CHAPTER IV

ORE PETROGRAPHY OF LODES

In this chapter, petrographic features of individual ore lodes and their significance in terms of understanding the gold mineralization are discussed.

West Prospect Lode

Detailed microscopic examination of approximately 41 polished ore mounts and a few thin sections revealed that the sulfide constitute up to 10-15 volume per cent of mineralized zones and commonly occur as fine to medium grained bands/layers. The layering is often deformed. Sulfides also occur as disseminations throughout the mineralized zones. Variation in the nature and abundance of bulk sulfides as well as individual sulfide minerals along the strike of the ore body has been studied. It was found that the amount of bulk sulfides as well as the amount of individual sulfide minerals vary quite significantly within a distance of 10 or 20 feet. However, the nature of sulfide mineralogy is remarkably similar along the strike of the ore zones. Pyrrhotite is the main sulfide mineral. Arsenopyrite, sphalerite, chalcopyrite, are present in minor amounts usually in the listed order. Loellingite occurs in trace quantities.
Among the oxides magnetite and ilmenite occur in moderate amounts. Gangue minerals constitute mainly cherty-quartz. Carbonates (calcite), chlorite and feldspar are present in variable amounts in addition to graphite. The metamorphic intergrowth textures among sulfides and between sulfides and silicates are common and show abundant triple junctions suggesting equilibrium among sulfides and silicates. The nature and mode of occurrence of individual sulfides in the lode are as follows:

Among the sulfide minerals, pyrrhotite, mostly hexagonal form is the most abundant, approximately about 70 volume per cent of the sulfides and it occurs as fine monomineralic layers, often intimately intergrown with other sulfides like sphalerite, chalcopyrite and arsenopyrite. It also occurs as fine granular composite aggregates. Minor amounts of pyrrhotite also occurs as inclusions in arsenopyrite and in magnetite. The width of the pyrrhotite bands varies from 0.1 mm to about 0.5 cm. At some places the pyrrhotite bands vary in their thickness and are found as very fine layers. Pyrrhotite bands exhibit deformational features like pinching and swelling (Fig. 4.1). At places traces of pyrrhotite along
with calcite mobilized into small fractures in the host rock cutting the schistosity (Fig. 4.2).

Individual grains of pyrrhotite-chalcopyrite-magnetite, pyrrhotite-magnetite-arsenopyrite, pyrrhotite-sphalerite-chalcopyrite, come in contact to produce triple junction forming a dihedral angle. However, the original grain fabric have been modified by syn-post mineralization deformation and partial annealing. Pyrrhotite often includes rounded to sub-angular silicate fragments showing "rock-ball" textures (Fig. 4.3).

Though arsenopyrite appears a widespread minor mineral in West Prospect lode, its occurrence is localized and thus its distribution is not uniform all over the ore lode. Arsenopyrite occurs as medium to coarse grained, subhedral to euhedral crystals often as isolated crystals and also as mutually intergrown with pyrrhotite and silicates. Coarse arsenopyrite commonly fractured and the fractures are healed by sulfides and silicates. Arsenopyrite also includes sub-rounded blebs of pyrrhotite and silicates (Fig. 4.4).

Among the base metal sulfides, sphalerite and chalcopyrite occur in minor amounts. They are fine to medium grained and often form as irregular inter-
Fig. 4.1: Photograph of polished ore mount (sample # KGF 14) showing monomineralic pyrrhotite bands with deformational features like pinching and swelling.

Fig. 4.2: Photograph of hand specimen (sample # KGF 18) showing secondary calcite and remobilised pyrrhotite cutting the schistosity of the host amphibolite.
Fig. 4.3: Photograph of polished ore mount (sample # KGF 17) showing the 'rock-ball' texture developed in deformed pyrrhotite.

Fig. 4.4: Photomicrograph of sample (# KGF 19) showing deformed arsenopyrite in association with anhedral pyrrhotite. Arsenopyrite also includes rounded pyrrhotite grains. (Reflected Light; 4X)
growths with pyrrhotite (Fig. 4.5) and also with magnetite. Sphalerite also occurs as tiny blebs dispersed all over the silicate gangue. Sphalerite is deformed by flattening and fracturing and at places it contains exsolved (?) blebs of chalcopyrite. Sphalerite in polished section displays a deep grey colour and shows reddish brown internal reflection probably suggesting its iron-rich nature. Chalcopyrite at places cuts pyrrhotite.

Loellingite occurs as inclusions in arsenopyrite and also present as independent crystals. It is fine-grained and subhedral in nature.

Ilmenite is present in minor amounts and occurs as subhedral to anhedral fine-grained discrete crystals along with the cherty horizons in association with sulfides.

The presence of free gold is not encountered in our microscopic examination of approximately 41 polished sections.

Based on our observed textural relations among various ore minerals, we would like to suggest the following general possible paragenetic sequence for the ore minerals in West Prospect ore lode.
Fig. 4.5: Photomicrograph of sample (KGF 14) showing sphalerite and pyrrhotite intergranular texture. (Reflected light: 16X)
Magnetite $\rightarrow$ loellingite $\rightarrow$ arsenopyrite $\rightarrow$ pyrrhotite $\rightarrow$ sphalerite $\rightarrow$ chalcopyrite.

However, we do not like to propose that this could be the original sequence of deposition of minerals, because from above description of various textural and structural features of ores, it becomes apparent that the original premetamorphic/predeformational features are quite obliterated and subsequently developed textures, cannot be used for inferring the original mineral paragenesis.

