CHAPTER I

INTRODUCTION

The interest in the study of ultramafic rocks centres around the fact that they are the direct representatives of the upper mantle material. Another, and none the less, significant feature is their occurrence in folded geosynclinal sediments in orogenic belts, generally regarded as having formed by alpine type intrusion. The upshot of the discussion of these two aspects of the subject is the formulation of the opinion that the ultramafic rocks are formed by tectonic emplacement of crystalline serpentinite, as a result of which they find themselves associated with rocks of low- to medium metamorphic grade like, greenschist, glaucophan schist, and amphibolite in alpine tectonic environment, notwithstanding the fact that they also occur interlayered with other rocks like peridotite, pyroxenite, gabbro, norite, and anorthosite in other associations. There are all gradations between these two environments; and, hence, in very many cases, the alpine type intrusion is not readily distinguishable from layered rock groups. In what follows in the thesis, stress is on these two associations in so far as the Nuggehalli schist belt is concerned, though other types of occurrences in geological literature are cited, such as, those associated with differentiated basic sills, batholithic intrusions,
kimberlites, ring complexes, and ultramafic lavas.

The ultramafic rocks described in this thesis are part and parcel of the Nuggohalli schist belt of the Hassan district, Karnataka State, India (Map 1). They are the repositories of the famous chromite deposits of Karnataka. Because of extensive mining operations being carried out in this area for over eighty years, the area has been visited by a number of workers from time to time for assessing the ore reserves and to probe into their genesis. The work carried out so far has revealed inseparable association of chromite deposits with the ultramafics. Several unpublished data that have been collected from drilling operations in this area by mines authorities have revealed close association of chromite deposit with unaltered dunites. No fresh samples of dunite have, however, been obtained from surface outcrops. The ultramafic rocks of the area, dunite, pyroxenite, and probably peridotite have generally been transformed to serpentinites, serpentine schist, and talc-chlorite-actinolite schist. The survey carried out by the author both at the surface and in mines has revealed the presence of other rock types, such as, anorthite rock, eucrite-anorthosite, komatiite peridotite, komatiite basalt, and komatiite picroite. The recognition of these varieties of rock types has greatly facilitated the discussion of origin of the ultramafic rocks of this area in much more unequivocal terms than what has hitherto been
conjecturally made based upon the highly altered ultramafic schists which have suppressed much of the details of origin on account of their intense deformation and metamorphism.

Much work in this area has all along been confined to the description of schistose rocks. The strike trends and dip of schistosity are broadly given in so far as these trends conform to the regional trends of the other rock types in the area. No comparison is made of structural features of the schists with the country rocks like quartzite, amphibolite, and gneisses with which the serpentinites are closely associated. In this thesis the ultramafics and chromite deposits are discussed in their regional setting by analysing the macro- and the micro-fabrics of adjoining quartzites, augen gneisses, and amphibolite. Orientation patterns of the sub-fabrics of quartz, mica, and hornblende of these rocks have been extensively studied by petrofabric methods to reveal the internal fabric of these rocks. These studies have revealed that the rocks of this area have come into existence during different periods of time and have been subjected to deformation repeatedly during geological times. Petrofabric diagrams reveal astonishing variations in orientation patterns, interpretation of which is sometimes complicated, but at the same time most interesting, because of the revelation of the direction of the operation of stress. Rocks of this area comprise igneous intrusives and sediments which are metamorphosed. This metamorphism has brought in contact metasomatic alterations.
The result of this is the formation of albitite and vermiculite in contact zones, a process recognised for the first time by the author to have operated in this area.

The origin of ultramafic rocks is thus discussed from a wider angle, from an array of facts gathered from local and regional geological setting, especially aided by a close examination of the contact rock types and a detailed petrofabric analyses of the adjoining country rocks.

Chromite deposits of the area are part of the petrogenic cycle by which the ultramafic bodies are formed. The form exhibited by the chromite deposits is closely related to the form, structure, and emplacement of ultramafic rock and to the later deformation to which these rocks, together with their adjoining country rocks, have been subjected.

