CHAPTER II

SCHISTOSITY OF SANDSTONE

II.1 CROSS TEXTURES

That the Ruggesballi schistose rocks occur in long narrow belts has long been recognized (Sampat Iyengar, 1907, 1910; Varadarajan, 1904). Its form, structure, and topographic expression fall in line with the other major occurrences in the other parts of the world (New Zealand Ultramafic belts (Challis 1903), Japanese Ultramafic belts (Niyashiro 1906)).

The Ruggesballi schist belt which has a length of twenty six miles in north-south direction and width of one and half miles is bounded on either side, in its outermost margin, by granitic gneisses (See 1). In Figure 1, the different rock types are diagrammatically shown in a block diagram. The schistose rock that is in direct contact with the granitic gneiss is the chlorite schist, greyish green in colour, running in sharply-defined narrow band continuously for the entire length of the belt. The chlorite schist in the western margin dips westwards and in the eastern margin dips eastwards. But the gneisses have opposite dip direction in both the margins bringing out a discordant relationship between the two. The discordant relationship between the chlorite schist and the gneiss in the eastern margin is the result of intrusion of granite gneiss into the chlorite schist. Later deformation has imparted
Foliation in the gneiss and schistosity in the chlorite schist. The boundary between the rock types has had influence in the development and orientation of foliation planes in the gneiss; that is, in this particular case, the foliation is parallel to the contact zone. Similarly the schistosity in the chlorite schist is also parallel to the contact. Away from the margin, a little eastwards, the gneiss dips eastwards marking the folded nature of the gneiss. The augen structure of the gneiss in the eastern margin, which is due to deformation during magmatic flow, is here relied upon to hold the view that the gneiss in the eastern margin is a later intrusive. The gneiss in the western margin is devoid of augen structure; throughout it has a consistent dip towards east. It is, therefore, inferred to constitute the floor on which the basic lava (that is the chlorite schist) has been extruded. The presence of quartzite and grit on the western margin is noteworthy. The grit forms a narrow band between chlorite schist and the gneiss. The grit is metamorphosed to a coarsely foliated gneiss which under microscope shows the detrital nature of quartz and feldspar grains characterized by smooth ellipsoidal outlines (Plate 1, Fig. 1) and their absolute freshness. Quartzite in the western margin is right within the chlorite schist but is distributed in a number of disconnected patches all along the length of the belt. In the northern extremity of the schist belt, especially at Pensamudra, quartzites have a typical bedded appearance emphasized by the presence of sericite mica along the
NOT TO SCALE

FIGURE 1
bedding planes. The quartzites are more massive in the middle and southern portions of the schist belt. Four bands of amphibolites are shown in the block diagram (Fig. 1). The two outermost amphibolites represent the early basic flows in the area and their trends are parallel to the trends of chlorite schist and quartzite with which they maintain contact. The inner part of the belt has rocks like actinolite-chlorite schist, tale-chlorite-serpentine schist, serpentine, amphibolite, and cuvierite-anorthosite-titaniferous magnetite, all occurring in close contact with each other in thin narrow parallel bands. These amphibolites form the two inner bands which are derived from the metamorphism of cuvierite-anorthosite. Massive beds of amphibolite and serpentine occur in the central part of the schist belt and they can be easily separated from the other associated schistose types. The schistose types are a mixture of chlorite-serpentine schist, tale-serpentine schist, actinolite-tale-chlorite serpentine schist, and actinolite-chlorite schist. The schistose rock types are transitional from one to the other with a highly variable concentration of tale, chlorite, actinolite, and serpentine in each type that it is impossible to demarcate definite rock units. It is not uncommon to see within a width of about ten ft of an outcrop, frequent alternations of bands of these schistose rocks, each of variable mineralogical assemblage. The tale-chlorite-actinolite-serpentine schist, massive serpentine, and amphibolite have composition akin to
Locatiite. This primitive komatiite lava has undergone
differentiation during extrusion, and that each differentiation
subsequently underwent metamorphism to give rise to the various
schistose types mentioned above. The frequent repetition of
these various schistose types is due to tight isoclinal folding
of the belt by later deformation. The isoclinal fold is
inclined because all the rocks dip in the same direction, that
is to the east. The last phase of igneous activity is late-
to post-tectonic, manifesting itself in the form of intrusives
represented by eucrite, anorthosite, anorthite rock, and dunite.
There are horizontal sheet-like fayalitic masses, a remnant of
the ultramafic magma occurring again as a lava flow. This is
shown in Lynagar area. Massive lens-shaped chromite bodies
occur within massive dunites. Chromite also occurs as small
nodules within serpentine-chlorite schist which are not on a
mappable scale. Titaniferous magnatite occur as well-defined
continuous bands within eucrite-anorthosite. Vein quartz,
magnatite, dolorite, and pyroxenite dykes occur as latest
intrusives cutting across all the other formations.

From a consideration of the geologic events, geologic
setting, and mass of field features examined, the following
stratigraphic sequence can be worked out for the rocks of
Huggaballi schist belt.
Table 1

Intrusives
Vein quartz, pegmatites, and colorite and
pyroxenite dykes
Mica gneiss
Pyroxenite

Pyroxenite dunite

Komatite picrite

Augen gneiss
Hornblende dyke
Serpentinite (altered pyroxenite)
Dunite-chromite lenses

Intrusives
Anorthosite-eucrite-anorthite, titaniferous
magnetite-amphibolite

Extrusives
Serpentinite-actinolite-chlorite-talc
schist with chromite nodules

Extrusives
Actinolite-chlorite schists
Amphibolites

Extrusives
Quartzite-quartz mica schists

Sediments
Grit
Thin primordial granite crust

Such frequent alternations of extrusive and intrusive phases of igneous activity, confined to ultramafic magmas is a common feature of Archean times (Viljeon and Viljeon, 1969; Annibauer, 1973; Glikson and Lambert, 1976).

