Chapter VI

Time Movement Relations
6.1 INTRODUCTION:

Principaliy there are three episodes of deformations of either the basal migmatised Aravalli sequence or the Pre-Aravalli rocks as outlined in chapter on the geological and structural setup. Microscopic studies on inclusions in porphyroblastic minerals help construct the metamorphic episodes as well with regard to their timing with deformation episodes (Fyfe et al. 1968). A metamorphic episode may be before, during or after a given deformation. Because there is a component of dextral shear parallel to foliation in some regions surrounding plutons, it is noteworthy that a component of rotation on porphyroblastic minerals such as felspar and garnet can be anticipated. The rocks in general have suffered highest metamorphism upto almandine amphibolite facies and the main porphyroblastic minerals are plagioclase (An$_{20}$ to An$_{40}$), garnet and rarely biotite. Apart from the main phase of metamorphsim,
there was second period of metamorphism probably a thermal high that produced retrogressive assemblages in rocks. This event may be timed when the intrusion of Erinpura granite in the Aravalli range took place at the end of Delhi orogenic cycle. Thus when there are three deformative episodes viz. D₁, D₂ and D₃, there are only two episodes of metamorphism mainly M₁, a dynamothermal one and M₂, a late exclusively thermal high.

The studies to this end in view were begun by Zwart (1960, 1962) at Leiden, Holland. Much of the later work was however carried by Sturt (Sturt and Harris 1961). Johnson (1961, 1962) carried out studies on these lines in the Caledonides of Scottish highlands. This work was also extended in the Precambrian of India by several geologists. The general consensus is that the mineral growth overlaps the deformation events. Sharma (1988) has recorded two stage garnet growth in the B.G.C. of Rajasthan. The mineral overlap may be during the static phase (period or interval) between deformational events or may be syntectonic or even outlasting the deformation.

6.2 GENERAL PETROGRAPHY :

Generally speaking the outer rings of granitic rocks have been converted into biotite rich schists but the tonalitic or mafic rings have been converted together with calcareous pelitic rocks into amphibolites with garnet occurring in the vicinity of calc-pelitic gneiss, schist and marbles which were classed by
Heron (1953) into Rialo series but later shown by Roy (1988) as belonging to Aravalli Supergroup.

6.3 GENERAL PRINCIPLES:

When Si or inclusions within the porphyroblast have the same trend as Se (external S fabric), the growth of porphyroblastic mineral is taken to postdate the fabric and generally during the static phase with respect to the event that produced external schistosity. If the inclusions within the parphyroblasts are at an angle to the trend of the external fabric, then the porphyroblastic mineral is taken to be prior to the related deformation event and the Si is taken as one related to earlier deformation and kind of frozen in. Consistent Si-Se relationships can also be found, if the porphyroblastic minerals grow over the crenulations that deformed the pre-existing fabric and in this case the growth of porphyroblastic minerals postdates the deformation that produced S-fabric and also the one that folded the previous S-fabric into crenulations. If the Si trails are sigmoidal and become consistent with the Se at the margins of the porphyroblastic mineral, the porphyroblast is believed to have rotated during the development of the given fabric and is synkinematic.

6.4 THE PORPHYROBLASTIC MINERALS:

The two porphyroblastic minerals common in the rocks at the rim of the pluton are those of oligoclase and garnet. Only pre-tectonic oligoclase
porphyroblasts are found which sometimes show deformation by brittle rupture. The garnets are of two kinds, those which were overgrowing the pre-existing $S_1$ related to the $D_1$ deformation and containing helicitic inclusions and those that were formed during and after the growth of $S_2$.

Those garnets which were formed during the $D_2$ deformation are generally showball garnets or garnets with sigmoidal inclusions, other garnets overgrow on the crenulations on $S_1$ and even on the kinks on $S_2$. The plagioclase growth has been continuous through out the series of deformation events.

6.5 THE ANIMATION MOVIE:

As a part of a compilation of a thesaurus on Structural Geology and Tectonics dedicated to the memory of late Prof. K.Naha, made by the author's supervisor, the author assisted in making an animation movie related to the development of showball garnets. The author regrets that owing to the lack of photomicrographic facilities, he cannot produce the different photographs to substantiate his observations. Fig.6.1 shows the 12 stages in the development of showball garnets taken from a series of 56 frames made by using the software CorelDRAW and CorelPHOTO-PAINT (7.0 versions). Needless to say that since the dextral rotation and foliation parallel shear is predominant in the region, particularly near the tips of the pluton, rotated garnets can be observed. There is a rigid body rotation of some garnets while the others have
COMPUTER SIMULATION OF SNOWBALL GARNET - ONLY 9 STAGES REPRODUCED FROM AN ANIMATION MOVIE

FIG. 6.1A
SNOWBALL GARNETS ANIMATION MOVIE WITH FIELD EXAMPLE

FIG. 6.2

Computer Simulation:
Snowball Garnets

The computer simulation appears above consists of two eight images of a sinistral rot of a garnet, each with an increment.
also deformed during the rotation. There was presumably a component of pure shear as well which considerably deformed some of the garnets making them optically anisotropic.

