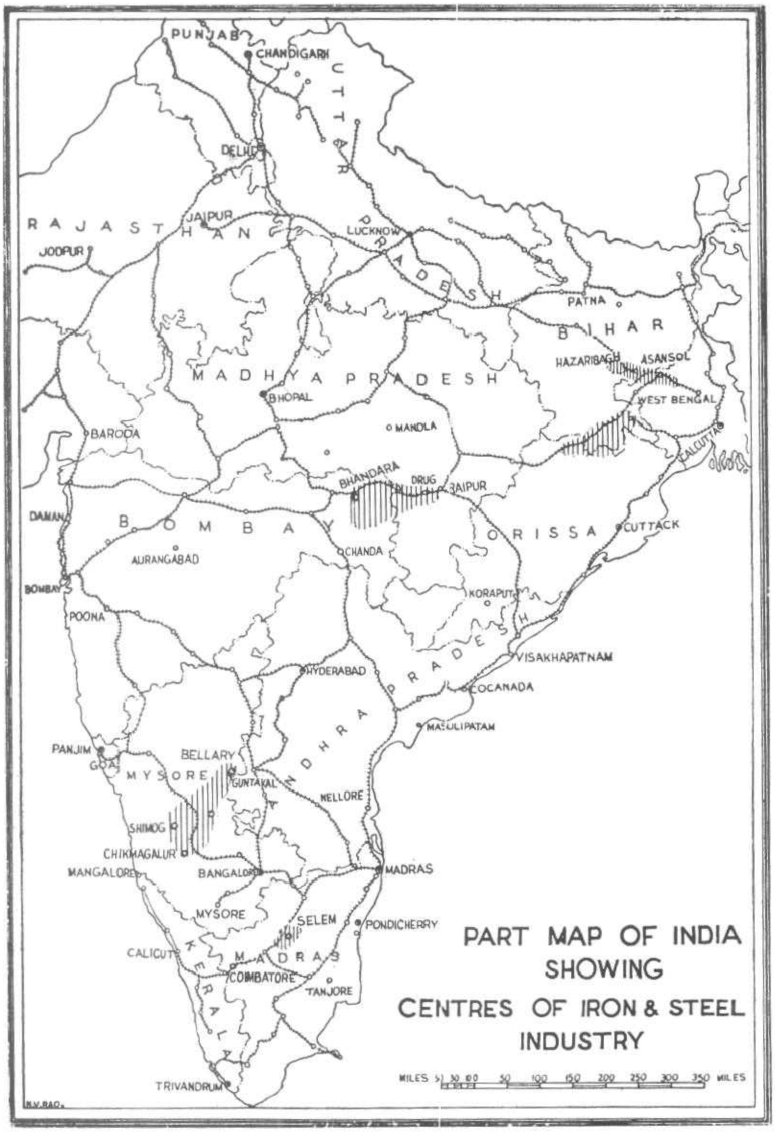
Principal mineral raw materials for Iron and Steel Industry

B. B. Engineer

PRINCIPAL mineral raw materials for iron and steel industry are ore, flux and fuel with minor quantities of refractory minerals such as chromite, magnesite, silica rock, fireclay and dolomite, required for making refractories that go to line the iron and steel furnaces. Manganese ore is also an essential raw material both in the manufacture of pig iron and for its ferro-alloys required at the steel-making stage. Small quantities of silica sand for foundry work and a host of other materials such as graphite, flourspar, aluminium, ferro-alloys, etc., are required directly or indirectly at one stage or the other in the process of making iron and steel; but these do not constitute the major or principal mineral raw materials and are beyond the purview of this paper. The following essential mineral raw materials are discussed here :

Iron ore, coal, flux, manganese ore, fireclay, chrome ore, magnesite and dolomite.



PART MAP OF INDIA SHOWING CENTRES OF IRON & STEEL INDUSTRY

IRON ORE

The chief minerals of iron are :

Hematite	...	Fe_2O_3	70·0% Fe
Magnetite	...	Fe_3O_4	72·4% ,,
Turgite, Goethite and Limonite	...	Hydrated oxides	59·8 to 66·3% ,,
Siderite	...	$Fe\ CO_3$	48·2% ,,
Pyrite	...	$Fe\ S_2$	46·6% ,,
Pyrrhotite	...	$Fe_x\ S_x$	over 38% ,,
Ilmenite	...	$Fe\ TiO_3$	36·8% ,,
Greenalite, Chamosite, etc.	...	Hydrous iron silicates	20% to 35% ,,

Of these, oxides and hydrated oxides are the most abundant in nature and are the usual ores of iron, hematite being the most common ore. Magnetite, though it is an oxide and carries a higher percentage of Fe than hematite, is not readily available in large quantities in India and besides it is generally not prepared for the blast furnace because of its hard and compact nature which gives slow reactions limited to the surface, also many magnetites contain impurities like high titanium or vanadium. However, the Swedish magnetite at Kiruna in Lapland which approximately carries 0·3% TiO_2, 56 to 71% Fe, 0·03 to 1·8% P, 0·5% S, 0·7% Mn, 1·5% SiO_2, 0·7% Al_2O_3 and 3% CaO is widely used in Europe[1]. In comparison with the low titanium Kiruna ores, some of the magnetite ores from Singhbhum, Bihar, give approximately[2]

TiO_2	...	...	13% to 28%
V_2O_3	...	...	0·5% to 8·8%

Mr. B. B. Engineer, M. Sc. (McGill), Mineral Officer, The Tata Iron and Steel Co. Ltd., Jamshedpur.

[1] Bateman ; Econ. Min. Deposits ; John Wiley, p. 572.

[2] Dunn, J. A. ; Vanadium-bearing titaniferrous iron ores in Singhbhum and Manbhum, Trans. MGMI 1937, pt. 3.

Fe	...	...	up to 60%
SiO_2	...	...	1·1% to 9·7%
Al_2O_3	...	...	1·02% to 4·38%
P_2O_5	...	...	trace to 0·97%

The high titanium and vanadium contents would, at present, preclude their use in smelting iron in blast furnace. Though no carbonate ore is used in India it is an important ore in Europe and is also used in minor quantities in North America though after sintering. Extraction of iron from ilmenite is an expensive and a complicated process. Ilmenite is therefore never an iron ore ; it is an ore for titanium, Neither the sulphides nor the silicates are used as iron ores because of the economics involved and the difficulty in extracting the metal from these.

Specifications

Basically, the iron ore should contain as high a percentage of iron as possible ; the higher the iron content the lower would be the amount of ore required, which besides other advantages leads to economical operations. However, in actual practice the choice is limited to the availability of the ores and iron content in the ores used for smelting purposes varies from country to country and ore to ore. For example, the U. K. Appleby-Frodingham plant uses almost the world's leanest ores, 18–22% Fe[3], whilst the average blast furnace iron ore charge in India varies from 58 to 60% in Fe content.

The ore should be as low in gangue minerals as possible. Silica in an ore is an impurity which is normally considered as waste, in that it simply adds to the slag volume calling for an increased coke consumption. Nevertheless occasionally it is of an advantage when slag volume or fluidity is necessary to help remove sulphur when the burden is disproportionately high in alumina[4]. About 12 to 18% Al_2O_3 in the slag is desired to give it the right fluidity for adequate removal of sulphur. Hence, as a rule an ore with a balanced silica-alumina ratio (1·5 : 1) is desirable. Impurities such as sulphur and phosphorus should be as low as possible. Sulphur in the Indian blast furnace ores is usually in the neighbourhood of 0·01 to 0·02%, except for the Mysore ores which are higher in sulphur, it being about 0·03%. Phosphorus much above 0·1% is considered high under Indian conditions, phosphorus below 0·1% being preferred for blast furnace ores. Ores for open hearth furnaces carry as low as 0·025% P. The presence of manganese in the blast furnace ore burden facilitates desulphurisation due to increase in the slag fluidity. Manganese content in world iron ores varies over a wide range—from under 0·1% to as high as 7–8%[5] and even higher, as in some North American manganeferous ores—the desired percentage, however, depends on the smelting conditions and the quality of the pig required. The ores consumed in Indian blast furnaces generally carry Mn from "trace" to about 0·8%[6]; this percentage of Mn in the ore being not sufficient, small amounts of low grade manganese ore are added to the blast furnace charge to give the desired quality of pig. In some foreign ores even lime and magnesia are important constituents. Michipicotan ore is an example where the presence of these renders it self-fluxing. However, in Indian ores CaO and MgO are practically absent. The presence of undue amounts of zinc aud arsenic may cause severe damage to the lining of the furnace[7], but few of the world's iron ores carry these in alarming proportions whereas the Indian ores are practically free from these elements.

Apart from the chemical considerations the physical make up of an ore is an important factor in its evaluation. Since the smelting process consists essentially of forcing a blast of hot compressed gases through the charge in the furnace, voids in the materials constituting the furnace charge, would be of primary importance. A very dense ore would give slow reactions confined to the surface. Porous ore is ideal for blast furnace.

The size of the ore that goes into the blast furnace is also important. Fine powdery ore tends to choke the furnace and the furnace tends to hang, it also gives increased flue losses. On the other hand very large chunks tend to slow down the rate of reduction and hence lower the rate of production. Very few modern furnaces use anything below 1/4″ ; the upper size range being about 4″. Narrowing down the size range of the ore and closely sizing the burden as a whole have led to increased output as in some British furnaces[8]. Sintering of the ore is a move in this direction.

In our iron ores, as consumed today, two main types are recognised :

(*a*) Hard ore : Steel blue in colour showing shades of grey, carrying
65 to 68% Fe, 0·8 to as much as 2% SiO_2
0·2 to 2% Al_2O_3, 0·02 to 0·05%P

(*b*) Soft ore : Shades of brown and red. It carries about
54 to 62% Fe, 2·5 to 8% SiO_2, 3·5 to under 7% Al_2O_3, trace to 0·15% P, trace to 0·8% Mn
with the SiO_2/Al_2O_3 ratio ranging roughly from 1 : 0·6 to 1 : 1·7.

---

3 Howat, D.D. ; Iron Ore Preparation, Operations Prior to Blast Furnace Smelting. Mine and Quarry Engineer, May 1953, p. 144–149.

4 Kingston, R. ; Evaluation of an Iron Ore for utilization in the Blast Furnace ; Iron and Coal Trades Review, May 21. 1954, p. 1196–7.

