DE

PETROLOGICAL STUDIES OF THE PRE-CAMBRIAN OF THE HIMALAYAS IN THE DODA DISTRICT OF JAMMU & KASHMIR STATE FALLING BETWEEN LONGITUDE 75° 30′ : 75° 40′ E AND LATITUDE 33° 3′ : 33° 10′ N

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(Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy of Jammu University)

Certified that this Thesis submitted by Prof. Rajinder Singh Didwal in fulfilment of requirements for the award of Ph. D. degree is worthy of consideration for this degree.

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STRATIGRAPHIC GEOLOGY

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CHAPTER - I

I N T R O D U C T I O N

1. Introduction

2. Location of the area

3. Communications

4. In-habitants

5. Methods of Investigation

CHAPTER - I

INTRODUCTION

1 - Introduction

The geological study of the area, falling between latitude 33° 3' to 33° 10' N and longitude 75° 30' to 75° 40' E, has been considered to be very vital as it provides a link in the stratigraphical formations of the Lesser Himalayas of Himachal Pradesh in the east with those of Kashmir in the north-west. The metamorphic and granitic rocks of the area under reference form a portion of crystalline rocks outcropping further east and south-east in Himachal Pradesh.

Owing to its inaccessibility, ruggedness of terrain and stupendous heights, this area has not received such attention by some of the eminent geologists working in Kashmir as it warranted. As such it had practically remained a virgin area and this is substantiated by the fact that no published work exists regarding the geology of this area, beyond a few abstracts embodied, in the Records of the Geological Survey of India, in respect of the work undertaken recently by some of the personnel of that august body.

The Kaplash anticlinal flexure in Doda region, is an important structural feature which separates the Kashmir basin from the Chamba one in Himachal Pradesh. The area under study is interesting as it lies in the mountainous knot which is formed by the joining of the NW extension of Dhuladhar Range with the Panjal Range. A portion of both ranges comes under study (Plate 2 and Plate 5, Fig. 1). Dhauladhar range is respresented by the extension of Kaplash subrange and is full of snow-clad mountains (Plate 4), which receive heavy snow during winter, and is covered by thick forests; whereas the Panjal range is represented by Siraj

subrange which is almost devoid of forests and comparatively look barren. Besides this the topography of Siraj Range, which is situated on the west of the river Chenab, is more complex as, there are steep and tortorous gradients as compared to Gallihan, Bapso and Gadiara sub-ranges of Kaplash range. Topography, climate, culture fauna and flora of both ranges ~~fro~~ form an interesting contrast with each other.

2 - Location of the area

Doda drives its name from Poppy fruit, obtained from poppy plantation, which was cultivated in abundance in the district in the past, though at present its cultivation is prohibited by law due to certain special reasons. The total area of the district is 11,347.7 sq. Km of which 136 sq. km. has been selected for study and it mostly lies in the central part of the Doda District which is surrounded by

(a) Udhampur and Kathua Districts of Jammu Division in the south and south-east direction;

(b) Anantnag District of Kashmir Division in the north-west;

(c) Leh District of Ladakh Division in the north and north eastern directions; and

(d) Chamba District of Himachal Pardesh State in east; as is shown in plate 1.

The area of my work is confined, in and around Doda city, covering in parts the tehsils of Doda and Bhaderwah of the Doda District.

3 - Communications

In the past only bridle path was there from Batote to Bhadarwah. It was much later that it was converted to motorable fair weather road from Batote to Bhadarwah but this suffered the

disadvantage that it remained blocked for months together because of common landslides. On this road even risk of life was involved as the path became slippery in rains. This route followed the course of the river Chenab.

It is very recently that a motorable road has been constructed connecting Batote with both Bhadarwah and Kishtwar at distance of 53 km. and 109 km. respectively. Near the Doda bridge, which is situated at a distance of 53 km. from Batote, the road bifurcates in two directions, one going south eastwards towards Bhadarwah and the other ~~north-we~~ a stwards towards Thathri enroute Kishtwar.

Though tarred motorable road has been constructed, still it is very difficult to negotiate the interior areas, especially in the Siraj Range, where even foot paths are not well developed. At places ~~only~~ these foot paths become mere tracks, a slight deviation from which might result into a fall thousands of feet below the cliffs, especially when sudden fast winds begin to blow alongwith the lashing out of heavy rains.