When the schist belt is examined blockwise, a departure
From the order of succession noticed in the gross feature is evident. A map of the area for each of these blocks, A to E (page 14), is given on a large scale so as to bring out in detail the lithological variations and structural features.

11.2 FIELD RELATIONS AND MESOEOEOIC STRUCTURES OF INDIVIDUAL BLOCKS

The regional setting given in the section (Chapter 11.1) on gross structure is also generally reflected in each block examined. The general northwesterly trend of these schistose formations shows divergences, locally, by taking bends and turns in the form of kinks and as drag folds and recumbent folds. Change in the direction of the trend of the dominant foliation plane has been recorded and shown in the map for each block.

A detailed analysis of the non-crystallographic fabric elements which bear a close relation to the regional trend is undertaken. The non-crystallographic fabric elements occur as penetrative planar and linear discontinuities (Turner and Weiss, 1963). These are mesostructural fabric features which are described here as foliation, schistosity (cleavage), and lineation. The earliest recognizable S-surface is designated as $S_1$, which is the lithological contact in the area, that is the plane of contact between rock type of whatever origin, and also the bedding plane recognised in the quartzite and grit. Incidentally, the earliest schistosity in the rocks is parallel to lithological
FIG. 2  Collective foliation ($S_0$ and $S_1$) diagram of rocks of Nugguballi schist belt. Contours 1.2 – 1.1 – 0.98 – 0.70 – 0.5%
contacts and to the bedding plane and hence $S_4$ includes schistosity also. The average strike of $S_4$-planes and bedding planes is shown in Fig. 2 prepared by plotting the poles to these planes. The planes strike N 14° W and dip 35° towards N 76° E. Other $S$-surfaces such as axial plane cleavages, fracture cleavages are designated as $S_2$, $S_3$, $S_4$ etc. in their relative order of development. The folding on $S_4$ is described as $F_1$ and on $S_2$ as $F_2$. Similarly lineations are designated as $L_1$, $L_2$ etc.

The poles of planar elements, that is the $S$-planes, are plotted on the lower hemisphere of Schmidt equal area net. For example, the pole of a northwest trending plane dipping northeast falls on the southwestern quadrant of the net. For this, the trend of the reference plane is brought onto the north-south diameter of the equal area net by rotating the overlay sheet, and the angle of inclination of the plane is counted from the center of the net along east-west diameter. Thus a vertical plane whose dip is 90° will have its pole on the primitive circle. Horizontal planes with zero dip will have their poles at the center of the net. Thus for all other inclinations the angle reads from zero at the center to 90° on the primitive circle. For plotting poles of linear elements, the plunge direction is brought to coincide with the east-west diameter of the net and the angle of plunge is counted from the circumference of projection. So, for the purpose of plotting the plunge
angle, the angles are counted from zero on the primitive circle to 90° at the center. For example, an east-west lineation plunging 30° west is plotted on the western half of the east-west diameter counting 30° from the primitive circle. The projection not used has a radius of 10 cm. The contour diagrams were prepared by placing the point diagram on a centimeter squared paper. Peripheral and central counters which have holes of one cm radius carved in it are used for counting. The procedure detailed by Fairbairn (1949), Knopf and Ingerson (1939) were followed for preparing the pole diagrams.

II.2.a Block 'A': Syrapur Area

2.a.1. Field Relations

This block is situated almost in the central part of the schist belt and may be considered as a most representative segment of the belt. Because of extensive mining operations going on in this area for chromite ore, all varieties of rock types could be obtained both at the surface and in the mines for a thorough study. The area which is surveyed on a scale of 330 ft to an inch is shown in the Map 2.

As the traverse is taken from the northeast, the schist belt can be approached from the terrain comprising mica granitic gneiss which grades onto augen gneiss. The augen gneiss is a variant of mica gneiss and forms a narrow thin zone in contact
with chlorite schist. The gneiss strikes northwest with a
dip of 50° to the northeast. The chlorite schist, the marginal
member of the schist belt, is in contact with the augen gneiss.
The strike of both the rocks is parallel but they dip against
each other only at the contact. Chlorite schist has a north
easterly dip of 70°, whereas the augen gneiss dips southwest at
50°. The schist has developed minor folds whose axes plunge
at 40° to 50° at angles of 25 to 70° (Plate 1, Fig. 2). The minor
folds disappear away from the contact. The contact between
the chlorite schist and the augen gneiss is a contact plane of
thrust as inferred from the petrofabric analyses of the augen
gneiss (Figs. 56 and 57). Quartz vein also occurs at the
contact between the augen gneiss and the chlorite schist. There
has been extensive development of verniculite in chlorite schist
at the quartz vein contact. A small xenolith of pencil gneiss
is exposed amidst chlorite-talc schist. The fabric of this
pencil gneiss is given in Figures 60 to 65. The pencil gneiss
is probably a chip of basement sialic crust brought up by the
ultramafic lavas and deformed and rolled repeatedly at the time
when the ultramafic lavas were metamorphosed to schist. Another
xenolithic occurrence within talc-chlorite-actinolite schist is
a mica granitic gneiss deformed into recumbent folds. The
presence of nepheline and calcite in this make the petrogenetic
history of this rock complex and unexplainable. The only
inference that can be drawn from this is that the two gneissic
Blocks have been picked up by the lava during its upsurge, and then the later deformation to which all these rocks have been subjected has compressed and rolled up these two monolithic gneissic patches into a pencil gneiss and a folded gneiss respectively. To the west, sheets of serpentine amphibolite, and talc-chlorite-actinolite-serpentine schists are exposed. The talc-chlorite-actinolite-serpentine schist splits up into a number of rock units with the appearance and disappearance of one or the other of these mineral constituents and also in the varying concentration of them. Thus, one can recognize within a narrow width of 5-10 ft, serpentine schist, talc-chlorite schist, actinolite-chlorite-serpentine schist, and serpentine-actinolite schist frequently alternating with each other, or even one grading into the other in all transitional stages, such that it becomes difficult to demarcate the boundaries between any two. Such frequent repetition of beds is common in eroded isoclinal folds. Since the noses are absent, the fold is non-plunging. Nodules of chromite occur in these schists between the foliation planes. They vary in size from one inch to seven feet. Some of the nodules are also flat, lensoid, often twisted. Along with chromite nodules, nodules of lizardite-antigorite-calcite, actinolite-chlorite, talc-actinolite-chlorite-serpentine are also found (Plate I, Fig. 3). A massive lens of serpentininite measuring 10 ft x 3 ft x 5 ft is seen in serpentine schist. The enclosing serpentine schist is horizontal and this has been pushed up due to the growth of
the lens (Plate I, Fig. 4). The way in which the serpentine schist scoops over the lens gives an impression that the lens has pushed up the enclosing serpentine schist during its growth. Such an occurrence of massive lensoid bodies and needles within an enclosing rock of the same composition is suggestive of breaking up of sheets of rocks into small blocks, each block being further compressed and rolled into lenses by later deformation whose effect is generally to impart a schistose fabric to the rock.

