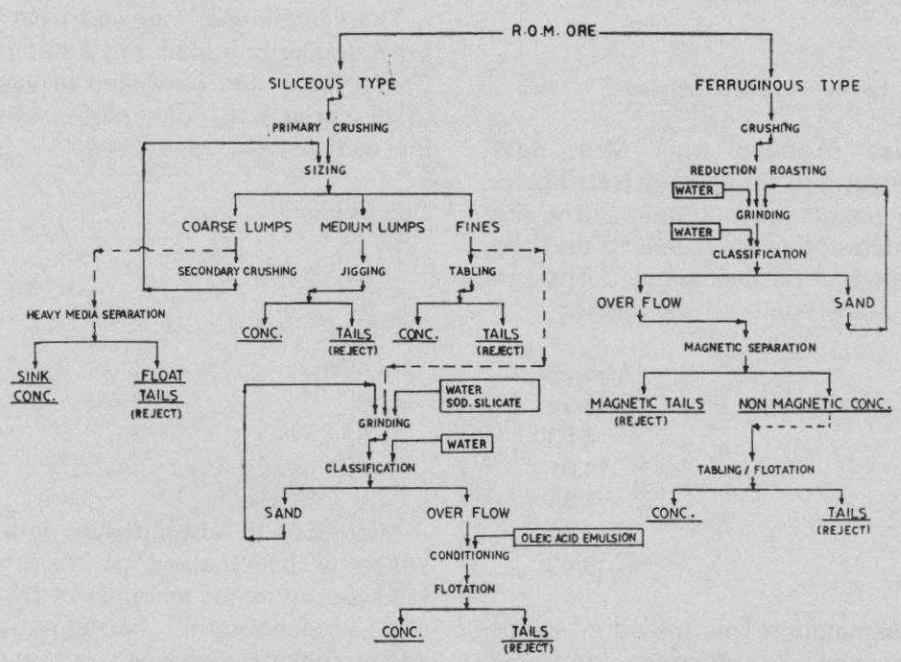
BENEFICIATION OF MANGANESE ORES

India is one of the leading manganese ore producing countries in the world. Its important ore deposits are located in Andhra Pradesh, Orissa, Bihar, Madhya Pradesh, Maharastra and Karnataka. Some workable deposits are located in Rajasthan also. The extent of the reserves, grades, production, exports, etc. are given in detail in Part I.

Indian manganese ores based on their mineralogical association may be broadly divided into: (a) siliceous type where in the siliceous minerals formed the gangue and which is upgraded by gravity methods, (b) ferruginous type where the gangue minerals contribute iron rendering the Fe-Mn ratio unfavourable for the use in metallurgical industry directly and which are beneficiated by reduction roast followed by magnetic separation & (c) garnetiferous ores where the gangue minerals are garnets contributing Fe, & SiO_2 which are beneficiated by flotation and/or electrostatic/high tension separation.

Beneficiation of siliceous ores is always simple and is effected by gravity methods and occasionally by flotation. It is difficult if the manganese bearing silicates are there in the ore. Ferruginous ores are beneficiated by reduction roast and magnetic separation method only when the iron is contributed by individual iron minerals



Flowsheet 3.1—General Flowsheet for beneficiation of manganese and chrome ores

like hematite, goethite etc. But if iron is present in chemical composition of the ore it is not possible to reduce the iron content with good manganese recoveries. Garnetiferous ores are beneficiated by flotation and/or electrostatic/high tension separation only. Gravity methods cannot help the separation due to the low difference in the specific-gravity of the ore minerals and the gangue.

Apart from these types, manganese ores having high phosphorous content may be grouped as high phosphorous ores. Presence of phosphorous may be due to the presence of (i) minerals like apatite, collophane etc., which are separated by flotation/leaching; and (ii) formation of solid solution with the ore minerals, in which case, it may not be possible to reduce the same. Considerable work has been done at NML on both these problems viz., reduction of iron and silica and reduction of phosphorous from the manganese ores.

Different types of manganese ores received from the various states of the country, were subjected to beneficiation studies on bench as well as pilot plant scale and the results achieved are briefly presented here. Tables 3.1 & 3.2 given at the end of this chapter summarizes the beneficiation test results of the various samples.

A. MANGANESE ORES FROM ANDHRA PRADESH

(i) Elluvial Ore from Koduru Mines

The sample was received from M/s. Seth Sreeram Durgaprasad and Fatechand Narsingdas —Chipurupalli, for beneficiation studies. The ore was having brownish appearance due to the iron oxides and consisted of 50 mm lumps. The ore in its as-received state analysed as follows:

Constituent	*Assay%*
Mn	33.94
Fe	4.53
SiO_2	14.01
Al_2O_3	8.50
Ba	8.65
P	0.49

Microscopic examination of the ore lumps indicated the presence of psilomelane followed by pyrolusite and vredenburgite as the chief manganese ore minerals, while quartz and altered felspars constituted the non-metallic gangue. Chemical analysis of the sample indicated that the ore was siliceous and high in phosphorous.

High intensity magnetic separation tests conducted with −20 mesh deslimed feed produced a magnetic concentrate assaying 42.2% Mn with 86.4% Mn distribution in it. Jigging test with −6 mm +20 mesh, and tabling with sized feed of −20 mesh from the sample crushed to 5 mm size, produced a jig concentrate assaying 44.78% Mn with 62.9% Mn distribution. The coarser table concentrate analysed 43.77% Mn with 4.8% Mn distribution. The medium and finer table concentrates analysed only 39.3% Mn and 39.4% Mn respectively. The combined jig and coarse table concentrate analysed 44.79% Mn with 67.7% Mn distribution.

Tabling tests with sized feed ground to −14 mesh −28 mesh and −35 mesh yielded concentrates respectively analysing 44.82% Mn with 65.3% Mn distribution, 45.02% Mn with 62.2% Mn distribution and 45.01% Mn with 58.6% Mn distribution. Phosphorous content of the magnetic and gravity concentrate varied from 0.37% to 0.28%. Attempts to reduce the same by flotation were not fruitful.

(ii) Bed Ore from Koduru Mines

The sample was received from M/s. R. B. Seth Sri Ram Durgaprasad and Fatechand Narsingdas, Chipurupalli, and consisted of lumps from 25 mm to 30 mm in size. Complete chemical analysis of the sample was as follows:

Constituent	*Assay%*
Mn	33.49
Fe	13.92
SiO_2	8.45
Al_2O_3	7.45
P	0.29
Ba	2.34
LOI	11.60

Microscopic examination indicated the presence of psilomelane as the chief ore mineral followed by minor amounts of pyrolusite, braunite and vredenburgite. Ferruginous clay, quartz, kaolin, calcite, limonite, and garnet formed the non-metallic gangue.

Jigging tests with −4+14 mesh sized ore from the ground sample yielded a concentrate analysing 45.06% Mn with 54.5% Mn distribution. Tabling tests with the sized −14 mesh feed produced a combined concentrate analysing 41.11% Mn with 17.6% Mn distribution. The combined jig and table concentrates analysed 44.03% Mn and 10.96% Fe with 72.1% Mn distribution in it. Reduction roast followed by magnetic separation with the combined concentrate at 35 mesh size produced a feebly magnetic Mn concentrate assaying 56.01% Mn, 5.69 Fe with 60.0% Mn distribution.

Tabling tests alone with −10 mesh sized feed produced a combined concentrate assaying 44.82% Mn with 62.5% Mn distribution. However it was observed that the coarser table concentrate analysed 45.2% Mn and 10.38% Fe.

Magnetic separation tests conducted with deslimed feed ground to 10, 20, 35 and 48 mesh size yielded magnetic concentrates varying in analysis from 37.56% Mn to 40.40% Mn. Phosphorous content of the concentrates was almost the same in all of them.

Reduction roast with −10 mesh sample followed by magnetic separation after grinding to 35 mesh size yielded (after removing the highly magnetic portion) a feebly magnetic concentrate assaying 49.29% Mn with only 50.8% Mn distribution. Although the grade was higher the recovery was poor. Similar tests conducted with washed −10 mesh sample yielded a feebly magnetic concentrate assaying 52.87% Mn, 5.68% Fe and 0.26% P with 66.6% Mn distribution.

Reduction roast tests with −4 mesh sample after screening out the −48 mesh fines which contained higher silica followed by magnetic separation at 35 mesh size yielded a feebly magnetic concentrate analysing 50.25% Mn, 6.30% Fe and 0.25% P with 65.3% Mn distribution in it. Flotation test to reduce the phosphorous content of the ore proved to be unsuccessful.

(iii) Manganese Ore from Chipurupalli

The sample was received from M/s. Gourisankar Mining Co., Chipurupalli, and consisted of 50 mm lumps down to fines. The sample analysed as follows :

Constituent	*Assay%*
Mn	25.82
Fe	10.89
SiO_2	25.16
P	0.13

Mineralogical examination of the sample revealed the presence of psilomelane and wad with quartz, limonite, garnet (spessartite) and gypsum. Garnet was found to be seggregated in the −20 mesh portions only.

Jigging tests at 6 mesh size with washed feed from which −20 mesh fines were removed, produced a concentrate assaying 47.9% Mn with 59.2% Mn distribution.

Jigging, tabling and electrostatic separation tests were conducted with the sized −14 mesh feed. The jig concentrate obtained with −14+28 mesh portion analysed 47.24% Mn, 8.37% Fe and 0.17% P with 45.8% Mn distribution. The −28 mesh fines were sized and then treated on shaking tables and the table concentrates were treated in electrostatic separator. The concentrate obtained from tabling followed by electrostatic separation analysed 46.78% Mn, 8.70 Fe and 0.17% P with 23.7% Mn distribution. The combined jig concentrate analysed 47.08% Mn with 69.5% Mn distribution.

Tabling tests with $-3\frac{1}{2}+20$ mesh after grinding to 14 mesh yielded a concentrate assaying 46.67% Mn, 7.39% Fe and 0.16% P with 59.3% Mn distribution.

Tests with the −14 mesh sized feed, followed by electrostatic separation of the table concentrate yielded a combined concentrate analysing 46.99% Mn and 8.35% Fe with 70.0% Mn distribution. Simple calcination of the gravity concentrate at 900°C by which MnO_2 will convert into Mn_3O_4 had improved the grade from 44.73% Mn and 43.07% Mn to 51.86% Mn and 49.50% Mn respectively.

Reduction roast of the $-3\frac{1}{2}$ mesh deslimed ore followed by grinding to 35 mesh and magnetic separation, yielded a feebly magnetic concentrate assaying 49.99% Mn, 7.88% Fe and 0.17% P with 68.9% Mn distribution. Similar tests with $-3\frac{1}{2}+20$ mesh portion produced a concentrate assaying 50.47% Mn, 8.37% Fe and

0.17% P with 70.6% Mn distribution. Reduction roast followed by magnetic separation tests with −14 mesh table tailings further yielded a concentrate assaying 51.49% Mn with an additional recovery of 9.9% Mn.

(iv) Manganese Ore from Marrivalasa—Salur

The sample was received from M/s. Devidayal (Sales) Ltd., Bombay, and was drawn from mines located at Marrivalasa, Salur, Srikakulam Dist. The ore consisted of 50 to 60 mm lumps and analysed as follows:

Constituents	*Assay%*
Mn	28.63
SiO_2	18.44
Fe	12.68
Al_2O_3	6.19
P	0.20
BaO	0.62
LOI at 400°C	8.25

Microscopic examination of the sample indicated the presence of psilomelane, pyrolusite, in association with quartz, garnet and ochre (limonite). Most of the garnet was seggregated in −35 mesh fines. Chemical analysis of the sample warrants the reduction of SiO_2, Fe & P contents of the ore in order to use it in the metallurgical industry.

As the garnet was concentrated more in the −35 mesh fines, the ore was crushed to 6 mm size and the −35 mesh fines were screened out. The +35 mesh portion was treated in mineral jig and the jig concentrate analysed 40.42% Mn, 10.02% Fe and 0.29% P with 60.5% Mn distribution in it. When the jig tails were ground to −35 mesh and treated on shaking tables after desliming, the table concentrate analysed 33.34% Mn with an additional 14.5% Mn distribution.

In another test the representative −4 mesh portion was screened on 28 mesh screen and +28 mesh portion was treated on tables. The table concentrate analysed 37.70% Mn with 59.4% Mn distribution. The −28 mesh portion after grinding to −65 mesh size was treated on tables. The table concentrate analysed 37.70% Mn with 59.4% Mn distribution. The −28 mesh portion after grinding to −65 mesh size was floated for the separation of garnet with 7.0 kg/tonne of H_2So_4 and 1.0 kg/tonne of Amine. Although the garnet floated well, quartz did not float well. So the flotation pulp was treated on shaking table. The table concentrate analysed 37.69% Mn with 3.8% Mn distribution in it. As the gravity methods did not yield good grade of concentrates, further tests were conducted with reduction roast followed by size reduction and magnetic separation.

