Introduction

The Precambrians of Dharwar Super Group occurring in the vicinity of Hungund town in Bijapur district are referred to as "Hungund Schist Belt" (unclassified greenstone belt). This is one of the very important greenstone belts of Karnataka Craton (Fig. 1). While the rich iron ores associated with this belt have interested from a long time the economic geologists and industrialists, the fascinating lithology and the structure of this schist belt has not been studied in detail. The belt stretches with an average width of approximately 18 km and length of 100 km. A distinctive feature of this belt is the banded iron formations of Archaean age. This belt is economically important and has been producing significant quantities of iron ores for the last 30 years or so.

The lithology of the Proterozoics of the area has been studied in detail (of late) by many investigators. These early works have been reviewed at a later part of this chapter. The review clearly shows that there is plenty of scope for the investigation of the BIF of this area, 1) to understand the stratigraphy of greenstone-granite complex and Proterozoics, 2) to know the origin of the rock types and associated ore formations,
GREENSTONE BELTS
and
High grade Schists of Karnataka State

Names of Schist Belt
1. Sargur
2. Holenarsipur
3. Kwarnadajet
4. Hadnur
5. Nagamangla
6. Nuggihall
7. Javagondanahall
8. Ghattingosahalli
9. Bababudan
10. West Coast
11. Kibbonahalli - Vallyur
12. Shydegudda
13. Mayakonda
14. Chitradurg - Gadag
15. Shiomoga - Goa
16. Hutyurdurga
17. Kolar
18. Sandur
19. Kushtagi
20. Hungund
21. Huttli
22. Manglar
23. Raichur

Fig. 1
3) to study the structural disturbances of this part of this schist belt, 4) to identify the ore minerals, 5) to beneficiate the low grade BIFs and 6) to study the amenability of iron ore fines for pelletisation. These aspects have prompted the author to take up the present work.

Location and accessibility: The area under investigation stretches between the longitudes 75°40' to 75°55' E and latitudes 16°05' to 16°15' N and is located in the Survey of India toposheets 47 P/11, 47 P/12 and 47 P/16. It is situated between Herkal and Amingarh, which forms the northern fringe of Hungund schist belt and eastern part of Kaladgi and Badami basins. The Belgaum - Raichur State high-way passes through the area. The nearest Railway Station is Bagalkot and is on Hubli - Sholapur Section of South Central Railway. Bagalkot and Hungund are the nearest towns. The area is easily accessible either by rail or road. Besides these two routes, unmetalled roads, a network of canal roads and kutcha roads connect most of the villages falling under the study area.

The presence of archeological monuments viz., Aihole and Pattadakallu forming tourist attractions have greatly enhanced the mobility for obvious reasons.
Eastern and western portions of the area can be approached (Fig. 2) by State highway (Belgaum - Raichur road) and northern and southern portions by motorable roads. Any point or place above the hill ranges or valleys can conveniently be reached via Amingarh and Bagalkot and thus the State highway is always kept busy throughout the day and night mostly by the ore carrying trucks and others. All the mined ores of this area find their destination at Bagalkot and there onwards the ore is moved either to Madras port or Karwar port for export.

Description of the Schist belt: The schist belt, with the blend of its beautiful picturesque and unique landscape features has quite a good potential of natural resources. The whole structure of Hungund schist belt strikes nearly WNW-WSW, with a length of about 100 km and with a width of approximately 18 km. The hill ranges thin out at their extremities and towards north they rest beneath Kaladgi (Middle protoroscoics) formations. Except towards east, on all other sides, this part of the schist belt is surrounded by middle to late Proterozoics viz., Kaladgi and Badami formations. Towards east it is in association with "Peninsular gneisses". The schistose lithology comprises of chlorite schist, phyllites, shales and BIF. These lithounits show the effect of low grade metamorphism. The parentage of these mildly metamorphosed formations
can be traced back mostly to sedimentary rocks. These have been intruded by mafic sills and dykes. Intrusions of acidic type are mostly represented by quartz veins. Lateritic cappings on most of the hill is indicative of severe supergene process under subtropical conditions. The potential reserves of iron ore deposits have made this region more significant. These iron ore deposits are being mined by private sectors. Since they do not make use of low to medium grade iron ore, blue dust and iron ore fines obtained during mining, it is necessary from the conservation point of view to adopt alternative methods for effective use of such ores which in reality exceeds in quantity when compared to the high grade ores.