I.1 Location

The schist belt forms a long narrow band running in N23°E direction for a length of twenty six miles with a maximum width of one and half miles. It extends from Arsikere in the north to Jambar in the south, and falls between geographical coordinates 76° 17' 20" E to 76° 29' 30" E, and 12° 58' 30" N to 13° 17' 43" N. The area mapped forms part of toposheet nos. 57 c/7, 8 and 57 D/5. Width of the belt varies from half a mile to as much as one and half miles.
The schist belt covers part of the districts namely, Tumkur and Hassan districts in Karnataka state, with the major part of it falling in the latter. Bangalore-Hemmavgar State highway at 10th milestone and Bangalore-Poona railway line at the same junction forms the northern limit of the schist belt. The Tiptur-Channarayapura road which runs almost parallel to the schist belt for some distance crosses the belt at the southern end.

The schist belt comprises small undulating mounds depicting the typical old peneplain topography as classified by Davis (1954). The chromite bearing parts of the belt normally show up as small mounds, or elevated areas, with a median ridge parallel to the strike of the rocks. Because of this type of topography, dendritic type of drainage pattern is seen, where the ephemeral streams form deep furrows perpendicular to the longer axes of the mounds. No perennial streams are present in the region. General topographic level is from 2800 ft to 2850 ft above mean sea level, and the most prominent landmark, a 3191 called Tagadur Rangaswamy betta (hill), is situated in the southern part of the schist belt. Granite inselbergs are common around Nugg geldalli in the southern end of the belt. Since the area lies almost in the transition zone between the western ghats (mountainous terrain with step-and-block structure) and the great maiden (comparatively flatter terrain) of the state, the climate likewise changes.
from humid type in the west to semi-arid type in the east of the region. Likewise, rainfall also varies from 15" to 25"
(450 mm to 525 mm) annually, and sometimes erratic changes cause near famine conditions. The southwest monsoon, the main source of rainfall, is between July and October. Water-table fluctuates from 25 ft to 40 ft according to season. The safe yield of water from bore-wells have been worked out to 1000 gallons per hour. Hence, there is no scarcity for groundwater in the area. Yet, on account of time-honoured agricultural practice well-irrigation for wet cultivation is not resorted to, except in the command areas of small tanks which are the only source of surface reservoirs.

The entire region is famous for the production of the best quality coconut which records the highest yield in the state. All valleys and minor stream courses are covered by palm gardens. Topography, climate, rainfall, and reddish brown soil are best suited for coconut palm cultivation. Other rainfed dry crops like Jowar, ragi, bajra and groundnut are grown especially on the elevated places.

Mean daily temperature varies from 22°C to 30°C during winter months of November to February, to 28°C to 35°C during summer months of March to June.

I.2 Previous literature

The area was surveyed as early as 1907 by Sampath Iyengar for the economic mineral deposits of Hassan district.
A map of this area was produced by him in 1919 on a scale of one inch = 1320 ft. The ultramafic schistose rocks are shown by him to occur as disconnected lenses in a linear belt between Nuggohalli and Arsikere. He gave the name Nuggohalli schist belt to these schistose rocks. Rock types described by him are hornblende schist, chlorite schist, talc schist, dunite, titaniferous magnetite, and pyroxenite bounded on either side by granitic gneisses. Chromite deposits are described as lenses occurring in the ultrabasic rocks.

A brief account of prospecting operations for chromite deposits carried out by calyx core drilling was given by Venugopal (1930). As the boreholes put were shallow no useful information could be gathered.

In a review of Dharwar geology, Pitchamuthu (1951) imagined that the ultramafic rocks of Nuggohalli schist belt occupy axial portion of north plunging Dharwar anticlinorium.

Radhakrishna (1957) investigated the chromite deposits, especially of Pyrapur area, and emphasized the elongated nature of its occurrence as did the earlier workers. He refers to a zone of intense crushing in the western margin and to regular succession of the ultrabasic complex from west to east. Other inference he has drawn is the concentration of chromite ores at the basal portions of serpentinitized dunite. He visualised the existence of ore forming liquids injecting as discordant bodies into the already consolidated ultrabasic rock.
Kaddakrishna has made many other statements regarding the origin of chromite and ultramafic bodies and they will be dealt with in the appropriate sections of this thesis, as they rise controversial issues.

