CHAPTER II

V-Ti magnetite ores

2. Introduction

In this chapter, the importance of V-Ti magnetite ores, geological setting, their types, mode of occurrence and distribution in different parts of the world with importance on Indian and Karnataka ore deposits are given for better understating of the present research work, along with the previous work done, objectives and method of investigation of the study area.

2.1. Vanadium

Vanadium is employed in the manufacture of special alloy steels, the major applications of vanadium is in steel making as an additive, since vanadium is a strong carbide-forming element that can raise the strength of ferrite considerably, it is used to increase the hardness, ductility and toughness of steel. Vanadium usually in the form of ferrovanadium or other vanadium alloys are favored to use in the steels manufacturing due to its strengthening effect produced by precipitation, hardening and refining of the ferrite grain, but vanadium as a pure metal is soft, malleable and ductile, but even a small amounts of impurities render it to hard and brittle due to its high melting point (~1,900°C), so vanadium is regarded as one of the refractory metals.

Vanadium is also used in the production of certain tool steels, especially the low alloy types and high-speed tool steels, which are used in elevated temperatures. The vanadium content in these kinds of steels are said to enhance wear resistance and increase their grain-coarsening temperatures to 1030°C. Other metallurgical applications of vanadium are in various alloys, principally those of titanium, in which the vanadium strengthens the pure
titanium metal, and in cast iron, in which it counteracts graphitization and acts as chill stabilizer.

Vanadium pentoxide is used directly as a catalyst in certain oxidation reactions. In addition to vanadium pentoxide, other vanadium compounds used in catalysis include ammonium metavanadate, vanadium oxytrichloride and vanadium tetrachloride. The world Consumption of vanadium in catalyst, ceramics and electronics (superconductors) is about 700 metric tons annually and is likely to rise appreciably in the next decade. Vanadium is also used in welding rods and permanent magnets made from vanadium pentoxide and ferrovanadium; photographic processes require vanadium chloride, as a colorant in ceramics and glass and as a drier in ink, paint and varnish.

A wide distribution of Vanadium is noted in the earth’s crust, it occurs rarely in sufficient concentration to be extracted profitably, Vanadium is produced as a byproduct of other commodities in the major exploration projects, such as iron, phosphorus, uranium, petroleum residues, coal and aluminum.

2.2. Titanium

Experimental works have shown that titanium can be used as a substitute in certain pipeline steels; however, as with niobium, titanium is added primarily for grain refinement and does not provide the strengthening produced by vanadium. Consequently, titanium bearing steels usually also contain vanadium. All the present industries in modern days directly or indirectly depend on the availability and supply of ferro-alloys, recently this industry, is considered as an index of economic prosperity.

Titanium is used in the manufacture of ferrotitanium, which is used in the making of special alloy steels and in aeronautical industries. Titanium metal and TiO₂ pigments are the two major products made from titanium minerals on which a major industries depend. It is
the chief opacifying pigment used in paint and other products such as plastics and papers, not only for white color but, for quite a range of colors. It has supplanted lead-based pigments in many of these ores. Titanium dioxide pigments commonly forms more than 20% by weight of some paints. The pigment industry consumes more than 90% of all titanium minerals mined.

The economic geology branch dealing with titanium begins focusing on rock suites that contain titanium largely in oxide mineral form, alteration state of ilmenite is of great importance in the ilmenite mining industry since slightly altered ilmenite containing about 54% TiO₂ is generally not considered to be of economic grade.

Titanium is sufficiently abundant in the earth’s crust, that it is customarily listed with the major elements. Titanium is present in rocks as oxide and silicate minerals. The minerals that account for most of the titanium in rocks are oxides (rutile, anatase, brookite and ilmenite) and silicates (sphene, biotite, calcicamphiboles and augite).

