GEOCHEMICAL INVESTIGATIONS ON CHROMITE DEPOSITS OF BHAKTARA HALLI, HASSAN DISTRICT, KARNATAKA, INDIA

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Abstract:
The study area is a part of Nuggihalli schist belt, of Dharwar craton. The area Bhaktara halli village falls on the Survey of India toposheet no. 52 C/8, 57D/11, 57D/12 lies between the Latitude N 13° 6.014’ Longitude E 76° 25.168’ of Chennarayapattana of Hassan district 30 kilometres from Arasikere, this is easily accessible by bus or trains on south eastern railways.

Chromite occurs in Karnataka in altered ultrabasic rocks (serpentinized peridotites) forming regular veins, lenses, and segregated pockets of various dimensions. Chromite deposits of various grades are found in the districts of Mysore, Hassan, Chikmagalur and Shimoga. There are several ultrabasic belts in the state, of which Nuggihalli schist belt, Hassan district and Sindhuvalli-Talur ultramafic belt are the most important. The major occurrences are in Byrapur, Bhakatarhalli, Jambur, Chikkonhalli, Tagadur, etc.

Chromite is the general word used for chrome ores and concentrates. The theoretical formula of chromite is listed as FeO.Cr$_2$O$_3$ containing 68% Cr$_2$O$_3$ and 32% FeO. In nature, however, at no place has chromite conforming to theoretical composition been observed. There is a wide variation in its chemical composition, the ratio of Fe: Cr varies from deposit to deposit. Iron is usually replaced by magnesium and chromite by aluminium and ferric iron. It is seldom, except in meteorites, that the chromite containing about 68% Cr$_2$O$_3$ has been found. The total iron content (FeO+Fe$_2$O$_3$) also varies greatly from as low as 12-13% to 27%. In a few cases the iron oxides have been found to exceed the theoretical composition. A small percentage of nickel, titanium, platinum and vanadium are found in association with chromite. Sometimes they are present in economic quantity and form a useful source of recovery. Chromite has a specific gravity ranging from 4.0 to 4.8. It crystallises in the isometric system but normally occurs in massive aggregates of crystals. In colour it is dark brown to jet black but gives a brown streak. In the laboratory, the samples have been studied, subjected to microscopic, chemical studies, infrared studies, X-ray diffraction studies and Differential Thermal Analysis (DTA) for determination of major oxides present in the sample. The details of the work have been quoted in this paper.

Key Words: Dharwar craton, Bhakthara halli, Serpentinized peridotites, X-ray diffraction, Differential Thermal Analysis (DTA), Infrared studies.

Introduction
Chromite is the general word used for chrome ores and concentrates. The theoretical formula of chromite is listed as FeO.Cr$_2$O$_3$ containing 68% Cr$_2$O$_3$ and 32% FeO. In nature, however, at no place has chromite conforming to theoretical composition been observed. There is a wide variation in its chemical composition, the ratio of Fe: Cr varies from deposit to deposit. Iron is usually replaced by magnesium and chromite by aluminium and ferric iron. It is seldom, except in meteorites, that the chromite containing about 68% Cr$_2$O$_3$ has been found. The total iron content (FeO+Fe$_2$O$_3$) also varies greatly from as low as 12-13% to 27%. In a few cases the iron oxides have been found to exceed the theoretical composition. A small percentage of nickel, titanium, platinum and vanadium are found in association with chromite. Sometimes they are present in economic quantity and form a useful source of recovery. The chromite deposits of South Africa are an important source of platinum. Turkish chromite contains 0.1 to 0.5% NiO. Chromite has a specific gravity ranging from 4.0 to 4.8. It crystallises in the isometric system but normally occurs in massive aggregates of crystals. In colour it is dark brown to jet black but gives a brown streak.

