CHAPTER - VIII

METAMORPHITES
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8.1 INTRODUCTION

The present area includes a good number of metamorphic rock units such as granite gneiss, amphibolite, biotite schist and calc-silicate rock. The granite gneiss is the most dominant rock unit which has covered the major portion of the area.

On the basis of the field petrology, the structural geology, the petrography and mineralogy, and the petrochemistry (Chapter 3,4,5,6) the following discussions on the different metamorphites have been put forwarded.

8.2 GRANITE GNEISS

I. Field evidences

(a) The granite gneiss grades from streaky gneiss (Photo 4) through weakly foliated gneiss to strongly foliated gneiss (Photo 6).

(b) Interfoliation of granite gneiss with biotite schist and amphibolite is very common (Photo 7,46).

(c) Granite gneiss, biotite schist and amphibolite are all affected by the same structural deformities namely the $F_1$ and $F_2$ folds (Photo 8,9).

(d) Foliation in biotite schist and amphibolite shows concordant relationship with the foliation of the granite gneiss (Photo 7,42).

(e) The mineral lineation in the enclaves (biotite schist and amphibolite) and granite gneiss shows a definite parallelism.
II. Petrographical and Mineralogical Evidences

(a) The granite gneiss is essentially composed of microcline, plagioclase, quartz and biotite (p. 59).

(b) From schist to gneiss a gradational increase in the plagioclase and quartz proportion and a relative decrease in the biotite proportion exist (Fig. 54).

(c) The accessories namely zircon, apatite and sphene are small and subrounded to rounded in shape (p. 62).

(d) Increase of microcline with decrease of plagioclase is marked (Fig. 53).

(e) Myrmekitic and perthitic intergrowths are common features in granite gneiss (Photo 74, 75, 76).

From the thin-section study it is observed that microcline is younger than the other constituents of the rock, the plagioclase is of stable composition, biotite is dirty greenish in colour and is strongly pleochroic, the decrease of plagioclase was accompanied by increase of microcline.

The crystalloblastic nature of the microcline is indicated by its relation to pre-blastic components (quartz, plagioclase and biotite, Photo 72) and by its synantectic reaction with pre-blastic growth. The corrosion (Photo 81) and reaction margin shown by pre-microcline minerals support later microcline crystallisation. The synantectic reaction of microcline with biotite often results in corrosion and replacement processes of the mica by the microcline (Fig. 66).
The quartz shows anomalous extinction which supports that a solid phase had been strained. Observations of quartz between plagioclase and microcline, and quartz with undulating extinction in fractures of plagioclase can be interpreted as plastically deformed quartz, squeezed between plagioclase and microcline.

The feldspars behave as brittle substances in comparison to the more plastic deformation of quartz. However, observations of undulating extinction shown by twinned plagioclase (Fig. 59) and bending of plagioclase twin lamellae (Photo 78) are evidences of plastic deformation of the feldspar. Again polysynthetic twinning shows a bending prior to fracturing. These observations are in accordance with the fact that, when the limit of elasticity is surpassed, ruptures take place.

Biotite represents an early phase of crystallisation. Biotite laths often represents a pre-blastic phase of crystallisation often corroded, enclosed and assimilated by later blastic feldspar and quartz (Photo 74). Bending of micas can take place due to tectonic deformation. In addition, undulating of the extinction of biotite may result under tectonic influences. Microfolds consisting mainly of quartz and biotite, show that the micro-folding has taken place without plastic deformation of the biotite. Observations shows that the biotite laths are re-oriented with deformed quartz. In such cases of micro-folding in gneisses, the tectonic deformation of the rock resulted in a re-orientation and rearrangement of the micas.
Observations show that zircons in granite gneiss belong to two different generations. Transformists consider the first zircon as representing a sedimentogenic phase, i.e. the zircon is subjected to rounding due to transportation in the erosion cycle and the overgrowths as representing a later generation under the influences and conditions of granitisation. From the observed textural patterns (1) rounded and corroded zircon of sedimentary derivation and (2) a new zircon crystallisation as overgrowths are blastogenic within the granitisation processes, it can be concluded that zircons different in age and derivation exist in the same granite, i.e. sedimentogenic zircons and new zircons formed within the transformation and granitisation. The above opinions are supported by Augustithis (1973, p. 58,59).