The talc-chlorite-actinolite-serpentine schist in the western part has at its western contact cuerite, titaniferous magnetite, and amphibolite. The cuerite is characterised by linear fabric of a pencil type due to the parallel orientation of the hornblende needles (Plate II, Figs 1 & 2). The fabric pattern of this cuerite is shown in Figure 60. The central part of the area forms the core with massive serpentine of greater width with large lensoid bodies of chromite. This serpentine has relic olivine grains and has come up as an intrusive body in the area. The massive serpentine is overlain by cavernous, brown fayalite dunite (Plate II, Fig. 3). This is highly weathered and no mineral could be identified. A crude flow layering is present (Plate II, Fig. 4). It contains horizontal sheet-like veins of magnesite about fifteen feet below (in a pit) the ground surface (Plate III, Fig. 1). The fayalite dunite is devoid of chromite. But in a drill hole
at a depth of 100 ft, chromite of one foot thickness was not
with. This chromite vein consists of coarse, perfect cubes
of chromite, indicating hydrothermal origin.

Drill hole data collected from other bore holes sub-
stantiate the stratigraphic sequence of rock formations given
in Table 1. At upper levels, ultramafic rocks and chromite
bodies are encountered, whereas at great depths the quartzite,
the oldest member of sedimentary sequence, over which have
flowed the extrusives, is not with. For example, in another
bore hole fresh rocks of serpentinite, tremolite-actinolite
schist, and anorthosite are encountered at a depth of 100 ft.
Contact between each member is sharp, but there are no contact
effects. Lack of contact effect may be attributed to the cold
intrusion of the serpentinite and the intrusion of anorthosite
as a relatively solid mass. A bore hole drilled in another pit
struck quartzite at a depth of 1000 ft. This sets the limit
for the occurrence of chromite and ultramafic rocks to a depth
of 1000 ft beyond which only the sedimentary quartzite and the
basement granite are supposed to underlie. The quartzite
thereby constitutes the floor on which the ultramafic lavas
have been extravasated.

2.a.ii Mesoscopic Structures

The strike of the rock formations is mainly determined by
the attitude of the earliest foliation plane $S_1$. The term
foliation is used in different senses by different writers.
British petrologists (Harker, 1932, p.203) restrict foliation to s-surfaces defined by lithological layering and used schistosity and cleavage to cover other types of s-surfaces. If we adhere to this definition, the s-surfaces of this area will not be foliation planes but will actually constitute schistosity, because the s-surfaces are due to the parallel arrangement of the flaky minerals like chlorite, talc, and serpentine, and prismatic needles of actinolite and tremolite. Any single specimen is not nonomineralic, but is an aggregate of all these minerals in various combinations and proportions. No layer is found to constitute a well-defined mineralogic layering, for s-planes developed are due to the parallel orientation of a combination of these minerals, such that the planes of separation or fissility are due to the highly cleavable nature of mineral grains and not to mineralogical banding. It will thus be seen that the term neither foliation nor schistosity can be applied strictly to the schistose formations of this area. However, the schistosity is markedly parallel to the boundaries of different rock types, such as, talc-chlorite schist, chlorite-actinolite-serpentine schist, talc-chlorite-actinolite schist, quartzite, and amphibolite that form parallel bands. When the disposition of all these rocks is considered together, the term foliation can be applied for the gross structural feature of the rocks of this area. Considered from all points of view, it may be useful to follow the usage in the United States of America and
describe all the essentially recognizable S-surfaces of metamorphic origin under the broad term 'foliation' so far as the rocks of the Kangezani schist belt are concerned.

Any structure precedent to \( S_4 \) in the schists is not decipherable, but if attention is paid to the adjoining quartzites in the western margin, the bedding planes in quartzites, marked by the presence of micro flakes along the planes, are parallel to foliation \( S_4 \). This is indicative of the gross lithological layering between the banded quartzite and the schists. The schist should, therefore, be a volcanic rock which must have established a flow contact with the quartzite. Whereas the quartzite has behaved passively towards the applied force, the volcanic rock has yielded to develop \( S_4 \)-plane parallel to the bedding plane of the adjoining quartzite.