Oriental Lode

Around 48 polished sections and a few thin sections were used to study the mineralogy and their textural features of the Oriental ore lodes. The sulfides constitute approximately 5-10 volume per cent of the mineralized zones and the sulfides occur as distinct bands/layers parallel to the schistosity of the host rock. Sulfides are medium to coarse grained and occur commonly as monominerallic bands. The ore is well-banded/layered with sulfide bearing mafic bands alternating with cherty bands. The sulfides are mostly confined to mafic bands, whereas cherty bands are generally barren of sulfides. The variation in the nature and amount of various sulfide
minerals with depth and also along the strike of the ore zones have been carried out. It is found that the total sulfide content and the proportions of individual sulfide minerals vary considerably along the strike as well as with depth. However, the type of sulfide minerals and the textural relations remain generally unchanged. Among the samples studied, the ones collected from 33rd level have relatively higher proportions of bulk sulfide content as well as the arsenopyrite content than that of other levels studied.

Among the sulfides, pyrrhotite is the main sulfide mineral followed by arsenopyrite, which together constitute approximately over 90 volume percent of the sulfides. Chalcopryite, sphalerite, ilmenite and calcite are present in accessory amounts, whereas loellingite and gold are present in trace quantities. Magnetite is present in significant quantities. Among the silicate gangue, cherty-quartz, amphibole, chlorite, biotite are present in variable proportions. On an average, arsenopyrite and magnetite contents in the Oriental lode are relatively more abundant than that of the West Prospect lode. The ores exhibit deformational and metamorphic features and the presence of intergrowth textures between sulfides and silicates.
are also common. At places, concentration of ore in "pressure-shadow" areas and recrystallization of the ore are generally present. The nature and mode of occurrence of various ore minerals along with their textures are as follows.

Pyrrhotite is the dominant iron sulfide mineral and is present mostly in hexagonal form. It occurs commonly as monomineralic bands/layers with variable width ranging in 2 mm to 0.5 cms. Individual grains are medium to coarse grained and occur as granular aggregates often highly deformed plastically. Pyrrhotite generally surrounds and also cut across arsenopyrite. Pyrrhotite bands associated with silicate and magnetite bands show often clear deformational features like pinching and swelling (Fig. 4.6). Pyrrhotite also occurs as rounded blebs in arsenopyrite, magnetite and also dispersed in silicate gangue. At places pyrrhotite often includes wall rock fragments (silicates and cherty-quartz) and the development of 'ball-textural' is commonly seen (Fig. 4.7). Pyrrhotite commonly shows intergrowth textures with silicates/magnetite/ arsenopyrite. Thus grain fabric has been modified by post mineralization deformation and metamorphism making interpretation of contact relations (or paragenetic sequence) with other minerals generally difficult.
Fig. 4.6: Photograph of hand specimen (sample # KGF 2036) showing pyrrhotite and cherty quartz bands with pinching and swelling nature.

Fig. 4.7: Photograph of polished ore mount (sample # KGF 56) showing 'rock-ball' textures developed in highly deformed pyrrhotite.
Arsenopyrite is the closest associate of pyrrhotite and it occurs as monomineralic bands/layers. Arsenopyrite crystals are medium to coarse grained and are well developed. Two varieties of arsenopyrite are distinguished in polished sections: (1) a coarse grained highly deformed, and shattered crystals type, and (2) a fine grained, relatively less deformed euhedral crystals. The earlier ones include gold grains and are relatively abundant than the latter. Like pyrrhotite, arsenopyrite also contain inclusions of silicates and other sulfide minerals, particularly pyrrhotite and loellingite. Generally arsenopyrite lie a little away from the pyrrhotite monomineralic bands and sometimes interlayering of these two mineral bands are also seen. In areas of deformation, the brecciated arsenopyrite is veined by pyrrhotite and rarely by chalcopyrite without replacing arsenopyrite.

Sphalerite and chalcopyrite are present in accessory amounts. Sphalerite is fine to medium grained and forms as irregular intergrowths with other sulfides particularly pyrrhotite and also with magnetite and ilmenite. At many places sphalerite is deformed and flattened and at places includes small
ovoid blebs of exsolved (?) chalcopyrite exhibiting typical "chalcopyrite decease". Chalcopyrite occurs as irregular patches occupying grain boundaries and also filling fractures in arsenopyrite. It also occurs as fine blebs disseminated in silicate gangue.

Loellingite is present in trace quantities. It is fine to medium grained and generally occurs in association with arsenopyrite and also as inclusions within arsenopyrite.

Magnetite is the abundant oxide and at places it is even more abundant than pyrrhotite. It occurs generally as distinct bands with variable widths. Magnetite is medium to coarse grained and subhedral in nature. It includes several tiny crystals of pyrrhotite, arsenopyrite and ilmenite (Fig. 4.8).

Gold generally occurs as patchy inclusions mostly in deformed arsenopyrite and occasionally in silicate gangue. Gold associated with arsenopyrite occurs in variable shapes but commonly as anhedral grains with subrounded to angular boundaries. The size of gold grains in arsenopyrite is also quite variable ranging from 1 micron to over 200 microns. At places gold also occurs in sub-microscopic sizes within arsenopyrite (Fig. 4.9). Gold associated
Fig. 4.8: Photomicrograph of sample (KGF 2036) showing subhedral magnetite in association with pyrrhotite. Magnetite also includes small blebs of arsenopyrite (Reflected Light; 16X).

Fig. 4.9: X-ray scanning image (sample # KGF 1648) of gold in arsenopyrite showing gold occurrence as minute grains and its distribution within arsenopyrite crystal (40 μm/cm).
with silicate gangue is generally coarse grained with subrounded to rounded boundaries.

Based on observed textural relations among various minerals, we would suggest the following general paragenetic order for the ore mineral in Oriental lode:

Magnetite → Loellingite → Arsenopyrite → pyrrhotite → Sphalerite → Chalcopyrite.