2.3. Mode of occurrence and importance of V-Ti magnetite ore deposits

Greenstone belts of the Precambrian age contain a variety of geological information in different tectonic settings (e.g. De Wit and Ashwal, 1995, 1997). The important issue pertinent to the mantle evolution through time is to characterize Archaean peridotite either of mantle origin or of crystallization products within the crustal greenstone sequence (e.g. Rollinson, 2007).

The ultramafic suite occurrence within the crustal greenstone belts are much important, which are often highly deformed and in general are either of komatiitic origin or the basal part of the layered intrusions. The experimental work on komatiitic rocks and geochemical studies of high-Mg and low-Ti volcanic rocks within greenstone belts suggest that some komatiites and komatiitic basalts of greenstone belts formed via hydrous mantle
melting process in subduction zone settings during the Archaean (e.g. Grove and Paraman, 2004, Mondal et al. 2006a). In this view, the understanding of geochemical evolution of the ultramafic bodies includes the V-Ti magnetite, within the Archaean greenstone belts and their bearing in crustal evolution, particular in terms of material addition and material recycling in the early history of earth.

V-Ti magnetite deposits occur in two forms as (a) stratiform type and (b) non-stratiform massif-type intrusive,

(a) **Stratiform type**: These types of V-Ti magnetite deposits occur in the layered ultramafic-mafic complexes of Precambrian age, which are closely associated with chromite deposits, have been reported to occur as differentiates of gabbro-anorthosite suite of rocks, most of these deposits are spatially associated with and genetically related to basic igneous activity as seen in some Archaean greenstone belts of the world as well as in the Dharwar craton (e.g. Bushveld Igneous complex of South Africa; Skaergaard Layered intrusion of Greenland; Boula Nausahi basic igneous intrusion of Orissa; Sinduvalli area of Sargur schist complex and Masanikere-Shivani complex; Channagiri Layered Complex).

(b) **Non-Stratiform types**: These are reported to occur as irregular veins lenses stringers in non-layered massif type of intrusive V-Ti magnetite deposits (eg. Adirondack complex, Allard lake and St.Charles anorthosite plutons of Canada and Duluth complex of USA).

In particular Ni, Cr, Ti, Fe and V are most important for steel making and the PGEs are vital in the automotive and health-care industries. In economic point of view the ultramafic-mafic igneous rocks are more significant source for the ortho-magmatic ores, chromite (source of Cr), magnetite (source of Fe,V and Ti), Ni-Cu sulfides (Ni, Cu) and platinum group elements (PGEs: Ti, Os, Rh, Ru, Pt, Pd) (Naldrett and Cabri,1976; Naldrett, 1981).
Komatiitic suites are important source for world class Ni-Cu sulfide deposits (e.g. Kambalda, Australia) where PGEs are minor resources within the greenstone sequence. The intrusive mafic layered complexes within greenstone sequences are important source for the Ni-Cu sulfide, Ti, V, Fe and PGE deposits. In addition, sill-like ultramafic bodies within the greenstone sequences are important source for the Ni-Cu sulfide, Ti, V, Fe, and PGE deposits; such as those found in the Archaean of Shurugwi ultramafic complex of the Zimbabwe craton in southern Africa (e.g. Rollinson, 1997). Similar types of rock suites are also found within the Archaean greenstone belts in the Indian Shield, examples include those of the Singhbhum craton in eastern India, and in the Dharwar craton in southern India (e.g. Radhakrishna and Naqvi, 1986; Saha, 1994; Rogers and Giral, 1997). In the Dharwar and Singhbhum cratons the layered ultramafics bodies are important source for chromite deposits which are highly deformed and occur within low-grade metamorphic rocks of the Iron Ore Group (IOG) mainly in the Nuasahi and Sukinda areas of Orissa state and in the Jojohatu area of Bijhar state, termed as NSJ ultramafic suite. In many places this suite of rocks are closely associated with gabbroic intrusions which are important source for V-Ti bearing magnetite deposits such as in the Nuasahi area of the Singhbhum craton and Tagdur area of the Dharwar craton (e.g. Mukherjee, 1966; Radhakrishna and Naqvi, 1986). The mafic suite in the Singhbhum craton is mostly found in Nuasahi-Nilgiri-Gorumahishani-Badampahar area, termed as NNGB-gabbroic suite. In the Singhbhum craton the ultramafic-mafic rock suites are closely associated with breccia-hosted PGE-deposits (e.g. in Nuasahi and Sukinda areas), which are developed in shear zones (Mondal and Baidya, 1997).