The strike of \( S_4 \) varies considerably from N 10° W to east-west; the direction of dip also varies, especially in the northern portion, having dip both towards northeast and southwest at varying angles of 5 to 85°. But the strike of \( S_4 \), statistically determined, is N 20° W with dip of 40° towards N 70° E, and is close to the data presented in Figure 2. Orientation data relating to \( S_4 \)-planes is presented in the Figure 3 which marks, in a stereographic projection, the intersection of segments of \( S_4 \) in the lower hemisphere of an equal area net. Projection of 49 planar segments yielded 1176 points as per the equation \( n(n-1)/2 \) (Sander, 1948-50, p.133; Turner and Weiss, 1963).
The points show a wide scatter, but the contoured diagram of this shows a center of gravity on primitive circle at 30° west of north and east of south (Fig. 4). \( \beta \)-axis is thus obtained which also marks the axis of folding, \( \pi \). The \( \beta \)-axis trends N 30° W - S 30° E with a zero plunge angle, indicating that the folds of this area are non-plunging. The trend of the fold axis is parallel to the strike of the formations. The scattering of points is due to overturning of beds, which dip at high angles, and also due to refolding of beds by later deformation. Since the \( \beta \)-axis obtained by the intersection method yields too many points, the structural interpretations drawn may turn out to be suspect and even complicated. Hence a more straightforward method of obtaining the \( \beta \)-axis was adopted by preparing the \( \beta \)-pole diagram. Figure 5 is the \( \beta \)-pole diagram obtained by plotting 49 poles to \( \beta \)-segments. The poles fall on a great circle of best fit which marks the \( \pi \)-circle (Sander, 1946-50, p.133). The normal to this, which is the \( \pi \)-axis, coincides with the \( \beta \)-axis of figure 1. This marks an unique example of the coincidence of \( \beta \) - and \( \pi \)-axes inspite of the fact that two methods are employed for determining the fold axis. The \( \pi \)-circle is actually the diameter of the circle with \( \pi \)-axis on the primitive circle indicating non-plunging nature of the fold. Deformation \( D_1 \) oriented N 60° E - S 60° W has given rise to \( S_1 \) plane.

The planes \( S_2 \) and \( S_3 \) of later origin superimposed on \( S_1 \).
have been analysed. In the diagram for the poles of \( S_2 \) and \( S_3 \) (Fig. 6), \( S_2 \) is found to be more prominent trending N 60° W and is almost vertical. So \( S_2 \) is an unfolded \( \varepsilon \)-plane intersecting \( S_4 \) at 21°. Another less prominently developed \( \varepsilon \)-plane, \( S_3 \), trending N 40° E, is decipherable from the maxima in the north-western and south-eastern quadrants. \( S_2 \) and \( S_3 \) are due to later deformation, \( D_2 \), operating in an east-west direction, such that \( S_3 \) has developed perpendicular to \( D_2 \), whereas \( S_3 \) that is at an angular distance of 45° from \( D_2 \) has developed later, after \( S_2 \) attained a dead position to mark the \( \alpha \beta \) plane for \( D_2 \).

Brittle fracture has been noticed in serpentinite. Serpentinite behaves as a brittle material as has been experimentally demonstrated by Raleigh et al. (1965). Poles of brittle fractures are plotted and are shown in Figure 7 as \( S_4 \). Its trend which is N 10° W, is markedly discordant with that of \( S_2 \) and \( S_3 \). Two maxima for \( S_4 \) suggest the deformation, \( D_4 \), has changed its direction of operation between N 20° W and N 10° E. Serpentinite occurs as a massive body which has emplaced itself along the axial planes of schistose formations by intrusion. The fracture \( S_4 \) may be incidental to this intrusive episode, or it might have been generated by another later deformation, \( D_4 \), after serpentinite emplacement.

Another characteristic tectonite fabric is lineation which appears in this area to be kinematically active. Four types of linear structure were recognized in this area, they are
listed below in the decreasing order of importance: 1. Parallel elongate lenses and nodules formed by aggregate of minerals like, chromite, actinolite-chlorite-serpentine-talc, actinolite-chlorite, chlorite-talc-serpentine. 2. Grooves. 3. Intersection of planes. 4. Linear parallelism of mineral components, such as, linear parallelism of hornblende prisms in ocrite, and pencil structure in pencil gneiss, and quartz rods.

In Figure 9, the different types of lineations observed are shown. Poles of lineations fall near the circumference of projection indicating low angle of plunge. The trend of the $S_1$-plane spreads from N 10° W to east-west, and the area occupied by the chromite nodules has a spread within the same range indicating that the chromite nodules lie essentially within the $S_1$-planes having their trend parallel with the fold axis, but plunging south and southeast at angles varying from 5 to 20°. Since folding $F_1$ is on $S_1$-plane, folding and lineation must have developed simultaneously, and are genetically related. Lineation represented by talc-chlorite-actinolite-serpentine nodules has a greater amount of spread. A few nodules occupy areas circumscribed by chromite nodules. Hence, their development is due to folding $F_1$ of $S_1$ and simultaneous with that of chromite nodules. But, whereas chromite nodules plunge in south and southeast directions, the talc-chlorite-actinolite-serpentine nodules plunge both in southeast and northwest direction. There are nodules of talc-chlorite-actinolite-serpentine plunging east,
northeast, and southwest. Their origin is incidental to the development of S<sub>2</sub> and S<sub>3</sub> cleavages.

Chromite and tale-chlorite actinolite-serpentine nodules having trends in south, southeast and northwest directions are due to an earlier stage of deformation (D<sub>1</sub>) that has produced F<sub>1</sub> folding. The tale-chlorite-actinolite-serpentine nodules associated with S<sub>2</sub>, and S<sub>3</sub> cleavages are due to later stage of deformation in addition to the earlier ones, whereas the hard brittle chromite nodules have resisted the later period of deformation and have thus remained unaffected. Some of the chlorite-tale-actinolite-serpentine nodules are associated with F<sub>2</sub> folding and are aligned parallel to L<sub>2</sub>.

There is a large body (A-lens) of chromite, flatly lenticular, occurring within massive serpentinite, plunging at an angle of 70° in SSE direction. This is described as type 2. The plane of flattening trends NE-SW and, hence, its deformation (D<sub>4</sub>) is due to the stress acting in the NW-SE direction.