Magnetite was the first mineral to form, then followed by loellingite then arsenopyrite. There are two generations of arsenopyrite - an earlier coarse grained porphyroblastic crystals, which are sheared and shattered and a latter fine grained euhedral crystals.

McTagaart West Lode

Detailed ore mineralogical studies on 16 polished ore mounts of the samples from McTagaart West ore zones reveal that the sulfides constitute approximately 5-8 volume per cent of the mineralized zones and commonly occur as well-banded, monomineralic layers. Sulfides also occur as disseminations throughout the silicate gangue of the lodes. The bulk sulfide content as well as the amount of individual sulfide minerals of the lodes is variable from one sample to the other within a distance of 5-10 feet along the strike of the ore.
zones, whereas the type or nature of sulfide minerals almost remain unchanged. The ore layers as well as the mineral grains show effects of deformation, metamorphism and recrystallization. Among the sulfides pyrrhotite and arsenopyrite are the dominant minerals and they alone make up more than 90 volume per cent of the sulfides. Loellingite, sphalerite, chalcopyrite and ilmenite occur in accessory to trace amounts. Gold is present in trace quantities. Presence of carbonate (calcite) phase is noticed. Among the oxides, magnetite is present in moderate to locally significantly higher amounts. Gangue minerals include cherty-quartz, amphibole and biotite. On an average magnetite is present significantly higher amounts in McTagaart West lode than any other sulfide lodes in the CKSB. Similarly arsenopyrite content seems to appear more in McTagaart West than the other sulfide lodes in the area.

Pyrrhotite, mostly in hexagonal form, occurs as granular aggregates often deformed plastically. Pyrrhotite generally surrounds and cut across arsenopyrite. Sometimes pyrrhotite also occurs as distinct monomineralic layers/bands with variable band widths ranging from less than 5 mm to approximately 1 cm and
are often intimately associated with magnetite bands. These bands very often show pinching and swelling features. Occasionally rounded blebs of pyrrhotite is also noticed as inclusions in arsenopyrite and in magnetite. At many places pyrrhotite includes sub-rounded clots of silicates.

Arsenopyrite is subordinate to pyrrhotite in its abundance. Arsenopyrite occurs as coarse grained anhedral often highly deformed crystals, surrounded and intruded by pyrrhotite (Fig. 4.10). Arsenopyrite also occurs as fine to medium grained euhedral crystals like phenocrysts swimming within the matrix of pyrrhotite. The deformed arsenopyrite crystals often include rounded blebs of pyrrhotite, magnetite and sub-rounded to angular patches of gold and silicates. The fractures in the coarse arsenopyrite crystals are healed mostly by sulfides and silicates. Arsenopyrite often exhibits typical metamorphic intergrowth with silicates resulting in 'sieve' texture (Fig. 4.11).

Chalcopyrite occurs as anhedral patchy grains in association with pyrrhotite. Chalcopyrite is also seen as tiny blebbly inclusions within pyrrhotite and at places it cuts pyrrhotite. In addition to this, chalcopyrite occurs as disseminations in silicate gangue.
Fig. 4.10: Photomicrograph of sample (KGF 43) showing highly deformed anhedral coarse arsenopyrite with rounded ilmenite inclusions. Arsenopyrite is also intruded by pyrrhotite (Reflected Light: 8X).

Fig. 4.11: Photomicrograph of sample (KGF 43) showing metamorphic intergrowth texture of arsenopyrite with silicates (Reflected Light: 4X).
Rarely sphalerite occurs as anhedral patches and are commonly deformed. At places sphalerite contains several ovoid inclusions of chalcopyrite showing what is known as 'chalcopyrite-decease' (Fig. 4.12).

Loellingite is present in accessory to trace amounts and occurs as subhedral crystals in association with deformed coarse grained arsenopyrite crystals. Sometimes, loellingite also occurs as inclusions in deformed arsenopyrite and at places as independent crystals in silicate gangue.

Presence of ilmenite in accessory amounts is noticed. It occurs as subhedral medium grained crystals in association with sulfides and also within silicates.

Magnetite is present in significantly higher amounts. At places its content overshadows pyrrhotite abundance or the total sulfide content itself. Magnetite generally occurs as distinct massive bands with variable band widths ranging from less than 5 mm to over 3 cms. The individual magnetite crystals are medium to coarse grained and are mostly subhedral to anhedral in nature. The width of the magnetite bands is mostly gradational and this observation is more apparent within a small polished ore mount (Fig. 4.13). Magnetite bands invariably contain numerous tiny
Fig. 4.12: Photomicrograph of sample (KGF 16) showing blebs of chalcopyrite in sphalerite known as chalcopyrite disease (Reflected Light: 16X).

Fig. 4.13: Photograph of polished ore mount of sample (KGF 41) showing magnetite bands with gradational width.
subhedral to euhedral crystals of arsenopyrite and blebs of pyrrhotite (Fig. 4.14).

Gold occurs very often both in sulfides and in silicates. It is fine to medium grained often occurs as irregular patchy, sometimes as skeletal grains. The occurrence of gold within coarse deformed arsenopyrite crystals is more frequent than its association with relatively undeformed euhedral arsenopyrite crystals. Based on our microscopic examinations on 10 polished ore mounts, we found that the frequency of occurrence of gold as inclusions in silicates is much more than that of gold in sulfides.

Our mineralogical and their textural studies on McTagaart West lodes suggests the following general order of paragenetic sequence of various ore minerals:

Magnetite → Loellingite → Arsenopyrite → Pyrrhotite → Sphalerite → Chalcopyrite.

