4.0 Indian Deposits and Reserves

4.1 DEPOSITS

The concentration of iron ore that occurs in sufficient quantity to be a source of sustained supply of raw material to industry and from which iron can be satisfactorily recovered under existing economic conditions or which may be usable in anticipated economic circumstances can be called deposits whereas the iron ores of mainly scientific interest are called occurrences[1].

The term deposit represents a purely practical concept imposed by economic consideration. What constitutes a deposit for a local smelter may be of no interest, however, high in grade, to a large steel combine to which size may be of more importance than grade. Further, it is not possible to predict when a deleterious constituent of an iron ore deposit will become a valuable product. Location has, of course, to be taken into account, and here, among other factors, the presence of adequate supply of high grade ore will reduce the value of local low grade deposits and also of high grade deposits less favourably situated. It is, therefore, evident from the above mentioned observations of the definition of iron ore deposit that it must be essentially on economic basis but must not be limited to utility alone.[1,2]

4.1.1 Types of Deposits[3,4]

The iron ore deposits of India can be broadly divided into the following six groups on the basis of mode of occurrence and origin.

4.1.1.1 Banded Iron Formations (BIF) of Pre-Cambrian Age

The BIF forms an important component of Archaean schist belt all over the world. They are particularly very well developed in India. Most of the Indian deposits are similar to those of Lake Superior regions of USA, Brazil, Venezuela, etc. Extensive outcrops of BIF are found in the States of Bihar, Orissa, Madhya Pradesh, Maharashtra, Karnataka, Goa and Tamil Nadu. The most common names used in India to designate BIF are Banded Haematite Quartzite (BHQ) and Banded Magnetite Quartzite (BMQ). In Bihar and Orissa, the names like Iron-Ore Series and Iron-Ore Group are used as stratigraphic names. Elsewhere in the world, names like taconite (Lake Superior), itabirite (Brazil), jaspilite (Western Australia) and Calico rock (South Africa) have been in use. In recent years, however, BIF has come to be generally acceptable both as a field term as well as stratigraphic term to designate iron-rich sedimentary rocks.

(i) Classification of BIF Group

James (1954) was the first to recognize and classify iron formations on the basis of dominant primary iron-rich minerals alternating with silica bands as oxide silicate, carbonate and sulphide facies. The relationship of the different facies was shown to be gradational, one type passing into the other, when followed from shallow water to deep water of the basin.

Gross (1965) distinguished two main types of iron formations from pre-Cambrian, viz. Algoma and Superior. The Algoma-type was dominantly Archaean in age and characterized by thin banding and absence of oolitic and granular texture, limited in lateral extent and closely associated with volcanic rocks and greywacke sediments. Carbon and pyrite-rich black shales were common. The Superior-type, on the other hand, was the characteristic formation of the

Proterozoic, and was laterally very extensive and closely associated with clastic sediments like quartzite, dolomite and pelitic rocks without showing any direct relationship with volcanic associations. There have been other attempts at classification of BIF like those of Dimroth(1976), Kimberley(1978) and Beukes (1980), but these have not come into popular usages. The two terms "Algoma" and "Superior" have, however, come to be widely used in literature. Recent studies, however, have exposed the difficulties in grouping iron formation into one or the other type. The BIF of India generally possess the characteristics of both Algoma and Superior types especially in Archaean schist belt.

There is another distinct type of iron formations which is seen confined to granulite terrains. This is a weakly-banded magnetite quartzite, forming part of a supracrustal sequence of quartzites, mica schists, marbles and metavolcanic amphibolites, completely engulfed in a voluminous mass of a tonalitic gneiss. The formation is highly folded and metamorphosed under granulite facies conditions. Typical examples are from the granulite regions of South India (Tamil Nadu, part of Karnataka and Kerala) which are different from the Archaean schist belt.[4]

Thus,the iron ore formation within the Indian shield can be divided into two main types :
(1) those lying within high grade region and (2) those confined to the Archaean schist (greenstone) belts. Among these, the first type occurs as narrow, highly deformed and metamorphosed belts within Archaean granulites and gneisses and represents formation of an older age group (>3,000 million years), formed in distinct tectonic environment and later incorporated within 'high grade' mobile belt. It is also named as Iron Ore Formation of high grade region. In this type, the primary features have been largely destroyed by deformation and metamorphism. Associated rock types include quartzite, metadolomite, metapelites and graphitic schists. There is no well marked stratigraphy indicating variation in depositional conditions. It is found in Tamil Nadu, Kerala, South Karnataka and Andhra Pradesh. Numerous occurrences of such metamorphosed banded quartzite magnetite rocks are also reported from Chotanagpur granite-gneiss belt of Bihar and banded gneissic complex of Madhya Pradesh, Uttar Pradesh and Rajasthan.

The second and the more extensive type, having characteristic akin to Algoma type, is the one confined to the schist belts formed during the period 2900-2600 million years. Continuous bands forming an integral part of the Late Archaean schist belts are more important and are confined to the States of Bihar, Orissa, Karnataka, Maharashtra, Madhya Pradesh and Goa. These form important repositories of rich iron ore deposits in India.

(ii) Origin of BIF

The origin of BIF is a controversial aspect on which no final opinion has been possible despite years of study in different parts of the world. However, it is considered that larger and more widespread deposits are of sedimentary origin. The volcanic nature of the period during which the Archaean Iron Formation was accumulated has also been recognized. The oldest iron formations like those of Isua were deposited probably in a submarine exhalative environment (Appel, 1980). Similar geological setting may be envisaged for the iron-formation of granulite regions of India. A controlling factor was probably the composition of ocean water during the Archaean. The pH and oxidation potential were significantly different from those of later years. The oceans of that period were major reservoirs of both iron and silica. Their source was mainly volcanogenic and partly terrestrial. Even cosmic origin is envisaged.

One view is that iron formation was deposited in shallow inland lakes, fresh water being considered a more likely vehicle for the transportation of iron and silica. Degradation of crusts similar to the present day lateritic crust as a result of advanced weathering is believed to have released bulk quantities of iron and silica. Gentle isostatic uplift of the land, compensating for the increasing load of sediments in the basin was responsible for the periodic influx of both chemical and clastic products of denudation into the basin (Cullen, 1963). Periods of intense depositions were preceded by a long period of accumulation of disolved iron and silica in sedimentary basins (Mel'nik, 1982).

Another view is that iron formation is essentially a product of diagenetic replacement of primary carbonate (Dimroth 1977). Although there are evidences of replacement, the process cannot account for the vast amount of iron in iron formation. Volcanic source for the iron and silica cannot be ruled out as there is close association of volcanic rocks with BIF. Gross (GA) concludes that hydrothermal effusive processes are principal sources of metal constituents in stratified iron formation and that modern metalliferous sediments and crusts formed in seabed are progenitors of older sedimentary formations preserved in the geological record (Simonsen, 1985).

The origin of the uniform banding, so characteristic of iron formation, has not been satisfactorily explained. Seasonal overturn of lakes, seasonal changes in temperature, supply of nutrients to siliceous organisms and perhaps some types of cyclic changes in climate, have been ascribed to account for the varve-like banding. The similarity of rhythmic microbands of iron formation to evaporite varves as in present day Red Sea environment has been pointed out by Trendall (1973).

The character of the Late Archaean, Early Proterozoic atmosphere is also one of the important aspects to be taken note of in considering the origin of iron formation. The atmosphere at that time was different from present day atmosphere and is believed to have been rich in carbon dioxide and nitrogen and deficient in oxygen. It was possible for the ferrous form of iron to occur in solution in warm sea water. Vast quantities of iron could thus get stored in the ocean and lakes of that period. Photodissociation of water vapour no doubt produced oxygen but that was very much limited. It was only when life first appeared on the scene, photosynthetic release of bulk oxygen became possible. The released oxygen combined with the dissolved iron in the ocean and precipitated it giving rise to iron-rich bands. Once the dissolved iron was used up, there was no further precipitation of iron (Cloud, 1973). The occurrences of baryte and iron formation in rocks as old as 3,000 million years indicate that the build up of oxygen in the hydrosphere took place much earlier than postulated by Cloud. Reddish to brown laminae in the BIF of Bababudan and Sandur (> 2.6 billion years) point to development of oxygenated atmosphere fairly early in the geological records.

The distinctive chemical composition shown by iron formation, restricted mainly to iron and silica, to the exclusion of other metallic compounds, is a feature which cannot be explained through inorganic chemical precipitation alone. Organic activity, on the other hand, could give rise to material with specific chemical composition. According to La Berge (1973), the uniformity of chemical composition of BIF is biologically controlled. A number of physical and chemical parameters seem to be consistent with biochemical and chemical origin for the iron formation.

Carey (1976) argues that the sea water is quite incapable quantitatively of transporting in solution large masses of iron and silica from local sub-aerial sources to deposition sites. Dust storms, according to him, were pan-global in character during Proterozoic and were responsible for large-scale transport of iron and silica and their deposition in broad eperic basins.

Towe (1983) has advocated a 'Delayed Oceanic Model' for the origin of BIF. According to this model, the early primitive crust, mainly mafic in character, was covered by shallow bodies of water, of which many were near hydrothermal vents. Continental masses were small, few in number and low in relief. No ocean, as such, existed. The extensive mafic crust was subjected to laterite-type weathering. The majority of early sedimentary environments was of shallow water and the general absence of continental relief precluded generation of clastic sediments. Sediments too were of limited extent confined to shallow water bodies of that primitive period. Oceans grew in volume through degassing and large amounts of iron and silica moved into the growing oceans where reduction of iron through interaction of organic matter placed it in solution. The overall sedimentary environment was one of transgressions with the growing volume of the oceans. The weathered crusts were 'Canibalized' and mostly eliminated through transfer to oceanic repositories. The model reconciles several observed facts in the geological record.

Holland (1973) had postulated upwelling of deep ocean water as an alternative source of iron in iron formation. Windley et al (1984) consider this alternative mode of transport of ferrous iron from a submarine hydrothermal source to a zone of precipitation as the dominant process in the deposition of iron-rich and iron-poor layers. Morris has come forward with an eclectic model which accounts for the deposition of BIF from upwelling ocean currents as a chemical sediment in a platformal environment. Iron, according to him, was precipitated largely by photo-oxidation of ferrous iron as it reached the surface rather than by biochemical process.

From the above views and concepts of the different workers, it may be concluded that our existing knowledge about the BIF is not adequate to build a satisfactory theory of origin. Therefore, a single mode of origin for all BIF cannot be thought of.

(iii) Characteristics of Ore of BIF Type

The BIF has given rise to vast accumulations of commercial grade iron ore deposits in India; more than 90 percent of the iron ore supplied to the industry comes from the BIF. The major ore minerals are haematite and magnetite. Important accumulations are in Singhbhum district (Bihar), Keonjhar district (Orissa), Bellary district (Karnataka), Bastar district (Madhya Pradesh) and in Goa. Magnetite ore deposits are mainly confined to the Chikmaglur district in Karnataka, and Salem and North Arcot districts in Tamil Nadu.

Different types of iron ore derived from banded haematite rocks met within the deposits of this group are (a) massive ore, (b) laminated ore and (c) blue dust. The massive ores occur as massive bodies in which no planar structures are seen. The laminated ores, though mineralogically and chemically similar to massive ores, have planar structures which may be very closely spaced giving rise to biscuity ores. The blue dust is a form of very fine-grained powdery ore consisting of loose haematite and martite crystals. It often occurs as pockets in harder ores and forms the major constituent at depth. Major part of blue dusts is minus 10 mesh in size and generally these are from 10 to 50 percent of 100 mesh size, the proportion of minus 325 mesh to 100 mesh fraction being 80 percent. In addition, float ore accumulations on the slopes and foot of the hills as a result of disintegration of in situ orebodies are commonly met with. The float ores are of different sizes and of different degrees of purity. In certain places, like deposits in the vicinity of Banspani in Keonjhar district, Bailadila range and Bellary-Hospet area, the float ore concentration is mostly free from any major impurities. The percentage recovery of ore from such horizons varies within very wide limits and is cent percent in some cases. Wherever such float ores are derived from massive or hard laminated orebodies, the grade of the float ore is fairly rich. Thus, in the float ore workings in the vicinity of Banspani and in Bellary-Hospet sector, grade of the ore is about 64 percent Fe or even more. The gangue minerals in case of float ores are usually shale, BHQ, dolerite and clay. Sometimes reconsolidated ore occurring as angular and sub-angular fragments cemented in the matrix of laterite is also noticed in float ore zones. For example, in Bihar and Orissa area, this type of recemented ore is found where it is locally called as "Canga". The embedded high grade iron ore pieces cannot be easily dislodged from adhering material. Though angular pieces can alone give 63 to 66 percent Fe, the overall material analyses only 55 to 60 percent Fe. The detailed description of major iron ore deposits of this group is discussed under sub-heading State-wise Distribution and Description of Important Deposits, para 4.1.2.[5]

4.1.1.2 Sedimentary Iron Ore Deposits of Siderite and Limonitic Composition [5]

These ores of siderite and limonitic compositions are found associated with the iron-stone shales of Lower Gondwana age occurring in the coalfields of Bihar and West Bengal and the ferruginous beds in the Tertiary formations of Assam and the Himalayas. Due to hydration, the sideritic ore is often changed to limonitic stone near the surface. These deposits are small and are of minor nature in India. They are heterogeneous in grade and modes of occurrences. They are also known as Bog Iron deposits. The iron minerals are accumulated as irregular bodies in stream beds and typically at the bottom levels of bogs and marshes where the Lower Gondwana sediments have deposited along with their organic debris. The deposits usually consist of porous, rubbly, nodular or concretionary material.[5]

In upper Assam, such deposits occur in Lakhimpur and Sibsagar districts. Here, two types of ores are found, one being the clay ironstones from the Eocene coal measures in the form of thin beds and nodules and the other impure limonite in the 'Sub-Himalayan' strata assigned to the Tipan group of Miocene age. The grade of ore is generally poor containing 20 to 40 percent iron in first type and 25 to 40 percent iron in second type. Though these deposits were extensively worked in the past, these are not of any significance now.

