CHAPTER II

STRUCTURAL GEOLOGY

Introduction, Structure of the Country rocks, Structure of the younger intrusives, Structure of the ultramafic-mafic Torappadi complex, The form of the ultramafic-mafic complex, Status of the intrusives in view of the structural framework, Conclusion.
INTRODUCTION:

The mafic-ultramafic layered complex of Torappadi, Arcot district (North), Tamil Nadu comprising pyroxenite, gabbronorite and iron enriched member of gabbronorite covers an area of about 2.5 km². Venkata Rao (1969) in a report mentioned about magnesite occurrence from this area but till now there was no published account on the structural geology of this ultramafic-mafic complex and adjoining terrain. Lately Bose et al. (1984), Ray and Maitra (1984) published brief observations on the structural features of this layered complex.

The occurrence of layered ultramafic-mafic bodies within high grade country rocks poses a unique problem. The spatial association of mafic-ultramafic layered bodies and associated granolites (as in the present area) is interesting and needs plausible interpretation. A survey of literatures on similar ultramafic-mafic layered rocks within (surrounding) granolitic rocks in other part of the globe indicates their occurrences. The possible interpretations swing among alternatives like 'intrusion in the country rock' (Bowes et al. 1964; Morrison et al. 1986), 'xenolith' (Windley et al. 1981, Conrad & Kay 1984) or 'structurally controlled emplacement as slice-ophiolite' (Copper and Reay 1983; Hatcher et al. 1984; Stanley et al. 1984). A review of such occurrences has been summarised in Table 2.1.
STRUCTURE OF THE COUNTRY ROCKS:

The area investigated is a part of the Eastern Ghats Precambrian belt. The country rocks in which the ultramafic-mafic complex of Torappadi occurs are high grade granolitic rocks and banded magnetite-quartz unit.

Compositional layers:

Primary sedimentary structures like bedding is preserved in the banded iron quartz formation of Kavuthimalai. The layers of magnetite and quartz represents original attitude of bedding. Parallelism of such layers with neighbouring contact with high grade granolite bands suggests possible concordance of the planar attitude of pre-metamorphic sediments with the bedding now preserved in the banded iron formation. The banded magnetite-quartz band serves as a key horizon indicating the nature of earliest fold ($\cong F_1$) in this area.

Foliation:

The other important structural elements developed in the granolites in mesoscopic scale (Weiss and Mc Intyre 1957) is the foliation. This structural plane is fairly well developed marked by sub-parallel plates of quartz, antiperthite and flakes of mica.

The foliation in the high grade granolite shows remarkable variation in strike over the area. The attitude of foliation changes progressively from west towards east. From the western
part of the area studied (to the west of Eraiyur malai) up to the eastern part (near Melnachipattu village) the attitude of strike of foliation varies considerably.

Mineral lineation:

At places, mineral lineation is defined by the elongated streaks of mica in the granolites. The attitude of mineral lineation varies implying that they were disturbed by later folds.

Style of folding:

The style of folding in the terrain is better revealed by the banded magnetite quartzite unit (Kavuthimalai area) and granolite; and in the latter unit it can be traced almost continuously. Further the mesoscopic folds developed in various scales (from a few inches to a few metres in amplitude) in the granolites offer a scope to examine the degree of structural homogeneity.

As discussed earlier, mesoscopic folds are very common in this area and they are both $F_1$ and $F_2$ folds, although $F_3$ fold is responsible for overall outcrop pattern of lithounits in the area. A brief resume of each of the fold types (generations) is given below:

$F_1$: This is the earliest fold and undoubtedly affects the original sedimentary bedding preserved by banded magnetite quartzite unit of Kavuthimalai (Plate 2.1). There it is found to be
refolded in a 'hook-like pattern' caused owing to superposition of later \(F_2\) fold \((F_2 = \text{tight to isoclinal with roughly east-west axial trace})\).

Exposure of \(F_1\) fold in this area without \(F_2\) interference is absent. In granolite, in analogy, the \(F_1\) folds have been established and their fold-elements are found to be disturbed by the later folds.

\(F_2\) : \(F_2\) folds are relatively rare and tight to isoclinal type (mesoscopic) with roughly east-west axial trace. \(F_2\) folds (single) are mainly found in the granolite. This is best developed in Palaya Kal area and reclined in nature (Plate 2.2).