Gold-Quartz-Carbonate Lodes

The ore samples from gold-quartz-carbonate veins from the Champion and Mundys lodes were studied for their mineralogy and textures.

The mineralised veins chiefly composed of milky white to colorless quartz, calcite and albite.
Fig. 4.14: Photomicrograph of sample (KGF 41) showing blebs of arsenopyrite and pyrrhotite as inclusions within magnetite bands (Reflected Light: 8X).
The lodes are generally devoid of sulfide minerals. However, when present, it is only in trace quantities approximately less than 0.1 to 1 volume per cent, and never exceeds more than one volume per cent. Sulfides mostly include pyrite, sphalerite, galena, arsenopyrite and chalcopyrite and occur mostly as fine disseminations within the quartz or along microfractures in the quartz veins (Fig. 4.15). However, very rarely sulfides, particularly pyrite also occurs in significant quantities. Trace quantities of ilmenite and magnetite are also present.

Quartz is essentially medium to coarse grained and is generally sheared. Scheelite is commonly present as scattered grains and as disseminated stringers in association with quartz (Fig. 4.16). Carbonate (calcite), tourmaline, chlorite, epidote, mica are present in variable amounts. Calcite is medium to coarse grained, creamy white in colour and sacroidal in nature. In many samples, the enclosed country rock amphibolite show evidences of intense shearing and mylonitization (Fig. 4.17) and carbonate alteration of calcic amphiboles. The contact between the country rock amphibolite and the vein is very sharp and marked by the presence of a thin layer of granular carbonate.
(Fig. 4.18). This is followed, as we proceed towards the vein, by a narrow zone of coarse calcite, highly deformed and the tensional cracks filled with fine grained calcite. Further, inside, the coarse quartz crystals are sheared and stretched and show highly undulose extinction (Fig. 4.19).

Gold occurs generally in native form as fine grained disseminations mostly in the range of less than 5 micron to 50 microns in association with quartz and also in close association with sulfides. It also occurs as coarse hackly masses often visible within quartz. However, in the samples studied, the distribution of gold is quite erratic, because its presence is observed in a very few samples and not so in many samples. This makes the gold analyses unrepeatable and therefore the reported gold values for the gold-quartz-carbonate lodes are undoubtedly unreliable. Thus, the occurrence of gold as visible grains along with its inhomogeneous distribution along the strike and down-dip of the ore veins makes difficult to characterise tenor of the ore body precisely, particularly when the study is primarily based on a very limited amount as well as small number of samples.
Fig. 4.15: Photomicrograph of sample (KGF 26) showing the occurrence of sulfides in quartz lodes. Sphalerite in association with pyrite and pyrrhotite occurring as independent grains is seen (Reflected Light: 16X).

Fig. 4.16: Photomicrograph of sample (KGF 35) showing the occurrence of scheelite as stringers within quartz. (Reflected Light: 16X).
Fig. 4.17: Photomicrograph of sample (KGF 1807) showing the replacement of calcic-amphiboles by calcite (Trans. Light: 2.5X, Crossed Nicols).

Fig. 4.18: Photomicrograph of sample (KGF 32) showing the sharp contact and the presence of granular calcite at the contact of ore and host amphibolite (Trans. Light: 2.5X, Crossed Nicols).
Fig. 4.19: Photomicrograph of sample (KGF 32) showing highly deformed coarse calcite with the tensive cracks filled with fine grained calcite and, highly sheared and stretched quartz with undulose extinction (Trans. Light 2.5X, Crossed Nicols).
The vein minerals typically show open space filling textures and exhibits effects of alternation. This feature can be well seen in the underground mine workings along the contacts of ore zones with the host amphibolite. There is an enrichment of calcite, which commonly make up to approximately 10 volume per cent of the vein, at the walls and quartz is the dominant vein mineral at the centre of the ore veins similar to the feature described before (Fig. 4.18). The wall rock assemblages are persistent along the strike and down the dip of the ore zones.

Mysore Mine

Detailed microscopic examination on 16 ore mounts of the samples collected from different lodes of the Mysore mine were studied for their mineralogy and textural features.

Our studies revealed that the sulfides make up approximately 5 volume per cent of the lode matter. Sulfides are fine grained and occur as layers and also as disseminations all over the silicate gangue. Among the ore minerals, pyrrhotite is the dominant phase with minor amounts of magnetite. Chalopyrite and sphalerite are present in accessory amounts. Sphalerite and chalcopyrite are commonly seen in western-most lodes.
relative to eastern lodes. Pyrrhotite occurs as anhedral granular masses generally as thin layers and quite often also occurs as disseminations in silicates. Pyrrhotite is highly deformed and also exhibit 'rock-ball' textures (Fig. 4.20). Sphalerite and chalcopyrite occur as anhedral grains in close association with pyrrhotite (Fig. 4.21). Pyrite is present in trace quantities and is fine grained generally occurs as rounded grains mostly within pyrrhotite and also in silicates (Fig. 4.22). The occurrence of arsenopyrite is far less common and only in very rare cases it is found as very small euhedral crystals within and in association with pyrrhotite (Fig. 4.23). Presence of gold have not been found in our studies.

Mallappakonda Lode

Microscopic studies have been carried out on 124 polished ore mounts and on few thin sections of the samples from Mallappakonda ore deposit for their mineralogical and textural studies. These studies have revealed that the host rock amphibole-quartzite show distinct bands of alternate light and dark coloured minerals. The sulfides, consisting mainly of pyrrhotite and arsenopyrite, occur within and/or near the amphibole-rich bands. The sulfides layers are parallel to the dark coloured amphibole-rich bands and are also similarly folded and deformed. The light coloured bands of the amphibole-quartzite consists
Fig. 4.21: Photomicrograph of sample (KGF 2) showing the occurrence of sphalerite, chalcopyrite in association with pyrrhotite (Reflected Light: 16X).
Fig. 4.22: Photomicrograph of sample (KGF 2) showing occurrence of pyrite, sphalerite and pyrrhotite. Pyrite occurs as rounded inclusions within pyrrhotite (Reflected Light: 16X).