5 Gustafson, J. K. and Moss, A. E. ; Role of Geologist in the Development of Labrodor-Luebec Iron Ore Districts, Can. Min. Jr. June 1953.

6 Viswanathan, S. and Anant Narayan, S. N. ; Blast Furnace Raw Materials, TISCO, Vol. II, No. 3, July 1955, p. 101.

7 Collins, L. N. ; TISCO, Vol. II, No. 3, July 1955, p. 114.

8 Howat, D. D. ; Iron Ore Preparation, Operations Prior to Blast Furnace Smelting. Mine and Quarry Engineer, May 1953, p. 144–149.

Either of these ores may be affected by later lateritisation in varying degrees, the most general effect of which is to increase Al_2O_3 and P contents of the ores.

The hard ore because of its physical make up, density, etc., is preferred as a charge for the steel melting shops rather than for the blast furnaces. In the open hearth it helps to oxidise the bath. Its consumption in the steel melting shops at Jamshedpur is about 0·03 ton per ton of steel. The soft ore is preferred in the blast furnace, because of its porosity which facilitates easy smelting. The typical blast furnace ore burden at the steel works in Jamshedpur is approximately as follows[9] and the consumption of ore per ton pig is usually under 1·7 tons.

Fe	...	...	57·9%
SiO_3	...	...	5·1%
Al_2O_3	...	...	5·3%
P	...	...	0·105%
Mn	...	...	0·45%

Occurrence

India's reserves of iron ore are amongst the world's largest—the "possible" estimated reserve being 21,000 million tons. Of these hematite ores are about 17,000 million tons, magnetitic ores 1,600 million and limonitic ores 2,000 million tons[10]. Of the total reserves about 15,000 million tons of hematitic ores are estimated between the States of Madhya Pradesh, Bihar and Orissa, the balance of 5,000 million tons of all varieties of ores being mainly distributed in Madras, Mysore and Bombay. There are a few occurrences in Uttar Pradesh, Rajasthan and Himachal Pradesh, but these are of hardly any economic value.

Madhya Pradesh

Large deposits of excellent quality ore occur in Bastar, Chanda and Drug districts. In Bastar district, Bailadila deposits are famous for their reserves. The ores approximately carry Fe 60 to 69%, P 0·065 to 0·12% and S 0·03 to 0·05%. About 610 million tons with a possible reserve of 3,600 million tons of this high grade ore, in addition to large quantities of silicious hematite containing 50 to 60% Fe are estimated at Bailadila[11]. Bailadila deposits are not easily accessible, being situated about 200 miles from the present nearest railhead. Their exploitation would naturally have to wait until there is a heavy demand for iron ore in that region of India unless these deposits are exploited for export through Visakapatnam.

Rowghat iron ore deposits are the largest in Madhya Pradesh carrying as much as 740 million tons; possible reserves have not been estimated[12]. Iron ranges from 60 to almost 66%, SiO_2 from 0·9 to 3·4% and P from 0·05 to 0·15%[13].

Chief deposits of Drug district are Dhalli-Rajhara range which runs zig-zag for about 20 miles and rises about 400 ft. above the general level of the country. About 114 million tons of high grade ore containing over 60% Fe have been estimated here. The deposits carry Fe, often, over 66%; SiO_2 between 0·56 and 1·4%; P 0·05 to 0·06, S 0·06% to 0·7% and Mn about 0·14 to 0·17%, but sulphur is somewhat higher than in most of the other Indian deposits. Dhalli-Rajhara deposits are now being developed for supplies to the steel plant at Bhilai, 55 miles away.

The ores of Jubbulpore are of no importance as a source of iron ore nor are they likely to be of much importance in the foreseeable future. The ores are low grade ranging from 45 to 60% in iron content, are mostly friable and mixed with shaly or siliceous impurities. The total reserves are of the order of 100 million tons[14].

Bihar and Orissa

South Singhbhum, Keonjhar and Bonai areas constitute the richest iron ore field of India. The Sasangda Range extending for over 30 miles from near Gua in South Singhbhum to South of Badamghar Pahar in Bonai possibly affords the greatest concentration of the ore in this field. It is from the Singhbhum-Keonjhar-Bonai region that the best part of the ores for the existing iron and steel plants in India is obtained and may continue to be obtained in the future. Over 7,000 million tons of ores are estimated here. These are hematitic ores analysing Fe 58 to 68% (average about 60%), SiO_2 from less than 1% to 7%, Al_2O_3 from under 1 to 7%, P ranging from 0·02 to 0·18% but normally within 0·1%, S 0·002 to 0·03%, Mn trace to 0·06 rarely up to 3·1[15]. It will be noted that P content is normally within tolerable limits while sulphur is usually low. Titanium is practically absent.

Mayurbhanj in Orissa also carries good hematite iron ores—of the order of 60 million tons[16]. Some of the Mayurbhanj ores analyse Fe 59%, SiO_2 4·63%, Al_2O_3 3·9% with P about 0·08%; a well-balanced ore for the blast furnace, whereas other ores are less rich and carry 54% Fe, 7·0% SiO_2 and 6% Al_2O_3. P in this case is a little higher, about 0·106%.

Magnetite deposits are also known in Singhbhum and Mayurbhanj. Some of the magnetite deposits of Singhbhum carry apatite as a dominant mineral. Such apatite bearing deposits are small and are of

9 Collins, L. N., Blast Furnace Operation, TISCO, Vol. II, No. 3, July 1955, p. 112.

10 Krishnan, M. S.; Iron Ore, Iron and Steel; Bull. G. S. I., 1954, p 182.

11 Krishnan, M. S.; Iron Ore, Iron and Steel; Bull, G. S. I., 1954, p. 147.

12 Ibid, p. 150.

13 Ibid, p. 150.

14 Ibid, p. 157.

15 Figures obtained from unpublished Geological Reports of the Tata Iron and Steel Co. Ltd.

16 Krishnan, M. S.; Iron Ore, Iron and Steel; Bull. G.S.I., 1954, p. 127.

no importance as a major source of iron, but received some attention mainly as a source of apatite which was worked intermittently for several years past[17]. The other magnetite deposits of Singhbhum, and Mayurbhanj are titaniferous and carry variable but small amounts of vanadium—about 2 to 7%[18]. The titanium content, ranging from 10 to 25% precludes the use of this ore in the iron and steel industry. About 5 million tons of magnetite ores have been estimated.

The only other district in Bihar where iron ore occurs is Palamau, the Gore magnetite deposit of which is well known. About 400,000 to 600,000 tons have been estimated here of high grade iron ore with Fe over 65%, very low P about 0·005 to 0·027% and fairly low S about 0·007 to 0·03%[19].

Clay iron stones and hematite also occur as lenticular detached bodies in the Barakar rocks of Bihar. But these are of no economic importance either in quality or in quantity.

Mysore

Since the re-organisation of the States and the consequent passing of Sandur into Mysore, the State of Mysore ranks as one of the richest iron ore bearing States in India. Prior to the merger of Sandur with Mysore, about 979 million tons made up of 764 million tons of hematite and 215 million tons of magnetite were estimated in Mysore with a possible reserve of 2,500 million tons[20]. But now to this about 130 million tons with a possible reserve of 300 million tons[21] will have to be added, bringing the total Mysore reserves to

proved : 1,109 million tons
and possible : 2,800 million tons

Reserves of ferruginous banded rocks carrying from 25 to 35% Fe would run to thousands of millions of tons.

The greatest concentration of iron ore in Mysore is at Bababudan range of hills, Chikmagalur district. About 462 million tons, mostly hematite, have been estimated here[22]. These are the only deposits in the whole of Mysore that are being economically worked today for smelting at the Mysore Iron and Steel Works, Bhadravati, 25 miles from the ore field. The ore is essentially hematitic. Iron content ranges from 55 to over 65% in the deposits[23], but the ore that goes into the blast furnaces on the whole carries Fe 58·53%, SiO_2 2·54%, Al_2O_3 5%, Mn trace up to 0·04% and P 0·05%. From the same source open hearth grade iron ore carries Fe 66·8%, SiO_2 0·54%, Al_2O_3 0·6%, P 0·004%, Mn trace[24]. It would be seen that the Bababudan ores for the blast furnace and more so for the open hearth are lower in P compared to the ores from Singhbhum-Keonjhar-Bonai region used in the steel works in other parts of India and that the alumina in the ore is greater than silica.

The ores of Sandur are similar to the hematite ores of Singhbhum-Keonjhar-Bonai. The iron content ranges from 57% to 68% (with an average well over 60%), SiO_2 from 0·06 to 1·6%, Al_2O_3 from 0·25 to 5%, P 0·025 to 0·08%, S from trace up to 0·19 usually below 0·06, TiO_2 trace.

The other important iron ore district in Mysore is Chitaldrug where 276 million tons of proved ore has been estimated[25]. Chitaldrug ores are a combination of hematites and limonites with the following approximate analysis :

Fe 68%, SiO_2 2% and Al_2O_3 1·65%

However, these ores are far away from the rail-head and it would be sometime before these could be exploited.

Less important iron ores occur in Shimoga and Tumkur districts; the ores being mainly magnetites. Some of these are titaniferous, carrying up to 11% TiO_2. Tumkur ores analyse Fe 51·54% to 61%, SiO_2 0·5 to 3·5%, Al_2O_3 1·75 to 3·92%, P up to 0·003%, S up to 0·24%, Cr_2O_3 0·69 to 3·09% and TiO_2 10 to 11·6%[26]. It would be seen that these titaniferous ores are unusually low in P and carry some Cr_2O_3. Radhakrishnan estimates about 131 million tons of such titaniferous magnetites at Tumkur. However, in view of the high titanium content it is doubtful if these would find any application in the manufacture of iron and steel. Shimoga ores, though like the Tumkur ores, are unusually low in P, about 0·004%, are low grade and carry an unfavourable SiO_2/Al_2O_3 ratio. The reserves are far too meagre, about 26 million tons[27], to support an iron and steel industry.

Deposits of minor importance are also found in Dharwar District.