Deposits of Karnataka
Chromite occurs in Karnataka in altered ultrabasic rocks (serpentinized peridotites) forming regular veins, lenses, and segregated pockets of various dimensions. Chromite deposits of various grades are found in the districts of
Mysore, Hassan, Chikmagalur and Shimoga. Of these, the deposits of Mysore and Hassan districts are most important from the commercial point of view. There are several ultrabasic belts in the state, of which Nuggihalli schist belt, Hassan district and Sindhuvalli-Talur ultramafic belt are the most important. The major occurrences are in Byrapur, Bhakatarhalli, Jambur, Chikkonhalli, Tagadur, etc. The Sindhuvalli-Talur ultramafic belt extends from river Kabini in the south to the north of Mysore city. The belt of ultramafic rocks stands as detached linear mounds or low ridges amidst surrounding gneissic terrain. The mineralisation is locally controlled with the chromite bodies being confined to serpentinites. The chromite bodies are found as lenses and small bands within serpentinites, the lenses are concordant in Sindhuvalli, Dodkatur and discordant in Talur area. The chromite grains are mostly anhedral, sub rounded and often compact.

The Nuggihalli greenstone belt is characterized by interlayered, metamorphic derivatives of dunite and peridotite with chromite layers, anorthosite, gabbroic anorthosite, gabbro with vanadium- bearing titaniferous magnetite bands, pyroxenite, and sediments and supracrustal remnants in a gneissic- migmatic complex. Chromite reefs, lenses, and layers of varying thickness occur in all the ultramafic exposures throughout the 60 kilometres stretch of the Nuggihalli belt.

The largest chromitite reef with a minor fault in the middle is found in the Byrapura chromite mine. In the chromite deposits of Nuggihalli belt, all the textural and structural types of ores associated with the magmatic crystallization. Based on the mode of occurrence, chromite deposits of the belt are further divided into two subtypes, namely, leopard and anti-leopard. In the leopard type chromite grains were seen moulded in serpentinitic sheath and the reverse relation prevails in anti-leopard chromites. Though layered or banded type of chromite is very

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common all the Nuggihalli belt, they are of relatively small scale and discontinuous unlike chromite layers from stratiform Bushveld complex, Stillwater complex or Sitamkundi complex.

On close inspection of any one group of layers it can be observed that there is a consistent way-up, with a sharper base and a gradational top of each of the chromite layers. The massive type of ore occurs as concordant to discordant bodies with respect to foliation of the associated serpentinites indicating movement of the ore bodies due to deformation. Micro- and macro- folding, faulting, mylonoyization, and brecciation are noticed in the chromite indicating deformation of the ore bodies after their emplacement. It appears that the massive type or chromite with in the ultramafic body belongs to a now-deformed, layered stratiform complex. Nodular chromites consisting of aggregates of spheroidal or ellipsoidal chromite grains embedded in serpentinite occur at places in the belt. Nodularity in the chromites is attributed to movements during deformational episodes by pallatization effect. The disseminated type of ore is wide spread in the belt and it is found that the degree of alteration is maximum in this type of ore. The other deposits in Karnataka are Kalangavi (Chitradurga district), Bande - Banur-Gajekaatte (Kadur district) and Amblikatte – Jhandimatti - Antargange (Shimoga district).

Physiography of the area

The study area is a part of Nuggihalli schist belt, of Dharwar craton.

Climate and rainfall:

Summers starts in March and lasts till May. April and may are the hottest months. It is during this season that humidity is quite less in the atmosphere. The month of June is very unpleasant as the humidity rate increases marginally. The average temperature in summers is 34° C with 75% humidity. Hassan has the average high temperature which ranges from 25° to 34° C and the lowest temperature going up to 15° to 25° C. Monsoon begins in June and continues till September. Temperature dips very low and the humidity percentage is quite high this time. Hassan receives an average rainfall of 1064.8mm per annum. Post monsoon season begins from October and extends up to December. During this season, an intermittent shower of rain is associated with north-east monsoon. Winter season extends from January to February which is pleasant and not extreme. Temperature during this season ranges from 32° C and reduces to 20° C or even below. Humidity percentage in winter is generally low. December and January are generally coolest months.

Previous work:

Foote (1900) is the earliest worker who has reported from this area, the occurrence of a band of schistose rocks with a double hematite crest, chlorite and hornblende schist at Tagadur betta running in NNW-SSE direction.