Fig. 4.23: Photomicrograph of sample (KGF 2) showing occurrence of small euhedral crystals of arsenopyrite in association with fine grained pyrrhotite (Reflected Light: 4X).
essentially of medium grained cherty quartz and the
dark coloured bands constitute mainly of amphibole
minerals of cumming tonite-grunerite series with minor
amounts of garnet, biotite, chlorite, magnetite, calcite and sulfides + gold.

The ore zones at Mallappakonda contain approxi-
mately up to 25 volume per cent of sulfide minerals
along with minor oxide phase. The sulfides are massive
to finely interlayered. The ore is highly coarse
grained and exhibit features of severe deformation and
recrystallization. Among the ore minerals, pyrrhotite
and arsenopyrite are the dominant ones and approximately
make up to 80 to over 90 volume per cent of the ore
minerals. The proportions of various ore minerals,
particularly pyrrhotite and arsenopyrite vary consid-
ernably among the samples along the strike and down dip
of the ore zones. However, the type of ore minerals
remain almost unchanged, a feature rather common to
all the sulfide lodes in Kolar Schist Belt. Among the
124 sections studied from different levels of the ore
body pyrrhotite is the more abundant sulfide than
arsenopyrite. Minor to trace amounts of magnetite,
loellingite, chalcopyrite and ilmenite occur and con-
stitute nearly 10 volume per cent of the ore minerals.
Gold occurs both in sulfides and in silicates as inclusions. In Mallappakonda the ore minerals show typical banding as seen in the stratiform deposits of younger age. Thus, at Mallappakonda despite folding and boundinaging of the host banded iron formation the ore bodies still maintain their original stratiform nature. The ore minerals of the Mallappakonda ore zones are exceptionally coarse grained and are highly deformed. Metamorphic intergrowth textures among sulfides and between sulfides and silicates with triple junctions are commonly seen. Recrystallization and at places concentration of ore minerals in pressure-shadows are also seen. The nature and mode of occurrence of various ore minerals are as follows:

Pyrrhotite is one of the two major sulfides and generally occurs as distinct bands varying in width from a few mm to a few tens of mm, and also occurs as disseminations. It is mostly hexagonal form and occurs as coarse grained subhedral to anhedral granular mass. It often occurs enveloping arsenopyrite crystals and also fills the cracks in deformed arsenopyrite. Trace quantities of pyrrhotite occurs as blebs in arsenopyrite and magnetite.
At places pyrrhotite also includes blebs of magnetite (Fig. 4.24). Pyrrhotite exhibits deformational twins, undulose extinction, kink bands developed as a result of deformation. At places, pyrrhotite is altered giving rise 'birds-eye' texture. Rock-ball texture (Durchbewegung texture) is commonly seen in which silicates (mostly chert-quartz) inclusions in pyrrhotite have been stretched and rotated as pyrrhotite matrix flowed under pressure (Fig. 4.25). At places pyrrhotite also includes fibrous or acicular crystals of silicates. Although for a quite a few samples arsenopyrite is the dominant phase relative to pyrrhotite, on an average pyrrhotite appears to be the more abundant phase for the entire Mallappakonda ore body.

Arsenopyrite occurs mostly as monomineralic layers with varying width ranging from a few mm to approximately 5 cms (Fig. 4.26). Changes in the arsenopyrite to pyrrhotite ratio across layering on a mm to cm scales has been observed. This variation may probably reflect original fluctuations in the rates of precipitation of arsenic and iron in the depositional environment. Arsenopyrite occurs in two distinct habits: (1) aggregates of coarse grained highly deformed and shattered crystals individually ranging
Fig. 4.24: Photomicrograph of sample (M I 17) showing anhedral pyrrhotite in association with magnetite. Pyrrhotite includes rounded grains of magnetite (Reflected Light: 16X).

Fig. 4.25: Photograph of polished ore mount (M I 5) showing rock-ball textures.
Fig. 4.26: Photograph of sample (M II N Winze) showing occurrence of arsenopyrite as distinct monomineralic layers.
in size from 1 cm to 2 cms in length and secondly as euhedral prismatic medium grained crystals. The coarse arsenopyrite is commonly fractured and the fractures are healed by sulfides and silicates and commonly contains appreciable quantities of gold as inclusions. Coarse deformed arsenopyrite crystals also carry quite often inclusions of loellingite, magnetite, pyrrhotite and silicates. The smaller and more common arsenopyrite crystals are euhedral in nature and occurs as phenocrysts in pyrrhotite matrix and are generally devoid of gold inclusions. Arsenopyrite exhibits metamorphic intergrowth textures (Fig. 4.27). Arsenopyrite in the alteration zones occurs as slender prismatic crystals often show marked lineation parallel to the schistosity.

Magnetite is present in minor amounts and occurs as medium grained subhedral to anhedral crystals often as deformed bodies in close association with pyrrhotite and arsenopyrite (Fig. 4.28). At places, magnetite also occurs as small deformed crystals spread all over the silicate gangue. In many places magnetite contains blebby inclusions of pyrrhotite and rarely gold as blebby inclusions. In some cases, magnetite cuts arsenopyrite, surrounds
Fig. 4.27: Photomicrograph of sample (M II 2) showing metamorphic intergrowth texture of arsenopyrite with silicates (Reflected Light: 4X).

