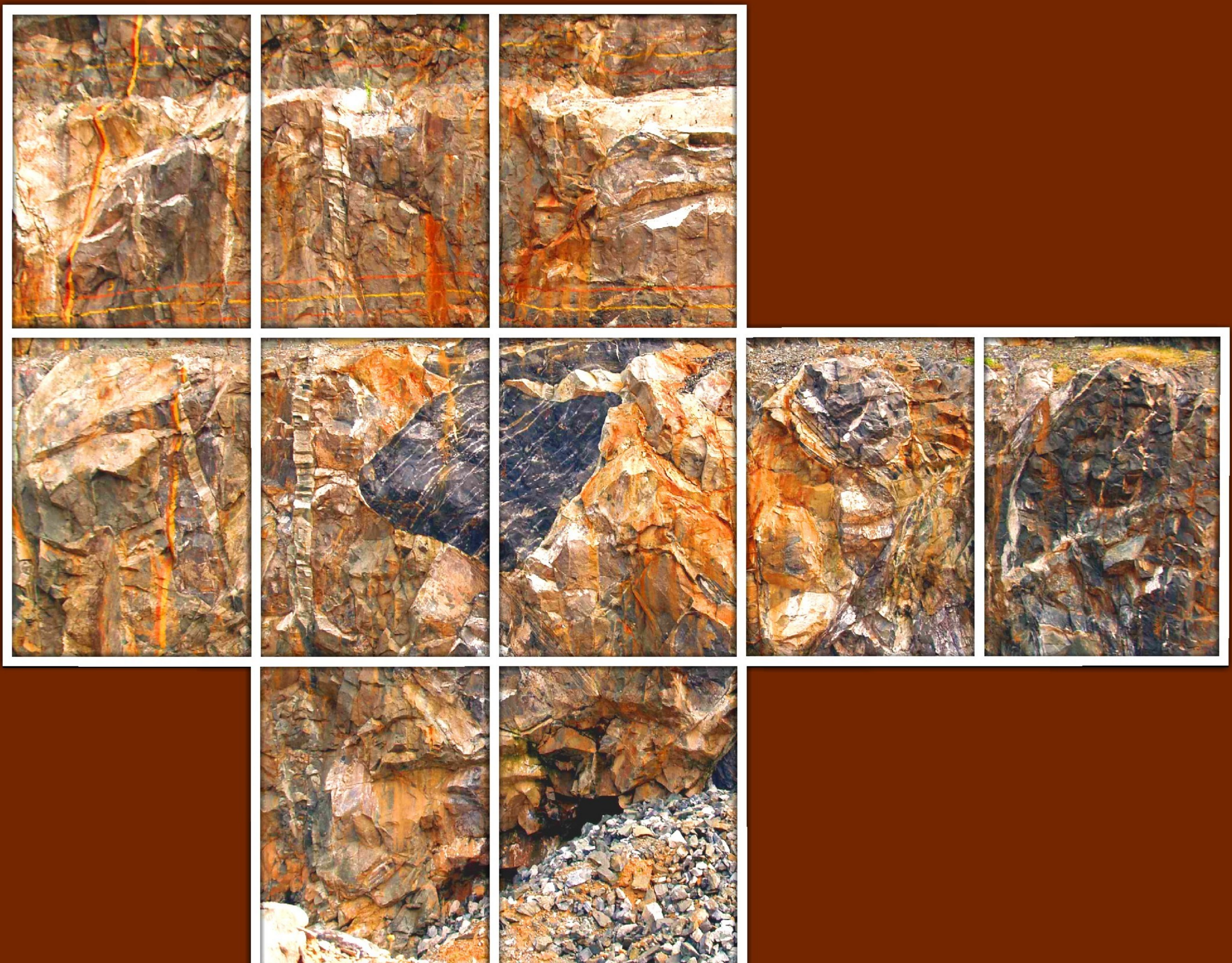
GOVERNMENT OF INDIA
MINISTRY OF MINES
INDIAN BUREAU OF MINES

Monograph on Chromite



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Monograph

on

CHROMITE

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CONCEPT AND GENERAL GUIDANCE

C.S. Gundewar
Controller General

Dr. B.P. Sinha
Controller of Mines (TMP)

COMPILATION, DRAFTING AND SCRIPT REVIEW

S.R. Roy
Regional Controller of Mines
(Publication Cell)

A.M. Kamble
Regional Mining Geologist
TMP Division

D.W. Parsodkar
Asstt. Mining Geologist
(TMP Division)

WORD PROCESSING

P.R. Tinguria & H.M. Kohale
Stenographers (Grade I)

GRAPHICS

A.S. Bedi, *STA(Drg.)*
J.W. Gulhane, *STA(Drg.)*
G. N. Lanjewar, *STA(Drg.)*

PUBLICATION SECTION

EDITING & VISUALISATION

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Eswar Singh K. R.
Assistant Editor

PRODUCTION

N. U. Kadu
Editor

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DTP FORMATTING

Rucha G. Warhade,
Jr. Technical Assistant

Preface

Chromium is a very important metal , although it is very rarely used in its metal form. The metal is an essential ingredient for stainless steel making and there are no cheaper substitutes. A large number of ferrochrome industry in the country is dependent on supplies of this important metal. India has a meagre resource base of only 2% of world resources of this metal and is an insignificant player in the world trade for this metal. The reported consumption of chromite in the organised sector increased by 25.4% from 2,159,500 tonnes in 2009-10, to 2,708,100 tonnes, in 2010-11. Almost entire consumption (98.9%) was in ferro-alloys/charge-chrome industry. India currently meets its internal requirement.

Since the release of the previous edition of this monograph, many new mines have been opened and some progress has been achieved in putting up better beneficiation plants. Some study on deleterious effects of hexavalent chromium which needed remedial action, has been done in the country and some mines have taken good steps for mitigation of harmful effects on the environment.

India is at the cusp of a tremendous effort needed for development of infrastructure in the country. Large supplies of stainless steel will be required just as experienced by the china. Augmentation of our indigenous resources and capabilities to bring out the finished product is desperately required. Exploration of deep seated ore bodies needs to be carried out on an urgent basis. Exploration efforts also need intensification, to identify more deposits of chromite in the country. Further restrictions on exports of chromite ore/concentrates may be desirable, in view of the limited resources in India and increasing demand from the steel industry.

The Indian Bureau of Mines had come out with a monograph on chromite in 1982. Since then a review of this important subject had become necessary and it gives satisfaction to place a new version of the monograph in the hands of the stakeholders. The new version is not an update and has been completely recast and it is likely to give important information on chromite in a ready capsule, in a concise form.

With the improved availability of information on the world wide web, a lot of information has been gathered from the internet and these have been acknowledged in the bibliography. We thankfully acknowledge the cooperation extended by managements of mines, metallurgical, refractory and chemical industries, who promptly responded to our request for information. Thanks are also due to many authors, mining companies and consultants, international and Indian, whose copyright material has been used in this monograph.

Gundewar

Nagpur

Dated: 31st July 2013

C. S. Gundewar
Controller General
Indian Bureau of Mines

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Chapter 1

CHROMITE

1.0 INTRODUCTION

Chromium is an important metal and has a wide range of industrial uses. The virgin metal is neither used by the stainless steel industry nor traded on any metal exchange.

Elemental chromium (Cr) does not occur in nature, but is present in ores, primarily chromite ($FeOCr_2O_3$). Chromite is an iron chromium oxide mineral and the only ore of chromium metal. Chromite is a metal used to induce hardness, toughness and chemical resistance in steel. The alloy produced is known as "stainless steel".

The stainless steel industry is the largest consumer of ferrochrome. There is tremendous scope in the Stainless steel sector in which chrome alloy is an ingredient. With the expected growth in utensil, automobile, oil-gas pipelines etc, the demand for stainless steel and thereby, for chromite is expected to grow in coming years. Indian ferro-alloys industry is an important player in the international market, exporting about 20 per cent of country's production. In addition, India has been one of the traditional exporter of chromite, particularly to countries like China and Japan.

In the early nineteenth century, chromium was primarily used as a component of paints and in tanning salts. Now 85 percent of its use is for metal alloys. It is variously alloyed with iron, nickel and tungsten to produce super alloys used in making tools, armour-plating and for jet engines. The remainder is used in the chemical industry and refractory and foundry industries.

In 1761, Johann Gottlob Lehmann found an orange-red mineral in the Ural Mountains which he named Siberian red lead. Though misidentified as a lead compound with selenium and iron components, the material was in fact lead chromate, now known as the mineral crocoite. In the mid 18th century analysis of "red lead" from Siberia showed that it contained quite a lot of lead, but also a further material.

In 1797, Nicolas-Louis Vauquelin received samples of crocoite ore. He was able to produce chromium oxide by mixing crocoite with hydrochloric acid. In 1798, Vauquelin discovered that he could isolate metallic chromium by heating the oxide in a charcoal oven. He was also able to detect traces of chromium in precious gemstones, such as ruby and emerald. A year or two after Vauquelin's discovery, a German chemist named Tassaert working in Paris found chromium in an ore now called chromite.

It is a mineral found in ultrabasic rocks such as peridotite. It is a high temperature mineral often found in the lower parts of magma bodies from the fractional crystallization process. It is also found in serpentines and other metamorphic rocks derived from the alteration of ultrabasic rocks. The name is commonly used for any Cr-rich mineral of the spinel group, particularly for the chromite-magnesiochromite series, and much of the mineral referred to as "chromite" in geological and petrological papers and mining statistics is predominately magnesiochromite. The Fe-dominant species chromite can be subordinate to rare in many "chromite" deposits, chromitites, and other "chromite"-bearing rocks.

India is endowed with a fairly large geological resource base of 203 MT in 2010. Odisha has the lion's share of 190 MT mostly concentrated in the Sukinda Ultramafic belt. The balance is distributed in several other Indian states such as Karnataka, Jharkhand, Andhra Pradesh, Maharashtra , Tamil Nadu, Goa and Nagaland. Kashmir and Manipur have small pockets of Chromite deposits.

India consumes about 70% of its production and exports the rest, amounting to about 0.7 MT. The world resources of shipping grade chromite is about 12 billion tonnes. World annual production is of the order of 30 MT indicating that it will last for about 400 years at the current level of production, whereas the Indian recoverable chrome ores will last for only 40 years. The distribution of the world production is limited to a few countries, principally South Africa and Russia, and hence the strategic importance.

In India, most of the mining is done by opencast method , to raise marketable ore +38%Cr_2O_3 and stacking subgrade ores ranging between 10 - 35% Cr_2O_3. The Chrome ore is beneficiated at the mine site. The Chromite industry poses a large risk for environmental pollution and requires close monitoring and protective measures. The inhalation of chromium compounds has been associated with the development of cancer among the workers in chromite industry. Animal studies show that Cr(VI) is generally more toxic than Cr(III), but neither oxidation state is very toxic by the oral route.

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Chapter 2

GEOLOGY, MINERALOGY, TYPES OF DEPOSITS AND MODE OF OCCURRENCE

2.0 INTRODUCTION

Chromite was discovered in 1765 by the Russian geologist Pallas, while working in a gold mine near Etaterinberg. Another source attributes the discovery to the German scientist Lehmann in 1766. Some however, believe that chromium was discovered by Vanquelin and Klaporth independently in a mineral obtained from Siberia, known as crocoite, a lead chromite. All the sources agree on one point that the mineral was named chromite by Vanquelin from the greek word 'khroma' meaning colour, in allusion to the varied colours of its compounds.

2.1 CHEMICAL COMPOSITION

Chromite is a member of the spinel group of minerals and consists essentially of ferrous and chromic oxides – FeO, Cr_2O_3, analogous to aluminates. Ferrous oxide is, however, often partly replaced by magnesia and chromic oxide by alumina so that there is transition to chrome spinel or picotite $(MgFe)O.\ (AlCr)_2\ O_3$. Further, with the replacement of chromic oxide by ferric oxide, there may be transition to magnetite, Fe_3O_4. Thus chromite is represented by the general formula $R''O.R'''_2O_3$ where R'' stands for a bivalent metal, mainly magnesium, ferrous iron with minor amounts of zinc, manganese, and nickel, and R''' represents a trivalent metal, i.e. chromium aluminum or iron .

Chromites of economic interest have Cr_2O_3 content of 25 to 65%. Predominantly, Cr_2O_3 ores range from 30 to 60%. This chromite mineral contains gangue, which is generally orthopyroxene, olivine, calcic plagioclase and their hydrous products, serpentine, chlorites and talc. In fact, the hydrous altered magnesian silicates are probably more commonly present than the original minerals (although they may reveal the original silicates from which they were derived) other less common to rare gangue minerals that have been found in various deposits, which include dolomite, magnesite, brucite, chromite tourmaline, uvarovite (Chrome garnet) kaolin, pyrite, mica and goethite.

2.2 MINERALOGY

Chromium occurs in minor amounts in such a large number of silicate minerals that a complete list of chromium bearing minerals would have little significance. The monoclinic amphiboles, pyroxenes, and chlorites are the most important group of chromium bearing silicates. Some of the chromium bearing minerals are listed below in Table 1.

Daubreelite is also another mineral which is known only in meteorites. Merumite is little known among the minerals containing chromium metal. The mineral Chromite is the only ore having commercial importance.

Table 1. : Some Chromium Bearing Ore Minerals

S.No.	Mineral	Chemical composition	Cr %	Cr_2O_3 %
1.	Chromite	$(Mg,Fe,(Cr,Al,Fe)_2O_4$	46.5	15-65
2.	Copiapite	Complex hydrous Iron sulphate	5.1	7.4
3.	Crocoite	$PbCrO_4$	16.1	21.9
4.	Dietzoite	$7Ca(IO_3)_2.CaCrO_4$	10.5	15.3
5.	Halotrichite	$(Fe,Mg,Ni)(Al,Cr)_2(SO_4)_42H_2O$	5.1	7.5
6.	Kaemmererite	$H_4Mg_2(Cr,Al)_2SiO_9$	-	variable
7.	Lopezite	$K_2Cr_2O_7$	24.2	35.4
8.	Merumite	$4(Cr,Al)_2O_3.3H_2O$	55.4	81.3
9.	Phoenicochroite	$3PbO.2Cr_2O_3$	12.0	31.2
10.	Stichtite-barbetonite	$2MgO_35Mg(OH)_2.2Cr(OH)_3$	15.6	22.3
11.	Uvarovite	$Ca_3(Cr, Al)_2(SiO_4)_3$	20.9	27.0
12.	Vanquelinite	$5(Pb, Cu) O.2Cr_2O_3.P_2O_5$	7.3	25.2
13.	Beidellite Volchons-koite	$(Al, Cr)_2O_3.3SiO_2. 4H_2O$	-	Variable upto 9

2.3 PHYSICAL PROPERTIES

Most of the physical properties of chromite vary with the composition of the mineral. High - iron chromites are hard; moderately to strongly magnetic; black with a metallic luster; opaque in thin section and have a dark brown to black streak. High alumina chromites are black in hand specimens, with a submetallic to pitchy luster; give a pale brown to greenish brown streak; are coffee brown in thin section and are very hard and non-magnetic. But most of the chromites are iron black, show a submetallic luster and can be scratched to produce a brown streak. They have uneven fracture; are brittle; and are non-magnetic or weakly magnetic. The softening point of commercial chromites varies from 1250^0 C to 1450^0 C depending on the impurities, particularly iron and silica, and decreases as the iron content increase. Chromite is neutral and is almost insoluble in slags. Pure chromite is said to have a fusion temperature of 2180^0 C, whereas commercial varieties have melting points between 1700^0 C to 1900^0 C. In thin sections, the colour ranges from cherry or brownish red in the high iron varieties to coffee brown in the more aluminous varieties. Some grains of chromite are translucent near the margins, possibly due to marginal oxidation of the grains. The grains of chromite are in the size range 0.02 to 0.8 cm with numerous euhedral and subhedral forms of isometric crystals . The specific gravity of chromite, varies between 4.5 and 4.8. Its hardness is 5 on Moh's scale.

Chromite is most easily distinguished from similarly appearing minerals by its brown streak, or powder, and by its mode of occurrence. It is distinguished from magnetite by its feeble magnetic properties, streak, and by yielding the reaction for chromic acid with the blow pipe.

2.4. TEXTURE

Many textural variations are seen among chrome ores arising probably from different combinations of features due to primary crystallization and modification by later movement . Chromite associate with hydrothermal minerals generally shows opaque rims and veins, whereas that associated with chromiferous silicates always shows "frayed margins" and continuity of translucent centers with opaque rims. In stratiform chromite deposits, euhedral chromite crystals give a characteristic mesh-like pattern. Grains of average size 0.1 to 0.5 mm across are packed around olivine or bronzite grains upto 1 cm in size. With a decrease of olivine or pyroxene content, chromite crystals coalesce to form layers of massive ore, and in this case too, the average grain size is less than 1 mm. But in massive ores of podiform type, individual irregular chromite grains commonly exceed 2.5 cm and in rare cases, attain dimensions as large as 15 cm. At places, the massive ores grade into granular ores, in which the chromite forms round or oval nodules of 5 to 25 mm in diameter in a matrix of olivine, serpentine, and rarely plagioclase. In some podiform ores, all gradations from nodules to octahedral crystals forms occur. In many cases, massive and nodular ores grade into disseminated ore, in which irregular chromite grains are mixed in all proportions with olivine or serpentine gangue.

The texture of massive and nodular ores appears to be primary and related to the original crystallization of chromite, whereas, in podiform deposits, a relict mesh structure shown by olivine and chromite is rarely found intact. In most podiform deposits, chromites show a "pull-apart" texture. In this the fractures, though irregular, show a statistical planar orientation which is best explained by a stretching of the ore in a direction normal to the orientation. This texture is shown best, perhaps in nodular ore by fractures transverse to the longest axis of elliptical nodules. The nodular texture also called 'grape', 'shot', 'pebbles' etc., consists of spherical to ovoid aggregates, mostly 5 to 40 mm in diameter. The nodule consists predominantly of chromite grains 1 to 5 mm in size in a silicate matrix.

In some chromite deposits, a cataclastic texture is somewhat common. It is formed as a result of tectonic events, but often first developed during serpentinization. Replacements are rare owing to the chemical stability of chromite. Lobate patterns of definitely corroded borders are sometimes found in the chromites which are within completely serpentinized country rock. Weathering generally acts very slowly on chromite as its effects are rarely detectable on chromite grains.

2.5 ORIGIN

All chromite deposits are believed to have formed by early crystal settling or by late gravitative liquid accumulation from magma. These processes aid in understanding how layered deposits form, but where differential pressures exist, liquid injection is more likely to form podiform deposits. Sampson, C.R. Ross and others believed the definite existence of late magmatic as well as early magmatic chromite. Based on the study of the structural relations of chromite with the associated minerals, Dasgupta thought that chromite was the earliest to crystallize or it crystallised only in part simultaneous with olivine. However, Samson advocated that chromite was formed from Hydrothermal solutions, for the most part immediately preceeding to or contemporaneous with serpentinization. These processes can be briefly described below:

2.5.1 Early magmatic (protomagmatic) segregation deposits - Chromite is believed to be formed earlier than olivine or contemporaneous with it and partly included in the grains in olivine. This genetic type includes the layer like segregations of chromite in the stratiform layered intrusions of platform areas such as Bushveld, the great dykes of Rhodesia, and Skaergaard of New Foundland.

2.5.2 Late magmatic (hysteromagmatic) deposits - Chromite is formed at a late magmatic stage and crystallizing with the last truly magmatic silicates, commonly either bronzite or plagioclase. In this genetic type, Sokolov(1948), recognized automagmatic (syngenetic with the surrounding rocks) and heteromagmatic deposits (injected and developed during the intrusion of residual ore silicate melts from the lower zones in the intrusive body). This generic type includes all the commercial deposits of chromite ores in the massifs of geosynclinal regions.

2.5.3 Hydrothermal deposits - Chromite is formed from hydrothermal solutions, for the most part immediately preceding to or contemporaneous with serpentinization . Chromite of such origin form nests and veins . According to Verma(1971), this type of origin applied to certain Indian deposits.

Thayer has discussed in detail the relative importance of each type, and according to him all the early magmatic chromite deposits are of sufficient size to be of economic interest. He believed that primary chromite separated from a magmatic body with the first minerals to crystallize out and the formation of the late chromium-rich magmatic differentiates can not easily be explained on the basis of the available field data. The formation of a chromium-rich late magmatic liquid fraction is not possible according to the normal course of magmatic differentiation as evident from the order of isomorphous susbstitution in magmatic minerals. This is supported by Goldschmidt who stated: " when different ions of similar size and of the same charge (valency) substitute each other during the crystallization of minerals from cooling igneous rocks, the sequence for entrance of the various ions into the crystal lattices is generally the sequence of decreasing bond strength. The electrostatic bond strength in case of identical electric charge is inversely proportional to the squares of the interionic distances; thereby the smallest ion is bounded preferentially. Thus, magnesium ions are bonded before the somewhat larger ferrous ions. In those cases where electronic bonds are present besides ionic bonds, the integral sum of bond strength is decisive. Therefore, nickel is concentrated in the earliest fraction of magnesium silicates from magmas, even though nickel and magnesium have virtually identical ionic radii, and chromium spinels crystallise before other spinellid minerals because of the contribution of electronic bonding in the minerals of trivalent chromium."

Thus, the basic principles of crystallization ensure that the first formed spinellids would be relatively rich in MgO and Cr_2O_3, and would be most stable. This principle of crystallization completely nullifies the theory of late magmatic formation of chromite.

A detailed study of Nausahi chromite deposit of India indicates that a part of the chromite may have crystallized later than olivine but simultaneous with pyroxene. Hence, this chromite deposit may be late with respect to olivine but early with respect to the magma as a whole. Mukherjee discarded the idea of gravitative separation of a chromium-rich late residual liquid and suggested that the only way of differentiation was in the form of crystals which settle down along with crystals of olivine and pyroxene.

In Cuba, the mobilization of the silicate matrix of chromite due to local heating has been shown to be an effective factor for its being injected as a crystal mush into the open fracture of peridotites. Hence, it is highly probable that chromite was carried up as autoliths during the emplacement of dunites and peridotites. The mechanism of this emplacement described in detail by Flint, Da Albear, and Guid explain satisfactorily several unsolved questions in the genesis of chromite deposit specially in the case of podiform deposit.

For explaining the chromite deposits occurring along shear zones, fracture planes etc., Mukherjee considered that the dunites and the peridotites were subjected to shearing movements. It is interesting to note that the shear planes are found confined to peridotite and dunite only while the adjacent quartzite, gabbro, etc. do not show any features of stress and strain. This indicates that shearing was caused not by any regional earth movement but by the presence of primary physical discontinuity in the ultrabasics themselves. These movements, most probably took place during the emplacement of dunites and peridotities with the autolithic veins of chromite.

A similar opinion has been expressed by Smith while studying the origin of the chromite deposits of Western New Founland. His conclusions are: "According to the gravitational crystallization theory forsterite and enstatite crystallized to form the ultrabasic zones. This caused removal of magnesia from the magma and relative enrichment in line, alumina and silica. Thus, the composition of the liquid moved into a region where spinel formed along with plagioclase and clinopyxones . The spinel settled out to form chromite layers, and at a lower temperature plagioclase and clinopyroxene alone crystalized , forming the overlying gabbroid rocks."

The principle arguments against this theory, is the absence of chemical variation in the olivine or orthopyroxene of the ultrabasic zones. No increase in iron content towards the top of the intrusions, typical of the olivines and orthopyroxenes of the skaergaard intrusion is found.

An explanation of the intrusions based upon emplacement of a crystal mush may take several forms. Beginning with the partial fusion of a periodotite earth layer to form a gabbroic fluid, interstitial to olivine (forsterite) crystals, one may invoke crystallization differentiation at depth, or injection before gravitative differentiation has succeeded in separating the solid and liquid fractions. The importance of gravitative differentiation prior to emplacement is impossible to evaluate, yet it may have been a potent factor in aiding the separation of the gabbroic and ultrabasic fractions of the intrusions. Filter pressing during injection of this partly differentiated mush into the crust caused the more fluid gabbroic material to advance ahead of the olivine mush. Reactions between these contrasting magmas during and after intrusion, but prior to consolidation, caused the formation of spinel and segregation of chromium. These chromite segregations formed lenses in the dunite marginal to the gabbroic rocks. This is a more complicated explanation than that of simple crystal setting, yet it can be used to explain the undifferentiated nature of the ultrabasic rocks better than can crystallization in situ. It also explains the wedge-shape of the ultrabasic zones down-dip, and the lens-shape of individual layers and groups of layers. It explains the banding of the rocks as a whole and as a flow structure.

Both the theories discussed by Smith do not apply to all types of stratiform deposits. The stratified sheets sometimes display gneissic structures with alternate bands of low grade and high grade chromitite, some times alternate bands of chromitite and barren rock, and sometimes a thick sheet of chromitite alone. Stanton discussed four possible conditions for the development of stratified sheets of various forms:

1. Stratification appears to be due to fractional crystallization leading to the settling of successive crops of crystals on the progressively rising floor of the intrusive sheets;
2. Development of large convection reels, with formation of crystals with the convecting magma as it moves across the top and down the sides of the chamber and sedimentation of the crystals as the magma moves across the floor;
3. Multiple injection of magmas drawn periodically from a deeper magma as it differentiates; and
4. Changes in mineral equilibrium boundaries accompanying changes in H_2O, O_2 and other partial pressures, leading to the formation and precipitation of different minerals in alternate or cyclic fashion.

Bateman, referring to the theories of Sampson and Ross, stated that many of the economic deposits of chromite pertain to the late magmatic stage also. He discussed the Bushveld igneous complex wherein layers of chromite show similar relations to the anorthosite as the layers of titanomagnetite. Some adjacent layers of chromitite transgress the grain structure of the enclosing parent anorthosite. Infact, there are certain intrusions of anorthosite in chromite, indicating thereby that chromite is later than anorthosite. Further, it has been observed that the vertical planinum pipes of the Bushveld complex carrying chromite and platinum in certain parts cuts across almost at right angle to the stratiform structures of the enclosing rocks . This further indicates that the pipe must have been formed later than the enclosing rock and it should, therefore, belong to the late magmatic stage. These evidences indicate that chromite may also be of late magmatic origin. The hypothesis of late magmatic gravitative accumulation giving rise to both concordant and injected bodies could apply to chromite and platinum also.

Bateman further discussed the findings of Vladimir Kovenko with respect to chromite deposits of Turkey. According to Kovenko, the commercial deposits of Turkey like those of the Urals, are definitely of late magmatic origin. Some of the main deposits have been described by him as injection veins and chimneys which resulted from the injection of chromite with magma accompanied by abundant mineralization. These evidences indicate the existence of mobile chromium-rich residual magma (late magmatic gravitative accumulation) which have been injected in the later stage in to the crust rock.

Stanton, discussing the formation of podiform, fusiform and vein type of deposits, stated : "Until recently, there has been a general belief that the Alpine type rocks were of a very fundamental nature – probably mantle material pinched into, and squeezed up, very deep faults. Lately, there have been alternative suggestions, supported by a number of field and composition features that they are in fact comparatively shallow differentiates of volcanic magma chambers, later serpentinized and squeezed into the great faults that had earlier localized the volcanism concerned. These observations also indicate that chromite deposits belong to both the magmatic stages, i.e. early and late magmatic stages.

Haldhar and Banerjee who studied in detail the chromite ore bodies of Karnataka are of the opinion that these ore deposits are very much similar in nature to those of Bihar and Odisha. There was early crystallization of chromite along with primary silicates, followed by reintrusion enmasse in the solid state proceeding the major organic movements.

Sittampundi chromite deposits of Tamilnadu have been studied by Subramaniam(1965) who considered that chromite here was formed as a result of magmatic differentiation of a basic melt followed by two superposed cycles of metamorphic-metasomatic transformation. Paithankar, who studied the ore deposits of Maharashtra was of the view that Pauni chromite deposit of Bhandara district belongs to the late magmatic stage and hydrothermal stage . But Nair and Singh who studied the same area in great detail believed that Pauni chromite represented primary differentiate of the ultrabasics. Later hydrothermal changes brought about the replacement of all the primary gangue minerals to give rise to various types of mineral assemblages.

According to Krishna Rao, the chromite ore of Kondapalli deposits (A.P.) was crystallized by magmatic differentiation and not by hydrothermal process. The deposits were formed much earlier than hydrothermal metamorphism of pyroxenites as shown by the serpentine veins formed cutting across the ore minerals. Further, absence of fuchsite or euvarovite suggested that the hydrothermal process was not involved in its formation.

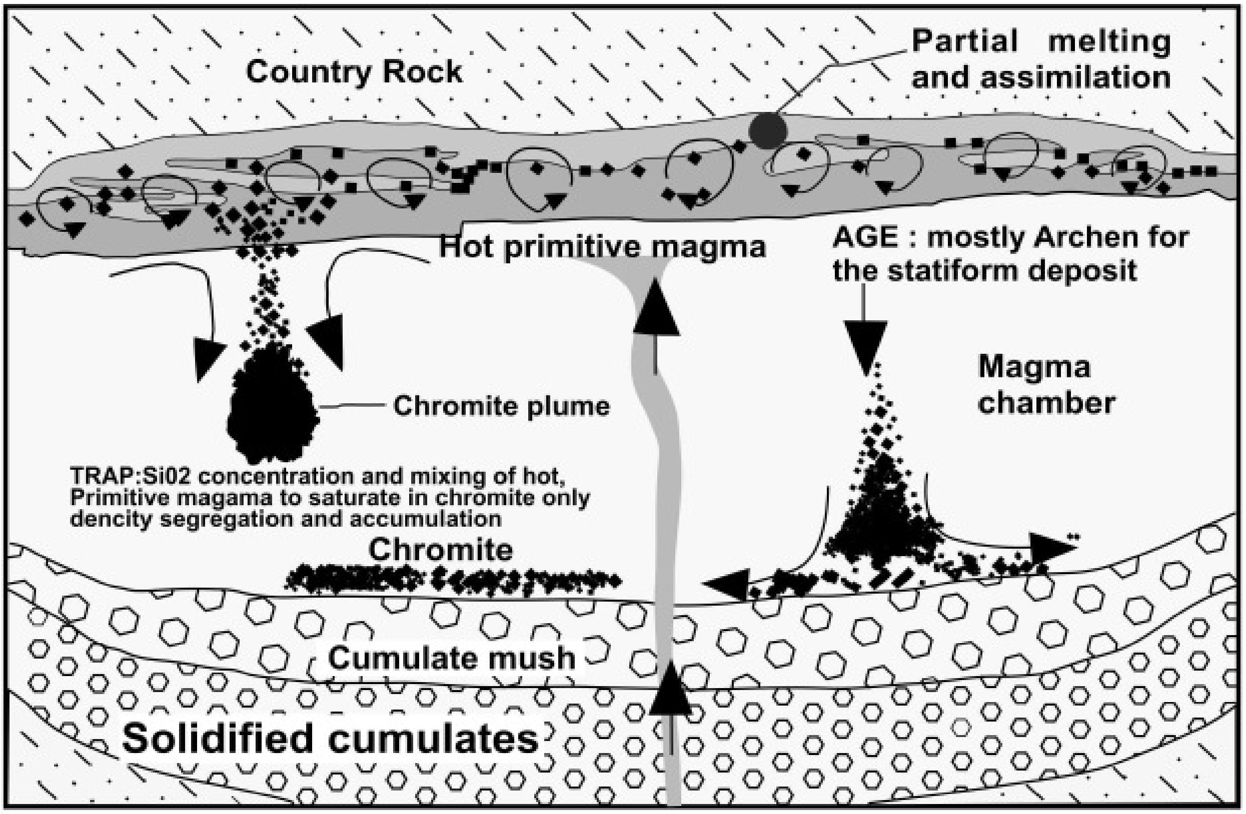
Sahu and Bagchi, who worked in Saruabil area in Odisha thought that these chromite deposits were formed under all the three stages i.e. early magmatic stage, late magmatic stage and through hydrothermal solutions. They were of the opinion that, in the magma chamber, the ultrabasics differentiated into two fractions, pyroxenite mass on top and chromite layers at the bottom. The pyroxenite mass was injected more or less parallel to the bedding plane of ferruginous shale but at places it cut across the latter as well. Prior to the final and full consolidation of the ultra basics, the early differentiated lenses which went to the upper layers of ultrabasic bodies were generally poor in concentration and small in size as compared to those which remained in the lower margin of the ultrabasics.

The ultrabasic body together with the chromite lenses was subjected at a later period through the action of hydrothermal fluids mainly composed of water and some carbondioxide. Due to the interaction of the hydrothermal fluilds, serpentinite and talc rocks were formed in weak planes and contacts along which chromite lenses included earlier. The enstatite and olivine associated with chromite were also altered to serpentine and talc. During this hydrothermal alteration, specs of chromite were released from enstatite and olivine. These chromite grains formed minute veins in serpentine and talc and at the same time, filled the larger fracture planes of the massif. The following evidence indicates that chromite was formed by hydrothermal solutions also:

1. Specks of chromite occur along the cleavage and fracture planes of altered enstatite and olivine;
2. fractures of euhedral chromite ores are filled by serpentine and massive chromite but without any crystal form; and
3. at places, the chromite ores were subjected to lateritasation resulting in the formation of hard and massive lateritic chromite ores.

According to Dev and Chakraborty, the major economic chromite deposits of the eastern part of the Indian peninsula were either late magmatic segregations or late magmatic injections in dunite and peridotite and the early magmatic or hydrothermal chromite are quite insignificant. Dasgupta believes that the ore deposits of Sukinda area, the most important chromite – bearing zone of eastern peninsula , was of early magmatic origin and indication of their late magmatic or hydrothermal origin were rather meagre. He also believed that crystallization and segregation of the ore minerals occurred before their emplacement in the present position and a great part of the melt remained sufficiently mobile by the agency of the mineralizer or by some other means. This helped the emplacement of chromite grains and crystals in their present position. Similar views were expressed by Mukherjee about another important deposit, ie. Nausahi chromite deposits of Odisha. He is of the opinion that a part of the chromite may have crystallized later than olivine but simultaneous with pyroxene. Hence, it may not be proper to group this chromite as late magmatic. Chromite may be considered late with respect to olivine but early with respect to the magma as a whole. Almost similar views were expressed by Chakraborty and Malik while studying the Maula Bhanj deposits of Odisha. Nandy and Subramaniam supported the view of Sahu and Bagchi.

From the above discussion it is evidently difficult to determine any definite process or stage of formation of different chromite deposits of India. But it is also evident that segregation and crystallization of chromite might have taken place in the early magmatic stage and its emplacement in the present position may be attributed to either the late magmatic or hydrothermal stage.



Source of Cr.periodotitic mantle; TRANSPORT of Cr. dissolved in magma

Fig. 2.1 : Contamination & Mining Origin of Massive Chromitite

2.6 MODE OF OCCURRENCE

Almost all chromite deposits are magmatic segregation in ultrabasic rocks, such as dunite, peridotite, pyroxenite, and serpentines derived from these rocks. Scattered grains of the minerals occurred throughout these rocks.

Chromite occurs in the host rock as masses, lenses, and dissemination. All economic deposits of chromite are in ultrabasic rocks and are either stratiform in layered intrusions (98% of world's chromite resources) or podiform In peridotite masses or dismembered ophiolites. Most of the world production of chrome ore comes from deposits associated predominantly with dunite (olivine rock) and to a smaller extent with tractolite (olivine – plagioclase rock) emplaced in irregular intrusive masses of olivine rich peridotite. But the largest potential deposits occur interlayered with pyroxene and olivine rich rock in the lower parts of stratified complexes of overall noritic composition. In Sithampundi area of Salem district of Tamil Nadu and in some parts of Transval, chromite is occurring within anorthosite.

Chromite deposits sometimes occur in the form of layers of chromitite rocks containing a large proportion of chromite. These layers lie within thick layered sequences of olivine and pyroxene rich rocks in the lower parts of noritic complexes. Such deposits generally run for good strike length as a narrow body. But most of the chromite deposits are characterized by irregular form of disseminated bodies, lenses, pods etc. showing varied relations to the enclosing rocks and also as erratic distributions. Deposits of this type range in size from a few kilograms to about 10 metric tonnes.

Geological data show that chromite bearing ultrabasic massifs are found in geosynclinal areas, junction zone of geosyncline with platforms and on platforms. They are known to be present in almost all geosynclinal areas over the world formed in different geological times pre-cambrian to meso-kainozoic. In these structures they occur in the form of belts. The chromite belts show close association with major faults in the area. The largest chromite fields are found in ultrabasics of the age group pre-cambrian (India), Caledonian – late Caledonia (USSR., Urals), Hercynian (Iran, Turkey, etc.) . Comparison of the known deposits of chromite of different ages show that the ancient structures in the folded areas are somewhat more favourable for locating economic deposits . This may be probably due to the deeper erosional truncation of their structure and ultrabasics confined in them.

Occurrences of chromite in widely varying proportions are always found in peridotite, peridotite-orthopyroxenite, norite, dunite-clinopyroxenite, gabbro-norite-harzburgites, picrite-dolerite, dunite-clinopyroxenite-iolites, and kimberlites. However, commercial deposits of chromite are known to be found only in peridotites and gabro-norite-harzburgites (in folded area) and peridotite-orthopyroxenite-norite (on platforms). The peridotite formation is most common in the geosynclinal area all over the world. The concentration and grade of the chromite depend on the petrographic composition of the rocks enclosing the ore body. High concentrations of ores very rich in chrome, are confined to the most differentiated massive bodies represented by the dunite-troctolite-harzburgite, and dunite-harzburgite formations.

Besides these natural modes of occurrence, chromite in varying concentrations occurs in the form of placer deposits when it is sometimes called “Black Sands”. The placer chromite deposits along the southern part of Oregon coast, USA, constitute one of the largest known reserves of chromite in that country. Similarly, the placer deposits along streams in Maryland, Pennsylvania and North Carolina have been worked economically. In Japan, sizeable quantity of the country’s reserves is estimated to be available in the stream placers northern Hokkaido. The Oregon sands, and for that matter all the placer deposits, are found mixed up with ilmenite and magnetite in varying proportions. This presents at times mining and separation problems.

Lateritic iron ores formed by the weathering of ultrabasic rocks contain an appreciable amount of chromium in the form of chromite. The Cuban lateritic ores range from 1 to 3 percent Cr, probably, mostly in the form of chromite. This low percentage of chromite in the laterite added to the costly and complicated method of extraction of chromium from laterite, may apparently lead one to regard the lateritic deposits as uneconomic. But the tonnage of ore available is so vast that they constitute a major proportion of the world reserve. The amount of chromium in the Cuban laterites alone is believed to be eight to ten times the reserves of entire deposits in North America.

2.7 TYPES OF DEPOSITS

Chromite deposits have been classified into different groups by different authors based on the shape, size, structural features, associated host rocks and genetic conditions. Sampson (1942) for the first time attempted to classify chromite deposits based on their shape and structural features. Later, Thayer (1960) too classified the deposits based on form, size and structural features. In addition, he described chromite deposits based on the associated host rocks . The latest classification is by Dorokhin and others (1969) based on the genetic conditions of the chromite deposits. The different types of classifications as made by different authors are described below :

2.7.1 Samson's Classification

Samson attempted to classify the chromite deposits on their shape and structure as follows:

a) Evenly scattered b) Schlieren banded c) Stratiform
d) Sackform e) Fissure form

1. Evenly scattered: The evenly scattered type never forms a source of economic ore. It may consist of chromite grains disseminated throughout the host rocks . These grains are usually corroded and give the impression of "early crystallization from the magma".
2. Schlieren banded: The chromite deposit found in the form of bands of concentrated chromite grains or chromitite have been denoted as 'Schlieren banded' type. In this bands chromite grains shows varied concentration and hence the bands do not show a clear cut contact zone Such deposits are generally of small size and very few of them have been found to be large enough to attract commercial importance. Individual grains of chromite generally show crystal form. Some bands in which minute crystals of olivine are present can be compared with the bands seen in the gneissic rocks. The main difference between these two types of bands is that the former bands generally run straight and contortions are rather uncommon. Some bands are strong, fairly rich and persistant, whereas others are seen in the form of fine sutures.
3. Stratiform: This type of deposit, which shows well defined and persistent bands of chromitite or chromite orezone generally runs over a considerable length as compared to its thickness. These deposits occur in igneous complexes, which represent extreme differentiation commonly with monomineralic rocks including dunite , bronzitite, and anorthosite. The bands run almost in horizontal position and distribution in rock type shows decreasing density from bottom to top. Chromite is generally found in the lower part of the series but well above the base. Some band shows numerous large lensoid shapes connected with each other in the form of beads, whereas some other split over tens or hundreds of metres.
4. Sackform: This type of deposit is most common type of chromite deposit. A major part of the world production comes from this type. Individual ore shoots are seen in the form of overall rounded shape, but with a somewhat irregular contact zone. The ore shoots generally contains pure chromite or rich concentration of chromite grains with interlocking features. The boundaries of the ore bodies are commonly sharp and well defined. These sackform bodies may be irregularly distributed or the distribution may be along certain planes . In some instances, there is distinct linear control, commonly with steep dips to form chimney-like loads.
5. Fissure form: The fissure form refers to those chromite deposits which have been controlled by pre-existing fissure. This class of deposits have been recognized in the recent past, typical examples being Salukwe deposits of Southern Rhodesia and Black Lake deposit of Quebec. Chromite in such deposits occurs in the form of ordinary veins. Some veins are fairly persistent and some are thin lenses with a small length. These veins may or may not be connected with each other by stringers.

In Black Lake deposits of Quebec, the chromite veins follows mappable faults, whereas in the Selukwe deposits of Southern Rhodesia chromite veins are located in the plane of schistosity.

In Oraje deposits of Yugoslavia, sacks of chromite ore are seen along a plane of jointing and fissuring.

2.7.2 Thayer's Classification

A. Based on form, size and structural features.

Thayer has also broadly classified chromite deposits based on form, size, and structural features into two types: (i) Stratiform and (ii) podiform

(i) Stratiform deposits:

Sratiform deposits are large igneous complexes of precambrian age and can be more than 5ft thick & cover thousands of kilometres in lateral extension associated with peridotite- pyroxenite, dunite - & anorthsite, well known examples are Bushveld Complex in South Africa, Great Dyke in Zimbabwe, Odissa in India & Madagascar. The steel poort main steam in the Bushveld complex shows a thickness of 110 to 125 cm, whereas it runs for a strike length of 65 km or more. No further sub division for this type of deposit has been made. These deposits are easy to determine, easy to extract and operate but they have low Chromium content & low Cr/Fe ratio.

(ii) Podiform deposit:

On the other hand, Podiform deposits are confined to younger orogenic belts and they are smaller than stratiform type shaped as pods, lenses & slabs. Podiform deposits show irregular form and erratic distribution. These show a wide variation in size, say from a body weighing a few kilo to a body weighing tens of tonnes. Most of the bodies, individually account for not more than 100 tonnes.

These are rich in chromium content & higher Cr/Fe ratio. They are the best sources for High carbon ferrochrome. Best examples of these deposits are Kazakhstan resources & some part of Zimbabwe deposit.

Thayer has further subdivided podiform deposits into the following groups based on the distribution of ore within the deposits:

A. Extensive tabular:
   (a) Disseminated
   (b) Massive
   (c) Discontinuous
B. Fusiform
C. Irregular

1. Extensive tabular deposits: The podiform deposit with two lateral dimensions much greater than thickness, say ten times or more have been denoted as 'extensive tabular' bodies. These deposits may end abruptly or may taper out gradually with or without branching at the pinching ends. These sometimes show disseminated grains of chromite arranged in thin layers parallel to the longer axis of the deposit. The contacts of ore zones are generally ill defined. This type falls into the 'disseminated' class of extensive tabular deposit. The 'massive' class of extensive tabular deposit show generally sharply bounded rich ore zones. Such ore zones may taper out irregularly at the end portions or may end abruptly. The 'discontinuous ' tabular deposit consist of flat lenses of chromite spread out within the mineralized zones like plums in a pudding. These lenses may be connected with each other by thin stringers or layers of chromite grains.

2. Fusiform deposits: Fusiform deposits are those in which one direction is much greater than the other two directions. These deposits tends to be uniform and equidimentional in transverse section and may be compared to a pipe shaped body. But ore concentration show great variation along the length of the body.
3. Irregular deposits: Chromite deposits having forms other than those defined above and with an irregular shape fall under irregular bodies.

The characteristics of stratiform and podiform deposit are as below:

A) Structurally, the stratiform deposits occur in Precambrian or Archean geosynclines, while the podiform deposits occur within Tertiary geo-synclines;

B) Stratiform deposits are generally associated with proxenite, peridotite and at times with dunite, whereas the podiform deposits are associated with dunite and serpentine;

C) Stratiform deposits exhibit bands and layers indicative of gravitative settling of chromite mush (Fig. 2.1.) whereas the podiform deposit show nodular structure and

D) The ores of stratiform deposits are commonly less aluminous and may tend to be ferriferous with a Cr: Fe ratio of about 2:1 or less. The ores of podiform deposits are generally more aluminous with a Cr:Fe ratio of more than 2:1.

Based on the associated host rock, chromite deposit have been grouped under two classes by Thayer. These are: (i) noritic or Bushveld class, and (ii) dunitic or California class.

(i) Noritic type: The noritic type of deposits generally occur in layers, which ranges from a few cm to a few metres in thickness and have an appreciable lateral extent. The behaviour of these chromite deposits is comparable to that of coal beds. The chromite-bearing belts occur in a definite sequence just like any other sedimentary deposit and the hidden deposits can be explored with reference to the sequence of exposed formations. But the chromite content in the entire deposit ranges from scattered grains to massive chromitite with a small admixture of silicates. The principal silicates are olivine and bronzite, with calcic plagioclase in small amounts. In these rocks, chromite is a primary igneous constituent of the rock, which appears to have crystallized more or less simultaneously with the other minerals during metamorphic process. Typical examples are the Bushveld Complex in the Transvall, the Great Dyke in Southern Rhodesia, and the Still-water complex in Montana.

(ii) Dunitic type: Dunitic type of chromite deposits show wide variation in form, structure and size of ore bodies and also in the degree of concentration within the individual ore body. In size, it may range from few kilos to several hundred thousand tonnes and in grade from lean disseminated ore containing scattered grains of chromite to massive high grade ore. Wide variations are to be noted in the form and structure of the ore bodies. Most of the ore bodies are in the form of irregular lenses, but other forms of pod, vein, pipe etc. are also common. Massive ore bodies containing mainly chromitite rocks show little internal structural variation probably because widely contrasting materials are not found in such rich bodies. In the disseminated ore bodies, chromite grains are rarely evenly distributed rather they show banding due to layering or lineation and irregular masses of higher grade ore. The ore zones generally show clearly alternating bands of high and low grade ore or bands of ore and barren rock.

A close study of host rock association shows that dunite or tractolite is universally associated with chromite ore bodies of the dunitic class. Most of the deposits are surrounded by a halo of dunite and the dunite zone may vary in thickness from a few cm to a few metres. Some of the deposits do not exhibit any halo or zone of dunites but the ore bodies at contact zones grade for a few cm from chromite in an olivine or serpentinised olivine matrix to pyroxene-bearing country rock. Except as occasional small protrusions, pyroxene is rarely seen as gangue mineral in deposits of the dunitic class.

Chromite concentration in dunite deposits is highly erratic, varying widely from one peridotite to another. Sometimes small ponds or lenses of chromite are scattered at random within the rock mass. Typical examples of "dunitic" deposits are seen in California, Cuba, Alpine areas, etc.

2.7.3 Dorokhin's Classification

Dorokhin and others have classified chromite deposits on the basis of genetic conditions as follows:

1. Early magmatic deposits,
2. Late magmatic deposits,
3. Eluvial-deluvial placers and
4. Residual deposits.

i. The early magmatic class is represented by disseminated, evenly scattered and Schlieren forms of deposits. The world's biggest Bushveld deposits and the Great Dyke in Southern Rhodesia belong to this type.

ii. Chromite deposits in the form of veins, lenses, and bands with well-defined irregular boundaries represent late magmatic deposit. These ore bodies are generally large in size and the ore bodies are sometimes traversed by gabbro and dunite dykes. In such type of deposit, the presence of chlorite, mica, chrome, tourmaline, etc. indicates that volatile components played a part in their formation. The structural features further indicate that the formation of these deposits was accompanied by tectonic deformation, which resulted in the squeezing of chromite grains into the fissure zones and also into the uplifted parts of the formations. Some deposits found in Philippines, Turkey and the USSR are of late magmatic type.

iii. The eluvial-deluvial placer deposits are formed by chromite grains disintegrated from primary chromite deposits and carried by natural agencies, and are seen generally along river beds. Typical examples are Maryland, Pennsylvania and North Carolina, USA, and North Hokkaido in Japan.

iv. In the case of deposit resulting from residual concentration, grains and fragments of chromites occur in clayey mass with limonite or other ultrabasic rocks. Weathering of ultrabasics results in the formation of magnetite and chromite grains, sometimes get concentrated in situ to form an economic ore zone. Examples of such belts containing chromite – bearing ultrabasics are:

   (a) along a considerable part of the Urals (Hercynian intrusions of peridotites and dunites);

   (b) in the Balkans, extending across Turkey, the Caucasus and farther into India (the so called Mediteranean belt of Cretaceous and Tertiary Ultrabasic intrusions);

(c) in the Chukatka, Peninsula through Japan and farther into Indonesia (Tertiary intrusions); and

(d) in Southern Rhodesia and South Africa, where the ultrabasic rocks of the Bushveld mass and of the Great Dyke (Precambrian) are confined to a zone striking in a meridional direction. The bulk of chromite resources are Precambrian and are concentrated in South Africa.

2.8 REFERENCES

1. **Chromites of India , Their Textural and Mineralogical Characteristics,** by R.K. Sahoo, J.K. Mohanty, S.K. Das and A.K. Paul*.
2. **International Seminar on Development of Chromite, Nickel and PGM Resources,** (28 Nov, 2010 Bhubaneshwar) SGAT & Dept Steel & Mines, Government of Odisha.
3. **Draft document on formulation of strategy for exploration, exploitation and devel opment for chromite in india**, by 'The sub-group on chromite' J.K.Nanda & B.K. Jena, Directors GSI; M. Sengupta, RMG, IBM, Nagpur & Naresh Nautiyal, Dy.GM(Exploration), MECL, March 2007.
4. Mineral Facts and Problems: CHROMITE; Monograph No.6**, March 1982, TMP Division, Indian Bureau of Mines, Ministry of Steel and Mines, Nagpur.**
5. Indian Minerals Yearbook- 2011; Indian Bureau of Mines, **Government of India, Ministry of Mines**; December, 2012.
6. **THAYER (TP), Mineralogy and Geology, in VOLY (MJ) Ed. Chromium**, Vol.I ACS Monograph No. 132, Reinhold Publishing Corporation, New York, 1956.
7. **THAYER (TP), Application of Geology in chromite exploration and Mining in Symposium on chrome ore of Central Treaty Organization held in Ankara**, Sept. 1960.
8. **Geological setting and mineralogy of the chromite and some associated minerals of Kathpal, Dhenkanal district, Odisha**, Chakraborty (KL) and Baidya (T), J. Geo. Soc. India, Vol.19, No.7, July, 1978.

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Chapter 3

INDIAN DEPOSITS

3.0 INTRODUCTION

Indian chromite deposits amount to about 2% of total world resources. In India, stratiform chromites are found in ultramafics intrusive into Archaean or Precambrian lithosequences of low or high metamorphic grade. Stratiform complexes were emplaced in the low grade greenstone sequences in Odisha, Jharkhand and Karnataka and in high grade granulite lithopackages in Tamil Nadu and Andhra Pradesh. Tertiary ophiolite sequences having ultramafic rocks and podiform chromite are known to occur in Manipur, Nagaland and Ladakh sectors of Himalayan belt and in Andaman islands of Indo-Burma arc.

The Indian chromite deposits have been classified into the following categories based on their association with different stratigraphic horizons of different geological ages.

A. Associated with ultramafics intrusive into:

(a) Archaean supracrustals (greenstone belts):

1. Sukinda and Boula-Nuasahi in Odisha,
2. Jojohatu-Roroburu belt in Jharkhand
3. Sinduvalli and Byrapur in Karnataka
4. Bhandara-Nagpur, Sindhudurg and Chandrapur belts in Maharashtra

(b) Precambrian Eastern Ghats Granulite Belt and Southern Granulite terrains:

1. Andhra Pradesh 2. Tamil Nadu

B. Associated with Tertiary Ophiolite sequences in Himlayan orogenic belt:

(1) Manipur (2) Nagaland (3) Jammu & Kashmir Himalayas and (4) Andaman & Nicobar Islands. The major economic deposits in the country occur in association with ultramafic intrusives intruding Iron Ore Group rocks in Odisha and Sargur Group in Karnataka, both of Archaean age.

