CHAPTER 9

EXPLORATION METHODS FOR MANGANESE MINERALIZATION

9.1 INTRODUCTION

Exploration is a team effort, the team being composed of a group of specialists in various phases of mineral resource development. The cost of the exploration is alarmingly very high but the profit, in terms of gross mineral value discovered is much greater, if a large deposit is discovered. In view of this, exploration efforts are a mammoth exercise aptly compared to “an elephant hunt”. Mineral exploration includes the prospecting or search for the mineral deposit. The search for mineral deposits started since the time early man began using minerals and rocks. In ancient Indian history, intelligent persons were sent on expedition to prospect for minerals. However several deposits were discovered by chance and some are initiated by the Geological Surveys of India (GSI) sometime after its inception in 1851. In the current scenario, many other agencies have came in to existence in India such as Mineral Exploration Corporation Limited (MECL), Indian Bureau of Mines (IBM) along with many other private, public sector and multinational undertakings. The current approaches on exploration for manganese in India during 2008-09 are shown in Table 9.1.

9.2 TECHNIQUES OF MANGANESE MINERAL EXPLORATION WITH REFERENCE TO THE STUDY AREA

Ability to reliably distinguish between uneconomic mineral deposits and economic mineralization is one of the major problems of mineral exploration. Due to deceptive nature of ore bodies and varied controls of mineralization, techniques used for mineral exploration also vary and therefore an integrated approach is adopted. Such approach leads to a structural and resource model of the deposit which has immense implications while evaluation of these resources. Remote sensing followed by ground and airborne geophysical surveys, stream sediment, litho geochemical surveys and core drilling have been used in carrying out at regional and detailed surveys for manganese ore. In general, closer and detailed exploration methods are usually needed as the manganese ore bodies are mostly occur as pocket type to lensoid ore bodies, however, in the study area, especially in and around Balaghat (Fig. 2.5), the manganese occurs as a continuous ore body albeit affected by deformation.
Table 9.1 Details of exploration activities in India for manganese ore during the year 2008-09.

<table>
<thead>
<tr>
<th>Agency State/ District</th>
<th>Location Area/ Block</th>
<th>Mapping</th>
<th>Drilling</th>
<th>Reserves/Resources estimated</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geological Survey of India Odisha/</strong></td>
<td>Kendujhar-Bonai</td>
<td>-</td>
<td>-</td>
<td>A resource of 0.66 million tonnes of manganese ore at 20% cut off grade.</td>
</tr>
<tr>
<td></td>
<td>Damurda block</td>
<td>-</td>
<td>-</td>
<td>A tentative resources from northern part of Damurda block has been estimated at 0.94 million tonnes with 20% Mn</td>
</tr>
<tr>
<td><strong>Director of Mining and Geology Jharkhand West Singhbhum</strong></td>
<td>Barajamda</td>
<td>1:50,000</td>
<td>34</td>
<td>Investigation was at a very preliminary stage.</td>
</tr>
<tr>
<td></td>
<td>Jhillingburu-I</td>
<td>1:50,000</td>
<td>7</td>
<td>271.00</td>
</tr>
<tr>
<td><strong>Director of Mining and Geology Rajasthan Banswara</strong></td>
<td>Kalakhunta, Tambosara, etc.</td>
<td>1:50,000 1:10,000 1:4,000</td>
<td>240 18 2.1</td>
<td>50</td>
</tr>
<tr>
<td><strong>Udaipur</strong></td>
<td>Umra, Chotisar,</td>
<td>1:50,000 1:10,000 1:2,000</td>
<td>150 15 1.5</td>
<td>Resources of manganese ore are estimated around 0.51 million tonnes.</td>
</tr>
<tr>
<td><strong>Manganese ore (India) Limited Madhya Pradesh Balaghat</strong></td>
<td>Bharweli Mine</td>
<td>02</td>
<td>1212.50</td>
<td>As on 1.4.2011, total resources of manganese ore were estimated at 24.50 million tonnes grade of 30-50% Mn.</td>
</tr>
<tr>
<td></td>
<td>Tirodi Mine</td>
<td>12</td>
<td>670</td>
<td>As on 1.4.2009, estimated 1.55 million tonnes</td>
</tr>
<tr>
<td><strong>Maharashtra Bhandara Nagpur</strong></td>
<td>Chikla Mine</td>
<td>02</td>
<td>470.70</td>
<td>Estimated 3.97 million tonnes of resources.</td>
</tr>
<tr>
<td></td>
<td>Kandri Mine</td>
<td></td>
<td></td>
<td>Estimated 1.97 million tonnes manganese ore resources.</td>
</tr>
<tr>
<td></td>
<td>Mansar Mine</td>
<td>03</td>
<td>598</td>
<td>Estimated 3.73 million tonnes of resources.</td>
</tr>
<tr>
<td></td>
<td>Beldongri Mine</td>
<td></td>
<td></td>
<td>Estimated 0.46 million tonnes of resources.</td>
</tr>
<tr>
<td></td>
<td>Gumgaon Mine</td>
<td>03</td>
<td>1160</td>
<td>Estimated 5.405 million tonnes of resources.</td>
</tr>
</tbody>
</table>