Fig. 4.28: Photomicrograph of sample (M I 17) showing magnetite, pyrrhotite relations. Pyrrhotite also occurs within magnetite (Reflected Light: 8X).
arsenopyrite and also includes crystals of arsenopyrite (Fig. 4.29).

Loellingite is present in accessory amounts and occurs as fine to medium grained anhedral to subhedral masses, mostly within arsenopyrite and also in association with arsenopyrite. At places, loellingite also occurs as independent crystals in the silicate gangue. Rarely loellingite is also present in significant amounts. On an average loellingite is more commonly associated with deformed coarse arsenopyrite crystals.

Chalcopyrite is generally rare and it is present in trace quantities as thin films along the grain boundaries of arsenopyrite. It also occurs as fracture fillings in arsenopyrite and pyrrhotite.

Bulk of the gold in Mallappakonda ore is closely associated with arsenopyrite, while minor quantities of gold also occurs as disseminations in silicate gangue. Very rarely gold also occurs as inclusions in pyrrhotite. Gold occurs as blebbly inclusions mostly in coarser, highly deformed arsenopyrite crystals, which are the main hosts for gold in Mallappakonda area. The grain size of gold occurring
Fig. 4.29: Photomicrograph of sample (M I 17) showing arsenopyrite, magnetite relations. Arsenopyrite also occurs as inclusions in magnetite (Reflected Light: 16X).
in arsenopyrite varies between less than a micron to 200 microns; however, on an average the gold grains that we see fall generally in the size range of 5 microns to 20 microns. In one of our sample gold is also found occurring as rounded blebs in pyrrhotite. At places gold is found as inclusions in silicate, which is an inclusion in arsenopyrite. At places gold is found occurring as surrounding magnetite within an arsenopyrite crystal (Fig. 4.30). Thus, the size of the gold associated with arsenopyrite and other sulfides is generally fine grained. In general, the greater the abundance of arsenopyrite, the more the number of gold particles seen in the polished ore mounts. Similarly, the coarser the grain size of arsenopyrite crystals the more is the number and size of gold inclusions found in them. In some of our samples, visible gold is also present in silicate gangue (Fig. 4.31). The gold inclusions associated with sulfides particularly arsenopyrite has generally angular boundaries whereas those with silicate gangue have smooth and rounded boundaries.

Based on our observations, it is estimated approximately that about 70 to 80 volume per cent of the free gold occurs as inclusions in arsenopyrite, while the rest mostly in silicate gangue. The bright
Fig. 4.30: Photomicrograph of sample (M II N Winze) showing occurrence of gold surrounding magnetite within highly deformed arsenopyrite. Arsenopyrite also includes blebs of pyrrhotite (Reflected Light: 16X).

Fig. 4.31: Photomicrograph of sample (M III 5 SW1) showing occurrence of gold in silicates. Arsenopyrite is also seen. (Reflected Light: 8X).
golden yellow colour of the gold in polished ore mounts probably indicates only trace quantities of silver content. The nature and mode of occurrence of gold particularly in native form associated with arsenopyrite and silicates may pose a problem for analytical studies.

Based on our above observations on the highly deformed and metamorphosed ore bodies of Mallappakonda area, we suggest the following order of formation of various ore minerals.

Magnetite is the first mineral to form and it subsequently porphyroblastically enclosing the later formed ore minerals. Later loellingite is formed, followed by arsenopyrite. There are two generations of arsenopyrite. The earlier coarse grained and highly deformed and the later is very fine grained and relatively less deformed/undeformed. Pyrrhotite is the next to form after arsenopyrite. Pyrrhotite is followed by chalcopyrite.

Chigarikunta Lode

Around 30 polished ore mounts of the samples from Chigarikunta ore bodies (Block I and Chigarikunta Centenary Block (CCB) areas) were studied for their detailed mineralogy and their textures. These studies indicate that the sulfide minerals constitute approximately
30 volume per cent of the mineralized bodies at Block I and approximately about 10 volume per cent at Chigarikunta Centenary Block area. However, our observations on Chigarikunta Centenary Block is primarily based on four samples only. In Block I, the sulfides occur as very coarse grained, massive ore body. Though all the sulfide minerals occur as anhedral grains, pyrite occurs as beautiful euhedral crystals. The variation in the nature and abundance of bulk sulfides as well as the individual sulfide minerals along the strike of the ore body at Block I have been studied and found that the amount of various sulfide minerals particularly pyrite and sphalerite vary quite significantly from one sample to the other sample within a distance of 10 feet. However, the bulk sulfide content as well as pyrrhotite content remain remarkably same. Pyrrhotite is the dominant sulfide mineral with significant amounts of pyrite, sphalerite and magnetite. Chalcopyrite, ilmenite occurs in accessory amounts. Arsenopyrite, galena and gold are present only in trace quantities. Among the gangue minerals, cherty-quartz is the predominant phase followed by chlorite, biotite and carbonate.

In Chigarikunta Centenary Block, mostly pyrite occurs as the dominant phase with minor amounts of
pyrrhotite and rarely chalcopyrite. Among the silicates, cherty-quartz is the dominant phase along with chlorite and mica.

Among the sulfides, pyrite occurs as exceptionally coarse grained. They are highly deformed by shearing along and/or parallel to the schistosity of the host rock (Fig. 4.32). However, some of the pyrite crystals got stretched/smeared perpendicular to the schistosity of the host rock as well as to the other pyrite crystals. At places few of the pyrite crystals are quite effectively sheared stretching for about 5 cms in length and some pyrite crystals give an appearance of phenocryst in the matrix of mafic host rock.

