Chapter 8
SUMMARY AND CONCLUSION
The Shimoga greenstone belt of Karnataka has long been known for the occurrence of quite large V-Ti-Fe deposits. The deposits investigated in the present study have shown several interesting and hitherto undocumented mineralogical and geochemical features.

The thesis is based on a detailed field study and mapping of 90 km² and 9 km² of area in Channagiri and Mulemane areas respectively on 1 cm = 0.125 km scale, microscopic examination of 140 thin sections including ores and 50 polished ore samples, modal analysis of 53 rocks, XRD study of separated ore samples, chemical analysis of 24 ores and 16 associated rocks, both for major and trace elements, and electron-probe microanalysis of 116 individual minerals of V-Ti-Fe ores.

The areas covered in the present study form parts of the Shimoga greenstone belt consisting of gneisses, schists, quartzites, phyllites, gabbro-anorthosite suite of rocks, ultramafics, V-Ti-Fe ores, dolerites, epidiorites and quartz veins.

ASSOCIATED LITHOLOGIES

In Channagiri area granitic gneisses of Peninsular gneissic complex are the most abundant and oldest (2.90-3.36 m.y old) rocks recognised. They are generally greyish white in colour, equigranular, medium to coarse grained, locally porphyritic and exhibit well developed gneissic banding/foliation with a general NNE-SSW trend and easterly dip. The gneisses are traversed by several younger quartzofeldspathic veins and lenses. Mineralogically, they contain abundant plagioclase and quartz.
Microcline occurs in small amounts. Biotite, muscovite, chlorite, calcite, sphene, zircon and iron oxides are the other minerals present. Chemically the gneisses are tonalitic and are comparable to similar Precambrian gneisses of other areas. Schistose rocks containing chlorite as the predominant mineral are the important lithological units of the area. They are highly folded and disturbed showing variable dip and strike. The schists are fine grained, greenish coloured, strongly foliated rocks comprising of the mineral assemblages quartz-chlorite-magnetite, quartz-chlorite-carbonate-magnetite and quartz-chlorite-muscovite-magnetite. The first two assemblages are most common and are made of 85-95% chlorite and quartz in their modal composition. There is no significant variation in the chemistry of the two common types except a high content of CaO, Na₂O and lower K₂O, SiO₂, Fe₂O₃ and MgO in the quartz-chlorite-carbonate schist. Quartzites interbedded with phyllite are well exposed at a number of places. They are dirty white in colour, fine grained, equigranular and compact with granulose texture. They are predominantly composed of quartz with minor muscovite, fuchsite, sericite and iron-oxides. The ultramafics are represented by actinolite-chlorite schists which are generally seen exposed on either sides of titaniferous magnetite bands and gabbro. The mafic rocks of gabbro-anorthosite suite occur as patches and bands of variable dimensions within the schistose rocks. They enclose bands and lenses of V-Ti-Fe ores. There is a clear intrusive relationship of this suite of rocks with the schistose rocks of the area. Based on petrographic and mineralogical
variations these rocks are classified as magnetite gabbro, gabbro, gabbroic anorthosite and anorthosite. Mineralogically, these are composed essentially of plagioclase, hornblende and pyroxene with secondary chlorite, calcite, epidote and quartz; magnetite and pyrite are the common opaques. Geochemically, these rocks show a tholeiitic affinity with limited variation in the content of SiO₂, appreciable variation in Al₂O₃, higher and widely variable CaO and a general increase in Ni and Cr with increase in MgO. From the occurrence of V-Ti-Fe ore bodies as lenses, pods and bands within gabbro-anorthosite suite of rocks, it is evident that there is a close genetic relation between the two, and they have been derived by a differentiated tholeiitic magma rich in iron. The associated ultramafics are also tholeiitic in composition with low alkalies. Dolerite dykes intrude the gneisses and schists of the area. Mineralogically, they are relatively simple with plagioclase and augite forming the major minerals. Magnetite, quartz, chlorite and epidote are the common accessories. The observed mineralogical characters suggest a possible genetic relation of all the dolerites of the area and their derivation from a single basaltic magma.

The area to the south of Devaranarsipur village is dominated by pyroxenite and serpentinite which have a general NNW-SSE trend with variable dip. These occur as minor intrusions within the granitic rocks of the area. The other rock types include talc-mica schist, steatite and quartzite. V-Ti-Fe ores occur as isolated bands and lenses within the ultramafics. Pyroxenite consists essentially of augite which is usually altered to
hornblende, chlorite and epidote. Serpentinites are mainly composed of antigorite, carbonate, talc and magnetite. These ultramafics hosting the V-Ti-Fe ores show an alkali poor tholeiitic affinity.

Peridotite/serpentinite and gabbro are the principal rock types of Mulemane area. Metasediments like quartzites and phyllitic schists occur as small bands. The ultramafics hosting the V-Ti-Fe ore bodies intrude the basement gneisses and in turn are intruded by epidiorite and dolerite dykes.

