CHAPTER VI

S T R U C T U R E

The structural geology of the Pilkholi-Ranikhet region at first sight appears to be simple, but the area's detailed structural investigation reveals an interesting and complicated structural history. It is found that the area has been affected by a series of deformational episodes. The author's attempt has been to build up a complete sequence of the structural events affecting the rocks of the area, and it is not unlikely that the structural history as built by him may throw a considerable light on the structures of this part of Himalayas in general.

Though the author does not claim to have completely understood the structural history of the region, he feels that the findings in the present areas may prove valuable and encouraging, and the future work along the avenues opened up by the present study, may lead to the solution of a number of problems of Himalayan tectonics.

The structure of the area has been mainly worked out on the basis of a detailed lithological and structural mapping of all the outcrops of the various rocks exposed in the area. A critical analyses of all the data - structural as well as petrological, has enabled the author to build up a probable sequence of tectonic events.

As it has already been mentioned at several places in earlier pages, the metamorphosed and deformed rocks of the Ranikhet-Pilkholi area belong to two tectonically distinct units. The rocks of the Pilkholi series (Chaubatia schists, Jhuladevi gneiss and Paniali schistose groups) which constitute the overthrust mass, form a part of the Garhwal nappe of Auden (1937). These are separated, from the underlying quartzites and slaty phyllites of the Krol nappe, by the Upradi thrust (south Almora thrust). Investigations have revealed that the constituent rocks of the two tectonic units show distinctive structural characters, and a detailed and systematic analysis of the various structural elements, has enabled the author to work out a coherent sequence of the various deformational episodes, each episode having left some marks on the rocks. A careful investigation and interpretation of minor structural elements of any deformed area generally leads to a proper understanding of its regional tectonic pattern. Structural geologists have found that various minor structures - both planar as well as linear, show a definite genetical relationship with major structures. In the present area too, a careful study of all the minor structures has been made in the field, and these have been analysed in the laboratory. The author has been able to fit in all the minor structural features with the major structures of the area. In order that the structural geology of the area is properly understood, the author, before proceeding ~~to~~ with the description and the discussion of the characters and evolution of the various structural features has preferred to give chronologically the main events of the area's structural history:

Episode I:

Geosynclinal overfolding; formation of Ranikhet overfold; development of the axial plane foliation (S_1). The related lineation (L_1) is characterised by minor fold axes, striping due to cleavage-bedding intersection, mineral orientation etc.

Episode II:

The passage of the overfold into the Upradi thrust, accompanied by the slipping, shearing and drag folding of the foliation (S_1) gave rise to, in the neighbourhood to the thrust, the phyllonitic cleavage and the drag folds (S_2).

The axes of the drag folds characterised the related lineation - (L_2).

Episode III:

Synformal folding of the Garhwal thrust (into North Almora thrust and South Almora thrust). Rocks of both Krol and Garhwal nappe were affected. Development of chevron folds and the associated strain-slip cleavage in pelites and semipelites(S_3).

The fold axes of this herringbone type chevron folds, and the related puckers, mark the dominant lineation (L_3) recorded in rocks both above and below the thrust.

Episode IV:

Open north south folding affected the rocks of both Garhwal and Krol nappes. Puckers related to this folding characterise the lineation (L_4).

Episode V:

Development of a number of faults.

I. Structural elements of the rocks of Garhwal Nappe:

(1) Minor structures related to the Ranikhet overfold (Episode I):

(A) Planar structures:

(i) Bedding (S)

(ii) Schistosity and gneissic foliation } (S_1)

(iii) Axial planes of minor folds }

(B) Linear structures:

(i) Axes of the minor folds on S in quartzites - mullions. }

(ii) Quartz rods and Boudinage. }

(iii) Mineral orientation. } (L_1)

(iv) Striping or ribbons. }

(2) Minor structures related to the Upradi thrust (Episode II):

(A) Planar structures:

(i) Phyllonitic cleavage. } (S_2)

(ii) Axial planes of the drag folds. }

(B) Linear structures:

(i) Axes of the drag folds. } (L_2)

(ii) Puckering due to thrust. }

(3) Minor structures (?) related with the folding of the Garhwal thrust (Episode III):

(A) Planar structure:

(i) Axial plane of the herring bone type chevron folding and the related strain-slip cleavage -(S_3) .