Current knowledge on orthomagmatic ore deposits in different types of rock suites (e.g. large layered intrusions, ophiolitic complex, and in komatiitic suites) at various parts of the world are developed quite far with many research efforts, still there is notable lack of scientific ultramafic information and understanding of extrusive and intrusive ultramafic-
mafic rock suites in various geological terrains of the Indian Shield. The noticeable gaps of knowledge are the detailed petrological and geochemical information of these rocks and economic potentials for orthomagmatic ores, especially for the Ni-Cu-sulfides and PGE resources. In addition, there is significant lack of knowledge regarding the geological age of these extrusive and intrusive rocks, for example the only available age data for the NNGB-gabbroic intrusions in the Singhbhum craton are by Auge et al. (2003).

The chromite deposits of the Nuaasahi and Sukinda the areas from Singhbhum craton was studied by Verma (1986) and Pal and Mitra (2004); and interpreted deposited to be either cumulates similar to those of large layered complexes such as the Bushveld complex or mantle rocks similar to those in Alpine type peridotities or ophiolites (e.g. Mondal et al. (2006a); and concluded that the Nuaasahi and Sukinda chromitites from Singhbhum craton are massifs which were crystallized from a mantle-derived boninitic or siliceous high-Mg basaltic magma that intruded into the volcano-sedimentary greenstone belts of a supra-subduction zone setting. Based on oxygen and Os isotopic studies of chromites from chromitites, they (Mondal et al. 2003a, 2007a) have found that there is no evidence for crustal contamination of the parental magmas for these chromitites. The monomineralic rocks consisting of primitive mineral of chromite, olivine, and orthophroxene suggest that their parental magmas are characterized in the Archaean magmatism, which were formed by high degree of mantle melting.

In the Indian Shield, Singhabum is the one of the important craton, where nearly 95% of the Indian chromite deposits along with one and only PGE deposits are located which are hosted within Mesoarchaean ultramafic-mafic rock sequences, Mondal (2008) pointed out that the Os isotopic and platinum group element (PGE) geochemical studies of chromites from the Nuaasahi and Sukinda massifs indicate presence of a subchondritic source of mantle domain beneath and within Singhbhum craton similar to that of Zimbabwean craton of
southeren African continent. The Os model age calculation indicates melt extraction from a sub-continental lithospheric mantle (SCLM) before 3.7 Ga age which are similar to the other ancient cartons.

However, in comparison with other occurrences, the Singhbhum craton of the Indian Shield and the Zimbabwean craton in southeren Africa are characterized by the presence of subchondritic lithospheric mantle domains within the SCLM, which were developed prior to 3.7 Ga. As a whole the study of Singhbhum craton, supports the premise that India was part of the African continent in pre-Gondwana times and even in early Archaean, suggesting the possible amalgamation and building up of a supercontinent with gondwana land during late Archaean.

2.4. V-Ti Magnetite Deposits of India

V-Ti magnetite ores of the states of Orissa, Bihar and Karnataka, are major deposits of India, this state accounts for the major Indian Chromite production and yields metallurgical, refractory and chemical grade of ores.

In Orissa the best grades of Indian chromite ores are extracted, they are found in the districts of Cuttack, Dhenkal and Keonjhar. Chromite occurs in the form of lenses in Cuttak district or in the form of tabular sheets as in the Sukinda ultramafic complex.