9.3 EXPLORATION CARRIED OUT IN BALAGHAT MINE

The area was first discovered in 1889, though planned exploration at Balaghat mine was carried from 1950 onwards. Since then, 74 boreholes have been drilled covering a total 14908 m (Fig. 9.1). The exploration was taken up in four phases. The first phase of exploration was carried by Central Province Manganese Organization (CPMO) for a period of 2 years i.e., 1951 and 1952, achieving 836.41m of drilling target with 5 numbers of boreholes. Out of these boreholes, borehole number 2 and 4 were drilled from underground (4th level). The second phase of exploration was conducted by Manganese Ore India Limited (MOIL). About 13 underground boreholes were drilled from 5th level to 6th levels, adding 1177.36 m of drilling to the total quantity drilled in phase first. This phase commenced in 1977 and after establishing 6th level, it was closed in the year 1983 (Ref MOIL’s mining plan).

The results obtained from both the phases were applicable for shallower depth only i.e. up to 6th level. In order to achieve results for lower level, MOIL entered a contractual agreement with Mineral Exploration Corporation Limited (MECL). As per the contract they were assigned to establish the deposit up to 12th level with 2000 (+10%) meters of drilling target. Accordingly MECL started the exploration in July 1983 and was discontinued in March 1984. Total of 2015.15 m could be drilled with 9 boreholes. The 4th phase or present phase was commenced in year 1990 and so for about 31 boreholes have been completed. The deepest boreholes (650 m) without deviation have been drilled during this phase, which has established the 23rd level (-320MRL) of Balaghat mine (Fig. 9.2). The quality of ore received from various boreholes is good with manganese percentage is up to 43 % with very low phosphorus percentage. At deeper levels the continuity of ore quality is also very good (Fig. 9.3).
Fig. 9.1: Geological map of Balaghat mine showing location of boreholes drilled up to 2011 with the location of production shaft and two lease-hold areas. Note that BH 22 in the south and BH 25 in north are proving the strike extension of the deposit.
Fig. 9.2: Geological map of Balaghat mine showing level of intersection drilled up to 2011, BH 70 in central part of the deposit is the deepest one proving -290 m MRL.
Fig. 9.3: Geological map of Balaghat mine showing quality of boreholes drilled up to 2012. In all boreholes Mn is ranging from 30-46%, SiO$_2$ 10-35 % Fe- 2-6% and P- 0.33 to 0.007 respectively.
9.4 DRILLING

9.4.1 Introduction

Drilling is the process of making a hole in the ground or rock. The material which is cut during may be used for purpose of testing mechanical properties, chemical analysis etc. which is the purpose of drilling in mineral exploration to delineate an ore body and to prove its depth persistence.

9.4.2 Classification of drilling methods

On the basis of material obtained from the hole, there are two main types.

1. **Core Drilling** - Where by means of drilling, core can be obtained. Diamond bits are used in core drilling.

2. **Non-Core-Drilling** - Where only cutting along with slurry can be obtained. Generally Tungsten Carbide (T.C) bits are used for this purpose (Figs.9.4 a, b and c).

Fig. 9.4 a: Schematic diagram showing various types of non coring bits, bits are generally used in shallow depth.