(B) Linear structure:

(i) Axes of the chevron folds and the puckering related to the chevron folding - (L_3).

(4) Minor structures related with the late north south folding (Episode IV):

(A) Planar structures: Nil

(B) Linear structures:

Faint puckering lineation - (L_4).

II. <u>Structural elements of the rocks of Krol Nappe</u>:

(A) Planar structures:

(i) Bedding - (S')

(ii) Slaty and phylitic cleavage - (S")

(iii) Axial plane of the chevron folds and strain-slip cleavage (Episode III) - (S_3)

(B) Linear structures:

(i) Fold axes of the minor chevron folds. } (L_3)

(ii) Puckerings. } (L_3)

III. Post Upradi faulting:

(i) Philpitri-Jhuladevi dislocation (F_1).

(ii) Kotali-Bajina dislocation (F_2).

(iii) Tipawala-Telgaon dislocation (F_3).

IV. Joints ~~pattern~~.

STRUCTURAL ELEMENTS OF THE ROCKS OF GARHWAL NAPPE:

(1) Minor structures related to the Ranikhet over fold:

(A) Planar structures:

(i) Bedding (S):

The term bedding is used here for the original sedimentary foliation. The sedimentary bedding is recorded only in the rocks containing layers of quartzites. The quartzitic bands of variable thickness, are mostly confined to the northern part of the area, above the gneissic group. At most places, the bedding is folded, giving rise to recumbent structures (Plate I.B) and mullions. This folded bedding, ideally seen at Deolikhet, Upatnala, and north of Chaubatia, is very helpful in proper understanding of the major structure. The fold axes of these characterise the dominant lineation (L_1) and the axial planes are marked by the principal metamorphic foliation of the pelites and semi-pelites (S_1). Sedimentary structures like current beddings etc. are no where recorded, and it is not clear whether they never existed at all or they were obliterated by deformation.

(ii) <u>Schistosity and gneissic foliation (S_1)</u>:

Development of secondary foliation is one of the most essential structural features of regional metamorphism. Progressive regional metamorphism has perfectly developed the schistosity (S_1), and it is clear that the development of schistosity is related to deformation.

The apparent parallelism between lithological banding and schistosity gives an impression of bedding schistosity. It is only by a careful investigation of the minor folds that the true nature of the schistosity is understood. The schistosity typically shows axial plane relation with the small folds, and it is thus obvious that the main foliation is the axial plane cleavage related to the major (reclined) structure. The existing foliation thus, is not a product of load metamorphism, though it is generally parallel to the bedding. The parallelism is due to the isoclinal nature of the folding.

Discussing the genesis of such a foliation in general, Merh (1964) writes that, "The development of cleavage, schistosity etc. is in someway related to deformation. In practically all areas of regional metamorphism - pre-Cambrian terranes as well as orogenic belts, rock folding on regional scale is always present and a characteristic structural feature of such areas is the axial plane relationship of the metamorphic foliation to the regional as well as small scale folds". Further, he points out that "In the areas of crustal deformation, horizontally directed compression would develop folds in competent layers, while the incompetent rock would deform by plastic flow in a direction normal to compressive force, the recrystallisation of the incompetent rock mass which would accompany its migration towards the closures of the fold, would develop an axial plane foliation. In case of isoclinal folding this foliation happens to be almost parallel to the bedding." Somewhat similar mechanism can be postulated in the present case also. Petrographic studies have however, revealed that metamorphic foliation of the area is not entirely a phenomenon of rock flowage under compression, but shearing stress too, was also effective all the time. This is clearly seen in the garnet porphyroblasts which frequently contain spiral inclusions of quarts. This suggests that the garnets rotated while growing. The mechanism of the rolling of the 'S' shaped garnets in the present area indicates differential slipping along the foliation during crystallisation. This fact indicates the dominance of shearing stress in the development of the metamorphic foliation. Turner (1948, p.151) has given a general rule for the interpretation of rotated minerals. A normal 'S' of inclusions indicates an 'anticlockwise' rotation of the porphyroblast, while a reversed 'S' marks a clockwise rotation. Harker (1952, p.220) has mentioned that, "As a result of differential movement the growing crystal is often sensibly rotated".