The −4 mesh sample was roasted at 550°C in a reducing atmosphere provided by the cokeoven gas. The reduced ore was ground to −20 mesh size deslimed and subjected to magnetic separation. After discarding the two highly magnetic portions, the feebly magnetic concentrate was obtained which analysed 47.10% Mn, 6.9% Fe and 0.2% P with 64.2% Mn distribution in it. Similar test conducted with a sample from which −35 mesh fines, containing the garnet was discarded. The reduced ore was ground, deslimed and four highly magnetic portions were removed before collecting two feebly magnetic portions. The combined feebly magnetic concentrates analysed 50.1% Mn, 6.29% Fe and 0.21% P with 47.7% Mn distribution. When the 4th magnetic concentrate assaying 43.88% Mn was also combined with the Mn concentrates, the product analysed 48.18% Mn, 8.73% Fe, and 0.24% P with 71.6% Mn distribution in it.

Test results indicated that although 48% Mn grade concentrates were produced from the sample, phosphorus could not be possibly brought down due to the intimate association of garnet with the minerals, which contribute both P & SiO_2 to the concentrates.

(v) Manganese Ore from Kodur Mine Dumps

The sample was received from M/s. Rai Bahadur Shreeram & Co. (Pvt.) Ltd., to conduct tests as per the flowsheet given by them. The test sample was all −25 mm size and contained 42.6% of −1 mm fines. Complete chemical analysis of the sample was as follows:

Constituent	*Assay%*
Mn	24.3
Fe	12.9
SiO_2	17.9
Al_2O_3	10.5
P	0.27
Ba	0.95
CaO	0.27

Examination of the sized sieve fractions indicated the presence of quartz, weathered felspars and limonite. Garnet was found seggregated in the −1 mm fines.

The ROM ore was crushed to 12 mm size, washed for the removal of the limonitic matter. Jigging tests with the washed −12 mm +16 mesh after close sizing to 4 sizes produced a combined concentrate analysing 44.1% Mn and 10.9% Fe with 42.5% Mn distribution. The −16 mesh fines were tabled after sizing produced a combined concentrate assaying 38.02% Mn with 20.8% Mn distribution. When the jig and table concentrates were combined, the product analysed 43.1% Mn, 9.8% Fe and 0.24% P with a total recovery of 63.3% Mn in it.

The gravity concentrates were ground to 35 mesh size and treated in high intensity magnetic separator with a view to improve the grade. After removing the highly magnetic portions. the feebly magnetic portion analysed 44.7% Mn, 9.1% Fe and 0.2% P wherein the Fe : Mn ratio has improved from 4.3 to 4.9. Flotation tests to separate the apatite from the manganese ore helped in reducing the P analysis from 0.25% to 0.20% only.

Heavy media separation tests with −12 mm +16 mesh sized portions produced concentrates (sink at Sp. gr. 3.0) varying in Mn content from 43.5 to 45.8% and the combined concentrate analysed 43.7% Mn and 10.9% Fe with 51.5% Mn distribution. Treatment of the −16 mesh fines on table produced a concentrate assaying 40.5% Mn.

Reduction roast at 550°C with coke-oven gas with −3+8 mesh portion followed by grinding to 35 mesh size and magnetic separation produced a feebly magnetic Mn concentrate (after removing the highly magnetic portion) assaying 47.3% Mn, and 6.6% Fe with 50.7% Mn distribution in it.

Tests conducted with −3 mesh deslimed feed, produced a Mn concentrate analysing 46.3% Mn and 6.2% Fe with 55.6% Mn distribution From the overall test results it was concluded that gravity methods do not help in producing a concentrate with 1 : 7 Fe/Mn ratio and P cannot be reduced below 0.2% level.

B. MANGANESE ORES FROM ORISSA

(i) Tisco Manganese Ore

A low grade ferruginous manganese ore drawn from their mines in Orissa was received from M/s. Tata Iron & Steel Co. Ltd., for the reduction of Silica, Alumina and Iron contents by washing and magnetising reduction roast process. The sample in its as received state analysed as follows :

Constituent	*Assay%*
Mn	26.8
Fe	28.8
Al_2O_3	6.5
SiO_2	6.64
P	0.11

Mineralogical examination indicated the presence of pyrolusite and psilomelane as the chief Mn minerals. Small quantities of clay and quartz were also observed in the ore. Chemical analysis of the closely sized products indicated that bulk of the silica and alumina were seggregated in the finer fractions.

Washing tests were conducted with ROM, 12 mm, 3 mesh and 6 mesh ground samples. Best results were obtained at −3 mesh size. The slimes analysed 11.0% Mn, 17.5% Al_2O_3 and 25.06% SiO_2 with 5.8%, 36.5% and 52.3% distributions respectively. Washing test with −3 mesh with the rejection of −28 mesh material after crushing only produced a concentrate assaying 27.2% Mn, 32.0% Fe with 80.7% Mn and 79.5% Fe distribution in it. The combined slimes and −10 mesh fines analysed 12.7% Al_2O_3 and 23.4% SiO_2 with 38% Al_2O_3 & 64.2% SiO_2 distribution in it.

A series of experiments conducted to determine the optimum conditions for the reduction roast and magnetic separation indicated that washed ore ground to −3 mesh for reduction, and −10 mesh grind for magnetic separation were optimum wherein the concentrate analysed 58.1% Mn. 4.54% Fe with 57.9% Mn distribution in it.

(ii) Sagur Manganese Ore

The sample was received from M/s. Mitra (India) Calcutta and was composed of lumps below 75 mm size. It had the following analysis :

Constituent	*Assay%*
Mn	29.06
Fe	17.98
SiO_2	1.78
Al_2O_3	14.40
P	0.05

As the sample was basically ferruginous in nature, washing and reduction roast followed by magnetic separation methods were tried. The sample was washed and then roasted in reducing atmosphere at 550°C and after grinding to 35 mesh size, it was subjected to magnetic separation. After removing the highly magnetic portion the non-magnetic portion analysed 46.92% Mn, 12.71% Fe and 0.073% P with 52.1% Mn distribution in it.

Similar tests with a finer feed yielded a magnetic concentrate assaying 48.98% Mn and 6.68% Fe with 31.8% Mn distribution. Reduction tests conducted at 560°C and followed by grinding to 20' mesh and magnetic separation yielded a concentrate assaying 48.89% Mn, 7.15% Fe and 0.095% P with only 34.0% Mn distribution. The P content was found increasing with the grade of the Mn content.

(iii) Barajamda Ore

The sample was received from M/s. Kharaswan Minerals Concerns Ltd., for the reduction of silica content. The ore was naturally low in iron content and analysed as follows :

Constituent	*Assay%*
Mn	35.7
Fe	9.2
SiO_2	26.2
Al_2O_3	3.7
P	0.038

The sample was stage crushed to −10 mesh size and then sized to −10+20, −20+48, and −48 mesh size and were treated separately on shaking tables. The respective concentrates analysed 48.0%, 44.02% and 48.97% Mn. The combined concentrates analysed 47.07% Mn, 6.07% Fe with 66.7% Mn distribution in it. The grade of the concentrate was quite suitable for marketing.

(iv) Silijora Manganese Ore

The sample drawn from Siljora Kalimati Manganese Mines, Siljora, Keonjhar Dist., Orissa was received from M/s. Rungta & Sons., Calcutta. The Ore consisted of 75 mm lumps and analysed as follows :

Constituent	*Assay%*
Mn	37.55
MnO_2	56.52
Fe	12.46
SiO_2	7.56
Al_2O_3	6.45
Ba	0.58
P	0.086
CaO & MgO	Trace
LOI at 350°C	4.16

Microscopic examination of the sample revealed the presence of psilomelane, pyrolusite, magnetite and hydroxides of Fe, i.e. goethite, limonite and minor amounts of hematite formed the ferruginous gangue minerals along with minor amounts of quartz. Manganese minerals were liberated from iron minerals at −10 mesh and from the siliceous minerals at 28 mesh size.

Direct magnetic separation with deslimed −20 mesh size after removing the highly magnetic product, produced a feebly magnetic concentrate assaying 41.77% Mn and 12.99% Fe with 99.0% Mn distribution.

Reduction roast at 500°C to 550°C with −3 mesh material followed by grinding to 28 mesh size and magnetic separation after removing highly magnetic portion, yielded a feebly magnetic, concentrate assaying 55.16% Mn, 3.17% Fe, 0.012% P and 15.28% $SiO_2+Al_2O_3$ with 70.1% Mn distribution in it. When this concentrate was combined with the 4th magnetic concentrate the product analysed 53.16% Mn, 5.59% Fe, 0.011% P and 14.54% $SiO_2+Al_2O_3$, with 85.6% Mn distribution . Although the $Al_2O_3+SiO_2$ content of the sample was high, the Mn/Fe ratio was good and may be used in the metallurgical industry. Similar tests with washed ore did not improve the grades or recoveries.

(v) Manganese ore from Sambalpur

The sample was drawn from Rairakhot mines and was received from M/s. Narsingdas Fathe-

chand Mor, Sambalpur — Orissa. The ore in its as received state consisted of 25 to 35 mm lumps without fines and had the following analysis :

Constituent	*Assay%*
Mn	38.53
Fe	17.50
MnO_2	52.20
Al_2O_3	5.02
SiO_2	3.83
BaO	4.03
P	0.35

The sample was rich in iron & phosphorous contents. Microscopic examination revealed the presence of pyrolusite, psilomelane and little braunite. The gangue minerals were magnetite, goethite and hematite and small quantities of quartz and garnet. The gangue minerals were liberated at 65 mesh size.

Magnetic separation at 35 mesh size produced a non-magnetic concentrate assaying 42.4% Mn, 10.9% Fe with 74.9% Mn distribution. Another test was conducted with ROM sample. The highly magnetic lumps were separated by hand magnet and were ground to 35 mesh size and the highly magnetic portion was removed. The non magnetic lumps were reduced to 3 mesh size and then subjected to reduction roast followed by magnetic separation at 65 mesh size. The non-magnetic portion analysed 54.3% Mn and 5.07% Fe. The combined non-magnetic concentrates analysed 50.1% Mn and 7.6% Fe with 70.8% Mn distribution in it.

Reduction roast with −6 mesh material followed by magnetic separation at −35 mesh size yielded after removing the highly magnetic portion, the combined feebly magnetic and non-magnetic portions analysing 57.9% Mn and 6.1% Fe (Mn/Fe — 9.5) with 74.5% Mn distribution. By careful adjustment of the magnetic field intensity so as to get Mn/Fe=7.0 ratio the corresponding concentrate would analyse 55.4% Mn with 81.0% Mn distribution.

Flotation tests conducted to reduce the phosphorus content helped to reduce the same to 0.29% only. Apatite and some garnet were removed by flotation and the rest of the phosphorus was in solid solutions with the ore and hence could not be lowered.

(vi) Kuttinga Manganese Ore

The sample was received from M/s. Jeypore Mining Syndicate for beneficiation studies. Complete chemical analysis of the sample was as follows :

Constituent	*Assay%*
Mn	38.9
Fe	10.7
SiO_2	7.8
Al_2O_3	4.9
Ba	1.2
MgO	3.3
CaO	0.19
P	0.35

Mineralogical examination of the sample revealed the presence of pyrolusite followed by psilomelane and braunite in the order of abundance. Goethite was the main gangue mineral followed by limonite, clay, quartz, felspar, mica and garnet. Goethite was liberated at 14 mesh and the rest at 65 mesh size.

Straight magnetic separation tests with deslimed −35 mesh feed, after removing the highly magnetic portion and rejecting the non-magnetic portion, produced a feebly magnetic manganese concentrate assaying 42.1% Mn and 10.8% Fe with 82.0% Mn distribution. Preheating and magnetic separation of the deslimed −10 mesh feed produced a magnetic concentrate assaying 47.6% Mn and 6.0% Fe with 74.8% Mn distribution. It may be seen in this case that the iron minerals turned non-magnetic by heating.

Reduction roast with 3 mesh feed followed by magnetic separation at −10 mesh size, after removing the highly magnetic portion produced a feebly magnetic manganese concentrate assaying 50.8% Mn, 6.2% Fe and 0.31% P with 94.1% Mn distribution in it. Attempts to reduce the phosphorous content of the ore by flotation were not successful.