In Raniganj area, the sedimentary iron ores occur in the form of thin beds of ironstone of variable thickness and frequently in the Ironstone Shale group of the Damuda Series in Raniganj coalfield which stretches over a distance of some 40 km with a width of 1.6 to 3.2 km. The ore is grey iron carbonate but near the surface it has been converted into brown hydrated oxide. The total thickness of ironstone shales is around 365 m and the the total area covered by this formation is about 112 sq km. The aggregate thickness of the ore is estimated at about 0.3 m in every 3.05 to 3.66 m of shale. In addition to these, haematitic clay ironstones also occur in small quantities in the shales of the Middle and Upper Barakar strata and also to some extent in the Raniganj strata in the eastern part of Raniganj coalfield.

Clay ironstones are also known to occur in the Karanpura and Auranga coalfields. In Auranga coalfields, these are found as string of nodules in Barakar rocks in a zone of ferrugenous shales, 3.2 km long and 60.9 m thick of which 10 percent may be considered as ore.

4.1.1.3 Lateritic Ores Derived from the Sub-Aerial Alterations

Lateritic types of iron ores are derived from the sub-aerial alteration of rocks, such as gneisses, schists, basic lava, etc. under humid tropical conditions. Some of the laterites of suitable composition may become exploitable ore but most of them contain too little of iron and too much of alumina along with other elements like titanium, nickel, chromium and manganese. The ores are generally concentrated at the top as a resultant alteration product of the iron-bearing parent rocks and consist of oxidised and insoluble rock constituents. They may consist of nodular red, yellow or brownish haematite and goethite. The capping is usually more thick over the basic rocks which contain high concentration of primary iron associated with nickel, chromium, manganese and titanium. Large stretches of Deccan Traps, the gneisses in the Western Ghats and the Chotanagpur plateau in Bihar, and the schistose rocks of many areas like those of Sandur are covered by such lateritic tops.[5]

4.1.1.4 Apatite-Magnetite Rocks of Singhbhum Copper Belt

These are supposed to have been formed by the magmatic activity associated with a pre-Cambrian diastrophic cycle, when the rocks of the shear zone were thrust and intruded by acid or intermediate igneous rocks. A zone of apatite-magnetite rock is found closely associated with the copper belt of Singhbhum. The rock is usually a mixture of apatite and magnetite with some biotite, chlorite and sub-ordinate quartz, and is generally found on the hanging wall side of the copper lodes. The apatite-magnetite ores are associated with granodiorite. These rocks form lenses of various sizes from a few centimeters to a few metres, arranged in an echelon pattern enclosing ancient schists of Archaean age. Largest lens is 274 m long and 18 m thick in the centre. They are sometimes bordered by granite. In these apatite-magnetite rocks, the dominant mineral is generally apatite but the proportions of the two

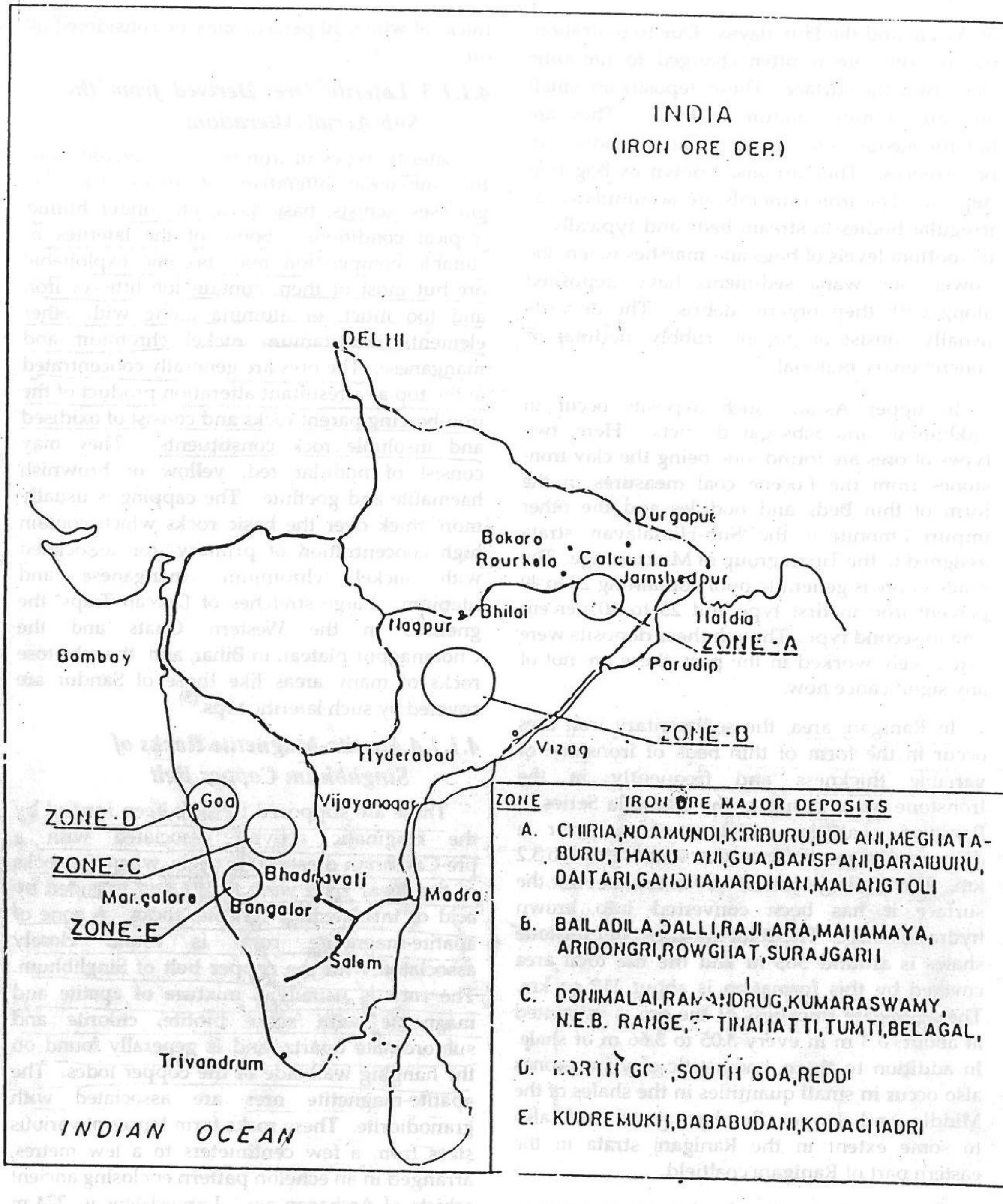


Fig. 4.1 : LOCATION MAP SHOWING MAJOR IRON ORE DEPOSITS IN INDIA

SOURCE : REFERENCE NO. 9

minerals vary considerably from place to place.[5]

4.1.1.5 Titaniferous and Vanadiferous Magnetites[5]

The vanadiferous-titaniferous magnetite deposits of south-eastern Singhbhum (Bihar), Mayurbhanj and Keonjhar (Orissa) and southern districts of Karnataka are associated with the gabbroid and ultrabasic rocks. This type of ore of Bihar and Orissa occurs as thin veins, lenses and pockets in gabbroid and ultrabasic igneous rocks which are often altered to serpentine and steatite or to epidorite. These ores do not form conspicuous outcrops and their presence is usually shown by the presence of the abundant debris scattered over the surface. Both magnetite and ilmenite are present in these ores and in many cases, appreciable amounts of haematite are also seen. Some apatite is generally found as an accessory mineral. The specific gravity of the magnetite ore ranges from 3.8 to 4.8. These magnetites generally contain a variable but small amount of vanadium in the form of microscopic inclusions of the mineral coulsonite (iron vanadium oxide). Generally, vanadium oxide content is less than 2 percent but occasionally it has been found to be as much as 7 percent. The titanium content on the other hand is much higher varying from 10 to 25 percent titania in different occurrences.

In Karnataka, small lense-like bodies of titaniferous magnetites occur in Tumkur district. These are generally associated with ultramafic rocks which occasionally contain chromite also. These deposits contain 55 to 61 percent iron, about 1 percent silica, less than 2 percent alumina, and very low sulphur and no phosphorus. The titanium content may go up to 12 percent. Some chromium is always present up to 2 to 3 percent. There is also a little vanadium in most of these ores. In Hassan district, titaniferous magnetites occur as linear bands with prominent outcrops in a narrow belt of Dharwar rocks which are composed of amphibolites and hornblende schists surrounded by peninsular gneisses and intruded by an ultrabasic complex. These titaniferous magnetites are brownish black to black in colour, hard to break and strongly magnetic. Titanium content of these ores is up to 10 percent whereas vanadium and nickel are present only in traces. Chromite forms about 4 to 5 percent by volume of these ores. Silica, sulphur and phosphorus are low.

4.1.1.6 Fault and Fissure Filling Deposits

Fault and fissure-filling deposits of haematite are minor occurrences seen in Veldurti and Ramalla Kota in Kurnool district of Andhra Pradesh. They occur in a fault zone traversing the gneisses and Cuddapah formations over a length of several kilometres. The orebodies form low hillocks or ridges which stand out well above the ground and are lens-shaped but they also form viens and stringers in the fault zone. The ore is generally haematite and is often slightly specular in character and also jaspery when it is siliceous. Sometimes, the vugs are seen to be lined with flat micaceous crystals of specular haematite. Several samples collected from these deposits vary from 50 to 65 percent iron, 3 to 18 percent silica, traces to 0.04 percent phosphorus and very low sulphur.[5]

4.1.2 Statewise Distribution and Description of Deposits - Occurrences

The larger and rich iron ore deposits are mainly found in the States of Bihar, Orissa, Madhya Pradesh, Karnataka and Goa (Fig. 4.1). Comparatively smaller deposits are found in Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu, Kerala and Rajasthan. Minor to very minor occurrences are reported also from Assam, Meghalaya, Nagaland, West Bengal, Uttar Pradesh, Himachal Pradesh and Jammu and Kashmir States. The agewise distribution of the Indian iron ore deposits is given in Table 2.1 (Chapter 2). Among the important States, Bihar and Orissa contain the maximum number of richer and larger deposits. The famous "Singhbhum-Keonjhar-Bonai group of deposits" occurs in both the States covering a total area of about 1,550 sq km and almost all the major deposits of these States are confined to it (see para 4.1.2.3). Following is the Statewise description of deposits:

4.1.2.1 Bihar

In Bihar, iron ore (principally haematite) deposits occur in a number of prominent hills in south-western part of Singhbhum district. The most important deposits of this district are Noamundi, Gua, Barajamda, Kiriburu, Meghahatuburu, Manoharpur and Chiria. The Chiria deposit is reported to be the single largest deposit in the country. The deposit covers Budhaburu, Bogordiaburu and other adjoining hills. The Manoharpur deposit is another important deposit adjacent to the Chiria deposit. The Noamundi deposits include those of Kotamatiburu, Pachriburu, Bondburu, Lagirdaburu, Baiburu, Haligutu, Cheriapetburu, Mahaburu and Baljori hill. In Gua area, rich deposits are found near Marang Ponga and between Pechahatu and Lipunga. An important deposit of iron ore associated with Kolhan series is found at Jhilingburu, south of Gua. Rich deposits of haematite are also found near Jamda (Sulpai area), Notoburu, Pansiraburu-Banlataburu and Salai. The Kiriburu and Meghahatuburu deposits of Singhbhum district are situated in the western limb of main Bonai iron ore range near Bihar-Orissa boundary.(5,6,7)

Apart from haematite, apatite-magnetite rocks are found closely associated with the copper belt of Singhbhum near Ramchandra Pahar, Kudad, Patherghera, Khejurdhari, etc. Titaniferous magnetite is found at several places near Dublabera and Sindurpur in Singhbhum district.(5)

Smaller deposits and minor occurrences of iron ore are also found in other districts. In Palamau district of Bihar, a magnetite deposit is situated at Gore village. This area is located at a distance of 14 km from Daltonganj. The picked up samples of the ore analyse Fe-65.2 to 68.3 %, P-0.007% to 0.015% and S-0.009 percent. This deposit is about 610 m in length with an average width of 27 m. Minor occurrences of magnetite associated with gneissic and schistose rocks have been reported from Sua and Kauria area. In Ranchi district, occurrence of haematite ore is found exposed on the surface in a patch of mica schist near Sikorda and concentration of magnetite-type ore is reported from Bagdanr and Mahantoli and at a few other places.(5,7,8)

Minor occurrences of iron ore are also reported from Santhal Parganas, Bhagalpur, Hazaribagh and Dhanbad districts of Bihar but these are not of much significance.(8)

The detailed description of important deposits/groups of deposits are covered in para 4.1.2.3.

