Chapter 4
MINERALOGY AND TEXTURES
MINERALOGY

INTRODUCTION

The ores mainly consist of granular aggregates of magnetite and ilmenite. The magnetite is usually not homogeneous and contains minute intergrowths of ilmenite and may also contain considerable amount of titanium (titanomagnetite). These minerals along with maghemite, hematite and goethite form nearly 90% of the individual ore bodies. Hogbomite and spinel are quite common. Chlorite is almost the constant silicate mineral present. Diaspore is of restricted occurrence; Kaolinite is recorded in the Mulemane ores. While chalcopyrite and pyrite are the ubiquitous sulphides, pyrrhotite and covellite are present in minor amounts.

MAGNETITE

Magnetite is the dominant primary oxide mineral phase occurring as euhedral, subhedral and anhedral grains exhibiting martitization at all stages. It is greyish white in colour with a pinkish tinge at places, isotropic and non pleochroic in character. It shows positive etch reaction with HCl and HF; negative with HNO₃ and KOH. Magnetite contains exsolution bodies in the form of lamellar ilmenite/ulvospinel, spinel, droplets/rods of hogbomite and idiomorphic to xenomorphic grains of chalcopyrite and pyrite. It is characterised by the development of lamellar, granular and emulsion intergrowth of ilmenite. Discrete grains of magnetite free from intergrowth are rare. Most of the grains (especially those from the Masanikere deposit) are partially or completely martitized mainly along
grain boundaries and weak planes. The degree of martitization is noticed to increase with the increase in the degree of weathering. Maghemite is found along the fracture planes of magnetite from which it is formed by oxidation. Magnetite shows pitted appearance having lot of silicate inclusions and high degree of corrosion. Perfect euhedral crystals of magnetite exhibiting mutual boundary texture with ilmenite and titanomagnetite are noticed in some of the ore sections from Ubraní, Devaranarsipur and Magyatahalli deposits (Plate-7A). The magnetites of Magyatahalli chlorite-rich ores occur in the form of anhedral grains which have optical continuity and often contain diffused chlorite along weak planes and also as inclusions (Plate-7B).

TITANOMAGNETITE

It is an optically homogeneous Fe-Ti spinel phase (according to the terminology of Buddington et al., 1963; Anderson, 1968; Himmelberg and Ford, 1977), and it occurs as subhedral to anhedral grains associated with magnetite and ilmenite. Under the microscope the mineral is grey but when compared to pure magnetite, it displays a more brownish tone, feeble anisotropism and weak reflection pleochroism. The electronprobe microanalyses confirm that it is essentially homogeneous and contains appreciable quantity of titanium (see table-7). The mineral turns brown with HCl and HF. Alteration of titanomagnetite usually along octahedral planes is common and it contains inclusions, lamellae or crystals of ilmenite, spinel, ulvospinel, pyrite and chalcopyrite.
ILMENITE

In polished sections, ilmenite shows distinct reflection pleochroism under oil in the shades of pinkish brown to brown. It is distinguished from the co-existing magnetite by its deep brown colour, strong pleochroism and anisotropism, parallel extinction and negative reaction to all etching reagents except HF, which turns it dark brown after 2-3 minutes. Ilmenite occurs:

1) as euhedral to subhedral granular aggregates of varying size (0.0001-1.594 mm²) associated with magnetite and titanomagnetite exhibiting granular or mutual boundary texture (Plate-7A),

ii) as broad (0.02-0.04 mm wide) and thin (less than 0.02 mm in width) lamellae continuing through magnetite grains in directions which conform to (111) and (100) planes (Plates 8A & B),

iii) as isolated grains usually small (less than 0.02 mm²), euhedral-subhedral in shape included within magnetite/titanomagnetite (Plate-8B), and

iv) as veins and blebs roughly parallel to the crystallographic direction of magnetite.

The granular ilmenite and co-existing magnetite and titanomagnetite grains commonly show the development of polygonal outlines generally exhibiting curved grain boundaries that meet at triple junction having an interfacial angle of 120° (Plate-9A). These ilmenites generally do not contain any exsolution bodies.