Varadarajan (1970) has produced a geological map of the schist belt on a scale of an inch to a mile and has described the rocks of the belt. His account follows on the lines advocated by Benson (1927), Hoos (1935), Thayer (1960) and accordingly ascribes an alpine type orogeny for the ultramafic rocks of the area on the basis of the relationship of dunite to tectonic direction, the distribution of chromite deposits, and the absence of stratigraphic tops and bottoms.

In a later contribution, Kaddakrishna (1967) brought into focus the close association of pyroxenites and gabbros with the peridotites of the schist belt and argued that all these rocks are the differentiated products of primary pyrolite of basaltic magma.

Varadarajan (1970) on the basis of chemical composition and fabric of olivine in dunite, infers that ultramafics of Nuggahalli schist belt were derived from the upper mantle and were tectonically transported to the orogenic belt and deformed during orogenic movement. According to him, the temperature of these ultramafic bodies at the time of deformation varied from about 750°C in the inner parts to 450°C in the outer parts. The rocks show metamorphism of greenschist and almandine-amphibolite facies. The knife-edge contact between serpentinite
and schist, brecciation along contacts, and the variation in metamorphic facies between metamorphosed serpentinite and enclosing amphibolites indicate intrusive nature of the ultramafic bodies.

Gravity surveys over the ultramafic lenses have revealed that these lenses are connected to a large mass below under the cover of thin gneissic rock (Guresky et al. 1970).

Regarding the emplacement of ultramafic rocks, Karunakaran (1970) has suggested that they might have intruded into the lower crust in the initial stages of an orogeny, and were later serpentinised followed by upward movement and emplacement into the upper crust in semisolid state as comparatively cold intrusion.

Nagamma and Phane (1971), on the basis of trace element analysis, consider the amphibolites of the schist belt to be ortho-amphibolites derived by the alteration of igneous rocks of dolerite of basaltic composition. And on the nature of distribution of trace elements they consider gneissoclinals to have been derived from the alteration of ultrabasic rocks. They concluded that there has not been any differentiation in the rocks of this region.

The Nuggohalli ultramafics have been assigned a pre-Dharwarian age by Srinivasan and Sreenivas (1971). They have interpreted the amphibolites as metabasalts extruded into a mobile geosyncline. These amphibolites are sill like.
On the basis of Cr-Mg rich provenance for the Chitaldrug and Shimoga metasediments, Srinivasan and Sreenivas (1972) suggested a Precambrian age (Archean) for the emplacement of ultramafics of Huggalalli schist belt. The gneisses on either side of the belt constitute a pre-Archeanian dome which also supplied sediments to Archean rocks.

From the geochemical considerations, Visvanathan (1974) has indicated the occurrence of rock of peridotite and basaltic komatiite affinities.

The very low alumina content, 0 to 14% of the orthoamphibolites led Sreenivas and Srinivasan (1974) to suggest that the magma generation occurred under a very thin crustal layer.

The ultramafic rocks of Huggalalli schist belt continues further south as disconnected bodies and are well exposed in Kadakola region, south of Mysore. Many workers have made comparative studies, to some extent, of the ultramafics of Huggalalli and Kadakola region.

Varadarajan (1970) has carried out petrofabric studies on olivine of dunites of these areas and concluded that they are of alpine type, and are emplaced in a cold condition. Olivine shows preferred orientation.

Srinivasan and Sreenivas (1972) have grouped ultramafic rocks of both the areas as Archean (2600 m.y.) and probably intruded along the structural dome between Chitaldrug and Shimoga belts.
Divakara Rao et al. (1973) on the basis of Ni, Pdd, and Co studies on ultramafics, and on comparison of the results with alpine type and others, have concluded that the anomalously high Ni/Co and Ni/Fe ratios they got for Karnataka ultramafics are due to crustal contamination and late-stage enrichment (at late constituents) during and/or after their emplacement into the crust in connection with the serpentinitisation process.