Lineation (L<sub>2</sub>-S<sub>2</sub>-D<sub>2</sub>) represented by grooves are found on the fracture planes of titaniferous magnetite and on S<sub>2</sub>-planes of the schistose formations. They trend north, but their plunge angle varies from 5 to 85°. The S<sub>2</sub> must have acted as a hinge about which the blocks have slipped as strike slips, oblique slips, and dip slips, either in steps or continuously, to produce grooves accordingly parallel to the direction of slip.
So S₂ appears to be a kinematically active plane.

Lineation (L₂ or L₃ – S₂ or S₃ – D₂ or D₃) formed by the intersection of 3-planes (S₁ and S₂ or S₃ in this case), and quartz rocks in schists and gneisses also trend north and plunge at angles varying from 5 to 55° similar to grooves.

Plots of poles of chromeite veins (planar) (Fig. 9) show that they are controlled by S₁ and S₂ since the plots fall perpendicular to these S-planes. It is interesting to note, but at the same time difficult to explain, the absence of veins along S₂.

II.2.b Block 'D' : Tagadur Area

2.b.1 Field Relations

The area immediately to the south of Byrapur, described here as block 'D', constitutes the Tagadur area. The schist belt actually broadens here and, as such, all the rock types are better exposed. The rock types in this area partake the lithological features and structural trends found in Byrapur area. But Tagadur area has a mark of distinction of its own in having all the ideal and characteristic rock types of ultramafic association more widely developed with a few additional rock types not found in Byrapur area. Massive amphibolite derived from the metamorphism of eucrite-enortheosite occurs in two distinct bands: Komatiitic picrite and albitite.
Four distinct bands of titaniferous magnetite are also exposed.

As in Byrapur, the schist is bordered on the east by augen gneiss. The narrow band of augen gneiss of Byrapur broadens here and forms a distinct outcrop. The rock is fresh, the eyes of augen are sharp and well-developed. It strikes N-S with almost a vertical dip.

Whereas the western margin of the schist belt at Byrapur ends abruptly under soil cover, at Togadur the schists are in direct contact with mica granite. The variants of mica granite occur as mica and hornblende granite gneiss. At places, mica gneiss develops augen structure.

It is found necessary to delinate the order of succession of the rocks in this area from the western most margin as the mica granite gneiss here is found to form the basement rock because of its easterly dip and the talc-serpentine-chlorite schist immediately to the east of this mica gneiss appears to be resting on the latter. An unequivocal evidence for this is found in a small stream course 3/4 mile WNW of A 3101 where the contact between mica granite gneiss and the overlying talc-serpentine-chlorite schist is well-exposed. At the contact between schist and gneiss, a small patch of albitite measuring ten feet in thickness is exposed. The albitite here has developed due to the interaction between the ultramafic rock and the granite. This is discussed in some detail in the chapter on 'Petrography' page 330. This schist is here thrown up into
minor folds and crenulations which plunge in the southern direction. To the east, the schist is succeeded by a thick band of amphibolite. With the appearance of quartzite in the middle of the amphibolite, the latter splits into two distinct bands. What is apparent here is that the two amphibolite bands constitute two distinct lava flows overlying and underlying the intervening quartzite bed. This quartzite does not outcrop in the northern portion of the area but is encountered at depth in a bore hole. Overlying the amphibolite is another set of flows, the metamorphosed equivalents of which occur as chlorite-talc schist and massive and banded serpentinite. Nodules of chromite of one foot to two feet length occur in the chlorite schist. Originally, the chromite must have occurred as a vein but was cut up later into small elongate nodules. The nodules lie within the planes of schistosity. Whereas the massive serpentinite is devoid of chromite, the banded serpentinite has a distinct layered appearance having alternate layers of chromite and serpentine. The thickness of chromite layers varies from 1 to 10 cm. The percentage concentration of chromite also varies in each band. The layers at places are drawn out into lensoid bodies of one to thirty feet in length. These have been extensively mined in the area. At places, the chromite layers enlarge into thick bands running for a length of up to 500 ft, and, as they are steeply inclined, they occur as large dyke-like bodies. Most probably the serpentine-nites were originally layered dunite later metamorphosed to
serpentinite. The massive serpentinite occurring to the south of A 3161 has developed pillow structures. Chemical analyses given in Chapter IV indicate the massive serpentinites to be pierrites. Development of superimposed secondary joints and the extensive weathering have destroyed, to some extent, the shape of the pillow structure in serpentinite.

Other features typical of a pillow lava observed in serpentinite are detailed below: The pillows vary in diameter from 1 to 4 feet with the longest pillow measuring 2.5 ft. In cross-section, it is conical, regular, irregular, ovoidal, and rounded. Deformation of underlying pillow (Plate III, Figs. 2 & 3) by sagging, due to the weight of another pillow coming to rest upon it, is commonly observed in several pillows. Convexity of the pillows is towards east which indicates the direction of younging is towards west. This confirms the stratigraphic succession already established. A thin concentric rim surrounding each pillow differing in texture and colour from the main body of the pillow has the appearance of a chilled border. Added to this there are radiating cracks and vesicles in a few pillows which are typical of pillow lavas (Plate III, Fig. 4 and Plate IV, Fig. 1). Vesicles are all filled up by iron rich antigorite. Serpentinite adjoining the pillows has developed hexagonal, pentagonal, and tetragonal columns (Plate IV, Fig. 2). This furnishes another evidence for the emplacement of ultramafic rock in a
subaqueous environment. The massive serpentinite, with a lot of siliceous ribbey material, which is exposed in the SE corner of the block, is very coarse and contains big plates of serpentine pseudomorphous after pyroxene. This is apparently derived from pyroxenite.