Iyengar (1906), who for the first time reported the occurrence of ultrabasics with pockets of chromite, chrome iron ore and magnetite, made a detailed survey of the belt and styled it as “Nuggihalli Schist Belt” after the village Nuggihalli in Chennarapattana Taluka of Hassan district. He described the chromite deposits of this area as irregular, pocket and non-continuous. He considered them as early magmatic segregates.

Venkataramaiah (1907), has done some work on the chemistry of the chromite ores of this region and has classified some of the chromite ores of the area into 3 groups - Iron black and compact, Greyish black, Speckled variety.

Pichamuthu (1951-1953) has given a structural interpretation of the Dharwar schist. He concluded that the ultrabasics of this region belong to the class of “Alpine type” of Benson, as they are related to orogeny and interpreted the structure of Dharwars, has recognised progressive metamorphism in Dharwar rocks from North to South. The Nuggihalli Schist Belt according to him falls within the amphibolites facies.

Radhakrishanan (1957) is of the opinion that the chromite ore bodies are invariably associated with bleached serpentinite. The larger lenses cut across the general trend of the country rock and are confined to the basal portions of peridotite. He says that the chromite deposits in the area belong to the sack and fissure forms.

Varadarajan (1964), According to him the chromite deposits of the area show all the characteristic features of the chromite associated with “Alpine type” ultrabasics. Based on the distribution, mineralogical and chemical characters, he considered them to have come up along with serpentinite as autoliths.

Phene (1969) is of the opinion that the ultrabasics in the Nuggihalli schist belt are cut across by the reefs, veins, and veinlets of chromite ore. Chromite ore in the region has three different forms, viz, Reef and lens form, Mottled or speckled form, which is further classified as Leopard, Anti-leopard and Banded form.

Damodaran (1976) has carried out geological, geochemical and beneficiation studies of chromites and chrome ores in the Byrapur and Shivani area. According to him, the structural and textural features are similar to those of the
podiform chrome ores reported elsewhere in the world and they are quite ferruginous. Chromite can be readily compared with those of their Uralian counterparts and are of early magmatic origin.

Materials and methods of the present work:

Toposheet no. 52 C/8 are considered and the area around Bhakatarhalli has been utilized for varies features have been recorded. The samples of dunite, serpentinite and different grades of chromites were collected from different zones of the mine. In the laboratory, the samples have been studied, subjected to microscopic, chemical studies, infrared studies, X-ray diffraction studies and Differential Thermal Analysis (DTA) for determination of major oxides present in the sample have been shown in the form of graphical, figures and photographs.

- To identify the major oxides in the samples
- The chemical analysis of chromite ore and
- Genesis of ore deposits

It is evident from the available literature that the occurrence of the chromite deposit though known since more than 100 years and lot of work has been done with respect to their geological setting, field character, mineralogy, geochemistry, geological dating and about the parameters responsible for the formation of these deposits during the process of magmatic crystallisation. The present investigation is based on:

- Field study and sample collection of the area.
- Microscopic examinations of thin section of parent rocks.
- I.R study of the chromite samples.
- XRD study of the chromite samples.
- D.T.A study of the chromite samples.
- Chemical analysis of the chromite samples.

A detailed field investigation of the Bhakatarhalli mine was carried out during the field work and the samples were collected from different parts of the mine. 5 samples representing chromite, low to high grade and associated host rock, dunite and its alteration product, serpentinite were collected. These samples are brought to the mineral processing unit in the Department.

Plate: 2.1 – Working mining pit of Bhakartahalli chromite mine.

Plate: 2.2 – Exposures of chromite in the mining pit.
Geology of the area:

(a)

Plate: 2.3 – Chlorite schist exposed at the upper level of the mining pit.

**Dunites**

No outcrops of dunites have been reported so far in the areas. However, dunites start appearing in subterranean levels from 200ft as has been observed in the “a” pit of Byrapur chromite mines. The rock persists up to a depth of 1000ft or even more. The rock is greenish black in colour and has veins and veinlets to traverse; serpentinisation of the rock is discernible only at shallower depths, besides that along the weak planes such as joints, faults and shear planes.