In the present area, it is clearly established that the metamorphic foliation (S_1) is not due to load but is an axial plane cleavage related to the reclined folding of a shale-sandstone sequence (Plate I.A). As the regional metamorphism was closely followed by migmatisation, the schists were gradually transformed into migmatitic gneiss. Thus, it is apparent that the gneissic foliation is derived from the schistosity, and genetically both are identical.

The folded quartz and felspar veins in the schists which could well be considered as the fore runners of the main migmatising event, clearly point out that the deformation and migmatisation synchronised atleast in part.

(iii) Axial planes of the minor folds:

A large number of minor folds, related to the recumbent folding have been recorded from the different parts of the Ranikhet-Chaubatia area. These minor folds can be classified as (a) Small folds in the psammitic layers in the Chaubatia schists. (b) Folded quartz and quartz-felspar veins in the schists and gneisses (Plate I.A). In the minor folds of both the categories, it is striking that the schistosity always shows an axial plane relation with them and these minor folds are related to the major structure. The shapes of these folds are very helpful in establishing the antiform. It has been found that minor folds to the north of the gneissic band, generally show 'S' shaped while those to its south, are of characteristic 'Z' shapes. (The shapes 'S' and 'Z' should be very carefully observed as they have to be recorded keeping in mind from which side they are viewed).

(B) Linear structures:

A variety of lineations have been recorded from the rocks in and around Ranikhet-Chaubatia, which obviously show genetic relationship with the major folding. They all are parallel to the axis of the fold and are in a way, example of 'b' lineation. These different types of lineations have been described below:

(i) Axes of the minor folds in quartzites (L_1):

The minor folds shown by quartzites and quartzitic bands in semipelitic schists, show characteristic 'S' and 'Z' shapes. The axes of all the minor folds show a fairly constant direction of plunge (between NNE and NE). At certain places quartzitic bands are so folded that they have developed fold mullions. These mullions plunge moderately due NNE. The amount of plunge however, varies between 4° and 20°. A good example of mullion structures is seen near Upat (Plate II.A). A few feet thick quartzite band shows recumbent folds in the nala to the south of Upat, where the repeated flexures of quartzite band has given rise to conspicuous fold mullions - which plunge as usual to the N15°E at an angle of about 10°.

(ii) Quartz rods and Boudinage (L_1):

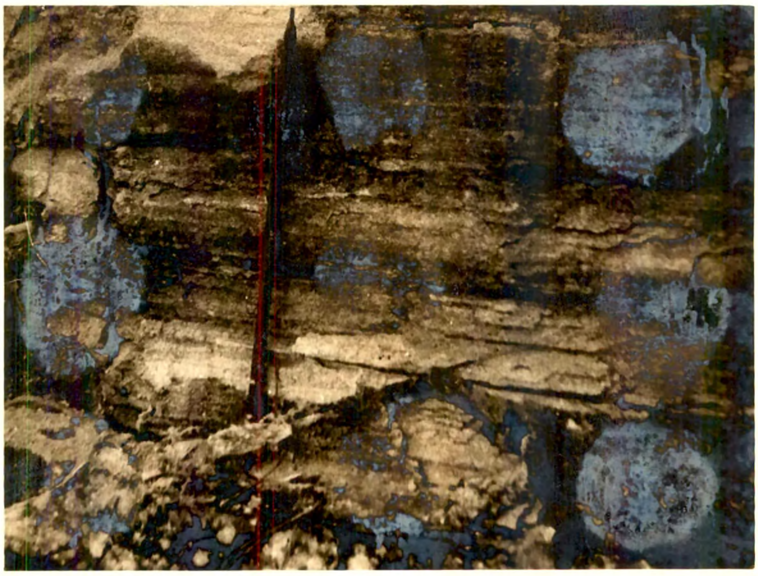
The schistose rocks of Ranikhet contain numerous thin veins of quartz, never exceeding a few centimeter in length. These veins have been characteristically involved in the differential slipping which accompanied the development of the schistosity. Either these quartz veins have folded (as very close 'Z's) giving rise to 'quartz rods' or they have been stretched as boudins.

