CHAPTER VIII

METAMORPHISM

1. INTRODUCTION

In the following pages, the metamorphism of the rocks of Halog area, as revealed by megascopic and microscopic study (Chapter IV), has been discussed. It is probable that the various deformatative phases (Chapter VII) have also influenced the characters of these rocks and a close relationship between the metamorphic episodes and deformative phases has been established.

2. GRADE OF METAMORPHISM

The rocks, showing a variation in metamorphic mineral assemblage, show a reversal and repetition in tectonic sequence. When the lithological groups of the area are arranged according to their stratigraphical succession (see Chapter IX), tentative metamorphic zones in relation to depth can be established which forms the broad divisions of the lithological units (Chapter IV, Table III). They correspond to mesograde and epigrade of metamorphism (Grubenmann and Niglee, 1910, vide Turner and Verhoogen, 1961).

The detailed petrographical paragenesis (Chapter IV) reveals that the rocks of the Halog area can be classified according to the appearance of index mineral. Barrow (1893) has shown Scottish Highlands
that the advancing metamorphism in argillaceous sediments is marked by the first appearance in turn of particular index mineral. The complete succession of Burrowian zone has not been observed in the Halog area. In addition to this, the rocks of the Halog area have been subjected to later episodes of metamorphism and tectonic inversion which have added to the difficulty in arranging the rocks of the Halog area according to the Burrovian classification. The rocks of the area, now, show increasing metamorphism upwards, i.e., inverse of metamorphic grades as following:

III - Garnet-biotite Zone (partly felspathised) - A part of Jutoqhs

II - Biotite-garnet zone - major part of Jutoqhs and a part of Chails

I - Chlorite-mica zone - Major part of Chails and some parts of para-autochthon unit

A similar zonal classification has been established by Das (1966) in the Chaukhutia area of Kumaon region. The zonal arrangement of minerals, like staurolite, garnet etc., which are the characteristic minerals of regional metamorphism, has been established in Chor area (Pilgrim and West, 1928; Kanwar, 1965).

It has been observed by various workers that the appearance of index minerals is also controlled by the original character of the sediments. Originally evolved by Goldschmidt (1911, vide Turner and Verhoogen, op. cit.), Eskola (1915, vide Turner and Verhoogen, op. cit.)
elaborated the facies concept. Eskola (op. cit.), while working in Orijarvi mining area, came to the conclusion that at a given constant temperature and pressure, the rocks of the similar chemical composition result in the formation of rocks having an isograd mineral assemblage. Tiley (1924, vide Turner and Verhoogen op. cit.) further modified the previous concept and defined a metamorphic facies as controlled by certain temperature and pressure range irrespective of process of transformation.

The mineral assemblage of the metamorphic rocks of the Halog area can be grouped into green schist facies of regional metamorphism. The controlling factors in this particular case are low to medium temperature and varying moderate pressure which became augmented during the various episodes of the Himalayan uplift. However, considering the present mineral constituents in different rock types of the Halog area, the following sub-facies of Turner (1948) may be recognised:

I - Quartz (albite) - muscovite - chlorite sub-facies

II - Quartz (albite) - biotite sub-facies

III - Quartz (albite) - almandine sub-facies

The classification of facies into sub-facies has been lately revised. The transitions regarding the sub-facies has been observed by Miyashiro (1961) who recognised 'Facies Series' under certain range of physico-chemical environment. Fyfe and Turner (1966) is of the opinion that 'the meaning of sub-facies corresponding to minor phase
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change often imperfectly explored has confused rather than classified the issues".

### 3. METAMORPHIC HISTORY

The polymorphites of the area have preserved the various records of metamorphic history which is observed in their structures, textures and mineral assemblages (Chapter IV). The data collected both from the field and laboratory investigations have helped in evolving a rational metamorphic history of the area which has been discussed in the following pages.

The formations of the Halog area have witnessed at least five episodes of metamorphism (Table XII).