**Peridotites**

Peridotite does not form a major rock formation in the area. A solitary patch of the rock measuring 15*4 meters is encountered at about 300 meters due south east of the “A” pit of the Byrapur chromite mines. The coarse grained rock is equigranular with well-developed pyroxenes and olivines.

**Pyroxenites**

Pyroxenites are essentially intrusives within the schist belt. The contact metamorphism suffered by the host rock is pronounced, as has been seen from the development of greenschists of various grades.
Green schist

The predominating ultrabasic rock in the area is serpentinite. The rock grades imperceptibly into a number of units of green schists, which include talc schist, anthophyllite, tremolite schist, chlorite schist, chlorite-biotite schist, chlorite actinolite schist, etc. In the field, the contacts between individual schist’s are not clear. Talc schist mostly occupies the margins of serpentinite in contact either with the amphibolites or the gneisses. Similarly, all the other schists too occupy the contact zones. The green schist’s are highly schistose.

Serpentinites

Next to amphibolites, serpentinites from the major lithological units in the area which occur as brownish to greyish brown colours elevated mounds and ridges. The serpentinites of the area can be generally grouped into two:
1. Altered, lateritic and spongy serpentinites,
2. Fresh and platy serpentinites.

The lateritic serpentinites are brown in colour and have ribs of chromite and magnetite. The rock when traced down to depths as in the “A” pit of Byrapur chromite mines is seen grading on to the dark greenish variety with closely spaced magnetite veins. This, in turn, is underlain by the dark and dense variety of dunites. A highly schistosed type of bluish green serpentinite occurs all along the fault and shear planes.

Chrome chlorites

Chrome chlorite in Byrapur area has been described by many previous workers. This mineral is obviously an alteration product of serpentinite and is found in association with calcite and cherty materials all along the weak planes such as shear planes, faults, joints, etc., within the massive chromite ore. The occurrence is clearly found at different working levels in Byrapur chromite mines. The mineral is kotschubeite.

Huntite-Magnesite Association

Huntite-Magnesite association has been reported for first time, from the altered serpentinites of Byrapur. The alteration products are of restricted occurrence, and are seen as veins and bands traversing the parent rock. The exposure is seen at about 300 feet due south of the “A” pit of Byrapur chromite mines.

Chromite deposits of Nuggihalli schist belt:

Geological set-up

The Nuggihalli schist belt extends for a strike length of 50 km in a NNW-SSE trend from near Arskere in the north to Kempinkote in the south. This schist belt forming a prominent linear belt of medium to high grade schists belongs to Sargur complex. The schist belt consists of amphibolites and quartzite of Belgumba formation and metaultramafites (serpentinites), meta-peridotites, meta-pyroxenites, tremolite-actinolite-chlorite schists and dunite.
with bands of chromite and titanomagnetites, anorthosites and gabbro belonging to Byrapura ultramafites. The belt is enclosed by peninsular gneiss with basic dykes cutting across all the formations, and forms a narrow tightly folded synclinal structure. The regional strike of the schistose rocks is N 20° W – S 20° E to N-S with a dip of 50° to 60° towards east. The axial plane schistosity (s1) trends in N 30° W – S 30° E direction.

Control of mineralisation

Mineralisation is lithologically controlled with chromite bodies being confined to serpentinites.