Swaminath et al. (1974) on the basis of lithology, relict stratigraphy of nignatites, and metamorphism, have grouped the ultramafics of Huggobaili along with the other similar rocks of Karnataka under Mecara group. The rock formations of this group show barrowian hornblende granulite subfacies in the south, and almandine-amphibolite facies in the north.

Naqui et al. (1974) have suggested that ultramafics of the above areas 'may belong to the missing greenstone sequence' older than granitic activity around 2400 m.y. (Crawford, 1969).

Divakara Rao et al. (1974) have opined that these ultramafics, which may belong to the older greenstone sequence, have been metamorphosed and granitised to form the vast surrounding gneissic terrain.

Janardhan and Srikantappa (1974), after a detailed petrological and chemical studies of the associated metasediments and the pyroxene granulites of ultramafics of Kadakola region, conclude that the ultramafic bodies are 'intrusive' into
the metasediments and granulites. The associated metasediments and pyroxene granulites have been correlated with the Shandelite series (orogenic cycle) of eastern ghats. The most interesting feature is, the age of the Shandelites (eastern ghat orogenic cycle) is placed between 1.6 and 2.5 b.y. (Parthar, 1973), whereas the ultramafics of Huggahalli have been considered to be older than champion and other gneisses whose age has been estimated to be 2800 m.y. This raises doubt whether the ultramafics of Huggahalli and Kadakola belong to the same age as has been suggested.

While discussing the geochemistry of Shivar ultramafics, Divakara Rao et al. (1975) have concluded that the dunites are older than peninsular gneisses on the following evidences; i) veins of peninsular gneisses cut across dunite; ii) enclaves of dunite in peninsular gneisses; iii) schistosity in the associated pyroxenite and dunite parallel to regional schistosity direction; iv) lack of any high temperature metamorphism of the gneisses due to intrusion of the ultramafics. It has been suggested that a magma similar to peridotitic komatiite can give rise, on differentiation, to dunite-pyroxenite-peridotite and amphibolite. The peridotite material has initially been derived from upper mantle as a more refractory crystalline residue composed largely of olivine and pyroxene left behind after partial fusion of the mantle to yield a basaltic magma. They also concluded that the Archean mantle
beneath the shield was peridotitic in nature and had higher concentration of siderophile elements than at present.

Clayton et al. (1970) have correlated the rock units of Archean terranes of Africa, India, Australia, Canada, and Greenland. The ultramafics of Zargchahli of Kurnool are correlated with those of lower greenstone group of other shield areas whose age is higher than 2700 to 3400 m.y. They consider that the earliest ultramafic-norite Archean volcanics, that is lower unveracut group, Sahulan group, Zargchahli group, and the lower greenstones of western Australia, possibly represent terrestrial analogues of lunar mare (1975). It is possible that ultramafic noritic-felsic volcanism which recorded 3.6 - 2.6 m.y. time-span, represents recurrent long-term effects of the deep crustal fracturing caused by the extraterrestrial impact, as in lunar maria. They conclude that the oldest rocks found in Archean shields are the above ultramafic-norite volcanics, associated felsic volcanics, and the derived sediments.

1.3 Methods of study

The form of the schist belt, which is elongate but very narrow, with some of the rock types not running for the entire length and with the chromite deposits occurring in detached isolated patches, has necessitated the detailed examination of the belt in conveniently sized blocks to get a full and clear
picture of variation in lithology, structure, and stratigraphy. However, initially, the schist belt was mapped on a scale of two inches a mile (Map 1) to get a picture of regional setting of the schistose formations. Detailed large scale mapping (Maps 2, 3, 4, 5, and 6) was later undertaken on selected blocks where chroynite deposits are prominent. Five such blocks were selected and mapped on a scale of one inch = 330 ft by plane table method. Blocks are numbered A to C in Map No.1. With the help of survey level and plane table survey, blocks A, B, and C have been contoured at intervals of ten ft. Contours in blocks D and E are color contours from the toposheet. Contouring was undertaken as part of the programme for estimating the chroynite resources of the area.