Madras

Salem District of Madras has a number of iron ore deposits some of which have been exploited in the past for indigenous smelting but none of these ores are used in the modern blast furnace. All the ores are essentially low grade and mostly magnetitic carrying about 35% Fe. The largest deposits are in Salem and Trichinopoly districts. These are banded magnetitic ores carrying a high percentage of silica. The bands vary in thickness from 5 ft. to over 60 ft. Representative samples of the more important bands give on an average about Fe 35%, SiO_2 47%, Al_2O_3 1·5% P 0·08%, S 0·007%, TiO_2 0·4%, MgO 1·3%, CaO 0·8%[28]. As would be seen from the analysis the ores are low

17 Krishnan, K. S.; Iron Ore, Iron and Steel; Bull. G.S.I., 1954, p. 121.
18 Ibid, p. 182.
19 Ibid, p. 119-120.
20 Ibid, p. 176 and 182.
21 Ibid p. 164 and 182.
22 Ibid, p. 175-176 and 182.
23 Percival, F.G.; Iron Ore, Jr. of Sc. Ind. Res., Feb. 1947, p. 64.
24 Krishna Rao, D.V.; New Steel Plant of Mysore Iron and Steel Works, Bhadravati; Jr. of Iron and Steel Inst., 1938, p. 165P.

25 Krishnan, M. S.; G.S.I., Bull. (Econ. Geol.), No. 9, p. 175.
26 Krishnan, M. K.; G.S.I., Bull. (Econ. Geol.). No. 9, p. 175.
27 Ibid, p. 175-176.
28 Krishnan, M. S. and Aiyengar, N. K. N.; Bull. G.S.I. No. 8 (Econ. Geol.); p. 52.

in S and cary some MgO and CaO. The analysis given above represents an average of samples of the magnetite rich bands but on large scale mechanical mining the run-of-mine ore is likely to be still lower in Fe content unless selective mining is resorted to. About 305 million tons with a possible reserve of 1,000 million tons, have been estimated here[29]. Laboratory tests indicate that some of these ores could be successfully beneficiated by magnetic separation on crushing down to 0·33 mesh[30]. The Salem ores hold promise of a good future, minerals such as limestone, dolomite, magnesite, etc. being available close by.

There are some scattered magnetite deposits in North and South Arcot and Coimbatore Districts, but these hardly appear to be of economic importance.

Andhra

Andhra has a number of scattered iron ore deposits, but none of these are likely to be of any economic importance in the near future. Those at Guntur and Nellore are of low grade magnetite-quartzite and hematite-quartzite. These amount to about 20 million tons. Those as Kurnool are of low sulphur hematite, but the grade is variable and the reserves are of the order of 3 of 4 million tons[31].

Bombay

Iron ore deposits are scattered in the districts of Ratnagiri as well as in the adjoining Portuguese territory of Goa. Though extensive, the deposits of Ratnagiri do not carry high reserves, the total estimated quantity being about 5 million tons. The deposits are associated with banded hematite quartzite rocks of the Dharwar age. The ores carry 45 to 60% Fe, with SiO_2 from 10 to 15%. P is somewhat high and may reach up to 0·7%.

The deposits of the Portuguese territory of Goa are of more importance. These carry up to 62% Fe, SiO_2 up to 2% and P 0·04 to 0·5[32]. The alumina is likely to be high because the ores are somewhat lateritic. Detailed information regarding reserves of the ores in Goa are lacking. However, the information published by the U.S. Bureau of Mines in their Mineral Trade Notes 1952, p. 82-83, gives the total reserves of ore of these deposits at 250 million tons. Krishnan thinks this to be highly exaggerated and he places the total indicated reserves at 20 million tons between Ratnagiri and Goa.

The deposits of Chanda District of Bombay, though high grade, are not extensive, the proved and indicated reserves being about 22 million tons.

There are scattered deposits ranging in age from Dharwar to Tertiary in the States of Assam, Bengal, Himachal Pradesh, Kashmir, Punjab and Rajasthan. Many of these are low grade and poor in reserves. None of these ores seem to be of any economic importance at present, nor are they likely to assume much importance in the foreseeable future.

COAL

Besides iron ore, the other important raw material required in very large quantities for the iron and steel industry is coal. Its essential use here is as fuel and as a reducing agent in the form of coke in the blast furnace. It is also employed in the manufacture of producer gas used in the open hearth furnaces. Some coal is also necessary for steam raising which is required for innumerable miscellaneous uses such as generating power, etc. Depending on its nature, viz., the physical and chemical properties, coal may be considered as coking (metallurgical), steam or gas coal.

The consumption of the various types of coal, viz., coking coal, steam coal and gas coal would vary considerably with the practices in the individual plants. The following table gives an idea of the quantities of each of these types of coal required for a typical integrated iron and steel plant producing about a million tons of iron and steel :

Coking (metallurgical) coal	1·4	million tons approx.
Steam coal ...	0·4	,, ,, ,,
Gas coal ...	0·19	,, ,, ,,
	1.99	,, ,, ,,
	say 2 million tons	

Specifications

Metallurgical coal :

It is the quality of metallurgical coal that directly has a bearing on the quality of coke, the two most important factors in the latter being its mechanical strength and purity determined by mainly (*i*) caking index and (*ii*) ash content. Coal used for metallurgical purposes in India has a caking index of over 15[33]. Ash in the coal acts simply as an inert material in the burden of the blast furnace, involving increased consumption of fuel and flux adversely affecting the economics of the operation. It is found that under identical operating conditions with each 1% increase of ash in the coking coal there is[34]:

(*i*) an increase in coke consumption by 4-5%;
(*ii*) an increase in limestone consumption by about 5% ; and
(*iii*) a decrease in production by 3 to 6%.

29 Krishnan, M. S.; Bull. G.S.I., No. 9, (Econ. Geol.), p. 172 and 182.
30 Krishnan, M. S. and Aiyengar, N. K. N.; Bull. G.S.I., No. 8 Econ. Geol.); p. 56.
31 Krishnan, M. S., Bull. G.S.I., No. 9 (Econ. Geol.), p. 168.
32 Ibid, p. 139.

33 Tata Index 15 is roughly equivalent to 22·8 British Standard Index.
34 Memorandum on the conservation of metallurgical coal by the Tata Iron and Steel Company Ltd., and the Indian Iron and Steel Company Ltd., 1949.

Sulphur is one of the most undesirable elements encountered in ferrous metallurgy, being responsible for many of the difficulties in blast furnace operations. Most of the sulphur in the charge is derived from the fuel. Fortunately Indian coals are low in sulphur, 0·5%, as compared to 1·3% S in British and American cokes, but the advantage of low sulphur content of Indian coals is greatly offset by the unfavourable composition of the blast furnace slags which carrying as high as 23–28% Al_2O_3 are poor desulphurisers. American and British slags rarely contain over 15-16% Al_2O_3 and are twice and thrice more efficient desulphurizers respectively than the Indian slags[35].

Phosphorus is another of the most undesired elements in a coking coal as it cannot be removed in the blast furnace slag and finds its way into the open hearth. Indian coals as a rule are high in P, containing about 0·12 to 0·15%. This, therefore, calls for use of large quantities of very high grade limestone in the open hearth process and additional fuel for melting these slags[36].

The specifications for metallurgical coal as appearing in the report of the Committee on Conservation of Metallurgical Coal are:

Ash	Not more than 15% (though up to 16–17% is being used at present)
Volatile ...	About 30% on ash-free basis and 26% in coal having 15% ash.
P	not more than 0·15%.
S	not more than 0·6%, but a slightly higher S can be tolerated if ash is much lower than specified above.
Coking index ...	15 min. (Tata Index) or 22·8 British Standard Index.
Swelling properties	not of much importance as the coals specified are free from harmful swelling properties.

The report however recommended that until coal with 15% of ash is made available to the steel industry, it should accept coal up to 17% in ash content.

In the interest of conservation washing of all coking coal is being adopted as a standard practice.

Coke made out of a coal of approximately the above specifications has about the following analysis and is considered as good coke:

Ash	21·12%
F.C.	78·0%
P	0·18%
S	0·57%
Vol. matter	0·88%
Moisture	1·4%

Steam coal

Apart from coal used for metallurgical purposes and for gas production that used for steam raising may be called steam coal. There are no very strict specifications for steam coal, this being essentially used for steam raising in boilers by virtue of its calorific value. Thus the higher calorific value the better is the coal considered. The other important factor in its evaluation is ash content. The ash content should not be very high, nevertheless it is proposed to use coal carrying about 30% ash, for steam raising. Steam coal does not have to possess any coking properties and could be entirely non-coking, though an appreciable part of the coal that goes for steam raising in the steel industry at the present day is low grade coking coal. The average approximate chemical composition of coal used for steam raising at the steel works at Jamshedpur is:

Ash	19·8% to 23·7%
B.T.U.	11,170 to 11,725
Volatile matter	27·9% to 30·7%
F.C.	48·3% to 49·5%
Moisture	1·9% to 2·5%

Gas coal

For gasification purposes a very high volatile content in the coal is desirable. Coking properties are immaterial, but normally coals with very high volatile contents are in the ordinary sense of the word "non-coking". Gas coal used at Jamshedpur analyses:

Volatile matter ...	37·3%
Ash ...	14·8%
B.T.U. ...	12,240
Moisture ...	2·4%
F.C. ...	47·8%