(vii) Joda West-Manganese Ore

The sample was received from M/s. TISCO Ltd. for batch and semi-pilot plant tests. It had the following analysis :

Constituent	*Assay%*
Mn	27.2
Fe	24.2
SiO_2	7.53
Al_2O_3	7.43
P	0.09
LOI at 950°C	11.09

Mineralogical examination of the sample revealed the presence of pyrolusite in bulk followed by psilomelane, hollandite, braunite and minor amounts of magnetite. Limonite was present as superficial coating while clay and bauxite were present as cavity fillings. Hamatite and magnetite in small amounts were also present.

Washing tests with −25 mm feed after removing the −20 mesh fines improved the grade to 27.5% Mn and 26.2% Fe with 83.3% Mn distribution.

The washed product was subjected to reduction roast and then ground to 10 mesh followed by magnetic separation with −10+20 mesh portion only. After removing the two highly magnetic portions, the combined feebly magnetic and the non-magnetic portions analysed 50.96% Mn and 8.09% Fe with 65.6% Mn distribution in it. However by closely controlling the magnetic field intensity a concentrate having a Mn/Fe ratio 7.0 was produced with 60% Mn distribution in it.

Similar test with −25 mm+20 mesh unwashed feed rejecting the −20 mesh fines produced a concentrate assaying 53.7% Mn with 68.0% Mn distribution having Mn/Fe ratio of 7.0 in it. The ROM ore was reduced to 12.5 mm size and the −20 mesh fines were rejected to lower the SiO_2 and Al_2O_3 contents. The +20 mesh product analysed 28.1% Mn and 24.8% Fe with 89.3% Mn distribution in it.

Washing of the −12.5 mm crushed ore and the treatment of the −20 mesh fines on shaking table for the recovery of Mn ore fines, produced a combined concentrate assaying 28.2% Mn and 25.6% Fe with 86.3% Mn distribution. This product when subjected to reduction roast and followed by magnetic separation at −10 mesh size after removing the two highly magnetic products produced a manganese concentrate composed of feebly magnetic and non-magnetic portions assaying 54.4% Mn and 6.4% Fe with 60.2% Mn distribution in it. By carefully adjusting the magnetic field intensity while removing the second highly magnetic portion a Mn concentrate assaying 52.5% Mn with 7:1 Mn/Fe ratio and having a Mn distribution of 61.8% was expected.

Continuous reduction roast tests were conducted with the washed and unwashed samples at 25 mm and 12.5 mm size lumps after screening out the −20 mesh fines in a vertical reduction kiln provided with electric heaters and all the results were found to be reproducible. Based on the continuous tests detailed flowsheet and equipment list was prepared and submitted to TISCO for a 600 t/day treatment plant. The manganese combined concentrate in this case assayed 51.7% Mn with a recovery of 62.0% Mn for Mn/Fe ratio of 7.0.

(viii) FerruginousManganese Ore from Silijora Kalimati Mines

The sample was received from M/s. Rungta Sons (P) Ltd., for the reduction of iron content. The sample consisted of 100 mm lumps to fines and analysed as follows :

Constituent	*Assay%*
Mn	37.5
MnO_2	55.9
Fe	16.4
SiO_2	1.2
Al_2O_3	9.0
P	0.08
BaO	0.09
CaO	0.08

Mineralogical examination of the sample indicated the presence of bulk of cryptomelane followed by pyrolusite and manganite. Hematite followed by laterite contributed the bulk of iron. Minor amounts of quartz were also present. The ore minerals and gangue were fairly liberated at 4 mesh and were almost completely liberated at 100 mesh size.

Magnetic separation tests with sized −28 mesh feed produced a combined non-magnetic concentrate assaying 44.9% Mn and 11.1% Fe with 67.6% Mn distribution in it.

Low temperature reduction roast followed by magnetic separation at −10 mesh size, after removing the two highly magnetic and non-magnetic portions yielded a combined feebly magnetic

and non-magnetic product analysing 51.9% Mn and 6.8% Fe with 62.7% Mn distribution in it with Mn/Fe ratio of 7.7:1, if the Mn/Fe ratio was maintained at 7:1 ratio, the grade of the concentrate would be 50.6% Mn with 67.0% Mn distribution.

Continuous reduction tests were conducted in a specially designed 200 mm dia vertical furnace fabricated at NML. The furnace was provided with electric heater to initiate the reduction and in-let for the coke oven gas. The reduced ore was collected from the bottom through a water seal. The ore was fed from the top and slowly descends by gravity while the reducing gases flow upwards.

Reduction tests were conducted with ore crushed to −25 mm size, and the magnetic separation was conducted after grinding the ore to different sizes. Two portions of highly magnetic material removed ; the manganese concentrate consisted of feebly magnetic and non-magnetic portions. The best results obtained with reduced feed ground to 65 mesh produced a concentrate assaying 52.6% Mn and 6.96% with 73.3% Mn distribution in it.

As the magnetic separation was conducted at a finer size, size reduction was done in two stages for magnetic separation. The reduced ore was ground to 4 mesh size and subjected to magnetic separation as earlier. The combined concentrate thus obtained analysed 52.3% Mn, 6.7% Fe and 0.087% P with 79.0% Mn distribution in it.

(ix) Rejects from S.G.B.K. Mines-Gurda

The sample was collected from rejects after hand picking the high grade lumps at SGBK Mines, Gurda area and was received from M/s. Sirajuddin & Co. The ore consisted of 50-75 mm lumps and free from fines. Complete analysis of the sample was as follows :

Constituent	*Assay%*
Mn	30.18
MnO_2	39.70
Fe	16.58
SiO_2	17.72
Al_2O_3	4.10
P	0.03
BaO	0.198
CaO	1.10
LOI at 300°C	3.38
LOI at 560°C	7.20

Microscopic examination revealed the presence of bulk of psilomelane followed by wad, pyrolusite and manganite. Goethite followed by hematite and quartz and felspar formed the ferruginous and siliceous gangue respectively. The gangue and manganese minerals were liberated at 100 mesh size.

Dry magnetic separation tests with the ore crushed to −48 mesh and −100 mesh size feed yielded concentrates assaying respectively 35% Mn and 31.8% Mn respectively. Low temperature reduction roast with −3 mesh feed followed by magnetic separation at 100 mesh size after removing the highly magnetic portion in two stages, produced a combined feebly magnetic and non-magnetic. Manganese concentrate assaying 40.1% Mn, 7.97% Fe with 58.7% Mn distribution in it.

When the non-magnetic portion of the test assaying 39.07% Mn, 5.05% Fe and 24.80% SiO_2 was further subjected to high intensity magnetic separation to separate the silicates, the magnetic concentrate analysed 41.58% Mn, 4.6% Fe and 22.4% SiO_2 with only 37.2% Mn distribution in it. In another test the reduced ore was ground to 100 mesh and subjected to single stage magnetic separation after desliming. The non-magnetic portion was treated on shaking table. The table concentrate analysed 56.4% Mn, 6.1% Fe and 11.6% SiO_2 with only 13.7% Mn distribution. Bulk of the Mn was lost in slimes and the magnetic concentrates.

Flotation tests with ROM ore ground to 65 mesh size (76.7% −200 mesh) employing 0.7 kg/tonne of NaOH, 0.5 kg/tonne of starch and 0.25 kg/tonne Armeen and removing the silicates from the ore improved the grade to 35.98% Mn, 18.0% Fe and 7.7% SiO_2 with 69.4% Mn distribution in it. Tests with deslimed feed did not improve any further. Flotation test conducted with the non-magnetic portion of the reduced feed, produced a manganese concentrate (flotation tails) analysing 57.06% Mn, 6.16% Fe and 10.23% SiO_2 with 48.5% Mn distribution in it.

(x) S.G.B.K. Ore (No. 2)

The sample was received from M/s. Serajuddin & Co. from their mines situated near Gurda Village, Keonjhar Dist. The sample consisted of 250 mm lumps down to fines and analysed as follows :

Constituent	*Assay%*
Mn	28.10
Fe	24.90
SiO_2	8.90
Al_2O_3	5.61
BaO	0.13
P	0.145
LOI at 350°C	5.25
LOI at 560°C	9.67
LOI at 900°C	11.47

Mineralogical examination of the sample indicated the presence of pyrolusite, psilomelane and hollandite. Goethite, lateritic material, quartz, ochre, hematite and felspars formed the gangue. Most of the gangue was liberated at 28 mesh size.

Direct magnetic separation tests did not help in reducing the iron content of the ore. When the sample was heated to 400°C and subjected to magnetic separation at 28 mesh size after desliming the magnetic concentrate analysed 43.8% Mn and 16.0% Fe with 69.4% Mn distribution.

When the sample was heated to 600°C, before separation, the concentrate analysed 48.0% Mn and 16.1% Fe with 76.2% Mn distribution in it.

Reduction roast followed by magnetic separation at 28 mesh size, yielded a non-magnetic product assaying 56.5% Mn, 6.0% Fe and 12.0% SiO_2 with 48.4% Mn distribution. Similar test with washed ore, yielded a concentrate assaying 58.5% Mn, 8.5% Fe, 7.4% SiO_2 and 0.141% P with 58.5% Mn distribution in it.

(xi) Lohandabad Manganese Ore

Three different samples of low grade manganese ore were received from M/s. Shivaji Nabhubhai. The samples consisted of 150 mm lumps to fines. The three samples were mixed in the proportion they were received and the mixed sample analysed as follows :

Constituent	*Assay%*
Mn	40.02
MnO_2	34.71
Fe	4.82
SiO_2	19.34
Al_2O_3	3.80
CaO	1.10
BaO	3.32
MgO	0.69
P	0.18

The sample was siliceous and phosphatic in nature. Mineralogical examination of the ore indicated the presence of braunite and psilomelane followed by hausumanite, pyrolusite, jacobsite, hollandite, sitaparite and vredenburgite. Quartz, garnet and pyroxenes formed the siliceous gangue followed by amphibole, barite, biotite, and felspar.

Tabling tests with −35 mesh sized feed yielded a combined concentrate assaying 40.9% Mn with 71.6% Mn distribution in it.

Electrostatic separation tests with sized −35 mesh and −65 mesh feeds produced concentrates respectively analysing 44.2% Mn and 10.3% SiO_2 with 57.0% Mn distribution and 43.1% Mn and 12.2% SiO_2 with 60.7% Mn distribution in them.

High intensity magnetic separation produced a magnetic concentrate assaying 42.6% Mn with 86.3% Mn distribution in it. Further treatment of the same in electrostatic separation improved the grade to 45.2% Mn and 9.7% SiO_2 with 63.4% Mn distribution. Anionic and cationic flotation tests did not produce any satisfactory results.

(xii) Ferruginous Ore from Koira

The sample was received from M/s. Orissa Manganese and Minerals Ltd., Koira, containing 125 mm lumps down to fines. Complete chemical analysis of the ore was as follows :

Constituent	*Assay%*
Mn	31.48
MnO_2	45.81
Fe	22.06
SiO_2	3.90
Al_2O_3	5.50
P	0.09
BaO	0.52
LOI at 350°C	4.60
LOI at 560°C	8.76
LOI at 950°C	13.24

Microscopic examination revealed the presence of pyrolusite, cryptomelane and psilomelane, manganite and wad. Goethite, hematite and quartz formed the gangue. The manganese minerals were liberated at a size below 28 mesh. Reduction roast followed by magnetic separation at −3 mesh size after removing all the magnetic portions, produced a non-magnetic concentrate assaying 55.9% Mn, 7.25% Fe with 55.1% Mn distribution in it. Similar test when the magnetic separation was conducted at −35 mesh size yielded a non-magnetic concentrate assaying 54.26% Mn and 7.5% Fe with 67.0% Mn distribution in it.

Low intensity wet magnetic separation at −3 mesh with reduced ore followed by demagnetizing and grinding to 100 mesh size, and magnetic separation removing all the magnetic portions produced a combined non-magnetic concentrate assaying 53.40% Mn and 7.4% Fe with 71.4% Mn distribution in it.

Pilot plant tests conducted in a 200 mm dia vertical reduction furnace equipped with electric heaters and counter current flow of ore and gas with −4 mesh material and wet magnetic separation produced a non-magnetic concentrate assaying 49.4% Mn, 6.89% Fe with 61.6% Mn distribution in it. Further attempts to recover the manganese minerals from the magnetic product after grinding were not successful. Similar test with dry magnetic separator produced a concentrate analysing 48.43% Mn and 6.74% Fe with 60.3% Mn distribution.

(xiii) Siliceous Ore from Orahuri Mines-Koira

The sample consisted of 100 mm lumps to fines and analysed as follows :

Constituent	*Assay%*
Mn	36.70
SiO_2	31.05
Fe	3.00
Al_2O_3	2.52
BaO	0.50
MnO_2	55.55

Mineralogical examination revealed that psilomelane, cryptomelane followed by pyrolusite formed the manganese minerals. Quartz, felspars and goethite formed the gangue. Gangue was liberated at 20 mesh size.

