STRATIGRAPHY, SEDIMENTATION AND STRUCTURE OF A PART OF BHAGIRATHI VALLEY, DISTRICTS UTTARKASHI AND TEHRI, U.P.

THESIS SUBMITTED BY :

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The thesis entitled "STRATIGRAPHY, SEDIMENTATION AND STRUCTURE OF A PART OF BHAGIRATHI VALLEY, DISTRICTS UTTARKASHI AND TEHRI, U.P." presented by Sri A. K. Jain, M.Sc. embodies the results of investigations carried out by him from April 1965 to August 1969 as a full time research worker in this University. The work was done under my supervision and guidance. I certify that this work has not been presented for the award of any other degree or diploma.

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Arvind Kumar Jain

ABSTRACT

The thesis incorporates results on the stratigraphy,structure and sedimentation in an approximately 900 sq.km. of the Lesser Himalayan terrain along Bhagirathi river,districts Uttarkashi and Tehri,U.P. On the basis of geological mapping on 2 cm.= 1 km. scale, various lithostratigraphical units have been established and described with their field,megascopic and microscopic characters. The folds, faults and thrusts have been described with their field evidences. The structure of the area deals with their mutual interrelationship and is elucidated with a number of vertical cross sections. The effects of folding and thrusting of rocks are structurally analysed in a part of the northern region with π-diagrams. A tectonic setup of the area has been attempted and is compared with adjoining regions of the Lesser Himalaya between Simla and Kumaon.

A number of thrusts are conspicuous by occurrences of mylonites and metabasics which have been dealt with respect to their field,megascopic and microscopic characters. The metamorphism,mode of emplacement and relationship of mylonites and metabasics with thrusting is discussed.

The sedimentological studies include insoluble residue and chemical analysis of carbonate rocks and heavy mineral investigations in arenaceous rocks. The insoluble residues from dolomites and limestones are described. The chemical data for calcium and magnesium is used in classification of the carbonate rocks. The insoluble residue and CaO/MgO relationship is compared with carbonate formations of the Lesser Himalaya.

The heavy mineral separations from quartzites are quantitatively,qualitatively and statistically analysed. The lateral and stratigraphical variability of zircon and tourmaline varieties from Quartzite Formation of the Garhwal Group is regionally studied to show their importance in stratigraphy,

structure and tectonic interpretation. The grain size data of zircon,tourmaline and quartz from heavy mineral separations of quartzites and thin sections of non-calcareous sedimentary rocks is statistically represented by the Smithson and Haggermann diagrams for purpose of their application in correlation and sedimentation of rocks.

The stratigraphy of the area is separately described and correlated with other Lesser Himalayan formations. On the basis of the above studies, sedimentation and tectonic history of the area is reconstructed.

In the last chapter,the conclusions are briefly enumerated.

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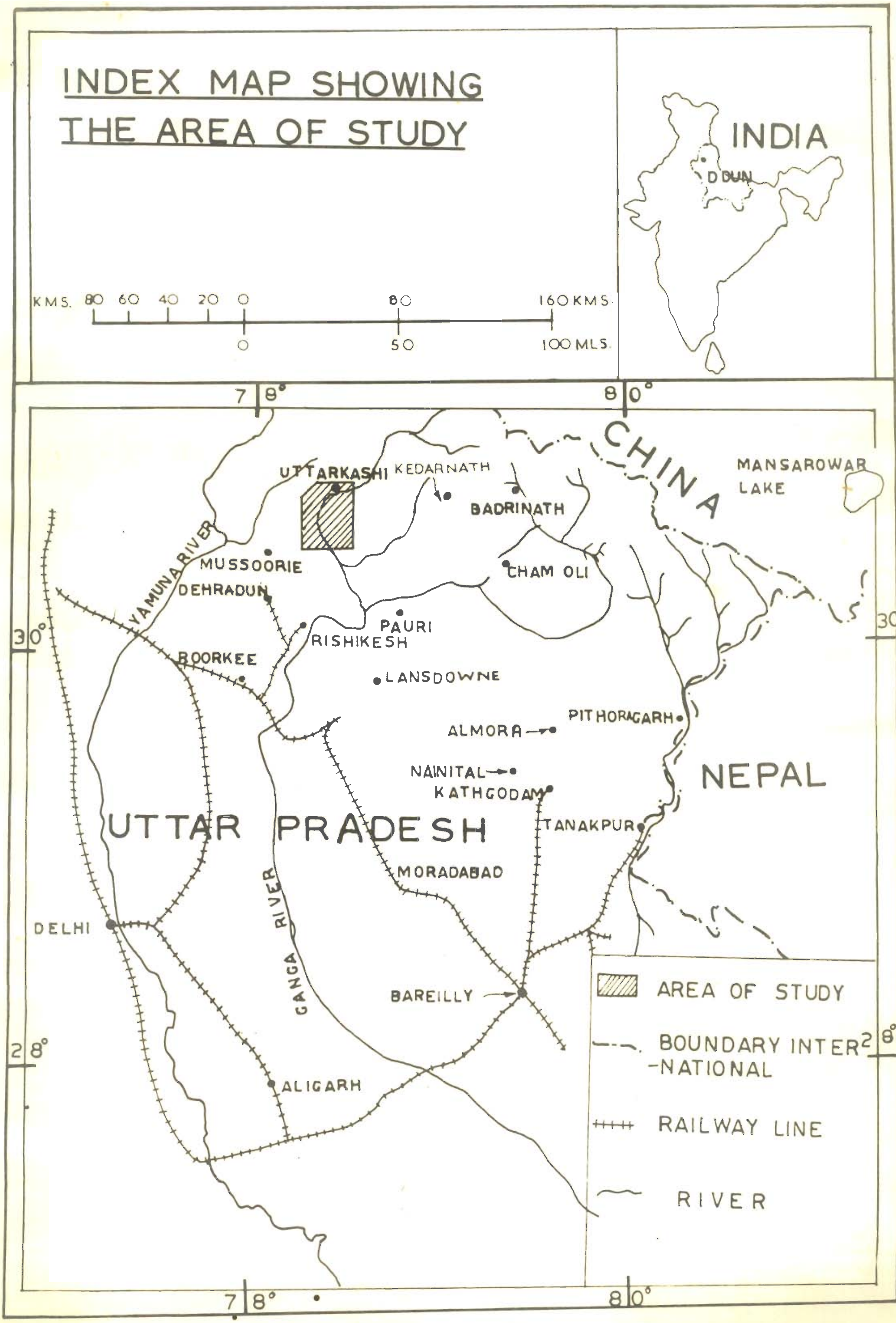

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THE AREA OF STUDY
INDIA
D DUN
KMS. 80 60 40 20 0 80 160 KMS.
0 50 100 MLS.
78°
80°
30°
28°
CHINA
MANSAROWAR
LAKE
UTTARKASHI
KEDARNATH
BADRINATH
MUSSOORIE
DEHRADUN
CHAM OLI
PAURI
RISHIKESH
ROORKEE
LANSDOWNE
YAMUNA RIVER
PITHORAGARH
ALMORA
NAINITAL
KATHGODAM
NEPAL
TANAKPUR
UTTAR PRADESH
MORADABAD
GANGA RIVER
DELHI
BAREILLY
ALIGARH
AREA OF STUDY
BOUNDARY INTER-NATIONAL
RAILWAY LINE
RIVER

CHAPTER - 1

INTRODUCTION

1.1 LOCATION OF THE AREA

The area under investigation lies in the Uttarkashi and Tehri districts of Uttar Pradesh and covers a part of the region commonly known as "Uttarakhand" (Map-1). It incorporates an approximately 900 sq.km. of the Lesser Himalayan terrain between latitudes 30°29' and 30°47' and longitudes 78°10' and 78°31' in the Survey of India toposheets no.53 J/6 and parts of 53 J/2,J/3,J/5,J/9 and J/10. The Bhagirathi river, one of the two chief tributaries of the River Ganga in the Lesser Himalaya, flows almost north-south across the area. The town of Uttarkashi*,the district headquarter and an important pilgrimage centre for the Hindus, is situated on its right bank and is approachable by 150 km. long all weather metalled road from Rishikesh, the last railway terminus in the foothills.**

In recent years the interior of the area has been made accessible by a number of new mule tracks and roads along which some of the best geological sections are exposed. The Uttarkashi road has been extended to Bhatwari and Harsil so as to connect Gangotri with Rishikesh. Similarly, Dharasu is now connected with Barkot by a 50 km. long road along the Khurmola Gad,while Uttarkashi is also approachable by another road passing through Bhaldiana and Lambgaon along the Jalkur Nadi. Light vehicular traffic is also possible on the Sarot-Chapra,Dhanaulti-Chapra, Silkyara- Bangaon,Gangori-Dodhi Tal and Tekhla and Netala 'logging section' roads (Map -2).

1.2 CLIMATE

The climatic conditions in the Lesser Himalaya are important governing

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* Refer appendix for the location

** In the text, this highway is referred as the Uttarkashi road and the milestones are given with reference to Rishikesh.

factors in carrying out field work without great hardships. Due to the varying altitudes from 800 to 3000 metres and topographical features, the diverse type of climates limit field season only to a few months. During the summer, the valleys are hot, humid and uncomfortable. The rainy season assumes its ferocity during 3rd week of June and continues till August. The winter season is very cold from December to March. It generally snows at higher altitudes while the rains are common in the valleys during winter. The temperature varies from -3°C to 35°C. The maximum annual rainfall is about 250 cm. However, the winter in 1966-1967 was throughout pleasant during which the main geological work was done.

1.3 PHYSIOGRAPHY AND DRAINAGE

As in any part of the Lesser Himalaya, the topography is typically immature, rugged, hazardous with thickly forested slopes. The area is characterised by the NNW-SSE to WNW-ESE trending prominent ridges and is separated from the Yamuna drainage system by a NE-SW ridge in the west and northwest. In the southwestern region, the Gorpha Dhar* joins with the Nag-Achrala Dhar and runs in the NW-SE direction. In the western part, many ridges trend more towards north northwest and north. On the left bank of the Bhagirathi river, the important ridges are formed by the dessication of ground by the Dhanari, Gamri and Dichli Gads,** and converge near hill 2890 metres.

The elevation of the area varies from 730 metres in the Bhagirathi valley near latitude 30°30' to the hill 2890 metres on the Baul Danda*. The topographical map of the area shows many peaks with more than 2500 metres in height. Of these the important ones are Deo(2648 metres) and Nagni Thak (2701 metres) and are made up of hard quartzites (Map -2).

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* Dhar and Danda equivalent to ridge.

** Gad equivalent to stream.

The area is drained by the mighty, turbulent perennial Bhagirathi, a tributary of the River Ganga. The Bhagirathi drainage system includes the following important streams:

(i) Nagon Gad flowing in the SE direction in the southwestern part.

(ii) Daski Gad, a SE flowing tributary of the Khurmola Gad in the central western part of the area.

(iii) Khurmola Gad draining the northwestern region with a S 20°E flow.

(iv) Rano, Sialam, Kaldi and Gawana Gads flowing towards south and draining a part of the northern region near Uttarkashi.

(v) Baragadi, Dhanari, Gamri and Dichli Gads draining the eastern region with a westerly and northwesterly flow.

(vi) Jalkur Nadi* flowing to the south.

The Pali Gad and Aglar Nadi flow to south and west respectively and belong to the Yamuna drainage system.

In the north, the Bhagirathi river flows almost east-west between Uttarkashi and Nakuri for about 10 km. and meanders in NW-SE and N 30°E-S 30°W directions. At Nakuri, the river takes a very sharp turn of 100° and changes its course to N 10°E-S 10°W for about 19 km. upto Dharasu. Further in the southeast, it flows NW-SE. The E-W trend of the river between Nakuri and Uttarkashi is peculiar to the area as it is characterised by a broad U-shaped valley in comparision to a typical V-shaped valley elsewhere. This feature appears to have been structurally controlled by the presence of Baragadi Fault and Uttarkashi Thrust (pp. 63 & 73) along the river course. This is also evidenced by another U-shaped valley of the Baragadi Gad along which the fault extends for considerable distance. The U-shaped valley of the river Bhagirathi has also been observed between Chunyali and Chham where the river flows along the Malli Anticline (p.60). Here, the valley is wide and beautiful with three

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* Nadi equivalent to small river but bigger than Gad.

flat cultivated river terraces. In addition, the other faulted U-shaped valley is of the Aglar Nadi.

Though the Bhagirathi river for most of the part in its upper course flows transversely to the regional NW-SE strike of the Central Crystalline Zone, it seems to have been effectively controlled by the strike of the Lesser Himalayan formations between Gangori-Netala, Nakuri-Uttarkashi and Dharasu-Chham.

The topography of the region is controlled by the lithology, strike and joints of the rocks. The variations in the trend of different ridges viz., Gorpha Dhar(N 60° W-S 60°E), ridge between Nagon and Daski Gads (N 55°W-S 55°E) Molthat Dhar(N 30°W-S 30°E) and Dano Dhar(N 10° W-S 10°E) are undoubtedly related to the variation in the strikes of the Nagthat, Dharasu and Quartzite Formations. Many northwest-southeast trending ridges in the eastern part of the area are similarly controlled by the strike of the Quartzite Formation.

A similar structural control over many streams is also apparent from their mutual relationships with the strike of the formations. Many of the valleys of Aglar, Nagon, Daski, Khurmola, Baragadi, Dhanari and Gamri Gads not only reflect this control, but even the slight changes of 20-30° in the strike directions of the formations are also imprinted in similar deviations in the stream courses. The main topographical features are shown in Map 2.

Adopting the drainage terminology as summarised by Howard(1967), the following drainage patterns have been identified in the area:

(i) Radial drainage pattern - It has been observed at Nagni Thak, Deo, Baul Danda and hill 2288 metres. The minor streams flow in all directions from these high peaks. The drainage is typical of the Quartzite Formation which comprises hard jointed quartzites.

(ii) Parallel drainage pattern - It is ubiquitously distributed and represents steep slopes.

(iii) Annulate drainage pattern - Such a pattern is developed by Baragadi, Dhanari and Gamri Gads in the eastern part. The rectangular pattern is oriented approximately NW-SE, NE-SW to N-S and E-W. The prominent NW-SE direction is controlled by the strike of the quartzites, bedding and other joints.

1.4 FLORA AND FAUNA

The thick forested cover over the rugged mountainous terrain is an important element in the landscape of the area. Accordingly, deciduous, dry subtropical and temperate forests are governed by elevation, temperature and precipitation. Shisham (Dalbergia sissoo), saal(Shorea robusta), tun, (Ecorelatona) are common at about 1200 metres. Chir (Pinus longifolia) forests are most common in the area between 1000 and 2000 metres and yield much of the revenue. At higher elevations deodar (Cidrus deodara) and barunj (Rhododendron arborcum) forests beautify the landscape.

Among the fruits, mango, banana, orange and lemon grow at lower altitudes while apple, appricot, citrus, peach, plum, pear, strawberry, kaphal etc. are more common at higher elevations. The crops are mainly wheat, rice and mandwa. The vegetables are mostly potato which is cultivated at higher altitudes in abundance besides tomato cabbage, chillies etc.

The fauna is on the decline due to unauthorised hunting. The big animals like bear, leopard and tigers are rarely seen. Other wild animals are pig, wolf, jackal, langaur, fox, spotted deer etc. Snakes and scorpions are common in the valleys, Some of the beautiful birds are cuckoo, golden eagles, pheasent, peacocks.

1.5 PREVIOUS WORK

The regional geology of Simla -Chakrata, Dehradun-Kalsi-Mussoorie and Pithoragarh -Almora regions of the Lesser Himalaya have been systematically worked out in detail by the various workers in the past 100 years. Medlicott (1864), Oldham (1883), Middlemiss (1891) and Holland(1908) paid more attention to the geology of the Simla-Chakrata- Mussoorie regions in the southern part of the Lesser Himalaya. The work in the late 19th and early 20th centuries has been summarised in certain important publications e.g.,"Geology of Himalaya ...." by Hayden (1908) and Burrard and Heron (1934).

The regional geological and structural work in the Himalaya gained momentum after the description of nappe structure in the Simla Hills(Pilgrim and West, 1928). After this, the contributions of Wadia (1931) (Syntaxis of NW Himalaya), Auden (1934a) (Geology of the Krol Belt), Auden (1937) (Structure of Garhwal), Heim and Gansser (1939) (Central Himalaya), West (1939) (Structure of the Shali Window), Valdiya (1962; 1964 a,b,c) (Geology of Pithoragarh region and Lesser Himalaya) and Gansser (1964) (Geology of the Himalayas) have thrown much light on the geology, stratigraphy and structure of the Himalaya. Of these, the contributions of Wadia (1932, 1938, 1955,1961) and Gansser (op.cit.) are valuable in understanding the regional structure of the Himalaya.

From the geological point of view, the present area has been paid little attention andwas investigated only along a few traverses.by Auden. Since his work in this part of Garhwal formsthe nucleus of all further studies and has been referred in this work every now and then, it has been reproduced as below. Auden's (1936) traverses to Gangotri along the Bhagirathi river in the Tehri Garhwal, covering a part of the present area have been summarised in the General Report of G.S.I. for 1935:

"The rocks encountered along Bhagirathi River as far as Sini(30°46': 78°35') consist of three groups in the following sequence:- top - schistose phyllites resembling Chandpurs, a thick series of quartzites and bottom - slates and limestones. The quartzites are well exposed from 78° 30' eastward to Sini and show a striking resemblance to those seen at Chamoli. Along this part of the valley, as along Alaknanda,there are extensive basic intrusive rocks, now as epidiorites. Still further northeast these are converted into hornblende schists. At Sini there is an abrupt change from sheared quartzites to the overlying schists and gneisses ....."

A somewhat more detailed account appeared in the General Report of G.S.I. for 1937:

" Mr. Auden has traced the Tons Thrust from Sarog (30°42':77°44') to Khand (30°32': 78°21') where it appears to terminate abruptly along the Bhagirathi River against major tectonic unit which divides the Barahat series from the overlying Chandpurs. The Barahat series is a newly recognized group of rocks consisting predominantly of quartzites together with limestones and occasional lavas. These quartzites resemble those of both Nagthat and Tal series but from their general relationships, Mr. Auden favours their correlation with the Nagthat (Jaunsar Series). They occupy extensive areas to the northeast of the Bhagirathi River and like the Nagthat quartzites show complex secondary folds. Near Pirhi hill (30°26':78°32') and Partapnagar, the associated limestones are mostly silicious dolomites containing bands of pale chert, but towards the northwest this type disappears,metamorphism increases and the limestones occur as fairly banded marbles similar to those in the Mandhali Series south of Chakrata. These marbles are to be seen near Giunota(30°45': 78°17') and just north of Barahat Rest House (30°45':78°27'). Amygdaloidal lavas occur near hill 5838 (30°30':78°28') and may represent a local development of Panjal Traps. A volcanic suite likewise is associated with quartzites, occurs south of Chamoli (30°24':79°20'). The Barahat series extends to the southeast into 53J/SE cropping out at Maniknath hill (30°22':78°40') and certainly joins up with the Chamoli group which Mr. Auden noticed along Alaknanda River in 1932 in sheet 53 J/NW. The SW boundary of this series with the overlying Chandpurs is regarded as thrust plane and has been traced from 30°46':78°17' to 30°24':78°32'. A large intrusion of dioritic rock grading into dolerite occurs on the east of Khurmola Gad just west of Guinota".

Further reference to Auden's work (1949) in the region appears in the General Report of G.S.I. for 1939.

"The main point of interest is that the Barahat series,first found in 1937, occurs in a tectonic window called by Auden as Chamoli Window.... Rocks exposed in the window are quartzites, dolomites and green beds including volcanics. Auden now proposes to substitute the name Garhwal Series in place of Barahat Series. Limestone .... appears to be overlained and underlained by quartzites and Auden thinks that the whole series may probably be equivalent to Nagthat-Blaini-Krol-Tal sequence of the Krol Tectonic Unit with two main differences (1) no tillite have been seen in Garhwal Series(2) amygdaloidal andesites (perhaps contemporaneous with Panjal Traps) are found in Garhwal Series but not in the Krol Unit. It is significant that Tejam Calc Zone of Heim and Gansser also occurs in a tectonic window below overthrust crystalline and that this zone is the southeast continuation of Auden's Garhwal Series".

In recent years, the Geological Survey of India has carried out systematic mapping of the area and the results of this work have now being communicated in the general report for 1964-65. In 1966-67, a team of geological trainees from the Indian Photointerpretation Institute,Dehra Dun have studied a part of the area for the aerial photo-interpretation of which a sketch map covering only the southwestern portion of the area has been published (Rupke,1968). A part of the southwestern region has also been traversed by Rao (1963,1968).

1.6 SCOPE OF WORK

The present work is a part of the assigned project in the Lesser Himalayan region between the Bhagirathi and Yamuna rivers under the Himalayan Geology Scheme of the University Grants Commission as has been implemented in the various Indian universities on the recommendation of late Prof.D.N. Wadia, F.R.S. at the Summer School on the Himalayan Geology, Simla in 1963.

In 1937, Auden in his tectonic map and cross-section across the Garhwal Himalaya(Map -10,Fig.57) has left a wide gap between the 'autochthonous zone' on the northern fringe of the Krol Nappe and the Central Crystalline Zone and equated this with the Krol Nappe tectonic unit with a question mark (also Auden,1949). Subsequently in 1949 he named this part of the inner sedimentary belt as 'Garhwal Series' and observed its occurrence in the 'Chamoli Window'.

With the aim of bridging this gap in the geology of Garhwal, the present worker has chosen this area which incorporates a major part of 'Garhwal Series' and covers a part of the northeastern region of the Simla-Krol Belt. No detailed publication dealing with the geology of the present area has so far appeared and therefore,this thesis is the first attempt on the geology of this unknown and important part of the Garhwal Himalaya.

1.7 FIELD WORK

The area under investigation was first visited in November-December, 1965 for a reconnaissance and was again traversed in May-June, 1966. The detailed geological work has been carried out during October to March, 1966-1967. About 8 months spread over in the three field seasons have been spent in the field. In addition, the adjoining areas have also been traversed for a better understanding of the regional structure. These traverses include (i) Uttarkashi-Bhatwari-Tiara along the Bhagirathi river, (ii) Uttarkashi-Dodhi Tal, and (iii) Barkot-Syanachatti along the Yamuna river. Besides this, another two months (May and June) in 1965 were also spent in the Srinagar-Rudraprayag area of the Tehri district.

Due to the inaccessibility and difficult terrain, the geological field work was mainly confined along the traverses dealing with the following aspects:

(i) Detailed geological mapping of the area with Brunton Compass on 2 cm. = 1 km. scale (1:50,000).

(ii) Collection and plotting of structural data.

(iii) Collection of representative samples of all rock types including systematic sampling of dolomites and limestones.

(iv) Preparation of geological field map, cross sections and sketches of important features which were also photographed.

1.8 LABORATORY WORK

The following laboratory investigations have been carried out during the present work:

(i) A critical study of relevant geological literature.

(ii) Petrographic studies - (a) study of megascopic characters of the samples, (b) study of nearly 350 representative thin sections, (c) modal analysis of various rock types by mechanical stage, (d) staining of nearly 50 dolomite and limestone samples and thin sections by Alizarine Red S.

(iii) Insoluble residue analysis of 39 samples of dolomites and limestones.

(iv) Chemical analysis of 26 samples of dolomites and limestones for their calcium and magnesium contents.

(v) Heavy mineral studies of 31 samples of the Quartzite Formation from the area in addition to 19 samples from Bhillangana-Srinagar-Rudraprayag and Bhagirathi-Yamuna valley regions.

(vi) Structural analysis of megascopic features from limited areas with the help of selective and synoptic contour diagrams.

(vii) Preparation of geological maps, cross sections, sketches etc. to elucidate the work.

CHAPTER - 2

GEOLOGICAL SETTING, LITHOLOGY AND PETROGRAPHY OF ROCKS

2.1 INTRODUCTION

The present area covers a part of the northeastern portion of the Simla-Krol Belt but it mainly lies within the Deoban-Tejam Zone of Gansser(1964). As has already been worked out by several workers e.g., Auden (1934 a) and Gansser (op.cit.), the lower sequence of rocks in these belts (pre-Blaini formations) generally comprises Algonkian to Lower Palaeozoic,unfossiliferous, arenaceous and argillo- calcareous sediments. Since the area has not been earlier studied in detail, the writer has mapped it on 2 cm. = 1 km. scale (1:50,000) (Map -3). On the basis of this mapping,the different rocks have been grouped into many lithostratigraphical units (Table 1):

The formations have been affected by metabasic and augen mylonites intrusives which are more abundant in the Garhwal Group. The rocks have generally suffered low grade metamorphism due to which many of the sedimentary textures are obliterated.

In the present work, nearly 50 thin sections and polished samples of limestones and dolomites were stained with Alizarine Red S for the identification of calcite and dolomite (cf., Friedman,1959; Dickson,1965). Calcite is stained to pink and purple colours while dolomite remained unaffected. Further,Mackee and Weir's (1953) classification of thickness of sedimentological unit has been adopted while Wentworth's (1922) scale of grain size is followed in describing the class limits for the clastic grains. The thickness of the lithostratigraphical units has been determined from many representative geological sections drawn across the formations.

Due to the meta-sedimentary character of the rocks, the following

TABLE - 1

CLASSIFICATION OF LITHOSTRATIGRAPHICAL UNITS OF THE AREA

PRESENT CLASSIFICATION	AUDEN'S CLASSIFICATION (1934a;1949)
(1) Laluri Formation Slates,quartzites and phyllitic slates.	(1) Mandhalis Quartzites,slates,limestones with conglomerates.
(2) Chandpur Formation Alternating phyllites and quartzites.	(2) Chandpurs Alternating phyllites and quartzites.
(3) Nagthat Formation Schistose quartzites,sericite quartz schists,arkoses etc.	(3) Nagthats Quartzites, sandstones, arkoses with conglomerates and minor slates and phyllites.
(4) Dharasu Formation Slates,phyllites and argillaceous quartzites.	(4) Simla Slates Slates,phyllites and graywackes.
(5) Bangaon Limestone Dark greyish black limestones.	(5) Deoban Limestone Dark grey limestones with minor slates.
(6) Garhwal Group Quartzites,limestones,dolomites, slates,phyllites,metabasics etc.	(6) Garhwal Series Quartzites,slates,limestones with amygdaloidal lavas.

descriptive classification has been used for the arenaceous rocks :

(i) The term quartzite is substituted for quartz arenite or orthoquartzites in conformity with the general usage.

(ii) The argillaceous quartzites refer to arenaceous rocks with more than 15% matrix and less than 10% feldspar and mica.

(iii) The terms micaceous and feldspathic quartzites have been used for arenaceous rocks with less than 10% detrital mica and feldspar respectively and minor amount of matrix.

(iv) Matrix is arbitrary defined as less than 0.03 mm. but must be largely interpenetrative due to metamorphism.

The stratigraphical relationships between various formations are complicated due to many large scale thrusts or faults along the contacts. Table 20 summarises the stratigraphy of each structural unit (Chapter 7). Here the formations have been described from south to north. The Part I of this chapter deals with their distribution, field and megascopic characters while the microscopic characters have been described separately in Part II.

2.2 BASIS OF NEW CLASSIFICATION

As has been shown in Table 1, the different lithostratigraphical units of the area are comparable to the classification of Auden(1934 a, 1949). Due to unmapped adjoining areas, new and modified classification has been adopted on the basis of the following criteria:

(i) Lithological characters and their associations which are comparatively different from the already established units.

(ii) Normal stratigraphical succession as evidenced from the gradational contacts and sedimentary structures.

(iii) Structural relationship of different lithostratigraphical units in the area.

(iv) Doubtful strike extension of the established formations due to unpublished work in the adjoining region.

(v) Association of basic rocks in the Garhwal Group rocks.

The "Code of Stratigraphic Nomenclature(1961)" has been adopted in classification of the lithostratigraphical units. The earlier stratigraphical names have been modified and a few names have been added to elucidate characters of the rock units. The term series, e.g., Chandpur Series and Garhwal Series has been changed to formation or group (Article 6). Though some of the lithostratigraphical units viz., Laluri and Dharasu Formations appear to be the strike extensions of the known series (Mandhali Series and Simla Slates respectively), new names have been used because of different and variable lithological characters and discontinuity in the geological work. This has helped in avoiding confusion with the present day nomenclature. The names like Dunda and Uttarkashi Formations describe varying lithological, stratigraphical and structural characters of probably the same sequence which is exposed in the Dunda and Uttarkashi Windows (Chapter 3).

PART -I GEOLOGICAL SETTING

2.3 LALURI FORMATION

2.3-1 MODE OF OCCURRENCE -

About 400-1000 metres thick sequence of slates, phyllites and quartzites is exposed on the Gorpha Dhar slopes and is designated as Laluri Formation after the village Laluri. The formation has been mapped from Chapra to Chham on right banks of the Nagon Gad and Bhagirathi river for about 15 km. in N60°W - S60°E direction. It overlies purple argillaceous quartzites of the Dharasu Formation and is delineated from the latter by the Tons Thrust (p. 66). The formation further extends in the northwest and southeast (Chapter 7) and dips uniformly to the S30°W at 30° on an average.

The Laluri Formation has been subdivided into 3 mappable Laluri A to C Members (Fig.1) which are conformable and show normal gradational contacts.

2.3-2 LALURI A MEMBER

The Laluri A Member, the lowest mappable lithostratigraphical unit of the Laluri Formation, consists predominantly of black friable slates and phyllitic slates with sporadic occurrences of quartzites, sandstones and limestones. It grades into the overlying greyish green phyllitic slates of the Laluri B Member but is dislocated against purple argillaceous quartzites of the Dharasu Formation. The thickness of the member varies from 0 to 300 metres. It pinches out at Kiari and extends for at least 15 km. in a narrow outcrop to Kandi in the southeast

The bulk of the Laluri A Member comprises black,splintry slates which crumple easily to very small fragments. These weather to dull brown and olive green surfaces with occasional white encrustations. In the southeast near Khand and Kandi, the slates are compact and phyllitic in character and develop distinct sheen and rarely wrinkled surfaces.

A characteristic of the Laluri A Member is impersistent occurrence of a greyish-buff, jointed, hard quartzite with a bluish hue. These are met with near Kiari, hill 1549 metres, Kunsi along the Sarot-Chapra road,Laluri, Gona,Birkot and near milestone 61/4 along the Uttarkashi road. Sometimes this quartzite is a useful marker horizon in mapping the member.

A small patch of black, coarse grained sandstone is intercalated with slates in southeast of Kunsi along the Sarot-Chapra road along with a small outcrop of dull brown, massive limestone. In addition, black, massive,cherty, nodular limestone is observed within the slates near milestone 61/4 on the right bank of the Bhagirathi river.

2.3-3 LALURI B MEMBER

The Laluri A Member grades to greenish phyllitic slates which have been classified into the Laluri B Member. It is exposed in a narrow outcrop between

Chapra and Ramolisera for nearly 15 km. along the strike. Like the Laluri A Member, it thickens from about 100 metres at Nala to about 400 metres at Ramolisera in the southeast.

The member comprises greyish green, thinly laminated(0.05-1 mm.), sheeny phyllitic slates with minor purple, slaty,argillaceous quartzite intercalations. These quartzites can be seen near Laluri. The slates weather to yellowish brown surfaces and are marked with small silica veins which develop a lineation.

These phyllitic slates and argillaceous quartzites bear strong resemblance with those of the Dharasu Formation. The Laluri B Member dips 30° due S35°W on an average.

2.3-4 LALURI C MEMBER

Overlying conformably the phyllitic slates of the Laluri B, the Laluri C Member is nearly 300 metres thick and is mappable for at least 14 km. along the strike from Andhiari to Ramolisera. Like the other members, it also extends for another 3-4 km. along the Maindkhal-Chham mule track in the southeast. The member consists of purple-green slates with intercalated gritty and argillaceous quartzites. The good exposures are seen near Andhiari, Kiari along the Sarot-Chapra road, 0.5 km. SW of Laluri forest rest house, and Naogaon. The member dips 30° due S35°W on an average.

Generally the slates are purple in colour but the green-purple-buff colour banding is not unconmmon. These grade to argillaceous beds of quartzites. There is a well developed slaty cleavage dipping in the SW at low angle to the bedding. The cleavages are marked with good micaceous sheen. The quartzitic beds are buff-grey,thickly bedded and get coarser to grits at places. The gritty quartzites show greyish purple elliptical and rounded quartz grains in a purplish recrystallised argillaceous groundmass (Fig.154).

2.5 CHANDPUR FORMATION

2.4-1 MODE OF OCCURRENCE

A thick sequence of laminated phyllites and quartzites conformably overlies the Laluri C Member and is classified into the Chandpur Formation (Fig. 1). As has been mentioned on p.13, the earlier Chandpur Phyllite(Auden, 1934 a) or Chandpur Series(Auden 1934 b) has been changed to the Chandpur Formation. Auden (1934b) has continuously traced the 'Chandpur Series' from west upto Nag Tibba. From the general consideration of the regional strike,it should extend in the area as the Chandpur Formation (p. 215).

2.4-2 FIELD AND MEGASCOPIC CHARACTERS

The formation resembles the typical 'Chandpur Phyllite' (cf. Auden, 1934a) and comprises greenish black phyllite and greyish green or greyish buff quartzite laminae on a fine scale (Fig. 155). As many as 18 to 20 laminae can be counted in one centimetre. Near Andhiari, the quartzitic layers are thicker and dominate over the phyllites. The overall quartzitic nature is apparent in contrast to the argillaceous character of the formation near Basul and along the Aglar Nadi. The sheeny phyllites occasionally show wrinkled surfaces due to an incipient slip cleavage which also develops a fine lineation. The rock is slaty near Basul without any micaceous sheen and weathers to greyish and mottled ash-grey-tan colours.

Interbedded with the Chandpur Formation are a few quartzite beds varying in thickness from 2 to 100 metres and have been noticed at Pokhri and 0.5 km. NW of Ardhiari. The quartzites are buff,massive and very coarse to fine grained. The contacts with the phyllites are sharp though a few phyllitic layers occasionally grade into the quartzitic beds.

The Chandpur Formation is mainly exposed in a 1.5 to 2 km. broad NW-SE trending outcrop between Andhiari and Basul on the northeastern slopes of the Gorpha Dhar and extends further to the southeast of latitude 30°30'.

The formation is approximately 800 metres thick and dips 30° due S30°W. It is overlain by the Nagthat Formation with a thrust contact (Basul Thrust).

Another exposure of the Chandpur Formation is mapped in the southwest between Thaturu and Bhawan Devi on left bank of the Aglar Nadi (Map 3) Here, the phyllites dip 15-50° in S to S50°W and abut against the northeasterly dipping Nagthat Formation which is separated from the Chandpurs by the Aglar Thrust (p. 64).

2.5 NAGTHAT FORMATION

Formerly designated as a stage of the Jaunsar Series(Auden,1934 a) but later separated into a separate series, namely the Nagthats(Auden 1934b; Pascoe,1959, p.452), the Nagthat Formation overlies the Chandpur with a thrust contact and is at least 1500 metres thick in the area (Fig.1). The formation is predominantly arenaceous and consists of sericite quartz schists,schistose quartzites and quartzites with minor amount of arkoses,slaty quartzites and schistose phyllites.

The sericite quartz schists are mainly developed in the vicinity of the Basul Thrust and grade to schistose quartzites further away from the thrust. These are greyish green, friable and strongly schistose. A prominent foliation is defined by two subparallel planes at low angles and is marked with elongated quartz and mica flakes.

The schistose quartzites and quartzites predominate over the other types and are approximately 500 metres thick on the Gorpha Dhar. These are buff grey, hard,jointed and occur in 10-70 cm. thick beds. The bedding is characteristically prominent and is marked with schistose phyllite intercalations. A few greyish white coarse quartz grains are visible as rounded clasts in a fine quartz rich groundmass. In these quartzites the foliation is poorly developed with a faint micaceous sheen.

The arkoses are met with in regions south of Deosari while the slaty quartzites are seen along the Bhawan Devi-Bhal footpath. The former are greyish, thickly bedded, medium grained in character and exhibit subrounded, white and porcellaneous feldspar grains. The slaty quartzites are buff-brown, fine grained and thinly cleaved.

An important feature of the Nagthat Formation is the occurrence of thin schistose phyllite intercalations in the schistose quartzites. Along the Dhanaulti road and 1 km. NE of Deosari the schistose phyllites are well developed and are dark greyish black, sheeny and laminated in character.

The change from the underlying Chandpurs to Nagthat Formation is abrupt with a sharp lithological contrast. While the Chandpur Formation is predominantly argillaceous, the Nagthats are arenaceous without any gradation at the contact. An abrupt increase in the metamorphic effects is also noticeable along the contact as compared with the underlying Chandpurs andis best observed at Basul, Koti, SW of Laluri and along Dhanaulti road. The phyllites develop a conspicuous sheen and are in fact, schistose phyllites.

The Nagthat Formation dips 10-50° in the SW and NE directions and is folded into the Deosari Syncline. It is bounded by the Aglar and Basul Thrusts in the southwest and northeast respectively.

2.6 DHARASU FORMATION

2.6-1 DISTRIBUTION

An interbedded sequence comprising of slates, phyllites and argillaceous quartzites is best exposed in the regions around Dharasu and occupies a vast area drained by the Bhagirathi river and Khurmola-Daski-Nagon Gads. The Dharasu Formation is nearly 2500 metres thick across the Chapra-Katkhet Section where it is exposed in nearly 10 km. wide track and windens in the northwest. It rapidly narrows to 1.5 km. in the southeast along the Bhagirathi, between Malli and Kandi where it is nearly 700 metres thick.

In the southwest and northwest, the Dharasu Formation underlies the Laluri A Member of the Laluri Formation with intervening Tons Thrust and Bangaon Limestone with a thrust contact respectively. In the northeast the Dharasus overlie the Garhwal Group rocks and are separated from the latter by the Dharasu Thrust. It is folded into four major folds of which the Daski Syncline is the most important.

2.6-2 FIELD AND MEGASCOPIC CHARACTERS

Lithology - The Dharasu Formation comprises an interbedded association of slates, phyllites and argillaceous quartzites. Of these, slates are nearly 300 metres thick near the base of the formation in the northwest on left bank of Khurmola Gad between Silkyara and Rari. These are dull olive-green to greyish black and thinly laminated rocks. At Bangaon these are phyllitic in character and have been locally mapped as Units B and C of the Dharasu Formation (Jain and Mithal, 1968) while at other places the slates imperceptibly grade to true phyllites.

The phyllites are predominantly greenish, laminated and arenaceous in character. Generally the laminations are green, greyish green with greenish grey hues and vary from 0.5-5 mm. in thickness. The green phyllites form distinct beds of varying thickness from 2 to tens of metres and extend laterally for some distance. Megascopically these resemble with phyllites of Laluri B Member of the Laluri Formation.

The rocks of the Dharasu Formation are dominantly arenaceous in character and are characterised by grey-green-purple, laminated, thinly bedded and massive argillaceous quartzites which look like 'wackes'. These quartzites are generally laminated (Figs. 136 & 156) to thinly bedded (0.5 mm - 15 cm.).
The argillaceous quartzites are grey-purple in colour with many shades of greenish grey, greyish green, dark greyish black, purple grey, and greyish purple. The quartzites imperceptibly grade to phyllites with individual

sedimentological unit measuring about 10 cm (Fig.135). The various shades in quartzites are intimately associated on a fine scale so that the formation cannot be subdivided into separate members. Nevertheless, the greyish and greenish argillaceous quartzites are more common on the left bank of Khurmola Gad and Bhagirathi river between Majhgaon-Dharasu-Pujargaon and are generally devoid of purple colours while the purple, massive argillaceous quartzites are more common along left bank of the Nagon Gad near contact with the Laluri A Member.

Generally, the argillaceous quartzites and phyllites are schistose along contact with the Garhwal Group of rocks. The contrast with the Garhwal Group is striking when in contact with the Dharasus e.g., at milestone 73/2 along the Uttarkashi road. The contact is impersistently marked with schistose metabasics near Soman and Ulya while the Dharasus are intruded by a metabasic sill at Rari.

<u>Sedimentary structures</u> - It is peculiar that the sedimentary structures in these rocks are generally lacking. However, a few 'ball and pillow' structures, trough current bedding and flute casts have been observed at some localities.

(i) 'Ball and pillow' structure - Pillow shaped concretions of greenish grey argillaceous quartzites are wrapped around by elliptical shaped laminae of the groundmass in the immediate contact with the concretions (Figs.145 &159). The pillows have been noticed (a) 0.5 km. north of Chapra on the right bank of Nagon Gad, (b) at milestone 2/1 along the Dharasu-Barkot road.

(ii) Trough current bedding - It is noticed in one outcrop of the purple grey argillaceous quartzites at milestone 70/4 along the Uttarkashi road and is locally inverted to the northeast.

(iii) Flute casts - Faint flute casts with S65°E trending oriented ridges occur on the undulating bedding surfaces in the greyish-green argillaceous quartzite outcrop at milestone 70/3 along the Uttarkashi road (Fig. 146).

Mesoscopic structures

(1) Planar structures (i) Bedding planes - The primary bedding or original stratification in the Dharasu Formation dips variably from 30° to 90° in N20°W to NE and S20°E to S80°E and N80°W. On the southern limb and in the core of the Malli Anticline,the rocks are steeply dipping to 50-70° due SW between Kandi and Chunyali along the left bank of the Bhagirathi river. The formation also dips steeply northeast of Dharasu along the Dharasu-Barkot and Uttarkashi roads (Fig. 135). The formation shows varibale strike at different places (Map 5). The strike of the formation swings to E-W near the Bangaon Thrust in sector 1 (Fig.7) while it trends N60°W -S60°E and N40°W-S40°E in sectors 2 and 3 near Jastwari and Katkhet respectively (Fig. 8 & 9). On northern limb of the Daski Syncline, the strike of the formation is NNW-SSE between Giunoti and Dharasu (Figs. 14,15 & 16) but even changes to NNE-SSW near Rauntal.

(ii) Slaty cleavage - The argiliaceous quartzites are cleaved and flaggy due to closely spaced slaty cleavage (Figs.151&156) which give rise to good slaty blocks locally called as 'parals' for construction purposes. The cleaved surfaces are sheeny due to micaceous minerals. While the bedding cleavage or schistosity parallels the original stratification, the slaty cleavage is inclined to the bedding (Fig.156). It dips gently to 35° S40°W on northern limb of the Daski Syncline. On the other hand, it dips 30° N30°E on southern limb of the syncline and at places even displaces the bedding by a few millimetres (Fig. 151).

The slaty cleavage is aligned paralled to the axial planes of minor folds in the core of the Nagon Anticline (Fig. 149)and dips 40-60° NE-N75°E.

(iii) Axial plane cleavage of minor kinks - Another fine cleavage due to minor kinks is found superimposed locally on the bedding planes or earlier slaty cleavage in the argillaceous quartzites along the Barethi-Chapra mule track (Fig. 152 & 157). It dips 40-70° SW-S75°W.

(iv) Joint planes - The argillaceous quartzites are closely and well jointed along the bedding planes. These are nearly vertical on both sides of river valley near Dharasu. In the phyllites, some minor joint planes are filled with fine silica veins and develop a lineation on the bedding surfaces. The rocks are highly friable and jointed in the vicinity of the Dharasu Thrust and develop loose scree material along left bank of the Bhagirathi river for considerable distance between Chunyali and Khalsi.

(2) Linear Structures(i) Axes of minor kinks - The axes of minor kinks form a promient lineation on the bedding planes or foliation and plunge to 10 -30° in the southeast (Figs.150 to 152& 157). This lineation is mainly confined on the southern limb of the Daski Syncline.

(ii) Minor wrinkles or microcorrugation: The sheenly phyllite surfaces are minutely wrinkled along discrete planes giving rise to a lineation plunging in the northwest and west at low angles between 10-30° on northern limb of the Daski Syncline.

(iii) Lineation due to joint fillings - Locally the silica filling along certain southeasterly dipping joint surfaces form regularly spaced lineations plunging by 5-15° in N to N30°E directions.

Folds - The formation is folded into four large scale NW-SE and NNW-SSE trending anticlines and synclines e.g, the Nagon and Malli Anticlines and Daski and Bharkot Synclines of which the Daski Syncline is the most important. The characters of these folds have been discussed elsewhere in detail (Chapter 3, pp. 59-60).

Thrusts - In the northeast, the Dharasu Formation lies against Garhwal Group of rocks and are separated from the latter by the Dharasu Thrust, while in the southwest it abuts against the Laluri A Member of the Laluri Formation due to the Tons Thrust. Another dislocation plane, the Bangaon Thrust,delineates the overlying Bangaon Limestone from the Dharasus in the northwest (Map 3). The contact features and other field evidences of these thrusts have been elaborated in Chapter 3.

2.7 BANGAON LIMESTONE

A part of a thick limestone sequence overlies the Dharasu Formation in the western region of the area near Bangaon. The limestone is conspicuous from a distance due to rugged, buff-brown coloured topographical features. It crops out near Bangaon along the Silkyara-Bangaon road. As has been noticed from the ridge, 1.5 km. NW of Bangaon, the limestone appears to be an eastward extension of a thick limestone succession which is exposed along the Yamuna river near Lakha Mandal.

Typically, the Bangaon Limestone is dark greyish black, fine grained, massive and is marked with a few pyrite specks. At times, the slate intercalations and colour variations in grey and black shades are conspicuous over the weathered surfaces. The limestones dip 30 to 90° due N30°E-N60°E and are thrust over the Dharasu Formation along a sinuous WNW-ESE and E-W trending Bangaon Thrust (Chapter 3). Near contact with the Dharasu Formation, limestones are argillaceous in character and are greyish green and thinly laminated. At the contact limestones are earthy brown and coarse grained in a 5-15 metres thick zone with thin phyllite bands.

2.8 GARHWAL GROUP

2.8-1 INTRODUCTION

In the type area of Uttarkashi, the Garhwal Series of Auden (1949), originally named as the Barahat Series*(Auden, 1938), is renamed here as the Garhwal Group (Article 6f - Code of Stratigraphic Nomenclature, 1961). Covering approximately half of the mapped area in the northeast, the Garhwal Group comprises a thick pile of low grade metamorphosed arenaceous and argillo-calcareous sediments with occurrences of metabasics and an augen mylonite

* Uttarkashi is also known as Barahat

TABLE - 2

LITHOLOGICAL CHARACTERS OF THE QUARTZITE FORMATION

Augen mylonites and metabasics along the Singuni and Dunda-Uttarkashi Thrusts respectively

	ROCK UNITS	CHARACTERS	DISTRIBUTION
QUARTZITE FORMATION	Purple and black slates.	Black and purple, arenaceous, friable and splintery.	Impersistent, occur only near the contact with the Dichli Dolomite.
	Micaceous quartzites.	Dark grey, medium grained, muscovite flakes visible	
	Purple quartzites	Purple, massive, hard, medium grained, with mud cracks	
	Quartzites	Buff-white, massive, hard, jointed, thickly bedded, medium to fine grained, occasional current bedding and ripple marks.	Widespread and predominate over the other rock units
	Schistose sericite quartzites	Buff-white, friable, medium to coarse grained, schistose, and lineated	In the immediate vicinity of the thrust planes
	Quartz schists	Buff-white, friable, strongly foliated and lineated.	
	Conglomeratic schistose sericite quartzites	Buff-white, friable, rounded and disc shaped pebbles and boulders of quartzites in sericite and quartz rich schistose groundmass	Near the base of the Quartzite Formation in southern belt

body.

In the northeast, the Garhwal Group is thrust upon by the Central Crystalline Zone along the Main Central Thrust. In the southwest,the group is overlain by the Dharasu Formation with intervening Dharasu Thrust.

Based upon the detailed mapping,lithological association,megasocpic and microscopic characters, the Garhwal Group has been further subdivided into four formations namely, Quartzite Formation, Dichli Dolomite, Dunda Formation and Uttarkashi Formation.

2.8-2 QUARTZITE FORMATION

Mode of Occurrence - The Quartzite Formation comprising a thick sequence of almost pure quartzites with occurrences of schistose sericite quartzites sometimes conglomeratic, quartz schists, metabasics and augenmylonites, occupy more than half of the Garhwal Group exposure (Map 3). It occurs in the following two belts:

(i) A southern belt lying south of 30°34':78°30' - Bagyalgaon-Singuni and hill 2239 metres, is bounded by the Singuni Thrust in the north and by Dharasu Thrust or Dichli Dolomite at its southwestern boundary.

(ii) A northern belt occupies the difficult, forested and higher elevations of the terrain around Uttarkashi between Jugaldi-Manpur-Dhauntri-Nakuri. Extending to the northeast upto Sainj and Kupra along the Bhagirathi and Yamuna rivers respectively, the belt is overlain by the Central Crystalline Zone along the Main Central Thrust. In the south, it is thrust over the Dunda-Uttarkashi Formation along the folded Dunda and Uttarkashi Thrusts (Chapter 3).

The lithological characters of the Quartzite Formation have been summarised in Table 2.

Field and megascopic characters - The Quartzite Formation comprises mainly buff-white, massive, hard ,thickly bedded, medium to fine grained quartzites (Fig. 130). The individual beds vary in thickness from 10 cm. to more than 150 cm. The bedding is occasionally marked with coarse grits but the colour changes in buff and white shades are more prevalent. Sometimes, even purple -green-grey colours are also seen at milestone 74/0 along the Uttarkashi road and near longitude 78°22' along banks of the Dichli Gad.

The contrast with dominantly argillaceous quartzites of the Dharasu Formation is profound and is more apparent when both are in immediate contact viz.,at milestone 73/2 along the Uttarkashi road. In comparison to the earlier described Nagthat Formation, the bedding in these quartzites is very poorly developed and lack any slaty or phyllitic intercalations. At places, it is even difficult to decipher the bedding due to their massive and jointed character. The formation lack any argillaceous or wacke beds except near contact with the Dichli Dolomite. Along the Dichli Gad, quartzites are ferruginous in character and are interbedded with 5-30 metres thick dark grey micaceous quartzites,purple and black arenaceous slates.

The quartzites are mostly medium to fine grained but are pebbly and conglomeratic in character near base of the southern belt at Khattukhal, Singuni,Bagyalgaon and along the ridge near hill 2174 metres (Fig. 131). However, the conglomeratic bed is absent at the road level (1020 metres).The bed is about 0-300 metres thick and appears to be lensoid in shape. It extends for about 8 km. in NW-SE along the strike. The bed is made up of buff-white, rounded,pebbles and boulders (10 to 40%) of quartzites which vary in diameter from 3 to 30 cm. These are disc to spheroidal in shape (Fig. 160) are are embedded in highly schistose quartz sericite rich groundmass(Fig. 159).

Close to the Singuni and Uttarkashi Thrusts,the quartzites are highly schistose and metamorphosed to quartz schists and schistose sericite quartzites. These are friable and profusely smeared with white sericite along the foliation planes (Figs. 161 & 162). The schistose varieties are best developed between Dhanpur, Foeld and Chaurikhal along the Uttarkashi Thrust and Sartali, Soman and Bagyalgaon along the Singuni Thrust.

Sedimentary Structures - The paucity of sedimentary structures is surprising in such a thick sequence of quartzites. The sedimentary structures, wherever observed, are upside and indicate that the Quartzite Formation is normal in its field occurrence except for local inversion. These include current bedding, ripple marks and mud cracks between milestones 73/6 to 74/4 and 80/0 along the Uttarkashi road and along right bank of the Dichli Gad near longitude 78°22'.

(i) Current bedding - The sedimentological units contain planar and festoon types of current beddings and in most cases the concavity in the latter points upside (Figs. 142 & 143). However, at milestone 80/0, these indicate an inversion of quartzites towards northeast (Fig. 144). A few palaeocurrent measurements along the road near milestone 74/0 give a southwesterly current.

(ii) Ripple marks - The ripple marks generally occur as casts on the lower surfaces of the bedding planes and are mostly symmetrical (oscillation ripple marks) with smoothly curved troughs and sharp edged crests (Fig. 140 & 141).

(iii) Mud cracks - The mud cracks have been noticed on trough of the ripple marks in one outcrop of the purple quartzites along the Dichli Gad (Fig. 141).

Thickness - The Quartzite Formation occupies wide expanse of the mapped region along left bank of the Bhagirathi river and is monotonously dipping in the southwest along the Jalkur Nadi between Dhauntri and Lambgaon.

Undoubtedly the quartzites are duplicated due to the Singuni Thrust, nevertheless, the formation appears to be enormously thick along the Jalkur and it is possible that a few thousand metres quartzites are exposed in this section.

Though it is difficult to measure camplete thickness of the Quartzite Formation due to uncertainty of the presence of possible intraformational faults or thrusts and complex folds, the reliable sections suggest following estimates of the thickness: (i) 50 metres near hill 2288 metres, (ii) 300-400 metres between Sartali and hill 2339 metres, (iii) 1200 metres near milestone 74/0 along the Uttarkashi road, (iv) 1,500 metres near Nakuri and (v) 1000 metres near Jakhni.

Dip and strike - On the regional scale, the Quartzite Formation strikes NW-SE but it trends more northerly near Nakuri and along the Dichli Gad near longitude 78°22'. The dips are variable between 15-90° in the N to E, S50°E to S and S80°W and N80°W to N60°W directions. The low dips are more prevalent near Maneri while the steep dips between 50 to 90° are observed near Nakuri, milestone 74/0 along the Uttarkashi road and Dichli Gad. However, the formation dips 45° on an average with NE and SW dips.

Joints - The quartiztes are well jointed with 5-6 sets of closely spaced joints. The prominent joints are mainly bedding joints and run for 5-10 metres (Fig. 130). A systematic joint study of the southern belt between milestones 73/2 and 74/4 on the Uttarkashi road gives bedding, strike and oblique joihts (Figs. 23 & 24). Near the thrusts quartzites are shattered and even powdered. The strike of the beds and joints obviously control stream courses of many small tributaries of the Baragadi, Dhanari, Gamri and Dichli Gads and Jalkur Nadi.

Mesoscopic structures - The quartzites are generally devoid of minor structures, but develop a prominent schistosity, mica lineation and slickersides along the Uttarkashi Thrust between Dhanpur, Foeld and Chaurikhal along the Uttarkashi-Lambgaon road. The foliation, slickensides and mica lineations are generally inclined at 15-60° in the northeast and southwest directions and have been structurally analysed (Chapter 3). Along the Singuni Thrust in the southern belt, the schistosity dips 35-60° SW and S60°W with mica lineation plunging in the same direction, while the slickensides plunge towards northeast along the Uttarkashi road.

Folds - Regionally, quartzites of the southern belt are uniformly dipping in the southwest and west and are devoid of any large scale folds. These are locally folded in NNW-SSE trending axes near 30°33':78°22' along the Dichli Gad. The rocks dip at high angles to 60-80° on the limbs.

The important N60°W -S60°E trending fold axis in the northern belt of quartzites runs along the Baragadi Gad and Bhagirathi river between Manpur, Uttarkashi and Matli where it makes a symmetrical anticline. The erosion of the crestal parts of this anticline has exposed the underlying Uttarkashi Formation into a window. Both limbs of the anticline are plicated into smaller NW-SE trending folds (Chapter -3).

Thrusts - It has been noted earlier(p.24), the Quartzite Formation occurs into two separate belts and is demarcated by the Singuni, Dunda and Uttarkashi Thrusts. Of these, the Singuni Thrust marks base of the southern belt and is characterised by about 300 metres thick augen mylonites which is well exposed at milestone 75/0 on the Uttarkashi road (Chapter 4). The southern contact of this belt is demarcated by the Dharasu Thrust on right bank of the Bhagirathi river. The northern belt is demarcated by occurrence of the metabasic rocks along the Uttarkashi and Dunda Thrusts (Chapter 3).

2.8-3 DICHLI DOLOMITE

Mode of occurrence - The southern Quartzite Formation belt is conformably overlain by a linear N-S and NW-SE trending outcrop of carbonate rocks, designated herein as Dichli Dolomite. The formation is well exposed on both banks of the Dichli Gad near its confluence with the Bhagirathi river and extends from hill 2208 metres to Khalsi for about 14 km. in the area. It has been observed continuing further to the southeast left bank of the Bhagirathi river upto Pirhi Hill (2742 metres) for another 16 km. The formation is conspicuous from a distance due to its rough brownish red and black mottled surfaces.

A complete sequence of the Dichli Dolomite is exposed on right bank of the Dichli Gad and is represented in Figure 2.

<u>Field and megascopic characters</u> -The Dichli Dolomite comprises nearly 300 metres thick sequence of intraclastic dolomites,algal dolomites and dololutites. The change from the underlying Quartzite Formation is very abrupt though a gradational zone of about 1 metre is marked with an impersistent arenaceous intraclastic dolomite. It is immediately succeeded by thinly bedded,coarse intraclastic varieties of dolomites(oosparite and intrasparite- cf., Folk, 1959, 1962)which make the base of the formation.

The intraclastic dolomites are generally greyish and purplish in colour with rounded, elliptical,circular and elongated greyish buff intraclasts of dolomite(Fig.164). These vary in size from 0.5 mm. to 2 cm. in diameter and are prominent over weathered surfaces. The interstices between the intraclasts are filled with coarse rounded,greyish,transluscent quartz in a dolomitic cement.

After a thin impersistent dololutite horizon, the intraclastic dolomites are succeeded by algal dolomites which can be easily identified in the field by their typical mound like vertical columns.These are more prominent on weathered surfaces (Fig.163). The algal dolomites are characertised by dome shaped, grey-white-purple coloured alternating curved laminae with an upward increasing diameter. The laminae are 1 to 5 mm.thick in the centre of the column and .. thin out near the contacts with the adjoining columns. In normal case, the concavity of these laminae points downward but is reversed where the beds are inverted, e.g.,near the Dharasu Thrust on left bank of the Dichli Gad.

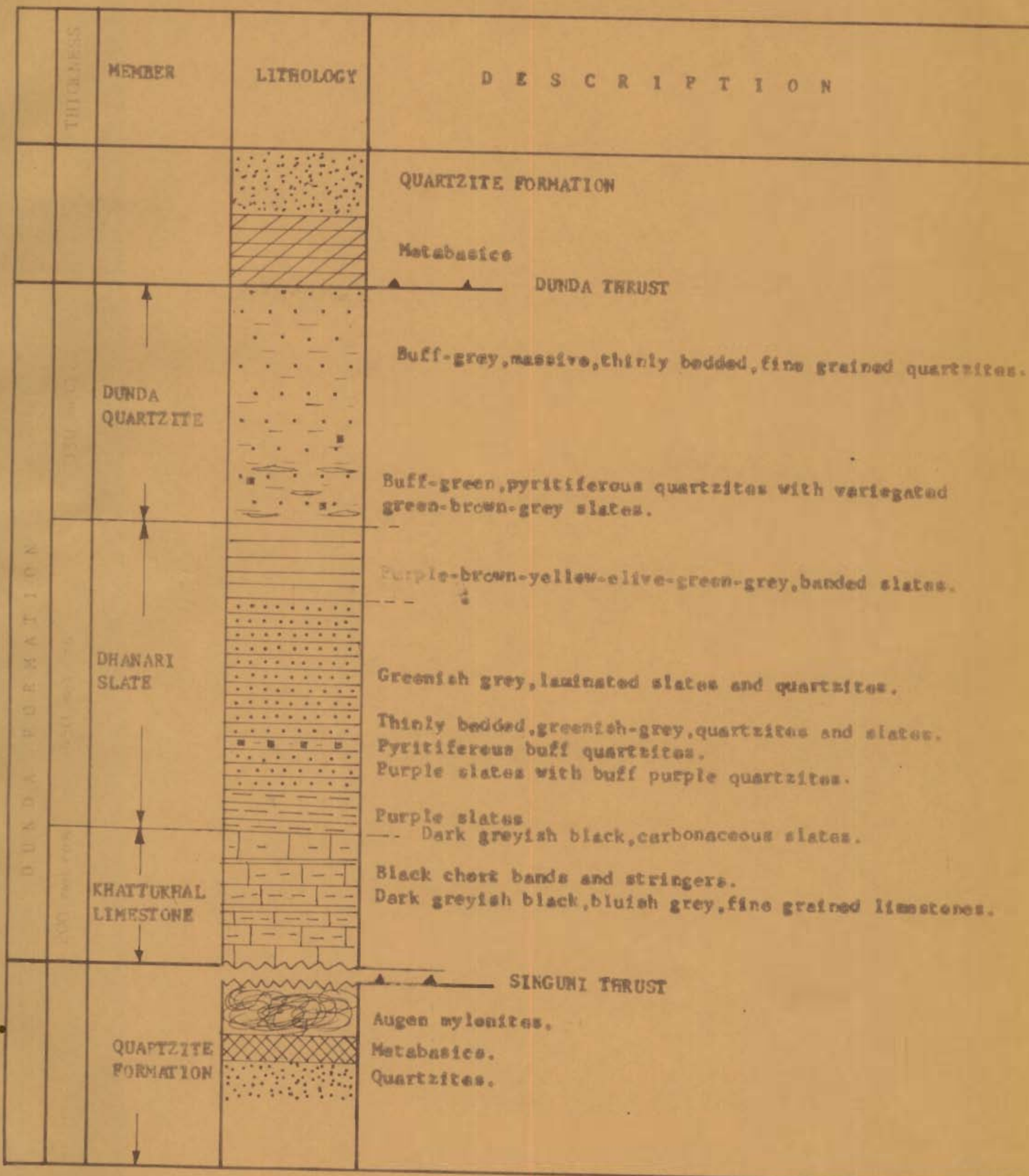
In form these appear to be stromatolitic structures and bear strong affinities with Collenia. These have been classified as Collenia columnaris (cf., Fenton and Fenton,1937). Similar forms of Collenia have been described from the following carbonate sequences of the Lesser Himalaya: Lower Shali Limestone (Valdiya,1962a,1967,1969), Upper Shali Limestone (Valdiya,1967,1969), Deoban Limestone of the type area (Valdiya,1969; Misra, 1969), limestones from the Tehri district (Nautiyal and Jain,1965) and Gangolihat Dolomites (Misra and Valdiya,1961, Valdiya,1969; Dixit,1966). It is noteworthy that Collenia has also been reported from the Precambrian formations of the Peninsular India: Lower Cuddapahs(Vaidyanathan 1961; Vishwanathia and Rajulu,1963), Lower Kaladgis (Vishwanathia,Rajulu,and Sathyanarayan,1964; Rajulu and Gowda,1966,1969) and Bhander limestones - Upper Vindhyans (Valdiya,1969; Misra,1969).

In the upper parts of the formation, the rocks are pinkish,massive, hard and fine grained dololutites with sharp conchoidal fractures. The dololutites are sometimes intercalated with purple green slates.

The formation is moderately to high dipping between 40° to 80° SW and W. Rocks are well jointed, some of which are filled with purple and white calcite and chert veins. The rocks weather to typical elephant-skin structure.

The formation is normal in its field occurrence with stromatolitic laminae pointing downward (Fig.147). It is locally inverted in the east near the Dharasu Thrust on left bank of the Dichli Gad where the concavity of the stromatolites points upward. The beds are intricately disturbed (Fig. 3) and folded into zig-zag chevron folds with subhorizontal axial planes along the Dharasu Thrust (Fig.4).

Figure. 5 STRATIGRAPHIC SEQUENCE OF DUNDA FORMATION ALONG THE UTTARKASHI ROAD



2.8-4 DUNDA FORMATION

The Dunda Formation comprises approximately 1000 metres thick sequence of limestones, slates and micaceous quartzites and is named after the Dunda village. The rocks are best exposed between milestones 75/4 and 78/0 along the Uttarkashi road. It trends NW-SE along the Dhanari Gad and Khattukhal stream* for about 25 km. in the area and extends for another 7 km. in the adjoining area to Gangani. The formation is folded into the Khattukhal Anticline and is exposed in the Dunda Window (Chapter 3) as it is found thrust upon by the Quartzite Formation. The Dunda Thrust limits the formation in north while the Singuni Thrust separates the Dundas from overlying quartzites in the south.

The Dunda Formation has been subdivided into three stratigraphical members i.e., Khattukhal Limestone , Dhanari Slate and Dunda Quartzite. Figure 5 presents lithostratigraphy of a representative section of the formation along the Uttarkashi road.

1. KHATTUKHAL LIMESTONE

The oldest exposed member of the Dunda Formation is seen along the Dhanari Gad and Khattukhal stream. It comprises bluish grey-black,thinly bedded,cherty,very fine grained limestones(calcilutites). The beds are 0.2 to 40 cm. thick and are marked with thin slate and chert intercalations in addition to variations in colour and granularity (Fig.133). Chert occurs as black stringers and sheets of varying thickness from 0.5 to 5 cm. Thin black slate intercalations are common near contact with the overlying member. In addition, the limestone is bluish grey,crystalline and crenulated in the vicinity of the Singuni Thrust (Fig.166).

A peculiar pellitiferous limestone,characterised by dark grey and black spheroidal and ellipsoidal pellets(0.5 to 6 mm. in diameter) embedded in a white crystalline groundmass is noticed at place nearly 1.5 km.NE of

* The stream flows through the Khattukhal village.

Nagla (Fig. 165).

The member is conspicuous from a distance due to its brownish rough weathered surfaces. It is highly fractured, jointed and ramified with calcite veins. Upon hammering the limestone gives a sulphurous odour.

The Khattukhal Limestone member is exposed into three linear detached outcrops for about 17 km:

(i) On the left bank of the Dhanari Gad near Singuni - the outcrop extends for about 4.5 km. between Painkhal and the Uttarkashi road and is about 1 km. in width. The best exposures are along the road between milestones 75/4 and 76/0. The limestones dip 15-70° due NE and SW.

(ii) On right bank of the Khattukhal stream- this exposure is 0.5 km. wide and extends for about 4.5 km. in a narrow linear outcrop between Khattukhal and Ulya. The limestones dip 30-60° in NE and N70°E directions.

(iii) On left bank of the Khurmola Gad between Ulya and Giunoti- outcrop is about 1.5 km. at its widest expanse and extends in NW-SE for about 8 km. with regional SW dips at 40°.

Generally, the member strikes NW-SE and dips between 15-90° in N to E and S to W directions. Nevertheless, the northeasterly and southwesterly dips are more prevalent. The member is exposed in the core of the Khattukhal Anticline as oldest member of the Dunda Formation and is conformably overlain by the Dhanari Slate on its northern limb. The southern limb of this anticline is largely concealed beneath the Singuni Thrust so that the overlying slates are repeated only along the road. The other outcrops of the member near Khattukhal and Sartali represent only partially exposed different limbs of the Khattukhal Anticline (Chapter 3).

2. DHANARI SLATE

The argillaceous sequence of the Dunda Formation has been called as the Dhanari Slate member and can be easily observed between milestones

76/0 and 76/6 along the Uttarkashi road. It extends along left bank of the Dhanari Gad and is well exposed near its confluence with the Bhagirathi river.

The Khattukhal Limestone member is conformably overlain by about 20 metres thick zone of black friable,carbonaceous slates which grade to overlying purple slates. These are overlain by alternating,fine grained,purple buff, quartzites and purple-grey-black slates (Fig. 167). The individual quartzite beds varying from 5 to 20 cm. are comparatively thicker than the slates. Near milestone 76/1 a 1.5 metre thick buff pyritiferous quartzite bed delineates these from the succeeding greenish grey quartzites and alternating slates. These vary in thickness from 1 mm. to 10 cm. The slates and quartzites are interbedded on a fine scale (Fig. 148) and resemble phyllites of the Dharasu Formation and Laluri B Member of the Laluri Formation. In upper parts of sequence, dull yellowish brown-purple-olive green-grey banded slates are predominant (Fig.134). These are exceedingly fine grained and devoid of any quartzitic beds. The banded slates conformably grade to the overlying Dunda Quartzite member.