In the study area towards north, the schistose formations (Archaean) are overlain by middle to late Proterozoics, which are mostly arenites, quartzarenites, argillites, carbonates, conglomerates and breccias. Of these, the Kaladgi formations show very low grade metamorphic effect. Archaean and Kaladgis have been subjected to more structural disturbances as compared to Badamis, which belong to late Proterozoic.

Physical features of the area

Topography: The topography of this region is very conspicuous and unique, for the surrounding vast area
is defined by general plains, with characteristic sandy soil. Physiographically the area is covered by linear ridge-like and horseshoe shaped hill ranges with broad valleys (Fig. 3). The shape of such magnificent topography is itself a reflection of a kind of structural disposition which is again a unique feature. The elevation of the area varies from 554 mts to 713 mts above MSL. The central portion of these hill ranges are mainly made up of BIF and quartzarenites. Valleys are rainfed and remain dry during summer (February to June) season.

**Climate, Rainfall and Drainage:** Generally the climate of the area is dry and arid. It is moderately cold (20°C) during winter months (November to February). In summer the sun is very severe during the months of April and May, temperatures often raising beyond 48°C. Rainfall is low and erratic in its distribution with an average rainfall of 600 mm annually.

Almost the entire part of this area sheds its drainage into the river Krishna, a major river that flows into Bay of Bengal. The north western and south eastern portions of the area are drained by Chatapurba and Malapurba rivers respectively (tributaries of Krishna river). Much of the rain water of this terrain
is regulated by the dendritic type (1st and 2nd order trellis pattern) of drainage pattern (Fig. 4). Most of this type of drainage either directly flows into the rivers as network of small streams and riverlets or is linked to some other streams which ultimately flows into the river Krishna. All these three rivers are harnessed near Bagalkot to form a reservoir, the water which is used for agricultural purposes.

Soil cover, Vegetation and Crops: Due to intense cultivation much of the plain country is characterized by thick uniform red sandy soil. At places, slightly elevated portions nearly always show thick mantle of lateritic soil. Very little natural vegetation cover is seen in this area. Only scanty bushes and shrubs are seen on the elevated areas and hill ranges. Jowar and bajra are the main crops grown in the area.

Nature and Frequency of Outcrops: On the whole it is fairly well exposed area, as such provide all the scope for detailed geological investigations. The alternating ridges and valleys amidst the surrounding plain country present themselves as well defined and prominent features providing a magnificent scenery. Outcrops in the plain country fields are nothing but the highly scattered and isolated small round or oval shaped mounds, the constituent rocks being either quartzarenites or BIF.
other locations of outcrops in this plain country are along flanks of nullas and road/railway cuttings, where highly altered and rudely foliated rocks are exposed. Outcrops in the hilly terrain are clearly accessible. In the hilly terrains, BIF and quartzarenites constitute main rock types, which can be traced along the strike for several meters. These often occur as steep, narrow cliffs (Plate I) owing to their high resistivity to weathering and erosion. Huge chunks of BIF and quartzarenites rolled down from steep cliffs along slopes and flanks are common. Plains, broad valleys, small isolated mounds are chiefly made up of phyllite, shale, granitic rocks, dolerite and chlorite schist.

Regional geology: The Archaen of Karnataka Craton of Southern India are the best example of a greenstone-granite complex, which grades into a high grade granulite-gneiss terrain from north to south (Fig. 5). Earlier, these rocks were described as "Archaean Complex". There are two groups of Supra crustal sequences, the older is known as Sargur Group (older greenstone) and the younger Dharwar Group (younger greenstone) of 3 and 2.5 to 2.9 Ga respectively (Glickson, 1982). They occur as belts and as isolated enclaves within a vast complex of gneisses called as "Penninsular gneissic complex". These two groups are also divided into
Fig. 5
gneissic complex and schistose formations.

The Sargur Group is represented by orthoquartzites, calc-silicates, metapelites, metaferruginous quartzites interlayered with basic metavolcanic rocks (Janardhan et al. 1978), thus this association is typical of intracratonic basin.