The myrmekitised reaction margin is due to a “synantectic” reaction between a pre-existing plagioclase and later K-feldspar (p.31). According to V. Mathavan, 1991, the intracrystalline and replacement model of Augustithis (1973) is to a large extent based on the evidence of corroded myrmekite and myrmekitic quartz. The vermicular quartz associated with plagioclase may have formed in the plagioclase by intracrystalline infiltration and replacement of quartz forming solution prior to the crystallization of microcline. Subsequent corrosion and replacement of plagioclase by microcline, set free the myrmekitic quartz from its association with plagioclase. Incorporation of these myrmekitic quartz grains by microcline results in the formation of intragranular myrmekites, many of which show protruding quartz. That the plagioclase twinning of the pre-existing host has exercised a control on the form of the later myrmekitic quartz. That in other cases, however myrmekitic...
quartz bodies have crossed the twin lamellae. That in such cases the twin lamellae has acted as a barrier which prevented the further penetration of quartz. That the inclusion of relics of fine plagioclase twinning in myrmekitic quartz bodies are all clear indications of replacement of the pre-existing plagioclase by the quartz-forming solutions as stated by Augustithis, 1973 (p. 29-34).

According to Augustithis (1973) the relation of perthite-cleavage can be seen as a direction of greater penetrability of the K-feldspar host to the perthite infiltrating solutions, however, metasomatic replacement can take place at the side walls as defined by the cleavages. In addition to the penetrability direction provided by cleavage directions, other directions of penetrability may be formed by tectonic fractures, fissures and strained planes within the microcline. The association of perthites along such penetrability directions is caused after the crystallisation of the host microcline and supports a later formation of these perthites (post-tectonic). This is in contradistinction to the unmixing hypothesis which would require a simultaneous crystallisation of the host microcline and the perthitic plagioclase. The side walls of the cracks act as 'paths' of greater penetrability within the microcline host along which the perthite-forming solutions penetrated as a result of which replacement perthites are formed. In contradistinction to the post-kinematic perthites, it is dubious whether the perthitic bodies following strain planes within the microcline are post or synkinematic.

Pronounced undulosity and fracturing in quartz grains, undulose extinction, bent twin lamellae and fracturing in plagioclase, micro-
folding in biotite, penetrative form of chlorite suggest the effects of post-tectonic forces. Chloritisation of biotite is a late-phase hydration.

The modal composition of the granite gneiss plotted on QAP diagram (Fig. 53) shows that the composition of the majority of the gneiss is granitic, with very few exceptions. While plotting in QPM diagram (Fig. 54), shows that majority falls on the gneiss field.

III. Petrochemical Evidences

(a) The niggli c Vs al-alk diagram shows that majority of the granite gneiss fall in the sedimentary field and also falls in the greywacke field (p. 81; Fig. 88, 89).

(b) The 100 mg-c-al-alk diagram shows that all the analysed samples are distributed away from the igneous trend line supporting the sedimentary parentage (p. 81, Fig. 90).

(c) In the niggli c against mg plot granite gneiss plot inside or very close to the typical pelite-semi-pelite field away from the karoo dolerite trend, showing a sedimentary origin (p. 81; Fig. 91).

(d) The positive correlation of K₂O and Al₂O₃ is more characteristic of sediments than of igneous (p. 83; Fig. 96).

(e) The K₂O-CaO discrimination diagram shows that granite gneiss falls in the granite and adamellite field (p. 82; Fig. 95).
Considering the above mentioned field, petrological and petrochemical evidences it may be assumed that the granite gneiss is para-gneiss and that they are the metamorphic and metasomatic products of some earlier sedimentary rocks (Huang, 1962, p. 416-17). Petrochemical evidences support the derivation of granite gneiss from argillaceous and arenaceous sediments. It may be mentioned that siliceous shale or impure feldspathic sandstones respond easily to metamorphism and transform easily to gneisses (Mehnert, 1969, p. 515).