4 - Inhabitants

The population on the eastern flank of the river Chenab is on the average good as compared to hilly areas; whereas on the Siraj Range population is sparse. The area is mainly inhabited by Hindus and Mohammandons. Among the Hindus, Rajputs arepredominant and have various castes like Kotwals, Minhas and Ranas. Brahamins, Buniyas, Harijans and Sikhs are also ~~present.~~ met with.

Principal language of the area is Dogri though Kashmiri is also spoken.

The people of the area are of Aryan Origin as is indicated by their fair complexion, broad eyes, long nose and ~~long~~ tall stature.

They are hard working and keep good health.

They are interested in dance and songs. They perform typical dance which is named as "Kud" in which both men and women folk take part and sing melodious songs.

The main occupation of the people here is agriculture, where on the fields both men and women toil together. Sheep breeding and bee-keeping are subsidiary occupations.

Gardening has also been encouraged recently in the area by horticulture department. They also find employment in the timber industry. Some people who are literate join government service in different departments of the State.

5 - Methods of investigations

The work conducted, to study the geology with special reference to petrological aspects, has been carried out more or less on the following lines :-

(a) A geological map was first prepared by me on the scale of 4 inches = 1 mile, covering an area of 136 sq.mile.

(b) Photographs indicating physiography and structural features were taken in the field wherever found necessary.

(c) Representative samples were collected in respect of all the exposed outcrops.

(d) About 250 slides of rock samples were prepared. The detailed study of microslides was made and care was taken to properly identify the various minerals with the help of finding their refractive indices and other optical properties.

For purposes of correct identification of some comparable minerals, under microscope staining tests were applied over uncovered rocks slides to differentiate (i) K-felspars from untwinned plagioclses and (ii) calcite from dolomite.

(e) Refractive indices were determined with the help of a [redacted] refractometer.

(f) Modal composition of important rocks was determined with the help of micrometer. ? and ocular point counter.

(g) Grain size study of all the important minerals has been carried out with the help of ocular and stage micrometer.

(h) For undertaking a study of heavy mineral assemblages usually liquids of special density were used for bringing about the separation of various fractions. Zircon separation was done and proved very useful for the understanding of the origin of granites.

(i) The chemical analyses of the representative samples of the rocks were carried out by conventional methods. TiO_2 and MnO percentages have been determined by universal colorimeter. Because of the absence of facilities in Government G.M. Science College, Jammu, majority of the samples have been got analysed by the various research institutions and to these I am highly indebted.

(j) X-Ray investigations of garnet, got carried out at the post-graduate department of Physics, Jammu University, Jammu, for finding out the exact determination of its species.

(k) Effects of regional metamorphism have been studied in the field in detail and the conclusions arrived at with the help of laboratory work.

(l) Maps, diagrams, graphs etc. were have been drawn to illustrate the text and this has been supplemented by the field photographs. In the laboratory recourse was taken to photomicrography for recording the mineralogical composition of rock specimens under investigations.

CHAPTER - II

HISTORICAL REVIEW

I - Previous work of the study area

II - Previous work of the adjoining region

CHAPTER - II

HISTORICAL REVIEW

I - Previous work of the study area

This area has been little studied by the early geologists and as a result of this very little published literature is available on this region as a whole. The available published work relating to it and the adjoining areas is reviewed in the following pages.

Middlemiss et,al. (1929) have provided the first direct reference to a part of this area in a report entitled," Ore deposits of lead-copper-zinc-iron and other metals" published by the then Mineral Survey Department of Jammu and Kashmir State. In this the authors have described the occurence of Galena in old slaty or schistose formations at Khaleni (33° 8' : 75° 35') and inferred their continuation towards NW-SE direction upto Buniyar in Kashmir Province, along the same line of strike. The NW-SE direction is the direction of the prevailing flexture axes (orogenic lines).

From that time onwards no work seems to have been done for a number of decades and it is only in recent years that officers of the Geological Survey of India have done some mapping in the area. The brief reports of their work have been published in the recent Records (1964 & 1966) of the Geological Survey of India. It is to be noted here that their brief reports embody the description of only a part of the area under reference, which is lying on the eastern side of the river Chenab whereas no mention of the area lying on the western side is available anywhere.

Kapoor (1964) has summarized geological features between

Assar and Bhaderwah as under :- 3

" The rock types met with are garnetiferous schists, slates and quartzites, which are intruded by porphyritic granite".