3.1 TYPES OF DEPOSITS

Chromite deposits are generally of two types viz., a) stratiform and b) podiform. The major economic ones are associated with magmatic layered complexes dominantly comprising dunite, peridotite and pyroxenite, some of which are chromitite and chromite bearing. The other type is a podiform chromite associated with ophiolitic sequences in orogenic belts as in indo-Burma arc and in the Himalayas. The chromite deposits may have associated occurrences or deposits of PGE, Au, Ni, Cu, Ti-V ores, iron ore (magnetite) etc. thereby enhancing the economic aspects of the chromite exploitation. In Sukinda and Baula-Nausahi belts of Odisha, the chromiferous ultramafics are of layered or stratiform type associated with dunite and peridotite. The minor occurrences known in Kashmir and Manipur-Nagaland Himalayas and in Andaman islands are of podiform type.

World wide, high-alumina chromite largely from podiform deposits is used in refractory applications, while iron-rich chromite from stratiform deposits are used for metallurgical and chemical applications.

Structurally, all the chromite fields are highly complex. Transverse and dip faults of various trends and magnitude, with numerous folding and intrusions of various dykes in chromite ore bodies are common features, posing difficulty in mining, development and exploration at depths.

3.2 INDIAN RESOURCES

World chromite resources are placed at over 12 billion tonnes. Over 95% resources are located in South Africa, Zimbabwe and Kazakhstan. Major deposits of chromite in India are in Odisha. As per UNFC, total resources (Provisional) of chromite in the country as on 1. 4. 2010 are 203 MT, comprising 53.97 MT reserves (27%) and 149.38 MT remaining resources (73%). More than 95% resources of chromite are located in Sukinda in Cuttack and Jajpur districts of Odisha. The remaining 5% reserves of the country are scattered over Jharkhand, Maharashtra, Tamil Nadu, Andhra Pradesh and Manipur.

Economically, proven reserves for chromite ore in India are reported to be around 1 per cent of total global reserves, but the country produces nearly 20 % of the world's output and accounts for 30 per cent share in the global trade in chromite ore. With the recent increase in world demand for chromite, India has stepped up its production to become third largest chromite producer in the world. In India, 97% of the total chromite deposits occur in association with Iron Ore Group and other 3% deposits belongs to Proterozoic Eastern Ghat Group and Tertiary Ophiolite formation. About 95% of the total chromite resources i.e. 203 MT is located in Sukinda and Boula-Nuasahi belt in Odisha. Against this strong resource base, the present production of chrome ore in the country is around 4.26 MT. At this annual rate of production, the resources are expected to last for several years. In other words, the country can meet any medium or long term demand, both by domestic industry and export commitments. The Life Index of chromite resource is approximately 77 years indicating a near comfortable position.

Life Index of Resource: The principle adopted for calculation of Life Index of Resource is to estimate the total then known reserves that are considered to be mineable by the present known technology and parameters on the one hand and the total annual demand for domestic use and export as estimated. Thus, the Life Index of chromite resource will be approximately 47 years (203 MT divided by 4.26 MT) indicating a near comfortable position. The total life index will have maximum implication for the metallurgical industry.

3.2.1 State-Wise Distribution of Deposits and Occurrences with their Resource Potential

On a cursory glance on the chromite resource map of India (Fig- 3.1), five clusters of deposits/ occurrences can be visualized. These are: 1.Jharkhand and Odisha, 2. Andhra Pradesh, 3. Tamilnadu, 4. Karnataka and Goa, and 5. Maharashtra. In the first cluster, Odisha has the largest resource, Jharkhand contributing a small percentage. In the second and third clusters, the chromiferous ultramafics have been emplaced into granulite lithopackage and are associated

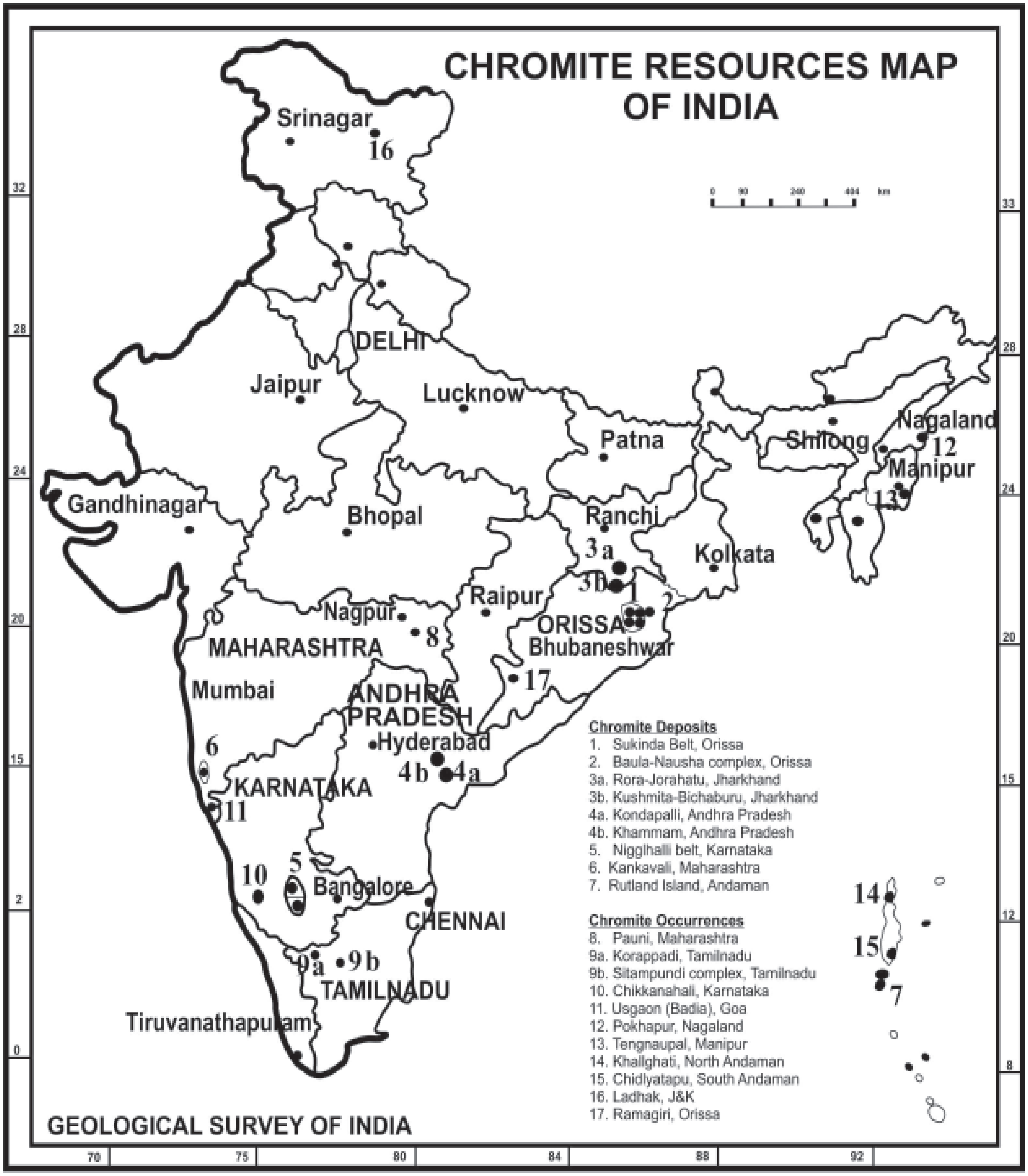

Fig. 3.1 : Chromite Resources Map of India

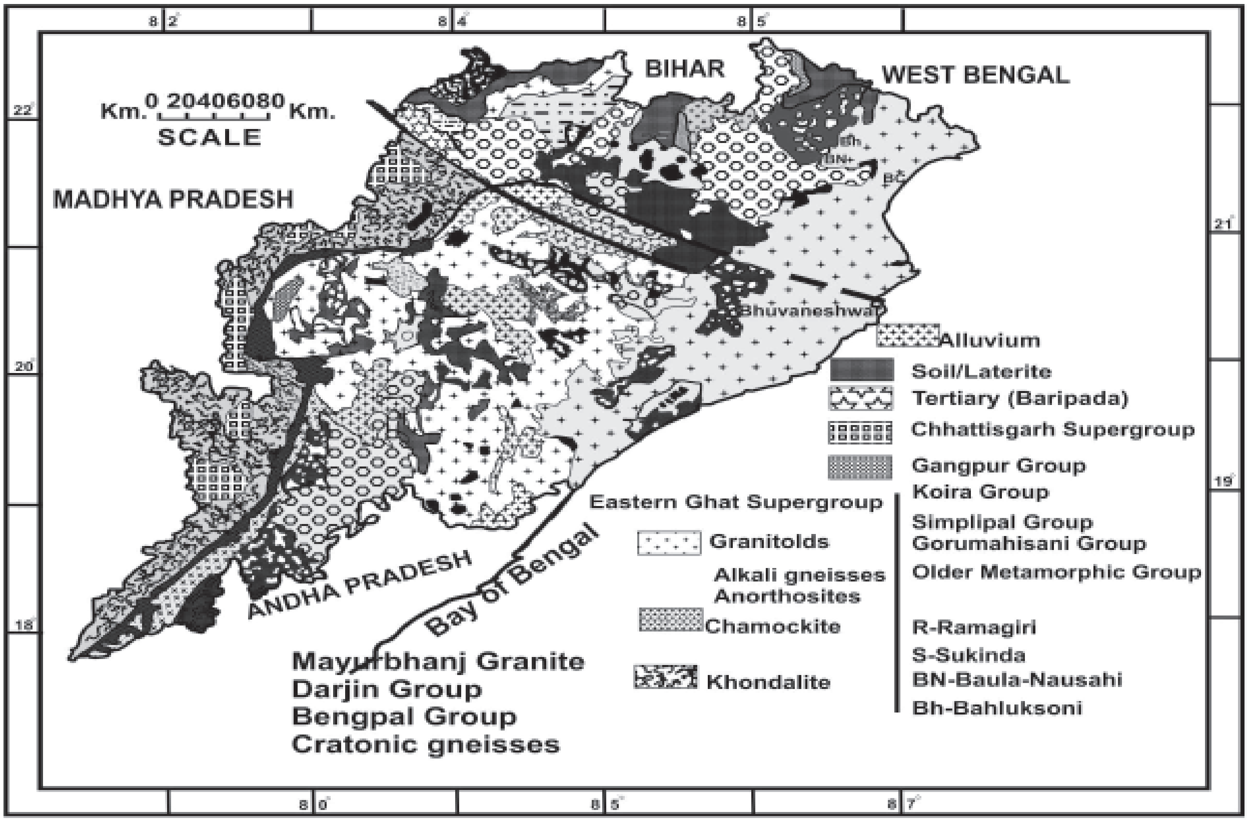

Fig. 3.2 : Outline Geological Map of Odisha showing location of Chromite Deposits/Occurrences in Odisha

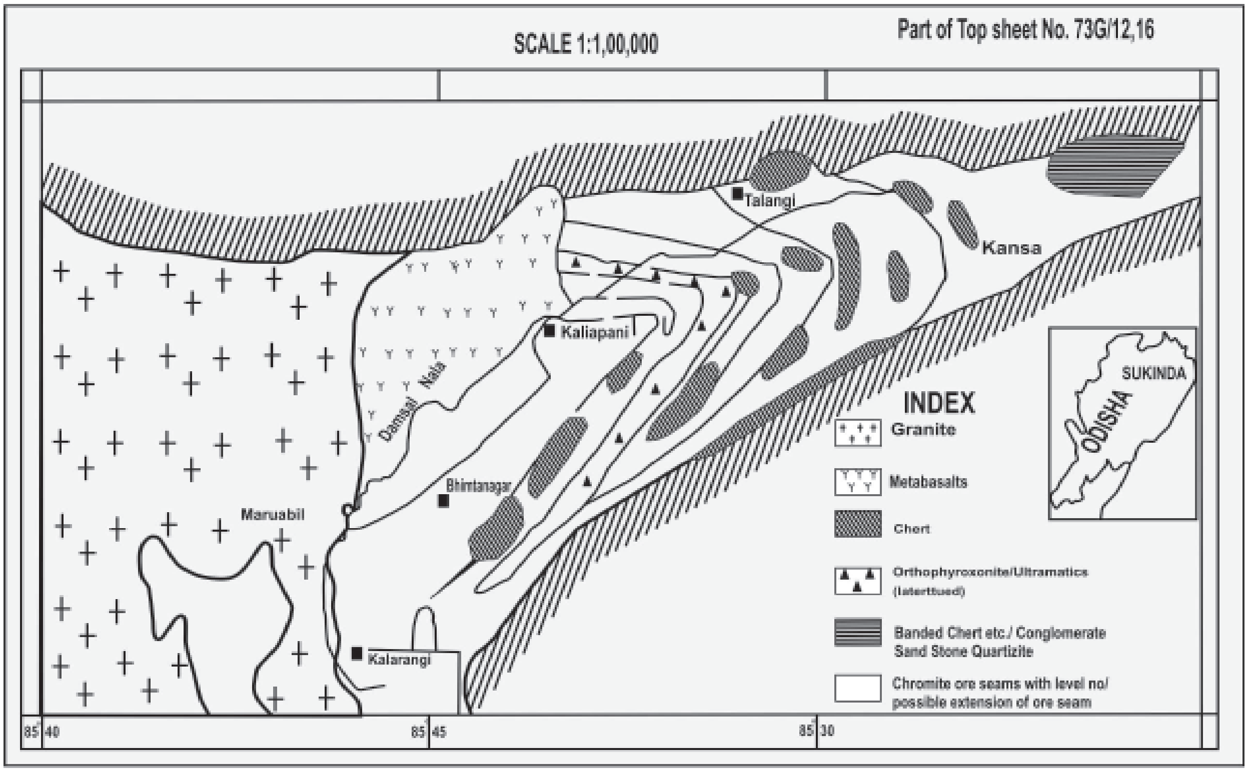

Fig. 3.3 : Geological Map of Sukinda Ultramatic belt (Sub) showing Distribution of Chromite Bands

with anorthosite and pyroxenite. In the fourth and fifth clusters, the host ultramafics are intrusive into a granite-greenstone lithoensemble of low metamorphic grade.

1. ODISHA

Major share (98.6%) of chromite resources in the country is located in Odisha. The major chromite deposits associated with ultramafic complexes are in Sukinda and Baula-Nausahi region. Minor occurrences have been reported in ultramafic rocks at Bhalukasoni and Ramgiri respectively in Balasore and Koraput districts (Fig-3.2).

I) Sukinda Belt:

Sukinda ultramafic complex (Lat.20°53′00" : 21°05′00" N ::Long. 85°40′00": 85°53′00" E, toposheet nos. 73 G/12 and 16) contributes nearly 95% of total chromite reserves of the country. This complex is located in Jajpur district between Kansa in the east and Maruabil in the west. It has been explored by geological mapping, drilling, sampling in different phases besides geophysical and geochemical surveys.

Geological set-up :

The Sukinda ultramafic field (Fig.3.3) is confined to an east-west trending valley lying between the Daitari hill range in the north and Mahagiri range in the south. The ultramafic rocks of Sukinda valley are emplaced within a sedimentary sequence of Iron Ore Supergroup, comprising Fig.3.3. Sukinda Ultramafic Belt (SUB). Lithopackage of banded chert, banded magnetite chert, banded epidote chert, fuchsite quartzite, cherty quartzite, banded hematite-jasper and metabasic lava which are overlain by a younger group of rocks comprising conglomerates, sandstone and grit, gritty quartzite, chromite quartzite and orthoquartzite with minor volcanics. The belt of supracrustals discontinuously extend from northeast of Sukinda to Maruabil/ Kathpal in an ENE direction for over 25 km.

The following geological succession can be given for Sukinda area :

- Soil and alluvium and laterite
- Dolerite dyke
- Granite and granophyre
- Meta-basic lava/Dolerite
- Chromiferous ultramafics (in a 45 sq km lopolithic structure)

Conglomerate, grit and orthoquartzite with placer chromite underlain by banded magnetite chert,shale and phyllite with alternating sequence of lava occur at the base.

Mode of formation, age and nature of mineralisation

The chromite mineralisation is confined to a Precambrian ultramafic body which has intruded in the form of a lopolith into the Precambrian supracrustals represented by low grade metamorphites comprising gritty quartzite and metavolcanics. The intrusive has a width of 2 to 5 km and extends for a length of nearly 25 km in an ENE-WSW direction from Kansa in the east to Maruabil and beyond, on the west. The ultramafic body consists of magnesite-rich serpentinised dunite-peridotite with chromite bands, besides subordinate amount of pyroxenite without chromite association representing the early magmatic products. The dunite-peridotite members are highly serpentinised and intensely lateritised giving rise to a nickeliferous laterite profile of variable thickness.

Table 1: Bandwise Details of Chromite Bands in Sukinda Belt

Band No	Character	Location
I	Moderately thick (0.3 m to 12 m), fairly continuous (200 to 1200m), extremely fine grained, hard and lumpy ore seams, siliceous, low to medium grade.	Exposed in O.B.II quarry of Sukinda mine of M/s TISCO Ltd, South Kaliapani lease-hold of OMC Ltd, Kamarda Chromite mine of B.C.Mohanty.
II	Thin (0.5 m to 2 m) lenses and bands,of 100 m to 500 m length, fine to medium grained, hard & lumpy, low to medium grade with high silica.	Exposed in Tailangi mine of M/s IDC Ltd, Kamarda Chromite mine of B.C.Mohanty, Sukrangi of M/s OMC, Saruabil of M/s Mishrilal mines.
III	Cluster of moderately thick (3 m to 12 m), lenticular but fairly continuous, 100 m to 200 m length, partly lumpy, fine to medium grained, low to high grade, associated with chert bands, high Fe-Cr ratio.	Exposed in South Kaliapani and Sukrangi mines of OMC Ltd, Saruabil of M/s Mishrilal Mines, Tailangi mine of M/s IDC Ltd. On the northern flank, band IV is being exploited in the Ostapal Chromite mine of FACOR where it is bifurcated.
IV	Thin (1 m to 6 m), lenticular, 200 to 300m, in length, partly lumpy, low to high	Exposed in South Kaliapani and Sukrangi mines of M/s OMC Ltd,
V	Moderately thick (3 m to 15 m), lenticular but fairly continuous (200m to 1000m), low to high-grade, soft,	Lower Brown ore seam of Kaliapani-Bhimtanagar exposed in Sukinda mine of M/s TISCO Ltd, to Sukinda mine of M/s IMFA, and Kaliapani & South Kaliapani of M/s OMC Ltd
VI	Very thick (15 m to 60 m,) continuous for about 7 km, medium to coarse grained, extremely friable and high-grade ore seam.	Upper Brown ore seam of Kaliapani-Bhimtanagar exposed in Sukinda mine of M/s TISCO Ltd, to Sukinda of M/s IMFA and to Kaliapani & South Kaliapani of M/s OMC Ltd

The repetition of dunite members and chromite ore seams has been attributed to rhythmic layering within the ultramafic complex. The presence of scour/slump structures in the chromite horizons of the Sukinda belt is characteristic of gravity controlled magmatic layering. The chromite deposit of Sukinda belt is mainly stratiform type and can be classified into the categories like lumpy ore, granular ore, friable ore, ferruginous ore, disseminated ore and banded ore.

In Sukinda belt the chromite outcrops generally lie under an overburden cover of 3 m to 9 m. The overburden is generally soft and consists of alluvium, murrum and laterite. The ore bands have dips ranging from 25^0 to 85^0 , but in general it is 75^0. The wall rocks are generally composed of soft, limonitised, silicified and talcose or serpentinised ultramafic rocks. The ore bands locally exhibit swelling and pinching both along the strike and dip.

The chromite ore bodies of Sukinda area occur in the six distinct stratigraphic levels which are more or less continuous throughout the ultramafic body. Details of the nature, dimension and distribution of individual bands / seams are provided in the Table - 1 .

The lenticular and banded forms of ore in different ore seams /bands are developed due to folding and frequent short displacements/ faulting, both along strike and dip, making the mineralisation in different bands discontinuous along the strike (Fig-3.3).

The ore bodies in Sukinda valley are in general enriched and the bulk density increases with depth. It reaches upto 3.3 beyond depths of 40 m to 50 m from the surface. Up to depths of 30 m from the surface, the recovery of high grade (>48% Cr_2O_3) is about 40%, of the medium grade (40 to 48% Cr_2O_3) about 20%, and of the low grade (<40% Cr_2O_3) is about 40%. The grade increases with the increase in the depth of mining and the recovery of high grade ore goes up to 70% while the recovery of medium grade and low grade ores are respectively about 10% and 20% .

CONTROLS OF MINERALISATION

The dunite members of ultramafic complex partially or fully altered to feebly schistose talc-serpentine mass are the host rock for chromite ore seams showing a lithological control. Following five major seams exposed discontinuously for a E-W strike length of more than 7 km with 1 m-40 m width have been identified from north to south in Sukinda ultramafic complex.

a) Lower Brown Ore seam
b) Upper Brown Ore seam
c) Sukrangi Ore seam
d) Kamarda Ore seam
e) Grey Ore seam or Mahagiri Ore seam

All the ore seams are mostly friable and partly lumpy, except for the Mahagiri Ore seam which is lumpy throughout and suitable for refractory use.

Dimensions of the ore bodies

The repetition of dunite members and chromite ore seams has been attributed to rhythmic layering within ultramafic complex. Continuity of one of the ore seams (Lower brown ore seam) has been established for more than 7 km on the surface while others have variable strike extensions from 200 m to 2 km. Depth continuity is ascertained to be more than 250 m from the ground surface as inferred from 4 boreholes in TISCO lease-hold area. Pinching and swelling of ore seams are normal features.

Chromite occurs as persistent thick bands, seams, lenses within ultramafic complex. Six seams have been delineated with thickness varying from 10 m to 50 m. One of the seams dipping south into Mahagiri hill comprises hard, lumpy and very fine grained ore and is designated as the Mahagiri seam. Rest of the seams have steep dip towards north. These are friable in nature and described as brown ores. The first brown ore horizon (Seam-1) is perhaps the thickest (40m thick) seam in the world. All the six seams are fairly thick and persistent both along the strike and dip of the intrusive as observed in the quarry and borehole sections from Saruabil in the east to Bhimtangar in the west. Further west at Kalarangi, Kathpal and Maruabil, these chrome ore bodies do not exhibit any regular alignment, rather these are exposed in discontinuous bands and lenses disrupted by the emplacement of younger granite.

Most of the area is covered with a lateritic profile, more than 50 m thick. Specks of chromite in laterite and association of secondary silica (chert) in close proximity are considered locally as the surface manifestations of chromite mineralisation in the northern limb of the fold of Bhimtangar block. Besides, a lumpy chromite ore seam has been established by drilling in

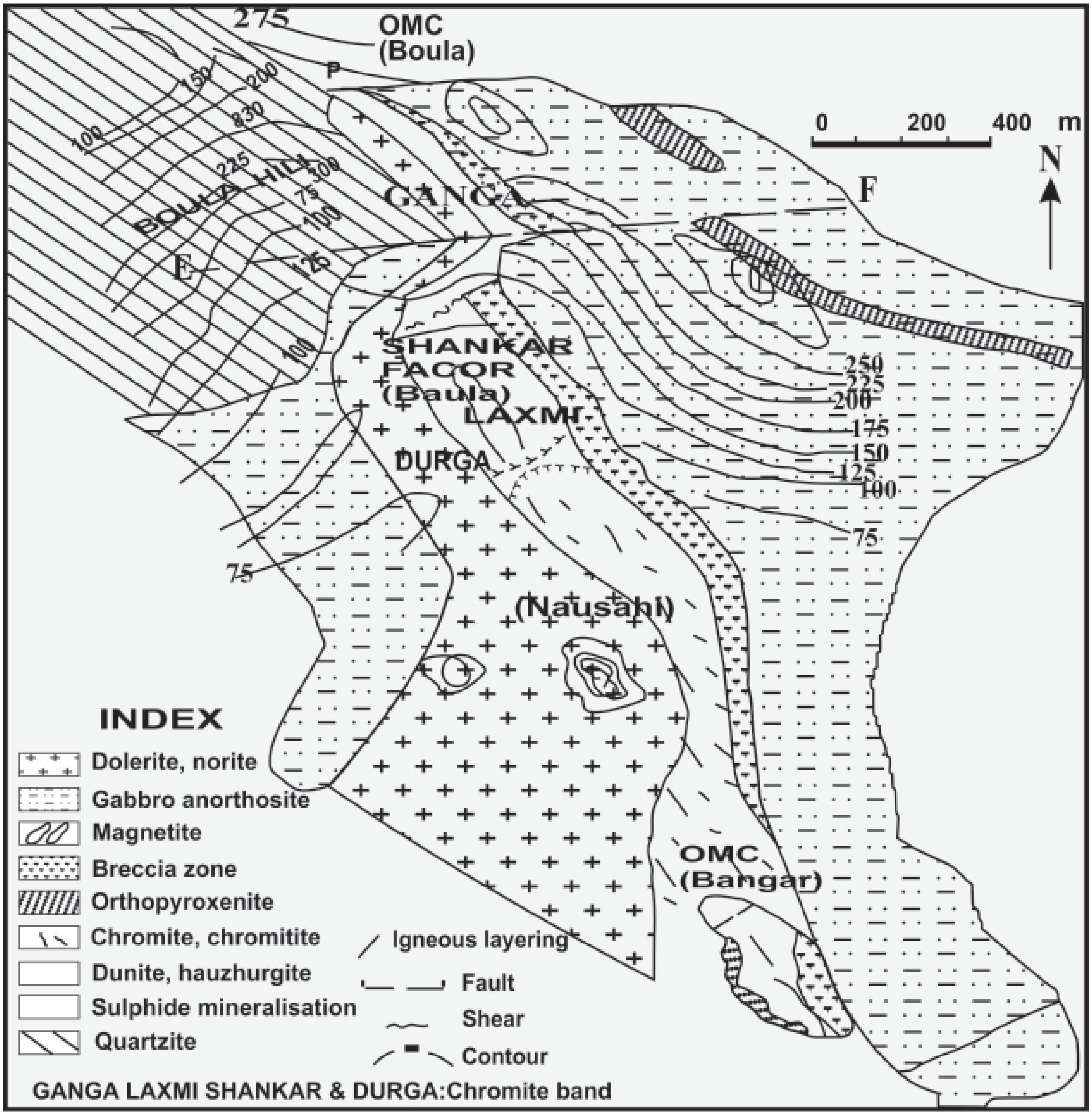

Fig. 3.4 : Geological Map of BNIC showing Distribution of Chromite Bands

Gurjang area in the northern limb of the folded structure. Mahagiri lumpy chromites are exposed for about 7 km in the southern limb of the fold in Bhimtangar block.

Grade

Based on the exploration carried out by GSI the following grades and reserves of chromite has been assessed in Sukinda belt.

i) Phase-I

Six distinct parallel chromite ore bodies are exposed disjointedly (Fig. 3.3). The cumulative strike length of each band is 7 km with 1 m-40 m width (Table 1).

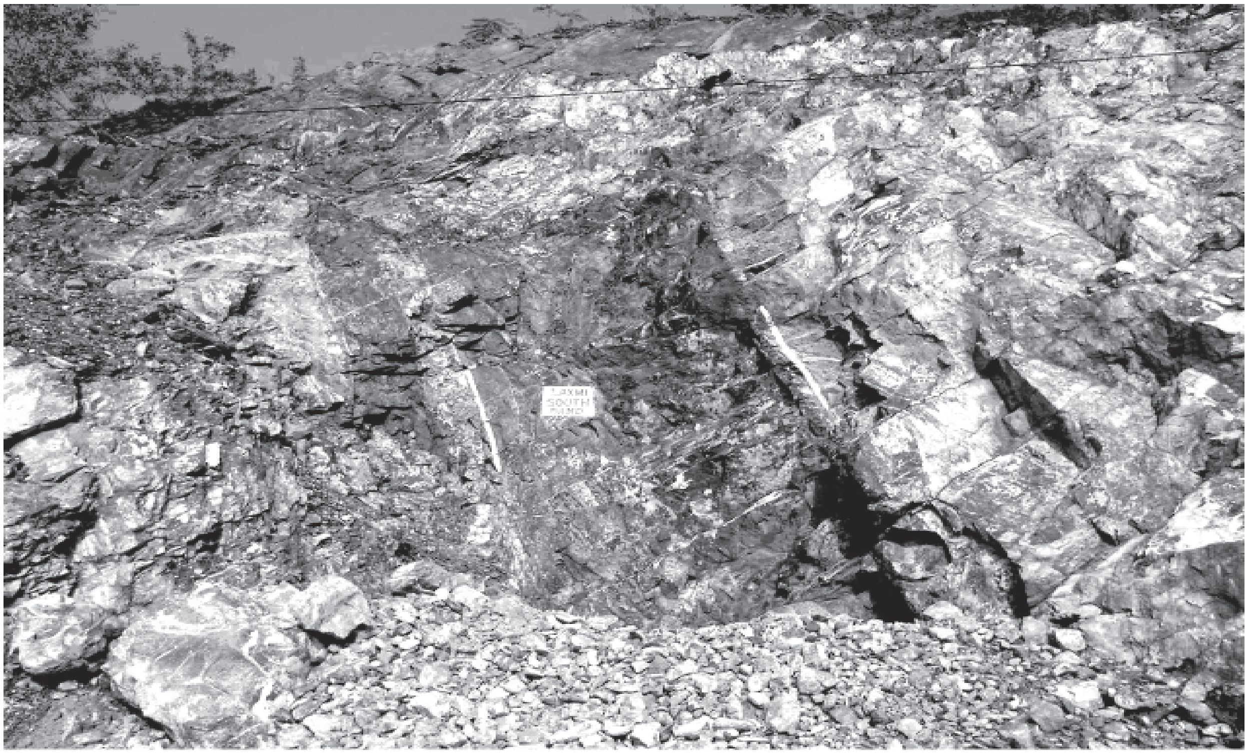

Fig- 3.5. Chromite (Lakshmi Lode) lode in Nausahi Mine Face lying between Serpentinised Dunite

The ore is generally friable except in Mahagiri band where it is mostly lumpy. The ore is mostly of charge chrome and metallurgical grade with +48% Cr_2O_3, 1-6% SiO_2, 5-8% C, 0.4% S and 0.3% P. Only upper weathered portions to a maximum thickness of 30 m may show 30-35% Cr_2O_3.

A generalised lithological sequence observed in the area is as follows :

	Soil, alluvium and laterite
Mafic-Ultramafic Complex (Intrusive) -	Dolerite/norite dyke Granophyre and granite Gabbro with lenticular or layers of Ti-V magnetite Chromiferous ultramafics (dunite-peridotite)
I.O.G. Supergroup -	Quartzite and quartz schist, minor BIF

The ultramafics are of Precambrian age. The gabbro body exposed in Bangur quarry, intrusive into the ultramafics hosting chromite is associated with PGE mineralisation. This body, dated at ~3.1 Ga, is considered to be one of the oldest (Auge et al., 2003).

Mode of occurrence, controls of mineralisation and age

In Baula – Nausahi belt(Figure 3.4), chromite is confined to ultramafic complex represented by serpentinised dunite – peridotite which is late magmatic intrusive into the older metamorphites. The older Precambrian metamorphites belonging to I.O.G. Supergroup consist of massive quartzite, ferruginous quartzite, quartz-sericite schist and metavolcanics.

The ultramafic body to the west of Nausahi, extends for about 3 km in a NNW-SSE direction from Phulijhorahuli down to the Jauthabahali. It is a dyke like body having distinct intrusive relationship with the older quartzite and epidiorite forming hills to the north. The ultramafic body has a maximum width of about 1 km in the middle tapering gradually towards north and south and mainly consists of serpentinised dunite periodite in the core and subordinate amount of pyroxenite at the periphery. The presence of scour/slump structures in the chromite zones/horizons of this belt is characteristic of gravity controlled magmatic layering. The width of individual band as revealed from borehole data, varies from 15 m to as thin as 10 cm. The Nausahi ores are inferior charge chrome grade. Iron and silica are higher than in Sukinda sector.

There are in general 3 lodes in north Baula block (Fig. 3.5) and 2 lodes in South Nausahi block (Fig.3.4) occurring as disjointed bodies. The chromite bodies occurring in the form of discontinuous bands and lenses, confined to the altered dunite peridotite are exposed in the central part of the mine. These bands have an average width of 5 metres and have a NW-SE to NNW-SSE strike with a moderate easterly dip and have been affected by shearing and faulting during post consolidation stage. The chromite seams in the Baula-Nausahi area are thin (3 m to 10 m), mostly hard and lumpy, and persists for a depth of more than 100 m as observed in borehole intersection.

Various chromite ore types are : lumpy and granular ore, friable ore, ferruginous ore, banded ore, disseminated ore and magnetic ore. The Fe-rich ore, ie., magnetic chromite / feritchromite is found in parts of Baula chromite mines of FACOR where both chromite and magnetite are intimately mixed posing problem for their separation (Table 2).

Grade

Table 2 : Ore Types in Baula-Nausahi Belt

Sl. No.	Type of ore	Grade
1.	Total non-metallurgical grade (including charge chrome and metallurgical grade ores lying within)	average grade of 35.35% Cr_2O_3
2.	Total metallurgical grade (free from charge chrome and non-metallurgical grade ores)	average grade of 50.06% Cr_2O_3
3.	Total charge chrome grade ore (including metallurgical grade lying within but free from non-metallurgical grade ores)	average grade of 43.99% Cr_2O_3
4.	Total of all grades	average grade of 37.75% Cr_2O_3

II) Bhalukasuni – Nilgiri belt:

Bhalukasuni (21°29′30" N : 86°42′00" E; 73 K/11) is located at a distance of 8 km from the sub-divisional headquarters Nilgiri, in Balasore district.

Geological set up

Bhalukasuni chromiferous ultramafic body forms a small segment on the eastern extremity of 50 km long ENE-WSW running Nausahi – Nilgiri belt, predominantly constituted of a suite of igneous rocks intrusive into the pre-existing Iron Ore Super Group of rocks represented by amphibolite, metachert and quartzite. The intrusives are dominated by gabbro – anorthosite suite at places carrying lensoidal bodies of magnetite (titaniferous-vanadiferous). Small bodies of serpentinised ultramafics rarely with pockets of chromite and hornblende granite – granophyre are the important lithotypes in the central and eastern part of this belt. The local stratigraphy of the area after Vohra et al., 1991, is shown below:

	Soil and alluvium
	Laterite
	Nilgiri Granite (2346 my)
Intrusives (Igneous Complex) —	Gabbro-Norite (magnetite bearing)
	Pyroxenite
	Serpentinite (chromiferous)
Iron Ore Supergroup —	Metachert – quartzite
Singhbhum Granite Complex —	Tonalite – Granodiorite suite of Kaptipada (3275 my)

Mode of occurrence, controls of mineralisation and age

A narrow zone of ultramafic rocks comprising serpentinised dunite, peridotite, pyroxenite interspersed with thin zones of gabbroic rocks has been encountered with cummulative thickness varying from 10.85 m to 11.75 m in boreholes. This zone thins out westward and occurs as detached bodies. Small discrete pockets of chromite occur in the serpentinised dunite.

The DGM, Odisha identified two small lodes – a western lode having a dimension of 50 m x 3.5 m x 4.5 m and a very small eastern lode with a dimension of 5.5 m x 2 m x 3.3 m.

Mineralisation is lithologically controlled with confinement of ore bodies to the serpentinised dunite peridotite rocks. Small bodies of chromite occur associated with serpentinised ultramafic rocks, seen as enclaves within gabbro-anorthosite and hornblende – granophyre suite of rocks. Chromite bodies are of podiform type resting on a plutonic mass of gabbroic rocks, occurring at a depth of 20 m from the surface.

Grade

The DGM, Odisha estimated for both massive and spotted variety (disseminated) of chromite with Cr_2O_3 content from 25.77 to 54.76 per cent.

Ramagiri

Ramagiri (18°46′00" N, 82°15′00" E) in Koraput district can be approached from Jeypore, a major town of western Odisha.

Geological set-up

The country rock is granite gneiss with thin bands and lenses of hornblende schist and chlorite-sericite-quartz schist. These lithounits form isolated outcrops in an otherwise soil covered area. Several chromiferous altered ultrabasics (at present an aggregate of talc and tremolite and/or talc-schist) are exposed occurring as intrusives into the Archaean Bastar cratonic gneisses. The largest individual body exposed in a nala section has a dimension of 10 m x 4 m. Detailed mapping reveal that the chromite bearing altered ultrabasics occur as discontinous patches over a length of 200m in N-S direction. Chromite forms neither distinct bands nor pockets, but is distributed throughout the altered ultrabasics as disseminated grains. Five channel samples collected from pits showed the following analytical results :

Cr_2O_3-24.07 to 27.49% and Fe(total) - 8.10 to 14.24%.

Table 3 : Reserves / Resources of chromite in Odisha as on 01-04-2010 (As per UNFC classification)

	Category	Code	Quantity (In '000 tonnes)
Reserves	Proved	111	31263
	Probable	121	6725
		122	15085
	Sub Total (A)		**53073**
Remaining Resources	Feasibility	211	1116
	Pre-feasibility	221	1189
		222	4335
	Measured	331	31722
	Indicated	332	35796
	Inferred	333	41431
	Reconnaissance	334	21359
	Sub Total (B)		**136948**
	GRAND TOTAL(A)+(B)		**190021**

Source: National Mineral Inventory-2010

2. JHARKHAND

Chromite deposits of erstwhile Bihar had a pioneering role in the early history of chromite exploitation in India. Small deposits of chromite ore are confined to the southern part of Singhbhum district presently in Jharkhand. Such deposits are exposed around Jojohatu, Hatmagariya, Keshargariya, Roroburu, Chitungburu, Kimsiburu, Kittaburu. Small occurrences of chromite are also found at Kusmita (22°05′ : 85°45′), Gurgaon (22°25′ : 85°10′03"), Tonto (22°20′ : 85°35′) and Janoa-Ranjrakocha (22°31′ : 85°38′) areas. Many of the deposits have been prospected by private parties but abandoned afterwards. The deposits are rather small, scattered, and the grade is generally inferior (30-40% Cr_2O_3). Total chromite reserve of Jharkhand is 0.736 million tones (IMYB, 2010).

I) Jojohatu – Roroburu Belt

Jojohatu (21°31′00" N: 85°38′00" E; 73 F/10 &11) lies about 25 km to the west of Chaibasa, the district headquarters of West Singhbhum. These occurrences are located in Anjadbera and Sahadeva Reserve forest area.

Geological set up

In the chromiferous ultramafic body of Jojohatu, three blocks identified as potential, namely at Kimsiburu, Kittaburu and Roroburu-Chitungburu are disposed from north to south having a cumulative length of 8 km with a surface width of 3 km.

In this belt, the ultramafic rocks hosting chromite are intrusive into the rocks of the Iron Ore Super Group represented by the Chaibasa Group. The Chaibasa Group of rocks comprise phyllites, chlorite schist, feldspathic quartz schist and quartzite. These rocks are folded and show a gentle plunge towards the north. The chromiferous ultramafic rocks have intruded along the axes of these folds. Gabbro, dolerite and quartz veins are the later intrusives into these rocks. Due to widespread steatitisation and serpentinisation of the ultramafic rocks, the nature of the original mineral constituents has been almost completely obliterated. The ultramafic rock contact with the rocks of Chaibasa Group, wherever visible, is marked by gradual steatitisation of the former leading to the development of talc-schist. The major litho units are cross-folded, and a number of faults and shear zones have developed. Lateritisation is common to many of the lithotypes.

The tentative stratigraphic sequence of the rocks found in the area is as follows :

	Laterite
	Quartz veins
	Gabbro
	Granophyre
Ultramafic rocks (Intrusives)	Dunite-peridotite-pyroxenite, largely serpentinised and chromiferous
Iron Ore Supergroup Chaibasa Group -	Shale, phyllite, slate, quartzite, hematite quartzite, dolomitic limestone and altered basic lava.

The ultramafic rocks though present at the ground level, form most of the hills of the area rising up to 650 metres above mean sea level. Due to extensive serpentinisation, the original mineral constituents of the ultrabasic rocks are altered to a large extent. The contact of ultramafic the host Iron Ore Group rocks, is marked by gradual steatitisation leading to development of talc schist.

Mode of occurrence and controls of mineralisation

There are several zones of shearing in the ultramafic rocks, along which chromite lodes are associated, thus showing an overall structural control for the chromite mineralisation in the area. These lodes occur as segregations, veins and lenses and are traceable for some distance as at Roro, Chitung, Karkatakuti and Southern Kimsiburu. Concentration of chromite is also seen as irregular bands, stringers, pods or disseminations and also as sacks. Thin bands and veins thin or pinch out because of faults.

The chromite deposits at Roro, is confined to a shear zone which has been overfolded with a gentle plunge towards the south. On the western slope of Karkatakuti, at Tattibera, chromite mineralisation is confined to a shear zone along the axis of a plunging anticline which has been cross folded, explaining the arcuate disposition of the mineralised zone. Deposits of Chitung hill, Kittaburu, Kimsiburu follow the same pattern. At Jumbliuli, 1 km NE of Jojohatu a vein of chromite is associated with a shear zone trending in N 40° W-S 40° E direction.

Chromite mineralisation is mainly in the form of magmatic segregtion and veins. Some eluvial placers as chromite rich talus are also reported.

Four mineralised bodies were identified by pitting and trenching. The dimension of ore bodies are as follows:

(a) At Jumbliuli, a thin chromite vein occurring in a sheared and altered ultrabasic rock was traced for over 300 m with the thickness varying from 22 cm to 26 cm.

(b) The Tilaisud deposit appears to be the continuation of the Roro chromite lode, which after being affected by a fault at Bechambara takes a turn and runs towards Tilaisud.

(c) In Barbasa – Karkatakuti area, a mineralised shear zone containing pods and lenses of chromite was found on the western slope of the Karkatakuti hill. These lenses can be traced over a stretch of 150 m and have a maximum width of 23 cm.

(d) In the pit at Rutapi, massive chromite in a serpentine matrix occurs in talcose phyllites. This vein-like body has a variable thickness and is irregular in disposition.

Grade

The chemistry of some of the chromite samples collected from all the prospecting pits in the area viz. Jumbliuli (near Jojohatu), Tilaisud, Karkatakuti (near Jojohatu) are quite encouraging, Cr_2O_3 ranges from 46% to as high as 51.6% and FeO from 16.46% to 21.23%. The chromite is of refractory grade. However, the chromite ore from Rutapi and partly from Roro and Tilaisud area are of poor grade.

An estimate of reserve has been made on the basis of the study of the lodes in the working mines and also in the accessible abandoned mines. The average thickness of chromite bodies is taken to be 22 cm and the extension of ore body in depth is taken as 30 m.

Kimsiburu Ore Body

The chromite mineralisation is associated with lenticular concordant bodies of serpentinised ultramafic rocks intrusive into the phyllites of Iron Ore Group and later folded along NW-SE axis.

The ore body is pockety in nature and it pinches off both along the strike and dip. Chromite is coarsely crystalline with interstitial serpentine and often interbanded with serpentine.There are two bodies of chromite in the area with the following dimensional details (Table 4).

Table 4 : Dimension and Reserves of the Two Lodes in Kimsiburu Ore Body

Lode	Dimension		Reserves	Remark
Lode no –1	Strike length Average Thickness Depth extension	300 metres 34.6 cm 75 metres	31,446 tonnes	GSI carried out drilling of 476.88 m in 8 boreholes The analysis of 5 core samples has shown Cr_2O_3 content varies from 41.58 % to 49.90%. The bulk of the ore body is of metallurgical grade and the rest is of refractory grade.
Lode no –2	Strike length Average Thickness Depth extension	80 metres 21 cm 50 metres	3,260 tonnes	
Total reserves			**34,706 tonnes**	

a) Ranjrakocha-Janoa Ore body

Three chromite lodes have been found in Rakingora hill to the north of Ranjrakocha village. These lodes can be traced for a distance varying from 100 m to about 0.5 km. The thickness of chromite veins and lenses vary from 20 cm to 25 cm (Table 5).

About 150 m west of the Rakingora occurrence, another mineralised shear zone contains a chromite vein of about 20 cm thickness. The vein is acutely folded and is traced for about 150 m. Another prospecting pit in the area north of Janoa revealed a 20 cm thick chromite vein. The early formed euhedral chromite occurs within both olivine and enstatite and is economically unimportant.

Table 5 : Grades and Reserves of Lodes in Ranjrakocha-Janoa Chromite Ore Body

Lode	Probable reserves	Remark
Lode no –1 Raja Khadan	9,600 tonnes	Chromite samples from Ranjrakocha, Janoa and Rakingora hill area shows 31.48 to 38.55 Cr_2O_3% , though two samples collected from near Janoa analyse Cr_2O_3 over 48%. In general, the percentage of iron is high. Two of the samples from Ranjrakocha show high MgO. Some of these chromite bodies can be used in the manufacture of refractories if the grade is improved by beneficiation. The chromite from Janoa is of metallurgical grade. The average thickness of chromite veins is taken as 20 cm and the extension of ore body in depth is taken to be 30 m.
Lode no –2 Rakingora Area	3,600 tonnes	
Lode no –3 Janoa area	34,706 tonnes	
Total	**15,600 tonnes**	

b) Bichaburu – Kusmita – Gurgaon Area

The rocks of the area have been affected by three generations of folding. The ultramafics and the associated chromite have been emplaced as small detached bodies along the axis of F_2 folds in NNW-SSE direction. The lenses and veins of chromite are aligned along the crest of these folds. These veins pinch off both along the strike and dip. The mineralistion appears to be along NNW-SSE direction controlled by shears. Chromite seem to be an early magmatic differentiate from same magma.

Dimension of ore bodies, grade and reserve

The grade of chromite is slightly inferior with Cr_2O_3 varying from 39.55% to 43.68%. The ore is amenable to washing with 68% recovery (Table 6).

Table 6 : Dimension of Ore Bodies, Grade and Reserve in Bichaburu – Kusmita – Gurgaon Area

Locality	Dimension of ore body		Reserve	Remark
Gurgaon	Strike length Thickness Depth extension	80 m 2 m 10 m	6,400 tonnes	The depth extension of ore body has been taken after allowing for a reduction of depth of 25 m in Kusmita and 29 m in Gurgaon area, as the chromite ore up to such depth has been removed by mining. The reserve of chromite in Gurgaon, Kusmita and Bichaburu area was estimated taking the dimension of ore bodies and specific gravity of chromite into consideration.
Kushmita	Strike length Thickness Depth extension	200 m 2.5 m 10 m	20,000 tonnes	
Bichaburu	Strike length Thickness Depth extension	30 m 7 m 30 m	12,000 tonnes	
Total reserve			**38,400 tonnes**	

c) Tonto area

The ore bodies in the area are in the form of veins, lenses and sacs with maximum thickness of 20 to 25 cm. The area is highly disturbed and the ore bodies are found to be discontinuous. The lenses and sacs tend to pinch out frequently both along the strike and dip. The grade of chromite ore in Tonto area is poor and can be used only by blending with some better grade ore (Table 7).

Table 7: Dimension of Ore Bodies, Grade and Reserve in Tonto Area

Locality	Dimension		Reserve	Remark
Hendeburu area	Strike length Thickness Assumed workable depth extension	200 m 0.2 m 15 m	2,400 tonnes	Reserve of chromite was estimated based on the dimension of ore body and specific gravity of chromite. The reserves estimated are tentative as the ore body can be worked to greater depth particularly in the Hartahatu area.
Hartahatu area	Strike length Thickness Depth extension	100 m 0.25 m 30 m	3,000 tonnes	
	Total reserves		**5,400 tonnes**	

Table 8 : Reserves /Resources of Chromite in Jharkhand as on 01-04-2010, (As per UNFC classification)

	Category	Code	Quantity (In '000 tonnes)
Reserves	Proved	111	-
	Probable	121	-
		122	-
	Sub Total (A)		**-**
Remaining Resources	Feasibility	211	-
	Pre-feasibility	221	-
		222	-
	Measured	331	15
	Indicated	332	98
	Inferred	333	623
	Reconnaissance	334	-
	Sub Total (B)		**736**
	GRAND TOTAL (A)+(B)		**736**

Source: NMI at a Glance, 2010

3. MAHARASHTRA

Bhandara – Nagpur, Sindhudurg and Chandrapur are three important chromite producing belts of Maharashtra.

I. Bhandara – Nagpur Belt

A. Pauni occurrences

Chromite mineralisation in this belt is associated with highly altered and sheared ultramafic rocks represented by dunite and steatitised serpentinite. These ultramafics occur as interstratified layers within tightly folded Sakoli metasediments represented by phyllites, quartzites and amphibolites which were subsequently intruded by granites. The ultramafics occur as parallel bands and lenses are silicified mostly along the margins. The ultramafics are noticed in similar horizons covering extensive areas intermittently exposed over a length of 40 km between Pauni in the east and Kharsingi in the west and are considered to have been emplaced along axes of folded Sakoli metasediments. The stratigraphic sequence of lithounits are given below:

Recent and sub-Recent		Alluvium and lateritic grit
Vindhyan		Shales, sandstones and conglomerates
Archaean	Post Sakoli	Chromite bearing ultramafic suite of rocks intruded by granites
	Sakoli Group	Interbanded phyllites, quarzites, gneisses and amphibolites

Mode of occurrence and nature and controls of mineralisation

Chromite deposits are located at about 2 km N and NW of Pauni (20°47′00" N: 79°39′00" E; 55 P/9) in Bhandara district. The chromite occurs as concordant pods and thin layers in dunite and steatitised serpentinite emplaced along the synclinal axes of folds in the Sakoli metasediments. Though the ore bodies lie roughly parallel to the foliation of the country rocks with their long axes parallel to the lineation, they do not show conspicuous flow structures. The concordant pods of chromite appear to have been shredded apart due to later folding and subsequent granite intrusions. The contact between the chromite lode and the serpentinites is sharp. Chromite is inferred to be early magmatic and has undergone solid-state emplacement along with the host ultramafic rocks.

Reserve and grade

A reserve of 0.48 million tonnes of ore with 52% Cr_2O_3 (beneficiated) is estimated up to a depth of 15 metres.

II. Chandrapur Belt

Taka (20°40′00" N:79°24′55" E; T.S. no. 55 P/6) in Nagpur district, Ballarpur (20°40′15" N: 79°23′15" E) in Chandrapur district, Dhamangaon-Puyardand (20°38′30" N 76°26′00" E) respectively in Nagpur and Chandrapur districts and Pitechua (20°38′30" N: 76°23′00" E) in Chandrapur district, are some of the important known occurrences of chromite in this belt. The chromiferous ultramafic rocks with associated ore bodies occur as intrusives in to the Archaean Sakoli group metasediments comprising quartzites, brecciated quartzites, banded magnetite quartzite, hornblende schists, anthophyllite schists, amphibolites and granite gneisses.

These Archaean rocks and intrusives are unconformably overlain by Gondwanas, Lameta beds and Deccan trap lava flows.

A generalised stratigraphic sequence in the area is as follows:

Recent to Sub-recent		Soil, alluvium
Upper Cretaceous to Lower Eocene	Deccan Trap	Basalt
	— — Unconformity — —	
Cretaceous	Lameta beds	Clay, chert, siliceous limestone and sandstone
	— — Unconformity — —	
Permo-Carboniferous	Kamthi Formation	Sandstone and shale
		— — Unconformity — —
	Barakars Talchirs Formation	Sand stone and shales, coal seams Sandstone and shales
	— — Unconformity — —	
Archaean	Intrusives	Ultramafic rocks, granite, aplites, pegmatites and quartz veins
	Sakoli Group	Amphibolites and schists, quartzites, brecciated quartzites and banded magnetite quartzites (BMQ)

Mode of occurrence and controls of mineralisation

Chromite mineralisation in the form of disseminated and concordant pods and lensoid bodies are confined to the altered ultramafic rocks , indicating a lithological control of mineralisation. These altered ultramafic bodies occurring in few isolated outcrops are represented by calcareous silicified ferruginous hard rocks (Birbirite). These birbirite lenses have variable dimensions (1 m x 1.2 m to 200 m x 20 m) and trend E-W to ENE-WSW in conformity with the general trend of foliation in gneisses and amphibolites.

Dimension of ore body

Table 9 : Dimension of Ore Bodies in Taka-Ballarpur Area

Name of the identified & explored body	Strike length in metres	Width / Thickness in metres	Depth extension in metres	No. of chromite bands
Body no.1	20-30	0.2-1.6	10-16	2
Body no. 2	100	0.25-3	40	14
Body no. 3	16-44	0.2-3.5	8-16	4
Body no. 4	16-24	0.45-1.20	12-22	3
Body no. 5	68	1.57	25	
Body no. 6	8-40	0.2-4.8	60	3

Reserve and grade

The ore body-wise reserve and grade of chromite in Taka-Ballarpur area as estimated by DGM, Maharashtra are presented in table-10.

Table 10 : Ore Body-wise Reserves and Grades of Chromite in Taka-Ballarpur Area

Body No.	In situ reserves in tonnes	Recoverable reserves in tonnes	Grade	
			Cr_2O_3%	FeO%
1	1700	1190	23.50	11.32
2	31960	22370	35.28	14.12
3	4440	3110	28.62	16.11
4	1390	970	30.75	17.00
5	5200	3640	30.19	11.24
6	10890	7620	28.30	14.54
TOTAL	**55580**	**38900**	-	-

Thus, the total in situ reserves and recoverable reserves in Taka-Ballarpur area are in the order of 55580 tonnes and 38,900 tonnes respectively. The Cr_2O_3 and FeO content ranges from 23.50 to 35.28% and 11.24 to 17.00%, respectively. Dhamangaon – Puyardand area is devoid of any significant mineralisation. Maximum Cr_2O_3 in the ore is 45%. This is a small deposit and the recoverable reserves are of the order of 660 tonnes with Cr_2O_3 content ranging from 22.81 to 35.15%.