Another band of tale-chlorite schist, carrying concordant lenticles and veins of chrome, occur in contact with serpentinite to the east. Nodules of chrome vary in size from 1 to 1 foot. The length of the vein varies from 1 to 200 ft. Bands of cuerite (gabbroic anorthosite), titaniferous magnetite, amphibolite, and tale-chlorite schist occur alternately in regular succession further east. The bands of rocks repeat due to isoclinal folding whose axial plane dips east. In the centralmost part of Tagadur block, titaniferous magnetite occurs in four distinct bands, each band of 10-25 ft in thickness. Between the bands of titaniferous magnetite outcrops of cuerite, gabbroic anorthosite, and amphibolite occur. All these rocks along with titaniferous magnetite grade into each other. This has lead some authors (Radhakrishna et al. 1974) to recognise a rock type under the name magnetite gabbro in which magnetite bands of 1/4" to 1 inch thickness alternate with cuerite. Titaniferous magnetite and amphibolite here are the differentiated products of cuerite. Titaniferous magnetite and cuerite carry veins and disseminations of copper and other sulphide ores to a little extent. A small band of pyroxenite is found
associated with gabbroic anorthosite. Because of the development of horizontally disposed cleavage, cuvette-gabbroic anorthosite occur as flat exposures. Actinolite-chlorite schist and tecto-serpentine schist to the east occur in contact with amphibolite on either side. Chromite bodies of all shapes - veins parallel to foliation, rafts, dyke (Plate IV, Fig. 3), and pillar forms (Plate IV, Fig. 4) occur within tecto-serpentine schist. These chromite bodies are thickly coated with a thin layer of tale. Each layer is striated in different direction indicating movement of chromite body at the time the rocks underwent deformation. The length of the chromite bodies varies from 1 to 300 ft and width from 1/2 to 10 ft. The amphibolite to the east of this which, incidentally, occurs in the eastern margin of the schist belt is the most prominently developed when compared to other amphibolites so far described. Between this amphibolite and the augen gneiss, a thin band of tecto-actinolite-chlorite schist appears. The schist is here thrown up into a drag fold. A big quartz dyke of about 10-15 ft wide runs intermittently for about a mile parallel to gneiss schist contact. This occurrence is common for the entire schist belt. In its run, the quartz dyke runs through both the schist, and the gneiss. Augen gneiss carries xenoliths of serpentine schist all along the eastern border. The planes of schistosity of serpentine schist are parallel to the gneissic foliation of the augen gneiss.
The area is traversed by dolerite and olivine dolerite dykes which have NE and S-W trend.

2.6.11 Tectonic Structures

The procedure described in p. 29 for the structural analyses is followed here also. The type of S-planes recognised in Byrapur area have the same extent of development in Tagadur area. The strike of $S_1$, which refers to strike of primary foliation and schistosity that parallel the lithological contacts and bedding planes, shows variation from N30° to N50° with a dip of 50-60° to the east. Rocks are overturned at places and hence dip towards west at varying angles of 20 to 60°. $\beta$-diagram (Fig. 16) prepared by the intersection of 45 $S_1$ segments shows the fold axis to have a trend in N21° E direction plunging at 10° in S 21° E direction. Figure 11 is the pole diagram obtained by plotting 48 poles to $S$-segments. Most of the $S$-poles are closely clustered, but 3 or 4 poles near the center of projection define the fold axis. The $\pi$ circle is drawn to pass very near these three points. The $\pi$ axis normal to the $\pi$ circle falls very near the $\beta$-axis.

The diagram for the poles $S_2$ and $S_3$ are shown in figures 12 and 13; figure 12 is after Lapham and McKague (1964) which shows only plot of poles of the planes similar to $S$-pole diagram from which a $\pi$ circle can be drawn. The contour diagram of this is shown in figure 13. $S_2$-planes are drawn
polar to the maxima and minima lying on the east-west
diameter. Their intersection lines the fold axis of second
generation fold, $S_3$. The fold axis obtained for $S_2$ more or
less coincides with the fold axis of $F_1$ on $S_1$. $F_2$ fold here
appears to have been superimposed by a later deformation $D_2$ on
the first generation fold, $F_1$. Since the fold axes of $F_1$ and
$F_2$ more or less coincide, it is quite possible that the later
episode appears to have followed closely upon the first. The
second generation of fold is not present in the Byrapur area.
This marks local discordances and structural discontinuity due
to heterogeneity of rock fabric and the change of direction of
stress due to heterogeneities. $S_3$-plane has a trend normal to
$S_2$ and $S_1$. These are clearly of later development. This may
be a cross fracture developed by deformation $D_2$.

Joints developed in chromite bodies, talc-chlorite schist,
titaniferous magnetite and amphibolite have been analysed and
shown in figure 14 (after Lapham and McKague, 1964). Large
number of poles along east-west diameter form a circle to
indicate that the axial plane of the fold and the fractures
have the same trend with fractures having a fan like attitude.
It seems likely that folding of $S_1$ has proceeded to some
critical stage before the fracture cleavage (joints) has begun
to form. The fracture cleavages may also be released joints
which normally develop parallel to the axial plane, when the
stress is released. Similarly, coeval with the development of
release joints, extension joints have developed as revealed by the concentration of poles in the northern sector of the figure.

As in Byrampur area, brittle fractures are developed in serpentinites. The poles lie in a small circle girdle as shown by circumscribing the cluster of points in the left half of the diagram (Fig. 14h). The trend of the fractures hence varies from NE to NNW to S. The brittle fracture can be related to two deformations, \( D_2 \) and \( D_3 \), each of which can be considered to produce its own set of brittle fractures in the serpentinite to give rise to fractures of varying trends as the stress chan es its direction of operation. An alternative explanation is quite possible wherein it can be surmised that brittle fracture in all orientation develop in a massive body during its intrusion.

Various types of linear elements of Byrampur area also occur here. Figure 15 is the plot of the various types of linear elements. Chromite nodules show a N-S trend and hence lie within the \( S_1 \) plane whose trend varies from \( 15^\circ \) to \( 80^\circ \). The nodules plunge both north and south at angles \( 15^\circ \) to \( 80^\circ \).