Occurrences

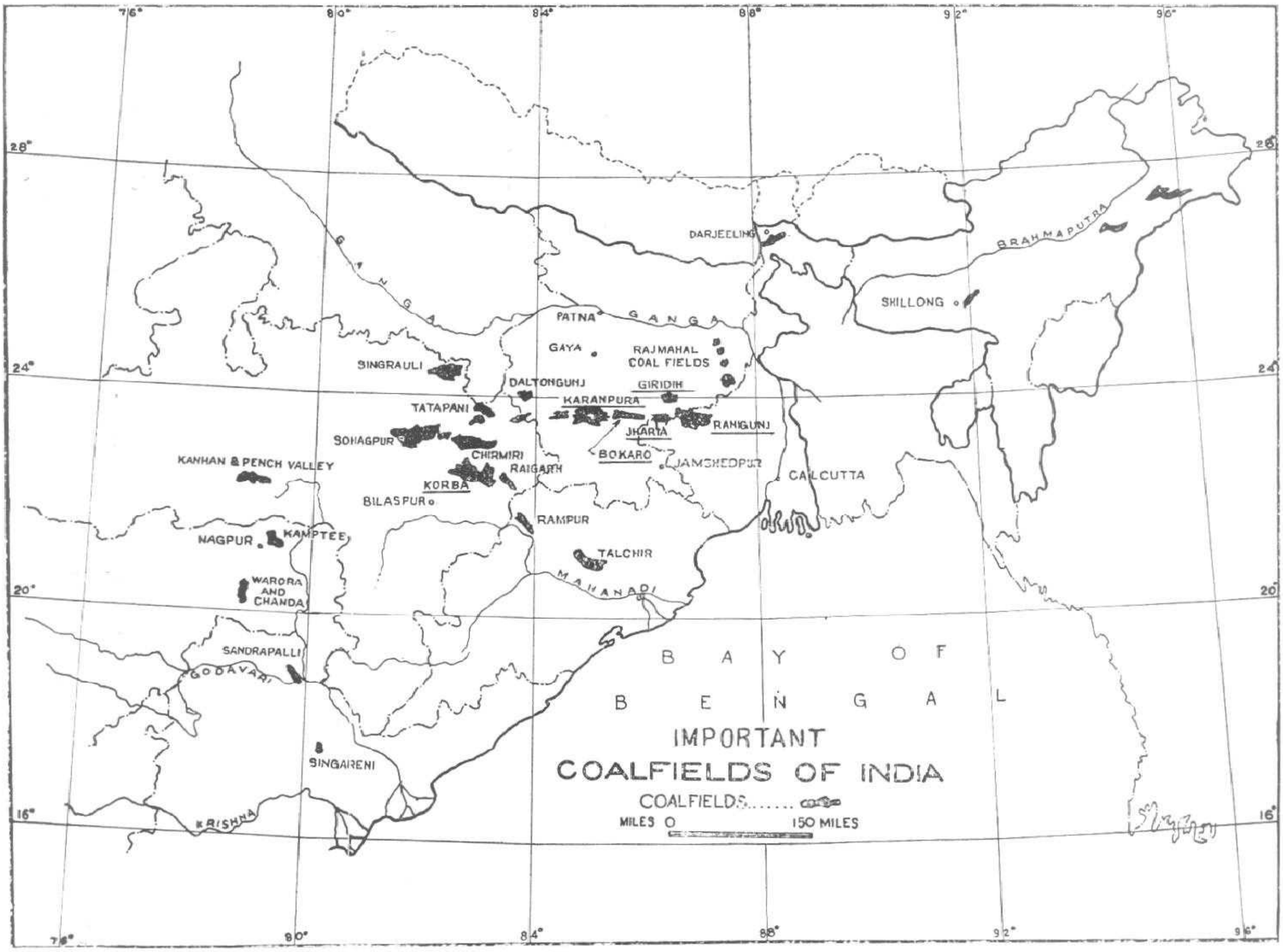
Metallurgical coal:

Coking coal reserves in India are confined largely to Bihar and Bengal and belong to the Gondwana age. Some strongly coking coal is available in Assam, but it is very high in sulphur—2 to 4%—and is hence not very suitable for smelting iron ore. The other great disadvantage with the Assam coal is the problem of transportation. The total reserves of coking coal in India are[37]:

	Million tons		Beneficiated million tons
Selected A	500	Coking coals with 15 per cent ash or less	500
Selected B	750	Coking coal with 15–17 per cent ash or less	600
Grade I and II	1,500	Coking coal with over 17 per cent ash but which could be beneficiated.	1,000
		Total ...	2,100

[35] Ibid, p. 12.
[36] Ibid, p. 13.

[37] Report of the Committee on Conservation of Metallurgical Coal, 1950, p. 50.



Assuming 75 per cent recovery of coal by the modern mining methods, the total recoverable coal according to the Committee is 1,600 million tons. With this 1/4 of weakly coking coal may be blended making the total figure of coal available for coking 2,000 million tons[38].

The important fields where the coking coal reserves are located are Jharia, Raniganj, Giridih and Bokaro. Besides the strong coking coal available in these fields, weakly coking coal is amply avilable in South Karanpura, Ramgarh, Kanhan Valley and Korba.

Very little of the semi-coking coals of Raniganj, Karanpura and Ramgarh are used for blending purpose at present though these are likely to be appreciably utilised for the purpose in the near future.

[38] Ibid

Jharia

Jharia coal field is the most important of all the coal fields of India, being responsible for the best part of the production of coking coal in India. Most of the coal, specially from the higher seams, is strongly coking. The total reserves of coking *in situ* coal is about 1,200 million tons of "Selected" A, B and 760 million tons of grades I and II[39].

Raniganj

Raniganj is famous for its gas coals; nevertheless it also possesses coking coal. Laikdih seam, for example, carries one of the finest coking coals in India with very low phosphorus content—about 0·04%. The estimate of total reserves of coking coal is

[39] Ibid, p. 46.

about 103 million tons, on a conservative side[40]. Usually the Barakar measures carry coking coal while gas coal occurs in the Raniganj measures.

Giridih (Hazaribagh)

Giridih is a small coal field carrying only three seams but the coal is of very high grade. The lower Karharbari seam, about 10 to 24 ft. thick, carries one of the finest metallurgical coals available in India with an extremely low phosphorus content, as low as 0·005[41]. All Giridih coals are low in sulphur and are of good coking quality. The estimated reserves are about 17 million tons[42].

Bokaro

A few miles to the west of Jharia is the 40-mile long Bokaro coal field carrying coal seams up to 123 ft. in thickness. Some of the coal of the western field is strongly coking. In the three most important seams in the western part of the field, which have so far been proved, 88 million tons have been estimated[43]. The ash content being somewhat high, most of the coal requires washing. Besides the West Bokaro field, the East Bokaro field is now going into importance, the most important seams being the famous Kargali and Bermo. The coal from these seams, though not strongly coking, is somewhat high in ash—about 27%—is fit for metallurgical purposes on washing and blending. The reserves in Kargali and Bermo have been estimated at 583 plus 220 million tons respectively or 805 million tons and are considered to be of great potential value.

South Karanpura, Ramgarh and Kanhan Valley coal fields

The coal fields of South Karanpura, Ramgarh and Kanhan Valley carry less important reserves of weakly coking coal. Practically the whole of the present production from these fields is used for steam raising.

The Arigada and Sirka seams of South Karanpura are low in ash (under 20%) with a low coking index. The estimated reserves are about 450 million tons, but these reserves have not been taken by the Committee on Conservation of Metallurgical Coal as coking coal reserves. Likewise the 188 million tons reserve in Ramgarh is also not taken into account by the Committee as the coal is of medium quality and weakly caking. Similarly 66 million tons reserve of weakly caking Kanhan Valley coal though low in ash—17%—is not considered by the Committee as coking coal.

Steam coal

Besides the Bihar and Bengal coal fields mentioned above which also give steam coal, other coal fields of Bihar and Bengal and those of Madhya Pradesh and Orissa carry good quality bituminous Gondwana coals. Tertiary coals are available in Assam, many of which are strongly coking, and North-West India, but these either because of their unfavourable locations or their quality—high sulphur—are not of much importance to the Indian steel industry. The coal used for steam raising in the Indian steel industry is at present supplied chiefly from Jharia and Raniganj. With the coming of the new steel plants in the Second Five Year Plan, coals from various fields in Bihar and Madhya Pradesh are also likely to be obtained. Korba coal field in Madhya Pradesh is being developed for supplies to the steel plant in Bhilai. The steel works at Bhadravati, Mysore, having no access to natural coal has to make the best of its forest resources.

Gas coal

Gas coal for the industry is chiefly obtained from Raniganj measures of the Raniganj coal fields. This is the only coal field in India which meets the country's requirements of gas coal. Volatile matter in the coal ranges from 37%. The ash is rather on the low side ranging from 9 to 15%, in exceptional cases going up to 20%. About 15% seems to be a good average for ash.[44]

FLUX

The function of the flux is to take up the impurities such as silica, alumina, etc. from the ore and fuel and form with these a light fused material which floats on the surface of the molten metal and which can be removed as slag. It further helps to lower the temperature of smelting. The most important raw materials which are used as flux are limestone and dolomite. In the early years of the steel works at Jamshedpur, dolomite was used quite satisfactorily as flux in the blast furnace. However, the relatively high consumption of coke was a disadvantage. Later, on account of this handicap the practice was dropped and limestone was used instead. At the present day limestone is invariably used all throughout India as flux because of the economics involved in its utilisation. But in view of the deficiency, in this country, of high grade limestone and in the absence of suitable methods of beneficiation of low grade stone, the iron and steel industry may have to take a certain proportion of dolomite in the blast furnace in the not very far future. In fact the works at Jamshedpur have already taken a step in this direction. With the use of washed coal and ore, utilisation of dolomite as a part of the flux in the blast furnace is likely to be no less economical than the practice of using 100% limestone flux with unwashed coal.

---

40 Ibid, p. 46.
41 A communication from the Director, Fuel Rusearch Institute to Mr. B. Sen.
42 Report of the Committee on Conservation of Metallurgical Coal, p. 47.
43 Ibid, p. 47.
44 Gee, E. R.; Records G.S.I., Bull. Econ. Minerals, No 16, 1948, p. 86.

Specifications

At the outset it may be stated that limestone carrying about 20% MgO or more may be considered as dolomite and when MgO is below 20% but over 10% as dolomitic limestone.

Specifications for limestone used in the blast furnace are less rigid than for stone used in steel melting shops. Silica and alumina in a flux are essentially inert materials which require additional flux and coke to remove them. Magnesia being a refractory material, its presence in flux requires higher temperature for smelting involving higher fuel consumption. Thus limestone with low MgO content is usually preferred though stone up to 4% MgO and over is being used in some of the Indian blast furnaces. There are no other appreciable impurities in limestone which could seriously affect its use in the blast furnace. Details of the specifications would vary with the smelting practices in individual plants and with the availability and the nature of the other raw materials. Limestone of the following analyses is, however, used at present :

		Tata Iron and Steel Company		Mysore Iron and Steel Works[15]	
CaO	...	47·5		48·3	
SiO_2	...	5·3	6·6	6·8	7·65
Al_2O_3	...	1·3		0·85	
MgO	...	4·1		1·86	

With the coming in of the new steel plants during the Second and Third Five Year Plans, the specifications of the blast furnace grade limestone are likely to be relaxed in some cases as known reserves of high grade limestone are limited. Stone with total acids up to 10% will have to be partly or wholly used as flux in blast furnaces.