III. Sindhudurg belt

A) Kankavli – Janoli – Vagda occurrences

In this belt, chromite deposits of Kankavli area are located in three different places namely, near Kankavli (16°16′00" N – 73°45′00" E), Janoli (16°17′00" N - 73°42′00" E) and Vagda (16°14′00" N - 73°45′00" E) all in Sindhudurg district (T.S. no. 47 H/11). Kankavli chromite deposit lies 2 km NE of Kankavli town, Janoli deposit lying at about 100 m NW of Kankavli deposit and Vagda deposit at about 1.6 km south of Kankavli town.

Exploration work in these areas include a preliminary prospecting by pitting by DGM, Maharashtra during 1958-59. This was followed by large scale geological mapping and bulk sampling of chromite deposits in the area in 1959-60 and geophysical survey in 1960-61 by GSI. On the basis of the recommendations made by GSI, detailed and systematic prospecting works were carried out by DGM, Maharashtra in 1971-72, 1972-73 and 1973-74.

Geological set up

In these areas the ultramafic rocks associated with chromite ore bodies occur as intrusives in to Archaean Dharwar Supergroup rocks comprising biotite schist, banded hematite quartzite, amphibolites. Later intrusives include granite, pegmatite and quartz veins. Proterozoic Kaladgi Sediments cover these Dharwar lithotypes in adjacent areas. Deccan basalts occupy the major portions of the area towards north and east. Large area of the region is covered by laterite and lateritic soil.

The regional trend of foliation of these predominantly Archaean rocks varies from NNW-SSE to NW-SE with steep dips of 60° to 80° mostly towards west.

Mode of occurrence and dimension of ore bodies/bands

In Kankavli – Janoli area, chromite occurs in a few discontinuous outcrops spread over a length of about 525 m. These are hosted by ultramafic rocks comprising mainly dunite which is altered at places to serpentinite, talc and tremolite schists. This ultramafic body with the included chromite occurs as a dyke and trends WNW-ESE, discordant with the regional trend of foliation in the country rocks. In Vagda area, the chromiferous ultramafic body extending NW-SE, intrudes the hornblende schist country rocks.

Dimension of the chromite ore bodies exposed at five locations in Kankavali – Janoli area and at three places in Vagda area as established by GSI (1959-60), are as in Table-11.

Table 11 : Dimension of Ore Bodies in Kankavali – Janoli and Vagda Area

Dimension	Kankavali – Janoli area					Vagada area		
	Band no.1	Band no.1	Band no.1	Band no.1	Band no.1	Band no.1	Band no.1	Band no.1
Length in metre	18	137	6	9	24	12	30.5	45.7
Width in metre	7.6	4.5	2.4	3	2.4	6	6	1.5

However, subsequent work by DGM, Maharashtra (1971-74) indicated three fairly well developed bands in Kankavali area with following established dimensions.

Dimension	Kankavali – Janoli area		
	Southern Band	Middle Band	Northern Band
Length in metre	150	170	40
Width in metre	3 to 10	1 to 5	0.1 to 4
Depth in metre	50	40	20

Nature and control of mineralisation:

The ore microscopic study of chromite and ultramafic rock samples from the area indicate that chromite occurs in small lenticular segregation and dissemination in serpentine ground mass. It forms thin lines branching randomly and there is no preferred orientation of chromite and other rock minerals. Inclusions of serpentine in chromite bands are also observed, suggesting that chromite is later than the ultramafic rocks into which it seems to have intruded. The occurrence of serpentine-talc-tremolite schist in the outer zone of the ultramafic bodies indicates a low grade metamorphism under dynamothermal conditions. Field evidences are suggestive of the emplacement of ultramafic bodies during the late stage of folding of the country rocks. Late magmatic processes involving residual liquid accumulation and injection also appear to have played their roles in shaping these chromite deposits.

Reserve and grade

The total estimated reserves of chromite in Kankavli and Vagda areas as estimated by GSI (1959-60) are of the order of about 71,300 tonnes with an assumed depth persistence of about 30 m. The Cr_2O_3 content varies from 32 to 38% and Iron varies from 12 to 18 %.As per the work of DGM, Maharashtra, the total in situ, recoverable reserves along with the grades of chromite are as follows: (Table 12).

Table 12 : Estimated Chromite Reserve in Kankavali – Janoli area and Vagda Areas

Occurrences	*In situ* Reserves in tonnes	Recoverable Reserves in Tonnes	Cr_2O_3%	FeO%	Al_2O_3%
(A) Kankavli	81132.00	56,792.40	31.04	22.05	12.63
South Band	49626.00	34,738.20	30.88	23.89	11.22
Middle Band	6590.00	4,613.00	31.03	28.50	7.78
North Band	137348.00	96,143.60	30.98	23.02	11.88
	(Total)	(Total) (say 96,000 tonnes)	(Average)	(Average)	(Average)
(B) Vagda	7215.00	5,000 tonnes	34.21	25.27	15.17
(C) Janoli	1110.00	800 tonnes	-	-	-

Thus, total recoverable reserves of chromite in these areas are of the order of 101800 tonnes with the grade ranging from 30 to 34% of Cr_2O_3 and 22 to 28.5% of FeO.

B) Gosaviwadi (16°13′00" N: 73°42′15" E; T.S. no. 47H/12) occurrence

This one also in Sindhudurg district, is another known occurrence of chromite in this belt. Here chromite occurs within altered ultramafic rocks ie., serpentinites and talc tremolite schist, associated with Precambrian hornblende schist. The strike extension of the ore body is 30 m with average width of 5m.

A reserve of 11,000 tonnes of ore with 39.07% Cr_2O_3 has been estimated (1976-77) and subsequently revised as 0.102 million tonnes by the DGM, Maharashtra (1991). (Table 13)

Table 13 : Reserves/ Resources of Chromite in Maharashtra as on 01-04-2010, (as per UNFC classification)

	Category	Code	Quantity (In '000 tonnes)
Reserves	Proved	111	53
	Probable	121	23
		122	-
	Sub Total (A)		**76**
Remaining Resources	Feasibility	211	05
	Pre-feasibility	221	-
		222	-
	Measured	331	43
	Indicated	332	67
	Inferred	333	441
	Reconnaissance	334	-
	Sub Total (B)		**556**
	GRAND TOTAL (A)+(B)		**632**

Source: NMI at a glance; 2010

4. ANDHRA PRADESH

In this State, chromite deposits occur as lenses and pods of small dimension in two distinct geological environments viz. (1) associated with the ultramafics of the metamorphosed, layered Chimalpad gabbro-anorthosite complex, intrusive into the Archaean high grade schists and gneisses in Khammam district, and (2) as lenses and disseminations in orthpyroxenite emplaced within charnockite and quartzofeldspathic gneisses of the Proterozoic Eastern Ghats Supergroup in Kondapalli Hills of Krishna district. The chromite of Khammam district is of low grade with average Cr_2O_3 content less than 40%, the other oxides being within the permissible limits of refractory grades.

The Kondapalli chromite ore has high Cr_2O_3 content (upto 52%) as also high Fe_2O_3 (about 18-35%). A description of the chromiferous ultramafics, the geological setting, mode of occurrence, nature and control of chromite mineralization in Khammam and Krishna districts is presented in the succeeding paragraphs.

A. Jannaram block

The Jannaram (17° 18′ N : 80° 24′ E; 65 C/7) block in Khammam district consists of granitoids and gneisses of the Peninsular Gneissic Complex into which mafic-ultramafic-anorthositic intrusive bodies were emplaced. Anorthosite, gabbro/leucogabbro, pyroxenite, websterite and dunite constitute the lithounits of the ultramafic complex. The area is predominantly soil-covered, with an in situ lens of chromite occurring within the ultramafic units. All the litho-assemblages of the intrusive complex exhibit conspicuous layering, but chromite occurs only as podiform lenses in places where the ultramafic units viz. dunite, pyroxenite, websterite form thickened sheaths within the layered sequence.

Dimensions of the ore body, ore characteristics and control of mineralisation

Chromite mineralisation in the Jannaram Block occurs in the form of pods/lenses within the thicker portions of the layered ultramafic-mafic assemblage, where the ultramafic unit predominate over the other cognate lithologies. The chromite lenses are parallel to the layering and vary in size from a few centimeters across up to 12.5 m x 2 m.

Though the isomodal/cryptic/phase layering of the intrusion is observed only in drill hole intersections, chromite does not exhibit stratigraphic parallelism with the other units. Hence, the occurrence of lenses of very little dimension within the layered sequence could not be worked out.

A single in situ lens (12.5 m x 2 m) of chromite is exposed which is inferred to extend along dip, at least up to 6 m. Chromite occurs as crystalline aggregates set in a matrix of olivine, talc, tremolite and pyroxenes. The ore is lumpy, hard, granular and black to steel grey.

Reserve and grade

The in situ lens has a reserve of 600 tonnes of chromite. Besides this, float chromite is present through out the block, which may yield about 500 tonnes (total 1100 tonnes). The average grade of chromite is 39.26% Cr_2O_3, 13.53% SiO_2, 17.87% FeO, 10% Al_2O_3.

B. Konayyapalem block

The Konayyapalem block (17°10′ N : 80°25′ E; 65 C/7) is located at about 6 km NE of Jannaram block. In a largely soil covered area a few outcrops of migmatitic gneiss, anorthosite, two lenses of chromite and ubiquitous float of chromite are observed. The two lenses of chromite 400 m apart, are enclosed within meta-ultramafic represented by tremolite schist.

In between these two chromite lenses, the continuity of the layered mafic-ultramafic assemblage was established by regular pitting and trenching. The trend of the igneous layering is NW-SE with moderate to steep dips due SW.

Dimensions of the ore body, ore characteristics and control of mineralisation

Chromite occurs as pods and lenses enclosed within the talc tremolite schist, pyroxenite, dunite and websterite and have very limited extension along strike and dip extension. The lenses are parallel to the layering. The mineralisation is restricted to thickened ultramafic layers. An in situ lens of chromite measuring 9 m x 2 m is present having an assumed dip length of 4.5 m.

Thick piles of layered mafic ultramafic-anorthosite rocks were intersected in the boreholes where occasional lens of chromite were struck which were considered as 'blind' lenses having limited strike length and dip extension.

The chromite is crystalline, granular, black to steel grey. The gangue minerals include talc, tremolite, serpentine and olivine/pyroxene.

Reserves and grade

The in situ lens is expected to yield a reserve of 324 tonnes with Cr_2O_3 : 39.55%, SiO_2, : 29%, FeO : 18.69%, Al_2O_3 : 11.86%.

C. Lingannapeta block

The Lingannapeta block (17°15′ N: 80°25′ E; 65 C/7) situated at about 4 km north of Konayyapalem block has an abandoned working which exposes talc-remolite schist, serpentinised pyroxenite/ dunite and a lensoid occurrence of chromite.

The working is strewn with float of chromite. Banding/layering strike NW-SE with steep (70°-80°) northeasterly dips.

Control of mineralisation

The chromite mineralisation is in the form of pods and lenses, enclosed within talc-tremolite schist, serpentinised dunite/pyroxenite. Borehole intersections in this block have established a huge thickness of ultramafic-mafic-anorthosite complex, showing distinct layering. Three seams of chromite were struck, enclosed within talc-tremolite schist.

Dimension, reserve and grade

Three lenses of chromite were intersected by drilling in this block between (1) 27.35 m and 42.00 m (2) 68.80 m and 71.60 m (3) 73.65 m and 76.85 m. The dimensions inferred are shown in table-18 for these lenses . A total reserve of 0.161 million tonnes has been estimated (Table 14).

Table-14: Dimension and grade of chromite bodies in Lingannapeta Block

Sl. No.	Lens-1	Lens-2	Lens-3
Length in m	80	10	10
Width in m	13	2.5	2.5
Depth extension in m	40	5	5
Reserve (0.161 MT)	0.16 million tonnes	500 tonnes	500 tonnes
Average grade (in %)			
Cr_2O_3	36.84	27.22	36.04
SiO_2	18.72	27.34	22.10
FeO	11.56	11.41	9.64
Al_2O_3	10.33	9.36	12.02
CaO	4.41	1.36	2.27
MgO	16.67	19.60	15.81

D. Sriramgiri block

The Sriramagiri block (17°20′ N : 80°24′ E; 65 C/7) is also similar in geological set up as that of the Lingannapeta block. Here, an open cast mine of Ferro Alloys Corporation Ltd., exposes the intrusive ultramafic litho-units comprising serpentinised pyroxenite, dunite, talc-tremolite schist and chromite having been emplaced into migmatites and gneisses of the Peninsular Gneissic Complex.

The chromite mineralisation occurs as parallel/concordant lenses in relation to the enclosing litho-units of ultramafic complex. The lenses have limited strike and depth extension.

Dimensions of the ore body

The open cast mine, along with the chromite lenses, extends over a strike length of 150 m. The thickness of the individual lense varies from 1 m to 3 m, but the entire zone in which chromite lenses are parallely disposed, is about 10 m. The dip length is assumed to be around 75 m.

Reserves

Total reserves (with tonnage factor of 4)	— 0.45 million tonnes
Chromite already mined out	— 0.09 million tonnes
Chromite available (probable category)	— 0.36 million tonnes

Average grade

Cr_2O_3 – 38.12%, FeO- 6.36%, CaO - 2.52%, SiO_2 – 26.65%, Al_2O_3 – 11.16% and MgO- 12.11%.

E. Kondapalli block

Acid and intermediate charnockites are most common rock types in the Kondapalli (16°37′ N: 80°32′ E; 65 D/10) Hills located in the western fringe of the Eastern Ghats granulite belt in

Krishna District. Charnockites are associated with pyroxene granulites, magnetite-hypersthene-quartz granulite, garnetiferous quartzo-feldspathic gneisses and pink garnetiferous granite gneisses. Pegmatites and quartz veins are intrusive into all these rock types.

A magmatic layered complex comprising a layered gabbro-anorthosites-websterite (pyroxenites) suite and a dunite-orthopyroxenite-chromitite suite were emplaced into the charnockite, quartzo-feldspathic gneisses and pyroxene granulites. The regional trend of the foliation is NNE-SSW to NW-SE with steep dips varying from 55^o to 80^o towards easterly direction.

Controls of mineralisation

Chromite in nine localities occur as irregular lenses, bands, pockets and disseminations in steeply dipping and pitching and lenticular bodies of orthopyroxenite. At places, thin chromite veinlets are seen on the walls of the chromite quarry occurring within intermediate charnockite.

Grade of the ore

The grade of the ore is Cr_2O_3 from 22.81 to 51.94%, SiO_2-0.05 to 8.30%, Fe_2O_3-17.94 to 38.94%, Al_2O_3-4.35 to 32.27%, CaO-1.65 to 2.10% and MgO from 6.80 to 20.66%.

This chromite is generally of poor quality, and even the ores containing high Cr_2O_3 content generally show high iron content, thus making them unsuitable for metallurgical purposes. These ores are, however, fit for use in the chemical industry.

Table 15 : Reserves /Resources of Chromite in Andhra Pradesh on 1-04-2010 (as per UNFC classification)

	Category	**Code**	**Quantity** (In '000 tonnes)
Reserves	Proved	111	-
	Probable	121	-
		122	-
	Sub Total (A)		**-**
Remaining Resources	Feasibility	211	-
	Pre-feasibility	221	-
		222	-
	Measured	331	-
	Indicated	332	15
	Inferred	333	172
	Reconnaissance	334	-
	Sub Total (B)		**187**
	GRAND TOTAL (A)+(B)		**187**

Source: NMI at a glance, 2010

5. KARNATAKA

Chromite occurs in the state in altered ultramafic rocks (serpentinised peridotites) forming regular veins, lenses, and segregated pockets of various dimensions. Workable deposits of various grades and of varying extent are found in the districts of Mysore, Hassan, Chikmagalur and Shimoga. Of these, the deposits of Mysore and Hassan districts are the most important from the commercial point of view.

There are several ultramafic belts in the state, of which Nuggihalli schist belt, Hassan district and Sindhuvalli – Talur ultramafic belt of Mysore district are the most important from the point of chromite mineralization . The major occurrences are at Byrapur, Bhaktarhalli, Jambur, Chikkonahalli and Tagadur.

A) Nuggihalli schist belt

This belt (13°06′00" – 13°13′00" N : 76°21′30" – 76°25′00" E; 57 C/8) in Hassan district extends for a strike length of 50 km in a NNW-SSE trend from near Arsikere in the north to Kempinkote in the south. This schist belt forming a prominent linear belt of medium to high grade schists belongs to the Sargur complex.

The belt consists of amphibolites and quartzites of Belgumba formation and meta-ultramafites (serpentinites), meta-peridotites, meta-pyroxenites, tremolite-actinolite-chlorite schists and dunite with bands of chromite and titano-magnetites, anorthosites and gabbro belonging to Bairapura ultramafites. The schist belt is enclosed by Peninsular Gneiss with basic dykes cutting across all the formations. The belt forms a narrow tightly folded synclinal structure. The regional strike of the schistose rocks is N20°W – S20°E to N-S with a dip of 50° to 60° towards east. The axial plane schistosity (S_1) trends N30°W – S30°E.

Mode of occurrence, grade

Mineralisation is lithologically controlled with chromite bodies being confined to serpentinites. Chromite occurs as massive lenses of varying dimensions, linear disconnected bands and as veins within the serpentinites. The dimension of the ore bodies and blockwise grade and reserve of chromite as established by GSI are as given in Table-19. Reserve figures for Byrapur block are based on the work done by DGM, Karnataka.

Table 16 : Dimension, Grade in Bhaktarahalli, Chikkonahalli, Tagadur, Jambur and Byrapur Blocks

Name of the Block	Dimension in m	Grade (in %)
Bhaktarahalli	23 m x 1.2 m	Cr_2O_3 36.40 , Cr/Fe : 1.5
Chikkonahalli	16.5-432 m x 0.15-2.72 m	Cr_2O_3 22.78-38.01, Cr/Fe : 0.74 – 1.5
Tagadur	27.2 – 179 m x 0.53 – 2.58 m	Cr_2O_3 27.33-36.95, Cr/Fe : 1.04-1.4
Jambur	12.0 – 185 m x 0.3 – 1.21 m	Cr_2O_3 33.19 – 49.09, Cr/Fe : 1.2 – 1.98
Byrapur		

B) Sindhuvalli – Talur belt

The Sindhuvalli (12°11′30" N : 76°38′00" E) -Talur (12°11′30" N:76°36′30" E) - Dodkatur (12°10′40" N : 76°36′30" E) ultramafic belt in Mysore district (all falling in T.S. nos. 57 D/ 11&12) extends from river Kabini in the south to the north of Mysore city. This N-S belt of ultramafic rocks stands out as detached linear mounds or low ridges amidst surrounding low lying gneissic terrain comprising dominantly hypersthene bearing gneisses, together with minor outcrops of hornblende pyroxene and hypersthene granulites. The general trend of foliation varies from N10°W – S10°E to N10°E-S10°W with very steep to vertical dips on either side.

The ultramafic rocks intruding the gneisses consist mainly of serpentinites and steatite schists, derived from the alteration of dunite, pyroxenite and hornblendite. There is a sharp contact between the serpentinite and the gneisses.

Ore body dimension and control of mineralisation

The mineralisation is lithologically controlled. The chromite bodies are found as lenses and small bands confined to serpentinites. The chromite grains are mostly anhedral, subrounded and often compact.

The exploration by drilling in Sindhuvalli, Talur and Dodkatur areas and examination of accessible parts of the old workings in Talur area have indicated that chromite occurs as tabular lenses and pencil shaped bodies having limited strike extensions.

In Sindhuvalli area, there is no possibility of striking economically workable chromite bodies up to a depth of 200 m below the surface/old workings. In Dodkatur area, a chromite body of only 0.55 m thickness was intersected in one borehole. In Talur area, no chromite ore body is more than 40 m in strike length. Thus, on the basis of data obtained by drilling, it is concluded that these areas hold no prospect for any economically significant chromite bodies.

a) Sindhuvalli – Dodkatur block

Data from 3 boreholes drilled below the old mine in Sindhuvalli area indicate that, the ore bodies are thin and the thickness of chromite bands vary from 0.18 m to 0.75 m.

In Dodkatur area, 5 boreholes drilled to find out the depth extension of the ore bodies below the 130 m in long old working, have encountered the chromite body only in one borehole for a mere 0.48 m thickness.

b) Talur block

The chromite bands encountered in the boreholes drilled below the old workings indicate their small and insignificant nature occurring as pods with strike length of 40 m and the thickness of 0.10 m to 0.44 m only.The grade of chromite bodies in different blocks are shown in table-17.

Table 17 : Grade of Chromite Bodies in Sindhuvalli, Dodkatur and Talur Blocks

	Sindhuvalli block	Dodkatur block	Talur block
Cr_2O_3%	37.5 – 46.95	38.64	19.92 – 40.05
Fe/Cr	-	1 : 1.7	1 : 1.6

c) Other deposits:

(i) Kalangavi : In Chitradurga district, low grade disseminated ore (below 31% Cr_2O_3) occurs within the ultramafics.

(ii)Bande-Banur-Gajekatte: In Kadur district, low grade chromite ore (30% Cr_2O_3) occurring as local disseminations was noticed.

(iii) Amblikatte – Jhandimatti – Antargange: In Shimoga district has sporadic ore concentrations in the expansive ultramafics, supporting some historical mining operations.

Table 18 : Reserves /Resources of Chromite in Karnataka as on 01-04-2010, (As per UNFC classification.)

	Category	Code	Quantity(In '000 tonnes)
Reserves	Proved	111	333
	Probable	121	395
		122	17
	Sub Total (A)		**745**
Remaining Resources	Feasibility	211	250
	Pre-feasibility	221	218
		222	96
	Measured	331	-
	Indicated	332	20
	Inferred	333	303
	Reconnaissance	334	-
	Sub Total (B)		**887**
	GRAND TOTAL (A)+(B)		**1632**

National Mineral Inventory, 2010

6. GOA

Large ultramafic pluton in Dudhsagar belt near Ponda has been recently confirmed to be chromiferous, though ore deposits are yet to be discovered in this Archaean greenstone association.

7. TAMIL NADU

Chromite occurs in Salem and Coimbatore districts in Tamil Nadu associated with high grade metamorphic rocks hosted in ultramafic complexes.

I) Karunglapatti and Sitampundi belt, Salem District

A total of 40 bodies in the form of lenses, bands and stringers occur between Karunglapatti and Sittampundi of which 18 are prominent. These isolated bodies are exposed over a length of about 12.6km. Length of the individual bands varies from 3 m to 52 m.

Hornblende-biotite gneiss is the dominant rock type in Karunglapatti (11º15':78º00'; 58 I/13) area. Anorthosite gneiss with two bands of chromitite occurs as conformable bands within the migmatite gneiss. One band associated with anorthosite gneiss has been traced for about 1.68 km in southwesterly direction. The other band is boudinaged, each boudin being 50-60m in length.

In Sittampundi (11 º14'10":77 º54'30"; 58E/16) area in the west one chromitite band with width varying from 15 cm to 1 m occurs discontinuously over a strike length of 1820 m. Another small band with width varying from 10 cm to 20 cm has been traced for about 100 m.

Chromite is fine to medium grained and at places banded. Modal proportion of chromite, hornblende and/or diopside is variable. The proportion of chromite varies from 35% to 50%.

Resources

Possible resources of 43,500 tonnes of chromitite has been estimated for the Karunglapatti area taking into consideration the occurrences beneath the Karunglapatti village also. This will be reduced to 25,425 tonnes of ore if the occurrence below the village is not taken into account.

The grade of chromite is:

Cr_2O_3 – 9.75%-27.16%; Fe_2O_3 – 17.58%-27.16%; SiO_2 – 7.60%-24%; Al_2O_3 – 23.17%-36.6%.

II) Solavanur, Mallanayakkanpalaiyam and Karapaddi areas

Solavanur (11° 24′30" : 77° 09′00"; 58 E/3), Mallanayakkanpalaiyam (11° 25′ 55" : 78°13′ 40" ; 58 E/3) and Karapaddi (11° 26′ 00" : 19° 45′ 00"; 58 E/7) areas in Coimbatore district expose migmatitic gneisses with patches of relict charnockite and conformable lenses of mafic-ultramafic suite of rocks comprising gabbro, garnetiferous gabbro, anorthosite, hornblende anorthosite, amphibolite, pyroxenite and chromiferous pyroxenite.

Chromite occurs as bands and segregations, confined to bronzitite or chromite-amphibole associated with anorthosite. Chromite ore is either compact and massive, or granular, having intergranular pyroxene and amphibole.

Chromite occurrence in these three areas/blocks is briefly as follows:

i) Karapaddi block: Float ores are spread over an area of ~0.2 sq km (1 km x 0.2 km). A 1 m thick band of chromite in pyroxenite was exposed in trench section.

ii) Mallanayakkanpalaiyam block: Disseminations of chromite occur in pyroxenite interbanded with anorthosite in an area of 1 sq km. There are four 2 to 10 cm wide parallel bands of chromite, within hornblende-rich anorthosite.

iii) Solavanur block : 5 cm thick bands of chromite within anorthosite and float ores occur in area (400 m x 10 m).

Resources

Resources of the order of 6000 tonnes up to 2 m depth and 30,000 tonnes up to 10 m depth have been estimated for these 3 blocks.

Grade of chromite in these three blocks is variable and is in the range of:

Cr_2O_3 : 21.79% to 27.87 %	Fe_2O_3 : 23.20% to 28%
SiO_2 : 7.82% 12.02%	Al_2O_3 : 19.19% to 22.81%

Table 19 : Reserves /Resources of Chromite in Tamilnadu on 01-04-2010, (As per UNFC classification)

	Category	**Code**	**Quantity** (In '000 tonnes)
Reserves	Proved	111	-
	Probable	121	-
		122	-
	Sub Total (A)		**-**
Remaining Resources	Feasibility	211	-
	Pre-feasibility	221	-
		222	-
	Measured	331	07
	Indicated	332	-
	Inferred	333	276
	Reconnaissance	334	-
	Sub Total (B)		**283**
	GRAND TOTAL(A)+(B)		**283**

Source: NMI, 2010

8. JAMMU AND KASHMIR

I) Brown Hill at Dras, Kargil District

Chromite in ultramafic bodies is emplaced within Sangeluma Group of rocks in Indus Tectonic zone, Ladakh. The Chromite of Brown Hill at Dras is present in the form of pods, veins, stringers and disseminations in the dunite body intruding Dras Volcanics. The chromite rich portion of the dunite has analysed 43 to 47% Cr_2O_3. The chromite bearing body extends NW-SE from the locality four kilometre north of Dras to Marpo La.

II) Kyun Tso-Shurok Sumdo, Leh District

Kyun Tso-Shurok Sumdo mafic-ultramafic body outcropping on either side of Tungakharu nala along Nidar valley, Leh district, Ladakh carry chromite mineralization in the form of bands, lenses, streaks and disseminations confined essentially to dunite, harzburgite and orthopyroxenite host rocks. The chromite bands, which vary from 1 m to 1.5 m in thickness and 8.0 m to 17.5 m in width have visual chromite concentration ranging from 50% to 85%. The ultramafic body carrying chromite mineralization out crops within the tectonised shergol Formation of Sangeluma Group and is bound on either side by regional faults. The total reserves of visible surficial chromite in 11 sq km area investigated are estimated to be about 950 tonnes.

In addition to the above main occurrences, chromite mineralization is also reported from Sanko area. The inferred reserves of chromite in Leh district, Ladakh have been estimated at 14,000 tonnes.

9. CHROMITE DEPOSITS OF ARAKAN SUTURE LINE

Cretaceous – Eocene ophiolitic ultramafics in a broadly N-S trend along the Indo-Myanmar frontier coinciding with Arakan Yoma suture line down to the Andaman and Nicobar Islands, are studied for chromites and their incidences to form ore deposits in areas such as Nagalad, Manipur and the Andamans.

I) Andaman Islands

Chromite occurs as small pods and layers of high grade ore and is confined to the altered dunite of peridotite assemblage. The bodies are located in places around Chiriatapu- Bedanabad in South Andaman, in Rutland Island, 'Jones' point hillock in Middle Andaman and Kalighat in North Andaman.

a. **Chiriatapu- Bedanabad in South Andaman:** About 1 km SSE of Chiriatapu guest house and about 1 km south of Bedonabad in South Andaman island ranging in dimension from 5cm × 2m to 10m × 4m. In all these cases chromite is massive and is enveloped by dunite. In Bedonabad are, barring the massive variety, rhythmic layers of olivine- chromite and pure chromite are encountered. Some are also as schlieren in dunite.

   Chromite concentration in dunite seldom forms single grain aggregate layers of chromite alternate with those of olivine, which are wavy in nature. The extension of these chromite bodies was probed by pitting and in most cases they were seen to be steeply dipping pinching bodies.

b. Rutland Island: At Mitha Nala, about 1km upstream from its confluence and near the confluence of Chain Nala of Rutland islands small schlierens of chromite occurs within dunite. The coastal tracts extending for an area of about 1km× 25m in between the confluence of these two streams is also strewn with chromite rich sand. Besides, at the south eastern tip of Rutland Island, off Portman bay, a comparatively large body (about 20m×10m in dimension) of massive chromite is encountered in the coastal tracts. In the eastern coast of Rutland island chromite occur as placers in a narrow stretch, and as thin stringers within serpentinised dunite and hartzburgite.

c. Jones' point hillock in Middle Andaman: A body of about 3m× 2m in dimension of massive chromite is found at the northern tip of 'Jones' point hillock of Middle Andaman. Typical nodular chromite occurs in this area. Small bouldery ore is also located in the Baker hill of Middle Andaman. In Panchabati area of Middle Andaman chromite pods are concentrated in a zone of aerial dimension 11×3.5 sq.m. hosted in a serpentinised harzburgite body. Chromite from Panchabati area shows Cr_2O_3 range from 49.50% to 50.50%.

d. Kalighat in North Andaman: A small pocket of massive chromite, about 4 m× 2 m in dimension, has been located in highly sheared serpentinite about 2km SE of Kalighat guest house. The ore is intensively crushed and fragmented showing polished slicken side due to relative movement of contiguous blocks.

The chromite bodies are too small and scattered and wide apart. They are not economically significant despite their high chromium and aluminum contents. The Andaman chromite is of typical Alpine – type following the classical; criteria of Thayer (1960 and 1964). The chromite bodies are hosted in the peridotite assemblage belonging to the hartzburgite sub type in Alpine type ultramafic rocks of Jakson – Thayer's classification. The characteristic features of Andaman chromites are listed below:

1. Chromite occurs in intimate association with dunite hosted by harzburgite and lherzolite.
2. Chromite occurs as layers, pods and schlieren bands displaying net, chain, occluded silicates, and occluded clot and mosaic related to stratiform deposits and rare nodular and orbicular textures, which are unique to the deposits related to ophiolite environment.
3. Chrome spinels in hartzburgite and lherzolite occur as intersticial phase generally found enclosing olivine and also rarely clinopyroxene is noticed.
4. Chromite rarely shows evidence of solid state deformation. The host rocks including dunite, harzburgite and lherzolite do not show evidence of recrystalization in the solid state as depicted by the mantle derived peridotites.
5. Chromite exhibits minor alteration to Ferritchromite and contains inclusions of olivine which is similar to the olivine in the ground mass.
6. Chromite is high aluminum and high chromium variety. Chromite chemistry shows a reciprocal variation in Cr and Al with low Fe^{+3}. Compositionally they are magnesio-chromite and fall in the compositional field of podiform chromite of Thayer (1964).
7. Mosaic textured chromite show lower unit cell dimension and incidentally enriched in aluminum compared to the nodular and clot textured type.

8. Very low TiO_2 content in chromite corresponds to the ophiolitic environment.

No detailed exploration was carried out as the deposits are sub-economic. Presently, there is no plan for further exploration.

10. MANIPUR

Chromite occurs in Manipur as small pockets, lenses and pods in Ukhrul and Chandel districts and is similar to those of Alpine type in its mode of occurrence, physical and chemical characters. They are associated with the meta-ultramafic rocks of the ophiolite suite. The host rocks are harzburgite, dunite, serpentinite and combination of these. Physically the chromites are of massive, granular, interbanded and podiform types. Besides, chromite is disseminated in dunite and peridotite in which it occurs as highly fractured, granulated and very rarely as idomorphic grains in serpentinised and bastitised pyroxenite.

Important occurrences have been observed at Sirohi-Gamnom areas of Ukhrul district, and Moreh area of Chandel district. Although no large deposit has been found so far, small occurrences of up to a few metres in extent have been prospected and worked by surface pitting. The chromite are of high grade with Cr_2O_3 content varying from 44 to 59%. Chemically, these are comparable with Alpine type chromite in high Cr_2O_3 content (44-59%) and low TiO_2 (trace), Cr/Cr+Al (0.59 to 0.88) and $Mg/Mg+Fe_2$ (0.46 to 0.74) content.

I) Sirohi area

This area is located at about 19 km to the east of Ukhrul. The varieties of chromite include massive, disseminated, and nodular chromite, which occur in small pockets. Amongst these, a small but sizeable chromite lense occurs to the north of the Sirohi peak at an altitude of 1120 m and is known as Northern Lense. It has a strike length of 11 metres and a width of 8 m and continues up to a depth of 2.5 m. Chromite has a Cr_2O_3 content of 47.68 to 56.59% and Fe_2O_3 of 13.91 to 15.21%.

The ore is massive, lumpy, compact and is composed of fine grains of lustrous chromite with very little gangue mineral (serpentine). At places they show slickensided surface. A transition zone between massive chromitite and host serpentinised perioditite is observed locally, represented by a weathered friable zone having brownish chromite grains and serpentine materials.

The disseminated chromite is a fine-grained compact variety, composed of chromite grains and minor serpentinite matrix occurring as small clots, patches and stringers. However, the serpentine content is highly variable. The nodular variety of chromite consists of rounded to ellipsoidal chromite grains, enclosed in a greenish matrix of serpentinised peridotite. The size of the chromite grains varies from 1 cm to 3 cm. At some places, the grains are at contact with each other without the presence of serpentine matrix. Sometimes, the nodules show a weak preferred alignment.

The chromite bodies of Sirohi area was being mined by M/s. Odisha Industries Ltd., a private enterprise, by selective quarrying. Most of the pits are of small dimension, ranging from 5 m x 5 m to 12 m x 12 m. Only three pits located north of Ranshokhong area are relatively of large dimension of about 20 m x 15 m x 6 m.

II) Gamnom area

This area is about 10 km southeast of Ukhrul and connected by an unmetalled road, which is jeepable only in dry season. Nine small chromite pockets are located in the near Gamnom over an area of 0.4 sq km, near 40 km-post on the Gamnom - Chassad road. These pockets are generally lensoid in nature and arranged in an *en-echelon* fashion. The intervening areas are covered with boulders of ultramafites and soil. The length of the lenses varies from 5m to 20 m and width from 1m to 5 m. Due to soil-covered nature of the area, it is difficult to ascertain the continuity of the lenses. The host rocks are serpentinised dunite or harzburgite. Most of the occurrences are composed of massive chromite, although disseminated and nodular types are also present. Sometimes, the latter two show transitional relationship with the former. The chromitite shows slickensided surfaces and the disseminated and nodular types have minor effects of recrystallisation.

In Harbui Khajui area, one small pocket measuring 20 m x 10 m is located on 2230 m peak. Its shape is lensoid and the host rock is serpentinite. The chromite is coarse grained and disseminated type.

The chemical composition of three types of chromite from a few samples in Gamnom block is given in Table 20.

Table 20 : Chemical Composition of Three Types of Chromite in Gamnom Block

Component (%)	Chromitite	Nodular chromite	Disseminated chromite
Cr_2O_3	44.07 to 49.05	45.63 to 46.39	35.75
Al_2O_3	18.40 to 20.50	16.30 to 20.00	10.20
Fe_2O_3	15.60 to 17.60	16.00 to 16.40	-
MgO	15.16 to 16.76	15.96	-
SiO_2	2.60 to 33.90	3.80 to 4.30	9.02
TiO_2	Traces	Traces	Traces

III) Moreh area

Float boulders of chromite of different types occur near Minou village, over an area of 0.5 sq km and some small pockets of chromite occur 5 km north of Moreh near Khundang Thabi, which were being worked by M/s. Odisha Industries Ltd.

Composition of different types of chromite from Moreh area are given in Table –21.

Table 21 : Chemical Composition of Chromites from Moreh Area and the Host Serpentinite

Component (%)	Chromitite	Nodular chromite	Disseminated chromite	Host serpentinised peridotite
Cr_2O_3	42.32 to 51.24	40.49 to 47.93	47.93	Traces
Al_2O_3	1.36 to 1.47	1.34 to 1.47	1.32	0.33
Fe_2O_3	13.12 to 14.04	13.06 to 14.37	13.26	6.35
MgO	3.64 to 10.24	5.72 to 8.54	5.90	40.14
SiO_2	13.12 to 15.54	14.05 to 16.92	15.20	33.16
TiO_2	Traces		Traces	Traces

Quality and utilisation prospect

The analyses of chromite from three blocks described in the preceeding paragraphs indicate that these are comparable with the podiform chromites (Cr_2O_3 - 45%) of Alpine belt. Low SiO_2 and Fe_2O_3 in majority of the samples suggest that the chromites would be suitable for refractory industries. From the metallurgical point of view, they are of grade I and grade II refractory types. Integrated geochemical and geophysical surveys may complement the geological data to locate more chromite bodies in this belt.

Table 22 : Reserves /Resources of Chromite in Manipur on 01-04-2010. (as per UNFC classification)

	Category	**Code**	**Quantity** (In '000 tonnes)
Reserves	Proved	111	03
	Probable	121	21
		122	52
	Sub Total (A)		**76**
Remaining Resources	Feasibility	211	-
	Pre-feasibility	221	-
		222	-
	Measured	331	-
	Indicated	332	529
	Inferred	333	6052
	Reconnaissance	334	-
	Sub Total (B)		**6581**
	GRAND TOTAL(A)+(B)		**6657**

Source: NMI, 2010

11. NAGALAND

Minor chromite occurrences are located in the ophiolite belt in Reguri and Washello areas of Phek district and Pang, Pokphu and Wui areas of Tuensang district. PGE concentration in ophiolite suite of Naga Hills is likely to be of low in view of the absence of massive chromite or chromitite.

Table 23 : Reserves /Resources of Chromite in Nagaland as on 01-04-2010(As per UNFC classification)

	Category	**Code**	**Quantity** (In '000 tonnes)
Reserves	Proved	111	-
	Probable	121	-
		122	-
	Sub Total (A)		**-**
Remaining Resources	Feasibility	211	-
	Pre-feasibility	221	-
		222	-
	Measured	331	-
	Indicated	332	-
	Inferred	333	3200
	Reconnaissance	334	-
	Sub Total (B)		**3200**
	GRAND TOTAL (A)+(B)		**3200**

Source: NMI, 2010

3.3 REFERENCES

1. **Indian Minerals Yearbook- 2010; Indian Bureau of Mines,** Government of India, Ministry of Mines**; December, 2011**

2. **Draft document on formulation of strategy for exploration, exploitation and development for chromite in india, by 'The sub-group on chromite'** J.K.Nanda & B.K. Jena, Directors GSI; M. Sengupta, RMG, IBM, Nagpur & Naresh Nautiyal, Dy.GM(Exploration), MECL, March 2007.

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Chapter 4

WORLD DEPOSITS

4.0 INTRODUCTION

According to Thayer (1964), the Chromite deposits are classified into two broad categories, viz. Stratiform & Podiform types. Stratiform deposits are iron rich ores utilized in metallurgy & chemical industries, while podiform deposits are high alumina ores utilized in refractory industry. World wide and country wide location of important stratiform and podiform deposits are given in Tables 1 & 2.

Table 1 : Some Important Stratiform Chromite Deposits of the World

Deposit/ Country	Type of the deposit	Cr:Fe	Age (Ma)	Tectonic setting
Bushveld Complex, S. Africa	Stratiform lobate	2.6	2050	Rifted shield
The Great Dyke, Zimbabwe	Stratiform dyke	3.2	2460	Rifted shield
Muskox, Canada	Stratiform dyke	1.2	1160	Rifted shield
Skaergaard, Greenland	Stratiform sheet	0.7	52	Rifted continental margin
Stillwater complex, USA	Stratiform sheet	2.8	2740	Faulted & tilted shield
Kemi, Finland	Stratiform sheet	2.6	2430	Faulted & tilted shield
Mashaba, Zimbabwe	Disrupted stratiform	3.9	2900	Folded & faulted sill Protoshield
Shurugwi, Zimbabwe	Disrupted stratiform	4.4	3500	Thrust-folded sill, Greenstone belt.
Campo Formosa,Brazil	Stratiform Sill	2.2	2000	Faulted shield margin.
Bard River sill, Canada	Disrupted stratiform	1.5	2700	Folded- faulted sill, Greenstone belt.
Akila, Greenland	Disrupted stratiform	1.8	3600	Folded &faulted high grade gneissic terrain

Table 2 : Some Important Podiform Chromite Deposits of the World

Deposit/ Country	Type of the deposit	Cr:Fe	Age (Ma)	Tectonic setting
Cuba	Podiform	2.7	80	Mantle tectonite
Acoje, Philippines	Podiform	3.3	80	Arc, Mantle tectonite
Kempirsai,Urals,Kazakhstan	Podiform	3.9	420	Uralian orogen
Troods, Cyprus	Podiform	2.7	80	Ophiolite
Zhob, Pakistan	Podiform	3.9	90	Himalayan orogen
New Caledonia	Podiform	4.2	10	Island Arc, mantle tectonite
Kalimash, Albania	Podiform	3	130	Alpine orogen
Orhaneli, Turkey	Podiform	4.2	90	Alpine orogen
Faryab, Iran	Podiform	3.5	80	Ophiolite
Semali, Oman	Podiform	3.7	95	Alpine orogen
Thetford, Canada	Podiform	3	500	Appalachian orogen

Globally, the chromite deposits are widespread (Fig. 4.1). Continent-wise and country- wise description is given below:

Table 3 : World Reserves of Chromium (In '000 tonnes)

Country	Reserves
World Total (Rounded)	350000
Kazakhstan	180000
South Africa	130000
India	44000
USA	620
Other Countries	N.A.

Source: Mineral Commodity Summary – 2011(USGS)

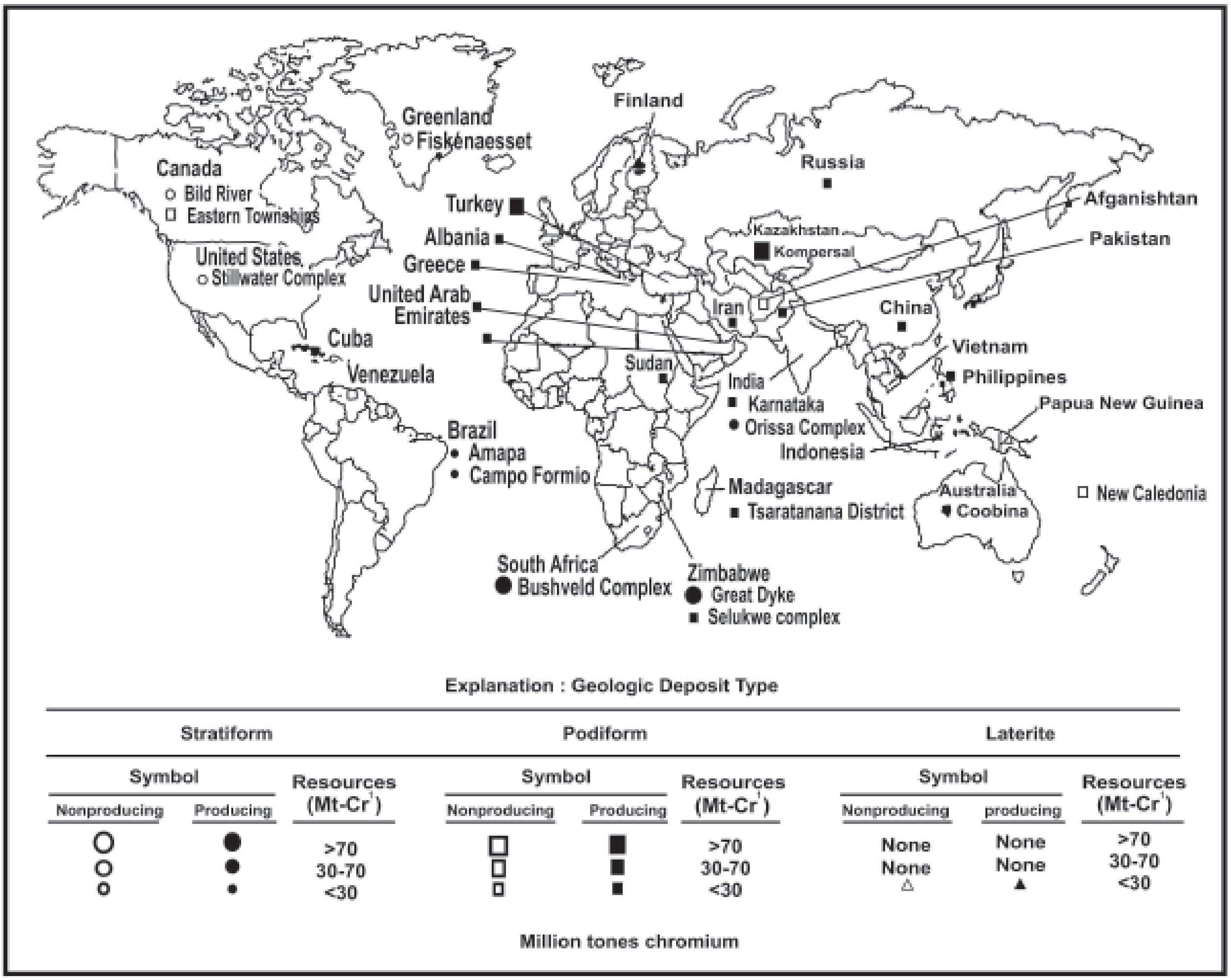

Fig: 4.1 : World Chromium Resources

4.1 AFRICA

4.1.1 South Africa

Most of South Africa's chrome mines are developed along the Eastern BIC, in the Steelpoort Valley. South Africa produced an estimated 9,600,000 t of chromium ore in 2009. Being the leading producer of chromite in the world, the chromite deposits of South Africa occur in the largest repository igneous mass which is universally known as " BUSHVELD" Igneous Complex(BIC). South Africa's entire chromite ore resources are located within the BIC where several chromite seams exist (Cramer et al., 2004). The economically exploitable seams are the lower group 6 (LG6) with a Cr-to-Fe (Cr/Fe) ratio of 1.5-2, the middle group 1 and 2 (MG1 and MG2) with a Cr/Fe ratio of 1.5-1.8 and the upper group 2 (UG2) with a Cr/Fe ratio of 1.3-1.4. Here chromite deposits are stratiform in nature and occur as tabular layers extending over tens of miles. These deposits occur in two horizons in the eastern section hosted by bronzite–dunite-chromitite and in three horizon in the western section hosted by bronzite-norite-chromitite. Eastern section has two zones. Basal zone known as transition zone and chromite bearing critical zone. Chromites deposits have been observed from near the base of the critical zone to 300 metre above. Principal economically important seam is the steel port main seam which is 87-120 cm thick and extended to the entire 64 km length. The western chromite seams are separated by intrusive alkaline complex which have been affected by faults, which drastically displaced the chromite seams. Age of these deposits is considered as Middle Precambrian chromite deposits here form together an irregular pearl shaped mass extending in an East-West directions for a distance of 500 km long & 240 km wide & covers total area of 66,500 Sq. Km. Platinum and its compounds, nickel, copper & iron sulphide are associated with chromite. South Africa is a leading chromite ore and ferrochromium producing country.

Samancor has two mining centres, namely Eastern Chrome Mines (ECM) in the Steelport area of Mpumalanga Province and Western Chrome Mines (WCM) near Rustenberg and Brits in Northwest Province. Both units now comprise three underground mining areas, each with a hoisting shaft, while WCM also includes an open-cut mine. Overall capacity is approximately 5.8 MT/y of run-of-mine ore. Over 80% of Samancor Chrome's chrome ore output is consumed in the production of ferrochrome in South Africa. The remainder of the ore is exported.

Chromex Mining's projects are located on the western and eastern limbs of the Bushveld Complex. Chromex currently has a New Order Mining Right over the Mecklenburg farm in the Limpopo Province, where it intends to mine chromite over a 10 year period.

The 271 hectare Stellite chrome project, located on the Western Limb of the Bushveld complex in South Africa, has a New Order Mining Right and 31.9 MT of chrome resources comprising four seams. The project has been extensively drilled and has had approximately 170,000 tonnes of chromite mined and sold both to the domestic and international chrome markets. Chromex currently produces 42% and 44% metallurgical grade chrome concentrate.

Xstrata Alloy's chrome mining operations mine the chromitite deposits developed within the Bushveld complex of South Africa. The Helena chrome mine is wholly owned by Xstrata, and lays to the south of Thorncliffe chrome mine on the Eastern Limb of the Bushveld Complex.

Assmang's Chrome Division consists of the Dwarsrivier chrome mine and the Machadodorp ferrochrome works both in Mpumalanga.

4.1.2 Zimbabwe

Zimbabwe is the only country to exploit both stratiform & podiform deposits on commercial scale. Here chromite deposits occur in two categories:

1. Large lenticular bodies in podiform deposits, the best example of this is Selukwe, Belingwe, & Mashaba and Gwanda deposits.
2. Parallel seama in Great Dyke deposits.

1. Podiform deposits of chromite was first discovered in Selukwe district. This deposit is situated around the centre of the country and covers an area of 1000 sq km. Host rocks belong to early precambrian period. Main host rock is peridotite. Here chromite occur as homogeneous lenses and tabular or pod like masses in the altered ultramafic rocks. Principal ore bodies are elongated lenses which measures upto 600 m along the strike, 140 m along the dip & thickness upto 20 m. The average size of the lenses being worked in the area measures 300 m along the strike, 60 m along the dip with average thickness of 12.5 m. The Mashoba & Gwanda deposits are rather isolated and are of minor importance.

2. Parallel seam of stratiform chromite deposits occurring in Zimbabwe is collectively called the Great Dyke deposits. This Dyke extend 555 km from the point located about 110 km north north-west of Salisbury to the point located 64 km east-north-east of Gwanda bisecting the country with 4-11 km width & covers total area of about 3.255 sq km.

This Dyke is an intrusive into the Archean granites. Four adjacent intrusive bodies forming this Dyke are seen from north to South named as (1) Musengezi, (2) Hartley (3) Selukwe & (4) Wedza. Rocks of the great Dyke are pseudo – stratified having a shallow geo-synclinal form. The layers of various rock type with sequence from bottom to top is i) serpentine and dunite, ii) Harzburgite, olivine, pyroxenite and picrite, iii) gabbro, gabbroic anorthosite, norite & quartz-gabbro. These deposits represent the greatest known reserves of standard metallurgical grade chromite in the world. The ore systematically varies from metallurgical grade at the northern end to the chemical grade at the southern end.

Zimbabwe produced chromite ore & ferrochromium. Chromex Mining plc (U.K.) purchased Falvect Mining (private) limited. A company that ownes chromite concessions in the shurugwe and Negzi areas, Zimbabwe Alloys reprocessed chromite ore dumps, improved chromium recovery in the furnace and recovered chromium from slag.

4.2 AMERICA

4.2.1 Brazil

Principal chromite deposits ore situated in Bahia & Minas Gerais in the vicinity of Compo Formosa. These deposits are of stratiform types. Ore zone measure upto a length 16km, thickness of massive ore layers is upto 2 m. Ore occurs in the belt of serpentine & talc schist rocks which are intrutive into granite gneiss & quartzite. In the Pedras-Protes Mine chrome ore bodies occur in large irregular lenticular masses. Brazil produces chromite ore, ferrochromium and stainless steel. Other deposits are Pedrinthas, Campinhos, Limseiro & Riachinho.

FERBASA currently mines chromite in two groups of mines located 90 kilometres apart in the central-north region of the state of Bahia, the district of Vale do Jacurici, with 15 mines and a north/south extension of around 120 kilometers, and the Campo Formoso district, with 9 mines. Its main mines are Pedrinhas, in Campo Formoso, and Ipueira, in Andorinha.

4.2.2 Canada

Chromite deposits in Canada are located in eastern Manitoba, Quebec, Ontario. The Bird river deposit in Manitoba is main deposit occurring within a steeply folded & highly faulted igneous complex. The ore occurs as lenses & pockets associated with serpentine. Noront Resources Ltd explored chromite mineralisation in the MC Faulds Lake area of Ontario. The Big Daddy Deposit in the Ring of Fire may be as much as 100% lumpy ore. Micon estimated that the Big Daddy Massive Chromite Domain contains an indicated resource of million tonnes averaging 40.66% chromium oxide (Cr_2O_3), and an additional inferred resource averaging 39.09% Cr_2O_3.