#### A. Episode I

This metamorphic event is restricted to Jutogh and Chail formations before the development of southern geosyncline (Pande, 1967). It has been observed by Pilgrim and West (1928) that the Jutoghs (allochthon) have undergone a metamorphism prior to deposition of para-autochthon rocks. So far in the Halog area, no definite evidence to prove the above hypothesis has been recorded. Yet, some of the minor structures give indications of these rocks to have undergone earlier metamorphism. This episode may be related to the development of $S_1$-surfaces in allochthon rocks, probably in the form of bedding cleavage. The development of chlorite-I and biotite-I may be related with this early phase of metamorphism.
B. Episode-II

The episode-II of metamorphism has effected both the units (allochthon as well as para-autochthon) of the area and from here onwards the metamorphic history of the allochthon unit runs parallel to those of the para-autochthon unit although differing in conditions of metamorphism. These conditions were dependent upon the original composition, temperature gradient and varying amount of pressure according to the depth of burial. It is presumed that the rocks of the area after being laid down in the southern geosyncline (Pande and Saxena, 1963) must have undergone a static deformation prior to the Himalayan orogeny. The metamorphic changes brought about as a result of this episode have been related to the load of sediments and geothermal gradient. Chlorite-I was developed in the para-autochthon rocks along with the development of bedding cleavage ($S_1$), while the bedding cleavage of allochthon rocks must have been accentuated to form bedding schistosity.

Daly (1915, vide Marker, 1952) manoed a part of British Columbia and reported that the cleavage and bedding were essentially parallel and had low dips over wide areas. He suggested a load metamorphism (static recrystallisation due to overburden load) origin for this area. However, the recent workers in metamorphic petrology have doubted that the load alone can cause any metamorphic changes in the rock (Turner, op. cit.). It may be presumed that the load in addition to geothermal heat might cause the reorientation and slight recrystallisation of the rocks at depth.
C. **Episode-III**

The episode-III of metamorphism is rather most important one in framing the chief characters of the rocks of the Ralog area. This episode represents a prolonged period of metamorphic changes brought about by varying (although interconnected) conditions and as such this episode may be divided into three sub-episodes.

The sub-episode IIIa is related with the progressive regional metamorphism. The garnet-biotite, biotite-garnet and chlorite-mica assemblages were attained in the allochthon rocks whereas the chlorite-mica assemblage was produced in the meta-sediments of para-autochthon unit. The deeply hurried, allochthon rocks were subjected to mesograde of metamorphism while meta-sediments of para-autochthon unit attained an epigrade of metamorphism. The synkinematic characters of the metamorphic minerals like garnet, i.e. the continuity of Si and Se surfaces (Chapter IV), strongly suggest that this metamorphism was synchronous with the development of schistosity ($S_2$) in Jutogh rocks. Thus, it may be presumed that the Phase-I of the Himalayan orogeny (Chapter VII) was also accompanied with the regional metamorphism.

The episode-IIIb is related with the geothermal metamorphism and partial migmatization. The geothermal metamorphism caused the development of porphyroblastic biotite-II superimposed over the dominant S-surfaces in the rocks of allochthon unit and banded phyllite (d1) of the para-autochthon unit (Chapter IV). The euhedral garnet (Plate XII, Fig. 4), which is superimposed over the main schistosity probably is also related with this phenomenon. During this sub-episode,
the basement rocks (Jutoghs) suffered migmatization (Pande and Saxena, 1963) but in the writer's area the migmatization is limited to only a small band measuring about 1 mtr. (Chapter III).

The sub-episode-IIIc is an ending phase of migmatization which was influenced by the hydrothermal solutions. These solutions acted upon the meso-grade minerals and resulted in the formation of low grade minerals. Thus biotite-I was retrograded to chlorite-II and porphyroblastic biotite-II changed into chlorite-III of similar textural behaviour with the main schistosity ($S_2$).

The problems in regional metamorphism of the Jutoghs Formation have not been dealt in detail. Kanwar (1965) has discussed these rocks from Chor area where he has related the regional metamorphism with the Chor granites and gneisses. Pilgrim and West (op. cit.) have suggested that the regional metamorphism was accompanied with recumbent folding and the end of this phase witnessed a granitic intrusion. Auden (1934) is also of the opinion that the regional metamorphism of the Jutoghs Formation is related with these granites.