With the increase of pressure and heat, these massive quartzo-feldspathic rocks gradually graded into patchy and streaky types with the development of gneissosity and foliation. The patches and streaks are mostly biotite which are thought to have been formed from the iron and magnesium contents of the original sediments (Rast, 1965, p. 80).

Thus it may be stated that the granite gneiss derived from argillaceous and arenaceous sediments as a result of metamorphism under the amphibolite facies condition accompanied by migmatisation and granitisation during the regional metamorphism.

The main metamorphism took place at P-T conditions of amphibolite facies. Metamorphic processes accompanied by tectonic influences were responsible for the development of the granite gneiss from the sediments. The granite gneiss in parts show gradation into migmatic variety (Maswood, 1973, p. 112). The study of the microtectonic history of the rock is marked by the stressed quartz and feldspar and undulose extinction of quartz. Similarly the distorted cross-hatch twinning is attributable to a phase of deformation. The gneiss is
regarded as the granitised product of the basic and the pelitic rocks (Maswood, 1981). Petrochemical evidences show that granite gneiss of the area falls in the adamellite and granite field.

8.3 AMPHIBOLITE

I. **Field evidences**

(a) The amphibolites occur as patches and lenses inside granite gneiss (p. 32; Photo 10).

(b) The amphibolites and granite gneiss exhibit a concordant relationship (p. 32; Photo 8, 46).

(c) The amphibolites exhibit the same structural features as in the granite gneiss (Photo 8).

(d) The contact of granite gneiss with the amphibolite is very sharp (p. 32).

(e) Amphibolites occur as inclusion inside grey porphyritic granite (p. 32; Photo 24).

II. **Petrographical and Mineralogical Evidences**

(a) The amphibolite is essentially composed of hornblende, plagioclase, with or without biotite, diopside and quartz. Sphene, magnetite, zircon, apatite, epidote, sericite, vermiculite occur as accessories (p. 68).
III. Petrochemical Evidences

(a) The AFM diagram demonstrates broadly the tholeitic trend of the amphibolites (p. 88; Fig. 106).

(b) In the niggli mg-c diagram the amphibolites closely follow the migmatic trend of Karoo dolerites of South Africa (p. 88; Fig. 91).

(c) The igneous trend is also apparent in the 100 mg-c-(al-alk) and (al-alk)-c diagrams (p. 88; Fig. 90, 88).

(d) The tholeitic affinity is also evident in the $\text{Si}O_2$–$\text{FeO}^*$/MgO diagram (p. 88; Fig. 109).

(e) Plots of $\text{TiO}_2$ vs iron enrichment ratio $(\text{FeO}+\text{Fe}_2\text{O}_3)/(\text{Fe}_2\text{O}_3 + \text{MgO})$ have been plotted. The amphibolites mostly fall in the field of ortho-amphibolites, and rarely fall in the para-amphibolite field (p. 88; Fig. 111).

(f) In the ACF diagram the chemical composition of the amphibolites falls very near to the field demarcated for the igneous rocks (p. 89; Fig. 112).

(g) The Fig. 113 depicts the plot of total alkali, as against silica which shows tholeiitic nature of the amphibolites (p. 89).

(h) In Fig. 114, the plots of the felsic index data $100 (\text{Na}_2\text{O} + \text{K}_2\text{O})/ (\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO})$ vs mafic index $100(\text{FeO} + \text{Fe}_2\text{O}_3)/(\text{FeO} + \text{Fe}_2\text{O}_3 + \text{MgO})$ indicate the middle stage of differentiation (p. 89).

(i) The predominant tholeiitic nature is well shown in the plots of
\( \text{SiO}_2 \) vs FeO / MgO and FeO vs FeO/MgO (p.89; Fig. 115, 116).