Dimension of the ore body

The dimension of the ore bodies observed in different blocks is as follows:

Name of the block and dimension-
(i) Bhakatarhalli 23 m x 1.2 m
(ii) Chikkonahalli 16.5-432 m x 0.15-2.72 m
(iii) Tagadur 27.2 – 179 m x 0.53 – 2.58 m
(iv) Jambur 12.0 – 185 m x 0.3 – 1.21 m

X-ray diffraction analysis:

The x-ray diffraction analysis was undertaken to determine mineralogy that cannot be identified or doubtful under petrographic microscope. This method is being used for quantitative and qualitative identification of mineral phases. The x-ray diffraction method is based on the principle that when a monochromatic beam of x-rays is passed through a mineral it is scattered by the atoms that compose the mineral. At specific angle of incidence, the scattered rays are in phase producing an intensified secondary beam. This phenomenon is known as “diffraction”. The wavelengths of x-rays are of the same order as the distance between atoms in the crystalline material and hence the crystals present will act as grading for diffracting x-rays. The general relationship is expressed by the Bragg’s law:

\[ n\lambda = 2dsin\theta \]

Where

- \( n \) - Order of diffraction,
- \( \lambda \) - The wavelength of x-ray,
- \( d \) - The spacing between planes of atoms, and
- \( \theta \) - The angle of incidence

Powder diffractometry is the method generally used to study the material. After a sample is ground to a fine powder (1-50µm) it is placed in the diffractometer. The direction of the primary x-ray beam remains constant as the sample rotates around an axis normal to the primary beam. The diffractometer is designed so that the goniometer arm and the attached tube rotate twice the rate of the sample. Thus, as the sample rotates through 2θ, which is the angle read on the goniometer. The geometrical arrangement of the diffractometer is such that only mineral grains whose lattice planes are parallel to the surface of the specimen holder will contribute to diffracted secondary beams that enter the detector tube. For this reason, the particle size must be small to ensure that a large number of correctly positioned grains are present. The analyses were carried out at National Institute of Oceanography XRD laboratory where the powder was mounted on glass slab and then was placed in the diffractometer. Chromite from the Bhakatarhalli mines is X-rayed. The powder diffraction patterns of the chromites are obtained using K- beta filter. The’d’ spacing is calculated following the Bragg’s equation and the intensities of the reflections are measured from the graph. The results are compared with the standard ones given in ASTM cards and the minerals are properly identified.

Table .2– X-ray diffraction analysis of chromite.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>I</td>
<td>d</td>
</tr>
<tr>
<td>2.50</td>
<td>VVS</td>
<td>4.76</td>
</tr>
<tr>
<td>7.17</td>
<td>L</td>
<td>2.91</td>
</tr>
<tr>
<td>4.81</td>
<td>M</td>
<td>2.48</td>
</tr>
<tr>
<td>3.58</td>
<td>L</td>
<td>2.05</td>
</tr>
<tr>
<td>2.93</td>
<td>L</td>
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</tr>
<tr>
<td>2.74</td>
<td>M</td>
<td>1.58</td>
</tr>
<tr>
<td>2.07</td>
<td>S</td>
<td>1.46</td>
</tr>
<tr>
<td>1.60</td>
<td>S</td>
<td>1.26</td>
</tr>
<tr>
<td>1.46</td>
<td>S</td>
<td>1.05</td>
</tr>
</tbody>
</table>
(1) Crystalline chromite from Bhakharhalli mine pit (sample A).
(2) Aluminium chromite (Ref: ASTM card)
(3) Iron chromite (Ref: ASTM card)

Comparison of x-ray diffraction analysis of chromites in Bhakharhalli mines and the other part of the world reveals that the d-spacing in the chromite world over are not constant. The variation is explained by many workers due to the variation in proportions of the major constituents that together form the chromites.

The abnormal structure of chromite is due to cyclic pulsation of the cooling melt. The discrepancies might be due to the imperfection in lattice, irregular temperature of crystallization, rate of cooling and the ionic substitution. Further, the relation between d-spacing and chemical composition of chromite will be found uniform only when the chromites crystallizes under the same P-T conditions.

**Infrared spectroscopy**

Infrared spectroscopy was carried out for 5 samples. It was carried out in the National Institute of Oceanography (NIO), Donapaula, Goa, using Fourier transforms infrared spectrometer, the region from 4000 – 500 cm\(^{-1}\) frequency (wave numbers) is scanned.