The orientation of the quartz rods remains fairly constant and confirms to the regional fold axis lineation-plunging (7° to 20°) due NNE. Good occurrences of quartz rodding have been recorded from Ranikhet-Chaubatia. Similarly the axes of boudins, too show identical plunge. Boudinage is ideally seen at Paniali.

(iii) Mineral orientation (L_1):

This lineation is not very common and is only occasionally recorded. In quartzites, it is characterised by a fine linear arrangements of quartz grannules which imparts a peculiar streakiness to the foliation surface. In schists and gneisses, it is somewhat coarse and consists

PLATE V



A. Quartzites from Chaubatia showing ribbon lineation.

B. Phyllites from Bamsyum showing late strain-slip cleavage.

of elongated particles of mica, of quartz and of quartz felspar. This lineation due to mineral growth also parallels the fold-axis lineation and plunges gently due NNE. The exact nature and origin of these lineations is not understood but it appears that their genesis may be related to the recrystallisation accompanied by internal rolling and rotation along 'b' direction.

(iv) Lineation due to striping (ribbon) (L_1):-

This type of lineation is often recorded in the psammitic rocks of Ranikhet and Chaubatia (Plate V.A). The intersection of cleavage (S_1) and bedding (S) has possibly given rise to this lineation as a result that the foliation surface is marked by narrow flat stripes or ribbons. In such type of lineation generally recrystallisation obscures the cleavage, and a prominent striping survives. It plunges moderately due NNE and is essentially related with the first folding.

It will be seen that all the above mentioned lineations are genetically related with one single structural episode - the overfolding of Ranikhet-Pilkholi rocks (Episode I).

(2) Minor structures related to the Upradi thrust:

(A) Planar structures:

(i) Phyllonitic cleavage (S_2):

As discussed earlier, with the continued activity of the deforming stresses, the Ranikhet overfold passed into the thrust. The sudden dislocation along the thrust caused intense shearing and crushing and brought down the metamorphic grade. The retrogression is characterised by the formation of phyllonites. These phyllonites show a fine cleavage which almost coincides with the main schistosity and has NW-SE trend in general with local variation the amount of dip varies from 20° to 35° due N. It is essentially a shear cleavage.

(ii) Axial planes of the drag folds (S_2):

The rocks to the south of Ranikhet in the vicinity of the thrust have developed characteristic drag folds. These drags are produced due to the folding of the schistosity (S_1), during the sudden bodily movement of these Ranikhet rocks along the thrust plane. The axial planes of the drag folds have the same orientation as that of phyllonitic cleavage in general.

Its strike varies from N60° to N120° with the varying amounts of dip (20° to 35°) due N or NE. The development of these axial planes (S_2) is broadly synchronous with thrusting. The variation in the dip and strike of the axial planes of these drags appears to be due to (1) the variation in the degree of dragging at different places, and (2) the effect of late foldings. The axial plane (S_2) of these drags are more or less same as that of the axial planes (S_1) discussed earlier. Inspite of their similarity with (S_1) it is quite evident that (S_1) is genetically connected with overfolding while (S_2) with thrusting.