Kapoor and Mallikarjan (1965) have indicated, in the enlarged area of their study between Assar and Bhadarwah, the large scale presence of granitic gneisses besides porphyritic ones. The presence of phyllites besides slates, mica schists and quartzites have been recorded. Regarding the folding of the rocks along the river Niru, they have made the following observations :-

" The formations have been folded into a NW-SE trending anticline in the Niru river area and are flanked by a synclinal ridge on the south-west".

Very recently, Sharma et al. (1973) during their mapping of Doda-Bhadarwah-Basantgarh region, covering an area of about 2500 sq. km. have revealed that the region is covered by rock formations ranging in age from Archaeon to Triassic. He has further suggested that these rocks are rooted here itself and are autochthonous.

II - Previous work in the adjoining region

Though no considerable work was executed by the personnel of the G.S.I., in the area under reference, yet a great deal of work has been carried out by them in the adjoining areas as is clear from the following paragraphs.

Tilak and Kapoor (1965) have described the presence of Salkhala Series in the adjoining area falling in the north and north-east direction. According to them, " The various rock types are mica schists, gneiss, granite and marble".

Raina and Alok (1972) in their work in Padar area have reported the presence of high grade metamorphic rocks such as granite gneiss, kyanite-garnetiferous gneiss, schists, quartzite, crystalline -

limestone, pegmatite and quartz vein.

The geologists of the Geological Survey of India, while concentrating on the demarcation of various geological formations in Kashmir, have casually referred to the presence of metamorphic rocks and biotite gneisses at Kishtwar. Among these workers may be mentioned Stolizcka (1866); Lyddekar (1876) and Col. McMohan (1885). McMohan took a traverse in Bhadarwah and adjoining areas and concluded that the Bhadarwah slates are of Silurian age and these rest unconformably over the Central Gneisses. These are succeeded by the conglomerate of Upper Silurian age, which in turn are succeeded by the Carboniferous - Triassic series with intervening band of Panjal trap in certain sectors.

In recent years, Wakhaloo (1968) and Wakhaloo and Dhar (1968, 1969, 1970, 1971 and 1972) while referring the rocks to be of Precambrian age have come across the various rock types, which they have assigned to medium grade of metamorphism, mostly falling within the amphibolite facies. They have also observed that towards Kashmir side, near the Sinthon pass, the Precambrians are overlain by the agglomeratic slates and Panjal Traps and this was recorded by them in the University Review, 1968.

Srivastava et, al. (1972) have reported in the Marau Valley of upper Chenab the presence of Salkhala series, comprising of quartzite, para-gneiss, phyllites and schists.

To the east and south-east of the area towards Bhadarwah and Bhalesha, a complete sequence of rocks from Precambrian to Trias has been discovered by the officers of the G.S.I. according to information published by that august body in the "News" Magazine(1970).

Later Alok and Sundram (1972) have reported as thus :-

"The rock units met are phyllites, schists, paragneisses and

quartzites of Salkhlas, Dogra slates and light to dark grey shales, limestones, agglomerates, tuffs, ash and cinder beds belonging to Permocarboniferous and lower Trias sequences. The strike and foliation ranges from N 10°E - S 10°E to N 85°W - S 85°E having 10°-80°dip in either direction. The permo-Trias sequence has yielded abundant fossils like Crinoid stems, Claraia, Productus, Spirifer, Eurydesma, Streptorhynchus and Stenopora".

Recently Sharma et. al. (1973) have done systematic geological mapping of Bhallesha - Bhadarwah area in detail and have made the discovery of fossiliferous carboniferous - Triassic sequence in the area, which according to them shows complete parallelism with the Carboniferous-Triassic sequence of Kashmir. These fossiliferous rocks are folded into a major syncline - the core of which is occupied by the youngest Dalmon limestone of Triassic age.

~~Previous work~~ In the Chamba area which lies beyond Bhadarwah in the adjoining Chamba territory, Fuchs and Gupta (1971); Singh (1972) Gour (1972) and Datta (1972) have made geological observations in that area. Fuchs and Gupta have considered the rocks ~~in Chamba~~ there to be ranging in age from Proterozoic to Triassic to form a synclinorium which is in strike continuation of Kashmir basin. Singh (1972) has also expressed continuation of the rock formations of Kashmir basin in Chamba synclinorium.