4.1.2.2 Orissa

In Orissa, iron ore deposits occur in the districts of Keonjhar, Sundergarh, Mayurbhanj, Cuttuck, Koraput, Sambalpur and Dhenkanal. Of these, the deposits of Keonjhar and Sundergarh districts are most important. The principal ore is haematite with iron content ranging from 55 to 69 percent. The iron ores are associated with both BHQ and banded-haematite-jasper (BHJ). In this State, the most important deposits containing the large reserves of high grade ore occur in the main Bonai range of hills running through Keonjhar and Sundergarh districts (for detail geological aspects, refer description of Singhbhum-Keonjhar-Bonai group of deposits). The important deposits occur in Thakurani Pahar located SE of Barbil, Roida near Bhadrasai, Joda East, Banspani, Khandbund, Jhilling-Langalotta, Joruri-Jalahuri, etc. In Sundergarh district, the deposits occur at Malangtoli, Godabudini, Khandadhar Pahar, Kalmang and near Koira. The well-known workable deposits of both Keonjhar and Sundergarh districts are Malangtoli, Bolani, Banspani, Barsua, Joda, Thakurani, Murgabera, Khandadhar and Kalta. Among these, Malangtoli deposit is the largest one containing highest reserves. The Fe content in its ore varies from 55 to 63 percent. In Barsua deposit, Fe content of the ore varies from 58 to 60 percent. The Bolani deposit ores contain average Fe 61 percent. The average Fe content in the ores of Thakurani, Joda, Jhilling-Banyalotta, Badamgarh Pahar is 63 percent.(6,7,8)

In Mayurbhanj district, the important haemtite deposits are Gorumahisani, Sulaipat and Badam Pahar. The Sulaipat deposit contains on an average 61 percent iron with low silica, alumina and phosphorus. In Gorumahisani area, three distinct lodes have been found. The average iron content in these lodes is about 60 percent. The ore occurring in Badampahar deposit is siliceous and somewhat inferior in quality.

In Cuttack district, large deposits of haematite occur in the Mahagiri and Tomka ranges in Sukinda area. The ore found near Patwali of Tomka area is very high grade and it extends over an area of one sq km up to Champajhar. The Daitari deposit in Cuttack district is a big deposit in which the average Fe content is 61.5 percent whereas Tomka deposit contains average 64.4 percent Fe in its ore.[7] In view of the division of the Cuttack district, all the aforesaid deposits now fall under the new district named "Jajpur District".

In Koraput district, small deposits of iron ore (haematite) occur in Hirapur hills which is located at a distance of about 9 km south-west of Umarkot. The average grade of ore of this area contains 61 percent Fe. In Dhenkanal district, low grade (Fe 55 to 56 percent) iron ores associated with BHQ occur in east of Sun Bhandari and between Bar Bhagdari and Narsinghpur. Occurrence of haematite ore is also reported from Malayagiri range of Dhenkanal district.[7,8]

Apart from haematite, occurrences of titanium-bearing magnetite have also been reported from Kumardubi, Betjharan, Nahapahari and at several places SW of Baripada. Minor occurrence of magnetite sand is reported from the shore of Chilka lake in Puri district. In this district, magnetite associated with ilmenite occurs in Sulia hill and to the north-east of Mahitama. Occurrences of magnetite have also been recorded in the laterite area near Basudeopur and near Murhi in Dhenkanal district. But these magnetite-bearing areas are not of much significance from economic point of view.[3,5,7,8]

4.1.2.3 Singhbhum-Keonjhar-Bonai Group of Deposits (Bihar & Orissa) [3,5]

These deposits form an important group of iron ore deposits in India and occur in a series of prominent hills stretching from south-western part of Singhbhum district of Bihar into the Keonjhar and Sundergarh districts of Orissa within an area of 1,550 sq km. In this region, more than 135 orebodies of varying dimensions have been recorded by H.C. Jones. The main Bonai iron ore range, nearly 48 km long, starts in Sundergarh district from a point near Routha to about 4.8 km south-west of Gua. This range is capped for the most part by massive haematite which is continuous except for short breaks at three or four places. Laterisation of cappings is evidenced but not pronounced. In the northern part of this range, there are parallel ore bands which may represent repetition of the same zone due to folding and faulting. The parallel ranges are capped by high grade ore beyond and north of Gua and these represent the crests of parallel isoclinal folds. Some larger orebodies of this region are situated in the hills/Pahar of Budhaburu, Bogordmburu, Kotamatiburu, Meghahatuburu, Parshriburu, Raijoriburu, Thakurani Pahar, Bara Pahar, Banspani Pahar and the hills near Kurband. A map showing iron ore deposits of the region is shown in Fig. 4.2 and typical geological cross-sections of a deposit in Singhbhum district (Fig. 4.3), Keonjhar district (Fig.4.4), Sundergarh district (Fig. 4.5) and Mayurbhanj district (Fig. 4.6)

TABLE 4.1: GEOLOGICAL SUCCESSION IN SINGHBHUM AND KEONJHAR [5]

	East Singhbhum (south of the share zone)	**South Singhbhum and Keonjhar**
Dhanjori Stage	Lavas Quartzite-Conglomerate	Kolhan Series (Purana)
--------------------	Unconformity --------------------	Unconformity --------------------
Iron Ore Stage	Phyllites and tuffs with lenticular arkose, conglomerate and quartzite	Phyllites and tuffs, with manganese and rare dolomite
	Banded quartzites, including haematite quartzite (impersistant)	Banded haematite quartzite (overlap)
	Phyllites, lenticular conglomerate and basic igneous rocks	Phyllites and tuffs, Sangramasai conglomerate and basic igneous rocks.

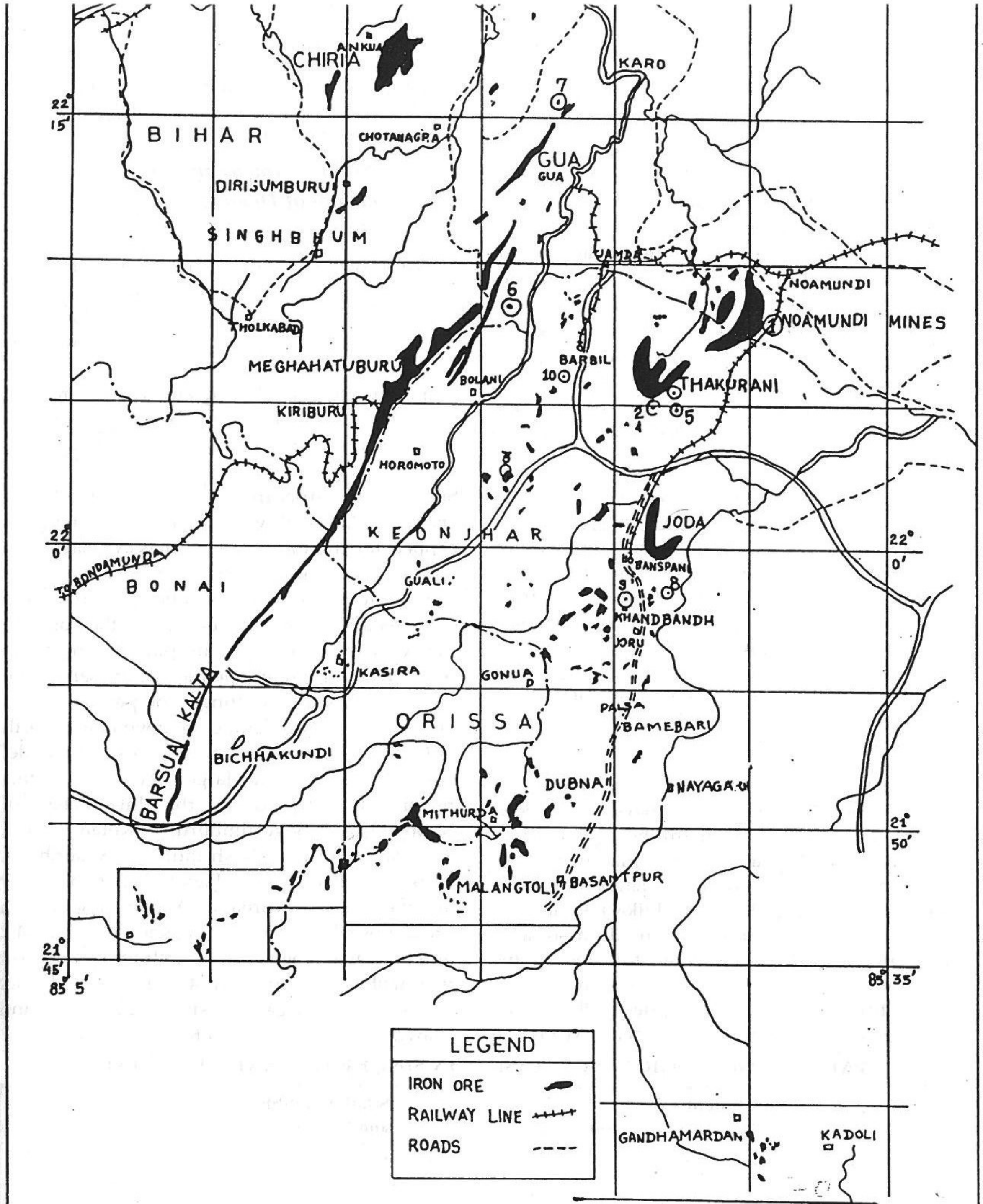


FIG. 4·2 LOCATION MAP SHOWING IRON ORE DEPOSITS IN BIHAR-ORISSA

1 NUAMUNDI	6 KARAMPADA
2 THAKURANI	7 GHATKURI
3 KASIA	8 JHILLING LANGALOTA
4 RAIKELA	9 KHANBANDH
5 THAKURANI	10 BARPADA KASIA

