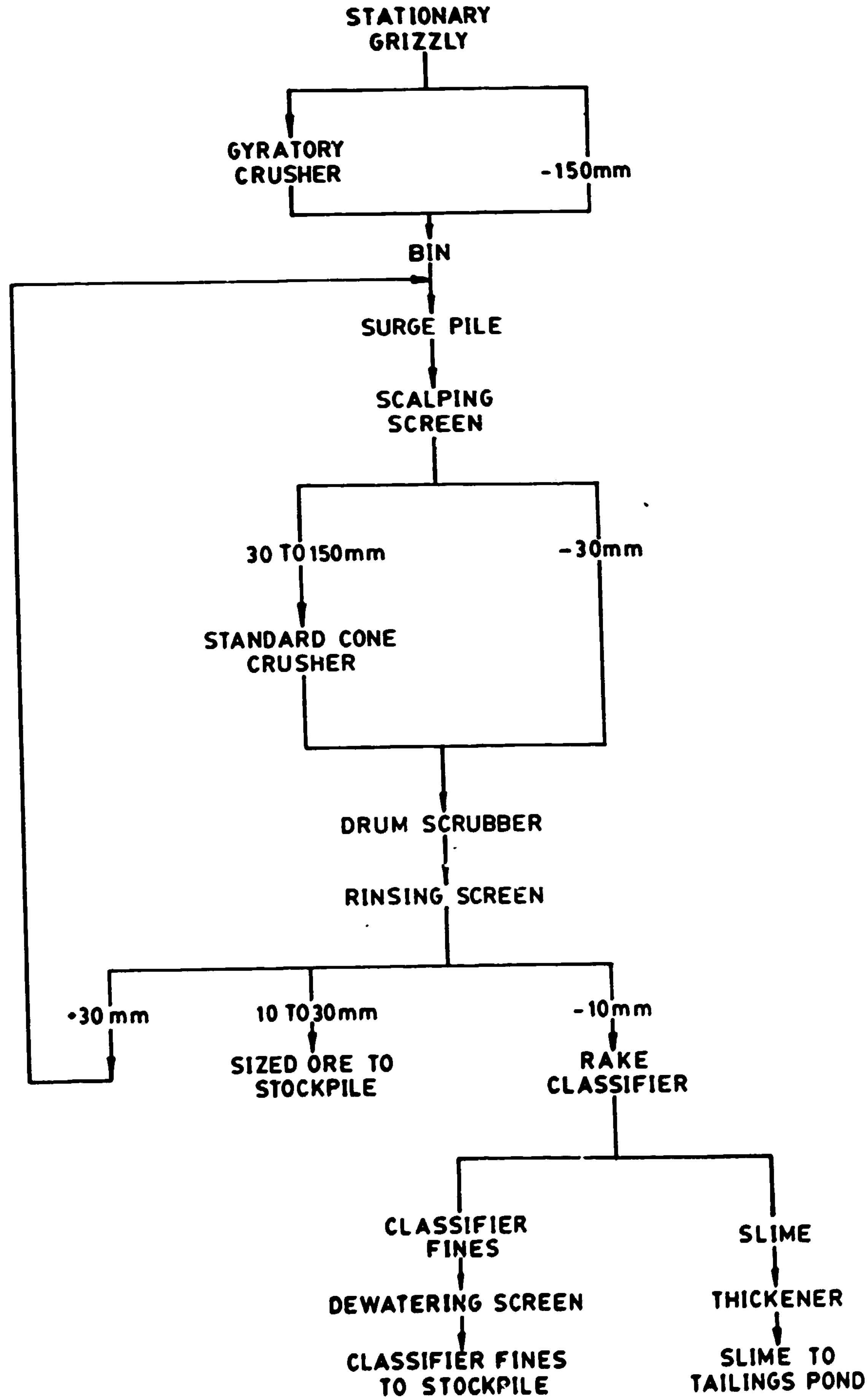

FIGURE-7

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