The chromite - bearing ultramafics of Sukinda area are concordantly intruded into Precambrian metamorphites, the intrusive has a width of 2-5 km and extends for more than 20 km with ENE-WSW trend from Kansa in the east to Maruabil in the west. The ultramafic body consists essentially of dunite peridotite with the chromitite bands and a subordinate amount of pyroxenite devoid of chromite mineralization. The pyroxenite is only marginally altered but the dunite peridotite members are highly serpentinised and intensely lateralized giving rises to a nickeliferous lateritic overburden of different thickness. The chromitite
bodies frequently occur in alternate layers with serpentine or limonite closely resembling the 
stratiform deposit of Stiliwater. The lenses and pockets of chromite of various shapes and 
dimensions that occur in some places resemble the sack form or podiform type in character. 
These lenses and pockets are few in number in the Sukinda valley compared to the larger size 
of the layered and banded type. In Dhenkal district, lumpy, metallurgical grade of ores are 
found.

The chromite deposits are situated near the southeastern fringe of the Boula state 
forest in Keonjhar district, ultra-basic rocks containing chromite occur as a lenticular band in 
epidiorite, lodes occur as steeply inclined veins and lenticular bodies of various sizes in the 
altered ultrabasic rocks. Both coarse and fine-grained ores are noticed and they are banded, 
massive, pitted and also occur as disseminations. Lateritic and float ore also found. The 
chromite ores of Orissa, with chrome to iron ratio of 3:1 in Keonjhar, Maruabil and Sukinda 
area ores are suitable for metallurgical process.

In association with the above chromite deposits, V-Ti magnetite ores are found. Near 
Nausahai village in Keonjhar District, V-Ti magnetite ores occur in basic rocks as discordant 
bodies having the form of a dyke and consists of coarsely crystalline magnetite-rich 
disseminations in the basic rocks, accessory in the basic rocks, float ore on the hill tops and 
hill slopes and also as placer sand in the beds of nalla’s draining the hills containing lodes of 
magnetite.

In Bihar, Singbhurn District is the major chromite ore deposits and the best grade ore 
are noticed in Jojohatu area, in Jojohatu area the ultrabasic rocks, like highly serpen 
tinised peridotite pyroxenite dunite and saxonite is chromite- bearing. Segregations of chromite in 
the host rock as Veins / lenses occur. Some chromite ores are also noticed in the quartzite at 
the ultrabasic - shale contact. Rurokharkakuni hill also represents occurrence of chromite,
which is big syncline plunging gently to the north and Singbhum district also have smaller deposits occurring at Kusmita, Gurgaon, Tonto Janoa and Ranjrakocha.

2.4.1. V-Ti Magnetite Deposits of Karnataka

The rocks of the Dharwar craton of Karnataka state show evidence of intense E-W compression but, do not appear to form part of a major orogenic belt. The Archaean gneissic complex of the Dharwar craton includes several supracrustal suites in the western block and isolated intricately folded mafic greenstone belts in the eastern blocks, although lithologically dissimilar and geographically separated the supracrustal belts of the western and eastern blocks are thought to have formed at the same time but evolved under different tectonic regimes. Limited age data on orogenic activity and rifting has indicated that the Dharwar craton become a stable block about 1.5 Ga ago.