Frequencies at which a material absorbed infrared energy depends on the internal vibration of the molecules and hence upon its composition. Infrared analysis involves the use radiation of much longer wavelength than that of visible light. The wavelength range of the spectrum classified as infrared is from 0.75 to 30 micron. But the important reason for studying minerals and crystals in the reason of 2 to 25 micron. To a mineralogist the infrared spectra scope is an effective tool for the identification of minerals and mineral aggregates. In a mineral the molecules of different atoms are grouped differently. Hence different groups give different characteristic absorption bands.

The mineral and rock samples under investigation are studied using Carl’zeiss UR-10 and X99 IR. Spectrophotometer is in null media. The mineral is finally agate and small quantity of the same quantity of the same is mixed with poor paraffin oil, thus forming a suspension of minute crystallites in a viscous medium. The resultant paste is then smeared over an alkali halide plate (of either NACI or KBr) and second halide plate is kept on the first one and squeezed to get a thin film of the compound in the oil. This is kept in the spectrometer and the radiation is passed. The resultant absorption spectrum is measured and the minerals are identified by comparing the values with those given in standard bands.
Table 1: Minerals identified in the IR spectrum of chromite with respect to wave number:

<table>
<thead>
<tr>
<th>Sample no</th>
<th>Wave number in cm⁻¹</th>
<th>Mineral identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1458.1(sb), 1483.2(sb), 1055.0(sb), 997.1(sb)</td>
<td>Chromite</td>
</tr>
<tr>
<td></td>
<td>966.3(sb), 891.0(sbb)</td>
<td>Olivine</td>
</tr>
<tr>
<td></td>
<td>3691.5(s), 3556.5(s)</td>
<td>Kaolinite</td>
</tr>
<tr>
<td></td>
<td>678.9(sb), 488.0(sb), 443.6(s)</td>
<td>Goethite</td>
</tr>
<tr>
<td>B</td>
<td>1070.4(bb), 985.6(sb)</td>
<td>Chromite</td>
</tr>
<tr>
<td></td>
<td>3679.9(s), 3660.6(s)</td>
<td>Kaolinite</td>
</tr>
<tr>
<td></td>
<td>657.7(sb), 507.2(s)</td>
<td>Goethite</td>
</tr>
<tr>
<td>C</td>
<td>1463.9(sb), 1481.2(sb), 1074.3(bb)</td>
<td>Chromite</td>
</tr>
<tr>
<td></td>
<td>989.4(sb), 889.1(bb)</td>
<td>Olivine</td>
</tr>
<tr>
<td></td>
<td>3685.7(s), 3662.6(s), 3651.0(s)</td>
<td>Kaolinite</td>
</tr>
<tr>
<td></td>
<td>459.0(sb), 439.7(s)</td>
<td>Goethite</td>
</tr>
</tbody>
</table>

Note: (sb) - shoulder band, (s) - sharp band, (bb) - broad band, (sbb) - strong broad band.

Conclusion:

The band position is observed 1483.2 cm⁻¹ to 990 cm⁻¹, which indicates the presence of chromite. The IR peak 678.9 cm⁻¹ to 488 cm⁻¹ is due to metal oxygen single stretching vibration. So it indicates the presence of Goethite. The sharp bands 3651 cm⁻¹ to 3556.5 cm⁻¹ due to the presence of hydroxyl group, this indicates the presence of Kaolinite. The band position is observed 966.3 cm⁻¹ to 889.1 cm⁻¹ indicates the presence of Olivine.

Fig: 4.1 infrared spectra of chromite (A)
Study of T.G.A analysis

The T.G.A has been widely used in mineralogical investigation. This investigation consists of studying the loss in weight of substance as it is being heated.

Sample A:
In this figure the T.G.A curve, the mineral shows a gradual loss of weight from 100°C to 400°C (2.961%), 400°C to 600°C (5.070%) and 600°C to 1100°C (5.960%). There is increase in the rate of loss of weight. The increase in weight loss is maximum between 600°C to 1100°C. And again there is loss of weight after 1100°C. The total weight loss is 0.647mg. The total weight loss is very low. So this ore contains more chromium.
Sample C: In this figure the T.G.A curve for low grade chromite shows maximum loss of weight in the temperature range between 550°C to 650°C (9.372%) and minimum in the temperature range between 650°C to 800°C (7.637%). There is an intermediate weight loss between 50°C to 550°C (8.298%). Again there is loss of weight during temperature increases. The total weight loss is 1.082mg. This weight loss shows that this ore contain more concentration other oxides. So it is a low grade chromite ore.