As already mentioned, specifications for limestone used in the open hearth furnaces are more rigid than for the blast-furnace-grade stone though the general principles for determining the specification are more or less the same in both the cases. Analyses of limestone used in the open hearth furnaces of the Tata Iron and Steel Company and Mysore Iron and Steel Works are given below :

		Tata Iron & Steel Company		Mysore Iron & Steel Works[46]	
CaO	...	48·89		49·60	
SiO_2	...	3·8	5·89	3·57	5·37
Al_2O_3	...	0·96		1·8 (includes Fe_2O_3)	
Fe_2O_3	...	1·13		—	
MgO	...	3·8		3·0	

As regards the requirements of limestone, where no self-fluxing ores are available as in India, a figure of 800–900 lb per ton of pig iron may be taken as the rate of consumption. Thus for a plant producing about one million tons of pig iron, over 440,000 tons of limestone would be required. In the steel melting shops the rate of consumption of limestone is approximately one fourth of that in blast furnace, roughly 200 lb per ton of steel. Thus for a steel plant producing about 1 million tons of steel, about 100,000 tons of limestone would be required. These are only guide figures. The actual consumption would vary depending on the quality of the various raw materials used.

Occurrences

Limestone and dolomite occur throughout India but it is only at a few localities that flux grade stone is available.

The most important occurrences of limestone and dolomite suitable for use in the iron and steel industry are in Sundargarh District of Orissa. These deposits supply almost the entire quantity of flux to the existing steel industry in India with the exception of the small iron and steel plant at Mysore. Limestone and dolomite of Sundargarh are of Archean age and occur associated with other calcarious and phyllytic rocks in what has been termed as the great Gangpur Anticlinorium by Dr. M. S. Krishnan. Because of the proximity of this zone to the iron and steel plants the importance of it is not only likely to be maintained but considerably increased in the near future. The plant at Rourkela will be getting its flux supplies from this area while the Durgapur plant and possibly the proposed plant at Bokaro would also have to depend upon Gangpur for limestone.

Limestone is also reported to occur in the Sabari River near Kottametta in the Koraputt District of Orissa.[47] Though the grade is apparently suitable for utilisation as flux, its reserves are not known. Transport also appears to be a problem. Cuddapah limestone is known to occur in Sambalpur District but it is somewhat argillaceous, siliceous or dolomitic and is hence unsuitable as flux.

Though cement-manufacture grade of limestone occurs abundantly in Bihar, occurrences of flux-grade stone are apparently limited to Archean deposits in some parts of Chota Nagpur. These are scattered deposits and in some respects their scattered nature might preclude bulk supplies being obtained from one source. Some of the stones are high in MgO being often associated with dolomitic limestone and dolomite. These could, however, be used on blending with low MgO limestone from Sundargarh. Exhaustive figures regarding the reserves of this low insoluble limestone are not readily available.

Large deposits of limestone are known to occur in Madhya Pradesh, particularly in Jabalpur District, Katni being the heart of the limestone industry in Madhya Pradesh. Most of the Vindhyan limestone of Jabalpur is used in the manufacture of cement or lime. Nevertheless within the Vindhyan

[45] Krishna Rao, D. V. ; The New Steel Plant of Mysore Iron and Steel Works, Bhadravati, India, Journal of Iron and Steel Inst., No. II, 1938, p. 163–183.

[46] Krishna Rao, D. V. ; The New Steel Plant of Mysore Iron and Steel Works, Bhadravati, India, Journal of Iron and Steel Inst., No. II, 1938, p. 163–183.

[47] Brown, J. C. and Dey, A. K. ; India's Mineral Wealth, 1955, p. 327.

deposits of cement grade and poor limestone, lie hidden beds and lenses of high grade stone suitable for use as flux. One such occurrence of flux-grade stone is at Jukehi near Katni where about 7 million tons of good limestone have been estimated. Intensive and extensive prospecting may prove the Jukehi-Kaimur limestone belt, which extends southwestwards to Rewa, to be a potential source of high grade limestone for the metallurgical industry. But the great handicap which this limestone suffers is its distance from the established and the proposed steel plants. For this very reason flux from Jukehi-Kaimur is not likely to assume any importance in the foreseeable future. This area, incidentally, offers an excellent field for expansion of the cement industry. However Cuddapah limestones of Drug District are likely to assume importance in the near future. Already the steel plant at Bhilai has planned to get its supply of limestone from Bhanpuri.

Mohtara in Bilaspur is estimated to contain about 10 million tons of good flux stone[48]. In Nandgaon, to the west of Drug District flux grade Cuddapah limetone stretches for about 30 miles between Khalewa and Arjuni. The reserves are expected to be high. There are also deposits of good flux grade Cuddapah limestone at Baraduar. But the known deposits there have been worked out. Extensive geological explorations may however help to disclose some hidden beds and lenses.

Andhra is very rich in limestone, the greatest concentrations of which are in the districts of Cuddapah and Kurnool. These limestones are low in magnesia and belong to the Kurnool and Cuddapah age. Narji limestone is typically a fine grained grey or buff stone which lies towards the base of Kurnool series, overlying the Cuddapah system. It is possibly the equivalent of lower Vindhyan limestone of Central India. Narji stone is by far more abundant and important than Vempalli limestone which is of lower Cuddapah age and is often dolomitic. Narji limestone follows a straight trend from near Cuddapah, northwestwards through Cuddapah and Kurnool Districts to Tungabhadra River and beyond. The reserves of these limestones are estimated at about 3,600 million tons in Cuddapah District and about 8,000 million tons in Kurnool District[49]. These limestones, at present, are employed in the cement industry, but some of the better grade stones analyse

$SiO_2+Al_2O_3$	...	about 4%
MgO	...	0·4 to 4·4%

There is reason to believe that an ample reserve of flux grade stone may be lying hidden within these immense deposits. Nevertheless the possibility of these stones being actually used as flux in the industry is rather scanty mainly due to its distance from the consuming centres.

In Madras occurrences of good limestone are in Salem and Madura Districts. In Salem, crystalline Archaean limestone occurs at numerous localities. Krishnan[50] here estimates, on a very conservative side, about 700,000 tons of limestone and dolomite up to a depth of 10 ft. or roughly about 7 million tons within a depth of 100 ft. A good part of the limestone could be used for metallurgical purposes. There are occurrences at Madura of high grade crystaline limestone. The width of the bands at Madura are much greater than those at Salem; one of the bands at Sunnambur is about 300 to 700 ft. wide. The estimates at Madura as given by Krishnan[51] amount to over 3 million tons of good quality limestone. Salem deposits are more favourably located than the Madura deposits. Salem limestone may, therefore, find use in the steel industry earlier than Madura stone.

Shimoga, Chitaldrug, Tumkur and Mysore Districts of Mysore State have moderate reserves of Archean limestone suitable as flux in the iron and steel industry. It is from the Bhadigund quarries in Shimoga District that the supplies of flux stone are made to the Mysore Iron and Steel Works. About 50 million tons of flux grade stone are estimated in Mysore[52]. These limestones carry usually about 2% MgO and as such are even lower in magnesia content than the Sundargarh limestone of Orissa.

Excellent flux grade limestone occurs in large quantities in Sylhet, now in East Pakistan. Its approximate analysis runs[53]:

SiO_2	...	...	0·5%
$Fe_2O_3+Al_2O_3$	...	...	1·7%
CaCO	...	...	about 95·4%
MgO	...	...	1·8%

Transport of it to the steel works is a major problem which has stood in the way of development of these deposits. For this very reason the chances of Sylhet limestone being utilised in the iron and steel industry are rather remote.

Low insoluble limestone also occurs in Yeotmal District of Bombay. Here the $SiO_2+Al_2O_3$ content is about 4%[54], with MgO as low as 0·2%. But other limestones in the same district are highly magnesian and at places range to dolomite. Vindhyan limestones occur in Chanda District, about 6 miles north of Warora. These are high grade and carry as low as 2% insolubles. Flux grade limestone is also available in Kutch peninsula. Except perhaps from the Chanda deposits, use of limestone from Bombay in the iron and steel industry is ruled out because of the long rail haulage involved.

Low insoluble limestone carrying as low as 1·5% silica plus alumina is being mined in Rajasthan for the purpose of lime burning, but again the long haulage involved debars its use in the steel works.

48 Brown, J. C. and Dey, A. K.; India's Mineral Wealth, 1955, p. 329.

49 Ibid, p. 331.

50 Krishnan, M. S.; Mineral Resources of Madras, Memoirs; G.S.I., Vol. 80, 1951, p. 187.

51 Ibid, p. 189–190.

52 Brown, C. J. and Dey, A. K.; India's Mineral Wealth, 1955, p. 335.

53 Dey, A. K.; A note on some high grade limestone in India; Jr. of Sc. and Ind. Res., July 1946, p. 19.

54 Brown, J. C. and Dey, A. K.; India's Mineral Wealth, 1955, p. 330.

To sum up, limestone and dolomite mainly occur in Sundargarh District of Orissa, Chotanagpur region of Bihar, Kurnool and Cuddapah Districts of Andhra, Salem and Madura District of Madras, Jabalpur, Drug and Bilaspur Districts of Madhya Pradesh and Chitaldrug, Shimoga and Tumkur Districts of Mysore. Of these, Sundargarh deposits are by far the largest and the most important as flux stone. Chotanagpur and Drug deposits, though not so extensive, are likely to be developed in the near future, whereas the development of Kurnool, Cuddapah, Salem and Madura deposits may take some time until iron and steel plants are established in South India. Shimoga District, of course, supplies the need of the existing steel plant at Bhadravati.

Limestones from Rajasthan, North and North-Eastern India and from deposits other than Chanda in Bombay are not likely to find use in the iron and steel industry in the foreseeable future chiefly because of the long rail haulage involved.

MANGANESE ORE

Manganese ore is of vital importance to the iron and steel industry though it is not required in large quantities. It could be said that no steel or iron as used today could be made without manganese ore as it imparts to steel certain qualities of ductility and strength. Manganese is used (1) in the blast furnaces in the shape of natural ore and (2) in the steel melting shops in the form of ferro-manganese.