Fig. 9.4 b-c: Photographs showing rock roller bit (None coring type), are used in pebbly beds.

9.4.2.1 Diamond drilling

Diamond drilling can be defined as hard rotary drill, which normally takes a core. It can drill hole in any direction and has ability to penetrate in hard and compact formations. The main difference is the type of drilling bit and in this case a diamond is used for cutting the rocks. It can be used both in open cast (open cut) and underground mining. Diamond bit cuts a cylindrical core of the rock through which it passes and it is the most popular type of drilling. In the Balaghat mine, diamond drilling is undertaken. Most of the exploration throughout the world is carried out by
diamond core drilling using conventional and wire line methods. These two methods are discussed in detail as most of the exploration in MOIL is carried out with these techniques.

9.4.2.1.1 Conventional drilling

In the conventional drilling, equipments such as drill rods, casings, core barrels, diamond tools etc. are used as per Diamond Core Drill Manufacturers Association (DCDMA) standards, Swedish standards for diamond core drilling. In some cases, Russian standards are also used. The drill rods convey the rotational torque and feed pressure to the core barrel, reamer shell and bit allowing the coolant fluid to pass through them. Different sizes of casings are used telescopically in the borehole, as per requirement, to protect the borehole from caving, water loss, and deviation problems and also to act as the least required annular space between drill rods and casings, for promoting better drilling condition. In conventional drilling system, the drill string comprising drill rods, core barrel, bit etc. has to be raised at the end of each of each run; usually 3 m and after recovering the core, the drill string is lowered again for the next run.

9.4.2.1.2 Wire line system

In the wire line system, the inner tube containing the core can be drawn with the help of "overshot assembly" through the core barrel and drill rods, with the help of a wire rope. The inner tube could be dropped to seat in the outer tube. This is a face discharge type core barrel. This system eliminates the raising and lowering of the string which takes about a shift or even more in deeper boreholes for recovering the core. Hence this system increases the drilling time of the rig giving higher output. The string would be taken out only when the bit has to be changed. The Russians have developed a wire line bit, which is collapsible and the worn out bit could be retrieved through the drill rod string and a new bit introduced. This eliminates even the time required for rising and lowering the string, thereby, increasing actual drilling time. There are limitations for this also. The thick kerfs of the bit reduce the penetration rate of drilling in very hard formation. Wire line system of drilling introduced in Balaghat mine since 2001.

It’s advantages are-

a) When deep diamond drilling is resorted, where the depth are of the order of 300 m or more.
b) Saving of time taken in screwing and unscrewing.
c) Avoids raising and lowering of rods.
9.4.3 Parts of drilling machines which are used in Balaghat mine-

9.4.3.1 Bit: The lower most portion of the drill rig is bit. Bits are steel made special shape tips which penetrate, crush ream and mix the rock material, bit may be circular, octagonal or cross shaped (Figs. 9.5 and 9.6). They are two types according to the material used.

9.4.3.1.1. Diamond bits: Diamond bit may be hand or machine set. Diamond must set in such a way so that the metal of a bit will not come in contact with the rock and must cover over another allowing all parts of the area to be cut to come in contact by a diamond in each reevaluation of bit. In hand set a small number of large diamonds are individually set in a bland shell where as in cast set large number size and quality of diamond differ from manufactures to manufactures (Fig. 9.5 a-b).

Fig. 9.5 a: Photograph of diamond bits showing various sizes of casing bits.
Fig. 9.5 b: Photograph showing various sizes of diamond bits with reaming shell (Wire line bits).

9.4.3.1.2. Tungsten carbide tipped bits: Sometimes instead of diamond tungsten carbide bits used which serves almost similar purpose for prospecting and is also cheaper (Fig. 9.6).

The bits which are in use in Balaghat mine are ‘Q’ series type. The corresponding diameter sizes of wire line bits use in Balaghat mine are described in tabular form (Table 9.2).