(j) Plots of k, alk, ti, and c against mg (Fig. 117); al, fm, c, alk, mg, against si (Fig. 118) and al-alk against c (Fig. 88) are more or less consistent with the crystallisation from a basic igneous magma (p.89).

(k) The plots of majority of the samples in the Ca-K-Na triangular diagram follow the generalized basaltic trend and similar to the composition of basalts and dolerites (p. 89,90; Fig. 119).

(l) The plots of the amphibolites in Fig. 120 are seen to follow the trend lines of the Palisades sill which belong to the tholeiitic series (p.90).

(m) The normative composition diagram (Fig. 121) shows fall of the amphibolites in the quartz normative tholeiites field.

From thin-section studies it is observed that the hornblende has developed in three different stages (Devaraju and Wodeyar, 1986). The first generation is the brownish-green hornblende which occurs in discrete xenoblastic grains in diopside amphibolite. The second generation hornblende has predominantly green colour, bears secondary relation with the clinopyroxene and the first generation brownish-green hornblende, and have developed subsequently, during retrograde metamorphism. It is observed in biotite amphibolite. The third generation of hornblende is thought to be related to reactions during late stage movements is predominantly bluish and bears secondary relationship with hornblende of the first and second generations and is observed in hornblende amphibolite.
According to Winkler (1979), in the labradorite—bytownite amphibolites the composition of plagioclase hardly changes as compared to that of the original basaltic rock. At higher temperature and in presence of water, hornblende is formed at the expense of pyroxenes and olivines. These amphibolites persist to the highest temperatures of metamorphism. Depending on composition some diopsidic pyroxenes may be present instead of almandine—garnet. However, at lower temperatures, pyroxene is absent in the andesine—oligoclase—amphibolite. It may be mentioned here that plagioclase \( \text{An}_{50-60} \) occurs in diopside amphibolite, plagioclase \( \text{An}_{25-40} \) occurs in biotite amphibolite and hornblende amphibolite. The water required for the transformation was derived by the process of migmatization itself (Winkler, 1967). The same migmatization added to the extra alkalies to promote the formation of biotite and transformation of brown hornblende to blue green hornblende. Examples of such transformation are reported from other areas of the world which bear evidence of polymetamorphism (Engel and Engel, 1962).

De Vore (1955) suggests that the transformation of an epidote—amphibolite facies hornblendeite to a granulite facies hornblendeite could release large amounts of Cr, Ni, Cu and Mg and the reverse transformation could release Pb, Zn, Ti, Mn and Fe. The latter explains the abundance of sphene and iron ore associated with hornblende.

The problem of distinction between meta-igneous or ortho-amphibolites and metasedimentary or para-amphibolites has been widely discussed in the past, however Leake (1964) showed that although...
chemical composition of an individual sample might not permit an unequivocal identification of its parentage, the chemical trends obtained when a suite of analyses from an amphibolite unit are plotted on chemical variation diagrams, can permit the distinction between rocks of sedimentary and igneous origin. The petrochemical evidence of the present amphibolites show trends towards the magmatic origin of basaltic and doleritic composition.

The sharp concordant relationship with the host rocks, evidence of fine-grained margin, presence of complex twin laws of plagioclase, equal abundance of hornblende and plagioclase, relatively low amounts of quartz and biotite suggest an igneous origin for the amphibolites (Ramsay, 1986).

8.4 BIOTITE SCHIST

I. Field Evidence

(a) Biotite schist occurs as compositional layerings with the granite gneiss (p. 34; Photo 7), and as inclusions in granite gneiss and grey porphyritic granite (Photo 11; Fig. 4,12).

(b) Biotite schist exhibits the same structural features as granite gneiss (p. 34; photo 9).

(c) Biotite schist exhibits a concordant relationship to the country rock (p. 34; Photo 9,50).

(d) The mineral lineations in the enclaves are parallel to the mineral lineations in the surrounding host rock unit (p. 34).
II. Petrographical and Mineralogical Evidence

(a) Biotite schist is essentially composed of biotite, plagioclase and quartz. Magnetite, sphene, apatite, chlorite, epidote, zircon are accessories (p. 72).