**V-Ti-Fe ORES**

The V-Ti-Fe bands of Channagiri area occur closely associated with gabbro-anorthosite suite of rocks showing intrusive relationship with quartz-chlorite-carbonate schists. The gabbro-anorthosite members are spatially associated with ultramafics. A gradational passage from gabbro and magnetite gabbro to V-Ti-Fe bands/layers is noticed. Ore bodies at Devaranarsipur occur as disconnected bands conformable with the general trend of the associated pyroxenite/serpentinite. The main ore body of Mulemane area occurs associated with peridotite/serpentinite and several small lenses of V-Ti-Fe ores occur within gabbro in the vicinity of the main ore body. V-Ti-Fe ores are medium to coarse grained, metallic black to earthy brown coloured and magnetic. The ores exhibit interlocking granular, exsolution, emulsion, replacement and occasionally cataclastic textures. Magnetite, titanomagnetite and ilmenite are the abundant minerals of the ores. Ilmenite and ulvöspinel form
exsolution, lamellar and needle-like intergrowths along the octahedral and cubic planes of magnetite and titanomagnetite. Besides, hematite, maghemite and goethite (martite) are ubiquitous secondary minerals, which are found replacing the primary minerals (magnetite and titanomagnetite and rarely ilmenite) along grain boundaries and weak planes.

The mineralogy of the V-Ti-Fe ores is relatively simple with only 3 to 4 Fe-Ti oxide minerals making up nearly 90% or more of the individual ore bodies. Högboomite and spinel are quite common. Chlorite is nearly always present. Diaspore is of restricted occurrence and kaolinite is present only in Mulemane ores. While chalcopyrite and pyrite are the ubiquitous sulphides, pyrrhotite and covellite are present in minor amounts.

Mineral chemical studies have shown:
1. a large variation in the content of V, Ti and Cr of the magnetites,
2. very little variation in the composition of ilmenites and their very low Fe₂O₃ content,
3. partitioning of minor and trace elements between magnetite and ilmenite,
4. concentration of vanadium of the ores mainly in magnetite and partly in ilmenite and hógboomite,
5. high Cr content of Magyatahalli chlorite-rich ores
6. considerable variation in Mg, Fe and Ti of hógbomites with some tending to be of zincian type,
7. existence of chlorites of repidolite, corundophilite, sheridanite and amesite character
8. occurrence of diaspore in the ores of different areas, and
9. the presence of kaolinite only in the ores of Mulemane area.

Chemically, the ores exhibit all the peculiarities of the
titaniferous magnetite deposits of the world which are observed
to be a type by themselves being distinctly different from both
iron meteorites and sedimentary/metamorphic iron ore deposits of
various kinds. The ores, besides being unusually enriched in Ti
and V appear to show relative concentration of a large number of
major and trace elements.

Significant differences in the major and trace element
contents of the different deposits are observed. Also within the
deposits of Channagiri area the range of variation in Cr, V, Mg,
Si and Cu is greater between the different ore bodies. Cr is
significantly higher in the Magyatahalli ores whereas V and Cu
are more in Masanikere ores. Fe²⁺ and Fe³⁺ vary significantly
between the deposits. The distinctive chemical features of the V-
Ti-Fe ores as compared with similar ores occurring elsewhere in
the world are,
1. higher SiO₂, Al₂O₃, MgO, Cu, Ni, Zn and Rb and lower TiO₂
   contents,
2. an average V₂O₅ content of 0.9%,
3. extreme variation in the content of Cr, and
4. uniformly depleted Ca and K and extreme variation in Li and
   Na.

The most common titanium-rich magnetite bodies of Channagiri
area have formed at a late stage and the rare chromium-rich
magnetite bodies have separated in the early stage of crystallization of an iron-rich basic magma which was initially enriched in Ti and V. The chlorite-rich chromiferous magnetite of Magyatahaili area might initially have formed as pyroxene-magnetite rock and subsequently under shearing and low grade metamorphism the assemblage changed over to a chlorite-rich magnetite.

The V-Ti-Fe bodies of Devaranarsipur area seem to have formed by filter pressing of a residual liquid enriched in V-Ti and Fe and injection into the associated pyroxenite/serpentinite. The main magnetite body of Mulemane area is a result of late magmatic accumulation of Fe-Ti oxide minerals and their injection into the associated serpentinite.

With the low hematite content of the ilmenites of all the V-Ti-Fe deposits studied, precise temperature and oxygen fugacities are not determinable. However, as the present compositions of titanomagnetite and ilmenite of the present study are closely comparable to those of the Fongen-Hullingan basic complex, Norway (Thy, 1982), the results obtained for the complex may as well be extended to the present study. The subsolidus crystallization conditions obtained for the said complex lie below 800°C and oxygen fugacity of $10^{-17}$ bar between the FMQ and MW buffer curves, or on the MW buffer. It may be suggested that ilmenite reequilibrated with titanomagnetite to the present composition in response to cooling along a path oblique to both ulvospinel and ilmenite isopleths in T-fO₂-X space.