Fig. 9.6: Photographs showing various sizes of T. C. bits.
### Table 9.2. Standard size of wire line diamond core bits ‘Q’ Series

<table>
<thead>
<tr>
<th>Size</th>
<th>Core Diameter (mm)</th>
<th>Hole Diameter (mm)</th>
<th>Hole Volume (liters/100 ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AQ, AQ-U</td>
<td>27.0</td>
<td>48.0</td>
<td>55.2</td>
</tr>
<tr>
<td>BQ, BQ-U</td>
<td>36.5</td>
<td>60.0</td>
<td>86.0</td>
</tr>
<tr>
<td>NQ, NQ-U</td>
<td>47.6</td>
<td>75.7</td>
<td>137.5</td>
</tr>
<tr>
<td>HQ</td>
<td>63.5</td>
<td>96.0</td>
<td>220.8</td>
</tr>
<tr>
<td>PQ</td>
<td>85.0</td>
<td>122.6</td>
<td>359.8</td>
</tr>
</tbody>
</table>

#### 9.4.3.2. Selection of Diamond Bit

For selecting diamond bit following point should be considerable.

a) **Diamond size:** In soft formation the diamond can be force to take a deeper depth producing large cuttings so the diamond must be larger in hard formation, smaller diamond should be used in soft formation.

b) **Number of stone:** There are two reasons for increasing the number of diamond as the hardness of formation increases. The size of the ground granules decreases as the rock hardness increases resulting in lower penetration rates for the same bit. To compensate for this more cutting points and maximum penetration.

c) **Diamond quality** – A large number indicate better quality of 85 is made up of flat irregular stone. Quality 120 consists of rounded more nearly pre feet stones (octahedral and dodecahedral) qualities in between are blander.

d) **Matrix**- Matrix herons during drilling in abrasive formations at soft matrix will wear away quickly. This leave the diamond over exposed. Where they can be dislodged easily from the bit resulting in excursive diamond loss. To prevent this harder matrix is always used in abrasive formations in fracture or broken ground hard matrix are recommended (Table 9.3).

However the performance of diamond bit also depends on rotation per minute (RPM). Rotation of diamond bit causes the diamond to tear chips from the rock. Therefore, generally speaking, the more rotation per minute the higher the rate of penetration (ROP). The rotation speed also serves to work the matrix to achieve a constant rate of exposure of new sharp diamond and release of the worn ones.
Table 9.3: General guideline for selection of diamond bits

<table>
<thead>
<tr>
<th>Rock formation</th>
<th>Diamond size</th>
<th>Matrix recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Soft</td>
<td>Talc, Bauxite</td>
<td>4/7 spc</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard</td>
</tr>
<tr>
<td>Soft</td>
<td>Gypsum, Rock salt, Coal etc</td>
<td>10/15 spc</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard</td>
</tr>
<tr>
<td>Medium Hard</td>
<td>Fluorite, Dolomite, Sandstone etc</td>
<td>15/25 spc</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard</td>
</tr>
<tr>
<td>Hard (Solid and Broken)</td>
<td>Apatite Soft Granite, coarse Gneiss etc.</td>
<td>25/40 spc</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard</td>
</tr>
<tr>
<td>Hard (Solid Formation)</td>
<td>Fine Gneiss, Hard Granite etc.</td>
<td>40/60 spc</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard</td>
</tr>
<tr>
<td>Very Hard (Solid Formation)</td>
<td>Quartz, Chert etc</td>
<td>60/80 spc</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Regular</td>
</tr>
</tbody>
</table>

9.4.4. Reamer Shell

For each corresponding bit size there is a reamer shell. This is attached above the functions of this reamer shell is to be maintain the gauge of the hole (Fig. 9.5b).

9.4.5 Core Barrel

Core barrels are used to receive core while drilling and to bring them to surface so core barrel serves as the receptacles to collect the core. It is a hollow cylindrical rod usually three meters in length, open at both ends. The lower end is served to the reaming shell or bit, while the upper end is connected with the drill rods. For a particular bit a corresponding size of the core barrel is used with similar nomenclature (Fig. 9.7). Core barrels are classified as under:

9.4.5.1 Single tube core barrel

These core barrels are used for drilling in hard and consolidated formations where the core does not get washed away, as the drilling fluid passes over it to reach the core bit. These are generally the least priced ones and are most commonly used. The circulating water passes down between the tube and the core thus the drilling water is always in direct contact with the core.