The nature and mode of occurrence of various ore minerals and their textural relations of Block I ore lodes are as follows:

Pyrrhotite is the dominant iron-sulfide mineral and mostly occurs as very coarse grained, anhedral granular masses. It also occurs as fine disseminations all over the silicate gangue. Pyrrhotite is mostly of hexagonal type. In some cases, pyrrhotite exhibits deformational twins and also fills the cracks in silicates. Pyrrhotite is closely associated with
chalcopyrite and magnetite, at places it encloses magnetite. Occasionally pyrrhotite includes 'white-flames' of pentalandite, and also often contains silicate inclusions. Rarely pyrrhotite also has inclusions of tiny crystals of arsenopyrite and pyrite. At places pyrrhotite grain borders are stained with reddish tinge.

Pyrite is next to pyrrhotite in its abundance. It occurs mostly as very coarse grained well developed crystals. However, pyrite also occurs as small rounded grains in silicates as well as in pyrrhotite. Some of the beautiful euhedral pyrite crystals are surrounded by massive pyrrhotite matrix and gives an appearance of a phenocryst of pyrite in the pyrrhotite matrix. Pyrite exhibits typical metamorphic equilibrium textures with triple junction points with silicates and with other sulfide minerals. At places pyrite quite often exhibits typical cataclastic deformational textures and the cracks are healed by chalcopyrite. Pyrite also show tongue textures. At places pyrite crystals are effectively stretched or smeared parallel to the original depositional layering. Inter-locking of pyrite with pyrrhotite and chalcopyrite is common and at places pyrite is closely associated with magnetite.
Chalcopyrite is present in accessory amounts. It occurs as medium grained anhedral crystals often in close association with pyrrhotite, magnetite and sphalerite. Chalcopyrite also occurs as tiny specks disseminated in silicates. In some instances, chalcopyrite occurs as worm-like bodies and at places it is closely intergrown with pyrrhotite and sphalerite. Chalcopyrite also exhibits flowage features. Rarely chalcopyrite includes gold grains.

Sphalerite is present in accessory amounts and occurs as medium to coarse grained anhedral grains closely associated with pyrrhotite. Sphalerite at places includes blebby inclusions of chalcopyrite, showing 'chalcopyrite-decease'. Rarely sphalerite also contains gold as sub-rounded inclusions (Fig. 4.33).

Arsenopyrite is present in very trace quantities. Its occurrence is far less common and only in rare cases it is found coexisting with pyrrhotite. It occurs typically as euhedral fine disseminations and very rarely it also occurs as very coarse grained (approximately 1 cm in length) euhedral crystals. At places arsenopyrite is also found as inclusions in pyrrhotite.
Fig. 4.32: Photograph of polished samples (CCB-NS) showing the highly deformed and stretched pyrite crystals aligned parallel to the schistosity of host rock.

Fig. 4.33: Photomicrograph of sample (C I-6) showing sphalerite and pyrrhotite relations. Sphalerite includes gold grains (Reflected Light: 8X).
Magnetite is also present in accessory amounts mostly occurring as medium grained, rounded to sub-rounded grains particularly in close association with pyrrhotite. At places magnetite is surrounded by pyrrhotite and at other places magnetite includes blebs of pyrrhotite.

Ilmenite is present in trace quantities and generally occurs as rounded inclusions in pyrrhotite.

Gold is present in trace amounts. It occurs as inclusions both in sulfides as well as in silicates. Gold occurs as hackly patches ranging in size from 50 microns to 100 microns in chalcopyrite and sphalerite as shown in Figure 4.33. Gold occurs as rounded to subrounded grains in silicates.

Based on our observations, we infer the following general paragenetic sequence of various ore minerals at Chigarikunta ore body.

Pyrite and sphalerite along with magnetite formed simultaneously followed by pyrrhotite. Chalcopyrite was the last sulfide phase to form.
Mineralogical Inferences

The mineralogical make up of all the gold ore deposits in the Kolar Schist Belt appears similar. However, there are significant differences between gold-sulfide lodes and gold-quartz lodes in terms of the quantity of various mineral phases, their nature of occurrence and their textural relations.

The sulfide lode essentially consist of cherty-quartz with sulfides ranging from 5 to 30 volume percent. In addition to this they have carbonate, amphiboles and oxides in significant amounts. Gold-quartz lodes on the other hand are mostly made of quartz with significant quantities of carbonates. A significant feature of gold-quartz lodes is their paucity of sulfides. This distinct mineralogical difference between gold-quartz lodes and gold-sulfide lodes strongly suggests that there are certain basic differences in the nature of genetic processes operated to give rise to the two types of ore lodes. In the gold-sulfide lodes banding/layering of ore minerals is a characteristic feature, whereas this is totally absent in gold-quartz lodes. The mineral constituents of the gold-sulfide lodes are highly deformed and recrystallized; whereas in the gold-quartz lodes the replacement and fracture-filling textures are commonly seen.
Although many of the general structural and stratigraphic features are similar in the various zones of gold-sulfide mineralization, but the ore bodies within each mining camp and in between mining camps show significant changes in their mineralogy.