The Dharwar Supracrustal succession mainly exposed in the northern part of the craton, comprises of quartzites BIF, chlorite schist and greywackes interlayered with basic to acid volcanic rocks (Swaminath et al. 1976). This sequence has been deposited unconformably upon the older gneiss basement (Chadwick et al. 1978, 1981). The Dharwar succession may have formed in a continental basin environment (Srikantappa et al. 1984).

Foote (1876) gave the name Dharwar system to these schistose formations, which occupy nearly 1,28,000 sq. km. The relative age of these two major groups has remained an unsolved problem for the last one century with opinion divided sharply among the geologists. In recent years, suggestions have come to split the greenstone belts of Karnataka craton into two major stratigraphic units, one older and the other younger than some of the members of the gneissic complex (Radhakrishna, 1974).
General geology: The rock formations of the area consist of (Fig. 6) granitic rocks, chlorite schists, phyllites, ultrabasic rocks, ferruginous shales, Banded Iron Formation (BIF), dolerites, conglomerates, quartzarenites and carbonates. Basic intrusives are represented by dolerites and acid intrusives are mostly quartz veins. The granitic rocks, schists, BIF, phyllites and shales belong to Dharwar Super Group (Archaean) and constitute the older sequence, which are overlain by Kaladgi Group of rocks (Middle Proterozoic) which consists of conglomerates, quartzarenites, breccia and carbonates. These are in turn overlain by Badami Group of rocks (Late Proterozoic) (Viswanathaiah, 1968, 1977), which are predominantly arenaceous and consist of sandstones and mudstones. In this part of the area iron ore occurs in BIF, which belong to Dharwar Super Group rocks and restricted to Ramthal hill range, where a prominent synclinal structure exists. Besides this, small deposit of asbestos is located in ultrabasic rocks within the chlorite schist.

Rocks of Dharwar Super Group: These rocks occur as bands and stringers aligned almost parallel to each other. There are 7 to 8 very large well defined and prominent bands. Strips and stringers of Dharwar rocks are relatively small and occur as isolated patches throughout the State. These are often named after local
places where they are well developed. Since all these
Dharwarian formations strike nearly north-south, occur
as well defined prominent schistose bands of varying
dimensions and are referred to by local names viz.,
Western Ghats, Shimoga - Goa schist belt, Chitradurg-
Gadag schist belt, Hungund schist belt and Hutti schist
belt etc. Rama Rao (1962) for the sake of convenience
of description, grouped them into five distinct zones
from west to east viz., western, west-central, central,
east-central and eastern. Their distribution is wider
in the northern part of Karnataka State (Fig. 5). These
exposures of Dharwarian formations according to one
school of thought are believed to be the remnants of a
great formation which formerly covered a large part of
the Peninsular India and which have escaped denudation
because they were tightly folded strips or roots of
anticlinorium plunging NNW.

The general strike of Dharwars in the northern part
of the State is NWW - SSW, which towards south becomes
almost N-S and after taking an arcuate swing runs NW-SE.
There is thus a sympathetic trend of each of the bands
running parallel to the regional strike. The rocks dip
westerly rather sharply in southern extensions, though
it is less so in the northern portions. Subsequently
a view has been putforth that the Dharwars in the type
area are disposed in a huge anticlinorium with a general
NNW plunge (Pichamuthu, 1951). Rama Rao (1962) and
Pichamuthu (op.cit) believes that there is a general
increase in the grade of metamorphism from northern part
of the State towards South, where the pyroxene granulites
(Charnockites) are found. However, there exist still
differences of opinion as regards; the basement on which
the Dharwar system has been laid, the actual time taken
for the formation of the system, the absolute age of
basic and ultrabasic intrusives and the age relationship
between Dharwar schists and gneissic complex. Rocks of
Dharwars are vivid and varied. They include volcanics of
various manifestations, schists of different crystalline
nature, deformed sediments, both clastics and non-clastics
and rocks of the nature of basic and ultrabasics.

Kaladagi and Badami Groups: These lithounits are
comparitively younger to the fore mentioned rock types
and extensively developed in the study area and it's
adjoining part (in the northern part of the State).
These belong to Middle to Late Proterozoic.