Cliffs Natural Resources Canada Inc. acquired a mine from Freewest Resources Canada Inc. in Ontario. Having completed the acquisition of Freewest Resources Canada Inc. and Spider Resources Inc. Cliffs owned 100% of the Black Thor and Black Label properties and 74% of the Big Daddy property in 2010. Cliffs planned to produce from 1 to 2 MT/yr of chromite ore out of which it would produce 400,000 to 800,000 t/yr of ferrochromium.

4.2.3 Cuba

The Eastern Part of Cuba has three main chromite producing districts viz., Camaguay, Mayari & Moa. Here chromite deposits are podiform type where chromite occur as lenticular or tubular masses associated with dunite and peridotite . The Mayari district produced metallurgical ore, while other two produce refractory grade ore.

4.2.4 United States of America

Chromite are is not produced in United States. However, it possesses shipping grade chromite reserves in Still Water Complex at Montana.

4.3 ASIA

4.3.1 Afghanistan

The chromite bearing area in Afghanistan is about 64 km South of Kabul & scattered over an area of 822.5 sq km. Ore is of refractory grade.

4.3.2 Iran

Chromite deposits of Iran are of podiform type & are grouped into two major serpentine belts, one in northern & other in southern. Northern belt known as Forumad Meshed belt & southern belt known as Esfandagh belt. They are formed as a result of magmatic segregation in ultrabasic rocks like serpentine peridotite & pyroxenite.

4.3.3 Pakistan

In Pakistan most important chromite deposit is of Muslimbagh area of Zhob valley about 120 km north east of Quetta & it is well exploited. This complex covers an area of 2560 sqkm. Deposits are of podiform type, where chromite occurs as veins & tubular lenses in ultramafic rocks.

4.3.4 Kazakhstan

At 300 million tonnes, Kazakhstan's chromium reserves are the second largest in the world behind South Africa. Kazakhstan is the third leading chromite producer after South Africa & India. Here, the deposits are of podiform type and occur in southern Ural Mountain region in Kempirsai massif, lying in Aktyubinsk district of Kazakhstan.These deposits extend in a direction of faultzone for 82 km covering total area of 920 km into width ranging between 0.6-31.6 cm and in intrusive with Precambrian sediments and lower paleozoic sediment. Rock types are amphibolite, peridotites, banded harzburgite, dunite, olivinite.

The state register lists 23 deposits with almost all industrial reserves owned by the transnational company, Kazkhrom. Mining is being carried out at nine deposits owned by Kazkhrom and one by Voskhod-Oriel. The country is currently producing about 4 million tonnes of chromium ore and this figure is expected to grow to 7 million in 2010 and 9 million by 2015.

Eurasian Natural Resources Corporation plc (ENRC) constructed a second 700,000 tpy pelletizing plant & working on installation of direct current furnace at Aklobe having production capacity of 440,000 to be completed in 2012.

Voskhod Chrome Mine and Plant

The deposit is located in North West Kazakhstan 90 km from Aktobe. It is mined by underground method, access being through decline and shaft. The mineralised zone consists of massive chromite, powdery chromite, Orbicular chromite, vein chromite and disseminated chromite. An average annual output of 1.3 million tonnes of mined chrome ore and 900,000 tonnes of lump, chip and concentrate is produced. An indicated resource of 19.1 million tonnes at 48.5% Cr_2O_3 with potential extension from the adjacent Karaagash deposit between 4-8 million tonnes is available.

4.4 EUROPE

4.4.1 Russia

Russia has chromite deposits widely spread along Ural mountain area. Chromite is associated with gabbro, norite rocks. Sopcheozero chromite deposit is located on Kola Peninsula. This plate shaped deposits is 24 m thick, extends 2 km to the south east & ranges from 16 m to 300 m depth. Russia mined chromite ore in Urals at Saranovskoe, Alapaevskoe & Komi region.

4.4.2 Finland

Finland has stratiform type of chromite deposits at Elizarvi about 7 km north east of town Kemi. Chromium is associated with ultrabasic sill- like intrusion having approximate lengh of 15 km & width 1.5 km. Ore distributed continually along the strike. Here chromium content is very low i, e, 27%.

Proven ore reserves at the Kemi Mine total some 36 million tonnes, while the quantity of mineral resources total some 87 million tonnes – estimated to a depth of one kilometre. According to a seismic research report produced by the Geological Survey of Finland in 2009, mineral resources at the Kemi Mine could turn out to be significantly greater than indicated by earlier estimates. The intrusion which contains chromium ore was found to extend to a depth of 2–3 kilometres and possibly to four kilometres, while the chromite layer possibly extends to a depth of 2–2.5 kilometres or more. Information in the new seismic research report indicates the existence of resources sufficient to allow several hundreds of years of mining activity. The decision to double mine output as part of ferrochrome production expansion was made in 2010 and the project is ongoing.

Outokumpu reported proven reserves of chromite ore at 36 MT graded at 26% Cr_2O_3, and indicated resources of chromite ore at 13 MT graded at 30% Cr_2O_3, and inferred resources of chromite ore at 74 MT graded at 29% Cr_2O_3, at its Kemi mine. Outokumpu produced 0.598 MT of marketable chromite ore from 1.3 MT of run-of-mine ore and 0.238 MT of ferrochromium compared with 0.247 MT of chromite ore from 0.9 MT of run-of-mine ore and 0.123 MT of ferrochromium in 2009.

4.4.3 Albania

Albania has podiform type of chromite deposit occur along Balkan part of Alpine mountain chain formed as a result of Alpine orogeny. This deposit is known as Kalimash. Here average grade of chromite is 42%.

The Bulqiza Massif is the most productive of 17 chromite-bearing ultramafic bodies in eastern Albania and has produced approximately 20 million tonnes of high grade chromite ores during the past 50 years. The Massif is composed of lower and upper layers of harzburgite, differentiated by increasing dunite facies and chromite lodes in the upper sequence, and overlying cumulate made up of dunite, pyroxenite and gabbro. The Massif can be described as a northwest-oriented ovoid mass, some 4-6 km thick and covering a surface area of 370 km^2, with a variable westward dip.

The Bulqiza Massif contains some 65 chromite deposits on which mining or significant development work has been undertaken and over 370 occurrences or showings. The principal mineralization occurs in the famous Bulqiza-Batra ore structure which has been developed and mined semi-continuously for a strike length of 5 km and through a vertical range of 900 metres in the Bulqiza mine and 450 metres in the Batra sector. The Bulqiza-Batra chromite ores consist of tabular-concordant layers of banded, semi-massive to massive mineralization within serpentinized dunite alteration envelopes containing disseminated mineralization. Ore thickness averages about 3 metres but is commonly thickened by folding. Grades typically exceed 40% Cr_2O_3. Sub-concordant, pipe-like and podiform styles of mineralization comprising deposits ranging in size from several hundred thousand to several million tonnes occur throughout the Massif.

Empire Mining Corporation has acquired exclusive exploration and development rights to four exploration licences, totaling 64.5 km^2. These are the **Bulqiza-Batra** Licence (38.8 km^2), **Bulqiza Veriore** Licence (6.9 km^2) , **Qafe Burreli** Licence (6.1 km^2) and the **Liqeni i Dhive** Licence (12.7 km^2). Empire plans to raise money by finding a partner either to help develop the mine or buy the product on a long term basis, perhaps from China, which has now turned into a key investor in the mineral industry.

4.4.4 Turkey

Turkey is the next chromite producing country after Kazakhstan . Deposits are of podiform type and occur in two main serpentine belts. Chromite occurs as discontinuous masses in tectonic belts related to Alpine orogeny. Ore occurs as lensoid bodies.

4.5 AUSTRALIA

The Coobina chromite deposit occurs at the western end of a 10 km long belt of ultramafics that lie within the Archaean granites of the Sylvania inlier. The chromite mineralisation occurs as massive chromite accumulations in lenses or pods at the extreme western end of the ultramafics. Up to 150 distinct chromite lenses have been mapped, with the largest recorded being about 340 m long and forming up to 6 m wide zones with multiple lenses.

Consolidated Minerals, also a manganese producer, acquired the Coobina project in 2001 and commissioned a new mining and processing operation in February 2002. Since the start of production, the company has become well established as an independent and reliable supplier of chromite to the world market.

4.6 REFERENCES

1. **International Seminar on Development of Chromite, Nickel and PGM Resources,** (28 Nov, 2010 Bhubaneshwar) SGAT & Dept. Steel & Mines, Government of Odisha.
2. **World Mineral Production,** 2005-2009; A BGS Publication.
3. **Mineral Commodity Survey**-2011, USGS.
4. **Industrial Minerals Publication.**

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PROSPECTING AND EXPLORATION

5.0 INTRODUCTION

The National Mineral Policy 2008, for non-fuel and non-coal minerals introduced by the Government in replacement of the National Mineral Policy, 1993, lay enormous thrust on the various aspects of mineral industry, such as regulation of minerals, role of State in mineral development, survey and exploration, database of mineral resources and tenements, strategy of mineral development, etc. Among other things strong emphasis is laid on the following:

1. To judiciously exploit and utilise the country's mineral potentialities, systematic regional and detailed exploration will be carried out using state-of- the-art techniques in a time bound manner. Zero-waste mining will be the national goal and mining technology will be upgraded to ensure exploration and utilisation of entire run-of-the-mine.
2. To make regulatory environment conducive to private investment, procedures for grant of mineral concessions, such as Reconnaissance Permits, Prospecting Licences and Mining Leases shall be transparent and seamless with security of tenure guaranteed. Prospecting and mining shall be recognised as independent activities with transferability of concessions playing a key role in mineral development.
3. Prospecting being a high-risk venture, access to risk funds from capital markets will be facilitated.

   This policy initiative is expected to encourage greater involvement of private sector in survey and exploration of minerals.

5.1 RESOURCES

World-wide resources of Shipping grade chromite are 12 billion tonnes sufficient to meet conceivable demand for centuries. About 95% of the world chromium resources is geographically concentrated in South Africa, Zimbabwe & Kazakhstan. Remaining countries contribute 5% (Table-1).

Table 1 : Country- wise distribution of Chromite Resources in World

Country	% Share
South Africa	84
Zimbabwe	6
Kazakhstan	5
India	2
Finland, Russia, Albania, Turkey	2
USA, Brazil, Canada & Others	1

5.1.1 Reserves

Out of world's total chromium reserves, about 88% are concentrated in Kazakhstan & South Africa. India & other countries possess conceivable quantity of reserves. World reserves scenario of shipping grade chromite is give in Table -2.

Table 2 : World reserves of Chromium (In '000 tonnes)

Country	Reserves
World Total (Rounded)	350000
Kazakhstan	180000
South Africa	130000
India	44000
USA	620
Other Countries	N.A.

Source : Mineral Commodity Summary – 2011(USGS)

5.2 INDIAN CHROMITE DEPOSITS

The Indian chromite deposits(resources/reserves in annexure I) occur in three distinct associations, which are as follows:

Archaean Greenstone association: Sukinda and Nuasahi in Odisha. Sinduvalli and Byrapur in Karnataka, Bhandara and Ratnagiri in Maharashtra, Roro and Jojohatu in Jharkhand and Ponda-Dudsagar area in Goa.

Proterozoic Granulite association: Kondapalli in Andhra Pradesh, Sitampundi complex in Tamil Nadu.

Mesozoic Ophiolite association : Chromite occurrences in Manipur, Nagaland, Andaman & Nicobar Islands and Jammu & Kashmir.

The economically important chromite deposits are mainly restricted within the Archaean greenstone belts. The distribution of the chromitites is very irregular and they occur as massive, disseminated, granular and nodular types, the latter being characteristic of chromites in ophiolites.

5.3 EXPLORATION AGENCIES

GSI, AMD, DGMs of various states, public sector companies like MECL in freehold areas, and the lessees themselves within their leaseholds continued their efforts in respect of surveying, mapping and exploration of new deposits and reassessment of old deposits/mines during 2009-10.

Role of IBM

IBM today, unlike earlier in the sixties, has no direct role to play in activities related to exploration for minerals. However, IBM, as a facilitator to the Mineral Industry provides technical consultancy services for conducting feasibility studies, environment impact assessments, environment management plans, etc.; conducts mineral beneficiation studies including mineralogical testing and chemical analysis and prepares mineral maps as an information tool. During 2009-10, IBM prepared 100 multimineral leasehold maps, with forest overlays on

1:50,000 scale, in respect of Gujarat and parts of Rajasthan. This completes 980 mineral maps for the mineral rich states of the country. Forest overlays are prepared in collaboration with Forest Survey of India.

5.4 PROSPECTING & EXPLORATION

The exploration approach primarily depends on the objectives of exploration programme, the degree of reliability of exploration data, the market trend and the specifications for various end-use industries. The following objectives are kept in view while planning the exploration programme.

- To delineate shape, size and geometry of the ore body precisely.
- To carry out chemical, physical, physico-mechanical and other specific properties through integrated laboratory studies in conformity with industry specifications.
- To study the nature and distribution of grade, degree of intensity of mineralisation and associated by-products/co-products as value addition.
- To estimate of reserves and grade as per UNFC system.
- To determine beneficiation and metallurgical characteristics.
- To determine ore to overburden ratio and other parameters to decide the type of mining.
- To carryout base line environment studies for future EIA/EMP.
- To determine ground water characteristics and its possible impact on mining operation.

Considering the above broad objectives, the following exploration methods, singly or in combination, depending on the ground conditions, is practiced.

1. Regional geological mapping (1:50,000, 1:25,000 & 1:10,000 scales)
2. Large scale geological mapping (1:5000, 1:2000 & 1:1000 scales)
3. Surface geophysical surveys (Gravity, Magnetic etc.).
4. Test drilling followed by detailed drilling at closer intervals in potential anomalous zones as per the prevailing norms. (Rotary, percussive or its combination)
5. Exploratory mining through shallower pitting, trenching followed by deep pits and adits.
6. Collection of representative bulk samples for beneficiation characteristics.
7. Laboratory studies on petrologic, chemical, physical, mechanical and metallurgical aspects.
8. Preparation of geological report.

5.5 CHROMITE DEPOSITS

Stratiform chromite deposits consist of laterally persist chromite rich layer a few (mm) to several (m) thick alternating with silicate layer. The silicate layer include ultramafic and mafic rock such as dunite, peridotite, pyroxenite and variety of others, less commonly gabbroic rocks generally found within basal portions of mafic. Ultramafic layered intrusions of Archean age such as the Bushveld igneous complex in South Africa and Canadian stratiform chromite deposits. The (average Cr_2O_3 = 10.7 %) . Each chromite band occupies a stratigraphic position. The layer are not deformed composed of small euhedral chromite crystals and do not exhibit nodular or orbicular texture. Chromite, the main ore mineral of chromium, crystallizes from a magma and, because it is denser than the magma, sinks to the bottom and accumulates in a process called crystal settling.

Podiform chromite deposits occur in peridotite and mafic complexes of alpine type, and are tabular, pencil-shaped, or irregular in form. In contrast with stratiform deposits, whose textures and structures reflect crystal settling and suggest analogies with sedimentary rocks, the textures of podiform deposits reflect extensive flowage, under magmatic conditions, as a stiff crystal mush and suggest analogies with metamorphic rocks. Though the ore bodies as entities may be parallel or discordant with wall-rock layering, interval linear and planar elements are generally parallel with those of the country rock. The relationships of the various structural elements are critical exploration guides.

5.6 PROSPECTING GUIDELINES FOR CHROMITE DEPOSITS

Stratiform:

1. Identify well layered mafic-ultramafic intrusions;
2. Prospect below the mafic cumulate portions of the intrusions (i.e. below the portion which is completely gabbroic).

Podiform:

1. Carefully prospect within all dunitic portions of Alpine-type peridotites (Harzburgite-Dunite components of ophiolite complexes).

5.7 METHODS

5.7.1 Geophysical

Since Podiform deposits are irregular in shape and unpredictable, gravity and electrical methods may offer some promise as exploration tools. Some geophysical methods, such as gamma-ray spectrometry and remote sensing, measure surface attributes; others, such as thermal and some electrical methods are limited to detecting relatively shallow features but may help identify features at greater depth. Secondary effects of deeper features, such as geochemical haloes, can often be identified by these methods as given in Table 3.

- Gravity method

Gravity measurements define anomalous density within the Earth. In most cases, ground-based gravimeters are used to precisely measure variations in the gravity field at different points. Gravity anomalies are computed by subtracting a regional field from the measured field, which result in gravitational anomalies that correlate with source body density variations. Positive gravity anomalies are associated with shallow high density bodies, whereas gravity lows are associated with shallow low density bodies. Thus, deposits of high-density chromite, hematite, and barite yield gravity highs, whereas deposits of low-density halite, weathered kimberlite, and diatomaceous earth yield gravity lows. The gravity method also enables a prediction of the total anomalous mass (ore tonnage) responsible for an anomaly. Gravity and magnetic (discussed below) methods detect only lateral contrasts in density or magnetization, respectively. In contrast, electrical and seismic methods can detect vertical, as well as lateral contrasts of resistivity and velocity or reflectivity.

Applications of gravity method for mineral deposit environmental considerations includes identification of lithologies, structures, and, at times, orebodies themselves (Wright, 1981). Small anomalous bodies, such as underground workings, are not easily detected by gravity surveys unless they are at shallow depth.

- Magnetic method

The magnetic method exploits small variations in magnetic mineralogy (magnetic iron and iron-titanium oxide minerals, including magnetite, titanomagnetite, titanomaghemite, and titanohematite, and some iron sulfide minerals, including pyrrhotite and greigite) among rocks. Measurements are made using fluxgate, proton-precession, Overhauser, and optical absorption magnetometers. In most cases, total-magnetic field data are acquired; vector measurements are made in some instances. Magnetic rocks contain various combinations of induced and remanent magnetization that perturb the Earth's primary field (Reynolds and others, 1990). The magnitudes of both induced and remanent magnetization depend on the quantity, composition and size of magnetic-mineral grains.

Magnetic anomalies may be related to primary igneous or sedimentary processes that establish the magnetic mineralogy, or they may be related to secondary alteration that either introduces or removes magnetic minerals. In mineral exploration and its geo-environmental considerations, the secondary effects in rocks that host ore deposits associated with hydrothermal systems are important (Hanna, 1969; Criss and Champion, 1984) and magnetic surveys may outline zones of fossil hydrothermal activity. Because rock alteration can effect a change in bulk density as well as magnetization, magnetic anomalies, when corrected for magnetization direction, sometimes coincide with gravity anomalies.

Magnetic exploration may directly detect some iron ore deposits (magnetite or banded iron formation), and magnetic methods often are useful for deducing subsurface lithology and structure that may indirectly aid identification of mineralized rock, patterns of effluent flow, and extent of permissive terranes and (or) favorable tracts for deposits beneath surficial cover. Geo-environmental applications may also include identification of magnetic minerals associated with ore or waste rock from which hazardous materials may be released. Such associations permit the indirect identification of hazardous materials such as those present in many nickel-copper or serpentine hosted asbestos deposits.

- Gamma-ray methods

Gamma-ray methods (Durrance, 1986; Hoover and others, 1991) use scintillometry to identify the presence of the natural radio elements potassium, uranium, and thorium; multi-channel spectrometers can provide measures of individual radioelement abundances. Gamma-ray methods have had wide application in uranium exploration because they provide direct detection. Thorium is generally the most immobile of the three radio elements and has geochemical behavior similar to that of zirconium. Thorium content, like uranium content, tends to increase in felsic rocks and generally increases with alkalinity.

Gamma-ray spectrometry, because it can provide direct quantitative measures of the natural radio elements, provides geo-environmental information concerning radiation dose and radon potential. Because uranium and (or) potassium are commonly enriched in or adjacent to some deposits, their presence may often be used to indirectly assess the potential for release of hazardous materials from ore or waste piles. Where sulfide minerals are present their oxidation accelerates uranium mobilization.

- Seismic methods

Seismic techniques have had relatively limited utilization, due to their relatively high cost and the difficulty of acquiring and interpreting seismic data in strongly faulted and altered igneous terranes, in mineral assessments and exploration at the deposit scale. However, shallow seismic surveys employ less expensive sources and smaller surveys than that of regional surveys, and the cost of studying certain geo-environmental problems in the near subsurface may not be prohibitive. Reflection seismic methods provide fine structural detail and refraction methods provide precise estimates of depth to lithologies of differing acoustic impedance. The refraction method has been used in mineral investigations to map low-velocity alluvial deposits such as those that may contain gold, tin, or sand and gravel. Applications in geo-environmental work include studying the structure, thickness, and hydrology of tailings and extent of acid mine drainage around mineral deposits (Dave and others, 1986).

- Thermal methods

Two distinct techniques are included under thermal methods (Table 3): (a) borehole or shallow probe methods for measuring thermal gradient, which is useful itself, and with a knowledge of the thermal conductivity provides a measure of heat flow, and (b) airborne or satellite-based measurements, which can be used to determine the Earth's surface temperature and thermal inertia of surficial materials, of thermal infrared radiation emitted at the Earth's surface. Thermal noise includes topography, variations in thermal conductivity, and intrinsic endothermic and exothermic sources.

Borehole thermal methods have been applied in geothermal exploration, but have seldom been used in mineral exploration. However, this method has potential usefulness in exploration and in geo-environmental investigations (Ovnatanov and Tamrazyan, 1970; Brown and others, 1980; Zielinski and others, 1983; Houseman and others, 1989). Causes of heat flux anomalies include oxidizing sulfide minerals and high radioelement concentrations. Conditions that may focus, or disperse, heat flow are hydrologic and topographic influences, as well as anomalous thermal conductivity. In geo-environmental applications, oxidation of sulfide bodies in-place or on waste piles, if sufficiently rapid, can generate measurable thermal anomalies, which can provide a measure of the amount of metal being released to the environment. Borehole temperatures may also reflect hydrologic and hydrothermal systems that have exploration and geo-environmental consequences. Airborne thermal infra-red measurements have applications in geothermal exploration, and may have potential in mineral exploration and in geo-environmental applications whenever ground surface temperature is anomalous due to sulfide oxidation, hydrologic conditions, or heat-flow perturbations due to structure or lithology (Strangway and Holmer, 1966).

Thermal infra-red imaging methods are a specialized branch of more generalized remote sensing techniques. Images obtained in this wavelength range may be used for photo-geologic interpretation or, if day and night images are available, to estimate the thermal inertia of the surface. Unconsolidated or glassy materials can be distinguished by their low thermal inertia. In places, thermal infra-red images can distinguish areas of anomalous silicification (Watson and others, 1990).

- Electrical methods

Electrical methods comprise a multiplicity of separate techniques that employ differing instruments and procedures, have variable exploration depth and lateral resolution, and are known by a large lexicon of names and acronyms describing techniques and their variants. Electrical methods can be described in five classes: (1) direct current resistivity, (2) electromagnetic, (3) mise-a-la-masse, (4)Self potential, and (5) Induced Polarization Method. In spite of all the variants, measurements fundamentally are of the Earth's electrical impedance or relate to changes in impedance.

Electrical methods have broad application to mineral and geo-environmental problems. They may be used to identify sulfide minerals, are directly applicable to hydrologic investigations, and can be used to identify structures and lithologies.

- Direct current resistivity method

Direct current resistivity method measure Earth resistivity (the inverse of conductivity) using a direct or low frequency alternating current source. Rocks are electrically conductive as consequences of ionic migration in pore space water and more rarely, electronic conduction through metallic lustre minerals. Because metallic lustre minerals typically do not provide long continuous circuit paths for conduction in the host rock, bulk-rock resistivities are almost always controlled by water content and dissolved ionic species present. High porosity causes low resistivity in water-saturated rocks.

Direct current techniques have application to a variety of mineral exploration and geo-environmental considerations related to various ore deposit types. Massive sulfide deposits are a direct low resistivity target, whereas clay alteration assemblages are an indirect low resistivity target within and around many hydrothermal systems. The wide range of earth material resistivities also makes the method applicable to identification of lithologies and structures that may control mineralization. Acid mine waste, because of high hydrogen ion mobility, provides a more conductive target than solutions containing equivalent concentrations of neutral salts.

- Electromagnetic method

Electromagnetic measurements use alternating magnetic fields to induce measurable current in the Earth. The traditional application of electromagnetic methods in mineral exploration has been in the search for low-resistivity (high-conductivity) massive sulfide deposits. Airborne methods may be used to screen large areas and provide a multitude of targets for ground surveys. Electromagnetic methods, including airborne, are widely used to map lithologic and structural features (Palacky, 1986; Hoover and others, 1991) from which various mineral exploration and geo-environmental inferences are possible.

- Mise-a-la-masse method

The mise-a-la-masse method is a little used technique applied to conductive masses that have large resistivity contrasts with their enclosing host rock. In exploration, application of this method is principally in mapping massive sulfide deposits. This method is useful in geo-environmental investigations of highly conductive targets; it has been applied to identify a contaminant plume emanating from an abandoned mine site (Osiensky and Donaldson, 1994).

- Self potential method

Several possible natural sources generate measurable direct current or quasi-direct current, natural electrical fields or self potentials. The association of a self potential anomaly with a sulfide deposit indicates a site of ongoing oxidation and that metals are being mobilized; other self potential anomalies are due to fluxes of water or heat through the Earth (Corwin, 1990). Geo-environmental applications include searching for zones of oxidation and paths of ground water movement.

- Induced polarization method

The induced polarization method provides a measure of polarizable minerals (metallic-luster sulfide minerals, clays, and zeolites) within water-bearing pore spaces of rocks. Polarizable minerals, in order to be detected, must present an active surface to pore water. Because induced polarization responses relate to active surface areas within rocks, disseminated sulfide minerals provide a much better target for this method than massive sulfide deposits, although in practice most massive sulfide deposits have significant gangue and have measurable induced polarization.

Induced polarization has found its greatest application in exploration for disseminated sulfide ore, where it may detect as little as 0.5 volume percent total metallic lustre sulfide minerals (Sumner, 1976). In geo-environmental studies, induced polarization surveys are principally used to identify sulfide minerals, but it may have other applications, such as outlining clay aquitards that can control mine effluent flow.

5.7.2 Remote Sensing Methods

Remote sensing includes methods that utilize images obtained in the ultra-violet, visible, and near infra-red bands of the electromagnetic spectrum (Table 3). Thermal infra-red observations, discussed previously under thermal methods, are also part of remote sensing. Remote sensing data are treated in image format, often in digital form, so that they can be processed conveniently. By comparison with known spectral responses of minerals or mineral groups, iron hydroxide minerals, silica, clay alteration, etc., can be defined over broad areas. Remote sensing can be used in geo-environmental studies to map surface alteration patterns (Knepper, 1989) and to identify anomalous vegetation patterns in areas related to abnormal metal content in soil (Birnie and Francica, 1981).

5.7.3 Other Methods

A number of other geophysical or quasi-geophysical methods have been used, or have potential application, in mineral exploration. Application of these methods in geo-environmental investigations has been limited, but should not be dismissed. Some peripheral techniques that have special uses (as in archaeology), whose utilization is not widely known in mineral exploration, that may directly apply to shallow geo-environmental investigations.

Examples of such techniques are ground-penetrating radar (used to image the shallow subsurface in electrically resistive rock; Davis and Annan, 1992), the piezoelectric method (used in studies of quartz veins; Volarovich and Sobolev, 1969), ultraviolet laser induced fluorescence (the Luminex method, used to identify scheelite, hydrozincite, and other fluorescent minerals; Seigel and Robbins, 1983), airborne gas sniffing (used in mercury exploration), the Russian CHIM (partial extraction of metals) electro-geochemical sampling technique, and radon sensing.

5.7.4 VLF-EM Method

Geophysical exploration for chrome ore deposits is rather complicated, and integrated geophysical methods should be used. For an integrated data interpretation respective data sets has been collected from VLF-EM (“Very Low Frequency”-electromagnetic), induced polarization (IP), gravity, magnetic and self potential (SP) data in southwestern Turkey. VLF-EM parameters such as the apparent resistivity, phase, real and imaginary components of the vertical magnetic field and tilt angle of the magnetic polarization ellipse were acquired.

Mapping of the VLF-EM resistivity, phase, real component of vertical magnetic field and filters (Fraser filter, 1969 and Karous and Hjelt filter, 1983) yields good results in distinguishing conducting ore bearing fault zones within the resistive ultrabasic rocks.

Table 3 : Summary of Geophysical Methods and their Characteristics Applicable to Prospecting and Geoenvironmental Studies (In method column : A, airborne surveys; B, borehole surveys; G, ground surveys)

Method	Physical parameter measured	Typical units	Relevant physical property	Typical source of anomaly	Depth of investi-gation
Gravity : A,B,G	Total attraction of earth,s gravity field (the vertical attraction of anomalous masses) Gradient of Earth,s gravity field	Milligals or gravity unit (0.1 mGal) Eotvos unit (109gal/cm)	Density	Rock density contrasts	All
Magnetic : A, B, G	Vector component, or total attraction of Earth,s magnetic field Gradient of Earth,s magnetic field	Nanotesla, or gammas Nanotesla/m	Magnetic susceptibility and remanent magnetization	Magnetic susceptibility and (or) remanent magnetization contrasts	Surface to Curie isotherm
Gamma-ray scintillometry: A,B,G	Rate of gamma-ray photons received	Counts/second	Quantity of K+U+Th and daughters	K+U+Th contrastsin Earth,s upper 50 cm	Upper 50 cm
Gamma-ray Spectrometry: A,B,G	Rate of gamma-ray photons received and their energy	Counts/second in spectral regions. If caliberated,%K and PPM equiv. U and Th	Quantity of K,U,Th and daughters	K,U,Th contrasts in Earth,s upper 50 cm	
Seismic refraction: B,G	Seismic energy travel time	Meters, milliseconds	Velocity of P or S waves	Structures or velocity layer contrasts	All
Thermal bore-hole or shallow hole : B	Thermal gradient or temperature	Degrees C/m degrees C	Thermal conductivity	Thermal flux or conductivity variations	Hole depth
Thermal remote sensing: A,G	Surface temperature day & night	degrees C	Thermal inertia	Thermal inertia contrasts	Abput 5 cm
Electrical (see text) Direct current resistivity : B,G Several varitions in electrode geometry	Electrode position (m), applied current (A), and electric field (mV)	Meter, amps, millivolts; typically converted to units of resistivity (Ohm-m)	Resistivity	Lateral or vertical changes in resistivity	About 2 km
Electromagnetic methods (see text):A,B,G many variations available	Dependent on method; ratio of received to applied electric and magnetic fields	Impedance (Ohms) or dimensionless ratio; units of conductivity(Sei-mens/m) or resistivity (Ohm-m)	Conductivity (inverse of resistivity)	Lateral or vertical changes in Earth conductivity	Shallow (10m; VLF; 100m, controlled source), intermediate (1km; AMT) deep (10 km;MT)
Mise-a-la-masse: G,G	Applied DC or low frequency AC field	Millivolts	Resistivity	Conductive body	A few hundred meters
Induced polarization: B,G	Resistivity change w/ frequency (PFE) Phase angle between transmitted and received signal (Φ) Normalized area of part of received voltage decay curve	Percent change Milliradians Milliseconds	Interface ionic polarization	Metallic lustre minerals and pore water Clay and zeolite minerals	About 2 km
Self potential: B,G	Natural near-static (direct current) electric field	Millivolts	Eh/pH electronic conductor; streaming potential and thermal coupling coefficients	Vertical change in Eh/pH caused by electronic conductor; ground water flow; thermal flux	A few hundred meters
Remote sensing: A	Reflected radiation intensity (UV,VIS,IR)	Recorded as optical or digital intensity image	Spectral reflectance, Albedo	Changed in Spectral reflectance, and Albedo	Surface only

5.7.5 Exploration Methodology

Generally, the preliminary exploration in the country is being initiated by GSI / State Directorates to locate the potential target areas and to assess its likely resources. Based on their findings on potentialities of various prospects, many of the prospects have been handed over to MECL and other exploration and mining agencies for further detailed exploration, in order to convert them to deposits by resources estimation.

Subsequent feasibility study of these deposits are undertaken for future investment for exploitation of the deposit. Further additional data have been generated by exploiting agencies for mine planning and actual mining operations.

The above approach has been broadly adopted, depending on the inputs in each activity on case to case basis and on the specified requirement during the course of exploration.

5.8 GEOCHEMICAL EXPLORATION FOR CHROMITE

In thickly covered areas, geochemical exploration methods are employed successfully for locating subadjacent chromite, nickel and cobalt deposits lying beneath laterite and soil within zones of mafic-ultramafic parent rocks.

This method comprises three stages of operations, the first stage being an orientation survey involving collection of representative samples of various types of mafic-ultramafic rocks along with their weathered mantle.

This is aimed at identifying the nature and extent of geochemical anomalies of Cr, Ni and Co. The second stage involves detailed sampling of the promising areas for delineation of position and form of the anomalies.

The third stage includes subsurface exploration by pitting followed by drilling in order to find out the composition of causative anomalies.

Study of vertical variation in metal contents across the weathered profile in the existing quarries and pits is very much necessary. Bed-rock sampling is to be carried out by collecting grab/channel samples from outcrops and exposures whenever available.

The information on the dispersion pattern of these elements is obtained from the analytical data of all the samples collected from the area which falls under two categories:

a) Primary dispersion, including hydrothermal dispersion, and
b) Secondary dispersion during the formation of the weathered mantle.

A. Primary dispersion:

The behaviour of Cr, Ni and Co during fractional crystallization of non-felspathic, accumulative type layered magmatic rocks is fairly well known from geochemical studies carried out by various workers. In such bodies, Cr crystallizes dominantly in the spinel phase, besides entering the early pyroxenes.

Nickel usually occurs in magnesian olivines and pyroxenes, the amount of Ni increasing with increase in Mg/Fe ratio, and Co enters in to the same minerals as Ni.

B. Secondary dispersion:

Secondary dispersion pattern of chrome-nickel can be classified into following categories:

i) Mechanical chemical dispersion in weathered mantle.
ii) Biochemical dispersion in plants.
iii) Geochemical dispersion in the drainage system.

5.9 RECENT EXPLORATION FOR CHROMITE

5.9.1 GSI

Major share (98.6%) of chromite resources in the country is located in Odisha. The chromite deposits occur in number of localities along NE-SW belt associated with ultramafic complexes of Sukinda, Baula- Nausahi (Figs. 5.1 & 5.2) and similar occurrences of ultramafic rocks at Bhalukasoni and Ramgiri. Sukinda chromite alone contributes nearly 95% of total chromite reserves of the country. It has been explored by geological mapping, drilling, and sampling in different phases. The Sukinda ultramafic complex was explored in different phases comprising of work viz. Geological mapping (1:2000 scale), drilling, pitting and trenching. As a result of this, a total of 145.022 million tonnes of chromite reserve of all grades have been established in Sukinda valley.

In Odisha, reconnaissance (G-4) stage investigation has been carried out during 2009-10 for chromite around Maulabhanj and Tangeria areas in Dhenkanal district to assess the potentiality of chromite mineralisation along the transition zone of Eastern Ghat Mobile Belt (EGMB) and Iron Ore Super Group (IOSG), south of Sukinda ultramafic complex. The presence of chromiferous ultramafic zone for a linear stretch of more than 1 km has been established through large scale mapping (1: 10,000 scale) supplemented by pitting/ trenching. In the identified favourable area (0.35 sq km) within ultramafic clan of rocks for chromite mineralisation, detailed mapping on 1: 2000 scale has been carried out. The visual estimate of Cr_2O_3 is about 20-25% (chemical analytical results were yet to be received). However, bedrock samples collected from old pits in the area during 2004-05 analysed Cr_2O_3 ranging from 29.17% to 49.43% and Fe_2O_3 from 17.72% to 34.33%.

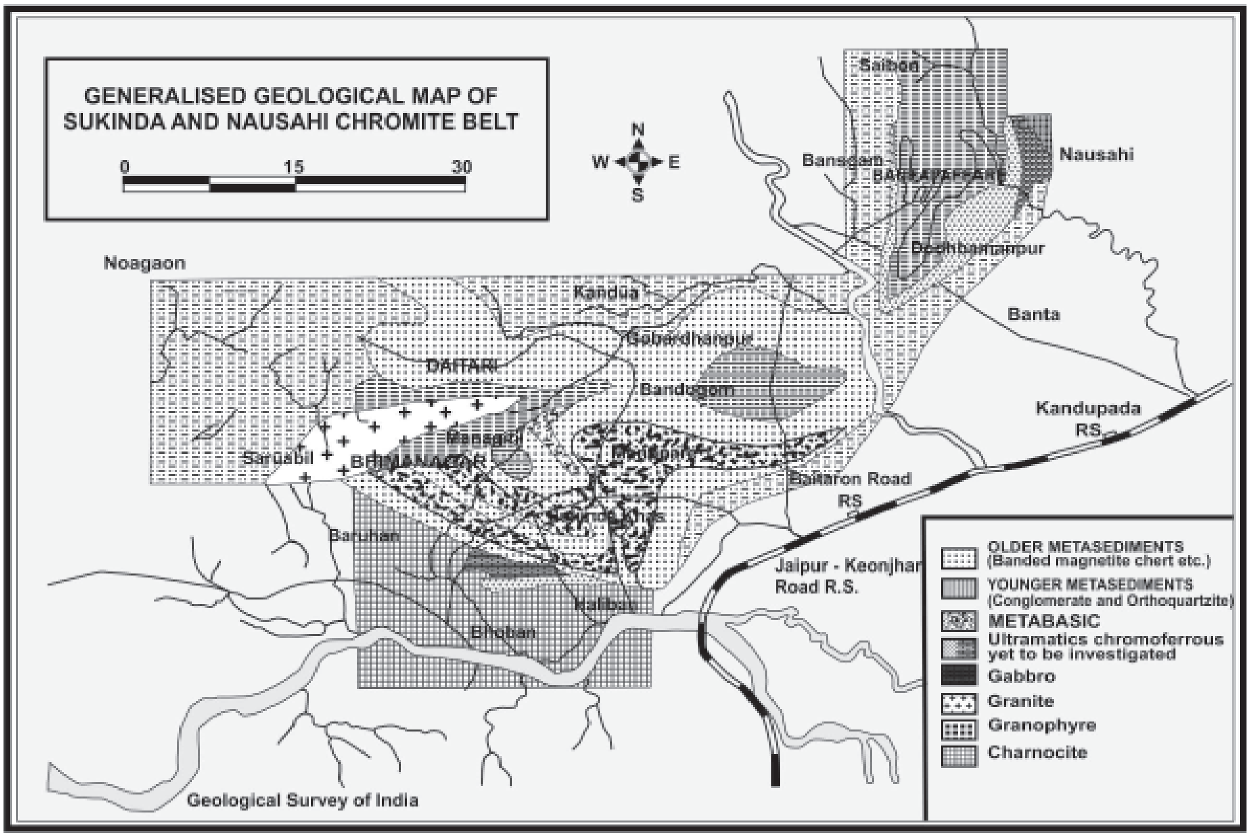

Fig. 5.1 : General Geological Map of Sukinda and Nausahi Chromite Belt

Bhalukasuni – Nilgiri Chromite : Location**:** Tehsil / Sub-division: Nilagiri ; District : Balasore.

The DGM, Odisha identified two small lodes. Chromite bodies are of podiform type resting on a plutonic mass of gabbroic rocks, occurring at a depth of 20 m from the surface.

Jojohatu – Roroburu belt: Location: District: West Singhbhum; Tehsil: Saraikell.

The average thickness of chromite bodies is taken to be 22 cm and the extension of ore body in depth is taken as 30 m.

Kankauli – Janoli – Vagda occurrences (by GSI 1959-60; by DGM, Maharashtra 1971-74) Location: District – Sindhudurg; Tehsil – Kankauli.

The total estimated reserves of chromite in Kankauli and Vagda areas as estimated by GSI (1959-60) are of the order of about 71,300 tonnes with assumed depth persistence of about 30 m. The Cr_2O_3 content varies from 32 to 38 per cent. Iron varies from 12 to 18 per cent.

While conducting reconnaissance (G-4) stage investigation for PGE in ophiolite belt in Manipur during 2009-10, three discontinuous lenses (3 m x 1 m) of massive chromite have been observed within serpentinised Ultramafic. The ophiolite suits are emplaced into the pelagic sediments of Tertiary age. The contact between sediments and ophiolite is sharp, sheared and shows intense brecciation (1-3m) Cr_20_3. with content of chromite varying from 44-59%.

5.9.2 MECL

The exploration carried out by MECL during 2009-10 had mainly to do with coal in various states, for base metals in Rajasthan and for gold in Jharkhand. No work for Chromite was done .

5.9.3 Exploration by Lessees: Fig 5.2.

- Tata Steel , Chromite exploration adopted in Sukinda valley

Chrome deposits are located in Sukinda chromite valley mainly occur as bands, lenses and pockets in the serpentinized dunite-peridotite. They are well differentiated layered igneous complexes and belong to the well known stratiform complexes of the world (Mohanty, 2006). The main large scale structural feature of the region is a moderately SW plunging synform with a moderately dipping north limb and sub- vertical south limb about which the Sukinda intrusion and surrounding meta-sedimentary rocks are folded. The area has experienced multi-phase deformation history, incorporating folding, faulting & jointing, intrusion of dyke, normal shearing and finally faulting.

Table 4: Exploration by Leases during 2006-2011

Year	No. of Bore Holes	Metres drilled (m)
2006-07	7	1299.0
2007-08	2	446.00
2008-09	12	2222.40
2009-10	13	3866.60
2010-11	28	8195.25
Total	**62**	**16029.25**

Table 5: Summary of additional resources due to exploration during 2008-11

UNFC Category of Resource/Reserve		Addition of Res/ Res during 2008-2011 (Million Tonnes)
Reserves (A)	Proved (111)	9.546
	Probable (112)	2.272
	Total	11.818
Resources (B)	Pre-feasibility (221+ 222 + 223) Measured (331) Indicated (332)	36.587 0.000 0.000 21.461
	Inferred (333)	58.047
Grand Total (A+ B)	**Total**	**69.865**

The mining lease of Sukinda Chromite Mine comprises of 406 hectares of land in villages Kalarangiatta, Kaliapani, Mahulkhal & Forest Block No. 27 in the Revenue district of Jajpur. Total 548 nos. of boreholes amounting 56,113.91 metres of exploration drilling has already been done till 31.03.2011 within the Mining Lease area of 406 ha. Ore persistence to depth of 375 m in the North Band, 235 m in the middle band and 175 m in the hard lumpy ore band have been proved.

History of chromite exploration in Sukinda valley started way back in 1949. Inquisitively, some boulders of chrome ore were casually reported by a local tribal named Kate Purti and immediately the occurrence of chromite in the valley was first brought to light by the geological wing of Tata Steel. The primary exploration work started with geological mapping and surface sampling, followed by pitting and trenching in friable ore bands. Gradually, the diamond core drilling with shallow bore hole was initiated, first by Tata Steel in the region to understand the lateral and downward extent of mineralization. Present geological knowledge about the mineralization of chrome in the region indicated that weathering horizon in the friable bands extended up to a depth of 250 m-300 m from surface.

In the past, many exploration programs have been undertaken with conventional drill machines and even with modern hydraulic drill rigs, but the problem of core recovery, hole stabilization and hole deviation could not be resolved. These challenges called for a major change in entire exploration strategy, from simple conventional drilling to more technically advanced, deep drilling with very accurate data gathering from the borehole.

Strategies adopted

After having understood the entire geological and structural set up and mineralization pattern of the area, new exploration strategies were formulated to address critical aspects, like identifying the location of fault plane at depth, prove depth transition from soft to hard strata and improve the confidence level of resource quantity and quality. Key strategies and scientific approaches adopted to address each challenge are briefly described in the subsequent paragraphs.

i) Deep hole drilling: As discussed, the exploration strategy was formulated to facilitate underground mine planning process, which needed exploratory data from deeper levels ranging from 300 m to 800 m from the surface. In view of this, angular bore holes were planned to intersect ore bodies at different, predetermined levels. To meet these requirements, high capacity, hydraulic drill machines like CS-14, CT-14 (Atlas Copco), LF-230 (Boart Long year) and KORES have been deployed, which are capable of taking up angular bore holes to a depth of 1000 m to 2000 m.

ii) Improved core recovery: High Core recovery is the essence of the exploration programme and hence the emphasis is on obtaining nearly 100% core recovery during the drilling operations. Based on in depth analysis of the factors impacting core recovery, following enablers were brought in to ensure optimum core recovery.Selection of the ideal drilling mud and polymer while drilling played the most important role to increase the core recovery and stabilize the hole. In the weathered formation it was important to evaluate the mixing proportion of the bentonite and other polymers which effectively formed the wall cake. Cementing also served as a common solution for hole stabilization in bad formations. To minimize the settling time of the cement liquor in the hole, quick setting compounds like CICA-40 and CICA-25 were used. In fractured formations, sealing agent, like AUS-PLUG by AMC, was used with standard drill barrels which prevented the loss of flush water and increased the hole stability. It was also essential to check the ingredient and chemical constituents of the ground water as all muds and polymers were to be mixed in the flush water. Water samples were collected from the pit and a few bore holes and tested in the laboratory for pH, hardness, dissolved solids, etc. and remedial measures were taken accordingly.

Selection of appropriate drilling bits, based on their matrix and population of diamond vis- à-vis, the abrasiveness of the formation played an important role. For soft and fine grained formations; drilling bits with softer matrix and denser population of diamonds were selected.

Careful selection of the core barrel and supporting drill rods were essential in controlling the deviation of the bore hole. Mostly, longer barrels were preferred instead of short barrels to avoid bore hole deviation. Heavy Core Barrels were found favorable in disturbed formations for keeping the hole straight. In case of intended deviation, flexible core barrel were used to deviate the borehole upward.

iii) Bore hole precision: As bore hole depth increases, the chances of deviation is also higher and more so when there is a difference in the hardness of formations. To keep a track on deviation of hole, digital bore hole deviation cameras were used. For precise data acquisition and constant monitoring of the path of the bore hole, deviation data were recorded systematically at every 25 m interval, However, this interval was narrowed down to even 5 m in case of highly disturbed formations.

iv) Core orientation: For underground mine development, capturing minor structural data with precise orientation is very important. For this purpose, spear marking technique was adopted in the initial phase. However, in the process of further improvisation, high precision digital core orientation tools were used in place of spear mark for securing oriented core and thereby deciphering the actual behaviour of the formation in the sub-surface by structural logging of the same. Steps taken as discussed above enabled in achieving nearly 100% core recovery, even in the softer formations, like limonite and weathered serpentinite rock formations.

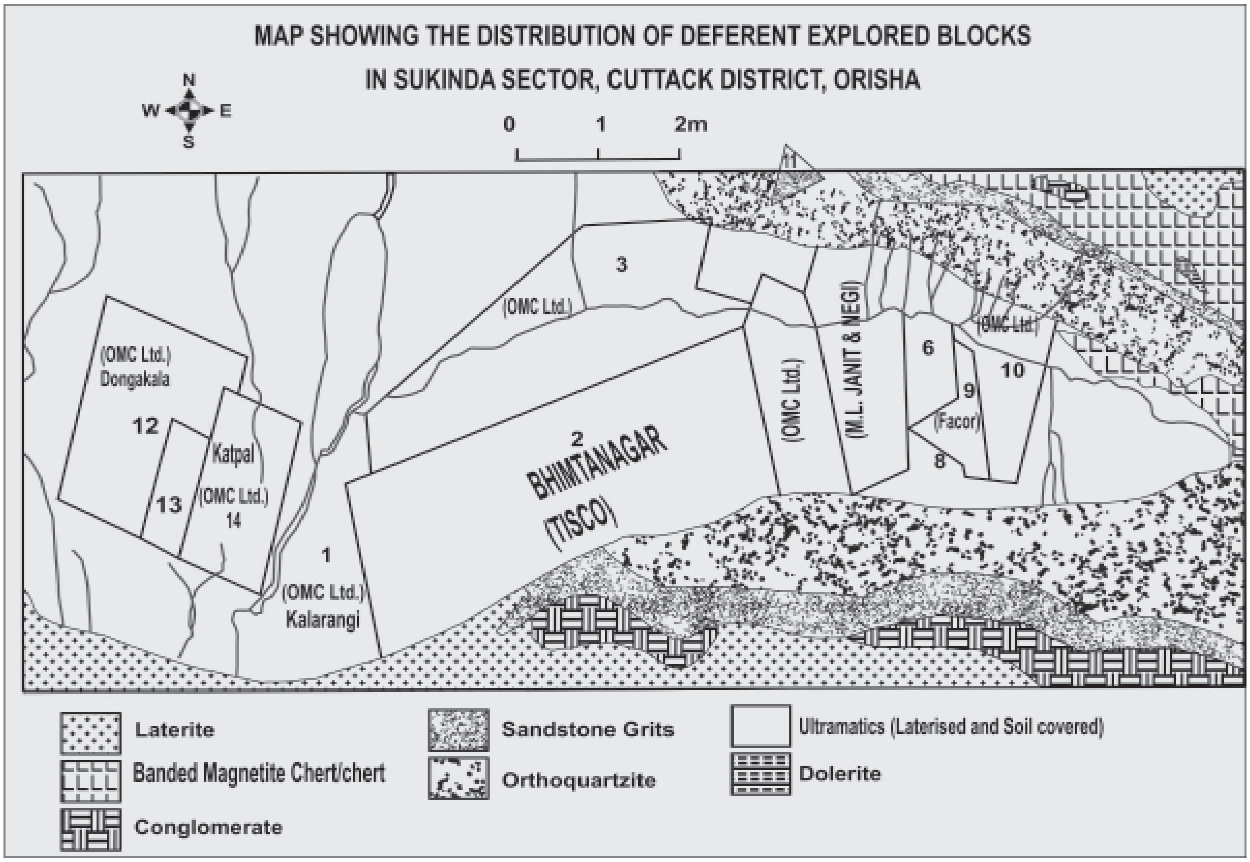

Fig: 5.2 : Exploration by Lessees

- FACOR

During 2009-10, M/s. FACOR carried out exploration in Boula chromite mine, Keonjhar district, Odisha by 417.8 m drilling in 19 boreholes; in Kathpal chromite mine, Dhenkanal district, Odisha by 2606.4 m drilling in 55 boreholes and collecting 276 sample and proved mineral reserves up to 60 m depth and in Ostapal chromite mine, Jajpur district, Odisha by 4,441.10 m drilling in 31 boreholes and collecting 196 samples.

- OMC Ltd

As on December 2011, the OMC Ltd has proved Chromite deposits up to a depth of 150 m from ground level(GL) in Band 1 and upto 60 m from GL in Band 4 of their South Kaliapani mine. In Sukrangi mine mineral deposit , it is proved to a depth of 60 m from GL and in Kathpal mine, it is proved to a depth of 80 m from GL. Exploration targets are lagging due to delay in forest clearance.

- M/s Indian Metals & Ferro Alloys Ltd

NUASAHI CHROMITE MINES

Deepest Bore hole intersection

Bore hole no.	Co-ordinate	Collar mRL	Angle and direction	Hole length	Depth of intersection	RL of intersection
122	X -1735. 0 Y- 3087 . 0	- 75mRL	62°down and direction -N233° degree.	169.90m	156.30m to 158 .77m	- 213 mRL to - 215mRL

Name of the mines	Bore hole no.	Surface collar mRL	Hole depth	Bore hole angle and direction
Sukinda mines (chromite)	SMC/ IM /14	137 .46	661 .04m	90°
Mahagiri mines	MMC / 07	182 . 90	377 .65m	60°, N 150 degree
Chingudipal mines	CCM- 21	147	63 . 50m	70°, Due north

SUKINDA MINES (IMFA)

Area in ha. : 116.760 ha

Total No. of Bore Hole drilled (as on 01.03.2013) : 46 nos. (11819.94 Metres)

Maximum depth of the Hole:

Hole No	Chromite Run(m)		MRL(m)
	FROM	TO	
SMC/IM/14	622	641	**-492.57**

Table 6: Reserve & Resourse Estimated as on 01.03.2013

Reserve / Resources As on 01.03.2013 (In Lakh Tonnes)					
Classification	**Code**	**Band-I**	**Band-II**	**G Total**	**Grade Cr_2O_3%**
Total Mineral Resources (A + B)		**275 .194**	**68.802**	**343 . 996**	
A . Mineable reserves					
1. Proved mineral reserves	111	41 .703	11.939	53 . 642	+ 30%
		NIL	1.620	1.620	10-30%
2. Probable mineral reserves	121	NIL	NIL	NIL	
Probable mineral reserves	122	NIL	NIL	NIL	
B. Remaining Resources					
1. Feasibility mIneral Resources	211	NIL	NIL	NIL	+ 30%
2. Prefeasibility Mineral Resources	221	145.164	4.873	150.037	+ 30%
Prefeasibility Mineral Resources	222	NIL	NIL	NIL	+ 30%
3. Measured Mineral Resources	331	NIL	26.080	26.080	+ 30%
4. Indicated Mineral Resources	332	68.248	12.972	81.220	
5. Inferred Mineral Resources	333	20.079	11.318	31.397	
6. Reconnaissance Mineral Resources	334	NIL	NIL	NIL	

MAHAGIRI MINES (IMFA)

Area in ha : 73.777 ha

Total No. of Bore Hole drilled (as on 01.03.2013) : 29 nos. (3283.96 metres)

Maximum depth of the Hole:

Hole No.	Chromite Run(m)		MRL(m)
	FROM	TO	
MMC/07	336.85	359.55	**-128.47**

Table 7: Reserve & Resourse Estimated as on 01.03.2013

Classification	Code	Quantity	Grade
Total Mineral Resources (A + B)		**9205052**	+30%
A . Mineable reserves			
1. Proved mineral reserves	111	2968373	+30%
2. Probable mineral reserves	121	Nil	
Probable mineral reserves	122	106005	+30%
B. Remaining Resources			
1. Feasibility mIneral Resources	211	Nil	-
2. Prefeasibility Mineral Resources	221	2619377	+30%
Prefeasibility Mineral Resources	222	129983	+30%
3. Measured Mineral Resources	331	1334672	+30%
4. Indicated Mineral Resources	332	862749	+30%
5. Inferred Mineral Resources	333	1183893	+30%
6. Reconnaissance Mineral Resources	334	NIl	-

CHINGUDIPAL CHROMITE MINES

Name of the Mines : Chingudipal Chromite Mines.
Area in ha. : 26.62 ha
Total No. of Bore Hole drilled (as on 01.03.2013) : 27 nos. (1219.20 metres)
Maximum depth of the Hole:

Hole No.	Chromite Run(m)		MRL(m)
	FROM	TO	
CCM-21	58	63	**83.78**

Table 8: Reserve & Resourse Estimated as on 01.03.2013

Classification	Code	Quantity in Lakh MT	Grade Cr_2O_3
Total Mineral Resources (A + B)		**5.286**	
A . Mineable reserves			
1. Proved mineral reserves	111	NIL	10 % & ABOVE
2. Probable mineral reserves	121	1.9785	
Probable mineral reserves	122	0.2025	
B. Remaining Resources			
1. Feasibility mineral Resources	211	1.1850	10 % & ABOVE
2. Prefeasibility Mineral Resources	221	NIL	10 % & ABOVE
Prefeasibility Mineral Resources	222	1.9200	
3. Measured Mineral Resources	331		
4. Indicated Mineral Resources	332	NIL	
5. Inferred Mineral Resources	333	NIL	
6. Reconnaissance Mineral Resources	334	NIL	

NAUSAHI CHROMITE MINES

Area in ha. : 40.468 ha

Total No. of Bore Holes drilled (As on 01.03.2013) : 171 nos. from underground.