(B) Linear structure:

(i) Axes of the drag folds (L_2):

As discussed earlier the rocks to the south and SSE of Ranikhet (in the vicinity of Upradi thrust) exhibit intense drag folding (Plate III.B). In hand-specimen, as well as in thin section the foliation 'S' is folded, the axes of these folds invariably plunging to the NNE at a gentle angle. The geometry and the orientation of these drag folds is identical to those of the minor folds recorded in the northern part of the area and this clearly indicates that the minor folds in

(ii) Puckering due to thrust (L_2):

Another lineation obviously related to the thrust is the fine puckering of the foliation of the phyllonites. Genetically, these puckers are identical to the drag folds discussed above. Originating by an identical mechanism, the puckers are faint and less pronounced drags. Their orientation is identical to those of drag fold axes. The puckers due to thrust movements are more striking in the vicinity of the thrust and are well preserved in phyllonites. They show a gentle plunge (varying between 8° to 25°) generally due N.

Nature and geometry of Upradi thrust:

In its present position, the thrust forms the southern flank of the synform into which the Garhwal nappe has been folded. Thus, the original trend and dip of the thrust must be different from what we record just now in the field. In its existing position, only the local geometry and the sense of movement can be suggested.

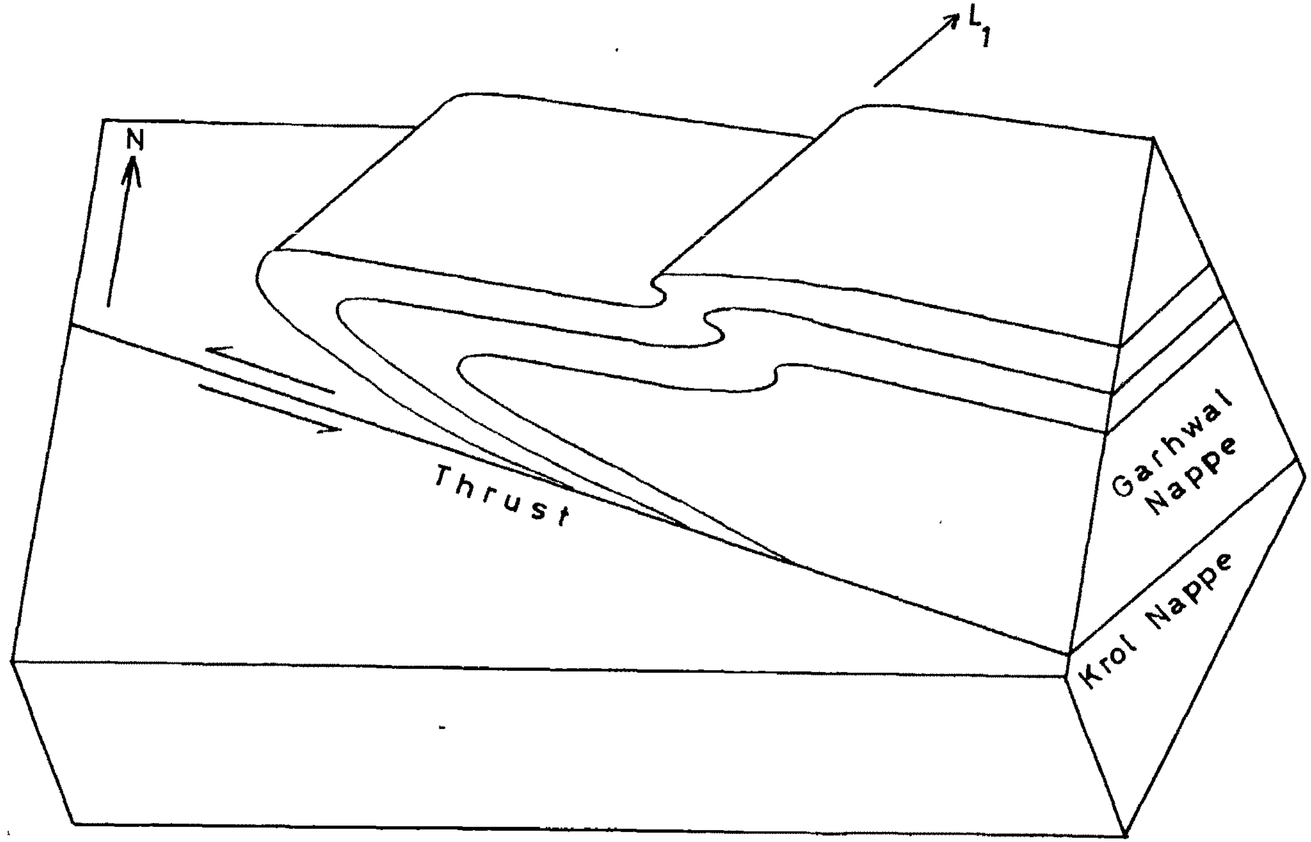


Fig 32 BLOCK DIAGRAM SHOWING THE RELATION BETWEEN OVERFOLD AND THRUST

It is reasonable to suppose that the thrust plane parallels the phyllonitic cleavage. If this is true, then the thrust can be taken as dipping moderately due NNE. As regards the sense of movement along the thrust, it should be understood that it is not at right angles to the strike of the thrust. The drag folds give an useful clue to this. The drag folds always develop in a direction at right angles to the slipping. Hence considering the drag fold axes, it could be surmised that the movement along the thrust has been due WNW (Fig. 32).

It also follows from present study that the origin and development of the thrust forms an integral part of the orogeny - consisting of folding, regional metamorphism and granitisation. Thus, not much time interval could be allowed between the various episodes. Folding synchronised with regional metamorphism and migmatisation. The thrusting seems to have followed immediately after. If the metamorphism and migmatisation took place during Lower Oligocene (Sarkar & others, 1965), then the thrust could also be dated near about the same period.