Kaladagi Group is characterised by conglomerates, quartza-
renites, breccias and carbonates. Whereas, Badamis are
characterized by quartzarenites. Both the formations
are separated by an angular unconformity. Since the major
part of the present study is confined to BIF and iron
ores which are Archaean, the author has not gone for
detailed study of Proterozoics of this region.

Classification: There have been several classifications of the rock formations belonging to Archaean complex of Karnataka, starting from Smeeth (1916), Rama Rao (1940) and latest by Radhakrishna (1983). These classifications applied to the rock formations of former Mysore State. With the reorganisation of the States in India, the boundary of Karnataka State extended in the north beyond 15th parallel. Considering all the rock formations of the new Karnataka State, Radhakrishna (1983) has given the classification of Dharwar's (Table 1). A glance at this table reveals that the lithounits of Karnataka State have been dated over 3000 M.Y. In this classification, in the present area, the gneissic rocks can be correlated to Peninsular gneisses (3100 to 3000 M.Y.) and schistose rocks of Dharwar Super Group to younger greenstone sequences (2900 to 2600 M.Y.) and the younger granites (2500 M.Y.) have not been noticed. This period between 2500 to 1600 M.Y. as at present is known as a period of no record in South India and is marked by the great Eparohean unconformity (Radhakrishna, 1983) and on which the Proterozoics have been deposited.

Previous work: The earliest account of the area has been given by Foote (1876) and later on by Roy (1958). Subsequently Viswanathalal and Satyanarayana (1968)
gave an account of the structural aspects of the area. Besides these, several officers of the State Department of Mines and Geology and Geological Survey of India (Pascoe, 1943; Krishnan, 1964; Muniswamanah and Gaikwad, 1971; Suchindan, 1980) have carried out geological survey work mainly in connection with prospecting for various minerals. Otherwise, the area has not so far been studied systematically and detailed study of BIF and their relation with associated lithologies has not been done.

Scope of the present study: In the present area, rocks belonging to Archaean and Middle to Late Proterozoics occur in close association. Economically important iron ore deposits and asbestos occur in lithounits belonging to Dharwar Super Group and limestone deposits in younger Proterozoics (Kaladgi). It appears that very little attempts have been made to study this area in detail. There does not exist a work which is aimed at a comprehensive study of iron ores of this region. Thus the present work gives the information on the geology of the area with:

1. 10 cms = 1.6 km (4" = 1 mile) scale geological map covering an area of 271 km²

2. a brief account of the associated lithologies,
3. a detailed account of field, petrographic, mineralogical, petrochemical and genetic character of BIF and associated iron ores,

4. an account of benefication of low grade iron ores (BIF) of this area and

5. amenability of high grade iron ore fines for pelletization (agglomeration) techniques.

This work is based upon:

a. a total of three months field study and geological mapping of an area of 271 km²,

b. microscopic/petrographic study of 120 thin sections,

c. ore microscopic study of 60 polished sections,

d. modal analyses of about 100 thin sections of different rocks,

e. X-ray investigation of haematite, magnetite and specularite minerals,

f. infra-red studies of ferruginous shales, laterites, BIF and iron ores,

g. chemical analyses of more than 50 samples of BIF, iron ores and 8 minerals which include haematite, magnetite and specularite minerals and 19 associated rocks,

h. sedimentological studies of 10 associated quartzarenites.
i. benefication of low grade iron ores adopting flotation, tabling and jigging techniques, and

j. agglomeration of iron ore fines adopting pelletization techniques.

Methods of Investigation:

Field Study, Mapping and Sample Collection: The area has been mapped to a scale of 10 cms = 1.6 km (4" = 1 mile) with an emphasis on the lithological varieties, the associated ores, their mutual relationships and the structures. About 350 rock samples including iron ores were collected for the purpose of benefication studies and also bulk iron ore fines were collected for the purpose of pelletization studies.

Microscopic/Petrographic Studies: Both transmitted light study and incident light microscopy has been employed. Ore samples and BIF samples were prepared suitable by polishing them. Polished sections were studied employing \( \mu \text{H-9} \) Russian microscope. The microindentation hardness (VHN) of ore minerals were determined employing microhardness tester (model 007, Japan). Etch tests were performed on several individual grains. Reflectivity of the ore minerals were measured employing LEITZ (WETZLAR) 389, Germany, microphotometer. Modal analyses were done employing six spindle integrated stage. Grain
shapes of the minerals of quartzarenites have been drawn employing camera Lucida.