The slate member is exposed for about 20 km. in a NW-SE trending narrow outcrop which bulges to about 1.5 km. across Khattukhal and Dunda. Between Painkhal and Khattukhal, the slates are exposed on northern limb of the Khattukhal Anticline and are not repeated on northern limb of anticline due to its concealment beneath the Singuni Thrust except a small patch of slates near the milestone 75/3. It conformably overlies the Khattukhal Limestone member between Painkhal and hill 2228 metres and narrows considerably in southeast and northwest,where these abut directly against the Singuni Thrust. The latter brings the overlying Quartzite Formation of the southern belt immediately in contact with the slates.

The slates dip 35° due N40°E on an average. The dips vary from 25° to 90° in the N30°W to E and S to S60°W directions. These are locally folded into sinuous NW-SE trending symmetrical anticline and syncline on left bank of the Dhanari Gad. The lower part of the member is tightly appressed into isoclinal folds (Fig. 148) with axial planes dipping 30-35° NE. The axes plunge 10-30° in N and NW directions (Map 7). On the other hand, slates near the Dunda Quartzite member are cleaved to rhombic blocks obliquely to the bedding planes at 15-45° in N to NE directions.

Contact relationship - The contact of the Dhanari Slate with the underlying Khattukhal Limestone member is characterised by thin alternating limestones and calc slates in a narrow gradational zone (i) near 1 km. east of Ulya on right bank of the Khattukhal stream, (ii) Khattukhal, (iii) in stream bed below the bridge at milestone 76/0 on the Uttarkashi road and (iv) about 0.5 km. SW of Painkhal.

A small lensoid outcrop of limestone is interbedded with slates 0.5 km. NW of Khattukhal and resembles the underlying limestone member.

The Dhanari Slate member grades to the overlying Dunda Quartzite. The contact between two members can be best seen at the following localities:

(i) On the right bank of stream, west of Jakhni village- the vertically dipping, purple-green, banded, slates on right bank of the stream become arenaceous and grade to purple-buff, fine grained quartzites in the stream bed.

(ii) About 1 km. south of Jakhni along the Dunda-Dang mule track- purple-buff slates become more arenaceous near the contact and imperceptibly grade to buff-grey, thinly bedded, fine grained quartzites.

(iii) At Dunda village- the purple-green, laminated, arenaceous slates are interbedded with buff-grey-green, hard quartzites at contact with overlying Dunda Quartzite.

(iv) On left bank of the Bhagirathi river about 1 km. NNW of Odalak- the greyish green-purple, arenaceous slates are interbedded with 10-15 cm.

thick dark micaceous quartzitic beds at the contact.

(v) At Odalak - near the contact with the overlying members, greenish buff-grey slates grade to purple-green, laminated micaceous quartzites.

(vi) About 1.5 km. WNW of Dhanari - the purple- green arenaceous slates grade to buff, micaceous quartzites.

3. DUNDA QUARTZITE

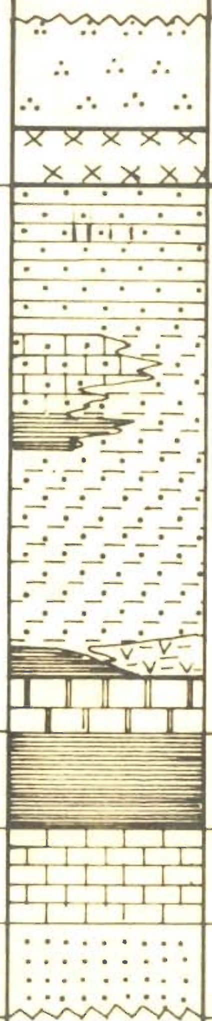
The slates are conformably overlain by predominantly arenaceous Dunda Quartzite member which is best exposed around Dunda between milestones 76/6 and 77/5 on the Uttarkashi road. As described above, the quartzites grade to the underlying Dhanari Slate and are overlain by metabasics of the Dunda Thrust Zone (Chapter 3).

The lower part of the sequence comprises buff-grey-green, thickly bedded, medium grained micaceous quartzites. The individual beds vary from 60 cm. to more than 200 cm. in thickness and are well defined by argillaceous intercalations, colour differences and grain size variations. The quartzites are argillaceous with numerous lenses of green and brownish, yellow, variegated, arenaceous slates. These occasionally show normal festoon current bedding near milestone 77/1. In the upper part of the quartzitic succession, rocks are buff-grey, thinly bedded (2-15 cm.), hard, fine grained quartzites devoid of variegated slates.

The member is exposed in a narrow NW-SE trending outcrop from Jakhni to the east of Paturi for about 15 km. and dips at about 40° to the northeast on an average. The quartzites show angular discordance with the overlying metabasics at many localities (Map 7) and are steeply dipping to 60-90° near this thrust contact. The member is locally folded and inverted near milestone 77/1 along the Uttarkashi road (Fig. 153).

In the northwest, the quartzites are overridden by the Dunda Thrust

FIGURE - 6 STRATIGRAPHY OF THE UTTARKASHI FORMATION



THICKNESS	MEMBER	LITHOLOGY	DESCRIPTION
			QUARTZITE FORMATION
			Metabasics
			UTTARKASHI THRUST
1500 m.	BARETI QUARTZITE		Grey buff, flaggy micaceous, quartzites Fawn grey, sandy arenaceous limestones Purple and grey arenaceous slates Greyish buff, purplish black green, micaceous quartzites with phyllite intercalations Metabasics with black phyllite intercalations : green and black phyllites
150 m.	UPPER UTTARKASHI LIMESTONE		Bluish grey, dark greyish black limestone
250 m.	POKHRI SLATE		Greenish, greyish black and purple, laminated slates and phyllites
200 m.	LOWER UTTARKASHI LIMESTONE		Greyish fawn, slaty limestones with buff quartzites and grey phyllites
150 m.	NETALA QUARTZITE		Buff-grey-green, quartzites with phyllite intercalations
		Base not seen	

near hill 2288 metres so that the metabasics abut directly against the Dhanari Slate member. In the southeast, the relationships are doubtful due to difficult terrain. The quartzites are purple-buff,ripple marked and current bedded on the ridge between two tributaries of the Dhanari Gad near Paturi, and can be confused with the Quartzite Formation of northern belt but differ from these by presence of characteristic blue,brown and green tourmaline (Chapter 6).

2.8.5 - UTTARKASHI FORMATION

The name Uttarkashi Formation has been given for a thick succession of quartzites,limestones,slates,phyllites and metabasics. The formation is exposed around the town of Uttarkashi and occupies lower elevations of the Bhagirathi valley between Netala and Nakuri.The axeshaped outcrop of formation measures 6.5 km. across strike at its widest expanse and runs for about 14 km. from Sada to Baun.It extends further northwest to Kutnaur along the Yamuna river.

The Uttarkashi Formation has been folded into WNW-ESE and NW-SE trending Netala and Baragadi Anticlines and Kot Syncline. The rocks have been faulted along the Baragadi and Kot Faults. As can be made out from Map 3, a thin belt of metabasics,emplaced along the Uttarkashi Thrust,separates this formation from the overlying Quartzite Formation. The erosion of the later has exposed the underlying formation into the Uttarkashi Window (Chapter 3).

Based upon the field, megascopic and microscopic characters, the Uttarkashi Formation has been subdivided into five members (Fig.6).

(1) NETALA QUARTZITE

The lowest member of the Uttarkashi Formation is exposed on both banks of the Bhagirathi river between Gangori and Netala. It is predominantly arenaceous in character and consists of buff-grey-green,thinly bedded quartzites. The individual beds vary from 10 to 60 cm. in thickness and can be made out in the field due to their colour and phyllitic intercalations. Occasionally, the quartzites are friable near Netala logging section. Generally it shows a bedding schistosity which is smeared with micaceous minerals.

A number of good exposures can be observed along the Uttarkashi road between milestones 91/0 and 91/4 and Gangori-Dodhi Tal road near the check-post barrier. At this locality, the quartzites are slaty with greyish black phyllitic intercalations.

The quartzites dip 10-40° due N-N40°E and 20-50° due S-S40°W on northern and southern limbs of the Netala Anticline respectively. In the NW and SE near Gangori and Hinna, the member is truncated by the Uttarkashi Thrust.

2. LOWER UTTARKASHI LIMESTONE

The quartzites are conformably overlain by about 200 metres thick greyish fawn, friable, slaty limestones which are poorly exposed on steep slopes of the Bhagirathi valley between Gangori and Saror. The limestones contain many thin buff quartzite and grey phyllite intercalations. Good exposures are only met with on the left bank of the Bhagirathi river near Saror suspension bridge and Iwain.

The limestones dip 30-70° due S40°W and N20°E on limbs of the Netala Anticline. It is considerably reduced along the strike due to its possible lensoid character or concealment beneath the thrust at Saror.

3. POKHRI SLATE

Overlying the limestones are greenish grey-black, friable, laminated and thinly bedded slates and sheeny phyllites. Occasionally, these are carbonaceous. The slates resemble (i) greenish grey, laminated slates of the Dhanari Slate, (ii) Laluri B Member of the Laluri Formation and (iii) phyllites of the Chandpur Formation.

Mode of occurrence - The Pokhri Slate is exposed into three NW-SE trending outcrops varying in length from 3-6 km. due to the folding:

(i) Between Hinna and Naid, the outcrop makes the northern limb of Netala Anticline with its subsidiary folds. The slates are folded into N60°W-S60°E trending anticline and syncline and dip 15-70° due N-N 40°E and S-S40°W. The black slates are highly puckered with axial planes dipping in 40-50° due NNW while their axes plunge 10-30° in WNW and parallel major fold axes.

Near Hinna the slates are interbedded with buff-green quartz sericite schists which also develop a strong mica lineation plunging 20-40° due NNE i.e., normal to the thrust front and fold axes.

(ii) The other slate outcrop also trends NW-SE for about 3 km. between Gangori and Iwain. The slates are about 250 metres thick. These are buff-grey and phyllitic in character and dip 20-40° in SW-W direction.

(iii) The southern most exposure between Matli and Sada runs in N60°W - S60°E direction along the strike. The slates are either exposed in core of the Baragadi Anticline or are interbedded with the upper limestone member on its southern limb. Near Dilsod,Pokhri and Kiangaon the slates occur in small detached outcrops which are truncated by the metabasics (Map 3). The slates are moderately inclined to S-S50°W and N-N20°E but are steep to 60-90° in the core of the anticline.

(4) UPPER UTTARKASHI LIMESTONE

It overlies the Pokhri Slate and can easily be identified from a distance by its typical fawn blackish rugged weathered surfaces. Though the member is comparable to the Lower Uttarkashi Limestone yet it is separated by the Pokhri Slate member.. It comprises bluish grey and dark greyish black,jointed fine grained, thinly bedded limestones which are frequently intercalated with thin (0.5 mm. -2 cm.) greyish black slates and phyllites (Fig.132).

Mode of occurrence - The member is folded into the Kot Syncline and Baragadi Anticline and is dislocated along two faults. It is exposed into two outcrops:

(i) In the north, the limestone lies on northern limb of the Kot Syncline and extedns for about 3 km. between Gangori and Mandon. It is not exposed on its southern limb due to faulting along the Kot Fault. The limestones are about 150 metres thick and dip 35° due SW. The outcrop is truncated by Uttarkashi Thrust in the NW and SE (Map 3).

(ii) The other outcrop is along left banks of the Baragadi Gad and Bhagirathi river and makes southern limb of the Baragadi Anticline. It is not exposed on its northern limb due to presence of the Baragadi Fault. The limestone is highly jointed and ramified with small calcite veins. It is highly folded along the bridlepath near Pokhri but is gently dipping in the river bed (Fig. 132). The limestones dip 20-75° due N60°W to S30°W.

(5) BARETI QUARTZITE

The uppermost Bareti Quartzite member of the Uttarkashi Formation is predominantly arenaceous with minor occurrences of slates, limestones and metabasics. The member is folded into the Kot Syncline and faulted north of Uttarkashi.

The thick quartzite succession overlies the Pokhri Slate on the right bank of Baragadi Gad and Bhagirathi river between Matli and Sada. The quartzites are greyish and buff coloured between Baun and Uttarkashi but more purplish, black and greyish green varieties are prevalent along the Uttarkashi-Lambgaon road. The bedding is distinctly marked with argillaceous intercalations and colour variations and varies from 1 mm. to 40 cm. or even more in thickness. These quartzites are dominantly argillaceous, slaty and even schistose in character.

The quartzites are exposed on the northern limb of the Baragadi Anticline but are not repeated on its southern limb due to faulting along its axis and concealment beneath the Uttarkashi Thrust.

The quartzites dip 15-50° due NNW and N30°E between Bareti and Uttarkashi but even dip 35° in N80°E and S60°E along the Uttarkashi-Lambgaon road. Bedding schistosity is prominent but another foliation is obliquely developed in the quartzites and dips 25° in N55°E to N85°E. These are sheeny in character due to preferably oriented mica which form a lineation plunging 10° due NNE (Chapter 3).

The quartzites are about 250 metres thick near Bareti in the Sialam Gad section and are well exposed along the Uttarkashi road at milestone 85/0. These are considerably thick to about 1000 metres in southeast along the Uttarkashi-Lambgaon road.

Near contacts with the underlying Pokhri Slate member, the quartzites are rich in slaty or phyllitic intercalations and grade to 50 metres thick slate horizon between Matli and Jakanri. These comprise greenish grey-purple, friable, arenaceous slates and phyllites and dip 30° due N-N30°E.

The slates grade to about 200 metres thick earthy brown,arenaceous limestones between Jugaldi and Bareti. The limestones are exposed in a narrow sinuous outcrop and pinch out near Jakanri. Good exposures can be seen along the canal between Matli and Bareti. The limestones dip 35° due NNE and N50°E but attain more easterly dips near Jugaldi.

The metabasics which are associated with the Bareti Quartzite member are mainly exposed on both limbs of the Kot syncline near Pata and dip 10-30° in NE and SW directions. At Tekhla, the thin dull greyish green and black phyllites occurring above the upper limestone member grade to greenish,jointed, massive and foliated varieties of metabasics. These are occasionally inter-calated with black phyllites and have appearence of quartzitic rocks.

The flaggy,greyish buff, fine grained micaceous quartzites overlie metabasics. The flaggy quartzites are nearly 150 metres thick. The rocks are laminated and thinly cleaved along the bedding. These dip gently to N-NNE and S-S 80°W in the core of the Kot Syncline near Pata and are truncated by Uttarkashi Thrust in the northwest.

PART - II MICROSCOPIC CHARACTERS

In this part, the microscopic characters of earlier described litho-stratigraphical units are dealt with while megascopic features of all rock types have been described earlier along with the field relations for a comprehensive account. In order to avoid repitions of very common features, salient microscopic properties of the rocks are described in these pages.

2.9 LALURI FORMATION

2.9-1 LALURI A MEMBER

(i) Black slates and phyllitic slates - The rocks are exceedingly fine grained with incipiently oriented fine mica. Many very fine sand size (0.12-0.06 mm.), angular to subangular quartz grains are embedded in a dark greyish brown matrix which is made up of brownish pleochroic mica. The matrix recrystallises to poorly oriented, pale green,fine grained,birefringent sericite flakes along ill defined foliation in the phyllitic slates and is interspersed with extremely fine grained magnetite or carbonateous matter. The accessory minerals are silt size zircon,tourmaline and carbonate rhombs (siderite?).

(ii) Quartzites - These are medium to coarse grained and predominantly consist of angular to subrounded interlocking quartz mosaic(95%). A few rounded grains show secondary overgrowth in optical continuity,while strong undulose extinction,subparallel vacuole trains,incipient elongation and intra- as well as inter-granular granulation along a few fractures are indicative of dynamic effects. Minor amount of recrystallised sericite (4%) is present in the interstices. The accessory minerals are rounded zircon and brown tourmaline.

(iii) Sandstones - These consist of coarse to very fine sand size(0.85-0.065 mm), subrounded to rounded quartz grains (50.4%). Most of the sedimentary textures like secondary overgrowth,shape,roundness and cavities in quartz grains are still preserved. The matrix fills interstices between coarse quartz grains and comprises incipiently oriented sericite flakes,iron oxide (35.6%)and finer detrital quartz.

(iv) Limestones - The brownish limestone is rich in minute dolomite rhombs with a few chert bearing thin calcite veins which replace brownish dolomite. The black nodular limestone is a mass of fine micritic calcite interspersed with chert.

2.9-2 LALURI B MEMBER

Phyllitic slates - These comprise alternating greenish sericite and colourless quartz rich laminae. Quartz clasts (0.18 - 0.06 mm.) are subangular to subrounded and exhibit strong undulose extinction. It coalesces with fine granoblastic quartz around margins (mortar texture) and indicate granulation. Fine sericite flakes are strongly aligned along the laminae and less in proportion in quartz rich layers. At places, porphyroblastic chlorite crosses the laminae. In addition, streaks of fine silt size iron ores,rounded zircon and bluish green tourmaline are also seen along the bedding planes.

2.9-3 LALURI C MEMBER

(i) Gritty quartzites - The gritty quartzites consist of (i) coarse to very fine sand size.(0.97-0.102 mm.), rounded to subrounded quartz grains, some of which show well developed secondary overgrowth, solution and pitting effects. Most of these are marginally granulated and develop mortar texture. The grains show strong undulose extinction. (ii) Medium to very fine (0.32-0.09 mm.), subangular to angular particles of quartz fill the interstices between coarse grains. Total quartz is about 88%.

Feldspar occurs in minor amount (1%) as subangular grains and is albite(An_{10}) in composition. Sometimes a few rounded phyllite and quartzite rock fragments are also seen in the matrix. The matrix (11%) is made up of strongly oriented sericite and chlorite flakes with fine grained quartz mosaic which grades into coarse grains thus indicating their derivation by granulation. The micaceous flakes sometimes penetrate and replace the detrital quartz. The accessory minerals are blue and brownish green rounded tourmaline (0.45-0.086 mm.). These are sometimes fractured and filled with quartz. Secondary overgrowth of pale bluish colour is also seen on a few tourmaline grains.

(ii) Purple slates - The purple arenaceous slates are comparatively rich in fine argillaceous contents and are devoid of coarse rounded quartz.

An increase in metamorphic effects from the Laluri A to C Member is noticeable and is evidenced by strongly oriented matrix, granulation and fracturing of quartz grains.

2.10 CHANDPUR FORMATION

(i) Phyllites - These comprise thin alternating quartz and sericite rich laminae. Generally the quartzitic layers are thicker being separated from adjoining sericitic laminae by fine mica rich layers (Fig. 197). No grading of the quartz is visible even in thin sections. Quartz (83%) occurs as fine sand to coarse silt size (0.13-0.052 mm.), angular to subrounded grains. Many coarse grains are porphyroclastic in character. Generally these are marginally granulated and exhibit strong undulose extinction. The finer quartz in the matrix coalesces with the clasts and appears to be a product of granulation.

Angular to subrounded plagioclase (3%), mainly albite, occurs as fine sand size grains, sometimes with bent twin lamellae. Some of the plagioclase grains are profoundly sericitised and fractured. The fractures are filled with polygonal quartz mosaic. Long slender muscovite wasps exhibiting higher birefringence than sericite are also aligned parallel to the bedding. Fine, strongly oriented, pale greenish sericite and chlorite flakes (13%) simulate clast boundaries. These also penetrate clastic quartz and feldspar grains along the margins. Generally, micaceous minerals make the bedding schistosity. A few flakes also lie at about 30° to the main foliation.

Brownish, zoned, prismatic and rounded colourless zircon (0.13-0.02 mm.), blue and green tourmaline (0.14-0.026 mm.) are characteristic accessory minerals. Sometimes a few rounded colourless apatite grains and rhombic siderite (?) are also met with.

(ii) Quartzites - Petrographically, the quartzite beds in the Chandpur Formation resemble with gritty quartzites of the Laluri C Member described above. Of significance is bimodal distribution of quartz and occurrence of minor amount of plagioclase and quartzite and phyllite rock fragments in sericite matrix. Quartz is subrounded to rounded and very coarse to medium sand size (1.02-0.28 mm.). It is embedded in medium to very fine sand size (0.26-0.065 mm.) angular to subrounded detrital quartz grains.

2.11 NAGTHAT FORMATION

(i) Sericite quartz schists - These are mainly developed along the Basul Thrust and consist of recrystallised, granoblastic, fine grained quartz mosaic and strongly oriented sericite, muscovite and chlorite flakes in alternating pelitic and semipelitic laminae. A few quartz clasts are still observed. The foliation is defined by strongly oriented micaceous minerals and is disrupted by a prominent strainslip cleavage (Fig. 199). This is more pronounced in pelitic layers and even terminates against semipelitic layers. In the initial stages of its development the sigmoidally twisted sericite flakes are noticed along regularly spaced discrete planes at high angles to the foliation. Some of the mica flakes also get oriented along newly developed slip cleavage. The advanced stage of its development is marked with recrystallisation of sericite along the new planes which ultimately coincide with the foliation.

(ii) Schistose quartzite and quartzites - Quartz (57%) is angular to subrounded, medium to very fine sand size (0.28 -0.10 mm.) and is mostly flattened along

TABLE - 3

MODAL ANALYSIS OF SAMPLES FROM LALURI-CHANDPUR-NAGTHAT FORMATIONS

S.No.	Formation & Member	Sample No	Quartz	Feldspar	Rock Fragments	Detrital mica	Matrix(Quartz + sericite, chlorite	Others	Total
1	Laluri A. Member (black sst.	6/347	50.7	-	-	-	12.5	35.6 - Iron oxide (Zircon, tourmaline)	99.8
2	Laluri A Member(Greyish buff quartzite)	6/349	95.6	-	-	-	3.8	0.2- Iron oxide 0.3- (Tourmaline)	99.8
3	Laluri C Member(gritty quartzite)	5/115	88.5	0.08	-	-	11.3	-	99.88
4	Nagthat	5/137	89.5	-	-	-	10.5	H.M. present	100.00
5	Nagthat	5/139	40.7	15.3	0.60 (1.4 - quartzite)	0.2	42.9	-	99.7
6	Nagthat	5/107	57.0	present	-	-	30.4 (recrystallised quartz) 12.6 (sericite)	-	100.00

Location:
6/347 - 0.5 km. NW Laluri on Sarot-Chapra road.
6/349 - Hill 1549 metres 1 km. NW Kansi.
5/115 - ½ km. WSW Laluri.
5/137 - At Deosari on left bank of Pali Gad.
5/139 - 2.5 km. N.Thature on left bank of Pali Gad.
5/107 - At Basul.

the foliation. A few relict rounded clasts are still observed. The grains are strongly undulose and composite with profound marginal granulation and appear to have produced much of the polygonal,granoblastic,fine quartz of the matrix (Fig.200). Sericite(12%) is abundant in amount and is strongly oriented along the foliation and sometimes wrap the clastic quartz.

(iii) Arkoses - The arkoses mainly comprise quartz and feldspar with small amount of phyllite and quartzite rock fragments in a recrystallised sericite and chlorite matrix (Fig.198). Quartz (41%) is subangular to subrounded and coarse to fine sand size (0.61 -0.13 mm.). The grains are moderately undulose and are marginally replaced by sericitic groundmass.

Feldspar,mainly albite and potash feldspar (about 15%) is subangular to subrounded,cloudy and sericitised. Some of the albite grains are broken and microfractured with bent cleavages. Sometimes these fractures are filled with quartz. The phyllite and quartzite rock fragments (about 5%) are subrounded to rounded in shape. The matrix is completely recrystallised to a preferably oriented felt like mass of sericite and chlorite.

The accessory minerals in arenaceous rocks of the Nagthat Formation include (i) zoned,prismatic and rounded colourless to brown zircon (0.110-0.065 mm.), (ii) green,brown,blue,rounded tourmaline (0.10-0.065 mm.) and (iii) iron oxide.

(iv) Schistose phyllites - These resemble phyllites of the Chandpur Formation except that the micaceous minerals are more strongly oriented in the former.

Table 3 summarises modal analysis of a few representative samples from Laluri,Chandpur and Nagthat Formations.

2.12 DHARASU FORMATION

(i) Slates - These are generally confined to the base of the formation near Silkyara and comprise incipiently oriented fine grained,brownish micaceous

TABLE - 4

MODAL ANALYSIS OF ARGILLACEOUS QUARTZITES FROM DHARSU FORMATION

S.No.	Sample No.	Quartz	Feldspar	Rock fragment	Detrital mica	Matrix (quartz+ sericite+chlorite)	Others	Total
1	5/78	64.5	5.8	1.6	0.09	25.4	2.4	99.79
2	A/192	37.5	2.4	1.5	0.6	57.7	1.5	99.9
3	A/286	25.4	2.8	1.4	0.4	68.2	0.20* 1.5**	99.9
4	5/74	53.3	5.3	-	0.8	39.0	1.0 (H.M.)	99.4
5	5/63	66.9	6.3	-	0.2	26.5	(H.M.)	99.9
6	A/288	38.8	0.92	0.705	-	57.3	2.3 (H.M.)	100.0
7	A/198	77. 8	1.6	0.7	-	19.6	0.3 (H.M.)	100.0

Location: 5/78 1 km. ENE Nala on Sarot-Chapra road.
A/192 - Sampur.
A/286 - 1 km. NE Dharasu, at milestone 3/0 on Dharasu- Barkot road.
5/74 - 0.75 km. ENE Kansi on Sarot-Chapra road.
5/63 - 1.6 km. SSE Jastwari on Dharasu-Bangaon mule track.
A/288 - 1 km. NNE Dharasu, at milestone 3/1 on Dharasu-Barkot road.
A/198 - Palonj near milestone 68/2 on Uttarkashi road.

* Calcite
** H.M.- heavy minerals

minerals (sericite and chlorite), subangular to subrounded silt size quartz and a few fine grained albite (An_5).

In immediate contacts with metabasics at Rari these slates exhibit occasional development of a few colourless skeletal and randomly oriented muscovite porphyroblasts indicative of minor contact metamorphic effects (Fig.211). The poikiloblastic muscovite shows numerous quartz inclusions. The preferably oriented sericite groundmass is occasionally displaced due to porphyroblastic growth. The accessory minerals are rounded,fine magnetite arranged in streaks along the bedding,apatite,zircon and tourmaline.

(ii) Phyllites - The rocks comprise alternating phyllitic and quartzose fine laminae with varying proportion of quartz,feldspar,musocivte,sericite and chlorite (Fig.214). It resembles phyllites of the Laluri B Member.

Sometimes the micaceous minerals recrystallise to linear,very coarse muscovite flakes(Fig.213). Minor amount of xenoblastic calcite is also seen in a few sections.

(iii) Argillaceous quartzites - (Table 4)

(a) Grey-green argillaceous quartzites - These mainly comprise quartz in abundant sericite and chlorite groundmass. Quartz (25 -78%) is angular to subrounded, medium sand to coarse silt size (0.39 to 0.028 mm.). Many grains are stretched along the foliation and show semicomposite and composite undulose extinction. The grain margins are generally penetrated by micaceous groundmass and granulated,while in a few cases grains are fractured.

Feldspar (1 to 6%) is albite (An_6) and untwinned potash feldspar and occurs as colourless,turbid,subangular to subrounded grains varying in size from 0.10 to 0.04 mm. In some thin sections,greyish slate and quartzite rock fragments (about 1%) have also been noticed as subangular to subrounded grains. Colourless long muscovite (0.5%) wasps are seen aligned parallel to the bedding.

The matrix (20 -68%) comprises strongly oriented,sericite-chlorite flakes and includes much of the granoblastic quartz. It even predominates over the detrital fraction,in that case, the latter appears 'to float' in the groundmass (Fig.215). Sericite is generally more common than chlorite and has even advanced along plagioclase twin lamallae and discrete fractures in quartz. The micaceous minerals are strongly oriented along bedding planes and wrap the clasts. In a few thin sections, the matrix is also oriented along planes which are inclined at about 30° to the main bedding foliation. Minor amount of xenoblastic calcite is present in some sections. The noteworthy accessory mineral is fine euhedral magnetie along the bedding.

(b) Purple laminated and massive argillaceous quartzites - In general, though all characters of the earlier variety are present in these quartzites, the following features are important in the purple laminated quartzites:

(i) absence of euhedral magnetite crystals,instead, the laminated varieties are typified by clusters of cherry red hematite (0.15-0.50 mm.) which alternate with sericite-chlorite-quartz rich laminae, (ii) the hematite laminae are generally displaced by slaty cleavages which are marked with iron oxide coating and sericite flakes at 40-50° to the main bedding schistosity (Fig.216) and (iii)the laminae exhibit microfaulting and microdragging in some cases.

In the purple massive argillaceous quartzites,quartz is less deformed and is subrounded to subangular with hematite coating (Fig.212).The finely divided hematite pigment is uniformly distributed in the matrix.

The accessory heavy minerals in these argillaceous quartzites include: (i) rare colourless,subrounded to rounded, silt size apatite,(ii) subangular to subrounded pink,green,blue and brown tourmaline (0.20 to 0.026 mm.), (iii) rounded to well rounded,colourless and brown zircon(0.143-0.026 mm.), (iv) angular to subrounded,colourless to straw yellow,pleochroic epidote in some grey green quartzites and (v) detrital rounded magnetite.

TABLE - 5

MODAL ANALYSIS OF QUARTZITES FROM THE QUARTZITE FORMATION

S.No.	Sample No.	Quartz	Matrix	Heavy minerals	Total
1	5/256 *	96.5	3.3	present	100.0
2	A/122	89.3	10.5	0.14	99.94
3	6/413	98.8	1.1	-	99.9
4	A/160	90.9	5.90	3.2	100.0
5	5/166	98.6	1.38	-	99.98
6	5/144	91.0	8.2	-	99.2
7	5/161	96.6	2.3	-	99.9
8	6/366	99.9	-	-	99.9
9	5/253	97.2	2.7	-	99.9
10	A/119	98.4	1.6	-	100.0

* 0.2% quartzite rock fragments.

Location: 5/256 - Jogat.
A/122 - Milestone 74/0 on Uttarkashi road
6/413 - 1.5 km. SE Mason.
A/160 - 2 km. ESE Malli on right bank of Dichli Gad.
5/166 - 2 km. E Foeld on Uttarkashi -Lambgaon road.
5/144 - 0.5 km. N Lambgaon on Uttarkashi-Lambgaon road.
5/161 - 1 km. NE Chaurikhal on Uttarkashi-Lambgaon road.
6/366 - 2 km. SSE Chaurikhal on Uttarkashi-Lambgaon road.
5/253 - 1 km. S Dichli on Chinyali Jogart mule track.
A/119 - 0.5 km. N Ranari near milestone 80/1 on Uttarkashi road.

TABLE - 6

MODAL ANALYSIS OF INTRACLASTIC DOLOMITES FROM DICHLI DOLOMITE

S.No.	Sample No.	Intraclasts	Oolites	Quartz (sand size)	Quartz (Silt size)	Sparry Cement	Total
1	6/44	9.3	-	30.6	13.7	46.2	99.8
2	A/390	21.9	0.4	17.0	17.8	42.6	99.7

Location: 6/44,-A/390 - 1.5 km. ESE Malli, near contact with Quartzite Formation on right bank of Dichli Gad.

2.13 BANGAON LIMESTONE

Typically the limestone is made up of incipiently oriented, fine calcite grains arranged in irregular,colourless and greyish alternating laminae. Minor amount of detrital angular quartz varying in size from 0.06 to 0.03 mm. is also distributed throughout the rock along with flaky sericite-chlorite and pyrite crystals.

Along the Bangaon Thrust, the limestone comprises coarse,recrystallised, granoblastic calcite with numerous unidentifiable inclusions.The clacitic mass is interspersed with a few silt size quartz grains.

2.14 GARHWAL GROUP

2.14-1 QUARTZITE FORMATION

The Quartzite Formation is overwhelmingly arenaceous in character and generally comprises more than 90% quartz with very minor amount of sericite and chlorite (less than 5%) (Table 5).

The accessory minerals observed in thin sections of the Quartzite Formation are apatite,zircon,tourmaline,pyrite and other opaque minerals (Chapter 6).

(i) Ferruginous quartzites - The rocks consist of detrital quartz in a finely distributed hematite and chlorite matrix. The quartz grains (75-90%) are well rounded to subrounded and vary in size from coarse sand to coarse silt (1.01-0.052 mm.). The medium sand size grains are 53.6% and fine sandsize 33.6%. These show bimodal distribution. Many finer quartz grains lie in interstices of the coarser quartz.

Generally, the quartz grains show straight extinction though many are feebly undulose,semicomposite and composite in character. The grains are generally devoid of inclusions but a few of the coarser ones have randomly oriented pale green rutile needles,liquid vacuoles and prismatic green tourmaline microlites (Fig.202).The coarser grains also show a higher degree of roundness with pitted and frosted concave surfaces due to (i) solution at the grain contacts and (ii) replacement of detrital quartz grains by hematite, chlorite, sericite, interstitial silica cement, quartz secondary overgrowths and pressure solution (Fig.202). Sometimes one or two rounded quartzite fragments are also seen in slide no.5/256.

In a few cases, secondary overgrowth lie in optical continuity on quartz grains and is more frequently developed upon coarser grains. Worn secondary overgrowths are also very rarely visible and are marked with liquid vacuoles (Fig.202). These indicate multicycling of the grains.

Hematite occurs as thin film over the detrial grains whereas chlorite fills the interstices and sometimes replaces hematite coating. Rarely silica cement(not in optical continuity) also fill the interstices.

(ii) Quartzites - Though exhibiting many of sedimentary characters described above, quartzites also show metamorphic effects. The rock is generally free from iron oxide coating, chemically deposited silica and chlorite. Like the earlier type, quartz(90-100%) is bimodal in which the coarser quartz (2.21-0.39 mm.) is rounded to well rounded. The finer grains (0.26 - 0.09 mm.) are subangular to subrounded and fill interstices or sometimes form distinct laminae (Fig.201). Most quartz grains are strained and exhibit moderate to strong undulose extinction, semicomposite and composite character, deformed lamellae and marginal granulation. Most of the quartz grains are not dimensionally obliterated though are interlocked with each other(mortar texture) (Fig. 203). The matrix (3%) is mostly interpenetrative, fine granoblastic quartz developed mainly due to granulation. Sericite and chlorite flakes occur as thin films which sometimes penetrate the grains.

(iii) Schistose sericite quartzites - Though there is no clear demarcation from main quartzites, this variety can be distinguished in the field by conspicuous micaceous sheen and also indicates higher degree of metamorphism.

In thin sections, the quartz grains are mostly elongated and lie parallel to the foliation. The grains are strongly undulose with composite extinction. These are intensely granulated along margins and are also fragmented along a few discrete planes which are marked with fine granoblastic quartz (Fig.204). Mostly coarser grains survive crushing and at places even secondary overgrowths are also preserved. The fine matrix is incipiently oriented quartz which seem to have been derived from the main detrital grains by the process of granulation. Minor percentage of flaky sericite and chlorite also lie along the foliation planes.

(iv) Quartz schists - Near the thrust contacts, the pure quartzites are highly schistose in character. The detrital quartz still survives intense granulation and occurs as a few rounded coarse relict clasts but most of the grains are extremely deformed,flattened and lie parallel to the foliation(Fig.205). The dimensional orientation is as much as 1:50. Generally, the elongated grains are extremely fragmented showing different optic orientations and marginal granulation. Occasionally some discrete conjugate planes,marked with granulated quartz,traverse the foliation at an acute angle. Strongly oriented,colourless to pale green sericite and chlorite flakes make foliation more prominent.

2.14-2 DICHLI DOLOMITE

(i) Intraclastic dolomites - These differ markedly from the algal dolomites and dololuties and are characterised by terrigenous quartz,intraclasts and oolites in coarse dolomite matrix. Table 6 presents modal analysis of some representative samples of the intraclastic dolomite.

Quartz - It is an important constituent in lower parts of the dolomite sequence (28-43%) and decreases in algal varieties. Generally, quartz occurs as subangular to well rounded grains in two size grades (Fig.206): (i) Coarse sand size grains (0.81 -0.2 mm.) are subrounded to rounded and vary from

17 to 30%. A few grains exhibit secondary overgrowth which can be distinguished from the core by drop like liquid inclusions. At margins the condary overgrowth is replaced by sparry matrix(Fig.206).The overgrowth is generally common over grains in sparry matrix but is absent from those embedded in micritic intraclasts.

(ii) The finer quartz grains 0.15-0.039 mm.) are subrounded to subangular and devoid of any secondary overgrowths.

Oolites - The following different types have been recognised in thin sections:(i) Single ring radial growth over quartz nucleus (Fig.210), (ii) Single ring radial growth over rounded intraclastic micrite nucleus (Fig.209), (iii) Single ring radial growth over micrite intraclasts with angular quartz (Fig.210), (iv) Many rings of radial growth (as many as 6) without any nucleus (Fig.210). (v) Single ring radial growth over an intraclast of oolite in any combination of the earlier types (Fig.209) (vi) In addition, oolitic growth has also been rarely noted on intraclasts made up of two components (a) an inner oolitic growth over (iii) variety and (b) an outer shell of intraclasts containing the oolitic growth of(i),(ii) & (iii) varieties with rounded to angular quartz embedded in sparry cement matrix.

Intraclasts - These are generally spheroidal,ellipsoidal or elongated and rarely irregular in shape. These are subangular to well rounded carbonate fragments (dolomite) with size ranging upto 2 cm. in diameter. Generally the intraclasts are made up of greyish dark and exceedingly fine grained micrite (Fig.208), which, at places,recrystallises to colourless microspar. At times,faint laminations are also noticed in the intraclasts. In many of these are embedded angular to well rounded, coarse sand to silt size(0.81-0.039 mm.) quartz. Along margins the intraclasts are invariably hazy and recrystallise to microspar.

Chert - It is exceedingly fine grained and occurs along contacts with allochemical constituents. Occasionally it contains numerous dolomite clots and grades to a coarser polygonal mosaic in the interstices due to replacement and cavity filling.

Matrix - Generally, the matrix comprises colourless,silt size dolomitic sparry cement in the interstices between the allochems(Figs.208,209 & 210). May a times the penetration ofsparry dolomite in detrital quartz,secondary overgrowth (Fig.206) and tourmaline indicates replacement.

Accessory minerals - The accessory minerals include prismatic and colourless zircon and brown,blue,green,rounded tourmaline.

(ii) Algal dolomites -These are fine grained and comprise about 1 mm. thick greyish pink,micrite and colourless alternating microspar laminae. Occasionally a few thin fine grained chert sheets are concordant with micrite laminae becoming coarser in the centre. The micritic dolomite sometimes recrystallises to colourless,coarse, patches. Minor amount of limonite coated,euhedral pyrite is sparingly distributed.

(iii)Dololutites and calc slates-The dololutites exhibit alternating micrite and microspar laminae which,at places,recrystallise to colourless,coarse spar. A few scattered angular,silt size quartz grains are also present in dolutites. When intercalated with slates,dololutites show colourless,alternating microspar and purplish sericite rich laminae which are finely impregnated with hematite.

2.14-3 DUNDA FORMATION

(1) KHATTUKHAL LIMESTONE - The limestone consists of alternating greyish micrite and colourless microspar laminae(about 0.5 mm. thick). The texture is granular with fine grained calcite (0.17 to 0.02 mm.).In the cherty

limestones,the chert bands are defined by dark grey,finely impregnated pyrite or carbonaceous material(Fig.217) and comprise calcite rhombs in microcrystalline chert groundmass which replaces rhombs along the margins and cleavages.

Near the Singuni Thrust,the slaty limestone is crystalline and exhibits fine,preferably oriented calcite. At places it recrystallises to colourless patchy,coarse calcite. A few scattered,angular silt size quartz and small sericite flakes are noteworthy.

The pellitiferous limestone from Nagla is crystalline with greyish, coarse calcite mosaic marked with dusty black inclusions which also define the ellipsoidal pellets (Fig.218). These are embedded in colourless,coarse calcite and fine cherty groundmass. Here,it may be added that samples collected by Jalote (personal communication) of the pellitiferous limestones from Deoban Limestone of the type area resemble megascopically and microscopically with this variety of the Khattukhal Limestone.

(2) DHANARI SLATE

Purple arenaceous slates - Generally the rock shows purple,alternating pelitic and semipelitic laminae varying in thickness from 0.5 to 2 mm. The preferably oriented pale greenish sericite-chlorite flakes predominate in the pelitic layers while angular to subrounded,medium sand to silt size (0.20-0.026 mm.) quartz is embedded in a purple hematite groundmass.The pelitic layers are disrupted by strain-slip cleavage. At places,the semipelitic layers are also deformed to "pinch and swells". The sericite flakes recrystallise along this cleavage which is normal to bedding near apex but is subparallel to laminae/near limbs of microfolds. Minor amount of disseminated hematite imparts a purple colour to the slates.

Banded slates - These are exceedingly fine grained rocks with incipiently oriented pale greenish sericite and chlorite felt mass, which is only rarely intercalated with quartz rich semipelitic layers. The elongated

TABLE - 7

MODAL ANALYSIS OF QUARTZITES FROM THE DUNDA QUARTZITE (DUNDA FORMATION)

S.No.	Sample No.	Quartz	Rock fragments	Feldspar	Matrix	Detrital mica	Accessory Minerals	Total
1	6/489	83.13	1.5	-	13.58	-	1.51	99.72
2	6/486	80.3	0.1	0.25	18.7	-	0.3	99.65
3	6/484	64.5	2.6	0.1	33.5	-	0.2	100.09
4	6/478	89.4	1.3	1.3	7.7	0.1	present	99.8
5	6/475	50.4	0.03	2.0	46.8	0.4	present	99.9
6	6/182	56.6	-	0.6	38.5	2.3	present	100.0

Location: 6/489 - Milestone 76/2 on Uttarkashi road.

6/486 - Near Dunda at milestone 75/5 on Uttarkashi road.

6/484 - South of Dunda.

6/478 - 0.5 km.ESE Dunda,at milestone 77/2 along Uttarkashi road.

6/475 - 0.5 km. SE Painkhal.

6/182 - 1 km. NNW Odalak, at contact with Dhanari Slate on left bank of Bhagirathi river.

muscovite wasps parallel the bedding in some thin sections. Minor amount of iron stained carbonate rhombs(? siderite) are also present. Discrete iron coated fracture cleavage is observed in the pelitic layers at 30-60° to bedding and discontinue at contact with semipelitic laminae.

The accessory minerals are very fine grained subrounded zircon and tourmaline.

(3) DUNDA QUARTZITE

Table 7 presents modal analysis of a few representative samples from the Dunda Quartzite.

(i) Quartzites- These quartzites are minor in occurrence and are quartz rich (89%), with minor amount of rock fragments (1.3%) in a silica and sericite matrix (7.7%).

Though resembling microscopically with arenaceous rocks of the Quartzite Formation,these also comprise a few rounded quartzite,chert and phyllite rock fragments and rarely abraded secondary overgrowths in some thin sections.

The matrix is made up of recrystallised and incipiently oriented pale green sericite with minor amount of chemically precipitated silica. The heavy mineral fraction comprises hematite,brown and green rounded tourmaline (0.16 -0.078 mm.) and colourless and brown rounded zircon (0.078 - 0-052 mm.).

(ii) Micaceous quartzites - The lower part of the Dunda Quartzite member chiefly comprises angular to subangular,medium sand to fine silt(0.14-0.026 mm) size quartz(50-80%) which exhibits strong undulose extinction. The grains are elongated and exhibit profound marginal granulation. In addition,many cloudy subangular,fine sand size feldspar (1 %) orthoclase,microcline and albite(An_6) are also noteworthy. The feldspars are highly sericitised along cleavages and twin planes. The detrital fraction is embedded in strongly oriented matrix(13-46%)of sericite,muscovite and chlorite with minor amount of fine quartz. The micaceous minerals penetrate clast and replace these along margins.

The accessory minerals are euhedral pyrite cubes; colourless and brown, prismatic and rounded zircon (0.15-0.013 mm.) and green,brown,blue,subrounded tourmaline(0.16-0.026 mm.)which are sometimes arranged in streaks.

(iii) Arenaceous slates -Petrographically,the arenaceous slate lenses resemble micaceous quartzites except that these contain a higher amount of sericite and chlorite.

2.14-4 UTTARKASHI FORMATION

(1) NETALA QUARTZITE - The quartzites are fine grained and are made up of strongly oriented sericite,chlorite and muscovite flakes in predominantly granoblastic and recrystallised quartzitic groundmass. Like the Quartzite Formation these lack feldspars,detrital mica and rock fragments.

In black phyllites,the pelitic laminae are rich in fine sand size(0.10-0.04 mm.) quartz while semipelitic laminae comprise medium sand to coarse silt size (0.28-0.06 mm.) quartz grains with varying amount of sericite and muscovite.

The accessory minerals are rounded,brownish and colourless zircon (0.065 - 0.026 mm.) with a few grains of broken and rounded blue,brown and green tourmaline(0.10-0.04 mm.).

(2) LOWER UTTARKASHI LIMESTONE - The limestone is made up of greyish,turbid, medium grained,recrystallised,interlocking and preferably oriented calcite (0.35-0.22 mm.) along poorly developed foliation. Minor amount of chert fill the interstices between calcite..A few scattered sericite and chlorite flakes are also found along the foliation.

(3) POKHRI SLATE - The slates are almost pure argillites and are characterised by strongly oriented sericite and muscovite flakes along the foliation. The micaceous minerals are finely impregnated with brownish carbonaceous material.

Occasionally these show semipelitic laminae with subrounded detrital quartz (0.14-0.05mm.).The identifiable accessory minerals are zircon and tourmaline.

The quartz sericite schists comprise fine nematoblastic sericite and chlorite flakes in a fine grained granoblastic quartz mosaic without any relict detrital grain.

(4) UPPER UTTARKASHI LIMESTONE - The pure varieties of the limestones comprise (i) fine grained (0.08-0.03 mm.) preferably oriented greyish interlocking grains along incipiently developed foliation(Fig.219) and (ii) coarse,colourless, granoblastic patches of recrystallised calcite. Minor amount of sericite is oriented along ill defined foliations.

(5) BARETI QUARTZITE

(i) Schistose feldspathic quartzites - The rocks mainly comprise detrital quartz and minor amount of feldspars in a recrystallised groundmass of sericite,chlorite and quartz.

The detrital quartz occurs as (i) subangular to subrounded grains varying in size from 0.17 to 0.05 mm. and (ii) a few well rounded coarse grains (0.65-0.45 mm.) embedded in the finer detrital grains. The rounded grains occasionally show normal and abraded secondary overgrowths with undulose extinction. A few grains of feldspar (0.13-0.065 mm.),orthoclase and albite(An_4), are randomly distributed (Fig.220) and never exceed 5% in the rock. A few slender muscovite wasps lie parallel to the bedding. The matrix is made up of sericite and chlorite flakes with granoblastic,fine grained quartz. The latter coalesces with the detrital grains and appear to have been evolved by granulation.

The accessories are euhedral pyrite; apatite; brown,green,blue and colourless tourmaline(0.14-0.052 mm.) and brown,colourless,prismatic and rounded zircon (0114-0.028 mm.).

(ii) Flaggy quartzites - These comprise scattered rounded to subrounded,medium sand to silt size(0.18 -0.06 mm.) quartz with a few turbid orthoclase and albite(An_4) grains. The detrital grains are embedded in strongly oriented matrix of sericite,muscovite and granoblastic quartz.

(iii) Slates and phyllites -Microscopically these are very similar to the Pokhri Slate(p.55) and contain many silt size(0.078 - 0.052 mm.)angular quartz grains in a sericite rich matrix.

(iv) Arenaceous and argillaceous limestones - The rocks largely comprise subangular to subrounded,medium sand to silt size(0.28 - 0.032 mm.) quartz and preferably oriented sericite flakes in granoblastic clacite groundmass. Some of the quartz grains are strongly undulose and are marginally replaced by calcite.

In argillaceous limestones,sericite flakes are preferably oriented with minor amount of angular,silt size quartz in distinct laminae which alternate with microspar calcite laminae. Minor amount of chert is also present. The accessory minerals are euhedral pyrite,zircon and rounded brown tourmaline.

(v) Metabasics - In thin sections,the metabasics are fine grained rocks comprising essentially fibrous hornblende and chlorite with minor amount of biotite,epidote,calcite and quartz. The accessory minerals are ilmenite, sphene and apatite. The petrographic characters resemble other metabasics and have been described in Chapter 5.

CHAPTER -3

STRUCTURE AND TECTONICS

3.1 INTRODUCTION

The present area is ideally suitable for the structural and stratigraphical studies across a section of the Lesser Himalaya in Garhwal since it incorporates the Deoban-Tejam Zone and northern parts of the Simla Krol Belt. The geological setting of the area has already been described in Chapter 2. In the present chapter, the important structural features e.g. folds, faults and thrusts have been established as a result of the detailed geological mapping. In order to decipher the relations between thrusting and folding of the rocks, a part of the region around Uttarkashi has been structurally analysed with the help of contour diagrams.

The structural and tectonic setup of the present area is illustrated with many geological sections and is compared with the Shali-Chakrata-Pithoragarh regions. Parts of the Bhagirathi, Yamuna, Alaknanda and Mandakani river sections have also been traversed for a better understanding of the regional structure.

3.2 MAJOR STRUCTURAL FEATURES

The major structural features in the area have been shown in Map 4

3.2-1 FOLDS

Like any other region in the Himalaya, the area has been subjected to complicated folding. Generally the folds are symmetrical or asymmetrical with NW-SE axes which can be traced nearly upto 20 km. In some cases, the axes of the folds are sinuous. It is noteworthy that a few folds are truncated by the thrust faults. The folds are described from south to north according to the formations.

TABLE - 8

CHARACTERISTICS OF S_1 DIAGRAMS: LALURI-DHARASU CHANDPUR-NAGTHAT FORMATIONS

Fig. No.	Sector No.	No. of poles	Contour values (%) and height of maxima (%)	Plunge & bearing of maxima	Strike and dip of average S_1 corresponding to maxima			Strike of Circle	Amount of Dip	Dip Direction.
					Strike	Dip amount	Dip Direction.			
7	1	78	1.3-4-7-10-13 (13)	30°/N180°	N90°-N270°	60°	N	N102°-N282°	32°	N192°
8	2	100	1.0-3-5-7-9(9)	48°/N212°	N122°-N302°	42°	N32°	N108°-N288°	50°	N198°
9	3	107	0.9-5-9-13-16(16)	60°/N233°	N143°-N323°	30°	N53°	N52°-N232°	90°	-
10	4	195	1-2-4-7-10(10)	60°/N238°	N148°-N328°	30°	N58°	N48°-N228°	84°	N318°
11	5	554	0.5-1-1.5-4-9-18 (18)	60°/N35°	N125°-N305°	30°	N215°	N36°-N216°	90°	-
12	6	140	0.7-2-6-9-12(12)	60°/N45°	N136°-N316°	40°	N226°	N60°-N240°	80°	N330°
13	7	100	1-3-5-7-9 (9)	50°/N100°	N10°-N190°	40°	N280°	N8°-N188°	50°	N98°
14	8	200	0.5-2-5-10-13(13)	23°/N78°	N168°-N348°	67°	N258°	N65°-N245°	50°	N155°
15	9	19	5-10=15-20(20)	44°/N78°	N168°-N348°	46°	N258°	-	-	-
16	10	185	0.5-2-4-6-8(8)	22°/N50°	N140°-N320°	68°	N230°	N52° -N232°	80°	N322°
17	11	75	1.3-6-16-20-26 (26)	30°/N70°	N160°-N340°	60°	N250°	-	-	-

(1) Folds in Laluri-Chandpur-Nagthat-Dharasu Formations

The geometry of the folds in these formations has been worked out with the help of 1633 observations on the bedding planes. Accordingly, the outcrop of these formations has been divided into 11 sectors and the poles to bedding planes(S_1) have been contoured on a Schmidt equal area net (Map 3, Table 8).

(i) Deosari Syncline - In the southwestern region, the Nagthat Formation makes nonplunging syncline which is named as the Deosari Syncline. Lying on the southern slopes of the Gorpha Dhar, the axis passes through Deosari and Bhal and trends N 125°- N 305° (Sector 5). The syncline is slightly asymmetrical towards the northeast with 30° S35°W and 20° N35°E dipping northern and southern limbs respectively(Fig. 11). In core of syncline, the formation gently dips to 10 - 15° in NE and SW.

The Laluri and Chandpur Formations make the northern limb of the Deosari Syncline but the former is missing on its southern limb due to presence of the Aglar Thrust. Along left bank of the Aglar Nadi, the southwesterly dipping Chandpur Formation indicates the possibility of a concealed anticline beneath the Nagthat Formation (Fig.52)

(ii) Nagon Anticline - The southernmost of the four large scale folds in the Dharasu Formation is the Nagon Anticline in immediate vicinity of the Tons Thrust. The anticline passes through Chapra, Nala, Kansi and Laluri for about 10 km. along right bank of the Nagon Gad. The axis of this anticline is truncated by the Tons Thrust near Kansi and seems to be concealed beneath the thrust near Bhoti.

The S_1 diagram in sector 4 indicates that the anticline is an upright symmetrical structure with 30° S38°W and 30° N58°E dipping southern and northern limbs respectively and plunges 6° N138° (Fig.10). It is characterised by many small asymmetrical folds marked with fan shaped axial plane cleavages in varying directions between 35-85° N14°E to S34°E (Fig. 149).

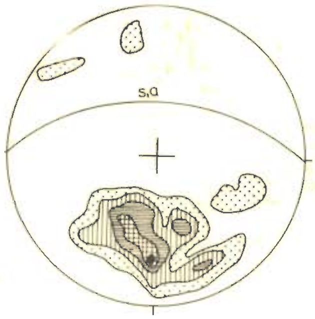


FIG. 7

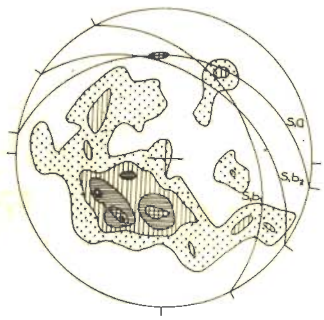


FIG. 8

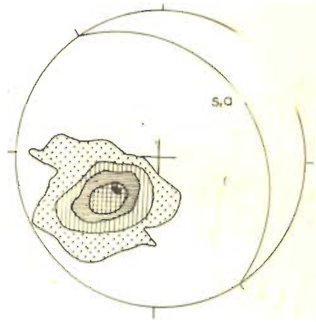


FIG. 9

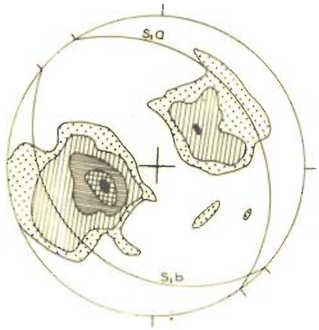


FIG. 10

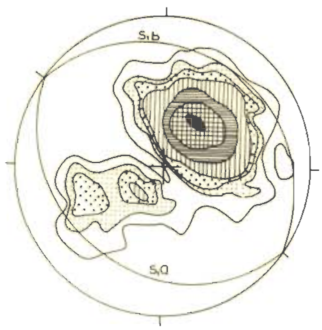


FIG. 11

FIG. 12

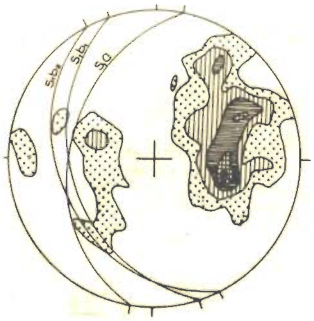


FIG. 13

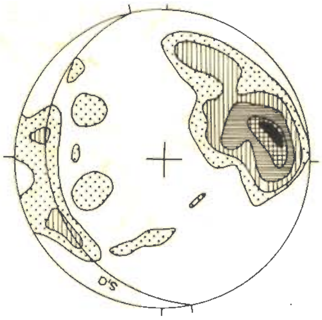


FIG. 14

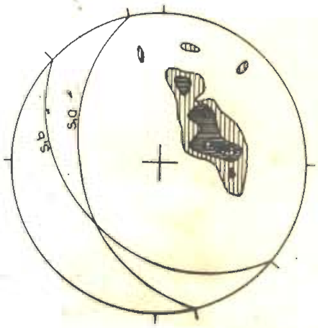


FIG. 15

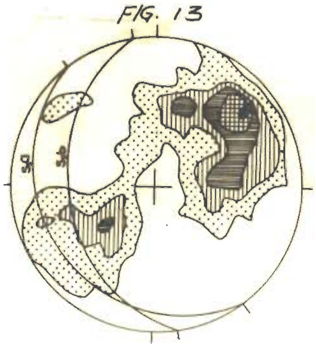


FIG. 16

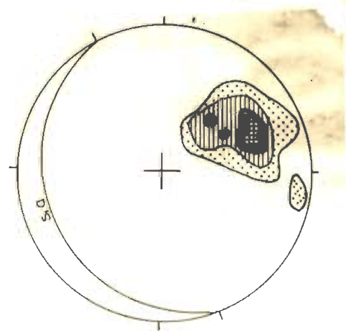


FIG. 17

(iii) <u>Daski Syncline</u> - The Dharasu Formation has been folded into a wide Daski Syncline which runs for at least 20 km. along southwestern slopes of the ridge between the Khurmola and Daski Gadsin NW -SE and NNW-SSE directions. The syncline plunges 40° N305° .In the northwest, it is symmetrical with its limbs dipping 60° in the N and WNW(Figs.7,17)(Sectors 1 and 11). The southwestern limb dips steeply near Bangaon(Fig.7) than in sectors 2 and 3 near Jastwari and Katkhet (Figs. 8 & 9).Regionally, this limb dips gently than the northeastern limb which averages 67° in sector 9; 40° in sectors 10 and 60° in sector 11 in a WSW direction (Figs.15,16 &17).

The syncline is asymmetrical towards northeast along the Bhagirathi river between Dharasu and Bheti due to the steepening of rocks to 60-80° on the northeastern limb. Near Bheti, the syncline appears to die out due to concealment of the southwestern limb beneath the Tons Thrust, since furthertowards southeast only the northeastern limb is exposed.

(iv) <u>Malli Anticline</u> - Running closely parallel and en-echelon to the Daski Syncline is the Malli Anticlinewith its steep southwastern and gently dipping northeastern limbs. The axis of the anticline runs for atleast 14 km. and trends from N 15°W -S 15°E to N -SE.It plunges 10° N158° in sector 6(Fig.12) and trends more northerly in sector 8(Fig. 14) on Uttarkashi road. In this sector, the anticline plunges 40° N335° and thus appears to be a doubly plunging structure.It is asymmetrical towards the northeast. The axis of this anticline runs along the left bark of the Bhagirathi river which flows in a sinuous course and cuts an anticlinal valley from Chunyali to Chham.

(v) <u>Bharkot Syncline</u> - A smaller Bharkot Syncline lies between the Malli Anticline and Dharasu Thrust near Rauntal.It trends N10°W - S10°E with a northwesterly plunge. The rocks are steeply dipping to 50-60° on its northeastern limb.The structure is asymmetrical towards the northeast and is cut off by the Dharasu Thrust in southeast at Malli.

(2) Folds in Garhwal Group

In the type area of Uttarkashi, the Garhwal Group rocks are exposed into a broad anticlinal structure(Map 4). . The axis of this anticline passes through Baun-Uttarkashi-Sada running for 20 km.near Baragadi Anticline.On the northern limb of this anticline, the Quartzite Formation dips 20 -50° towards northeast between Hinna and Sainj and is overlain by the Central Crystalline Zone along the Main Central Thrust. The southern limb of this anticline mainly exposes southwesterly dipping quartzites of the southern belt which dip at 40-70° beneath the Dharasu Formation.

(i) Khattukhal Anticline - The Dunda Formation is exposed into a major anticline which is partly concealed beneath the Dunda and Singuni Thrusts on its northern and southern limbs respectively. The axis of this Khattukhal Anticline runs along the left bank of the Dhanari Gad where the oldest Khattukhal Limestone member is exposed in its core. The NW-SE trending anticline appears to die out or is concealed beneath the Singuni Thrust near Painkhal.

The anticline is symmetrical with 30-35° dipping limbs butturns asymmetrical towards the north along the Uttarkashi road where the limestones are dipping steeply on its southern limb (Map. 7).

The other members of the Dunda Formation are cut off by the Singuni Thrust on the southern limb of this anticline except a small patch of the Dhanari Slate along the road near milestone 75/3 (Map 7). The axis is truncated by the thrust . 1 km. south of Khattukhal. The narrow northeasterly dipping limestones on the right bank of the Khattukhal stream(p..32) represent only a part of the northern limb while the southern limb is not exposed since it appears to be concealed beneath the Singuni Thrust (Fig. 59).Nevertheless, the wide limestone outcrop overlying the Dharasu Formation between Dang-Shyalna-Giunoti(also noted by Auden,1938) dips regionally in the southwest. This outcrop possibly represents the southern limb of the Khattukhal

Anticline and is separated from the northern limb due to the Singuni Thrust between hill 2288 metres and Giunoti (Fig. 59).

Running close to the Khattukhal Anticline are two smaller fold axes in the Dhanari Slate member along the Dhanari Gad. The folds are symmetrical in character and are confined only to the slates.

(ii) Baragadi Anticline- The Uttarkashi and Quartzite Formations have been broadly folded along three NW-SE trending axes around the town of Uttarkashi, the southernmost of these folds is the Baragadi Anticline. Running along the Baragadi Gad and Bhagirathi river for about 10 km.the axis is sinuous in N 75° W -S 75°E and NW-SE directions. Between Sada and Uttarkashi, the anticline is symmetrical with 30-40° dips in N-NE and S-SW directions on the limbs but it turns asymmetrical towards northeast near Pokhri due to steepening of southern limb where the rocks dip 60-70° in the south.

In the southeast, the Baragadi Anticline runs across the thrust zone of the metabasics and the overlying Quartzite Formation near Sada. In the northwest between Malti and Baun the anticline is concealed beneath the southwesterly dipping metabasics while the Uttarkashi Formation is exposed on its northern limb between Dilsod and Jugaldi.

(iii) Kot Syncline- North of the Baragadi Anticline is a symmetrical WNW-ESE trending Kot Syncline which exposes the flaggy quartzites and metabasic rock units of the Bareti Quartzite member in its core. The syncline plunges towards southeast with gentle dipping limbs to 10-30° in NE and SW. It runs for atleast 4 km in the Uttarkashi Formation. Locally the syncline appears to be recumbent in character near Kot where the rocks dip 12-40° NNE at higher points and 20-30° WSW at lower elevations. The sinuous thrust zone with metabasics and overlying Quartzite Formation outcrops between Manpur-Saror in the southeast and Gangori-Jugaldi in the northwest also appear to have been broadly flexured along the Kot Syncline.

(iv) Netala Anticline - Another mappable fold in the Uttarkashi Formation is the Netala Anticline with its WNW-ESE axis. It can be studied between Hinna and Gangori along the Bhagirathi river. From Gangori the axis curves northward and can be traced along the Kaldi Gad. This anticline is symmetrical with 20 -50° N- NE and S-SW dipping limbs and exposes the oldest Netala Quartzite member of the Quartzite Formation in its core. The overlying metabasics and Quartzite Formation are also folded along this axis.

(v) Other Folds - Besides the above mentioned large scale folds, the thrust zone of metabasics around Uttarkashi is characterised by many small noses and closures, which are generally dissected by streams flowing along the fold axes. These are marked with the opposite dipping foliation planes at about 20° in the NW -SE and E-W directions in the metabasics (Map 3). Near Giunla, the metabasics are folded in an arcuate anticline. The thickened metabasic exposure is possibly due to the overturning of the thrust zone towards the northeast, while the upper contact of these metabasics dips to the southwest at about 30-40° (Fig. 58, S_{6-7}).

Another large scale NW-SE trending anticline in the metabasics and overlying Quartzite Formation lies between Sankrona and Chaurikhal where thrust zone is considerably thickened. The anticline appears to be asymmetrical towards the northeast and is characterised by northeasterly dipping strain-slip cleavage (p.77) at 30-50°.

Besides this, a NW-SE trending syncline also lies between Foeld and Dhanpur exposing the metabasic zone on its limbs.

3.2 -2 FAULTS

(1) Baragadi Fault - The area is relatively free from small or large scale faults, hence only a few faults could be established in the field. The notable of these faults is the Baragadi Fault along axis of the Baragadi Anticline. Here, the Upper Uttarkashi Limestone member which is exposed

on southern limb of the anticline is not repeated on its northern limb. The fault runs between Dilsod and Sada for about 8 km. along the Baragadi Gad and Bhagirathi river which are characterised by a typical wide U-shaped valley.

(2) Kot Fault - It lies north of Uttarkashi where the Upper Uttarkashi Limestone member at Tekhla is not repeated on southern limb of the Kot Syncline. The fault runs along the contact of quartzites and metabasics(Bareti Quartzite member). The downthrow along the Baragadi and Kot Faults has caused the absence of the Upper Uttarkashi Limestone exposure in . region between these faults(Fig. 58). The 4 km. long Kot Fault also displaces the metabasic thrust zone by about 0.5 km.near hill 2 133 metres(Map 3).

(3) Shyalna Fault- The Dharasu Formation is separated from overlying Khattukhal Limestone by Shyalna Fault which runs for about 9 km. with a sinuous NW-SE and E-W trend between Dang and Giunoti. It is evidenced by considerable flowage of limestone along the contact which is characterised by infrafolia recumbent folds along the bedding planes. On the Darasu-Barkot road between milestones 13/0 and 14/0, the Dharasu Formation dips gently (15-20°) in the NE while the overlying limestones are dipping vertically or at very high angles in the NE and ENE (Fig.133). The steep limestone escarpment along left bank of the Khurmola Gad also indicates presence of this fault.

3.2-3 THRUSTS

In the area, the most important structural features are a number of thrust faults which have complicated the stratigraphical relationships because these thrusts delimit formation boundaries. In these pages the thrusts have been discussed from south to north.

(1) Aglar Thrust - In the southwestern corner of the area, the phyllites of the Chandpur Formation are exposed for about 6 km. along the left bank of

the Aglar Nadi. The rocks dip 15-60° due S - S50°W between Thaturu and Bhawan Devi whereas the overlying Nagthat Formation dips at 20-60° due N 20-50°E on the right bank of the nadi (Figs.52 & 53). Such an unusual relationship between the two formations can be explained only by a dislocation plane, hereafter called as the Aglar Thrust which has been previously mapped as a fault along the nadi by Auden(1934 a). The following evidences favour the presence of the thrust:

(i) Opposite dipping Chandpur and Nagthat Formations along two banks of the Aglar Nadi.

(ii) Discordance of about 15° in the strike of the Chandpur and Nagthat Formations along the Aglar.

(iii) A U-shaped valley of the Aglar Nadi - a characteristic feature of some of streams along the dislocation planes in the region.

The Aglar Thrust runs in the WNW - ESE direction for at least 6 km. along stream course which is controlled by this thrust.