In Karnataka Sargur supracrustal extending about 250 km from Sargur in the south to Shivani in the north of Karnataka State is the major Chromite and V-Ti magnetite-bearing ultramafic-mafic complexes. The Chromite and V-Ti magnetite-bearing complexes of this area occur as lenses, sheets, disrupted and discontinuous layers, tectonically interleaved, deformed and have metamorphosed along with the associated supracrustal rocks. It is generally agreed that several distinct types of chromite bearing ultramafic gabbro complexes exist, but it is difficult to group these complexes into one or the other type, due to the fact that rock types, mineral associations and mineral compositions of these complexes overlap each other. Also, distinctive primary features in some stratiform complexes have been partially obliterated by subsequent metamorphism and deformation as a consequence of which the complexes resemble Alpine or concentric complexes, as proposed by Jackson and Thayer (1972). Perhaps as a result of perceiving of the problem in a piece meal, since these Ultramafic rocks have earlier been classified as Alpine type intrusive, (Pichamuthu, 1960,
Phene, 1969, Varadarajan 1970, Naganna et. al., 1977) as komatiitic submarine extrusive
(Divakar Rao et. al, 1975, Naqvi and Hussain, 1979, Srinivas and Srinivasan, 1974,
Vishwanatha, 1974 and Sudhakar, 1980) as concentric complexes (Vasudev and Srinivasan,
1979). Jackson and Thayer (1972) have emphasized that not one criterion is diagnostic, but
several criteria put together will have a classificatory value. The original igneous
stratigraphy, the process of differentiation of the magma and the mode of emplacement may
be explain despite a strong tectonic and metamorphic overprint, in many cases by careful
investigation of the field relations, petrography and geochemistry of the complexes and by
studying the layers of V-Ti magnetite found within the ultramafic complexes.

The occurrences of V-Ti magnetite and ultramafic mafic complex in Karnataka state
was first recorded in 1889 by Slater in Shimoga District (Krishnan, 1953) and its mining
began in 1957. Karnataka state has been the chief producer of the mineral in India as listed;
Hassan and Mysore Districts are the chief chromite producing areas in the state. Minor
deposits of various grades have been reported from Chitradurga, Chikkamagalur and
Shimoga Districts. Hassan District has Chromite and V-Ti magnetite deposits reported from
Nuggihalli and Holenarasipur schist belts.

In Shimoga District sporadic occurrences have been reported from Hamahalli,
Jandimatti and Antharagange (Krishnan, 1953), which are not of economic importance. The
chromite bearing V-Ti magnetite deposits of the Masanikere - Shivani area (Govindaiah, S. et
1996): occur within the ultramafic gabbro-anorthosite suite of rocks emplaced in the
platformal miogeosynclinal sequence of Dharwar supergroup of the Karnataka craton, South
India.

Masanikere - Shivani area forms a part of the Shimoga green-stone belt which is one
of the several greenstone belts of various dimensions striking NW-SE or NNW-SSE engulfed
in granite-gneiss terrain which is referred to as Peninsular gneissic complex. V-Ti magnetites
are confined to gabbro-anorthosite suite of rocks and the chromite deposits are confined to serpentinised ultramafic rocks, Govindaiah et. al., (1989) based on the field relations, mineralogical, textural and geochemical characteristics of the ultramafic mafic rocks and their associated V-Ti magnetite ore bodies concluded that their genesis is intimately related to fractional crystallization in the concentration of Substantial amounts of Fe, V and Ti in the late-stage residual magma and the V-Ti magnetite layers are considered to have developed largely by in situ bottom crystallization and subsequent textural evolution of Ti-magnetite layers is believed to have taken place due to variations in oxygen fugacity during subsolidus cooling which resulted in the development of wide range of ulvospinel, pleonaste and ilmenite micro-intergrowths.