Peter Misch (1949), while describing the paragneisses of Nanga Parbat, suggested that the regional metamorphism is synkinematic with the Himalayan orogeny, which also granitized the Salkhalas (homo-taxial of Jutoghs, see Chapter IX). However, "the crystallisation in general and granitization in particular continued after deformation ceased." Norites from Nanga Parbat, which are related with the Panjal volcanics (Cretaceous-Eocene, Wadia, 1932) have also been regionally
metamorphosed along with the Salkhala meta-sediments (Peter Misch, op. cit.). This observation suggests that the 'synkinematic' regional metamorphism took place during the Tertiary period along with the Himalayan orogeny. The similar phenomenon seems to occur in Simla-Hills as well.

The regional metamorphism of the Jutoghs (Kanwar, op. cit.) and Salkhalas (Peter Misch, op. cit.) seems to have been controlled exclusively by temperature. It is possible to explain the zoning in metamorphic facies by postulating a thermal dome (Wenk, 1962). As a special case, it has been found in the Alps that the isogrades of the thermal dome cut across the structural trend (Wenk, op. cit.). Zwart (1967) does not agree with the idea of thermal dome and he is of the opinion that the higher temperature is reached as a result of deeper burial (Miglee and Miglee, 1965).

The presence of any such geothermal dome in the Himalaya has been suggested by Pande (Personal communication). Whether the isogrades in the Himalaya cut across the structural trend or not, is still an open chapter to be investigated. The thermal dome may take its source of heat from the same source which granitized the Jutogh meta-sediments and probably this took place in phases after the main schistosity in the rock was produced.

The confining pressure seems not to have played a greater role during the regional metamorphism, although, it might have caused in accentuating the geothermal heat. It may be presumed that the directed pressure might have played a vital role in localizing the
high grade rocks. Thus the core of recumbent fold in Chor area acquired a ketazonal metamorphism, which however, the metasediments of the Halog area escaped. Probably this localization has been modified as a result of some post-kinematic recrystallization (Peter Misch, op. cit.).

Granitization has been defined as the process by which the solid rocks are converted to the rocks of granitic character without passing through magmatic stage (Read, 1957). It has been said that there are granites and granites (Read, op. cit.) and the same is true for the granites and gneisses of the Himalaya. Some of them are synkinematic, some are recrystallised older granites while some of them are metamorphic (Pande, personal communication). Pande et al. (1965) have assigned metamorphic origin of Kumaon gneiss and they have referred Ranibagh granites as tectonic one. The Mandi granites show the evidences of intrusion (Pande, Personal Communication).

D. Episode-IV

The episode IV of metamorphism is a prominent phase of retrogression which has been related with the thrusting of allochthon rocks (Phase-II, Chapter VII, Table XI). This episode is observed only in the allochthon rocks and especially the effect is intensified near the thrust zones and the Halog dislocation. The retrogression is caused by destructive metamorphism. The biotite and garnet are at times completely degenerated to Chlorite-IV. The garnet has been granulated to small fragments (Plate XIII, Fig. 6) and the chlorite-III and earlier chlorite have been bent and, at times, fractured.
The reverse process of metamorphism (or retrograde metamorphism) has been emphasised by Becke (1909, vide Knopf, 1931, p. 5) when he introduced the term 'diaphthoresis' to indicate the development of index minerals of lower zone at the cost of the minerals peculiar to upper zone. The diaphthoresis has been observed to be related with the inner differential movements, "that in some way, whether by increased heat due to friction, or by the facilitated passage of solution, or by both, promote a molecular interchange and rearrangement that result in diaphthoresis" (Knopf, op. cit., p. 7).

E. Episode-V

The episode-V of metamorphism marks the last stage of metamorphic changes brought about in the rocks of the Halog area. It is related with the last stage of faulting and dislocations in the area. This episode is characterised by total mylonitization, bracciation and diaphthoresis in the weak zones.