(2) Basul Thrust - Along northern slopes of the Gorpha Dhar, the base of the Nagthat Formation is marked with an approximately 50 metres wide crushed zone of extremely powdered, friable and highly cataclastically deformed quartz schists (Fig. 199). This is in sharp contrast with less metamorphosed phyllites of the Chandpur Formation which lies against this crushed zone of the Nagthats. These cataclastic effects can be observed even at 800 metres in the direction of dip along the Dhanaulti road where quartzites still display a schistosity. The following features strongly indicate the presence of the thrust:

(i) An abrupt increase in the metamorphic effects in the Nagthat Formation.

(ii) The presence of an extremely friable and powdered crushed zone at contact between the Nagthat and Chandpur Formation.

(iii) An abrupt lithological change from phyllites of the Chandpur Formation to well bedded quartzites of the Nagthat Formation.

The above characters are well marked along base of the Nagthat Formation at Basul,Kot and at a place 2.5 km. southwest of Laluri. Map 3 and synoptic S_1 (poles to the bedding planes)diagram drawn for the Nagthat Chandpur and Laluri Formations(Fig.11, Sector 5) reveals that these dip 30° due S 35°W on an average and do not show any angular discordance between them. Therefore, it is evident that the Basul Thrust is essentially a bedding thrust and dips approximately 30° S40°W. It trends N 50°W -S 50°E between Basul and Andhiari for about 10 km.

The strike continuity and similarity in the phenomenon of increased cataclastic effects at Kaudia where the Nagthats are more metamorphosed to quartz schists(cf.,Auden,1934 b) indicate its possible extension for another 13 km. at least upto this locality.

(3) <u>Tons Thrust</u> - Auden (1934b,1938) extended the Tons Thrust from Sarog to Sindhol and Khand on the northern flank of the Krol Nappe. The present mapping indicates that the Tons Thrust extends further from Khand to Kandi in southeast and does not terminate against any other fault or thrust as interpreted by Auden(1949). To sum up, the Tons Thrust can be mapped from Sarog to Kandi for about 50 km. in WNW-ESE direction and is an important structural feature in the Garhwal Himalaya.

The Tons Thrust is well exposed along right banks of the Nagon Gad and Bhagirathi river at Chapra,Kiari,Laluri,Khand and Kandi.It separates uniformly SW dipping Laluri Formation from the Dharasu Formation. On the basis of the field studies and geological map of the area (Map 3), the following evidences support the continuation of the Tons Thrust:

(i) Truncation of the Nagon Anticlinal axis between Nala and Kansi.

(ii) Concealment or truncation of the southwestern limbs of the Daski Syncline and the Nagon Anticline near Bheti by the Tons Thrust (Fig. 54).

(iii) Non-repetition of the Laluri Formation on the northern limb of the Nagon Anticline (Figs.52 to 55).

(iv) Occurrence of the friable, crushed and splintery slates of the Laluri A Member near the thrust zone.

(v) Variation in the strike directions of the Laluri and the Dharasu Formations -the Laluri Formation strikes N 55°W -S 55°E while the Dharasu Formation trends N 32°W -S 32°E in the immediate vicinity of the thrust. The πS_1 diagrams for the two formations indicate a difference of 23° between strikes (Map 5, sectors 4 and 5, Figs. 10 & 11).

(vi) Juxtaposition of two contrasting lithological associations along the thrust i.e., the black slates of the Laluri Formation and purple argillaceous quartzites of the Dharasu Formation.

(4) Bangaon Thrust - In the western parts of the mapped area, the contact of the Dharasu Formation with the overlying Bangaon Limestone also appears to be a thrust contact. Though it has been observed in a small area around Bangaon yet it appears to extend westward along the Yamuna river as a fault (Dhoundial and Ali, 1967). This has been named as the Bangaon Thrust (Jain and Mithal-1968). In general, the thrust makes an arcuate disposition from NW-SE to WSW-ENE with northerly dips at about 45°. The following evidences are indicative of the presence of the Bangaon Thrust:

(i) A change in the regional N 40°W - S 40°E and N 60°W-S 60°E strike of the Dharasu Formation in sectors 2 and 3 respectively to E-W in sector 1 near the thrust zone (Map 5, Figs. 7 to 9).

(ii) Presence of WSW-ENE trending cross folds parallel to the thrust front in a narrow zone of the Dharasu Formation near Pujargaon.

(iii) Development of 5 to 14 metres thick zone of recrystallised limestone along the contact near Bangaon.

(iv) An increase in preferred orientation of carbonate minerals in the Bangaon Limestone near the thrust plane. Away from the thrust zone, limestones do not show any orientation of minerals.

(v) Truncation of the Daski Syncline axis near the hill 2716 metres in northwest.

(vi) Angular discordance of dips near the thrust plane - at pleaces the Bangaon Limestone dips vertically along the road near Bangaon while underlying Dharasu Formation at 40°-50° due NNE.

(5) Dharasu Thrust - The southwestern boundary of the Garhwal Group rocks is demarcated by a major dislocation in this region and is designated as the Dharasu Thrust after the village Dharasu. It is characterised by a sinuous course in NW-SE, N-S, and NNE-SSW between Khalsi and the hill 2208 metres but trends NNW-SSE between Soman and Giunoti. On a regional scale, it dips towards west and southwest. The following field observations support the thrust:

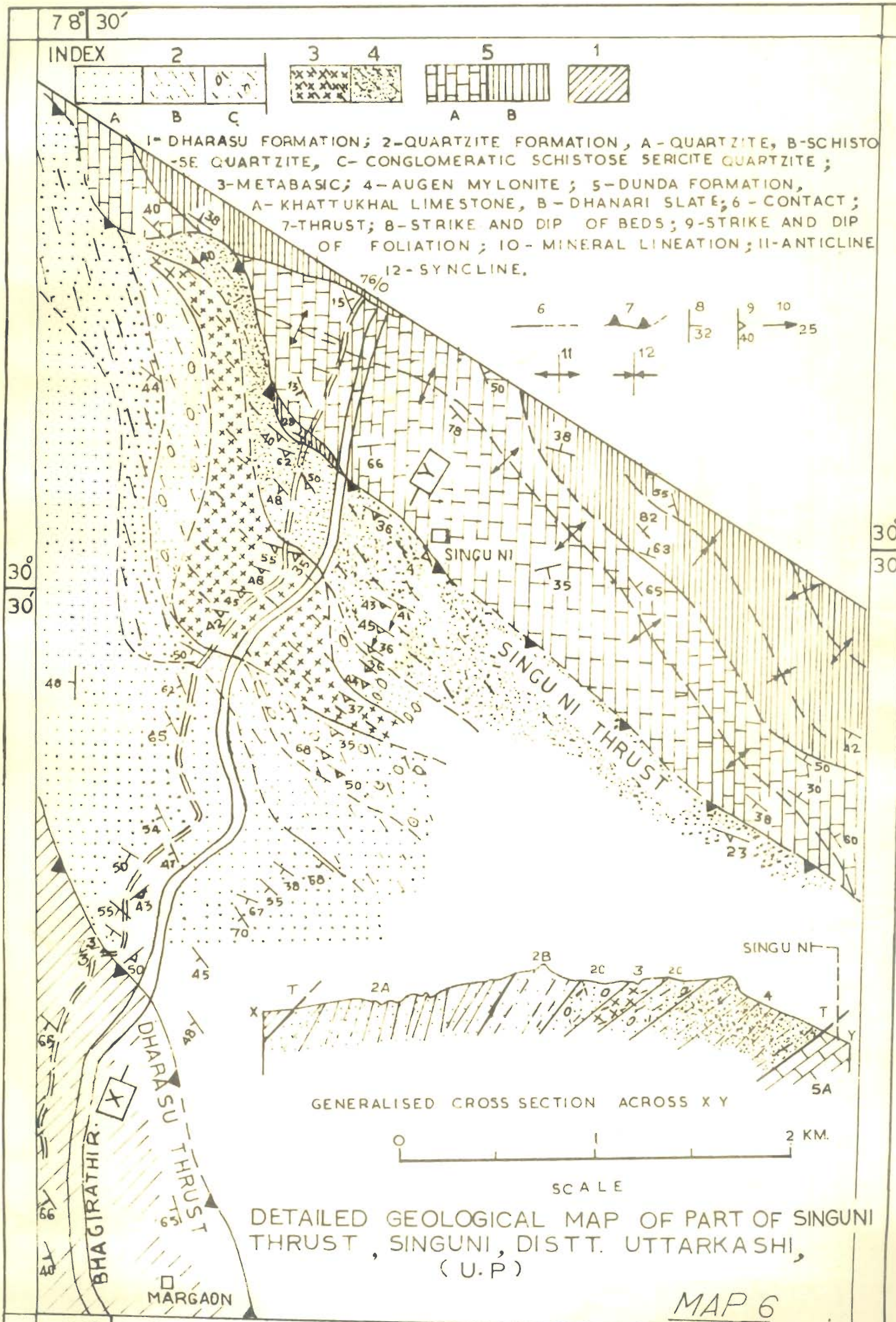
(i) Development of highly disturbed and deformed zone in the Dichli Dolomite along the thrust between Malli and Khalsi (Fig. 3). The zone is marked with zigzag, NNW plunging chevron folds(Fig. 4).

(ii) Truncation of the Bharkot Syncline axis near Malli (Map 4).

(iii) Abutment of gently dipping (NE and ENE)Dharasu Formation against the highly dipping (60°-80°, westerly and southwesterly)Dichli Dolomite between Malli and Chham (Map 3, Fig. 55).

(iv) An abrupt change of the lithological association - the Quartzite Formation comprising white,buff,pure quartzites and Dichli Dolomite (stable shelf association) lie in contact with the greyish green laminated argillaceous quartzites and phyllites(unstable shelf association)for a considerably distance along the contact (Chapter 8).

(v) Development of friable schistose phyllites and argillaceous quartzites indicating a higher degree of metamorphism of the Dharasu Formation



DETAILED GEOLOGICAL MAP OF PART OF SINGUNI THRUST, SINGUNI, DISTT. UTTARKASHI, (U.P)

MAP 6

near the thrust.

(vi) Impersistent occurrences of metabasics along the thrust at Ulya and Soman a characteristic feature of many thrust zones in the Garhwal and Kumaon region.

The Dharasu Thrust extends in the northwest to Gangani along the Yamuna river and separates metabasics and the Dharasu Formation from the underlying Dunda Formation (Map. 11). This has resulted in pinching out of dull green slates of the Dharasu Formation in the northwest. The Dharasu Thrust also conceals the Quartzite Formation of the southern belt and Singuni Thrust. Further in northwest, closure of the Garhwal Group outcrop around Banchangaon (cf., Auden, 1949) implies possible concealment of the Dharasu Thrust beneath Main Central Thrust.

The Dharasu Thrust is considered here synonymous with the Nalupani Fault of Dhoundial and Ali (1957) and the 'major tectonic unit' of Auden (1938). According to Auden (Map 10), this unit passes from Ciunoti (in the present area) to 30° 24':78°32' near Pirhi Hill, 30°14': 78°40' near Srinagar across the Alaknanda river to Tilkannikhal where it bounds the Dudatoli crystalline mass towards north (Auden, 1937, 1949; Dutta and Kumar, 1963, 1968). From this it is likely that the Dharasu Thrust merges with the North Almora Thrust of Heim and Gansser (1939) in Almora and the Lidhiya Thrust of Valdiya (1962) in Pithoragarh regions.

(6) Singuni Thrust - The Quartzite Formation of the southern belt is thrust over the underlying Dunda Formation along a NW-SE and NNW-SSE trending and southerly dipping dislocation plane - the Singuni Thrust. The following field relations are noteworthy (Map 6):

(i) Truncation of the Dhanari Slate member on the southwestern limb of the Khattukhal Anticline between Bagyalgaon and Khattukhal except for a small patch of the slates at milestone 75/4 along the Uttarkashi road .

(ii) Truncation of the Khattukhal Anticline axis in the northwest near Khattukhal village.

(iii) Concealment of the Khattukhal Limestone member on the southwestern limb of the anticline between Khattukhal and Ulya. Further northwest, the thrust also cuts the northeastern limb(Fig. 59,S_8- S_{11}).

(iv) Discordant relationships of the southern Quartzite Formation belt withunderlying members of the Dunda Formation at the following localities (Map 3):

(a) Locality 30°45' 50" : 78°17' 40" about 1.75 km. NE of Giunoti -friable drab green and purple Dhanari Slate member dips 20°E and is overlain by southwesterly dipping schistose sericite quartzites of the Quartzite Formation. Similar relations have also been noted at locality 30°40' :78°17'52" 1.25 km. north of Sartali (Fig.59 , S_{12}- S_{14}).

(b) 0.75 km. east of Ulya - the overlying southwesterly dipping schistose quartzites (Quartzite Formation)are in contact with the easterly dipping Khattukhal Limestone. Further north and also near Khattukhal, the same field relations have been observed where the quartzites dip 30-50° due S50°W (Fig.59,S_8-S_{11}).

(c) About 3 km southeast of Paturi- the metamorphosed sericite quartz schists dipping 20° to S40°W, overlie the N-S and NNE -SSW trending Dunda Quartzite member.

(v) Incipient development of preferred orientation of calcite grains in the Khattukhal Limestone near the thrust plane.

(vi) Development of deformed, crenulated and slaty Khattukhal Limestones at milestone 75/3 along the Uttarkashi road and near Dang (Fig.160).

(vii) Occurrence of highly metamorphosed(at least upto garnet zone) and cataclastically deformed augen mylonites(refer Chapter 4) over low grade metamorphosed(chlorite zone)Dunda Formation between Khattukhal and Bagyalgaon.

(viii) Higher degree of metamorphosed schistose quartzites and quartz schists of the Quartzite Formation over slates and limestones of the Dunda Formation.

(ix) An increase of metamorphic effects in the Quartzite Formation near the thrust e.g.,along the Singuni-Margaon mule track(Chapter 4).

The Singuni Thrust parallel Dharasu Thrust for a considerable distance and possibly coalesces with it in the northwest beyond latitude 30°48'. In the southwest it is marked with highly deformed quartz schists along the Uttarkashi-Lambgaon road at 30°34':78°30' and steps over the Dunda Thrust.

(7) Dunda Thrust - Limiting the Quartzite Formation outcrop of northern belt in the southwest, the Dunda Thrust is conspicuous by about 100-800 metres thick metabasic rocks. The thrust zone is defined by the northeasterly dipping metabasics which separate the southwesterly and highly dipping Quartzite Formation from the Dunda Formation. The following important and noteworthy field characters support the thrust plane(Map 7).

(i) Continuous occurrence of metabasic rocks along the structurally discordant formation boundaries - a characteristic feature of many thrusts in Garhwal and Kumaon regions. On a regional scale, while the overlying Quartzite Formation dips towards southwest, the Dunda Formation generally dips in northeast.

(ii) Relatively steep dips of the underlying Dunda Formation in comparison to metabasic rocks and can be noted at the following localities:

(a) On the left bank of a small stream, 0.3 km. west of Jakhni (Map 7,S_2)- the metabasics are well foliated to 20° due NE on the left bank of the stream. Below the thrust contact, the Dunda Quartzite member dips 33° dueN25°E but the same bed steepens at lower altitudes to 65° N45°E. Within 200 metres from the contact, the quartzites are vertically dipping with N 30°W-S 30°E strike.

(b) About 1 km. SE of the previous locality along the same stream - metabasics directly overlie the Dhanari Slate and conceal the Dunda Quartzite. At about 200 metres above the Uttarkashi road, the quartzites dip 70° NE while the metabasics at 20° N12°W.

(c) At milestone 75/5 along the Uttarkashi road - the contact is distinctly abnormal. Here metabasics dip at 25° N30°W while the underlying Dunda Quartzite is folded with a dip of 60 -70° N85°W and S 80°E near the contact. Further south, along the road, the quartzites are even inverted towards the north and twisted (Fig.153).

(d) At Odalak - The metabasics dip at 40° N65°E while the Dunda Quartzite member is relatively steeply dipping(Map 7,S_4)

(e) 0.5 km. east of Koti - the underlying quartzites dip at 75° S while metabasics are gently inclined to 45° N30°E.

(iii) Opposite dipping metabasics and the overlying Quartzite Formation.- on a regional scale,the metabasics dip in the northeast while the Quartzite Formation in the southwest. The following localities are important for distinct field relations:

(a) At the ridge crossing between Shyalna-Kunsi mule track - the metabasics are foliated in the 20° NE direction but overlying quartzite dip 30° S80°W near the contact (Fig. 59,S_{13}).

(b) At Jakhni - the metabasics dip 30° N20°E whereas the Quartzite Formation is inclined at 60 - 70° S50°W (Map 7, S_2).

(c) Near Bhinoti - the quartzites dip 50° S30°W and overlie the well foliated metabasics which gently dip towards northeast (Map 7).

(d) At Koti - the basic rocks dip 40° N30°E but the quartzites are either vertical with N 30°W-S30°E strike or dip 70-80° to the southwest (Fig. 59,S_{1-2}).

The northeasterly dip of the metabasics undoubtedly indicates regional inclination of the Dunda Thrust. The thrust extends in the northwest and crosses the Yamuna river at a point about 3 km. NE of Gangani where north-easterly dipping metabasics possibly extend beneath the SW inclined Quartzite Formation (Map 11). The thrust passes through the hill 2288 metres, Jakhni, Dunda, Odalak,Koti and ccelesces with Singuni Thrust in the southeast possibly near Dingaon. It extends for atleast 35 km.

(8) Uttarkashi Thrust - Like the southern Quartzite Formation belt, quartzites of the northern belt are thrust upon the Uttarkashi Formation along the NW-SE trending Uttarkashi Thrust which is also conspicuous by the occurrence of metabasics along the thrust zone. The following field characters support the presence of this thrust:

(i) Truncation of the lithological boundaries by the metabasic zone- as is evident from the geological map(Map 3),these truncated contacts are best observed at 2 km. NW of Pata,Gangori village,along the Uttarkashi - Dodhi Tal road, Hinna,Mandon,and Sada where the thrust zone runs obliquely to different members of the Uttarkashi Formation.

(ii) Discordant relations of metabasic zone with the underlying Uttarkashi Formation - in the field, the metabasic zone is discordant with rocks of the Uttarkashi Formation at Pokhri and Dilsod where the Upper Uttarkashi Limestone member is found steeply dipping and plicated (Figs. 52 & 57-S_5).

(iii) Occurrence of girdle shaped metabasic outcrops along formation contacts. The metabasics truncate many of the structural trends in the Uttarkashi Formation at many small closures(Map 3).

(iv) Discordant relations of the metabasic zone with the overlying Quartzite Formation at the following localities:

(a) Near milestone 81/1 along the Uttarkashi road - the upper contact of metabasic zone with quartzites runs almost N-S while these dip 35°SW and 65° S30°W respectively(Map 3).

(b) 1 km. south of Bareti along left bank of the Bhagirathi river - metabasics are well foliated at low angles to 30° S40°W whereas overlying quartzites dip 65° S (Fig. 58- S_{6-7}). Here the contact is also marked with nearly 100 metres wide intensely crushed zone in the quartzites.

(c) At Sankrona ridge along the Uttarkashi - Lambgaon road - similar angular relations are observed where the Quartzite Formation dips at relatively higher angle to 30 -60° (Fig.58 - S_2). Also at the contact, quartzites occur as stretched lenses within the metabasics (Fig.138).

(d) At a place nearly 1.5 km. north of Foeld on the road - the metabasics dip 15 -20 ° NE whereas the overlying quartzites are dipping at 50 -70° in same direction (Fig.58-S_1). Further in the southeast along the road, quartzites maintain their northeasterly inclination at 40-50° while metabasics are dipping 30-40° in NW direction near the contact (Map 8).

(v) An increase in metamorphic effects along the thrust contacts - the quartzites are strongly schistose and develop white sericite mica along foliations with a prominent lineation all along the thrust contact between Sada, Dhanpur, Sankrona and Chaurikhal (Fig.161).In the Uttarkashi and Quartzite Formations these effects are more prominent where the metabasic zones is either absent or thinly developed e.g. at Hinna, Naid.

In the north, the Uttarkashi Thrust dips at 30° -40° towards NE between Naid and Hinna but is sinuous further in the northwest and southeast. In northwest, it passes through Gangori and hill 2153 metres with a general NE-SW trend but attains the usual NW-SE strike further in the northwest near Jugaldi. Taking a sharp turn near Hinna, the thrust crosses the Uttarkashi road at longitude 78° 30' and trends almost NNW-SSE between Iwain and Manpur. After a sharp turn at Dhanpur and Sankrona, the zone trends NW-SE further southeast.

In the south, the Uttarkashi Thrust dips southwest at about 20-30° on an average between Sada and Dilsod but like the northern trace, it dips towards northeast between Matli and Baun, thus indicating an overturning in the NE (Fig.58-S_{7-8}). From a look at the map (Map 4) it is evident that the Uttarkashi Thrust is folded into a symmetrical anticlinal,domal shaped structure with subordinate warpings and fold closures. Both traces of the thrust are 7 km. apart across the strike near Uttarkashi but narrow to only 1 km. in the northwest between Matli and Baun.

The Uttarkashi Thrust crosses the Yamuna river at Pujargaon and is characterised by similar anticlinal structure as along the Bhagirathi river (Map 11). The lower trace of the thrust zone forms a closure near Sada but upper margin of the thrust zone extends further southeast at least upto Chaurikhal. The entire length of the lower trace of thrust zone is about 25 km. and that of the upper trace 32 km.

3.3 MINOR STRUCTURES AND THEIR ANALYSIS

3.3-1 INTRODUCTION

The minor structures in the various rock types have been studied from southern and southeastern region around Uttarkashi. This particular region has been selected because of good development of the minor structures along the Uttarkashi road upto Bareti and Uttarkashi -Lambgaon road section upto Chaurikhal.

The various planar and linear structural elements like the bedding planes, foliations and lineations have been critically studied and mapped in the field. In the following pages, an attempt is made to decipher their behaviour from different zones on the basis of the structural methods as described by Turner and Weiss (1963).

In general, the selected area comprises of the following three tectonic zones(also refer pp. 94-97):

(i) An autochthonous zone of the Uttarkashi Formation which is exposed in a window. In the defined limit of the selected area, the uppermost Bareti Quartzite member is folded into the Baragadi Anticline and is faulted along its crest.

(ii) Uttarkashi Thrust zone with the metabasics.

(iii) The allochthonous Quartzite Formation of the northern belt which has been thrust over the Uttarkashi Formation along the Uttarkashi Thrust, marked with the metabasics. The quartzites are folded along NW-SE axes and occurrs into detached outcrops due to erosion.

3.3-2 STRUCTURAL ELEMENTS

(1) Planar structures - In the area, the three main planar structures (S planes) are bedding planes (S_1),foliation or schistosity (S_2) and strain-slip cleavage(S_3).The rocks are better jointed in the allochthon but the systematic joint analysis could be carried out only at a few localities where the accessibility is easy in this zone.

(i) Bedding planes (S_1) - The primary lithological and compositional layering formed during the deposition of the sediments is designated as bedding planes (S_1). In the autochthonous zone,it is defined by alternating pelitic and semipelitic layers,colour and grain size variations. The regional strike of S_1 is NW-SE but varies to NE-SW and N 75° E-S75°W in the autochthon near Dobha. The dip is 35° on an average.

While S_1 is absent in the thrust zones, it is poorly developed in quartzites of the allochthon and is marked with faint colour and grain size variations. The bedding dips both in the NE and SW in this zone.

(ii) Foliation (schistosity) (S_2)- The most prominent secondary planar structure in all the zones is the foliation(S_2). In the autochthonous zone,it is defined by preferably oriented quartz grains and sericite-muscovite flakes. It dips 35° due N 60°E on an average. In the metabasics of the thrust zone,

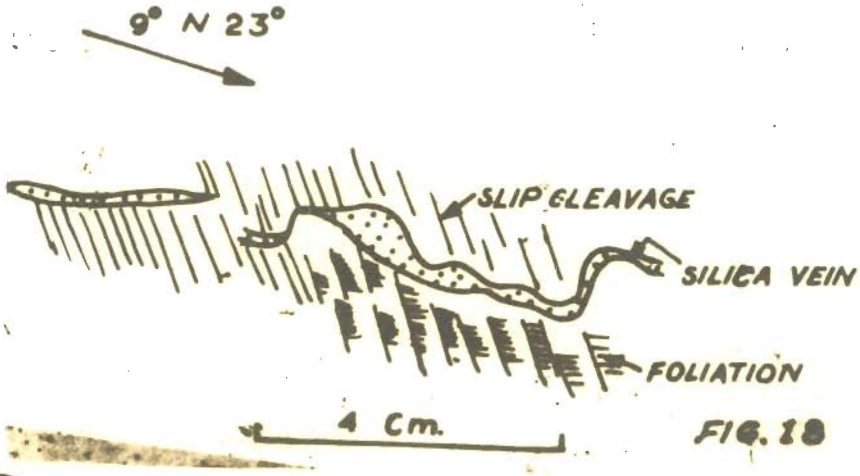


FIG. 18

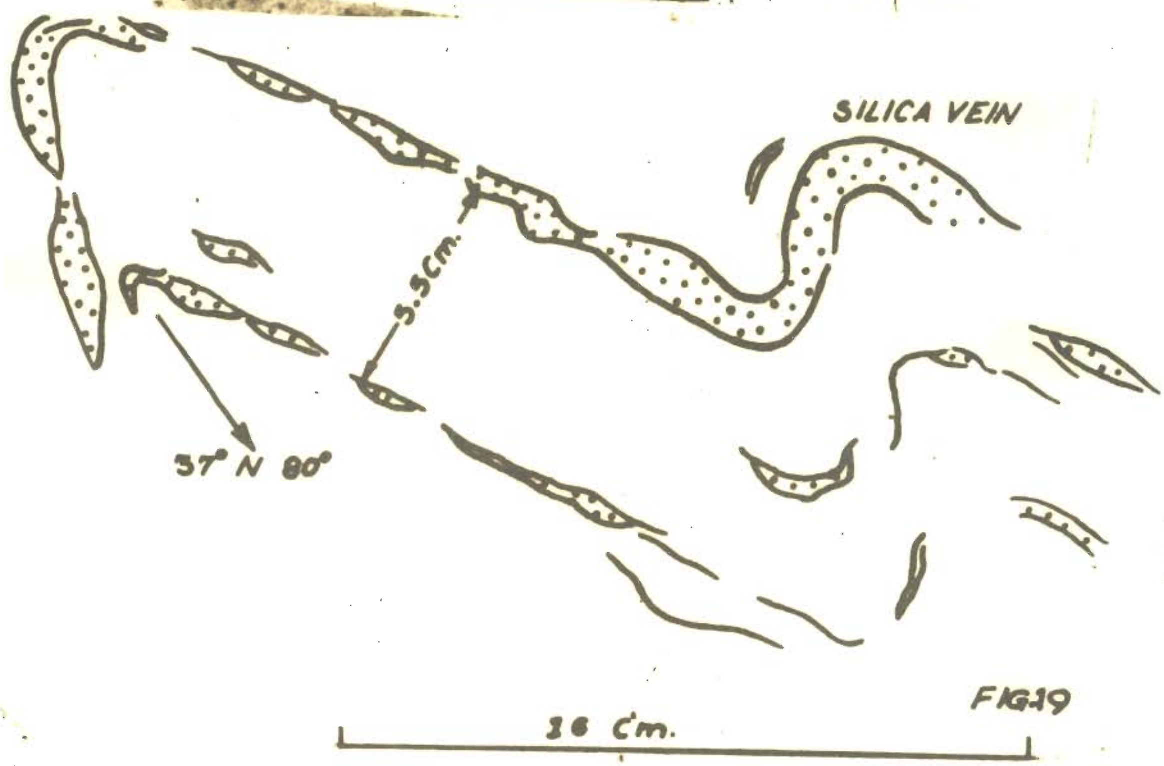


FIG.19

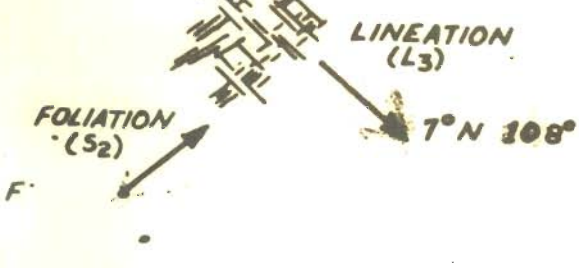


FIG. 25

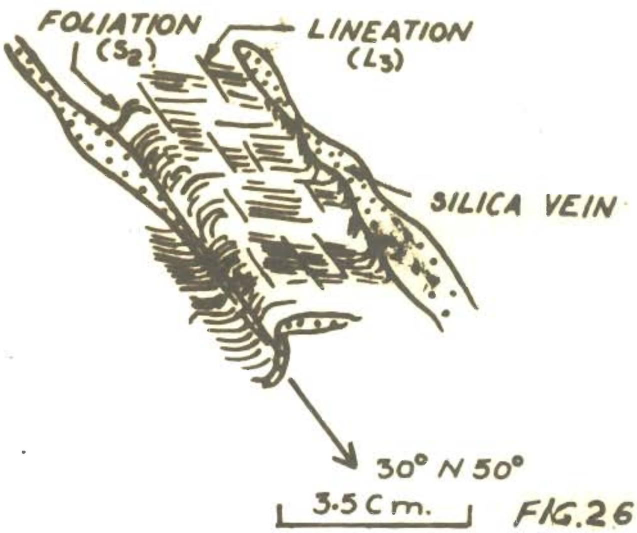


FIG.26

it is characterised by preferably oriented chlorite flakes (Fig.232) and prismatic hornblende along the foliation and dips both in the NE and SW directions at about 30°. In the allochthon, it displays good lustrous surfaces due to the strongly oriented sericite(Fig. 161) with 30° NEand SW dips.

(iii) Strain-slip cleavage (S_3) - It is perceptible only in the metabasics and is considered here as S_3. It is defined by (i) closely spaced discontinuous fine slip planes (Fig.18), (ii) axial plane cleavage of the slip (Figs.170 & 172) and minor asymmetrical folds on S_2 (Fig. 19).In thin sections, the sharp flexuring of the earlier S_2 planes has rotated flaky chlorite along the newly developed planes of recrystallisation (Fig.232). S_3 dips consistently 30° due N30°E on an average.

Though the strain-slip cleavage is generally defined by refolding of an earlier cleavage or schistosity on a small scale, it is generally shear fractures which have been referred by various names e.g.,false cleavage and herringbone structure(Badgley,1965, p.284). Similar structures have also been called as crenulation cleavage (Rickard,1962) and microlithons(De Sitter,1956). Turner and Weiss(1963) described these new slip surfaces as follows:" The surfaces of slips i.e.,strain-slip cleavages are not discrete fractures but rather laminar domains of intense strains.The domains may become foci of syntectonic or post-tectonic recrystallisation of mica so that ultimately the strain-slip cleavage evolves into a foliation". However, Badgley(op.cit.,p.285) maintains that in certain cases these are certainly discrete fractures with minor slip movements along the planes.

(iv) Joints - The systematic joint study could only be carried out in the allochthonous Quartzite Formation between Foeld and Dhanpur on both limbs of a syncline.

The joints in the quartzites are sharp and straight but a few major joints extend for about 20 metres. These are open and gaping due to tension.

FIG. 20

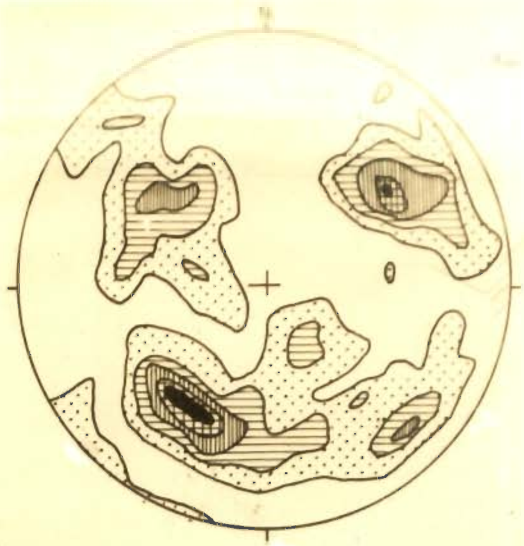


FIG. 21

FIG. 22

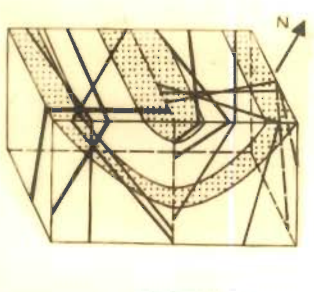


FIG. 23

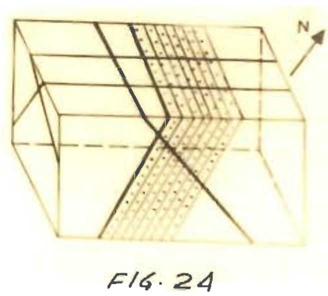


FIG. 24

T A B L E -9

CHARACTERISTICS OF ORIENTATION OF JOINT PLANES

Fig.No.	Location	No.of poles	Contour values (%)	Maxima plunge	Bearing	Strike and dip of average joint planes corresponding to maxima		
						Strike	Amount of dip	dip direction
20	Northern limb of syncline in quartzites (Dhanpur)	69	1.5-3-4-6-7	52°	N58°	N148°-N328°	38°	N238°
21	Southern limb of the syncline (Foeld)	297	0.3-1-2-3-4	60°	N48°	N138°-N318°	30°	N228°
				12°	N130°	N40° -N220°	78°	N310°
22	SW dipping quartzites (milestones 73/2 -74/4)	140	0.7-2-4-5-6	38°	N50°	N140°-N320°	52°	N230°
				40°	N210°	N120°-N300°	50°	N30°

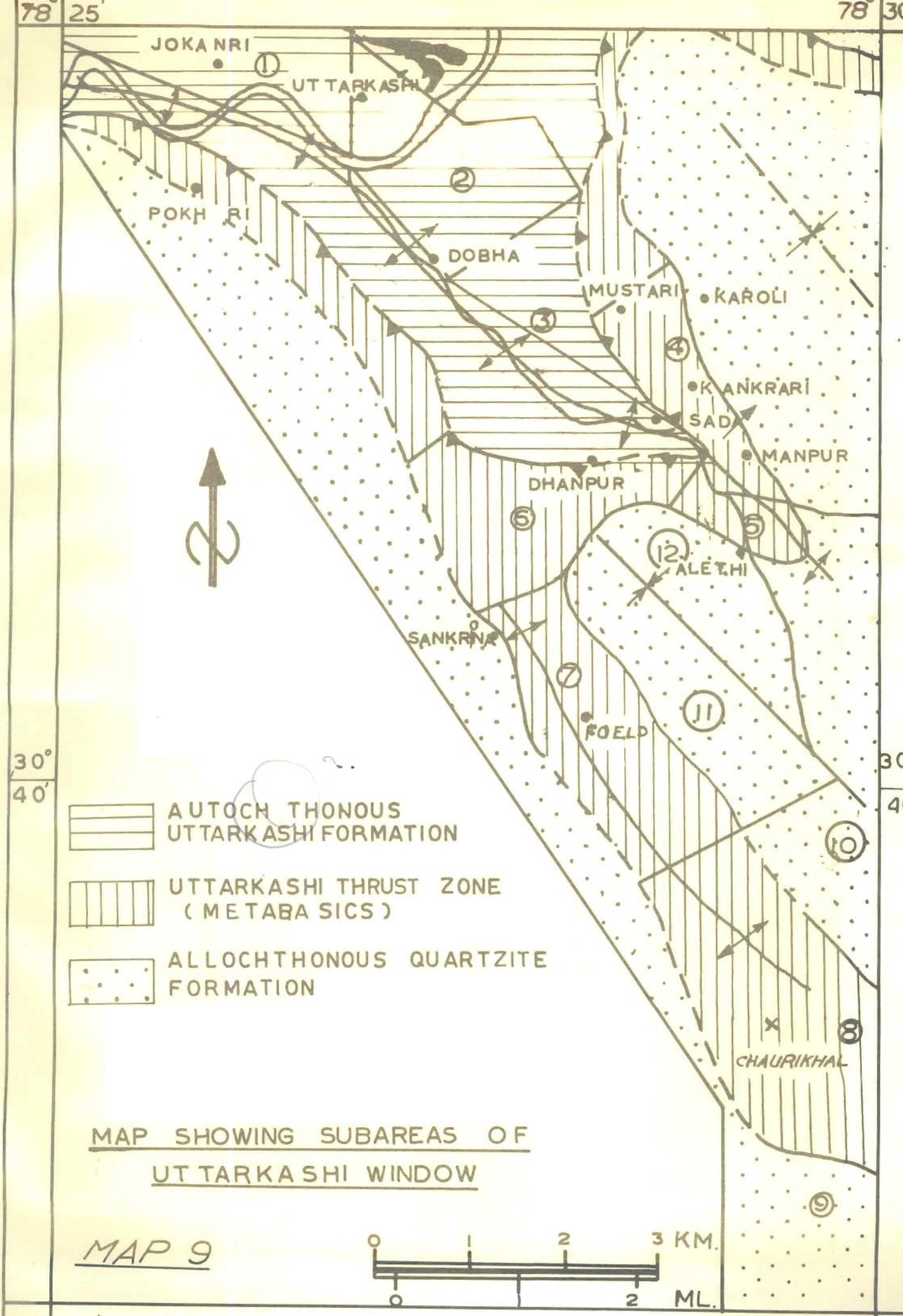
The π-diagrams of the joint planes show one or two maxima with many submaxima arranged in a circular girdle(Figs.20 & 21). In relation to the bedding, these are strike, dip, oblique and bedding joints (Fig.23). Due to absence of the conjugate pairs, these does not appear to be related to the fold geometry.

In comparison to the joint pattern with the southern Quartzite Formation belt the systematic joint analysis along the Uttarkashi road between milestones 73/2 and 74/4 reveals only dip, strike and bedding joints (Figs.22 & 24).The NE dipping strike joints are invariably polished and slickensided indicating shearing along the planes. Table 9 summarises the orientation of the joint planes.

(2) Linear structures - The significant linear structures are as follows -

(i) Mineral lineation on S_2 (L_1) -This is marked by dimensional elongation of quartz and sericite mica along S_2 planes in autochthonous and allochthonous zones(Figs.161-162). L_1 is continuous throughout the rock and is penetrative in comparison to the superficial slickensides on joint planes. Mica lineations vary in intensity depending upon the nearness to the thrust zone, competency of rocks and other local conditions. It plunges towards NE at low angles (0 -30°) in the autochthon and NE and SW between 0-70° in allochthonous zone. L_1 is normal to the major fold axes and thrust front thus appear to be 'a' lineation in the direction of tectonic transport.

(ii) Slickensides and groovings (L_2) - These are generally confined to joint planes of the rocks from allochthon and autochthon.The field relations with other planar and linear structures show that the L_2 plunges opposite to S_1, S_2 and L_1. At places,it is not differentiable from L_1 due to overlapping,though in general, it appears to have formed later than L_1. The L_2 plunges 5-60° NE and SW and generally trends normal to the thrust zone and fold axes in the 'a' direction.



MAP SHOWING SUBAREAS OF UTTARKASHI WINDOW

MAP 9

T A B L E - 10

SELECTIVE AND SYNOPTIC π S_1 S_2 & LINEATION C
OF UTTARKASHI WINDOW ZONE

	S_1							
	Fig. No.	Sector No.	No. of Readings	Contour value & height of maxima	Orientation of S_1 maxima	Dip & Strike of S_1: Strike	Dip & Strike of S_1: Dip & Direction	F N
Selective	27	1	21	5-15-20-25(25%)	70°/N180°	N90°-N270°	20°/N0°	2
Selective	29	2	83	1.2-5-10-15-17(17%)	56°/N264°	N174°-N354°	34°/N84°	3
Selective	31	3	71	1.4-4-10-14-20(20%)	50/N225°	N135°-N315°	40°/N45°	[illegible]
Synoptic	33	.	175	0.5-3-5-8-11(11%)	50°/N258°	N168°-N348°	40°/N78°	[illegible]

* Micalineation (L_1) plunges 0-25°/N-N45°
slickensides (L_2) plunge 2-23°/N5°-N40°

** L_1 plunges 5-25°/N340°-N45°

*** (Fig.35) - L_1 (36%) plunges 10°/N22°.

T A B L E - 10A

SELECTIVE AND SYNOPTIC πS_2, πS_3 AND LINEATION CHARACTERS OF UTTARKASHI THRUST ZONE

Fig. No.	Sect- or No	πS_2: No. of read-ing.	πS_2: Contour value & height of maxima	πS_2: Orientation of S_2 maxima.	Dip & Strike of S_2: Strike	Dip & Strike of S_2: Dip direction
36	4	38	3-9-15-21-27-33%(33%)	60°/N210°	N120°-N300°	30°/N31°
37	5	37	3-9-15-21-27(27%)	57°/N38°	N128°-N308°	33°/N218°
38	6	47	2-6-8-13-15(15%)	70°/N45°	N135°-N315°	20°/N225°
39	7	58	1.7-5-9-12-15(15%)	(i)52°/N90° (ii)70°/N240°	N-N180° N 30-N210°	38°/N270° 20°/N320°
40	8	32	3-6-12-19-25(25%)	50°/N28°	N118-N298°	40°/N208°
41		165	0.6-3-6-9-11(11%)	(i)54°/N35° (ii)58°/N212°	N125°-N305° N122-N302°	36°/N215° 28°/N32°

Fig. No.	πS_3: No. of read-ings	πS_3: Dip & direction	Microcorrugation (L_3): No. of read-ings.	Microcorrugation (L_3): Plunge
36	23	36°-76°/N37-N93°	25	0-30°/N305° to N19°
37	8	18-62°/N5-N82°	6	8-36°/N115 to N146° & N28 to N348°
38	12	15-70°/N354-N68°	15	0-66°/N215 to N328°
39	30	36-75°/N38-N93°	31	5-34°/N279 to N354°
40	4	28-46°/N358-N42°	4	4-14°/N315 to 322°
41	79 (Fig.42)	S_3 dips 30°/N32° and strikes N122-N302° corresponding to maximum 13%. Contour values 1.3-4-8-12-13%	81 Fig. 43	Maximum(10%) plunges 20°/N314°. Contour values 1-4-5-8-10%

T A B L E - 11

SELECTIVE AND SYNOPTIC S_1, S_2 AND LINEATION CHARACTERISTICS OF ALLOCHTHONS QUARTZITE FORMATION ZONES

	Fig.No.	Sector No.	S_1 No.of Readings	S_1 Dip and strike of S_1	S_2 No. of Readings.	S_2 Dip and strike of S_2	Lineation
Selective	44	9	4	26-45°/N202-N232°	16	26-52°/N135 -N184°	L_1 plunges 10-58° between N188°-N225°
	45	10	7	16-72°/N42-N68°	35	18-60°/N48 -N116° (30°/NE on an average)	L_1 plunges 26-74° btween N204°-N304° L_2 plunges 0 -44° between N26°-N64°
	46	11	45	28-90°/N240-N195° and N32-N92°	4	8-70°/N305-N60°	L_1 plunges 15-30°/N228-N246° and N45-N65° L_2 plunges 4-72°/N198-N270°
	47	12	3	40-50°/N185-N254°	7	15-44°/N180°-N238°	L_1 plunges 24-51° between N46°-N78° L_2 plunges 40-70° between N195°-N255°.
Synoptic	48		59	60°/N66° on an average corresponding to maximum (17%) Contour values 1.7-3-14-17%	62 (Fig. 49)	30°/N74° on an average corresponding to maximum (12%). Contour values 1.6-4-8-11-12%.	L_1 plunges 30°/N60° on an average (Fig.50). L_2 plunges 4-70°/N216-N240°(Fig.51).

(iii) Microcorrugation or minor puckers(L_3) - These are confined to metabasics of the thrust zone. The L_3 is generally formed by (i) corrugation of the S_2 surfaces due to minor slip movements along the S_3 planes (Figs.25,171 &173). (ii) silica roddings and minor fold axes on S_2 surfaces (Fig.26). It generally plunges in NW at low angles (0-40°).

3.3-3 STRUCTURAL ANALYSIS

The decipher behaviour of the different structural elements described above in the tectonic zones (p.76), 758 planar and 270 linear data, collected mainly along the road sections are plotted on 3.25 cm =1 km. scale (2"=1 mile) map with suitable symbols (Map 8). The three zones have been subdivided into 12 sectors (Map 9). The selective diagrams have been prepared on the Schmidt equal area net to determine the degree of structural homogeneity of the region. The structural geometry has been discussed separately for each zone with the help of the synoptic πS_1, πS_2, πS_3, L_1,L_2 and L_3 diagrams (Tables 10,10A &11). As will be noted, the emphasis has been laid on π pole diagrams since it has been found that β-diagrams are unreliable in areas of inhomogeneous fo folding (Ramsay,1964).

(1) Autochthonous zone- The three sectors of the autochthonous zone incorporate the northern limb of the Baragadi Anticline along right banks of the Bhagirathi river and Baragadi Gad and comprise uppermost Bareti Quartzite member of the Uttarkashi Formation.

Sector 1 - It covers the Uttarkashi road section between Bareti and Uttarkashi and includes thickly bedded micaceous quartzites.

The πS_1 diagram(Fig.27) shows a well defined maximum(25%) in south.The The bedding planes S_1 strike E-W and dip 20°N. On the other hand, the πS_2 diagram (Fig.28) with two maxima (24%) in the southwestern quadrant shows an incomplete elongated girdle. The S_2 planes strike N304° and N335° and dip 55° and 48° respectively towards NE. Though S_1 strikes parallel

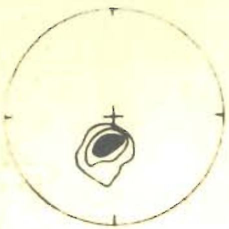


FIG. 27

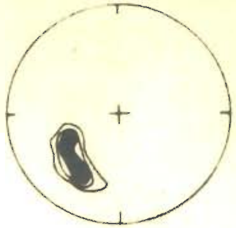


FIG 28

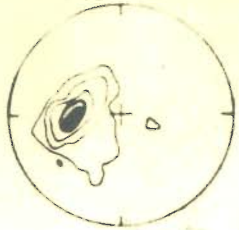


FIG.29

FIG.33

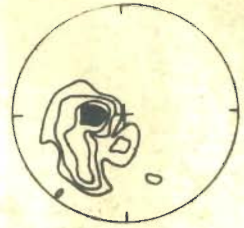


FIG.34

FIG 35

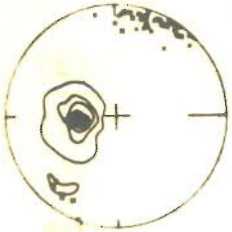


FIG. 30

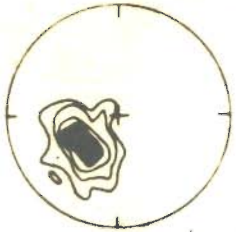


FIG. 31

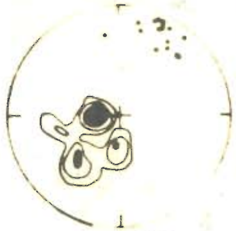


FIG.32

FIG. 36

FIG.37

FIG.38

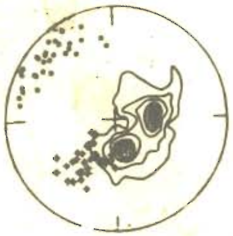


FIG. 39

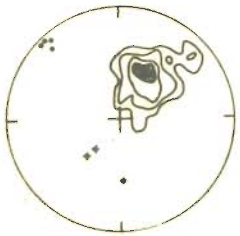


FIG. 40

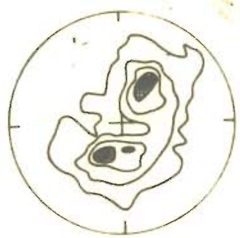


FIG.41

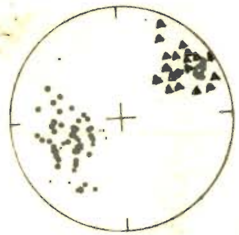


FIG 45

FIG.46

FIG. 47

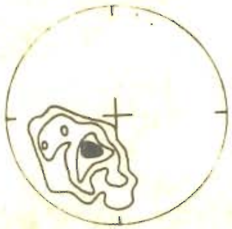


FIG.42

FIG.43

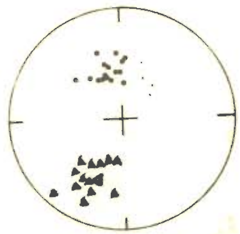


FIG. 44

FIG. 48

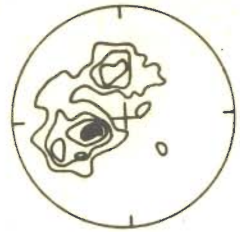


FIG. 49

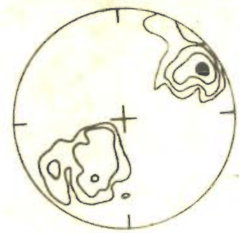


FIG 50

FIG. 51

to the trend of the Baragadi Anticline fold axis in this sector S_2 is inclined at about 45° to it but parallels the NW-SE thrust front in the region.

Sector 2 - It incorporates a part of the Uttarkashi-Lambgaon road between Uttarkashi and Dobha and consists of thinly alternating quartzites, slates and phyllites of the Bareti Quartzite member.

The πS_1 diagram (Fig.29)shows a single maximum(17%) with an incomplete girdle. The S_1 planes dip 34° N84°. Unlike the sector 1, the strike of S_1 planes is oblique to the NW-SE trending anticlinal axis in this sector by about 40° and can possibly be related to the N-S thrust zone near sector .

In the πS_2 diagram (Fig.30), the S_2 planes dip 30° N90°. Like the S_1 foliation also parallels the Uttarkashi Thrust zone in this sector. The prominent mica lineation L_1 plunges 0-25° in N to N45° on the foliation planes and shows a maximum(32%) which plunges 8° N23°.The slickensides and groovings L_2 plunge both in NE and SW at low angles possibly representing minor interplanar slip movements along the shear planes (Fig. 30).It is significant to note that L_1 and L_2 are oriented normally to the regional NW-SE Uttarkashi Thrust in the 'a' direction of tectonic transport.

Sector 3 - It mainly includes the Uttarkashi-Lambgaon road section between Dobha and Sada and is made up of phyllites and micaceous quartzites. The diagram(Fig.31)shows a maximum (20%) in the southwestern quadrant. The πS_1 planes strike N135°-N315° and dip 40° N45°. The πS_2 diagram (Fig.31) includes prominent maximum(24%) and two submaxima (16%) in the south western quadrant. The S_2 planes dip 28° N90°.

In this sector L_1 lineation plunges at 5-25° N340°-N45° with a concentraction in NNE direction, normal to the fold axes along 'a' direction of movement.

Synoptic characters of the autochthonous zone - The synoptic πS_1 diagram (Fig.33)for these sectors shows a well defined maximum(11%) in the southwestern quadrant with an incomplete girdle. The S_1 planes strike

N168° .N348° and dip 40° N78°.The synoptic π S_2 diagram(Fig. 34)gives a well defined maximum(16%) and a submaximum(12%) in the southwestern quadrant and form an incomplete girdle. Accordingly,the S_2 planes dip 23° N85° and 40° . N46° respectively.

The synoptic L_1 diagram (Fig.35) shows a maximum (36%) which plunges 10° N22°.

From the comparative study of the selective,synoptic diagrams and structural map of the autochthonous zone,certain broad conclusions regarding tectonic movements can be drawn:

(i) The S_2 planes parallel the Uttarkashi Thrust front near different sectors and hence do not seem to coincide with **the axial plane of** the Baragadi Anticline. On the other hand, it appears to have been effectively controlled due to changing orientation of the thrust zone.

(ii) The strike of S_1 and S_2 planes in sectors 2 and 3 does not coincide with the regional WNW-ESE and NW-SE Baragadi Anticline axis as is also evidenced from the synoptic π S_1 and π S_2 diagrams.

(iii) The foliation S_2 appears possibly to have been evolved by intergranular and intragranular slip movements during the thrusting as is indicated by profound granulation of the rocks. Similar interpretation has been put forward by Cloos(1946) for the Moine Schists: " Undulations are parallel to the bedding and cleavage showing that thrusting must have been nearly parallel to the bedding and that the cleavage may have formed parallel to the thrust plane during the thrusting process".

(iv) The orientation of mineral lineation L_1 on S_2 planes is normal to the regional NW-SE trend of the Uttarkashi Thrust,Baragadi Anticline and Uttarkashi Formation and indicates 'a' direction of tectonic movement.It is noteworthy that minor recumbent fold axes,mineral lineations and slickensides have been recently recorded in the'a' direction of tectonic movement of the Almora Nappe(Sarkar,at al.,1965; Merh and Vashi,1966).

(2) Uttarkashi Thrust Zone - The girdle shaped thrust zone comprises a sinuous outcrop of metabasics which occur as chlorite schists,amphibolites and metadolerites. Occasionally thin lenses of buff-grey,slaty quartzites are also met with parallel to the foliation. The zone separates the underlying autochthonous Uttarkashi Formation from allochthonous Quartzite Formation, and has been subdivided into 5 sectors on the basis of structurally homogeneous domains.

Sector 4 (Fig.36) - It covers a part of the thrust zone between Mustari and Manpur. The π S_2 diagram shows a well defined maximum(33%) in the southwestern quadrant. The average foliation planes strike N121° -N301° and dip 30° N30°.

A few S_3 -strain-slip cleavages also dip towards NE at about 50° while the associated L_3 lineation plunges 0-36° in N 305°-N20°.

Sector 5(Fig.37) - It includes a part of the southwestern flank of the thrust zone between Alethi and Dhanpur.Here the π S_2 diagram indicates a strong maximum(27%) in the northeastern quadrant and a sub maximum(9%) in the southeast. From this, it is therefore evident that the foliations strike N 128° N308° and dip 33° N218° on an average while another less important direction in N98°- N278° with 50°N dip is decipherable from the submaximum. The great circles corresponding to the maximum and submaximum intersect at the point β which plunges 11° N290°.

A few poles to S_3 planes fall in the southwestern quadrant and dip in the NE. L_3 plunges in the NW at low angles. A comparison with sector 4 reveals that the foliation S_2 has been folded along NW-SE Baragadi Anticline axis whereas S_3 dips consistently towards NE. The L_3 plunges in the 'b' direction and coincides with the β-axis of the anticline,as calculated from the intersection of S_2 planes.

Sector 6 (Fig. 38) - It covers the U-shaped exposure of the thrust zone between Dhanpur and Sankrona. The π S_2 diagram shows a prominent maximum(15%) in the northeast and a submaximum(8%) in the southeast quadrants. Accordingly the foliation S_2 strikes N135° - N315° and N70° - N250° and dips 20° N225° and 38° N340° respectively. Here also, their corresponding great circles intersect point β which plunges 12° N275°. In comparison with sector 5, foliation strikes more northerly and dips in the same direction near closure of a syncline which, as inferred from the β -intersection, plunges in the west at about 10°.

A few scattered poles to the S_3 planes fall in the southwest and indicate a north and northeasterly dip of the strain-slip cleavage. The L_3 lineation plunges variably between N204° and N328° at low angles. As in earlier sectors, the S_3 and L_3 maintain their consistent direction in contrast to the variable attitude of the S_2 planes, thus suggesting a late structure related to the folding. This is also evidenced from the similar plunges of L_3 and β -intersections.

Sector 7 (Fig.39)- It includes the Uttarkashi-Lambgaon roadsection between Sankrona and Santangaon. The π S_2 diagram is characterised by two maxima(15%) in the southeastern quadrant. The foliation planes dip 38° N270° and 20° N320° on an average. The great circles of the two maxima intersect at point β which plunges 20° N320° like the earlier sectors. The two prominent maxima of the foliation S_2 indicate a NW-SE fold axis as has been mapped in the field (Map 8).

The poles to the S_3 planes fall in the SW quadrant so that these dip 30° N60°. Their intersection on S_2 i.e., L_3 lineation plunges 5 -34° N280°-N354° and coincides with the β -axis of the major folds in the 'b' direction. The results of this sector confirm the earlier observations in other sectors of the thrust zone that strain-slip cleavage(S_3) dips uniformly towards NE irrespective of the altitude of foliation S_2 while the L_3 plunges NW towardsdirection of the fold axis.

Sector 8 (Fig. 40) - It covers the southern part of the road section and falls southern limb of an anticline in the thrust zone. The πS_2 diagram shows a single maximum(25%) in the northeastern quadrant. From this, the S_2 planes strike N118° -N298° and dip 40° N208°. While a few poles to S_3 planes fall in the southwest and indicate a dip towards NE, the L_3 plunges uniformly at low angles to NW.

Synoptic characters of the thrust zone - The synoptic πS_2 diagram (Fig.41) shows two small maxima(11%) in the northeast and southwest quadrants and a submaximum (9%) towards south. The foliation planes corresponding to the maxima strike NW-SE and dip 28° N32° and 36° N215°.The great circles intersect at the point β plunging 6° N315°.This indicates that the S_2 planes have been folded into N 55°W-S55°E trending folds with a plunge towards NW of about 10°.

In the synoptic πS_3 diagram (Fig.42) a single maximum(13%) is seen in the southwestern quadrant. The S_3 planes dip 30° N32° and strike N 122°-N302°.

There is a marked preferred orientation in the synoptic L_3 diagram with a maximum(10%) which plunges 20° N314° (Fig.43). It is noteworthy that L_3 plunges approximately in the same direction as the β -fold axes.

On the basis of the structural map, selective and synoptic diagrams, following conclusions have been drawn for the Uttarkashi Thrust zone:

(i) The NW-SE strike of the S_2 planes coincides with regional trend of the thrust zone even in the individual sectors.

(ii) As has been pointed elsewhere (Chapter 5) that the metabasics are emplaced along the Uttarkashi Thrust,it appears possible that these have suffered structural deformation and metamorphism during the thrusting movements and have developed a prominent S_2 foliation.

(iii) The S_2 planes have been folded along NW-SE axes which plunge at low angles towards NW. This has been observed in the individual sectors and synoptic πS_2 diagram.

(iv) While S_2 planes are heterogeneous in character in the metabasic tectonite body, the strain-slip cleavage(S_3) tends to maintain a regular orientation and possibly defines the axial planes of the major folds.

(v) The microcorrugation (L_3) plunges uniformly towards NW and coincides with β intersections of the S_2 planes. It trends parallel to the fold axes hence it is 'b' lineation.Thus, both the S_3 and L_3 are related to major folding of the S_2 planes and appear late structures superimposed upon the earlier foliation(cf., Rickard,1962).

(vi) It is evident that while S_2 has possibly developed during sub-horizontal thrusting movements and is later folded,the S_3 and L_3 have originated under different stress conditions during the folding movements.The adjustment is achieved by slips on surfaces cutting across the foliation. This can take place while the stresses are inclined at high angles between 40 to 60° (Turner and Weiss,1963).

(3) Allochthonous zone

The overthrust Quartzite Formation of the allochthonous zone comprises quartzites,schistose sericite quartzites and quartz schists. It has been subdivided into the following 4 sectors.

Sector 9 (Fig. 44) - It covers a part of the Uttarkashi-Lambgaon road south of Chaurikhal. Here in the quartzites, the bedding S_1 is poorly marked and dips 26 -45° N200° -N232° with their poles falling in the northeastern quadrant. On the other hand, the S_2 planes dip 43° N168°. It is noteworthy that the strike of the S_2 planes coincides with the E-W trend of thrust zone near sector 9. The mica lineation (L_1) developed on S_2, plunges 38° in N210°.

Sector 10 (Fig. 45) - This covers the road section between Foeld and Chaurikhal. S_1 is again poorly developed in this sector and dips 16 -74° N42°-N68° opposite to bedding S_1 in sector 9. The S_2 planes dip 30° N71° on an average and their poles form a maximum (21%) in the southwestern quadrant.

The mica lineation L_1 plunges 0-54° N24° to N73° but on an average it is gently plunging in N 60°. A comparison with sector 9 reveals that like the S_2 planes, L_1 is also folded along a NW-SE axis and trends normal to thrust front and fold axis in the 'a' direction of movement. The slickensides L_2 plunge in the opposite direction towards N 204 -N304° between 22 -62° and possibly suggest minor interplanar post-tectonic movements.

Sector 11 (Fig.46) - It covers a part of the allochthonous zone along road in the north of Foeld. S_1 planes are comparatively better developed and dip variably in the NE, NW and SW between 28-90° but their poles show a concentration in the SW indicating an average dip of 60° in N60°. In this sector, S_1 is folded along NW-SE trending axes which plunge in the northwest.

The S_2 planes generally dip towards NE at about 30° while L_1 lineation on the foliation planes plunges in 25° N60°E and 15-30° N228-N246° and thus it has also been locally folded in thissector.Minor slip movements are indicated by L_2 (slickensides)which plunges in the SW between 4° -72° (30° on an average).

Sector 12(Fig.47) The sector incorpbrates the road section near Dhanpur.The bedding S_1 is poorly developed and dips 40- 50° N185 -N255°. The poles to the S_2 planes are widely scattered in the NE and NW quadrants with a general southwesterly dips at about 40°. L_1 consistently plunges 40° N240° on an average but a few L_2 lineations plunge towards NE. A comparison with sectors 10 and 11 of the allochthonous zone indicates that S_1, S_2, L_1 and L_2 are folded along a NW-SE syncline in the quartzites.

Synoptic characteristics of allochthonous zone - The synoptic S_1 diagram (Fig. 48)for the allochthon shows a well defined maximum(17%) and a submaximum (14%) in the southwestern quadrant but a few poles also fall in the northeastern quadrant. The S_1 dips 60° N66° and 20° N45° respectively and intersect each other at β in the northwest. This indicates that the quartzites have been folded along N 161-N 341° trending axes which plunge 12°NNW.

The πS_2 diagram (Fig.49) has a strong maximum(12%) in the southwest quadrant and hence the S_2 dips 30° N74°. The poles to the foliation are considerably scattered towards north with a submaximum (8%). From the comparison with the synoptic πS_1 diagram it is apparent that S_2 is not related to the folding. As has been shown earlier, its trend is either subparallel or parallel to the thrust zone in the individual sectors.

The diagram for mica lineation L_1 shows a prominent maximum(21%) plunging 30° N60° and a submaximum(7%) which plunges 40° N212°(Fig. 50),i.e , normal to thrust front and fold axes in the 'a' direction of movement. L_2 shows a varied plunge between 4-70° in the N216 -N 240° and N 50°(fig.51).

On the basis of the comparison of selective,synoptic diagrams and structural map of other zones,the following conclusions have been drawn for the allochthon:

(i) S_1 has been folded along NNW-SSE trending axes which plunge towards NNW at low angles.

(ii) The pattern of folding of S_2 in the allochthon is less distinct since the majority of these dip either towards ENE or SSE and only a few in the SW. These trend subparallel to the thrust front and appear to have been possibly evolved during the thrusting movement.

(iii) Though S_2 dips variably,the penetrative mica lineation L_1 plunges consistently towards N 60°E and S30°W. It is generally normal to the thrust front in the 'a' direction of tectonic movement similar to slickensides, grooves and mica lineation in the Almora Nappe(cf., Sarkar,et al.,1965)

(iv) In comparison to the autochthonous zone, L_1 is inclined 38° more towards east in the allochthon while it is oriented at 106° to L_3 of the thrust zone.

(v) The tectonic movements as indicated by 'a' mica lineations(L_1) thus appear to be variable between NNE- N60°E directions.

(vi) While the thrust zone is homogeneous with respect to the S_3 and L_3, the allochthon is heterogeneous in relation to all the structural elements.

3.3 -4 CONCLUSIONS

On thebasis of the above detailed structural analysis in a part of Uttarkashi Window region, the following tectonic history can be made out for this particular region:

(1) Deposition of (i) thick allochthonous Quartzite Formation of northern belt at least 15 km. north of its present position.As can be inferred from the (Map3), these quartzites have been thrust along the Dunda-Uttarkashi Thrusts which are 15 km. apart and (ii) the Uttarkashi Formation in its present position.

(2) During the initial phases of the Himalayan Orogeny,broad tilting and flexuring have taken place by the forces from the northeast.

(3) In the advanced phase of the orogeny,the thrusting movements were dominant and have developed a subhorizontal dislocation plane in the Quartzite Formation along which it has been thrust upon the younger Uttarkashi Formation.

(4) During advancement of the allochthon along the Uttarkashi Thrust, the emplacement of the basic rocks as doleritic sheets took place and has possibly facilitated the southward movement of the allochthon.

(5) During the thrusting process, the autochthon,allochthon and thrust zones were possibly metamorphosed.This is evidenced by profound calaclastism along thrust in these zones which have acquired the foliation(S_2). The penetrative mica lineation L_1 also seems to have been formed during the thrusting processes along the 'a' direction of the tectoic transport from the northeast.

GUIDE TO THE GEOLOGICAL CROSS SECTIONS

Fig. 52 - Geological cross section through the area.

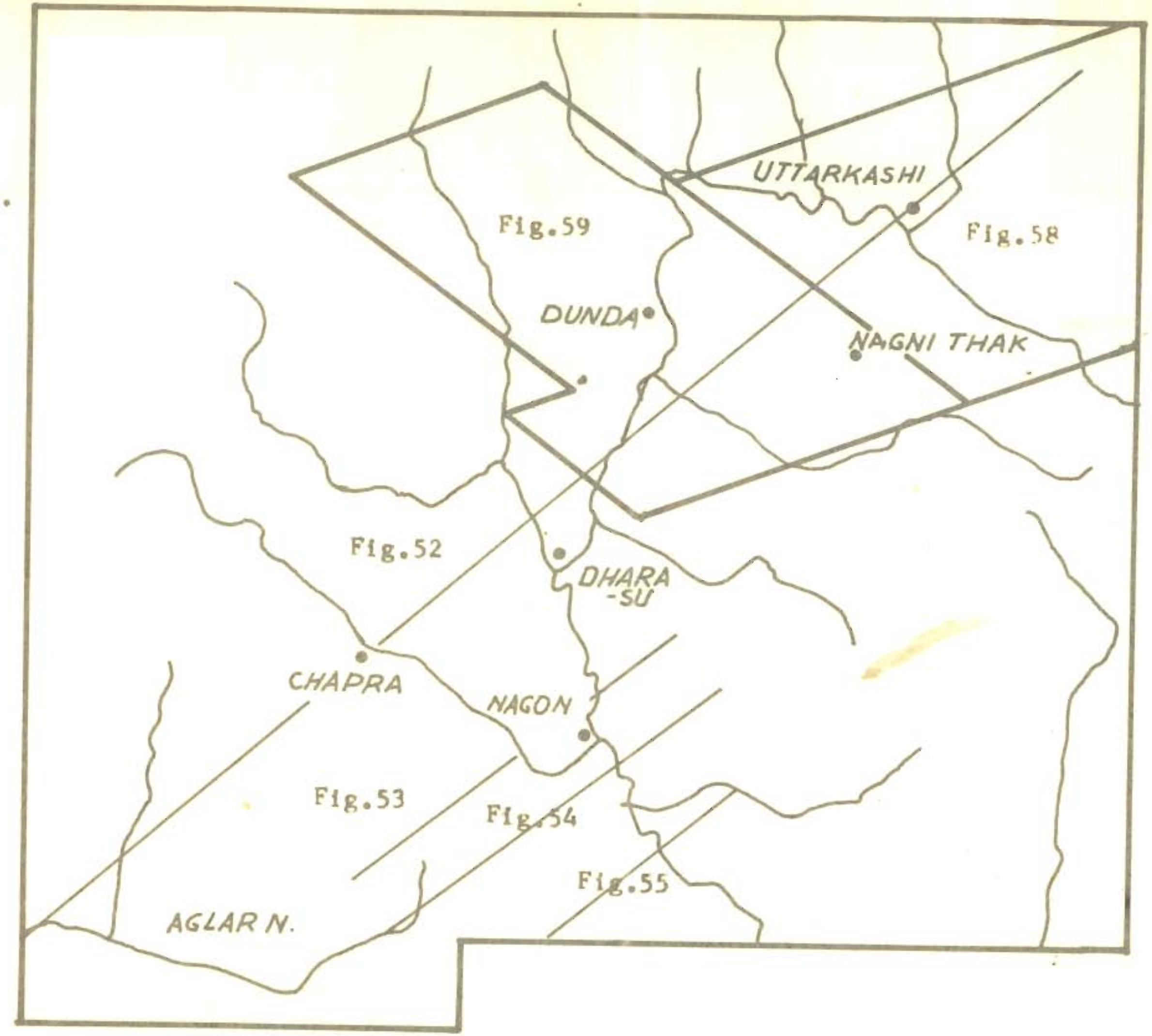
Fig. 53 - Section through Laluri-Pujargaon.