Datta (1972) and Gaur (1972) have in their note given the complete succession as under :-

Kalhel Limestone: Limestone with interbedded phyllite and slate

Salooni formation: Quartzite, slate & calcareous phyllite

Manjir formation: Pebbly phyllite, slate and limestone

Chamba formation: Quartzite, phyllite and quartz schist

Chauri formation: Phyllites, pelitic schists, banded bluish-quartzite

Vohra (1967) has described the rocks in the south and south-west direction of the area under study consisting of granites, gneisses, mica schists, limestone, pebble to cobble bearing phyllite, slate, quartzite and shale which are overlain by Panjal Trap. The regional trend is WNW-ESE with moderate to steep dips on both sides. He has further pointed out the presence of synclinal structures near village Ramsu which have lithological units showing different grades of metamorphism and lithology from the Salkhala-series. These lithological units have at the base phyllites with pebbles and cobbles followed by grey phyllites with some carbonaceous phyllites and limestone. He has suggested that this lithological unit should be named "Ramsu formation". Phyllites of this formation are associated with Nickeliferous phrrhotite and pyrite. He has indicated the extension of formation through Pogal-Paristan to Assar and Jathi. At Jathi " Ramsu formation" is also associated with gypsum.

CHAPTER - III

PHYSIOGRAPHY AND STRUCTURAL FEATURES

A - Physiography

(a) Topography

(b) Drainage

(c) Climate

(d) Irrigation and cultivation

(e) Flora and fauna

(f) Landslides

B - Structural features

I - Planer structures

(a) Stratification (S_0)

(b) Axial plane schistosity (S_1)

(c) Axial plane schistosity (S_2)

(d) Slip schistosity (S_3)

II - Linear structures

(a) Lineation

(b) Puckers on schistosity

(c) Mullion structure

III - Major structures

(a) Joints

(b) Folds

(c) Faults

IV - Deformational and Metamorphic History

CHAPTER - III

PHYSIOGRAPHY AND STRUCTURAL FEATURES

A - Physiography

(a) Topography

Geographically Burrad has divided the long alignment of the Himalayas into four sections (i) The Punjab Himalayas from the Indus to the Sutlaj (ii) Kumaon Himalayas from the Sutlaj to the Kali (iii) Nepal Himalayas from the Kali to the Tista (iv) Assam Himalayas from the Tista to the Brahamputra. Geographically Doda area belongs to the Punjab Himalayas.

Geologically the Himalayas has been divided into the following stratigraphical belts or Zones:-

(1) Outer Himalayas or Sub-Himalayas zone. This zone is entirely composed of upper Tertiary rocks. This zone intervenes between Lesser Himalayas and the plains.

(2) Lesser Himalayan zone or Middle Himalayan zone. It comprises of Dhauladhar range and Panjal range. It forms intricate system of ranges. It shows orthoclinal structure. F.Drew(1875) included this zone under middle mountains which lie between outer hills and high ranges of perpetual snow.

(3) Great Himalayan zone. It comprises of innermost line of high ranges above the limit of prepetual snow. The average height of these ranges is 20,000 ft. Zanskar range, lying north of Lesser Himalayas, is the prominent range of this zone.

(4) Trans-Himalayan zone or Tibetan zone. This zone is composed of continous ranges of highly fossiliferous marine sedimentary rocks ranging in age from earliest Palaeozoic to Eocene age. This zone mainly occurs beyond the highest elevations.

The area is situated in the Lesser Himalayan zone. It forms the mountainous knot between NW extension of the Dhauladhar Range and the Panjal Range (Plate 2 and Plate 5, Fig. 1). The area lying on western flank of the river Chenab indicates the development of Siraj range, a branch of Panjal range, running in NS direction

whose spurs are abutting against the river (Plate 6, Fig. 3 & 5). The area lying on the eastern flank of the river Chenab indicates the abutting spurs of the branches of Kaplash range, Barasu Range and Gadiara range which are linked to Dhauladhar range through its intermediatary ranges (Plate 5, Fig.2). The extension of Dhauladhar ranges into the study area through its branches indicates NESW trend.

The mountain system of the area under consideration consists of various ridges with undulating strike and dips and chief of these are the following :-

Khol, Digher, Durbeni, Sarsi, Padri, Mundella, Kula, Drasu and Sewa situated east of the river Chenab and Lal Dharaman, Koti, Dushnan, Hanch and Heinshwa occur west of the Chenab river.