(3) Minor structures (?) related with the folding of the Garhwal thrust:

The author has recorded some minor structures, which are superimposed on the structures described above. Unlike the 'S_1' and 'S_2' and 'L_1' and 'L_2', which are genetically related with the development of the nappe, there are planar as well as linear structures of a date later than the thrusting, and are found in the rocks of both Garhwal as well as Krol nappes.

(A) Planar structures:

(i) Axial plane of the herring-bone type chevron folding and the related strain-slip cleavage (S_3):

The author has come across chevron type of folding of the schistosity (S_1). At some places folding is so sharp that fold hinges have broken and given rise to a characteristic strain-slip cleavage (S_3) (Plate V.B). This cleavage is seen to be almost vertical and striking EW to ESE-WNW. In the neighbouring Majkhali area, Desai & Merh(1965) have reported widespread development of a herringbone or chevron type folds which have given rise to an identical vertical strain-slip cleavage. The development of this cleavage (S_3) is essentially due to microfolding and fracturing along the hinges. It cuts across the foliation (S_1).

(B) Linear structures:

(i) Puckers related to the chevron folding:

The fold axes of the herringbone and chevron folds discussed above, mark the lineation 'L_3'. This lineation is frequently reocrded in the area, though it is more common in the area to the E & NE in the neighbourhood of Majkhali. It is either plunging very gently to the WNW or ESE or is subhorizontal.

There are few evidences in the area to fix the date and exact nature of the genesis of these superimposed structures - S_3 & L_3, but the investigation by the author in collaboration with Merh and Desai (Merh & Vashi 1965; Desai & Merh 1965) in the areas to the E and SE of the Ranikhet-Pilkholi region, do throw some light on the nature of these structures. It is found that this herringbone strain-slip cleavage and the related pucker, lineation are related to the folding of the Garhwal nappe into a synform - the two flanks of which mark the N- and S- Almora thrusts of Heim & Gansser (1939).

(4) Minor structures related with the late N-S- folding (Episode IV):

The last folding affecting the rock is a gentle NS flexuring. This is seen in the synformal and antiformal open folds seen in the area, and easily recognised on the map. No conspicuous planar structures are related to this folding, only a faint puckering lineation is developed.

(A) Planar structures:

Nil

(B) Linear structures:

Faint puckers are gentle often recorded, in the pelites and semipelites which show a gentle plunge of 15° due N.