Tabling tests with −20 mesh sized feed yielded a combined concentrate analysing 51.5% Mn with 51.78% Mn distribution in it. High intensity magnetic separation tests produced a magnetic concentrate assaying 52.70% Mn, 3.65% Fe and 4.10% insolubles with 79.4% Mn distribution in it.

Large scale high intensity magnetic separation tests with −20 mesh feed after desliming and sizing on 48 mesh screen produced a coarse concentrate assaying 51.92% Mn, and finer concentrate assaying 53.09% Mn. The combined concentrate assayed 52.3% Mn, 3.45% Fe and 4.15% insolubles with 80.6% Mn distribution in it. Flotation of the slimes using cationic collectors, yielded a concentrate analysing 47.25% Mn, 5.38% Fe and 8.33% insolubles with an additional Mn recovery of 11.7% in it.

(xiv) Sintering of Siljora-Kalimati Ore Fines

The manganese concentrate fines produced (I.R. No. 151/59) by reduction roast followed by magnetic separation analysed as follows

Constituent	*Assay%*
Mn	49.60
Fe	7.90
SiO_2	1.1
Al_2O_3	9.40
P	0.098

The coke breeze used for the sintering analysed as follows :

Constituent	*Assay%*
Fixed carbon	72.7
Volatile matter	2.9
Moisture	0.6
Ash	23.8

Sinter plant consisted of a combustion chamber fitted with a gas burner and seated above the sinter box with a cast iron grate. The sinter box is fitted over a wind box which is connected to the exhaust fan through a pipe over which water is sprayed for cooling. The air suction for the wind box was measured with a water gauge.

The sinter feed was prepared by mixing prepared sinter fines, coke breeze and water in

varying proportions with the concentrate fines. The optimum water and coke breeze requirements were determined to be respectively 10% and 6%. After sintering, the ore was converted to manganous state (MnO) and analysed 53.5% Mn, 8.1% Fe, 3.4% SiO_2, 10.2% Al_2O_3 and 0.11% P.

(xv) Manganase Ores from Keonjhar

The sample was received from M/s. Rungta & Sons., Chaibasa for beneficiations studies at 10 mm size for the utilization of the concentrate in the blast furnace. The sample analysed as follows :

Constituent	*Assay%*
Mn	40.00
MnO_2	58.60
Fe	14.00
SiO_2	4.12
Al_2O_3	5.55
BaO	0.62
P	0.09

Examination of the sample under microscope indicated psilomelane, pyrolusite and cryptomelane were the chief manganese minerals while lepidocrocite, goethite, limonite and hematite formed the iron bearing gangue minerals. Quartz and argilaceous matter formed the non-metallic gangue. Liberation of the gangue from the manganese minerals was expected at 100 mesh size.

Tabling tests with 48 mesh sized feed and magnetic separation tests at 48, 65 and 100 mesh size did not show remarkable reduction in iron content. Reduction roast followed by magnetic separation at 20, 65 and 100 mesh size produced non-magnetic concentrates respectively assaying 52.2% Mn and 10.22% Fe, with 36.2% Mn distribution, 53.6% Mn and 9.9% Fe with 30.0% Mn distribution and 53.25% Mn and 10.5% Fe with 33.3% Mn distribution in them. The Mn/Fe ratio varied from 4.9 : 1.0 to 5.4 : 1.0 whereas the metallurgical grade of manganese ore ratio should have Mn : Fe ratio of 7 : 1.

C. MANGANESE ORES FROM MADHYA PRADESH

(i) Kachidana Ore

The sample was received from the Indian Bureau of Mines and consisted of lumps in size from 12 mm to 125 mm. The sample analysed as follows :

Constituent	*Assay%*
Mn	41.60
SiO_2	14.60
Fe	8.46
P	0.20

Mineralogical examination revealed the presence of braunite, pyrolusite ; Jaspery silica, quartz, garnet etc. formed the non-metallic gangue.

Jigging with −4+28 mesh coarse fines and tabling with −28 mesh fines were conducted. The jig concentrate analysed 51.18% Mn, 6.37% Fe and 6.45% SiO_2 with 60.1% Mn distribution in it. The jig tails were ground to −28 mesh size and treated on shaking tables after combining with the original −28 mesh fines and sizing. The combined table concentrate analysed 43.5% Mn, 7.72% Fe and 13.4% SiO_2 with 22.7% Mn distribution in it. The combined jig and table concentrates analysed 48.9% Mn, 6.28% Fe, 8.64% SiO_2 and 0.19% P with 82.8% Mn distribution in it.

Straight tabling tests with sized −28 mesh feed produced a combined concentrate analysing 47.66% Mn, 7.8% Fe, 8.48% SiO_2 and 0.19% P with 69.3% Mn distribution in it.

High intensity magnetic separation and electrostatic separation tests to separate the garnets from the table concentrates were not successful. Flotation test using anionic and cationic collectors to improve the recovery of manganese minerals were also not successful.

(ii) Mansar Ore

The sample was received from M/s. Central Province manganese ore Co. and analysed as follows :

Constituent	*Assay%*
Mn	32.67
SiO_2	27.48
Fe	10.13
P	0.46

The sample had a high phosphorus content. Microscopic examination revealed the presence of braunite followed by psilomelane and pyrolusite. The gangue minerals were quartz, mica, clay, baryte, apatite and rhodonite.

Jigging tests with −10+28 mesh portions followed by grinding the jig tails to −28 mesh size and tabling along with −28 mesh ROM fines after sizing produced a combined concentrate analysing 45.0% Mn with 75.8% Mn distribution.

Tabling tests with −20 mesh sized feed produced a combined concentrate assaying 45.2% Mn with 68.4% Mn distribution. Similar tests with −48 mesh feed, produced a combined concentrate assaying 47.71% Mn, 12.84% Fe, 12.92% SiO_2 and 0.24% P with 61.7% Mn distribution in it.

Magnetic separation tests with a feed ground to 20 mesh and sized on 48 mesh screen produced a combined magnetic concentrate analysing 42.9% Mn and 0.29% P with 89.1% Mn distribution. Tabling of the magnetic concentrate produced a concentrate assayed 48.9% Mn and 0.14% P with 55.6% Mn distribution. Treatment of the table middlings after grinding produced a table concentrate assaying 47.74% Mn and 0.22% P with an additional 9.6% Mn distribution.

Flotation tests to separate apatite conducted under different conditions were not quite successful. In no case the P content could be reduced below 0.20%. When a manganese concentrate produced by differential flotation of apatite followed by manganese minerals, the product analysed 46.43% Mn and 0.07% P with 43.1% Mn recovery in it. As the grade and recovery were poor, direct flotation was considered not worth practising.

Magnetic separation at −20 mesh size, followed by flotation of the magnetic concentrates using 0.75 kg/tonne of Sod. silicate and 1 : 1 mixture of oleic acid and diesel oil for the separation of apatite in 3 stages, followed by two cleanings produced a concentrate analysing 47.95% Mn, 10.92% Fe, 13.08% SiO_2 and 0.03% P with 54.4% Mn distribution in it.

(iii) Tirodi Ore

The sample was collected from the dumps at Tirodi mines of C.P. Manganese Ore Co. Ltd. The sample consisted 75 mm to 150 mm lumps and analysed as follows :

Constituent	*Assay%*
Mn	27.39
SiO_2	33.40
Fe	7.47
P	0.36

The ore was siliceous with high phosphorus content in it. Jigging tests with −8+14 mesh ground product yielded a concentrate with 41.09% Mn and 23.4% Mn distribution. The jig tails were crushed to 14 mesh and after removing the −28 mesh fines was mixed with the −14+28 mesh portion of the ROM and then treated in jig. The concentrate analysed 38.78% Mn and 8.16% Fe with 20.4% Mn distribution. The combined jig concentrate analysed 39.97% Mn with 47.6% Mn distribution. Treatment of the over-all jig rejects and the −28 mesh ROM fines by high intensity magnetic separation yielded concentrate respectively analysing 38.37% Mn an 35.53% Mn with 10.2% and 14.2% Mn distribution. The combined jig and magnetic concentrate analysed 38.78% Mn, 16.28% SiO_2 and 12.32% Fe with 72.0% Mn distribution in it.

Magnetic separation with −14 mesh sized feed produced a combined concentrate assaying 40.77% Mn, 13.33% Fe, 15.11% SiO_2 and 0.31% P with 60.9% Mn distribution in it. Tabling tests followed by magnetic separation, Magnetic separation followed by flotation and flotation tests did not show any improvement on the grade or rejection of iron content of the sample. Magnetic separation with a feed ground to −20 mesh size followed by electrostatic separation with the magnetic middlings produced a combined concentrate analysing 41.9% Mn, and 0.21% P with 71.8% Mn distribution in it.

(iv) Balaghat Ore

The sample was collected from Netra Mines in Balaghat, Dist ; and was received through Indian Bureau of Mines. The sample in as received state consisted of 65 mm lumps and analysed as follows :

Constituent	*Assay%*
Mn	29.24
MnO	27.99
MnO_2	11.97
SiO_2	31.26

Constituent	*Assay%*
Al_2O_3	2.60
Fe	7.77
CaO	4.30
MgO	2.89
P	0.26
S	0.35
BaO	1.92
LOI at 900°C	1.45

Mineralogical examination indicated the presence of braunite as the chief mineral followed by hematite, jacobsite and hausmanite. Amphiboles and calcite formed the non-metallic gangue. Manganese minerals were well liberated at 48 mesh size.

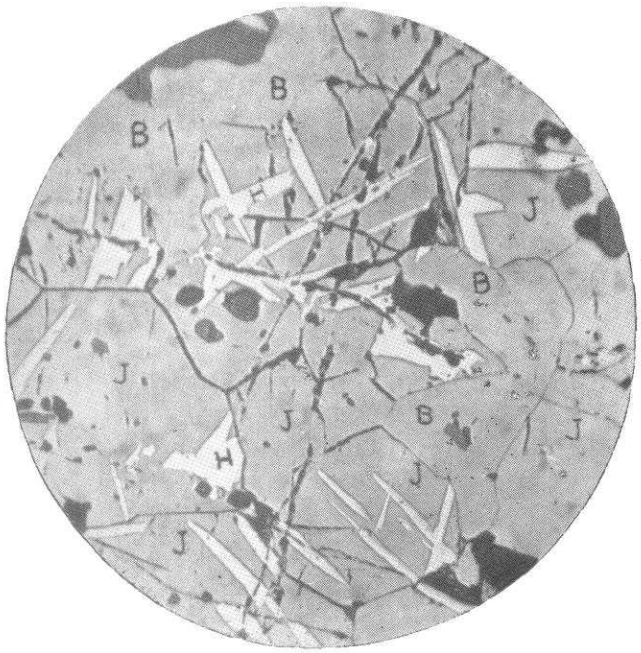


Fig. 3.1 Jacobsite grains (J) containing hematite (H) lameller. The latter end abruptly at the border of Braunite. X112 Reflected Illumination. Manganese ore from Balaghat, Madhya Pradesh, for Bhilai Steel Plant.

Heavy media separation tests at sp.gr. 3.2 with −65 mm +6 mesh sized lumps indicated that the grade of the concentrate (sink product) was poorest at the coarse size and gradually improved as the size decreased. Similar results were obtained when the −6 mesh fines were treated on tables after sizing. Due to the close association of the silicates and the minerals, this method was not successful.

HMS tests with crushed −12.5 mm +6 mesh

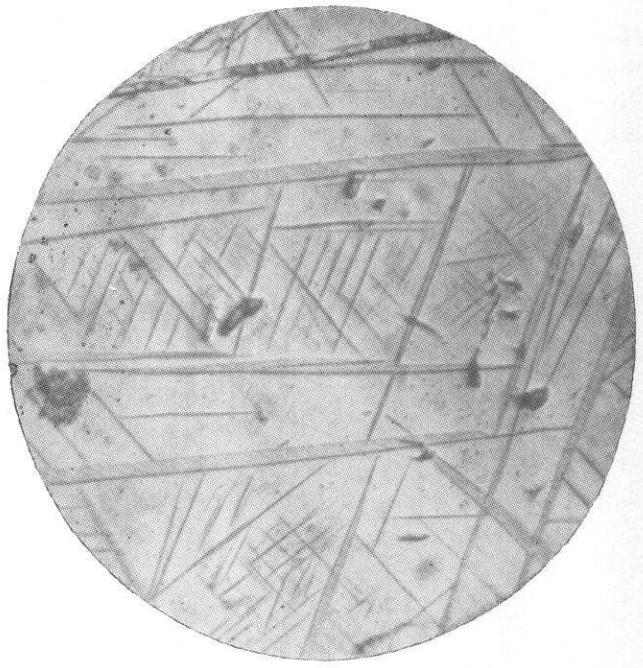


Fig. 3.2 Vredenburgite—Etched with $Sn Cl_2$ for 1 min. (highly magnetic grains). X336 Reflected illumination. Balaghat, Madhya Pradesh (Bhilai Steel Plant).

portion at sp.gr. 2.6 followed 3.2 produced a concentrate (sink) assaying 39.2% Mn and 7.66% Fe with 73.2% Mn distribution. The float obtained at 3.2 was ground to 6 mesh and then combined with the −6 mesh ROM fines analysed 22.5% Mn.