\(F_3\) : \(F_3\) fold in this area is most conspicuous and is responsible for overall outcrop pattern. The spectacular change of strike of foliation from west to east as observed in the studied area is due to influence of this \(F_3\) fold and altogether three synforms and two antiforms (alternating) have been mapped in this terrain.

From the structural analyses of fold elements following pertinent observations could be made :-

1. Axial Planes of \(F_2\) folds dip at moderate angles (either towards SSW or SSE) and the axes usually have high dip (\(>30^\circ\)). The poles to such axial planes \((\approx F_2)\) have been affected by \(F_3\) fold and they distribute themselves in a great circle girdle (Fig. 2.3).
2. Poles to foliation planes of granolite country rock (in the east of Pachal village, i.e. to the east of a vertical line drawn through Pachal; Fig. 2.8A) define a great circle girdle and the controlling fold axis is $F_3$ which plunges $70^\circ$ towards $180^\circ$. Thus the last fold ($\approx F_3$) is responsible for the swing of strike of foliation of granolite country rocks (Fig. 2.4).

3. Similar observation could be made from Fig. 2.5 which corresponds to the sector lying to the west of Pachal village. As before, here also $\beta F_3$ plays key role in controlling attitude of structure of country rocks.

4. When the poles to axial planes ($\approx F_1$) have been plotted (Fig. 2.6) they form a distinct great circle girdle being controlled by $F_2$ axes.

Fault:

To the extreme eastern side of the area studied, by noting the offset of the strike of banded iron formation, presence of a small fault has been inferred. This runs NNE-SSW.

Structure of the Younger Intrusives:

The area investigated also reveals some younger intrusive rocks namely pyroxenite and gabbronorite and these are found to be distinctly different from the bulk of the Torappadi layered ultramafic-mafic rocks on salient petrochemical grounds (see Chapter-VI for detailed discussion). These intrusives appear to
be more advanced in comparison to the different rock members of the Torappadi complex. Nevertheless, similar to the ultramafic, mafic and iron-rich mafic members of the Torappadi Complex, the younger intrusives also display 'layering' which is very conspicuous (discussion in detail in a subsequent section).

When the attitude of the igneous layering ($S_{ig}$) of these intrusives are compared to that of granolite country rocks, parallelism of such layers are very pronounced.

The orientation diagrams (Figs. 2.4 and 2.5) clearly show that the poles to $S_{ig}$ of intrusives and that of foliation planes of country rock (granolite) define an identical great circle girdle. Thus the country rocks and intrusives are co-folded which is reflected in the orientation diagrams. The figures 2.4 and 2.5 clearly show that both the country rocks and the intrusives have been affected by common $F_3$ deformation thus suggesting that these intrusives are pre-$F_3$. Absence of $F_1$ and $F_2$ closures (lack of penetrative structures corresponding to $F_1$ and $F_2$) on the intrusives and presence of only overall closure ($\approx F_3$) indicate that these intrusives have been emplaced at a relatively later period with respect to the ultramafic-mafic rock members of Torappadi.
STRUCTURE OF THE ULTRAMAFIC-MAFIC TORAPPADI COMPLEX:

The ultramafic-mafic complex of Torapaddi represented by different lithomembers viz. pyroxenite, gabbronotire and iron enriched gabbronorite occupy the core of the synformal structure formed by the granolites serving as country rock.

Igneous compositional Layers ($S_{ig}$): Igneous layering ($S_{ig}$) is pronounced in the ultramafic-mafic complex of Torappadi as well as in the (late) advanced intrusives of Melnachipattu, Eraiyur and adjacent areas. Both phase and compositional layering is present in the Torappadi complex. Layering in ultramafic-mafic bodies is a phenomenon which has received considerable attention (Wager and Brown 1967; Campbell 1978; Maaloe 1978; Mc Birney and Noyes 1978; Rice 1981). The arguments of Campbell (1978), Maaloe (1978), Mc Birney and Noyes (1979) and Irvine (1980) suggest that simple crystal settling does not lead to layering, and a number of mechanisms have been put forward in place of the classic contention. In view of this, this issue cannot be settled, but some aspects of the Torappadi layered ultramafic-mafic body are of interest in considering this problem.

Three types of layering are observed in the Torappadi body:-

(1) Classical layering of the Skaergaard type (Wager and Brown 1967; Mc Birney and Noyes 1979) where the primary dip was likely to have been low.
2. Development of layering parallel to the contacts where initial dips are perhaps steep; but this layering is not genetically distinct from type (1).