6.6 SI-SE RELATIONSHIP IN PARPHYROBLASTS

Fig. 6.3A: Pre $D_2$ garnet containing helicitric inclusions

Fig. 6.3B: Syn- to post- $D_2$ garnet growing over the $S_2$ schistosity

Fig. 6.3C: Sigmoidal inclusions trains in garnet suggestive of syntectonic growth of garnet during $D_2$
**Fig. 6.3D**: Garnet grew after the deformation $D_2$ which folded $S_1$ fabric.

Fig. 6.3A to C show the different types of garnets that suggest that garnet growth was predominant during the entire deformation sequence. But category 1 garnet (Fig. 6.3A) shown in A are rare and those in C are most common. The biotite growth was primary as well as during the metamorphism. The growth of hornblende occurred during $D_2$ deformation and therefore the temperature must have reached to the maximum during $D_2$ deformation with most of the hornblende-biotite of second generation and garnet crystallised or grew.

Fig. 6.3 D shows that the garnet grew after the deformation $D_2$ which folded $S_1$ fabric and grew on tops of $D_2$ related microbules.

No sigmoidal trails are seen in plagioclase. The porphyroblasts of this mineral show only the helicitic inclusions of $S_1$ and sometimes $S_1$ as $S_e$ consistent with Si.
6.7 THE BRITTLE DEFORMATION OF PLAGIOCLASE:

Most of the plagioclase in different sections is seen fractured and faulted suggests that this may be because of the high competence of plagioclase relative to other minerals. Fig. 6.3 Shows the fractured plagioclase with twinning on albite law discernible in some fractured grains while those on pericline in other. Fig. 6.3 F shows the growth of garnet over D₂ related kink-bands structures.

Fig. 6.3E : The fractured plagioclase with twinning.

Fig. 6.3F : Garnet growth over D₂ related kinks.
Because C and S planes are dominant where S-C mylonites are developed and in other regions, the fracturing and displacement of many minerals along the C or shear planes, can be seen. The biotite crystals do not show brittle deformation but the bands containing these could be found displaced along the C planes.

6.8 THE LATE THERMAL HIGH :

This metamorphism appears to be related to the event which caused minor D₃ buckling of pre-existing structures. This caused chloritization of garnet (Fig. 6.3 G), destruction of original fabric and the development of hornfelsic characters in some rocks, particularly those rich in calcite and quartz and also caused polygonisation of the pre-existing fabric; this metamorphism therefore had retrogressive effects on the existing mineral assemblage.

Fig. 6.3G: Chloritization of garnet and destruction of original fabric.
6.9 TIME MOVEMENT RELATIONS OF MINERAL GROWTHS:

The relationship between the two metamorphic episodes and the deformation events are tabulated in table 6.1 and also diagrammatically shown in terms of mineral growth and deformation sequence graph in table 6.2.

**TABLE - 6.1**

<table>
<thead>
<tr>
<th>Metamorphic Episodes</th>
<th>Deformation events</th>
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</thead>
<tbody>
<tr>
<td>1. Primary biotite, Pre D₁ garnet Pre-Untala deformation event. found in supracrustals.</td>
<td></td>
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<tr>
<td>2. Growth of Biotite, and Deformation D₁ Plagioclase.</td>
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<td>3. Matric coarsening</td>
<td></td>
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<td>5. Rupture of minerals.</td>
<td>Foliation parallel shear during D₂.</td>
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<tr>
<td>6. Rupture of plagioclase</td>
<td>Deformation D₃</td>
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<tr>
<td>7. Retrogressive effects</td>
<td>Deformation D₃</td>
</tr>
</tbody>
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**TABLE 6.2**

<table>
<thead>
<tr>
<th>Minerals</th>
<th>Pre D₁</th>
<th>D₁</th>
<th>D₂</th>
<th>D₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
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<td>Biotite</td>
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<td>Chlorite</td>
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<td>Plagioclase</td>
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<td>Garnet</td>
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<td>Hornblende</td>
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6.10 PLOTS OF DEFORMATION VERSES METAMORPHISM

Depending upon the appearance of a particular mineral assemblage under a particular P-T regime, the relationship between deformation and metamorphism can be graphically illustrated. This has been attempted in fig.6.4 in which ordinate represents various index minerals such as chlorite, Biotite, Hornblende and Garnet.

![Graph](image)

Fig. 6.4: Time/Temperature graph for Untala Granite.

As illustrated in the graph, most of the garnets and Hornblende development occurred during the static phase prior to D₁ and during and after D₂ episoders, also marked by migmatisation in the area. Thus, the first peak of metamorphism was achieved during the D₂ phase when garnet developed on the tops of crenulations but this growth probably ceased after the D₃. Folds in the field are not associated with any mineralogical reconstitution and are domainal in nature.
The $M_2$ (may not be exclusively thermal as mentioned earlier but dominantly thermal caused retrogression of the existing mineral constituents. Broad correlation event is shown in fig.6.4.