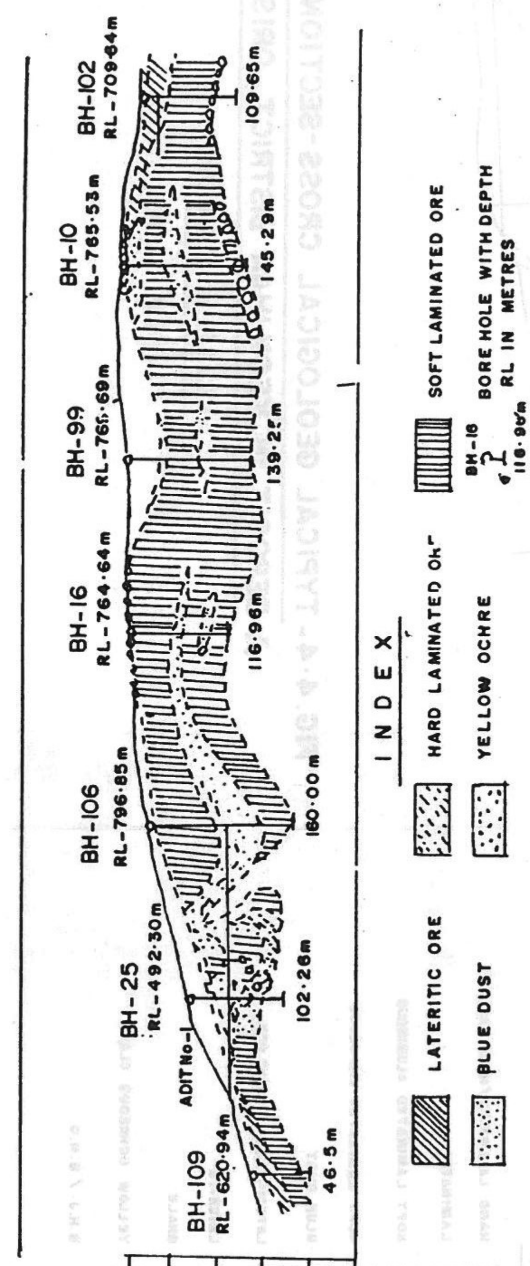


FIG. 4·3 - TYPICAL GEOLOGICAL CROSS SECTION OF A DEPOSIT IN SINGHBHUM DISTRICT, BIHAR

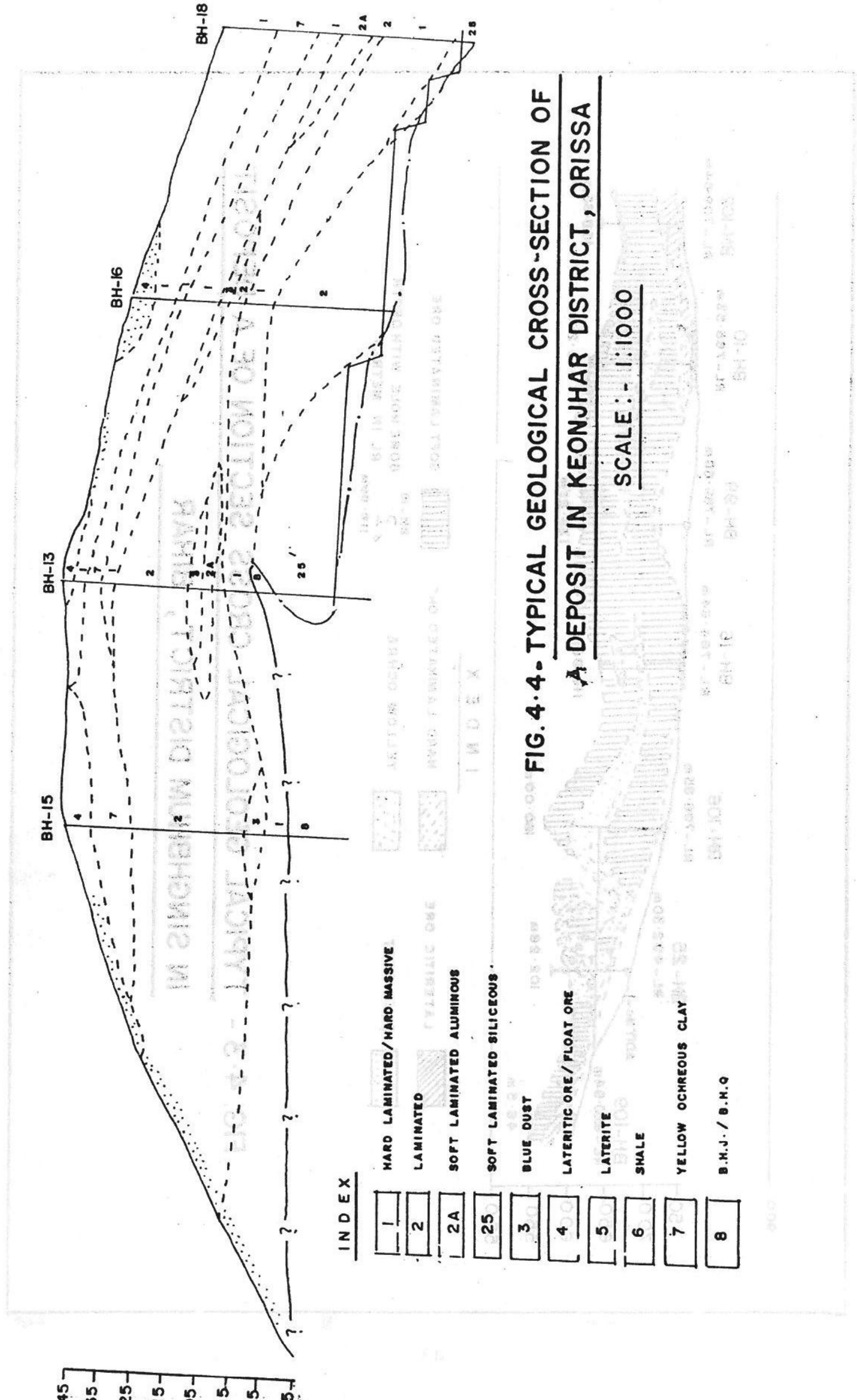
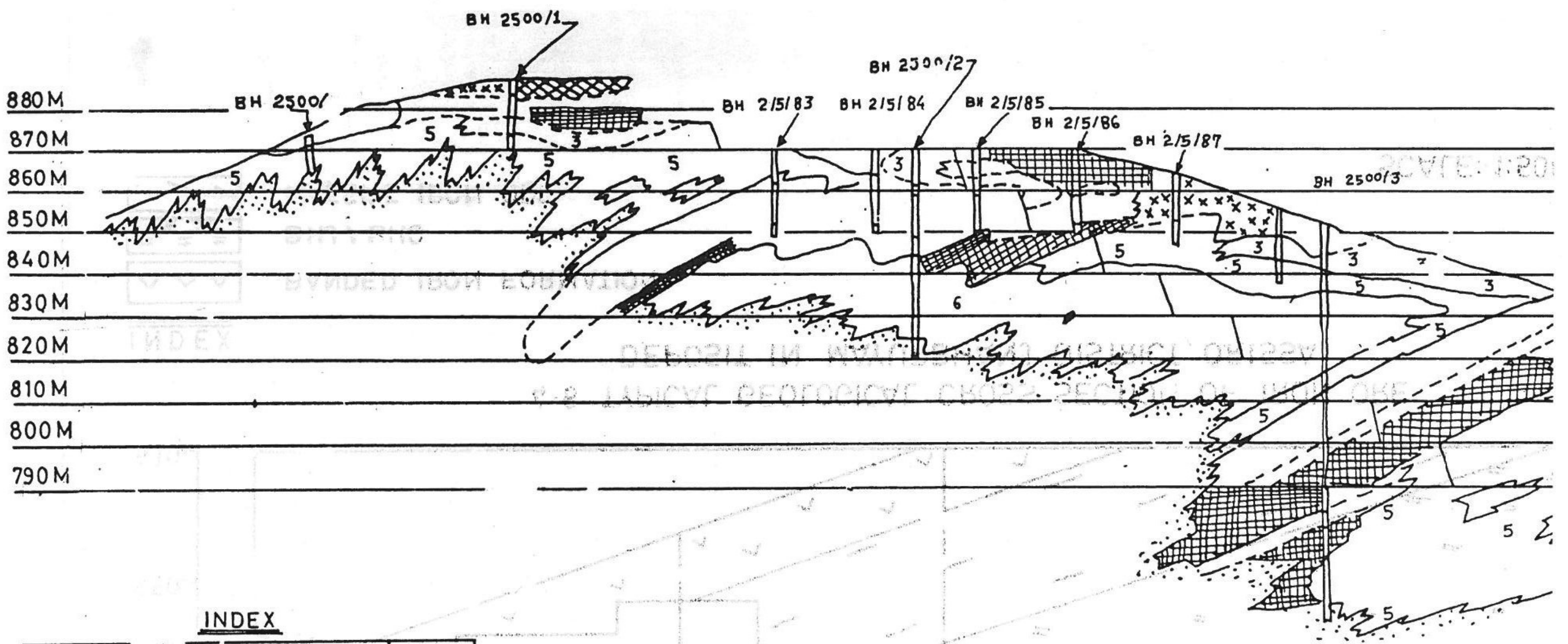


FIG. 4·4 - TYPICAL GEOLOGICAL CROSS-SECTION OF A DEPOSIT IN KEONJHAR DISTRICT, ORISSA

SCALE : - 1:1000



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MASSIVE ORE	1
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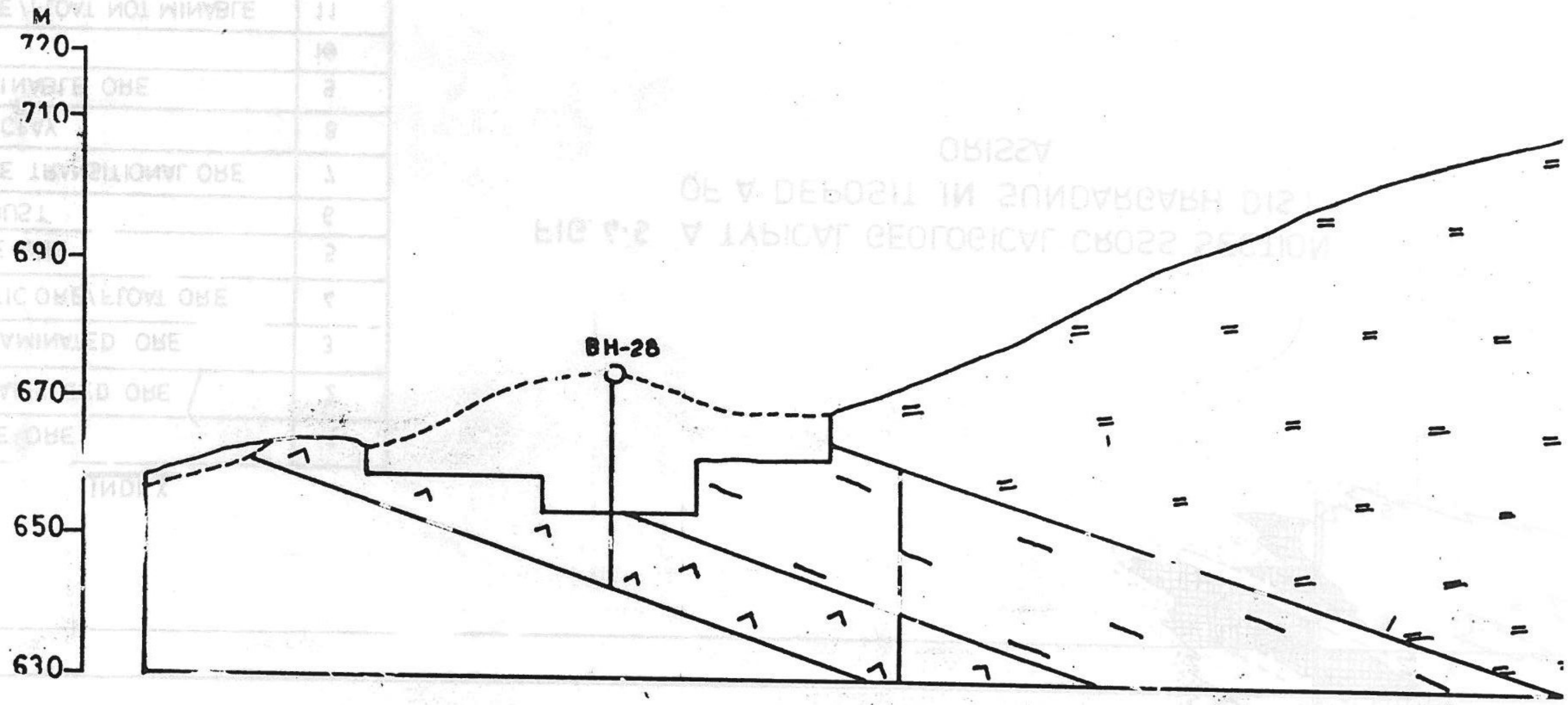
FIG. 4·5 A TYPICAL GEOLOGICAL CROSS SECTION OF A DEPOSIT IN SUNDARGARH DIST. ORISSA

SCALE-1:1000



4·6 TYPICAL GEOLOGICAL CROSS-SECTION OF IRON ORE DEPOSIT IN MAYURBHANJ DISTRICT, ORISSA

INDEX

- BANDED IRON FORMATION
- BHJ / BHQ
- MASSIVE IRON ORE

SCALE:-1:500

The rocks exposed in this region consist of a series of pre-Cambrian sedimentary formations known as the Iron Ore Series. The general strike of the formations in northern Singhbhum is E-W, but gradually changing over to NW-SE in the eastern part and in the adjoining area of Mayurbhanj. This part of Singhbhum is marked by a zone of shear along which rocks have been thrust towards the south and metamorphosed. The Iron Ore Series consists mainly of BHQ of jasper, phyllite and shales with intercalations of lava flows. The BHQ/BHJ are associated with bodies of iron ore. Some older rocks, amongst which are quartzites, hornblende schists and mica schists are found amidst the Iron Ore Series in south Singhbhum. The geological succession of east Singhbhum, south Singhbhum and Keonjhar is given in Table 4.1(see p.41) .

The rocks of the Iron Ore Series in south Singhbhum, Keonjhar and Bonai give rise to a rugged topography. The beds of BHJ form prominent ridges rising to about 750 to 920 m in altitude. The lower ground is occupied by phyllites, lavas and shales. The whole succession of the rocks is folded into a series of asymmetrical or slightly overturned anticlines and synclines. The rocks have NNE-SSW strike with general westerly dip. It is generally regarded as a syncline pinching towards the north, with an overfolded western limb in which the important iron ore deposits of Keonjhar occur.

The BHJ consists of alternating bands of jasper or chalcedony and haematite containing varying proportions of iron oxide and silica. The silica in the jasper bands is sometimes chalcedonic and sometimes microcrystalline. The bands vary in colour from grey or white to lavender, red and brown to black and show intense crumpling and contortion and minute faulting and dislocation. The thickness of individual layer varies considerably from almost the thinness of a sheet of paper to as much as 25 mm or more while the average is about 2.5 mm. The banding is not always regular as the bands slightly buldge or thin down when followed over some distance. The maximum thickness of the haematite jasper formation is stated to be about 914 m in Bonai sector and about 305 m in the iron ore range on the border of Keonjhar and Singhbhum. Due to extreme folding, the apparent thickness is often deceptive.