Mineral Separation: Minerals required for chemical analyses, X-ray and infra-red studies were separated by hand picking, employing bar magnet and high intensity "Frantz isodynamic" separator (model 2-1, New Jersey). Repeated separation using bromoform as heavy media, after crushing the sample to nearly 100 mesh size was done to get pure crop of minerals.

X-ray studies: Powder X-ray diffraction patterns were obtained using separated pure crop of minerals and ores employing powder diffraction unit (Model Pm 9920/05, Holland). In all the cases, the experimental set-up comprised of 30 Kv and 15 mA current, Fe, Kα radiation, Ni filter and scanning speed of 20 mm/minute. The "d" spacing were determined by referring the measured 2θ values to a ready reckoner. The interpretation of XRD patterns were done comparing the "d" spacing values with the standards given in A.S.T.M. powder data files and tables compiled by Berry and Thompson (1962).

Infra-Red Studies: Infrared patterns were obtained by using Perkin-Elmer infrared spectrophotometer and nujol mull as medium for different ores and rocks. The interpretation of infrared patterns has been accomplished comparing the bands with those given by Fredericson.
Chemical Analyses: The iron ores, BIF, rock and mineral samples were chemically analysed for the major elements viz., FeO (t), MgO, CaO, Na₂O, K₂O, Al₂O₃, TiO₂ and trace elements Cr, Cu, Ba, Zn, Ni, Co, Sr and Li. All the elements except FeO were determined by digesting 0.2 gms of the finely powdered BIF and iron ore samples in acid digestion teflon bombs, with 5 ml HF, 5-10 ml HCl, 5 ml HNO₃, while 5 ml HF, 5 ml H₂SO₄ for other rock samples. In all the cases, after thorough digestion of the samples 50 ml of saturated boric acid solution was added and the volume made to 100 ml by adding distilled water. The solutions so prepared were stored in polythene bottles, and the determinations of elements were made employing Atomic Absorption Spectrophotometer (Schimadzu, Model AA 6300, Japan). The solutions of international standards viz., 0-2, OSP-1, PCC-1, UB-N, BR-N, AGV-1, BX-N, W-1, 513, 184 and 187 were used. The effect of interference was minimised by using different gas combinations such as AIR-C₂H₂, N₂O - C₂H₂.

FeO determination was made by digesting the finely powdered samples in a platinum crucible, using H₂SO₄ following the procedure given by Langmyhr and Graff (1965). SiO₂ determinations for BIF and iron
ores were made gravimetrically. Loss on ignition (LOI) was determined by heating the powdered sample (one gm) in a muffle furnace at a temperature of 1000°C for nearly two hours in silica crucibles.

Chemical analyses of samples of benefication studies:
Analyses of FeO of the feed and concentrate were carried out following potassium-di-chromate method and taking 0.3 to 0.4 grams of the sample. Residue left behind after thorough heating of the sample was reckoned as silica.

Sedimentological studies: Free grains required for sedimentological studies were obtained by repeated soaking of quartzarenites in sodium thiosulphate saturated solution. The soaking was done after crushing the samples to a size of one cm$^3$. After ensuring the liberation of grains they were subjected to sieve analysis.

Beneficiation studies:

a. Flotation: Flotation of low grade iron ores was carried out in a single flotation cell of two litres capacity.

b. Tabling: Tabling of BIF was done using Wilfley table.

c. Jigging: Jigging of BIF was carried out in laboratory size mineral Jig.
d. Agglomeration: Pelletization technique was employed for agglomerating the iron ore fines. Pelletization was carried out in a disc pelletizer. Repeated experiments were carried out to obtain better pellets by varying the binder concentration.
SECTION B

STRUCTURAL GEOLOGY AND STRATIGRAPHY
Structural Geology: The structural geology of the area appears to be complex. Since it is beyond the scope of the present study, attempt for detailed structural study has not been made. The description given here covers essentially the major and general structural features of the area.