Advantages of single tube core barrel:

a. It is simple in design.

b. No reduction of core size is necessary in solid un-fractured rock while using it.

c. It’s maintenance cost is low.

d. Its drilling rate is higher.

Disadvantages are as discussed below:

a. It’s core recovery is poor except in solid zones.

b. Water flushes the core so some core is destroyed in this type of barrel.
c. Core is always found rubbing against the barrel.

**9.4.5.2 Double tube core barrel**

This consists of a double tube. Drilling water passes through the annular space between the outer and inner tubes (Fig. 9.8) without coming in contact with the core.

Advantage of double tube core barrel:

a) Core recovery is good.

b) Drilling cost is lower.

**9.4.5.3 Triple tube core barrel**

In very loose formations, where it is not possible to recover core samples even by using face discharge type barrel, the triple tube core barrel is used. This possesses a third tube inside the inner tube of a rigid type core barrel.

![Fig. 9.7: Photographs showing NQ and BQ core barrel](image1)

![Fig. 9.8: Photographs showing NQ and BQ inner tube.](image2)

**9.4.6 Drill Rods**

It is above the core barrel up to the surface and is flush jointed. The designation used for various drill rods are E rod, A rod and N rod. They are 1, 2, 5 and 10 feet in length (Fig. 9.9). The standard specification for drill rods are given in Table No 9.4.

**9.4.7 Core Catcher**

Core catcher is a device fitted on the lower end of the core barrel and in such a way that once the core enters the core barrel, it prevent the core to slip back in the hole. It is also breaks the core at the lower end and when the core barrel is being lifted (Fig. 9.10).
9.4.9. Swivel Head

Above the chuck is the swivel head. This by virtue of its contact with the prime mover, rotates the entire drilling strings to convert the rotational motion to the engine about horizontal axis in the one about the vertical axis, is the main function of the swivel head.

9.4.10. Water Swivel

On the top of the swivel head, the water swivel the ball bearing arrangements allow the free rotation of the drilling column while the hosepipe remains stationary (Fig. 9.11). The other end of the hosepipe is connected to the pump. Thus water is conserved if there is some water loss the level of the water in the tank is maintained by outside supply. The purpose of circulating water as follows-

a) To keep the bit cool.

b) To bring the sludge particles.

c) To lubricate the sludge practical, thus reducing the friction.

Table 9.4: The standard specification of drill rods

<table>
<thead>
<tr>
<th>Size</th>
<th>O. D. (m.m)</th>
<th>I. D. (m. m)</th>
<th>Wt. kg per 10 ft</th>
<th>Coupling I.D. (m.m)</th>
<th>Treads per inch</th>
<th>Content Liter/ 100 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>33.3</td>
<td>21.4</td>
<td>12.7</td>
<td>11.1</td>
<td>3</td>
<td>11.0</td>
</tr>
<tr>
<td>A</td>
<td>41.3</td>
<td>28.6</td>
<td>17.2</td>
<td>14.3</td>
<td>3</td>
<td>19.5</td>
</tr>
<tr>
<td>B</td>
<td>48.4</td>
<td>35.7</td>
<td>20.8</td>
<td>15.9</td>
<td>5</td>
<td>30.5</td>
</tr>
<tr>
<td>N</td>
<td>60.3</td>
<td>50.8</td>
<td>22.2</td>
<td>25.4</td>
<td>4</td>
<td>61.7</td>
</tr>
<tr>
<td>RW</td>
<td>27.8</td>
<td>18.2</td>
<td>8.6</td>
<td>9.3</td>
<td>4</td>
<td>7.9</td>
</tr>
<tr>
<td>EW</td>
<td>34.9</td>
<td>22.2</td>
<td>14.0</td>
<td>12.7</td>
<td>3</td>
<td>11.7</td>
</tr>
<tr>
<td>AW</td>
<td>44.4</td>
<td>30.9</td>
<td>19.7</td>
<td>15.9</td>
<td>3</td>
<td>22.9</td>
</tr>
<tr>
<td>BW</td>
<td>54.0</td>
<td>44.5</td>
<td>19.0</td>
<td>19.0</td>
<td>3</td>
<td>47.3</td>
</tr>
<tr>
<td>NW</td>
<td>66.7</td>
<td>57.2</td>
<td>24.5</td>
<td>34.9</td>
<td>3</td>
<td>78.3</td>
</tr>
<tr>
<td>HW</td>
<td>88.9</td>
<td>77.8</td>
<td>38.6</td>
<td>60.3</td>
<td>3</td>
<td>145.0</td>
</tr>
</tbody>
</table>