The topography, as depicted, is that of hogback and cuesta. There is a fundamental connection between evolution of landforms with respect to structure and composition of the rocks in it. Usually it is found that hogbacks with domal structures are the products of weathering of granites and granitic gneisses which attain stupendous heights of 366 meters and over.

The highest peak is that of Khol (plate 4).

The second important topographic feature is that of a cuesta type. It is predominently found in schists which surround the granitic masses (Plate 8, Fig.1).

Weathering and differential erosion have been the major factors in carving the topography of the area. The highest peaks are very steep to almost vertical on account of the erosion of the jointed gneisses of which these are compond. Frost action is very common and the disintegration is taking place very fast along the dip joints resulting in the formation of streams which are fed by the melting of snow

on the peaks. The peak of Khol , as is indicated in Plate 4, which typically stands as a pinnacle with vertical and steep slopes and is the result of fast disintegration by frost action.

At lower levels, as in Padri near Dedni and in Mundella area, the granites show the phenomenon of exfoliation which is due to chemical weathering.

> " In chemical weathering the sheets have been notably decayed and discoloured. The work is performed by solution which penetrate slowly along the cleavage cracks of crystals and between the grains and thus induce the formation of new minerals of larger volume". Blackwelder, E.(1925).

It is due to Katamorphism and particularly hydration which is the chief cause of peripheral expansion which results in the formation of concentric shells and makes them weaker. Exfoliation thus makes the rock break easily along concentric shells and fast removal of them by other agencies. Exfoliation is well shown at Padri in granite (Plate 7, Fig. 4). Weathering of granite is intense in Bhala area due to chemical weathering. It is due to the high temperature developed during the formation of granite that biotite has been affected mostly. ~~Biotite~~ It has oxidized along cleavage lines resulting in the formation of haematite. This has further resulted in the development of fractures to help weathering in the later stages. In Bhala area, extreme weathering of this type has resulted in the formation of montmorillonite, which has changed the rock to gruss. Further granodiorite at Mundella is less altered than granite. It provides Parkland topography of Southern laramie Range of Colorodo (U.S.A), and has shown lesser alteration of granodioritic rocks as compared to surrounding granites (Eggler, Larson & Bradley, 1969).

Among the schists, biotite schists are mostly affected by ~~more probably~~

the rising temperatures which has resulted in the formation of haematite. Further weathering has resulted in the formation of montmorillonite.

Hence biotite schists due to their easy alteration have become the paths for the subsequent streams forming dendritic drainage pattern in the homoclinal ridges.

Differential erosion has also made quartzite cliff (Plate 10, Fig.6) and quartz dykes of very hard nature to stand in prominent relief over easily erodable schists.

At Bhala, Khalleni and Doda the rich weathered material is formed over fresh rocks due to intensive weathering.

(b) Drainage

The major drainage pattern is a radial one on a regional basis but locally owing to the development of consequent, subsequent and obsequent streams a typical dendritic pattern is formly established (Plate 48).

The typical drainage system is depicted in the Kaplash Range and in its two constituent minor branches of Marmat Range and Galhian Range.

To the north of Kaplash Range flows the river Niru and its tributary Kankhela stream; towards its west flows Bach stream and Baggar stream; towards its south there is a flow of small tributaries of Baggar stream and towards its east flows the river Devachitta. This establishes the radial pattern.

River Chenab is an antecedant river which has formed a deep gorge in the area (Plate 6, Figs. 3 & 5) by its down cutting while the uplift of the mountains has kept pace with it.

It is indeed a mighty river which is also known as Chandra-Bagha after its two tributaries, the Chandra and the Bagha which have their source on the opposite sides of the Baralacha pass (16000 ft.). In Lahoul, the two tributaries join at Tandi and flow through Chamba, Pangi and Padar in north-western direction upto Kishtwar, where river Wadwan joins it and the river Chenab takes the south easterly trend upto Thathri where it again makes a bend to take westerly trend before it passes through the study area. After this, the river Chenab passes through Ramban and at Arnas it takes southerly trend to pass through Akhnoor to join the river Beas near Multan. The nick points of the river formed near Kishtwar, Thatri and Arnas are due to its meeting with the harder rocks which change the trend of its flow. The river which is full of rapids and mountain gorges in the upper course cuts its way through gneisses, schists and slates. In its upper course it passes through snow-clad mountains which provide perrinal source of water to it.