The attitude and character of s-planes, fold axis, lineations, and joints of all rocks were measured in the field following Lapham and McGee (1964) and plotted on the geological map. Structural terminology used following Freedman et al. (1964) is, $S_0$ for denoting bedding, for example, in quartzite where the mica reveals the original bedding plane, $S_1$ for foliation (schistosity), $S_2$ for first cleavage, $S_3$ for second etc., the subscripts 0, 1, 2 etc. denoting the order of development. Similar subscripts are used, $F$ for fold, $L$ for lineation, $A$ for fold axis, and $D$ for deformation. Since all the mesoscopic elements cannot be shown in the geological map, stereographic projection method was employed for structural
analysis. For this, poles of planes and lines were plotted on the lower hemisphere of the equal area projection. Such diagrams have been prepared for each block mapped. These diagrams are helpful for correlating sequential deformation pattern with regional orogenic history as advocated by Lapham (1964), Freedman (1964), Lapham and Dessett (1966), and Lapham (1967). Petrofabric diagrams for quartz, mica, and hornblende subfabrics cut from oriented specimens of the associated rock types have also been prepared by following the usual universal stage procedure. 66 diagrams have been prepared on the lines and procedures given by Sander (1949-50), Fairborn (1949), Knopf and Ingerson (1938). Ultramafic rocks of the area are not amenable for this microfabric study as no olivine grains have ever been obtained. Such as were obtained from bore holes contained too few grains, not more than fifty five, for any tangible fabric study. However, since most of the ultramafic rocks are schistose, it was found desirable to bring out a correlation between the mesoscopic fabric of the schistose rocks and the microfabric features of the adjoining quartzites, gneisses, and amphibolites which have ideal mineral components for a fabric analyses, with a view to getting a picture as to whether the latter rock types conform to the same tectonic and structural pattern as that exhibited by the ultramafics.

Samples of rocks and ore minerals numbering three hundred were collected from surface exposures, and from cores of bore holes drilled in several key localities for the estimation of chromite
and copper deposits, and almost the same number of microsections were made to study the petrography and mineralogy of the rocks. Fifty oriented rock specimens of gneiss, quartzite, and amphibolite were collected following the procedures described by Landor (1945-56), Hall (1936), Fairbairn (1949), and Phillips (1960) for petrofabric study.

Optic axial angle, extinction angle, birefringence of various minerals and twin laws of plagioclase feldspar were determined with the help of Leitz 4-axes universal stage. The 2V was measured directly by noting the angle between the emergence of the optic axes. Anorthite content and twin laws were determined following the methods of Berkshire (1924), Reinhardt (1937), Minitin (1936), Turner (1951), Corvi (1951), and Slemons (1962). Birefringence of minerals were determined following the method given by Naidu et al. (1964).

Modal analyses were carried out for some of the selected rocks on Leitz six-spindle integrating stage.

Chemical analyses of a few selected samples of rocks were carried out following the rapid analysis procedures given by Shapiro and Drannock (1962), Biley (1960), and Groves (1961).

The author sought the help of the Geology Department of the Nysore University for making use of X-ray diffraction apparatus available there for the identification of serpentine minerals and garnets. Through the courtesy of the Physics
Department of the Indian Institute of Science, Bangalore, trace element analysis was carried out by mass spectrophotograph.

The author is aware of pretty good number of workers who have visited this area for one type of investigation or the other and it can be said that the area is more or less thoroughly explored. A review of their work has revealed a few lacunae. One such drawback in the earlier works is the lack of detailed structural data. The author here has undertaken a detailed structural analyses by resorting to large scale mapping. Petrofabric analyses of the adjoining rock types are a new method of attack for solving the problem of emplacement of ultramafic rocks. Detailed mapping and examination of samples of bore holes have revealed the existence of new rock types hitherto unrecognized by others. Structural control of chromite and other ore bodies is analysed by a detailed mesoscopic study.