9.4.12 Casing Pipes

Casing pipes are available in four standard sizes, Ex, Ax, Bx, and for rods and couplings E, A, B, and N. Other slightly different sizes are also obtainable (Fig. 9.12). There may be flush-coupled casing or flush jointed casings, the function of casing pipe is to-

a. Prevent coring of soil.

b. Prevent loss of water.

c. Reduce the friction between drilling string and rock core.
9.5. SURFACE ARRANGEMENT

9.5.1 Engine: The engine supplies power to the rig for operation. The engine may be power driven, gasoline driven, diesel driven, engine is most commonly used, and strength varies from 50 HP to 90 HP.

9.5.2 Derrick: A simple arrangement provided with the slave the top centered over the drill head with ropes or cables. They are made up of steel pipes three or four in number (Fig. 9.13).
9.5.3 Water pump: It is attached to drill machine. This may operate by same prime mover (Fig. 9.13).

9.6 Drill Core

Cores are the solid cylindrical portions of the subsurface material obtained as a result of core drilling (Figs. 9.14 a-b). These are important for the geologist and the mining engineer as the entire study of the subsurface geology is based on the study of core recovered.

9.6.1 Core recovery: - Core recovery can be expressed mathematically as follows:-

\[ \% \text{ recovery} = \frac{\text{Length of the core}}{\text{Length of the run}} \times 100 \]

The geologist always aims for 100 % recovery, but in the practice it is seldom possible. Factors affecting the core recovery

a. Nature of the formation
b. Feed of the machine
c. Nature of the bit and core barrel
d. Skill of the drilling

9.6.2. Storage

Core is usually kept for permanent storage in flat trays fitted with cleats dividing the tray length wise in to compartments 1/16" to 1/8" wider than the diameter of the core. The arrangements of core in core boxes are of two patterns:
9.6.2.1 Serpentine pattern: In this pattern, both ends (first and last cone sample) of the core must be on the same side as shown in Fig. 9.15 a.

9.6.2.2 Book pattern: It is necessary for this arrangement that first and last sample will be on the opposite side. In Balaghat mine core box arranged in book pattern in core box (Fig. 9.15 b).

Fig. 9.14 a: A close photograph showing fractured manganese ore in core box of Balaghat mine.

Fig. 9.14.b: Photograph showing cores of sericite schist in core box of Balaghat mine.

Fig. 9.15 a: Diagram showing core box arrangement in serpentine pattern.

Fig. 9.15 b: Diagram showing core box arrangement in Book pattern that is most widely practiced in the study area.

Through drilling, the geological formations at depth can be indentified and their disposition and grade variations can be visualized. From the extensive drill data obtained from the study area, various lithologs have been prepared to understand the disposition of the ore load (Figs. 9.16 a-c).
Lithologs are prepared and core is preserved for future reference as drilling is very costly operation and should not be required to be repeated.

Fig. 9.16a: Diagram showing litholog of borehole numbers 52, 67, and 59 drilled at Balaghat mine depicting the ore-bearing zones at different levels.
Fig. 9.16 b: Diagram showing litholog of borehole numbers 46, 68, 62, and 63 drilled at Balaghat mine depicting the ore-bearing zones at different levels.
Fig. 9.16 c: Diagram showing litholog of borehole numbers 65, 48, and 57 drilled at Balaghat mine depicting the ore-bearing zones at different levels.

9.7 SOLID ORE BODY MODELLING

In Balaghat mine total 74 boreholes have been drilled covering a total 14908 m length, among which 55 boreholes are completed successfully below the ore zone. By the help of these 55
boreholes the solid ore body modeling in 3D has been done to calculate the exact resource of the Balaghat manganese deposit and to understand the structural model of the deposit (Figs. 9.17 a-d).