Treatment of the combined −6 mesh product in a jig after sizing produced a combined concentrate assaying 38.31% Mn and 8.46% Fe with an additional 14.4% Mn distribution. The jig middlings were ground to −32 mesh size and tried by magnetic separation and tabling methods. By the magnetic separation method, after rejecting the highly magnetic, feebly magnetic and non-magnetic portions, the medium magnetic portion analysed 41.52% Mn and 7.3% Fe. On similar treatment with the −32 mesh fines of jig concentrate it improved the grade from 35.89% Mn to 49.0% Mn with 4.4% distribution out of 5.6%.

The combined −12.5 mm crushed ore concentrate (HMS + jigging + Mag. Separation) analysed 39.75% Mn with 89.2% Mn distribution in it.

Direct magnetic separation of the combined ROM and HMS middling −6 mesh fines produced a magnetic concentrate after rejecting the highly magnetic portion, assaying 38.92% Mn and 8.14% Fe with 14.2% Mn distribution.

Tabling of the combined −6 mesh product produced a concentrate assaying 35% Mn 7.89% Fe with 12.0% Mn distribution.

The sample was crushed to 3 mesh and then sized on 6 mesh. The coarser portion when subjected to HMS tests at sp.gr. 3.2 yielded a sink product assaying 40.74% Mn. But due to the larger amount of fines, and the grade being on the lower limit, this method was further worked.

Combined jigging and flotation test were conducted with the ROM sample after crushing to −3 mesh size and sizing on 8 mesh and 26 mesh screens. The −3+8 mesh product on jigging yielded a concentrate assaying 40.62% Mn and 8.57% Fe with 30.2% Mn distribution. The middlings of this treatment were ground to −8 mesh size and then sized on 20 mesh screen. The −8+20 mesh portion was treated on jigs and the concentrate analysed 40.29% Mn and 9.53% Fe with 12.6% Mn distribution in it. The jig middlings were in turn crushed to −20 mesh size and all the −20 mesh fines (ROM+coarse and fine jig middlings) were treated on shaking tables after sizing.

The coarse concentrate analysed 42.58% Mn, the medium concentrate analysed 44.92% Mn and the fines concentrate analysed 48.48% Mn. All the table middlings when combined analysed 37.43% Mn and on magnetic separation yielded medium magnetic concentrate assaying 43.7% Mn.

The combined jig, table and magnetic concentrates analysed 42.04% Mn with 75.3% Mn distribution in it.

Direct tabling, tests with −48 mesh sized feed produced a combined concentrate assaying 48.66% Mn with 41.0% Mn distribution in it. The table combined middlings on magnetic treatment produced a medium magnetic concentrate assaying 45.82% Mn with an additional 20.8% Mn distribution in it. The combined table and magnetic concentrates analysed 47.71% Mn, and 10.40%. Fe with 61.8% Mn distribution in it.

(v) Miragpur Ore

The sample was received from Sri R. B. Seth Gopikisan Agarwal, Tumsar, and consisted of 75 mm lumps to fines. Complete chemical analysis of the sample was as follows:

Constituent	*Assay%*
Mn	35.45
Fe	8.19
SiO_2	19.72
Al_2O_3	8.51
P	0.098
Ca	2.30
Ba	2.08
MnO_2	27.63
LOI at 400°C	3.42
LOI at 800°C	6.32

Examination of the samples under microscope revealed the presence of braunite and psilomelane. Garnet, hematite and quartz formed the gangue minerals. Vredenburgite, rhodonite, amphiboles, microcline and clay were also observed in small quantities.

Flotation tests with a feed ground to 45% −200 mesh using 2.2 kg/tonne of Amine to float the silicates and garnets produced a tailing (Mn concentrate) assaying 40.78% Mn, 7.50% Fe and 0.98% P with 30.8% Mn distribution.

Flotation with cocoamine acetate of Armac & Co. followed by high intensity magnetic separation, produced a feebly magnetic concentrate assaying 41.39% Mn, 8.05% Fe and 0.095% P with 39.6% Mn distribution in it.

Electrostatic separation tests with a closely sized 65 mesh feed yielded a combined concentrate assaying 39.85% Mn, 7.42% Fe and 0.088% P with 40.3% Mn distribution in it.

Reduction roast followed by magnetic separation at −48 mesh size produced a feebly magnetic product (4th product) assaying 43.06% Mn, 6.02% Fe with 56.6% Mn distribution in it. When a slightly stronger magnetic portion which was removed before this product (3rd product) was combined with 4th product, the combined sample analysed 42.05% Mn, 7.1% Fe with 78.6% Mn distribution in it with a slightly lower Mn/Fe ratio.

Similar test with −65 mesh feed after removing 4 magnetic portions produced a 5th (feebly) magnetic concentrate assaying 41.99% Mn and 5.04% Fe with 41.0% Mn distribution. When the 4th magnetic product was also combined, the concentrate analysed 41.78% Mn, and 5.9% Fe with 60.9% Mn distribution in it.

Reduction roast and magnetic separation with −65 mesh material followed by the electrostatic separation of the sized feebly magnetic manganese concentrate, produced a combined concentrate assaying 46.23% Mn, 6.6% Fe and 0.10% P with only 30% Mn distribution and a Mn/Fe ratio of 7.0.

(vi) Jhabua Ore

The sample was received from M/s. Thakurlal Shivprakash Poddar drawn from their Rambhapur mine and consisted of 50 to 75 mm lumps. The sample analysed as follows :

Constituent	*Assay%*
Mn	28.80
MnO_2	32.74
SiO_2	22.38
Al_2O_3	2.37
Fe	5.90
P	0.19
CaO	10.73
BaO	2.45
LOI at 900°C	11.77

Examination of the sample under microscope revealed the presence of braunite, psilomelane and pyrolusite which formed the ore minerals. Quartz, calcite and iron oxides formed the gangue.

H.M.S. tests conducted with the sized −25 mm ore at sp.gr. 3.0 produced a concentrate assaying 39.75% Mn with 49.8% Mn distribution in it. Combined jigging and tabling tests with sized −4 mesh feed produced a combined concentrate assaying 41.88% Mn, 9.93% Fe and 10.92% SiO_2 with 75.5% Mn distribution in it. When the combined jig table concentrate was subjected to reduction roast followed by magnetic separation at −4 mesh size, the non-magnetic products analysed 47.57% Mn, 6.16% Fe and 11.84% SiO_2 with 53.8% Mn distribution in it. Similar test with −10 mesh feed produced a concentrate assaying 48.89% Mn, 5 6% Fe, and 12.12% SiO_2 with 57.7% Mn distribution in it.

Direct tabling tests with sized −20 mesh feed produced a combined concentrate assaying 40.67% Mn, 9.9% Fe and 11.7% SiO_2 with 65% Mn distribution.

High intensity magnetic separation with a sized −10 mesh feed produced a magnetic concentrate assaying 40.5% Mn with 86.4% Mn distribution in it. This product when subjected to reduction roast and magnetic separation, the non-magnetic manganese concentrate analysed 47.0% Mn, 5.3% Fe, 11.9% SiO_2 and 0.2% P with 59.7% Mn distribution in it.

Straight reduction roast and magnetic separation with −10 mesh feed produced a concentrate assaying 40.0% Mn and 4.2% SiO_2 with 62.7% Mn distribution.

(vii) Kuno-Madai Ore

The sample was received from M/s. Karnidanji Dhadiwal, Nagpur and consisted of 25 mm lumps. Complete chemical analysis of the sample was as follows :

Constituent	*Assay%*
Mn	33.5
Fe	9.6
SiO_2	19 6
Al_2O_3	5.8
P	0.175
CaO	1.26
MgO	1.42

Mineralogical examination revealed the presence of psilomelane, pyrolusite and braunite and the gangue composed of hematite, quartz, felspar, and calcite. Ore minerals and gangue minerals were very finely interlocked.

Both anionic and cationic flotation tests for the separation of manganese minerals from the non-metallic gangue did not help in separation.

Reduction roast followed by magnetic separation at 65 mesh size produced a feebly magnetic manganese concentrate assaying 40.9% Mn with 68.5% Mn distribution in it. Flotation tests to reduce the silica content were not successful.

D. MANGANESE ORES FROM KARNATAKA

(i) Nagri-Joida Ore

The sample was received from M/s. Lalbhai Patel & Co. Bombay, consisting of 100 mm lumps to 25 mm lumps. Complete analysis of the sample was as follows :

Constituent	*Assay%*
Mn	34.71
Fe	18.49
P	0.03
SiO_2	3.93
Al_2O_3	6.70
Ba	Trace
LOI at 350°C	4.56
LOI at 560°C	8.78

The sample chiefly consisted of psilomelane with small amount of pyrolusite; limonitic ocher, laterite, magnetite and quartz formed the gangue.

Direct magnetic separation at 35 mesh size, after discarding the highly magnetic and non-magnetic portions, yielded a concentrate assaying 39.39% Mn and 14.32% Fe with 68.1% Mn distribution in it. Similar tests with a pre-heated product at 400°C after discarding the highly magnetic and non-magnetic portion, produced a manganese concentrate assaying 44.71% Mn and 9.24% Fe with 61.6% Mn distribution in it.

Reduction roast followed by magnetic separation with 20 mesh feed, after discarding the two highly magnetic portions, yielded a combined feebly magnetic and non-magnetic concentrates analysing 54.99% Mn, and 6.68% Fe with 80 2% Mn distribution in it. Similar test conducted with 35 mesh feed yielded a concentrate analysing 57.36% Mn and 5.91% Fe and 0.062% P with 81.2% Mn distribution in it.

(ii) Sandur Ore

The sample was received from M/s. Sandur Manganese and Iron Ores Ltd. and composed of 75 mm lumps. Complete chemical analysis of the same was as follows:

Constituent	*Assay%*
Mn	30.18
Fe	21.90
SiO_2	0.99
Al_2O_3	12.40
P	0.03

The sample was rich in iron with very low silica and phosphorous contents. Examination of the sample under microscope revealed the presence of psilomelane and pyrolusite. Ferruginous ochre contributed the iron in the ore and small amounts of magnetite were also observed.

Magnetic separation test conducted with 100 mesh sample reduced the Fe content from 21.8% to 18.38% and improving the Mn content to 31.46%. Reduction roast followed by magnetic separation at 100 mesh with unwashed ore after removing all the magnetic portions yielded a concentrate analysing 47.2% Mn, and 10.32% Fe with 46.2% Mn distribution in it. Similar test with a washed ore yielded a concentrate analysing 54.4% Mn and 7.29% Fe with only 33.7% Mn distribution.

(iii) Shimoga Ore

The sample was drawn from K. B. Mines of M/s. S. Lal & Co. The ore consisted of 25 mm to 75 mm lumps with little fines and had the following analysis:

Constituent	*Assay%*
Mn	37.9
MnO_2	46.7
Fe	8 2
SiO_2	20 6
Al_2O_3	2 9
P	0.071
BaO	0.19

Mineralogical examination of the sample indicated the presence of pyrolusite as chief mineral followed by psilomelane and braunite. Quartz and goethite formed the bulk of the gangue followed by pyroxenes and ochre.

Flotation tests using NaOH & Sod. Silicate to depress the silicate gangue, produced a concentrate assaying 45.8% Mn, 9.0% Fe and 12.8% SiO_2 with 74.6% Mn distribution in it. Attempts to float off the silicates using starch and amine produced a manganese concentrate assaying 47.7% Mn, 10.1% Fe and 7.1% SiO_2 with 71.6% Mn distribution in it.

Magnetic separation tests with sized 65 mesh feed, preheated to 400°C, produced a magnetic conc. assaying 45.6% Mn, 8.4% Fe and 12.3% SiO_2 with 59 2% Mn distribution in it. Similar test with 48 mesh sample yielded a concentrate assaying 47.1% Mn, 7.19% Fe and 9.8% SiO_2

with 50.9% Mn distribution, when the 48 mesh sample was pre-heated to 600°C, before magnetic separation, the concentrate analysed 49.3% Mn, 6.7% Fe and 12.0% SiO_2 with 61.1% Mn distribution in it. Cationic flotation of the slimes yielded a concentrate assaying 48.1% Mn, 8.8% Fe and 6.6% SiO_2 with an additional 24.1% Mn distribution. The combined magnetic and flotation concentrates analysed 49.0% Mn, 7.3% Fe and 10.4% SiO_2 with 85.2% Mn distribution in them.