In the area under reference, the river Chenab flows very fast with sharp currents descending from an altitude of 3000 feet (Plate 6, Fig. 4). It forms a narrow gorge of about 5000 feet in depth amongst the sharp slopes of the mountains (Plate 6, Figs.3&5), as it winds its way mostly through mica schists though occasionally encountering gneisses and phyllites. The presence of river terraces at different level of its course indicate that its rejuvination has taken place during the various phases of mountain building activities in the Caenozoic area.

The Niru,which is one of its tributaries on its left flank, forms the principal consequent stream (Plate 7, Fig. 3) of the area and is flowing parallel to the homoclinal ridges thereby giving rise to a strike valley. It together with its tributaries drains about 3/4th of the study area and cuts its way through granites and granitic gneisses, at higher reaches whereas at intermediate altitudes it passes through gneisses and slates and in lower reaches it passes through mica-schists and gneisses and ultimately joins the river Chenab at Doda bridge. Subsequent streamlets to it (Niru Stream) have been formed through the passage of these through granites and gneisses along the joints of these rocks.

The Niru has its source at Kaplash (14410 feet) and is joined by many streamlets from Seoj Dhar near Bhaderwah which form a dendritic pattern. The perennial source of water in the stream is provided by the snow-clad peaks of Kaplash, Seoj, Khol and Ghati (Plate 4).

In the intermediate and lower reaches it is also joined by many subsequent streams, which flow mainly through biotite schists. The perennial source of water in these streamlets comes from the springs. These subsequent streams have mainly made their way through often biotite schists indicating thereby the effectiveness of diff-erential erosion in this region.

The Kankhela stream, after its confluence with Bhallela streamlet at Bhala, makes the main subsequent stream of river Niru.

This stream, alongwith its tributaries, mainly drains through gneisses and granites. These streams and their tributaries, in their upper courses, have generally developed a dendritic pattern.

These streams alongwith their tributaries flow very fast over the gneisses. In the Bhallela stream itself there are glacial boulders (Plate 6, Fig. 6). The perennial source of water in these stream-lets is the melting of snow from snow-clad mountains (Plate 4) which receives heavy snow during winter and also from the springs present in the area.

Another consequent stream on the left flank of the River Chenab is Bach streamlet near Khalleni which in general drains through gneisses, phyllites, marble and schists. Many tributaries join it as subsequent streamlets moving through weaker rocks of marble and phyllites. The drainage pattern in general is dendritic. It is a youthful valley and one of its tributary near Khaleni shows the formation of waterfall (Plate 7, Fig. 2).

Now coming to the right flank of the river Chenab, the streams of Udianpur, Doda and Jodhpur constitute its main consequent streams. These streams made their way through schists and gneisses along fault planes which have offered the places of least resistance for them. They are joined by subsequent streams producing a dendritic pattern.

These streams of both the flanks are in youthful stage. Cascades have been observed in case of Jodhpur stream (Plate 7, Fig. 1), and water-fall near Khaleni. In short the general pattern of drainage is formed by various consequent, subsequent and obsequent streams which have developed a dendritic pattern

side by side with the main radial drainage of the region (Plate 48). The whole of the drainage flows into the river Chenab which is an antecedent river.

The area exhibits many outstanding geomorphic phenomena which are described as under :-

i) Marked parallelism of ridges and valleys which is generally in NW-SE direction;

ii) A striping influence of alternating weak and strong beds upon topographic forms;

iii) River Chenab flows in a transverse direction to the regional mountaneous structure;

iv) Lesser stream valleys are controlled by lithologic variations as it has been observed that the subsequent streams have invariably cut their way through softer mica schists;

v) Due to differential erosion, the hogbacks and Cuestas are the important geomorphic features carved out of the region.

(c) Climate

The climate of Doda District in general has wide variation, as even in summer months temperatures depart from subzero temperatures on the mountaneous peaks of Kishtwar and Bhadarwah to milder temperatures in the valleys of Bhaderwah at lower heights and then to typical heat on the outskrits of Siraj Range. Therefore this area indicates a zone of "microclimate" - the name suggested by Croll D.(1970) for vast variation of climate in a small particular zone.

It has been observed that whereas branches of Kaplash subrange experience a pleasant temperate climate in summer, the Siraj Sub-Range of the Pir Panjal, due to its lower altitude and direct sunshine and barren cliffs, experiences a tropical climate. Doda city enjoys a temperate climate due its constituting a transitional zone receiving, as it does, both summer and winter rains. The annual rain fall, recorded here, is 112 cm. and the snowfall amounts to 5.6 cm.