The major structural feature of the area is a fold system. A very striking structural phenomenon is the orientation of most of the structural elements (nearly) parallel to the general trend of the area. During the field work mesoscopic and some macroscopic structural data were collected and are represented in the map (Fig. 7).

Structural features: The structural features recorded are:

1. Folds
   a. major folds
   b. minor folds
2. Planar structures
   a. banding, lamination and bedding planes
   b. schistosity/foliation
   c. fault planes
   d. joints.
3. Linear structures
   a. fold axes
4. Unconformities
5. Ripple marks and cross bedding, and
6. Inliers
Folds:

a. **Major folds**: In general, the folds are relatively better preserved and well defined in the central part of the area. Two distinct phases of tectonic movements as indicated by two periods of folding ($F_1$ and $F_2$) each forming large scale folding with corresponding axial plane schistosity have been observed. The two periods of folding are:

i) ($F_1$): This is a minor phase of tectonic movement which caused the development of minor folds in the lithounits of Dharwar Super Group. These are mostly intraformational minor folds in BIF. The axial plane ($A_1$) of this coincides with the Dharwarian trend WNW-SSW to NW (in this part) with a westerly plunge of 10 to 15°. Varieties like plunging symmetrical to asymmetrical anticlines and synclines, some of them having sharp noses are dominant. Such folds are well preserved around Herkal and Amingarh (Plate II A & B). This movement is pre-Kaladgi. During this post-Dharwar - pre-Kaladgi stage of deformation, BIFs and associated argillaceous and schistose formations have been deformed as a result of stresses acting nearly NE-SW direction and as such BIFs show WNW-ESE trending fold axis and displaced by strike slip faults.
ii) \( (F_2) \): This is post-Kaladgi and a major tectonic movement which developed axial plane \( (A_2) \), cleavage \( (S_2) \) almost parallel to \( S_2 \) surface and also caused refolding of \( F_1 \) fold system. During this tectonic movement, the area appears to be subjected to compressional force which acted on NNE-SSW direction, throwing the sediments of Dharwar Super Group and Kaladgi formations into series of anticlines and synclines with the major axis lying WNW - ESE (Fig. 7), which is almost the same trend of axis of Pre-Kaladgi deformation. Thus the area north and northwest of Bagalkot consists of a prominent anticline, the flanks of which are preserved with its axis running WNW-ESE direction and plunging 10° to 30° towards west. The area around Amingarh comprises a prominent syncline (Fig. 7) with its axis coinciding with the axes of earlier folds. The wavelength of both anticline and syncline varies from 0.5 to 1.0 km, with high amplitude. During this period of tectonic movement, the Kaladgi Group of rocks developed many individual doubly plunging anticlines and synclines, with their axes parallel to each other and also parallel to the major axis of the basin (from the study of adjacent area). With the series of domes and basins known to occur in Kaladgi basin, and the occurrence of inliers of Dharwar Super Group rocks, the author is inclined to
believe that the sediments of Kaladgi Group once formed series of anticlines and synclines. This post-Kaladgi deformation is set in after the deposition of Kaladgi sediments over the BIFs. Thus the BIFs have undergone a second stage of deformation and further cross folded.

There is development of drag folds with their axial planes \( (A_2) \) being parallel to the major fold axis. These are well developed in BIFs as crenulations (Plate. III A) on limbs of minor folds and consist of small wrinkleings showing symmetrical, assymmetrical, chevron and monoclinic folds. These appear to have been developed during the waning period of \( F_2 \) deformational episode.

b. Minor folds: Minor folds are very well developed in BIFs, where the bands exhibit mesoscopic folding. Most of these are assymmetrical folds and the axial planes of these folds are oriented parallel to \( S_2 \) (as these are developed during \( F_1 \) folding). This conformable relation of the minor folds to the regional structural pattern is suggestive of their tectonic origin. The general restriction of the folds to specific zones within the individual strata reflects the difference in plasticity from one zone to the other during the deformation.
Planar Structures:

a. **Banding/Lamination/Bedding planes:** In some of the BIFs and arenaceous rock outcrops the original bedding planes (S1 surface) are clearly seen. These S1 surface are not so well developed in other lithounits. Banding is a conspicuous feature in BIFs, which is due to the variation in mineralogy/and chemistry, grain size/texture and colour. There is large variation in thickness of individual bands. Interm at places these bands are laminated on a scale of mm or fraction of a mm. Banding may be even, uneven or maculate.