3. Layering formed by cumulates (generally mafic) have been noticed. Sudden crystallisation of one or more phases might be possible by rapid influx of introduced liquid and subsequent cooling of the introduced liquid by mixing may then give rise to layered appearance by mechanism of flow differentiation (Bhattacharjee and Smith 1964; Marsh and Maxey 1985) and sedimentation mechanism.

Style of folding:

The Torappadi ultranafic-mafic layered body renders an arcuate shape in plan (arrowhead pattern). This arcuate disposition is clearly owing to the fold interference caused on the igneous compositional layering ($S_{1g}$) of the layered rocks. The outcrop pattern reveals that the complex occurs in two detached bodies separated by a septum of granolite country rock in between. This may be explained by the phenomenon of folding and subsequent erosion at an antiformal hinge region yielding the septum of country rock in between the two folded blocks (Fig. 2.7).

For convenience of structural analysis, the complex may be divided into domains of 'early' and 'late fold' (Fig. 2.8C) namely domains A, B and C.
When the poles to igneous layering are plotted for the northern (Fig. 2.9) and southern block (Fig. 2.10) it is found for both the cases that the igneous layerings \( (S_{ig}) \) are dominantly controlled by the \( F_3 \) fold plunging 70° towards 180°.

Besides the large megascopic fold, few mesoscopic folds had been produced on igneous layering in both the domains A and B. Representative axial planes of such mesoscopic folds may thus be constructed for each of these sectors. Such average axial planes have orientations 66°/74° SE in domain-A and 104°/70° S in domain-B respectively (Fig. 2.11). Their mutual intersection is marked by \( \beta \) (plunging 70° towards 180°) which is in harmony with the last fold axis.

**Joints:**

Besides planar structure like igneous lamination \( (S_{ig}) \), a number of joint planes have also been measured in the Torappadi complex. The \( \Pi \) - poles of the joint planes are plotted in Fig. 2.12 and it is found that there are two distinct clusters of \( \Pi \) - poles. When great circles are erected corresponding to these, they intersect at 'I'. The attitude of 'I' coincides with last fold axis i.e. \( \beta F_3 \). Thus these joint sets are (hol) joints with respect to the last fold axis \( (F_3) \).

**THE FORM OF THE ULTRAMAFIC-MAFIC COMPLEX:**

The Torappadi complex with all its lithomembers have an arcuate shape in the plan. The conformity in the attitude of foliation in the ultramafic-mafic members of Torappadi, with that
in the enclosing granolites is remarkable. The emplacement of ultramafic-mafic members of Torappadi thus appears to be much controlled by the foliation plane of the country rock, the plane of contact between the complex and the granolites also seems to have some influence in emplacing the body.

The overall outcrop pattern of the ultramafic-mafic body compares well with the form of enclosing granolites in the area. This close similarity in structural geometry too is revealed by plotting the foliation poles of country rocks and that of Torappadi mafic and ultramafic members (Fig. 2.4 and 2.5). The girdle pattern defined by the poles for the country rocks is comparable with that obtained for the igneous layerings of Torappadi ultramafic and mafic members.

Furthermore, the plan of structural deformation in the rocks of the Torappadi complex and surrounding granolites are interestingly similar. Both of them are polyphasedly deformed, the country rocks suffered three phases of folding: $F_1$, $F_2$ and $F_3$ while the rocks of the complex have been deformed by atleast two generations: $F_2$ and $F_3$. Lack of recognition of $F_1$ fold in igneous compositional layering ($S_{ig}$) of the ultramafic-mafic members of Torappadi complex inhibits us to conclude firmly whether they are pre-$F_1$; but presence of a distinct arrowhead pattern clearly suggests them to be pre-$F_2$ and $F_3$. 
STATUS OF THE LATE INTRUSIVES IN VIEW OF THE STRUCTURAL FRAMEWORK:

As discussed earlier, the late intrusives (developed in Eraiyur, Melnachipattu and Kavuthimalai areas) also bear distinct igneous compositional layerings ($S_{ig}$) but petrologically the intrusives appear to be much distinct than the Torappadi rocks (as discussed in Chapter VI). The structural geometry of the intrusives (Fig. 2.8A) are also seemingly different from that of the layered ultramafic-mafic rocks of Torappadi. The intrusives show only broad flexures due to the $F_3$ fold. Thus the intrusives were emplaced at a later period; these are probably post-$F_2$ and pre-$F_3$. A summary of the salient structural features of presently-studied area is given in Table -2.2.