Exploratory holes

Drilled during 2011-12 —> 12 nos. covering 1342. 50 m (u/g)

Drilled during 2012-13 (upto 1st March 2013) - nil

Total Reserves Grade wise : As on 01.03.2013 (Quantity in Lakh Tonne)

Table 9: The UNFC Code of the Nausahi Chromite Mines Reserve as on 01.03.2013

Classification	Code	Quantity in Lakh MT	Grade (Cr_2O_3%)
Total Mineral Resources (A + B)		**32.63**	All Grades
A . Mineable reserves			
1. Proved mineral reserves	111	8.45	+40 to 52%
		2.52	Below 40%
2. Probable mineral reserves	121	Nil	
Probable mineral reserves	122	3.94	+40 to 52%
		1.31	Below 40%
B. Remaining Resources			
1. Feasibility Mineral Resources	211	Nil	-
2. Prefeasibility Mineral Resources	221	5.68	+40 to 52%
		1.42	Below 40%
Prefeasibility Mineral Resources	222	1.39	+40 to 52%
		0.15	Below 40%
3. Measured Mineral Resources	331	Nil	-
4. Indicated Mineral Resources	332	Nil	-
5. Inferred Mineral Resources	333	6.22	+40 to 52%
		1.55	Below 40%
6. Reconnaissance Mineral Resources	334	Nil	-

- Other lessees

In Baula – Nausahi belt, there are in general 3 lodes in north Baula block and 2 lodes in South Nausahi block occurring as disjointed bodies. The chromite bodies occurring in form of discontinuous bands and lenses, confined to the altered dunite / peridotite, are exposed in the central part of the mine. These bands have an average width of 5 metres. The chromite seams in the Baula-Nausahi area are thin, (3 m to 10 m) small, mostly hard and lumpy, and persists for a depth of more than 100 m as observed in borehole intersections.

The exploration activity undertaken by other lessees has also been described in the chapter- VI.

5.10 GSI - STRATEGY FOR CHROMITE EXPLORATION IN TWELFTH FIVE YEAR PLAN

The assessment of exploration status of chromite reveals that out of the total potential area of 2720 sq km which includes 2690 sq km in peninsular India and 306 sq km in Extra peninsular region, the total area explored is 604 sq km which includes 88.5 sq km lease hold areas. Therefore, free hold explored area comes to be around 516 sq km. The total unexplored area is 2116 sq km.

In furture, apart from the programme of exploration aimed at proving the strike-wise and depth-wise continuity of the known bodies in known and present mining areas, future programme of exploration should aim at intensifying the areas of search based on scientific reasoning.

The geological set up of the chromite fields of Sukinda valley and adjoining Nuasahi chromite area of Odisha, assume significance and possibility of locating new chromite ore bodies in the area has to be attempted. Already through exploration 100 sq km area in Sukinda valley and 60 sq km area in Nausahi area have been found to be potential of holding all the major chromite deposits of the country. The rest of the areas have to be covered by ground survey during the XIIth Plan period. The work will cover mapping, geophysical and geochemical surveys and drilling.

The Sitampundi Complex of Salem district is a major source of chromite in Tamil Nadu. Further investigations can be planned in this complex.

In Karnataka, chromite rich belts show presence of layered complexes in association withgreenstone belts represented by Sargurs.

In Singhbhum district, Jharkhand along Jojohatu-Roro belt, small chromite ore bodies occur as bands in altered ultramafics, intrusive into the Precambrian Iron Ore Group.

Chromite deposits in Maharashtra occur in Bhandara-Nagpur belt, Sindhudurg belt and Chandrapur belt in association with the ultramafics of Sakoli and older Groups.

5.11 REFERENCES

1. **Base Document of CGPB Committee-I on Ferrous Minerals: Chromite Ore; Geological Survey of India Eastern Region** Government of India, Ministry of Mines; August, 2011.
2. **Indian Minerals Yearbook- 2010; Indian Bureau of Mines,** Government of India , Ministry of Mines; December, 2011.
3. **Controls of Mineralization and Application of Suitable Exploration Techniques for Evaluation of Magmatic Deposit: A Case Study From Sukinda Chromite Deposit ,**by R K Upadhyay, R Mohanty, P Mallick and T S Suresh Kumar .Tata Steel Limited.
4. **Exploration of chrome ore in Southwestern Turkey by VLF-EM,** by M. Bayrak.
5. **Geophysical Methods in Exploration And Mineral Environmental Investigations**, by Donald B. Hoover, Douglas P. Klein, and David C. Campbell.
6. **Principal features and origin of podiform chromite deposits, and some observations on the Guelman-Soridag District, Turkey**, T. P. Thayer.
7. **Draft document on formulation of strategy for exploration, exploitation and development for chromite in india, by 'The sub-group on chromite'** J.K.Nanda & B.K. Jena, Directors GSI; M. Sengupta, RMG, IBM,Nagpur & Naresh Nautiyal, Dy.GM(Exploration), MECL, March 2007.
8. **Principal features and origin of podiform chromite deposits, and some observations on the Guelman-Soridag District,** Turkey, T. P. Thayer.

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ANNEXURE I: Indian Reserves / Resources of Chromite as on 1.4.2010

(By Grades) (In '000 tonnes)

Grade	Reserves				Remaining Resources								
	Proved	Probable		Total (A)	Feasibility	Pre-feasibility		Measured	Indicated	Inferred	Reconn-aissance	Total (B)	Total Resources (A+B)
	STD 111	STD 121	STD 122		STD 211	STD 221	STD 222	STD 331	STD 332	STD 333	STD 334		
All India : Total	31652	7165	15153	53970	1371	1407	4431	31787	36525	52497	21359	149377	203347
By Grades													
Refractory	4074	923	704	5701	547	-	-	15	240	3262	-	4064	9765
Charge-chrome	10984	868	9565	21417	495	1107	1679	6332	29840	11508	-	50961	72378
Low	26	27	-	53	-	-	-	-	-	3713	-	3713	3766
Beneficible	8245	2912	2668	13825	255	279	710	12457	1843	5610	-	21154	34979
Ferro-chrome	6304	1689	1353	9346	74	20	88	12805	2794	13280	-	29061	38407
Others	175	746	-	921	-	-	-	168	15	-	-	183	1104
Unclassified	1844	-	863	2707	-	-	1953	9	1778	14963	21359	40062	42769
Not-known	-	-	-	-	-	1	1	-	16	161	-	179	179

Chapter 6

MINING

6.0 INTRODUCTION

Around the year 1901, world chromite production was about 53,000 tonnes which increased to the present figure of 32 million tonnes . The need to free steel from corrosion led to the discovery of steel containing chromium, namely stainless steel. The first authentic stainless steel was made on 13th August 1913. Over the years, a group of steel containing a minimum of 10.5% chromium came to be regarded as stainless steel. The demand for stainless steel drives the search for chromium resources and its exploitation. Ninenty per cent of the chromite resources of India are located in Odisha state followed by Karnataka. Mining for chromite is carried on only in these states although minor occurences of chromite are recorded in many states of India.

Domestic production of chromite started in undivided India in 1903 from Baluchistan amounting to a meagre 286 tonnes. Chrome ore had been discovered in India in 1903 in the state of Odisha. Then, mining opened up at some chromite deposits in Mysore state in 1907, Bihar in 1915, Maharashtra in 1940, Odisha in 1942, Manipur in 1976 and production gradually picked up. In those years, almost entire quantity was exported. After independence the internal consumption of chromite, for various purposes, gradually increased. Consumption by chemical and refractory industries started and in the 1970s, ferrochrome plants came up in a big way, thus augmenting production. Side by side detailed exploration carried out by GSI, DMG (Odisha) and OMC etc. established high resources in Odisha sector, augmenting all India resources from a meagre 4 million tonnes in 1961 to almost 186 million tonnes in 1995 with recoverable reserve at 83 million tonnes.

There are a total of 35 mining leases for chromite in India and there are currently 21 mines. The Sukinda chromite mine of TISCO is the largest opencast chromite mine in India. South Kaliapani (OMC); Kaliapani (Balasore alloys); Sukinda (IMFAL); and Ostapal Mines (Facor) are the other principal mines of chromite and these mines produced 3553000 tonnes of chromite ore during 2010-11, being 83% of the total production of the mineral for that year. India' s production of the mineral has been fluctuating and after a high in 2006, the production had been steadily dropping and has started picking up again from 2010-11.

The Sukinda deposit is the largest in India, where it occurs in ultramafic intrusive extending over a length of 20 Kms along the strike in ENE-WSW direction and is 2-5 Kms across. Chromite occurs as seams or bands which are extensive and consistent. There are six bands, bands I and II being prominent. The bands are high grade upto +50% Cr_2O_3. The ore is increasingly soft and friable as depth increases. The band six dips southwards to Mahagiri hill and also contains hard lumpy fine grained ore.

Most mines are reaching the economic pit limit for opencast mining, from 40-80 m. Problems faced in mining in the area is the soft ore and also the host rocks which causes problems of ground control in underground mining and does not allow pit slopes steeper than 30 degrees in open pits in most areas, except Mahagiri hills. Lack of adequate space for waste disposal is also a big problem, which has resulted in unstable high dumps. Separate dump area need to be provided in the nickel bearing limonitic horizon in the laterite zone for future use.

It is observed that,

(1) The height of the dumps varies from 4 m to 80 m. The abnormal height of 80 m in Bhimtanagar Chromite mine of M/s TISCO is due to inadequacy of areas for dumping waste material.
(2) The percentage of waste dump areas in mines ranges from 5 to 40 %.
(3) The surface area occupied by the mine working varies from 4 ha to 161 ha.
(4) The high range of surface area utilization (11 to 100 %) in some mines are due to areas occupied for other activities like residential colony, plant and offices etc.
(5) The stripping ratio of the mining leaseholds ranges from 1:1.8 to 1:15.

These aforesaid figures are indicative of the seriousness of the problem for future development of mines. It will help the situation, if

(i) the state government takes appropriate steps at the earliest to grant alternative areas outside the mining lease-holds to counter this problem of inadequacy of dump area as well as their height, and
(ii) underground mining method, be taken up, considering high stripping ratio in some of the mines, and future economic mining operations.

Again, the fragmentation of the mining leases has restricted

a) the scope of better mine planning,
b) developing sufficiently large mines, and
c) mine development up to the economic depths by opencast mining methods.

This coupled with lack of technology for underground mining is definitely hampering the development of mines and will also restrict economic recovery of the chromite ore from the mines. A lot of ore is likely to be locked in the lease boundary restrictions in the case of contiguous mines, apart from limited development along the dip of the ore body by opencast means because of restricted strike length.

Since the deposits extend to depths greater than the pits, it has been suggested to start underground workings below the open pits, leaving a 20 m thick layer of hardened cement fill . The pits can then also be used for backfilling the wastes. This will require the wastes to be first beneficiated to recover the +10% Cr_2O_3 values available in most of the dumps.

The use of mill tailings or other waste for filling in underground mines, using cut and fill or post fill of open stopes will depend on the type of fill material available, its rheological properties to determine its flow characteristics and subsequent insitu drainage.

Another problem in the availability of internal dump room in open pits in the Sukinda area is that the lease holds are relatively short along the strike, preventing mining to pit limit and moving along strike to create room for backfilling.

The Director General of Mines Safety (DGMS) has issued an instruction for the mines of Sukinda region under which the pit slope up to 50 m of depth from the surface is to be maintained at 30^0 slope and for working below 50 m of depth the pit slope is to be maintained at 25^0. For overburden dump yards the dump slope is to be maintained at 37.5^0, the dump height can be made up to 30 m beyond which a suitable terrace is to be maintained.

6.1 MINES IN ODISHA STATE

6.1.1 Sukinda Chromite Mine of Tata Steel

Sukinda Chromite Mine is located in the Jajpur district of Odisha in forest land. Mining is done by open pit method in two blocks in the Mahagiri range. The ore is lumpy and friable ore type and pyroxenite type. Total geological resources as on 31.3.2011, are estimated as 76.91 million tonnes and mineable reserves are estimated as 14.2 million tonnes .

Shovel dumper based mechanised mining is carried out. The height of the benches varies between 6 m to 8 m. Tata-Hitachi 3.5 cum hydraulic excavators and 35 T dumpers are used to remove the overburden and the ore is mined in slices by 0.9 to 2 cum shovels and transported to the stockyard for dressing ,sorting and stacking. Twenty five Tonne Tetra / Volvo trucks are also used for transporting the ore to stack yards. The Mine uses motorgraders for road maintenance.

Drilling (150mm dia) and blasting is mainly required in the overburden benches in hard quartzite and ultrabasic rocks/serpentinites and sometimes in the ore also. The stripping ratios for the two pits are 3.78 (for the OBX quarry which is the larger quarry) and 6.88 in the lumpy grade mine, OBII.

The High and medium grade ore is processed and marketed directly, the low and below low grade ores/ beneficiable grade ores(+10% Cr_2O_3) are stacked separately for beneficiation in the chrome ore beneficiation plant of capacity 6.5 lakh tonnes per annum of chrome concentrate . Apart from the fresh generation of beneficiable grade ore from the quarries, the ultimate feed to the plant is achieved by suitably blending the same along with the mineral rejects and available old stocks of beneficiable grade ores. The ROM of lower grades or beneficiable grade of friable ore is sent to the low grade stacks / blending yard from where it is fed to the Chrome Ore Beneficiation Plant having an average feed grade of 30% to 38% Cr_2O_3.

It is also being proposed that the tailings containing upto 14-17% Cr_2O_3 will be reprocessed to recover metal values. Column flotation coupled with magnetic separation is planned to get a finished product upto 47% Cr_2O_3. In 2011-13, the mines produced 14,26,933 MT of friable, lumpy and pyroxenite ore, lumpy being the least and friable in largest quantity.

6.1.2 Proposed Underground Mining

Underground working by cut and fill/sub-level stoping in the unweathered zones in friable ore and southern lumpy ore bands are contemplated depending on extent of fracturing and condition of orebody/wall rocks. The filling wherever required, will be done with the rejects from the development drives and also from mill tailings stocked in the tailings dam. System of declines for trackless mining is proposed. Tata Steel in collaboration with CLRI has developed a process to use Organic Reductants to reduce the hexavalent chromium to trace levels in the concentrate.

6.1.3 Chromite Mines of M/s Indian Metals & Ferro Alloys Ltd

The IMFA operates three mines in the Jajpur district of Odisha. The Sukinda and the Mahagiri chromite mines are operated by opencast method of mining and the Nuasahi mine by underground method. The IMFA has another lease at Chingudipal with an area of 26.62 ha in forest land in the same district. Mining has not started.

Fig. 6.1 : Open cast Sukinda Chromite Mine of TISCO

Sukinda: The lease area is 116.76 ha of non-forest land having 90.302 lakh tonnes of mineable reserves and total resources of 132.667 lakh tonnes grade averaging 44-46% Cr_2O_3. Last exploration was in 2010-11. The pit is 50 m deep and bench height of maximum 8 m. Small size machinery consisting of Hydraulic excavators and small trucks and tippers are used. The mineral occurs in two bands in a major intrusive of ultramafics consisting of alternate bands of chromite, dunite, peridotite and Orth-pyroxenite. The Band-1 is being mined and it is thick, continuous and friable. Band 2 is thinner and friable and will be mined later. Very little blasting is required. The production during 2011-12 in four grades ranging from 30-40% to +52% was 220000 tonnes which was entirely consumed in the company's charge chrome plant in the state.

Mahagiri : The ore ranges in three grades from 40% to +52%. The opencast work is likely to last another five years and will be closed at + 185 m RL. Due to soft and highly weathered rock below this level, a large parting was necessary to be left. Therefore, underground development work has already been started at the mine since January 2009, after leaving a 50 m solid barrier below the open-pit. The underground mine will work with a vertical shaft and decline, using trackless machinery, the method of work being Sub-level stoping with consolidated hydraulic backfill (containing cement mix).

Nausahi underground mine. The lease area is 40.468 ha mostly in non-forest land, except for 0.339 ha, has mineable reserves of 16.87 lakh tonnes and total resources of 30.99 lakh tonnes of grades in +52%; 40-51.99% and 30-39.99%. The last exploration was done in 2010-11. The mine is worked by underground method at present and access is through two inclines extending from +72m RL to -45m RL and -105m RL respectively. Current working level is at -105 m RL. The inclines are interconnected at -45m RL.

The development is through drives and raizes for an open sub-level stoping method of mining. The level interval is 60 m and sub-levels are driven at 30 m in competent strata. In case of weak strata, the level interval is reduced to 10-15 m. The slot raise is developed in the ore at the f/w contact and is widened upto the h/w. The longhole rings are blasted against this free face. Longhole drilling machines, dth drills and Cavo and Eimco 21 rocker shovel loaders are used and haulage is through battery locos. In future a shaft will be sunk for from surface to -225m RL making more interconnections at different main levels to the inclines. In 2010-11, the mine produced 102305 tonnes of Cr_2O_3 in all grades, lumps being the main fraction.

6.1.4 Chromite Mines of Orissa Mining Corporation Ltd (OMC)

The OMC operates two mines at present out of a total of eleven leases in Jajpur, Keonjhar and Dhenkanal districts of Odisha state. These are the South Kaliapanai and Sukrangi mines in Jajpur district. Eight of the other leases are waiting for forest clearance and one is waiting for environmental clearance. Exploration work is also suspended in these leases for the above reasons. Exploration in the working lease has been ongoing in 2011-12. The mines which are working operate by the opencast method.

South Kaliapani Mine : This mine has a lease area of 552.457 ha and the total resources as on 30.12.2011 are 235.46 lakh tonnes in three grades, +48%, 48-42% Cr_2O_3 and 42-10%. There are two pits D & F, one partly mechanised and the other fully mechanised. The bench heights are maintained at 6 m. The mechanised mine is 1260 m x592 mx 80 m and the manual one is 550 m x 238 m x 22.5 m. The mechanised workings operate with Volvo 2.45 cum, and 4 cum hydraulic excavators, wheel loaders and 25/35 T tipper trucks, along with other supporting machinery, including a motorgrader. The other pit operates manually and a section works with smaller machinery. The ore grading +10-40% $Cr_2O_3$is separately stacked for the purpose of beneficiating in the COB plant in the lease area of capacity 3.24 lakh tonnes per annum. The mine has cumulatively produced 10.12 lakh tonnes of ore in 2010-11.

The lease area is 73.777 ha, mostly in forest land, having mineable reserves of 32.2 lakh tonnes of +30% Cr_2O_3 and the total resources are 93.5 lakh tonnes. The last exploration was in 2010-11. The depth of working is 19m with bench height of maximum 6m . The chromite band VI is hard and lumpy. The mining is with similar mechanised method and equipment. The OB is currently being backfilled in the pit. The mine produced 48622 tonnes. The OMC supplies chrome ore to 57 Ferro-chrome, chemical and refractory industries within and outside Odisha. The supply grade varies from 42/44% Cr_2O_3 to +54% Cr_2O_3.

Sukrangi Mine: This mine has a lease area of 382.709 ha and the total resources as on 30.12.2011 are 44.42 lakh tonnes in five grades, +54% Cr_2O_3, 54-48% Cr_2O_3 , 48-42%, 42%-30% Cr_2O_3 and 30- 10% Cr_2O_3. The mine is being operated by opencast semi-mechanised method with bench height of 6m. The pit depth has reached 54m. 100mm dia wagon drilling, 3.2cu m/2.8 cu m Komatsu and Daewoo excavators and Tipper trucks with supporting machinery are used. The ore is transported to the COB plant at Kaliapani mines. Ore grading 5-25% is retained in a separate dump for future upgradtion. The mine has produced 9215 tonnes of ore in 2010-11.

Bangur Chromite mine : The mine has been opened with two inclines and levels established at +30m, 0 level and -30m RL. It is proposed to work the mine to -60m RL. The mine was to work by open stoping with panels developed with intervening solid 10m rib pillar for support. The mine has produced around 4000 tonnes per annum for four years and is presently not working since 2010 for want of EC.

6.1.5 Chromite Mines of FACOR

The company operates three mines in three districts of Odisha state , namely Ostapal mines (72.843ha mostly forest land) in Jajpur, Kathpal mines (113.312 ha forest land) in Dhenkanal and Boula mines (187.03 ha forest land) in Keonjhar districts. Among these, the Ostapal mines is worked by opencast method, while the other two only have underground workings.

Ostapal Mines: The mine has mineable reserves of 55.585 lakh tonnes and total resources of grade around 40% Cr_2O_3. The last exploration done is in 2010-11. The mine is operated with three small capacity (1.5 cubic metre) hydraulic excavators and small tippers and other supporting equipment. The mine produced 179870 tonnes of Chromite ore fines, in three grade ranging from 40 to 52% Cr_2O_3. The mineral is used in making charge chrome and the Facor alloy plant in AP. The below 40% mineral is beneficiated in the company's COB plant in Ostapal. Some concentrate is exported also.

Kathpal Mines: The mine has mineable reserves of 4.976 lakh tonnes and total resources of 17.095 lakh tonnes of Cr_2O_3 grading from 40 to 52%. Exploration was done in 2010-11. The ore body is highly disturbed having limited strike length resulting in quick exhaustion of orebody in a given level causing development expenditure for deeper levels. Open stoping with basic underground equipment is practiced. The mine produced 19481 tonnes of lumps and 1816 tonnes of fines in 2010-11. The mineral was used internally to produce charge chrome and the alloy plant in AP.

Boula Mines: The mine has mineable reserves of 31.75 lakh tonnes and total resources of 50.1 lakh tonnes. There are four grades, 35-38%, 38-44%, 38-42% and 42-50% Cr_2O_3. The mine produced 91889 tonnes of mineral as lumps grading -40% Cr_2O_3 in 2010-11. Sub level open stoping with longhole drilling is practiced. The mineral was used internally to produce charge chrome and the alloy plant in AP.

6.1.6 IDCOL Ferro-Chrome and Alloys

Talangi Chromite Mines: The mine in Jajpur district, has a lease area of 65.683 ha partly in forest land. The mine has mineable reserves of 3.563 lakh tonnes and total resources of 6.243 lakh tonnes of Cr_2O_3 grading from 30 to 52%. The ore body occurs as vein & lenses in weathered ultramafics . The deposit is highly folded and exhibits high dip varying from 70-80 degrees. The ore zone is covered by loose sediments consisting of boulders, pebbles. The (-) 30% mineral is beneficiated at the COB plant. The mine operates by opencast method and the pit is 47 m deep. The bench heights in ore are 1.2 m and those in waste are 5 m. Small hydraulic excavators and tippers with supporting machinery is used for production and handling waste to the dump and for backfilling the pit. The IDCOL mine produced 95,959 tonnes of ore fines in 2010-11.

6.1.7 Balasore Alloys Ltd

Kaliapani chromite mine: The mine in Jajpur district, has a lease area of 64.463 ha, in non-forest land, area under the pit being 17.85 ha. The mine has mineable reserves of 31.55 lakh tonnes and total resources of 63.76 lakh tonnes of Cr_2O_3 lumps and fines grading from 32 to

52%. The mine operates by opencast method and the pit is 73 m deep. The bench heights in ore are 8 m and those in waste are 8 m. Small hydraulic excavators are used for loading and tippers with supporting machinery is used for production and handling waste to the dump. The mine produced 2,44,260 tonnes of ore fines in 2010-11 and handled 728429 cu m of waste and 38263 toones of tailings. The mine has a beneficiation plant (20tph) which is fed mineral of average grade 30% and has a product grade of + 50%, located in the lease area. The mineral is internally consumed in the alloys plant of the company.

6.1.8 JSL Stainless Ltd

Jindal chromite mines : The mine in Jajpur district has a lease area of 24.24 ha in forest land and 64.76 ha in non- forest land, area under the pit being 24.4 ha. The mine has proved and probable reserves of 46.90 lakh tonnes out of which 1.996 lakh tonnes is directly acceptable grade and 5.7 lakh tonnes are beneficiable grade. The total resources are 84.66 lakh tonnes of Cr_2O_3 lumps and fines in bands I , II and VI, grading from 38 to 44%. The mine operates by opencast method and the pit is 75 m deep. The bench heights in ore are 6.0 m and those in waste are 6 m. Small hydraulic excavators of 2.5 cu m are used for loading and 25/35T trucks with supporting machinery, inc. a grader, is used for production and handling waste to the dump. The mine produced 99,855 tonnes of lumps, fines and concentrate in 2010-11 and handled 1167602 cu m of waste and 337112 tonnes of tailings. The mine has a beneficiation plant (10tph) which is fed mineral of average grade 28-30% Cr_2O_3 and has a product grade of 43-46%, located in the lease area. The mineral is internally consumed by the company.

6.1.9 Misrilall Mines Pvt Ltd

Saruabil chromite mine: The mine in Jajpur district has a lease area of 224.633 ha in forest land and 22.225 ha in non- forest land, area under the pit being 41.22 ha. The mine has proved and probable reserves of 29.31 lakh tonnes, 2010-11. The total resources are 39.34 lakh tonnes of Cr_2O_3 lumps and fines grading from 40 to 52%. The mine operates by opencast method and the pit is 55 m deep. The bench heights in ore are 6.0 m and those in waste are 6 m. Small hydraulic excavators of 2.5cu m are used for loading and 25/35T trucks with supporting machinery, inc. a grader, is used for production and handling waste to the dump. The mine produced 1,04,000 tonnes of lumps, fines and 14183 tonnes of concentrate in 2010-11 and handled 4,23,000 cu m of waste and 12217 toones of tailings. The mine has a beneficiation plant (20tph) with 54-56% recovery , which is fed mineral of average grade -40% Cr_2O_3 has a product grade of +52 %, located in the lease area. The mineral is internally consumed and also exported (+40 –52% Cr_2O_3) from the Paradeep port by the company.

6.1.10 B.C.Mohanty & Sons Pvt Ltd

Kamarda chromite mine: The mine in Jajpur district has a lease area of 107.24 ha, mostly in forest land. The mine has mineable reserves of 16.37 lakh tonnes and total resources of 18.07 lakh tonnes of Cr_2O_3 grading from 10 to 48%. The mine has a beneficiation plant of capacity 3000 TPM. The mine operates by opencast method and the pit is 37 m deep. The bench heights in ore are 1.5 m and those in waste are 6 m. Small hydraulic excavators along with a larger wheel loader are used for loading and tippers with supporting machinery is used for production and handling waste to the dump. The mine produced 87,500 tonnes of ore fines in 2010-11. The mineral is sold to ferrochrome plants in the area and sometimes exported.

6.2 CHROMITE MINES IN KARNATAKA

The Mysore Minerals Ltd, a state owned company is the only producer of Chromite in Karnataka. Although Chromite mainly occurs in Hassan and Mysore districts of the state, the Sinduvalli underground mine in Mysore district has been abandoned and the other deposits have minor reserves. The working mines, five in number, including an underground mine are in the Hassan district.

The MML has estimated reserves of 12,36,000 tonnes of chromite in their mining leases of 988.48 hectares in the Nuggehalli schist belt of Hassan district. The ores are ferruginous and the average Cr/Fe ratio is around 1.9. The grade of ore varies from 25-43% Cr_2O_3. Nickel, Cobalt, Vanadium are the trace metals present in the ore.

The open-pit mines are manual to semi-mechanised and use only small backhoes and hydraulic shovels and 20-25 tonne trucks to handle the OB and manual sorting picking and loading of ore. Byrapur mines is the underground mine, producing very small quantities in recent years. The mines cumulatively produced 8942 tonnes of ore in 2010-11.

6.3 INTERNATIONAL

6.3.1 Kazakhstan

Robust growth in India and China's construction sectors has translated into significant increases in demand for ferro alloys. Ferro alloy output will have to double in the next decade if it is to keep up with expected growth in stainless steel production. Ongoing power outages in South Africa's ferro alloy production sector leave the Kazakh market well placed to capitalize from the expected increases in demand. At 300 million tonnes, Kazakhstan's chromium reserves are the second largest in the world behind South Africa's.

ENRC is solely responsible for Ferro alloy production in Kazakhstan with 2.4 million mt of chromium and 1.3 MT of manganese ore extracted in the first half of 2010. Chromium extraction increased by 25% from 2009, reflecting sustained increases in global demand. Very much aware of the huge potential in Kazakhstan's vast ferro alloys reserves, Russian mining conglomerate Mechel recently entered the market on the back of its acquisition of London-based Oriel Resources.

Mechel is currently developing a US$250 million mine at Voskhod, and is ENRC, a leading diversified natural resources group with integrated mining, processing, energy, logistical and marketing operations. The Group's assets are mostly located in the Republic of Kazakhstan.

Kazakhstan's mining opportunities seem vast. The country's interests stretch from coal and chromium to silver, nickel and industrial metals, and recent statistics show 95% of the elements in Mendeleev's periodic chart are found here. Proven chromium reserves in Kazakhstan amount to a third of the world's chromium reserves. The state register lists 23 deposits with almost all industrial reserves owned by the transnational company, Kazkhrom. Mining is being carried out at nine deposits owned by Kazkhrom and one by Voskhod-Oriel. The country is currently producing about 4 million tonnes of chromium ore and this figure is expected to grow to 7 million in 2010 and 9 million by 2015.

Kazakhstan is the ultimate mining and metallurgical country producing 25 different kinds of ferrous, non-ferrous and precious metals. Some 233 mining enterprises produce a wide variety of commodities - coal, iron ore, chromites ores and ferroalloys, alumina, copper, lead, zinc, steel, titanium sponge, uranium, barites and others. Mining activities are currently being carried out at 2,000 mines in Kazakhstan, which consists of prospecting at 132 mines (7%), extraction at 1,213 (61%) and both activities at 641 (32%). The start of the industry's regeneration came in 1994 when it developed new mineral deposits by encouraging foreign investment. By 2000, the country's mining sector employed 126,000 workers, about 5% of the country's workforce.

Virtually the entire mining sector had been privatised by 1998 and in exchange for permission to operate Kazakh mines and gain shares in profits and ownership rights, foreign companies invested in modernisation, increasing production and exports, decreasing costs, and upgrading technology. Kazchrome is the world's single largest chrome ore miner, operating a 600 000 tonne per year pellet plant in the town of Khromtau, in the northwestern Kazakh region of Aktobe. A new plant, expected to be running at full capacity by the end of 2009, will add to production, and supply most of its pellets to Kazchrome's ferro-alloy smelters in Aksu and Aktobe.

Voskhod Chrome Mine and Plant : The deposit is located in North West Kazakhstan 90 km from Aktobe. It is mined by underground method, access being through decline and shaft. The mineralised zone consists of massive chromite, powdery chromite, orbicular chromite, vein chromite and disseminated chromite. The average annual output is 1.3 million tonnes of mined chrome ore and 900,000 tonnes of lump, chip and concentrate. Production based on development ore commenced in 2008. The indicated resource of 19.1 million tonnes at 48.5% $Cr_2O_3$with potential extension from the adjacent Karaagash deposit of 4 to 8 million tonnes. Bateman carried out the pre-feasibility study in 2005. SRK (DFS Study Manager), DRA designed the plant based on Mintek's MPD test work data from Voskhod core samples . Lumps form 52.3% averaging 48% $Cr_2O_{3.}$

6.3.2 South Africa

World resources are estimated to be greater than 12 billion tonnes of shipping-grade chromite, sufficient to meet demand for centuries. In the region, 95% of the world's chromium resources are concentrated in Southern Africa and Kazakhstan. South Africa is the world's largest producer of ferrochrome. The country holds about 70% of the world's total chrome reserves, mostly located in the Bushveld Igneous Complex (BIC) ores, and produces 75% of the world's ferrochrome. India and Kazakhstan are other major producers.

With low electricity prices, South Africa has been able to expand chromite and ferrochrome production more or less continuously since the AOD process was developed in the 1960s to use ferrochrome smelted from lower-grade ores. Chromite is mined primarily from the UG2, and LG and MG chromitite seams of which the UG2 also contains significant amounts of PGE's. Thus several platinum mines produce chromite as a by product. There are several primary chrome mines, specifically maintained to provide chromite feed to the developing ferrochrome industry. Most of South Africa's chrome mines are developed along the Eastern BIC, in the Steelpoort Valley. South Africa produced an estimated 9,600,000 tonnes of chromium ore in 2009.

Samancor was created in 1975 and is South Africa's leading exporter of chemical-grade chromite and foundry sand. Samancor Chrome is the second largest ferrochrome producer in the world, with total chromite resources exceeding 650 million tonnes. These are expected to support current mining activity for well over 200 years at the current rate of extraction. South Africa currently supplies in excess of 50% of worldwide charge chrome demand. Over 80% of Samancor's chrome ore output is consumed in the production of ferrochrome in South Africa. The remainder of the ore is exported.

Samancor has two mining centres: Eastern Chrome Mines (ECM) in the Steelport area of Mpumalanga Province and Western Chrome Mines (WCM) near Rustenberg and Brits in Northwest Province. Both units now comprise three underground mining areas, each with a hoisting shaft, while WCM also includes an open-cut mine. Overall capacity is approximately 5.8MT/y of run-of-mine ore.

Underground, Samancor relies mainly on room-and-pillar mining, typically with low-angle adits connecting to a horizontal access level. Thin seams limit the scope for mechanisation and blasting and relies on drilling with hand-held pneumatic jackleg units. The ore is mined either up-dip or down-dip in rooms approximately 20 m wide, with the roof supported by ore pillars. Scrapers haul chromite to ore passes that load trains on the haulage level. The trains load a conveyor in the hoisting adit. The dimensions in the Waterkloof/Millsell mining block have allowed WCM to replace scrapers with load-haul-dump machines. The open cut mine uses 8 tonne -capacity loading shovels and 40 toonne -capacity trucks. Chromex mining's projects are located on the western and eastern limbs of the Bushveld Complex. Chromex currently has a New Order Mining Right over the Mecklenburg farm in the Limpopo Province where it intends to mine chromite over a 10 year period.

The 271 hectare Stellite chrome project, located on the Western Limb of the Bushveld complex in South Africa, has a New Order Mining Right and 31.9MT of chrome resources comprising four seams. The project has been extensively drilled and has had approximately 170,000 tonnes of chromite mined and sold both to the domestic and international chrome markets. Chromex currently produces 42% and 44% metallurgical grade chrome concentrate. Xstrata Alloy's chrome mining operations mine the chromitite deposits developed within the Bushveld complex of South Africa. The Helena chrome mine is wholly owned by Xstrata, and lays to the south of it's Thorncliffe chrome mine on the Eastern Limb of the Bushveld Complex. Assmang's Chrome Division consists of the Dwarsrivier chrome mine and the Machadodorp ferrochrome works both in Mpumalanga.

6.3.3 Australia

Australia has a single working chromite mine in the Pilbara region of Western Australia, near the indigenous community of Jigalong. The mine produces high grade lump chromite in the range of 300,000 tonnes per year. The Coobina chromite project is about 80 kilometres south-east of Newman and 585 kilometres south of Port Hedland in WA.

Consolidated Minerals, also a manganese producer, acquired the Coobina project in 2001 and commissioned a new mining and processing operation in February 2002. Since the start of production, the company has become well established as an independent and reliable supplier of chromite to the world market.

The Coobina chromite deposit occurs at the western end of a 10 km long belt of ultramafics that lie within the Archaean granites of the Sylvania inlier. The chromite mineralisation occurs as massive chromite accumulations in lenses or pods at the extreme western end of the ultramafics. Up to 150 distinct chromite lenses have been mapped, with the largest recorded being about 340 m long and forming up to 6 m wide zones with multiple lenses. Ore is produced from open pits generally with a waste to ore ratio of 6:1, using a hydraulic excavator and dump trucks. Chromite ore is sourced from several pits to allow blending of ores from various deposits. The ore is then crushed and screened to remove fines and then beneficiated through a heavy media drum plant. Product from Coobina is trucked to Port Hedland where it is exported to major overseas markets, primarily to China. Consolidated Minerals June 30 quarterly reported that 76200 tonnes of chromite ore was produced for the quarter ending June 30, 2011, a 122 per cent increase against the previous corresponding quarter. Due to strong demand, chromite sales for the quarter had increased by 156 per cent compared to the June 2010 quarter. Consolidated Minerals planned to increase production at Coobina as chromite ore prices increased and to meet a rise in demand resulting from successful marketing initiatives.

6.3.4 Canada

The Big Daddy Deposit in the Ring of Fire may be as much as 100% lumpy ore. Micon estimated that the Big Daddy Massive Chromite Domain contains an indicated resource of million tonnes averaging 40.66% chromium oxide (Cr_2O_3), and an additional inferred resource averaging 39.09% Cr_2O_3. Cliffs Natural Resources Inc. (United States) reported that its chromite ore resources in Ontario were in the prefeasibility stage of development. Having completed the acquisition of Freewest Resources Canada Inc. and Spider Resources, Inc. Cliffs owned 100% of the Black Thor and Black Label properties and 74% of the Big Daddy property in 2010. Cliffs planned to produce from 1 to 2 MT/yr of chromite ore out of which it would produce from 400,000 to 800,000 t/yr of ferrochromium.

6.3.5 Finland

The Kemi chrome deposit is situated close to the town of Kemi on the coast of the Gulf of Bothnia in northern Finland. The deposit was discovered in 1959 and after detailed geological and metallurgical investigations the mine was established in 1968. In 2005, the ore production moved entirely underground. Today, the annual production is around 1.3 million tonnes of ore. The production of upgraded lumpy ore totals some 200 000 tonnes and fine concentrate about 400 000 tonnes. The chromium oxide contents of the concentrates are 35.0 and 45.0 %, respectively.

Proven ore reserves at the Kemi Mine total some 36 million tonnes, while the quantity of mineral resources total some 87 million tonnes – estimated to a depth of one kilometre. According to a seismic research report produced by the Geological Survey of Finland in 2009, mineral resources at the Kemi Mine could turn out to be significantly greater than indicated by earlier estimates. The intrusion which contains chromium ore was found to extend to a depth of 2–3 kilometres and possibly to four kilometres, while the chromite layer possibly extends to a depth of 2–2.5 kilometres or more. Information in the new seismic research report indicates the existence of resources sufficient to allow several hundreds of years of mining activity. The decision to double mine output as part of ferrochrome production expansion was made in 2010 and the project is ongoing.

Finland produced chromite ore (Kemi Mine), ferrochromium (Tornio Works), and stainless steel (Tornio Works). Outokumpu produced 0.598 MT of marketable chromite ore from 1.3 MT of run-of-mine ore and 0.238 MT of ferrochromium compared with 0.247 MT of chromite ore from 0.9 MT of run-of-mine ore and 0.123 MT of ferrochromium in 2009. The company reported proven reserves of chromite ore at 36 MT graded at 26% Cr_2O_3, and indicated resources of chromite ore at 13 MT graded at 30% Cr_2O_3, and inferred resources of chromite ore at 74 MT graded at 29% Cr_2O_3.

6.3.6 Albania

The Bulqiza chromite deposits, within the historically productive, chromite-bearing Bulqiza Ultramafic Massif, Albania are among the largest folded stratiform occurrences in the world with the famous Bulqiza-Batra mine containing production plus reserves of about 18 million tonnes. The ores are characterized by exceptionally high grade (+40% Cr_2O_3) and metallurgical quality (CrFe ratios of 3:1) and command premium prices in global markets. The Albanian chromite ores were discovered in 1942 and the famous Bulqiza mine developed in 1948. Production in 2007 was 285,000 tonnes with roughly half from the privatized Bulqiza mine with the balance from small-scale surface and underground pillar-robbing operations by local miners.

The Bulqiza Massif is the most productive of 17 chromite-bearing ultramafic bodies in eastern Albania and has produced approximately 20 million tonnes of high grade chromite ores during the past 50 years. The Massif is composed of lower and upper layers of harzburgite, differentiated by increasing dunite facies and chromite lodes in the upper sequence, and overlying cumulate made up of dunite, pyroxenite and gabbro. The Massif can be described as a northwest-oriented ovoid mass, some 4-6 km thick and covering a surface area of 370 km^2, with a variable westward dip.

The Bulqiza Massif contains some 65 chromite deposits on which mining or significant development work has been undertaken and over 370 occurrences or showings. The principal mineralization occurs in the famous Bulqiza-Batra ore structure which has been developed and mined semi-continuously for a strike length of 5 km and through a vertical range of 900 metres in the Bulqiza mine and 450 metres in the Batra sector. The Bulqiza-Batra chromite ores consist of tabular-concordant layers of banded, semi-massive to massive mineralization within serpentinized dunite alteration envelopes containing disseminated mineralization. Ore thickness averages about 3 metres but is commonly thickened by folding. Grades typically exceed 40% Cr_2O_3. Sub-concordant, pipe-like and podiform styles of mineralization, comprising deposits ranging in size from several hundred thousand to several million tonnes, occur throughout the Massif.

Empire Mining Corporation has acquired exclusive exploration and development rights to four exploration licences, totaling 64.5 km^2. These are the **Bulqiza-Batra** Licence (38.8 km^2), **Bulqiza Veriore** Licence (6.9 km^2) , **Qafe Burreli** Licence (6.1 km^2) and the **Liqeni i Dhive** Licence (12.7 km^2). Empire plans to raise money by finding a partner either to help develop the mine or buy the product on a long term basis, perhaps from China, which has now turned into a key investor in the mineral industry.

ACR Albanian Chrome [a subsidiary of DCM DECOmetal GmbH (Austria)] produced ferrochromium for export at its Elbasan smelter using chromite ore from Bulqiza Mine. ACR planned to upgrade the Bulqiza Mine and Elbasan smelter and renovate the ferrochromium smelter at Burrel. ACR would increase its ferrochromium production capacity to 72,000 t/yr from the current 36,000 t/yr with the addition of a third furnace at Burrel.

6.3.7 Brazil

FERBASA began operating in the town of Campo Formoso (state of Bahia) as a mining company with the purpose of producing chrome ore. It is the largest producer of ferrochrome alloys in Brazil. FERBASA currently mines chromite in two groups of mines located 90 kilometres apart in the central-north region of the state of Bahia: the district of Vale do Jacurici, with 15 mines and a north/south extension of around 120 kilometres, and the Campo Formoso district, with 9 mines. Its main mines are Pedrinhas, in Campo Formoso, and Ipueira, in Andorinha. The Pedrinhas mine became operational in 1961 through the open-pit mining method, which continues until today, removing around 1,000,000 m^3 of material "in situ" per year. Its products are hard lump and chromite concentrate (foundry-grade) and production is running at 120,000 t/year.

The Ipueira mine began producing chrome ore in 1973 as an open-pit mine. It currently produces 880,000 t/year of run of mine (ROM) through underground mining, the sub-level caving and sub-level open stope methods. Its products are hard lump - 276,000 t/year, chromite sand (foundry-grade) - 24,000 t/year and chromite sand (foundry-grade) - 48,000 t/year. The Company holds mining rights over nearly 85% of Brazil's chromite reserves, located 430 km from the port of Salvador.

Mining

Normally, the main access is via tunnel or shaft, through which the electrical, water, compressed-air and ventilation systems are installed, workers and machines circulate, and the material is extracted. The most commonly used items of equipment include crawler drills (jumbos), fan drills, load haul dumpers (LHDs) and regular loaders, haulage trucks, scalers, utility platforms and self-propelled concrete sprayers. Special attention is given to rock mechanics in order to ensure gallery stability and, consequently, adequate safety and hygiene conditions, since ventilation and dust and gas control play an essential role in operational productivity. Once extracted, the larger grain sizes (above 2") are mechanically separated, resulting in lump ore. Subsequently, the finer grains are treated via size reduction, classification and concentration through the use of crushers, mills, sieves and hydro-gravimetric and magnetic separators, resulting in chromite concentrate, which is used in metallurgy, and chromite sand, which is sold in the domestic market.

Mining operations are focused on chrome ore (chromite), and are carried out in two mining complexes, located in Campo Formoso (whose main mine is the Coitezeiro mine), and in the Vale do Jacurici, in Andorinha (the Ipueira and Medrado mines). These locations are approximately 430 km from Salvador. Brazil produced chromite ore, ferrochromium, and stainless steel. Brazil reported 2009 chromite ore production of 365,210 t (140,786 t Cr_2O_3-content), exports of 75,334 t, and imports of 11,953 t. Brazil produced from chromite ore reserves of 3.824 MT, mostly in Bahia State. In 2009, Brazil produced 131,048 tonnes of chromium ferroalloys, exported 5,063 tonnes, and imported 6,030 t (Ramos, 2010).

6.4 REFERENCES

1. **www.e-mj.com.KAZAKHSTAN MINING, DECEMBER 2010**
2. **Outokumpu Ojy, 2011.** CHROMIUM—2010 [ADVANCE RELEASE]

3. Mintek (Study Manager)
4. **International Seminar on Development of Chromite, Nickel and PGM Resources**, (28Nov, 2010 Bhubaneshwar) SGAT & Dept. of Steel & Mines, Government of Odisha
5. **Indian Minerals Yearbook- 2011; Indian Bureau of Mines,** Government of India , Ministry of Mines; December, 2012
6. **Draft document on formulation of strategy for exploration, exploitation and development for chromite in India**, by 'The sub-group on chromite' J.K.Nanda & B.K. Jena, Directors GSI; M. Sengupta, RMG, IBM,Nagpur & Naresh Nautiyal, Dy.GM(Exploration), MECL, March 200

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Chapter 7

CHROMITE ORE BENEFICIATION

7.0 GENERAL PRACTICES

Chromite ore is a combination of chromite minerals and gangue minerals that are separated through the beneficiation process after mining. Chromite mineral is the chromium-rich component of a complex family of spinel group oxide minerals comprising aluminium, chromium, magnesium, and (or) iron in solid solution. The chromium-rich components are magnesium chromite ($MgCr_2O_4$) and iron chromite ($FeCr_2O_4$). Gangue minerals comprise one or more silicate minerals. Gangue minerals affect the performance of chromite products, because beneficiation does not completely separate them from chromite ore. Metamorphosis of ore can result in the Cr_2O_3 reporting to the gangue minerals stream (tailings) during beneficiation (Greico, 2010).

Mineral beneficiation of chromite ore is the exploitation of physical properties, such as density and chemical, magnetic, and surface characteristics, to produce concentrates. Current chromite ore beneficiation practice is to separate chromite ore from gangue minerals via dense media separation or gravity separation, which take advantage of the higher density of chromite minerals [4.3 to 4.5 grams per cubic centimetre (g/cm^3)] compared to that of silicates (the gangue minerals) (2.6 to 4.0 g/cm^3).

The purpose of beneficiation is to render the ore physically (granulometry) and chemically suitable for subsequent treatments. Operations typically serve to separate and concentrate mineral values from waste materials, remove the impurities or prepare the ore for further refinement. Beneficiation activities do not change the mineral values themselves other than by reducing (crushing and grinding) or enlarging (pelletising and briquetting) particle size to facilitate further processes. Chromite ore is beneficiated for processing using several methods. The ore source, end use sector requirements, mineral characteristics of the ore deposits, gangue mineral assemblage and the degree of dissemination of constituent minerals determine the beneficiation practices and methods that are used. A general representation of a chromite ore beneficiation process is shown in Figure 1 and consists of two sections, i.e.

1. communition (preparing the material for subsequent unit operations)
2. and concentration (Murthy et al., 2011; Abubakre et al., 2007).

In the feed preparation section the run-of-mine ore is screened from ±220 mm to 75 mm. This is followed by a primary and secondary crushing stage separated by screening to produce an offset of less than 3 mm. The secondary crushers offset is recycled back and rescreened. The crushed ore is then further grounded to less than 1 mm. In the concentration section the ore is upgraded using conventional gravity techniques like spiral concentrators and shaking tables (Murthy et al., 2011:377).

Though gravity techniques are well established and widely accepted for the concentration of chromite ore, such techniques become inefficient and complex while treating fine size particles of less than 75 μm. Recovery is a concern particularly in finely disseminated ores due to its inherent complexities. Each gravity separation technique delivers its maximum efficiency under specific operating conditions and particle size range (Murthy et al., 2011:377). Heavy medium and gravity concentration methods are the most commonly used beneficiation processes. Heavy medium separation is the most economical method when coarse particles ranging between 10-100 mm need to be treated. In the case of finer particles, jigs, spirals and shaking tables are used. Spirals are, however, the most important among gravity concentrators and are currently the preferred choice. Chrome can be recovered within the range of 80 to 85% when using these processes (Gu & Wills, 1988; Howat, 1986).

Gravity separation methods predominate over flotation techniques (Nafziger, 1982). Flotation is thus not a major method of beneficiation for chromite ores. In some instances fatty acids, such as oleic acid, have been used where flotation has been adopted as a method of separation. Chromites from different locations exhibit a wide variation in surface properties which is a major difficulty when making use of flotation (Gu & Wills, 1988).

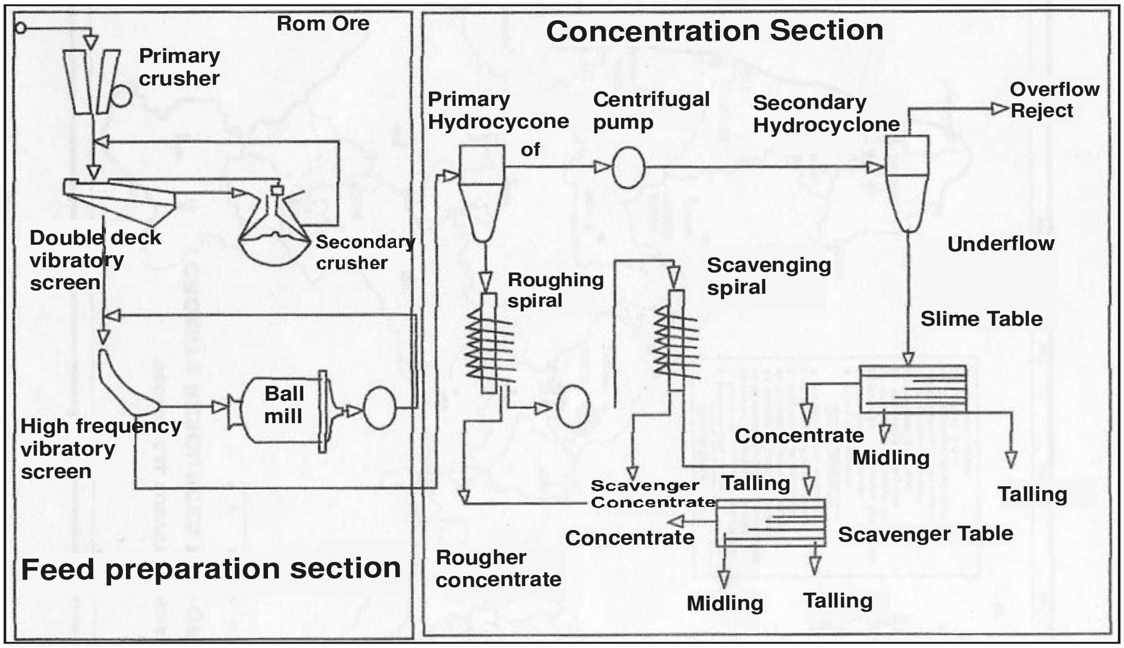

Fig. 7.1 : General Process Flow sheet for Chromite Ore Beneficiation (Murthy et al., 2011)

All chromites are paramagnetic at room temperature. Their magnetic capacity is dependent on the Fe^{2+} content (Owada & Harada, 1985). It has been speculated that this ferromagnetism is predominantly present in the sections more concentrated with Fe^{2+} because of the non-uniform distribution of magnetic ions in the crystalline structure. Low-intensity magnetic separation (about 0.1 T) is used to reject the magnetite from paramagnetic chromite material, but is inefficient in separating the chromites that are present in fine intergrowths with other materials.