Fig. 54 - Section through Bhal-Bharkot.

Fig. 55 - Section through Basul-Khand.

Fig. 58 - Sections through the Uttarkashi Window.

Fig. 59 - Sections through the Dunda Window.



Orientation diagrams for Uttarkashi Window region

Autochthonous Zone

Fig.27 πS_1 diagram - Sector 1

Fig.28 πS_2 diagram - Sector 1

Fig.29 πS_1 diagram - Sector 2

Fig.30 πS_2 diagram with -L_1 (dots) and L_2 (cross)-Sector 2

Fig.31 πS_1 diagram -Sector 3

Fig.32 πS_2 diagram with L_1(Dots)- Sector 3

Fig.33 Synoptic πS_1 diagram

Fig.34 Synoptic πS_2 diagra m

Fig.35 Synoptic L_1 diagram (contoured) with L_2(cross)

Uttarkashi Thrust Zone

Fig.36 πS_2 diagram (contoured) with S_3 poles(plus) and L_3 (dots) - Sector 4.

Fig.37 πS_2 diagram with S_3 poles (plus) and L_3 (dots) - Sector 5

Fig.38 πS_2 diagram(contoured) with S_3 poles (plus) and L_3 (dots)- Sector 6

Fig.39 πS_2 diagram (contoured) with S_3 poles (plus) and L_3 (dots) - Sector 7.

Fig.40 πS_2 diagram(contoured with S_3 poles (plus) and L_3(dots) Sector -8

Fig.41 Synoptic πS_2 diagram

Fig.42 Synoptic πS_3 diagram

Fig.43 Synoptic L_3 diagram

Allochthonous Zone

Fig.44 Poles to S_1(small dots) and S_2(big dots),L_1(triangle)Sector 9

Fig.45 Poles to S_1 and S_2; L_1 and L_2 (cross) - Sector 10.

Fig.46 Poles to S_1 and S_2 ; $L_1$and L_2 - Sector 11

Fig.47 Poles to S_1 and S_2; L_1 and L_2 - Sector 12

Fig.48 Synoptic πS_1 diagram

Fig.49 Synoptic πS_2 diagram

Fig.50 Synoptic L_1 diagram

Fig.51 Synoptic L_2 diagram

(6) The thrusting phase is followed by a dominant folding phase. During this phase,the three zones have been folded along the common axes.

(7) The folding of the zones has given rise to opposite dipping S_1,S_2 and L_1 elements along NW-SE axes.

(8) During this folding phase of the thrust zone,the strain-slip cleavage (S_3)and microcorrugation lineation(L_3)were formed due to minor slips along the new foliation planes. The competent and brittle masses of autochthon and allochthon behaved differently with possible development of slickensides(L_2)and faulting in the rocks.

(9) The erosion of the allochthon and the thrust zones has exposed underlying autochthon into the Uttarkashi Window. It appears that the erosion has not been deep enough in the southeast between Sankrona and Chaurikhal so as to reach the autochthon,otherwise another window of the underlying rocks would have been exposed.

3.4 STRUCTURE OF THE AREA

In the present area, the detailed geological mapping has revealed a number of folds, faults and thrusts which have been elaborated and established in the earlier pages of this chapter. The following account deals with their structural interpretation and structure of the area which has been elucidated with the help of many cross sections.

3.4 -1 SOUTHERN REGION

As can be made out from the geological map (Map 3) and Figures 52,53, 54 & 55 , the southern region lies in the southwest of the Dharasu Thrust and consists of the widespread, steeply dipping and folded Dharasu Formation. Across the Chapra-Soman section (Fig. 52), the formation is exposed for nearly 10 km. but dwindles to only about 1.5 km. in the southeast along Bhagirathi river (Fig. 55). The formation has been folded along four NW-SE and NNW -SSE trending axes - the Daski and Bharkot Synclines and Nagon and

Malli Anticlines.

The Nagon Anticline is truncated by the Tons Thrust near Kansi and Bheti and is not exposed across the Basul and Khand villages (Fig. 55). Purple argillaceous quartzites of the Dharasu Formation are folded along this anticline and dip beneath the Laluri Formation on its southern limb(Figs.53,54 & 55). On the other hand, the Daski Syncline with a NNW-SSE axis in centre of wide Dharasu Formation outcrop extends for at least 20 km. between 34°41'30": 78°15' and Bheti. Along this axis, the formation is mainly exposed in a syncline and is warped at its northern and southern margins due to Malli and Nagon Anticlines respectively.

The Malli Anticline has been traced all along the left bank of Bhagirathi river between Dharasu and Chham but its northeastern limb is truncated by the Dharasu Thrust in the southeast of Malli(Fig.55). Another small Bharkot Syncline lies in between the Malli Anticline and Dharasu Thrust near Pujargaon and is truncated by the latter at Malli.

The Dharasu Formation is thrust over the southern Quartzite Formation belt of the Chamoli Window(northern region) along the Dharasu Thrust and in turn, is overridden by the (i) Laluri Formation along the southerly dipping Tons Thrust and (ii) Bangaon Limestone alomg the northerly dipping Bangaon Thrust.

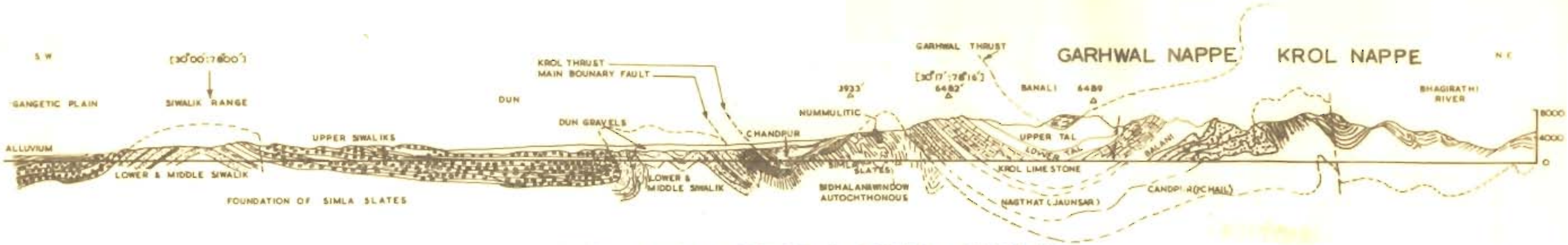
The Dharasu Thrust passes through the hill 2339 metres, Sartali,Mason Soman, hill 2208 metres, Malli and Baldogi and runs for about 40 km. across the mapped area. In the northwest, it trends NNW-SSE and separates greenish grey argillaceous quartzites and phyllites of the Dharasu Formation from schistose sericite quartzites of the Quartzite Formation between Mason and Pujargaon.It is impersistently marked with the metabasics at Soman and Ulya. The thrust takes a northerly swing between Pujargaon and Malli and then changes to NW-SE. In the southeast, it aeparates the gentle and NE dipping Dharasus from highly inclined Dichli Dolomite formation between Malli and Chham (Figs.54 & 55).

Along right bank of the Nagon Gad, the Dharasu Formation dips at about 40° beneath the Laluri Formation and is overridden by the latter along Tons Thrust. This thrust has been originally extended by Auden (1938) upto Khand but on the basis of the present mapping, it has been traced further to Kandi in a N60°W -S60°E direction for about 15 km. in the area. It may also be added that it extends further to the SE towards Bhaldiana outside area.

The gently dipping Laluri Formation is exposed on the southern limb of the Nagon Anticline and is succeeded conformably by thick alternating phyllite and quartzite sequence of the Chandpur Formation.This,in turn, is overlain by the Nagthats which are separated from the former by Basul Thrust along northern slopes of the Gorpha Dhar(Figs.52 to 55).

The Nagthat Formation has been folded into a N60°W -S60°E trending Deosari Syncline and dips gently in its core. Only about 10 km. northeast of Mussoorie, the formation is thrust upon the Chandpurs along the northeasterly dipping Aglar Thrust which appears to join with the Basul Thrust at the base of the Nagthats (Figs.52 & 53).

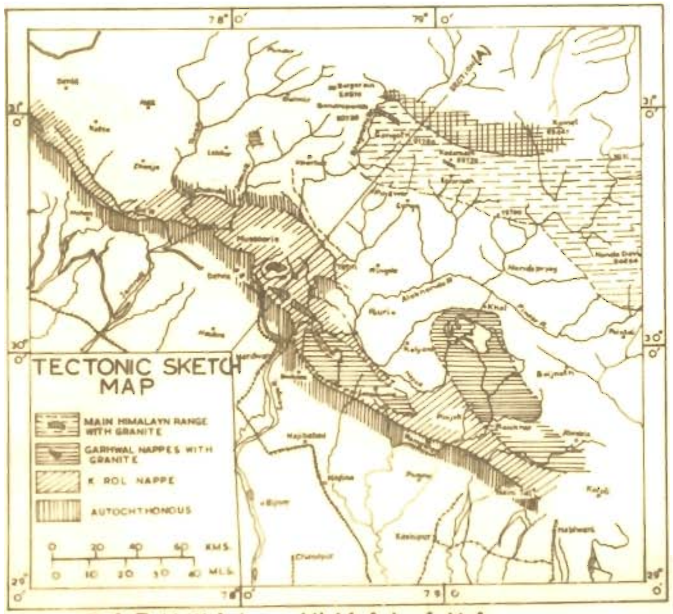
In the southern region of the mapped area, Auden (1938) considered Tons Thrust terminating against another thrust- the major tectonic unit (Dharasu Thrust in this work)at Khand. Further, he interpreted the Tons Thrust as a counter thrust to the Krol Thrust along which the Krol Nappe is thrust upon the autochthonous Simla Slates zone(Fig.57 , Map 10). The mutual relation along borders of the Simla-Krol Belt undoubtedly indicates an autochthonous position of the Simla Slates which are at places unconformably overlain by the Lower Tertiary formations and exposed in many small windows e.g., Bhidalna and Parahat Windows beneath the Krol Nappe (cf.,Auden,1934 a,1937).



SECTION ACROSS SIWALIK RANGE & LOWER HIMALAYA

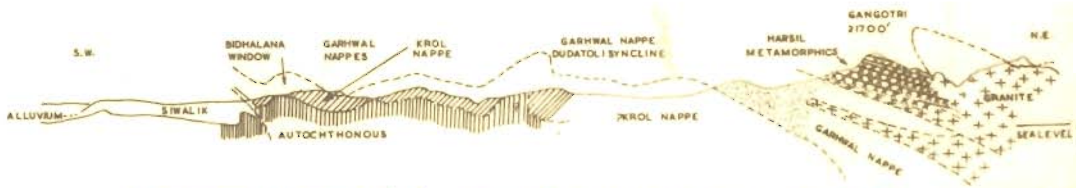
0 4 8 KMS.
0 2 4 6 MLS.

FIG. 57



GARHWAL HIMALAYA

MAP. 10



TECTONIC SECTION (A) ACROSS THE GARHWAL HIMALAYA

0 10 20 30 KMS.
0 10 20 MLS.

AFTER J.B. AUDEN, 1937

FIG. 56

However, on the basis of the observations cited above(pp. 66 &68), the Tons Thrust and Dharasu Formation are found extending along the strike for considerable distance along the Bhagirathi river and are not truncated against any thrust or major tectonic unit. Similar purple-green-grey argillaceous quartzites and phyllites resembling the Dharasus have been observed all along left bank of the Bhagirathi river upto Tehri and extend even to Diul along Bhillangana river(Nautiyal-personal communication). Though the phyllites at Srinagar, Devprayag, Kirtinagar and Tehri undoubtedly resemble Chandpur Formation, their exact structural relationships can only be known after the detailed mapping.

It is evident that the Dharasu succession has been thrust over the Garhwal Group of rocks along the Dharasu Thrust and thus constitute a separate allochthonous thrust sheet, herein tentatively termed as the Dharasu Thrust Sheet. In the area, this sheet dips beneath the Krol Nappe (Laluri-Chandpur-Nagthat Formations) which has overridden the Dharasu Thrust Sheet along Tons Thrust. This structural interpretation of the allochthonous Dharasus markedly differs from viewpoints of Auden(1937) who considered Simla Slates (equivalent of Dharasus) as autochthonous in this part of the Garhwal Himalaya (Map 10). However, Bhargava and Srikantia (1967) worked out an intervening thrust sheet of the Simla Slates below the Krol Nappe in Punjab Himalaya.

In the Krol Nappe(Auden, 1934a, 1937) or the corresponding Krol Nappe I (Valdiya, 1964 b) succession of the area, the Laluri-Chandpur-Nagthat Formations are thrust upon the Dharasus along the southerly dipping Tons Thrust which appears to join with the Krol Thrust(cf., Auden, op.cit.). Further, the Nagthat Formation is folded into the Deosari Syncline and is bounded by Basul and Aglar Thrusts in the north and south respectively. From the opposite dipping characters of thrusts at base of Nagthat Formation, these seem likely to join underneath to form a synclinally folded thrust sheet which appears to have slided over the Chandpur Formation. It is significant to note that the Laluri-Chandpur-Nagthat Formations are devoid of the Blaini-Krol-Tal sequence which is confined to the south of the Aglar Thrust into a narrow belt in the core of the Mussoorie Syncline (cf.,Auden,1934a). The Deosari and Mussoorie Synclines lie parallel to each other without any intervening anticline which appears to be concealed beneath the Aglar Thrust.

The occurrence of the Nagthat Formation as rootless thrust mass is supported by recent findings of the Jaunsar Klippe over the Krols in Gambher section (cf.,Bhargava and Srikantia,1967).

3.4 - 2 NORTHERN REGION

Chamoli Window

The northern region consists of widespread rocks of the Garhwal Group which has been previously known as the Barahat or Garhwal Series(Auden,1938, 1949). According to him, these rocks are exposed in the Chamoli Window. In the north, the Chamoli Window is bounded by the NE dipping Main Central Thrust which has been noted outside the present area at (i) Kupra along Yamuna valley,(ii) 30°53': 78°31' along the Uttarkashi-Dodhi Tal bridle path and (iii) Sainj along the Bhagirathi river. At these localities,the Central Crystalline Zone comprising of the gneisses and schists with minor occurrences of amphibolites, marbles and quartzites is thrust over the Quartzite Formation of the northern belt. In the south, the Dharasu Thrust separates the rocks of the Chamoli Window from the overlying Dharasu Formation.

On detailed mapping in the Uttarkashi region it has been observed that the structure of the Chamoli Window is more complicated than hitherto realised. The different lithostratigraphical units of the Garhwal Group are intricately folded and thrust amongst each other along the Uttarkashi,Dunda and Singuni Thrusts (Map 4). As a result, the follwoing several large scale structural units within the main Chamoli Window can be recognised :

(i) Uttarkashi Thrust Sheet - The Dunda and Uttarkashi Thrusts are persistently marked with metabasics along the thrust zone which demarcates the contacts of the northern Quartzite Formation belt from the Dunda-Uttarkashi Formations (pp. 71& 73). In the northern parts of the area, the Uttarkashi Thrust dips 30 -40° in the NE between Hinna and Naid but on the left banks of the Baragadi Gad and Bhagirathi river it dips in the SW. Thus it is evident that the Uttarkashi Thrust has been folded into an anticline with NE and SW dipping thrust zones in the north and south respectively (p. 74, Figs. 52 & 58).

The Dunda Thrust is also characterised by the metabasics in the thrust zone and dips in the NE at low angles of about 20 -30°(pp. 71-73, Figs. 52 & 59). The characteristic occurrences of the metabasics and their opposite dipping nature along Dunda Thrust and southern trace of the Uttarkashi Thrust are very significant and are considered as major factors in the analysis of the area. From this it can be concluded that the Uttarkashi Thrust extends underneath the Quartzite Formation and joins with the Dunda Thrust into a synclinal structure (Fig. 60).

The folded nature of the Dunda and Uttarkashi Thrusts clearly indicates that the northern Quartzite Formation belt is not occurring in its original place and is allochthonous in character. This allochthonous zone is thrust over the Uttarkashi-Dunda Formations from the northeast to southwest as a folded thrust sheet. This has been named as the Uttarkashi Thrust Sheet. From a close study of the map, the different profile sections and horizontal measurements in NE-SW direction of the thrust zones, it can be inferred that the Uttarkashi Thrust Sheet has moved for at least 15 km. southwestward from its original place.

(ii) Nagni Thak Klippe - The erosion of the Uttarkashi Thrust Sheet has left a remnant of an elongated southwesterly dipping quartzite outcrop between Baun-Pokhri-Chaurikhal-Koti-Jakhni. In the south, this is bounded by the Dunda Thrust while in the north, the southern trace of the Uttarkashi Thrust limits northern boundary (Fig. 52). Billings (1962,p.184) defined such an isolated body as "klippe" - a remnant, of the overthrust sheet due to deep erosion.

The Nagni Thak Klippe is about 15 km. in the NW-SE direction while the maximum width is about 7 km. between Pujargaon and Pokhri. This klippe extends to the Yamuna river as a narrow exposure(about 3 km.) between Gangani and Kutnaur.

(iii) Singuni Thrust Sheet - The Singuni Thrust separates the southern Quartzite Formation belt and the overlying Dichli Dolomite from Dunda Formation and is characterised by nearly 300 metres thick, southwesterly dipping augen mylonites in the thrust zone between Khattukhal and Bagyalgaon. In the southeast, Singuni Thrust conceals Dunda Thrust along the Uttarkashi-Lambgaon road near 30°40': 78°30' but it coalesces with the Dharasu Thrust near Rari in the northwest.

As has been explained earlier(pp.69 -71), the Singuni Thrust conceals different members of the Dunda Formation and also truncates the Khattukhal Anticline axis at Painkhal and Khattukhal. Thus it is evident that southwesterly dipping Quartzite Formation and overlying Dichli Dolomite are thrust upon the Dundas along the Singuni Thrust and are allochthonous in relation to the Dunda Formation. From its disposition, this is a separate SW dipping allochthonous thrust sheet called as the Singuni Thrust Sheet. At the outset, the Uttarkashi and Singuni Thrust Sheets could be considered as a single folded structural unit of the same allochthonous zone. However, in view of the following characteristic important features, it is difficult to consider the Singuni Thrust Sheet as a southward extension of the Uttarkashi Thrust Sheet:

(i) Absence of metabasics along the Singuni Thrust at the base of the southern thrust sheet. On the other hand, the Uttarkashi Thrust Sheet is conspicuous by its presence along the Uttarkashi and Dunda Thrusts while the latter, at places, is only 0.25 km. from the Singuni Thrust.

(ii) Occurrence of mylonitised quartz and feldspar porphyry (augen mylonites) along the Singuni Thrust between Khattukhal and Bagyalgaon on the left bank of the Dhanari Gad(Chapter 4).These are found to be absent along the Dunda Thrust along right bank of the gad.

(iii) Abnormal variation in thickness of the allochthonous Quartzite Formation on the right bank of the Bhagirathi river. These quartzites are nearly 200 metres thick in the southern thrust sheet but are more than 1500 metres thick in the north.

(iv) Marked variation in the metamorphic effects along the Dunda and Singuni Thrusts. These quartzites are metamorphosed to schistose sericite quartzites and quartz schists along the Singuni Thrust in the southern sheet and develop mortar texture,profound granulation and elongation of quartz grains. The above features are imperceptible along the Dunda Thrust.

(v) Distinct heavy mineral characters of quartzites in both the thrust sheets (Chapter 6) which, at places, are only 1 km. apart.The southern thrust sheet of the quartzites is characterised by zircon and increasing amount of tourmaline varieties,whereas the northern Uttarkashi Thrust Sheet is marked with zircon.

(iv) Autochthonous Window Zones - From the foregoing discussion on the structure of the major Chamoli Window it is clear that the overthrust Quartzite Formation sheets are allochthonous in character over the underlying rocks of the Dunda and Uttarkashi Formations. As a result of deep erosion of the overthrust sheets of quartzites, the Dunda and Uttarkashi Formations are exposed in two elongated windows.

According to Billings(1962,p.184), a window is an erosional structural feature where the underlying rocks are exposed beneath the overthrust sheet of rocks. In the present area, these elongated windows are defined by encirclement of the underlying Dunda-Uttarkashi Formations by the overthrust quartzites on their three sides, while in the northwest the windows are open atleast upto Yamuna river.

(a) Uttarkashi Window (Fig. 58)- The window is named after the Uttarkashi town where it exposes the underlying Uttarkashi Formation beneath Uttarkashi Thrust Sheet quartzites. The axe shaped window structure is defined by persistent metabasic girdle in the Uttarkashi Thrust zone. The window closes near Sada but the upper trace of the thrust zone extends further southeast atleast upto Chaurikhal.

A series of cross sections drawn across the Uttarkashi Window has revealed that the oldest Netala Quartzite member of the Uttarkashi Formation is exposed in the core of the Netala Anticline between Gangori and Hinna and is overlain on its limbs by the Lower Uttarkashi Limestone and Pokhri Slate members (S_4-S_6). On both banks of the Bhagirathi river, these members are flanked by the metabasics and Quartzite Formation (S_4-S_5).

On the other hand, the Upper Uttarkashi Limestone, lying conformably over the Pokhri Slate, extends between Mandon and Tekhla on the northern limb of the Kot Syncline but is largely concealed beneath the overthrust quartzites both in the northwest and southeast (S_4, S_7). The limestone member is overlain by metabasic and flaggy quartzite rock units of the Bareti Quartzite in core of the Kot Syncline and is faulted down on its southern limb by the Kot Fault (S_5-S_6). Close to the hill 2133 metres, the metabasics and the overlying quartzites are displaced by about 0.5 km. due to this fault(S_7). The upper limestone member is again faulted down by the Baragadi Fault due to which this limestone member is completely absent on the limbs of the Baragadi Anticline and Kot Syncline (S_3-S_8).

Another exposure of the Upper Uttarkashi Limestone member lies on southern limb of the Baragadi Anticline between Sada and Dilsod and is well represented in sections S_3-S_6. It is underlain as well as overlain by

Pokhri Slate near Pokhri (S_5). The conformably overlying youngest, Bareti Quartzite member occupies the northern limb of the Baragadi Anticline between Sada and Panjala.

The Uttarkashi Window extends between Kutnaur and Kupra along the Yamuna river with a NW-SE trend for about 22 km. It narrows considerably to 1.5 km. and is widest to 7 km. across Uttarkashi. Along the Yamuna river, underlying purple-green-black slates and greyish micaceous quartzites of the Uttarkashi Formation are separated from overlying buff-white schistose sericite quartzites of the Quartzite Formation by thin metabasics and are folded into an anticline (Map 11).

(b) Dunda Window (Fig. 59)- The Dunda Window is exposed in southwest of the Uttarkashi Window and is defined by the northeasterly dipping metabasics along the Dunda Thrust at its northern margin. In the south, the window is bounded by another southwesterly inclined Singuni Thrust. In field, the latter is conspicuous by occurrence of nearly 300 metres thick augen mylonites. In this window are exposed different members of the Dunda Formation e.g., Khattukhal Limestone, Dhanari Slate and Dunda Quartzite beneath the overthrust sheet of the Quartzite Formation (Map 7, Fig. 52)

A series of geological sections explain the structure of the Dunda Window. Along northeastern boundary of the Dunda Window, the allochthonous quartzites of the Uttarkashi Thrust Sheet dip 60-70° in the SW direction and rest over the northeasterly inclined (about 20 -30°) metabasics in the Dunda Thrust zone (S_1-S_{17}).

In the window zone, the uppermost Dunda Quartzite member of the Dunda Formation dips steeply at 40 -80° in the northeast and is overlain by thrust zone of the metabasics with an angular discordance between Dhanari and hill 2288 metres (S_1- S_{10}). Here it may be added that the angular discordance along NE boundary of the Dunda Window cannot be considered due to an unconformity. The structural relationships with the NE dipping Dunda Quartzite thrust zone and SW inclined overlying Quartzite Formation, as elaborated on pp. clearly indicate the existence of a dislocation plane along which these metabasics occur(also refer Chapter 5). Further in the northwest, the thrust zone possibly conceals the Dunda Quartzite member and rests directly over Dhanari Slate (S_{11}-S_{17}).

In the southeast along left bank of the Dhanari Gad, the Khattukhal Limestone is exposed in the core of the Khattukhal Anticline between Painkhal and Khattukhal as the oldest member of the Dunda Formation (S_3-S_6). In section 7, this limestone is completely concealed beneath the Singuni Thrust. Sections 8 to 11 show that the Khattukhal Limestone outcrop occurring on the right bank of the Khattukhal stream(Chapter 2, p. 32) dips uniformly to the northeast on the northern limb of the anticline, but on the southern limb of Khattukhal Anticline this limestone is completely concealed beneath the Singuni Thrust. This indicates the overriding of the Singuni Thrust Sheet on the Khattukhal Limestone member. Further in the northwest, the structure is complicated due to the complete truncation of the limestones in the window zone which comprises the Dhanari Slate member only. As has been noted in Chapter 2(pp. 32), the sinuous outcrop of the Khattukhal Limestone dips regionally in the southwest between Dang-Shyalna-Giunoti while the quartzites of the Singuni Thrust Sheet extend uninterruptedly towards northwest as a narrow belt bounded by the Singuni and Dharasu Thrusts(S_{11}-S_{16}). The limestone outcrop overlies the Dharasu Formation in the southwest of the thrust sheet, outside the window zone. Due to its south and southwesterly dips, this outcrop possibly represents the limestones on the southern limb of the Khattukhal Anticline.

Like the Uttarkashi Window, the Dunda Window is a narrow elongated tectonic structure which is 2½ km.wide across the Dunda village. This window has been observed extending atleast upto Yamuna river for about 25 km. in NW-SE direction. Here, the dark greyish limestones with slaty intercalations are folded into an anticline near Gangani (Map 11). The rocks are delineated by the metabasics along the Dunda and Dharasu Thrusts on both sides of window. In the southeast, the window extends to Paturi and possibly closes near Dingaon due to truncation of the Dunda Thrust beneath Singuni Thrust.

Comparison with other regions

As has been discussed in the foregoing pages, the northern region of the area encompasses many new structural units in this part of Garhwal. In view therefore it would not be out of place to discuss and correlate these units with the adjoining areas in the Lesser Himalayan region. Firstly, structure of the northern region is compared with the adjoining regions which have also been traversed during the course of this study. Then these structural units of the Chamoli Window are compared with the Shali-Chakrata-Kumaon regions.

(i) Yamuna River Section (Map11) - The Chamoli Window is approximately 13 km. wide in the northwest along the Yamuna river in comparison to its 27 km. width along the Bhagirathi and is bounded by the Main Central Thrust and the Dharasu Thrust in the north and south respectively. Structurally, it consists of the Uttarkashi Thrust Sheet, Nagni Thak Klippe, Uttarkashi and Dunda Windows which are relatively narrow along the Yamuna.

In this section, the Singuni Thrust Sheet pinches out somewhere between Rari and Yamuna river due to concealment of the Singuni Thrust and Quartzite Formation beneath the Dharasu Thrust. The latter brings Dharasu Formation and metabasics in contact with the Dunda Window.

The Chamoli Window closes nearly 10 km. NW of the Yamuna river section around Banchangaon (Auden, 1949) due to possible truncation of the Dharasu Thrust by Main Central Thrust.

(ii) Jalkur Nadi Section - Along Jalkur Nadi section on the eastern margin of the area, the extensive thick Quartzite Formation of the allochthonous zone dips uniformly towards southwest between Lambgaon and Dhauntri. These quartzites lie on the southern limb of the anticlinal structure in which the rocks of the Chamoli Window are exposed in the area (p.61).

An examination of this section indicates that the Dunda and Uttarkashi Windows do not extend upto 78°30'. The monotonous allochthonous Quartzite Formation of the Uttarkashi and Singuni Thrust Sheets are repeated by the Singuni Thrust. Further towards east of this section, the Uttarkashi Thrust Sheet appears to be partially or completely concealed beneath the Central Crystalline Zone due to a southerly swing in the strike of the Main Central Thrust(Map 12).

(iii) Bhillangana River Section- Lying 16 km. SE of the Jalkur Nadi, the Bhillangana river section has been traversed by Seitz et al.(1963), Tewari (1963) and Nautiyal (personal communication). Their work reveal that the Garhwal Group rocks have considerably narrowed to a 9 km. wide exposure and are thrust upon by the Central Crystalline Zone along the Main Central Thrust which has been located at Ghansali. At Diul in the south, the group is dislocated against the overlying Chandpur Series by another thrust, an extension of the Dharasu Thrust(p.69).

The discovery of a patch of metasedimentaries beneath anticlinally folded Central Crystalline Zone in the Ghuttu Window is of considerable importance(Tewari,1963). The samples collected by Nautiyal from this window zone include slates and dolomitic limestones which are comparable with rocks of the Dunda-Uttarkashi Formations and schistose sericite quartzites with the Quartzite Formation of the present work. The mere coincidence of the Ghuttu-Dunda-Uttarkashi Windows and the axes of anticlines in the Crystalline Zone and Garhwal Group in the same strike is not fortuitous.

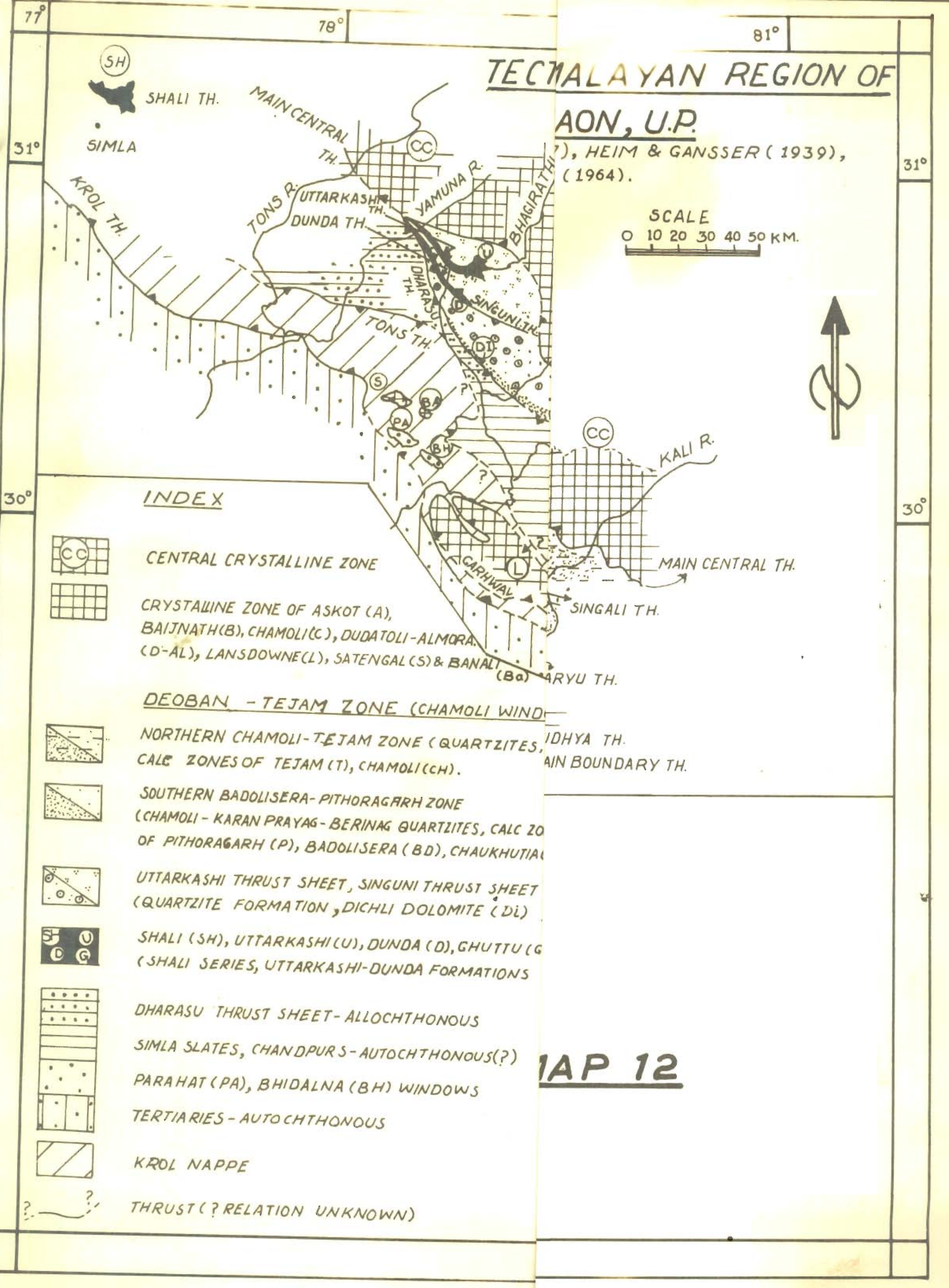
Further, the narrowing of the Garhwal Group along the Bhillangana river, when analysed critically with reference to the above observations indicates possible continuation of the autochthonous Dunda-Uttarkashi Formations and as well as the allochthonous Quartzite Formation beneath the Central Crystalline Zone at least upto Ghuttu. This differs from the earlier views of Tewari (1963) that the Ghuttu Window rocks are possible extension of the Chandpurs or Simla Slates as autochthonous or para-autochthonous zone below the crystallines.

(iv) Srinagar- Rudraprayag area - Further SE of the Bhillangana river section, the mapping by the present worker in this area indicates that the Garhwal Group rocks of the Chamoli Window are complicately folded with WNW-ESE trending axes but the regional southwesterly dips are still decipherable. From the strike continuity and heavy mineral characters of quartzites (Chapter 6) it is evident that the southern Singuni Thrust Sheet of the Quartzite Formation and Dichli Dolomite extends in this region.

In the north, the quartzites are delineated by the Main Central Thrust which is seen along the Nailchami Gad for considerable distance with a WNW-ESE trend. Further in the east, it swings to NE-SW near Lounga and crosses the Mandakani river further NE of Kurchhola.

It is significant that the normal current bedded quartzites of the Quartzite Formation have been noticed upto the Mandakani river near longitude 79°0' and are capped by slates and dolomitic limestones with Collenia (Nautiyal and Jain, 1965).

(v) Northern Chakrata region - In the northwest of the Yamuna river section, the structure of the northern Chakrata region is not well known. However, the area shows extensive development of pure white sericite quartzite and pebbly quartzites of the Middle and Upper Chail Series. These are thrust over Deoban- Mandhali Series along the Chail Thrust and form the Chail Nappe (West, 1932; Fuchs, 1968).



77°
78°
81°
31°
30°
TECTIALAYAN REGION OF
AON, U.P.
7), HEIM & GANSSER (1939),
(1964).
SCALE
0 10 20 30 40 50 KM.
SH
SHALI TH.
SIMLA
MAIN CENTRAL TH.
CC
KROL TH.
TONS R.
UTTARKASHI TH.
YAMUNA R.
BHAGIRATHI
DUNDA TH.
DHARASU TH.
SINGUNI TH.
TONS TH.
DI
S
BA
PA
BH
CC
KALI R.
L
GARHWAL
MAIN CENTRAL TH.
SINGALI TH.
(Ba)
ARYU TH.
IDHYA TH.
AIN BOUNDARY TH.
INDEX
CENTRAL CRYSTALLINE ZONE
CRYSTALLINE ZONE OF ASKOT (A), BAIJNATH(B), CHAMOLI(C), DUDATOLI-ALMORA (D-AL), LANSDOWNE(L), SATENGAL(S) & BANALI
DEOBAN - TEJAM ZONE (CHAMOLI WIND
NORTHERN CHAMOLI-TEJAM ZONE (QUARTZITES, CALC ZONES OF TEJAM (T), CHAMOLI(CH).
SOUTHERN BADOLISERA-PITHORAGARH ZONE (CHAMOLI - KARAN PRAYAG - BERINAG QUARTZITES, CALC ZO OF PITHORAGARH (P), BADOLISERA (BD), CHAUKHUTIA
UTTARKASHI THRUST SHEET, SINGUNI THRUST SHEET (QUARTZITE FORMATION, DICHLI DOLOMITE (Di)
SHALI (SH), UTTARKASHI (U), DUNDA (D), GHUTTU (G (SHALI SERIES, UTTARKASHI-DUNDA FORMATIONS
DHARASU THRUST SHEET- ALLOCHTHONOUS
SIMLA SLATES, CHANDPURS- AUTOCHTHONOUS(?)
PARAHAT (PA), BHIDALNA (BH) WINDOWS
TERTIARIES - AUTOCHTHONOUS
KROL NAPPE
THRUST (? RELATION UNKNOWN)
IAP 12

(vi) Shali area - The structure of the Shali area resembles with the Chamoli Window and more closely with the Dunda-Uttarkashi Windows. The Shali Series comprising of alternate sequence of quartzites, slates and limestones is exposed into,a broad anticlinal domal Shali Window and is thrust upon by the Chail Nappe succession(Chail Series) along the Shali Thrust which,like Dunda and Uttarkashi Thrusts is sometimes characterised by the metabasics (Pilgrim and West, 1928; West,1935, 1939; Rao and Bhan,1969). The Chail Nappe with the Lower Chail Series possibly dips beneath the Simla Slates on southern flank of the Shali Window(West,1935) and is overlain by the Jutoghs in the northern Indus regions. The structural similarity of the Shali Window and the Dunda-Uttarkashi Windows is more striking due to their occurrence in the strike direction and lithological resemblance of the window zone rocks e.g., Shali Series and the Dunda-Uttarkashi Formations (Chapter 7).

(vii) Lower Kumaon Region - In this region, the structure of the Chamoli Window has been worked out in some detail by Auden (1935,1949). Heim and Gansser (1939), Valdiya(1962, 1964 b) and Gansser (1964). From the descriptions of Auden, Heim and Gansser, it is evident that the Chamoli Window rocks (Garhwal Series of Auden -1949) have been classified into the Deoban-Tejam Zone by Gansser (1964). The Chamoli Window extends to the east at least upto the Kali river along the Nepal border for a total length of about 270 km. (Auden , 1949). It is delineated by the Main Central Thrust and North Almora Thrust and is overlain by the Central Crystalline Zone and Dudatoli-Almora thrust mass in the north and south respectively. Along the Alaknanda river, the Chamoli Window bifurcates into a northern Chamoli-Tejam Zone and southern Badolisera-Pithoragarh Zone which are separated from each other by the crystalline thrust mass axis of the Chamoli-Baijnath-Askot (Gansser, 1964,p.94).

From the tectonic map (Map12) compiled by the present worker it is evident that the Garhwal Group may be extending eastward into the southern

Badolisera-Pithoragarh Zone while the northern Chamoli-Tejam Zone is partially or completely concealed beneath Central Crystalline Zone in the west.

Many of the stratigraphical and structural relations are still unknown in the northern Chamoli-Tejam Zone since it is uncertain whether the sedimentary succession is normal or inverted as in the case of the southern zone (Gansser,1964,p.95).

The structure of the eastern parts of the Badolisera-Pithoragrah Zone comprising an older Berinag Quartzite and a younger Calc Zone of Pithoragarh horizons is marked by a complete inversion of the stratigraphical succession in Pithoragarh, Bageshwar and Ganai areas (Misra and Valdiya,1961; Valdiya, 1962, 1964b; Misra and Banerjee,1965, 1968,1969; Misra and Kumar,1965,1968;/ Kumar, 1969). It belongs to the Krol Nappe II (Valdiya,1964 b) and Chail Nappe sequence of Fuchs (1968).

However, the controversy still goes on regarding the scale of inversion. Gansser (1964,p.95) writes that " ....while some sections are undoubtedly inverted I would not follow Valdiya in applying this concept to the whole sedimentary section of inner zone in the Lower Kumaon Himalaya".

In the present area, the predominantly slate-limestone-quartzite succession of the Dunda-Uttarkashi Formations are thrust upon by normal sequences of allochthonous Quartzite Formation and Dichli Dolomite. But their equivalents and possibly the strike continuations in the Pithoragarh-Bageshwar-Ganai regions are inverted (refer Chapter 7). It is evident that somewhere between longitude 79°0' and Ganai-Bageshwar area(west of longitude 79°45'), the sedimentary sequence of the Chamoli Window observed in the present area, seems to have suffered a complete inversion in the eastern parts of the Badolisera-Pithoragarh Zone. The exact nature of this structural inversion can only be known after regional work between longitude 79°0' and 79° 45'.

In the light of the above, it may be noted that it is unnecessary to assume the huge recumbent anticline between the frontal normal Simla-Krol succession and inner inverted sedimentary sequence of Pithoragarh as has been postulated by Valdiya (1962). This is also untenable from the viewpoint of correlation of the lithostratigraphical units (Chapter 7). In case Valdiya's (1962, 1964 c) structure and correlation of stratigraphically older Berinag Quartzites with Nagthats/Jaunsars of the Simla-Krol Belt is accepted, then the younger Calc Zone of Pithoragarh will automatically become equivalent to the Krol Series, a view which has been rejected by Misra and Valdiya (1961) and Valdiya (op.cit.).

However, the present correlation of the Garhwal Group lithostratigraphical units with the Pithoragarh stratigraphy and the Mandhali-Chandpur-Nagthat sequence of the Simla-Krol Belt removes the above anomali (Chapter 7) by correlating the Nagthats, Dunda-Bareti, Shali and Saryu Valley Quartzites (recently renamed as Rautgara Quartzites - Valdiya, 1968).

On the basis of the above structural and stratigraphical comparison the present worker tentatively suggests that the sedimentary succession within the Deoban-Tejam Zone has been complicately folded into a recumbent anticline east of longitude 79°0'. Due to this, the normal succession in each tectonic unit of the Chamoli Window in the Uttarkashi-Srinagar-Rudraprayag regions is inverted in the eastern parts of the Badolisera-Pithoragarh Zone. From this, it would appear that the Chamoli Window sequence of the present area possibly belongs to normal upper limb of this recumbent anticline while lower inverted limb is represented by the Pithoragarh-Bageshwar-Ganai-sequence.

Here, it would also not be out of place to mention about the widespread autochthonous zone in the area comprising of the Dunda-Uttarkashi Formations which are exposed into the windows. The strike extension, lithological similarities and general structural features put the Shali and Ghuttu Windows in the same autochthonous unit in comparison to the overlying allochthonous zone. Though the autochthonous rocks of all the above named windows are broadly similar, the allochthonous zone differs widely from the Chail Series of the Shali Window, Quartzite Formation of the Dunda- Uttarkashi Windows and the Central Crystalline Zone of the Ghuttu Window. It is therefore apparent that this widespread narrow belt of the autochthonous zone as exposed in the Shali, Dunda, Uttarkashi and Ghuttu Windows along the same strike is just not a mere coincidence but indicates a sedimentological and tectonic control in the inner parts of the Deoban-Tejam Zone. The extension of this autochthon may in fact be more widespread than hitherto realised and can be mapped by similar occurrences of more windows in this zone.

Thus, the Shali Series, Uttarkashi -Dunda Formations and Ghuttu Window rocks are possibly exposures of an elongated,narrow belt of autochthonous rock formations for nearly 150 km. in the inner sedimentary Deoban-Tejam Zone These parallel the outer Simla-Krol Belt succession and broadly correspond to the Deoban-Mandhali-Chandpur-Nagthat succession. Nevertheless it cannot be compared with the Blaini-Krol-Tal sequence (also Chapter 7). This autochthon occurs beneath the different allochthonous units e.g., the Chail Series, Dharasu-Quartzite Formations and Central Crystalline Zone. The autochthon belt also possibly occupies a lower tectonic position than the Krol Nappe and is intervened by the Singuni and Dharasu Thrust Sheets in the area. A similar interpretation has recently been put forward by Bhargava and Srikantia (1967) for the para-autochthonous Shali Series. which is separated from the outer Simla-Krol succession by a thrust sheet of the Simla Slates in the Punjab Himalaya.

3.5 TECTONIC SETUP

Based upon the above detailed study of the structure in the area, a cross section from the Aglar Nadi in the south(about 10 km. NE of Mussoorie) to Chapra and Uttarkashi summarises the several tectonic units (Map 4 ,Fig. 60) namely, the (i) Krol Nappe, (ii) Dharasu Thrust Sheet and (iii) Chamoli Window with its other structural units i.e., (a) autochthonous Dunda and Uttarkashi Windows and (b) allochthonous Uttarkashi and Singuni Thrust Sheets.

(iii) Chamoli Window - The Chamoli Window is comprised of nearly 27 km. wide belt of the thick sequence of quartzites, limestones and slates of Garhwal Group. It is delineated by the Main Central Thrust in the north and Dharasu Thrust in the south. Further, the following two tectonic units have been recognised within the Chamoli Window:

(a) An autochthonous sequence of the Uttarkashi-Dunda Formations, exposed in the smaller Uttarkashi and Dunda Windows in the north and south respectively. These windows occur beneath the overthrust Quartzite Formation and Dichli Dolomite as two elongated structures and have been observed closing on three sides in the area.

(b) The allochthonous Quartzite Formation and Dichli Dolomite which are thrust over the autochthonous Dunda-Uttarkashi Formations along the Uttarkashi, Dunda and Singuni Thrusts as two separate sheets. Of these, the northern Uttarkashi Thrust Sheet is a folded structure and is delineated by the Main Central Thrust in the north while the Dunda Thrust limits its southern boundary. The sole of the thrust sheet is marked with thin but persistent metabasics all along the Dunda and Uttarkashi Thrusts. The thrust sheet is partly eroded by the Bhagirathi river, Baragadi and Dhanari Gads to form the Nagin Thak Klippe between the two thrusts.

The southern Singuni Thrust Sheet of the Quartzite Formation and Dichli Dolomite has moved over the Dunda Formation and Uttarkashi Thrust Sheet along the Singuni Thrust which is at places, characterised by augen mylonite occurrences. This thrust sheet dips beneath the Dharasu Thrust Sheet which is thrust over the former along the Dharasu Thrust.

CHAPTER - 4

AUGEN MYLONITES

4.1 INTRODUCTION

The effects of cataclastic breakdown and granulation have been profound in the rock formations of the area(Chapter 2). These are more pronounced near some of the thrusts but are typically observed along the Basul,Singuni and Uttarkashi Thrusts. In addition, a thick augen mylonite body has been found along the Singuni Thrust.In the present chapter are given the field,megascopic and microscopic characters of the augen mylonite and its relation to the thrusting.

4.2 TERMINOLOGY OF MYLONITIC ROCKS

The term mylonite(from Greek mylon = a mill) was first introduced by Lapworth(1885) for "microscopic pressure breccias with fluxion structure in which the interstitial dusty,silicious and kaolinitic paste has only crystallised in part". He observed a complete gradation from mylonites to the Moine Schists above the Moine Thrust and called certain finely laminated and colour banded rocks as 'variegated schists'. A few other types even showed considerable recrystallisation and were included in'augen schist'.i.e., a fine grained, laminated rock with augens or fragments of original rock with cataclastic textures set in " a secondary crystalline matrix of quartz and mica arranged in fluxion bands" (Lapworth,op.cit.). Later Teall(1918) and Harker(1950, p.169) illustrated the transformation of a parent Lewisian Gneiss to a typical mylonite.

Since the original, precise and well illustrated examples of the mylonites by Lapworth,several authors have given diverse names and terminology to explain these complex rocks, which are the products of extreme mechanical deformation(Quensel,1916; Knopf,1931; Walters and Campbell,1935; Hsu,1955; Christie,1960; Reed,1964). Christie (op.cit.),on the basis of structures and textures, classified the mylonites as (i) primary mylonitic rocks and (ii) secondary mylonitic rocks. The terminology of all the cataclastic rocks has been excellently elaborated by Reed(1964). Adopting his classification, the following types of the mylonitic rocks can be identified in the present area:(i) augen mylonites,(ii) ultramylonites and (iii)augen schists.

4.3 MODE OF OCCURRENCE, FIELD AND MEGASCOPIC CHARACTERS

As stated earlier, the mylonites are developed along the Singuni Thrust which separates the overlying southern Quartzite Formation belt from the Khattukhal and Dhanari Slate members of the Dunda Formation(Chapter 3). These rocks are overlain by the schistose sericite quartzites and metabasics with sharp contacts. Though several minor varieties can be identified but the most common and predominant type is a dark greyish green mylonitic rock which is best exposed near the milestone 75/1 along the Uttarkashi road and Singuni-Margaon mule track where these attain a thickness of nearly 350 metres. These rocks occur in a narrow linear body for atleast 5 km. in NW-SE direction along the strike. The rocks taper off in NW near Khattukhal village but are poorly exposed near Dhanari in the southeast (Map 6).

Mainly the mylonitic rocks comprise augen mylonites with minor occurrences of augenschists and ultramylonites. The augen schists generally overlie the augen mylonites but are in juxtaposition with the thrust near Paturi due to pinching off the other varieties.

The augen mylonites are characteristically marked with many rounded and rectangular, augen shaped, white, porcellaneous porphyroclasts of feldspar while quartz is generally augen shaped, greyish and transluscent. These vary in size from 1 - 10 mm. The porphyroclasts are embedded in an extremely fine grained dark greyish green fluxion banded and laminated groundmass of micaceous minerals which wrap around the augens (Fig. 175). The colour

TABLE - 12

MODAL ANALYSIS OF THE MYLONITIC ROCKS

S.No.	Sample No.	Quartz porphyroclasts	Feldspar porphyroclasts	Quartz + Sericite	Biotite	Recrystallised quartz	Muscovite	Total
1	6/296	11.95	17.82	1.10	-	11.95	-	99.92
2	6/297	9.86	22.63	59.21	0.51	6.38	1.38	99.97
3	5/180 *	8.79	20.20	51.84	4.00	14.75	0.62	100.00
4	6/301	22.58	16.36	13.34	-	29.08	28.62	99.88
5	5/179	12.77	8.04	72.63	-	6.42	0.13	99.99
6	6/302	22.95	-	44.12	-	12.71	20.19	99.97
7	6/303	14.32	9.74	52.14	-	9.10	14.86	100.16

* Minor amount of garnet present

Location: 6/296,6/297 - Along Singuni-Margaon mule track.

5/180,6/301 - Uttarkashi road section near milestone 75/1.

5/179,6/302 - Khattukhal.

6/303 - 0.5 km. SW Painkhal.

variations in black,dark grey,greyish green and buff shades mark the strong and conspicuous schistosity in the augen mylonites(Fig.177). The mineral orientation of quartzo-feldspathic and micaceous minerals and grooving on the foliation planes define a strong penetrative lineation(Fig.174). Along the road the quartz veins are occasionally and irregularly injected parallel to foliation planes.

The ultramylonites are exceedingly fine grained and occur as dark grey and black stringers,streaks and laminations in the augen mylonites and can be identified in the thin sections. The occasional occurrences of the augen schists are light greyish green, micaceous and talcose with numerous greyish,coarse grained,transluscent quartz and white,rounded feldspar augens(Fig.176).

The mylonites are directly overlain by metabasicsbetween Khattukhal and the Uttarkashi road but a small patch of schistose sericite quartzites occurs in between these rocks along the Singuni-Margaon mule track(Map 6). The contacts with overlying rocks are sharp without any assimilation of the material.

The mylonites are strongly foliated and dip 25-60° in the S and SW directions.The conspicuous penetrative lineation is developed on the foliation and plunges consistently 35 -40° in the S 30° W and SW directions.

4.4 MICROSCOPIC CHARACTERS

Table 12 presents modal analysis of some of the representative samples of the mylonites.

4.4 -1 Augen mylonites

Texture - The texture is strongly schistose and exhibit profound cataclastic effects with recrystallisation of the original cataclastically deformed constituents in which sometimes it is even difficult to identify the cataclastic effects. However, the relict original minerals are still preserved as quartz and feldspar porphyroclasts.

Mineralogy - These essentially consist of porphyroclastic quartz and feldspar which are embedded in a fluxion type of very fine grained and banded groundmass of sericite,chlorite,biotite and quartz alternating with well recrystallised large muscovite flakes. A few porphyroclasts of pink garnet are also seen. The accessory minerals are the iron oxide and zircon.

Quartz - It occurs as (i) coarse augens and (ii) fine granulated mass. The quartz augens(9 -14%) are coarse grained (0.25 - 2.5 mm.) and are sometimes stretched into elongated lenses. These are arranged en-echelon with the crest of an augen lying at the 'tail' of the other and are generally doubly convex in shape with a few concavo-convex types.

The quartz augens are strongly undulose and are granulated into small pieces which coalesce with each other into mortar texture (Fig.224). The margins of the augens are indistinct due to the presence of fine quartz grains(0.03 - 0.065 mm). The granulation effects are more pronounced near the tails and in the crestal parts of the augens. A few discrete fractures run across in many of the quartz augens and are generally oriented obliquely to the foliation. The fractures are marked with fine quartz grains,which in their advanced stage of development even separate the augens into different segments.

The granulated fine quartz is mostly associated with sericite in the groundmass. The individual grains are equidimensional with mild undulose extinction and indistinct contacts, but at places it is incipiently elongated. Generally the granulated quartz coalesces with the augens around the margins and fractures indicating profound granulation of the augens. At places quartz veins cut across the feldspar augens (Fig.223).

Feldspar (16 -22%) - It occurs as medium to fine grained (2.00 - 0.065 mm.), rectangular,ovoid and augen shaped prophyroclasts. The feldspars are generally associated with quartz augens in distinct bands and show preferred orientation of twin planes, cleavages and perthite growths. The following varieties have been identified in the augen mylonites.

(i) Potash feldspar augens with brownish to colourless unresolvable inclusions.

(ii) Perthite porphyroclasts - intergrowth of colourless, twinned albite (An_6) patches of the same birefringence and optical orientation with cloudy potash feldspar.

(iii) Albite porphyroclasts (An_6) (Fig.223).

Feldspar generally shows mild undulose extinction, intragranular and marginal granulation, microfracturing and displacement of the twin lamellae indicating the cataclastic effects (Fig.221). The porphyroclasts are marginally embayed and lobed by sericite-chlorite felt groundmass and show marginal replacement and sericitisation. At places, sericite even extends along twin planes and fractures and in the advanced stage the porphyroclasts are gradually lost in the groundmass (Fig. 222).

Sericite - It is light pale green, exceedingly fine grained and strongly oriented along the foliation. The flakes wrap around the porphyroclasts. Sometimes randomly oriented droplets and small sericite flakes are also met with along the fractures, cleavages and twin planes in the feldspar porphyroclasts.

Chlorite (45 -66%)- Chlorite is generally associated with sericite as tiny greenish flakes in the groundmass and is identified by its lower birefringence. In the groundmass, sericite, chlorite and quartz (granulated) is about 45 -66% of the rock. Another deep green, pleochroic variety of chlorite is somewhat coarser in size and surrounds a few almandine porphyroclasts (Fig.226).

Muscovite (1 - 28%) - Quartz - sericite - chlorite felt mass, at many places, is found alternating and grading into well defined, colourless, folia of coarse muscovite.

Garnet (Almandine)- A few grains are pink, fine grained (0.75 - 0.065 mm. and subhedral. It is strained, regularly fractured and is marginally surrounded by chlorite and magnetite (Fig. 226).

Biotite (0.5 - 4%)- Biotite occurs as fine grained, light brownish, pleochroic flakes and is seen grading to muscovite and sericite in the groundmass.

Accessory minerals-Minor amounts of magnetite near the periphery of garnets and euhedral, dark brown, prismatic zircon are also present.

4.4 -2 Augen Schist

Though exhibiting some of the features of previously described augen mylonites, the augen schists are marked with the following characters:

(i) The texture is typically crystalloblastic with flattened quartz and occasionally feldspar augens embedded in a groundmass of quartz, sericite and muscovite arranged in alternating folia (Fig. 225).

(ii) A few quartz augens are completely broken into small irregular mosaic showing composite extinction(Fig.225).

(iii) A few broken albite and potash feldspar augens are generally fine grained and are mostly replaced by sericite.

(iv) The sericitisation of feldspar augens is a common feature and in many cases these augens grade to the sericite-quartz felt in the groundmass.

4.4 -3 Ultramylonites

The ultramylonites generally occur as streaks and stringers in the augen mylonites. These are exceedingly fine grained, aphanitic, unresolvable brownish mass along the foliation with black isotropic masses. In the reflected light, these stringers are yellowish white with steel grey metallic lustrous grains of ilmenite(?).

4.5 DISCUSSION

In the area, the mylonitic rocks consisting of the augen mylonites, ultramylonites and augen schists are found developed only along the Singuni Thrust. The porphyroclastic nature of the rock and coarseness of the minerals like quartz, albite,perthite and potash feldspar,occurring as rectangular and augen shaped porphyroclasts suggest a possible quartz and feldspar porphyritic character of the original rocks which may have been emplaced along the thrust and later deformed to the augen mylonites. Hence these augen mylonites are not genetically related to the overlying quartzites and underlying slates and limestones.

Such deformed quartz and feldspar porphyritic bodies and related rocks e.g. mylonitised migmatites,mylonites etc. have also been observed near or along some of the thrust planes in the Lesser Himalaya(Heim and Gansser,1939; Pande,1956; Das,1962,1966a) and along some other major faults and thrusts e.g.,San Andreas Fault Zone (Walters and Campbell,1935), Great Glen Fault (Kennedy,1946; Shand,1951; Eyle and MacGregor,1952), Moine Thrust (Lapworth,1885; Teall,1936; Harker,1950; Christie,1960, 1963). Brevard Fault Zone (Bryant and Reed,1962; Reed and Bryant, 1964) and Alpine Fault(Suggate,1963; Reed,1964).

Heim and Gansser(op.cit.,p.27) noticed about 2800 metres thick,greyish-green slaty(also porphyritic and gneissic)quartz porphyry at Ramgarh which has been later identified as migmatites and mylonitised migmatites(Pande,1956). Similar slaty quartz porphyry have also been found near the North Almora Thrust at Chaukhutia(Heim and Gansser,op.cit., pp.47,57) and are now classified into mylonites and related rocks (Das,1966a).

The development of mylonites along the Moine Thrust has been a matter of controversy regarding their relation to the metamorphism of Moine Schists along the Moine Thrust. It has been argued that (a) mylonites were formed subsequently to the regional metamorphism of Moine Schist due to cataclastic deformation along the Moine Thrust (Horne,1930; Read,1931, 1934; Phillips, 1937, 1945) or (b) mylonites were contemporaneous to the regional metamorphism of Moine Schist in the movement zone between Moine Nappe and the Foreland (Lapworth, 1885; Peach,1930; Kennedy,1949; MacGregor,1952;Bailey,1955 ; Christie,1960,1963).

Christie(1960) concluded that the primary mylonitic rocks originated during the regional metamorphism of the Moine Schist. Such a view is also supported by the structural data(Christie,McIntyre and Weiss,1954; Christie, 1956,1963) whereas the secondary mylonitic rocks were formed during another phase of deformation.

On the other hand the Brevard Fault Zone in North Carolina exhibits good development of low grade retrogressively metamorphphosed phyllonites, blastomylonites and porphyroclastic blastomylonites from the gneisses and highly metamorphosed schists (Bryant and Reed,1962; Reed and Bryant 1964). Megascopic and petrofabric studies of structural deformation along this fault zone suggest a sub-horizontal strike- slip movement of great magnitude which has obliterated and rotated the structural trends of the adjoining areas subparallel to the fault zone (Reed and Bryant,op.cit.).

The difficulty in identification of cataclastic effects is apparent from the descriptions of Shand (1951) and Eyles and MacGregor(1952). The Great Glen Fault, according to Eyles and MacGregor(op.cit.), is marked by a broad belt of cataclastic and mylonitic rocks for about 65 km. in length whereas Shand(op.cit.),observed a few minute lenticular veinlets of mylonites which might have been originated in any hard rock that has been folded.

A new terminology and comprehensive account of the mylonitic rocks along the Alpine Fault, South Island,New Zealand has been given by Reed (1964). Suggate (1963) observed development of fault pug,fault breccia and shatter rock along the Alpine Fault due to the recent movement while occurrences of cataclasites have been attributed to late Tertiary phase of Kaikoura Orogeny and mylonites to late Jurassic Rangitata Orogeny (Reed,1964).

Near the Singuni Thrust, a prominent foliation dipping, towards the southwest and an equally strong mica lineation plunging in the same direction is developed both in the quartzites and mylonitic rocks. The lineation plunges almost normally to the strike of the foliation and the thrust,It appears possibly'a'lineation in the direction of the tectonic transport as has been opined for the mylonitic rocks along the North Almora Thrust (Das,1966a) due to the main movement of the Almora Nappe(Sarkar et al.,1965).

As has been discussed in Chapter 2, the effects of cataclastism in the overlying quartzites e.g.,strong undulose extinction,deformation lamellae, composite and semicomposite characters of the quartz grains,decrease in grain size,preferred dimensional orientation,intragranular and marginal granulation progressively increase towards the Singuni Thrust and are best observed along the Singuni-Margaon section. These effects appear to be somewhat identical along the Great Gren Fault (Walters and Campbell,1935); Glencoul Thrust(Crompton,1963); Moine Thrust(Harker,1955,p.166; Christie,1963), in the Appalachian quartzites, near the thrusts (Fellows,1943) and in the Precambrian Finnish quartzites (Hietanen,1938). Riley(1947) and Weiss(1954) observed similar cataclastic and recrystallisation effects in the quartzites and other crystalline rocks. Walters and Campbell(1935) noticed the following changes in the quartzites with increasing cataclastism:

(i) Fracturing of rocks into coherent,megascopically visible breccia or protomylonite.

(ii) Development of typical mortar structure due to the shearing of quartz grains.

(iii) Intragranular shearing and granulation to a stage of development of augens and lenticles.

(iv) Ultimate formation of the ultramylonites.

The mineral assemblage of mylonitic rocks along the Singuni Thrust corresponds to the green schist facies(cf.,Turner and Verhoogan,1960, p.533), but the sporadic development of garnet,at places, indicates that the mylonites were initially subjected to higher grades of metamorphism probably at greater depth and pressures. The retrogressive metamorphic effects in these mylonites (garnet-chlorite + magnetite,biotite-muscovite and sericite) suggest a still lower grade of metamorphism belonging to the quartz-albite-muscovite-chlorite subfacies of the green schist facies. A possible range of temperature and pressure for green-schist facies, as experimentally postulated by Fyle, et al. (1958), may be 300° to 500°C and 3000 - 8000 bars respectively. It appears possible that the shearing and recrystallisation in these mylonitic rocks even to higher (garnet zone) grade conditions may have taken place under stress conditions and later under lower metamorphic conditions at shallow depths.

The predominance of augen mylonites over other types of mylonitic rocks indicate that the deformation is partly ruptural and partly crystalloblastic (Knopf, 1931; Reed and Bryant, 1964).

The overlying quartzites have been subjected only to the lowest grade of metamorphism with the development of quartz-sericite-chlorite assemblage. Their structural and metamorphic homogeneity with the mylonitic rocks indicate contemporaneous development of these features which are more pronounced near to the thrust.

4.6 CONCLUSION

It may be concluded that (i) mylonitic rocks were probably emplaced originally as quartz and feldspar porphyry along the Singuni Thrust, (ii) the metamorphic and structural effects were more prominent due to the thrusting and (iii) the mylonitic rocks might have been subjected initially to a higher grade of metamorphism and later were metamorphosed at shallow depths during the thrusting process.

CHAPTER - 5

METABASICS

5.1 INTRODUCTION

The present work in a part of the Bhagirathi valley region has brought to notice widespread development of metabasic rocks hitherto unreported. This chapter includes their field characters, petrography, metamorphism and mode of emplacement. In addition, the salient features of the metabasics from Maneri in the Quartzite Formation have been briefly summarised for comparing its mineralogical textural characters in response to the increasing metamorphic grade from south to the north in the Deoban-Tejam Zone.

5.2. PREVIOUS WORK

A few metabasic bodies have been reported from the present area(Auden, 1936,1938,1949), though their occurrences as sills, dykes, lava flows and ash beds appear to be widespread in Kashmir, Simla, Garhwal and Kumaon (McMohan, 1883,1886,1887; Middlemiss,1890 a,b; Pilgram and West,1928; Wadia,1937; Heim and Gansser,1939;Pande,1949; Gansser,1959, 1964; Valdiya,1962,1965; Kanwar,1966; Misra and Banerjee,1967; Das,1968 etc.).

Auden(1936,1938) reported an epidiorite intrusive in the Deoban-Tejam Zone at Rari and other unspecified localities. Further, he pointed out their amygdaloidal character in the Garhwal Group in contrast to their non-amygdaloidal nature in the Simla-Krol Belt(Auden,1949).

5.3 METABASICS FROM THE PRESENT AREA

5.3-1 <u>Localities and mode of occurrence</u> - These metamorphosed basic rocks occur as metadolerites, chlorite schists, amphibolites, amygdaloidal metabasics and metadiorites and have been mapped at the following localities in the present area (Map 3):

(1) <u>Nagthat Formation</u>- A 50 metres thick sill extends for about 2.5 km. along

the strike of the formation at 3 km. SW of Laluri. Another small body is also observed near Chapra.

(ii) Dharasu Formation- A thick metabasic sill runs between Mason and Rari and extends to Gangani along the Yamuna river.

(iii) Quartzite Formation - Small impersistent metabasic sills and dykes are noticed at (a) 1.5 km. ESE of Malli,(b) Dichli and (c) milestones 75/0,80/0 and 80/4 along the Uttarkashi road.

(iv) Dharasu Thrust - Impersistent metabasics are mapped at Ulya and Soman.

(v) Utterkashi Formation - These are mapped in Bareti Quartzite at Kot.

(vi)Dunda Thrust - A continuous metabasic body occurs along the thrust between hill 2339 metres, Dunda and Koti and extends upto Kutnaur along the Yamuna river.