In Bhadarwah there are five seasons very well demarcated from one and another. These constitute to the (i) spring season between March

to May; (ii) summer in the months of May and June; (iii) rainy season in the months of July ~~and~~ to September; (iv) autumn season in the months of ~~September~~ October and November and winter season extends from December to February.

In winter heavy snow is seen at high peaks (Plate 4) which begins to melt in summer. Some of the beauty spots of the area, which also serve as hill resorts for summer season, are Lal Dharaman, Dedni, south of Dedan and Trawn (Plate 6, Fig.1).

(d) Irrigation and cultivation.

The cultivation is done on terraced ground. Here irrigation is with narrow canals locally named as 'Kools' at places, but mainly tiller is depended upon Monsoon or winter rains.

Maize, rice or millet is the main cultivation of the area.

Among the fruites, apple, pear and apricot are commonly found in gardens. As much of the soil is preserved and sufficient underground water and heavy rains are there, on the ~~eastern~~ left flank of the river Chenab, the area is highly cultivated. But areas in Siraj Range where slopes are steep with thin soil cover and less of underground water available, cultivation is difficult and comparatively much less.

(e) Flora and fauna

In the area few highest points are barren, but others are covered with grassy meadows and tall trees (Plate 6, Fig.1) especially in the many offshoots of Kaplash sub range. At lower levels, at the end of spurs, creepers, ferns, shrubs and herbs are present.

The important forests of the area consist of ~~are~~ Pinus Excelsa, Pinus Longifolia, Cedrus Deodara, Silver fir (Picea webliana),

Birch, Popular, Chinar, Oak and Spruce. Among the shrubs wild pomegranate are common. At higher levels, above Bhala, the forests contain "Mushrooms".

It is interesting to note that though thick forests occur on the branches of the Kaplash Sub-range on the left bank of the river Chenab, the Siraj sub-range is barren and towards north is devoid of forests except a few hill tops.

The principal wild animals found in the area are deers, musk-deers, monkeys and pijjarr (pijjarr is an animal of shikar). Snakes are also found.

The area has abundant livestock comprising of cows, bulls, buffaloes, sheep, goats, horses and mules.

(f) Landslides

These are very common feature and play an important part in carving out the topography of the area. The landslides have produced steep slopes at the spurs of mountain ranges and their branches.

Two main landslides of Doda area are (1) Malhori landslide and (2) Doda landslide occuring near Beoli. Malhori landslide provides the general trend of landslides in the area in a typical manner.

Malhori landslide as indicated in the (Plate 5, Fig.2) is the main landslide, on the Jammu-Doda road, resulting in the blockade of road so frequently. It is a rockslide and has taken place in phyllites. The rocks are highly jointed and occur in a shear zone. Longitudional joints are dipping 85° towards SW and transverse joints at 42° towards SE at the crown of the landslide area. The presence of gauge on the eastern flank of Malhori and

a wide gap of fifty feet near the crown of the landslide clearly indicates the presence of a steep fault along which the movement has taken place. The main causes of the Malhori landslide described by ~~Didwal~~ the author (1974) are :-

i) weak rocks comprising of phyllites;

ii) presence of steep fault;

iii) abundant underground water;

iv) undercutting by river Chenab;

v) absence of vegetation; and

vi) the presence of steep slopes.

The Malhori landlide can be controlled ~~by~~ as under :-

(a) by developing natural slope;

(b) by making proper drainage channels by fixing up buttress near the river Chenab;

(c) by tempering and filling the deep joints and fractures; and

(d) by encouraging vegetation.

The general causes and the ~~solution~~ controls suggested for Malhori landslide can also be aptly applied to the landslides at other places ~~in general~~, in the area under reference, such as the Doda landslide ~~is also similar in nature and can be controlled by the methods mentioned above~~.

B - Structural features

I - Planer structures

The main types of planer structures, referred as S-planes by Sender, 1948; Turner, 1948; ~~and~~ Naha, 1965; Ravinder Kumar et.al., 1970 and Chander Shekhar, 1973, are also recognisable in the area under reference. The S-planes are marked by stratification (S_o), axial plane schistosity (S_1), axial plane schistosity (S_2) and slip schistosity (S_3). Out of these planner structures S_2 is very commonly developed.