In a high-intensity magnetic field (about 1 T) chromite can be extracted as a magnetic product from the gangue material (Gu & Wills, 1988; Nafziger, 1982). South African chromite ores are relatively friable and easily break down to the size of the chromite crystals (Gu & Wills, 1988). Due to this friability, it is common to only recover 10-15% lumpy ore (15 mm < typical size range< 150 mm) and 8-12% chip or pebble ores (6 mm < typical size range< 15 mm) during the beneficiation process employed after chromite mining. The remaining ore would typically be in the < 6 mm fraction, which would usually be crushed and/or milled to < 1 mm and then upgraded utilising typical gravity separation techniques (e.g. spiral concentrators) to approximately 45% Cr_2O_3 content. This upgraded < 1 mm ore is commonly known as metallurgical grade chromite ore (Glastonbury et al., 2010) Table 1.

Table 1 : Common Methods Adopted in Chromite Beneficiation

Sl.No.	Method	Advantages	Disadvantages
1.	Heavy Media Separation(HMS)	i) Better separation if the gangue is siliceous. ii) Possible to get coarse concentrates.	Separation is not good if the gangue is ferruginous and when chromite is finely dispersed.
2.	Jigging	-do-	-do-
3.	Reichart Cone Separator	i) High capacity. ii) Possible to treat pulp having vide range particles.	i) Requires to treat pulp with high percentage of solids. ii) Concentrates produced require cleaning.
4.	Spirals	i) Better separation possible to get cleaner concentrates directly. ii) Pulp with low percentage of solid can be treated.	i) Limited capacity and throughputs.
5.	Tabling	Good for cleaning.	Less capacity operation.
6.	Bartles-Mozley Separator	Good for recovery of chromite from slimes.	Not a continuous process unit(Batch operation).
7.	Bartles Cross Belt	Good to recover chromite from tailings.	-
8.	Wet High Intensity Magnetic Separator(WHIMS)	High gauss strength and possible to separate paramagnetics at very fine size.	Restricted use due to high capital costs.
9.	Flotation	Useful to pre-concentrate low grade ores which requires very fine grinding to liberate chromite.	Gravity concentration after flotation is necessary to obtain cleaner concentrates.
10.	Multi-gravity separation	Useful to concentrate low grade ores which require fine grinding for liberation.	-
11.	Column Flotation	Finds utilization in concentration of low grade ores with low Cr:Fe ratio.	-

7.1 BENEFICIATION OF A LOW GRADE CHROME ORES

Beneficiation of a low grade chrome ores is an essential step towards optimum utilisation of natural resources. Some of the age old practices like hand-picking, size reduction, screening are still in use to upgrade and prepare chromite ore for use in the industry. During mining, ferruginous and siliceous chromite ore fines are created as rejects and have no market value.

These low grade rejects can be utilised after suitable beneficiation which help in conservation of high grade ore where resources are limited in the country. Simple gravity separation by tabling is very commonly practiced when the gangue is siliceous in the form of serpentine and talc. Besides tabling, washing, screening and classification are practiced in case of friable ores. Heavy media separators and Jigging are employed to recover coarse chromite. Humphrey's spirals or Reichart spirals are quite effective to concentrate chromite, prior to tabling. For high throughputs, these units are used in parallel and multiple units. Reichart cones are also employed for high capacity and to treat comparatively unsized feeds.

Bartles-Mozley concentrators are used to treat slimes and recover fine chromite. Bartles Crossbelt concentrator and GEC Duplex concentrators are employed to recover chromite from plant tailings. Wet High Intensity Magnetic Separators (WHIMS) are being used either to recover chromite from slimes or to remove free iron oxides and to improve grade of Cr_2O_3 and Cr/Fe ratio of gravity concentrates. Froth flotation offers as an alternative technique to concentrate chromite from lower grade ores which require fine grinding for liberation. One of the few commercial plants to be operated is the Dyke flotation plant of African Chromite Mines Ltd in the Northern part of Rhodesia. The processes adopted are attrition scrubbing, desliming and flotation with a tall oil-fuel.

Recently, multi gravity separators, an enhanced gravity technique finds their wide applicability in the concentration of chromite ore fines. The fines produced as a result of the inefficiency of conventional separation equipment at fine particles size and due to finely grained feed optimisation problems always create a problem for conservation at mine site. MGS unit solves this problem to the larger extent.

Application of column flotation has been applied intermittently since the early 1960s for the upgradation of low grade chromite ore with low chromium iron ratio. New methods will be required to process lower grade or mineralogically more complex chromite ore deposits. Future beneficiation may incorporate preconcentration, sensor-based sorting, or higher density cut points of dense media separation.

7.2 BENEFICIATION OF CHROME ORE FOR REFRACTORY

As such chrome ore contain higher amount of SiO_2. In some of the Magnesia Chrome refractory the chrome ore having low SiO_2 (1%) is required. Therefore, as such chrome ore is beneficiated through washing with water to remove the gangue materials from the chrome ore. The typical analysis of low silica chrome ore is shown in Table-

Table 2 : Typical Analysis of Low Silica Chrome Ore

Chemical Constituents	Wt (%)
Cr_2O_3	57
Al_2O_3	11.5
Fe_2O_3	17.5
MgO	12.6
SiO_2	0.7

7.3 CHROMITE ORE PROCESSING IN OTHER COUNTRIES

7.3.1 South Africa

Samancor's concentrators – three for ECM and three plus a fluidised bed dryer for WCM – are individually configured to treat specific feed and yield a particular product range. Bushveld chromite is conveniently milled to recover a fine concentrate by gravity and elutriation techniques. However, ferrochrome furnaces need a porous charge so that lumpy ore and chips is also recovered by dense medium separation to mix with the fines. The fines may be agglomerated at the smelters, either by briquetting or using the Outokumpu pelletisation and preheating system, to reduce the amount of lumpy ore and chip required. Further, gravity separation and elutriation steps yield the specific grain sizes and reduced levels of impurities, such as silica, required for the chemical and foundry sand markets. Samancor currently operates a flexible smelting system with capacity in excess of 1MT/y of ferrochrome at three sites.

7.3.2 Turkey

Although spiral concentrators, Reichert cones, and Multi Gravity Separators (MGS) are used for chromite beneficiation, hydrosizer and shaking table combinations dominate the applications in Turkey. Chromite ores generally include serpentine and olivine as gangue minerals. The separation of chromite from its gangue minerals by gravity concentration method is easy. As Burt R O (1984) mentioned, when there is a reasonable difference in specific gravity between chromite and its gangue mineral, separation can be achieved easily. Shaking tables are globally widely used gravity concentration equipment in chromite treatment. Although the capital and the operating costs are higher than the competing equipment, the shaking tables are commonly preferred in gravity concentration methods due to the high efficiency of the operation. The separation can also easily be observed. It is a peculiarity of shaking tables that, when correct operating conditions are maintained, table performance is excellent and can rarely be surpassed by other types of separators (Deurbrouck and Palowitch, 1968).

Three different rod mill discharge chromite ores named as Kartaltepe, Kiraz and Sevgi from the region of Eskisehir-Turkey were investigated. Wet screening was applied to obtain the particle size distributions of the mill discharge samples that were taken from the plant. By using stereo-microscope, the liberation degrees of the minerals were determined in different size fractions. Shaking table was used for the concentration of size fractions classified by hydrosizer.

The gravity concentration methods were applied to Eskisehir chromite ores, which were named as Kartaltepe, Kiraz and Sevgi. The expected grade and recovery values for chromite could not be attained when the ore used as it received from rod mill discharge. Liberation analysis showed that the finer grinding was required to recover the middling particles as liberated. The enrichment process was repeated after finer grinding was applied to the same ore types. The results clearly implied that the recovery and the grade values were increased in both fine and coarse particles for Kartaltepe ore. These values also were increased in fine fraction for Sevgi ore. But it was noticed that there were still problems in the grade and the recovery values for Kiraz ore. Grinding the particles to very fine sizes caused them to report to the tailing part of the shaking table which resulted as an increase in the grade of the tailing for Kiraz and Sevgi ores. Therefore, it is suggested that the use of MGS for fine particle sizes will be more efficient.

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7.4 RESEARCH AND DEVELOPMENT

During mining operations to raise marketable ore (+38% Cr_2O_3) to the tune of 4 million tonnes and more p.a., sufficient quantities of sub-grade ores (10-35% Cr_2O_3) are also being excavated from these mines. In order to conserve these strategically valuable chrome resources, their beneficiation is very much essential and the major mine owners in the area like TISCO, OMC, FACOR and ICCL have been able to establish Chrome Ore Beneficiation (COB) plants at their mine sites. R&D studies in this regard have been carried out by organizations like RRL (now IMMT), Bhubaneswar, BARC, IBM and NML to help the industries. Leaner siliceous ore and ferruginous ore with impurities like talc, serpentine, chert, limonite and hematite etc. have been put to simple gravity techniques using tabling, jigging, spiral and classifier. Also d80 value for different types of chrome ore samples has been observed to be varying between 75 to 150 ìm as revealed from liberation studies in the laboratory. Product characteristics of the beneficiation plants are given in Table 2.

As learnt from the spinel composition of BNIC ores, beneficiated concentrates will be having lower Cr/Fe ratio. The highly magnetic ore of Boula has not responded to the conventional beneficiation processes and results in low Cr/Fe ratio. In case of lean chrome ores of TISCO extraneous iron in the form of goethite/limonite which is intimately associated with chromite, poses problem in complete removal. The beneficiated concentrates as well as naturally occurring friable ore are being agglomerated in these plants before being utilized as charge for ferrochrome production. FACOR and TISCO are using briquettes and pellets to some extent in their units at Randia and Bamnipal.

Table 3 : Product Chacteristics of Chromite Ore Beneficiation Plants at Different Mines

Agency	Plant Location	Rated feed capacity & grade	Concentrate output & grade
FACOR	Boula	1,00,000 tpa 15-21% Cr_2O_3	22,000 tpa 42-45% Cr_2O_3 Cr/Fe: 1.4- 1.7
TISCO	Bhimtangar	12,00,000 tpa 30-38% Cr_2O_3	6,25,000 tpa 47-50 % Cr_2O_3 Cr/Fe:2.6–3.0
OMC	Kaliapani	3,24,000 tpa 30-35% Cr_2O_3	1,50,000 tpa 52-55% Cr_2O_3 Cr/Fe:2.5 & above

Chrome ores and the associated rocks of Odisha have been well characterized earlier by the authors and co-workers at Regional Research Laboratory (now IMMT) that brought out significant mineralogical, chemical and liberation data which had been very much helpful in overall utilization of chrome ore resources.

Composition of clean chrome spinels of SUB and BNIC are having marked differences as shown below in Table 4. This indicates that low grade Sukinda ores on beneficiation can yield a concentrate with high Cr/Fe ratio and that of BNIC can yield a concentrate with Cr/Fe ratio not exceeding 2.

Table 4 : Chemical Composition of Clean chrome Spinels of Odisha Deposits

Location	Cr_2O_3	FeO(t)	Al_2O_3	MgO	Cr/Fe ratio
SUB	57.5-59.4	13.2-15.9	10.7-12.7	11.41-14.01	3.30-3.88
BNIC	49.4-54.9	23.7-26.68	9.8-14.4	8.9-11.64	1.67-2.04

The Institute of Minerals & Material Technology (IMMT), Bhubaneswar (CSIR) conducted roasting studies for Tata Steel Ltd, Sukinda, to recover the chromite values from plant tailings and based on the results pilot plant column was designed & installed at the COB plant. Laboratory tests indicated possibility of recovery of 44% Cr_2O_3 from a feed grade of 17-18% Cr_2O_3. Chromite overburden material from different mining sites in Sukinda district was collected for dry beneficiation studies by wet & dry processes to find nickel concentration. The feed sample of COB containing 0.9% Ni was enriched to 0.95% in – 45 micron fraction. In a study conducted for Ferro Alloys Corp. Ltd, investigations were conducted to improve the chrome-iron ratio of chromite concentrates of COB plant and recovery of chromite value lost in the plant tailings. The result of investigation indicates that a commerical grade concentrate can be recovered by combination of hydro cyclones and gravity tables. OMC Ltd executed an agreement with M/s HWMIPL for a new stand-alone chrome ore beneficiation (COB) plant of feed capacity of 1.5 lakh tpy to upgrade low grade chrome ore to high grade as well as a tailing pond for the existing and new COB plant at South Kaliapani mine.

Modification of existing COB plant to enhance its efficiency was also under consideration at Kaliapani mine.

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A number of new equipment have been recently installed in the Ore Dressing Laboratory of IBM. For gravity separation, Reichert Tray Test Assembly, GEC Duplex Table concentrator, Dynamic Heavy Media Separator (Triflow), Mozley's MGS are now available. For magnetic separation, Wet High Intensity Dry Magnetic Separators are available. There is a good scope for using latest equipment for gravity and magnetic separations in laboratory testing. IBM has carried out a number of bench and pilot plant scale studies using these equipment.

Salient achievements of Chromite beneficiation studies carried out during 2004 to 2012 are:

1. Pilot plant scale study on a ROM chromite ore sample from Sukinda mine, Jajpur District, Odisha for M/s Tata Iron & Steel Company Ltd, Dist. Jajpur, Odisha.

   The sample assayed 38.15% Cr_2O_3, 14.60% Fe(T), 23.50% Al_2O_3, 2.98% Silica, 6.10% MgO, and 7.8% LOI. The process adopted comprises grinding at 28 mesh size followed by hydro - classification employing Floatex Density Separator and separate treatment of classifier overflow, underflow and regrinding of coarse (underflow) followed by gravity separation. The composite concentrate assayed 54.03% Cr_2O_3, 11.46% Fe(T), 0.67% SiO_2, 15.29% Al_2O_3, 7.95% MgO and 3.38% LOI with 82.2 % Cr_2O_3 recovery (Wt % Yield : 58.40) This concentrate is of very high grade and suitable for use in ferrochrome production.

2. Bench scale beneficiation studies on chromite ore (sub-grade) sample from Sukinda, Jajpur District, Odisha for M/s Indian Metals & Ferro Alloys Ltd. (IMFA).

   The as received sample assayed Cr_2O_3- 34.25%; Fe(T) 22.39%, Al_2O_3 14.57%; SiO_2 5.90%; MgO 4.98%; CaO 0.28%; TiO_2 0.35% and LOI 7.17% with an objective to develop bench scale beneficiation process flow-sheet for obtaining a marketable grade chromite concentrate (+48% Cr_2O_3). The final chromite concentrate obtained assayed Cr_2O_3 50 to 52%, Fe(T) 15 to 16%, Al_2O_3 10 to 11%, SiO_2 1.5 to 2.0% MgO, 6.5 to 7.0% and LOI 3 to 3.5% with overall Cr_2O_3 recovery of around 80% (Wt% yield 52 to 55). Thus the bench-scale beneficiation studies in IBM indicated that the sample is amenable to beneficiation and capable of producing a high/marketable grade chromite concentrate (+50% Cr_2O_3) with high Cr_2O_3 recovery (80%).

3. Capacity enhancement validation of COB Plant of M/s TISCO

   As per the instructions of Ministry of Steel, M/s TISCO entrusted the work for capacity enhancement validation of their Chrome Ore Beneficiation Plant from 4 lakh tones per year to 7 lakh tonnes per year of chromite concentrate, to be duly validated by IBM. Consequent to the above, a team of officers from Ore Dressing Division, IBM visited the COB Plant from 10.8.2005 to 16.8.2005 for assessing the capacity of each and every piece of equipment in the circuit, metallurgical balance, capacity utilization, percentage metal recovery and the grades of the concentrate and tailings.

   Based on the metallurgical balance obtained during the test work it can be concluded that the plant can produce about 7 lakh tonnes per year of chrome ore concentrate (dry basis) assaying 50-52% Cr_2O_3 by treating the ROM assaying 38-40% Cr_2O_3 with a wt % yield of 60-65% and plant availability of 90% i.e. 7800 hours per year, with a plant feed rate of 170 tonnes per hour on wet basis or 150 tonnes per hour on dry basis.

4. Upgradation of Low Grade Dumped Chrome Ore

   Chrome ore assaying 35 to 40% Cr_2O_3 are treated in the chrome ore beneficiation plant of M/s OMC to produce chromite concentrates assaying around 48-50% Cr_2O_3. Ores assaying 28-35% Cr_2O_3 generated during mining to the tune of 10 lakh tonnes are being stacked separately over the years as sub-grade material. IBM authorities in compliance with the Mineral Conservation Policy decided to take up beneficiation studies on this stacked sub-grade material identified during the joint inspection by Ore dressing division and MCCM division. The studies carried out in Modern Mineral Processing Laboratory and Pilot Plant at Nagpur indicated that from the dumped material assaying around 30% Cr_2O_3 a composite concentrate assaying 50-51% Cr_2O_3 could be produced with a Cr_2O_3 recovery of 75%, thus paving the way for the utilization of this sub-grade material for the production of marketable concentrate.

7.5 CHROMITE ORE BENEFICIATION AT THE MINES

There are 34 beneficiation plants put up in the country out of which six are captive and 28 are non-captive beneficiation plants. Among these six captive plants, five are major beneficiation plants operating in the country, which are owned by four parties. The present status of these plants is discussed below.

7.5.1 Boula Mine Plant

Boula mine in Keonjhar district and Ostapal/Kathpal mines in Odisha are owned by M/s Ferro Alloys Corporation Ltd. The capacity of Boula Mine is 100,000 tonnes per annum. The mine is of low grade chromite ore with average feed grade assaying 16% Cr_2O_3 and Cr:Fe ratio of 0.7 – 0.9. The plant is designed for both low grade lumps and fines with a minimum of 10% Cr_2O_3. The process adopted is gravity separation using spirals and gravity tables after desliming. The concentrate (minus 1 mm size) obtained assays 40-44% Cr_2O_3 with Cr/Fe ratio of 1.6 – 1.8. The plus one mm (+1 mm) fraction is stacked for processing at Boula COB Plant.

The Ostapal/Kathpal Mines treats the low grade friable fines in the Boula plant. The fines produced at the Boula mine plant are supplied to the company's charge chrome plant at

Rakha Balasore distsrict, where it is briquetted and used in the manufacture of charge chrome in conjunction with lumpy chromite ore in the ratio of 50:50.

7.5.2 South Kaliapani Mine COB (OMC)

The COB plant has the throughput capacity of about 3,24,000 tonnes per annum. The feed grade is 33% Cr_2O_3 and concentrate assaying 50-52% Cr_2O_3 with Cr:Fe ratio of 2.9:1, other grade is 52-54% Cr_2O_3 with Cr:Fe ratio of 3:1 is obtained. The plant operating since 1995 needs modification. Single stage crushing with hammer mill, wet screening, rod mill for regrinding, primary and secondary classification using hydrocyclones and sizing with hydrosizer is practiced. A tailing thickener recycles water for the plant.

7.5.3 Sukinda Chromite COB Plant, TISCO

Screening and crushing of the ROM friable ore is done at the Lumpy Ore Processing Plant (LOPP). The LOPP has a capacity of 60 MT per hour. This is basically for recovery of direct marketable grade ore depending on customer requirements. A part of this ore is mixed with the nickelliferrous limonites from the contact zone and having inferior grade is sent to the beneficiable grade stacks. Here the ore is blended.

Apart from the fresh generation of beneficiable grade ore from the quarries the feed to the plant is achieved by suitably blending the same alongwith the mineral rejects and available old stocks of beneficiable grade ores, having +10% Cr_2O_3. Contact zone material/mixed ore from underground mine shall also be fed to the COB Plant. The average feed grade to the plant is estimated to be 30-38% Cr_2O_3. The plant has seen a lot of process and capacity improvement to a throughput of 6.5 lakh tonnes per annum.

The feed preparation consists of passing the oversize (>75mm) through a Doble toggle Jaw crusher and after scrubbing and screening a second stage of cone crushing >25mm material. <25>3mm particle size are reduced in the ball mill to < 1mm. Classification circuit consists of hydrocyclone and primary and secondary Floatex. Spirals are used for the beneficiation of coarse, fines and ultrafines material. The dewatering of material from spirals is done in screw classifier. The ultrafine concentrate is dewatered in the vacuum belt filter.

Three products, coarse, fines and ultrafines are obtained. Recovered water is circulated back to the beneficiation circuit. It is further proposed to beneficiate the tailings to recover chrome values. A column floatation technique together with magnetic separation is to be adopted. With this it will be possible to upgrade the Cr_2O_3 percentage in the tails from 14-17% to 46-47% in the final concentrate.

7.6 REFERENCES

1. **Indian Minerals Yearbook- 2011; Indian Bureau of Mines,** Government of India , Ministry of Mines; December, 2012.
2. USGS- 2010 Minerals Yearbook-Chromium Advance Release.
3. **Chromites of India, Their Textural and Mineralogical Characteristics,** R.K. Sahoo, J.K. Mohanty, S.K. Das and A.K. Paul* IMMT &* Retd. Prof. of Geology, Utkal University, Bhubaneswar.
4. International Seminar on Development of Chromite, Nickel and PGM Resources, (28 Nov, 2010 Bhubaneshwar) SGAT & Dept Steel & Mines, Government of Odisha.

5. Beneficiation of Eskisehir Chromite Ore, Özgür Özcan, Damla Güçbilmez ,Department of Mining Engineering, Hacettepe University, 06800, Beytepe, Ankara, Turkey.
6. A Note for Monograph on Chromite, Ferroalloys & Minerals, Tata Steel, Bhubaneshwar, Odisha.

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Chapter 8

USES AND SPECIFICATIONS

8.0 INTRODUCTION

Chromite (FeO Cr_2O_3 or $FeCr_2O_4$) is the only source of chromium metal used in the manufacture of different metallurgical products. Because of its multifarious uses, chromite is considered to be a versatile strategic mineral. In the world as a whole, about 94.5% of the total production is used in the metallurgical industry, 3.5% in the refractory & foundry industry and 2% in chemical industry.

In 1900, "chromic iron ore" was used to describe what we now call chromite ore. Chromium is used as an alloying element, in chemical compounds, and in refractory materials. It played an important role in metallurgy as an alloying element. Chromium and tungsten were being alloyed with iron to make tool steels that permitted large increases in industrial productivity. Chromium was also used to make armour plating hard. These, along with the use of chromite ore as a refractory in steel-producing furnaces, made chromium a critical and strategic material during World War I. Production picked up during World War I and again during World War II.

It was not until 1910 to 1920 that the alloying role of chromium with iron to make stainless steel was developed in France, Germany, the United Kingdom, and the United States. Once this was understood, however, stainless steel became an integral part of the steel industry, accounting for more than 2% of steel production. Stainless steel manufacture, while small compared with steel production of all grades, nonetheless accounts for about 60% of chromium consumption. Stainless steel, which didn't even exist in 1900, accounts for most of the chromium consumed today, and its share in steel production is growing. Chromium chemical use has grown since 1900; chromite refractory use, however, has been reduced because of technological developments. Superalloys, which are engineering alloys of chromium and nickel used in aggressive environments and were also non-existent in 1900, are an important strategic use of chromium because they are used to make the internal workings of jet engines.

Some Other Uses

The following uses for chromium are gathered from a number of sources:

- used in plating to produce a hard, beautiful surface and to prevent corrosion.
- used to give glass an emerald green colour. It is responsible for the green colour of emeralds and the red colour of rubies.
- wide use as a catalyst.
- dichromates such as $K_2Cr_2O_7$ are oxidising agents and are used in quantitative analysis and also in tanning leather.
- lead chromate as chrome yellow is a pigment.
- compounds are used in the textile industry as mordants.
- used by the aircraft and other industries for anodising aluminium.

In 2010-11, of the Indian chromite production of 4262207 tonnes , 2708100 tonnes was internally consumed of which 98.9% was consumed by the ferro-alloys/charge-chrome industry. In addition to above, chromite in substantial quantities is also consumed in small-scale ferrochrome units. The chemical industry in India consumed only 0.0015% and the refractory industry consumed 0.009% only. A list of chromite based industries is presented in the Annexure I to this chapter.

Chromium metal is an important alloy in ferrous metallurgy. It is used in the manufacture of alloys along with other metals such as nickel, cobalt, molybdenum, copper, titanium, zirconium, columbium, vanadium and selenium etc.

8.1 METALLURGICAL USES

The main use of chromite is in metallurgical industry especially in the manufacture of ferro-chrome, silico-chrome, charge-chrome and chromium metal. Chromium is used in metallurgical industry to enhance the properties like hardness, creep strength and resistance to corrosion, oxidation, wear and galling. Before chromite can be used for steel making, it has to be converted to ferrochromium.

Production of ferrochromium alloys from chromite

The International Chromium Development Association provides a description of the process of producing ferrochromium alloys from chromite. Chrome ore in various sizes is typically charged into a submerged AC electric arc furnace and reductants (coke, coal and quartzite) are added. The smelting process is energy intensive, requiring up to 4,000 kWh per tonne of material. Slag is separated from the liquid ferrochrome and tapped into ladles for further processing. Liquid ferrochrome is then poured into moulds and after cooling, crushed into sizes as required by the customers. Crushed ferrochrome is railed to final customers or harbours, for shipment.

In the early days of high-carbon ferrochromium production, the furnaces were supplied with high-grade, lumpy chromite from countries such as Zimbabwe, but with the increasing demand from the 1970s, other countries, South Africa in particular, commenced production from their lower-grade ores. The alloy produced from these ores became known as charge chrome because the chromium content was lower and the carbon content, and in particular the ratio of C:Cr was very much greater than in high-carbon ferrochromium. This did not suit the stainless steel makers who required as little carbon as possible entering their melts for each chromium unit and who were, therefore, had to use larger amounts of the more costly low-carbon ferrochromium to compensate.

However, the situation changed radically with the advent of the argon-oxygen decarburising (AOD) and vacuum-oxygen decarburising (VOD) processes. These processes enabled the steelmakers to remove carbon from the stainless melts without excessive oxidation and losses of chromium.

A more advanced attempt to overcome the problem of ore fines was the introduction of DC arc or plasma furnace technology. The DC arc furnace uses a single, central hollow graphite electrode as the cathode, with an electrically conducting refractory furnace hearth as the anode. The furnace operates with an open bath, so there is no problem with overburden, and the chromite fines, together with coal and fluxes, are fed directly into the bath through the hollow electrode. The furnace has a closed top. Some of the advantages of DC arc furnace operation are: use of fine ores without agglomeration, use of cheaper reductants and greater choice of reductants, higher chromium recoveries, deliberate changes in the charge composition are reflected rapidly in the slag or metal, and closed top operation allows furnace off-gas energy to be used.

Another approach to friable ores has been to pelletise them, after further grinding if necessary with binder, reductant and fluxes and pass them through a rotary kiln where they are hardened (sintered), pre-heated and pre-reduced to a degree before charging to a submerged arc furnace.

A further development in treating ore fines by kiln pre-reduction used unagglomerated chromite fines and low cost coal, with fluxes, as the feed to the kiln. Self agglomeration of the fines was achieved close to the discharge from the kiln where the charge becomes pasty in a high temperature zone of approx. 1,500ºC. Very high degree of reduction were achieved (80-90%) so that the downstream electric furnace (DC arc) became essentially a melting furnace.

A more recent approach, and one which is being installed by more plants, is again by pelletising. Pellets are produced with coke included and these are sintered and partly pre-reduced on a steel belt sintering system. From there, the pellets are delivered to pre-heating shaft kilns, submerged arc furnaces and which operate as direct feed bins, making use of the off-gas heat from the furnaces. Lump ore, coke and fluxes are also directed to the feed bins.

In addition to the technologies already discussed, there have been various other approaches to smelting chromite. These include rotary hearth sintering and pre-reduction of pellets, and fluidised bed pre-heaters for chromite fines.

Some intensive development work has been carried out in Japan upon entirely coal/oxygen based smelting processes using no electrical energy, sometimes referred to as smelt-reduction processes.

8.2 FERRO-CHROME

Ferro chromium is an intermediate product used as an additive in making stainless steel and special alloy steel. Ferro chrome alloy is mainly classified into two types namely (i) low carbon ferrochrome and (ii) high light carbon ferrochrome. For ferro-chrome Cr: Fe should be 2.8:1; Cr_2O_3=48% (min) and for charge chrome Cr : Fe should be 1.6 : 1; Cr_2O_3 = 44% (min).

a) **Low carbon ferrochrome (LC,F,Cr):** It has a carbon content of less than 0.1% (maximum). It is very important alloy required in the production of various heat and corrosion resistant steel, stainless steel and precipitation hardenable stainless steel. These stainless steel are mainly used in the manufacture of kitchenware, domestic utensils, chemical manufacturing equipments, food processing and dairy equipments, surgical instruments, aircrafts, cryogenic vessels and nuclear power stations, space vehicle components etc. A typical low carbon ferrochrome contains 67-75% of chromium 0.025 to 0.05% carbon and less than 1% silicon.

b) **High Carbon Ferro-Chrome (H.C.F.Cr.):** It is a carbon content of 4% and above. It is mainly used in the production of alloy steels and used as resistant to heat, corrosion and oxidation. It is used in the manufacture of low alloy steel and alloys, cast iron, high alloy steel, and various stainless steel. A typical high carbon ferro-chromium contains, 66-70% Cr, 5 to 6% carbon and 1-2% Si.

(i) **Silico-Chrome (Si-Cr) :** The intermediate type of ferro-chrome alloy is silico-chrome which is used to produce low carbon but high silicon ferrochrome. It contents 35-42% Cr, 39-45% Si and 0.05% C.

(ii) **Charge-Chrome :** Chromium in charge chrome is less than 60%. Most charge chrome plants operate at 50 to 55% chrome, carbon 8%, iron around 35 to 40%. In ferro chrome, chrome is more than 60%, iron around 31%,carbon around 8%. Therefore, charge chrome is prepared with low quality ore. More charge chrome is required to make same quantity of stainless steel as compared to using ferro chrome. It is a low chromium high carbon ferro-chrome with higher silicon content. It is used in the manufacture of stainless steel, other alloys and special steel. It is similar to high carbon ferro-chrome but contains lower percentage of chromium. The end use of both alloys is same. In stainless steel production, stainless steel scrap or mild steel scrap is charged as raw material. The charge chrome is also used (instead of stainless steel scrap) as raw material for the manufacture of stainless steel, hence it is termed as charge-chrome.

(iii) **Chromium Metal :** In 2010-11, India produced 1595 Kg of the metal. It is used in the production of a wide variety of non-ferrous alloys, which are used for making electric resistance wires , corrosion resistant alloys, non ferrous metal cutting tools, welding rod tips and hard facing material.

Chromium metal is extracted by alumino-thermic and electrolytic processes. Chromium metal can also be produced by silicon reduction or carbon reduction method. Commercial chromium metal is produced either by electrolysis of a chromium containing electrolytic chromite oxide or by alumino thermic reduction of pure chromic oxide.

Three types of metallic chromium are produced :

(i) High Carbon, which contains more than 87% Cr and 9 to 11% C.
(ii) Low Carbon, which contains more than 97% Cr and 0.10% C.(maximum).
(iii) Electrolytic, which contains more than 99.5% Cr and 0.2% C.

8.3 REFRACTORY USES

The use of chromium in refractories is second in importance to its metallurgical applications. Chromite possesses highly desired refractory properties. The energy required to produce a chromite refractory product is much lower than most of the other refractories, because chromite is already in the refractory oxide form and requires no pre-calcination . Its hard coarse crystalline nature which when crushed breaks into angular granules, thus giving good bondage and strength to the brick. A typical analysis of a chromite suitable for refractory purpose is 45-55 % Cr_2O_3, 10-20 % Al_2O_3, 14-20 % Fe_2O_3, 10-18 % MgO and less than 10 % SiO_2. Chromite as a refractory is very important because of its high melting point (21800 ^{o}C), moderate thermal expansion, neutral chemical behavior, and relatively high corrosion resistance. Chromite enhances thermal shock and slag resistance, volume stability and mechanical strength. In refractory industry Cr_2O_3 should be a minimum of 40%. In addition, chromite is also used in ceramic industry and electrode making industry.

The chromite refractory bricks may be made from the crushed ore moulded to shape with a binder and fired at high temperatures. Chromite is used in refractory either as a mixture with dead burnt magnesite (DBM) or only chromite itself. The chromite content in brick varies from 25 to 100% depending upon the use for which it is required. The mixed bricks have greater strength and refractoriness than ordinary chrome bricks and are more resistant to basic slags.

The major use of chromite refractories is in open hearth steel furnace, where its neutral characteristics are made use of to insulate basic refractories (such as magnesia and dolomite) from acid refractories (such as silica and fireclay). In electric arc furnaces, chromite refractories are used in the side walls and roof linings. They are used in glass making furnaces where chromite resists chemically corrosive substances. Chromite bricks are also used to a lesser extent in other furnaces such as induction furnaces, soaking pits and cement kilns. They are also used in the processing industries for copper, lead, zinc and aluminium.

In contact with iron oxide, it forms a solid solution (a homogeneous crystalline phase composed of different minerals dissolved in one another) with iron oxide and expands considerably, causing the refractory to crumble. This phenomenon is called 'Bursting'. It is found that Indian Chrome Ore contains less iron Oxide compared to Chrome Ore globally.

8.3.1 Application of Different Types of Chromite based Refractories

(i) Chrome bricks: These bricks contain minimum 40% Cr_2O_3. They are used in ingot soaking pits, reheating furnace hearths, copper reverberatory furnaces, pusher type furnaces and soda recovery furnaces in the manufacturing of sulphate cellulose. They are also used as dividing layer between acid and basic brick work.

(ii) Chromite magnesite brick: These bricks normally contains 21-22% Cr_2O_3 and 35-48% MgO. They are resistant to basic slag, mechanical and chemical effects of vollatiles, dust and furnace atmosphere.

The uses of this bricks are given below:

Open Hearth Furnace - Front and back walls above the slag line, vertical air and gas uptakes and side walls of slag pockets.
Electric Arc Furnace - Side walls above slag levels
Soaking pit - Walls
Re-heating furnace - Hearth and Walls
Paper and Cellulose Industry - Soda recovery furnace
Glass Tank Furnace - Walls of regenerators
Non-Ferrous Metal Industries - Working lining of reverberatory converter and flash smelting furnace.

(iii) Chrome–Magnesite Bricks (Chemically bonded): These bricks normally contain 18 to 22% Cr_2O_3 and 35 to 48% MgO. The important uses of these bricks are in :

Electric Arc Furnace - Side walls above slagline
Open Hearth Furnace - Roof, front and back walls
Non-Ferrous Industries - Copper Reverberatory Furnace

iv) Magnesite-Chrome: These bricks contains 57 to 76% MgO and 13 to 15% Cr_2O_3. The main uses of magnesite-chrome (Burnt) bricks are in :

Electric Arc Furnace - Side walls
Open Hearth Furnace - Roof, front and back walls

Basic Oxygen Furnace	- Side walls and bottom
Secondary Steel Making Units	- Bottom and side walls of AOD, VAR and VAD Vessels
Non-Ferrous Metal Industry	- Working lining of reverberatory furnace, converter and flash smelting furnace.
Rotary Kiln	- Burning zones of hard driven kiln producing cement, lime, calcined dolomite and dead burnt magnesite
Glass Tank Furnace	- Regenerator Super Structure

(v) **Magnesite-Chrome (Chemically bonded):** These bricks contain 57-67% MgO and 11 to 15% Cr_2O_3. They are chemically bonded and non-fired. The main uses of these bricks are:

Electric Arc Furnace	- Side walls and roofs
Open Hearth Furnace	- Roof, front and back and uptakes
Non-Ferrous Metal Industry	- reverberatory furnace roof and smelting furnace.

(vi) **Foundry Sand:** Chromite sand is used as a moulding medium in steel foundries all over the world. Resistance to metal penetration is one of the most important properties of chromite sand. Its moulding properties are slightly superior and also cheaper than Zircon sand. Both chromite and Zircon possess very low rates of thermal shop. Therefore, sometimes chromite is used in Zircon in 50:50 ratio in foundries to obtain best results.

Table 1 : IS Specifications of Chromite Sand for Foundries

(IS: 6788-1973; Reaffirmed 2008)

a) Chemical

Sl.No.	Constituent (on dry basis)	Requirement (%)
1.	Cr_2O_3	44 min
2.	Fe_2O_3	26 max
3.	SiO_2	04 max
4.	CaO	0.5 max
5.	MgO	As agreed
6.	Clay	0.75 max
7.	LOI	1.0 max
8.	Moisture	0.5 max
9.	pH value	Between 7.0 and 9.0

b) Physical

The material shall be of two grades, namely, fine and coarse. The shape of grains should be mostly subangular and the fusion point should not be below 1800^0 C. The fineness of the two grades of chromite sand shall conform to the following requirements (Table 2).

Table 2

I.S.Sieve	Fraction Retained on	
	Fine Grade(F) (%)	Coarse Grade (C)(%)
710 microns	-	5 max
500 microns	-	10 max
355microns	-	10-25
250 microns	3 max	10-25
212 microns	18 max	10-20
150microns		10-20
106 microns	70 min	7-20
75 microns		12 max
PAN	12 max	6 max

8.4 IN CHEMICALS

Chromium chemicals find application in the manufacture of wide variety of end products, namely, clothing, furniture, footwear, vehicles safety matches etc. Ore with Cr:Fe ratio 1:6 and a minimum of 44% Cr_2O_3 is acceptable for chemical end-use. The most objectionable impurities are silica and lime. BIS has suggested the specification (IS 4737-1982) for chemical industry.

Sodium bicarbonate (Sodium dichromate) is the basic chemical produced directly from chromite. From sodium bichromite ($Na_2Cr_2O_72H_2O$), the following important chromium chemicals are made.

i. Chromic Acid - $CrO_2(OH)_2$
ii. Potassium Dichromate - $K_2Cr_2O_7$
iii. Basic Chromium Sulphate - $CrOHSO_4Na_2SO_4$
iv. Chrome Oxide Green - Cr_2O_3
v. Sodium Chromate Hydrated - Na_2CrO_4-$4H_2O$
vi. Potash Chrome Alum - $K_2SO_4Cr_2(SO_4)_3$-$24H_2O$

Sodium bichromate is produced in the form of orange red crystals, which is highly soluble in water. The main use of this chemical is in leather tanning industry for producing chrome leathers. It is used as mordant in dyeing of textiles, for wood and metal preservation, manufacture of colour glass, manufacture of chrome pigments, organic chemicals oxidation and bleaching of oils, fats and waxes.

It is used as additive in drilling muds to prolong the life of drill strings. The uses of various chromium chemicals are given below:

(i) **Chromic Acid ($CrO_2(OH)_2$)** : It is also called chromium trioxide or chromic anhydride. It is available in the form of small red flakes. The best known use of the chromium chemical is in the electroplating (chrome plating) of metals for either decorative effect or for resistance to wear and corrosion. Other uses are as an oxidizing agent for organic chemicals and as laboratory reagent. Electroplating is done in the case of boilers, refrigerating brines, air conditioning systems, cooling towers, diesel engines, automobile engines, domestic appliances, etc.

(ii) **Potassium Bichromate ($K_2Cr_2O_7$) :** This is availale in small orange coloured crystals. The special use of this chemical is in the manufacture of safety matches, pyrotechnics and explosives. Other uses are in printing inks, synthetic perfumery, glues and adhesives, process engraving and lithography, photography and film processing and as an analytical reagent in laboratories.

(iii) **Basic chromium sulphate($CrOHSO_4Na_2SO_4$)** : It is available in the form of a fine free flowing spray dried powder, leaf green in colour. The two major uses of this chemical are in leather tanning and in the manufacture of mineral khaki. Chrome tanning has an edge over vegetable tanning as the operation in the former lasts only for a few hours against several days in vegetable tanning. Besides, the leather obtained by this chemical has exceptional wear resistance qualities through it is somewhat deficient in water resistant quality. The finished leather derived from raw skins and hides is mostly chrome tanned and it finds good export market.

(iv) **Chrome Oxide Green (Cr_2O_3)** : It is available as finely ground green powder. Chrome oxide green which essentially consists of 97 to 99% of chromic oxide is used in paints both oil and cement varieties, particularly for outside applications where they are required to withstand severeweather condition. Other uses are in the manufacture of linonium , ceramic glasses, coloured glass, stainless electrodes, buffing and polishing compounds. It is also used in the manufacture of chromium metal.

(v) **Sodium Chromite Hydrated (Na_2CrO_4-$4H_2O$)** : This is available in small yellow colour crystals. It is used mostly as an anticorrosive salt including water and chilled brine system. It can also be used in inhibitor formulations and in the manufacture of chrome pigments and other chromium chemicals.

(vi) **Potash Chrome Alum (K_2SO_4-$Cr_2(SO4)_3$-$24H_2O$):** This is available in small violet red crystals. It is used in good quantities in photography in fixing bath. Other uses are as a mordant in textile in dyeing industries and for tanning certain special varieties of leather.

Some chromium chemicals find use in the manufacture in medicine. Another chromium chemical, i.e. chromium dioxide (CrO_2) finds use in high quality audio and video-magnetic recording tapes. Certain amount of chromium in soil is essential to plant growth, but higher concentration may be undesirable.

8.5 SPECIFICATION AND GRADE OF CHROMITE ORE (38 – 55% Cr_2O_3)

(1) Metallurgical (ferrochromium)

Traditional grades require hard and lumpy ore with >46% Cr_2O_3 with Cr: Fe ratio >3:1 + high magnesium and <3% SiO_2 grades for argon oxygen decarburisation (AOD) steelmaking can handle a fine and a Cr: Fe ratio of 1.5:1. Grade C (“charge”) containing 50-55% Cr derived from high-Fe chromite with Cr: Fe ratio of <1.8 grade B containing 56-64% Cr derived from chromite with Cr: Fe ratio of 1.8-2.5, grade A containing >64% Cr derived from high-Cr chromite with Cr: Fe ratio of >2.5.

Table 3 : BIS specifications of chromite for metallurgical industry (IS: 10818-1984) (Reaffirmed in 2008)

S. No.	Characteristics (on dry basis)	Grade (%)			
		Low carbon	High carbon ferrochrome	Silicochrome/ ferrochrome	Charge chrome
1.	Cr_2O_3 percent, (min)	48	48	48	44
2.	Total iron percent, max(as FeO)	15	16	15	18
3.	Al_2O_3 percent	13	13	13	10
4.	SiO_2 percent, (max)	5	8	10	12
5.	CaO percent, (max)	5	5	5	5
6.	MgO percent, (max)	14	16	14	12
7.	Sulphur*(as SO_3) percent, (min)	0.1	0.1	0.1	0.14
8.	Phosphorous (as P_2O_5) percent, (max)	0.005	0.02	0.02	0.2
9.	Cr:Fe. (min)	3:1	2.8:1	3.1	1.6:2
10.	MgO. Al_2O_3 (range)	-	1.4	-	-

Sulphur (as SO_3) and phosphorus (as P_2O_5) may be determined as agreed upon by the supplier and the purchaser.

(2) Refractory chromite

Relatively low (30-40%) Cr_2O_3 and high (25-32%) Al_2O_3 with >57% Cr_2O_3 + Al_2O_3 (the combination controls refractoriness); low SiO_2 is required (<1% in S. African and 3.5% Turkish ore) along with low (<15%) Fe, ground to –10 or even –65 mesh.

(3) Foundry sand

>44% Cr_2O_3 with max. 26% Fe_2O_3, <4% SiO_2, 0.5% CaO, 0.5% moisture, 0.5% LOI.

(a) Chemical

Table 4 : BIS specifications of chromite for refractory industry (IS:10819-1999) (First Revision, reaffirmed 2010)

S. No.	Chemical Characteristics (On dry basis)	Grade-I, percent by mass	Grade-II, percent by mass	Grade-III, percent by mass
1.	Loss of ignition	1.5 max	1.5 max	1.5 max
2.	Cr_2O_3	52 min	50 max	48 min
3.	Total iron (as FeO)	16 max	18 max	18 max
4.	SiO_2	3 max	7 max	9 max
5.	MgO	15 max	15 max	15 max

(b) Physical

The chromite shall be hard, massive, fine-grained, serpentine-free and lumpy ore. It shall be of the size range (-) 150 to (+) 50 mm.

Table 5 : BIS specifications of chromite sand for foundry industry (IS: 6788-1973) (Reaffirmed 2008)

S .No.	Characteristics (on dry basis)	Requirement %
1.	Chromite oxide (as Cr_2O_3), percent by mass, (min)	44.0
2.	Total iron as (FeO), percent by mass. (max)	20.0
3.	Alumina (as Al_2O_3), percent by mass, (max)	14.0
4.	Silica (SiO_2), percent by mass, (max)	7.0
5.	Lime (as CaO), percent by mass, (max)	3.0
6.	Magnesia (MgO), percent by mass, (max)	14.0

(4) Chemical – approx. 40-45% Cr_2O_3 and low Cr: Fe ratio preferred with low Al ^Mg (increases soda ash demand) and SiO_2. Friable ore facilitates chemical attack.

Table 6 : BIS specifications of chromite for chemical industry (IS: 4737-1982) (Reaffirmed in 2008)

S. No.	Characteristics (on dry basis)	Requirement %
1.	Chromium oxide (as Cr_2O_3), percent by mass, min	44.0
2.	Total iron as (FeO), percent by mass. max	20.0
3.	Alumina (as Al_2O_3), percent by mass, max	14.0
4.	Silica (SiO_2), percent by mass, max.	7.0
5.	Lime (as CaO), percent by mass, max	3.0
6.	Magnesia (MgO), percent by mass, max	14.0

(5) Flour – 40-44% Cr_2O_3 and low metallic impurities.

The specifications of chromite vary for different end-use industries. The Cr: Fe ratio is one of the important factors to be considered before deciding the end-use of the mineral.

8.6 REFERENCES

1. **Mineral Facts and Problems: CHROMITE; Monograph No.6**, March 1982, TMP Division, Indian Bureau of Mines, Ministry of Steel and Mines, Nagpur.
2. **Draft document on formulation of strategy for exploration, exploitation and development for chromite in India, by 'The sub-group on chromite'** J.K.Nanda & B.K. Jena, Directors GSI; M. Sengupta, RMG, IBM, Nagpur & Naresh Nautiyal, Dy.GM(Exploration), MECL, March 2007.
3. **MINING WATCH CANADA**, January 25, 2011.
4. **Note for Monograph on Chromite, Ferroalloys & Minerals**, Tata Steel, Odisha.
5. **Chromium-USGS2000.**
6. **Indian Minerals Yearbook - 2011; Indian Bureau of Mines,** Government of India , Ministry of Mines; December, 2012.

ANNEXURE - I

Mineral - Based Industries

Charge Chrome Plants	Bamnipal Randia Choudwar	TISCO FACOR ICC Ltd
Ferrochrome Plants	Jajpur Road Theruvali	IDCOL IMFA
Refractory Plants	Rajganpur Belpahar Meramundali	OC Ltd TR Ltd Nav Bharat Ferro alloys
Chrome Briquetting	Balasore	Ispat Chromite Ltd
Chrome Ore Beneficiation	Jajpur	Visa Industries
R & D activities	Bhubaneswar	IMMT

Industries	**Specification of ore consumed**
Balasore Alloys Ltd, Balgopalpur	Lumps;Cr_2O_3+30%, Fe_2O_3: 20%max., SiO_2:5% Chrome ore fines: Cr_2O_3:44-54%,. Fe_2O_3: 11-17%max., SiO_2:1.9-2%, Concentrate: Cr_2O_3:40-56%, Fe_2O_3: 12-15%(max)SiO_2: 1.8%
FACOR Charge Chrome Division,Randia	Lumps: Cr_2O_3 41%, fines: Cr_2O_3: 46%, Friable Cr_2O_3: 42%.
IDCO Ferro Chrome & Alloys Ltd, Jajpur Road	Cr_2O_3: 42-52%., Cr:Fe: 3.0, SiO_2: 6% max.
Indian Charge Chrome Ltd, Choudwar, Cuttack	Cr_2O_3: 40-48%., SiO_2: 15 % max.
IMFA Ltd, Therubali Choudwar	Cr_2O_3: +30 – 52%
TATA Steel, Bamnipal	N.A.
Orissa Industries Ltd, Lathikata	Cr_2O_3: 52-54%, Fe_2O_3: 15-18%(max);SiO_2: 3-5%
IFGL Refractories, Kalunga, Sundargarh	Cr_2O_3: 52% min.
Tata Refractories Ltd, Belpahar	Cr_2O_3: 48-50%min., SiO_2: 5-9% min.
Krebs & Cei India Ltd, Kalma, Mayurbhanj	Closed since 2006

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Chapter 9

PRODUCTION & CONSUMPTION OF CHROMITE

9.0 INTRODUCTION

The Economics of Chromium was published by Roskill in early 2009 and made the following important observations:

- Around 94% of global chromite production is destined for use in the metallurgical industry, for the production of ferrochrome, with the remainder produced for use in the foundry, chemical and refractory sectors.
- Around 70% of global chromite production is consumed domestically in ferrochrome production in the country of origin.
- The stainless steel industry is by far the largest consumer of ferrochrome. Until the beginning of the downturn in the global economy, stainless steel production had shown large increases.
- Demand in developing countries such as China and India helped global output increase at an annual average rate of 5.4% for the period 2000 to 2007, with China alone accounting for over 60% of this rise in global stainless production.
- Any changes to supply have a large impact on the price (Fig. 9.1).
- Electricity constraints have led much planned new capacity in South Africa to be delayed or cancelled.

Chrome ore production in the world for the last 20 years is growing steadily almost at an annual rate of 4 to 5%. Around 1990, the production was about 11 million tonnes which has reached a figure of 30 million tonnes in 2010 (Table 1 & 1a). This substantial increase is primarily due to rising global stainless steel demand, particularly by Chinese imports. South Africa was the leading producer, contributing about 36% to the total world production, followed by Kazakhstan (29%) and India (14%). Other significant producers were Turkey, Brazil, Finland and Zimbabwe.

Table 1. : World Production of Chromium Ores and Concentrates (In '000 tonnes)

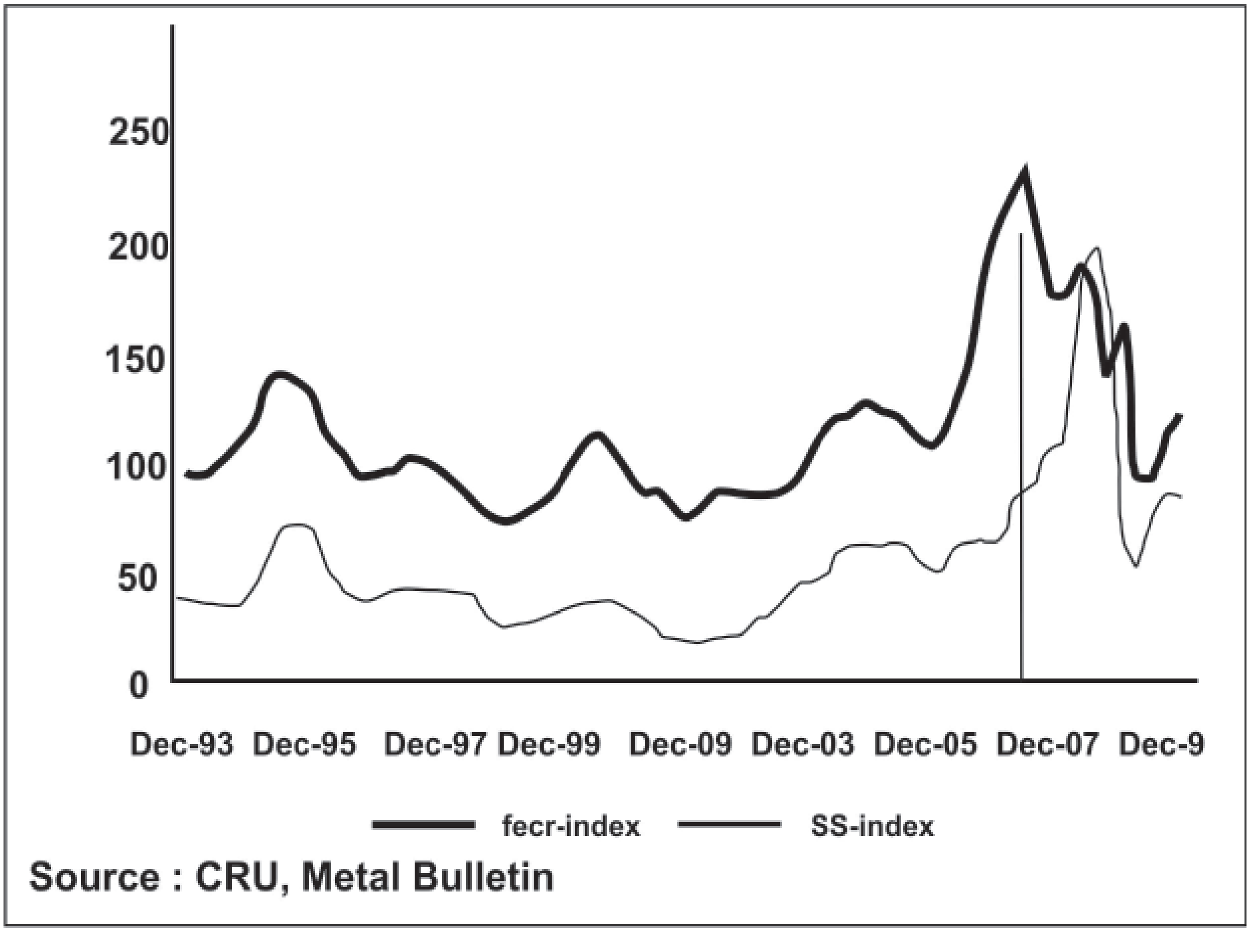
Country	2008	2009	2010
World : Total	**23600**	**23467**	**30000**
Brazil	706	700	700
Finland	614	247	598
India	4073	3413	4262
Kazakhstan	3552	8059	8594
Russia	913	416	-
South Africa	9683	6865	10871
Turkey	1886	1770	1904
Zimbabwe	442	194	510
Other countries	1830	1803	2561

Source: IMYB-2011

Table 1a : World Production of Chromium Ores and Concentrates (In '000 tonnes)

Country	2008	2009	2010*
Albania	232	274	289
Kosovo	– –	2	– -
Madagascar	84	60	134
Sudan	27	14	57
Afghanistan	7	7	6
China	220	280	220
Iran	269	255	275
Oman	784	730	802
Pakistan	115	92	257
Philippines	15	14	16
UnitedArab Emirates	34	24	25
Vietnam	1.3	.40	37
Australia	57	75	74

Source : World Mineral Production – 2005 – 2010 (BGS), *Chromium 2010(advance release)



Source : CRU, Metal Bulletin

Fig. 9.1 : Stainless Steel Price Index vs. Ferrochrome Price Index

The ferrochrome industry is driven primarily by the metallurgical industry, which accounts for 94% of all chrome ore produced, out of which nearly 90% of chrome ore is consumed by the stainless steel industry. Primary chrome ore, accounts for over 60% of the stainless industry's total chrome ore requirements, with stainless scrap supplying the rest.