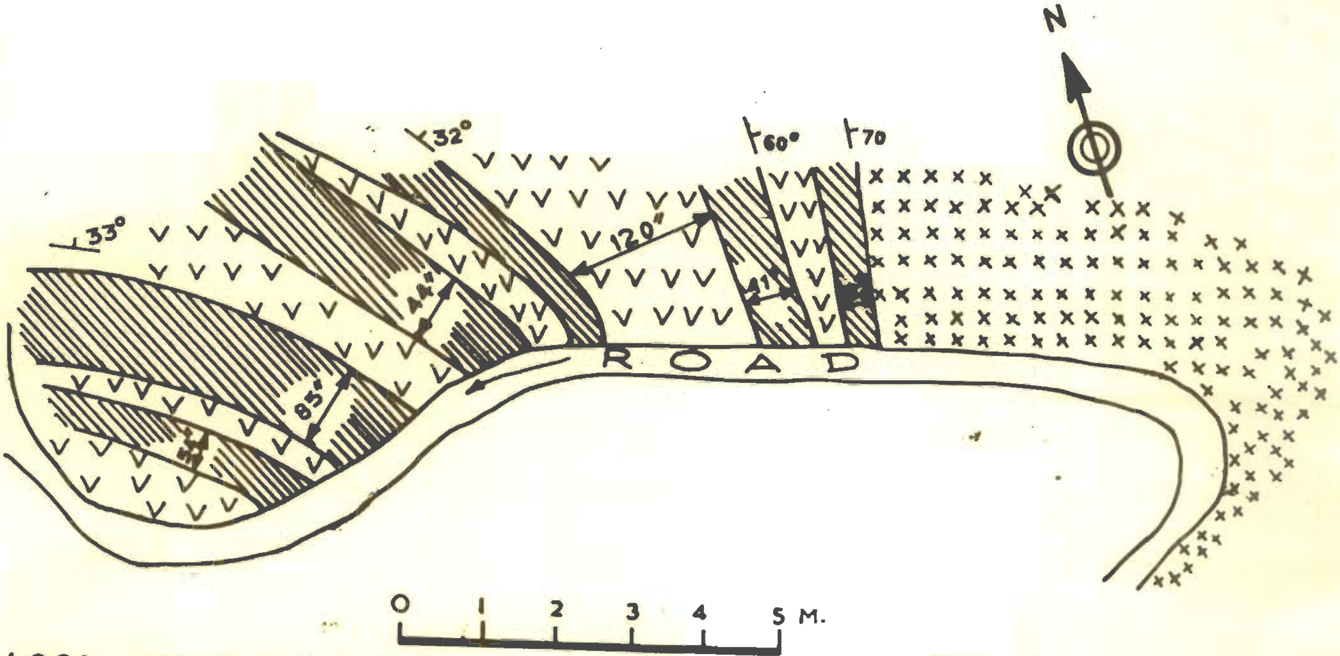
(vii) Uttarkashi Thrust - A sinuous metabasic outcrop is noticed along this thrust between Jugaldi- Uttarkashi -Chaurikhal and extends upto Kupra along the Yamuna river.

Metabasic at Rari - A N-S and NW -SE trending,concordant metabasic sill occurs in the basal Dharasu Formation slates between hill 2520 metres and Nagla on the left bank of the Khurmola Gad and possibly tapers off at Mason.It extends further northwest to the Yamuna river at Gangani.

Near the lower margin,the metabasic rock is dark green,malenocratic,fine grained,massive and nonfoliated with buff feldspars filling interstices between hornblende prisms. But, at places,it is schistose and metamorphosed to chlorite schists.

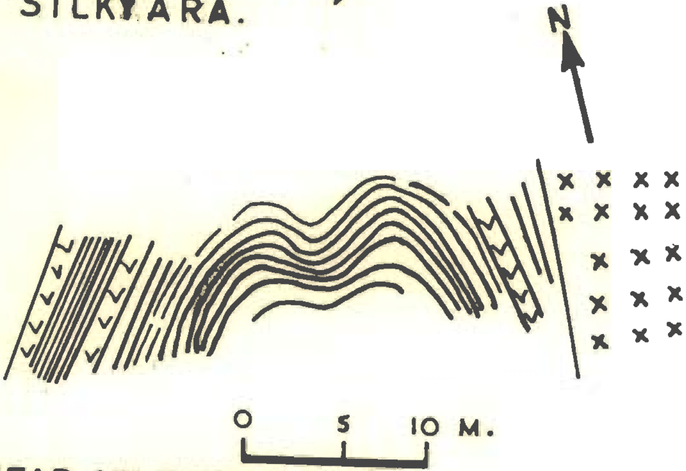
The considerable part of the body appears to be dioritic in composition and is mesocratic.,medium to coarse grained, nonfoliated and massive with quartz,feldspar and randomly oriented dark green hornblende prisms. Near the upper margin many quartzo-feldspathic bands sharply permeate the slates and vary from a few centimetres to 300 cm. in thickness (Fig.61). These are buff,medium to coarse grained comprising of quartz,feldspar and muscovite.

DIAGRAMATIC SKETCHES SHOWING UPPER CONTACT OF METABASIC & COUNTRY ROCKS ALONG ROAD NEAR RARI.



LOC:- MILESTONE 17/6 NORTH OF F.R.H, SILKYARA.

FIG. 61

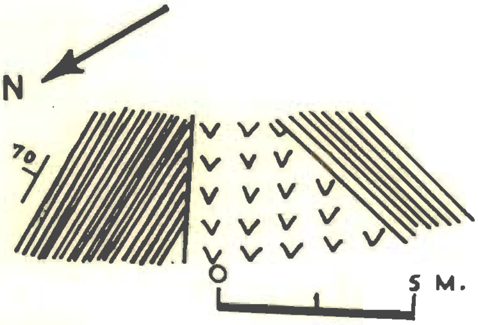


LOC:-NEAR MILESTONE 17/7 NEAR SILKYARA.

FIG. 62

LEGEND

- METABASIC
- QUARTZOFELDSPATHIC BANDS
- SLATES
- 30 DIP AND STRIKE OF BEDS



LOC:- ROAD SECTION AT F.R.H, SILKYARA.

The metabasics dip at about 40° due SW and W. Minor folding near the upper contact is decipherable along the Dharasu-Barkot road between milestone 16/5 and 17/7 (Figs.62&63). Immediately near the contact,the slates and quartzo-feldspathic bands dip 50-60° due northeast(Fig.63). The metabasic is highly weathered with yellowish encrustations and is extremely firable. Exfoliation weathering,facilitated by jointing,is characterised by spherical and ellipsoidal balls upto 1 metre in diameterat the upper margin (Fig.139).

Metabasics along Dunda-Uttarkashi Thrust - The most widespread occurrences of the metabasics in the area are along the Dunda and Uttarkashi Thrusts as thin,linear and sinuous bodies in the thrust zones which separate the underlying Dunda-Uttarkashi Formations from the overthrust Quartzite Formation. Their field and structural relationships have been elaborated in Chapter 3.

Megascopically,the metabasics are dark greenish black,green and greyish green with varying density,granularity and compactness. These are predominantly metadolerites,amphibolites and chlorite schists with a few occurrences of amygdaloidal metabasics. The metadolerites are generally massive,dark and heavier than the schistose varieties. These are generally medium to fine grained but the individual minerals are not indentifiable in most of the specimens(Fig.169). A few samples of the metabasic near Khattukhal contain clusters of dark greenish black hornblende.

In general, the metabasics are poorly to strongly foliated in character. The strongly foliated chlorite schists are locally developed near the margins of the thrust zone and are crenulated due to strain-slip cleavages(Figs.170 &172)and its lineation (Figs.171& 173)between Kankrari,Dhanpur,Foeld and Chaurikhal.

On the other hand, a few metabasic samples from Garh and Baun show dark green,preferably oriented and elliptical shaped chlorite patches in light greyish green schistose groundmass. Still a few others from Dunda,Pujargaon and Dhanpur consists of circular,irregular and partially filled amygdules and vesicles with quartz and drusy white porcellaneous mineral(Fig.168) Some amygdules are lined with purple hematite & vary in size from 2 mm. to 1.5 cm.

5.3-2 Microscopic characters

Texture - The metabasics are generally fine grained but the coarser varieties are more common near Rari. The original igneous textures are mostly obliterated. While the partially enclosed plagioclase laths in augite(blasto-subophitic) are occasionally preserved in coarser metadolerites,the blasto-intergranular texture is more common in the fine grained amygdaloidal meta-basics from Dunda,Pujargaon and Sankrona. In these varieties, the interstices between the randomly oriented plagioclase laths are filled with chlorite and hornblende. The irregular and circular amygdaloidal cavities are partially or completely filled with quartz and feldspar and are sometimes marked with purple ferruginous coating on minerals. The graphic growth of quartz and feldspar is seen in a few thin sections of the metadiorites from Rari.

The minerals invariably show indistinct and gradational boundaries thus rendering modal analysis ineffective. The new metamorphic textures are not completely developed. The fibrous hornblende and chlorite flakes are in various stages of preferred orientation in the metadolerites while in the chlorite schists the foliation is prominently developed due to strongly oriented chlorite flakes and is crenulated by strain-slip cleavage in many thin sections (Fig. 232).

Mineralogy - The most common mineral constituents of these metabasics are feldspar,hornblende and chlorite with variable amount of biotite,epidote, zoisite,sericite,muscovite,calcite and quartz. The original augite has been noticed only in a few thin sections. Quartz is an important constituent in the metadiorites from Rari and chlorite schists, The accessory minerals are zircon, apatite,ilmenite,leucoxene,sphene and hematite.

Augite - In these metabasics the mineralogical alterations are so complete that the original augite is a rare occurrence. It is colourless to pink, faintly pleochroic and occurs as relict hypidiomorphic crystal with good prismatic and basal cleavages. The twinning on(100) plane is also noticed in a few cases (Fig.228). The schiller structure in the pink variety is well defined due to small,opaque and preferably oriented iron oxide(?)rods.

Only rarely augite alters to acicular uralite along cracks and periphery near the contacts with plagioclase. Also of minor occurrences are the partial psuedomorphs of brown hornblende containing colourless,relict augite pathces with common cleavage direction and gradational margins.These patches extinct at about 45° indicating the optical continuity of the original augite. Sometimes complete pseudomorph of bluish green hornblende with crystal habits of augite are also met with (Fig.227). More commonly augite grades partially or completely to pale green hornblende(Fig.227),green biotite or chlorite (Fig. 229).

Hornblende - Variable amount of hornblende is ubiquitously distributed in most of the metabasics and decreases in percentage in chlorite schist and upper portions of the metabasic at Rari. In the fine grained metabasics from Pujargaon and Dunda,it is intergranular and prismatic in character. More commonly, it is in the various stages of alteration and preferred orientation along the foliation planes as tabular crystals and fibrous asbestiform subparallel aggregates with frilled margins.

(i) Brown Hornblende - A few tabular hornblende crystals show pleochroic brown core(X= pale yellow, Y = pale brown, Z =brown; Z>Y >X) with extinction upto 30 -35°. These even contain a few augite relicts. The brown hornblende is medium size and subhedral with good basal and prismatic cleavages. It is surrounded by a green bluish green actionlitic variety(Fig.230) and chlorite which have indistinct and gradational contacts with the brown variety. It shows higher relief and stronger birefringence than the green hornblende.

(ii) Uralite - It occurs rarely as pale bluish green acicular fibers along cracks and cleavages and is oriented normal to the relict augite boundaries.

(iii) Bluish green and green actinolitic hornblende -These are most common varieties of hornblende and occur as subhedral plates with frilled margins. The bluish green hornblende is moderately pleochroic (X = yellow green, Y = green, Z = bluish green, Z > Y > X) and shows an extinction upto 20°. Wherever good petrogenic relations are seen, the bluish green variety borders the brown hornblende (Fig.230) and sometimes even contains the relict augite inclusions. It even pseudomorphs completely after augite with the preservation of basal cleavage (Fig.228). It changes to pale green colour and looses its birefringence,pleochroism and relief.The pale green hornblende develops frilled margins. It is either surrounded by chlorite(penninite or prochlorite) or brownish green biotite (Fig.231).

Feldspar - (i) Plagioclase - It occurs as medium to fine grained and hypidiomorphic laths. The boundaries are generally ill defined and corrugated near hornblende due to the reaction. These are sometimes elongated with strong undulose extinction and are cataclastically deformed. Rarely,the twin planes are bent and fractured.

The original composition of the plagioclase is only rarely known which is sodic labradorite(An_{50}) with extinction upto 30-32° on(010) planes. More commly, it is albite(An_{3-10}) or sodic oligoclase (An_{13}), (extinction between 8-13° on (010). Many plagioclase laths occur in blasto-subophitic fashion and are partially enclosed in the hornblende plates but many are randomly oriented in the blasto-intergranular fine grained varieties.

The laths are highly riddled with numerous zoisite,sericite and rarely muscovite and calcite inclusions. The polysynthetic twinning is poorly developed. In many cases the zoisitic granules are uniformly distributed throughout the laths but in others, these are concentrated either in the cores or near the margins.

(ii) Alkali feldspar - It is only observed in the metadiorites at Rari and is subordinate to plagioclase. It occurs as subhedral,pinkish cloudy grains with a good cleavage. Sometimes it is graphically intergrown with quartz and even perthitic growths with albite are also seen in a few thin sections.

Biotite - (i) Brown biotite - A straw yellow to reddish brown,strongly pleochroic,subhedral variety of biotite occurs as distinct flakes with iron oxide inclusions in the metadiorites at Rari.

(ii) Brownish green biotite - A pale green to brownish green,moderately pleochroic biotite is more common and is generally found as fine flakes along cleavages and margins of the green hornblende.

(iii) Green biotite - It is fine grained with distinct pleochroism from light pale green to green colour. It is generally interfoliated with chlorite and is detectable only by its higher birefringence and absorption. Wherever all stages of replacement are developed,this variety is seen surrounding brownish green biotite and,in turn,is bordered by chlorite. In other cases,the green biotite directly fringes the green hornblende.

Chlorite - Chlorite is an important constituent of the metabasics and is abundant in the schistose varieties. It occurs as pale green to green,faintly pleochroic flakes with abnormal interference colours and is penninite.The other common variety shows grey and pale colours of the first order and appears to be prochlorite.It is generally seen along cleavages and periphery of the green hornblende (Fig.231) and augite(Fig.229). The complete chlorite pseudomorphs after hornblende is a rare occurrence. It even interfoliates with green biotite and hornblende. In the chlorite schists,it occurs as fine grained,preferably oriented flakes which are sometimes crenulated due to the strain-slip cleavage (Fig.232).

Quartz - Minor amount of granoblastic quartz is present in all the metabasic varieties. It is abundant in the metadiorites at Rari and chlorite schists. In the metadiorites, it is anhedral, medium to coarse grained. At places, it exhibits strong undulose extinction and is stretched along the foliation. Rarely it is interstitial between the plagioclase laths. At places, in the metadiorites at Rari, quartz is graphically grown with feldspar.

Zoisite - Many plagioclase laths show fine grained, dark brown clusters of highly birefringent zoisite granules. These are either uniformly distributed within the plagioclase or more rarely concentrated along margins or in the core of the laths.

Sericite - Sericite occurs as fine, preferably oriented flakes along cleavages and twin planes within the plagioclase laths.

Muscovite - A few colourless muscovite flakes characterise the metadiorites at Rari in the interstices between quartz and feldspar.

Calcite - Colourless, xenoblastic and preferably oriented calcite patches are observed along the foliation in some amphibolites. Calcite is generally associated with epidote.

Epidote - Small, colourless to pale green, idioblastic to xenoblastic epidote grains are sometimes enclosed in the plagioclase laths or associated with chlorite. In a few cases, thin epidote veins cut across the grain boundaries.

Apatite- Minor amount of minute euhedral, hexagonal, stubby prismatic with basal partings and long slender crystals of apatite are common in all the types of metabasics. The hexagonal variety is present in biotite and hornblende while the long slender crystals occur in the quartz filled interstices.

Zircon - Minute, colourless, euhedral prismatic zircon with dark margins occurs only rarely as inclusions in hornblende and quartz in the metadiorites.

Sphene - Fine clusters of dark brown birefringent granules of sphene are observed as inclusions in chlorite and along the ilmenite.

Hematite - Fine purple hematite is disseminated in albite and quartz along the walls of some amygdules.

Ilmenite-Leucoxene - Ilmenite occurs as subhedral,tabular and skeletal hexagonal crystals with steel grey metallic lustruous bars in the reflected light. Along the margins it alters to pale white leucoxene.

5.4 METABSIC FROM MANERI

5.4-1 Occurrence - The thick metabasic intrusive in the Quartzite Formation at Maneri is observed along the Bhagirathi river in the northern part of the Deoban-Tejam Zone near the Central Himalaya. It is dark greenish,medium to fine grained and well folieted schistose rock and become gneissose in the northeast due the seggregation of plagioclase lenticles. The foliation is characterised by preferably oriented dark green hornblende and dips 30-35° due N and N60°E. The incipiently developed mineral lineation due to the hornblende prisms plunges 20-45° in N10°E to N 75°E direction.

5.4-2 Microscopic characters

Texture - The metabasics show nematoblastic texture with preferably as well as randomly oriented hornblende prisms along the foliation. At places, the porphyroblastic growth of hornblende and oligoclase has also taken place with numerous quartz and biotite inclusions. The grains margins are not distinct.

Mineralogy (i) Hornblende - The preferably oriented prisms of dark bluish green, pleochroic hornblende(X - straw yellow,Y = yellow green, Z - deep bluish green) show higher relief and birefringence than the hornblende from the present area. Its extinction is upto 16°. The porphyroblastic,medium size hornblende contain numerous quartz and biotite inclusions.

(ii) Oligoclase (An_{28}) - It is generally colourless and xenoblastic in the foliation planes but a few porphyroblasts are also seen displacing the foliation. These contain numerous clinozoisite,biotite and hornblende inclusions.

(iii) Quartz -It generally occurs in the foliation as granoblastic grains with straight extinction. A few grains of quartz are also incipiently elongated.

(iv) Biotite - It is straw yellow to deep brown, strongly pleochroic as tiny flakes in the foliation.

(v) Chlorite - Small pale green flakes of chlorite occur around prophyroblastic and prismatic hornblende margins.

(vi) Clinozoisite - It is seen as greyish,well crystallised,fine clusters in the groundmass and porphyroblasts of oligoclase and exhibits anamolous blue interference colours.

(vii) Ilmenite and sphene - Dark brown,fine grained stringers of sphene occur around relict opaque,black ilmenite in the foliation.

5.5. MINERALOGICAL CHANGES AND METAMORPHISM OF BASIC ROCKS

The petrographic study of these metabasics has revealed widespread mineralogical and textural changes due to the low grade metamorphism. A few relict igneous minerals and textures are invaluable in the petrogenesis of these metabasics. A typical example of the following mineralogical changes is the metabasic body at milestone 75/0 along the Uttarkashi road:

(i) Calcic plagioclase- albite(sodic oligoclase)+zoisite+sericite+quartz

(ii) Pyroxene- hornblende- biotite -chlorite

(iii)Ilmenite -leucoxene -sphene.

5.5-1 Calcic plagioclase-albite(sodic oligoclase)+zoisite+sericite+quartz

Profound saussuritisation or low grade metamorphism of original calcic plagioclase laths(labradorite-An_{50}) has produced an aggregate of minerals which, in many cases, simulate the lath boundaries.The zoisite granules are mostly concentrated along the margins and are useful in deciphering the lath contacts. The plagioclase is mostly albite-sodic oligoclase(An_{13}) but the former(An_{3-10}) is more common. Sericite is seen along the cleavages and twin planes.

With increasing metamorphic effects, the plagioclase laths appear less distinct and a few new minerals are formed due to the chemical reaction between the plagioclase and mafic minerals. In the initial stages,epidote appears as fine granules around the plagioclase laths. At this stage,scattered xenoblastic calcite also develops in a few cases. With the appearance of foliation, zoisite of plagioclase laths disappears and give place to epidote and calcite.

Wiseman(1934) observed that albite(An_{3-4}) is the characteristic plagioclase in the chlorite zone and changes to a more calcic plagioclase with increasing progressive metamorphism of the basic rocks in the garnet zone (also Philips,1930). Accordingly, Wiseman suggested that anorthite of the original basic rocks is partially or completely used in the formation of epidote and albite.

$$3\ Ca\ Al_2Si_2O_8 + CaO + H_2O - 2\ Ca_2Al_3\ (SiO_4)_3OH$$

$$4\ Ca\ Al_2Si_2O_8 + H_2O - 2\ Ca_2Al_3(SiO_4)_3OH + Al_2O_3 + 2\ SiO_2$$

Due to a change in plagioclase composition, the following authors have successfully worked out the grade of metamorphism of the basic rocks:

(i) Transformation of albite-epidote assemblage to a lime plagioclase from epidote-amphibolite to amphibolite facies (Eskola,1939; Barth,1951; Ramberg,1952).

(ii) Abrupt change of albite(An_{0-7}) to oligoclase (An_{15-30}) (Turner,1958; Noble,1962) and a sharp break from An_5 to An_{20} (de Waard,1959), An_{10} to An_{20}

(Lyons,1955) and An_{12} to An_{15} (Compton,1955) in the plagioclase composition of the metamorphosed basic rocks from the green schist to almandine-amphibolite facies.

In the Michigan and Vermont-Hampshire terrains, albite is widespread in the chlorite zone of progressively metamorphosed basic rocks and changes to oligoclase near the upper limit of the biotite zone(James,1955; Billings and White,1950).

Thus the plagioclase composition(An_{3-10}) in the metabasics of the Uttarkashi region indicates that these are mostly metamorphosed to green schist facies though a slightly higher grade is also indicated by sodic oligoclase (An_{13}).

The metabasic at Maneri in the Garhwal Group near the Central Himalaya is marked by calcic oligoclase(An_{28}) thus indicating a higher grade of metamorphism. This can be placed in the staurolite-quartz subfacies of the almandine-amphibolite facies(Turner,1958, p.229.)

In the Lesser Himalayan region of Pithoragarh,Valdiya(1965) observed albite in the metabasics of the basal Berinag Quartzite sequence while main bulk of the basic rocks is metamorphosed to biotite zone with oligoclase-andesine (An_{28-34}) as the characteristic plagioclase. While albite and oligoclase are found only in the basic rocks of the Chamoli Quartzite along the Alkananda river, andesine and labradorite are common in the metabasics and amphibolites of Simla-Krol Belt,crystalline zone and thrust bound basic rocks of the Kumaon region (Heim and Gansser,1939,pp.52-61).

Zoisite and sericite are common in the metabasics of the present area. Its paragenesis may be represented by the following equation (Deer,et al. 1963b , p.190).

$$3\ CaAl_2Si_2O_8 + Ca(OH)_2 - 2\ Ca_2Al_2Si_3O_{12}(OH)$$

Anorthite Zoisite

5.5-2 Pyroxene- Hornblende - Biotite - Chlorite

In the present case, one of the important and widespread mineralogical change is gradual alteration of original pyroxene of the basic rocks to chlorite through the following stages: augite — brown hornblende — bluish green hornblende (actinolitic)— fibrous pale green hornblende — brownish green biotite — green biotite — penninite —chlorite (undifferentiated).

In the initial stages, a fine acicular pale bluish green uralite forms around the periphery of augite where the metamorphic effects are incipient. But in a fewcases the relict augite has been observed partly or completely enclosed by brown hornblende which appears to be pseudomorph after augite.The cleavage directions are generally common to both augite and brown hornblende.

In the second stage, the prismatic and fibrous variety of bluish green and green actinoli-tic hornblende is developed. The contacts between the brown and bluish green hornblendes are gradational; the prismatic cleavage of the former passes uninterruptedly to the bluish green hornblende. The latter appears to be developing from the brown hornblende. The actinolitic variety completely replaces the brown hornblende and in that case, it encloses relict augite or may even replace augite. Generally the bluish green actinolitic hornblende becomes pale green and fibrous near the margins and gradually looses its colour.

In the next stage, the brownish green biotite develops as fine grained flakes along the cleavages and periphery of bluish green hornblende. It appears to have formed earlier than the green biotite in the mineralogical sequence.

The alteration of bluish green hornblende to green biotite is more frequent than to the brownish green variety. When all stages are developed, the replacement of brownish green biotite by green variety is also seen.

The last mineralogical transformation in the series is the formation of two varieties of chlorite i.e., penninite and prochlorite(ordinary chlorite). Penninite has been observed along the cleavages and periphery of the bluish green actinolitic hornblende and is also interfoliated with the green fibrous hornblende. The prochlorite occurs as fine flaky aggregates along periphery or cleavages of green hornblende and biotite.

(i) Uralite - Uralite, an acicular fibrous light pale bluish green variety (Deer, et al., 1963a) has been occasionally seen in the metabasics of the present area. The formation of uralite (uralitisation) may take place by the following processes:

(i) Hydrothermal activity during the late stage of crystallisation of magma (Deer, et al., 1963a, p.307; Hatch, et al., 1951, p.298).

(ii) Retrogressive dynamic and thermal metamorphism (Harker, 1950, pp.107, 174, 357).

(iii) Low grade regional metamorphism (Wiseman, 1934).

The presence of uralite in the metabasics along cracks, cleavages and margins of augite indicates that uralite has possibly formed due to the hydrothermal action of water enriched magmatic fluids or during the initial stages of metamorphism.

(ii) Actinolite and hornblende - A variety of hornblendes are developed during the metamorphism of the basic rocks in the green schist and almandine-amphibolite facies and have been extensively used in the metamorphic zonation.

Though a strongly pleochroic, dark bluish green hornblende has been observed directly forming from pyroxene in the initial stages of metamorphism

(Sutton and Watson,1950,1951), a pale green to bluish green actinolitic hornblende as irregular plates with frilled margins,is the most frequent variety in the green schist facies(Tilley,1928,1938; Wiseman,1934; Turner, 1935; Hutton,1940; James,1955). It has a low refrective index(Vogt,1927; Eskola,1925; Wiseman,1934) and thus resembles with those from the metabasics of the area.

Generally, the colour of hornblende is related to the grade of metamorphism (Deer,et al.,1963 a,p.307). A pale green actinolite is characteristic of the lowest grade metamorphism and coexists with hornblende while the bluish green and greenish brown hornblende are typical of intermediate and higher zone respectively (Wiseman,1934; Eskola,1952; James,1955; Shido,1958; Engel & Engel,1962.

Wiseman (1934) suggested a simultaneous origin of hornblende and chlorite from the original pyroxene and feldspar in the SW Scottish Highland epidiorites in contrast to the formation of hornblende from chlorite in the Start Green Schist (cf., Tilley,1923). He maintained that "when a basic rock undergoes low grade regional metamorphism, the anorthite molucule of the original plagiocalse is partially or completely used in the production of hornblende and chlorite from the original pyroxene". The whole reaction must be facilitated by abundant water. Thus a common assemblage of hornblende,chlorite, epidote,albite and sphene is characteristic of low grade metamorphism of basic rocks (Wiseman,op.cit.).

The retrogressive metamorphism also appears to be an important factor in the production of hornblende and chlorite from plagioclase and pyroxene of the original basic rocks and may develop chlorite,calcite, biotite and white mica(Wiseman, op.cit.).

The metabasics from the area develop different amphiboles under low grade metamorphic conditions. The brown hornblende is fringed by a bluish

green actinolitic hornblende which is frilled to colourless and pale margins. It is evident from the enclosed augite relicts that the low grade metamorphism of the original augite and plagioclase assemblage has initially produced a brown hornblende in minor amount which is later converted to the characteristic actinolitic variety. In the present case,the actinolitic hornblende has been apparently found developing from (i) augite,(ii)brown
and chlorite from (i) augite,(ii) brown horrblende,
hornblende,/(iii) bluish green actinolitic hornblende and (iv) green biotite. Hence it is difficult to point out precisely the products of progressive and retrogressive metamorphism which appear to be closely related (cf.,Pande, 1949).

The emplacement of basic rocks along the thrusts and shear zones during the orogenic movements will evolve intense retrogressive metamorphism and the evidence for which are not lacking. Many of the metabasics are fine grained chlorite schists which may not be due to chilled margins but sheared contacts (cf., Poldervaart,1953; Engle and Engel,1962;Nair,1968). The effects are more pronounced in thin metabasic bodies along the Dharasu and Main Central Thrusts. These contain chlorite,quartz and albite thus indicating profound retrogressive metamorphism.

A higher grade of metamorphism is indicated by more intense colouring of hornblende in metabasic at Maneri which can be placed between upper biotite and garnet zones.

(iii) Biotite - Various shades of biotite have been observed due to hydrothermal alterations(Schwartz,1958), dynamic (Wiseman,1934) and thermal -regional metamorphism of the basic schists(Tilley,1924,1926; Phillips,1930; Shido,1958; Miyashiro,1958; Engle and Engle,1962).

The characteristic biotite from the area is brownish green and green, though the pyrogenic deep reddish brown biotite is occasionally present in the metabasics at Rari. As has been previously mentioned, the brownish green variety appears to have preceded the green biotite and develops from bluish green actinolitic hornblende. The observation that hornblende changes to biotite which, in turn, alters to chlorite has been made by several workers and is attributed to shearing (Wiseman, 1934).

The deep brown biotite characterises the metabasics at Maneri. This can can be well correlated with increasing grade of metamorphism as also evidenced by other textural and mineralogical changes.

In the Lesser Himalayan region of Pithoragarh, the green biotite has been noted in the basic rocks from the basal Berinag Quartzites and brown biotite from the main sequence in the chlorite and biotite zones (Valdiya, 1965). It is also likely that biotite and chlorite retrograde after hornblende in the metabasics of the present area (cf., Pande, 1949).

(iv) Chlorite - The chlorite rich assemblages in the low grade metamorphosed basic rocks are widespread (Wiseman, 1934; Tilley, 1938; Hutton, 1940; James, 1955; Shido, 1958; Miyashiro, 1958) and appear to be dependent upon the accessibility to $H_2O + CO_2$ solutions (Turner, 1935; Tilley, 1938).

Chlorite is an important constituent of the metabasics of the area and is minor in amount in the metabasic at Maneri. The chlorite which fringes the pyroxene is possibly formed during the progressive metamorphism along with hornblende in these metabasics. The other types which appear to have been derived from hornblende and biotite might have developed during the retrogressive phase (Wiseman, 1934; Pande, 1949; Tilley 1938) opined epidote as the most likely source for the alumina needed in the formation of chlorite.

Actinolitic hornblende + epidote — chlorite + CaO + SiO_2

5.5-3 Ilmenite — leucoxene — sphene

Another mineralogical transformation includes ilmenite of the original basi rocks. It develops skeletal bars in the brownish leucoxene mass in the metabasics and sometimes changes to granular sphene.

5.6 METAMORPHIC TRENDS

The various authors have worked out different metamorphic trends in the basic rocks after Teall's (1885) observations on the transformation of a dolerite dyke into amphibolite. Wiseman (1934) identified following three zones in the normal trend of metamorphism of basic rocks:

(i) Chlorite and biotite zones - chlorite,pale green hornblende, epidote, albite; igneous textures preserved.

(ii) Garnet zone - oligoclase- andesine,dark green hornblende; original textures destroyed.

(iii) Silliminite zone - diopside, garnet; original textures destroyed.

Wiseman's(op.cit) normal trend of metamorphism of basic rocks have been found widely occurring in other parts of the world(Tilley,1938; Eskola,1939; Turner,1948; Pande,1949; James,1955; Shido,1958; Miyashiro,1958;Barnes,1959; Das,1968). On the other hand, Sutton and Watson(1951) observed dark bluish green hornblende and andesine directly developing from pyroxene and plagioclase in the initial stages of metamorphism with the preservation of the igneous textures. In more advanced stages(stage 4), the metamorphic trend merges with Wiseman's normal trend with the formation of andesine,dark bluish green hornblende with marked schistosity and lineation.

Turner(1935) observed different green schist mineral assemblages in the basic rocks under varying H_2O and CO_2 conditions. The failure of basic rocks to respond to metamorphism of the country rocks is mainly due to the accessibility of water (Poldervaart,1953). Hence it seems possible that the three metamorphic trends as visualised by Sutton and Watson(1951)may possibly depend upon the water content rather than to the changing pressure and temperature conditions(Wilcox and Poldervaart,1958).

The metabasics of the present area show the normal trend of Wiseman(1934) with minor differences and develop the following mineral assemblage:

Pale-
/bluish green actinolitic hornblende - albite - oligoclase - chlorite-
epidote - (brown hornblende- quartz - biotite - calcite- ilmenite).

5.7 MODE OF EMPLACEMENT

5.7-1 Other regions of the Lesser Himalaya - Many basic rocks and their metamorphic derivatives have been reported from the Lesser Himalayan region between Simla and Kumaon. The opinions regarding their mode of emplacement may be grouped as follows:

(i) Basic rocks as intrusives into the country rocks as sills and dykes (Pilgrim and West,1928; Auden,1934a, Pande 1949; Addy,1967; Bisaria 1967; Das,1968; Dutta,1968; Pande,1968; Bisaria and Saxena,1968, Pande and Kumar,1969 ; Kanwar,1966,1969; Pande and Chadha,1969).

(ii) Contemporaneous emplacement of basic rocks during sedimentation as ophiolites(Gansser,1959, 1964;Valdiya,1965) and tuffs (Misra and Banerjee, 1967).

(iii) Tectonically controlled occurrences along thrusts and shear zones(Heim and Gansser,1939; Gansser,1959; 1964; Valdiya,1962,1965; Misra and Banerjee, 1968; Pande,1968).

(i) Basic rocks as intrusives - Pilgrim and West(1928) considered hornblende schist and amphibolite intrusives in the Jutogh Series as older than the recumbent folding and metamorphism of the rocks while Kanwar(1966)and Bisaria (1967) opined that these amphibolites were intruded before the deposition of the Chail Series.

Many small intrusives sills and dykes of the basic rocks have been found in the Mussoorie region of the Simla-Krol Belt (Auden,1934a; Singh,1966; Salapaka,1966). Pande (1949) observed such an epidiorite sill at Ramgarh, which has contaminated the adjoining quartz porphyry to quartz diorite.

Das(1968) reported many small metabasic sills from Dwarahat-Chaukhutia area in the western part of Almora-Dudotoli thrust sheet.

Heim and Gansser(1939,p.49; Auden(1937), Dutta (1968) and Pande (1968) observed many metamorphosed intrusives in quartzites of the Chamoli and Pithoragarh districts. Auden(1949) emphasised their amygdaloidal character in the Deoban-Tejam Zone in comparison to their non-amygdaloidal nature in the Simla-Krol Belt.

(ii) Contemporaneous with sedimentation - Recently, Gansser (1959,1964)& Valdiya (1965) viewed some of these basic rocks of the Deoban-Tejam Zone in the Kumaon region as ophiolites being pene contemporaneous with sedimentation. The lack of contact effects and their occurrences as alternating concordant sheets in the country rocks favour this hypothesis. However,Valdiya(personal communication)now considers these as non-ophiolitic in character.

(iii) Tectonically controlled occurrences - An interesting feature of the geology of the Kumaon region is tectonically controlled occurrence of some of the basic rocks along the thrust planes and shear zones. Heim and Gansser(1939), Gansser(1959,1964), Valdiya(1962,1965),Das (1968 and Misra and Banerjee (1968) observed that Almora-Dudotoli,Baijnath and Askot crystalline thrust masses, Main Central Thrust, Singali and North Almora Thrusts are bordered by thin persistent metabasics. Though the normal contacts between quartzites and calcareous rocks of the Deoban-Tejam Zone in Bageshwar-Pithoragarh areas are sometimes marked with the metabasics(Valdiya,1962, 1965; Misra and Banerjee,1967,1968), these appear to be faulted along which the metabasics are emplaced in the Kanalichina area(Pande,1968).

5.7-2 Metabasics of the present area - The present area shows widespread development of metabasics which are mainly confined to the Garhwal Group rocks. These have been observed as (i) concordant and discordant intrusive sills and/dykes (ii) tectonically emplaced metabasics.

Many of the smaller metabasic bodies are broadly concordant as these generally follow the strike of the country rocks but show angular discordance in the amount of dips. The examples of such bodies are (i) metabasics at milestone 75/0 on the Uttarkashi road (Map 6) and (ii) metabasics northeast of Dunda at milestone 80/0 (Map 7). In the former case,the lithological units are also even cut by the metabasic. In this connection, it is noteworthy that Misra and Banerjee(1968) observed that "very often these basic rocks show structural discordance with the metasedimentaries ..." in Bageshwar area.

The contact effects are generally lacking upon the country rocks possibly due to the fact that many of these bodies occur in pure quartzites. The metabasic at Rari is fine grained at the lower margin and has sporadically metamorphosed slates of the Dharasu Formation (p.46).

The most important occurrences of the metabasics are along the Uttarkashi and Dunda Thrusts which are characterised by persistent metabasics extending extending upto Yamuna river for about 25 km. The field and structural features of these metabasics have already been discussed in Chapter 3. Considering that the contact between the Quartzite and Uttarkashi-Dunda Formations is a folded thrust(Chapter 3, p. 94), the following possibilities may exist for the occurrence of the metabasics along the thrust:

(i) Metabasics were emplaced along the zone of weakness concomittantly during the thrusting.

(ii) Metabasics were intruded along a pre-existing zone of thrust plane.

(iii) The metabasics themselves constitute a distinct thrust slice, bounded above and below by two low angle thrusts.

(iv) The metabasics are one of the lithological unit of the Quartzite or Dunda-Uttarkashi Formations.

The fourth possibility is simply ruled out due to the structural relationship with the rock units especially along the Dunda Thrust where the metabasics show a regional discordance with Dunda and Quartzite Formations (Maps 3 &7; Figs.52 & 59).

The third possibility that the metabasics form a separate thrust slice, bounded above and below by two thrusts will unnecessarily complicate the structure when the relationships can easily be explained even by assuming the the presence of a single plane.

The following evidences strongly suggest the first possibility that the metabasics wereemplaced along the Dunda-Uttarkashi Thrusts during the thrusting movements:

(i) The metamorphic effects upon the rocks are maximum near the thrusts where the metabasics are absent or very thinly developed e.g,along the northern margin of the Uttarkashi Thrust between Hinna,Netala,Gangani and at Sankrona along the southern margin. Though the lithology is almost the same, the metamorphic effects are minimum where the metabasics are relatively thick along the Dunda and Uttarkashi Thrusts e.g., at Odalak ,Dunda,Jakhni and Ratulisera.

In the second alternative,the metamorphic effects should have been uniformly distributed if the metabasics were intruded along a zone of weakness and later metamorphosed.

(ii) Lithological contacts,faults and fold axes are some of the other possible zone of weaknesses in the Dunda and Uttarkashi Formations but there is no development of metabasics along these zones. This bespeak in favour of the first possibility that the metabasics are emplaced during the thrust movements.

(iii) The development of more schistose varieties e.g.,amphibolites and chlorite schists near contacts with the formations indicates more intense deformation along the margins whereas in the latter case, the metabasics should have developed chilled margins.

(iv) The development of foliation indicates that the structural deformation and metamorphism of the metabasics were contemporaneous to the thrusting(Chapter 3). In contrast, an intrusive should have been compact and nonfoliated viz., metabasic at Rari. This also focusses attention to the smaller bodies which are schistose in character.

(v) The metabasics show progressive and retrogressive metamorphism. In the second case, the progressive metamorphism is the possibility if thrusting may be considered before the metamorphism of the country rocks.

From the foregoing discussion, it is evident that the metabasics were emplaced along a zone of dislocation during the thrusting of the older Quartzite Formation over the Uttarkashi-Dunda Formations and were then folded to develop Uttarkashi and Dunda Thrusts in the north and south respectively.

A few metabasic bodies impersistently occur along the Dharasu and Main Central Thrusts and indicate a similar mode of emplacement.

The smaller metabasics e.g., at milestones 75/0 and 80/0 along the Uttarkashi road are structurally discordant with the country rocks and were possibly emplaced along small shear zones. It is not intended here to impress upon a complete lack of the normal intrusives (not related to the shear zones) and concordant basic sheets and metatuffs etc. but care should be taken to work out detailed structural features which may be useful in deciphering their mode of occurrence.

Gansser(1959,1964) and Valdiya(1965) pointed out ophiolitic character of these basic rocks as submarine lava flows contemporaneous with the sedimentation in the Kumaon region. The ophiolitic occurrences determine subsequent tectonic (thrusting)events in contrast with the earlier views that these intrude along the pre-existing tectonic features(Gansser,1959).

TABLE -13

COMPARISON OF IMPORTANT CHARACTERS OF OPHIOLITES AND METABASICS OF DEOBAN-TEJAM ZONE, DIST. UTTARKASHI, U.P.

OPHIOLITES (AUBOUIN, 1963)	PRESENT AREA
(1) Ophiolites suite shows wide compositional range consisting of (a) fine grained rocks: basalts, spillites and pillow lavas. (b) medium grained rocks; dolerites and (c) coarse grained rocks: peridotites, pyroxinites, gabbros, diorites and quartz diorites.	(1) Basic rocks are mainly fine to medium grained doloritic rocks which now occur as metabasics; rarely amygdaloidal.
(2) Fine grained basalts and spillites enclose coarse grained rocks.	(2) Fine grained near the margins due to shearing; coarser and less schistose in the centre.
(3) Ophiolitic magma pours directly upon sea bed contemporaneous with sedimentation.	(3) Absence of chilled contacts.
(4) A thick shell of spillites and pillow lavas at the top in direct contact with sea water and a thin doleritic skin at the base in contact with the floor.	(4) Angular structural discordance.
(5) Presence of ophiolites in eugeosynclines and form most distinctive feature.	(5) Complete absence of eugeosynclinal sediments like bedded cherts, radiolites, flysch.
(6) Absence of ophiolites from miogeosynclines.	(6) Complete absence of pillow lavas though spillitic nature is uncertain.
(7) Typical association of ophiolites with radiolites in ophiolite-radiolite series or diabase-radiolite series.	(7) Tectonically controlled metabasics more common; emplaced concomittantly with thrusting.

Table 13compares the salient features of the ophiolites as have been summarised by Aubouin(1963,pp.151-159) and the metabasics of the present area. The most imoortant feature of the ophibolite suite is their association with radiolites,bedded cherts and flysch sediments. Their association with such sediments is of fundamental importance in the classification of eugeo-syncline and miogeosynclines(Stille,1940;Kay,1951).

Thus it may be seen that these metabasics which have similarities with those of the Kumaon region, do not posses any of the typical features of the ophiolites to which Valdiya also agrees(p.139) but, however, he maintains their emplacement contemporaneous with sedimentation(Valdiya,1968).

5.8. THRUSTING IN RELATION TO MYLONITES,METAMORPHISM AND METABASICS

Valdiya(1965) observed an increase in the grade of metamorphism of metabasics towards the top of the Berinag Quartzites in the Pithoragarh region and regarded that most of these were metamorphosed to biotite and garnet(?) zones in the Middle and Upper Berinags. This supports the earlier conclusion that the sequence in the region is inverted (Valdiya,1962,1965). In comparison , the metabasics of the present area are metamorphosed to chlorite and biotite zones in an uninverted sequence of rocks. In the north-east, the metabasics at Maneri show a higher grade of metamorphism upto upper biotite and garnet zones with a similar mineralogical assemblage as the widespread metabasics of the Berinag Quartzites. This possibly indicates an eastward increase in metamorphism which is also strengthened by the fact that the greater part of the Berinags is overwhelmingly schistose(cf.,Valdiya,1962) whereas the quartzites of the present area are generally schistose near the thrust contacts.

An increase in the cataclastic effects towards the Singuni thrust at the base of the normally bedded southern Quartzite Formation belt clearly demonstrates its role in the metamorphism of the rocks (Chapter 4). Similar increase of cataclastism has been noticed by the present worker towards the Main Central Thrust at Sainj and along the Yamuna valley near the top of the normally bedded quartzites. These cataclastic effects along the Uttarkashi, Dharasu and Basul Thrusts develop highly schistose rocks in localised zones and may thus be correlated with the the thrusting phenomenon. The similar effects have also been observed in the Berinar Quartzites which are more metamorphosed near the overlying crystalline thrust masses(Gansser,1964; Valdiya,1962,1965).

Pande and Kumar(1968), while considering metamorphism in relation to thrusting in the Himalaya, noted that the mylonites and fault breccia may develop in the zone of cataclasis along the thrusts e.g,Chail Thrust. Similarly, Dutta and Kumar(1964) attributed such vertical and abrupt metamorphic change between the underlying less metamorphosed Mandhalis and more metamorphosed Chandpurs to the thrusting.

On the other hand, many of the thrusts and faults in the southern Lesser Himalayan and Foothill Zone of Garhwal and Himachal Pradesh are generally marked with fault breccia, crushed material etc. and exhibit signs of recent activity (Krishnaswami,1962; Jalote,1962; Jalote,1966,1968).The absence of metamorphism,cataclasites and mylonites along these thrusts is significant. The development of crushed Chandpur Phyllite and friable carbonaceous material etc. along the Krol Thrust (Jalote,1966) and other brecciated rocks may be correlated with near surface and relatively younger movements(cf., Reed,1964). This possibly indicates a relatively shallow depth of these thrusts and faults including the Krol Thrust in the Foothills and Sub-Himalayan Zones. In the inner Lesser Himalayan region of the area, some of the thrusts are either marked with mylonites and metamorphism and appear to have evolved at greater depths.

Further,many of the thrusts in the Shali,Garhwal and Kumaon regions of the Deoban-Tejam Zone are characterised by thin metabasics. Example of such

TABLE - 14

CHARACTERS OF SOME IMPORTANT THRUSTS IN GARHWAL, U.P.

PROBABLE SHALLOWING OF THRUSTS	NORTH (Sainj)	DEOBAN - TEJAM ZONE	MAIN CENTRAL THRUST	Impersistent chlorite schists; increase in metamorphic effects towards top in Quartzite Formation near thrust; development of foliation, micalineation and quartz sericite schists.
			UTTARKASHI THRUST	Persistent metabasics; metamorphic effects maximum wherever metabasics are absent; schistose quartzies; development of foliation and micalineation.
			DUNDA THRUST	Persistent metabasics; metamorphic effect minimum wherever metabasics are thick.
			SINGUNI THRUST	Impersistent mylonitised quartz and feldspar porphyry; increasing metamorphic effects towards the sole of thrust in Quartzite Formation; schistose sericite quartzites; development of foliation and mica lineation.
			DHARASU THRUST	Impersistent metabasics; increased metamorphic effects in Dharasu Formation along thrust zone; crushing of rocks;
		SIMLA-KROL BELT	BASUL THRUST	Sericite quartz schists and schistose quartzies in thrust zone; increase in metamorphic effects; development of foliation and mica lineation.
			TONS THRUST	Fault breccia and crushed slates; lack of metamorphism.
	SOUTH (Rajpura)		KROL THRUST	Fault breccia, crushed Chandpur phyllites; friable carbonaceous matter; lack of metamorphism; typical of other thrusts in foot hills.

thrusts are the Shali Thrust in the Shali area; Uttarkashi, Dunda and Dharasu Thrusts in the present area; Main Central Thrust; Singali Thrust; Askot, and Baijnath crystalline thrust masses and North Almora Thrust (Heim and Gansser, 1939; West, 1939; Gansser, 1959, 1964; Valdiya, 1962, 1965; Misra and Banerjee, 1967, 1968; Das, 1968; Rao and Bhan, 1969). These metabasics in the area have been emplaced during the thrusting movements and must have facilitated such movements.

Table 14 summarises some of the features of the thrusts across Garhwal from south to north.

5.9 AGE OF METABASICS

The age of these metabasics is problematic since these have been found in the unfossiliferous rocks of uncertain stratigraphy and has been considered from Precambrian to Tertiary by various authors.

The viewpoint that the metabasics are contemporaneous with the sedimentation of the Berinag Quartzites and Calc Zone of Pithoragarh (cf., Gansser, 1959, 1964; Valdiya, 1965) implies a Precambrian to Lower Palaeozoic age for such intrusions. The presence of basic tuffs in the metasediments (Misra and Banerjee, 1967, 1968) also reflects the same age for the metabasics.

Pilgrim and West (1928), Kanwar (1966) and Bisaria (1967) favoured a Precambrian age for the hornblende schists in the Jutogh sediments due to their absence from the Chails.

Auden (1934a) postulated the Tertiary age for the dolerites of the Simla-Krol Belt.

A study of published literature reveals that the basic rocks have not been observed in the Tertiary formations (Nummulitics, Subathus and Siwaliks) of the Garhwal Himlaya. Further, most of the thrusts and faults of Outer and Sub-Himalayan Zone including the Main Boundary Fault and Krol Thrust are devoid of basic rocks in Garhwal whereas many of the thrusts of the Deoban-Tejam Zone of Garhwal and Kumaon area are characterised by such occurrences.

As has been discussed earlier,the tectonically emplaced metabasics of the area are distinctly related to the thrusting movements. The earliest evidences for the upheaval and movements during the Himalayan Orogeny date back to Upper Cretaceous to Eocene (Krishnan 1960,p.490; Wadia,1964; West and Wadia, 1964). The absence of basic rocks from the Tertiary formations indicates a possible pre-Tertiary age for their intrusions in Garhwal. It may be worthwhile to correlate (i) a probable pre-Tertiary age of the basic rocks,(ii) tectonically controlled occurrences along many thrusts and shear zones in the Deoban-Tejam Zone and (iii) their absence from the Krol and other thrusts and faults of the Outer and Sub-Himalayan Zone of Garhwal with the earliest phases of the Himalayan Orogeny which is approximately Upper Cretaceous in age.

5.10 CONCLUSIONS

1. The basic rocks are metamorphosed in conformity with the associated sediments to chlorite and biotite zones and exhibit an increase in metamorphism to garnet zone in the north near the Central Himalaya.

2. The metabasics along the Uttarkashi and Dunda Thrusts and impersistent bodies along the Dharasu Thrust were emplaced during the thrusting movements. The absence of basic rocks from the Tertiary formations and thrusts of Foothills and Sub-Himalayan Zone of Garhwal suggests a possible Upper Cretaceous age for the thrust bound metabasics in the area at the commencement of Himalayan Orogeny.

3. Minor angular discordance in many of the metabasics with country rocks indicate their possible localisation along shear zones.

4. The absence of pillow lavas and typical ophiolitic characters in the metabasics and their emplacement during the thrusting suggest that these were

not contemporaneous with the sedimentation.

5. Many of the thrusts in the area are marked with metamorphism, metabasics or show development of mylonites in contrast to the occurrence of shatter rocks and fault breccia along thrusts of the Foothills and Sub-Himalayan Zone including the Krol Thrust. Possibly the thrusts in the area originated at greater depths than the Krol and other thrusts of the border region.

CHAPTER - 6

SEDIMENTOLOGICAL STUDIES

PART - I INSOLUBLE RESIDUE AND CHEMICAL ANALYSIS OF CARBONATES

6.1 INTRODUCTION

The unfossiliferous carbonates in the Deoban-Tejam Zone comprise limestones, dolomitic limestones, dolomites and magnesites and have been grouped into Deoban Limestone, Shali Limestone (lower and upper) of the Shali Series, Calc Zone of Tejam and Pithoragarh etc. These have been considered equivalent to each other or even with the Krol-Tal Series by the various workers.

In the present area, the carbonate rocks have been classified into Dichli Dolomite, Khattukhal Limestone, Bangaon Limestone and Lower and Upper Uttarkashi Limestone members of the Uttarkashi Formation. The field characters and petrography of these rocks have already been described in Chapter 2. Here the insoluble residue and chemical characters of some of the carbonates are dealt and an attempt is made to find out a possible criterion for their correlation with other carbonates of the Lesser Himalaya. For the purpose, 39 samples from the Dichli Dolomite, Khattukhal Limestone and Upper Uttarkashi Limestone have been studied for their insoluble residues and of these, 26 samples have been partially analysed for their calcium and magnesium contents.

6.2 INSOLUBLE RESIDUE

6.2 -1 PREVIOUS WORK

In the Mussoorie region, Raju and Bhattacharya (1962) have recently confirmed the lithological classification of the Krol Series as proposed by Auden (1934 a). Prakash and Singh (1958) have worked out residue character of the Tal Series in Nilkanth area near Rishikesh, U.P., while some localised studies on insolubles have also been carried out in the Calc Zone of Pithoragarh by Valdiya (1965), Kumar (1967), and Misra and Banerjee (1968).

GRAPHICAL DISTRIBUTION OF INSOLUABLE RESIDUE DATA

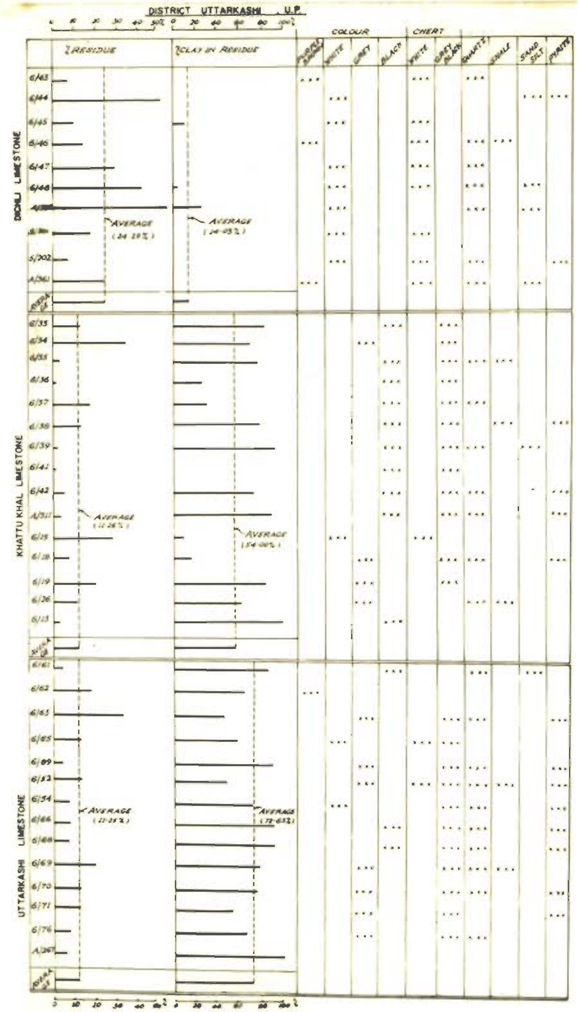


FIG. 64

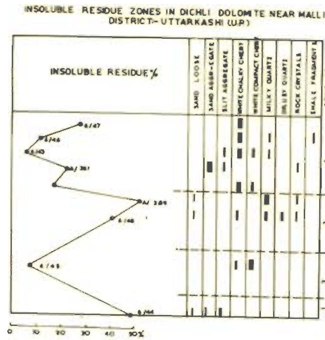


FIG. 65

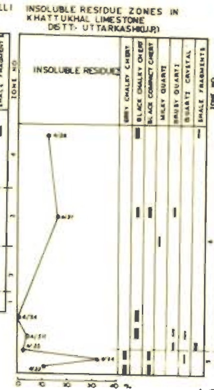


FIG. 66

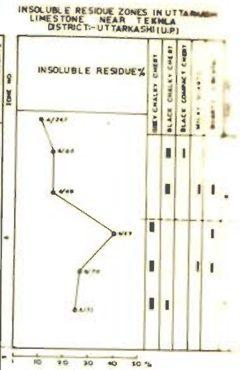


FIG. 67

RELATION BETWEEN MgO/CaO-INSOLUBLE RESIDUE-CLAY CONTENT OF CARBONATE ROCKS, DISTRICT UTTARKASHI, (U.P.)

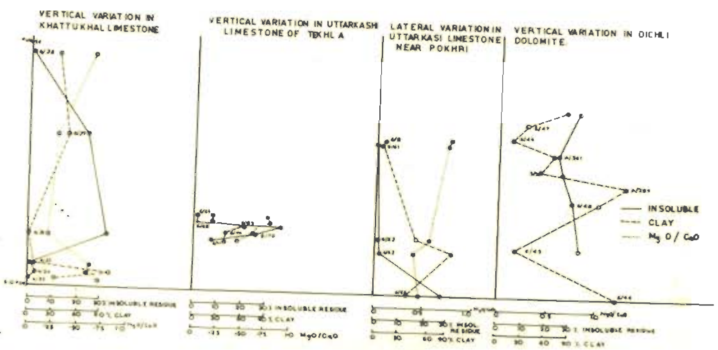


FIG. 71

6.2-2 METHOD OF STUDY

In the present work, the technique of insoluble residue separation described by Ireland (1936) and Twenhofel and Tyler(1941) and terminology of Ireland (1947,1958) has been adopted. In brief, about 10-15 gm. of rock samples has been dissolved in dil.HCl. This has been followed by washing, drying and weighing of the residue. The clayey content is calculated by carefully decanting the finer fraction. The insoluble residue is studied under binocular microscope. A part of the insoluble residue is also studied petrographically. The relative distribution of the insoluble residue is shown in Table 15.Figure 64 presents the data graphically.

6.2-3. DESCRIPTION

General Characters: (i) Colour - The colour of the insoluble residue varies from almost white to grey and black but in a few cases it is even purple, green and brown. The Dichli Dolomite insoluble is predominantly white with occasional shades of light grey and purple, while the residues from the Khattukhal and Upper Uttarkashi Limestones are mostly dark grey and black in colour.

(ii) Percentage - The amount of insoluble residue also varies widely from 0.00 to 52.53% (Fig.,64). The Dichli Dolomite is characterised by higher percentage of insoluble between 6.69 to 52.53% and averages 24.27% while the Khattukhal and Upper Uttarkashi Limestones carry 0.00 to 33.37% and 3.33 to 32.57% with an average of 11.26% and 11.25% respectively.

Arenaceous Material : (i) Detrital sand (loose) - Detrital sand is mostly confined to the lower parts of the Dichli Dolomite and is absent in the insolubles from the limestones. It comprises mainly subangular to well rounded frosted quartz grains varying in size from 0.8 to 0.06 mm. In general, the grains are transluscent to opaque,pitted and ellipsoidal to spheroidal in shape (Fig.207). In thin sections, the margins of grains are embayed and lobed due to the replacement by dolomite(Fig.206). A few rounded and pitted tourmaline grains are also observed.

(ii) Detrital silt (loose) - Subangular to subrounded, moderately sorted and frosted silt size quartz grains are also seen in a few residues of the Dichli Dolomite.

(iii) Aggregates - White and pink coloured, poorly to well consolidated aggregates in a few residues from the Dichli Dolomite consist of subrounded to well rounded frosted quartz, The pink colour is due to iron oxide coating.. In thin sections, the well consolidated fragments show secondary overgrowths of silica which also acts as a cementing material. Sometimes effects of pressure solutions at the grain contacts are noteworthy.

Argillaceous Material:(i) Clay - The clayey fraction in the insoluble residue includes pale-green . birefringent, fine needles of sericite or chlorite. In addition, the clayey portion marks paper black and forms a thin film over the wet residue from the Khattukhal and Upper Uttarkashi Limestones. The average clayey fraction in the insoluble is relatively higher in the Khattukhal and Upper Uttarkashi Limestones than the Dichli Dolomite and is 54.00, 72.63 and 14.03% respectively.

(ii) Shale fragments - Buff, purple, brown and greyish green coloured shale fragments are noticed in a few insolubles. The shale is friable,porous, granular and platy in character.

Quartz -It is ubiquitously present in minor amounts and is characterised by two varieties:(a) small, transparent,anhedral to subhedral rock crystal (b) anhedral, white, opaque, quartz pieces with partially developed pyramidally terminated crystals (drusy quartz).

Chert - Chert is an important constituent in the residue and occurs as (a) hard, opaque, white raised plates as joint fillings, (b) granular, black fragments, (c) white-grey-black, porous, sponge like chalky masses which are most abundant.

Under low magnification, the granular and platy chert display fine grained, polygonal quartz mosaic while the chalky chert is resolvable only in the high magnification and consists of microcrystalline quartz and greenish sericite-chlorite needles.

Pyrite - Small quantity of pyrite is present in the residue from Upper Uttarkashi Limestone and to a lesser extent in the Khattukhal Limestone. It is rare in the Dichli Dolomite. Pyrite occurs as (i) small bronze coloured cubes, pyritohedrons and aggregates, (ii) finely disseminated specks in chert.

Carbonaceous material - It is dark brown to black in colour as exceedingly fine masses and marks paper black.

6.2-4. INSOLUBLE RESIDUE ZONES

The variations in the insoluble residue assemblages, percentage of residue and clayey material suggest that these limestones may possibly be divided into eight possible zones. Their vertical and lateral extension could not be established due to lack of properly exposed stratigraphical sections.

Dichli Dolomite - The stratigraphical section along right bank of the Dichli Gad gives four possible zones in the formation (Fig. 65).

Zone -1 - The lowest zone of the Dichli Dolomite lies above the Quartzite Formation and consists of detrital quartz as loose grains and consolidated aggregates. The residue is about 49%.

Zone 2 - The next zone is low in residue content (about 7%) and consists of white, granular and chalky chert.

Zone 3 - Comprising about 36% residue, the zone is diagnosed by white quartz pieces with minor amount of rock crystal, drusy quartz, white chalky chert and rounded quartz.

Zone 4 - The insoluble in the upper most zone averages 10% and is marked with white chalky chert with minor amount of sand and silt aggregates, white granular chert, quartz and shale fragments.

Khattukhal Limestone - The Uttarkashi road section at milestone 76/0 reveals two possible zones (Fig.66).

Zone 5 - The zone is characterised by grey chalky and black granular chert and yields upto 33% insoluble which consists of 80% of the clayey content.

Zone 6 - The zone contains black chalky chert with minor amount of shale fragments, black granular chert, rock crystal and drusy quartz. The average insoluble is 5% containing 60% clayey material.

Uttarkashi Limestone - The Upper Uttarkashi Limestone member at Tekhla gives 2 possible zones(Fig. 67).

Zone 7 - The lower zone is diagnosed by grey chalky chert with minor amount of black chalky chert, rock crystal and drusy quartz yielding about 15% insoluble having 68% clayey content.

Zone 8 - The upper zone is marked by black chalky chert with 7.7% insoluble containing 92% clayey material.

6.2 -5 DISCUSSION

The importance of work on the insoluble residue in the identification, stratigraphy and correlation of the carbonate rocks cannot be neglected in these complex Lesser Himalayan sequences. A review of the literature indicates that the most extensive work on the insoluble residues has been carried out in the Palaeozoic carbonate sequences of the Interior Basins of the United States between the Appalachian and Rocky Mountains and has contributed much to the stratigraphy and correlation of rock formations (Martin, 1931; McQueen,1931; Hills,1935; Ireland,1936, 1947,1958, Crowley and Hendricks,1945; Grohskopt and McCracken,1949; McCracken,1955; Edwards,1957; Willard,1961; Carpenter and Schmidt, 1962).

Martin (1931) and McQueen (1931) elaborated method of preparation, terminology and application of insolubles in the surface and subsurface geology for the correlation and identification of Palaeozoic sequence in Oklahoma. Hills(1935) has successfully carried out insoluble residue work in the Cambrian-Ordovician rocks and has further subdivided the formations into members. The preliminary work by Willard(1955,1961), Lessentine (1955) and Hills(1935) in the Cambrian carbonates indicates the value of frosted and rounded quartz, shale and black shale fragments,chert,feldspars,silt and clay in the correlation and stratigraphy of eastern Pennsylvania region.

McCracken (1955) applied insoluble residue in the subdivision of Upper Arbuckle Formation of Missoori and southern Kansas into 19 zones and established their regional validity. He based his insoluble residue zones on varieties of residue assemblage, percentage and repetition of their occurrences.

Edwards(1957, in Carpenter and Schmidt,1962) emphasised the quantity of the insoluble residue as an important factor in correlation of the Cynthiana Formation of Ordovician age along the Ohio river,though it was later found as an invalid criterion in the stratigraphy of the region(Carpenter and Schmidt, 1962). The extreme vertical and lateral variability of statistical and qualitative parameters of the light and heavy minerals from the Cynthiana Formation of NE Kentucky make the correlation impossible.

The extensive work on the insoluble residues from thick pre-Mississippian carbonate formations of Oklahoma has indicated its value in correlation of surface and subsurface strata (Ireland,1936). He identified allogenic and epigenic constituents in the insolubles which have elucidated the sedimentation and diagenesis of the sediments. Ireland (1958) emphasised the diagnostic characters of sand and chert which can be differentiated by colour, lustre, transparency and texture. The insoluble residue work has been especially useful in Texas, Kansas, Oklahoma,Illinois, Missoorie and is extensively used in correlating thick Palaeozoic carbonates (Ireland,1958).

In the present area, the Dichli Dolomite markedly differs from the Khattukhal and Upper Uttarkashi Limestones insolubles in the following aspects, though the latter two bear close resemblance with each other:

(i) The Dichli Dolomite contains high insoluble residue percentage and low clayey content. On the other hand, the Khattukhal and Upper Uttarkashi Limestones are comparatively low in insoluble content with high percentage of clayey material.

(ii) The light coloured insolubles, namely white, purplish and greyish are typical of the Dichli Dolomite while dark grey and black residue is obtained from the limestones.

(iii) Detrital quartz and silt are present in the Dichli Dolomite but are found absent from the Khattukhal and Upper Uttarkashi Limestones.

(iv) White, platy and chalky chert is common in the Dichli Dolomite whereas the Upper Uttarkashi and Khattukhal Limestones give a dark grey and black chalky and granular chert.

(v) Pyrite is abundant in the Upper Uttarkashi Limestone and is minor in the Khattukhal Limestone. It is quite rare in the Dichli Dolomite.

Some local investigations of the insoluble residue have been carried out in some of the carbonate sequences of the Lesser Himalaya. Raju and Bhattacharya (1962) have confirmed the validity of . lithological classification of the Krol Series by Auder (1934a) on the basis of the insolubles along Rajpur-Mussoorie mule track. Accordingly, the Krol C,D and E members are characterised by fluorite flooding; detrital quartz and authigenic feldspar; and authigenic chert, mudstone and clayey aggregates respectively. Further, the Krol limestone is very low in the insoluble percentage (Mehta,et al.,1963; Raju and Bhattacharya,1962) in contrast to high percentage of insolubles from the Tal limestone in the Nilkanth area(Prakash and Singh,1958; Singh and Ranhotra,1959).

Valdiya(1965),Kumar(1967) and Misra and Banerjee(1968a)reported authigenic quartz, chert, pyrite and clayey minerals in the carbonates of the Calc Zone of Pithoragarh from Pithoragarh,Ganai and Bageshwar areas. It is noteworthy that the insolubles from the Dichli Dolomite resemble with Gangolihat Dolomite residue. Moreover, the insoluble residues from the present area and Calc Zone of Pithoragarh area higher in percentage in contrast to its low percentage from the Krols and are mineralogically different from the Krols and Tals(Table 16). It should be noted that much more extensive study is needed before any useful regional characteristics may be suggested in the correlation and zonation of these carbonates. The present study,however, indicates contrasting insoluble residues from the Krols, Tals and Deoban-Tajam Zone.

6.2 -6 GENESIS OF INSOLUBLE RESIDUE

The importance and validity of insoluble residues in identification and correlation of the carbonate rocks depend upon the fact that a stratum is characterised by a typical insoluble residue if the clastic conditions, provenance, transportation and sedimentary environment remain constant during its deposition (Ireland,1958). The slight changes in these conditions may not be reflected in carbonate fraction of the rock but will produce a diagnostic insoluble residue to differentiate the stratum from the other.

The genetic relationships of many insoluble varieties appear to be controversial(Ireland,1947,1958).However, the genesis of some of the diagnostic properties e.g., colour,arenaceous material, chert and pyrite of the insoluble residue from the carbonates of the present area are briefly discussed.