Reduction roast followed by magnetic separation at 20 mesh size after removing two highly magnetic portions, produced combined feebly magnetic and non-magnetic concentrate assaying 46.8% Mn and 4.2% Fe with 84.5% Mn distribution. The non-magnetic portion taken alone analysed 48.7% Mn 2.3% Fe with 66.1% Mn distribution.

Cationic flotation of the magnetic products excluding the highly magnetic portion, produced a concentrate assaying 56.1% Mn, 7.3% Fe and 10.3% SiO_2 with 71.3% Mn distribution. Alternatively anionic flotation tests using NaOH, Sod. silicate and pine oil with cleanings, a manganese concentrate assaying 53.7% Mn, 6.1% Fe and 15.3% SiO_2 was produced with 62.1% Mn distribution in it.

(iv) Shivraijpur Syndicate Ore

The sample was received through the Indian Bureau of Mines and consisted of 4 mesh fines only. Complete chemical analysis of the sample was as follows :

Constituent	*Assay%*
Mn	36 50
Fe	10.25
Al_2O_3	6.94
SiO_2	19.07
P	0.38

The sample contained high phosphorous.

The sample was sized on 8 and 14 mesh screens. The two coarser fractions were treated by jigging and the −14 mesh fines were treated on table after hydrosizing. The combined jig and table concentrate analysed 46.3% Mn, 8.2% Fe, 5.5% SiO_2 and 0.28% P with 74.5% Mn distribution in it.

Tabling tests with sized 14 mesh feed yielded a combined concentrate assaying 47.9% Mn with 61.8% Mn distribution in it. Flotation and magnetic separation tests conducted to reduce the phosphorous content of the ore did not help its reduction below 0.26% P.

(v) Amritapura Ore

The sample consisted of 20 mesh fines and was received from M/s. Devidayal (Sales) Pvt. Ltd., Bombay. The ore analysed as follows :

Constituent	*Assay%*
Total Mn	29.87
MnO_2	46.62
Fe	6.86
SiO_2	35.45
Al_2O_3	3.80
Alkalies	1.12
BaO	0.33
P	0.06

The sample was siliceous in nature. Microscopic examination of the sample revealed the presence of pyrolusite and minor amounts of psilomelane. Quartz followed by goethite altered felspars, and garnet formed the gangue.

Tabling tests after sizing yielded good grades, but the recovery of Mn was low. Flotation tests with the sample as received employing 0.3 kg/tonne of sodium silicate at pH 10.0 yielded a concentrate assaying 46.81% Mn with 73.5% Mn distribution in it. Tests using a finer feed did not show any marked advantage.

Flotation tests using a mine to float off the silicates, did not help in getting better results than the one mentioned above.

(vi) Kumsi Manganese Ore

The sample was received from the State Mineral Development Bureau and consisted of 25 mm to 75 mm lumps. Complete analysis of the sample was as follows :

Constituent	*Assay%*
Mn	34.40
MnO_2	50.80
Fe	4.50
SiO_2	30.30
Al_2O_3	3.00
P	0.39
BaO	0.39
CaO	Trace

Mineral examination of the sample revealed the presence of pyrolusite and manganite. Quartz, followed by minor amounts of felspar, goethite, mica, hematite formed the gangue, which were liberated at 100 mesh size.

Tabling tests with sized feed respectively of 20 mesh and 48 mesh sizes yielded combined concentrates assaying 47.1% with 47.5% Mn distribution and 43.2% Mn with 52.2% Mn distribution in them. Tabling tests with sized feed at 65 mesh size followed by the magnetic separation of the table middlings and tailings, and flotation of the slimes yielded a combined concentrate assaying 46.1% Mn and 9.2% insol with 88.5% Mn distribution in it.

Straight magnetic separation at 48 mesh size yielded a magnetic concentrate assaying 44.7% Mn with 66.5% Mn distribution. Magnetic separation with deslimed 100 mesh feed followed by flotation of the slimes yielded a combined concentrate assaying 48.2% Mn and 5.9% insol. with 88.5% Mn distribution.

Anionic flotation tests yielded a concentrate assaying 46.5% Mn and 7.6% insol. with 59.9% Mn distribution after one cleaning. Cationic flotation tests with 100 mesh feed using 1.5 kg/tonne of NaOH, 0.75 kg/tonne of starch, 0.4 kg/tonne of Rosin Amine D Acetate and 0.1 kg/tonne of pine oil, yielded a concentrate assaying 47.5% Mn and 4.9% insol. with 87.7% Mn distribution in it.

E. MANGANESE ORE FROM RAJASTHAN

(i) Banswara Ore

The sample consisting 36 to 0 mm lumps was received from the Director of Mines and Geology, Rajasthan, and analysed as follows :

Constituent	*Assay%*
Mn	38.82
Fe	5 00
SiO_2	21.58
Al_2O_3	6.70
P	0.15
BaO	1.51
CaO	0.42
LOI at 800°C	6.38

Mineralogical examination of the sample revealed the presence of braunite and polianite. Quartz, garnet, hematite and magnetite were the gangue minerals.

Magnetic separation with sized 35 mesh feed produced a combined highly magnetic concentrate assaying 48.87% Mn with 12% Mn distribution in it. Tabling tests with sized 65 mesh feed produced a combined concentrate assaying 45.1% Mn with 41.2% Mn distribution in it. Anionic and cationic flotation tests did not produce any encouraging results.

Electrostatic separation tests with deslimed and sized 65 mesh feed produced a combined concentrate assaying 48.0% Mn, 4.21% Fe, 8.19% SiO_2 and 0.09% P with 60.3% Mn distribution in it. When the middlings were also combined with the concentrate the product analysed 47.04% Mn with 64.8% Mn distribution in it. Tests with 48 mesh deslimed feed produced a combined concentrate assaying 47.10% Mn, 4.51% Fe, 8.46% SiO_2 and 0.11% P with 70.4% Mn distributions. When the middlings were also combined, the Mn grade came down to 46.19% with 81.1% Mn distribution in it.

(ii) Kanji Ore

The sample was received from the Kanji Mines of M/s. R. B. Mulchand Gungachand containing 75.0 mm lumps. The sample analysed as follows :

Constituent	*Assay%*
Mn	21.74
Fe	14.23
SiO_2	3.46
CaO	18.22
Al_2O_3	1.89
P	0.58
MgO	Trace
LOI at 950°C	19.90

The sample contained high iron and phosphorous. Examination of the sample under microscope revealed the presence of psilomelane and pyrolusite as the chief ore minerals while calcite, goethite and quartz formed the gangue. Altered apatite was also present in finely dispersed state.

Tabling tests with sized 35 mesh feed did not show any improvement. Reduction roast followed by magnetic separation at 20 mesh size, after discarding the highly magnetic portions, yielded a feebly magnetic concentrate assaying 34.7% Mn and 4.6% Fe, and 0.45% P with 57.6% Mn distribution. Interlocked calcite was found to be present in the concentrates which was responsible for the low Mn content of the sample. Similar test conducted with reduction roast and washing before magnetic separation, where the feebly magnetic concentrate assaying 33.17% Mn was combined with the slimes assaying 41.09% Mn, the combined product analysed 35.8% Mn, 5.45% Fe and 0.39% P with 66.4% Mn distribution.

Reduction roasting and magnetic separation tests conducted with washed ore yielded a combined feebly magnetic concentrate and slimes assaying 34.5% Mn, 6.6% Fe and 0.38% P with 58.4% Mn distribution in it. Flotation tests conducted to separate the apatite were unsuccessful.

F. MANGANESE ORES FROM MAHARASTRA

(i) Balaghat Mines

Sample I: The sample consisted of −6 mm +1.5 mm and analysed as follows:

Constituent	*Assay%*
Mn	43.13
Fe	6.10
SiO_2	12.57
Al_2O_3	1.72
P	0.105
LOI	7.08

The grade of the concentrate was to be improved to 48% Mn. Microscopic examination of the sample showed the presence of hollandite, braunite, psilomelane, pyrolusite and hausmanite. Quartz and mica formed the gangue.

Treatment of the sample in Harz Jig produced a concentrate assaying 47.62% Mn, 6.38% Fe, 5.92% SiO_2 and 0.11% P with 89.8% Mn distribution in it. When the sample was treated in a mineral jig, the concentrate analysed 47.95% Mn, 6.41% Fe, and 5.70% SiO_2 with 88.4% Mn distribution in it.

Both the concentrates were of acceptable grade for export as well as for internal consumption.

Sample 2: This sample consisted of −25 mm +6 mm lumps are analysed as follows:

Constituent	*Assay%*
Mn	43.73
Fe	5.03
Al_2O_3	1.78
SiO_2	14.86
P	0.106
LOI	5.40

Because of the coarse size, the sample was treated in Harz Jig and the concentrate analysed 48.03% Mn, 5.61% Fe, 6.81% SiO_2 and 0.108% P with 89.5% Mn distribution. This concentrate was better than the fines concentrate with an acceptable grade.

(ii) From Tirodi

Four different samples designated as A, B, C & D were received from M/s. Manganese Ores (India) Ltd. for beneficiation studies. They were similar to each other in mineralogical composition and physical appearance. They differ in chemical composition only. All the samples were treated by gravity methods only as per the given flow sheet in 1) Jigging the ore in it as received state 2) jigging and tabling after sizing and 3) crushing, jigging and tabling. The end products were meant for export and should contain 48% Mn with 1:7 ratio of Fe:Mn.

Sample A: The ore consisted of 25 mm lumps down to fines in it. The sample analysed as follows:

Constituent	*Assay%*
Mn	39.95
Fe	10.65
SiO_2	16.81
BaO	2.81
P	0.136
S	0.132
LOI	2.71

The sample was coated with micaceous clay and was composed of hollandite, sitaparite, pyrolusite and psilomelane. Quartz, felspar and micas formed the gangue.

Treatment of the sample in its "as received state" in Harz Jig yielded a concentrate assaying 45.0% Mn, 12.0% Fe and 92% Mn distribution in it.

Treatment of the ore in Harz Jig, mineral jig and on shaking table after sizing, yielded a combined concentrate assaying 46.87% Mn, 12.75% Fe and 6.09% SiO_2 with 89.9% Mn distribution in it.

Sample B: The sample was similar to sample A in physical appearance and mineralogical composition. Complete chemical analysis of the sample was as follows:

Constituent	*Assay%*
Mn	29.70
Fe	13.80
SiO_2	25.40
BaO	2.30
P	0.06
S	0.33
LOI	2.80

This sample was poorer than the sample A. Treatment of the sample in its "as received state" in Harz jig produced a concentrate assaying 40.2% Mn, 16.4% Fe and 9.5% SiO_2 with 90.0% Mn distribution in it.

Sizing of the sample followed by treatment in a jig and shaking table yielded a combined concentrate assaying 40.2% Mn 15.9% Fe and 10.2% SiO_2 with 90.1% Mn distribution in it. Similar test after reducing the feed to 19 mm size produced a concentrate assaying 42.1% Mn, 17.0% Fe and 7.5% SiO_2 with 86.9% Mn distribution in it. All the test results indicated the high silica in the products and it could not be further reduced on account of its fine dissemination in the ore.

Sample C: The sample consisted of −25 mm lumps down to fines, having the following analysis:

Constituent	*Assay%*
Mn	35.80
Fe	9 50
SiO_2	17.35
P	0.34
S	0 074
Al_2O_3	5 80
BaO	1.20
LOI	0.82

Treatment of the sample in its "as received state" in Harz jig produced a concentrate assaying 45.02% Mn, 10.7% Fe and 6.5% SiO_2 with 69.6% Mn distribution. Jigging and tabling tests after sizing yielded a combined concentrate assaying 45.4% Mn, 10.7% Fe and 6.3% SiO_2 with 79.5% Mn distribution in it. Similar test with −19 mm crushed feed yielded a combined concentrate assaying 48.1% Mn, 11.8% Fe and 5.2% SiO_2 with 74.5% Mn distribution in it.