Differential Thermal Analysis (DTA):
Differential Thermal Analysis is an effective tool in identifying minerals. In this instrument the temperature difference relative to a thermally inert material are measured during the heating or cooling of the sample. The thermocouples embedded in the two substances are measure the differential temperatures and the one embedded in the chromite is used the furnace temperatures. Any endothermic and exothermic occurring in the substance results in its temperature lagging behind or leading beyond that of the inert material respectively. This is the principle of DTA.

Sample A: The mineral has given two endothermic peaks at different temperatures. One is broad between 700°C to 900°C and other is narrow at 50°C to 150°C. There is only one exothermic peak around 350°C to 550°C. The graph shows a tendency of one more exothermic peak after 1200°C, which is the characteristic of mineral chromite.

Sample C: The mineral has given 3 endothermic peaks at different temperatures.

- narrow endothermic peak between 50°C to 150°C,
- sharp endothermic peak between 550°C to 700°C,
- Small endothermic peak between 800°C to 850°C.

There is only one exothermic peak around 500°C to 600°C. The graph shows a tendency of one more exothermic peak after 1200°C, which is the characteristic of mineral containing chromite. Comparing both graphs, endothermic and exothermic peaks show almost same range of temperature it clearly indicates that both ores are chromite and that they have melting point higher than 1200°C.

Chemical analysis:
The major chemical constituents like Cr₂O₃, Al₂O₃, Fe₂O₃, FeO and SiO₂ are analysed using geochemical experiments for the samples taken. Chromite is an iron chromium oxide: FeCr₂O₄. Theoretically chromite is an oxide of chromium and iron with 68% of Cr₂O₃ and 32% of FeO. However, this is the composition is found in natural chromite. The composition of naturally occurring chromite varies from place to place in accordance with the magmatic environment in which the ore minerals are formed. It is an oxide mineral belonging to the spinel group. Magnesium can substitute for iron in
variable amounts as it forms a solid solution with magnesio chromite (MgCr₂O₄) substitution of aluminium occurs leading to hercynite (FeAl₂O₄).

Chromite is found in peridotite from the Earth’s mantle. It also occurs in layered ultramafic intrusive rock. In addition, it is found in metamorphic rocks such as some serpentines. An ore deposit of chromite forms as early magmatic differentiates. It is commonly associated with olivine, magnetite, serpentine, and corundum. The vast Bushveld igneous complex of South Africa is a large layered mafic to ultramafic igneous body with some layers consisting of 90% chromite making the rare rock type, chromitite. The Stillwater igneous complex in Montana also contains significant chromite.

Geochemical investigation carried out on 8 samples collected from Bhakatarhalli mines.

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>Cr₂O₃</th>
<th>Al₂O₃</th>
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<th>FeO</th>
<th>SiO₂</th>
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<td>20.00</td>
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</tr>
<tr>
<td>5</td>
<td>39.72</td>
<td>12.76</td>
<td>12.80</td>
<td>20.37</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>51.12</td>
<td>5.19</td>
<td>5.61</td>
<td>22.88</td>
<td>2.11</td>
</tr>
<tr>
<td>7</td>
<td>30.70</td>
<td>14.75</td>
<td>21.28</td>
<td>14.52</td>
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</tr>
<tr>
<td>8</td>
<td>49.75</td>
<td>10.57</td>
<td>10.57</td>
<td>19.15</td>
<td>1.38</td>
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</tbody>
</table>

Table 5.1 - Chemical analysis data of sample no. 1-8.

**Chromium (Cr₂O₃):** It is the major chemical constituent present in chromite. The chromium range is varying between 30.70 to 59.24. The average grade of the ore is 46.62. The ore with chromium content 48-52% is a high grade ore, chromium content 40-48% is a medium and 32-48% is a low grade ore.