The chief minerals of Indian manganese ore are Braunite, Jacobsite, Hausmannite, Psilomelane, Cryptomelane, Pyrolusite, Manganite, Wad, Rhodonite, Spessartite, etc. Besides these minerals the ores also carry gangue minerals such as SiO_2, Al_2O_3, Fe, P, etc. Of the manganese minerals, supergene oxides, viz., Psilomelane, Cryptomelane, Pyrolusite, etc. mainly constitute the ores which are used today in the iron and steel industry in the country. Braunite, Jacobsite and Hausmannite, etc. are also being reduced in electric furnaces for the manufacture of ferro-manganese.

Specifications

Ores used in the blast furnaces for making pig iron carry about 30% Mn, about 20% Fe, 7% SiO_2, 6% Al_2O_3 and about 0·08% P. On the other hand ores used in the manufacture of ferro-manganese are of a higher grade. They should have a manganese/iron ratio of not under 6 and preferably even 7·5, if standard grade ferro-manganese is to be made. A committee appointed by the Government of India on the ways and means of setting up ferro-manganese plants in India and on the beneficiations of low grade ores laid down the following specifications of manganese ores for the production of standard grade ferro-manganese:

(*i*) The manganese/iron ratio should be 6 : 1 minimum. It may preferably be 7·5 : 1.

(*ii*) The phosphorus content should not exceed 0·1, but if extremely low phosphorus coke is available for reduction of ore the phosphorus content of the ore may be permitted to go up to 0·15%.

(*iii*) Silica and alumina contents may not normally exceed 8 and 10% respectively, but the total of the two may not exceed 12%.

About 2 tons of high grade manganese ore are required to produce 1 ton of ferro-manganese. Normally, with the type of iron ores used in the country, for the manufacture of pig about 1·3 tons of low grade manganese ore are required for the production of 100 tons of pig. The quantity of ferro-manganese required varies with the nature of the steel required. On an average for a plant producing about 1 million tons of ingot steel, the requirement is of the order of 13,000 tons.

Occurrences

India is one of the richest countries of the world as far as manganese ore reserves are concerned. It stands second only to the U.S.S.R. which claims a reserve of about 550 million tons against a total world reserve of 1,000 million tons[55]. Indian reserves of manganese ore are estimatad at about 100 million of which 60 million tons are of marketable grade[56]. These are distributed mainly in Madhya Pradesh, Orissa and Bihar, Bombay, Mysore and Andhra. A few minor deposits are found in the other states of the country, but these are of no economic importance.

Madhya Pradesh

The manganese ore deposits of Madhya Pradesh occur in an E-W arcuate belt about 130 miles long and of a width of up to 16 miles. As many as 200 deposits have been located in this belt, but the bulk of the ore is confined to about 20 deposits which have been the largest and most regular producers till now. This belt covers the districts of Balaghat, Chindwara, Nagpur and Bhandara. The latter two districts have now gone to Bombay. These four districts put together viz. Balaghat, Chindwara, Bhandara and Nagpur, constitute the richest manganese ore field of India, having an aggregate estimated reserve of the order of 60 to 80 million tons, with about 35 to 45 million tons of 48% Mn ore. Now that Nagpur and Bhandara fall in the State of Bombay, reserves of Madhya Pradesh proper would be considerably reduced. The characteristic features of Madhya Pradesh ores are their relatively low iron contents and hard and lumpy nature. "Oriental Mixture" which

[55] Dehauff, G. L., Jr., Global aspects of manganese ore supply. Symposium Del Manganeso, XX Congresso Geologico Internacional, Mexico, Tomo I.

[56] Sondhi, V. P.; Manganese Ores in India. Symposium Del Manganeso, XX Congresso Geologico Internacional, Mexico, Tomo IV.

is a typical product of the Madhya Pradesh mines analyses

Mn	49·25%
Fe	7·5%
P	0·15%

with a Mn/Fe ratio of 6 : 5

Such ores are well suited for the manufacture of ferro-manganese in electric furnaces.

Orissa and Bihar

The principal occurrences in Orissa and Bihar are located in the Jamda-Koria Valley covering parts of Singhbhum district of Bihar, Keonjhar district of Orissa and Bonai sub-division of the Sundargarh district, also of Orissa. The bulk of the reserves is in Orissa, those in Bihar are of secondary importance. The deposits are spread over a length of over 30 miles from Jamda in Singhbhum running South and then South-West. Most of these deposits are shallow and of supergene origin. Since the ores are intermingled with large amounts of gangue minerals and earth, recovery of high grade ores is low compared to the recovery in Madhya Pradesh. Further, the ores are characterised by high iron content as compared to the ores of Madhya Pradesh. Consequently the ores with a high manganese/iron ratio are not ample, though available. The reserves of manganese ore in this valley have been estimated at 4·5 to 6 million tons. Of this, about 2 million tons may be of grade suitable for the manufacture of substandard ferro-manganese. A typical analysis of first grade manganese ore from this field is: Mn 48·64%, Fe 7·38%, SiO_2, Al_2O_3 3·2% and P 0·12%.

The other sizable deposits in Orissa are in Koraput and Kalahandi districts. These are however mainly of low grade ores which are very high in phosphorus. The average P reported is 0·22 to 0·34%[57]. First grade ore is sparingly available. Thus, although a ferro-manganese plant has already been set up in Rayagoda in Koraput district, it has to depend for supplies of high grade ore from Madhya Pradesh. Estimates of ore in Koraput and Kalahandi are of the order of 1 million tons.

Besides the above mentioned deposits, the only other known deposits in Orissa and Bihar are at Bolangir Patna and Gangpur. Nevertheless these are of little economic value and very little ore is being worked from these areas. There are no other known sizable deposits in Orissa and Bihar.

Bombay

Besides the deposits of Nagpur and Bhandara, referred to above, which now fall within the revised boundaries of the State, other important occurrences are at Panchmahal. Panchmahal ores are fairly low in iron, though the phosphorus is somewhat on the high side. Nevertheless the Committee set up by the Government of India on the ways and means of setting up ferro-manganese plants in India and on the beneficiation of low grade manganese ores was of the opinion that it may be possible to select high grade ores from Panchmahal with relatively low phosphorus for the manufacture of ferro-manganese. The same Committee estimated the reserves at about 1 million tons[58].

Mysore

The manganese ore deposits of Mysore may be divided into two main groups:

(*i*) North Kanara
(*ii*) Shimoga-Chitaldrug-Bellary.

The ores consisting mainly of Psilomelane, Pyrolusite, Wad, etc., occur as tabular or irregular deposits.

The North Kanara ores are extremely low in phosphorus content and as such are of very special value. The Committee just referred to above in their report gave the following analysis of manganese ore from the district:

Mn	...	...	47–54%
Fe	...	...	5–9%
SiO_2	...	...	about 2%
Al_2O_3	...	...	2–4%
P	...	...	0·015–0·03%

These ores occur in an approximately 30 miles long NW-SE belt between Karwar and Dharwar. These are believed to be mainly shallow deposits. The reserves have been estimated at about 2 million tons of which 0·75 million tons may be suitable for ferro-manganese production.[59]

The ores of group (*ii*) and particularly the Bellary ores, like the North Kanara ores, are low in phosphorus which ranges from 0·02 to 0·05% and are well suited for blending with high phosphorus ores from other deposits in India for the production of ferro-manganese. Typical analyses of ores from Bellary area are[60]:

Mn	...	...	39·47–54·39%
Fe	...	...	5·38–19·4%
SiO_2	...	...	0·3–1·0%
P	...	...	0·016–0·033%

It would be seen that the ores are somewhat high in iron though very low in phosphorus. If some economic way of reducing the iron content of the ores is found, these ores would be well-suited for the manufacture of standard grade ferro-manganese.

57 Prasad Rao and Murty, Y.G.K.: Manganese ore deposits of Orissa and Bihar, India, Symposium del Manganeso, XX Congresso Geologico Internacional, Mexico, Tomo IV.

58 Report on the Ways and Means of Setting up Ferro-Manganese Plants in India and on the Beneficiation of Low Grade Manganese Ore by the Committee appointed by the Government of India.

59 Report on the Ways and Means of Setting up Ferro-Manganese Plants in India and on the Beneficiation of Low Grade Manganese Ores by the Committee appointed by the Government of India.

60 Karunakaran, C.; Manganese Ore Deposits of Mysore, India, Symposium del Manganeso, XX Congresso Geologico Internacional, Mexico, Tomo IV.

It would be worthwhile pursuing beneficiation of such ores with a view to reduce the iron content and making the ores suitable directly for the manufacture of ferro-manganese for special austenitic steels. Shimoga manganese ores are smelted in electric furnaces of the Mysore Iron and Steel Works at Bhadravati for the manufacture of ferro-manganese.

The reserves of run-of-mine manganese ore in Bellary, Shimoga and Chitaldrug are estimated at about 3 million tons[61]. Thus the total reserves of run-of-mine ores in Mysore would be about 5 million tons laying at the disposal of Mysore the lowest phosphorus ores of India.

Andhra

The deposits of Andhra Pradesh are mainly on the eastern coast and located mainly round about Garividi, Kodur, Duvvam, etc., between Vizianagram and Srikakulam. The ores are mainly of low grade, though ores up to 50% have been despatched from here. The bulk of the ore as despatched from these deposits carry Mn 37–46%, Fe 11–15%, SiO_2 6–8% and P 0·2–0·4%[62]. It would bo seen that the ores are very high in phosphorus and are also high in iron. Unless these could be suitably beneficiated, these cannot be used directly for the manufacture of ferro-manganese. The total reserves estimated in these deposits by the committee set up by the Government of India and referred to earlier was 3 to 4 million tons.

REFRACTORIES

Refractories in the present case mean materials which could withstand temperature of 1,400° and higher without fusing and also resist chemical attack, abrasion and spalling. Such materials are much in demand in the iron and steel industry where they are used in various forms, chiefly as bricks to line the furnaces. The most important refractory minerals required in the industry are fireclay, chromite, magnesite, dolomite and limestone. Besides these, Asbestos, Kyanite, Feldspar, Bentonite and Bauxite are also required in very small quantities. Each of these minerals either by itself or in combination with one or more produce a special type of refractory which has a specialised use in the steel industry. For example, fireclay refractories are utilised mainly in lining the blast furnaces. Magnesite bricks are used for lining bottoms of open hearth furnaces, whereas chrome and silica bricks also find special uses in these furnaces. Silica bricks are also used in coke ovens. Dolomite is specially used for fettling furnaces.