Sample D: Complete chemical analysis of the sample was as follows:

Constituent	*Assay%*
Mn	29.50
Fe	9.50
SiO_2	30.30
Al_2O_3	14.24
BaO	1.94
P	0.33
S	0.44
LOI	1.36

Jigging test with sample in its "as received state" produced a concentrate assaying 45.0% Mn, 10.9% Fe and 9.3% SiO_2 with 74.1% Mn distribution in it. Jigging and tabling tests with the sized ore yielded a combined concentrate assaying 46.6% Mn, 11.97% Fe and 8.98% SiO_2 73.6% Mn distribution in it. Crushing to 19 mm followed by jigging and tabling treatments, the combined concentrate analysed 47.89% Mn, 12.42% and 7.67% SiO_2 with 78.6% Mn distribution in it.

All the test results with respect to each sample indicated that the iron content increased with the raise in the grade of the ore. Samples A, C & D could be beneficiated to 47% Mn and above but sample B due to very close association of silicate gangue could not be improved to the same level. Mn/Fe ratio did not change in all the samples on account of the iron present in the composition of the manganese minerals.

(iii) Beneficiation and Agglomeration of Kandelwal's Manganese fines

The sample consisted of 3-0 mm fines and had the following chemical analysis:

Constituent	*Assay%*
Mn	36.00
Fe	9.04
SiO_2	17.62
Al_2O_3	3.68
BaO	1.37
P	0.125
S	0.270

The sample was higher in silica and had a lower Mn/Fe ratio.

Examination of the sample under microscope revealed the presence of pyrolusite, psilomelane, sitaparite, braunite and wad. Quartz, mica, garnet, felspar and hydro-hematite formed the gangue. Traces of apatite and calcite were also observed. Tabling tests with the sample in its as received state produced a concentrate assaying 44.37% Mn and 9.19% Fe with 71.4% Mn distribution in it.

Tabling tests with the ore crushed to 28 mesh size and sizing, yielded a combined concentrate assaying 47.41% Mn, 9.3% Fe and 8.56% SiO_2 with 75.1% distribution in it. In both the tests the grade of the concentrates were good but the Mn/Fe ratio did not improve to 7.0.

High intensity magnetic separation tests with deslimed and sized 20 mesh feed yielded a combined concentrate assaying 48.11% Mn, 9.45% Fe and 10.6% SiO_2 with 50.2% Mn distribution in it.

Reduction roast followed by magnetic separation tests with the sample yielded a feebly magnetic concentrate after discarding the highly magnetic and non-magnetic portions assaying 48.8% Mn, 8.1% Fe and 12.9% SiO_2 with 83.4% Mn distribution and Mn/Fe ratio 6.0.

Pelletization and sintering tests were conducted with the concentrate produced from shaking tables. Pellets produced under the optimum conditions of −200 mesh dry ground feed mixed with 1.5% Bentonite and 2.0% dextrine produced a green compression strength of 2-3.15 kg/pellet. After heat hardening, the strength improved to 215 to 238 kg/pellet.

Batch sintering studies conducted under varying conditions of moisture, coke breeze, and return sinter fines indicated that under the optimum conditions of 6% moisture, 30% sinter fines and 5% coke breeze a sinter with a shatter size stability of 71.4% was produced. The sinter analysed 52.0% Mn, and 8.46% Fe with a size stability of 71.4%.

G. MANGANESE ORES FROM OTHER AREAS

(i) Barajamda (Bihar) Ore

The sample was received from M/s. Kharasawan Minerals Concern (P) Ltd., consisted of 50 to 12 mm lumps and had the following analysis :

Constituent	*Assay%*
Mn	30.56
MnO_2	4.46
Fe	10 22
SiO_2	28.32
Al_2O_3	5.60
P	0.039
BaO	0.40
LOI at 500°C	7.00

Microscopic examination of the sample revealed the presence of pyrolusite and psilomelane along with quartz and minor amounts of goethite. The gangue was liberated at 35 mesh size.

Tabling test conducted with 35 mesh sized feed yielded a combined concentrate assaying 47.6% Mn, 9.2% Fe and 6.0% SiO_2 with 41.5% Mn distribution.

Magnetic separation tests with deslimed and sized 35 mesh feed yielded a combined feebly magnetic concentrate assaying 42.95% Mn, 12.74% Fe and 5.0% SiO_2 with 53.7% Mn distribution in it.

Reduction roast and magnetic separation test with 35 mesh feed after removing two highly magnetic products and the non-magnetic product yielded a concentrate assaying 40.07% Mn, 7.7% Fe and 30.52% SiO_2 with 80.1% Mn distribution.

When the non-magnetic concentrate was subjected to flotation using amines, a manganese concentrate assaying 53.95% Mn, 7.7% Fe and 7.9% SiO_2 was produced with 63.7% Mn distribution in it.

Reduced ore was treated on shaking table and then subjected to magnetic separation ; the non-magnetic concentrate assayed 61.2% Mn, 4.62% Fe and 9.52% SiO_2 with 55.1% Mn distribution in it.

(ii) Manganiferous Clay from Goa

The sample was received from M/s. Chowgule & Co. and contained almost 38% moisture in its "as received state." Complete chemical analysis of the sample was as follows :

Constituent	*Assay%*
Mn	8.60
MnO_2	10.60
Fe	33.60
Al_2O_3	16.80
SiO_2	13.30
S	0.33
FeO, CaO, MgO	Trace
P	
LOI	14.00

No manganese mineral could be identified under the microscope although the etch test indicated the presence of psilomelane. Kaolinite type clay and hydroxides of iron were identified.

Washing and desliming tests indicated almost uniform distribution of Mn in the sand and slimes, but the later part contained slightly higher iron. Similar results were obtained with hydro classification tests.

Tabling tests with 20 mesh feed yielded an iron concentrate and a tailing assaying 33.8% Fe and 9.7% Mn with 96.1% Mn distribution in it. Wet magnetic separation tests were also unsuccessful. Reduction roast followed by magnetic separation tests yielded a highly magnetic concentrate assaying 41.3% Fe and 11.2% Mn, while the feebly magnetic and non-magnetic portions analysed 27.7% Fe and 7.6% Mn. Flotation tests were also unsuccessful in the separation of non-magnetic gangue.

(iii) Manganese Ores from National Carbon Co.

Two different samples were received from the firm for the reduction of the iron content to the lowest possible level for use of the ore in the dry battery industry.

Sample No. 1 :

The sample was of 6 mesh size and analysed as follows :

Constituent	*Assay%*
Mn	52.09
MnO_2	74.50
Fe	5.90
SiO_2	2.80
Al_2O_3	2.30

Wet magnetic separation tests with the sample in its "as received state" produced a non-magnetic concentrate assaying 53.6% Mn and 4.6% Fe with 88.5% Mn distribution. Similar test at 35 mesh size produced a concentrate assaying 53.7% and 4.5% Fe with 94.2% Mn distribution in it.

Dry Magnetic separation tests with deslimed 35 mesh feed produced a non-magnetic product assaying 54.2% Mn and 3.6% Fe with 69.4% Mn distribution in it.

Tabling with 10 mesh sized feed followed by magnetic separation of the table concentrates, yielded a combined non-magnetic concentrate assaying 55.4% Mn and 3.4% Fe with 63.9% Mn distribution in it. When the non-magnetic product of the slime was also combined, the product analysed 54.6% Mn and 3.6% Fe with 78.2% Mn distribution.

Sample No. 2 :

The sample consisted of 60-25 mm lumps and considerable amount of fines and analysed as follows :

Constituent	*Assay%*
Mn	50.60
MnO_2	75.20
Fe	5.32
SiO_2	4.72

Microscopic examination revealed the presence of pyrolusite, cryptomelane with minor amounts of jacobsite and braunite. Magnetite, hematite, goethite and quartz formed the gangue. Silicates were fairly liberated at 14 mesh size while the other iron minerals at 65 mesh size.

Magnetic separation tests at 10 mesh size produced a concentrate assaying 52.17% Mn, and 4.01% Fe with 93.9% Mn distribution.

Tests conducted at finer size did not show any imprcvement over the grade or recovery. The non-magnetic concentrate when further treated

in a high intensity magnetic separation, after rejecting the two highly magnetic products and the non-magnetic products, a feebly magnetic concentrate assaying 51.98% Mn, 2.91% Fe was produced with 86.5% Mn distribution in it.

Pilot Plant tests were conducted with the ore crushed to 35 mesh size, followed by continuous magnetic separation (drum type). The concentrate analysed 52.17% Mn and 3.77% Fe with 94.0% Mn distribution.

Wet magnetic separation with 200 mesh feed produced 53.57% Mn and 3.89% Fe grade with 90.8% Mn distribution.

(iv) Manganese Ore from Malaya

The sample was received from the Director, Eastern Mining & Metal Corpn., Federation of Malaya for beneficiation tests. The ore comprised of 150 mm lumps down to fines and analysed as follows:

Constituent	*Assay%*
Mn	18.9
MnO_2	25.2
Fe	18.2
SiO_2	14.6
Al_2O_3	15.5
BaO	3.7
CaO	1.6
P	0.059
LOI at 950°C	12.47

Microscopic examination of the sample indicated the presence of psilomelane followed by minor amounts of magnetite and pyrolusite, goethite, lepidocrosite, laterite clay filling in the inter-granular space and quartz formed the gangue. Most of the gangue minerals were liberated at 28 mesh size.

Washing of the sample after crushing to 50 mm size rejected 25% of the feed with only 1.6% Mn distribution in it. The washed ore analysed 26% Mn with 98.4% Mn distribution in it. HMS tests with the washed −50 mm +6 mesh portion produced a grade of 43.9% Mn, 10.2% Fe and 2.1% SiO_2 with 31.4% Mn distribution.

Magnetic separation tests conducted at 10 mesh 28 mesh sizes did not produce encouraging results. Similar tests with preheated sample with

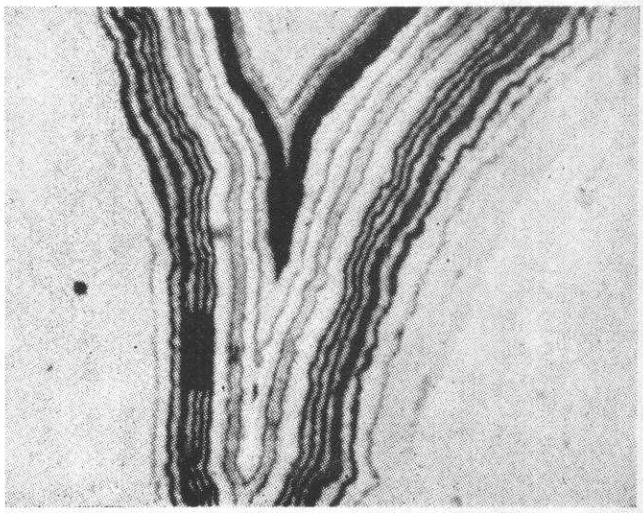


Fig. 3.3 Showing Colloform Psilomelane with concentric bands. Reflected Illumination. X140. (Manganese Ore from Malaya)

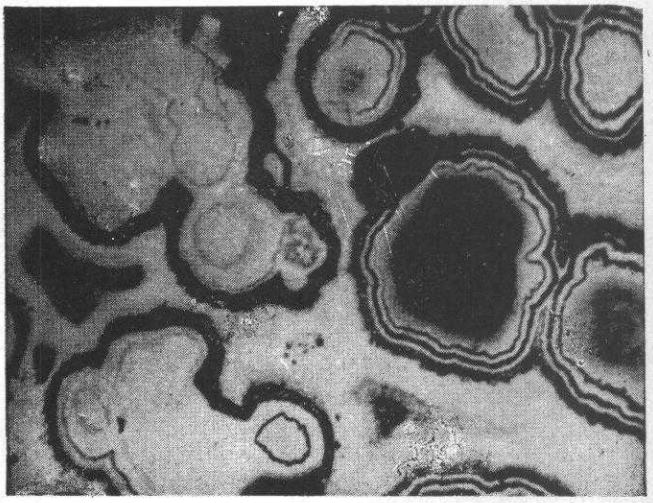


Fig. 3.4 Showing botryoidal Psilomelane with Colloform bands. X44. (Manganese Ore from Malaya).

sized 10 mesh yielded a combined concentrate assaying 41.8% Mn, 8.9% Fe and 3.5% SiO_2 with 63.7% Mn distribution. Another test with 28 mesh feed, a concentrate assaying 42.1% Mn, 8.6% Fe and 3.7% SiO_2 was obtained 64.4% Mn distribution in it.

Reduction roast followed by magnetic separation at 28 mesh size after discarding the three highly magnetic portions, a combined feebly magnetic and non-magnetic concentrate assaying 48.3% Mn, 4.1% Fe and 7.3% SiO_2 with 67.2% Mn distribution was obtained.