STRUCTURAL ELEMENTS OF THE ROCKS OF KROL NAPPE:

(A) Planar structure:

(i) Sedimentary bedding (S'):

Immediately below the Upradi thrust, to its south, are the rocks which belong to the Krol nappe. As already mentioned, in the vicinity of the thrust is a group of quartzites with frequent interbedded argillaceous layers. The sedimentary bedding is clearly seen at numerous places, and is characteristically recorded in the flaggy quartzite layers as well as in the underlying limestone. The limestone exposed in the Kuchgadh nala, below Bamsyum, ideally shows the sedimentary bedding due to alteration of calcareous and non-calcareous (arenaceous as well as argillaceous) lamminie.

The occurrence of current bedding at some spots, indicate that the rocks to the south of the thrust constitute an uninverted succession.

(ii) Slaty and phyllitic cleavage (S"):

The slaty or phyllitic rocks which occur in association with the quartzites, show a well developed metamorphic cleavage, which is parallel to the bedding. The author is not in a position to say anything definite in respect of the ture nature and genesis of this cleavage. Though in all probability, the foliation nearer to the thrust may be related to the dislocation (? S_2), on going away from the thrust with the decreasing effect of the thrust, the original foliation (S") becomes prevalent. It is possibly an earlier metamorphic cleavage, whose true nature and genesis can be understood only after a detailed study of the area further south.

(iii) Axial plane of the chevron folds and strain-slip cleavage (S_3) - (Episode III):

Though not very frequent, the chevron folds and the related strain-slip cleavage 'S_3', is occasionally recorded. As usual they strike WNW-ESE and cuts steeply the earlier foliation. Merh (1965) has reported strong development of such cleavage in the chloritic rocks in the Kosi river about 10 kms. from Khairna bridge on Almora road.

(B) Linear structures:

Lineations of two generations are recorded.

(i) Fold axes and puckers related to the episode III. These are roughly ESE-WNW to E-W and sub-horizontal or plunge with a few degrees only to E or W.

(ii) Faint puckers (L_4) related to the last N-S folding (Episode IV) which has affected rocks of both Garhwarl and Krol nappes. These are occasionally recorded in pelitic layers and plunge due N or NNE.

DEFORMATION OF STRUCTURAL ELEMENTS:

Having established the sequence of tectonic events, the author now proposes to consider the effects of the superimposition of one structure on the other.

(1) <u>Effect of episode (II) on structures related to episode (I)</u>:

(i) S_1 (schistosity) drag folded into S_2, the orientation of S_1 and S_2 identical.

(ii) L_1 (1st lineation) shows no effect.

(2) <u>Effeet of episode (III) on structures related to episode (I)</u>:

(i) S_1 (schistosity) has developed herringbones type chevron folds (S_3).

(ii) L_1 (1st lineation) shows variation in the amount of its plunge.

(3) <u>Effects of episode (IV) on structures related to episodes (I and II)</u>:

(i) Development of open north-south flexures.

(ii) The fluctuations in the directions of the plunge of L_1 and L_2.

(4) <u>Effects of episode (IV) on the related structures of episode (III)</u>:

(i) Change in the axial plane direction of the S_3.

(ii) Change in the plunge of the L_3, so that it either plunges gently due WNW or ESE or it is subhorizontal.

III. Faults:

The area is traversed by a number of faults, some of them run through the entire mapped area, and even extend beyond it. The author has recorded three main faults. Two of them, which cut across the thrust, are obviously of post-thrusting period while about the third which runs approximately parallel to the thrust, no definite date can be fixed. As regards the age of the faults, the author, in the absence of suitable evidence is unable to make any definite statement. However, these could be tentatively correlated with the Recent faults of Auden (1948).

(i) Philpitri-Jhuladevi dislocation (F_1):

This fault (F_1) marks one of the major dislocations. Striking NE-SW, it cuts across the thrust. The extension of this fault even beyond the area towards the SW is easily traced. A conspicuous nala occupies most of the fault zone and can be well traced from Jhuladevi in the NE to extreme south west beyond the village Tana. In its NE part, it cuts through schists. The effect of this fault is very clearly recorded at several places and shows a marked vertical displacement of about 100 meters, the south eastern block being the downthrow side.