In Nuggihalli area chromite and V-Ti magnetite bearing layered ultramafic mafic complex emplaced into the metasediments of Sargur group to form Nuggihalli schist belt, consists of serpentinised dunite, peridotite, metapyroxenite, metagabbro (amphibolites) and anorthosite, Srikantappa et, al, (1985); The V-Ti magnetite layers are confined to the gabbro anorthosite suite of rocks, whereas the chromite ore bodies are restricted to ultramafic rocks. The serpentinised dunite is strongly layered with layers of chromite. Vinayaka et. al., (1999) opine that the chromite-V-Ti magnetite ore bodies are stratiform in nature and chromite is formed in situ by early magmatic segregation and the Ti magnetite with exsolved phases of ilmenite, ulvospinel, pleonaste is formed by late magmatic residual segregation through insitu bottom crystallization in response to episodic increase in FO2. The ultramafic-mafic complex should be designated as layered ultramafic-gabbro (minor anorthosite) complex based on the chromite distribution was suggested by Nijagunappa and Naganna (1983). But based on the textural and chemical features Naganna et. al., (1978) and Sahoo and Nair (1982) concluded that the Nuggihalli schist belt are of are podiform.
In **Mysore district** the Cr-V-Ti magnetite bearing ultramafic-mafic complex is encountered in the Sinduvalli area of Sargur schist belt and extends for 22 km with an average width of about 200 m. The ultramafic rocks form a distinct but conformable unit within the surrounding basement gneisses, which have a regional strike of about 15°. The Sargur schist complex comprises a portion of the high-grade gneissic terrain of Karnataka and contains a variety of ultramafic and associated basic rocks and enclaves of metasediments consisting of orthoquartzites, banded ironstones, carbonates as well as K-rich pelitic rocks, the ultramafic rocks of Sinduvalli are layered and vary in composition from the dominant spinel-dunite through harzburgite-dunite, bronzite peridotite to pyroxenite (Janardhan and Srikantappa, 1974). Due to competency variations during the several deformational events that have taken place, the ultramafic bodies now have been highly deformed and little can be said concerning their original relationships. They are spatially associated with gabbroic rocks, which are now represented by hornblendites and pyroxene granulites, minor gabbroic anorthosites, occurring as concordant sheets which in some cases exhibit mineral layering (Janardhan and Ramachandra, 1978), and associated with the ultramafic rocks or occur as discrete bodies within the surrounding migmatitic gneisses. Srikantappa et. al., (1980 and 1984) opines that the chromite deposits of the Sinduvalli area belong to stratiform type deposits.

In **Hassan district** the Holenarsipur schist belt at southern parts of Holenarsipur, a few thin veins and patches of chromites in ultramafic rocks and V-Ti magnetites in gabbroic rocks have been reported in Doddakadnur and other places between Kabbur and Yennehole Ranganbetta.

In **Chikkamagalur District** low grade chromite deposits containing 25 to 30 % Cr₂O₃ have been reported from Bandre, Banur and Bijekatte in Tarikere taluk near Shivani railway station (Krishnan, 1953). These chromite deposits are confined to ultramafic rocks and
associated with V-Ti magnetite deposits, which are confined to the anorthosite of rocks exposed in the adjacent Masanikere region of Shimoga District.

2.5. Previous work on the study area.

H.K. Slater (1905 of MGD Records Vol. VI.P26) was the first to carry out regional survey of the area to the east of Benkipur (Bhadrawati now) and in channagiri Taluks, During 1902-1915 He mapped a portion of the Shimoga belt recognized the meta-sediments and met-Volcanic and classified the rock formations exposed in the vicinity of Devarnarsipur village as igneous schists.

B.Jayaram (1915 MGD Records Vol.XIV P.5) carried out a revision survey in parts of Bhadravathi and Channagiri Taluks and classified the formation exposed in the vicinity of Devarnarsipur as ultra-basic suits. V.T. Venugopal (1921) was the first to notice the occurrence of the V-Ti Magnetite ore bands at Devarnarsipur. S.Lakshmana Rao (1939 MGD Records XLI P.46 to 51) has Studied the titaniferous magnetite ore bands exposed at Devarnarsipur, with a view to ascertain their economic value. He was the first officer to determine the $V_2O_5$ content of the ore of Devarnarsipur area which indicated 0.50% $V_2O_5$ and the reserves of the deposit was assessed at 65,000 tones.

B.G.Channappa and K.S.Raghuveera (1974) assessed the quality and quantity of the ore, by collected samples of prospecting (pits total 4) sunk in the area. A drilling exploration program was carried out by drilling 3 bore holes at an angle of inclination of 55°E of 422.03 Meter total Depth to know the ore depth. The V-Ti magnetite ore was intersected in all bore holes. The intersection width ranges from 1 to 9 meters and detailed study was done by classifying them into three deposits based on their position namely Northern, Southern and South-East part. Finally concluded that the deposit found near Devarnarsipur area was small in extent and good in quality for mining with higher percentage of $V_2O_5$ (0.56%) and TiO2
(11.67%) as the ore body is very near to Industrial town Bhadravati it a promising deposit in the logistic view.