The banded jasper is frequently seen to change into hard massive iron ore when followed laterally. It occasionally passes into laminated ore with a shaly appearance or into lenses or pockets of powdery ore which easily falls to powder if disturbed. The powder ore contains aggregates of granular or flaky haematite and martite and is apparently the residual iron ore left behind after silica has been leached away completely from the original BHJ. Often partially altered or unaltered masses of haematite jasper showing a certain amount of iron enrichment are also found amidst the ore.

The various types of ores found in this region are massive ore, laminated ore, shaly ore, powdery ore and micaceous ore. These are described as under :

The massive ore exposed at the surface in several deposits is a massive dark-brown to steel grey with well-marked joint planes. It generally weathers into large blocks. This type of ore has a specific gravity of about 5 and contains high percent of iron. The lumpy ores of the Singhbhum-Keonjhar and Bonai deposits are of superior quality. The iron ore content in the ore is generally +63 percent and it is hard and massive in character. It gradually becomes medium hard or soft laminated type at depth.

The laminated ore consists of laminae with clear bedding planes with open spaces in between filled partly or wholly by powdery ore or more often by a shaly substance. The ore is generally compact but may be appreciably porous. The more porous type of laminated ore is poor in quality and it may contain 55 to 60 percent iron. The specific gravity of porous ore is around 3.5 whereas the specific gravity of compact variety of laminated ore is up to 5.0.

The shaly type of ore is generally met with at some depth and has a shaly texture with silky lustre. The iron content of such ore varies from rich to as poor as containing 50 percent with a fair amount of siliceous and aluminous matter intercalated between the layers.

Powdery ore occurs as pockets and lenses. The distribution of powdery ore pockets and lenses in these deposits is most erratic. When in situ, it shows bedding and may contain lumps of laminated ore within it. It is generally dark blue to black in colour and consists largely of haematite and sometimes some quantity of martite. It is generally quite rich containing 66 to 69 percent iron. Major part of powdery ore is less than 10 mesh in size and as much as 40 to 50 percent of it may be as fine as 200 mesh.

Important Deposits of Singhbhum-Keonjhar-Bonai Group

Chiria deposit (West Singhbhum district, Bihar) : The deposit located near Chiria village in Singhbhum district, Bihar, is the largest single iron ore deposit in the country. Structurally, this deposit forms a part of the north-western limb of the "Iron Ore Synclinorium". It covers in a tabular blanket over the high topographical hills and ridges of Sarand Reserve Forest, namely the peaks of Budhaburu, Bogorduiburu and other adjoining hills. The deposit extends for a strike length of 6.5 km and has average width of about 2.5 km. The strike of the orebody is due NNE-SSW, which is parallel to the plunge of synclinorium. Geologically, the formations comprise oldest metasedimentary-metavolcanics of Iron Ore Group. The BIF exhibits converging dips resulting in a major synforms and antiforms. The thick portion of the ore is localised selectively in synformal trough.[6,9,10]

MECL has explored this deposit during 1976 and 1979 in two phases (Phase I & Phase II) and has assessed the reserves of iron ore of 2000 Mt of which, about 1970 Mt of reserves contains average Fe 62.15 percent.[9]

The principal ore types of the deposit are soft laminated, hard laminated and blue dust. Apart from these, yellow ochre and lateritic types of ore are also found in this deposit.[9]

Noamundi deposit (Singhbhum district, Bihar): The iron ore deposits found near Noamundi village in West Singhbhum district, Bihar are situated at a distance 58 km south-west of Chaibasa. This area is characterised by a number of low topped ridges and knols covered by fairly dense forest. The maximum height recorded in the area is 500 m (above MSL) attained by the hill west of Baljori. The pre-Cambrian rocks of the region consist of basic lava, banded haematite jasper/quartzite with iron ore, phyllite and chert of Iron Ore Series. These are uncomformably overlain towards north by the rocks of Kolhan Series consisting of sandstone, conglomerate and shales/phyllites. The intrusives like dolerite occur mainly in the rocks of Iron Ore Series and quartz veins in the Kolhan Series. Soft and friable, very coarse grained to gritty, highly ferrugenous sandstone (Tertiary ?) occurs as small and big patches in certain parts of the area. Laterite of Recent origin usually occurs as capping over the phyllites and shales in the northern and southern part of the area.[11,12]

Structurally, Noamundi area appears to be the eastern limb of the Iron Ore Synclinorium which is complicatedly folded. The iron orebodies generally occupy the top portions of the hills and elongated in N-S direction. The depth persistence of the ore zone is up to 100 m below the surface. The main ore types are hard, soft, friable and blue dust, each varying in its chemical and physical properties. The ore contacts are highly irregular and sometimes one variety merges with the other. About 30 percent of the ore of the Noamundi deposit constitutes blue dust. Apart from the main types of ores, Canga and lateritic ore also occur in this deposit.[11,12]

The most important iron ore mine in Noamundi area is Noamundi iron ore mine of M/s TISCO which is the captive source of iron ore for Jamshedpur steel plant. The mine consists of 11 blocks and a total lease area of 11.6

TABLE 4.2 : CHEMICAL COMPOSITION OF DIFFERENT TYPES OF ORES OF NOAMUNDI MINE OF M/S TISCO

Type of Ore	Chemical Composition (%)		
	Fe	SiO_2	Al_2O_3
Hard ore	64.0 - 69.0	0.3 - 2.3	0.6 - 5.7
Soft ore	57.0 - 66.8	0.3 - 4.5	2.6 - 3.8
Friable ore	59.0 - 66.0	0.8 - 4.9	2.7 - 9.0
Blue dust	64.0 - 69.0	0.2 - 2.4	0.2 - 2.6
Canga	56.0 - 64.0	1.0 - 7.5	3.7 - 9.5
Lateritic ore	10.4 - 64.9	0.1 - 48.8	2.72 - 53.2

sq km. The chemical analysis results of different types of ore obtained from this mine are given in Table 4.2.[12]

Kiriburu and Meghahatuburu deposits (West Singhbhum district, Bihar) : These deposits are situated in the midst of thick Saranda Forest in West Singhbhum district of Bihar just near the Orissa border. The deposits found on the western limb of famous Bonai Iron Ore Range form a part of Iron Ore Series.[13]

The Kiriburu area is located at a distance of 24 km from Barajamda. The orebody occurs as a cap over a number of flat-topped hills with three hills rising to about 900 m (above MSL). The area slopes down to steep valleys both to north-west and south-west directions. The orebody situated in north block of Kiriburu mine is approximately 2,000 m in length and 300 m in width. The difference in elevation between the highest point on the orebody and the lowest point on the contact is 100 m. The general trend of the orebody is roughly N 15^0 E to S 15^0 W. The deposit is worked separately in three different hills, viz. Hill No. 1, Hill No. 2 and Hill No. 3. The major ore types prevalent in the area are laterite/lateritised limonitic ore, soft laminated biscuity ore, hard laminated ore, porous laminated ore and powdery ore/blue dust. The average specific gravity of lumpy ore is 3.82 and powdery ore 4.05.[13,14] The lateritic/limonitic ore of this area is generally of poor quality whereas other types of ores contain on an average iron 63.56 percent, silica 1.77 percent, alumina 4.77 percent and phosphorus 0.069 percent.[13]

The Meghahatuburu deposit is located at a distance of 5 km from Kiriburu deposit. Like Kiriburu, the orebody of Meghahatuburu occurs on the undulating hills with central portion rising to 918 m (above MSL). The deposit slopes down to steep valleys both in the northern and southern directions. The general ground level is 570 m but in eastern side it is 900 m. The mineable block in Meghahatuburu mine has a strike length of 960 m with average width of 450 m. The exploration data have revealed that the deposit contains about 121.8 Mt of iron ore reserves with an average grade of Fe 63.29 percent, SiO_2 2.4 percent, Al_2O_3 2.65 percent, to a depth of 120 m.[14]

Malangtoli deposits (Keonjhar and Sundergarh districts, Orissa): The Malangtoli iron ore deposits form an important part of Singhbhum-Keonjhar-Bonai group of deposits and occupy the southern tip of the famous horse-shoe-shaped Bonai synclinorium. In all, there are 48 iron ore deposits of variable sizes in this sector which spreads over an area of about 200 sq km in parts of Keonjhar and Sundergarh districts of Orissa. The pre-Cambrian sedimentary sequence (known as Iron Ore Series) in which the whole clan of deposit is nested includes schist, shales, tuffs, phylllites, basic rocks, banded-haematite-quartzite/jaspers. Lateritisation is very common feature in almost all the rock types. Iron ore bodies are generally found on or near the top of the hill ranges. Generally, isolated or detached bands/bodies of banded-haematite-quartzite/jasper and cherty formations are seen to occur in conformity with the surrounding rocks.[15]

Structurally, the Bonai Range is a folded synclinorium with the southern closure attaining comparatively open nature and plunging gently towards NNE, and the hill ranges broadly delineate the folded limbs of synforms, with close repetition of strata due to superposition of fold system. Various investigations carried out in Malangtoli area have proved that Malangtoli deposit shows a synformal geometry which has been modified by the superposition of fold system. The main structural elements preserved in the orebodies are foliation, megascopic folds and minor folds of drag type.[15]

The distribution of ore is generally influenced by the complicated fold geometry. Depth persistence of iron ore is generally considerable in the areas affected by doubly plunging synform. The maximum-depth of the ore is seen almost in the central region and minimum thickness of ore is in the areas which are occupied by doubly plunging antiforms/ inverted cones/domes.

GSI has carried out initial exploration on a group of 14 deposits of Malangtoli area located between Piropokri to the north and Sirkagutu to the south and named these 14 deposits in alphabetical order (A to N). All these 14 deposits are separated by intervening shales and banded-haematite-quartzite/jasper. Such intervening barren patches have debarred the complete set of 14 deposits from becoming a complete block. However, some sort of continuity is established among 3 major deposits, i.e. F,G and B. On an average, these deposits form a composite block occupying an area of 3.5 km.^{2} Among these, the deposit F is the major one where the depth persistence is recorded up to 130 m. In Malangtoli group of 14 deposits, M/s OMC has a mining lease of 52.26 sq km covering nearly 11 deposits. The main ore types in general are soft, laminated, hard massive, powdery and lateritic.[15]

Thakurani deposit (Keonjhar district, Orissa): It is one of the oldest deposits in Keonjhar district. Thakurani Pahar in which this deposit is situated, consists of three semi-parallel ridges (trending NE-SW). These ridges apparently form a "W"-shaped structure. The iron ore group of rocks form a low, N to NNW plunging asymmetrical synclinorium, slightly overturned towards SE. The rocks in the area are disturbed by a number of NE-SW trending faults. The major one is present between the Deojhar volcanics and Thakurani volcanics.

The iron ore zone extends approximately for about 10 km in length and 5 km in width close to Barbil town. The iron content in the ore generally varies from 62 to 64 percent. The types of ore found in this area are (i) hard laminated/massive, (ii) soft laminated, (iii) powdery and (iv) lateritic ores.[15 a]

Banspani deposit (Keonjhar district, Orissa): The Banspani deposit covers an area of about 20 sq km and lies in Champa sub-division of Keonjhar district. The area forms a part of the Bonai-Keonjhar belt. The iron ore group of rocks exhibit an "U"-shape structure in this area. The general trend of the rocks is in NNE-SSW direction. The iron ores are generally associated with banded-haematite-jasper and to a less extent with ferrugenous to clayey shales and cherts. The ore varies in nature both physically and chemically. The physical character of the ore varies considerably from place to place both laterally and vertically. The iron content in ore varies from 63 to 69 percent. The hard lumpy variety of ore of this area is most suitable for sponge iron industry. The types of ores found in this area are (i) hard massive, (ii) hard laminated to medium hard laminated, (iii) soft and friable to powdery ore zone and (iv) lateritic ore. The powdery ore generally occurs in partings and joint fillings. Occasionally, thin bands of hard massive and laminated ores occur within the soft friable/powdery ore zone. Haematite is the main constituent of ores. However, minor quantities of goethite, martite, limonite and magnetite have also been recorded in this area. At places, the lateritic ores of this area contain numerous small cavities. These cavities are often filled with limonite, goethite and ocherous material.[15 b]

4.1.2.4 Madhya Pradesh

Large deposits of excellent quality iron ore are found in Bastar and Durg districts of Madhya Pradesh. Smaller deposits occur in Jabalpur, Rajnandgaon, Gwalior and Betul districts. Minor deposits and occurrences of iron ore are also reported from the localities of Bilaspur, Balaghat, Chhatarpur, Indore, Khandwa, Raigarh, Raipur, Sagar and Satna districts of the State.[5,7,16]

Baster District

Baster is a well-known district with its two important iron ore-bearing areas, viz. Bailadila range and Rowghat area. Bailadila range contains extensive deposits of haematite- type iron ore. The Bailadila range is located in the southern part of the district where 14 iron ore deposits occur along the crests of two parallel ridges, i.e. 5 on the west and 9 on the east of the range. They are Sonadehi Dongri, Pargal Hill, Khandighat Dongri, North Hahaladdi Hill, South Hahaladdi Hill, Tarai Kholi Hill, Bajimari Dongri, Dorkenhur Dongri, Ghoradar Dongri, Pitehur Dongri, Hill west of Amapara, Hill NW of Kwachi Katel, Berahus Donger and Hakirihur Donger. These deposits are better known as Deposits No. 1 to 14. Out of these fourteen deposits, eight deposits, viz. Deposit No. 1,2,3,5,6,10,13 and 14 are fairly large and contain substantial reserves of high grade iron ore.