STATUS OF THE TORAPPADI COMPLEX:

The Torappadi layered ultramafic and mafic members appear to be structurally similar to the country rocks. Windley et. al. (1981) has summarised three important structural characters for these layered ultramafic-mafic rocks in granulite belt and these are: (a) the layered complexes abut a wide variety of rocks b) the complexes were engulfed in calc-alkaline deformed and recrystallised material and c) the complexes were deformed contemporaneously with the surrounding rock mass. The presently studied Torappadi complex may be relegated to ophiolites (Maxwell 1969; Thayer 1969; Cooper and Reay 1983; Stanley et al. 1984; Hatcher et. al. 1984 as discussed under Chapter IX) where
possibilities of diapiric upwelling exists and partial melting of mantle material (preferably in a dry environment) might have taken place along thrust zones.
<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Rock type/Locality</th>
<th>Broad structural setting/tectonic environment</th>
<th>Source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Ultrabasic and basic rocks (Lewishian of Scotland).</td>
<td>Ultrabasic and basic rocks occur as intrusives; they suffered coeval folding and granulite facies metamorphism; also isoclinally folded and followed by box-like fold.</td>
<td>Bowes et al. (1964).</td>
</tr>
<tr>
<td>4.</td>
<td>Ultramafic and mafic rocks (Bighorn Mountain, Wyoming).</td>
<td>Ultramafic and mafic rocks were formed during at least two distinct episodes of igneous injection.</td>
<td>Manzer (Jr.) and Heimlich (1974).</td>
</tr>
<tr>
<td>5.</td>
<td>(Meta) peridotite-(Meta) gabbro sequence, Northern Italy.</td>
<td>Contact between the metagabbro and peridotite are extremely sharp and parallel to the small scale mineralogical layering, emplaced as ophiolite slice.</td>
<td>Pamic (1977).</td>
</tr>
</tbody>
</table>
Following features are important: Windley et al. (1981)
(a) the layered complexes abut a wide variety of rocks, (b) the complexes were engulfed in calcalkaline material (now deformed and recrystallised) and (c) the complexes were deformed contemporaneously with intrusion of tonalitic sheets by thrusting and isoclinal folding.

---

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Rock type/Locality</th>
<th>Broad structural setting/tectonic environment.</th>
<th>Source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.</td>
<td>Ultramafic and mafic ophiolites.</td>
<td>At Vaurinos (Greece); only harzburgite has a tectonic fabric. Troodos (Cyprus): Differential deformation in different units. Canyon Mountain (Oregon, USA): Earliest deformation affected gabbro only.</td>
<td>Thayer (1980).</td>
</tr>
<tr>
<td>10.</td>
<td>Ultramafic-mafic layered rocks.</td>
<td>Following features are important: Windley et al. (1981) (a) the layered complexes abut a wide variety of rocks, (b) the complexes were engulfed in calcalkaline material (now deformed and recrystallised) and (c) the complexes were deformed contemporaneously with intrusion of tonalitic sheets by thrusting and isoclinal folding.</td>
<td>Contd.....</td>
</tr>
</tbody>
</table>
TABLE - 2.1 (Contd.)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Rock type/Locality</th>
<th>Broad structural setting/tectonic environment.</th>
<th>Source of data</th>
</tr>
</thead>
</table>

Contd......
May be related to ophiolite slice emplaced along thrust, all the bodies are polydeformed; reveals "punctured basketball" and "Watermelon seed" type structure in mafics and ultramafics.

Tectonic setting indicative of accretionary terrains.

Archaean intrusion in the Wabigoon Subprovince, Ontario.

Large scale intrusive contacts with associated margin series with the ophiolitic rocks.
### SUMMARY DATA OF STRUCTURAL FEATURES