b. **Schistosity:** It is the common structure observed in most of the rocks of this area. It is mesoscopic structure, and as such foliation is also included here. It is defined by preferred orientation of tabular minerals like amphibole, chlorite and feldspars. Schistosity is well exhibited by chlorite schist and phyllites and foliation by gneisses. Although the general direction of schistosity of most of the rocks in this area is WNW-ESE, other local variation is also a common feature.

This WNW-ESE and sometimes NW-SE strike direction is the S2 axial plane schistosity (foliation), which has developed during P1 folding of the schist belt. These S2 foliations are predominant in the older formations.
Axial plane cleavages represent $S_2$ surface which were developed during $F_2$ folding and are almost parallel to $S_2$. These are well seen in chlorite schist and phyllites. Crenulations occurring in the form of drag folds at the limbs of $F_1$ folds in BIF constitute minor phases. The $F_2$ deformational episode appears to have been followed by mild tectonic movement that developed these conjugate folds. These structural features are well exposed south of Herkal and west of Amingarh.

Banding, lamination, bedding planes (and even schistosity) are all essentially relic primary sedimentary structures. These original structures appear to have largely guided the deforming forces.

6. Fault planes: Fault planes are not as common as planes of schistosity. As the rock formations of this part of the area have been subjected to at least two periods of major deformations, the rocks also have been subjected to faulting. The faults mapped in this area run in NW-SW direction (in most of the cases) and the fault planes are traceable for a long distance. The fault plane of the fault occurring east of Herkal trends NE-SW along which river Ghataprabha flows (Plate. III B). The fault which occurs south of Kamatgil, through which river Malaprabha has made its course. Some of the faults are traceable only in
rocks of Dharwar Super Group and in such cases fault planes die out beneath Kaladgi formations, indicating their pre-Kaladgi age. At places, NW-SE running fault planes run in both Dharwar Super Group and Kaladgi lithounits, as such they are post-Kaladgi.

d. Joint planes: Joint planes are the most predominating planar structures in the rocks of this part of the area. Almost all rocks including older gneisses to younger intrusives, Kaladgi and Badami lithounits possess joints. A number of sets of joints are recognised. Strike joints both in vertical plane and horizontal plane appear in BIF to the east of Herkal and south of Kamatgi and these do not appear in overlying Kaladgi formations. At places, these joints which are intersecting obliquely are close enough to cause brecciation of banded iron formations. Obviously these might have been developed during $F_1$ folding ($F_1$ tectonic movement).

The sediments of Kaladgi Group possess three sets of joints near Sirur and north of Bagalkot. These may be related to $F_2$ folding. In the study area Badami Group of rocks occupy a small part and are jointed and horizontal set of joints are well developed.
Linear Structures:

a. Fold axes: As two periods of deformation are recognised viz., \( F_1 \) and \( F_2 \), corresponding two fold axes are designated as \( A_1 \) and \( A_2 \). \( A_1 \) is minor, whereas \( A_2 \) represents a major fold axis which has followed \( A_1 \) axis. The direction of \( A_1 \) constitutes the directions of prominent \( S_2 \) schistosity or foliation. \( A_2 \) represents a major fold axis of a series of anticline and syncline which have been developed in rocks of Dharwar Super Group and Kaladgi formations during \( F_2 \) folding and is almost parallel to \( A_1 \). There is a development of axial plane cleavage (\( S_3 \)) parallel to \( A_2 \). During the last phase of folding some drag folds have resulted and the fold axes (\( A_3 \)) of such drag folds run in various directions but majority show axes parallel to \( A_2 \).

Unconformities: Two unconformities are recognised. The first one occurs below Kaladgi sediments, over the denuded surfaces of Dharwar Super Group of rocks, and is represented by a basal conglomerate horizon. This is a polymictic type and consists of pebbles of various sizes of banded haematite quartzite, banded haematite jasper and fragments of phyllites set in a sandy matrix. This is well exposed south of Ramthal.
The second unconformity is recognised between sediments of Kaladgi and Badami Group and is noticed south of Sirur (here a small band of conglomerate is traced which grades into quartzarenites of Badami Group). The Badami formations dip gently (Plate. IV), whereas the underlying Kaladgi formations dip at high angles, which probably indicates an angular unconformity between them.