Based on mining method used in the Balaghat manganese deposit borehole cross sections are prepared at interval of 60 m in the north part and 45 m in south part. After calculating the volume in different levels, geological resource is estimated by multiplying the volume of the ore body with specific gravity.

The deposit model is also very important for mine planning and excavation drawn for long term and short term resource planning. Factors such as: Quantity of ROM required ore characteristics, rock formation and their strength property, occurrence and quantum of waste to be handled in underground, final product quantity and their grades, beneficiation technique to be used, equipments and related infrastructures, lease area available for excavation / mining, etc are main key factor effecting the resource planning (Mukherjee et al., 2009b).

![Solid Ore body model of Balaghat manganese deposit showing three dimensional extent of manganese mineralization, viewed from (a) north western side of the deposit (b) northern side of the deposit (c) longitudinal vertical view (d) southern side of the deposit (after CMPDI 2012).](image)
9.8 RESERVE/RESOURCE ESTIMATION USED IN BALAGHAT MINE

As per United Nation Framework classification (UNFC) the manganese deposits at Balaghat mine are categorized as stratiform to strata bound and tabular deposit exhibiting regular habit. The deposit has been evaluated axis-wise as per guideline at UNFC and has been categorized as:

a) Proved mineral reserve (111)
b) Probable mineral reserve (121)
c) Feasibility mineral resource (211)
d) Prefeasibility mineral resource (222)
e) Indicated mineral resource (332)

9.8.1 Proved Mineral Reserves (111):
This category of reserves have been considered for blocks between channel 1 and 65 as under exploitation/development i.e., 9th, 10th, 11th and 12th level. The present Holmes shaft is sunken up to 12th level (Fig. 8.1). The ongoing exploitation/mining activities have generated sufficient geological and geo-chemical information for the blocks, which are under development. As the market is very much favorable and expected to continue so, the future exploitation at levels, which are under development, will be economical-feasible under present techno-economic and environment conditions (Figs. 9.18-9.19).

It is expected to continue the reasonable demand for manganese in forthcoming years. The area between 12th and 15th level is well explored and the data on geology is elaborative. Under present techno-economic conditions, the deposit is feasible for exploitation. The quality/grade that will be produced will meet the requirement of industries.

9.8.2 Probable mineral reserve (121)
Ore zone had been excavated from surface up to 8th level. After 25 m of stoping, 5 m ore pillar is left for support of upper level. This pillar is known as crown pillar. It is left throughout the strike direction. This pillar cannot be excavated by the present mining method. Hence it is categorized in 121 categories (Figs. 9.18-9.19).

9.8.3 Feasibility Mineral Resource (211)
Below 15th level to 16.5th level the area covered by detailed exploration is categorized under 211 (Figs. 9.18-9.19). This area is explored by number of boreholes. The data generated on quality and quantity ore behaviors etc. is feasible for economic extraction. The present technology of
exploitation may need change, as at the deeper level the strata are expected to be under stressed conditions.

9.8.4 Prefeasibility Mineral Resource (222)

This category is considered for blocks between chainage 65 and 72 and between 18\textsuperscript{th} level to 19.5\textsuperscript{th} level. Geologically it is established that the phosphorous (P) content increases on either side and also thins out with distance. After certain depth, the wall rock showing poor strength. Under the circumstances, the data on the quality of rock mass is to be established. Modification in present method of exploitation, as well as raise in demand of high ‘P’ at market scenario is essential. Sufficient geological data from boreholes and adjacent mining activities have been generated to place the zone under pre-feasible category. However the final economy will depend on the type of exploitation (Figs. 9.18-9.19).

9.8.4 Indicated Mineral Resource (332)

The remaining area has been considered as 332. These zones need few additional boreholes to generate date on quality, ore behavior and recovery factor etc. In absence of above data feasibility cannot be ascertain. Moreover the area beyond chainage 74 to the south is under environmental constrains. There are dwellings at surface past opencast history suggest the ore zone is high P in nature (Figs. 9.18-9.19). Total category wise in-situ ore reserve and resource of Balaghat mine is given in Table 9.5.