Magnetite containing composite lamellar exsolution
Intergrowth of ilmenite are common in all the ore bodies studied except in the chlorite-rich magnetite ores of Magyatahalli. In the latter case, the Ti is located in titanomagnetite and the thin ulvospinel component within the magnetite grains; and very rarely as small granular blebs within the magnetite/titanomagnetite grains. Broad lamellae of ilmenite which are unevenly spaced (Plate 8A) are along (111) and (100) planes of the magnetite host. Fine lamellar intergrowths are usually along (111), forming trellis network or widmanstatten texture (Plate-8B). The occurrence of both fine and broad lamellae within a single grain of magnetite is also common. The length of these ilmenite lamellae varies from 0.02 mm to 0.62 mm.

Ilmenite also occurs as grains within magnetite and at places the granules continue as lamellae through the host (Plate-9B). Fracturing of ilmenite grains due to deformation is also noticed in some sections (Plate-10A).

According to Buddington and Lindsley (1964), broad ilmenite lamellae and separate granules are developed as a result of increased oxygen fugacity at high subsolidus temperature. With decreasing rates of diffusion of ilmenite within the magnetite-ulvospinel solid solution, ilmenite is prevented from leaving the solid solution host and remains either as lamellae or internal granular exsolution.

HOGBOMITE

Hogbomite was first described by Gavelin (1916) from Lapland, Sweden. Since then, hogbomite has been described by
different workers from many parts of the world (Agnes and 
Middleton, 1985; Friedman, 1952; Wilson, 1977; Gatehouse and 
et al. 1988; Wilson, 1977; Zakrzeski, 1977). Hogbomite from India 
was reported for the first time by Devaraju et al. (1981) from the 
Fe-Ti deposit of Madangere, Karnataka.

Hogbomite has a chemistry similar to that of spinel in that
it readily incorporates Zn and Cr, and it differs in that,
considerable amount of TiO₂ is present. It is commonly formed by
the alteration of spinel (Friedman, 1952; Zakrzeski, 1977). An
exsolution like origin of hogbomite from magnetite was also
suggested by Devaraju et al. (1981) and Grew et al. (1989).

Hogbomite in accessory amounts is common in the V-Ti-Fe ore
bodies of all the areas of the present study. It is greyish in
colour and brighter than spinel. It occurs:
1) as discrete prisms, laths and plates occupying interstices
	 of ore grains (Plate 10B & 11A),
2) as tiny exsolved drops, blebs and rods in magnetite,
3) as slender scales and shreds rimming the spinel grains, and
4) as replacing magnetite/titanomagnetite along the margins
	 (Plate-11B).

In hand specimen, it cannot be readily distinguished from
the iron-oxides both because of its blackish colour and fine
grain size. In transmitted light, the mineral shows deep brown
colour, moderate pleochroism, one set of longitudinal cleavages,
irregular cracks, occasional moderate to weak zoning near borders
and rare polysynthetic twinning. In reflected light, the mineral is grey in colour and is anisotropic. Usually it is seen along the margins of Fe-Ti oxides and enclosed in magnetite and titanomagnetite and less commonly within ilmenite. At places, hogbomite grains appear to replace magnetite/titanomagnetite (Plate-11B).

SPINEL

Spinel is grey in colour with low reflectivity. It occurs:
1) as exsolution granules within magnetite/titanomagnetite and ilmenite (Plates 12A & B),
2) surrounding the ilmenite lamellae as specks, tiny lenses, thin lamellae and droplets, and
3) at the contact between the primary ilmenite and magnetite/titanomagnetite.

It is more in Mulemane and Devaranarsipur ores commonly bordering the ilmenite lamellae (Plates 8A & B) but occurs in all the areas studied except in the chlorite-rich magnetite ores from Magyatahalli. The exsolutions of spinel are very fine, visible as scattered dust-like particles only at high magnifications. It is usually aligned parallel to (100) planes of magnetite/titanomagnetite. Both ilmenite and spinel are often found together in a single host crystal.

The spinels are of two generation. The first generation spinels form exsolution spots, discs and lamellae within magnetite/titanomagnetite and ilmenite, and those that are concentrated along intergranular boundaries (see Faessler and
Schwartz, 1941; Lamoen, 1977). The second generation spinels are fine grained and are concentrated along the borders of ilmenite lamellae.

CHLORITE

Chlorite occurs ubiquitously as the main gangue mineral. It forms scaly aggregates located interstitially between the ore minerals or all the V-Ti-Fe ore bodies studied, except the Mulemane body. The chlorite-rich-magnetite ores of Magyatahalli have a modal chlorite content as high as 37% to 70%. It also occurs as inclusions and along weak planes (JS-74) (Plate-7B) within magnetite. It is crystalline and green in colour characterised by pleochroism in the shades of pale green to dark green and commonly showing undulatory extinction.