Ripple marks and Current bedding: Both these primary sedimentary structures have been noted only in the quartzarenites of Kaladgi and Badami formations about 1 km east of Tummarmatti and south of Sirur. The ripple marks measure from crest to crest 2 to 4 cms and have an amplitude of 2 cm. In general these are symmetrical and bear the characters of oscillation ripple marks. In these ripple marks, crests are nearly rounded as troughs.

The current bedding (Plate. V ) consists of an alternation of cross strata and horizontal strata. Most of the quartzarenite beds dip at moderately to steep angles. Preservation of these primary structure is suggestive of deposition in shallow esturine environment.
**Inliers:** As mentioned earlier, in the study area, the rock types belonging to different age groups occur in close association. As such, the occurrence of inliers is very common. In the synclinal basin (south eastern part) inliers of Dharwar Super Group of rocks are located at west of Kamatgi, 2 km east of Ramthal, 3 km south east of Bevinal village and N 40° W of Amingarh.

Above described structural studies have brought out the following salient features viz.,

a) There is a contrast in the inclination of reefs of BIF in relation to overlying Kaladgi and lithounits of Dharvar Super Group are overfolded,

b) the area has witnessed two major phases of deformations, where $P_1$ has affected only older rock types, while $P_2$ has affected both Archaean and Proterozoics. As such the BIFs show both pre-Kaladgi and post-Kaladgi folding and cross folding.

c) there is evidence of clear separation of three different group of rocks, viz., presence of basal conglomerates separates Dharwar Super Group rocks from Middle Proterozoic Group (Kaladgi Group), which in turn is separated from Badami Group (Late Proterozoics) by an angular unconformity,
d) Sediments of Dharwar Super Group and Kaladgi Group show evidences of tectonic movements, whereas, those belonging to Badami Group are horizontal and do not show any evidences of structural disturbances, and,

e) based on the outcrop patterns of Kaladgi and Badami sediments, two basinal configurations could be assigned.

Stratigraphy: Based on the field and laboratory studies of the lithounits occurring in the present area, a stratigraphic succession is proposed in Table 1, alongwith the stratigraphic succession for South Indian rocks proposed by Radhakrishna (1983). The lithounits of Dharwar Super Group of the study area can be correlated to the rocks belonging to the age range of 3000 M.Y. to 2600 M.Y. (Radhakrishna, op cit).
Stratigraphic succession of south India (after Radhakrishna, 1983)

<table>
<thead>
<tr>
<th>Time (Ma)</th>
<th>Rocks</th>
<th>Minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>3600</td>
<td>Oldest crust - SIALIC / MAFIC (?)</td>
<td></td>
</tr>
<tr>
<td>3400</td>
<td>Ancient supracrustals (Sargur type)</td>
<td>Cr, Ni, Fe, Cu, Au</td>
</tr>
<tr>
<td>3200</td>
<td>Older greenstone (Kolar type)</td>
<td>Au, Ag, Cu, Wo</td>
</tr>
<tr>
<td>3100</td>
<td>Peninsular gneisses</td>
<td>Beryl - Columbite - Tantalite - lithium - mica</td>
</tr>
<tr>
<td>3000</td>
<td>Au-U bearing Qz-conglomerate</td>
<td></td>
</tr>
<tr>
<td>2900</td>
<td>Mafic volcanics</td>
<td>Cu, Zn, As, Sb</td>
</tr>
<tr>
<td>2800</td>
<td>Lime stone</td>
<td></td>
</tr>
<tr>
<td>2700</td>
<td>Iron formation</td>
<td>Au, Fe, Mn</td>
</tr>
<tr>
<td>2600</td>
<td>Manganese marker horizon</td>
<td></td>
</tr>
<tr>
<td>2500</td>
<td>Fe-oxide complexes</td>
<td></td>
</tr>
</tbody>
</table>

Stratigraphic succession of Herkal Amingarh area