Colour - (Fig. 64) indicates a possible correlation between the colours of the residues and its main constituents. The white colour is caused by presence of stable minerals like quartz free of impurities(Weller,1960; p.173) in insoluble residue from the Dichli Dolomite while the light purple shades indicate exceedingly small quantity of hematite (cf., Pettijohn, 1957,p.347).

The insoluble residues from the Khattukhal and Upper Uttarkashi Limestones are characteristically grey or black and impart a similar colour to the rock. Most of the grey and black shades are caused by finely disseminated iron sulphide or carbonaceous matter preserved in the reducing environments(Weller, op.cit., p.173; Carozzi,1960, p.319). A few residues mark paper black thus indicating the presence of carbonaceous matter which along with pyrite appears to have given a dark grey or black colour to the insoluble from the Khattukhal and Upper Uttarkashi Limestones.

Arenaceous material - The arenaceous material in the Dichli Dolomite comprises mainly frosted, rounded to subangular, loose quartz grains and aggregates. The frosted nature of the quartz grains has been attributed to various cause:(i) aeolian action similar to the sand blasts on the glass plates (Weller,op.cit., p.92; Pettijohn,1957,p.70), (ii) scour action in agitated waters (Anderson,1926), (iii) incipient quartz overgrowths (Roth,1932), (iv) pressure solutions along the grain contacts (Heald,1956), (v) differential solution of grain surface by percolating groundwater (Pettijohn,op.cit., p.70) and (iv) marginal replacement of quartz by carbonate minerals (Heald,1956; Walker,1957; Pettijohn, op.cit.,p.70).

Thus, it appears possible that frosted rounded quartz in the Dichli Dolomite had long abrasion history producing spheroidal and ellipsoidal grains which might have been frosted during the transportation. The frosting has been definitely more pronounced due to the marginal replacement of grains by dolomite as observed in many thin sections.

Chert - White granular chert in the Dichli Dolomite residue occurs in thin plates as joint fillings. The source for secondary silicification appears possibly the marginally replaced detrital quartz (Walker,1957) which has supplied sufficient silica in solution to be deposited into joints.

The origin of chalky chert is vague and controversial (Ireland,1936). Black chert occurs as thin streaks and stringers parallel to the bedding planes in the Khattukhal Limestone. In thin sections, greyish microcrystalline chert replaces and merges with fine grained, partially developed calcite rhombs. After the acid treatment, calcite dissolves away and produces chalky chert which sometimes grades to compact granular waxy chert.

Patterson and Von der Borch(1965) reported direct precipitation of chert as opal christobalite gel in the lakes of South Australia. Sievers(1957) opined that the connate water contains silica $Si(OH)_4$ solution which upon crystallisation produces small euhedra and microgranular chalcedonic aggregates in the limestones.

Pyrite - Carozzi(1960, p.346) stated that "microscopic examination of the black limestones shows that the association of pyrite with $CaCO_3$ and with organic matter(represented by carbonaceous residue) is a very general one". The source of sulphide appears to be the nitrogenous content of organic matter under the reducing conditions. In the limestones, he also found an intimate association of pyrite and calcite and indicated that "the formation of pyrite preceded the crystallisation of carbonate or at least

Chemically, the Khattukhal Limestone bears strong resemblance with the Upper Uttarkashi Limestone and differs with the Dichli Dolomite which contain high MgO percentage.

6.4 MAGNESIUM -INSOLUBLE RESIDUE RELATIONSHIP

In recent years considerable attention has been paid to the $\frac{MgO}{CaO}$-insoluble residue relationship and its bearing on the process of dolomitisation. Many studies have shown a direct relationship between high magnesian and high insoluble residue content (Lesley,1879; Steidtmann,1917; Decker and Merritt,1928; Roy, et al., 1955; Chilingar, 1956 a,b; Fairbridge,1957; Bisque and Lemish, 1958,1959; Murray, 1960; Dunbar and Rodgers,1961; Schmidt,1964).

Steidtmann(1917) noticed that the pure limestones and dolomites contain relatively less insoluble residue than the dolomitised limestones which have a higher proportion of the residue. Decker and Merritt(1928) observed higher impurities with a higher magnesian content from Arbuckle Group of carbonate rocks in Oklahoma.

Increasing impurities with a higher magnesian content has been noticed by Roy et al. (1955) from Mississippian rocks of Iowa, Fairbridge(1957) and Dunbar and Rodgers(1961, p.223-224) plotted data published by Lesley (1879) and suggested an increasing tendency in the insoluble residue percentage with higher $MgCO_3$ for a section of Ordovician rocks of Pennsylvania.

Chilingar(1956 a) demonstrated a high insoluble-dolomite relationship and suggested high $\frac{Ca}{Mg}$ ratios with higher percentage of chert,stringers and nodules in the limestones but this data do not represent $\frac{Ca}{Mg}$ - insoluble residue relationship (Chilingar,1956 b).

Bisque and Lemish(1958) related the magnesian content with insoluble residue percentage and established a high insoluble-high magnesium relation in Devonian Cedar Valley Formation as well as in the concrete aggregates of carbonate rocks. Bisque and Lemish(1959) observed the presence of illite,chert and pyrite in the insoluble,though a relationship between clay minerals and insoluble has not been studied. Similarly Folk (in Hatfield and Rohrbecker,1966) established a higher average insoluble content in the more dolomitic beds of the Axemann Formation in Pennsylvania.

Similar studies by Murrary (1960) in the Charles Formation (Mississippian) at Saskatchewan demonstrate that a high insoluble percentage containing large amount of silt and clay size quartz(not clay minerals) is associated with higher dolomite percentage. Schmidt(1964) also noticed an increase in dolomite content in the Gigas beds(Jurassic) of Germany towards the northern boundary of Saxony Basin and correlated it with increasing clay content. An increase in magnesian content is recorded towards the top of a dolomitised horizon succeeded by shales in a Devonian reef in Ludec oil field (Waring and Layer,1950).

On the contrary, Goldich and Parmalee(1947) reported a complete lack of insoluble-dolomite relationship in the Ellenburger Group (Ordovician) in Central Texas and a similar lack of relationship has also been noticed by Zenger(1965) in the study of the Lockport Formation (Niagran) in New York. Hatfield and Rohrbecker(1966) also recorded a complete lack of dolomite/calcite ratio with quality or quantity of insoluble residue throughout the Devonian Ten Mile Creek Dolomite of NW Ohio.

A detailed examination of the published literature also indicates a lack of any established relationship between high magnesian content and clay minerals The high magnesian-high insoluble percentage as described earlier does not necessarily indicate a corresponding high percentage of clay minerals in the insoluble (Hatfield and Rohrbecker,1966). The possibility of clay minerals providing the necessary magnesian ions for the transformation of limestones to dolomites has been elaborated by Parkers(1957), Zen (1959) and Kahle(1965). The possible mechanism for the transfer of magnesian ions appears to be

RELATION BETWEEN Mg (AS MgO) %. INSOLUBLE RESIDUE CONTENT FROM UTTARKASHI AREA

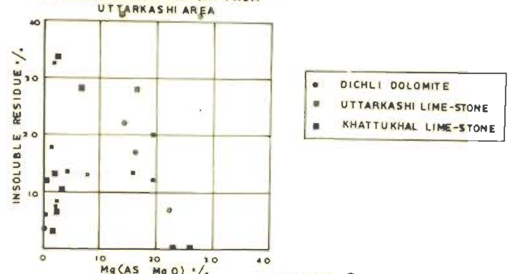


FIG. 68

RELATION BETWEEN INSOLUBLE RESIDUE AND CLAY CONTENT FROM UTTARKASHI AREA

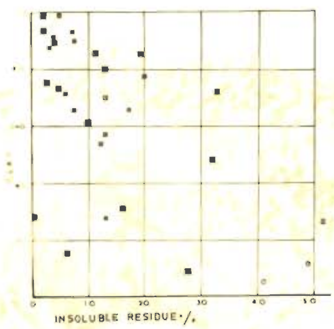


FIG. 69

RELATION BETWEEN Mg (AS MgO) % AND CLAY CONTENT (% RESIDUE) UTTARKASHI AREA

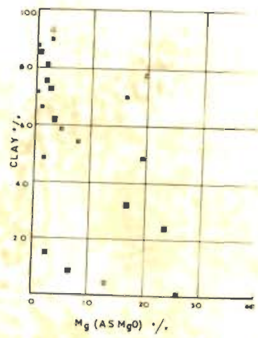


FIG. 70

RELATION BETWEEN Mg (AS MgO)% OR MgO/CaO & INSOLUBLE RESIDUE OF DOLOMITES & LIMESTONES FROM DIFFERENT FORMATIONS OF LESSER HIMALAYA.

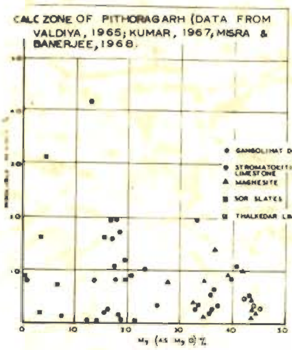


FIG 72

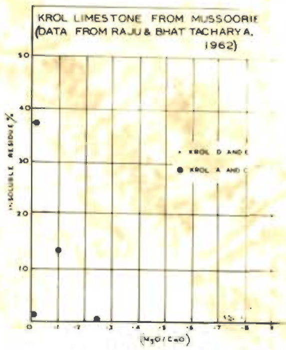


FIG. 73

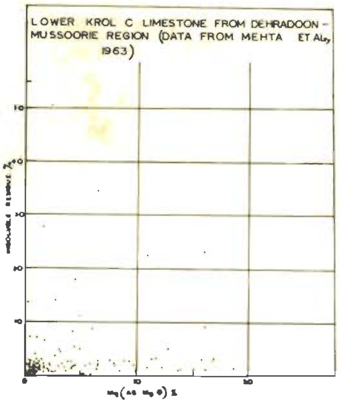


FIG. 74

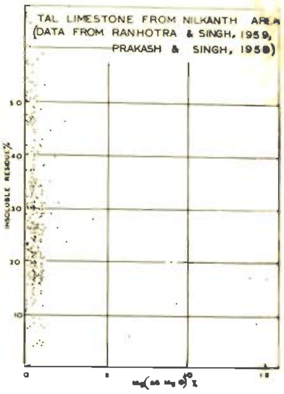


FIG. 75

(i) ionic exchange of magnesium from magnesian bearing clay minerals(Zen,1959; Kahle,1965), (ii) clay minerals acting as semipermeable membranes to impede migration of magnesian ions and (iii) to act as nucleus for crystallisation of dolomite(Kahle 1965). This possibility means an association of higher clay content with high dolomite content to provide necessary magnesium for the formation of dolomite.

The present work on the carbonates of the Uttarkashi district clearly indicates lack of correlation between high insoluble-high magnesium content(Fig. 68) Moreover, a high clayey content and low insoluble residue percentage(Fig. 69) and low MgO - high clayey content in the insoluble (Fig. 70)are suggestive from this study. Fig.71 shows lateral and vertical variation between $\frac{MgO}{CaO}$ - insoluble residue and clayey content in the residue from the different sections.

6.4-1 OTHER AREAS OF LESSER HIMALAYAS

Some localised data on the chemical and insoluble residue studies are now available from Calc Zone of Pithoragarh (Valdiya,1965; Kumar,1967; Misra and Banerjee, 1968a),Krol limestone (Raju and Bhattacharya,1962; Mehta et al.1963) and Tal limestone (Prakash and Singh,1958; Singh and Ranhotra,1959)(Figs.72,73,74 and 75). The plotting of the available data on MgO and insoluble residue indicate that the Calc Zone of Pithoragarh,like the carbonates of the present area shows a complete lack of any relationship between MgO - insoluble residue percentage (Fig. 72) and it appears possibly to be characteristic of the carbonates from this inner sedimentary Deoban-Tejam Zone.

Raju and Bhattacharya (1962) reported an appreciably low insoluble residue in the highly dolomitised Krol D and E members of the Krol limestone (Fig. 73). A similar study of the Krol C member by Mehta, et al.,(1963) from the Mussoorie area gives very low insoluble residue percentage in the limestones or slightly dolomitised rocks (Fig.74). The Tal limestones ,on the other hand, contain high insoluble residue averaging about 30% and are characterised by exceedingly low MgO percentages (Fig. 75) (cf. Prakash and Singh, 1958; Singh and Kanhotra, 1959).

6.5 CONCLUSIONS

The present study deals only with a few chemical and insoluble residue data and should be carried out more extensively in other carbonate sequences of the Lesser Himalaya before any regional correlation and zonation is attempted. However, this study brings to notice the following worth mentioning characters:

(1) The chemical and insoluble residue characters of the Khattukhal and Upper Uttarkashi Limestones resemble with each other and may hence suggest a possible correlation. On the other hand, the Dichli Dolomite differs petrographically as well as in chemical and insoluble characters but resembles more with the Gangolihat Dolomite of the Calc Zone of Pithoragarh.

(2) The carbonates of the present area do not show any relationship between insoluble residue and magnesium content, like the carbonates from the Calc Zone of Pithoragarh. This may probably be characteristic of carbonate sequence of the Deoban-Tejam Zone.

(3) The analysis of data from the Krol and Tal limestones of the Simla-Krol Belt from some localities indicates that the Krol C member is characterised by low MgO-low insoluble residue percentages. The Krol D and E members give a high MgO - low insoluble residue percentages. On the other hand, the Tal limestone show high insoluble-low MgO percentage.

(4) The study indicates that the insoluble residue-magnesian relationship in carbonate sequences of the Lesser Himalaya is characteristic of the individual formation and should be confirmed on the regional basis. This may possibly form an important criterion in correlating these unfossiliferous and complex carbonate sequences.

PART - II HEAVY MINERALS

6.6 INTRODUCTION

The accessory heavy minerals(specific gravity greater than bromoform, 2.85), though rarely exceeding 1 to 2 percent of the total constituents in a sandstone, have been extensively used in solving a variety of problems. The sensitivities of the heavy mineral associations to the geological processes have contributed to the stratigraphical identification,classification and correlation of horizons, tracing the tectonic history of source and depositional areas,palaeogeographical conditions and petrogenic characters of the source rocks (Milner,1962).

The heavy minerals have been particularly useful in the post-tectonic molasse type of sediments viz., Siwalik System of the Himalaya. Though the other Tertiary formations in Outer and Lesser Himalayas have recently been locally analysed for their heavy mineral suites, the data is almost lacking from the pre-Tertiary formations.

In the following pages, an attempt has been made to work out systematically the qualitative,quantitative and statistical parameters of heavy minerals from the formations of the area.

6.7 METHOD OF STUDY

In recent years some workers have successfully carried out heavy mineral investigations by simply crushing the rock samples(Henningsen,1963; Stanley,1964, 1965). A reduction in the heavy mineral accuracy has been noted for flysch type of sandstones(Stanley, op.cit.). However, the quantitative data on crushing of various indurated sandstones, especially the orthoquartzites indicate that it is an easy method and the results of heavy mineral analysis approximately represent their actual distribution (Henningsen,1967).

31 quartzite samples from the Quartzite Formation of both the northern and southern belts in the area have been selected for the heavy mineral separation. The framework of quartz grains in these quartzites is bounded by thin coating of micaceous minerals, silica cement and interlocking of margins thus rendering most of the disintegration methods ineffective. Vertical pressure of mortar and pestle is found to be more useful than rotary motion in crushing the samples. Utmost care has been taken to avoid powdering of the samples. Approximately 20 - 30 gm. of crushed sample is passed through 40 mesh sieve to remove the coarser particles. The sieved fraction is carefully decanted before boiling with dil.HCl and stannous chloride to remove impurities like iron oxide and clayey coating over the grains. The heavy mineral residue is then obtained by ordinary bromoform liquid separation and is mounted in the canada balsam. The heavy mineral studies include:

(i) Qualitative examination of the residue.

(ii) Counting of nonmicaceous- nonopaque heavy mineral grains.

(iii) Micrometric measurement of length and breadth of all tourmaline and zircon grains present in the 31 heavy mineral slides of the Quartzite Formation from the area. Besides, the grain size data for quartz, zircon and tourmaline have also been obtained from many thin sections of all the non-calcareous sedimentary rocks including the Quartzite Formation. 30 to 50 undeformed quartz grains per thin section are generally measured.

(iv) Regional distribution and stratigraphical variability of important mineral species, namely zircon and tourmaline. For this purpose, 14 more samples of the southern Quartzite Formation belt from the Bhillangana valley and Rudraprayag - Srinagar area have been quantitatively studied for their nonmicaceous-nonopaque heavy mineral fraction. The study also includes 2 samples (A/131, A/184) from the Bhagirathi valley and 3 samples(A/162,A/151,A/165) from the Yamuna valley of the northern belt from outside the defined limit of the area.

6.8 HEAVEY MINERALS

6.8-1 OPAQUE MINERALS

The opaque heavy minerals include pyrite and leucoxene. Pyrite is present in many samples and is authigenic in character. It generally occurs as euhedral cubes and rectangular crystals. A few grains are also angular and corroded. Many show orange limonitic coating. Leucoxene is rounded and yellowish white in reflected light.

6.8-2 NONOPAQUE- NONMICACEOUS MINERALS

(1) Tourmaline - (i) It has been subdivided into the following five varieties based upon their maximum absorption:

Z	X
Blue	Colourless, light blue, pink.
Green	Pale green, pale brown.
Brown	Pale green, yellow.
Pink	Light pink, colourless.
Black	Dark brown, opaque.

The opaque tourmaline can easily be identified by their black or dark brown non-metallic lustre in the reflected light. The difference between green and brown tourmaline is sometimes difficult in the transmitted light. Strong condensed light has been used for identifying colour of maximum absorption in such cases.

(ii) The tourmaline grains vary in length from 0.07 mm. to 0.42 mm. (average 0.15 mm.) and from 0.03 mm. to 0.30 mm. in breadth (average 0.08 mm.).

(iii) The following three habits of tourmaline have been distinguished:
(a) rare, prismatic, euhedral crystals with single terminated pyramids(Fig.183), (b) perfectly rounded, globular to ellipsoidal grains and are most common (Figs.185& 186), (c) rare irregular and anhedral crystals with rounded edges (Fig. 180).

(iv) In texture, most tourmaline grains are devoid of any imperfections and exhibit smooth rounded surfaces (Fig.185).However, a few anhedral grains show subconchoidal fractures (Fig.180). Rarely an imperfect cleavage and basal parting are also noticed (Fig.179).

(v) In thin sections, a few grains are highly fractured and displaced along irregular planes but the overall grain shape is still preserved. The fractures are filled with quartz.

(vi) A few grains also develop pitted and corroded surfaces due to intra-stratal solution at contacts with other minerals.

(vii) Most of the tourmaline grains are free from any inclusions. In a few grains, the common type of inclusions are (a) globular and elongated cavities sometimes marked with coloured walls extinguishing along with the grains (Fig. 178), (b) needle-shaped microlites of nonbirefringent mineral(locally abundant) (Fig. 182). A few grains contain abundant cavities and microlites (Figs.187& 188) but the others commonly have only 2 -3 such inclusions.

(viii) Delicate overgrowth of colourless to very faint bluish, pleochroic tourmaline is common (Figs.181 ,184 ,186 & 188). The growth is about 0.06 mm. on an average but rarely exceeds even to 0.16 mm. The overgrowth is invariably at one end of the grains and has been noticed upon all coloured varieties of tourmaline.

The overgrowths sometime even cover half of the grain and comprise of frilled margins interwoven with quartz of the matrix (Figs. 184 &186). Commonly, it has sharp margins with the grains but sometimes overgrowth has a gradation zone (Fig. 181). Worn overgrowth of bluish colour has been rarely observed over very few grains.

(2) Zircon - (i) In transmitted light, zircon is colourless, yellowish brown and pink in colour. Opaque black malacon zircons are not met with while the pink hyacinth zircon is very rarely represented in the heavy mineral suite.

All the coloured varieties are cloudy, milky white,transluscent to opaque in the reflected light.

(ii) In length, zircon varies from 0.04 mm. to 0.43 mm. while the breadth ranges from 0.03 to 0.28 mm. The coarsest varieties are generally rounded cloudy zircons.

(iii) The shape of zircon varies from perfectly globular and ellipsoidal grains (Fig. 193), to prismatic euhedral grains (Fig.195). Most of the euhedral grains show varying degree rounded edges between the prismatic and pyramidal faces (Figs. 195&192). Only rarely the euhedral grains show no abrasion (Fig. 195) The euhedral zircons are characterised by elongated (100) and (110) prisms with obtuse dipyramids(111) (Figs.189,195 &196)and only rarely with (001) faces. Most euhedral zircons are doubly terminated (Figs.195&196) but singly terminated pyramids are not uncommon. Further, both the dipyramidal faces may be equal in length as well as have a longer face than the other (Figs.192,195&196).

(iv) A few elongated rounded and prismatic zircons show fractures which in some grains are oriented normal to prismatic faces as basal partings(Fig.194).

(v) A large number of rounded and prismatic zircons appear turbid and brownish in transmitted light. Invariably all the coloured varieties show clouding. In reflected light it is more contrasting as turbid, milky white, transluscent to opaque portions. Many grains are uniformly clouded while others are partially clouded, more so along the fractures.

(vi) Many unidentifiable inclusions are present in zircons. These are
(a) colourless, globular and ellipsoidal cavities (Figs.184,190 &191),
(b) elongated and needle shaped microlites of zircon, quartz and other birefringent minerals.

(vii) Rarely zircons show well preserved corroded margins.

(viii) While only a very few grains show overgrowth phenomenon, none exhibits outgrowths. The overgrown material is colourless to pale brown and lighter in colour than the core and is free from any inclusions. The overgrowth tends to form euhedral crystals. The growth has generally taken place over darker rounded zircon core which varies from elongated ellipsoidal to globular in shape. Rarely it is euhedral prismatic with sharp edges. In a few grains the overgrowth takes place by successive addition of material of lighter and darker material producing characteristic zoning (Fig. 189).

(ix) In the present work, the following varieties of zircon are identified on the basis of shape and transparency: (a) colourless rounded zircon, (b) colourless prismatic zircon, (c) cloudy rounded zircon and (d) cloudy prismatic zircon.

(3) Rutile - . It is mostly yellowish brown to reddish brown and occurs as rounded equidimensional to elongated prismatic grains. Rarely faint pleochroism into yellowish and reddish tinge is noticed.

(4) Staurolite - It is colourless to straw yellow and is faintly pleochroic Occurring in a few samples, the grains are generally subrounded, equidimensional and exhibit patchy extinction. A few inclusions of iron oxide and rutile(?) needles have also been noticed.

(5) Andalusite - It has been observed in one sample. It occurs as subhedral, and subrounded colourless grains with numerous carbonaceous inclusions.

(6) Kyanite - Colourless, elongated, prismatic kyanite appears in a few samples. The grains show two sets of prominent cleavages at right angles and are rounded along the edges. The extinction varies from 0-30°.

(7) Garnet - Colourless and pink anhedral garnet has been noticed with many quartz and other unidentifiable mineral inclusions. The grains have rounded edges and show many conchoidal fractures (Fig. 191).

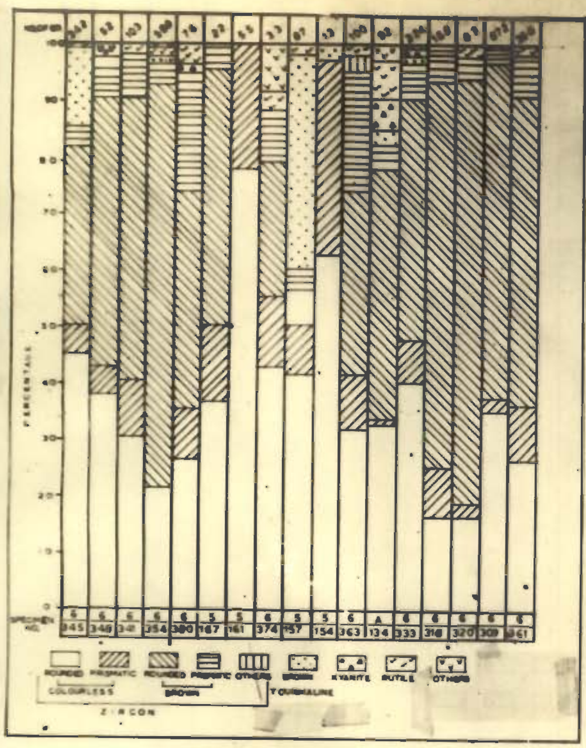


FIG. 76

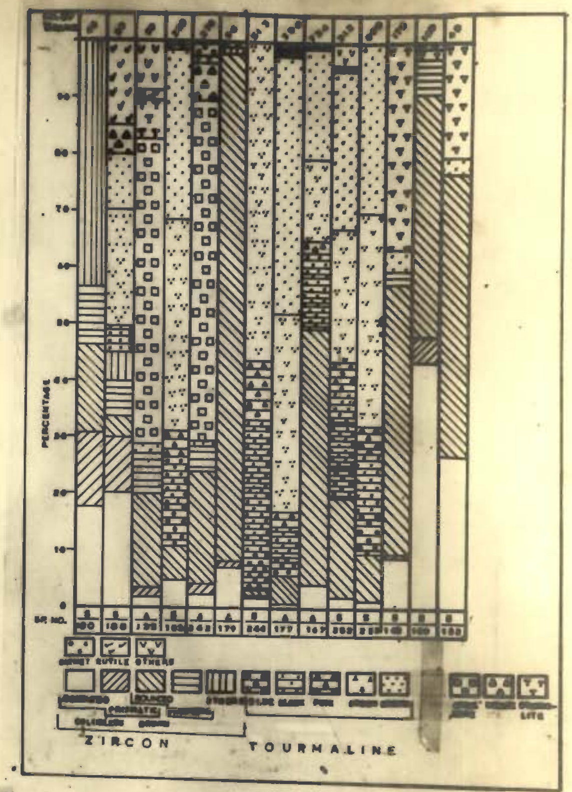


FIG. 77

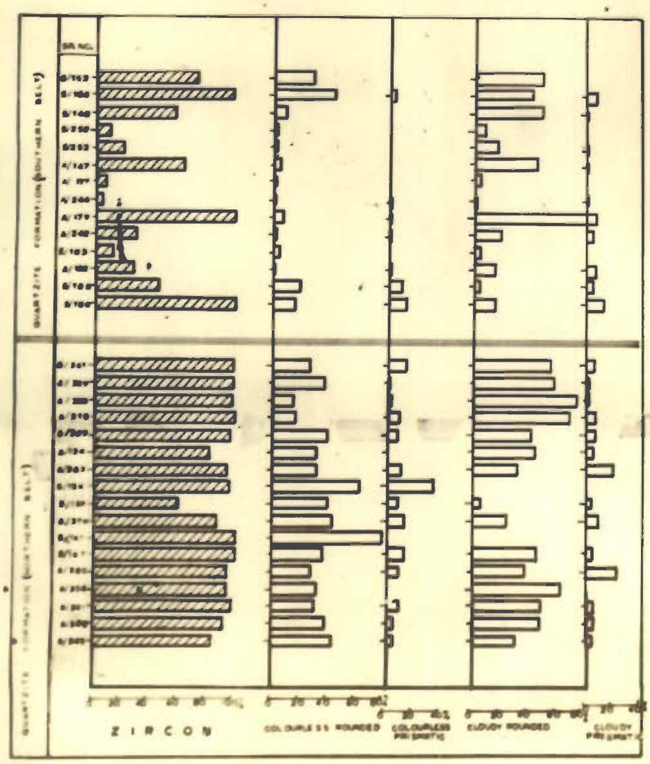


FIG. 78

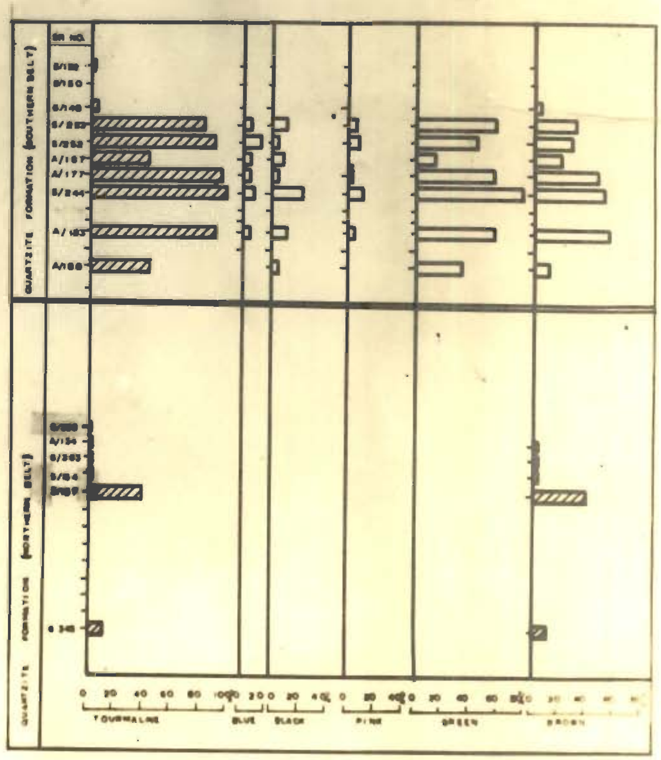


FIG. 79

(8) Other minerals - Some of the thin sections of the Quartzite Formation contain rounded apatite grains which appear to have been digested during acid treatment. Rounded apatite, tourmaline and zircon varieties have also been observed in the Uttarkashi, Dunda, Dharasu, Laluri, Chandpur and Nagthat Formations during their routine petrographic studies. In addition to these, rounded hematite, magnetite and epidote chracterise the Dharasu Formation.

6.9 RESULTS OF HEAVY MINERAL STUDY

Based upon percentage by number, Tables 18 and 19 summarise relative abundance of the heavy minerals in the Quartzite Formation from the northern and southern belts respectively. The last column represents ZTR or resistent index (total percentage of zircon, tourmaline and rutile)as defined by Hubert(1962).

A series of histograms have been drawn to represent heavy mineral data graphically. From their study, the heavy mineral characteristics of the two Quartzite Formation belts have been discussed with the aim to find out whether the heavy minerals can form a basis for differentiating otherwise similar quartzites. The results may not be definite since only 31 samples have been analysed from relatively large outcrop in the area, but are strongly suggestive because of heavy mineral studies of additional samples from the adjoining areas.

The nonmicaceous-nonopaque fraction of the heavy minerals comprises mostly of zircon and tourmaline of different varieties (Figs 76 & 77). In general, while zircon is about 90% on an average in the northern belt, it decreases to 45% in the southern belt. On the other hand, tourmaline increases from 5 to 44 % in the southern belt. These differences are more apparent when studied individually.

6.9 -1 Zircon (Fig.78) - The percentage of total zircon is significantly higher in the northern belt than southern belt of the Quartzite Formation. It is generally above 75% of the fraction and even reaches to 99% in many samples. Out of 17 samples from the northern belt, only 2 samples have zircons below 70%. On the other hand, it is impersistent in the southern belt and varies considerably from 3 to 98%. Of the 14 samples, as many as 10 separations contain zircons below 70%.

Although rounded colourless zircon has been recorded in all the samples of quartzites, it is relatively abundant in the northern belt and averages 36% while it decreases to 10% in the southern belt. Many quartzite samples from the south contain less than 5% of rounded colourless zircon. Similar relations persist for the rounded cloudy zircon though its amount is higher (30%) than the colourless variety (10%) in the southern belt.

Both colourless and cloudy prismatic varieties of zircons deplete in abundance to 1.5% in the southern belt from 7.5% in the north. The distribution is also irregular in the southern belt because of dropping out prismatic zircons in many samples. The relative abundance of each variety seems to be typical of both the belts and suggests a possible criterion for differentiating two belts of the Quartzite Formation.

6.9 -2 Tourmaline (Fig.79) - The northern belt is marked impersistently with subangular brown tourmaline which even exceeds to 63% (sample A/165). Of the 22 samples including those from outside regions of the Bhagirathi and Yamuna valleys, the brown variety has been recorded in 11 separations but its percentage is below 3% in most samples. Brown tourmaline is more than 13% in only 3 samples and is subangular in the northern quartzite belt in comparison to its well rounded globular to ellipsoidal character in the southern belt. Of the 14 samples from the southern belt, brown tourmaline is present in 10 separations and varies in amount from traces to 46% but most of the samples contain more than 15%. The type of brown tourmaline and its higher percentage are significant.

Unlike the brown tourmaline, the green variety is restricted mainly to

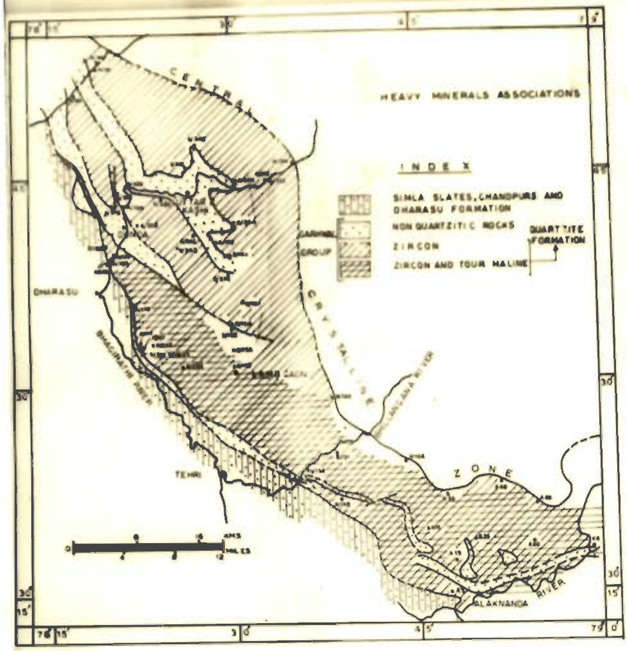


FIG. 80

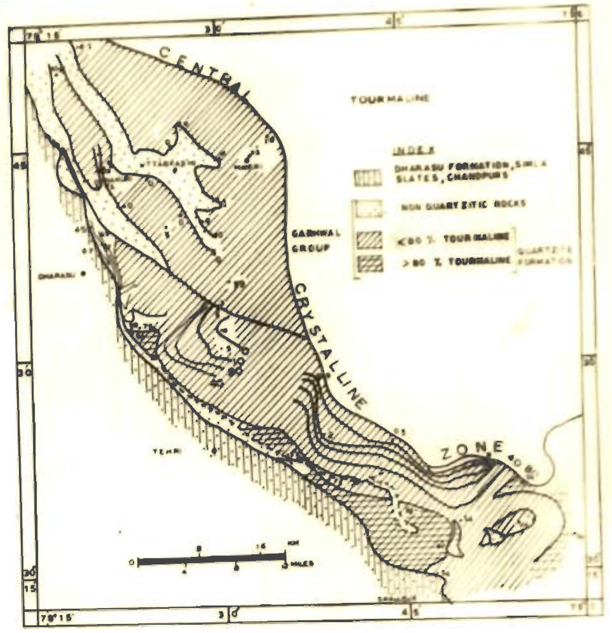


FIG. 81

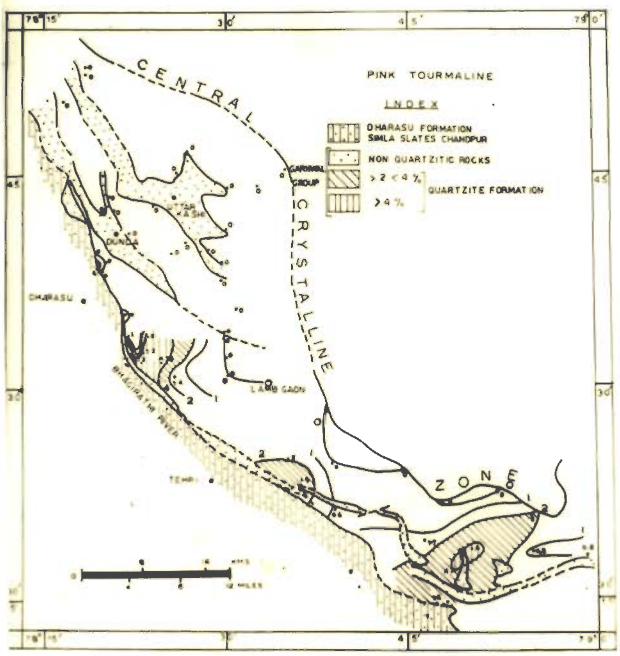


FIG. 82

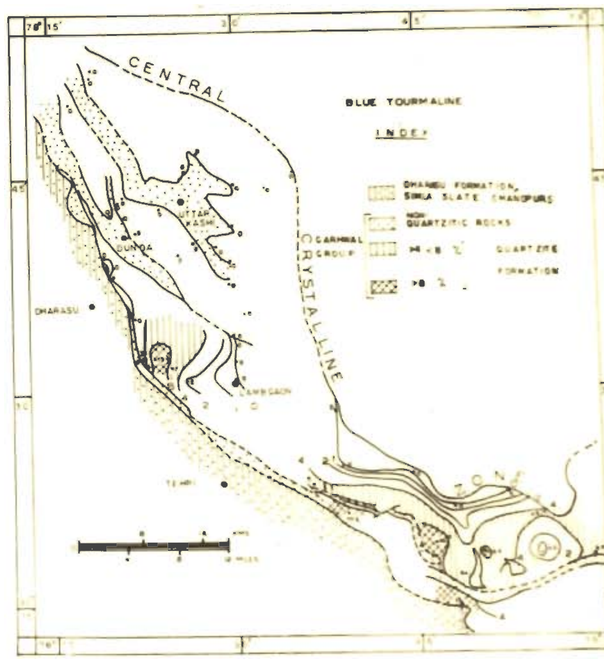


FIG. 83

the southern belt and amounts to 1 - 38% of the fraction. On an average it is 15% and equals brown tourmaline in percentage. Green tourmaline has been noticed in 9 separations of the southern belt.

Although pink tourmaline is present in 7 samples of the southern belt, it never exceeds 11% and is normally much lower (2.3% on an average). Blue and black tourmalines, like the pink variety are confined to the southern belt. Thus pink blue, black and green tourmaline are typical of the southern Quartzite Formation belt.

6.9 -3 Other minerals - Staurolite and garnet, though make up a very small fraction of the heavy mineral suite of the southern belt, are suggestive of minor differences. Staurolite is totally absent while garnet is present only in one sample from the northern belt. Rarely flooding of andalusite is noticed in one sample of the southern belt quartzites. Kyanite and rutile are more or less uniformly distributed.

6.10 REGIONAL DISTRIBUTION AND STRATIGRAPHICAL VARIABILITY

The regional distribution and stratigraphical variability of important heavy minerals are more apparent when plotted on maps (Figs.80 to 87). The following heavy mineral associations have been noted in the Quartzite Formation (Fig. 80):

(i) A northern zone characterised by the predominance of zircon, comprises whole of the northern belt and basal parts of southern belt mainly along the Singuni and Main Central Thrusts.

(ii) A southern zone consisting of zircon and an increasing amount of tourmaline occupies the large part of the southern belt outcrop.

For deciphering any systematic regional distribution of important minerals, the relative percentages of tourmaline and zircon of the two associations have been plotted by means of isolines whose value increase in geometrical progression (Figs. 81 to 87). For the purpose, the samples from the adjoining regions have also been incorporated in the study for better regional patterns.

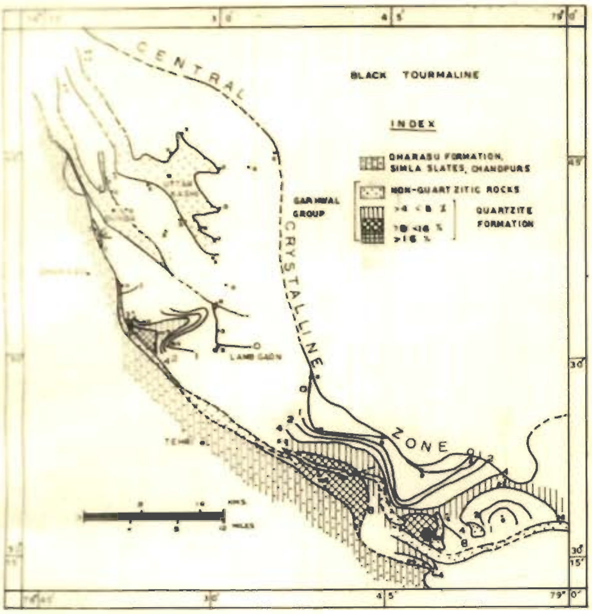


FIG. 84

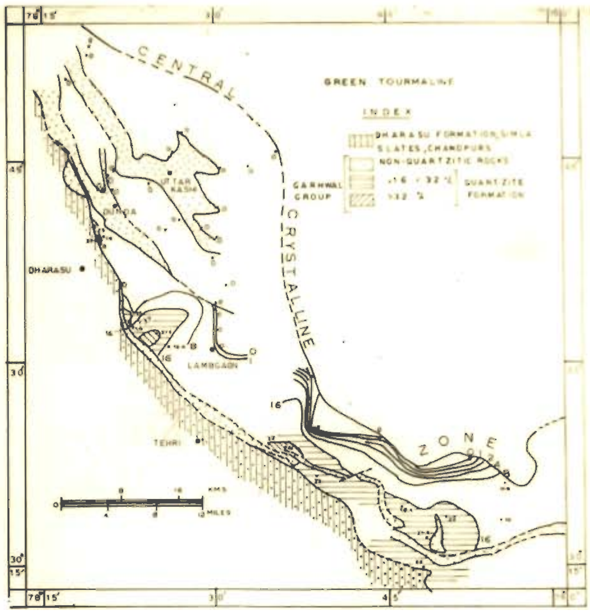


FIG. 85

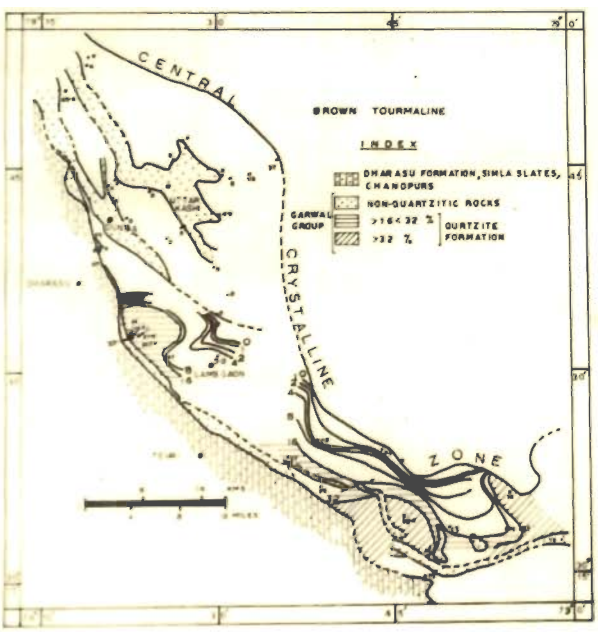


FIG. 86

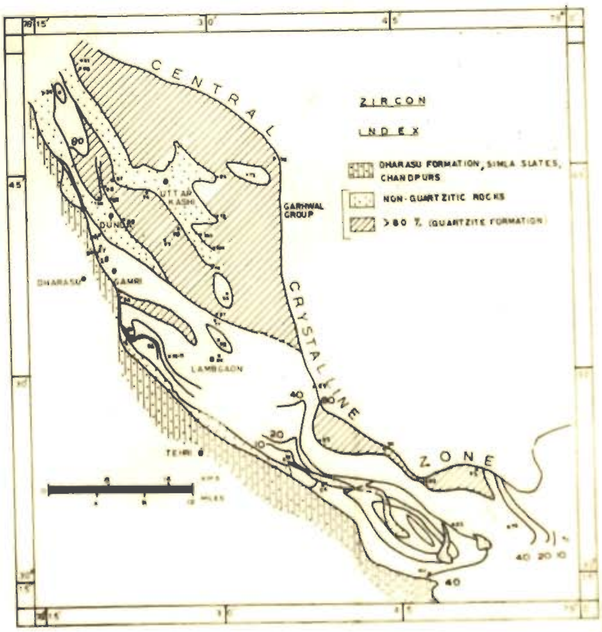


FIG. 87

Tourmaline gradually increases from 0 to more than 80% from northeast to southwest in the southern belt (Fig. 81). Near the Dharasu Thrust and Dichli Dolomite, the quartzites generally contain more than 80% tourmaline in the present area and also in Bhillangana-Rudraprayag regions(samples S/183, S/244, S/252, S/734,D11, A 15). However, a decrease is noted southeast of Gamri (sample A /179) while the tourmaline percentage again increases along the Mandakani valley (sample C4).

The distribution of zircon also presents distinct patterns (Fig.87). Most of the northern belt samples contain more than 80% zircon except samples A/131, A/165.and S/157 . While basal quartzites of the southern belt are rich in zircon, a gradual decrease in its percentage is evident from northeast to southwest, near Srinagar (samples D11,A15) and eastward along the Mandakani valley (sample C4).

Regional distribution of the 5 tourmaline varieties has been graphically studied in the southern belt of the Quartzite Formation. Like the tourmaline group, each variety presents distinct distributive patterns with a general increase in their percentages towards southwest in the stratigraphically younger horizons. Pink tourmaline, though minor in amount, increases from 0 to 8% towards south and west along the Dichli Gad(Fig. 82). Similarly the blue and black types increase in the southwest (Figs. 83 & 84). Their percentages are more than 8 and 16 along the Dharasu Thrust respectively. Brown tourmaline presents a more clear picture and is more than 32% along the Uttarkashi road (sample S/183), Dichli Gad (sample A/177) and near Srinagar (samples D 11, A 15) (Fig.85). An eastward increase in the brown variety is noticed along the Mandakani Valley (samples C 40, C 4). Green variety shows a more or less similar pattern with maximum concentration (32%) along the Bhillangana valley and Dichli Gad (Fig.86). It may be noted that distributive pattern of the tourmaline group is largely influenced by variability in the brown variety (Figs. 81 & 86).

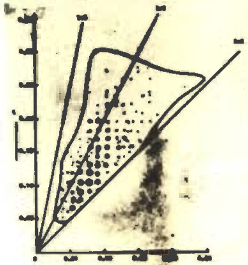
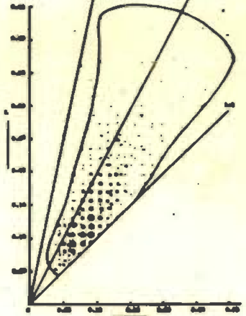


FIG 88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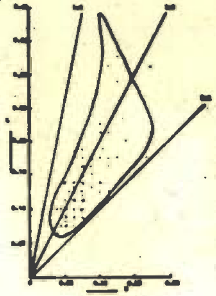


FIG. 90


FIG 91


FIG. 92

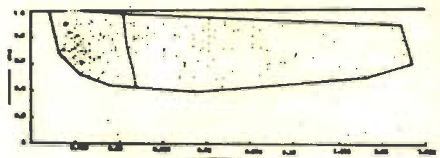
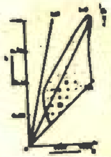


FIG. 93


FIG. 94


FIG 108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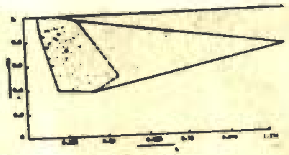
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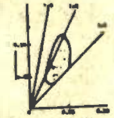
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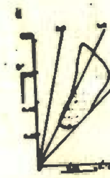
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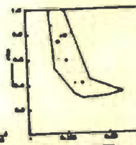
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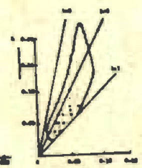
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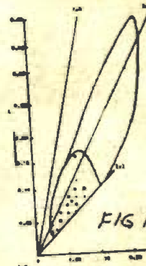
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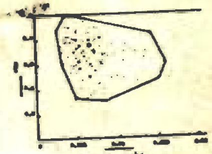
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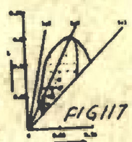
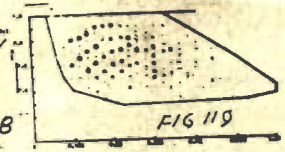


FIG 117


FIG 118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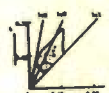
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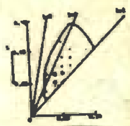
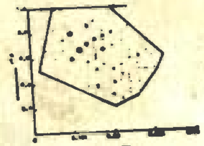


FIG 121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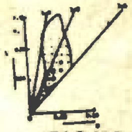


FIG 123

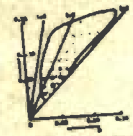


FIG 124


FIG. 125

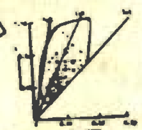


FIG 126

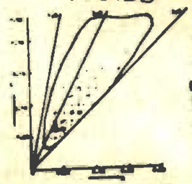


FIG. 127


FIG. 128

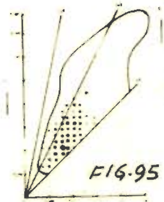


FIG. 95

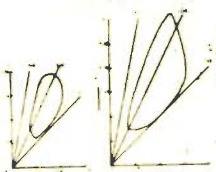


FIG 96 FIG. 97

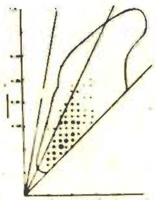


FIG. 98

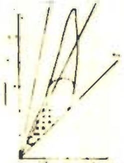


FIG. 99


FIG. 100


FIG. 101


FIG 102

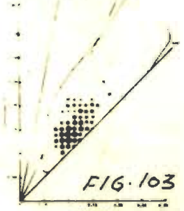
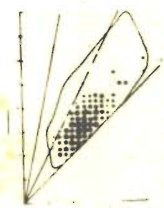


FIG. 103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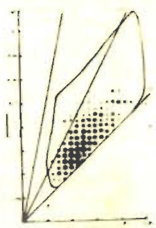
FIG 105

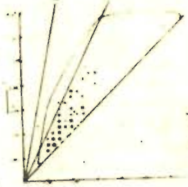
FIG. 106

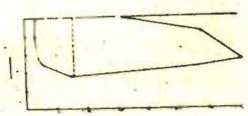
FIG. 107

Similar distributive patterns with isoline maps for different zircon varieties and garnet have also been attempted. Their patterns are irregular and no linear progression has been noted.

6.11 STATISTICAL ANALYSIS OF GRAIN SIZE OF HEAVY MINERALS AND QUARTZ

The grain size data of important resistant minerals viz., quartz, zircon and tourmaline from the thin sections and heavy mineral separations have been statistically studied with the help of Smithson and Haggermann diagrams (cf., Smithson, 1939). The characters of these curves have been briefly described below:

6.11 -1 Quartzite Formation (Northern Belt) - The rounded colourless zircon from the northern Quartzite Formation belt, varying from 0.04 to 0.30 mm., is generally less than 0.14 mm. in length. The catena of the Smithson diagram lies flat on 1:1 line with a relatively few grains showing higher elongation and none as much as 1:5. Majority of the grains are between 1:1 to 1:2 in ratio (Fig. 88). In comparison,. a few rounded cloudy zircon grains are coarser (0.43 mm. in length) though like the colourless rounded varieties, most grains are less than 0.14 mm. in length. The catena of the diagram is flat upon 1:1 line with most of the grains below 1:2 ratio (Fig.89).

The prismatic colourless zircon varies in length from 0.05 to 0.39 mm. The catena does not lie upon 1:1 line and encloses many grains nearing 1:5 elongation ratio (Fig.89). In length, the prismatic cloudy zircon is shorter than its colourless counterpart. The ovoid shaped catena is not flat and contains nearly 35% grains between 1:2 and 1:5 (Fig. 91). The zircon characteristics from the northern belt closely resemble rounded cloudy variety with similar shape of the catena and distribution of the grains (Fig. 92). The zircons are on an average 0.09 to 0.16 mm. in length and 0.06 to 0.11 mm. in breadth.

The bimodal character of quartz is clear from the Haggermann diagram (Fig. 93).The finer quartz is 0.09 to 0.39 mm. in length while the coarse grains vary from 0.43 to 1.66 mm. The B/L ratio is greater than 0.6 for many grains thus indicating a tendency towards higher sphericity and roundness.

6.11-2 Quartzite Formation(Southern Belt)- The rounded colourless zircon varies from 0.06 to 0.23 mm. with most grains falling below 0.15 mm. in length. The catena lies flat on 1:1 line with only 10% grains exceeding 1:2 elongation ratio (Fig. 94). On the other hand, rounded cloudy zircon ranges considerably from 0.04 to 0.39 mm. in length. The catena lies flat on 1:1 line with most grains falling below 1:2 elongation ratio but about 6% grains exceed 1:2 and none reaching 1:5 (Fig.95). The prismatic colourless zircon grains fall within an oval shaped catena with length ranging from 0.06 to 0.19 mm.(Fig.96). The length of the prismatic cloudy zircon grains varies from 0.06 to 0.30 mm. The catena is elongated with 20% grains having 1:2 to 1:5 elongation ratio (Fig. 97).

The zircons from the southern belt subscribe an elongated catena lying flat upon 1:1 line. The shape is largely governed by rounded cloudy zircon. A large number of zircons are generally 0.09 to 0.15 mm. in length and 0.06 to 0.10 mm. in breadth(Fig. 98).The thin section measurement of zircon reduces its grain size considerably. The length varies from 0.03 to 0.30 mm. but is generally less than 0.09 mm. (Fig. 99).

The length of the pink tourmaline grains varies from 0.08 to 0.31 mm. with most of them lying between 1:1 and 1:2 ratios. The catena of the Smithson diagram lies flat upon 1:1 line (Fig.100). The catena for the blue tourmaline also lies flat upon 1:1 line and contains most grains below 1:2 ratio(Fig.101). The grains vary in length from 0.07 to 0.26 mm. The black tourmaline grains are considerably less elongated than 1:2 ratio and vary in length from 0.07 to 0.32 mm. The diagram shows a flat catena upon 1:1 line (Fig.102).The green tourmaline varies considerably in length from 0.06 to 0.43 mm. and lies within an elongated flat catena on line 1:1. Most of the grains fall below 1:2 elongation ratio (Fig. 103). The flat elongated catena on 1:1 line for the brown tourmaline contain most of the grains below 1:2 ratio with length varying from 0.07 to 0.39 mm. (Fig.104).

The tourmaline from the southern Quartzite Formation belt is on an average 0.11 to 0.19 mm. in length and 0.09 to 0.15 mm. in breadth. The rectangular shaped catena lies flat on 1:1 line and resembles the brown tourmaline variety (Fig.105). Thin section data show reduction in grain size for tourmaline. The diagram forms a flat catena on 1:1 line. Most grains lie below 1:2 ratio (Fig.106).

Like the northern belt, quartz from the southern belt is also bimodal in character. The finer grains are 0.078 to 0.273 mm. in length while coarser are 0. 357 to 1.365 mm. The Haggermann diagram is elongated in character and resembles the northern belt. Most grains tend towards greater equidimensional character with B/L ratio more than 0.6 (Fig.107).

The grain size data of zircon, tourmaline and quartz from the thin sections of other formations reveal the following characteristics of the diagrams:

6.11 -3 Laluri Formation -

(a) Laluri A Member - The zircons from the impersistent quartzites of the lowest member of the Laluri Formation are 0.025 to 0.15 mm. in length with most of the grains lesser than 0.065 mm. The catena is elongated towards 1:2 line and tends to 1:5 line (Fig.108). Tourmaline is 0.055 to 0.20 mm. in length with most of the grains lesser than 0.10 mm. The catena lies flat on 1:1 line with a few elongated grains about 1:2 ratio (Fig.109). Quartz is mostly fine grained and varies from 0.078 to 0.198 mm., though some of the grains even reach 1.95 mm. in length.The Haggermann diagram is elongated and triangular in shape (Fig.110).

(b) Laluri C Member - Zircon varies from 0.03 to 0.11 mm. in length (Fig.111 while tourmaline even reaches 0.20 mm. in length (Fig.112).

6.11 -4 Chandpur Formation - Quartz is 0.039 to 0.156 mm. in length. The catena of the diagram is narrow with many grains having B/L ratio below 0.6 (Fig.113).

6.11 -5 Nagthat Formation - Zircon is 0.03 to 0.22 mm. in length with most grains falling below 0.07 mm. The catena is elongated along 1:2 line and tends towards 1:5 (Fig.114). On the other hand, tourmaline varies considerably from 0.03 to 0.40 mm. though most grains fall below 0.10 mm. The catena is flat upon 1 :1 line and is elongated towards 1:2 (Fig.115). Quartz forms a polygonal shaped catena and varies in length from 0.032 to 0.208 mm. B/L ratio falls to 0.3 (Fig.166).

6.11 -6 Dharasu Formation - Zircon is about 50% of the tourmaline amount and varies from 0.03 to 0.15 mm. in length though the grains are generally less than 0.07 mm. The catena lies flat upon 1:1 line and contains only a few grains exceeding 1:2 ratio (Fig.117).The catena of the Smithson diagram for tourmaline is flat upon 1:1 line and extends beyond 1:2 ratio. The grains vary in length from 0.03 to 0.22 mm., though most of them fall below 0.10 mm. in length (Fig.118). The Haggermann diagram for quartz shows an elongated polygonal shaped catena enclosing the grains between 0.026 to 0.39 mm. in length, though most of them are less than 0.185 mm. The B/L ratio is generally above 0.5 but there are relatively a few grains with higher ratio than 0.7 (Fig. 119).

6.11 -7 Dunda Formation: Dhanari Slate - Comprising about 7% of the total tourmaline amount, zircon is 0.03 to 0.09mm. in length from the Dhanari Slate. The catena encloses about 6% zircons between 1:2 and 1:5 lines but does not touch the latter (Fig. 120). On the other hand, tourmaline is coarser and varies from 0.03 to 0.14 mm. with large number of grains less than 0.06 mm. in length. The catena lies flat upon 1:1 line and reaches only upto 1:4 ratio (Fig.121). The Haggermann diagram drawn for quartz shows a polygonal outline with the grains varying from 0.013 to 0.26 mm. in length. The grains are elongated as majority of them have B/L ratio between 0.2 to 0.7 (Fig.122).

Dunda Quartzite - The wing-like catena for zircon from the Dunda Quartzite member extends from 1:1 to 1:5 with the grains varying from 0.07 to 0.15 mm. About 12% grains are equidimensional and many of them have an elongation ratio between 1:2 and 1:5 (Fig.123). On the other hand, the flat catena for tourmaline on 1:1 nearly reaches 1:5 line but most grains fall below 1:2 ratio. The grains are generally below 0.06 mm. and vary in length from 0.03 to 0.15 mm. (Fig.124). Though only a few quartz grains are coarser than 0.26 mm., these vary from 0.26 to 0.416 mm. in length. Some grains show lower B/L ratio than 0.5. The catena of the Haggermann diagram is elongated polygonal in shape (Fig. 125).

6.11 -8 Uttarkashi Formation - Zircons from the uppermost Bareti Quartzite member are 0.03 to 0.15 mm. in length, though generally are finer than 0.08 mm. The catena lies flat upon 1:1 line and touches even 1:5 line with many grains lying between 1:2 and 1:5 elongation ratio (Fig.126). Tourmaline is about 33% of the zircon amount and varies from 0.03 to 0.22 mm. in length with most grains below 0.10 mm. Lying upon the 1:1 line, the catena of the Smithson diagram nearly touches 1:5 elongation line (Fig. 127). Quartz varies considerably from 0.03 to 0.585 mm. in length and shows a polygonal shaped Haggermann diagram. The B/L ratio even reaches as low as 0.2 though generally it is about 0.4 (Fig. 128).

6.12 DISCUSSIONS ON HEAVY MINERAL RESULTS

6.12-1 Criteria of recognition of formation - The Quartzite Formation of the northern belt is identified by high percentage of zircon in comparison to the southern belt. The percentages of the four zircon varieties also deplete considerably in the southern belt.

Though minor amount of brown tourmaline is met with in the northern belt, other varieties namely blue, pink, green and black tourmaline are conspicuously absent. Increasing amount of tourmaline in stratigraphically younger horizons of the southern Quartzite Formation belt is the most characteristic feature. The maximum concentration of the tourmaline varieties is noted near the contact with the Dichli Dolomite. Impersistent occurrences of staurolite, kyanite and garnet signify minor mineralogical changes in the overall ultrastable zircon-tourmaline rich suite but these cannot be regarded as diagnostic of the southern belt.

A seemingly excellent method to verify the zircon-tourmaline relationship in two belts is to study samples from the areas lying outside the definied limits of the present work. For the purpose, 5 samples from the Bhagirathi and Yamuna valleys have been incorporated in the heavy mineral study of northern belt (p. 164). The analyses confirm the results of the heavy mineral characteristics of the northern belt. Additional 14 samples covering parts of Bhillangana-Srinagar-Rudraprayag areas of the southern belt have been studied for the confirmation of the heavy mineral results. Table 19 and Figs. 81 to 87 clearly demonstrate that the heavy mineral characteristics of the southern belt. The results can easily be relied upon for further extensive work in the quartzites.

6.12 -2 <u>Importance in structural interpretation</u> - The confirmation of lateral extension of the quartzite belts have also been found useful in interpretation of regional structure of the adjoining areas. The unmapped regions between the Yamuna and Bhagirathi valleys raise some doubts about continuation of the structural units in the northwest. The contrasting heavy mineral characters especially the tourmaline varieties in the southern belt undoubtedly indicate that the quartzites of this belt pinch out in northwest between Rari and Yamuna river. Moreover, the Singuni Thrust separating these quartzites from the underlying Dunda Formation appears to have been concealed beneath the Dharasu Thrust. The quartzites along the Yamuna valley between Gangani and Kuprā are thus northwest extension of northern belt in the strike which belong to the Uttarkashi Thrust Sheet (p. 100). These have similar structural disposition as along the Bhagirathi river between Dunda and Sainj.

Similar structural interpretation regarding the extension of the southern belt quartzites in the southeast is strengthened by the heavy mineral data. Due to the unsurveyed area between longitude 78° 30' and Bhillangana river, their possible extension in the southeast appears doubtful. The quartzites along the Bhillangana valley and further southeast might be considered as belonging to the northern belt due to a southerly swing in the strike of the quartzites. The heavy mineral characters of the quartzites(Table 19. and Figs. 81 to 87 from the Bhillangana-Srinagar and Rudraprayag regions undoubtedly prove that, on the contrary, the southern belt quartzites of the Singuni Thrust Sheet extend in the southeast (p. 102). The quartzites of the Uttarkashi Thrust Sheet are possibly concealed beneath the Central Crystalline Zone due to a northerly swing of the Main Central Thrust.

Another structural problem was the possible extension of the Dunda Quartzite member in the southeast due to narrowing of the Quartzite Formation. The presence of brown, green, pink and blue tourmaline in the quartzites exposed between two tributaries of the Dhanari Gad clearly indicates that these belong to the Dunda Quartzite member, since the northern and basal southern Quartzite Formation belts are devoid of these varieties.

6.12 - 3 Results of grain size analysis - The following conclusions have been drawn from the grain size measurements of zircon, tourmaline and quartz from the samples and thin sections of non-calcareous sedimentary formations of the area:

(i) Thin sectioning of the heavy minerals namely zircon and tourmaline reduces their true grain size in comparison with the heavy mineral residues.

(ii) On an average zircons of all the varieties from the northern and southern belts of the Quartzite Formation are essentially of the same size. A few grains of rounded and prismatic cloudy varieties are coarser than the colourless zircons from both the belts.

(iii) The shape of Smithson diagrams for zircon is similar in character from both the belts of the Quartzite Formation and is only slightly modified by a few scattered grains.

(iv) The average size of tourmaline from the southern Quartzite Formation belt is coarser than the associated zircon.

(v) The average grain sizes of zircon, tourmaline and quartz are coarser in the Quartzite Formation in comparison to the other formations of the area. The size of these minerals is similar in the Nagthat Formation, Dunda Quartzite and Bareti Quartzite. The Laluri Formation and Dhanari Slate comprise finer zircon and tourmaline grains than the other arenaceous formations while the Dharasu Formation is intermediate in grain size between the Quartzite Formation and others.

(vi) Bimodal character of quartz has been observed in both the belts of the Quartzite Formation. Though a few quartz grains are coarser in the northern belt, their average grain size remains the same.

(vii) The shape of the Smithson diagrams for zircon and tourmaline for the Quartzite Formation of the southern belt is distinct from the other formations of the area and cannot be compared with them. On the other hand, the Nagthat Formation, Dunda Quartzite and Bareti Quartzite have similar distribution of average zircon and tourmaline grains. The shape of their Smithson diagrams are mutually comparable if only a few scattered zircon and tourmaline grains are not taken into consideration.

(viii) The Haggermann diagrams for quartz from both the belts of Quartzite

Formation have similar shape and size distribution but differ considerably from those of the other formations. The Dharasu Formation shows a different pattern of the Haggermann diagram while those of the Nagthat Formation, Dunda Quartzite and Bareti Quartzite bear strong resemblance with each other and are mutually comparable.

The Smithson and Haggermann diagrams for zircon,tourmaline and quartz from other formations of the Lesser Himalaya are now available (Valdiya,1965; Misra and Banerjee,1968a).A comparison of these diagrams reveals that the Quartzite Formation bears strong resemblance with the stratigraphically equivalent Bering Quartzites of Pithoragarh and Bageshwar areas regarding size, distribution and shape of the diagrams for zircon, tourmaline and quartz while the relations with other formations are not clear.

6.12-4 Phenomenon of sedimentary authigenic tourmaline - Krynine(1946) classified sedimentary authigenic overgrowth as one of the important tourmaline types and observed its restricted stratigraphical and widespread lateral distribution in the Central Appalachian Mountains. In the Quartzite Formation, the overgrowth is faint bluish and pleochroic in character upon varied coloured tourmaline grains. It contradicts the earlier observation that the colour of the overgrowth resembles the nucleus (Stow, 1932).The uniform colour of the overgrowth indicates minor changes in the chemical composition during its formation in relation to the nucleus and has been attributed to richness of magnesium content and possible Ca and Na (Krynine, op.cit.). The overgrowth is restricted to the antilogous pole of the C - axis(Atly, 1933).The frosting and pitting of smooth tourmaline surfaces at grain contacts is one of the possible local source for the production of solutions necessary in the formation of the overgrowth and appears to have taken place early during the diagenetic process as is evidenced by interfingering of the authigenic tourmaline and quartz. On the other hand, fracturing and removal of tourmaline material in solution from some of the grains which still show well preserved rounded outlines suggest that the intrastratal solution of tourmaline grains is,in part, also added by metamorphism.

Secondary authigenic tourmaline overgrowth has also been observed by Rao (1952),Gokhale and Bagchi (1959), Bagchi and Gokhale(1959), Awasthi (1961) and others from the Vindhyans, Cuddapahs and Kurnools. In the Lesser Himalaya, the stratigraphical significance and lateral distribution of the authigenic secondary tourmaline overgrowth can be fully understood after detailed heavy mineral studies of other formations.

6.12 -5 Problem of alteration of heavy mineral assemblages - The occurrence of ultrastable heavy minerals in the mineralogically and texturally mature quartzites confirms the views of Hubert(1962) that the heavy mineral stability, as measured by ZTR ratio is usually directly related to the maturity of the light fraction. In this regard, two possibilities should be considered:

(i) The heavy minerals derived by the erosion of the source rocks differ little from those in these quartzites. In other words, the heavy minerals are valid indicators of the provenance conditions.

(ii) The heavy mineral assemblages have been significantly modified i.e., the heavy minerals do not represent the original assemblage derived from the source area.

In this regard Van Andel(1959) elaborated four processes which are capable of altering the original heavy mineral suites.