In 2008, world ferrochrome consumption fell by 11% after demand collapsed in the final quarter (Table 2). The year 2009 saw consumption persist at the same level, but began to recover. World consumption of ferrochrome, is expected to rise led by the stainless sector but also due to gains in offtake from the non-stainless end-uses (Tables 2 & 3).

Global stainless steel production rose 3.3% to a new record in 2011 as higher output from China more than offset lower output from the Americas and the rest of Asia, data from the International Stainless Steel Forum showed. Global stainless steel production reached 32.1 million metric tonnes in 2011, compared with 31.1 million tonnes in 2010. China, the world's largest stainless steel producer, increased output of the corrosion resistant steel product by 11.9% to 12.6 million tonnes in 2011.

Total world crude stainless steel production for 2012 looks set to reach an all-time record figure of 34 million tonnes. This would be a 0.8 percent increase on the previous high, set in 2011. MEPS anticipates moderate growth, in global terms, of around 3 percent in 2013, year-on-year, resulting in an annual crude stainless steel output of 35 million tonnes.

Economic and industrial growth in China has slowed considerably. MEPS estimates that the published figure for Chinese crude stainless steel production will increase by 1.1 percent this year, to achieve a total of over 14.3 million tonnes. This is far below the typical rate of expansion recorded in this country in recent years. In the longer term, prospects are bright, with growth expected to average 6% pa between 2010-15. Stainless steel will remain the key driver of higher ferrochrome consumption (Table 4).

Table 2 : Chrome Ore Production and Consumption (kt)

Country	2007	2008	2009	2010	2011E	2012F	2013F
South Africa	9,650	9,680	6,870	10,900	11,000		
Kazakhstan	3,690	3,630	3,330	3,830	3,900		
India	3,320	3,900	3,760	3,800	3,800		
Other Countries	4,840	6,590	5,340	5,170	5,300		
Total production	**21,500**	**23,800**	**19,300**	**23,700**	**24,000**	**26,343**	**28,220**
Apparent Consumption	**20,925**	**18,650**	**14,575**	**22,228**	**22,933**	**26,343**	**28,220**

Table 3 : Regional Breakup for Ferrochrome Production and Consumption (In million tonnes)

Country	2007	2008	2009	2010	2011	2012	2013
S Africa	3.56	3.24	2.16	3.59	3.51	3.97	4.36
China	1.40	1.28	1.25	2.17	2.40	2.70	2.80
Kazakhstan	1.20	0.96	0.98	1.16	1.17	1.25	1.51
India	0.82	0.75	0.74	1.00	1.07	1.34	1.34
Brazil	0.17	0.19	0.12	0.20	0.20	0.20	0.20
Others	1.39	1.23	0.70	0.97	1.02	1.28	1.28
Total Production	**8.37**	**7.46**	**5.83**	**8.89**	**9.17**	**10.54**	**11.29**
Total Consumption	**7.60**	**6.77**	**6.74**	**9.04**	**9.67**	**10.35**	**11.07**

Table 4 : World Stainless Steel Production – 2006 to 2009 (in MT)

Country/Region		2006	2007	2008	2009	2010
2011						
China/Honkong		5363000	7610000	7344000	9750700	11100000
12600000						
Japan	4087000	3980800	3564300	2606600	3440000	
Korea	2278000	1940000	1617000	1677000	2038000	
Taiwan	1640500	1515000	1296800	1444000	1667000	
India	1776800	1850200	1544000	1690300	1900000	
America	2998400	2695300	2482300	2100000	2917000	2500000*
European Union		9375900	8109200	7827700	5974100	7484000
7900000*						
Eastern Europe	229700	232000	212700	139800	188000	
Others	689700	657100	528500	588000	609000	
Total	**28439000**	**28510400**	**26417500**	**25970600**	**31343000**	**32100000***

Source data: ICDA *Market Watch

Table 5 : Stainless Steel end-use Consumption (MT)

Country/Region	2007	2008	2009	2010	2011E	2012F	2013F	2014F	07-15 (growth)
China	7.82	7.9	9.41	11.35	12.37	13.19	14.08	14.91	8.10%
Europe	6.49	6.2	5.2	5.75	5.96	5.98	6.11	6.24	2.30%
Other Asia	5.2	4.78	4.47	5.23	5.32	5.56	5.81	6.03	9.10%
Americas	3.38	3.09	2.36	2.68	2.95	2.99	3.11	3.22	-0.10%
Rest of the World	2.73	2.75	2.99	3.53	3.78	3.97	4.36	4.72	0.30%
Global	25.62	24.72	24.43	28.54	30.38	31.69	33.47	35.12	4.60%

9.1 OBSERVATIONS

- Demand for chrome ore has been expanding by some 5% annually over past decade, while chrome ore output was marginally lower at an average of 4.6% per annum. Thus, new chrome ore resources need to be explored.
- Depletion of chrome ore grades will drive exploration of mines attracting cross border investment.
- Backward integration is required to overcome the shortage of power throughout the industrial chain of chrome ore, ferrochrome and stainless steel.
- South Africa is caught in a tight spot because of shortage of power, which is compelling it to increase ROM chrome ore exports instead of beneficiated chrome ore and ferrochrome.
- Toughened export tax regime in South Africa, China and India to increase chrome ore and ferrochrome prices.
- Kazakhstan holds a strong position as compared to other countries as it has cash-rich ferrochrome producers who have vertically integrated plants though it holds only 5% of world chrome ore resources.

- Geopolitical situation.
- Producers: South Africa, Kazakhstan and India.
- Consumers: China, Europe US and Asia.
- Non-availability of low ash low phosphorus coking coal prices is likely to create some strain for India and China.
- Need for process innovation to directly manufacture stainless steel from chrome ore/liquid chrome.
- Dynamics of ferrochrome will mainly depend on stainless steel trend, which will mainly be driven by growing dominance of China's stainless steel industry.
- Augmentation of power supply in South Africa might change the dynamics of chrome and ferrochrome industry post 2012.
- Substitute for chromium – none.

Table 6 : Major World Chrome Ore and Ferrochrome Projects

Project	State/Province	Country	Operator	Status
Dinapigue Nickel Mine	Luzon	Philippines	Unspecified Company of Entity	Construction
Oregon Chromite/Heavy Mineral Sands Operation	Oregon	United States	IDM International Ltd	Construction
Co Dinh Chromite Project	Thanh Hoa	Vietnam	Vietnam National Coal-Mineral Industries Group	Feasibility Study
Acoje Chromite/Laterite Nickel Project	Dinagat	Philippines	Gupana, C.B. (Estate of)	Adv. Exploration
Bulgiza Chromite Project	Diber (Dibre)	Albania	Empire Mining Corp.	Adv. Exploration
Hemlok Chromite/Heavy Mineral Sands Deposits	Oregon	United States	IDM International Ltd.	Adv. Exploration
Kimberly Clark Chromite/Heavy Mineral Sands Project	Oregon	United States	Kimberly Clark Corporation	Adv. Exploration
McFaulds Lake Chromite/Nickel/Copper Project	Ontario	Canada	Cliffs Natural Resources Inc.	Adv. Exploration
Range Well Chromite Deposits	Western Australia	Australia	Atomaer Holdings Pvt. Ltd	Adv. Exploration
Seven Devils Chromite/Heavy Mineral Sands Project	Oregon	United States	IDM International Ltd	Adv. Exploration
Shepard Heavy Mineral Sands Project	Oregon	United States	IDM International Ltd	Adv. Exploration
Westbrook Heavy Mineral Sands Project	Oregon	United States	IDM International Ltd	Adv. Exploration
Weyco Chromite/ Heavy Mineral Sands Deposit	Oregon	United States	IDM International Ltd	Adv. Exploration
Borroloola Zinc/Lead Project	Northern Territory	Australia	Sandfire Resources NL	Exploration
Boyne Chromite Project	Queensland	Australia	AusNiCo Limited	Exploration
Coolac Nickel/Copper/Gold Project	New South Wales	Australia	Meridian Minerals Limited	Exploration
Eastbank PGE Project	Ontario	Canada	Northern Shield Resources Inc.	Exploration
Hammer Hill Nickel / Cobalt / Chromite Project	Northern Territory	Australia	Arafura Resources LIMITED	Exploration
Highbank Lake PGE Project	Ontario	Canada	Northern Shield Resources Inc.	Exploration
Madagascar Chromite Project		Madagascar	OM Holdings Limited	Exploration
Peel Fault Gold Project	New South Wales	Australia	Gossan Hill Gold Limited	Exploration
PNG Chromite Project	Morobe	Papua New Guinea	OM Holdings Limited	Exploration
Symons Hill Gold Project	Western Australia	Australia	Askins, Paul Winston	Exploration
West Coobina Chromite Project	Western Australia	Australia	Atlas Iron Limited	Exploration

9.2 CONCLUSIONS

Chromium market is highly consolidated and is represented by a few miners and producers in South Africa and Kazakhstan. This makes it possible to cut down supply whenever there is a reduction in stainless steel production to curb the downfall in prices. The chrome ore and ferrochrome industry is struggling hard to meet the demand emanating from the stainless steel producers, particularly from China.

Considering the various triggers and concerns as discussed in the previous pages, it seems that shortage of chrome ore and ferrochrome may last for many years; probably till 2013 and the industry will be subject to wild price fluctuations (Fig. 9.2).

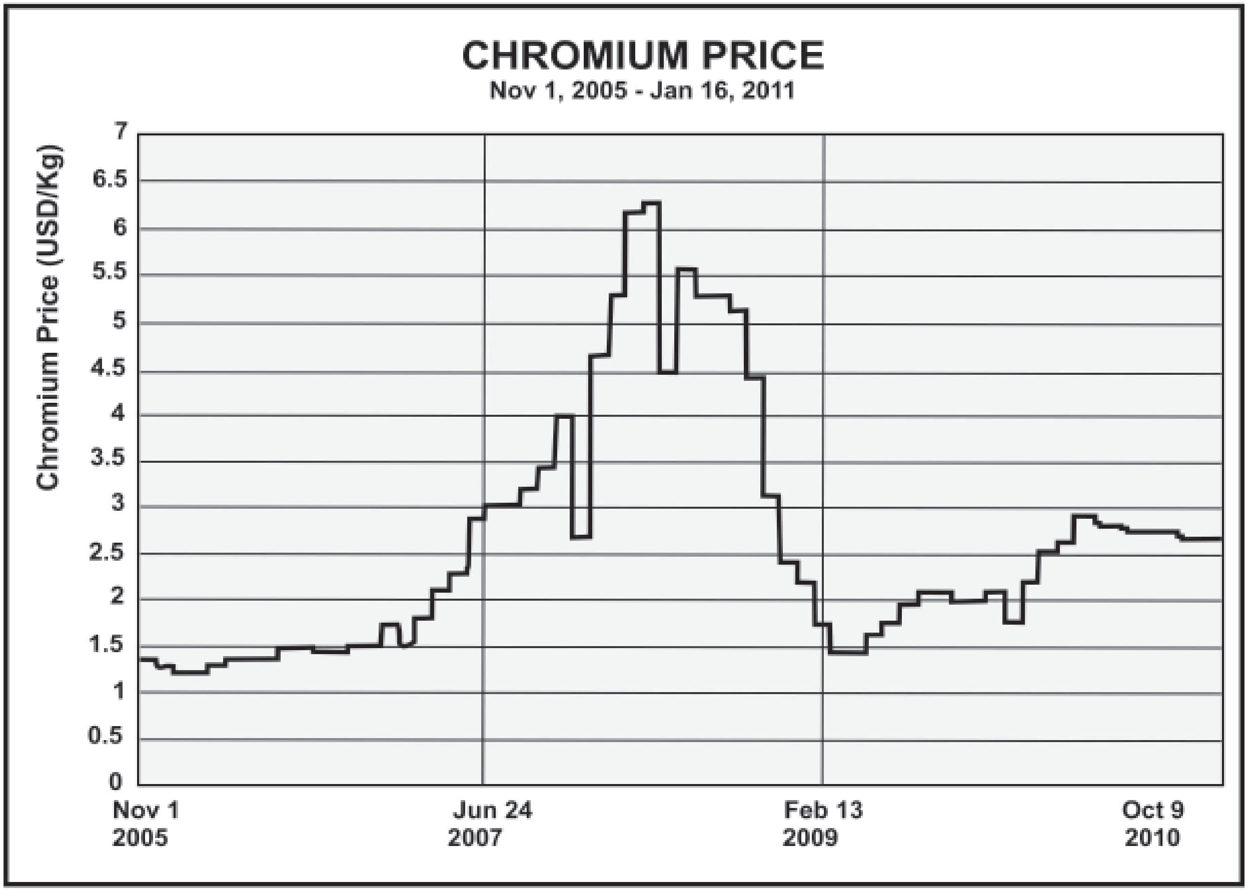


Fig. 9.2 : Chromium Prices

Ferrochrome companies who have already integrated backwards into chrome ore mines and power plants have an edge to "Outperform" for a long period keeping the existing scenario in view.

9.3 COUNTRY WISE ANALYSIS IN BRIEF

9.3.1 South Africa

South Africa possess the largest reserves of chromite in the world and is also the largest producer of chrome ore and ferro-chromium. South African chromite production comes mostly from stratiform deposit within Bushveld Igneous Complex. The chromite from Bushveld is generally friable and predominantly of chemical grade.

Samancor, a major player, owns and operates chromite mine, produces ferro-chromium, and co-owned major stainless steel production facilities. Suedeloktra S.A. has captive chromite mine and ferro-chromium production facilities. Bayer A.G. (Germany) owned a chromite mine and chromium chemical production facilities.

South Africa is a dominant force in the production and export of ferro-chrome. There are about 3 billion tonnes reserves available in the country. South African production has grown at 3 % pa. The rest of the world has experienced growth of 6.8% pa. The production of chromite in South Africa was 6.4 million tonnes in 2002, contributing about 44% to the world production. It exported 1.5 million tonnes of chromite, contributing about 30% to the world exports in 2002. In 2010, South Africa was the leading producer, contributing about 36% to the total world production. It produced 10,871,095 metric tonnes of chromite ores in the year and 3,607,132 metric tonnes of ferrochrome of all types.

South Africa's market share is being eroded, due to a deterioration in the country's competitive position and electricity supply constraints. There are several reasons for the loss of competitiveness:

- Hefty increases in power tariffs of upto 3 % pa.
- Appreciation of the Rand.
- Rail capacity constraints have boosted transport costs.
- Labour costs are rising.
- Shift from OP to UG mining and higher percentage fines in feed have lifted costs.

Capacity in South Africa is expected to decline slightly in the next five years. Power shortages in South Africa imply no greenfield projects or brownfield expansions in the country in the next five years. South Africa will still see, however, a substantial increase in production in the period 2010-15 as capacity utilisation is currently running at well below the Eskom imposed maximum. Raw chromite ore fetches considerably less than refined chromium on the market, and is subject to massive price fluctuations.

South African chromite miners have been selling raw ore to China at prices significantly below what other producing countries have been getting. Mining Weekly reported in March 2010 that "China bought the 2.9-million tonnes [of raw chromite ore] from South Africa at the comparatively low average price of $215/t including cost, insurance and freight (CIF), compared with the $360/t CIF (67 % more) it paid for raw ore from India. China also paid 35% more for the raw ore it bought from Turkey." South Africa may export a greater volume of raw chrome ore due to its inability to beneficiate the ore because of insufficient electricity. Though ferrochrome producers are very bullish on the future demand, availability of power remains a key concern. South Africa, the leading exporter of chromite ore, has threatened to restrict chromite ore exports by imposing export duties to encourage domestic vertical integration.

Stethite & Mecklenburg projects of Chromite Mining plc (UK), Northam and Cronimet Mining GmbH (Germany), Bokfontein mine of Hernic Ferro Chome (pty) Ltd, Skychrome property of International ferro metals Ltd, (Australia), Boshook & Magareng mines of Xsrata (Switzerland) are enhancing the production in near future. Tata Steel Ltd (India) started production from its two 75 tpy furnaces from the new ferro chrome plant at Riched Bay. For this plant chromite ore is supplied from South African region. ASA Metals (pty) Ltd installed two furnaces of 66 MVA capacity beneficiation & pelletisation plant of 600,000 tpy capacity. Chromex Mining plc completed processing plant to treat 40,000 tonnes per month of r.o.m. in 2009.

9.3.2 China

China does not have significant chromium resources. At around 1.5 m tonnes in 2008, Chinese ferrochrome production has grown at an annual average rate of 28% per year, for the period 2002 to 2010. Its ferrochrome industry is based entirely on imports of ore and stainless steel scrap.

It produced 0.2 MT of chromite in 2010. Chinese output of ferrochrome has expanded from 200-250,000 tpy at the beginning of the decade to over 2.17 million tonnes in 2010. Growth in Chinese FeCr production is dependent on securing ore from overseas, especially South Africa.

China has achieved 18% of total ferrochrome production as it is importing more than 40% of its chrome ore requirement from south Africa at a very low price i.e. around USD 215/ tonne CIF as compared to India which is receiving around USD 360/tonne CIF for a similar quantity of chrome ore. Thus South Africa is helping high cost Chinese ferrochrome producers, which may not otherwise survive, to compete.

9.3.3 United States of America

US chromium resources are mostly in Stillwater Complex in Montana. The steel industry in North America has been in decline for decades, since the price of oil went up in the 1970s, with the growth of inexpensive steel production capacity in other parts of the world. Fourteen percent of all chromite is consumed in the USA, but there is almost no domestic production. The Stillwater Mine produces chromite but does not market it, and a small new mine in Oregon is about to go into production.

9.3.4 Turkey

Turkey is the fourth largest exporter and sixth largest producer of chromite in the world. There are about 8 million tonnes reserves available in the country. Chromite occurs in Turkey in three belts:

(i) Northern Alpine region: North of Ankara, chiefly around Cankuni consisting of fan deposits.
(ii) Southern Alpine region: South of Ankara consisting of 6 deposits.
(iii) Central Alpine region: West of Ankara consisting of 3 deposits.

The regions known for important deposits are Guleman Elazig, Kopdag, Erzincan, Koycegic, Fethiye, Mugla, Kavak, Karsanti, Adana, Bursa and Kayesare. The southern region is the most important from the point of view of production and grade. In Turkey, the chromite industry comprised of large and small chromite ore producers, with one major producer Etibank General Management. The State Corporation Etibank is the largest producer of chromite in the country operating several mines and two ferro-chromium plants. The production of chromite was 1.9 MT during 2010. It produced 1.7 MT of chromite in 2010. Its output of ferrochrome has remained around 60000 tpy.

9.3.5 Zimbabwe

Zimbabwe is the fourth largest producer of chromite in the world. The most prominent geological features in Zimbabwe is the Great Dyke which has a strike length of 530 km, width varying from 5-11 km, covering an area of nearly 7500 sqkm and extending to a depth of more than 3000 m. The Great Dyke is known for its unique stratiform-type chromite seams of metallurgical grade. The Great Dyke consists of four segments namely (I) Musengezi Complex (ii) Hartley Complex (iii) Selukore Complex and (iv) Wedza Complex.

The chromium industry of Zimbabwe comprises large companies vertically integrated from chromite ore mining through ferro-chromium production. Presently, there are only three companies in operation. Production of chromite during 2010 was 0.51 MT and ferrochrome around 150000 tonnes.

9.3.6 Kazakhstan

Kazakhstan is the third largest producer of chromite in the world. Its chromite reserves are palced at 290 million tonnes. The chromite deposits occur in the Sveidlovsr region, the east of Ural Mountains associated with basic and ultrabasic instrusions. The ore bodies are stratiform masses.

The "Donskoye Ore Mining and Enrichment Combine" was the major chromium ore mining area in Kazakhstan. The 'Donskoye Combine' operate four surface mines and two underground mines. Kazakhstan produced 8.594 MT of chromite ore in 2010 out of which 1.16 MT was used to make ferrochrome.

9.3.7 Brazil

Brazil is also one of the important producers and exporters of chromite in the world. Cia De Ferro Ligas da Bahia S.A. has chromite ore mining and ferro-chromium production facilities. During 2010, Brazil produced 0.7 MT out of which 0.2 MT was used to make ferrochrome.

9.3.8 Albania

Albania is a less significant player of chromite. The reserves are placed at 6 million tonnes. The areas namely, Northern Albania and Bulqlze-Martanesh area are actively involved in the production of chrome ore. During 2010, Albania produced 0.2 MT of chromite ore and about 8000 tonnes of ferrochrome.

9.3.9 Finland

Finland is one of the important exporters of chromite to the European countries. The reserves of chromite are placed at 41 million tonnes. In Finland, Outo Kumpu Oy owned and operated chromite mine and has ferro-chromium and stainless steel production facilities. During 2010, Finland produced 0.6 MT of chromium ore.

9.4 FERROCHROME INDUSTRY IN INDIA

The Indian ferrochrome industry can be divided into three categories:

- Fully integrated – having access to both chrome ore and electricity.

- Partially integrated – having access to either chrome ore or electricity.
- Non - integrated – manufacturing on bought out chrome ore and electricity.

Fully integrated producers would definitely have a competitive cost structure, while partially integrated producers especially those having captive chrome ore (see annexure for gradewise production of chromite) would be better placed than producers having captive power (Fig. 9.3). Non-integrated producers would do well only when the price of ferrochrome is high.

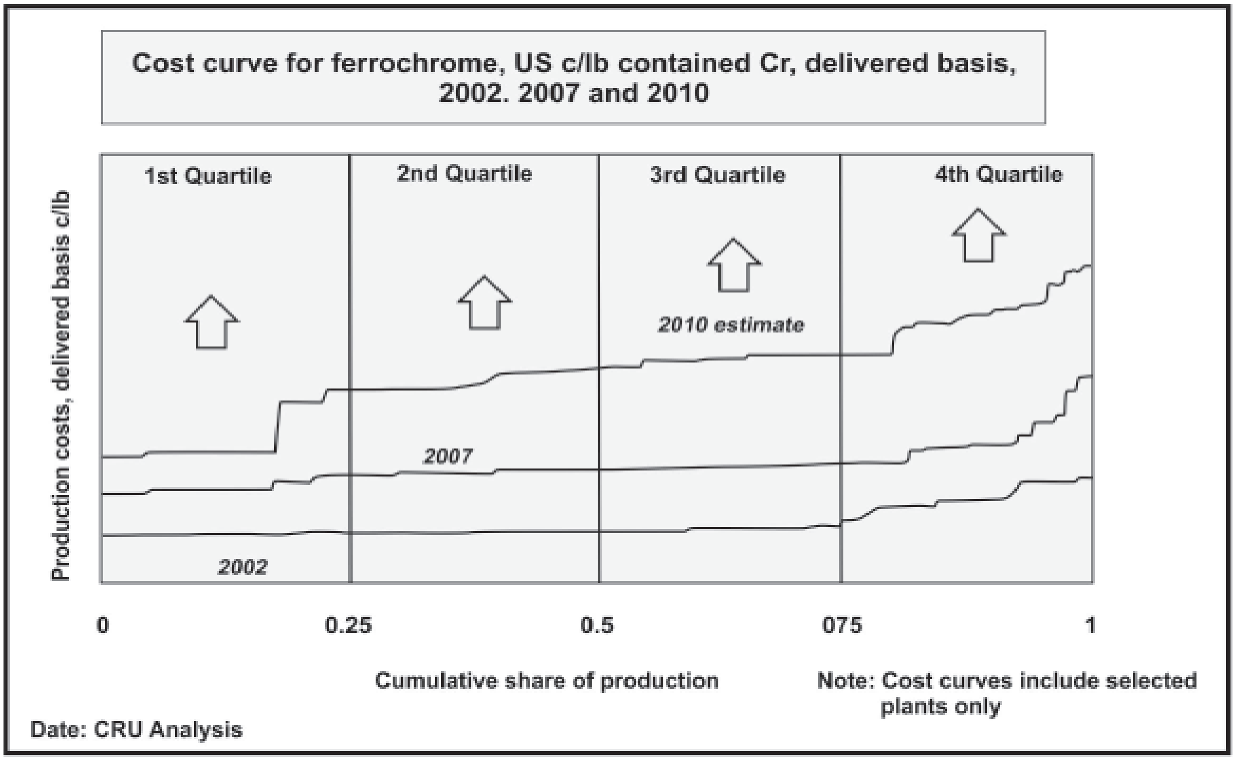


Fig. 9.3 : Ferrochrome Production Costs have Risen Sharply in a Decade

Many producers are now planning to set up CPP's, with power tariffs in India being one of the highest in the world, selling power gives rise to alternate revenue stream. Stainless steel production in India is growing at 5-6% per year, but per capita consumption of 1 kg compared to 10-18 kg in developed countries indicates a potential remaining to be tapped.

Production of ferro-chrome/charge-chrome was mainly reported by Ferro Alloys Corporation Ltd , Shri Vasavi Industries Ltd, Balasore Industries Ltd, Tata Steel Ltd and Indian Metal & Ferro - Alloys Ltd. As per the Indian Ferro – Alloys Producers' Association, 890,916 tonnes and 1030,000 tonnes of ferro-chrome/charge-chrome was produced in 2009-10 and 2010-11, respectively. The production of low carbon ferro-chrome was 2000 tonnes in 2010-11 as compared to 2,007 tonnes in 2009-10 . Tata Steel Ltd, Ferro Alloys Corporation Ltd and Indian Charge-chrome Ltd were amongst the major producers of charge-chrome in India. The charge chrome contains 50 to 60% chromium and 6 to 8% carbon. Hard lumpy chromite is used upon for high carbon ferro-chrome, while friable ores and fine briquettes are used for low carbon ferro-chrome. Briquettes fines along with lumpy ores were also consumed in charge-chrome plants.

9.5 THE MAJOR FERRO-CHROME PRODUCERS

Ferro Alloys Corporation Ltd, Garividi, Andhra Pradesh; GMR Technologies and Ind. Ltd, Srikakulam, Andhra Pradesh; Jindal Steel & Power Ltd, Raigarh, Chhatisgarh; Standard

Chrome Ltd, Raigarh, Chhatisgarh; SAL Steel, Kachchh-Bhuj, Gujarat ; Balasore Alloys Ltd, Balasore, Odisha; IDCOL Ferro Chrome plant, Jajpur Road, Odisha, Indian Metals and Ferro Alloys Ltd, Theruballi, Odisha; Jindal Stainless Steel Ltd, Dubari, Odisha; Nava Bharat Ferro Alloys Ltd, Dhenkanal, Odisha; Utkal Manufacturing Services Ltd, Choudhwar, Odisha; Rawat Ferro Alloys, Cuttack, Odisha; Rohit Ferro Tech P Ltd, Bishnupur, West Bengal and Shri Vasavi Industries Ltd, Bishnupur, West Bengal are the major ferro-chrome producers.

The important plants which produced chromite based refractories were Tata Steel Ltd (formerly OMC Alloys) , Orissa Industries Ltd, Burn Standardar co. Ltd., Bhilai Refractories Ltd, Joglekar Refractories and Ceramics (P) Ltd and Associated Ceramics Ltd.

A sizeable quantity is also produced by units in the small scale sector.

Table 7: Gradewise Production of Chromite, 2010-11 (By Sectors, States and Districts)
(Qty in tonnes, value in Rs. 1000)

State/ District	No. of Mines	Production by Grades : Cr_2O_3 Content								
		Below 40%		40%-52%		52% & above			Total	
		Lumps	Fines	Lumps	Fines	Lumps	Fines	Concn.	Quantity	Value
India	21	133733	1495217	138780	1024328	48	749777	720324	4262207	22955675
Public sector	8	8471	214901	0	447763	0	477280	107383	1255798	10894034
Private sector	13	125262	1280316	138780	576565	48	272497	612941	3006409	12061641
Karnataka	3	8471	20	-	-	-	-	—	8491	36851
Hassan	3	8471	20	-	-	-	-	-	8491	36851
Odisha	18	125262	1495197	138780	1024328	48	749777	720324	4253716	22918824
Dhenkanal	1	3271	-	15382	1817	-	-	-	20470	151921
Jajpur	13	58729	1495197	82548	984905	48	749777	720324	409152	22252198
Keonjhar	4	63262	-	40850	37606	-	-	-	141718	514705

9.6 REFERENCES

1. International Seminar on Development of Chromite, Nickel and PGM Resources, (28 Nov, 2010 Bhubaneshwar) SGAT & Dept. of Steel & Mines, Government of Odisha.
2. Market Watch, The Wall Street Journal.
3. Special Commodity Insights Bulletin-2012, KPMG.
4. Data: CRU Analysis.
5. Industrial Minerals Publication.
6. USGS- 2010, Minerals Yearbook-Chromium Advance Release.

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Chapter 10

WORLD TRADE, CONSUMPTION & PRICES

10.0 INTROUDCTION

World resources of shipping-grade chromite are more than 12 billion tonnes, sufficient to meet conceivable demand for centuries. The price and market for chromite are closely related to the growth of the steel industry. The price of chromite is determined, not by metal exchanges like the London Metals Exchange, but by negotiation between individual buyers and sellers. It is confusing (to say the least) to sort out the price of raw chromite from processed ferrochromium and processed chromium.

The countries which possess sizeable quantities of resources are Kazakhstan, South Africa, Finland, India, Russia, Turkey, Brazil and Albania. About 88% of world's 480 million chromium reserves are concentrated in Kazakhstan (46%) and South Africa (42%).

10.1 VALUE CHAIN

There is a tremendous amount of value addition during the process of conversion of chrome ore to ferrochrome, and thus, almost all major producers across the globe have captive sourcing of chrome ore, except Chinese manufacturers.

Due to the current circumstances prevailing in South Africa, the benefits availed by South African producers since a long period are getting passed over to chinese producers of ferrochrome.

CHROME ORE	**FERROCHROME**	⇨	**STAINLESS STEEL**
3.0 – 3.5mt	**1mt**		**3.0 – 3.5mt**
~ **$ 150 - $300/mt**	~ **$2000 - $3000/mt**		**$1500 - $4000/mt**

10.2 DEMAND / SUPPLY

Demand for chrome ore, which is driven by demand for ferrochrome, is expected to move in line with the increase in demand for stainless steel. USGS has estimated a resource base of more than 12 billion tonnes but ~95% of it is located in Southern Africa and Kazakhstan. Additionally, barely any new mines have been opened in the last five years with expansion in capacity coming from existing mines only. At the same time, India, the third largest producer of chrome ore, with only 2 % of the global resources, has only 47 years of production life left at the current level of production. Thus, the market is expected to remain in balance in the years to come with the increase in operating rates and additional capacity of prominent new projects to be only sufficient enough to meet the increase in demand.

South Africa plays a significant role in the world's output of ferrochrome contributing around 38% of the total in 2011. Recently, the mining industry has been hit badly because of the shortage of electricity. Eskom (South African Power Utility) has revised power tariffs in the last two years and is planning to revise them further up in the coming years. Because of this, major producers in South Africa have entered into an agreement with Eskom for reducing their production capacity and participating in electricity buy-back program. Merafe Resources and International Ferro Metals Ltd are lowering their output till the end of May 2012 under this program, resulting in a 30 per cent production loss.

Industry stocks of ferrochrome were reduced to very low levels in 2008 and have not yet been replenished. Indeed, we believe it will take market surpluses in 2011, 2012 and 2013 before stocks return to comfortable levels (Table 2). The combination of rising production costs and low inventories of ferrochrome suggest that prices will remain well above $1.00/lb for at least the next five years (Fig 10.1).

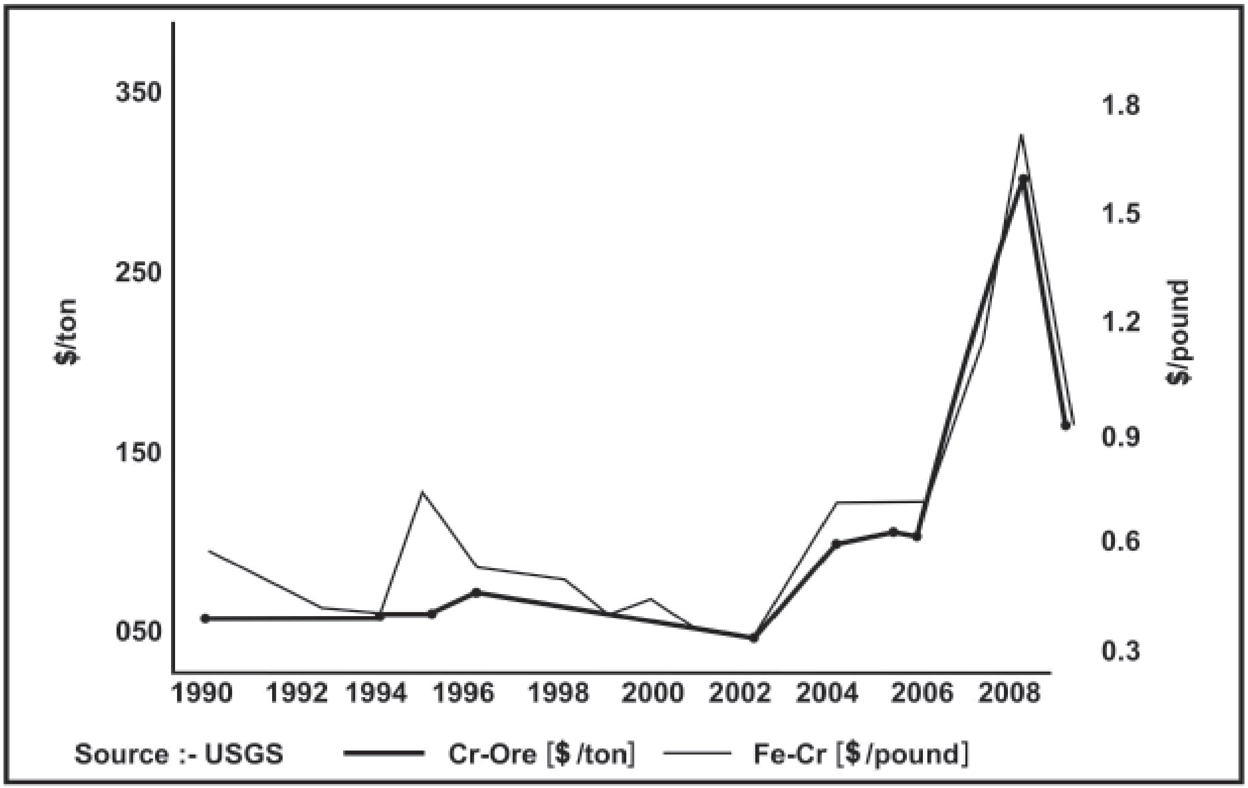


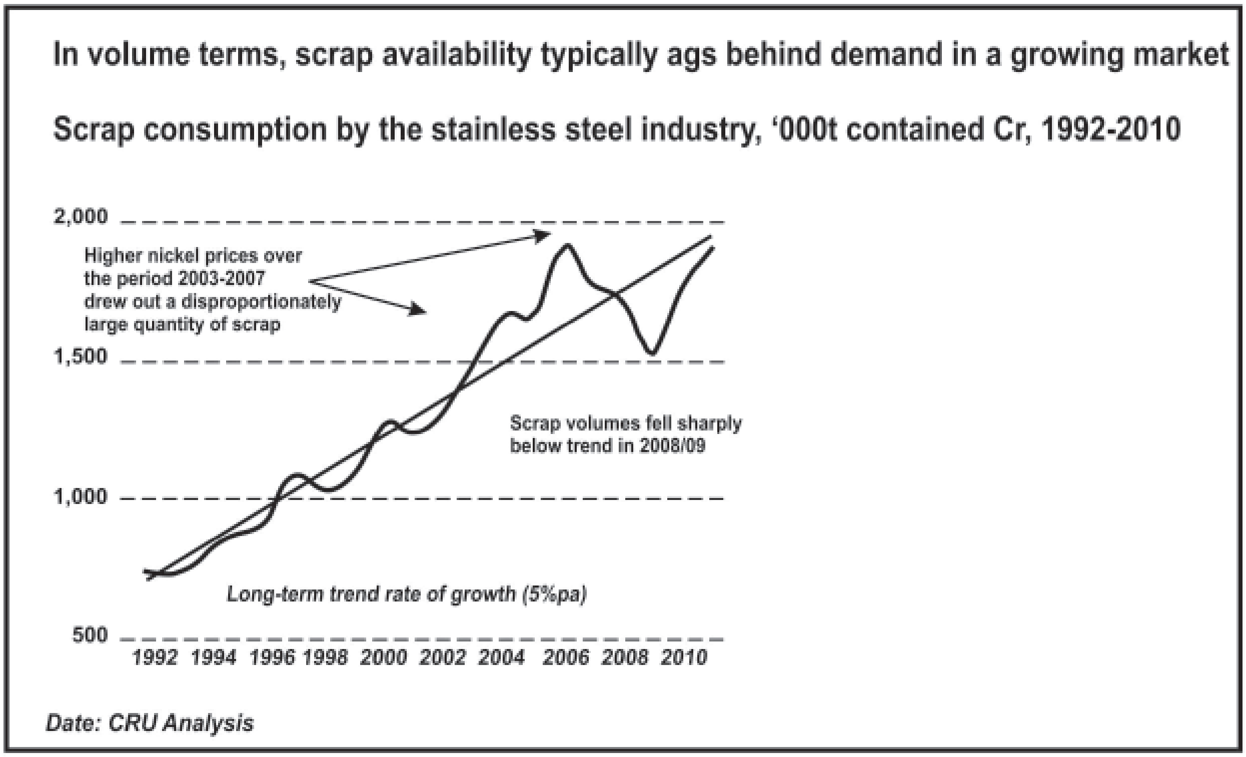
Fig: 10.1. : Cr Ore/ FeCr Prices

Stainless steel production reached record levels in China and India in the year 2008. Following this, chromite ore and ferrochrome prices reached record levels (Fig.1), which forced governments to look at ways to reduce prices and costs. Chromite ore producers wanted to export more ore, while ferrochrome producers wanted to limit chromite ore exports to secure their source of ore. As a result, ferrochrome producers promoted chromite ore export taxes and quotas that chromite ore exporters sought to reduce. Stainless steel producers promoted reduced import duties on ferrochromium, while promoting increased import duties onstainless steel mill products.

Export of raw ore from India to China was down 24.7% year- on -year in 2009, because of an export duty imposed by the Indian Government to discourage ore exports. This is primarily because when chrome ore is smelted into ferrochrome, there is a significant value addition. The supply vacuum for China was quickly filled by exports from South Africa. China produces 18% of world ferrochrome, 40% of its supply of chrome ore coming from South Africa.

10.3 AVAILABILITY OF SCRAP

There has been a shortage of scrap since 2008-09 (Fig. 10.2). Lower levels of industrial output during the recession have restricted the creation of stainless scrap. Long-term future potential for scrap growth is 5% pa. Asia's share of the available scrap will increase but will not come close to covering the region's total requirements. There are lags (15-18 years) between the consumption of stainless steel and its recovery, in the form of old scrap. China will not be a major generator of old scrap, for some years yet.



In volume terms, scrap availability typically ags behind demand in a growing market

Scrap consumption by the stainless steel industry, '000t contained Cr, 1992-2010

Higher nickel prices over the period 2003-2007 drew out a disproportionately large quantity of scrap

Scrap volumes fell sharply below trend in 2008/09

Long-term trend rate of growth (5%pa)

Date: CRU Analysis

Fig. 10.2 : Scrap Consumption by the Stainless Steel Industry

10.4 CHINA'S IMPORTS OF CHROME ORE

Due to the increase in demand for stainless steel in China and lack of availability of chrome ore, imports of chrome ore increased rapidly in China especially over the last 5 years. China's imports of chrome ore increased from 2.82 MMTPA in 2005 to 6.76 MMTPA in 2009 (Table 1). India was a major exporter to china in 2005 and 2006, but because of the increase in the export tax on chrome ore by the government, this demand of China was drawn out of the country. During 2007-2009, South Africa and Turkey have been increasingly catering to the chrome ore demand of China, with South Africa supplying almost 42.89% of the total imports of chrome ore by China in 2009.

Table 1 : China's Imports of Chrome Ore

Country	MMTPA				
	2005	2006	2007	2008	2009
India	0.98	1.34	0.98	0.55	0.41
South Africa	0.33	0.87	1.96	2.60	2.90
Turkey	0.62	0.74	1.08	1.18	1.29
Australia	0.20	0.22	0.22	0.07	0.14
Kazakhstan	0.07	0.11	0.20	0.20	0.17
Oman	0.05	0.07	0.34	0.81	0.69
Pakistan	0.15	0.20	0.30	0.38	0.30
Others	0.42	0.52	0.79	1.05	0.86
Total	**2.82**	**4.07**	**5.87**	**6.85**	**6.76**

Table 2 : The Global Supply/Demand Balance

	2009	2010	2011	2012	2013	2014	2015
Ferrochrome consumption, m tonnes % change	6.8 +0.9%	8.3 +20.9%	8.9 +7.3%	9.2 +4.0%	9.8 +6.6%	10.7 +8.4%	11.1 +3.7%
Ferrochrome supply*, m tonnes % change	6.1 -19.0%	8.3 +36.6%	9.0 +8.1%	9.6 +6.8%	10.0 +4.4%	10.5 +4.7%	10.9 +11.3%
Market balance, m tonnes	-0.7	0.0	+0.1	+0.4	+0.2	-0.2	-0.2

*Including production and change in official stockpiles.

10.5 DEVELOPMENTS AROUND THE WORLD IN THE LAST DECADE

2000 - 2007

Demand in developing countries such as China and India helped global output increase at an annual average rate of 5.4% for the period 2000 to 2007, with China alone accounting for over 60% of this rise in global stainless production. Any changes to supply have a large impact on the price.

2008

Chinese production has started to increase rapidly. At around 1.5MT in 2008, Chinese ferrochrome production has grown at an annual average rate of 28% per year, for the period 2002 to 2008. Three countries dominate output of ferrochrome. In 2008, South Africa, Kazakhstan and India accounted for around 67% of total world production. The 2008 financial crash had a major effect on chromium markets. "The onset of the economic downturn from mid-2008 has seen demand for chromium plummet, with prices following a similar path. Ferrochrome consumption fell by 3.5% in 2008, in year-on-year terms as major Asian and European consumers reduced orders to a minimum in an attempt to run down inventories, as demand from end-users declined sharply.

Export prices for ferrochrome have fallen by 68% for the ten months to May 2009, as demand from stainless steel, the main end-use for ferrochrome, has collapsed. In response to weakening demand and falling prices, producers have cut production, in some cases ceasing operations all together. Around 70% of world ferrochrome production capacity was suspended in the first quarter of 2009, with the Xstrata-Merafe joint venture operating at 20% of capacity since December 2008, while Samancor Chrome suspended all production in the first quarter of 2009."

2010

1. Ferrochrome demand has picked-up strongly, returning to pre-recession levels in the first quarter(Q1).
2. Stainless sector has driven the recovery (stimulus packages and end to destocking are key influences but real demand also showing signs of recovery).
3. China has led the way… others have been slower to rebound.
4. Shortages of scrap have boosted demand for primary ferrochrome.
5. Supply response has been measured.
6. Production problems have adversely affected some producers- (eg. Indian producers have had difficulty securing ore).
7. Elsewhere, producers have been cautious over re-starting too much capacity too quickly (concern over levels of demand in last two quarters, especially in Europe and China).
8. Global stocks of ferrochrome are extremely low (producer cutbacks during the downturn were savage).

The world production of chromite increased from 23.5 million tonnes in 2009 to 30 million tonnes in 2010. South Africa was the leading producer, contributing about 36% to the total world production, followed by Kazakhstan (29%) and India (14%). Other significant producers were Turkey, Brazil, Finland and Zimbabwe. Consumers of chromite are resorting to vertical integration of the industry. Consequently, the ferro-chromium producing capacities are migrating from stainless steel producing countries to chromite producing countries.

In 2010, the industry was once again bullish, anticipating considerable increase in demand. Xstrata, the world's largest chromium producer, started building a 4.9 billion rand ($710 million) smelter in South Africa to feed demand for the stainless steel ingredient. The sustainability of this new economic growth over the long-term is highly questionable.

2011-2012.

Chrome ore prices saw a steady rise over mid 2010 to mid 2011 (Fig. 3) because of higher energy costs in South Africa, hike in Chinese demand and overall tighter supply.

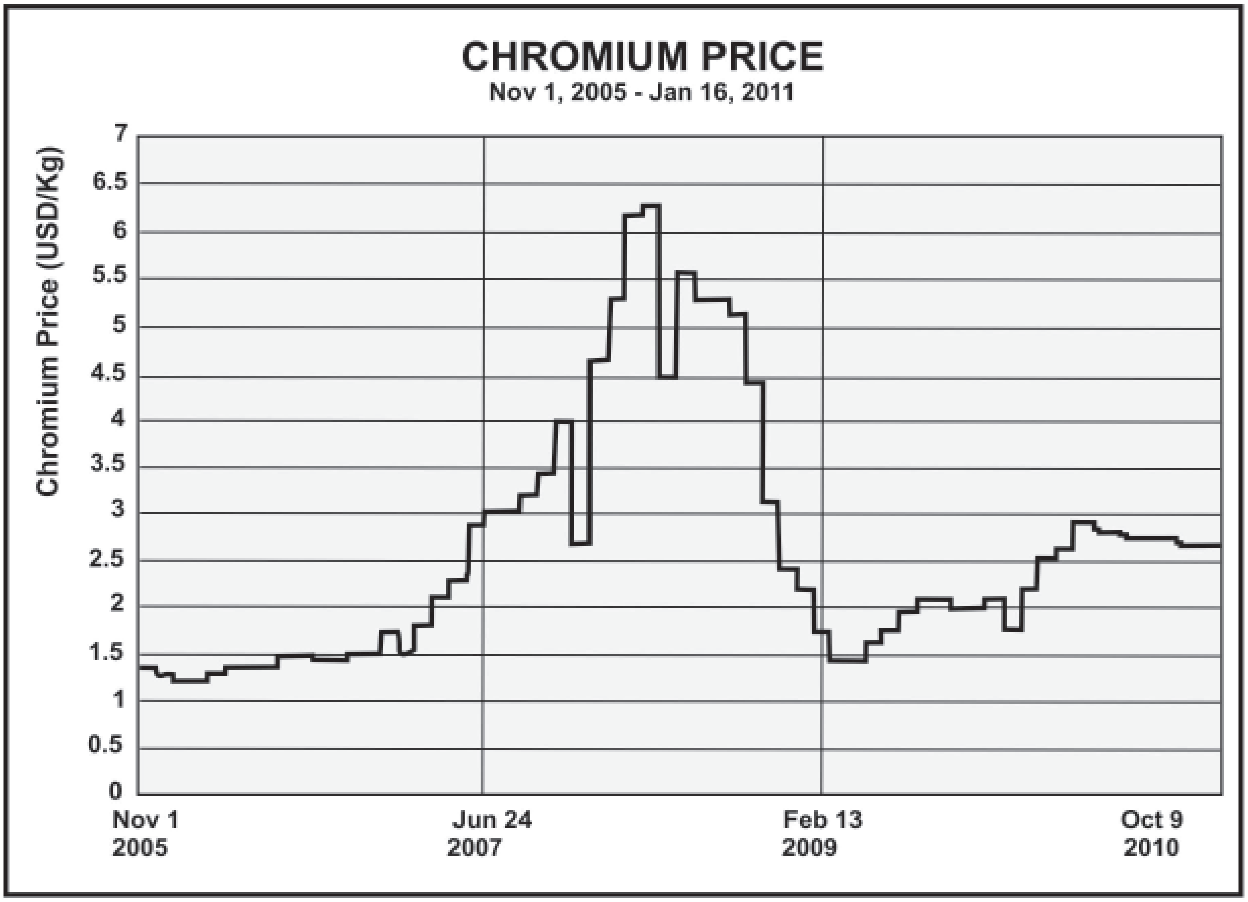


Fig. 10.3 : Chromium Prices

Chinese demand is expected to grow at a CAGR of 6.11 percent with other Asian countries expected to grow at ~4 percent. Total world crude stainless steel production for 2012 looks set to reach an all-time record of 34 million tonnes.

10.6 CHANGE IN TRADE PRACTICES AND INVESTMENT CLIMATE

Dutta (2010) reported that India, like China, Germany, and the United States, classifies chromite ore as a strategic raw material. India has been restricting the export of chromite ore. The United States stockpiled chromite ore, which is currently being sold. China is investing in South Africa and Zimbabwe to gain access to ore supplies and is discouraging ferrochromium export via export duty. The European strategy emphasizes conservation and recycling. South Africa, the leading exporter of chromite ore, has threatened to restrict chromite ore exports by imposing export duties to encourage domestic vertical integration. The chromium industry relationship between China and South Africa was observed by Xstrata plc to be complementary for chromite ore and competitive for ferrochromium. The complementary nature of the chromite ore industry between China and South Africa resulted from the fact that China consumed muchmore chromite ore than it could produce, while South Africa produced much more chromite ore than it consumed. The competitive nature of the ferrochromium industry between China and South Africa resulted from the fact that both China and South Africa produced ferrochromium. China's ferrochromium industry is not a threat to that of South Africa because South Africa is a lower cost producer (Xstrata plc, 2010). China, as the leading consumer of chromium materials, and South Africa, as the leading producer of chromium materials, were expected to reach an accommodation through trade and investment.

As per Metal Bulletin Review report, the demand for ferrochrome surged to new heights in the first quarter of 2011, but demand receded in the second and third quarter amid reduced demand from stainless steel mills as they faced reduced demand from their customers due to Euro zone crisis. But in the long run, in line with expectation of increase in stainless steel demand, demand for Ferrochrome is expected to increase. The consumption is expected to reach ~11 MT by 2013 at a CAGR of 7 percent per annum. South Africa's ability to produce ferrochrome from its chromite ores is restricted by an inadequate power supply.

Table 3 : Exports of Chromite : Total (By Countries)

Country	2009-10		2010-11	
	Qty (t)	Value (₹'000)	Qty (t)	Value (₹'000)
All Countries	**689081**	**8012506**	**172866**	**2860676**
China	618976	7189030	149908	2468087
Japan	25000	340374	22750	389397
South Africa	-	-	196	2992
Malayasia	-	-	2	110
UAE	36	3300	10	90
UK	-	-	-	-
Other countries	45069	479802	-	-

Table 4 : Imports of Chromite : Total (By Countries)

Country	2009-10		2010-11	
	Qty (t)	Value (₹000)	Qty (t)	Value (₹'000)
All Countries	**95842**	**860966**	**86456**	**904750**
Oman	28417	221648	56076	475726
Saudi Arabia	21707	268383	12074	214249
UAE	34523	257698	9622	112381
Turkey	9356	95448	6953	74532
China	137	4468	359	9441
USA	-	-	542	5874
Iran	1520	9941	456	4750
Singapore	-	-	80	1347
Nigeria	-	-	54	1288
Chinese Taipei/Taiwan	-	-	60	1196
Other countries	182	3380	180	3966

10.6.1 India

India produced 4.262 million tonnes of chromium ores during 2010. Indian Ferrochrome production has increased from around 300,000 tonnes in 2000 to over 1 MT in 2010. Indian producers have benefited from growing local demand as well as rising export demand.