Table 9.5: In-situ ore reserve/resource of Balaghat manganese deposit as per UNFC as on 1.4.2012 in tonnes

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>INSITU RESERVE/RESOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proved Mineral Reserve (111)</td>
<td>9712035</td>
</tr>
<tr>
<td>Probable Mineral Reserve (121)</td>
<td>2505904</td>
</tr>
<tr>
<td>Feasibility Mineral Resource(211)</td>
<td>2759838</td>
</tr>
<tr>
<td>Pre-feasibility Mineral Resource (222)</td>
<td>5087504</td>
</tr>
<tr>
<td>Indicated Mineral Resource (332)</td>
<td>4223431</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>24288711</strong></td>
</tr>
</tbody>
</table>

Source: MOIL reserve status 2012
Fig. 9.18: Pie chart showing the in-situ ore reserves of different categories at Balaghat mine as per UNF classification as on 1.4.2012 (Ref: MOIL reserve status 2012).

Fig. 9.19: Longitudinal section showing level wise, category wise ore reserve status of Balaghat mine as per UNF classification.
9.9 DISCUSSION

Detailed studies have been conducted to understand comprehensive geological aspects including petrological, ore mineralogical characteristics, structural setting of the ore body, geochemistry of host rocks and different ore types with a view to understand the genesis of manganese ore mineralization in the study area to visualize the concept based exploration on these manganese deposits for prognosticating the lateral and depth persistence of the ore.

Continuous exploration is very much essential in view to enhance the resource base of manganese ores in the study area. And hence, the processes involved in different stages of prospecting, regional and detailed exploration, resource evaluation, mine planning and excavation of these ores have been studied.

With the help of exploration database and analysis on gap areas, new acceptable norms and parameters have been suggested to carry out various exploration activities. Resource estimations have been done as per the norm suggested by United Nations Framework Classification (UNFC), under economical, feasibility and geological axis. Attempts have been made to establish geological, stratigraphical, lithological, mineralogical, physiographical and structural guides for direct or indirect predictions of manganese mineralization in the area for further exploration.

The future prospects of exploration can be established and exploration plans were made by taking help from detailed scientific studies and the area of influence of boreholes in order to intercept the ore bed at about every 50 m along the strike and at about 100 m depth interval (Fig. 9.20). The point of intersection was prefixed and accordingly inclination, location surfaces were fixed so that borehole should ideally intercept the ore zone at stipulated horizon.

In the current and fourth phase of operations, plans are to be made to locate the ore body below the 25th level (-320MRL) with the help of a 700 m length boreholes from the surface. The ore horizons have been explored by surface boreholes between chainage 1400 and 6300 and the ore zone encountered high phosphorous content beyond these chainage hence, further detailed exploration is stalled at the moment.

However, there is a significant improvement in the market conditions and even the high phosphorous manganese ore is also saleable. Looking at the market scenario, a program is to be initiated to explore the depth persistence of the ore horizon up to 25th level between chainage 100 on the north-eastern portion and 7300 in the south-western part, to cover strike length of the ore body to nearly 2.0 km (Fig. 9.20).
Due to some infrastructure related problems, some areas could not be explored from surface level and is now being proposed to conduct detailed exploration surveys using underground boreholes in the exposed areas (Fig. 9.20). The general strike direction of the deposit is N25°E – S25°W, but changes have been observed from chainage 2300 which moves towards north-western direction that is further crosses the lease area due to the recumbent fold pattern (Fig. 6.10 e). The curved geometry of the ore body is increasing with the depth (Figs. 6.13 c-f, 9.17 a-d) and ore is also fractured (CMFRI, 2012). Hence in the north-western part of the deposit is proposed to be developed with the help of at least 25 more boreholes at each 100 m interval along strike as well as dip direction (Fig. 9.21).

Fig. 9.20: Map showing area of influence at 50 m, 75 m and 100 m interval of borehole drilled and proposed drilling in underground area.
Systematic geological, petrological, mineralogical, structural and geochemical, studies could lead to the understanding the metallogenetic evolution, genetic aspects and chemical characterization of different manganese ore types and host rocks. Keeping in view of these aspects, detailed deposit scale geochemistry on manganese has been attempted to evaluate the physico-chemical conditions, paleo-environment of deposition and host rock characteristics and genetic evolution of the ores and in the further use of exploration.