Talc chlorite nodules have varying plunge direction. Some nodules occupy areas in the diagram circumscribed by chromite nodules. Hence their development is due to folding, \( F_1 \) on \( S_1 \), and simultaneous with that of chromite nodules. Some talc-chlorite nodules have a plunge towards west and northwest.
These directions are parallel to the axes of drag folds whose trend varies from south to southeast. Probably talc-chlorite nodules lie on the axial planes of drag folds. The axis of drag folds here is also the axis of intersection of $S_2$-planes. The axis of intersection plunge generally towards southeast.

Poles of chromite veins, tabular, occurring along the plane of schistosity coincide with $S_1$ and $S_2$ planes (Fig. 15). The occurrence of chromite as tabular bodies here is incidental to the development of $S_1$ and $S_2$ planes and is controlled by the latter.

II.2.c Block 'C': Jambar Area

2.c.1 Field Features

Jambar area forms the southern tip of the schist belt. The schist belt practically narrows down here such that rocks get compressed into a tight fold. This constriction of the belt has resulted in the elimination or concealment of some rock types found in the areas to the north. The schist belt that has otherwise a general northwesterly trend suddenly takes a bend in this area changing its trend to E-W and to N 68° E. This indicates refolding of the isoclinal fold into a gentle monocline. Attendant upon the monoclinal flexing has been shearing movement in the east-west direction along the schistose planes to produce drag folds whose axial planes trend N 68° E. The rocks dip here towards N and NW directions.
marking a change in the direction of dip consistent with the change in the direction of strike.

The northern boundary of this belt commences with the exposure of titaniferous magnetite. This is in close contact partly with anorthite rock, but mostly with antigorite-talc-chlorite schist to its south. This antigorite-talce-chlorite schist shows intricate drag folding characteristic of incompetent beds which undergo plastic flow under intense deformation. Further south, a massive serpentinite body outcrops. The southern portion of this serpentinite is traversed by a number of jaspery quartz which stands out as ribs because of their resistance to weathering. Such jaspery quartz which has been leached out is redeposited along the joint planes to form druses. Such veined serpentinites are normally free from chromite.

Chromite occurs in both the rock types described above. In antigorite-talce-chlorite schist, the chromite occurs along the planes of schistosity as stringers and nodules. In account of tight folding which characterises this block, chromite stringers are cut up into disconnected lenses whose alignment along a single line indicates the first stage of boudin development. The lenses are smeared by thin films of talc. The form of the chromite body is entirely different in massive serpentine. It occurs in parallel bands interspersed with
serpentinite, and also as vein material traversing across these bands. The banded structure suggests rhythmic segregation of serpentine (olivine) and chromite into layers before or during the emplacement of the magma. Where the segregation is incomplete, chromite and olivine get indiscriminately mixed up to form bands which are distinguishable as a zone of mottled ore in the serpentinite body. Lensoid bodies of chromite also occur in massive serpentinite. These have northeasterly plunge whose trend is parallel to the axes of drag folds. The main chromite body appears to have been drawn out into drag folds.

Boreholes driven through serpentinite for chromite exploration struck dunite at a depth of 60 ft. This raises the question as to whether the serpentinization of ultramafic body is an act of weathering or is due to imbibition of meteoric waters during intrusion. These dunites carry bands of mottled ore as the main chromite body.

2.c.ii Mesoscopic Structure

A sudden shift in the direction of strike characterises the structure of the Jambur area. The northwesterly strike of the rocks in the northern part sweeps into an east-west trend, the rocks getting overturned in this process. The resulting structure which takes the shape of a monoclinal bend on a megascopic scale really assumes a synform. As the synform
developed, layers were compressed throwing up actinolite-chlorite-serpentine schist into minor drag folds which have an axial trend from N 40° E to N 70° E with a plunge angle of 30 to 80°. At the north-eastern corner of the map, the rocks are tightly folded into antiform which has a north-south axial trend. There are drag folds in the limbs of this antiform which have plunge both to north and south. The structure of this block is highly complex.

Structural analysis of this area is shown in Figures 16 to 20. Figure 16 is the β-diagram obtained by the intersection of sixteen S_4 segments. The maximum in the northeastern quadrant shows a plunge direction and angle of N 67° N and 45° respectively, for the fold axis. The π axis in Figure 17 coincides with β. S_2 is also recognized in the field, which makes a low angle of 10-15° with S_4. In Figure 16, the fold axis obtained from the contoured S_2 pole diagram coincides with the axis (β and π axes) of the fold on S_4. As in Tagadur area, the F_2 fold here is superposed by a later deformation, D_2, on the first generation of fold, F_1. D_2 thus appears to have followed closely upon D_4.

The linear elements observed in the rocks are axes of drag folds, intersection of S-planes, grooves, and nodules of chromite and actinolite-chlorite-serpentine. The linear fabric of the rock is analysed in Figure 19. All these linear elements cluster on the northeastern quadrant of the figure in which lies
the fold axis. It is evident, therefore, that lineations parallel with the fold axis, and that the development of $S_2$-planes and lineations are coeval.

The plot of poles of the chromite veins is shown in figure 30. They fall in southern sector of the $S_2$ planes in the figure. These may be interpreted as segregation veins formed during or along with the development of $S_2$ planes.

II.2.d Block 'd': Gobhikhali Area

2.d.1 Field Features

Gobhikhali block constitutes the area lying immediately north of Byrapur block. As in Byrapur, the schist is in contact with augen gneiss in the eastern border, and the western border vanishes under the soil cover.