(a) Alteration by weathering - The removal of less stable heavy mineral species due to weathering under suitable conditions has been demonstrated by many authors(Dryden and Dryden,1946; Sindowski,1949; Weyl,1952), though the opinions differ regarding their order of stability (Pettijohn,1957, Table 95). The prolonged weathering of broad, low relief regions in the source area under stable tectonic conditions can effectively alter a less stable heavy mineral suite to zircon, tourmaline and rutile rich association(Van Andel,1959).

Such weathering conditions in the source area for the Quartzite Formation are evidenced by mineralogical maturity of light and heavy minerals. Thus, weathering of the heavy minerals in the removal of less stable species before transportation of the detrital material appears to have played a prominent role in the concentration of ultrastable minerals like zircon,tourmaline and rutile in the Quartzite Formation.

(b) Alteration by selective abrasion - The experimental work dealing with effects of the mechanical abrasion of minerals has clearly demonstrated that the heavy minerals offer variable resistance to wearing processes(Pettijohn, 1957,pp.558 -561). On the contrary,the study of river transported sediments even to 1500 km. has not supported these experimental results(Russel,1939; Van Andel,1950). Only in conditions of prolonged quiescence,very long reworking of detritus for the thick, Quartzite Formation may possibly result in destruction of the mechanically less stable species (cf.,Van Andel,1959).

(c) Alteration by selective sorting - The third possibility is that the composition of the heavy mineral assemblages can be modified by selective sorting of the sediments during transportation and deposition. Van Andel(1954) has shown its importance in the variation of the Rhine delta assemblages but on the other hand, Stanley(1963) considered it insignificant in removal of the heavy mineral species in the Alpine flysch.

The average grain size of quartz, zircon and tourmaline from different formations of the area supports the view of Udden (1914), Russel (1936), Rittenhouse(1943) and others that small heavy mineral grains settle down with larger light minerals in the same depositional environment. Due to similarity of the average grain size of zircon and quartz from the northern and southern belts of Quartzite Formation and the universal association of zircon and tourmaline in coarse sediments, it seems unlikely that the latter can be selectively sorted from zircon to develop two associations in these quartzites.

(d) Alteration by intrastratal solution - The loss of less stable heavy mineral species after the deposition of the sediments has been referred as intrastratal solution. The decreasing complexity in heavy mineral suites with geological age has led Pettijohn (1941,1957,p.676) to conclude that the older sediments seem to have lost their less stable species by intrastratal solution.

The absence of relict less stable heavy minerals and typically corroded and hacksaw margins are indicative of minor and insignificant role played by the intrastatal solution in the Quartzite Formation. On the other hand, the restricted ultrastable mineral suite of these quartzites indicate that diastrophism and tectonism of source anddepositional areas ultimately control the occurrence of heavy minerals rather than their stability and intrastratal solution(cf.,Krynine,1942; Van Andel,1959; Chanda,1960;Gazi,1965; and Sinha et al., 1967).

In conclusion, the heavy minerals in the Quartzite Formation are possibly not representative of the minerals originally eroded from the source area. Prolonged, weathering and abrasion under stable tectonic conditions appear to have favourably altered an originally less stable heavy mineral suite to an impoverished restricted ultrastable assemblage consisting of zircon, tourmaline and rutile with minor amount of garnet,staurolite and kyanite.

Hence the varieties of zircon and tourmaline and minor amount of other minerals can only be relied upon for deciphering the composition of provenance which has supplied detritus for the thick Quartzite Formation. However, absence of many tourmaline varieties in the northern belt of the Quartzite Formation is difficult to explain by the known processes of alteration as enumerated above and reflects mineralogical changes in the source area.

6.12 -6 Provenance of Quartzite Formation -

(i) Location of source area - One of the difficult aspects of the problem is the location of the source area for the thick Quartzite Formation. Lack of sufficient palaeocurrent structures like current bedding and ripple marks has made this task more difficult. As has been mentioned in Chapter 2(p.26), a few current bedding directions in the Quartzite Formation are indicative of southwesterly currents thus point towards a northeasterly source for the supply of detritus.

West(1935a), Wadia and West(1964) and Krishnaswami and Swaminath(1965) observed two separate and parallel geosynclines within the Himalayan range separated by the present crystalline axis which constitutes the Central Himalaya. The Central Himalayan Geanticline,as it has been designated by Wadia(1955,1961), comprises Archaean and Precambrian rocks with large intrusive granites(Wadia and West,op.cit.).Based upon the arkosic character of the Lower Palaeozoic Nagthat Quartzites, Auden(1934 a) envisaged some granites of pre-Palaeozoic age. The granitic rocks of the Central Himalaya have been assigned different ages from Pre-cambrian to Tertiary(Pande and Saxena,1968).The composition of the Central Himalayan Geanticline has been best described by Gansser(1964, p.235),"Gneisses,migmatites,crystalline schists,thick quartzites and some tectonized granite intrusions form the basal part of Main Central Thrust sheet and may be compared with the Archaean rocks of Indian shield. In the upper part of the crystalline thrust mass follow conspicuous marble, lime silicates horizons with amphibolites and psammite gneisses and the huge schistose section which reflect the Algonkian(Purana) part of the shield rocks".

It is tentatively proposed that the Central Crystalline Zone which is thrust upon the Garhwal Group of rocks possibly constitute the bulk source for the Quartzite Formation during the Algonkian period.

(ii) Characters of source rocks - The restricted ultrastable heavy mineral suite of the Quartzite Formation comprising mainly zircon,tourmaline and rutile limit the correct interpretation of the parent source rocks in a very broad sense. As has been elaborated previously(pp. 182-183), prolonged weathering and abrasion of the detritus for these thick quartzites appear to have considerably modified the source rock. material to eliminate many unstable heavy mineral species. Hence the parent source rocks of this formation can only be worked out from the varietal characters of tourmaline and zircon.

In the present case,the colour and internal morphology of tourmaline can be the possible reliable indicators of source rock conditions. Based upon Krynine's(1946) classification of tourmaline types and Deer et al. (1962 a, p.315), the following primary rocks are indicative of ultimate source for the Quartzite Formation:

(a) granitic rocks - dark brown, green or pink tourmaline ; small to medium size grains with bubble inclusions.

(b) pegmatitic rocks -blue tourmaline, also other colours;large grains.

In the Central Himalayan Geanticline source area after the formation of argillo -arenaceous rocks from these two primary rocks, the sediments were possibly subjected to low to high grade metamorphism, migmatisation and affected by large scale igneous intrusions to develop a complex metamorphic terrain during the Pre-cambrian (Gansser,op.cit. p.235). Pegmatized injected metamorphic terrain comprising of slates,phyllites,metaquartzites,quartz schists,quartz mica schist etc.will further add brown,pink and green tourmaline varieties.For this type of complex terrain"long period of peneplanation characterised by vigorous and prolong chemical decay are especially favourable for the concentration of tourmaline types in the produced detritus at the expense of other less stable mineral species. Such periods of diastrophic quiesence increase both the relative abundance of tourmaline in the following sediment and also the absolute number of tourmaline varieties into it", (Krynine,1942,1946).

The distinction between the first cycle and multicycled material is of importance(Pettijohn,1957,p.312) but the definite evidences like abraded overgrowths upon tourmaline are generally lacking in the Quartzite Formation. The secondary overgrowth upon tourmaline can survive next cycle of sedimentation (Krynine,1946) but its delicate nature can possibly be largely or completely destroyed under prolonged abrasion which the detritus for these quartzites must have suffered. The general considerations viz.,coarseness of quartzites,bimodal character,mineralogical and textural maturity of light and heavy minerals indicate that these are possibly reworked supracrustal, low to high ranking metamorphic and acid igneous rocks of the Central Himalayan Geanticline which has largely contributed the ultrastable tourmaline.

The preponderance of rounded,ellipsoidal and globular zircon in comparison to prismatic or euhedral varieties clearly indicate their multicycle character(Pettijohn,1957, Table98). Most of the grains are devoid of any overgrowth and outgrowth. Such overgrowths upon the rounded zircon covers have been generally considered as a strong evidence for the sedimentary origin of the granites and granite gneisses due to high grade metamorphism and granitisation of sediments(Poldervaart 1950,1956;Wyatt,1954; Eckelmann and Kulp,1956; Eckelmann and Poldervaart,1957). Thus, the lack of such features in the zircons of the Quartzite Formation possibly reflects magmatic characters of the primary acid igneous source rocks of the Central Himalayan Geanticline during the Precambrian times.

Though the significance of zircon in many geological problems has been recently doubted due to its widespread development during authigenesis and low grade metamorphism (Saxena 1966) the rounded zircon has been considered diagnostic of sedimentary and metasedimentary rocks(Wyatt,1954; Vitanage,1957; Verspyck,1961; Murthi and Siddique,1964). The character of many zircon varieties remains unchanged during low grade metamorphism and has also helped in correlation and tectonic interpretation (Carroll et al.,1957; Marshall,1967).

The zircons from Central Himalayan Geanticline have not been studied in detail so that these can be helpful in the interpretation of characters of the source rocks. The recent study of zircon morphology is the only available work(Gupta,1966, 1968).It has been noticed that the zircons alter to euhedral form with increasing metamorphism and subsequent migmatization. The clouding of zircon is more common in the metasediments than in their final metamorphic derivations i.e.,gneisses (Gupta,1968).

Minor amount of staurolite,garnet and kyanite in the southern belt of the Quartzite Formation is indicative of the high ranking metamorphic provenance.

6.13 SIGNIFICANCE OF HEAVY MINERAL STUDIES

As has been mentioned (Chapter 2), the Quartzite Formation is possibly the oldest lithostratigraphical unit in the area of probably Algonkian age but is occurring above the younger Dunda-Uttarkashi Formations due to the thrusting into two separate sheets(Chapter 3). Based upon the similar field, megascopic and microscopic characters, it has been found practical to group these into a single formation. The quartzites contain an ultrastable,limited heavy mineral suite comprising mainly zircon and tourmaline.

Though the concentration and richness of zircon in the fine grained argillaceous sediments have been primarily attributed to its small size and high specific gravity(Rittenhouse,1943), its occurrence as the only important heavy mineral in the northern belt seems to be peculiar. It becomes more apparent because of the total absence of tourmaline except the brown varieties in the north while in the stratigraphically younger beds of the southern belt, tourmaline has been noticed gradually increasing in abundance and variety. Due to the almost universal association of tourmaline and zircon in the arenaceous rocks,it becomes difficult to explain the absence of tourmaline from the northern belt by the above mentioned processes of alteration(p.182).

penecontemporaneous with it, a late formation does not appear to be supported by observations". Similarly Edwards and Becker(1951) observed that iron sulphide occurs in some modern muds and is seggregated after burial and has crystallised to pyrite.

Weller(op.cit., p.173) mentioned that even 5% of iron sulphide will impart a dark grey or black colour to the rock. This explains the grey and black colours of the insoluble residue and hence of the rocks from the Uttarkashi and Khattukhal Limestones, due to the presence of small cubes and finely disseminated pyrite.

6.3 CHEMICAL ANALYSIS

Out of the thirtynine samples analysed for the insoluble residue study, twentysix samples were selected mainly along three sections of the Dichli Dolomite,Khattukhal and Upper Uttarkashi Limestones for the chemical analysis. 10-15 gm. of the sample was powdered and made fine in the agate mortar. About 1 gm. of the weighed powder was completely dissolved in dil.HCl. The solution was made to 250 c.c. and was titrated for calcium and magnesium by E.D.T.A. (Ethylene Dinitrilo Tretraacetic Acid) after precipitating iron and aluminium (cf., Jordy,1955). The data for calcium and magnesium are presented in Table 17

6.3 -1 RESULTS

The terminology for the classification of carbonate rocks on the basis of calcium and magnesium is diverse (Pettijohn,1957; Chilingar,1957). In present work the carbonates have been classified according to Pettijohn(1957, p.418). Three samples contain an excess of MgO than 21.6% - the theoritical value for dolomite and do not fall into any category defined by Pettijohn. These are magnesian dolomites. The average MgO% for the Dichli Dolomite, Khattukhal and Upper Uttarkashi Limestones is 16.8, 6.3 and 8.53 respectively.

Taking into consideration the above facts, it is tentatively proposed that the northern belt quartzites are comparable with the lower southern belt quartzites on the basis of zircon rich characters of the heavy mineral suite. These possibly had a zircon rich provenance which was mainly devoid of tourmaline. The gradual increase in abundance and varieties of tourmaline in the stratigraphically younger horizons of the southern belt thus indicate possible switching of the source rocks which, upon slow peneplanation and uplift, gradually were exposed and shed tourmaline rich detritus along with small amount of zircon upon deeper erosion. A change in the source rocks is also reflected by the minor changes in zircon varieties and impersistent occurrences of kyanite, staurolite and garnet in the southern belt.

The gradual increase in tourmaline percentage in the stratigraphically younger horizons of the southern Quartzite Formation belt seems to be a regional phenomenon and cannot be called as fortuitous. The observation, not only holds good for the present area, but is also valid for the Bhillangana valley - Srinagar-Rudraprayag areas for about 80 km. along the strike of the formation.

A similar situation appears to be occurring in some areas of Almora and Pithoragarh districts where a recent study of heavy mineral characters from the Ganai area reveals that the stratigraphically older Simal Formation of the Berinag Quartzites Group is devoid of any tourmaline while the younger Salia Formation by its abundance (Kumar, 1969a). Keeping in view that the stratigraphical succession in parts of Almora-Pithoragarh area is completely inverted (that is why the younger Salia Formation is exposed at the base - Misra and Kumar, 1968), an increase in tourmaline in the stratigraphically younger beds of the quartzites is more significant and appears to have taken place near the contact with carbonate rocks (Dichli Dolomite/ Gangolihat Dolomites). In case this relationship is properly established in the Berinag Quartzites on a regional scale, it can be an important criterion for the stratigraphical inversion of the sequences where the reliable sedimentary structures are lacking in the quartzites and will form a sound basis for the stratigraphy, correlation and structure of these complicated rocks of the Deoban-Tejam Zone.

CHAPTER - 7

STRATIGRAPHY AND CORRELATION

7.1. INTRODUCTION

The complex stratigraphical problems of the Lesser Himalayan region especially between Simla and Kumaon can be successfully tackled only if the systematic mapping from one end to the other is undertaken with a view to establish the strike relationships amongst the pre-Tertiary formations. Due to complete absence of recognisable fossils in the pre-Tertiary sequences, the stratigraphy and correlation of rocks in this part of the Lesser Himalaya have been solely based upon the grade of metamorphism and lithological variations which have largely been affected by the thrusts and shears of great magnitude. Thus these factors have rendered such correlations dubious in nature.

Since the present area encompasses the Deoban-Tejam Zone and northern parts of the Simla-Krol Belt of Gansser(1964,p.85), it is logical to review the stratigraphy of both the belts in order to point out the salient points for correlation. In the present chapter, the stratigraphical relationships of the various formations in the area are discussed and then correlated with other lithostratigraphical units of the Lesser Himalaya.

It may be emphasised that, though some of the unsurveyed regions between Simla and Kumaon have now been mapped by the Geological Survey of India, Oil and Natural Gas Commission, Atomic Energy Department and State Directorates of Geology & Mining, the geological maps are not made available to other research workers in the field. Amidst such handicaps, the regional correlation of the formations can only be tentative.

7.2 PRE-BLAINI STRATIGRAPHY OF SIMLA-KROL BELT

As a result of the systematic geological mapping Pilgrim and West(1928) worked out the following pre-Blaini stratigraphical sequence in the Simla Hills :

Formation	Probable age
Blaini Conglomerate	Lower Gondwana
Simla Series(Infra-Blaini)	Lower Palaeozoic
Jaunsar Series	Purana
Chail Series	Purana
Jutogh Series	Archaean

In this scheme, the stratigraphical grouping is primarily based upon the grade of metamorphism. The most metamorphosed e.g.,Jutogh Series, though occurring higher up in the sequence due to large scale thrusting,were regarded as the oldest.

On the basis of the revised and detailed mapping of the Simla area and the southeastern region, Auden (1934a,1937,1939) proposed the following pre-Blaini stratigraphy of the Simla-Krol Belt:

Auden(1934a)			Auden (1937)
Solon Area	Tons Area		Garhwal Region
Blainis	Blainis		Blainis
Unconformity	Unconformity		Unconformity
Jaunsars with possible Mandhalis	Nagthats Chandpurs Mandhalis	Jaunsar Series	Nagthats
Simla Slates with Kakarhatti Limestone	Deoban Limestone Simla Slates(Morar-Chakrata beds)		Chandpurs Simla Slates

It should be pointed out that the fundamental difference in the Pilgrims and West's (1928) and Auden's(1934a) schemes is the stratigraphical position of the Simla Slates. This has been considered as younger to the Jaunsar Series by Pilgrim and West and older to the Jaunsars by Auden. In the Kalsi-Chakrata regions, the Jaunsar Series assumes great thickness and consists of the Nagthat, Chandpur and Mandhali Stages. Auden(1934b) reported continuation of the Chandpur Stage upto Nag Tibba and Nagthat Stage upto Kaudia. Auden (1936) raised these stages to respective series due to their considerable thickness and great development in the Kalsi-Chakrata region and postulated a thrust between Mandhalis and Chandpurs on the northern limb of the Jaunsar Syncline. Also, the Nagthats appear to have unconformable contacts with underlying formations indicating Palaeozoic earth movements in the Himalaya. Thus, Pascoe(1959, p.452) enumerates the following succession:

Nagthats

———— Unconformity

Chandpur Series

———— Thrust

Mandhali Series

From the above account, it is evident that over a great part of the Simla-Krol Belt, the Nagthat-Chandpur-Mandhali sequence is stratigraphically normal but is plicated by thrusting and unconformity in the Kalsi-Chakrata region.

7.3. STRATIGRAPHY OF THE DEOBAN-TEJAM ZONE

The published geological work in this inner sedimentary belt mainly deals with the eastern Kumaon region and Shali-Deoban-Chakrata area in the west. For the purpose of description, these have been dealt separately.

7.3 -1 Eastern Kumaon Region - Gansser(1964, p.85) has divided the Deoban-Tejam Zone into a northern Chamoli-Tejam Zone lying between the Main Central

Thrust and the Askot-Baijnath crystalline thrust masses and a southern Badolisera-Pithoragarh Zone occupying the region between the latter and the Almora-Dudatoli mass.

The southern zone consists of a thick sequence of quartzites, limestones dolomites, slates and metabasics. The predominantly argillo-calcareous rocks have been grouped into the Calc Zones of Badolisera (Heim and Gansser, 1939) and Pithoragarh (Misra and Valdiya, 1961; Valdiya, 1962, 1964c). The arenaceous rocks have been named as the Quartzite Series (Misra and Valdiya, 1961) or Quartzite Zone of Berinag (Valdiya, 1962, 1964c) which is ranked as a group being called as the Berinag Quartzites (Misra and Banerjee, 1968). The stratigraphy of the sedimentary zone of the Badolisera-Pithoragarh Zone in the Pithoragarh-Bageshwar-Ganai regions is as follows (Valdiya, 1962):

Calc Zone of Pithoragarh	Thalkedar Beds Sor Slates Stromatolite limestones and Magnesite beds Gangolihat beds
Quartzite Zone of Berinag	Purple phyllites of Asurchula-Nag Belt Massive purple quartzites and pebbly beds Sericite quartzites and chlorite-schists of Charma-Berinag Belt Amphibolites

In the revised stratigraphy of this region, Valdiya (1969) raised the Calc Zone of Pithoragarh to the group rank and reclassified it into four formations e.g., Gangolihat Dolomites, Sor Slates, Thalkedar Limestones and Rautgara Quartzites.

The work of Misra and Valdiya (1961), Valdiya (1962, 1965), Misra and Kumar (1965, 1968) and Misra and Banerjee (1965, 1968) indicates that the whole sedimentary succession in the Pithoragarh,Bageshwar and Ganai regions of the Badolisera-Pithoragarh Zone is inverted.

The northern Chamoli-Tejam Zone has been investigated by Heim and Gansser(1939), Auden (1935) and Gansser(1964,pp.95-98). The following sequence has been worked out by Auden(op.cit.) along the Alaknanda river:

Volcanic Suite (top)

Karanprayag and Chamoli Quartzites

Massive limestones (bottom)

The thick quartzites are seen overlying the massive dolomite sequence between Chamoli and Main Central Thrust. But the stratigraphical relations between the quartzites and dolomites are still uncertain (Gansser,1964, p.95).

7.3-2 Central Garhwal Region - As has been classified here, the central region covers an area between the Yamuna and Alaknanda rivers of the Deoban-Tejam Zone. Auden's work(1935, 1936, 1938,1949) in this region has shown thick development of limestones,dolomites,quartzites,slates and basic rocks which have been grouped into the Barahat Series or Garhwal Series (p.7).

Auden(1936) indicated a lower slate and limestone sequence followed by a thick series of quartzites which overlie and underlie the limestones along the Bhagirathi river. The massive limestones and dolomites have been reported at the following localities: north of Uttarkashi,Giunoti,Pirhi (Auden,1938); Manwa Devi,Ganpurgarh (Auden,1935); Maniknath and Sera with stromatolites (Nautiyal and Jain,1965).

The traverses by Nautiyal(1953) and Tewari,Sethi,Kakkar and Seitz(1963) broadly confirmed the earlier views without contributing much to the stratigraphy of the region.

7.3-3 Western Chakrata-Deoban-Shali region- The inner sedimentary zone appears to be represented by a thick series of limestones,shales and dolomites known as the Deoban Limestone in the north of Chakrata. These are underlain by the Simla Slates though the contact relations are still obscured. In the north, the Deoban Limestone is overlain by the Mandhali Series. Oldham(1883) reported closely chambered shells from the Deobans which have been recently identified as stromatolites(Misra,1969; Valdiya,1969). On the other hand, the Mandhali boulder beds grade into the Deobans and contain boulders of limestones and dolomites derived from them (Oldham,1883). Hence the Deobans will automatically be placed stratigraphically below the Mandhalis (Pascoe,1959,p.825).

In the north of Simla, the Shali Series comprising of quartzites,slates and limestones is exposed below the Chails in the Shali Window (Pilgram and West,1928; West,1939). The following stratigraphy of the Shali Series has been worked out by West (op.cit.):

	Subathu and Dagshais	
	————————————	Unconformity
Shali Series	Madhan Slates	
	Shali Quartzite	
	Upper Shali Limestone	
	Shali Slate	
	Lower Shali Limestone	
	Khaira Quartzites	
	————————————	Shali Thrust
	Chail Series	

7.4 <u>STRATIGRAPHY AND CORRELATION OF LITHOSTRATIGRAPHICAL UNITS OF THE AREA</u>

In the area, the mutual stratigraphical relations are complicated due to the presence of large scale thrusts along many lithostratigraphical contacts,sedimentary facies variation across the strike of the beds and their unfossiliferous character. An orderly description of their field,megascopic and microscopic characters has been given in Chapter 2,while the Chapter 3 incorporates their structural disposition in the field. On the basis of the gradational contacts between many lithostratigraphical units, Table 20 summarieses the stratigraphy of each structural unit separately while their mutual correlation has been given in Figure 129..

The normal overthrust Quartzite Formation, probably the oldest lithostratigraphical unit of the Garhwal Group, resembles the Netala Quartzite member of the Uttarkashi Formation. Both are conspicuous by absence of the detrital mica, rock fragments and feldspars and are mineralogically mature.

On the other hand, the carbonate rocks of the area comprising of the Dichli Dolomite, Khattukhal Limestone, Lower Uttarkashi Limestone and Bangaon Limestone are mutually comparable. The Dichli Dolomite conformably overlies the Quartzite Formation and occupies the same stratigraphical position as the Lower Uttarkashi Limestone above the Netala Quartzite. The Khattukhal Limestone and Lower Uttarkashi Limestone are different in lithology from the Dichli Dolmite but bear strong resemblance with each other and Bangaon Limestone - an eastward extension of the Deobans. These possibly appear to be the two facies of the Deobans (Chapter 8).

The Pokhri Slate of the Uttarkashi Formation has been correlated with the Dhanari Slate member of the Dunda Formation. These slates overlie the Khattukhal and Lower Uttarkashi Limestones and are also compared with the Laluri and Chandpur Formations of the Simla-Krol Belt in the area. These are generally carbonaceous and nonlaminated in the lower part (Laluri A Member, basal few metres of the Dhanari Slate and the Pokhri Slate outcrop near Netala). The slates become arenaceous in the middle part of their sequence e.g., Laluri C Member, purple quartzites and slates of the Dhanaris and quartz sericite schists of the Pokhri Slate member near Hinna. The argillaceous sequence is laminated in character in the upper part (Chandpur

Formation, upper parts of the Dhanari Slate and Pokhri Slate).

Though the Upper Uttarkashi Limestone is identical in character with the Lower Uttarkashi Limestone, it resembles with the Khattukhal Limestone chemically as well as in the insoluble residue. The limestone member pinches near Sada and Dilsod along the strike and appears to be lensoid in shape.

In the present area, the Nagthat Formation has been correlated with the Dunda Quartzite and Bareti Quartzite members of the Dunda and Uttarkashi Formations respectively. These quartzites have similar lithology,though the Bareti Quartzite member also contain a metabasic and arenaceous limestone horizon.The quartzites are conspicuously characterised by well defined bedding, argillaceous intercalations and buff-grey-green-purple colours. The quartzites are invariably micaceous and feldspathic in comparison to buff-white,pure, mineralogically mature quartzites of the Quartzite Formation. The contrast is striking and is characteristic of the two arenaceous horizons.

From the foregoing correlation of the lithostratigraphical units of of the area, it is evident that the Dunda and Uttarkashi Formations can easily be correlated with each other. These formations are exposed in the Dunda and Uttarkashi Windows and are separated from eath other by the Nagni Thak Klippe of the overthrust Quartzite Formation (p. 94). From their opposite dips beneath the remnant Klippe, it can be inferred that these two formations represent a more widespread sequence which, in the present area is exposed into two windows (pp.96-100).

The Dharasu Thrust separates the Garhwal Group of rocks, from the Dharasu Formation, the stratigraphy and correlation of which will be discussed on p. 208).

7.5 CORRELATION WITH OTHER REGIONS OF THE LESSER HIMALAYA

Table 21 summarises possible correlation of the lithostratigraphical units of the area with other formations of the Lesser Himalaya between Simla and Kumaon regions.

7.5 -1 Garhwal Group - In the central region of the Deoban - Tejam Zone, the Garhwal Group corresponds to the Barahat Series or the Garhwal Series of Auden(1938,1949) or to the Garhwal Window Series (Dutta and Kumar,1963).

7.5-2 Quartzite Formation and Netala Quartzite - Possibly the oldest lithostratigraphical unit of the Garhwal Group, the Quartzite Formation (= Netala Quartzite of the Uttarkashi Formation) occurs in a normal succession which has been thrust over the Dunda and Uttarkashi Formations and is conformably overlain by the Dichli Dolomite in the southwest.

Auden(1936,1949) observed extensive development of the quartzites which overlie and as well as underlie the slates and limestones along the Bhagirathi river. These quartzites have been grouped here as the Quartzite Formation of the Garhwal Group.

From the tectonic map of Garhwal and Kumaon (Map 12) it is evident that the Quartzite Formation is relatively narrow along the Bhillangana river. Similar schistose sericite quartzites have also been noticed in the Ghuttu Window (Nautiyal-personal communication).It is apparent that a part of the Quartzite Formation extends beneath the Main Central Thrust (p.101) to reappear again between Mandakani and Alaknanda rivers. It extends in the southeast as a normal succession into the Srinagar- Rudraprayag area and joins with the Chamoli-Karanprayag Quartzites along the Alaknanda river where the similar quartzites are overlying slates and limestones (cf., Auden,1935).

The eastern region of the Deoban - Tejam Zone exhibits thick and widespread quartzites which have been grouped into the Berinag Quartzites in the southern Badolisera - Pithoragarh Zone (Gansser,1964,p.94). These comprise fawn, milky white,massive quartzites, sericite quartzites,ortho-quartzites, purple phyllites and metabasics in the Almora and Pithoragarh districts.

The Quartzite Formation has been correlated with the Berinag Quartzites on the basis of their lithological similarity (except the purple phyllites in the latter), the presence of the metabasics and their stratigraphical position below the dolomites containing Collenia (Dichli and Gangolihat Dolomites). Undoubtedly these thick quartzites of the area join with the Karanprayag -Chamoli Quartzites and Berinag Quartzites (Map 12).

Similar sericite quartzites have also been noticed in the northern Chamoli-Tejam Zone (Gansser, op.cit., pp.94-96) near the Main Central Thrust with phyllites and schists intercalations whereas in the central region along the Bhagirathi and Yamuna rivers, these are devoid of any phyllites near this thrust.

It is interesting to note that the Berinag Quartzites, though strati-graphically older than the argillo-calcareous sequence of the Calc Zones of Pithoragarh and Badolisera, overlie the latter (p. 194) because the whole pile of the metasedimentaries has been found to be inverted. This is evidenced by a number of primary sedimentary structures, reversal grade of metamorphism and sedimentary facies (Misra and Valdiya,1961; Valdiya,1962; Gansser,1964,p.94; Misra and Banerjee,1965,1968,1969; Misra and Kumar,1965,1968). On the other hand, the Quartzite Formation has been observed in a normal succession in the Uttarkashi, Srinagar and Rudraprayag areas between longitudes 78° and 79° but is thrust over the predominantly argillo-calcareous Dunda-Uttarkashi Formations (Chapter 3).

In the northwest, the Quartzite Formation extends upto the Yamuna river and appears to pinch out around Banchangaon due to the tapering off the Garhwal Group rocks (cf.,Auden,1949). Along the Yamuna,it is exposed in two outcrops of the northern belt. The southern Quartzite Formation belt has considerably narrowed down to about 200 metres near Giunoti and pinches out between Rari and Yamuna river (p. 100). This is also evidenced from the heavy mineral data (Chapter 6).

In the western region of the Deoban- Tejam Belt, it is noteworthy that the Quartzite Formation resembles with the middle and upper stages of the Chail Series which comprises pure quartzites,quartz schists and schistose grits(West,1932). In the northern Chakrata, the Chail Series is separated from the underlying Mandhali Series and Deoban Limestone by the Chail Thrust. Oldham's (1883) Bawar Series corresponds to the Middle and Upper Chails(West,1931,1932). When traced in the northwest to the Shali area, the Chail Series shows only the lower stage comprising of grey slate,phyllite, talc schist and banded limestone and is thrust over the Shali Series as the Chail Nappe (West,1935).

Pascoe (1959,p.438) has summarised the equivalents of the Chail Series as follows:" The tendency of the recent work suggests the possiblity that the Upper Jutoghs, Upper Salkhalas and Lower Chails are more or less equivalent and the Simla Slates,Dogra Slates,Attock Slates,or Hazara Slates, as they have been variously called,corresponds to the Upper and Middle Chails; another possibility is that Chandpur Series of the Garhwal area is equivalent to the Chail Series".

It is significant to note that the Chail Nappe succession appears to be widespread in the Deoban-Tejam Zone than hitherto realised(Fuchs,1968). On the basis f the above discussion, it is tentatively proposed that in the northern Chakrata area, the Quartzite Formation may possibly be represented by the Middle and Upper Chail Series.

The lowest Khaira Quartzite member of the Shali Series consists of pure white-purple quartzites with pebble beds and occasional chert(West,1939). Similar stratigraphical position is occupied by the Netala Quartzite in the Uttarkashi Window and thus the Khaira Quartzite may also be equated with the Quartzite Formation.

7.5-3 Dichli Dolomite - In the present area the Dichli Dolomite with normally disposed Collenia has been correlated with the Bangaon Limestone,Khattukhal and Lower Uttarkashi Limestones.

The Dichli Dolomite is exposed along left bank of the Bhagirathi river and has been observed by the present worker extending to the southeast as a continuous narrow belt for considerable distance at least upto Pirhi hill. Auden(1938) observed silicious dolomites and pale chert at Pratapnagar and Pirhi hill while Nautiyal(personal communication)mapped light bluish grey dolomitic limestones between Diul along the Bhillangana river and Maniknath hill as truncated small outcrops along the thrust. The traverses in Srinagar-Rudraprayag area revealed a few occurrences of greyish dolomitic limestone patches with Collenia at Sera (Nautiyal and Jain,1965). These limestones are underlain by normal current bedded quartzites(= Quartzite Formation). In the central region, the occurrences of these dolomitic limestones near a major thrust plane (Dharasu Thrust in the area which joins with the North Almora Thrust (Chapter3), are noteworthy.

In the eastern region of the Deoban-Tejam Zone, grey dolomitic limestones which can be compared with the Dichli Dolomite are extensively developed in the Calc Zones of Chaukhutia,Badolisera,Pithoragarh,Tejam and Chamoli. In the Calc Zone of Chaukhutia, the limestones are exposed from Manwa Devi to Ganpurgarh,Dhanpur,Pokhri,Chaukhutia, Dewalikhal etc.(Auden 1935; Heim and Gansser,1939; Das,1966). Due to its stratigraphical position above the Quartzite Formation (= Berinag Quartzites),general lithology and stromatolites(Collenia), the Dichli Dolomite has been correlated with the

Gangolihat Dolomites of the Calc Zones of Badolisera and Pithoragarh and with the Kapkot Dolomite of the Calc Zone of Tejam (cf., Misra and Banerjee, 1968). In the former two calc zones, the Gangolihat Dolomite is characterised by thick, extensive magnesites and stromatolites with inverted cup shaped laminae (since the whole sequence is inverted, p.104). In recent years, stromatolites have been found as one of the most useful criterion for correlating these unfossiliferous calcareous rocks of the Lesser Himalaya(Misra and Valdiya, 1961; Valdiya, 1962, 1964c, 1969; Gansser, 1964; Misra and Banerjee 1968; Misra and Kumar, 1968; Misra, 1969).

On the other hand, the Dichli Dolomite and its equivalents in the area (p. 197)have been correlated with the Deoban Limestone of the Chakrata area in western region of the Deoban-Tejam Zone. These may also correspond to Lower Shali Limestone of the Shali Series and Naldera-Kakarhatti Limestones of Simla area.

The Deoban Limestone comprises thinly bedded, pale bluish grey, mephitic, fine grained limestones with shale intercalations. It is characterised by closely chambered shell columns, pseudo-organic stromatoporoidal or stromatolitic structures(Oldham, 1883; Pilgram and West, 1928; Pascoe, 1959; p.825; Valdiya, 1969). A few samples collected from the type locality of Deoban Limestone by Jalote(personal communication) comprise similar black pellets in white crystalline groundmass as observed in the Khattukhal Limestone near Nagla. The Deoban Limestone extends to the east upto the Yamuna river(Rao, 1968; Dhoundial and Ali, 1967) and possibly joins with the Bangaon Limestone (Jain and Mithal, 1968).

The Deoban Limestone was first correlated with the Krol limestone (Oldham, 1883)but due to (a) prevalent shaly bands and difference in lithology (b) the presence of pseudo-organic structures and (c) its stratigraphical position below the Mandhali or Blaini Series(p. 196)has rendered this correlation outdated. The pseudo-organic structures, so widespread in the Deobans been recently identified by Valdiya (1969) as species of <u>Collenia</u> and resemble with those from the Dichli Dolomite(Chapter 2, p.30).

On the other hand, the Dichli Dolomite and Deoban Limestone have been compared with the Lower Shali Limestone which comprises pink calcitic banded limestone and massive grey dolomitic limestone with occasional chert (Pilgrim and West,1928; West,1939). Valdiya's(1962a,1967,1969) findings of <u>Collenia</u> and magnesite in the Lower Shali Limestone with the time controlled variation in the morphology of stromatolites also supports this correlation. In fact, the stratigraphical position of the Lower Shali and Lower Uttarkashi Limestones is similar,though the latter is devoid of <u>Collenia</u>.

Pilgrim and West(1928) and Auden(1934a) suggested that the Deoban Limestone is an expanded development of the Kakarhatti Limestone. The prevalent pseudo-organic structures in the latter, which have been identified as <u>Collenia</u> in many other cases, may be significant in equating them with the Deobans and hence with the calcareous rocks of the present area. Also it may be noted that while Pilgrim and West(1928) and Auden(1934a) considered the Kakarhatti Limestone at the base of the Simla Slates,the recent mapping by Srikantia and Sharma(1967) and Rao and Bhan (1969) indicates that this limestone sequence does not occur at the base of the Simla Slates.

7.5-4 <u>Laluri Formation</u> - The presence of the Tons Thrust along contact of the Mandhali Series and Morar-Chakrata beds(Simla Slates) and its extension upto Khand in the present area(Auden,1938) implies that the immediately overlying Laluri Formation is the possible extension of the Mandhalis.

The Mandhali Series is very thinly developed in the Solon area and is often confused with the Blaini Series(Pilgram and West,1928; Auden,1934a, Raina,1963). It shows its maximum development between Kalsi and Chakrata but again narrows considerably near longitude 78°5'. At this locality,it is exposed in an equally wide outcrop as the Laluri Formation. The Bansa Limestone horzon is continuously thinning out from Kalsi to the east and appears to have pinched out between longitudes 78°5' and 78°15' (cf., Dutta and Kumar, 1964). The limestone is only rarely met with in the Laluri A Member while the Laluri C Member is occasionally gritty. The absence of typical Mandhali limestone, boulder beds and doubtful geological relations in the adjoining area justify a separate name for the possible Mandhalis in the area. The following evidences favour such a correlation of Mandhalis with the Laluri Formation.

(i) Variable character of the Laluri A to C Members.

(ii) The presence of the Tons Thrust along lower contact of the Laluris with the Dharasu Formation(= Morar - Chakrata beds).

(iii) Conformable contact with the overlying Chandpur Formation.

(iv) Resemblance of the Laluri A and B Members with the slates and phyllites of the Mandhali Series (horizon f- Auden, 1934a).

(v) The strike continuity of the formations.

The Laluri Formation has been observed extending southeast of the area along the Maindkhal-Chham mule track but its further extension is doubtful as is evident from the Auden's (1937) geological section across Garhwal (Fig. 57) across Banali-Kaudia which is about 10 km. SE of Kandi.

7.5-5 <u>Chandpur Formation</u> - The Chandpur Formation comprises thinly alternating phyllite and quartzite laminations and lies conformably over the Laluri Formation.

The Chandpur Formation is the eastward continuation of the Chandpur Series which has been previously mapped by Auden(1934a) upto Nag Tibba, 8 km. WNW of Andhiari. The geological section across the Garhwal Himalaya (Auden, 1937) (Fig. 57)shows its widespread development along the Bhagirathi river where the Chandpurs have also been compared with the Chails (Pascoe, 1959, p. 438).

The terms Chandpurs or Chandpur Series have been repeatedly used by various workers for the overthrust crystalline masses of Lansdowne, Almora-Dudatoli, Askot, Baijnath etc. of the Garhwal Nappe and have thus caused confusion. On the basis of its typical lithology and stratigraphical position between the Mandhali and Nagthat Series of the Simla-Krol Belt, it is suggested to restrict the usage of the term Chandpur Formation to typical unmetamorphosed or low grade metamorphosed rocks.

Thus, the Laluri and Chandpur Formations are equivalents of the Mandhali-Chandpur Series respectively of the Mussoorie and Jaunsar Syncline. The Laluri Formation has also been correlated with the Mandhali Series of northern Chakrata region. In the area Laluri-Chandpur Formations are equated with the Dhanari Slate member of the Dunda Formation and Pokhri Slate of the Uttarkashi Formation(p. 197). These slate horizons have also been compared with the Sor Slates and Punger Valley Slates of the Pithoragarh, Bageshwar and Ganai areas of Kumaon.

Oldham(1883,1888) and West(1931,1932) observed fine development of the Mandhali Series in the northern Chakrata region where it lies conformably over the Deoban Limestone and contains numerous boulders derived from the underlying limestones. Hence the Mandhalis should be considered younger to the Deobans (Pascoe, 1959, p.825). After accepting correlation of the Deoban Limestone with lower carbonate sequence of the Deoban-Tejam Zone (Dichli Dolomite, Khattukhal-Lower Uttarkashi Limestones, Bangaon Limestone, Lower Shali Limestone, Naldera-Kakarhatti Limestones and Gangolihat-Kapkot Dolomites) with some confidence, the Mandhali-Chandpur Series and Laluri-Chandpur Formation can also be compared with the Shali Slate. This slate member comprises shales, red shales, slates and slaty limestone intercalations and is conformably underlain by the Lower Shali Limestone.

Similar correlation of Laluri-Chandpur Formation with the Sor Slates (grey olive green and black slates with protoquartzites and slaty limestone intercalations) and the Punger Valley Slates will not be out of place. It should be emphasised that the Sor Slates cannot be compared with the Simla Slates as postulated by Misra and Valdiya(1961), Valdiya(1962) and Misra and Banerjee(1968), since the mapping of greater part of the Simla-Krol Belt and the revised geology of the Simla region has indicated that the Simla Slates are older than the Jaunsars, Mandhalis/Blainis and Deobans(cf.,Auden,1934a; Gansser,1964,p.99; Dhoundial and Ali,1967; Rao,1968).

7.5-6 Nagthat Formation and Uttarkashi Formation - In the area, the Nagthat Formation is an extension of the Nagthat Series of Auden(1934a) which is characterised by sandstones,arkoses,schistose quartzites,quartz schists,grits, purple green slates and phyllites. Auden (1934b) also observed Nagthats extending upto Kaudia lying 13 km. SE of Basul. In the cross section (Fig. 57), Auden (1937) has shown two exposures of the Nagthats with intervening Chandpurs on the northeastern limb of the Mussoorie Syncline. It is possible that the northern exposure of the Nagthat Series with a faulted SW margin is extending in the present area as the Nagthat Formation. On the other hand, the Nagthat Series is represented by the Jaunsar Series in the Simla Hills (Auden,1934a) (p. 193).

The upper arenaceous horizon in the area comprising of the Nagthat Formation, Dunda and Bareti Quartzites has been compared with the Shali Quartzite of the Shali Series and Saryu Valley Quartzites or Rautgara Quartzites in the Pithoragarh and Ganai regions of the eastern Deoban-Tejam Zone. The Shali Quartzites is made up of white quartzites with chert while the Saryu Valley Quartzites comprise greyish pink protoquartzites and purple slates. The Saryu Valley Quartzites were not previously considered as a separate stratigraphical horizon but were correlated with the Berinag Quartzites (Valdiya,1962). "In spite of a number of contrasting characters, these quartzites may be equated with those of the Asurchula-Nag Belt to the north" (Valdiya, op.cit., p.39). Further on p.40, Valdiya mentioned that " it is just as well likely that the two quartzites are quite different stratigraphically. In that case, the Saryu Valley Quartzites become the upper most (stratigraphically)member of Calc Zone similar to the Shali Quartzites of the Shali Series" as has been shown in the correlation Table/22. However, the later work in the Pithoragarh and Ganai areas indicated that the Saryu Valley Quartzites distinctly form the uppermost horizon of the Calc Zone of Pithoragarh (Valdiya,1965; Misra and Kumar,1968) and have been renamed as the Rautgara Quartzites(Valdiya,1969).

In the area, the intervening Upper Uttarkashi Limestone of the Uttarkashi Formation thus becomes equivalent to the Upper Shali Limestone of the Shali Series since both are underlain by the slate horizon and overlain by an arenaceous member. The Upper Shali Limestone consists of grey dolomitic limestones with sheets of chert and Collenia (Valdiya,1967,1969). In the eastern region of the Deoban-Tejam Zone, the Upper Uttarkashi Limestone is stratigraphically equivalent to the Thalkedar Limestone of the Calc Zone of Pithoragarh and Badolisera with Collenia (Kumar, in press). This correlation clearly indicates that, though an upper limestone horizon is developed in the Deoban-Tejam Zone, it appears to be impersistent. Its regional distribution can only be confirmed after more work in this zone.

7.5-7 Dharasu Formation - The Dharasu Formation occupies about 10 km. wide track in northwest and narrows down considerably near Chham. From the tectonic map of Auden (1937, Map.10) the formation appears to be an eastward continuation of the widespread Morar-Chakrata beds. In the Chakrata area, these beds are steeply dipping and comprise dark grey slates with purplish sandy or shaly beds being characterised by typical concretions like the Simla Slates (Auden,1934 a,b; Pascoe,1959,p.452).

On the other hand, Auden(1937) extended the Simla Slates as an autochthonous zone upto the Bhagirathi river. However, Auden(1936,1937,1938,1949) also observed extensive development of the schistose phyllites comparable to the Chandpurs along the river. In many subsequent general reports of the Geological Survey of India, these rocks were compared with the Chandpurs along the Bhillangana and Alaknanda rivers.

Thus, it is evident that the Chandpurs, Simla Slates and to some extent Chails have frequently been confused with one another in this part of Garhwal. Pascoe(1959,p.445) mentioned that " it may be found that most of the Chandpurs and the Chails are metamorphosed Simla Slates, though as Auden points out the unaltered, Chandpurs are generally of a different lithological type from the Simla Slates consisting typically of fine alternating bands,averaging3 mm. in thickness of phyllite and quartzite."

In the present area, however, it is possible to map the Dharasu Formation (= Simla Slates or Chakrata-Morar beds) and Chandpur Formation separately. The preliminary observations along the Uttarkashi road between Chaham and Tehri led the present worker to infer that the Dharasu Formation extends as a thin narrow outcrop along left bank of the Bhagirathi river upto Tehri where these are characterised by typical purple-grey-green alternating phyllite and argillaceous quartzites. Nautiyal's mapping(personal communication) of similar purple-grey argillaceous quartzites and green phyllites along the Bhillangana river near Diul indicates its further extension in the southeast. However, at Tehri and between Devprayag-Kirtinagar-Srinagar along the Alaknanda river, the sheeny phyllites and thinly alternating quartzite-phyllite resemble with the Chandpurs hence are shown undifferentiated due to doubtful relations with the Dharasus in this part (Map.12).

A great dislocation, the Dharasu Thrust separates the overlying Dharasu Formation from the Garhwal Group rocks and it is difficult to correlate the

Dharasu Formation(Morar-Chakrata beds or Simla Slates) with other formations of the area. The Dharasu Formation is overlain by the Bangaon Limestone- an extension of the Deoban Limestone with a thrust contact, along which the movements appear to be of little magnitude. In the southwest region of the area, the Dharasus are overlain by the Laluri Formation(= Mandhali Series) with intervening Tons Thrust. The contact between the Simla Slates and Mandhali Series has recently been interpreted as an unconformity(Rao,1968).

On the other hand, in the Chakrata and Yamuna river sections, the Deoban Limestone. overlies the Morar-Chakrata beds(Simla Slates) with an unconformable or faulted contact (Dhoundial and Ali,1967). The general relationship of these beds indicates that the Morar-Chakrata beds(Simla Slates) are older than the Mandhali Series or Deoban Limestone (Auden 1934a). Hence it may be considered that the Dharasu Formation (=Morar-Chakrata beds) is older than the equivalents of Mandhalis/Deobans i.e., the Bangaon Limestone and Laluri Formation. The formation occupying this position in the Garhwal Group is the Quartzite Formation(=Netala Quartzite) but the contrast is so great that on the basis of lithology it is difficult to correlate them in the absence of any time stratigraphical control. If (i) Pascoe's(1959 p.825) contention that the Simla Slates may be taken as equivalents of the Middle and Upper Chail Series,(ii) the lithological similarity of the Middle and Upper Chails with the Quartzite Formation and (iii) Fuchs's(1968) observation regarding the widespread Chail Nappe development in the Deoban-Tejam Zone are accepted, then the Quartzite Formation and Dharasu Formation may be considered as two facies of one rock sequence, brought in juxtaposition due to a great dislocation.

7.5-7 <u>Bangaon Limestone</u> - Part of a thick succession of the Bangaon Limestone extends in the west upto Yamuna river (Jain and Mithal,1968) and has been recognised as the continuation of the Deoban Limestone of the type area (Dhoundial and Ali,1967; Rao,1968).

7.6 SUMMARY AND CONCLUSION

The detailed correlation of the Lesser Himalayan rocks of the Śimla-Krol Belt and Deoban -Tejam Zone indicate:

(i) a widespread lower quartzite horizon comprising of the Khaira Quartzite, Quartzite Formation - Netala Quartzite, Chamoli-Karanprayag-Berinag Quartzites,

(ii) a lower equally widespread carbonate succession characterised by stromatolites and pseudo-organic structures in many of them i.e.,Lower Shali Limestone, Deoban Limestone, Bangaon Limestone, Dichli Dolomite,Khattukhal-Lower Uttarkashi Limestones, Gangolihat and Kapkot Dolomites,

(iii) an argillaceous sequence with limestone intercalations - Shali Slate, Mandhali Series,Laluri Formation, Chandpur Series/Formation,Dhanari-Pokhri Slates, Sor Slates and Punger Valley Slates,

(iv) an impersistent upper carbonate horizons - Upper Shali Limestone,Upper Uttarkashi Limestone and Thalkedar Limestone,

(v) an upper quartzite sequence - Shali Quartzite, Nagthat Series/Formation, Jaunsar Series, Dunda-Bareti Quartzites and Saryu Valley Quartzites.

Though the views of earlier workers regarding the correlation of individual Simla-Krol Belt and Deoban-Tejam Zone have been accepted to some extent, the opinions differ regarding their mutual relationships especially between the carbonates. Oldham(1883), Heim and Gansser(1939), Auden(1935,1938,1948, 1949, 1951,1953) and Pande and Saxena (1968) opined that the Simla-Krol Belt succession may be considered equivalent to the inner Deoban-Tejam Zone with some facies variation.

On the other hand Gansser(1964, p.98) stated that " at a first glance correlation with sediments of Krol belt seems feasible. This is certainly not the case for the calcareous sediments where stromatolitic structures were noted, and here I would agree with Misra and Valdiya(1961,1962) who correlated the Pithoragarh carbonates with the Deobans."

TABLE -22

STRATIGRAPHICAL CORRELATION OF LESSER HIMALAYAN FORMATIONS

(After Valdiya, 1962; Misra and Banerjee, 1968)

SIMLA AREA (Pilgrim and West, 1928)	SHALI AREA (West, 1939)	BAGESHWAR-PITHORAGRAH AREAS (Valdiya, 1962; Misra and Banerjee, 1968)
	SHALI SERIES	
	Shali Quartzite	Saryu Valley Quartzites
	Upper Shali Limestone	Thalkedar Limestones
Slate Stage	Shali Slate	Sor Slates
Naldera-Kakarhatti Limestones	Lower Shali Limestone	Gangolihat Dolomites**
---- Unconformity ----		
Jaunsar Quartzites	Khaira Quartzite	Berinag Quartzites*

* Berinag Quartzites=Nagthats.
** Gangolihat Dolomites = Deoban Limestone.

On the basis of lithology and important stromatolitic structures(Collenia) Misra and Valdiya(1961), Valdiya(1962,1964c),Misra and Banerjee(1968),Banerjee (in press), Misra and Kumar(1968) and Misra(1969) have emphasised that the carbonates of the Deoban-Tejam Zone are much older belonging to the Purana age, and hence cannot be correlated with the Krols. In fact, the recent work by Valdiya(1969) on stromatolites indicate their age about 1200 million years in contrast to Permo Carboniferous (Auden,1934a) or Jurassic(Tewari and Kumar, 1968) age for the Krols. This is also supported by their stratigraphical position with respect to Blaini/Mandhali Series(p.192).

The present work on the stratigraphy and correlation accepts the view-point that the calcareous rocks of the present area cannot be correlated with the Krol limestones as is also indicated by a few data on insoluble residue and MgO/CaO relationship(Chapter 6). Instead it favours correlation with the Deoban-Shali-Pithoragarh type of carbonates.

In his regional mapping of the Simla-Krol Belt from Solon to Rishikesh Aden (1934a,b,1935,1936) has proved that the whole sedimentary sequence occurs in a normal stratigraphical succession with local imbrications. On the other hand, the observations of many workers in the Pithoragarh-Bageshwar-Ganai areas in eastern region of the Deoban-Tejam Zone have indicated a complete inversion of the metasedimentaries. Hence the Berinag Quartzites occurring physically at the top are considered stratigraphically older than the Calc Zone of Pithoragarh (p.194),(Misra and Valdiya,1961; Valdiya,1962;Gansser,1964, p.94; Misra and Banerjee,1965,1968; Misra and Kumar,1968). The Berinags were correlated with Jaunsars of the Simla area and . Nagthats of the Simla-Krol Belt, (Valdiya,1962; Misra and Banerjee,1968)(Table 22).Then the stratigraphically younger Calc Zone of Pithoragarh will automatically be equivalent of the Blaini-Krol-Tal sequence of the Simla-Krol Belt,which has been catagorically refuted by Misra & Valdiya (1961): " the limestone-slate series of Pithorgarh does not resemble and cannot be correlated with Krol series".

On the other hand, Gansser(1964,pp.98-99) observed that " .... the quartzites are then comparable to the Jaunsars. This would make sense if the sections were not inverted. Some of the sedimentary sequence is however certainly inverted and therefore some of the quartzites are older than the carbonates. Since Valdiya accepts Pilgrim and West's stratigraphy(1928) by placing the Jaunsars below the Simla Slates(changed later by West,1931),the lowest quartzites corresponds to those Jaunsars. Following Auden(1934)and Straigraphic Lexion(1957), I would place the Jaunsars above the Simla Slates and thus above the Deoban type limestone. We have,however, seen that quartzites occur below and above the carbonate sections."

Many of the objections to Valdiya's(1962) scheme of correlation of the Simla-Krol Belt and the Deoban-Tejam Zone can be explained by not correlating Berinag Quartzites and its equivalent Quartzite Formation in the area with the Jaunsars and Nagthats and by adopting Auden's(1934a) stratigraphy of the Simla-Krol Belt. Instead, the widespread Shali Quartzite, Dunda-Bareti Quartzites and Saryu Valley or Rautgra Quartzites have been equated with the Nagthat and Jaunsar Series. The older arenaceous horizons comprising of Khaira Quartzite, Quartzite Formation, Netala Quartzite,Berinag-Chamoli-Karanprayag Quartzites underlie the Deoban-Shali Gangolihat type of limestones thus supporting the viewpoint of Gansser(1964). These are provisionally considered as equivalents to Middle and Upper Chail Series of West(1932).

According, the argillaceous sequence comprising of the Sor Slates, Shali Slate, Dhanari-Pokhri Slates of the Present area become equivalent to the Mandhali (Laluri)- Chandpur sequence of the Simla-Krol Belt. These slates cannot be compared with the Simla Slates due to their older stratigraphical position than the Mandhalis and Deobans.

CHAPTER - 8

SEDIMENTATION AND TECTONIC HISTORY

8.1 INTRODUCTION

The reconstruction of sedimentary environmental conditions in the area are largely handicapped by (i) the presence of large scale thrusts, (ii) paucity of continuous exposures, (iii) profound diagenetic recrystallisation and low grade metamorphism which has oblitered grain shape and their boundaries and (iv) lack of environmental and time-stratigraphical units due to absence of fossils.

Amongst such liminations, any attempt to unravel sedimentation and tectonic history of the area can only be tentatively, highly generalised and very preliminary in nature. Table 23 succintly summarises sedimentary and tectonic conditions in the area.

8.2 SEDIMENTATION

8.2-1 QUARTZITE FORMATION

The thick Quartzite Formation comprises pure, buff-white quartzites and their metamorphic derivatives e.g., schistose sericite quartzites and quartz schists. Minor occurrences of conglomeratic varieties are seen near the base of southern belt of the formation while ferruginous quartzites occur near contacts with the overlying Dichli Dolomite (p.25).

These quartzites are comprised of more than 90% quartz with minor amount of chlorite-sericite and can be classified as orthoquartzites (Krynine, 1948; Folk, 1954; Dapples, Krumbein and Sloss, 1953; Pettijohn, 1954, 1957; Hubert, 1962) or quartz arenite (William, Turner and Gilbert, 1954) or quartzose sandstones (Krumbein and Sloss, 1963, p.169). The undeformed quartz grains are subrounded

rounded,fine to coarse sand size with bimodal distribution (Figs.93 & 107).

All these characters indicate high degree of textural maturity(Folk, 1951, Pettijohn,1957,p.299) and reflect very prolong chemical weathering, abrasion and transportation of the detritus which may have been slowly winnowed to almost pure quartz rich rocks.Such characters are best developed under stable tectonic conditions in the source and depositional areas.

The rariety of worn secondary overgrowth on quartz,zircon and tourmaline grains possibly indicate predominance of first cycle sediments under tectonic stable conditions. Accordingly,Krynine(1942a) and Krumbein and Sloss(1963, p.549) postulated that many quartzite deposits indicate long continued chemical and mechanical transformation of grains in a single cyrcle of transportation and deposition. The occurrence of rounded quartz and tourmaline grains in quartzites of the present area support this viewpoint (Folk,1960).

The almost total absence of argillaceous intercalations in these thick quartzites is surprising though such an observation has also been made in other arenite sequences of the world (Pettijohn,1957,p.298). Minor purple and black slates and micaceous quartzite intercalations near contact with the carbonate sequence of Dichli Dolomite reflect changing environmental conditions.

The depth of water must have remained very shallow and never exceeded a few metres with occasional atmospheric exposures for short durations. Such a phenomenon is evidenced by mud cracks,current bedding and ripple marks. The oxidising conditions are indicated by rare purple coloured ferruginous quartzites occurrences (p.25).

The bimodal character of quartz grains from the northern and southern Quartzite Formation is characteristic of these rocks. The coarse grains are better rounded and sorted and are embedded in the finer detrital quartz fraction which exhibits a lesser degree of roundness (p.49). This has been ascribed to textural inversion (Folk,1959). Such a phenomenon is also supported by the occurrence of quartzite pebbles and boulders in these formations (p.25). According to Folk (op.cit.),these characters are developed due to occasional turbulance or mixing of products from high and low energy levels or from two different sources. However, a recent study by Folk(1968) also suggests a desertic environment for such bimodal character of quartz.

It is significant that Krynine(1943,1946) propounded stable shelf conditions to the peneplanation stage during the initial stages of the geosynclinal cycle. Recently,Fuchs (1968) has also advocated such conditions for the Nagthats and similar quartzites of the Lesser Himalaya.

In addition, the tectonic stability in the source and depositional areas is also reflected by the restricted heavy mineral suites which mostly comprise zircon,tourmaline and rutile (Chapter 6). In these rocks, the ZTR ratio is generally higher than 90% thus indicating that the stable tectonic conditions concentrate the light and heavy mineral fractions and ultimately control the composition of sandstones (Krynine,1942,1951; Folk,1956; Hubert,1962).

The stable shelf tectonic conditions are well represented in the high energy littoral and beach environments where the continuously shifting waves must have worked ceaselessly for a long time over each grain of the slowly depositing sediments and have concentrated the sand size quartz.

The provenance for such thick quartzites is difficult to visualise due to lack of significant palaeocurrent data. A few current beddings indicate a north and northeasterly source of detritus. As has been elaborated in Chapter 6,(p.185), the present Central Crystalline Zone or Central Himalayan Geanticline might have been provenance for these deposits during the Precambrian.

Such stable shelf, beach and lagoonal environmental conditions are also envisaged for the stratigraphically equivalent Berinag Quartzites in the Pithoragarh region (Valdiya,1965). Possibly the Chamoli-Karanprayag Quartzites were also deposited under similar stable shelf conditions which seem to cover at least 270 kms. long track of the Chamoli Window.

8.2-2 DICHLI DOLOMITE

The deposition of the pure arenite Quartzite Formation has been suddenly interrupted and is followed by thick carbonate Dichli Dolomite formation. This abrupt change in the supply of detritus material is reflected in a very narrow(one to two metres) gradational zone between two formations.

Intraclastic dolomites - The basal parts of the Dichli Dolomite are rich in allochemical intraclasts,oolites and sand constituents in a sparry coarse cement (pp. 29,50-52). The intermixing of rounded to subrounded quartz with carbonates is suggestive that the detritus was shed into the basin even after the commencement of carbonate sedimentation.

The micritic,rounded and fine grained character of the individual intraclasts implies that these were originally deposited as microcrystalline ooze in calm,protected environments without any turbulence. The intraclasts were weakly consolidated before the penecontemporaneous erosion has produced these rounded intraclastic fragments (Folk,1957,1959). Their association with oolites and sparry cement also reflects transportation and deposition of intraclasts in the turbulent,agitated, high energy envrionmental conditions in the basin of deposition.

The oolitic growth in these dolomites is found around various types of nuclei (p.51) including the intraclasts. In some cases many of the intraclasts also contain oolites. The formation of oolites is a definite evidence of clear, warm and shallow agitated waters in the high energy environments(Illing,1954).

In addition, the formation of oolites and intraclasts seems to be simultaneous with each other.

The sparry cement in these intraclastic dolomites indicate that the currents were capable of washing away microcyrstalline ooze and strong enough to transport fairly large intraclasts (Folk,1959).

Algal Dolomites - The overlying micritic algal dolomites reflect a change in the environmental conditions of deposition. Their micritic character indicate that the agitated waters were calmed down for a favourable precipitation of microcrystalline ooze(Folk,op.cit.) . Further, the algal dolomites with stromatolitic growths provide a positive evidence of clear,shallow,marine and closed basins.On the basis of knowledge gained on recent stromatolites, Cloud(1942)& Ginsburg (1955,1960) concluded that the algal stromatolitic structures flourish in clear,shallow, marine and well protected basins of very shallow depths. These authors report that the stromatolitic growth is favourable in 10 metres deep fresh water or 30 metres in the saline waters. Logan(1961) observed that the intertidal zone and intermittantly flooded mud plains are most suitable environmental conditions for their prolific growth Donaldson(1963),Logan,Rezak and Ginsburg(1964) consider these as organo-sedimentary structures and their various forms and types being due to the environmental factors.

Dololutiles and calc slates - The uppermost parts of the Dichli Dolomite formation comprise dololutites and calc slates. Texturally,the micritic dololutites reflect a change to calm water conditions. These rocks may have been deposited in protected shallow lagoons under oxidising conditions as is indicated by purple colour of slates and insoluble residue.

From the above, it is evident that the Dichli Dolomite and Quartzite Formation were deposited in extremely shallow waters and belong to the platform facies of Sloss(1947), orthoquartzite-carbonate facies of Pettijohn (1957, p.613) or may correspond well to the stable shelf association of Krumbein and Sloss(1963,p.603).

8.2-3 LALURI A MEMBER

The Laluri A Member predominantly comprised of black slates and phyllitic slates which were undoubtedly deposited as black amorphous mud and later compacted to shales. Such a deposition can take place in a reducing anaerobic, euxinic environments with very low oxidation - reduction potential, poor bottom ventilation and very slow rate of sedimentation(James, 1954; Pettijohn, 1957, p.622; Dunbar and Rodgers, 1961, pp.202-208; Krumbein and Sloss, 1963, p.566). Such anaerobic conditions might have been generated below the mud-water interface.

Similar conditions of deposition are also possible during the deposition of the basal Dhanari Slate and Pokhri Slate members of the Dunda and Uttarkashi Formations.

8.2-4 KHATTUKHAL LIMESTONE, LOWER AND UPPER UTTARKASHI LIMESTONES AND BANGAON LIMESTONE

As has already been described in Chapter 2, the Khattukhal Limestone member of the Dunda Formation is characterised by thinly bedded and laminated, dark grey and black micritic limestones with black chert stringers and slate intercalations. The limestones grade to the overlying black slates of the basal Dhanari Slate. These limestones contain grey-black, carbonaceous and pyritiferous insoluble residue. According to Krumbein and Sloss(1963,p.570), such lentiform micritic limestones represent euxinic restriction, quite and stagnant water conditions within the pH stability field of $CaCO_3$. Similar depositional conditional conditions can also be imagined for the Lower and Upper Uttarkashi Limestones and Bangaon limestone which resemble the Khattukhal Limestone(Chapter 7)

The euxinic reducing environmental conditions might have been unfavourable for the stromatolitic growths which need oxidising conditions in the intertidal zones. Here, it may be added that the distinct petrographic, chemical and insoluble residue of the Dichli Dolomite may in fact be due to diverse environmental conditions. It is likely that topographical and basin relief which are ultimately controlled by tectonism of the region are the possible causes for two different environments. Such an inference is based upon their stratigraphical position in relation to the Deoban Limestone which in the area is possibly represented by stable shelf and euxinic facies of carbonates.

8.2-5 DHARASU FORMATION

This comprises laminated, grey-green-purple argillaceous quartzites, slates and phyllites (p.19). The quartzites of the Dharasu Formation can be best described as quartz wacke (Krumbein and Sloss, 1963, p.169) or may be broadly classified as clayey protoquartzites (Pettijohn, 1957). These quartzites are less sorted, mineralogically and texturally immature in comprison to the Quartzite Formation. The slates are invariably silty in character and grade imperceptibly to the quartzites. The laminations are seen on a fine scale with grey and purple colours.

According to Dapples, Krumbein and Sloss (1949), Weller (1960) and Krumbein and Sloss (1963, p.505), the above characters can be best ascribed to unstable shelf conditions of deposition with an oxidising and reducing chemical environment.

On such an unstable shelf the rate of subsidence is greater than the rate of supply of detritus, so as to reduce the time durin which environmental agents operate on sedimentary material before burial (Krumbein and Sloss, op.cit.,). It is evidenced by poor sorting, increase in finer argillaceous material in quartzites, poor rounding of detrital grains etc. The low energy environment is indicated by delicate preservation of the lamination

(Pettijohn,1957,p.553).

As indicated earlier (p.210), the Dharasu Formation occupy the same stratigraphical position as the Quartzite Formation with regard to the overlying Deoban type of limestones(Bangaon Limestone,Dichli Dolomite in the area. If this explanation is accepted then we have to presume their deposition in two different environment during the same period. This may be possible by assuming stable and unstable self conditions for the Quartzite and Dharasu Formations respectively. It is feasible that under stable shelf conditions, the finer quartz, labile constituents e.g., feldspars,mica and rock fragments and clayey material werewinnowed and removed to deeper,unstable quite water conditions. This winnowed detritus might have been deposited as the Dharasu Formation. The gradational zone between the two formations is being concealed by the Dharasu Thrust. At least their stratigraphical position and similarity of the finer quartz grains testify this.But due to complete lack of any time-unit control and normal stratigraphical contacts between these formations, this viewpoint remains more or less hypothetical.

8.3 TECTONIC HISTORY

On the basis of the field and laboratory investigations which have been detailed in earlier pages, the tectonic interpretation of this part of the Lesser Himalaya is attempted.

During the Precambrian,the deposition of possibly the oldest Quartzite Formation seems to have taken place under stable shelf conditions. In case of the northern belt,the basin of deposition was at least 15 km. northeast of its present geographical position. Possibly,simullaneous with the above, the Dharasu Formation was deposited under unstable shelf conditions.

The above clastic sedimentation was followed by predominantly chemical precipitation due to abrupt stoppage in the detrital supply from the source area.

The Dichli Dolomite,Khattukhal,Lower Uttarkashi and Bangaon Limestones were deposited possibly during the same period under different environmental conditions.

The chemical precipitation was interrupted by deposition of the argillaceous,Laluri-Chandpur Formations, Dhanari and Pokhri Slates. At places,carbonates were again accumulated in small basins(Upper Uttarkashi Limestone).