<table>
<thead>
<tr>
<th>Rock</th>
<th>Structural elements</th>
<th>Nature of fold present</th>
<th>Geometry of folds</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country Rocks.</strong></td>
<td>Bedding, foliation planes axial planes of fold and mineral lineation, discontinuity surface (fault), Joint planes.</td>
<td>( F_1, F_2 ) and ( F_3 ) ( F_1, F_2 ) mesoscopic ( F_3 ) megascopic and also mesoscopic replicas.</td>
<td>( F_1 ) &amp; ( F_2 ) isoclinal and co-axial, ( F_1 ) &amp; ( F_2 ) offers hook shaped interference. ( F_3 ) cross fold, relatively open, steeply plunging towards south. Presence of alternate synforms and anti-forms from west to east of the study area.</td>
<td>( F_1 ) axial planes affected by ( F_2 ) fold.</td>
</tr>
<tr>
<td><strong>Igneous Rocks of Torappadi Complex.</strong></td>
<td>Igneous compositional layering ( (S_{ig}) ), axial plane of mesoscopic fold on ( S_{ig} ). Joint planes.</td>
<td>Early &amp; late fold ( (\approx F_2 ) &amp; ( F_3 ) ) ( F_2 ) and ( F_3 ) distinctly present, ( (F_1 ) may or may not be present), ( F_2 ) on ( S_{ig} ) present in mesoscopic scale; ( F_3 ) in megascopic scale.</td>
<td>Early and late folds. Superposition yields characteristic 'Arrow-Head' pattern. ( F_2 ) (megascopic): lowly plunging ( (\approx 20^\circ) ) axial trace = NE-SW in domain A. ( F_3 ) (megascopic): a synform, plunging steeply towards south.</td>
<td>Rocks of Torappadi complex distinctly earlier than ( F_2 ) and ( F_3 ); may or may not be earlier than ( F_1 ).</td>
</tr>
<tr>
<td><strong>Intrusives.</strong></td>
<td>Igneous compositional layering ( (S_{ig}) ).</td>
<td>Affected by ( F_3 ) fold only, renders broad ( F_3 ) controlled wraps.</td>
<td>( F_3 ) present on meso-and mega scales. ( F_3 ) is steeply plunging towards south.</td>
<td>Intrusives are affected by ( F_3 ) only. ( (Post F_1 ) &amp; ( F_2 ) ).</td>
</tr>
</tbody>
</table>
Plate - 2.1  Photograph showing 'hook-like superposition pattern' (caused owing to superposition of $F_2$ upon $F_1$) developed in banded magnetite quartzite of Kavuthimalai.

Plate - 2.2  Photograph showing reclined type $F_2$ fold developed in granolites. (Palaya Kal exposure).
Fig. 2.3 TT-pole diagram for country rock around Torappadi. Poles to axial planes of folds have been depicted with different symbols.

- Poles to axial planes ($\approx F_2$) affected by $F_3$ (in $F_3$ domain).
- Poles to axial planes ($\approx F_2$) not affected by $F_3$ (in $F_2$ domain).

Contours at 1% - 2% - 2.5% - 5% - 12% - 15% - 20% per 1% area.

- $\alpha F_3$ (axis) plunges $70^\circ - 180^\circ$

Fig. 2.4 TT-pole diagram for country rocks and intrusives around Torappadi. Poles plotted were corresponding to $S_{lg}$ of intrusives and foliation planes of country rocks. All poles lie in the same great circle girdle. Total 200 poles.
Fig. 2.5 TT-pole diagram for country rocks and intrusives around Torappadi. Poles plotted were corresponding to $\text{S}_{ij}$ of intrusives and foliation planes of country rocks. All poles lie in the same great circle girdle. Total 130 poles.

- $\text{NF}_3 (F_3 \text{ axis})$ plunges 70°-180°
- Contours at 1% - 2% - 4% - 5% - 9% - 19% - 28% per 1% area

Fig. 2.6 Orientation diagram for country rocks around Torappadi.

- Poles to axial planes ($\approx F_1$)
- Fold axis ($\approx F_2$)
Fig. 27. Schematic diagram showing attitude of earlier folds $(F_1, F_2)$ involving both igneous as well as Country rocks. Septum of Country rock has been exposed by erosion.
Fig. 2.9 TT-pole diagram for igneous rocks of Torappadi complex (northern block). Poles plotted were corresponding to $S_i g$ of igneous rocks. Total 56 poles.

Fig. 2.10 TT-pole diagram for igneous rocks of Torappadi complex (southern block). Poles plotted were corresponding to $S_i g$ of igneous rocks. Total 210 poles.
Fig. 2-11 Orientation diagram for igneous rocks of Torappadi Complex showing attitude of axial planes.

MN represents average axial plane ($\approx F_2$) in domain-A. PQ represents that of domain-B. $\odot NF_3 = F_3$ axis

I represents mutual intersection of the two great circles.

Fig. 2-12 Orientation for joint planes in the Torappadi Complex. Two great circle girdles represent orientation of two sets of joints respectively.