Besides, small deposits of magnetite are also found in SE of Tedum Metta, along the stream N.E. of Suki Metta and along the stream west of Mulraju Metta where magnetite is associated with garnet - grunerite - schist.[3,5,8]

Another area, i.e. Rawghat is located at about 29 km NNW of Narainpur tehsil of Bastar district. Here, in all, 6 deposits known as Deposit A to F are located.

Massive as well as micaceous haematite ores also occur in the Ari Dungri hill near Parrekare area. Low grade lateritic iron ore occurs on the ridge of Guingenar and on the southern side of Kaingar valley. The detailed discription of geology, structure and ore characteristics of Bailadila deposits and Rawghat depoits is given below:[5,8,16]

Bailadila deposits: The iron orebodies of Bailadila deposits (Fig. 4.7) are associated with banded haematite quartzite. The rocks in which they occur are called Bailadila Iron Ore Series which resemble Iron Ore Series of Singhbhum-Keonjhar-Bonai of Bihar and Orissa and belong to the Upper pre-Cambrian age. The orebodies do not appear to confine to any particular horizon, for they attain their maximum development near the junction of the haematite-quartzite and the underlying ferruginous schists which themselves are quite rich in iron. They are thought to be due to the enrichment of the haematite quartzite and to some extent of the formations underlying them. Most of the deposits are composed of haematite ore but there are also few small deposits of magnetite ore.[3,5] The geological succession of this range is given in Table 4.3.

Detailed geological mapping and prospecting in the entire range have revealed that the orebodies occupy roughly NE-SW to NW-SE trending synclinal troughs. This fold is usually isoclinal and often slightly overturned. This is followed by two stages of superimposed folds, the earlier, a reclined fold roughly N-S trending and giving rise to a strong down dip lineation while the latter varies in its geometry from a conjugate set with sub-horizontal axial planes to a fairly tight fold.

The two main ridges in the range are actually synclines and the valley in between them is an eroded anticline. The ridges are about 1,219 m in height above the mean sea level. BHQ normally occurs along the upper portion of the eastern flank of the eastern ridge and on the portion of western flank of the western ridge.[3,5]

The Bailadila ores have been broadly divided into laminated ore and massive ore. The former is generally manifested by flank ore and blue dust which are considered to have formed by physical degradation of laminated ore. Patches of undergraded laminated ore are found locally, mostly enveloped within shale units. The massive ore is represented generally in two colours, i.e. steel grey and blue. Most of the deposits show one of its edges marked by a high cliff constituted entirely by massive ore which is usually juxtaposed against the ferruginous shale unit at its bottom (which sometimes contain pockets of BHQ). The other edge of the deposit is generally constituted by laminated ore. In general, near the surface, the ore is massive and compact, where the original banding has largely disappeared. Quite often, at the surface, a kind of fairly high grade laterite ore is underlain by good compact ore. Float ore in large quantities is also found on the hill sides surrounding the major deposits. At places, recemented ore comprising blocks of iron ore of varying sizes cemented together by a ferruginous matrix is also found. The iron content of Bailadila ores generally varies from 60 to 69 percent. The siliceous haematite ores contain 55 to 60 percent iron and the lateritic haematite 45 to 55 percent iron. The characteristics of some typical samples

TABLE 4.3 : GEOLOGICAL SUCCESSION OF BAILADILA IRON ORE RANGE

Intrusive Rocks	Pegmatite, dolerites and basalts, granites, injection gneisses, aplites and charnockites.
Kepayi Stage	Quartzites
Bailadila Iron Ore Series	Calc-schist, amphibolites, diopside, quartz granulites, banded ferruginous quartzites and grunerite, and magnetite quartzite schists.
Bengpal Series	Andalusite - gneiss, anthophyllite cordierite gneiss, biotite and garnetiferous schists.
Pendulnar Stage	Quartzite with intercalations of andalusite and cordierite gneiss.

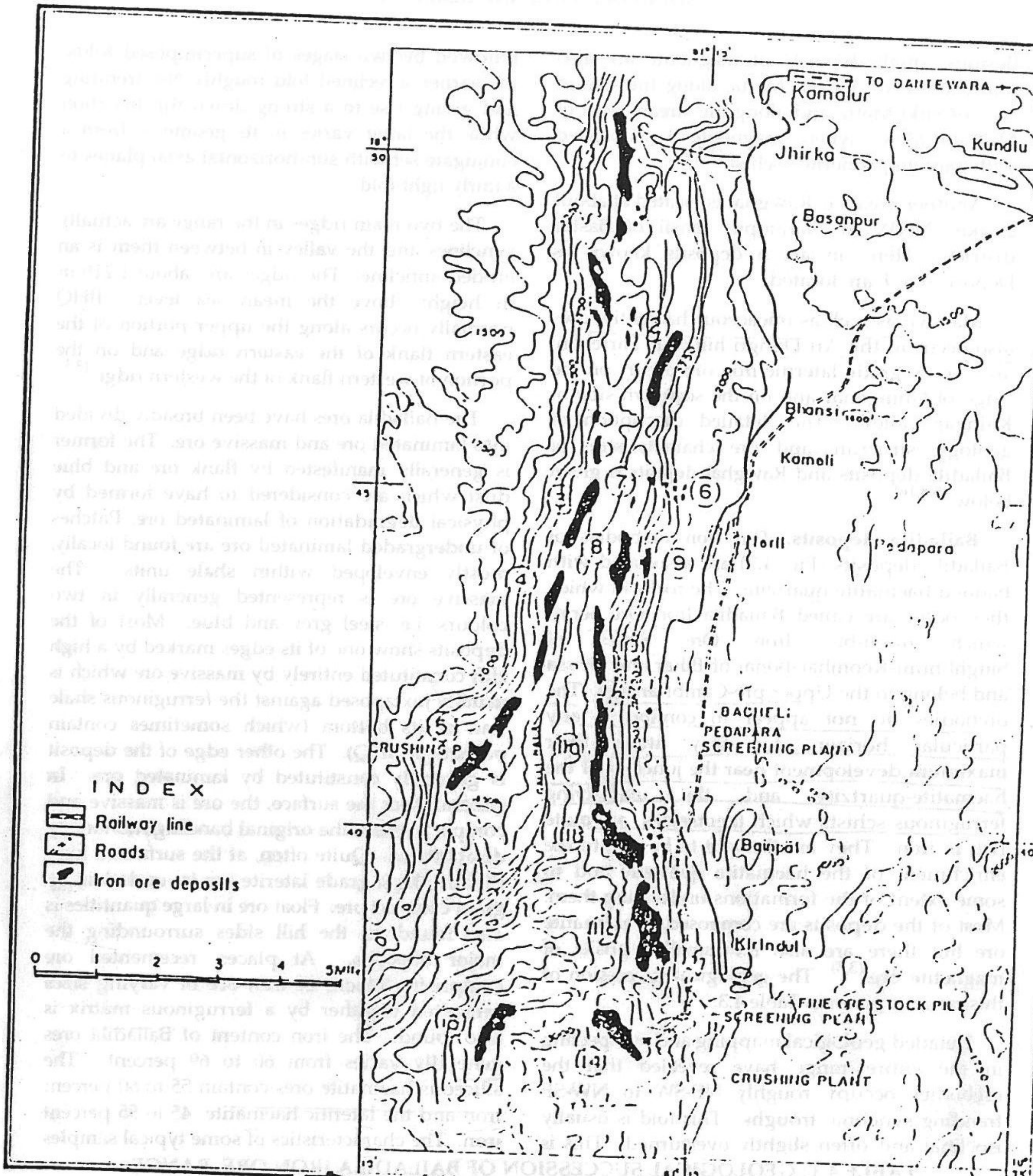


FIG. 4.7 : LOCATION MAP SHOWING IRON ORE DEPOSITS IN BAILADILA REGION

SOURCE : REFERENCE NO. 9

representing different types of ores are given in Table 4.4.[3,5]

TABLE 4.4 : CHARACTERISTICS OF DIFFERENT TYPES OF BAILADILA ORE [5]

Type of ore	Physical characteristics	Sp. gr.	Iron %
1. Massive	Dense and compact	5.11	68.26
2. Massive laminated	Compact & hard laminated	4.69	67.00
3. Laminated	Laminated but laminae somewhat loose held/soft laminated	4.19	63.47
4. Lateritic	Porous, lateritic material enclosing grains of haematite	4.46	47.46

Rawghat deposit: The iron deposits of Rawghat area are located about 20 km WNW of Narainpur. The villages at the foot of the hills of Rawghat area are Bhaisgaon and Aturbera. In all, six deposits, i.e. A to F are located in this area. The geology of these deposits is very similar to that of Bailadila area.[3,17]

The geological succession met within the area is given in Table 4.5.[17]

TABLE 4.5 : GEOLOGICAL SUCCESSION OF RAWGHAT DEPOSITS

RECENT		Laterite, float ore, canga, soil
ARCHAEAN		Quartz and quartz epidote veins Basic lava and dykes
	Bailadia Group	Banded haematite quartzite(BHQ) and banded haematite jasper Shale and phyllites Quartz
	Intrusives	Basic dykes
	Bengpal Group	Granite gneiss, migmatite and granite Mica schist, quartz sericite schist Grunerite magnetite quartzite pyroxene quartzite

The iron ore deposits are associated with banded haematite quartzite of Bailadila group forming almost continuous hillocks. The outcrops are 'M'-shaped with an antiform enclosing the plain of Kolar and complementary synform in east (Deposit 'E' and 'F') and west (Deposit 'A' 'B' 'C' and 'D'). The area comprises the metasediments of Bengpal Group which includes pyroxene quartzite, hornblende schist, grunerite magnetite quartzite, mica schist and quartz sericite schist. The metasediments occur as isolated patches and enclaves within granite trending NW-SE and dipping 30-70° towards south-west. The granite gneisses and schists are uncomformably overlain by banded haematite quartzite and banded haematite jasper with associated iron ores of the Bailadila Group. These are intruded by basic rocks, quartz and quartz epidote veins. The valley portions are filled up with lava flow and laterites.[17]

Except Deposit 'E', all other deposits (A,B,C,D and F) are located in eastern limb of Rawghat and they start from the nose of Rawghat synform and end with Takrel block. The Deposit 'E' is located in the western limb of Rawghat synform at the antiform closure, south-east of Phulpar village. The main synform runs NE-SW and plunges 20 to 25° towards SW. Another set of prominent folds, cutting across the ore deposit has been developed roughly along NW-SE direction, plunging north-westerly. This coincides with the general trend of basic dykes and quartz veins exposed in the area.[17]

In Deposits A to E, the ore is generally massive, hard and compact but porous ore is also associated. The hard variety is generally predominant and the grade uniformly high. The Deposit 'F' is the largest and richest deposit of this area. It extends practically along the whole length of the south-western ridge of Rawghat, from a point 2.4 km west of Karkegaon to the extreme western end of the ridge to about 2.4 km west of Aturbera village. The orebody occupies the entrie summit of the ridge and dips at 35° into the Anjrel valley on the west. On its dip slope, there is a fairly widespread laterite cap. The orebody is mostly composed of soft to medium hard, bluish grey, porous, laminated

TABLE 4.6 : CHEMICAL ANALYTICAL RESULTS OF IRON ORE OF A TO F DEPOSITS OF RAWGHAT AREA

Deposit	Fe %	SiO_2 %	P %
A	64.21	1.75	0.156
B	NA	NA	NA *
C	59.86	3.41	0.10
D	63.13	2.13	0.072
E	65.8	1.52	0.047
F	66.0	0.91	0.055

* The ore is more or less similar to Deposit A.

ore which has frequently undergone lateritisation although good outcrops of rich steel grey hard and compact massive ore also occurs in this area.[3,5,17]

The analytical results of some typical samples of different deposits are given in Table 4.6[3]