**Alumina (Al₂O₃):** Alumina is the one of the constituent of chromite. The content of alumina is varying between 5.83 to 14.75. Depending on the grade of the ore, alumina content varies. In high grade ore the alumina content is less and vice versa.

**Fe₂O₃:** It is the minor constituent of chromite. The content of Fe₂O₃ is varying between 2.87 to 21.28. The average content of Fe₂O₃ is 11.09. The percentage of Cr₂O₃ and Fe₂O₃ are inversely proportional to each other.

**FeO:** It is the major constituent of chromite. The content of FeO is varying between 13.76 to 22.88. The average content of FeO is 18.02. The percentage of Cr₂O₃ and FeO is closely related to each other. In high grade ores the FeO content is less and in low grade the FeO content is more.

**SiO₂:** It is the minor constituent of chromite. It doesn’t show any close relationship with chromite.
Variation diagrams:

A careful study of variation diagrams show the content of different chemical constituent present in chromite ore with respect to Cr$_2$O$_3$ during the chemical analysis of chromite ore of Bhakatarhalli, the following conclusions are emerged out as significant:

- Variation diagram between Cr$_2$O$_3$ and Fe$_2$O$_3$ shows that as the content of Cr$_2$O$_3$ increases the content of Fe$_2$O$_3$ decreases.
- Variation diagram between Cr$_2$O$_3$ and Al$_2$O$_3$ shows that as the content of Cr$_2$O$_3$ increases the content of Al$_2$O$_3$ decreases.
- Variation diagram between Cr$_2$O$_3$ and FeO shows that as the content of Cr$_2$O$_3$ increases the content of FeO decreases.

It clearly shows that chromium content increases as the content of other oxides decreases.

Conclusion

- From the field visit, it can be concluded that the deposits are disseminated podiform deposits occurring as lenses in serpentinized dunite.
- Due to which perfect bench and face method of mining cannot be used as ore body is not continuous.
- The ore can be visually classified into high grade, medium grade and low grade depending on the grain size.
From the textural and mineralogical microscopic investigations, the following conclusions can be drawn:

- The chromites under study are formed in the early stage of magmatic crystallization indicated by leopard and anti-leopard texture.
- The chromites are ferruginous in composition.
- From Infrared Spectroscopy study, it can be inferred that the ore contains:
  - Chromite (1483.2 cm\(^{-1}\) to 990 cm\(^{-1}\)),
  - Olivine (966.3 cm\(^{-1}\) to 889.1 cm\(^{-1}\)),
  - Kaolinite (3651 cm\(^{-1}\) to 3556.5 cm\(^{-1}\)) and
  - Goethite (678.9 cm\(^{-1}\) to 488 cm\(^{-1}\)) minerals.
- The X-ray diffraction study indicates that the chromite from the ore is structurally identical to alumina chromite. Even though it's chemically identical to ferruginous/iron chromite.
- The TGA-DTA examinations show that the ore is not pure chromite; it contains other metal oxides and hydroxides which confirms the Infrared spectroscopy study.
  - The variation diagrams show the content of different chemical constituent present in chromite ore with respect to Cr\(_2\)O\(_3\) during the chemical analysis of chromite ore of Bhakatarhalli, the following conclusions are emerged out as significant: Variation diagram between Cr\(_2\)O\(_3\) and Fe\(_2\)O\(_3\) shows that as the content of Cr\(_2\)O\(_3\) increases the content of Fe\(_2\)O\(_3\) decreases.
  - Variation diagram between Cr\(_2\)O\(_3\) and Al\(_2\)O\(_3\) shows that as the content of Cr\(_2\)O\(_3\) increases the content of Al\(_2\)O\(_3\) decreases.
  - Variation diagram between Cr\(_2\)O\(_3\) and FeO shows that as the content of Cr\(_2\)O\(_3\) increases the content of FeO decreases.
  - It clearly shows that chromium content increases as the content of other oxides decreases.

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