Ultimately the sedimentation in the area ended with deposition of arenaceous sequence comprising of Nagthat Formation,Dunda and Bareti Quartzites. However, it should be noted that the exact shape of basins and their geographical distribution is difficult to unravel because of limited area and large scale Himalayan tectonics and is beyond the scope of the present work.

In the initial stages of the Himalayan Orogeny which dates back to the Upper Cretaceous,broad flexuring and tilting of rocks have taken place. During the subsequent dominantly thrusting phase,the area witnessed the formation of a subhorizontal dislocation plane in the northern Quartzite Formation belt which was thrust from NE to SW over the Dunda-Uttarkashi Formation. The Uttarkashi Thrust Sheet,as has been named in this work,is persistently marked with metabasics at its base. The emplacement of metabasics have been contemporaneous to the movement of this thrust sheet. The foliation (S_2) in the metabasics and Uttarkashi-Quartzite Formations/ is developed during metamorphism and thrusting while quartz,sericite and muscovite (L_1 lineation) recrystallised in the 'a' direction of tectonic transport.

The truncation of the Dunda Thrust by Singuri Thrust indicatesthat the Singuni Thrust Sheet moved over the Uttarkashi Thrust Sheet after full scale development of the latter. The formation of the Dharasu Thrust Sheet and Krol Nappe (thrust sheet?) took place in succession since the former overlaps the Singuni Thrust Sheet in the northwest. Their gradual southward disposition and overlapping clearly indicate successive development of the thrust sheets from northeast to southwest.

The thrusting was followed by the folding phase of the orogeny during which these thrust sheets were folded. The metabasics at the base of Uttarkashi Thrust Sheet acquired strain-slip cleavage (S_3) and microcorrugation (L_3) during this phase. Nevertheless, it may be noted that the Uttarkashi and Dunda Thrusts were folded definitely later than their development. Other examples of folding of thrusts in the Lesser Himalaya are Krol and Tons Thrusts, North and South Almora Thrusts etc. However, truncation of many fold axes and their limbs e.g., (Baragadi, Nagon and Khattukhal Anticline and Bharkot Syncline also indicates overlapping of the two phases in certain cases.

Later, the faulting of rocks took place and succeeded the folding phase. Possibly the rocks near Uttarkashi acquired slickensides(L_2) during the faulting.

The formation of large scale thrusts was mostly facilitated by lithostratigraphical boundaries and has unfortunately complicated stratigraphical control over the tectonics of the area. From the superimposition of many of the thrusts e.g., Dunda, Singuni and Dharasu Thrusts, it can be inferred that these formed at the different stages of the main Himalayan Orogeny. The thrusts of the inner Deoban-Tejam Zone are marked with augen mylonites (Singuni Thrust) or metabasics (Dunda, Uttarkashi and Dharasu Thrusts) and metamorphism (Singuni, Dharasu and Uttarkashi Thrusts). But those of the southern regions including the Simla-Krol Belt are characterised by crushing and shattering of rocks (Tons, Aglar and Krol Thrusts).

The absence of metabasics from thrusts and Tertiary formations of the Outer and Sub-Himalayan region of Garhwal and their persistent tectonically controlled occurrences along some of the thrusts in the area can possibly be correlated with the Upper Cretaceous age for thrusting in the inner Deoban

Zone. Possibly these thrusts in the north evolved earlier than those of the Foothills which are dated from Eocene to Pliocene in age. There seems to be migration of the thrusting phase from north to south in the Lesser Himalaya (Gansser,1964,p.247) coupled with similar shifting of the Tertiary sedimentary basins towards the south.

One of the significant feature from tectonic consideration of the area is the presence of large scale thrust sheets with normal sedimentary succession. In fact the nappes with huge recumbent folds are absent in this part of the Lesser Himalaya as have been interpreted elsewhere by many authors(Pilgrim and West,1928; West,1935; Auden,1937; Valdiya,1964b; Fuchs,1968). The concept of vertical tectonics,recently introduced by Eremenko and Dutta(1967) in the Simla Hills,is also not supported by observations made in the field,though many of the thrusts are inclined at moderate angles and do not exhibit any topographical control over their alignment.

The presence of normal large scale thrust sheets has also been observed by Bhargava and Srikantia(1967) and Gansser(1964) who noted that "the Krol Thrusts are generally normal thrust sheets and not reversed recumbent folds as assumed by some authors" (p.247). In fact Gansser has used the term thrust sheets in place of nappe while discussing the Lesser Himalayan structure and tectonics, " ....that we actually have to deal with the thrust sheets and not recumbent nappes"(p.90). The presence of a large scale recumbent structure may possibly be confirmed after more detailed studies in the Deoban-Tejam Zone between longitudes 79° and 79°45' as indicated by the present work on stratigraphy and correlation of this zone.

CHAPTER - 9

CONCLUSIONS

The thesis is the first systematic geological work on the stratigraphy, structure and sedimentation in an approximately 900 sq.km. of the Lesser Himalayan terrain along the Bhagirathi Valley in Uttarkashi and Tehri districts of Uttar Pradesh. The area comprise Algonkian to Lower Palaeozoic rocks of the Simla-Krol Belt and Deoban-Tejam Zone of the Gansser(1964). This chapter summarises important conclusions of the present study.

The various rocks of the area have been classified into the following lithostratigraphical units:

1. Laluri Formation - slates,quartzites and phyllitic slates.
2. Chandpur Formation - alternating quartzite and phyllite sequence.
3. Nagthat Formation - schistose quartzites,sericite quartz schists,arkoses etc.
4. Dharasu Formation - slates,phyllites and argillaceous quartzites.
5. Bangaon Limestone - dark grey limestones.
6. Garhwal Group - (i) Quartzite Formation - quartzites,quartz schists,schistose sericite quartzites,metabasics and augen mylonites.
   (ii) Dichli Dolomite - intraclastic and algal dolomites and dololutites.
   (iii) Dunda Formation - slates,limestones and micaceous quartzites.
   (iv) Uttarkashi Formation - slates,phyllites, limestones, feldspathic and flaggy quartzites,metabasics.

The structural interpretation of various folds and thrusts in parts of the Simla-Krol Belt and Deoban-Tejam Zone succession of the area clearly indicates that in the southern region the Dharasu Formation has been folded into an important Daski Syncline and is thrust over the Garhwal Group of rocks along the Dharasu Thrust. The formation dips beneath the Krol Nappe and constitute the Dharasu Thrust Sheet.

The Garhwal Group rocks are broadly exposed in an anticlinal Chamoli Window of Auden (1949) and are delineated by the Main Central Thrust and Dharasu Thrust in the north and south respectively. Within the main Chamoli Window, the folded character of the Dunda and Uttarkashi Thrusts with metabasics in the thrust zones has been interpreted as a folded thrust sheet. This Uttarkashi Thrust Sheet of the allochthnous Quartzite Formation has moved at least 15 km. southwest over the autochthonous Dunda and Uttarkashi Formations. On the other hand, the Singuni Thrust with mylonites in its thrust zone demarcates the southerly dipping Singuni Thrust Sheet. The erosion of these sheets has exposed underlying formations in the autochthonous Dunda and Uttarkashi Windows.

The detailed structural analysis of different zones in a part of the Uttarkashi Window region has revealed that the thrust zone, allochthon and autochthon acquired foliation (S_2) and mica lineation (L_1) during thrusting phase. These zones were then folded along common axes which produced opposite dipping S_1, S_2 and L_1. The strain-slip cleavage (S_3) and microcorrugation (L_3) were formed during the folding phase of metabasic thrust zone.

A comparison with adjoining structural units put the Shali-Dunda-Uttarkashi Chuttu Windows in the same strike of an autochthonous belt which runs for nearly 150 km. in inner parts of the Deoban-Tejam Zone. This belt is exposed into small windows parallels the Simla-Krol Belt but is stratigraphically older than the Blaini-Krol-Tal sequence. In the area, the thick Quartzite Formation and overlying Dichli Dolomite are normal sequences of the allochthonous zone and are thrust over the Dunda-Uttarkashi Formations. The normal sequence of quartzites extends upto longitude 79°0' but is inverted along with overlying carbonates in eastern parts of the Deoban-Tejam Zone.

The Singuni Thrust is characterised by thick occurrence of mylonites which include augen mylonites,augen schists and ultramylonites.From the relict porphyroclastic character of quartz,potash feldspar and perthite,these mylonites appear to be quartz and feldspar porphyry intrusive along the thrust. These have been initially subjected to higher grade of metamorphism but were later metamorphosed at shallow depths during the thrusting process.

The widespread metabasics in the Garhwal Group comprise metadolerites, amphibolites and chlorite schists. A series of textural and mineralogical transformations have taken place in response to the changing metamorphic conditions in the green schist facies, due to which the original doleritic and fine grained basic rocks were gradually metamorphosed to chlorite schists. Many smaller metabasic bodies are structurally discordant with country rocks and appear to be intrusives as sills and dykes along shear zones. The more widespread metabasics along the Uttarkashi and Dunda Thrusts and a few impersistent bodies along the Dharasu Thrust were emplaced during thrusting movements.

The insoluble residue from carbonate rocks e.g., Dichli Dolomite,Khattukhal and Upper Uttarkashi Limestones are characterised by variable colour and percentage, detrital sand and silt,clay,shale fragments and different chert and quartz varieties. The chemical and insoluble residue characters of the Khattukhal and Upper Uttarkashi Limestones resemble each other and suggest their possible correlation. The carbonates of the area do not show any relationship between insoluble residue and MgO/CaO ratio. Similar relationship has also been noticed in carbonates from the Calc Zone of Pithoragarh.This may be typical of the Deoban-Tejam Zone calcareous rocks.

The heavy mineral separations from both belts of the Quartzite Formation comprise predominantly a variety of zircon and tourmaline with minor amout of rutile,staurolite,kyanite,andalusite,garnet,leucoxene and pyrite. The comparative study of these heavy minerals indicates that the northern quartzite belt comprises more than 90% zircon in its nonmicaceous nonopaque fraction while in the southern belt, percentage of all five tourmaline varieties increases in normally disposed stratigraphically younger beds. The regional lateral and stratigraphical variability of zircon and varieties of tourmaline are significant and also hold good for quartzites in the adjoining areas.

The heavy mineral suite of the Quartzite Formation appears to be greatly modified during long period of peneplanation characterised by vigrous chemical weathering of the source area and transportation of detritus to the depositional site. On the basis of varietal characters of tourmaline and zircon, it is proposed that the source rock area for these quartzites was possibly complex metamorphic terrain of the Central Himalayan Geanticline during the Precambrian. A change in the source rock characteristics is inferred from different heavy mineral suites of the northern and southern belt of quartzites.

In the area, the mutual stratigraphical relations are complicated due to large scale thrusts along formation contacts. The oldest,normal and overthrust Quartzite Formation resembles the Netala Quartzite member of the Uttarkashi Formation while the overlying Dichli Dolomite and Lower Uttarkashi Limestone and Khattukhal Limestone are mutually comparable. The predominantly argillaceous rocks of the Laluri-Chandpur Formations,Dhanari Slate and Pokhri Slate are considered equivalent to each other. The Upper Uttarkashi Limestone also resembles Khattukhal limestone in insoluble residue and chemical composition.

The correlation of the Lesser Himalayan rocks,as has been worked out by the present worker reveals widespread quartzite,carbonate and slate sequences while an upper limestone and quartzite horizon is impersistently developed at places. Some of the present day discrepancies in stratigraphical correlation of the Deoban-Tejam Zone and Simla-Krol Belt can be removed by not correlating

Quartzite Formation (Berinag Quartzites) with the Nagthats. Instead, the upper quartzite sequence comprising of Shali Quartzite, Dunda-Bareti Quartzites and Saryu Valley Quartzites (Rautgara Quartzites) has been correlated with the Nagthats and Jaunsar Series. The older arenaceous horizon comprising of Khaira Quartzite, Quartzite Formation, Netala Quartzite, Karanprayag-Chamoli-Berinag Quartzites underlie the Deoban-Shali-Dichli-Gangolihat type of limestones.

The Quartzite Formation and Dichli Dolomite were deposited under shallow stable shelf conditions, while unstable shelf conditions have been worked out for the widespread Dharasu Formation. The euxinic conditions were prevalent at certain localities during the accumulation of the Laluri A Member, Khattukhal, Bangaon, Lower and Upper Uttarkashi Limestones.

The sedimentary sequence has been largely broken into thrust sheets which seem to have evolved successively, the northern most Uttarkashi Thrust Sheet being the oldest.

APPENDIX

LIST OF LOCALITIES

Locality	Latitude	Longitude
Alethi	30°41'15"	78°29'10"
Andhiari	30°34'	78°14'
Bagyalgaon	30°38'20"	78°23'25"
Baldogi	30°31'15"	78°23'
Banchangaon	30°54'	78°14'
Bangaon	30°41'20"	78°11'25"
Bareth	30°41'40"	78°16'45"
Bareti	30°44'10"	78°24'35"
Barkot	30°38'40"	78°13'
Basul	30°30'30"	78°19'
Baun	30°45'30"	78°21'35"
Bhaldiana	30°28'20"	78°24'
Bhanolti	30°41'	78°22'
Bharkot	30°34'	78°21'
Bhatwari	30°39'	78°25'35"
Bhawandevi	30°29'	78°14'
Bheti	30°32'40"	78°20'
Chamiala	30°38'	78°29'
Chapra	30°35'	78°15'
Chaunra	30°18'20"	78°46'30"
Chaurikhal	30°38'50"	78°29'30"
Chham	30°30'50"	78°22'35"
Chirpatiakhal	30°21'20"	78°55'
Chunyali	30°35'	78°19'
Dang	30°42'15"	78°19'
Deo	30°32'30"	78°20'25"
Deosari	30°32'35"	78°12'15"
Devprayag	30°6'40"	78°36'10"
Dhanari	30°39'	78°23'30"
Dhanaulti	30°23'	78°15'
Dhanpur	30°41'40"	78°28'30"
Dharasu	30°37'	78°18'50"
Dhauntri	30°37'	78°31'

Locality	Latitude	Longitude
Dichli	30°32'45"	78°24'
Dilsod	30°44'	78°23'50"
Dingaon	30°35'50"	78°27'40"
Diul	30°23'	78°35'
Dobha	30°43'	78°27'
Dodhi Tal	30°52'	78°31'30"
Dunda	30°41'40"	78°21'
Foeld	30°40'20"	78°21'10"
Gamri	30°37'	78°22'
Gangani	30°50'	78°15'15"
Gangori	30°45'40"	78°27'25"
Gangotri	31°0'	78°56'
Gaphar	30°30'30"	78°18'30"
Ghansali	30°24'	78°40'30"
Ghunti	30°22'	78°36'30"
Ghuttu	30°23'	78°35'
Giurla	30°45'	78°22'
Giunoti	30°46'	78°17'
Gona	30°32'45"	78°19'
Gilang	30°32'	79°31'
Hill 1549	30°33'45"	78°17'15"
Hill 2153	30°45'	78°25'35"
Hill 2174	30°38'35"	78°21'50"
Hill 2208	30°35'50"	78°22'
Hill 2288	30°43'20"	78°19'20"
Hill 2339	30°45'	78°19'35"
Hill 2521	30°46'30"	78°16'25"
Hinna	30°44'25"	78°30'30"
Iwain	30°44'25"	78°29'
Jastwari	20°38'	78°15'
Jogat	30°31'15"	78°25'30"
Jokanri	30°44'	78°25'35"
Jugaldi	30°45'	78°22'
Kandi	30°30'5"	78°22'40"
Kaudia	30°32'30"	78°22'
Kansi	30°33'30"	78°16'25"
Katkhet	30°36'15"	78°16'25"

Locality	Latitude	Longitude
Khalsi	30'30'45"	78°24'30"
Khand	30'22'	78°21'
Khattukhal	30°41'	78°20' 25"
Kiangaon	30°43'	78°26'
Kiari	30°34'45"	78°15'15"
Kot	30°44'35"	78°27'20"
Koti	30°32'	78°18'
Kumrara	30°31'30"	78°22'30"
Kunsti	30°44'10"	78°19'40"
Kurchhola	30°25'	78°56'
Kuara	3 °54'	78°21'
Kutnaur	30°52'20"	78°18'30"
Lakha Mandal	30°43'55'	7 °4'
Laluri	30°33'	78°18'
Lambgaon	30°30'30"	78°30'10"
Launga	30°24'	78°54'
Majhgaon	30°44'	78°15'40"
Malli	30°33'	78°21'
Mandon	30°44'10"	78°27'40"
Maneri	30°44'40"	78°32'25"
Maindkhal	30°29'20"	78°17'
Manpur	30°41'40"	78°29'10"
Margaon	30 38'	78°21
Mason	30°41'30"	78°19'
Mathyana	30°18'40"	78°58'30"
Morar	30 30'45"	78°16'25"
Mussoorie	30°25'	78°3'30"
Mustari	30°43'	78°28'20"
Nagla	30°44'	78°16'40"
Nagri Thak	30°41'15"	78°25'25"
Nagon	30°34'30"	78°20"
Nag Tibba	30°35'	78°8'40"
Naid	30°46'	78°28'
Nakuri	30°44'10"	78°21'10"
Naogaon	30°30'50"	78°20'25"
Nala	30°34'10"	78°16'25"
Netala	30°45'10"	78°29'10"

Locality	Latitude	Longitude
Odalak	30°40'35"	78°21'20 "
Painkhal	30°39'30"	78°22'50"
Paloni	30°33'	78°20'20"
Panjala	30'46'30"	78°22'
Pata	30'45"	78°27' 20"
Paturi	30°38'	78°44'25"
Pirhi	30°25'	78°32'
Pokhri	30°43'20"	78°25'25"
Pratapnagar	30°28'	78°28'
Punargaon	30°35'20"	78°21'30"
Ramolisera	30°30'30"	78°21'10"
Rari	30°46'	78°16'
Rishikesh	30°4'40"	78°18'
Rudraprayag	30°16'20"	78°59'
Sada	30°42'	78°29'
Saini	30°46'	78°35'
Sampur	30°34'20"	78°19'40"
Sankrona	30°41'50"	78°27'20"
Sarag	30°42'	78°22'
Saror	30°44'	78°29'50"
Sarot	30°33'	78°21'30"
Sartali	30°43'20"	78°18'
Shyalna	30°43'	78°17'25"
Silkhal	30°16'	78°47'30"
Silkyara	30°45'	78°16'
Sindhol	30°37'	78°5'
Singuni	30°40'	78°17'25"
Soman	30°40'10"	78°9'50"
Srinagar	30°10'	78°47'40"
Syanachatti	30°54'30"	78°22'
Tehri	30°21'	78°29'
Tekhla	30°45'	78°2 7'
Thaeli	30°27'	78°42'
Thalan	30°42'	78°28'40"
Thaturu	30°30'	78°9'
Tiara	30°51'30"	78°37'30"
Tilbada	30°21'	78°59'
Tilkannikhal	30°12'	79°06'
Timli	[illegible]	

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FIG. 130

FIG. 131

FIG. 132

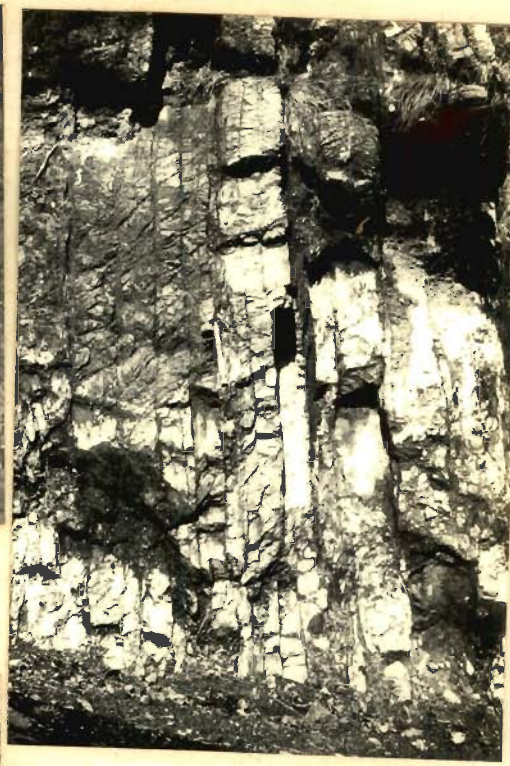

FIG. 133

FIG. 134

Fig.135 Thinly bedded argillaceous quartzites. Individual beds are separated by bedding joints and measure about 2 metres. Rocks dip 50°due S70°W. Loc. Uttarkashi road at milestone 71/4.

Fig.136 Thinly bedded greyish green argillaceous quartzite(light shade)bed (10-15 cm) grade to green phyllite(dark shade).Loc. Uttarkashi road at milestone 74/5.

Fig.137 White small quartz and feldspar porphyroclasts in augen mylonites. Thin Silica veins permeak the folation. Pen plunge 50° due S10°W.Loc. Uttarkashi road near milestone 75/0.

Fig.138 White quartzite lens (Quartzite Formation) in highly crumpled chlorite schist. near the Uttarkashi Thrust zone. Loc.Sankrona on Uttarkashi-Lambgaon road.

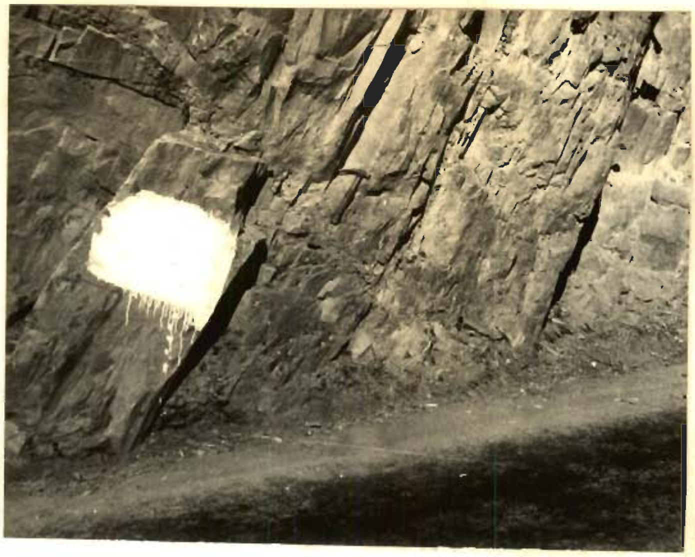

FIG. 135

FIG. 137

FIG. 136

FIG. 138

Fig.139 Exfoliation weathering in metadiorite facilitated by jointing. Fresh spherical nodules come out from highly weathered metadiorite. Loc. Dharasu-Barkot road at milestone 17/0.

Fig.140 Cast of symmetrical ripple marks on lower surface of quartzites. Note sharp crests and smooth troughs. Loc. Uttarkashi road at milestone 74/1.

Fig.141 Normally disposed symmetrical ripple marks on the lower surface of a bed. Mud cracks on troughs in laminated quartzites and slates. Loc. 1.5 km. ESE Malli on right bank of Dichli Gad.

Fig.142 Section of Parallel current bedding in pure quartzites. Beds dip 60° due S75°W. Loc. Uttarkashi road at milestone 73/6.

Fig.143 Normally disposed festoon current bedding marked with colour laminations in pure quartzites. Beds dip 40° due SW. Loc. Uttarkashi road at milestone 74/0.

FIG. 139

FIG. 140

FIG. 141

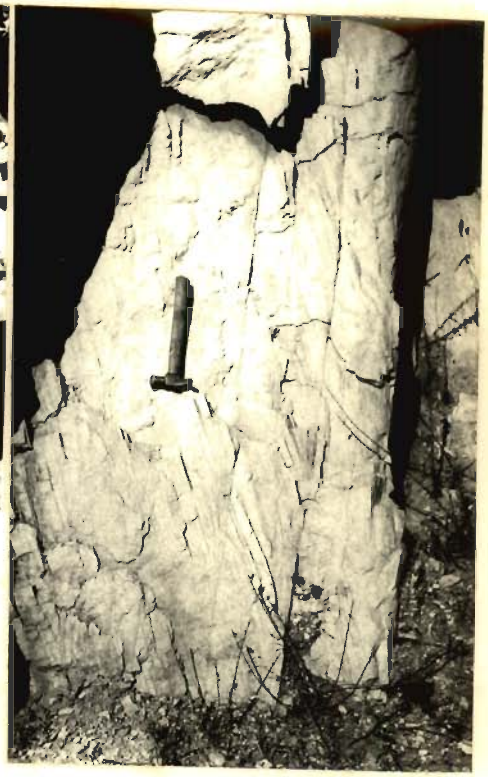

FIG. 142

FIG. 143

Fig.144 Inverted trough current bedding in quartzites; beds are inverted towards NE. Loc. Uttarkashi road at milestone 80/0.

Fig.145 Ball and pillow structure in argillaceous quartzites. Elongated, elliptical shaped structure is wrapped by ground-mass. Loc.0.5 km. NE Chapra on right bank of Nagon Gad.

Fig.146 Broad undulatory rippled surface with poorly developed faint flute casts. Loc. Uttarkashi road at milestone 70/4.

Fig.147 Dome shaped vertical stromatolite columns jointed together in algal dolomite. Loc. 0.5 km. E Malli on right bank of Dichli Gad.

Fig.148 Tightly apressed isoclinally folded laminated slates of Dhanari Slate member. Pen on the bedding surface. The axial plane dips 50° due N60°E. Loc. Uttarkashi road at milestone 76/1.

FIG. 144

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FIG. 147

FIG. 148

Fig.149 An asymmetrical syncline in massive argillaceous quartzites. Hammer along axial plane cleavage which dips 60° due E. The limbs of the fold dip 85° due S 60°W and 30°due E. Loc.Kansi on Sarot-Chapra road.

Fig.150 Minor puckers in laminated argillaceous quartzites. Axial plane of these puckers dip 60° due WSW while their axes (lineation of the slaty cleavage) plunge 10° due SE.Loc.Barethi on Dharasu -Chapra mule track.

Fig.151 Trace of bedding surface on slaty cleavage in laminated argillaceous quartzites. The beds dip 25° due N 10°W while slaty cleavage dips 35° due N60°E. Minor puckers form a lineation plunging 10° due S50°E on the cleavage. Loc.Jastwari.

Fig.152 Puckers and kink folds in friable argillaceous quartzites. Axes plunge 10° due S30°E and axial plane dips 80° N60°E. Loc. Barethi.

Fig.153 Recumbent fold in Dunda Quartzite member. Beds at lower altitude dip 75° due S 70°E while in the centre 85° due S85°E and near top 45°due S20°W. Loc. Uttarkashi road between milestones 77/4 and 77/5.

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FIG 149

FIG. 150

FIG 152

FIG. 151

Fig.154 Gritty quartzite from the Laluri C Member of Laluri Formation exhibiting ellipsoidal and spheroidal coarse quartz grains in 2 cm. thick bed. Sp.No.6/398, Loc.-0.5 km.Kiari.

Fig.155 Very fine alternating phyllite and quartzite laminae in phyllites of the Chandpur Formation. Sp.No.5/97,Loc.1 km. SW Laluri.

Fig.156 Laminated argillaceous quartzite of the Dharasu Formation. Faint,closely spaced slaty cleavage with micaceous sheen lie at 40° to the bedding. Sp.No.A/392, Loc -Sarot.

Fig.157 Same speciman. Sharply bent foliation by axial plane cleavage and lineation of kink folds.

Fig.158 'Ball and pillow' structure from argillaceous quartzites of the Dharasu Formation. Ellipsoidal concretion is wrapped by laminae of the groundmass. Sp.No.6/434.Loc. milestone 2/1 Dharasu-Barkot road.

Fig.159 Conglomeratic schistose sericite quartzite from Quartzite Formation with coarse sand to granule size quartz in strongly schistose groundmass. Two elongated pebbles (3-6 cm.) lie flattened along the foliation. Sp.No.5/177,Loc.0.5 km. E Soman.

FIG. 154

FIG. 155

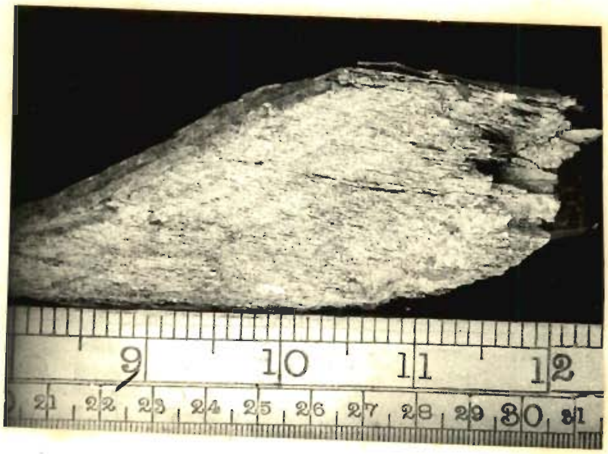

FIG. 156

FIG. 157

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FIG. 159

Fig.160 A quartzite boulder (14x11.5x 4 cm.) from conglomeratic schistose sericite quartzite of Quartzite Formation. The surface is marked with sericite mineral lineation. Sp.No.6/298, Loc.0.75 km. SW Singuni.

Fig.161 -Schistose sericite quartzite from northern belt of Quartzite Formation with a strong sericite -muscovite-quartz mineral lineation(L_1) along the foliation (S_2). Sp.No.5/160,Loc.1 km. N Chaurikhal on Uttarkashi-Lambgaon road.

Fig.162 Schistose sericite quartzite of Quartzite Formation with poorly developed foliation. Mica and quartz mineral lineation is prominent. Sp.No.5/163, Loc. 2 Km.NW Chaurikhal on Uttarkashi -Lambgaon road.

Fig.163 Stromatolitic structure(Collenia columnaris) showing an upward increase in diameter of the laminae;algal dolomite from Dichli Dolomite. Sp.No.A/310,Loc.1.5 km.ESE Malli.

Fig.164 Intraclastic dolomite from Dichli Dolomite. Elliptical, circular and elongated intraclasts (1.5 to 0.5 cm.) in dolomitic matrix. Sp.No.E 25,Loc.1.5 km.ESE Malli.

Fig.165 Pellitiferous limestone of Khattukhal Limestone member (Dunda Formation). Elliptical and circular pellets (0.5 -2 mm) in white crystalline calcite. Sp.No.6/12,Loc.15 NW Nagla.

FIG. 160

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FIG. 165

Fig.166 Strongly crenulated slaty Khattukhal Limestone. The crenulation and defined by calcite veins. Sp.No.6/473, Loc.Milestone 75/4 Uttarkashi road.

Fig.167 Thinly bedded argillaceous slaty quartzite of Dhamari Slate Member of the Dunda Formation. The trace of bedding plane on slaty cleavage is seen. Sp.No.6/475, Loc.Painkhal.

Fig.168 Irregular, partially filled amygdule cavities (drusy quartz) in fine grained schistose amygdaloidal metabasic. Sp.No. 6/27, Loc.0.5 km.W Dhanpur.

Fig.169 Massive dark metadolerite with poorly defined hornblende prisms. At other places(not in photo) clustering of hornblende prisms is seen. Sp.No.6/199, Loc. milestone 75/0 Uttarkashi road.

Fig.170 Strain-slip cleavage(S_3) along axial plane of slip fold in weathered, chlorite schists. The foliation (S_2) is sigmoidally kinked between adjoining, closely spaced cleavage (1.5 mm.) Sp.No.6/164, Loc.1.5 km.WNW Pata on Tekhla logging section road.

Fig.171 Same specimen. Strongly corrugated foliation(S_2) surface micro-corrugation or minor puckers (L_3) due to minor slips.

FIG 166

FIG. 167

FIG. 168

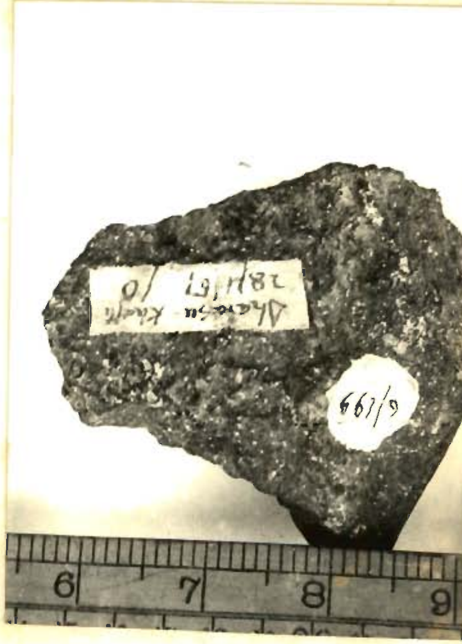

FIG. 169

FIG. 170

FIG. 171

Fig.172 Asymmetrical minor slip folds in chlorite schists. Thin Silica veins permeate along foliation (S_2). Strain-slip cleavage (S_3) is 0.5 to 1 mm. apart as discrete planes. Sp.No.6/118, Loc.Kankrari.

Fig.173 Same specimen. Strongly developed minor puckers (L_3) on foliation planes due to intersection of strain-slip cleaave (S_3) and foliation(S_2).

Fig.174 Strong mica lineation over rough foliation surfaces in augen schists. Sp.No.6/302, Loc.0.5 km. SE Khattukhal.

Fig.175 Polished specimen of augen mylonite. Rectangular to augen shaped porphyroclast of feldspar and quartz are embedded in laminated,fluxion micaceous mass. Silica veins permeate foliation near the top. Sp.No.6/301, Loc. milestone 75/1 on Uttarkashi road.

Fig.176 Polished specimen of augen schist. Elongated quartz augens (0.5-5 mm.) in undulatory schistose micaceous groundmass. Sp.No.6/302.

Fig.177 Polished specimen of augen mylonite. Numerous rectangular and qugens of feldspar and quartz in dark fluxion banded groundmass. Sp.No.6/296,Loc.Along Singuni-Margaon mule track,0.5 km.SW Singuni.

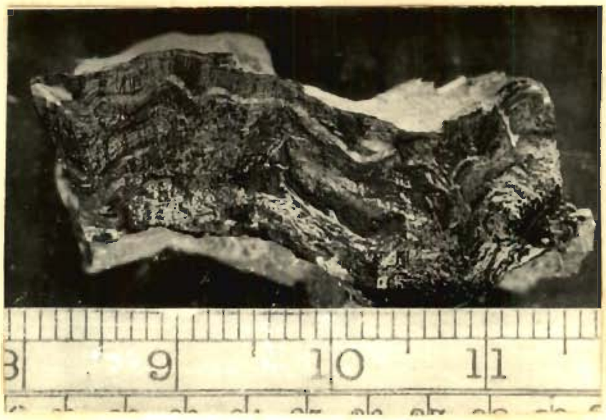

FIG. 172

FIG. 173

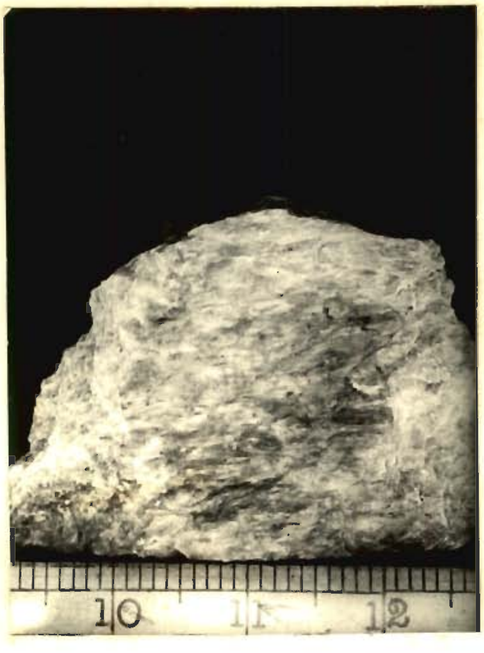

FIG. 174

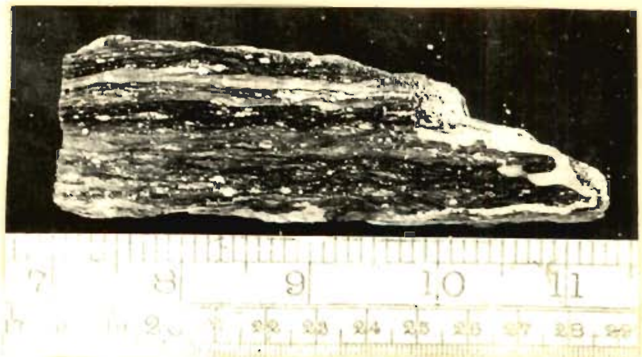

FIG. 175

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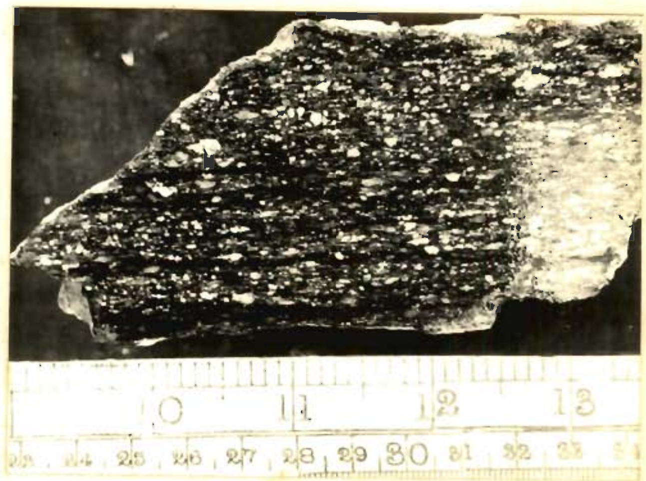

FIG. 177

Tourmaline characteristics from southern Quartzite Formation belt

Fig.178 Large birefringent microlite inclusion (tourmaline?) in green tourmaline. Pol.X 160.

Fig.179 Striations as basal partings in rounded pink tourmaline. Pol. X 160.

Fig.180 Anhedral brown tourmaline with conchoidal fractures.Pol.X 160.

Fig.181 Secondary authigenic tourmaline overgrowth upon rounded brown tourmaline with a gradational zone. Pol. X 160.

Fig.182 Black,opaque,nonbirefringent needle shaped microlites in rounded green tourmaline. Pol. X 160.

Fig.183 Prismatic euhedral pink tourmaline. Pol X 160.

Fig.184 Authigenic secondary overgrowth upon rounded,fracture,green tourmaline with sharp contacts. Globular inclusion in brown rounded zircon in right hand corner. Pol. X 160.

Fig.185 Typical heavy mineral assemblage from southern belt. Rounded tourmaline of various shades and inclusions. Pol. X 45.

Fig.186 Heavy mineral suite in thin section (sp.No.A/160). Rounded f fractured tourmaline with secondary overgrowth.Three dark brown prismatic and rounded zircons. Pol.X 90.

Fig.187 Rounded pink tourmaline with many globular inclusions. Pol. X 160.

Fig.188 Elongated,elliptical green tourmaline with numerous bubble inclusions in the centre. Secondary overgrowth incipiently developed.Pol.X 160.

FIG. 178

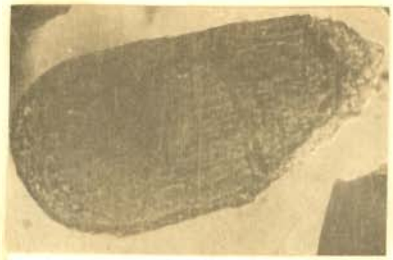

FIG 179

FIG. 180

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FIG. 183

FIG. 184

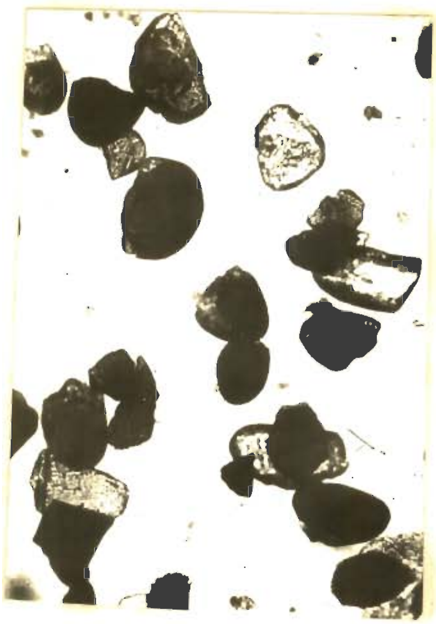

FIG. 185

FIG. 186

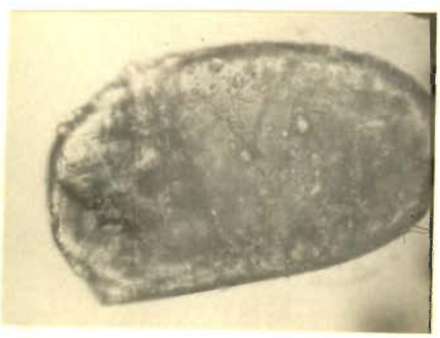

FIG. 187

FIG. 188

Zircon Characteristics from Quartzite Formation

Fig.189 Zoned prismatic rounded zircon with radial fractures Pol. X 160.

Fig.190 Globular mineral inclusion in zircon. Pol.X 160.

Fig.191 Rounded colourless zircon with globular microlites; subhedral yellowish garnet below Pol.X 160.

Fig.192 Large prismatic brown zircon with longer prismatic faces than the dipyramids.Pol.X160.

Fig.193 Typical heavy mineral assemblage from northern Quartzite belt. Very well rounded zircons of varying transparency. Pol.X70.

Fig.194 Rounded elongated zircon with basal partings.Pol.X 160.

Fig.195 Twinned doubly terminated prismatic colourless zircon with sharp edges. Pol.X 160.

Fig.196 Twinned prismatic zircon showing rounding of edges.Pol.X 160.

FIG. 189

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FIG. 196

Fig.197 Typical phyllite from Chandpur Formation. Silt size quartz rich laminae (0.2 mm) are defined by thin sericite laminae. (Sp.No.5/106). Pol.X 45.

Fig.198 Subrounded sand size quartz and a few albite embedded in sericite chlorite rich recrystallised matrix in quartzites from Nagthat Formation.Mica replaces clasts along margins and fractures (lower right hand). (Sp.No.5/139),Cross X 90.

Fig.199 Cataclastically deformed quartz schist of Nagthat Formation near Basul Thrust. Elongated and marginally granulated quartz clasts in strongly oriented quartz-sericite groundmass along the foliation. Strain -slip cleavage intersect foliation at high angle along which quartz and sericite also recrystallise (Sp.N .6/415),Cross X 45.

Fig.200 Cataclastically deformed sericite schistose quartzite from Nagthat Formation.Fine granulated quartz of groundmass with coalesces with lensoid coarse quartz clasts. Sericite-chlorite wrap quartz,clastss(Sp.No 5/107),Cross X 90.

Fig.201 Quartzite from southern Quartzite Formation. Well rounded very coarse sand size detrital quartz embedded in fine sand size quartz exhibiting bimodal distribution.Large quartz grain shows deformed lamellae.(Sp.No.A/315),Cross X 15.

Fig.202 Ferruginous quartzite from southern Quartzite Formation.Well rounded quartz exhibits worn secondary overgrowth and pitting of surface by matrix. Prismatic tourmaline microlite inclusion in another quartz grain.Matrix is ironoxide and chlorie. (Sp.No.A/198),Cross X 90.

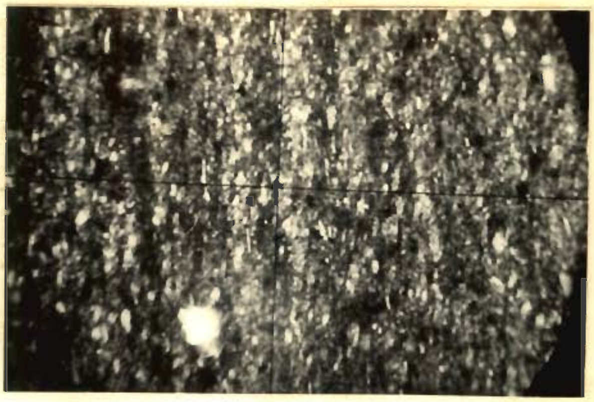

FIG. 197

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FIG. 200

FIG. 201

FIG. 202

Fig.203 Fine grained quartzite (Quartzite Formation).Interlocking detrital quartz,incipient grains elongation and profound granulation along margins. Sp.No.5/189,Cross X 90.

Fig.204 Profoundly granulated detrital quartz in schistose sericite quartzite of Quartzite Formation. Fine quartz of groundmass coalesces with detrital grain(mortar texture). A few fractures run across quartz clast. Sp.No.A/130,Cross X 90.

Fig.205 Extremely elongated (1:5) quartz grains along foliation and exhibiting profound granulation in quartz schist near Singuni Thrust of Quartzite Formation. Sp.No.5/153,Cross X 45.

Fig.206 Bimodal quartz from intraclastic dolomite of Dichli Dolomite formation.Coarse quartz grains are well rounded and exhibit silica secondary overgrowth and marginal replacement by dolomite. Sp.No.A/390,Pol.X 90.

Fig.207 Coarse rounded detrital quartz from insoluble residue of intraclastic dolomite.Sp.No.6/44.Reflected light; X 15.

Fig.208 Dark micrite dolomite elongated pellet with oolitic growth. Note a few angular quartz grains in pellet.Matrix comprises rounded quartz with dolomite cement.Pol.X 90.

FIG. 203

FIG. 204

FIG. 205

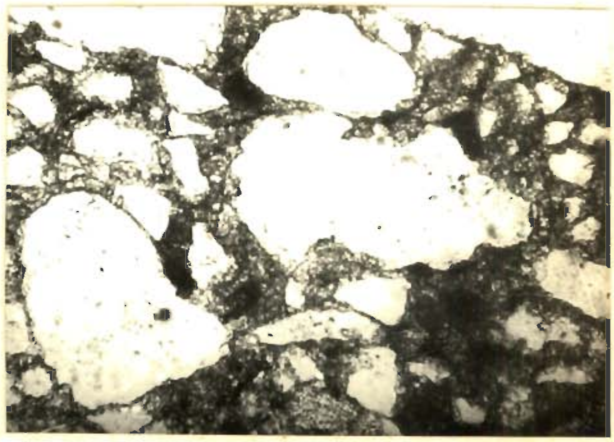

FIG. 206

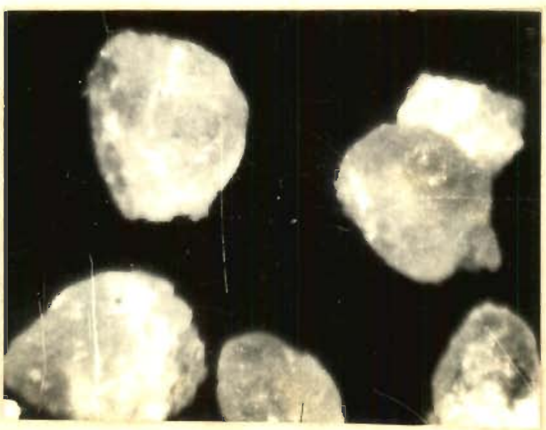

FIG 207

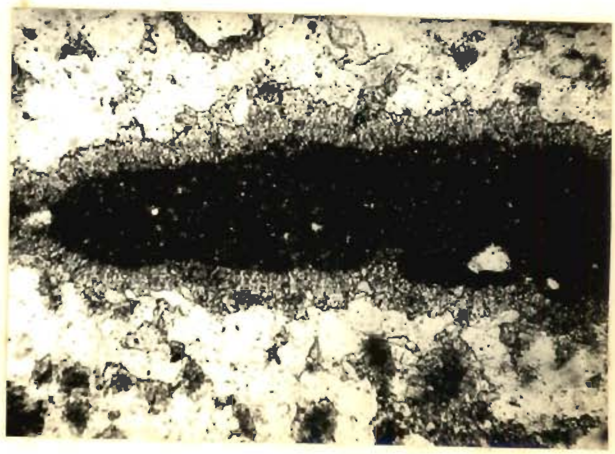

FIG 208

Fig.209 Composite oolite exhibiting single ring growth over nucleus of (i) oolite without nucleus,(ii) oolite with micrite nucleus. In upper hand corner oolite growth over quartz nucleus is seen. Sp.No.A/389, Pol.X 90.

Fig.210 Many rings of oolite growth without nucleus. Also oolites with quartz and micrite nuclei are embedded in quartz rich matrix. Sp.No.A/389. Pol.X 90.

Fig.211- Poikiloblastic muscovite with quartz inclusions in preferably oriented sericite and chlorite groundmass in slates of Dharasu Formation. Sp.No.6/398, Cross x 100.

Fig.212 Subrounded fine sand size quartz embedded in chlorite-sericite felt mass.Thin iron oxide coating over quartz is prominent in purple argillaceous quartz of Dharasu Formation.Sp.No.A/191, Pol.X 90.

Fig.213 Well crystallised and strongly oriented muscovite flakes in pelitic laminae alternating with granoblastic quartz rich semipelitic layer in phyllites of Dharasu Formation.Sp.No. A/382. Pol. X 90.

Fig.214 Silt size quartz embedded in fine sericite-chlorite felt groundmass of phyllitic slates(Dharasu Formation)Note an angular quartz clast in the centre is marginally replaced by sericite. Mica rich laminae alternate with semipelitic layers.Sp.No.6/434.Pol.X 70.

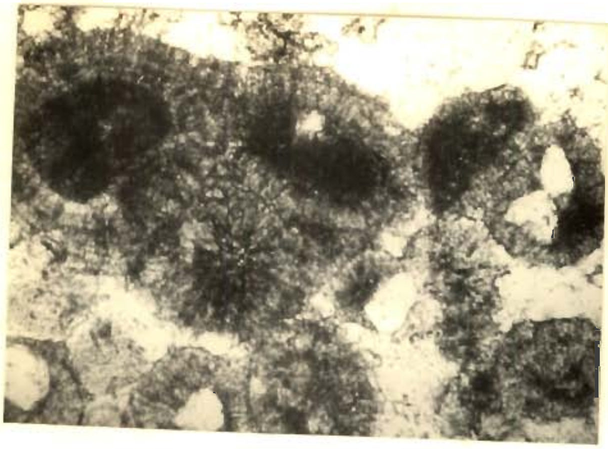

FIG. 209

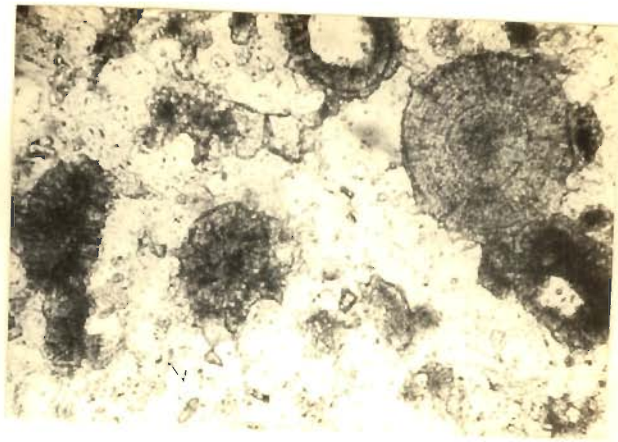

FIG. 210

FIG. 211

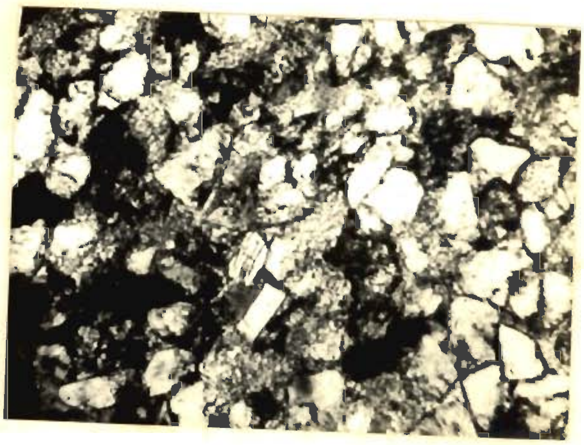

FIG. 212

FIG. 213

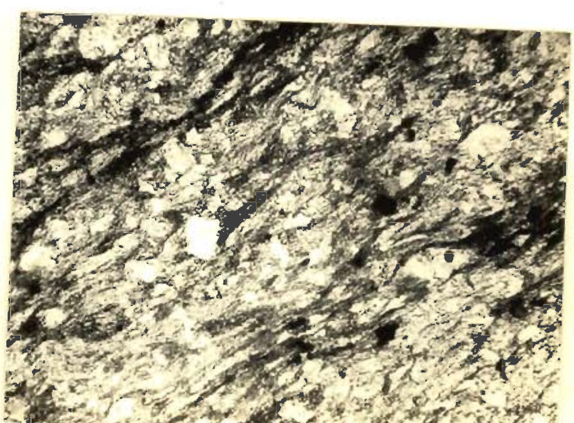

FIG. 214

Fig.215 A typical argillaceous quartzite of Dharasu Formation. Subrounded quartz is marginally replaced by strongly oriented sericite rich matrix.Note marginal granulation in quartzgrain in left corner and fragmentation at the top. Sp.No.6/437,Cross X 70.

Fig.216 Fine grained purple laminated argillaceous quartzite of Dharasu Formation exhibiting microdisplacement of two hematite rich laminae by slaty cleavage marked with hematite coating and recrystallisation of sericite. Sp. No.A/191,Pol.X 20.

Fig.217 Gradational contact between dark,carbonaceous chert and calcite rich laminae.A few clacite rhomb are seen in colourless calcite laminae.Sp.No. Pol. X 70.

Fig.218 Elliptical shaped pellets defined by carbonaceous inclusions embedded in colourless calcite and cherty groundmass. Recrystallisation has obliterated internal structure of pellets. Pellitiferous limestone from Khattukhal limestone member. Sp.No.6/12. Pol.X 20.

Fig.219 Recrystallised,interlocking and preferably elongated calcite in limestone (Upper Uttarkashi Limestone.Sp.No. 6/68,Cross X 70.

Fig. 220 Subrounded quartz and albite clasts in strongly oriented sericite-chlorite matrix (feldspathic quartzite from Bareti Quartzite member).Sp.No.A/133,Crossed X 70.

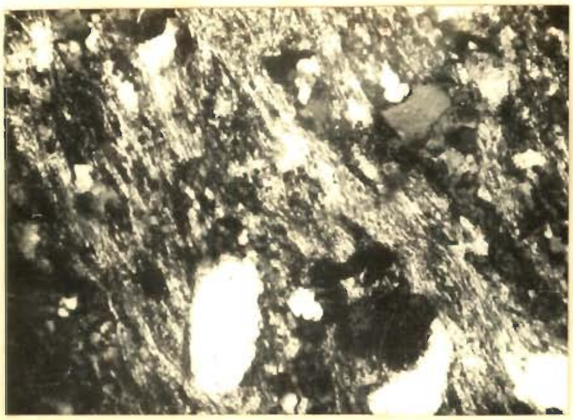

FIG 215

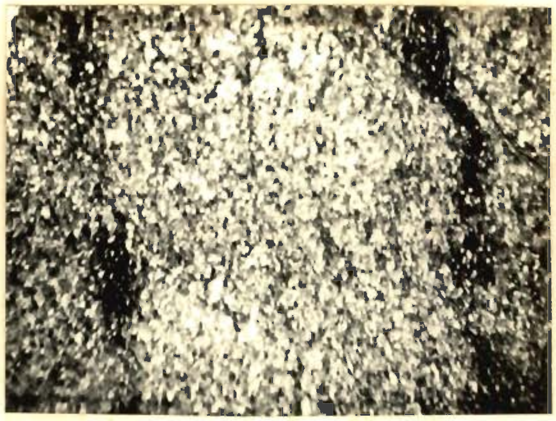

FIG. 216

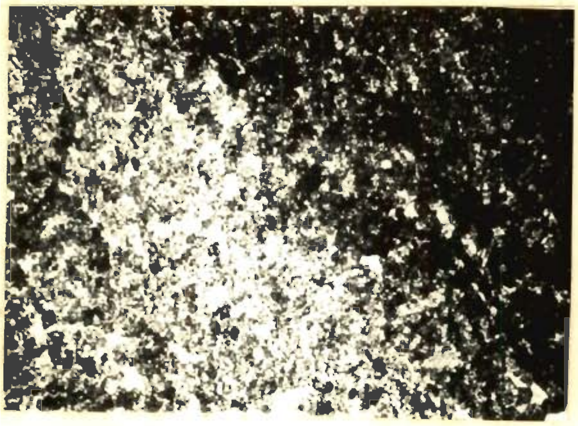

FIG. 217

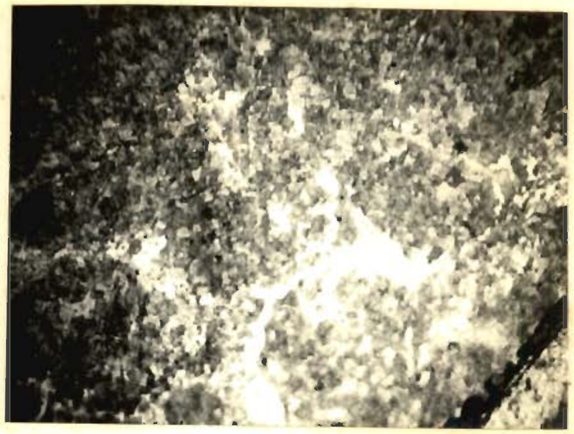

FIG. 218

FIG. 219

FIG. 220

Fig.221 Albite porphyroclast exhibiting microfracturing, displacement and profound sericitization and replacement by sericite. Augen mylonite. Sp.No.6/297, Cross X 100.

Fig.222 Perthite porphyroclast from augen mylonite; profound replacement by sericite of the groundmass along fractures aligned parallel to the foliation. Sp.No.6/296, Cross. X 45.

Fig.223 Highly sericitised albite porphyroclast in fine strongly oriented sericite chlorite groundmass. A quartz vein cut across the clast. Note gradual replacement of albite by sericite.

Fig.224 Profundly granulated margin of a broken quartz porphyroclast in augen mylonite. Few discrete fractures run across porphyroclast. Sp.No.6/303, Cross X 45.

Fig.225 Coarse well crystallised muscovite flakes alternate with fine sericite quartz in augen schist. Quartz augen is highly fractured and granulated at the tail. Sp.No.5/179, Cross X 45.

Fig.226 Regularly fractured garnet (almandine) Porphyroblast surrounded by chlorite in sericite quartz rich groundmass of augen mylonite. Sp.No.5/180, Pol. X 45.

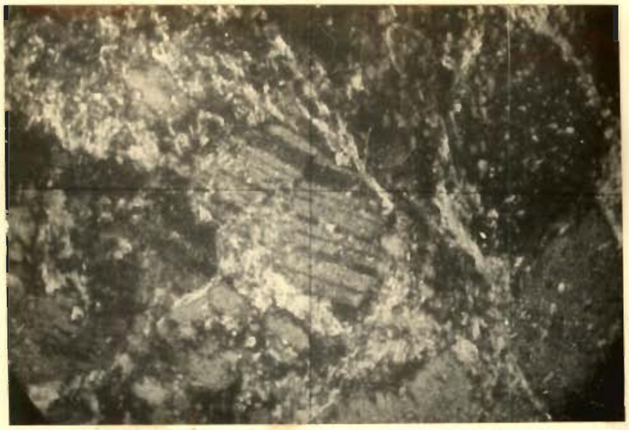

FIG. 221

FIG. 222

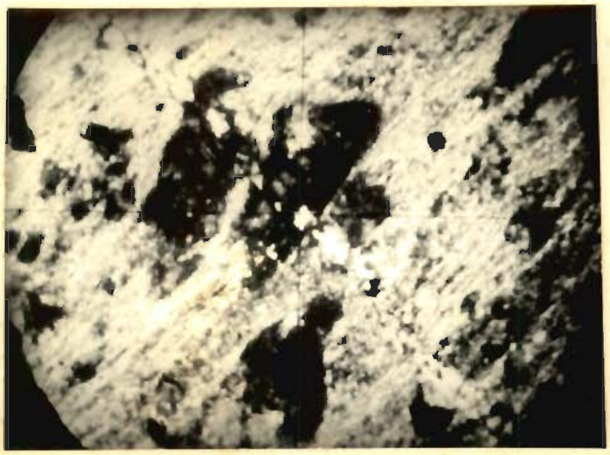

FIG. 223

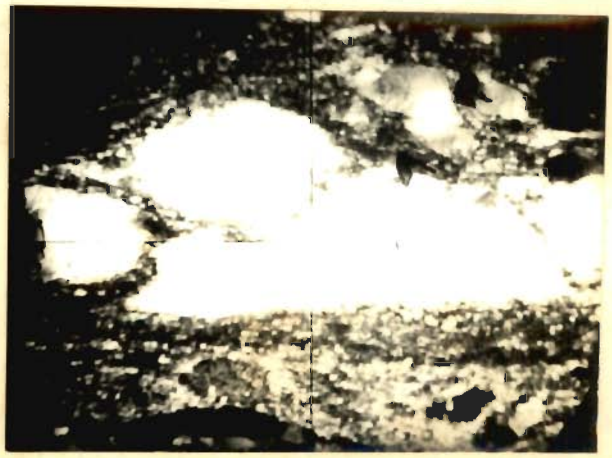

FIG. 224

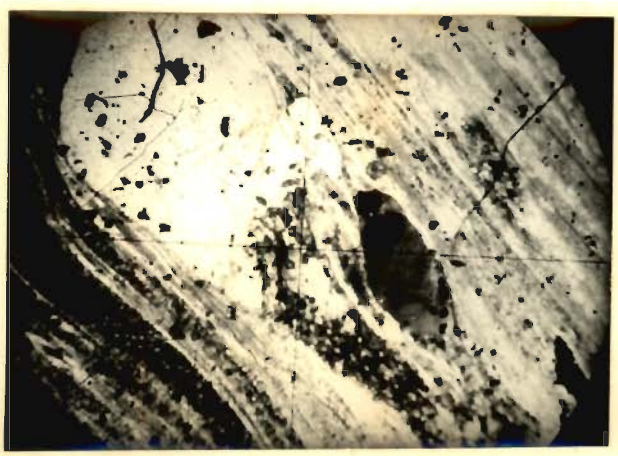

FIG 225

FIG. 226

Fig.227 A complete pale green hornblende pseudomorph after augite. Note preservation of basal pyroxene cleavage which is the margins are chloritised and corrugated. Metabasic.Sp.No. 61/181,Pol.X 90.

Fig.228 Twinned basal augite hypidiomorphic crystal in metabasic embedded in chlorite rich groundmass. Sericitised albite lath is is seen in upper left corner. Sp.No.6/196, Crossed X 90.

Fig.229 Profoundly chloritised augite crystal along margins and cleavages,hazy, and corrugated margins.Chlorite is strongly oriented along the foliation in schistose metabasic. Sp.No. 6/182. Pol.X 90.

Fig.230 Brown prismatic hornblende altering to pale bluish green hornblende along margins in metabasics. Note common prismatic cleavages. Sp.No.A/73,Pol. X 90.

Fig.231 Highly chloritised basal pale green hornblende in quartz-albite-chlorite rich groundmass. Sp.No.A/316, Pol.X 90.

Fig.232 Sigmoidally twisted chlorite due to strain-slip cleavage in chlorite. A few chlorite flakes also recrystallise along this slip cleavage. White mass is quartz. Sp.No.6/134 Pol.X 40.

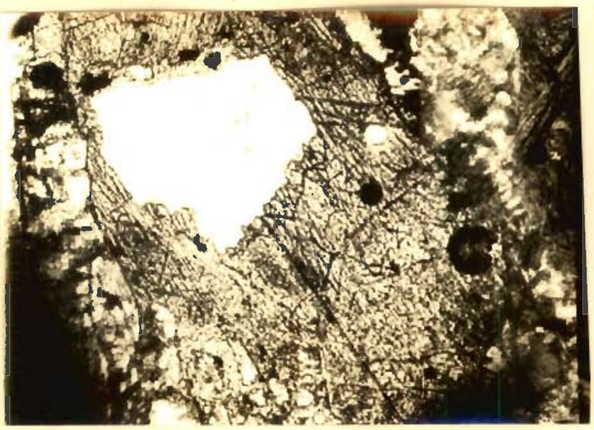

FIG 227

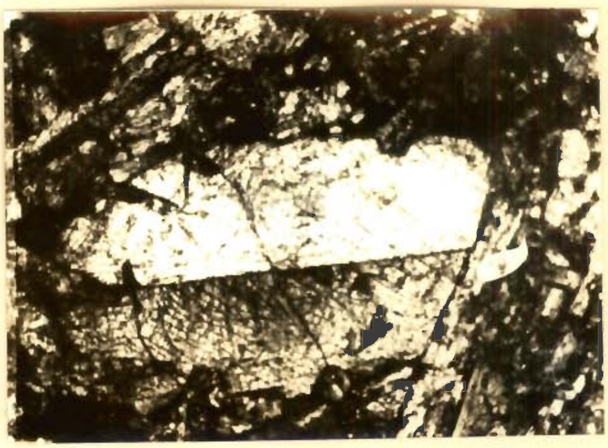

FIG. 228

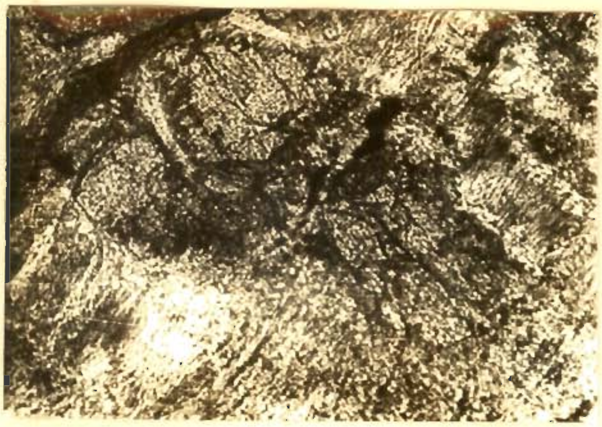

FIG. 229

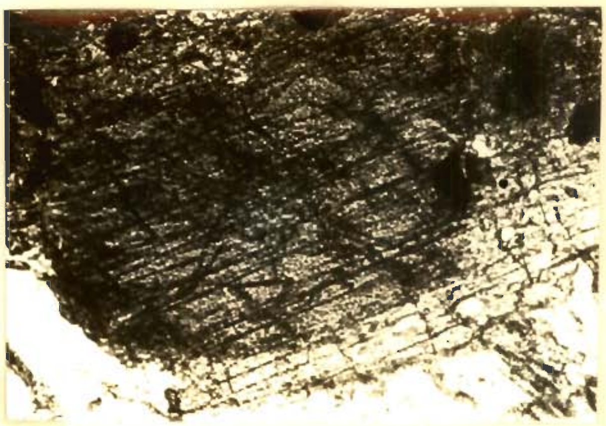

FIG. 230

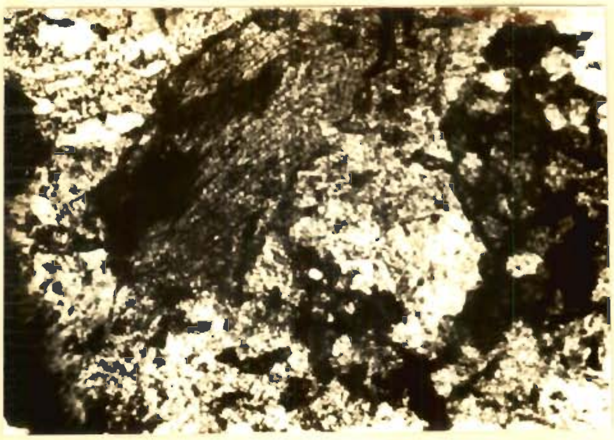

FIG. 231

FIG. 232