(ii) Kotali-Bajina dislocation (F_2):

Another major fault having an identical strike as that of (F_1) is traced along the nala near the village Kotāli. This fault passes through Kotali-Bajina and Chamoli in the area. Unlike the fault (F_1), It is a tear fault, the dominant movement being in the horizont al sense, though a few meter's downthrow of NE block is not ruled out. It is essentially a dextral strike-slip fault. Both faults 'F_1' and 'F_2' have affected the thrust and are obviously younger than the later.

(iii) Tipawala-Telgaon dislocation (F_3):

The Kuchgad nala for the most part, flows along this fault zone. It is almost parallel to the thrust plane. This fault can be clearly traced at Bokanyan temple near Bamsyum. The effect of this fault is clearly seen in the Kuchgad nala. This fault does not show any appreciable vertical displacement. At first sight considering the strike of the fault, one is tempted to connect this with the thrust but careful study of the nature of movement along the fault, it becomes difficult to establish any genetic relationship between this fault and the thrust. This fault too is of strike-slip type with dextral movement. The relative age of this fault cannot be determined with the existing data.

The occurrence of faults is established on the basis of numerous clearcut evidence in most cases. The field data collected to establish the fault could be summarised as under:

(1) Displacement of exposures has been taken into account. For fault (F_1) it is quite clear in Jhuladevi area. The gneisses SW of

Jhuladevi show a clearcut downthrow of about 100 meters. In the same way along the fault (F_2) and (F_3) lateral displacement is clearly recorded in the nala near Bamsyum and Kotali.

(2) Occurrence of rocks of different tectonic units on the two sides of the fault planes are recorded. This is clearly seen west of Tana village along the fault (F_1) where pink massive quartzites (Nagthat) come in contact with sericite-chlorite-phyllonites (Chandpurs).

(3) Slicken-sides are frequently recorded and are represented by smooth parallel striation and fine grooves. They are well preserved in psammites and semi-pelites. Good examples of slicken-sided surface are recorded along the NW side of the fault (F_3) in Kuchgad nala, right below the village Bamsyum.

PLATE VI

Joints in quartzites of Jhuladevi.

(4) Occurrence of crush-breccia is observed in the Kuchgad nala.

(5) Straight narrow alluvial zone in the nalas are also an indication of strike-slip faulting and are characteristic features of this part of region well seen along fault (F_3).

(6) Silicification along the fault planes in the form of veins is more common.

IV. <u>Joint pattern</u>:

No special study of the joints has been attempted. However, data regarding the numerous joint sets has been collected to give an overall picture of the joint pattern of the area.

Generally, the joints are better developed in psammites (Plate VII), though semi-pelitic variety and gneissic rocks too show fairly good joint sets. Pelitic rocks, on the whole show poor joints. The various readings taken at different outcrops all over the area clearly show that the joint patterns of the two tectonic units i.e. Garhwal and Krol nappes are somewhat different (Fig. 5). In the account that follows, various joint sets have been described in order of their prominance:

Set (1) North-South joints:

Strongly developed and recognised practically all over the area, are joints with a N-S strike and steep dip (of 70° to 80°) to the east. At several places they are almost vertical. Possibly this set becomes NNW-SSE in the southern part of the area. At places minor displacement of about a meter is seen along those joints. This joint set is obviously later than the thrusting.

Set (2) ESE-WNW joints:

Joints belonging to this set are very common and very conspicuous in the rocks of the Krol nappe below the thrust. Their strike is ESE-WNW and dip steeply (60° to 80°) due north. At some places, in the southern part of the area the dips of these joints are very steep, being about 40° to 50° due north.

Set (3) ESE-ENW joints:

These joints are common throughout the area and show almost the same strike as that of set (2) but are dipping (70° to 80°) due south. At places these are vertical. These joints become nearly E-W at some places but their dips remain same as described.

Set (4) NE-SW joints:

This joint is not very common and confined only in the southern part of the area. They are quite conspicuous near Upradi and Bamsyum. These joints show NE-SW strike and are dipping about 60° to 80° due NW. Possibly this set may be related to the thrust in some manner.