TABLE 3.1 BENEFICIATION RESULTS OF MANGANESE ORES

Locality & State	Assay % ROM	Beneficiation Methods	Assay % Conc.	Recovery % Conc.	Remarks
1	2	3	4	5	6
Andhra Pradesh					
(1) Kodur (Eluvial Ore)	33.94 Mn, 4.53 Fe, 14.01 SiO_2, 0.49 P	Sizing & tabling at 10 mesh	44.82% Mn, 0.28% P	65.3% Mn	Siliceous Ore
(2) Kodur (Bed Ore)	33.49% Mn, 13.92 Fe, 8.45 SiO_2, 0.29 P	Reduction roast and magnetic separation	50.25% Mn, 6.30 0.25 P	65.3% Mn	Ferruginous
(3) Chipurupalli	25.82 Mn, 10.89 Fe 25.15 SiO_2, 0.13 P	Reduction roast and magnetic separation at 35 mesh	49.88% Mn, 7.88 Fe, 0.17 P	69.8 Mn	Ferruginous & siliceous
(4) Marrivalasa (Salur)	28.63 Mn, 18.44 SiO_2, 12.68 Fe, 0.20 P	Reduction roast and magnetic separation at 35 mesh size	50.1 Mn, 6.29 Fe, 0.21 P	47.7 Mn	Ferruginous & phosphatic
(5) Kodur (Dumps)	24.3 Mn, 12.9 Fe, 17.9 SiO_2, 0.27 P	Reduction roast and magnetic separation at —3 mesh size	46.3 Mn, 6.2 Fe, 0.2 P	55.6 Mn	Ferruginous & phosphatic
Orissa					
(1) Tisco	26.8 Mn, 28.8 Fe, 6.64 SiO_2, 0.11 P	Reduction roast at 3 mesh & mag. separation at 10 mesh	58.1 Mn, 4.54 Fe,	57.9 Mn	Ferruginous
(2) Sagur Ore	29.06 Mn, 17.98 Fe, 1.78 SiO_2, 0.05 P	Washing, reduction roasting and magnetic	48.89 Mn, 7.15 Fe, 0.095 P	34.0 Mn	-do-
(3) Barajamda Ore	35.7 Mn, 9.2 Fe, 26.2 SiO_2, 0.038 P	Sizing and tabling at 10 mesh	47.07 Mn, 6.07 Fe	66.7 Mn	Siliceous Ore
(4) Siljora Ore	37.55 Mn, 12.46 Fe, 14.0 Insol., 0.086 P	Reduction roast and magnetic separation at 28 mesh size	53.16 Mn, 5.59 Fe, 14.54 Insol., 0.011 P	86.5 Mn	Ferruginous siliceous
(5) Sambalpur Ore	38.53 Mn, 17.50 Fe, 3.83 SiO_2, 0.35 P	Reduction roast at 6 mesh & magnetic separation at 35 mesh	57.9 Mn, 6.1 Fe, 0.29 P	74.5 Mn	Ferruginous & phosphatic
(6) Kuttinga Ore	38.9 Mn, 10.7 Fe, 7.8 SiO_2, 0.35 P	Reduction roast at 3 mesh & magnetic separation at 10 mesh	50.8 Mn, 6.2 Fe, 0.31 P	94.1 Mn	-do-
(7) Joda (West)	27.2 Mn, 24.2 Fe, 7.53 SiO_2, 0.09 P	Washing, Tabling, Reduction roast & magnetic separation	52.5 Mn, 7.31 FeFe	61.8 Mn	Ferruginous ore & low yield
(8) Siljora Kalimati	37.5 Mn, 16.4 Fe, 1.2 SiO_2, 0.08 P	Reduction roast & magnetic separation at 10 mesh	50.6 Mn, 7.1 Fe	50.6 Mn	Ferruginous

TABLE 3.1—Continued

1	2	3	4	5	6
(9) S.G.B.K. Rejects	30.18 Mn, 16.58 Fe, 17.72 SiO_2, 0.03 P	Magnetic Separation & flotation of non magnetic	57.06 Mn, 6.16 Fe, 10.23 SiO_2	48.5 Mn	Siliceous Ore
(10) S.G.B.K. Ore No. 2	28.10 Mn, 24.90 Fe, 8.90 SiO_2, 0.145 P	Washing, reduction roast & & magnetic separation	58.5 Mn, 8.5 Fe, 7.4 SiO_2, 0.141 P	58.5 Mn	
(11) Lohandabad	40.02 Mn, 4.82 Fe, 19.34 SiO_2, 0.18 P	High intensity magnetic separation & electrostic separation	42.2 Mn, 9.7 SiO_2	63.4 Mn	
(12) Koira Ore	31.48 Mn, 22.06 Fe, 3.90 SiO_2, 0.09 P	Reduction roast, low intensity wet magnetic separation & high intensity dry magnetic separation	53.40 Mn, 7.4 Fe	71.4 Mn	Ferruginous
(13) Orahuri Ore (Koira)	36.7 Mn, 31.05 SiO_2, 3.0 Fe	Desliming and magnetic separation of the sand and flotation of slimes	51.5 Mn, 3.6 Fe, 6.12 SiO_2	92.3 Mn	Siliceous
(14) Keonjhar (M/s. Rungta & Sons)	% Mn 40.0, MnO_2 58.6, Fe 14.0, Al_2O: 5.55, BaO 0.62, P 0.09	Tabling tests and magnetic separation tests of the sample at 48, 65 and 100 mesh size did not show any reduction in Fe content			
	Psilomelane, Pyrolusite, cryptomelane, lepidocrosite, goethite, hematite, quartz, liberation of the manganese minerals at 100 mesh size	Reduction roast followed by magnetic separation at 40,	Mn% Fe%	Mn%	Ferruginous
		—20 mesh	52.2 10.22	36.6	
		—65 mesh	53.6 9.9	30.0	
(15) Barajamda Ore	30.56 Mn, 10.22 Fe, 28.32 SiO_2, 0.039 P	Reduction roast; tabling and magnetic separation	61.2 Mn, 4.62 Fe, 9.52 SiO_2	55.1 Mn	Siliceous
Madhya Pradesh					
(1) Kachindana Ore	41.6 Mn, 14.6 SiO_2, 8.46 Fe, 0.20 P	Sizing and tabling at 28 mesh size	47.66 Mn, 7.8 Fe, 8.48 SiO_2, 0.19 P	69.3 Mn	Siliceous
(2) Mansar Ore	32.57 Mn, 10.13 Fe, 27.48 SiO_2, 0.46 P	Magnetic separation at 20 mesh and tabling	47.95 Mn, 10.92 Fe, 13.08 SiO_2, 0.03 P	54.4 Mn	Siliceous
(3) Tirodi Ore	27.39 Mn, 7.47 Fe, 33.40 SiO_2, 0.36 P	Magnetic separation at 20 mesh and electrostatic separation of non-magnetic	41.91 Mn, 0.21 P	71.8 Mn	Siliceous & phosphatic

TABLE 3.1—Continued

1	2	3	4	5	6
(4) Balaghat Ore	29.24 Mn, 31.26 SiO_2, 7.77 Fe, 0.26 P	Sizing and tabling at 38 mesh followed by magnetic separation of the table middlings	47.71 Mn, 10.4 Fe	61.8 Mn	
(5) Miragpur Ore	35.45 Mn, 8.19 Fe, 19.92 SiO_2,	Reduction roast and magnetic separation at 65 mesh	46.23 Mn, 6.6 Fe, 0.1 P	30.0 Mn	
(6) Jhabua Ore	28.8 Mn, 5.90 Fe, 22.38 SiO_2, 0.19 P	Reduction roast and magnetic separation at 10 mesh	40.0 Mn, 4.2 SiO_2	62.7 Mn	
(7) Kuno-Madai Ore	33.5 Mn, 9.6 Fe, 19.5 SiO_2, 0.175 P	Reduction roast and magnetic separation	40.9 Mn	68.5	Difficult to beneficiate
Karnataka					
(1) Nagri-Joida Ore	34.71 Mn, 18.49 Fe, 3.93 SiO_2, 0.03 P	Reduction roast and magnetic separation at 10 mesh after desliming	57.36 Mn, 5.19 Fe, 0.062 P	81.2 Mn	
(2) Sandur Ore	30.18 Mn, 21.90 Fe, 0.99 SiO_2, 0.03 P	Washing, reduction roast magnetic separation at 200 mesh size	52.6 Mn, 7.15 Fe	54.9 Mn	
(3) Shimoga Ore	37.9 Mn, 8.2 Fe, 20.6 SiO_2, 0.071 P	Reduction roast and magnetic separation at 20 mesh	46.8 Mn, 4.2 Fe	84.5 Mn	
		Cationic flotation	56.1 Mn, 7.3 Fe 10.3 SiO_2,	71.3 Mn	
		Aniomic flotation	53.7 Mn, 6.1 Fe, 15.3 SiO_2,	62.1 Mn	
(4) Shivrajpur	36.5 Mn, 10.25 Fe, 19.07 SiO_2, 0.38 P	Tabling at 10 mesh with sized feed	47.9 Mn, 0.26 P	61.8 Mn	P could not be reduced
(5) Amritapura Ore	29.87 Mn, 6.86 Fe, 35 45 SiO_2, 0.06 P	Flotation with one cleaning	55.11 Mn	60.9 Mn	
(6) Kumsi Ore	34.4 Mn, 5.4 Fe, 30.3 SiO_2, 0.07 P	Tabling and magnetic separation at 65 mesh	46.1 Mn, 9.2 Insol.	88.5 Mn	
		Cationic flotation	47.5 Mn, 4.9 Insol.	87.7 Mn	
Rajasthan					
(1) Banswara Ore	38.82 Mn, 5.0 Fe, 21.58 SiO_2, 0.15 P	Electrostatic separation at 48 mesh size	47.1 Mn, 4.51 Fe, 8.46 SiO_2, 0.11 P	70.4 Mn	
(2) Kanji Ore	21.74 Mn, 13.24 Fe, 3.46 SiO_2, 0.58 P	Washing, reduction roast and magnetic separation	34.5 Mn, 6.6 Fe, 0.38 P	58.4 Mn	

TABLE 3.1—Continued

1	2	3	4	5	6
Maharastra					
(1) Moil Ore I	43.13 Mn, 6.10 Fe, 12.75 SiO_2, 0.05 P	Jigging in harz jig	47.62 Mn, 6.38 Fe, 5.92 SiO_2, 0.11 P	89.8 Mn	
(2) Moil Ore II	43.73 Mn, 5.03 Fe, 14.86 SiO_2, 0.106 P	-do-	48.03 Mn, 5.61 Fe, 6.81 SiO_2, 0.018 P	89.5 Mn	
(3) Tirodi Ore A	39.95 Mn, 10.65 Fe, 16.81 SiO_2, 0.136 P	Sizing, jigging and tabling at 13 mm size	47.3 Mn; 12.8 Fe, 6.69 SiO_2	90.5 Mn	
(4) Tirodi Ore B	29.7 Mn, 13.8 Fe, 25.4 SiO_2, 0.06 P	-do-	42.1 Mn, 17.0 Fe, 7.5 SiO_2	86.9 Mn	
(5) Tirodi Ore C	35.8 Mn, 9.5 Fe, 17.35 SiO_2, 0.34 P	-do-	48.1 Mn, 11.8 Fe, 5.2 SiO_2	74.5 Mn	
(6) Tirodi Ore D	29.5 Mn, 9.5 Fe, 30.3 SiO_2, 0.33 P	-do-	47.89 Mn, 12.42 Fe	78.6 Mn	
(7) Kandelwals Ores	36.0 Mn, 9.04 Fe, 17.62 SiO_2, 0.125 P	Reduction roast and magnetic separation	48.8 Mn, 8.1 Fe, 12.9 SiO_2	83.4 Mn	Pelletization also done

TABLE 3.2 SUMMARY OF RESULTS OF MANGANESE ORE BENEFICIATION STUDIES—OTHER AREAS

(1) Manganiferous clay from Goa	8.60 Mn, 33.2 Fe, 13.3 SiO_2, Trace P	Reduction roast and magnetic separation	11.2 Mn, 41.2 Fe	—	Not feasible at all
(2) Ores from National Carbon Co. I	52.09 Mn, 5.90 Fe, 2.80 SiO_2	Sizing and tabling at 10 mesh followed by magnetic separation	55.4 Mn, 3.4 Fe	63.9	Battery grade
(3) Ores from National Carbon Co. II	50.06 Mn, 5.32 Fe, 4.72 SiO_2	Wet magnetic separation at 200 mesh	53.57 Mn, 3.89 Fe	90.8	-do-
(4) Malaya Ore	18.9 Mn, 18.2 Fe, 14.6 SiO_2, 0.059 P	Reduction roast and magnetic separation at 28 mesh size	48.3 Mn, 4.1 Fe,	67.2 Mn 7.3 SiO_2	

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