The ore mineralogy of all the gold-sulfide lodes in the Central Kolar Schist Belt area appears similar in a broad sense. However, there are significant difference in the amount, nature and type of ore mineral assemblages between western and eastern sulfide lodes. The amount of sulfide minerals in the ore zones generally show a tendency to decrease from west to east, whereas that of oxide minerals particularly magnetite increases from west to east. On an average, the sulfide and oxide mineral bands are very thin and finely laminated in the west lode and the width of these bands increases gradually in the eastern lodes. Among the sulfides pyrrhotite is ubiquitous in all the ore lodes, but sphalerite and chalcopyrite are present in significant amounts only in western lodes. The sulfide and oxide minerals are fine grained in the western lode and are relatively medium to coarse grained in the lodes. However, arsenopyrite remains coarse grained and well crystallined in all the lodes. The proportion
of arsenopyrite in sulfides seems to increase from west to east, but the variation does not appear to be systematic. Arsenopyrite occurs as distinct bands in the eastern lodes which is not so conspicuous in the west lodes. The presence of gold grains is rare in west lode whereas it is very commonly seen both in sulfide and silicate minerals in the eastern lodes. The textural and the deformational characteristic features of both sulfide and oxide minerals remain similar in all the gold-sulfide lodes of the Central Kolar Schist Belt.

In the Mysore mine area at the southern part of the Central Kolar Schist Belt, though our studies are based on 11 samples, but our observations are similar to what we found in the northern part of the Central Kolar Schist Belt. In Mysore mine area also the sulfide content of the lodes decreases from west to east and banding of the ore minerals is common in all the lodes. Among the sulfides pyrrhotite is dominant and ubiquitous. Arsenopyrite seems almost rare, but when it is present it occurs as small euhedral crystals in the samples studied. Sphalerite and chalcopyrite are present in moderate amounts in the west lode and their content decreases significantly in
the eastern lodes. Microscopic studies did not indicate the presence of gold in all the samples studied from all the lodes.

In South Kolar Schist Belt, particularly at Mallappakonda the amount and nature of sulfide mineralogy is essentially similar in all the ore zones, along the strike and along the dip. However, in the samples studied the distribution of pyrrhotite and arsenopyrite is rather heterogeneous. Samples are either dominated by pyrrhotite or by arsenopyrite. The nature of ore mineralogy and their textural relations among themselves and with silicates is similar all over the ore body. Mallappakonda ore zones are significantly enriched in arsenopyrite relative to other ore bodies in the Kolar Schist Belt. Further, ore minerals, particularly arsenopyrite are very coarse grained in the South Kolar Schist Belt relative to the Central Kolar Schist Belt.

In Chigarikunta, at Block-I the sulfide content and the ore mineralogy (pyrrhotite-pyrite-chalcopyrite-sphalerite) is consistent along the strike of the ore body. Arsenopyrite is present only in trace quantities. However, at centenary block the sulfide mineralogy is essentially pyrite with trace quantities of pyrrhotite and chalcopyrite. Arsenopyrite is almost absent at centenary block.
If we look at the ore mineralogy of the gold-sulfide lodes occurring all along the strike of the schist belt, it is remarkably simple with only minor variations. The sulfide contents of the lodes vary quite significantly, however, it is around 10 volume per cent at Central Kolar Schist Belt, 25 volume per cent at Mallappakonda and around 30 volume per cent at Chigarikunta. Among the sulfides pyrrhotite is ubiquitous in its presence in all the ore bodies of the ore schist belt; however, it is present only in trace amounts at centenary block. Similarly arsenopyrite is almost present in all the ore bodies. Its occurrence is almost rare/trace in Mysore mine area, Chigarikunta block-I and at centenary block, but is exceptionally high at Mallappakonda. Sphalerite and chalcopyrite are present in minor amounts at Central Kolar Schist Belt and their occurrence is trace/rare at Mallappakonda and at Chigarikunta centenary block. However, sphalerite and chalcopyrite are present in significant amounts at Chigarikunta block-I. Among the sulfides pyrite is present in trace to minor amounts at South Kolar Schist Belt, particularly at Chigarikunta block-I, and is present exceptionally higher amounts at centenary block. Loellingite is relatively more abundant in Mallappakonda ore lode.
The presence of higher amounts of sulfides in the Kolar gold-sulfide lodes probably suggests that reduced aqueous sulfur species could be dominant in the ore forming solutions during the deposition of the ore minerals. The very high abundance of sulfides at South Kolar Schist Belt ores relative to Central Kolar Schist Belt ores suggests that relatively higher amounts of reduced aqueous sulfur species dominated the mineralising fluids at South Kolar Schist Belt. The presence of pyrrhotite-arsenopyrite-loellingite equilibrium assemblage with high arsenic contents in arsenopyrite in many ore lodes suggests moderate to higher temperatures to which they had been subjected to (Ketchmar and Scott, 1976). The mineral assemblages and arsenic content of arsenopyrite in the Chigarikunta lode may suggest somewhat lower temperatures. The variation in the nature and type of various sulfide minerals from one ore body to the other in the schist belt is probably controlled by many natural factors. Important among these could be: (1) the chemistry of the solution, (2) temperature of the solution, and (3) physico-chemical environment of deposition.

We observe, among the several gold-sulfide lodes studied, no systematic variation in the proportions of
various ore minerals from one lode to the other along the strike of the schist belt. This suggests that all these ore bodies may not be related to each other in their depositional environment. However, this does not necessarily mean that they are not stratigraphically equivalent. They could have as well formed under different environmental conditions from solutions of variable chemistry. It is also possible that all the ore lodes in the schist belt need not be stratigraphically equivalent.

In the Central Kolar Schist Belt the presence of higher sulfide content, higher amounts of base metal sulfides and higher contents of potassium, aluminium bearing minerals in west lode relative to eastern lodes along with their broad ore zones with fine layering of sulfide minerals suggests that the west lode could probably represent a deeper portion of the basin. Similarly the presence of higher amounts of arsenopyrite and magnetite in the eastern sulfide lodes relative to west lode along with their narrow ore zones with thicker banding of ore minerals suggests that the ore minerals in the eastern lodes could have been precipitated relatively under shallow water conditions.