This part of the area is covered with several agricultural fields. Hence the regular order of succession of the formation cannot be traced. The rock types found in this area that is, talo-chlorite-serpentinite schist, hornblende schist, massive serpentinite, titaniferous magnetite, pyroxenite, and chromite occur in isolated scattered patches. The only contact established is between amphibolite and augen gneiss and between talo-chlorite-serpentinite schist and massive serpentinite. Massive serpentinite forms small mounds, and is highly weathered into a brownish or greyish brown mass with ribbed and rugged
appearance. These ribs are formed of opaline silica and magnesite. This massive serpentinite is free from chromite, a feature common to the entire belt. There is one exposure of titaniferous magnetite in the north eastern part of the area. A big quartz dyke is exposed on the eastern margin having a length of 2000 ft in N135°E direction and a width of 6 ft.

Nodules, lenses, and small veins of chromite occur along the planes of schistosity in serpentinite-talc-chlorite schist. Lenses vary in size from 4 inches to 5 feet.

2.d.11 Mesoscopic Structure

The direction of strike and dip is highly variable and inconsistent, and hence no correlation can be established between the structural features of this area and the adjoining area. The β-diagram of $S_1$ planes (Fig. 21) has scattered maxima and submaxima in the girdle, by which is meant that no fixed fold axis can be established.

The diagram for the poles of $S_2$ and $S_3$ are shown in figure 22. $S_2$ is more prominent trending N 52° W with a dip of 52° towards N2. $S_3$ is less prominent and trends N 14° E with a dip of 76° towards east. Figure 23 shows the orientation of brittle fractures. The fractures fall in line with the orientation of $S_3$ planes. Another deformation, $D_3$, may be visualised for both $S_3$ and brittle fracture in serpentinite. Chromite veins and lenses are confined to the $S_2$ plane. The area bears the impress of three periods of deformation $D_1$, $D_2$, $D_3$. 
and by correlative with $S_1$, $S_2$, and $S_3$ respectively, but the
direction of stress is variable and cannot be correlated with
the stress direction interpreted for Bymatur and Togadur areas.
The highly diverse nature of the trends of the $S$-planes in this
block as well as in Janbur, rules out any possibility of a
uniform deformation having operated in this area. A uniform
deformation becomes non-uniform under geological conditions
where one is dealing with an isotropic bodies. This anisotropy
arises because of irregularities in the body's shape, existence
of weakened zones at the contact between different rocks,
heterogeneity in grain size, and differences in internal
structure within the same rock type. Stresses applied on such
bodies are non-uniform and the distribution of stress in space
becomes complex. In such cases, as Belousov (1962) has
pointed out, the position of the principal stress axis for each
infinitesimal part of the rock, individually, will have to be
determined and the changes in the position of these axes during
the course of deformation calculated. Hence, what should be
realised in the structural analysis of the Nuggleballi schist
belt is the non-uniformity of the plastic deformation, because
of the irregularities in the shape of the rock body and weakened
zones at the contact between rocks, and different degrees of
competency of each rock because of difference in grain size and
variable mineral composition, on account of which the stress
direction gets complexly redistributed which further results in
the deviation of the S-planes from their regular direction.

II.2.c Block 'L': Pensamudra Area

2.e.1 Field Relations

The northern extension of the schist belt terminates at Pensamudra. As usual, the schist belt is in contact with granitic gneiss on the eastern border. These gneisses occur in several types varying from granodiorite from the outermost margin to mica augen gneiss as the schistose formation is approached. Xenoliths of steatitised serpentinite occur within the mica gneiss. Steatite body shows slightly obliterated pillow structures. Sericite quartzite occurs marginal to the schist belt in the western border. Garnet-actinolite-chlorite schist occurs in the strike trend of the quartzite. This may be the metamorphosed equivalent of calcareous sandstone. Farther west it is nothing but a vast stretch of agricultural soil for ½ mile after which granite exposures make their appearance. Thus the schist belt here is delimited by granite gneiss in the east and quartzite in the west. Quartzite which has NNW to NW trend has an outcrop width of 1400 ft. It has an easterly dip. It is overlain to the east by a succession of rocks, such as, amphibolite, talc-chlorite schist, serpentin-nite-chlorite schist, banded serpentinite, talc-chlorite-actin-olite schist, and massive serpentinite in the order mentioned. All these formations have NW strike and an easterly dip. Serpen-tinites present are both massive, derived from dunite and
pyroxenite, and banded (layered). In the banded type, the lighter band consists of serpentine minerals and the darker bands of chromite grains and flaky chlorite. The massive serpentine is derived from pyroxenite, because big plates of serpentine pseudomorphous after pyroxene are present. Fibrous tremolite occurs along the foliation planes of serpentine-chlorite schist. The importance of this part of the belt lies in the existence of large deposits of vermiculite occurring in contact between pegmatite and serpentine. Pegmatite runs as a sheet parallel to the foliation plane in serpentine and has brought about vermiculitisation in serpentine. The sequence of formation of vermiculite and other hydrous minerals has gone on by a process of metamorphic differentiation in the way described by Phillips and Hess (1936) and Thayer (1966). Chromite occurs as thin bands (Plate V, Fig.1) and as small lenses having thickness from 1/4 inch to 1 inch.

2.e.11 Mesoscopic Structure

The strike of the rocks varies from N 30° W to N 70° W. The beds dip at angles from 20°–85° both towards NE and SW. Here the isoclinal fold of the area passes over into an asymmetric fold. The fold plunges NW as deduced from the direction of plunge of drag folds, quartz rods, and cleavage mullion in quartzite and amphibolite. -axis (Fig.24) marking the axis of fold also shows the plunge direction towards N 48° W at an angle of 7°. Bedding planes, S₂, in quartzite are parallel to the S₄ planes of the schists.
roles of joints developed in quartzite and serpentinite fell in the same sector circumscribed in figure 25. The brittle fractures are diagonal to the foliation plane and appear to have developed in response to $\mathbf{B}_3$ directed along $N 65^\circ S - S 65^\circ E$. 