[61] Ibid

[62] Straczek, J. A. and Krishnaswami, S.: Manganese Ore Deposits of Vizagapatam District, Andhra, India, Symposium del Manganeso, XX Congresso Geologico Internacional, Mexico, 1956.

FIRECLAY

Specifications

Fireclay like any other clay is a complex aluminium silicate carrying varying proportions of impurities such as silica, alumina, iron oxide, lime, manganese, etc. The effects of the various constituents of the clay on its properties are as follows:

Presence of quartz in a fireclay decreases plasticity and shrinkage and helps to make clay refractory; if coarse, it has to be removed. Silica in colloidal form increases the plasticity. Alumina makes clay refractory. Iron oxides lower fusion temperature and act as flux just like lime, magnesia and alkalies. Lime forms undesirable lumps of quick lime while burning. Carbon is driven off during heating.

Besides the chemical composition of the clay its physical properties are of importance. These are:

(*i*) Plasticity of the moulding property of the clay which permits the clay to be shaped before burning. Non-plastic clays have to be mixed with plastic varieties to give them the desired plasticity.

(*ii*) Shrinkage; if this is high either during the moulding or the burning stage, the clay will be unsuitable for firing.

(*iii*) Fusibility; this should not be below 1,600°C.

The fireclay as used by the Tata Iron and Steel Company for the manufacture of fireclay bricks has the following approximate chemical analysis:

SiO_2 ...	... 50–59%
Al_2O_3 ...	... 25–34%
Fe_2O_3 ...	... 1–2%

Its fusion point is over 1,600°C with the P.C.E. cone ranging from 28 to 33.

Occurrences

Fireclay occurs widely in India. It is mainly associated with coal measures specially of Gondwana age. Excellent fireclays occur in the Raniganj coalfield, in the Surguja coalfield of Madhya Pradesh and the Himgir coalfield of Sambalpur. Tertiary fireclay is also available in the Godavari region and South Arcot district of Madras. Other localities where fireclay has been reported are in the Kasi Hills of Assam, in the Rajmahal Hills of Santal Parganas of Bihar, Karanpura coalfields and in numerous areas of South India. But the more important occurrences which at the moment are of economic value to the iron and steel industry are (1) Raniganj deposits of Bihar and West Bengal, (2) Hazaribagh deposits of Bihar and (3) Belpahar clays of Sambalpur district of Orissa. Large reserves of good fireclay are locked up in the Surguja coalfield of Madhya Pradesh, but these are not likely to be utilised until adequate transport facilities are made available. In Raniganj fireclays belonging to the lower and middle measures of the Barakar series are found in numerous seams, up to several feet in thickness. Fireclays of Jharia coal fields also belong to the same formations as the Raniganj clays and occur in seams of variable thickness. But these fireclays require careful selection and proper blending for successful use.

CHROMITE

Chromite is employed in the preparation of refractory bricks and cement used for lining and repairing furnaces.

The three principal uses of chromite are[63]:

(1) For making straight chrome brick, i.e. without mixing it with any other raw material.
Such chrome bricks are used for special lining of soaking pits in which steel ingots have to be heated before rolling them into semi-finished steel products.
Chrome bricks are neutral materials and hence they are used as a separating layer of bricks between acidic and basic types of refractory bricks, e.g., in the construction of the hearths of open hearth, one starts with firebrick which is an acidic type of refractory, then puts on a course of neutral chrome brick and on the top of it magnesite bricks which are basic in character.

(2) For making composite bricks of chrome and magnesite.
These are the so-called chrome-magnesite bricks used extensively in the steel melting furnaces, particularly in its front walls, e.g., the front walls of duplex plant furnaces.

(3) Chrome ore is ground to fine powder and used as such, as mortar for laying chrome bricks or chrome-magnesite bricks.
Ground chrome ore is also mixed with either fireclay and water or liquid sodium silicate and made into a paste. This paste is used in plastering eroded portions of front wall, thus preventing them from further damage.

Specifications

Chromite used for refractory purposes need not be of a very high grade, but should contain at least about 40% Cr_2O_3 and combined Cr_2O_3 plus Al_2O_3 should be greater than 57%, though over 60% is often preferred. Iron oxide and silica should normally be under 10% and 6% respectively. As regards the physical nature of the ore, as a rule hard lumpy ore is used for making bricks, while the ground material is used for making cement. But refractories engineers do not always agree on this point as a very good hard chrome ore may not necessarily make good refractory bricks under given conditions.

Occurrences

In Bihar chromite occurs associated with ultrabasic rocks in what is called the Singhbhum Chromite Belt about 15 miles west of Chaibassa. More important occurrences of chromite are in Orissa, particularly in the Baula, Sukinda and Dhenkanal regions. There they occur associated with ultrabasics in the Archean rocks in a NE-SW belt. Very large reserves are expected in this region. Although accurate figures of these are not readily available it is believed that the deposits of Orissa constitute the largest concentration of chrome ore in India and possibly one of the largest in the world.

Low grade chrome ore carrying about 26% Cr_2O_3 on an average occurs in the Sittampundi area of Madras. Some of the tests conducted for the refractivity of these low grade ores showed that they began to soften at about 1,700°C[64]. About 220,000 tons of crude ore within a depth of 20 ft. from surface have been estimated in Madras by Krishnan[65].

Nuggihalli schist belt of Hassan District of Mysore is rich in chrome ore. The grade of the ore ranges widely, but could be used mainly for refractory purposes. As these ores are rather high in iron their use for metallurgical purposes is precluded. About half a million tons of various grades of chromite have been estimated in this belt[66]. The best deposits are at Byrapur and Bhaktarahalli, both of which are worked by the Mysore Government. There are deposits of chromite also in the Mysore and Chitaldrug districts, but these are not of much value.

Minor occurrences of chrome ore are known in the Savantvadi and Ratnagiri districts of Bombay. But these are of no value to the industry at the present time.

MAGNESITE

Specifications

Magnesite is used either directly in preparing raw magnesite bricks, or more often is calcined at 800 to 850°C or dead burnt at 1,600/1,800°C before making refractory bricks. Dead burnt magnesite is also used as granules or peas. These are often mixed with ground dolomite and rammed into the basic open hearth furnace bottoms as a concrete. The most important use of magnesite refractories is in the basic open hearth furnace. The modern tendency, however, is to replace straight magnesite bricks by chrome magnesite bricks because of the latter's better load bearing capacity and thermal shrinkage resistance[67].

The raw magnesite which is used in the steel works at Jamshedpur for the manufacture of bricks has the following analyses :

MgO	...	...	46·3 –46·7 %
SiO_2	...	...	0·9 – 1·2 %
Al_2O_3	...	...	up to 0·14%
Fe_2O_3	...	...	0·28 –0·72%
CaO	...	...	up to 1%
Loss	...	...	50·7 –51·6 %

(Of late there has been some relaxation in the SiO_2 content).

63 Mitra, H. K ; A personal communication to B. Sen.

64 Krishnan, M.S. ; Chromite, Bul. Geo. Sur. Ind., Series "A", Econ. Geol. No. 7, 1953, p. 24-25.

65 Ibid, p. 25.

66 Ibid, p. 26.

67 Mitra, H.K. ; Recent Advance in Refractory Technology, Inst. Chemicals (Ind). Proc. Vol. XII, Parts III & IV, 1940, p. 108.

Occurrences

The magnesite used in India for refractory purposes comes mainly from Salem in Madras district, where India's largest and best deposits occur. In the Chalk Hills, as the hills in which magnesite is found are called, the mineral occurs as veins and lenses of different sizes in ultra basic rocks. Mining is essentially by open pit method and although some of the veins continue to depths no underground mining has been resorted to, so far.

Occurrences of a less important nature but which are of value to the industry are in the Mysore district of Mysore State. There are occurrences of magnesite also in U.P., but these are of no value. The total reserves of Indian magnesite are estimated at about 100 million tons[68] up to a depth of 100 ft. from the surface. Of these the bulk of the concentration is in the Chalk Hills of Salem.

DOLOMITE

The crushed dolomite either in its raw state or more usually after dead burning is used as a refractory material in the manufacture of steel. The calcined material after crushing is suitably sized and after mixing with tar or similar other substances is used for ramming hearth bottom. This is known as fettling. Though less stable than magnesite, dolomite is used in the furnaces mainly because it is cheaper. Dolomite used for refractory purposes is usually purer than that used as flux. The refractory dolomite used in the works at Jamshedpur, has the following analysis:

MgO	...	...	20·85%
CaO	...	...	30·26%
SiO_2	...	...	1·92%
Fe_2O_3	...	...	0·7 %
Al_2O_3	...	...	0·6 %

A dense fined grained variety of dolomite is preferred particularly because of its stability in the furnaces. The coarse-crystalline variety has a tendency to break up while calcining in a rotary furnace.

Occurrences

As a rule limestone and dolomite occur in the same geological formation. The occurrences of limestone have been described elsewhere and it could be said in general that it is in the same localities that dolomite for refractory uses could also be found. The best known Indian occurrences of dolomite are in Sundargarh district of Orissa, where a number of such deposits have been located. Some of these are far from the present rail head while others are not of sufficiently high grade stone to be of use for refractory purposes. The most important source from which dolomite for refractory purpose at present is obtained is Panposh and Birmitrapur. Panposh dolomite, because of its physical nature, is found to be more suitable for refractory purposes than the coarse-crystalline varieties of Birmitrapur. There is no doubt that with the setting up of new steel plants, even the Birmitrapur variety of dolomite will find extensive use as a refractory raw material. Besides the occurrences in Sundargarh, there are only a few known occurrences in the rest of India of dolomite which can be suitably used for refractory purposes. One such known occurrence is at Baraduar in Bilaspur district (Madhya Pradesh) from where high grade fine grained Cuddapah dolomite is supplied to the steel plant at Jamshedpur.

Although the known occurrences of the dolomite are few, there is little doubt that intensive investigation of the known limestone and dolomite country of Orissa and Madhya Pradesh will prove good reserves of high grade dolomite.