PYRITE

Pyrite (grain size less than 0.3 mm²) is most abundant among the sulphide minerals which occurs along the grain boundaries of Fe-Ti oxide and as discrete grains within magnetite, titanomagnetite and ilmenite (Plates 10A & 13A). In the ores of Devaranarsipur, pyrite usually occurs within chlorite. It is yellowish white in colour occurring as xenomorphic to idiomorphic grains, marginally corroded showing irregular outlines (Plate-13A). Alteration to pyrrhotite is common and exhibits replacement relationship with magnetite along the grain boundaries.

CHALCOPYRITE

Chalcopyrite occurs in lesser amounts than pyrite. It is
characterized by its bright yellow colour, very high reflectance and isotropism. Two generations of chalcopyrite are noticed. The primary chalcopyrite predominates in all the ore associations. The early generation chalcopyrite occurs within the Fe-Ti oxides and is pitted and distorted. The later generation chalcopyrite is seen filling the fractures of earlier formed minerals especially magnetite and pyrite. The Masanikere ores analyse modally more percentage of disseminated chalcopyrite. In the Devaranarsipur ores, chalcopyrite usually occurs as specks within the chlorite matrix, and in the ores of Mulemane, it is also seen occurring as inclusions within hogbomite grains (Plate-11A). It also occurs as inclusions within pyrite (Plate-13A), but is a rare phenomenon. Alteration of chalcopyrite to covellite is observed along the borders. Generally chalcopyrite is irregularly distributed as small specks and in patches; grain size normally less than 0.001 mm².

**DIASPORE**

Diaspore has been noticed occurring as scales and elongated crystals occupying the tight joints, fissures, cavities and other weak planes in the V-Ti-Fe ores of Mulemane, Magyatahalli and Devaranarsipur areas. It is white in colour and displays pearly lustre (see also Devaraju et al.1985).

**KAOLINITE**

Kaolinite is present only in the ores of Mulemane area and forms the most important hydrous alumino-silicate. It is white to off-white in colour and occurs mainly in the cracks and fractures
of the ore body and along the boundaries of the Fe-Ti oxide grains. Studies reveal that there is no uniformity in the distribution of this mineral and varies within the limits of the ore body. There is, however, increase of kaolinite in the outcrops where the ores are coarse grained.

The d-spacing measured and the X-ray diffractogram obtained (Fig. 12) for the separated kaolinite (JNK-13B) shows prominent peaks at 7.09 Å and 3.53 Å with a number of smaller peaks comparable to those reported in the powder diffraction data file (JCPDS.,1967).

TEXTURAL FEATURES

INTRODUCTION

The V-Ti-Fe ores of the different deposits studied display a variety of textural characters. The ore in hand specimen is massive, medium grained (Mulemane ores are coarse grained) with an overall granular texture, metallic black to earthy brown colour. The specific gravities of these ores are given in Table-4. The grain contacts do not show up readily in hand specimen but the textures are easily recognised in polished sections. The ores are composed largely of Fe-Ti oxides. The proportion of silicates and sulphides vary from deposit to deposit. The silicate, which is mostly chlorite, is interstitial to the Fe-Ti oxides.

GRANULAR OR MUTUAL BOUNDARY TEXTURE

This is the overall texture of the ores of all the V-Ti-Fe deposits studied, in which individual ore minerals have smooth, regular contact (Plate-7A) without any projection of one mineral...
Fig. 12 XRD pattern for kaolinite
## Table 1

### Specific Gravity Measurements for the Ores

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<td>3. MAGVATAHALLI</td>
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<td>1) Compact ores</td>
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<td>2) Chlorite-rich Magnetite ores</td>
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<td>4. UBRANI</td>
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<td>6. MULEMANE</td>
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into the other (Schwartz, 1951). The ore consists mostly of granular aggregates of magnetite, titanomagnetite and ilmenite. They differ in their size and exhibit polygonal outlines. The grain boundaries are generally straight to gently curved, which meet at triple junction having an interfacial angle of 120° (Plate-9A). Small polygonal crystals of ilmenite are located interstitially between the bigger magnetite, titanomagnetite and ilmenite grains. The occurrence of ilmenite as discrete grains and aggregates suggests contemporaneous crystallization with magnetite. Also, if the cooling of the solid solution is slow, the ilmenite tends to diffuse to the margins of the magnetite forming granular ilmenite (Edwards, 1965).