Durg District

The Rajhara deposit is the most important deposit in this district. It is located on the ridge called Dalli and Rajhara hills. Another important deposit, viz. Kauchar occurs SW of Dalli Rajhara. Iron ore deposits are also found at the peak south of Jharandalli, in the flat-topped ridge Kondekosa and in the ridge SW of Kondekosa. Besides, lateritic ores are reported near Khairgarh, Borla, Katul Kassa, Jurlakhar, Chutrala and Kumi. The important deposits of this district, viz Rajhara and Kauchar are described as under:[3,5]

Rajhara deposit: Extensive deposits of high grade iron ore associated with banded haematite quartzite occur on the ridge called Dalli and Rajhara hills. Large lenticular patches of high grade ore are found at different locations. The stratigraphic succession of the area is given in Table 4.7.[3,5]

TABLE 4.7 : GEOLOGICAL SUCCESSION OF RAJHARA DEPOSIT

Recent	Laterite and recemented ores
Intrusive unclassified Post-Dharwar to pre-Cuddapah	Basic intrusives and quartz veins, granite, diorite and granite gneiss, Trap
Archaeans	Ferruginous shale, phyllitic at places
Dharwar (possibly homotaxial with Chilpi Ghat Series of South Singhbhum and Orissa)	Highly chloritic phyllite, laminated iron ore, massive ore Banded haematite quartzite & grit Talcos phyllite Banded quartzite Phyllites and schist Basement not known

Structurally, the Dalli-Rajhara range forms the southern limb of a house-shoe-shaped pitching synclinal basin comprising Dharwar metamorphites. The iron ore formations constitute the fringe of the basin whereas the centre is composed mainly of a series of lava flows having occasional inliers of iron ore formation. The iron ore formations are undulated and have rendered the shape of the basin to be a synclinorium. The ore is mostly haematite with traces of magnetite. The ore of this area is generally high grade. Some typical samples of Rajhara (surface sample) analyse Fe - 66.35 percent, SiO_2 1.44 percent and P - 0.058 percent and boreholes samples analyse Fe - 68.56 percent, SiO_2 0.71 percent and P - 0.064 percent.[3,5]

Kauchar deposit:- Kauchar deposit occurs SW of Dalli-Rajhara at a distance of 12 km. Here, the banded haematite quartzite are overlain and underlain by ferruginous shales and phyllites. The succession of the rock type met within the area is given in Table 4.8.

TABLE 4.8 : GEOLOGICAL SUCCESSION OF KAUCHAR DEPOSIT

	Laterite	
Purana formation	Gritty quartzite conglomerate	
Dharwars	Igneous	Quartz veins Dolerite and epidiorite Granites (gneissose and massive) Diorite and granodiorite. porphyrities Basalt, gabbro, pyroxinite epidiorite, etc.
	Metasediments (Bailadila iron ore series)	Pink ferruginous shale Banded haematite quartzite with iron ore Ferruginous shales and phyllites

Banded haematite quartzite forms prominent ridges and has been folded into series of anticlines and synclines. Several orebodies comprising massive and laminated haematite ore are found at or near the top of the ridges. However, earthy limonitic brecciated and lateritic types of ores are also present in subordinate quantities. The colour of the ore varies from steel grey to brownish grey, becoming progressively yellowish in the limonitic variety.[5]

4.1.2.5 Karnataka

The iron ore deposits of Karnataka can be classified broadly into three groups, namely, sedimentary deposits comprising banded ferruginous quartzites of Dharwarian age from

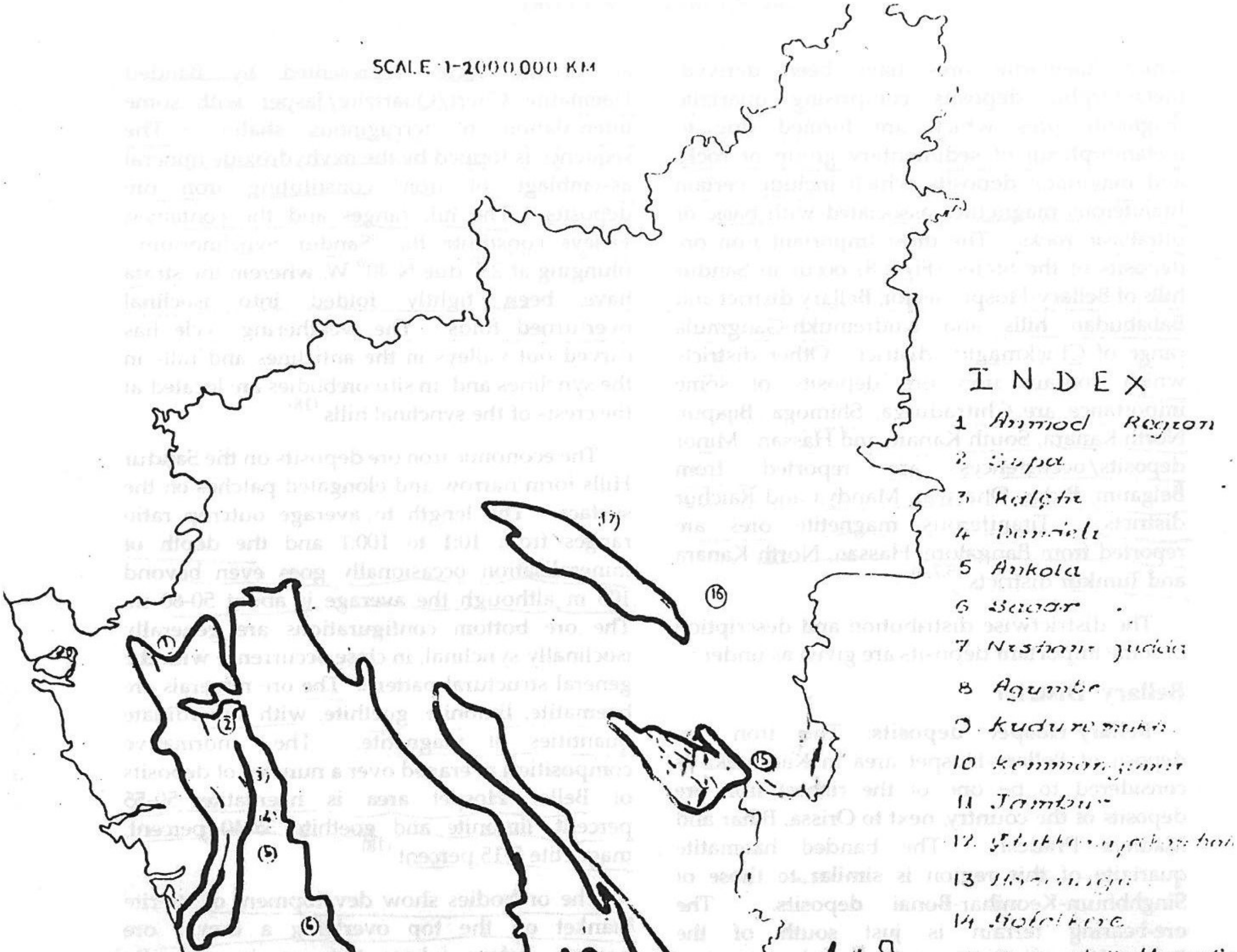


FIG.4.8 : LOCATION MAP SHOWING IRON ORE DEPOSITS IN KARNATAKA STATE

which haematite ores have been derived, metamorphic deposits comprising quartzite magnetite ores which are formed due to metamorphism of sedimentary group of rocks and magmatic deposits which include certain titaniferous magnetites associated with basic or ultrabasic rocks. The most important iron ore deposits of the States (Fig.4.8) occur in Sandur hills of Bellary-Hospet sector, Bellary district and Bababudan hills and Kudremukh-Gangmula range of Chickmaglur district. Other districts which contain iron ore deposits of some importance are Chitradurga, Shimoga, Bijapur, North Kanara, South Kanara and Hassan. Minor deposits/occurrences are reported from Belgaum, Bidar, Dharwar, Mandya and Raichur districts. Titaniferous magnetite ores are reported from Bangalore, Hassan, North Kanara and Tumkur districts.[5,7,8]

The districtwise distribution and description of some important deposits are given as under :

Bellary District

Bellary-Hospet deposits: The iron ore deposit of Bellary-Hospet area in Karnataka is considered to be one of the richest iron ore deposits of the country, next to Orissa, Bihar and Madhya Pradesh. The banded haematite quartzite of this region is similar to those of Singhbhum-Keonjhar-Bonai deposits. The ore-bearing terrain is just south of the Bellary-Hospet Railway line and comprises Ramdurg, Kumaraswamy, Donimalai, Thimmappanagudi and Devadarigudda sections along the eastern and western ranges of Sandur hills as well as the Copper Mountain near Bellary town. The height of these plateau-topped hills is usually over 1,000 m above MSL as compared to the level of 500-600 m in surrounding plains.[5,18]

The order of superposition of rocks in the Sandur Group of Dharwar Super-group indicates a typically eu-geosynclinal succession. The lowest horizon comprises lava flows/chlorite schist, with a few intercalated lenticular bands of conglomerate and banded magnetite chert/quartzite. This has been non-comformably overlain by argillite facies (phyllites, etc.) and after an off lap, passes into an arenite facies represented by Banded Haematite Chert/Quartzite/Jasper with some intercalation of ferruginous shales. The sequence is topped by the oxyhydroxide mineral assemblage of iron, constituting iron ore deposits. The hill ranges and the contained valleys constitute the "Sandur Synclinorium", plunging at 23^{0} due N 40^{0} W, wherein the strata have been tightly folded into isoclinal overturned folds. The weathering cycle has carved out valleys in the anticlines and hills in the synclines and in situ orebodies are located at the crests of the synclinal hills.[18]

The economic iron ore deposits on the Sandur Hills form narrow and elongated patches on the surface. The length to average outcrop ratio ranges from 10:1 to 100:1 and the depth of mineralisation occasionally goes even beyond 100 m although the average is about 50-60 m. The ore bottom configurations are generally isoclinally synclinal, in close occurrence with the general structural pattern. The ore minerals are haematite, limonite, goethite, with subordinate quantities of magnetite. The normative composition averaged over a number of deposits of Bellary-Hospet area is haematite 50-55 percent, limonite and goethite 35-40 percent, magnetite 5-15 percent.[18]

The orebodies show development of laterite blanket on the top overlying a lumpy ore horizon below where the ore is generally compact. Underlying this, however, is the powdery ore horizon, wherein the material is powdery or loosely held. Overall proportion of the powdery ore in a deposit is just less than half. There is, however, transition between the two and even intercalation of one type in the other. The iron orebodies of this region is highly oxidised. Ore has been generally defined here by 55 percent of the total iron or more although various enterprises choose to name the ore at different cut-off grades even down to 50 percent iron. An idea of the total composition of the ores may be obtained from Table 4.9 (see page 57) based on the available analysis data from all over the area and from a number of sources.[5,18]

The different types of ores such as massive, compact laminated, laminated and powdery

TABLE 4.9 : RANGE OF CHEMICAL COMPOSITION OF BELLARY HOSPET ORES

Constituent	Wt %
Fe	55 - 69
SiO_2	0.2 - 10
Al_2O_3	0.9 - 15
TiO_2	0.2 - 1.2
MnO	0.1 - 2.1
P	0.02 - 0.16
S	0.005 - 0.05
CaO	0.05 - 0.2
MgO	0.03 - 2.1
H_2O	2 - 12

ores differ in their iron content. Generally, massive ore varies in its iron content from 67 to 69 percent; compact laminated ore contains on an average 67 percent iron; laminated variety shows average 65 percent iron; and powdery ore contains generally above 65 percent iron.[5]

Chikmaglur District

Deposits of Bababudan hills: In Chikmaglur district, important iron ore deposits are found in Bababudan hills. The chain of hills, shaped like a horse-shoe is about 22 km wide in east-west direction and 19 km in north-south direction. On the tops of this chain of hills, iron ores, some hundreds of meters thick, occur in discontinuous masses. One of them is the well-known Kemmanugundi iron ore field which is being worked by opencast mining to feed the iron ore to iron and steel works at Bhadravati. This ore contains between 57 and 62 percent iron with phosphorus content ranging from 0.05 to 0.09 percent. In Kalhattigiri region in the south-eastern portion of this chain of hills, iron ores cover a very wide area. Much of the ore exposed here is chiefly haematite with some amount of limonite. The ore shows iron content between 55.11 and 64.22 percent and phosphorus 0.044 and 0.057 percent. The deposits of Kemmanugundi and Dhupadgiri are being exploited by M/s Visveswarya Iron and Steel Works, Bhadravati.[7]

Near Masanikere, close to Bhadravati, vanadium-bearing iron ore is also reported.[7]

During 1981-82, GSI has carried out large-scale mapping of Bababudan range. In the course of mapping, two deposits of high grade haematite ore containing 63 to 68 percent iron were located, one at the head of the Shankasole nala and the other to the east of Virupakshivan on the Kemmanugundi-Chikmaglur road. The Shankasole deposit contains two parallel bands of haematite separated by a band of phyllite. The bands are (a) 450 m long, 60 m wide and 30 m deep (b) 350 m long, 40 m wide and 20 m deep. The bands strike N 60° W-S 60° E and dip varies from 20 to 45° due south-west. The East Virupakshivan deposit also contains two bands which are separated by phyllite. The bands strike NW-SE and dip at 30° due NE. These bands measure (i) 420 m x 20 m x 20 m and (ii) 350 m x 20 m x 20 m.[19]