SUMMARY AND CONCLUSIONS

India is well endowed with most of the principal raw materials required for the production of iron and steel. Nevertheless, there are some minerals such as iron ore, which are in preponderance over the others. There are others such as limestone which may be considered to be comparatively in short supply. The following table shows at a glance the position of the three most important raw materials in respect of their capacity to produce ingot steel:

Raw materials	Reserves	Maximum quantity of ingot steel that reserves of these raw materials could help to produce
	Million tons	Million tons
Iron ore	21,000	10,000–12,000
Coking coal	2,000	1,500
Flux limestone (up to 6% insolubles readily available)	100	200

At the end of the Second Five Year Plan, the country will be producing about 6 million tons of ingot steel per annum. At this rate iron ore will last 1,600 years, and coking coal over 200 years, but the readily available flux limestone would be adequate for a little over 30 years, unless new deposits are located and proved within economic distances from the steel works. At the end of that period of 30 years, advanced technology, particularly in the beneficiation of limestone, would make the lower grades of limestone which are at present considered unusable, suitable as flux. Replacement of limestone by dolomite as flux should also be considered as limestone reserves get depleted. Dolomite suitable as flux is fairly abundant relatively close to the steel works and further large reserves of limestone and dolomite of lower grade are also abundant

68 Aiyengar, N. K. N.; Bull. Geol. Sur. Ind., Series A, Econ. Geol. No. 6, p. 42.

which could be suitably beneficiated. The steel industry should not be complacent on the probable advance of technology and it is imperative that from now on extensive and intensive geological exploration of the known areas of limestone and dolomite be undertaken. This would help to discover not only some hidden additional reserves of flux grade stones but also help to know the areas of marginal grade stones which could be suitably beneficiated in the future. The shortage of suitable limestone has been felt both by the steel and cement industries and the latter has already taken steps to beneficiate low grade limestone.

From the point of view of availability of raw materials the following are the centres round which the iron and steel industry can develop and grow:

(*i*) *West Bengal-Bihar*: comprising areas around Durgapur and Asansol.

(*ii*) *Bihar*: Hazaribagh district including Bokaro.

(*iii*) *Bihar-Orissa*: comprising Singhbhum-Keonjhar-Sundargarh areas. It includes Jamshedpur and Rourkela.

(*iv*) *Madhya Pradesh-Bombay*: comprising parts of Drug, Bhandara and Chanda.

(*v*) *Mysore*: includes Chickmagalur-Chitaldrug-Shimoga-Sandur areas, and

(*vi*) *Madras*: around Salem.

Acknowledgment

The author wishes to express his grateful thanks to Mr. Balaram Sen for having inspired this work and for enlightening discussions, to Mr. N. C. Nandy for having critically gone through the paper and to all those who helped in its preparation.

DISCUSSIONS

Mr. T. Krishnappa, Mysore Iron and Steel Works: I am sure Mr. Engineer's paper will serve as a very valuable source of information regarding the raw materials in India. As we are now going to manufacture special steels in India we will need ferro-alloys like ferro-tungsten, ferro-molybdenum, ferro-vanadium, etc. I would like to know what is our position regarding the raw materials required for these alloys.

Mr. B. B. Engineer (Author): We have very large resources of high metallurgical grade reserves of chrome ore in Orissa, particularly in the Bawla and Sukinda areas. The reserves have not been very clearly estimated but they are supposed to be the largest in India and compare very well with one of the very best in the world. As regards ferro-tungsten we do have occurrences of wolfram particularly in the Bankura district of Bengal and in Jodhpur, Rajasthan, but these are known to be small in size and low in grade. I suppose we shall have to do some research on it and establish certain facts to know more about its possible utilisation. The position of ferro-manganese has, of course, been well established and dealt with at length in my paper.

Mr. P. I. A. Narayanan, N.M.L. Jamshedpur: Mr. Engineer has dealt at length with our reserves of iron ore, coal and limestone and has said that the situation regarding limestone is not satisfactory. As sintering has now come to stay and more and more sinter will be used for the blast furnace charge in future, I wonder why we should not start using our low grade limestone after beneficiating and getting it in the form of a fine powder suitable for production of self-fluxing sinter. The Associated Cement Companies have already started beneficiating limestone for the manufacture of cement; two plants are already in operation and a third one will start within a very short time. I am sure such steps will considerably help in increasing our reserves of limestone.

Mr. D. N. Sharma, The Tata Iron and Steel Co. Ltd.: I endorse the views expressed by Mr. Narayanan on increasing our reserves of limestone. As our ores have a high alumina content, dolomite could be used and as a matter of fact it is time that our steel plants start using more dolomite and less limestone.

Mr. T. Krishnappa, Mysore Iron and Steel Works: The position of coke in India has already been discussed by many speakers. The manufacture of ferro-alloys which is now being taken up on a large scale will require coke of very low ash content. I would like to know if there is any scope in the Indian coke industry to produce such a coke or if any work has been undertaken in this direction.

We also require anthracite for the Soderberg electrode in the Tysland hole furnaces used for the manufacture of ferro-alloys. Anthracite is not locally available. Will the author kindly let us know if any steps are taken to examine the suitability of Indian raw materials for this purpose.

Dr. A. Lahiri, Director, C.F.R.I., Jealgora: Referring to the question of coke for manufacture of ferro-alloys, I would say that it is possible to prepare it, provided we are clearly told of what is exactly required.

For the past one or two years, for example, there has been some enquiry for the production of a coke to be used for carbide manufacture and in this case a very low phosphorus and very low ash coke were required. We have been able to prepare it in certain integrated type of plants but there is always the extra cost involved. It is possible to prepare coals with say 5% ash so as to get 8 to 10% ash in the coke and with very low phosphorus but the cost of production would be of the order of about 80 to 90 rupees a ton and selling price might reach 100 to 110 rupees a ton, if only sized coke is required. Obviously, price is the main factor to be considered in case of such requirements, otherwise we could have completely ashless carbon prepared from coal. We developed a process at the C.F.R.I. for extracting out the ash by treatment with anthecen oil and by filtering off the ash, we could get coal produced in this way with about 0·01% ash. That has of course to be further treated for coking and possibly subjected to high temperature treatment to make it suitable for any particular use. But unless we get your exact specifications it is difficult to give the economics and resources. If very small quantities of any particular type are required it will be difficult to persuade anybody to make that coke. In the carbide industry, for example, they are only wanting ten to twenty tons of a specified quality of coke and nobody is prepared to manufacture it. If there is a substantial demand and if the economics can bear it, these kinds of coke could certainly be produced. We have done quite a lot of work on these lines but it has not been put in practice due to lack of firm demand and lack of willingness to pay for it. Recently we have actually made a wagon-load of coke in our pilot plant by special methods of washing. The coke contained 8% ash with 0·003% phosphorus and we could have made it still lower had we wanted, but again cost factor comes in and has to be considered. If we are informed of any particular requirement in quantity and in quality we shall certainly be able to prepare a scheme for getting that particular coke.

Mr. B. V. Mahabale, Mysore Kirloskars: Dr. Lahiri's previous remarks on the reserves of metallurgical coal in India are indeed very encouraging. He has further said that he can suggest ways to prepare the right type of coke for each foundry. I need not say how much this will help the production metallurgists to give good castings, but unfortunately this is not actually coming up in practice. Will Dr. Lahiri be kind enough to tell us why his plans are not given a concrete shape at present?

Dr. A. Lahiri, C.F.R.I., Jealgora: Again in this connection the main trouble has been that no assessment was made on the demand for coke. No one knows how much of it would be required and of which quality. There has not been any conscious or intelligent demand from the side of the consumer to get a particular coke and as a result of it most of the merchant coke ovens, today, are more than 30 years old; they have no preparation plant and are practically outmoded and outdated. Only about 2 or 3 years ago we carried out a survey. You will be surprised to hear that out of 1,700 questions we circulated to the registered foundries only 200 brought replies. In spite of this lethargic attitude of the consumers, we carried out a very long campaign as a result of which a special committee was appointed by the Government for assessing the demand for foundry coke. I am happy to say that it was then decided to install a 1,000-ton a day coke oven at Durgapur which is now on heat and will go into production from 26th February 1959. But, in the meantime, the demands have again gone up and recently another committee was appointed to examine the question and they find that two more plants of that size will be required.

Now, how are you getting your coke? You are getting a little of it from by-product ovens and the rest, nearly a million tons, from beehive and kilns gathering with ash going up to 30 to 35%! Such materials are sold in the market in the name of metallurgical coke for foundries; and you have been putting up with it without making any protest that you want a better coke and that you are prepared to pay for a better type of coke! Today's cost of a modern by-product coke oven and the present price of coal including preparation and other costs do not permit the economic production of coke at the present control rate of Rs. 44·75 a ton. This is why people who could set fire to and quench anything they came across were able to sell coke at cheaper rates and made a soaring business of it. There has been one or two protests during the presidential address of the Indian Foundry Association. But there has not really been any persistent campaign. We, on our own, took up the question and in 1954 issued a survey report on the requirement of hard coke. We assured that one million tons of additional coke will be required. The Durgapur coke oven was specifically built for that. But again, as I said, the demand today has far exceeded the calculations at that time.

Mr. G. V. S. Iyer, N.M.L.: Some points have been raised by previous speakers on the production of ferro-alloys and the necessity of processing the required raw materials from indigenous sources, and special mention was made of manufacturing Soderberg paste used in electric furnaces. In this connection mention may be made of the work that is being carried out in the Refractory Division of this laboratory to develop the Soderberg paste from low ash coal, instead of petroleum coke or anthracite. The Soderberg paste industry in India is, perhaps, not developed to such an extent as to utilise low ash coal but experiments carried out in this laboratory have established the fact that low ash coal can be used for making the paste. Dr. Lahiri pointed out that he could supply such low ash coals if specifically asked for. He wanted to know the size specifications and limits and impurities that could be tolerated. I would like to inform him that size is not very critical and fine size material can be employed as the process involves briquetting and heat treatment, before making the Soderberg paste. The requirements of coal for this purpose are estimated to be of the order of 7,000 tons. Cost factor will, of course, be of prime importance. We are told that low-ash coal is available from Assam and I understand that slightly higher sulphur or phosphorus contents of these coals are not detirmental for employing them in making Soderberg paste.

Dr. A. Lahiri, C.F.R.I., Jealgora: Our Pilot Plant can be used for quantities such as 5,000 tons of low ash coal per year and as I have already said we can meet the requirements of the consumers if they come forward with a specific demand and the willingness to pay for processing of the material.