(b) There is a gradation increase in the plagioclase and quartz proportion and a relative decrease in the biotite proportion from schist to granite gneiss (Fig. 54).

(c) The accessories viz. zircon and apatite are mostly subrounded to rounded in shape (p. 74).

III. Petrochemical Evidences

(a) The variation diagram c Vs al-alk (Fig. 88) shows that the biotite schist falls in the sedimentary field. Again Fig. 89 shows that the samples fall in the greywacke field (p. 90-91).

(b) The 100 mg-c-(al-alk) diagram (Fig. 90) shows that the samples fall very near to the greywacke field (p. 91).

(c) The niggli c against mg plot (Fig. 91) shows that the samples fall in the typical pelite-semi-pelite field (p. 91).

(d) The ACF plots (Fig. 122) show that the two biotite schist samples fall in the pelitic field (p. 91).

(e) The ternary plots of $\text{Al}_2\text{O}_3 - \text{CaO} - \text{FeO}$ (Fig. 99) show that the biotite schist falls very near to the greywacke field (p. 91).

(f) The low $\text{Na}_2\text{O}/\text{K}_2\text{O}$ is in favour of pelitic rocks (p. 91).
(g) The low average of Na$_2$O and higher K$_2$O concentration show affinity towards sedimentary parentage (p. 91).

(h) The excess of molecular Al$_2$O$_3$ over molecular CaO+Na$_2$O+K$_2$O indurated by normative corundum is characteristic of pelitic and different groups of sedimentary rocks (p. 91).

Thus based on the above evidences and mineral assemblages of the rock unit, it may be stated that original argillaceous and arenaceous sediments were subjected to the low grade regional metamorphism and was highly deformed.

It can be sugested that the biotite schist of the present area might have owed their origin by regional metamorphism of clay and shale mixture sediments (Barua, 1972).

On the basis of the mineral assemblage, the biotite schist is determined as being in the amphibolite facies of metamorphism (Heinrich, 1956).

Biotite schist represents original pelitic sediments that later were subjected to the regional metamorphism (Maswood and Goswami, 1978).

8.5 CALC-SILICATE ROCK

I. Field Evidences

(a) The calc-silicate rock occurs in bands. Different combinations of the constituent minerals give different colours to the bands (p. 35).
(b) The calc-silicate rock occurs conformably as compositional layerings and lenses with the $S_1$ foliation of the granite gneiss.

II. Petrographical and Mineralogical Evidences

(a) The rock is essentially composed of diopside, garnet, quartz, epidote, plagioclase $\pm$ calcite. Sphene, apatite, zircon, actinolite are accessories (p. 75).

Calc-silicate rock is generally taken to indicate their sedimentary origin. A siliceous impurity is a dolomitic limestone simply recrystallizes as isolated quartz bands. Impure limestones contain in addition to calcite various amounts of clays, quartz, dolomite, iron oxides and feldspars. Regional metamorphism forms minerals such as pyroxene (commonly diopsidic) garnet (grossular) and epidote (Spry, 1974, p.267-268).

The segregated bands of the rocks are formed as a result of metamorphic differentiation i.e. process of chemical diffusion (Ramburg, 1952; p. 215).

Lenses of the calc-silicate rock are considered as $S_0$ where it is parallel to $S_1$ of the granite gneiss. This is considered on the grounds that during polyphase deformations and metamorphism of the associated rocks, the rocks might have been destroyed and dislocated and trapped there in course of subsequent granitisation of the host rocks (Barua, 1977).

The presence of diopside, plagioclase, grossularite, grossularite with quartz and plagioclase together with the development
of axial planar foliation \( (S_1) \), granoblastic textures, association of migmatite and metasediments suggest that rocks belong to amphibolite facies of metamorphism (Turner and Verhoogen, 1960, p. 544-553; Winkler, 1967, p. 106; Turner, 1968, p. 307) and to medium-grade of metamorphism (Winkler, 1973).