Exports

Exports of chromite decreased to 0.17 million tonnes in 2010-11 from 0.69 million tonnes in the previous year. Out of total chromite exported in 2010-11, bulk share of about 60% was of chromite concentrate, while chromite lumps and other chromite together accounted for 40 per cent. Exports were mainly to China (87%) and Japan (13%). In 2010-11, about 22 tonnes of chromium & alloys and scrap was exported mainly to Indonesia and USA .

Imports

Imports of chromite decreased to 86 thousand tonnes in 2010-11 from 96 thousand tonnes in the previous year. Out of total quantity of chromite imported in 2010-11, lumpy chromite accounted for 93%, while concentrate and other forms accounted for remaining 7 per cent. Imports were mainly from Oman (65%), Saudi Arabia (14%), UAE (11%), and Turkey (8%). Imports of chromium & alloys in 2010-11 were 706 tonnes compared to 640 tonnes in the previous year. Imports were mainly from Russia and UK (80%).

Trade policy

The Ministry of Commerce and Industries, Department of Commerce, had come out with the new Foreign Trade Policy (FTP) for the period 2009-2014. As per the present Export-Import Policy as amended and effective from 05.6.2012, the imports of chromium ore lumps, friable ores and concentrates are freely allowed.

The export policy on chromite is as follows:

Tariff Items HS Code	Item	Export Policy	Nature of restrictions
26100000	(a) Chrome ore other than (i) beneficiated chrome ore fines/ concentrates(maximum feed grade to be less than 42%Cr_2O_3): and (ii) those categories of chrome ores mentioned as permitted through STEs (State Trading Enterprises)	Restricted	Exports permitted under licence other than categories given below
26100030	(b) Beneficiated chrome ore fines/ concentrates(maximum feed grade to be less than 42%Cr_2O_3)	STE	Export through MMTC Ltd
26100040			
26100030	(c) Chrome ore lumps with Cr_2O_3 not exceeding 40%	STE	Export through MMTC Ltd
26100090	(d) Low silica friable/fine ore with Cr_2O_3 not exceeding 52% and silica exceeding 4%	STE	Export through MMTC Ltd
26100090	(e) Low silica friable/fine chromite ore with Cr_2O_3 in the range from 52 to 54% and silica exceeding 4%.	STE	Export through MMTC Ltd

10.7 REFERENCES

1. Mining Watch Canada, January 25, 2011.
2. Mining.com June2011.
3. **Indian Minerals Yearbook- 2011; Indian Bureau of Mines,** Government of India , Ministry of Mines; **December, 2012.**
4. **Ferrochrome MarketOverview,** Outokumpu's Capital Markets Day, September 2010, Vanessa Davidson Managing Consultant, CRU ,Nickel & Chrome Group.
5. http://minerals.usgs.gov- CHROMIUM.
6. Data: CRU Analysis.

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Chapter 11

ENVIRONMENT

11.0 GENERAL

The degradation of air, land and water due to mining activities is a matter of concern. Care for the environment, therefore, has received unprecedented attention in recent years so that mineral exploitation and its impact is adequately managed with institutionalized efforts based on organized and planned steps. Many legal enactments to ensure sustainable mineral development have been made during the last three to four decades, taking into consideration the impact on environment due to mining and associated activities.

Chromium pollution is common in chemical industries and contamination of surface and groundwater around chrome chemical factories, tanneries and plating industries have been widely reported. But report of chromium pollution around chromite mines is particularly rare.

Chromium can exist in several valence states, zero to six, but zero (metallic), trivalent and hexavalent species are common. The trivalent state of the element is predominant in nature, but extremely immobile and locked up in chromites and some silicate minerals. Whereas the hexavalent forms is highly mobile and rare. However, the hexavalent Cr is thousand times more toxic than the trivalent Cr (Gauglhofr and Bianchi, 1991). In aqueous medium, the stability of chromium species is Eh - pH dependant (Baes and Mesmer, 1977).

The crustal abundance of chromium is 100 ppm(Liu, 1982) and the element is mostly confined to early formed oxides and silicates. Accumulation of the element takes place in ultramafic rocks in chromite deposits where Cr_2O_3 may reach as high as 60%, but the entire lot of the metal is in trivalent form and locked up in oxide and / or silicate lattice. Therefore, the lithogenic chromium has never posed danger for chromium toxicity.

The most common and stable form of chromium is trivalent Cr(III) which is not generally considered toxic. Another form of chromium - hexavalent chromium Cr(VI) is, however, highly toxic. It is a powerful oxidant at low or neutral pH. It is produced industrially by the oxidative roasting of chromite with calcium or sodium carbonate. It is generally believed that Cr(VI) is only created by human agency. The relationship between Cr(III) and Cr(VI) depends on pH and oxidative properties of the environment. Ground water has been known to contain up to 39µg/L of total chromium of which 30µg is present as Cr(VI). Residues from mining and processing chromite are often toxic, not only because of the presence of Cr(VI) but because of the reagents and other waste materials in overburden and wastes. Abandoned and closed chromium production sites require long-term monitoring, containment and clean-up.

Almost all the hexavalent chromium in the environment arises from human activities. It is derived from the industrial oxidation of mined chromium deposits and possibly from the combustion of fossil fuels, wood, paper, etc. In this oxidation state, chromium is relatively stable in air and pure water, but it is reduced to the trivalent state, when it comes into contact with organic matter in biota, soil and water. Chromium can strongly attach to soil and only a small amount can dissolve in water and move deeper in the soil to underground water. There is [a natural] environmental cycle for chromium, from rocks and soils to water, biota, air, and back to the soil. However, a substantial amount (estimated at 6.7 x 10 kg per year) is diverted [by human and natural processes] from this cycle by discharge into streams, and by runoff and dumping into the sea. The ultimate repository is ocean sediment. Fish do not accumulate much chromium in their bodies from water.

11.1 IMPACT OF MINING ON ENVIRONMENT

Although, the area under mining activity is small, the damage caused to environment is significant. Environmental damages resulting from mining in general can briefly be enumerated as follows:

i) Air pollution by dust and gases due to drilling, blasting , mine haulage and transporation by road and also from waste heaps;
ii) Water pollution due to chemical, atomic and other harmful elements present in the mine and processing plants effluents, leachates from old waste dumps; contamination of mine associated water seems to be a major irritant;
iii) Modifying water regime such as surface flow, ground water availability and lowering down of water tables;
iv) Soil erosion, soil modification with dust and salt;
v) Noise and vibration problem in mine and its effect on adjoining habitat including wild life;
vi) Alteration of the land form;
vii) Deforestation affecting flora and fauna; and
viii) Spoiling natural aesthetics with untreated waste dumps.

Chromium contamination of air comes from emissions of coal-based power plants and industrial chimneys of iron & steel and ferrochrome industries, from spray paintings, chrome baths, refractory industries and mining of chromites and magnesite. In rural areas, Chromium in atmosphere rarely exceeds 1ng/cu.m of air but towns with major iron & steel industries may have 1000 times more.

Some other sources of emission of chromium are:

i) Incineration of municipal refuse and sewage sludge.
ii) Cement producing plants, since cement contains chromium.
iii) Waste waters from electroplating, leather tanning, and textile industries when discharged into lakes and rivers.

11.2 CHROMIUM IN THE ENVIRONMENT

Honda (1988) has estimated that the release of lithogenic chromium after all natural barrier of precipitation and absorption can best contribute to the extent of less than 0.5 ppb Cr into the ground water, which is equivalent to the global lithogenic release (Hem, 1970), but reported a higher range of 4 to 7 ppb in many regions of India.

Chromium (III): In aqueous systems, soluble Cr(III) can be present as Cr^{3+}, $Cr(OH)^{2+}$, $Cr(OH)_2^+$, and $Cr(OH)_4^-$. Additionally, the precipitated phase $Cr(OH)_3$ predominates between pH6 and pH12 (Rai et al, 1987)

Chromium (VI) : Chromium (VI) exists in the environment as part of several compounds, Cr(VI) is present in solution as monomeric forms; H_2CrO_4, $HCrO_4^-$ (hydrogen chromite), CrO_4^{2-}

and CrO_3(Chromium (III)) oxide) or as $Cr_2O_7^{2-}$ (dichromate). This is because Cr(VI) is not present in the environment as a free cation, Cr^{6+}, [whereas Cr(III) does not exists in the environment as Cr^{3+} as previously mentioned]. In fact, all Cr(VI) species are oxides.

Chromium in water : Chromium(VI) (Cr(VI)) in groundwater has generally been assumed to be anthropogenic(man made) contamination, since it is used in a number of industrial applications, including electroplating, panning, industrial water cooling, paper pulp production, and petroleum refining. Chromium (III) (Cr(III)) , the most common form of chromium (Cr) in the natural environment, is highly insoluble and relatively immobile . However, Cr(VI) minerals have been found in nature (Chapter 2), and the ability of Manganese (IV) Oxide (MnO_2) to oxidize Cr(III) to Cr(VI) is well known.

Chromium in the Atmosphere : The majority of chromium in the atmosphere (approximately 60% to 70%) is owing to anthopogenic sources. Chromium from natural sources accounts for the remaining amounts (Seigneur and Constantinou, 1995). Human activities that can product chromium in the atmosphere include metallurgical industries, refractory brick production, electroplating, combustion of fuels, the production of chromium chemicals(i.e. CrO_4^{2-} and $Cr_2O_7^{2-}$, pigments, Chromium (VI) oxide(CrO_3), chromium salts), the cement industries production of phosphoric acid (H_3PO_4) in thermal processes, and combustion of refuse and sludges (Nriagu, 1988). Natural sources of chromium include volcanic eruptions, erosion of soils and rocks, air borne sea salt particles and smoke from forest wildfires(Pacyna and Nriagu 1988). Average atmospheric concentrations of chromium ranges from 1ng/m3 in rural areas to 10ng/m3 in polluted urban areas (Nriagu 1988).

The two stable oxidation states of chromium in the atmosphere are Cr(III) and Cr(VI). Atmospheric particles do not contribute to the chemical reaction that control occurrence and ratio between Cr(III) and Cr(VI). Instead, precipitation, complex formation, and oxidation reaction influence the abundance and ratio of Cr(III) and Cr(VI).

Chromium in Groundwater : Cr(III) tends to be relatively immobile in most groundwater because of the precipitation of Cr(III) compounds of low solubility (for eg. $Cr(OH)_3(s)$, $FeCr_2O_4(s)$, $(Fe1\text{-}x'Crx)(OH)_3$ (solid solution)) in neutral to alkaline pH range (i.e. above pH4). This results in low Cr(III) dissolved concentrations Cr(VI) tends to be moderately to highly mobile in most shallow groundwater aquifers. This tends to be owing to two major factors: (1) the lack of solubility constraints; and (2) the low to moderate sorption of Cr(VI) anionic form in neutral to alkaline waters. Geochemical study, including leaching experiments by Godgul (1994), Godgul and Sahu(1995) has shown that Cr(VI) can be generated from chromite if the chromiferous deposit is soaked in alkaline pore water and has undergone deuteric oxidation like weathering and lateritization.

Chromium in Soil : "Metals" exists in soil solution as either free (uncomplexed) metal ions (e.g. Cr^{3+}), or in soluble complexes with inorganic or organic ligands, associated with mobile inorganic and organic colloidal material. A complex is a molecular unit where a central metal ion is bonded by a number of associated atoms or molecules (e.g. $Cr(OH)_4^{2-}$), and these associated items or molecules are termed ligands (i.e. OH- is a ligands). Precipitation and sorption are the main metal retention mechanism in soil. The pH of the soil system is a very important parameter, directly influencing sorption/desorption, precipitation/dissolution, complex formation, and oxidation-reduction reactions. The pH affects several mechanism of metal retention of soils both directly and indirectly.

Behaviour of Chromium in Soil : Chromium commonly exists in two oxidation states in soils, Cr(III) and Cr(VI). Forms of Cr(VI) in soils are as hydrogen chromate ion($HCrO_4^-$ predominant at pH < 6.5 or CrO_4^{2-} predominant at pH 6.5), and as dichromate ($Cr_2O_7^{2-}$) predominant at higher concentrations and at pH 2 to 6 . $Cr_2O_7^{2-}$ is more toxic to humans than CrO_4^{2-}.

11.3 PHYSICAL AND CHEMICAL CHARACTERISTICS

Cr(III) is a stable oxidation state and slowly reacts to form complexes. Because of its low kinetic energy potential, Cr(III) is not a strong oxidizer and it appears that the stomach's acidity is enough to keep the Cr in the Cr(III) state. Cr(VI) is not as stable as Cr(III) because it is strong oxidizing agent, is fast reacting, and likely forms complexes. As with many toxic substances, exposure to metals by inhalation, poses the greatest risk. However, for Cr(VI) to be inhaled, a person must be exposed to chromium fumes or airborne dust in industrial processes such as cutting or welding, chromium metals or to Cr(VI) in airborne dust or water droplets. Some scientists suggested that Cr(VI) can cause cancer even when inhaled as an aerosol by showering in Cr(VI) – contaminated water. Disagreement still exists over the safe limits of Cr(VI) ingested as drinking water. There remains a debate by experts about the absorption potential that Cr(VI) might have in the stomach's acid environment. There does not appear to be a perceptible odor or taste that chromium in any form imparts to drinking water.

11.4 EXPOSURE PATHWAYS

The common exposure routes for any adverse health effects, carcinogenic or non-carcinogenic, for Cr(III) and Cr(VI) are

1. Ingestion(eating/drinking)
2. Dermal contact(skin penetration)
3. Inhalation(breathing)

The exposure could be acute (<14days), intermediate (15 to 364days) and chronic (>year). The USEPA considers Cr(VI) to be carcinogenic by inhalation only. Gastric juices rapidly reduce Cr(VI) to Cr(III), which in small quantities is an essential nutrient. The reduction process appears to be 100% complete so that no Cr(VI) can be detected in the gastrointestinal tract and the blood after ingestion of Cr(VI). This is the reason why Cr(VI) is not considered a health hazard by ingestion. For some, a significant health concern is the possible adverse effects of human ingestion of Cr(VI) in drinking contaminated groundwater or surface water. This exposure risk is still being debated within the scientific community.

Dermal contact may be experienced by swimming/bathing and contact with contaminated soil; and workers in the Cr industry. Cr(VI) compounds are generally much more soluble in water as compared to Cr(III) compounds, Cr(VI) will penetrate the skin 10,000 times faster. Penetration by both is possible at an equal rate in case of skin lesions. A common form of Cr(VI) is chromate, a compound containing the chromate ion, CrO_4^{2-}, such as potassium chromite K_2CrO_4. CrO_4^{2-} enter the blood stream through breaks in the skin . CrO_4^{2-} blood poisoning occurs when CrO_4^{2-} destroys red corpuscles.

Inhalation of Cr(dust, fumes, aerosol) is the important intake mode. Inhalation is also an important human exposure pathway; however, it is less likely to be associated with exposure to Cr(VI) – contaminated soils and groundwater and more likely associated with industrial process such as welding, cutting, heating of Cr alloys and work related practices which create Cr(VI) fumes and airborne dust. Due to its higher solubility with water, Cr(VI) causes nasal damage, lung damage and is transferred to the blood from the lungs. Remnants continue in the lungs and cause cancer, contributing greatly to its toxicity.

11.5 REGULATORY REGIMES

The permissible limit of chromium in drinking water is 50 ppb (0.05 mg/L) (As per WHO standards). In India, the prescribed standard for discharging into surface water bodies is 0.1 mg/l and that of potable water is 0.05 mg/l. In the US, neither the federal or state governments limits Cr(VI) concentration in water, but both regulate total Chromium. The USEPA Drinking Water Maximum Contaminant Level (MCL) for total Cr is 100 ug/L. California limits total Cr in drinking water to 50 ug/L. Total Cr for contaminated site generic soil screening level is 390 mg/kg for ingestion, 270 mg/kg for inhalation, and 2.0 mg/kg for migration to ground water (USEPA, 1996).

11.6 HEALTH

Cr(III) is an essential nutrient that helps the body use sugar protein and fat. The minimum human daily chromium requirement for optimal helath is unknown but a daily ingestion of 50 ug/L to 200 50 ug/L is estimated to be safe and adequate according to the ASTDR(1989).

Elemental chromium (Cr) does not occur in nature, but is present in ores, primarily chromite ($FeOCr_2O_3$) (Hamilton and Wetterhahn, 1988). Only two of the several oxidation states of chromium, Cr(III) and Cr(VI), are relevant, based on their predominance and stability in the ambient environment and their toxicity in humans and animals. Chromium plays a role in glucose and cholesterol metabolism, and is thus an essential element to man and animals (Schroeder et al., 1962). Non-occupational exposure to the metal occurs via the ingestion of chromium-containing food and water, whereas occupational exposure occurs via inhalation (Langard, 1982; Pedersen, 1982). Workers in the chromate industry have been exposed to estimated chromium levels of 10-50 $\mu g/m^3$ for Cr(III) and 5-1000 $\mu g/m^3$ for Cr(VI); however, improvements in the newer chrome-plating plants have reduced the Cr(VI) concentrations 10 to 40 times (Stern, 1982).

Chromium(III) is poorly absorbed, regardless of the route of exposure, whereas chromium(VI) is more readily absorbed (Hamilton and Wetterhahn, 1988). Humans and animals localize chromium in the lung, liver, kidney, spleen, adrenals, plasma, bone marrow and red blood cells (RBC) (Langard, 1982; ATSDR, 1989; Bragt and Van Dura, 1983; Hamilton and Wetterhahn, 1988). There is no evidence that chromium is biotransformed, but Cr(VI) does undergo enzymatic reduction, resulting in the formation of reactive intermediates and Cr(III) (Hamilton and Wetterhahn, 1988). The main routes for the excretion of chromium are via the kidneys/urine and the bile/feces (Guthrie, 1982; Langard, 1982). Animal studies show that Cr(VI) is generally more toxic than Cr(III), but neither oxidation state is very toxic by the oral route. In long-term studies, rats were not adversely affected by ~1.9 g/kg/day of chromic oxide [Cr(III)] (diet), 2.4 mg/kg/day of Cr(III) as chromic chloride (drinking water), or 2.4 mg/kg/day of Cr(VI) as potassium dichromate (drinking water) (Ivankovic and Preussmann, 1975; MacKenzie et al., 1958).

The respiratory and dermal toxicity of chromium are well-documented. Workers exposed to chromium have developed nasal irritation (at <0.01 mg/m^3, acute exposure), nasal ulcers, perforation of the nasal septum (at ~2 µg/m^3, subchronic or chronic exposure) (Hamilton and Wetterhahn, 1988; ATSDR, 1989; Lindberg and Hedenstierna, 1983) and hypersensitivity reactions and "chrome holes" of the skin (Pedersen, 1982; Burrows, 1983; U.S Air Force, 1990). Among the general population, contact dermatitis has been associated with the use of bleaches and detergents (Love, 1983). Compounds of both Cr(VI) and Cr(III) have induced developmental effects in experimental animals that include neural tube defects, malformations, and fetal deaths (Iijima et al., 1983; Danielsson et al., 1982; Matsumoto et al., 1976).

The inhalation of chromium compounds has been associated with the development of cancer in workers in the chromate industry. The relative risk for developing lung cancer has been calculated to be as much as 30 times that of controls (Hayes, 1982; Leonard and Lauwerys, 1980; Langard, 1983). There is also evidence for an increased risk of developing nasal, pharyngeal, and gastrointestinal carcinomas (Hamilton and Wetterhahn, 1988). Quantitative epidemiological data were obtained by Mancuso and Hueper (1951), who observed an increase in deaths (18.2%; $p<0.01$) from respiratory cancer among chromate workers compared with 1.2% deaths among controls. In a follow-up study, conducted when more than 50% of the cohort had died, the observed incidence for lung cancer deaths had increased to approximately 60% (Mancuso, 1975). The workers were exposed to 1-8 mg/m^3/year total chromium. Mancuso (1975) observed a dose response for total chromium exposure and attributed the lung cancer deaths to exposure to insoluble [Cr(III)], soluble [Cr(VI)], and total chromium. The results of inhalation studies in animals have been equivocal or negative (Nettesheim et al., 1971; Glaser et al, 1986; Baetjer et al., 1959; Steffee and Baetjer, 1965).

Based on sufficient evidence for humans and animals, Cr(VI) has been placed in the EPA weight-of-evidence classification A, human carcinogen (U.S. EPA, 1991a). For inhalation exposure, the unit risk value is 1.2E-2 (µg/m^3)$^{-1}$ and the slope factor is 4.1E+01 (mg/kg/day)$^{-1}$ (U.S. EPA, 1991a).

11.7 HEXAVALENT CHROMIUM IN CHROME BEARING REFRACTORIES

Chrome bearing compounds containing Cr^{+6} is classified as toxic and carcinogenic compound which is not environment friendly. When chrome based refractories are exposed to severe environmental conditions like high temperature, high pressure and contact with alkali and alkaline earth oxides during use, the transition of Cr^{+3} to Cr^{+6} in air is accelerated and occurs at notable rates. Cr^{+6} is generally formed at the slag/chromites refractories interface during cooling of a magnesia chrome brick lines furnace. Cr^{+6} formation tendency is reduced in presence of tetravalent oxides like Sio$_2$, Tio$_2$, etc.

Following factors are affecting the formation of Cr^{+6}:

1. Higher amount of alkali oxides and CaO in chrome-based refractories as well as in slag.
2. High pressure.
3. Smaller particle size.
4. Use of chromites in sintered form.
5. Calcium aluminate, calcium silicate, calcium alumino silicate slag.
6. High basicity slag.
7. Cooling rate.

Hexavalent chromium compounds (chromium IV) are generally recognized as toxic with chromic occupational exposure associated with an increased incidence of bronchial cancer. Trivalent chromium is used in raw material for refractories, paints and pigments production and are known either as chromite (chrome ore) or chromic acid (chromium sesquioxide Cr_2O_3). Trivalent chrome increases resistance of refractories to molten metals glasses and slags and as green pigment in paints and plastics where a high heat tolerance is required.

The perception that refractory grade chromite ore is environmentally hazardous was challenged in a letter on use of refractory grade chromite (McCracken, 1999). The refractory production process itself does not cause the conversion of trivalent chromium found in chromite ore into hexavalent chromium, which is the environmentally unfriendly form of chromium. Hexavalent chromium compounds are formed under high temperature refractory furnace conditions when chromite is exposed to alkali-bearing materials. The resulting hexavalent chromium, which is not stable and is converted to trivalent chromium, can be dissolved and mobilized in the environment. Chromite use in refractories improves the refractory materials' resistance to spalling and slag and promotes volume stability and structural strength.

11.8 WASTE MANAGEMENT

As Cr(VI) are soluble in water and known to be carcinogenic, the end users are increasingly conscious of this problem due to more stringent environmental regulations. Spent magnesia chrome refractory is classified as a solid hazardous waste when it has over 5 ppm Cr(VI). Therefore, concerted efforts have been made to reduce and recycle the solid waste. Many refractorys are disposed as land fill. Recycling and waste management of refractory is extremely difficult since associated costs are difficult to quantify. Also since many recyclable spent refractorys are low value items it is always cheaper to buy new raw materials than to use recycled materials. Only about 10% of total refractory production is recycled. Refractory manufacturers in India are procuring the recycled chrome bearing materials from different users and using in the formulation depending on the quality and application. In some cases, there is an agreement between the supplier and end user for buying back the recycled material.

11.9 ENVIRONMENTAL PROBLEMS DUE TO CHROMITE MINING IN SUKINDA VALLEY (ODISHA) AND PROPOSED REMEDIAL MEASURES

Mining activity only enhances the process of leaching by way of increased particle – water interaction. Many workers have detected Cr(IV) and soluble Cr(III) in mine sludge, effluents and quarry waters, in waters of Damsala river that drains Sukinda chromite belt, in the well water samples of the region, even along some downstream sections of Brahmani river though in lesser amount and in Dharmra estuary (COMAPS), 1992-93, Godgul, 1994, IBM-BRGM, 1998-99, OPCB, 2000.

An integrated analysis of textural, chemical and leaching data of the samples point to the release of immobile Cr(III) either (mostly) from chromite and silicates and possible movement of the oxidized species to the aquatic regime of the region. This is substantiated by Cr levels of mine floor water samples which shows as high as 1000ppb of total Cr. The leached and transported chromium flux either in particulate or in solution would automatically enhance the chromium level in sediments and waters of the downstream region – the proximate Damsala Nala, the distant Bramhani river to some extent and the Dhamra region at the farthest end where the element has been detected in sediment ,suspended solids and water under COMPAS program of DRDO.

Table 1 : Reported Chromium in Water, Suspended Particles and Sediments at Dhamra

Cr in :	Stn D.1	Stn. D.3
Water (ppb)	3875	3123
Particulates (ppb)	3888	4670
Sediments (ppm)	25	21

Indian Bureau of Mines has carried out IBM BRGM project under collaboration of BRGM, France, titled "Development of Application Techniques in relation to Environmental Management of Mines and Waste Recoveries". The overall objectives of the project was,

"To acquire essential sophisticated analytical equipment, transfer of state-of-art technology to IBM on analytical techniques, training on mining site specific environmental impact assessment (EIA) methods and pollution abatement technology & preparation of Regional Environmental Impact Assessment (REA), techno-economic recovery of valuable mineral from toxic wastes or to neutralize them, to assess existing and potential environmental impacts of mining operations, to find mine site-specific solutions under Indian technical, legislative and socio-economic conditions."

Based on the existing range of adverse environmental impacts, the nature and level of production, availability of mineral reserves and environmental sensitivity of the areas, chromite mines of Sukinda valley in Orissa were selected for the joint study by IBM & BRGM for preparation of Regional Environmental Impact Assessment. (REIA)

The study area covers 12 nos. of chromite mines in Sukinda Valley. Mines have been divided into two groups in Table 2.

Table 2: Number of Mines under REIA Study

A - East Group		B - West Group	
Name of the mine	**Operating Agency**	**Name of the mine**	**Operating Agency**
1. Kalarangi	OMS	1. Kathpal	OMC
2. Sukinda(Bhimtanagar)	TISCO	2. Kathpal	FACOR
3. Kaliapani	OMC	3. Birsal	OMC
4. South Kaliapani	OMC		
5. Ostapal	FACOR		
6. Sukerangi	OMC		
7. Tailangi	IDCOL		
8. Saruabil	MMPL		
9. Kamarda	B.C. Mohanti		

11.10 THE REGIONAL ENVIRONMENT ASSESSMENT (REA) & ITS RESULTS

The REA and minewise EMP of these 12 mines are based on the data generated from monitoring stations, judiciously selected for analysis of air, water, noise, dust and other vital parameters. Monitoring has been carried out as per the norms laid down by Indian Bureau of Mines and

MOEF. The summary of the results obtained from these monitoring sites followed by risk analysis performed is given in table 2.

Main Results of the REA Monitoring for Sukinda

Air quality : Work zone: Seasonal data exceed the standard, where as in Villages & colonies, RPM also exceeds the limit at Tisco Colony, Kaliapani colony, Chinguripal village, Kamarda village, Bandhania village, Ostapal colony.

Dust track : SPM is 2 to 3 times greater during winter.
Dust gauge : Largest dust fall : Kaliapani road side in February, March
Noise Dust material content : Cr, 0.4-3%, CrIV, 0.01-0.08%, Ni, 0.03-0.3%
Source monitoring : data exceeds standards for drilling machine.
Work zone monitoring : data exceeds the standards at Ostapal, South Kaliapani and Tailangi mines.
Ambient noise : data exceeds the standards at Chinguripal, Kamarda and Tailangi villages.

Background levels* Air : SPM 53 to 110 μg/m3 and RPM 32 to 69 μg/m3 in villages
Soils : in laterite, Cr up to 5-7% and Ni up to 0.5%

(Background level : Natural concentration unaffected by mining activities is considered as background level.)

Topic	**Main features**
Nala sediment	*Cr: 0.3-27%;CrVI: 30-104mg/kg; Ni40-1090 mg/kg
Paddy field sediment	*Cr: 0.04-2%;CrVI: 6-190mg/kg; Ni40-580 mg/kg
Waste and Ore	*Ore :Cr= 48% Tailing:Cr=25%; Dump:Cr=7%, Ni upto 0.6%
Leaching tests	*Leachate of nala sediment : Cr. Total = CrVI = 2-12mg/l *Leachate of Paddy sediment : Cr. Total = CrVI = 0.7 mg/l
Surface water	* 23 out of 31 monitoring stations exhibit CrVI above drinking water standards (upto 3.4 mg/l). * 6 stations exhibit Hg above drinking water standards (upto 0.02 mg/l). * No specific trend season wise.
Ground water	* 32 out of 33 monitored wells exhibit at least one Cr VI above the drinking water standard (upto 0.6 mg/l). *6 wells exhibit Hg above drinking water standards (upto 0.01 mg/l) Pit water and seepage water* Cr VI concentration = 0.07-2.14mg/l. Highest concentrations are observed at South Kaliapani and TISCO mines. *Dust Metal content : Cr 0.4-3%, CrVI 0.01-0.08%, Ni 0.03-0.3%.
Fauna and Flora	*Paddy: Cr:16-740 mg/kg; CrVI: <0.001-142mg/kg. *Fish: Cr:180-5700 mg/kg; CrVI: 14-115mg/kg. *Milk: Cr: <0.001-0.69 mg/kg. *Fruits : Cr:10-112 mg/kg; CrVI: = 5-28 mg/kg. *Aquatic grass: Cr:430-22300 mg/kg; CrVI: <0.001-29mg/kg.

Observations

- Surface water quality exceeds the standard for drinking, acquatic lives, and fish for Cr upto (0.6 mg/l), in most of the Damsal nallah valley outstream Gurujangpal village (west of Sukaraugi lease).
- Surface water is suitable for irrigation only in the upper part of the valley.
- Paddy sediment quality(6 to 190 mg/kg) exceeds the Cr standard for agricultural soil in the most of the fields and Ni in few places investigated.
- Ground water quality upto (0.6mg/l) exceeds the standard for drinking water in the most of the wells that were investigated.
- Air quality (Cr 0.4-3%, Cr VI 0.01 to 0.08%, Ni 0.03 to 0.3%) does not meet the RPM and / or SPM 2 to 3 times greater standards at Chinguripal, Bandhania, Kamardha, Telangi and on the dumping yards under operation.

Result and Conclusion of REA

Chromite contamination is observed in the entire zone of influence of mining activity. Traces of mercury higher than drinking water standard from sources, which could not be identified, have also been noticed in some areas. It has conclusively brought to the fore that ultimately the main risk in the chromite belt is associated with the drinking water contamination with hexavalent chromium and transfer of these pollutants throughout the food chain to paddy field, fruits, vegetables and aquatic flora and fauna.

The impacts have affected the whole of Sukinda valley and in the framework of the EMPs, solutions must not only be sought at the sources, i.e. at individual mining lease scale (exploitation, waste management and effluent treatment), but also regionally i.e. at valley scale(transport, land use, water resources management). This involves of mine management and rehabilitation of inhabitants in and around mining belt, and co-ordination between State and Central Government administrative agencies to effectively ensure sustainable development of this very important chromite bearing belt in India.

The areas and factors requiring attention in Sukinda valley chromite belt is the main risk associated with hexavalent chromite in the water and transfer of the pollutants throughout the food chain including paddy fields, fruits, vegetables and aquatic flora and fauna. Presently, treatment of mine water and processed water is being done with the help of water treatment plants installed by the mining companies as a mitigation major and the result obtained is far below the requirement.

11.11 S & T SCHEME ON ATTENUATION OF HEXAVALENT CHROMIUM IN SUKINDA CHROMITE BELT BY BIO-REMEDIATION TECHNOLOGY

In another study, (a S & T Project in association with Utkal University) the Mining Research Cell, Indian Bureau of Mines, during 2008-09 had investigated the attenuation of hexavalent chromium in Sukinda chrome belt by bio-remediation technology which is apparently environment-friendly. The objective of the project is basically to address the problem of hexavalent chromium, present in mine discharge water, which may cause environmental pollution of the water bodies, soil, flora and fauna of the surrounding area.

The project was to carry out field investigations for attenuation of hexavalent chromium through biological treatment, by allowing mine discharge water to pass through the paddy/ grass fields for the conversion of hexavalent chromium, which is carcinogenic, to trivalent chromium and to demonstrate the results to the local mine management, which is eco-friendly and cost effective. The analysis shows encouraging results indicating reduction of hexavalent chromium to trivalent (which is not harmful) to the extent of permissible level in down stream water. It is further observed that most of the hexavalent chromium is absorbed in the root region of plants and does not transmit to seed level.

Hexavalent chromium which is a water pollutant, carcinogenic in nature and has got adverse effect on fertility of soil as well as micro-biological activities, gets reduced after passing through certain weeds, grasses and aquatic plants. For this purpose, pilot test experimental plots were selected near south Kaliapani Chromite mine, where mine discharge water was allowed to pass through different crops cultivated within this area. Two crops of paddy were taken periodically, along with different types of para grasses and water hyacinth in the experimental field in which mine discharge water was used under controlled conditions. Periodical sampling of water, soil and plant species were carried out.

The result shows that the main negative impact generated by mining activity is water contamination by hexavalent chromium, a contamination that has propagated through the food chain to include paddy fields fruits and vegetable and aquatic flora & fauna. Mining activity has also, although to a lesser degree, degraded air quality and is the cause of conflict of use with farmers and local communities whose farmland has been diminished and degraded to accommodate the increasing amount of mining waste.

11.12 HEXAVALENT CHROMIUM TREATMENT AT SUKINDA CHROMITE MINE (TISCO)

Presence of hexavalent chromium in mine water of Sukinda valley was reported way back in the year 1990. Tata Steel was the pioneer in finding out a suitable method of treating hexavalent chromium by engaging NEERI, Nagpur. Based on the findings of NEERI, the company established an effluent treatment plant in the year 1993 and used pickle liquor as the reagent for treatment, which was first of its kind in the country. After successful trial of the pilot plant, a full fledged effluent treatment plant with latest technologies of automatic dosing and suspended solid removal mechanism was established in 2002 to ensure that the water quality met all the parameters prescribed by statutory authorities at an expenditure of about Rs 50 lakhs.

In the course of mining, ground water gets accumulated in the quarry floor. In the open cast chromite mines the water percolates into the quarry and dissolves hexavalent chromium making it unsuitable for discharging out of lease as it is because of higher concentration of the ion. The prescribed standard for discharging into surface water bodies is 0.1 mg/l and that of potable water is 0.05 mg/l.

Mine water is first pumped out to a reservoir tank. From the reservoir, water is reused within the lease as makeup water chrome ore beneficiation, sprinkling on the haul road, vehicle washing in the work shop and gardening. The excess water is discharged out of lease boundary after proper treatment in the effluent treatment plant (ETP). To take care of surface run-off, two more ETPs are there at the lease boundary located at Geological camp and Jagannath temple with Ferrous Sulphate solution treatment facility and settling pits to remove hexavalent chromium and suspended solids.

Monitoring of hexavalent chromium

The excess water from the reservoir is fed to the ETP and at the inlet channel; Ferrous Sulphate solution is added to reduce the hazardous hexavalent chromium to non-hazardous trivalent chromium. There is a mechanism to automatically control the dosage of Ferrous Sulphate solution as per the quantity/ rate of flow of inlet water to the ETP. Then the water passes through the filter beds to filter out suspended particles so that clear and hexavalent chromium free water goes outside. To ensure that the outgoing water does not contain hexavalent chromium, a qualitative test is carried out once in every hour at the ETP by the trained people. Moreover, the inlet and outlet water of ETP are analyzed every day quantitatively at our own laboratory by UV spectrophotometer/ ICP and once in a month by an outside laboratory, authorized by State Pollution Control Board. Although the acceptable limit of hexavalent chromium in outlet water is 0.1 mg/l, the hexavalent chrome content is maintained to be below detectable limits.

Capacity of ETP and its facilities is 715 Kl / hr of quarry water.

11.13 GENERAL MITIGATIONAL MEASURES

Treatment of waste water for removal of chromium is widely pursued in many industries, but no information exists for similar attempt in mining industries mainly because: (a) the lithogenic chromium in minerals and rocks are immobile, (b) the area of dispersion leaching is large and (c) the rate of natural leaching is infinitely slow, that is concentration is low.

The first step in treatment of any waste water is to precipitate and immobolise the contaminant followed by isolation of the precipitated, although most heavy metals are precipitated rapidly by adjustment of the pH of the medium. Cr(VI) is highly soluble and does not easily precipitated out of solution. Consequently, treatment of chromium usually consists of a two stage process, first, the reduction of the hexavalent chromium to trivalent form and second, the precipitation of the trivalent chromium. Alternative methods are by (a) adsorption by activated carbon or a mixture of activated carbon and sludge (Adams, 1979), peat(Moo et al, 1976), zeolites, soil and clays (Wentink et al, 1972), fly ash (Netzer et al, 1983), silica gel(Rigo, 1974) and (b) by water hyacinth cultivation (Anon, 1975).

Treatment of solid, liquid or gaseous effluents is possible only when the contaminated substance is collected at a site or chamber for remediation.

- Create sediment traps by check dams across drainage channels to prevent particulate chromite movement, which also means added advantage of watershed harvesting and restoration of greenery.
- Scavenging property of goethite, the most common mineral in laterite is utilized to scavenge the polluting element when chromium rich water percolates through the laterite . Similarly the abundant manganese in the top soil when converted to manganous state by amendment of peat or humus or by vegetation, plantation and grass turfing, would help in "Dechromification" of the hexavalent chromium (Bartlett & James, 1988)
- A separate investigation on dispersion of hexavalent chromium from a chrome chemical factory using Sukinda chromite in Bombay suburb has shown that its chromiferous effluent is extensively dechromified when the effluent channel passes through the sprawling cattle sheds around the factory (Godgul & Sahu). The sheds obviously provide the reducing environment for conversion of the mobile hexavalent Cr to Cr(III) with consequent immobilization. Development of cattle sheds (Dairy practices), animal husbandary trades (Hatchery, Piggery etc.) around the dumps and quarries as supplementary vocation in domestic scale by mine workers or commercial scale by corporate sector along critical

regions will not only mitigate the basic problems of chromium pollution but also usher a parallel economic growth and development of Sukinda valley.

11.14 GEOPHYSICAL INVESTIGATIONS IN GEOENVIRONMENTAL STUDIES

The major geoenvironmental concerns related to investigations described below include:

i) identifying abandoned and concealed mine openings,
ii) tracing toxic substances, including metals or radiative species released to air and (or) water, resulting from sulfide mineral oxidation, and
iii) delineating geologic structures that control the flow of potentially toxic water.

Geologic relations outline the surficial distribution and concentration of potentially toxic sources. Geophysical investigations can provide limited means to trace pollutants and their sources in the subsurface without drilling or opening shafts (King, 1993; Paterson, 1995). If drilling and mine shaft operations are permissible,an additional array of geologic, geochemical and geophysical surveys, including cross-hole tomography and in-shaft techniques, become available, but these are beyond the scope of this discussion.

Abandoned mine workings

Abandoned mine workings may be an environmental hazard because of the possibility of subsidence or collapse. They can also channel contaminated ground water flow, particularly if they are located in sulfide mineral-bearing rock and contain water. Several geophysical strategies enable identification of lost mine workings. In general, the deeper and smaller such workings are, the harder they are to locate using geophysical techniques.

Geoelectrical work has also been successful in tracing cave systems. In the majority of reported cases, the caves were in resistive limestone strata. Direct current resistivity is particularly useful in identification of air-filled openings, though in some instances the caves were partly or completely filled with water. Electromagnetic methods, particularly at very low frequencies, are also efficient where cave floors are covered by conducting clay deposits.

Summary

Many geophysical methods commonly used in exploration have potential application to geoenvironmental investigations. Although these methods have mainly been used to identify pollutants and record their dispersion from mine areas, their application is not limited to studies of this sort. For instance, geophysical monitoring of pollutant activity, which requires significantly greater study, is another aspect of geoenvironmental investigations. Monitoring differs from detection chiefly in recurrent use of geophysical techniques. The effort required to extend application of geophysical techniques to naturally occurring pollutants related to mineralized, but unmined, rock or to other cultural concentrations of toxic or potentially toxic substances is minimal and could be of considerable assistance in meeting national needs for healthy environmental conditions (Henderson, 1992).

11.15 REFERENCES

1. **CHROMIUM (VI) HANDBOOK**, by Independent Environmental Technical Evaluation group (IETEG).

2. **Mineral Facts and Problems: CHROMITE; Monograph No.6**, March 1982, TMP Division, Indian Bureau of Mines, Ministry of Steel and Mines, Nagpur.
3. **International Seminar on Development of Chromite, Nickel and PGM Resources**, (28 Nov, 2010 Bhubaneshwar) SGAT & Dept. of Steel & Mines, Government of Odisha.
4. **Hexavalent chromium treatment at Sukinda chromite mine** – Source Tata Steel.
5. **Geophysical methods in exploration and mineral environmental investigations**, by Donald B. Hoover, Douglas P. Klein, and David C. Campbell).
6. **Environmental Health Criteria 61, International Programme on Chemical Safety**, published under the joint sponsorship of UNEP, ILO and WHO, Geneva 1988.

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Chapter 12

FUTURE OUTLOOK AND CHALLENGES

12.0 INTRODUCTION

After the 2008 financial crisis that put the chromium industry into recession in 2009, the year 2010 was a period of recovery. World chromite ore, ferrochromium, and stainless steel production decreased during 2008 to 2009; and then increased from 2009 to 2010, with 2010 production of ferrochromium and stainless steel exceeding that of 2008, leading to the expectation that chromite ore production would continue to increase. In the next 5 years, consumption is forecast to grow at an annual average rate of 6 % pa. The 2010 increase is well distributed between China and the developed world, but in the coming years will depend heavily on China.

- Global ferrochrome production is recovering faster than consumption in 2010. However, this does not imply that the industry is willing or able to produce at full capacity. Some production restraint is still in place.
- Power shortages in South Africa imply no greenfield projects or brownfield expansion in the country in the next five years. Instead, new capacity will be installed in other locations, namely China, India, Kazakhstan, Russia and Finland.
- Industry stocks of ferrochrome were reduced to very low levels in 2008 and have not yet been replenished. Indeed, we believe it will take market surplus in 2011, 2012 and 2013 before stocks return to comfortable levels.
- The combination of rising production costs and low inventories of ferrochrome suggest that prices will remain well above $1.00/lb for at least the next five years.

Agnello (2010) reported that foundry-grade chromite, which accounted for 3% of global chromite ore consumption, was used as core and molding sands, initially used in manganese steel casting, and has moved to the manufacture of alloy and carbon steel castings and nonferrous metal castings. Since 1970, about 70% of foundry capacity in developed countries closed, resulting in a shift of casting to Southeast Asia and developing countries. Refractory-grade chromite is used more in shaped-refractory (80%) than in monolithic products. Magnesite-chromite refractories are preferred in nonferrous metallurgy (such as copper, lead, and zinc refining); however, the cement, lime, and glass industries have moved away from using magnesite-chromite bricks because of environmental considerations associated with the disposal of used refractories.

About 850,000 tonnes of sodium dichromate was produced in 2008 from about 1.25 MT to 1.3 MT of chromite ore. The sodium dichromate was converted to chromium oxide (34%), chromic acid (29%), chromium sulfate (23%), and other chemicals (14%). Agnello forecast of chromium sulfate production, which is used in leather manufacturing, to increase between 1% and 1.5%; chromic acid, which is used in metal finishing and to preserve wood, to increase between 3% and 3.5%, and chromium oxides, which are used in alloy, ceramic, and pigment manufacture, to increase between 2% and 3%. Historically, three events outside the chromium industry (the dissolution of the Soviet Union, the economic growth of China, and the world financial crisis in 2008–09) have had significant impacts on the chromium industry, making industry analysts and company planners sensitive to the potential for such events.

12.1 GLOBAL DEMAND

- Presently (2010) the Global Chrome Alloy production (Ferro and Charge Chrome) is estimated at 8.2 MT pa with India contributing about ~ 0.8 MT pa (~10%), in the wake of steady growth in Carbon (1380 MT pa), Stainless Steel (31 MT pa) and Alloy Steel (20 MT pa).
- Stainless Steel has grown at a CAGR of over 4% during the last 10 years and is expected to grow @ ~ 5% over next ten years. This will trigger similar growth rate (~6%) of demand for Ferro Chrome, and hence Chrome Ore after factoring scrap availability.
- World Stainless Steel demand has been driven by US, Europe & Japan until mid 2000. Currently, China is the single largest producer (11 MT pa) and consumer of stainless steel with highest growth rate, followed by Korea, Taiwan and India.
- 33 % of the world's chrome alloys (2.8 MT pa) are currently consumed by China and the country imports ~ 8 MT pa of chrome ore/concentrate out of total g lobal traded volume of ~9 MT pa.
- However, in India, the stainless steel industry has grown at a CAGR of ~12% over the last 10 years and expected to grow @ ~6-8% for the next ten years.
- India is expected to be amongst the top 5 stainless steel producers and markets by 2015 (which shall account for ~10% of the global SS production)
- Indian ferro chrome industry has registered a significant growth @ ~15% over the last decade and expected to grow @ ~ 5-6 % in the next decade, driven by both domestic and Chinese demand.
- The chrome ore requirement in India is expected to grow @ ~ 5 %.

12.2 GLOBAL SUPPLY

South Africa is the largest producer of,

- Ferro chrome(~3.5 MT pa, 40% of world production)
- Chrome ore (16 MT pa, 66% of world production),

  South Africa is also the largest consumer (~9 MT pa) and exporter (7 MT pa) of Cr Ore followed by Kazakhstan (~3.5 MT pa), and India (produces ~ 3 million tonnes). About 70% of total chromite ore reserves in the world are in South Africa, followed by Kazakhstan (17%), Zimbabwe (5%) and India (4%). Especially for India, expedited exploration programme will help to augment the country's chrome ore reserves.

- Capacity utilization of ferro-chrome industry hovers around 80-85%.

12.3 CHINA TO DOMINATE STAINLESS STEEL INDUSTRY

China produced 11 MMTPA of stainless steel in 2009, up 30% from 2008. By 2015, Chinese melt capacity is expected to reach 21.7 MMTPA which is 50% higher than 14.5 MMTPA achieved in 2009. Conservatively, Chinese melt production could rise between 16 to 18 MMTPA by 2015(+5 to +7MMTPA compared to 2009). With this capacity, theoretically China would be producing 55% of the world's stainless steel. To meet the forecast numbers, China needs to import heavily. Almost 4.5 to 9MMTPA of chrome ore or 1.5 to 2.5 MMTPA of ferrochrome needs to imported by China every year. This is because its resources are not enough to cater to such a huge demand of raw material required to produce stainless steel. Thus, China's growing consumption of stainless steel will definitely drive the demand for chrome ore and ferrochrome.

12.4 INDIA

12.4.1 Exploration and New Technology Development in Mining & Beneficiation

An Expert Committee constituted by the Ministry of Steel, Government of India had recommended the need of detailed exploration in all the potential areas in Odisha, Karnataka and ophiolite belt of North-Eastern region with a view to estimate resources to a depth of 500 m in Sukinda belt and estimation of resources in all other potential areas. Ferro-chromium production being electrical energy intensive, the location of such plant will reflect a cost balance between raw materials and electrical energy supply. The Report of the Working Group 12th Plan Period, Planning Commission, has estimated chromite production at about 5.01 million tonnes by 2011-12 and 7.37 million tonnes by 2016-17 at 8% growth rate. The apparent consumption is estimated at 2.74 million tonnes by 2011-12 and 4.35 million tonnes by 2016-17 at 8% growth rate. The Working Group has also made the following recommendations :

(i) Chromite resources are located to the extent of 90% in Odisha, predominantly in Sukinda Valley. The mines are going deeper and ore is becoming friable at lower levels. Exploration of deep seated ore bodies needs to be carried out on urgent basis.
(ii) Exploration efforts also need intensification to identify more deposits of chromite in the country. Underground mining technology needs to be promoted.
(iii) Development of suitable technology needs to be developed for beneficiation of low grade, friable chromite ore (30% Cr_2O_3) fines which are available in sizeable quantity in India.
(iv) Further restrictions on exports of chromite ore/concentrates are desirable in view of the limited resources in India and increasing demand for steel industry.
(v) R & D is required for development of suitable technology for extraction of Nickel from the Chromite overburden from the Sukinda area of Odisha.
(vi) Acquisition of technology assets abroad pertaining to application of low grade iron ore and other technology for pig iron, sponge iron and pelletisation. Further, for technology gathering participation in mining technology related events such as PDAC, China Mining Expo. etc. and organize mining technology related events in collaboration with CII and FIMI.

12.4.2 Imports vs Indigenous Production in India

There have been no imports of chrome ore during the last 5 years.

12.4.3 Export Possibility for India

The Chrome Industry in India was identified as an export-oriented business in the late 1960s as domestic Steel production base was low. However, the chrome industry flourished in 1980s & 90s in line with global and Indian growth stories. Subsequently, China fuelled the growth and provided the due opportunity for Indian chrome exports to grow rapidly. After 2005, there has been a significant shift in Indian chrome industry due to rapidly growing domestic demand leading to progressively reducing exports from India. In future, both in short and long term, Indian market would grow at a healthy rate and hence Indian chrome industry will continue to concentrate on domestic industry as compared to overseas markets.

12.4.4 Domestic/ Export Markets

So far the major demand for stainless steel in our country had been traditionally for the production of utensils. With the increasing pace of infrastructure development of our country as well as increase in the production in the white goods and automobile sectors, it is likely that there shall be substantial growth in the domestic markets in the near future.

12.4.5 Challenges to the Ferro alloy Industry

Ferro alloys industry in India has never been globally competitive, despite its rich ore deposits and low-cost manpower, essentially due to:

a) Insufficient availability and high cost of electric power.
b) Increasing ore and reductant cost.
c) Non-availability of low-ash, low-phosphorus coking coal in the country for the production of desired coke with low-ash, and low-phosphorus contents, making import of such coke at a high cost imperative.
d) High-cost and insufficient infrastructural facilities (both road and rail) for rapid transportation of ore from mines to plants.
e) Stiff competition from producers and exporters of ferro alloys in other countries like South Africa, Kazakhstan, China, Russia, Mexico, Australia etc. due to global trade agreements which has made drastic reduction in customs duty on imports necessary.
f) Wide fluctuations in the international price of ferro alloys depending on demand versus supply.

At present, the ferro alloy Industry is facing problems due to high input prices of manganese and chrome ores, coal, coke and high energy tariff. On the other hand, it is not getting required prices from the steel producers. This has slowed down the production of ferro alloys in 2011-12. Ferro alloys being intermediate products, their fortunes are linked to the state of well being of the steel industry. In the first half of 2011, the steel industry witnessed sustained momentum in recovery of steel demand globally carrying over from 2010. This, despite a series of anticipated and un-anticipated negative developments like the ongoing Euro area sovereign debt crisis, the earthquakes in Japan, the political and social unrest in some countries of Middle East region, leading to the surge in Oil prices, increase in coal and coke prices and the tightening of Government monetary measures in many emerging economies.

World Steel Association had forecast that apparent steel use will increase by 6.5% to 1308 million tonnes in 2011. In 2012, it forecasts that world steel demand will grow further by 5.4%. Global stainless crude steel production increased in the first half of 2011 by 3.8% compared to the same period in 2010. Total production for first six months of 2011 was 16.4 million tonnes, a new all time high. However, increase in production was restricted to China and Eastern Europe region, compensating for losses in other major areas. India is expected to show strong growth in steel use in the coming years due to its strong economy, massive infrastructure needs and expansion of industrial production in 2011-12. India is expected to be one of the highest in growth of steel consuming nations in the next decade. With this steel scenario globally and domestically, the ferro alloy Industry estimates that the consumption of ferro alloys will increase domestically and internationally in the coming years.

Domestic Ferrochrome Capacities and Additions

	FY'12	Capacity Addition over 5years in'000 t	FY'17
IMFA	216	70	286
JSL	190	75	265
ROHIT	165	55	220
FACOR	138		138
TATA STEEL	105	150	255
BALASORE	95	105	200
NVFAL	75		75
VISA inc Bao Steel	50	150	200
Others	211	50	301
TOTAL INDIA	1245	655	1975

12.5 REFERENCES

1. USGS- 2010 Minerals Yearbook-Chromium Advance Release.
2. Data: CRU Analysis.
3. International Seminar on Development of Chromite, Nickel and PGM Resources, (28 Nov, 2010 Bhubaneshwar) SGAT & Dept Steel & Mines, Government of Odisha.
4. Special Commodity Insights Bulletin-2012. KPMG.
5. **Indian Minerals Yearbook- 2011; Indian Bureau of Mines,** Government of India , Ministry of Mines**; December, 2012.**
6. **Indian Ferro Alloy Industry - Present Status and Future Outlook ,** C.N. Harman Director (T) & N.S.S.Rama Rao, DGM (Production) , FACOR Alloys Limited , Shreeramnagar, Vizianagaram. A.P.

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