2.6. Objectives of the present investigation

The gabbro-anorthosite suites of rocks are the hosts for the V-Ti-magnetite in the Devarnarsipur area of Shimoga district in Karnataka. Since there is lack of comprehensive account on V-Ti-magnetite ores and the associated gabbro-anorthosite suites of rocks deposits in concerned with the mineralogy, textures, chemistry and genesis, around Devarnarsipur, these deposits are taken up by the author for a detailed investigation, in the present research work.

The aim of the present investigation is to understand the mode of origin of the V-Ti-magnetite deposits and their associated gabbro-anorthosite suite of rocks based on their geological setting, mineralogy, petrography and major and trace element chemistry.

In the present research work the following Objectives are focused

1. Preparation of the geological map of the Devarnarsipur area.

2. Identification of ultramafic-mafic rocks and classification based on the mineral assemblages and textures based on their geological setting and thin section studies.

3. Identification and classification of ore mineral assemblages, their textures and their interpretation to know the paragenesis, based on ore petrographic studies.

4. To understand the major and trace elements behaviors and genesis of ultramafic-mafic rocks and their associated V-Ti magnetite ores.

5. Synthesis of data on field setting, mineralogy, petrology, and geochemistry of the ultramafic-mafic rocks and associated V-Ti magnetite for developing a genetic model for these deposits and rocks.
2.7. Investigation Methodology

The methodology followed in the present investigation of V-Ti magnetite ores of Devarnarsipur area are 1) Field studies and 2) Laboratory investigation.

2.7.1 Field Studies

The area under investigation was located in Survey of India Toposheets No.48-O/09 and 48-O/13, based on these topo-maps field visits were carried out and many representative samples of both V-Ti magnetite ores and associated ultramafic and mafic rocks type were collected from the exposed outcrops, systematically. Field photographs of both V-Ti magnetite ores and associated ultramafic and mafic rocks were taken to make out their mode of occurrence in the field; structural textures are noted and described with dips and strike direction of these exposures. All exposures encountered are mapped on to a geological map.

2.7.2. Laboratory investigation.

Thin sections of ultramafic and mafic rocks are prepared from the collected field samples in the laboratory and subjected to detailed petrographic and mineralogical studies, under the petrological microscope (Leitz Laborlux Pol-II), minerals and their textural features were identified, the optical properties of minerals like colour, cleavage, pleochroism, extinction angle and mutual relationship existing among them are noted and photomicrographs displaying these textural features are presented and mode of occurrence of various minerals are discussed.

Polished surfaces of chromite bearing V-Ti magnetite ores are prepared from the collected field samples in the laboratory and polished ore samples were subjected to a detailed ore microscopic study using Leitz Reflected light ore microscope, several ore minerals are identified based on their optical properties such as colour, pleochroism, and
isotropism/anisotropism etc. Several ore textures were identified, described and interpreted. Photomicrographs of both colour and black & white showing various textural have been taken and presented in the thesis and based on photomicrographs mode of occurrence of various ores have been discussed, a probable paragenetic diagram has been drawn and presented, based on the identified textures to know the order in which the individual ore minerals are formed.

2.7.2. Chemical analysis - XRF.

Representative V-Ti-magnetite ores and the associated ultramafic-mafic rocks of selected samples are subjected to chemical analysis. The major element data of five samples of ultramafic rocks (three dunite and two pyroxenite samples), five samples of gabbro-anorthosite suite of rocks (three gabbro, one anorthositic gabbro, one gabbroic anorthosite) and four samples of V-Ti magnetite ores along with their critical elemental ratios as well as trace elements Cr and Ni presented were obtained by X-ray Fluorescence Spectrometry (XRF), at Air-borne Mineral Surveys and Exploration Wing of Geological Survey of India. Bangalore.