During the course of mapping in northern part of Bababudan range, three blocks, namely (i) Kalhatgiri (ii) Kemmangundi north-east and Totlukhan-Hebbegiri were identified where thick bands of banded magnetite quartzite occur.[19]

Keeping in view the successful implementation of Kudremukh project, where low grade iron ore is beneficiated to yield a concentrate of 67 percent iron, these banded magnetite quartzite-bearing blocks are important. Here, uninterrupted exposures of BMQ occur over lengths varying from 2.5 to 11.0 km and thickness varying from 100 to 240 m. The ore generally compares well with that of the Aroli deposit of Kudremukh in terms of Fe content, i.e. 35 to 40 percent.[19]

Kudremukh deposits: The hill ranges between Kudremukh and Gangamula contain extensive deposits of magnetite ore at Gagrikal, Nellibidu and Aroli. The ridges and hills of this region are quite rugged and often reach an elevation of about 1,200 m and more above the MSL. The iron ore formations are considered to be metamorphosed iron-bearing Dharwarian rocks of sedimentary origin. Lithologically, the region consists of rocks of varying nature. They include fine and coarse-grained hornblende schist, amphibolite, garnetiferous chlorite schist, banded magnetite quartzite (BMQ) and opalscent quartz gneiss. The amphibolite occurs as massive outcrop and forms the base of the BMQ. It is course-grained rock and consists primarily of hornblende, actinolite, biotite tremolite, etc. The amphibolite bands varying in thickness from few millimetres to 20 m frequently interbedded with BMQ and such waste rock form a mush of 20 percent of the whole deposit.[5,7]

In Aroli deposit, the BMQ occurs above the amphibolites and it forms a series of asymmetrically overturned folds. The true thickness of BMQ bands is around 100 m. The strike of the iron ore formation varies from N-S to NNW-SSE and dip of the beds is generally toward east varying from 30 to 85^o. The average dip is around 40^o. The folds are plunging towards north with the plunge of 8 to 20.^{o} The area is highly jointed with two major sets of joints. One set of joint has its strike perpendicular to fold axis and other set makes an angle with the first set. These joints have played an important role in weathering and oxidation of BMQ. The iron ore formation near the surface has undergone weathering, rendering the ore friable as silica and alumina have been partially leached out leaving unfilled spaces between the layers. This forms the upper horizon of BMQ in which magnetite is partially oxidised to haematite. Besides oxidation, the silica and iron bands have partially lost their binding material thus making the iron ore soft and friable. The depth of the weathered zone varies from place to place and is thicker in the ridge than in valleys. The soft weathered zone varies in depth from 30 to 50 m. Underlying this soft weathered zone, a transitional hard weathered zone occurs. The thickness of this hard weathered zone is about 30 m. This partially oxidised ore zone consists of hard and compact iron and silica bands which are fine grained. In both these weathered ores, iron content varies from 38 to 40 percent or say the average iron content is about 39 percent.[5,20,21]

Below the transitional weathered zone lies the fresh zone of magnetite-quartzite as primary ore zone in which magnetite has remained un-oxidised or very little oxidised. Both iron and silica bands are quite hard and compact and contain together, on an average, about 31 percent iron. Along with magnetite and quartzite, iron silicates are also present. Sometimes other minerals like pyrite and calcite also occur within the ore. The iron ore produced from Kudremukh area is fully amenable to beneficiation and it can be concentrated to produce concentrate analysing 67 percent iron content.[5,20,21]

Other Districts of Karnataka

In Chitradurga district, iron ores analysing 54 to 68 percent iron occur in a series of parallel hills between Sivaganga and Hiriyur. The best quality of ore is reported from Ipara area where the haematite ore has iron content of 68.02 percent. In Chitradurg-Tumkur belt, iron ore deposits are confined to certain localities in the western part though banded haematite quartzite bands are continuous over the entire length of the belt. The areas are intricately folded and iron ore is localised in some of the fold closures. Massive ore on the surface becomes laminated ore at depth; at further depth, it becomes powdery ore and finally it reaches to the banded-haematite-quartzite layer. The average grade of in situ ores contain 55 to 58 percent iron. However, the lumpy ore recovered varies from 59 to 68 percent iron, 0.57 to 0.94 percent alumina, 0.72 to 5.06 percent silica with minor quantities of manganese and titanium. Phosphorus and sulphur are present in traces.[7,22]

In Shimoga district, iron ore occurs in Shiddarahalli and Channagiri taluks. The iron ore is also found in Joldhal, Gangur, Bhadigund and Shankargudda areas. In Kumsi area, low grade ores containing 55 percent iron are reported from Chattanahalli. The Chattanahalli deposit extends over a strike length of 360 m with an average width of 80 m.[8,22]

In North Kanara district, smaller deposits are reported from Anmod, Kodalgadde and Apsarakonda areas. The iron ores have been formed due to selective leaching of silica from magnetite quartzite and replacement of argillite by iron and preserved on geomorphologically favourable locations. Generally, iron ore occurs above the altitude of 757 m above the MSL. The iron ore is essentially composed of haematite with minor amounts of magnetite and limonite. In this area, the iron ore of economic importance occurs in Hatkhamba, Shiroli, Kunang localities and also in Avarcha and Siddhi hills.[7,23]

In Bijapur district, haematite beds are found in the Kaladgi Series of rocks at Amingarh, Bassargi and Bisnal. In this district, four beds of haematite quartzite are located. In this district, workable deposits of iron ore occur in Aiholi and Hiremagi - Ramthal localities of Hungund taluk. These deposits are presently under active exploitation by M/s Doddhanwar and Brothers. The Hiremagi-Ramthal deposit contains hard massive and soft-friable types of ores. The iron content in ore varies from 58 to 66 percent. The Aiholi deposit, which is almost in continuation of Hiremagi-Ramthal deposit, is of hard laminated and soft laminated types.[8]

In Mandya district, magnetite ores occur within charnockites in the neighbourhood of Malvalli. The principal exposures are found near Muddur, Tippur, Husugur, Hullahalli and in between Karalkatti and Hulalhur.[8]

4.1.2.6 Goa

Goa is a small State covering an area of about 3,701 sq km. It is the only State in the country where largest number of iron ore deposits (Fig. 4.9 and 4.10) are concentrated in such a small area. The major part of Goa is covered by the rocks of pre-Cambrian age consisting of quartz-sericite-schist, metavolcanics, quartz-chlorite schists, quartz-chlorite-biotite schist, metagreywacks, conglomerate (tilloid), pink phyllites with lenticular bodies of banded manganiferous and ferruginous quartzites and upper metagreywacke intruded by ultrabasic and basic sills and dykes, granites and gneissic granites, dolerite dykes and vein quartz.

The iron ore deposits are generally confined to pink phyllite horizon which has a wide distribution. The pink phyllite of this region resembles the shales in the well-known Singhbhum-Keonjhar-Bonai iron ore region of Bihar and Orissa.[5,7,24]

The stratigraphic succession of the region is given in Table 4.10.[24]

The iron ore deposits consisting essentially of haematite and partly of magnetite, limonite and goethite occur with the banded ferruginious quartzites and ferruginous phyllites as reef, lensoid bodies and as cappings of varying dimensions at and near the surface. Generally, they occupy crests and slopes of the hills and mounds. The higher the hills and the steeper the slope, the better is the size of the deposit. Thus, they are controlled by geomorphological setting of the area.[5,24]

Occasionally, narrow, irregular deposits are also found along the edges or rims of plateau. Towards the interior, where the terrain is flat or gently slopping, the concentration of iron ore is poor and the ore tends to be shaly and admixed with laterite. Generally, the deposits are present on the eroded limbs of major anticlinal folds, the axes trend in general NW-SE direction.[24]

Generally, close to the surface, the ore deposits consist of hard lumpy ore followed at depth by friable and powdery ore (known as blue dust). In general, if the lumpy ore at the surface is good in grade and thickness, the powdery ore occurring below lumpy ore is also good in quality and quantity. If, however, the lumpy ore is admixed with considerable proportion of laterite, the powdery ore below it

TABLE 4.10 : STRATIGRAPHIC SUCCESSION OF ROCKS IN GOA

Recent	Alluvium soil
Recent to Sub-Recent	Laterites
Upper Cretaceous to Lower Eocene	Deccan Traps
Pre-Cambrian	Younger dolerite dyke Pink porphyritic granite Gneissic granite Ultrabasics and basic intrusives Upper metagreywacke Pink ferruginous phyllites with manganiferous chert breccia and banded ferruginous quartzites (with iron and manganese ores) Metagreywacke with conglomerate (tilloid) Quartz-chlorite-biotite schist Quartz-chlorite-schist with thin beds of quartzites Meta-basalt with associated acid flows and tuffs and thin beds of quartz-chlorite schist.

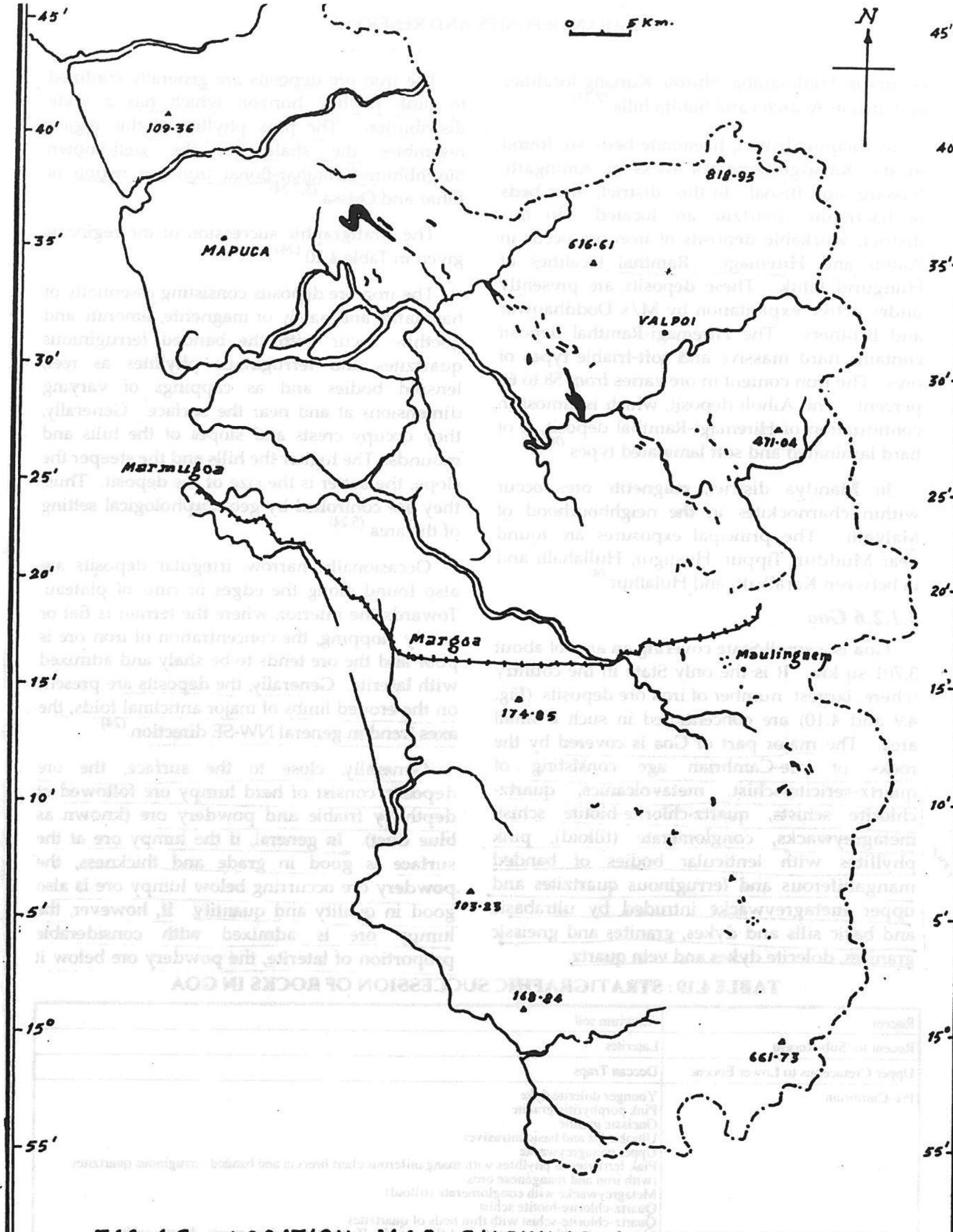


FIG. 4.9. LOCATION MAP SHOWING IRON ORE DEPOSITS IN GOA STATE