EXSOLUTION TEXTURES

Lamellar intergrowth: lath shaped minerals oriented along crystallographic directions in a grain or crystal is a common type of texture in these ores. The most common is the lamellar intergrowth of ilmenite with magnetite/titanomagnetite. Ilmenite occurs as coarse and fine lamellae along the cubic planes of magnetite which have sharp margins against magnetite and no enlargement or swelling is observed where such lamellae intersect. The width of ilmenite lamellae varies considerably and both coarse and fine lamellae along (111) planes of the host magnetite form equilateral triangles (Plate-8A). The broad ilmenite lamellae along (100) planes make an angle of 90° (Plate-8B). The fine lamellar intergrowth of ilmenite with magnetite forming "Widmanstatten texture" or "trellis intergrowth" is noticed in the V-Ti-Fe ores of all the areas except in the
chlorite-rich magnetite ores from Magyatahalli. The ilmenite of trellis intergrowth may be a product of oxidation of ulvospinel dissolved in magnetite. The origin of lamellar intergrowth is generally attributed to unmixing or exsolution (Brunton, 1913; Singewald, 1913; Ramdohr, 1953; Schwartz, 1931). Ilmenite lamellae are sometimes seen to project into the adjacent grains of magnetite (Plate-13B).

**Internal granule exsolution**: Though such type of exsolution is less common, it has been noticed in the ores of all the localities. Here, small polygonal ilmenite occurs within bigger grains of magnetite/titanomagnetite which is unoriented and is scattered with no replacement relationship between the two (Plate-9B).

In the Magyatahalli chlorite-rich magnetite ores lamellar intergrowth of ilmenite is rare. Ilmenite component in these ores occurs as small internal granule exsolution which is seen only under high magnifications.

**Emulsion texture**: Minute blebs of ilmenite within magnetite are scattered without any crystallographic orientation.

**Cloth - microtexture**: Is formed by the exsolution of ulvospinel in the (100) planes of host magnetite. This texture is usually recognised under crossed nicols.

Inclusion of spinel, pyrite, chalcopyrite and hògbomite within magnetite/titanomagnetite; chalcopyrite within pyrite, ilmenite, magnetite and hògbomite; pyrite within magnetite and ilmenite is
common. Idioblastic grains of pyrite within magnetite/ilmenite/titanomagnetite and along grain boundaries give rise to "panidiomorphic texture".

Högboomite occurs as coarse to fine prismatic crystals in close contact with magnetite (Plate-10B) and also as exsolution intergrowth within magnetite. The mutual relationship of högboomite with magnetite indicates that högboomite is an exsolved phase of magnetite. Chlorite appears to have been diffused in magnetite along weak planes simulating exsolution lamellae along definite crystallographic directions (Plate-7B) in the chlorite-rich magnetite ores of Magyatahalli.

SECONDARY TEXTURES

Replacement texture: The most common feature noticed in these V-Ti-Fe ores is the replacement of one mineral by another and various textures are developed either due to partial or complete replacement. The replacement of magnetite and titanomagnetite (Plate-14A) along grain boundaries and along octahedral planes is the most usual feature noticed even in the freshest surface ore samples. Martite which is a pseudomorph of hematite after magnetite is found to replace magnetite and titanomagnetite. When magnetite is partially replaced by martite, it produces moth eaten pattern in which irregular relict patches of magnetite are seen. The intensity of martitization, however, varies from one ore body to the other, being very much intense in the Masanikere ores. Ilmenite is more resistant to replacement but still replacement along fractures is noticed in some sections. When the
martitization is complete, original ilmenite lamellae unaffected by martitization occur as relics, giving rise to "relict texture".

Goethite derived by oxidation-hydration is found to replace magnetite, titanomagnetite, ilmenite and martite along margins producing "colloform bands" (Plate-14B).

Replacement of ilmenite by leucoxene is seen in several sections. It is grey in colour and less anisotropic than ilmenite.

Cataclastic texture: Fracturing of ilmenite grains is occasionally noticed (Plate-10A). This feature is related to deformational forces which were locally active after the consolidation of the ore intrusion.