(a) Stratification (S_o)

It is represented by compositional layers of sedimentary origin. A regular platy structure is present in the quartzite at Malnai. Under microscopic study parallel arrangement of rounded zircons conclusively proves its sedimentary origin (Plate 14, Fig. 3). It shows dip of 55° towards N E.

(b) Axial plane schistosity (S_1)

It is obtained by the first phase of movement by which the original bedding was folded into flextural folds with a prominent axial plane schistosity (S_1) .

(c) Axial plane schistosity (S_2) or foliation

It is the most prevalent planer structure developed in the study area. The regional strike of the foliation in the area is NE - SW. The foliation dip of the rocks vary from 85° to 27° in the schists and the foliation of gneisses varies from 60° to 35°. The steep schistosity is seen developed below Doda city (Plate 9, Fig. 4). In mica schists, the schistosity is most conspicuous and is marked by parrallel arrangement of muscovite and biotite flakes.

(d) Slip schistosity (S_3)

It is conspicously developed in mica schists at Doda bridge and at Bhata near Bhuba. These consist of closely spaced impersistant joint planes along which shearing has taken place as is indicated by fracturing and granulation.

II - Linear structures

(a) Lineation - Its following types have been recognized :-

(1) L_1 Lineation. It is shown by the intersection of S-1

and S-2 planes (2 1 2) ~~and~~ is indicated by puckers, Puckers have been observed near Doda bridge (Plate 11, Fig. 1) and at Badraon (Plate 11, Fig. 2) Dhrara and Koti. The lineation may be grouped as "b" lineation as it shows general parallelism with the recognisable fold areas. Puckers showing "b" lineation, have plunge towards S 55°W indicating that pressure was from NE.

(3) L_3 Lineation. It is shown by prominent linear fabric, developed by quartz rods with pronounced mullion structure (Weiss, 72). Mullion structure is developed near Teson (Plate 9, Fig. 2).

(4) L_4 Lineation. It is shown by banded gneisses near Beoli and Krara and is indicated by parallel arrangement of ~~quartzo-felspathic bands.~~ mica flakes along the foliation plane.

(5) L_5 Lineation. This is exhibited by the appearance of lenticular ~~banding xxxxx~~ components in the foliation plane of banded ~~gxxx~~ gneisses of Krara (Plate 12, Fig. 2) and Doda bridge.

(6) L_6 Lineation. It is indicated by microcorrugation lineation due to the development of puckers on S-2 plane (Plate 11, Fig. 2). The mechanism involved for the development of such a type of lineation is as suggested by Cloos (1946) is comparable to the making of corrugated iron by rolling sheet metal longitudinally and allowing for lateral shortening normal to the direction of rolling.

(b) - <u>Puckers on schistosity</u>

These are commonly found near the shear zone and are of ~~xxx~~ various wave lengths ranging from a fraction of 1 mm. to 35 mm. The greatest amplitude of these has been found at Bhata (Plate 8,Fig.3),

whereas near Doda bridge (Plate 11, Fig. 1); Badraon and Khaleni (Plate 9, Fig. 1) the amplitudes are smaller. The nature of all these, however, indicates that the pressure has come from NE direction.

(c) - Mullion structure

The structure is indicated by quartz rods (Plate 9, Fig. 2) which have developed linear fabric with pronounced mullion structure (Weiss, L.E. 1972). The quartz rods, indicating this structure have been observed near the village of Teson in sillimanite biotite - schist at its contact with granites. As soon as quartz veins are formed in schists due to metamorphic differentiation, subsequent interal movement crumples them to form cylindroidal quartz rods (DE-Sitter, 1959). This strcuture clearly indicates that deformational forces were active resulting in the formation of quartz rods.

III - Major structures

(a) Joints

Joints are well developed both in gneisses and schists in various directions throughout the region. In gneisses there are three main sets of joints (Plate 8, Fig. 6) described as under :-

i) Dip or cross joints parallel to acplane constituting first order joints,

ii) strike joints, parallel to fold (B) axis, represent second order tension joints, and

iii) oblique joints are diagonal both to the dip joints and the strike joints.

As regards the schistose rocks only two types of joints are seen viz., types(i) and (ii) mentioned above (Plate 9, Fig. 4). The type (i)joints are dipping at an angle of 85° mostly in N-S direction whereas the type (ii) joints invariably dip at an angle of 20° in E-W direction, (Plate 9, Fig. 4). Such a nature of joints in gneisses and schists has been observed by Pitcher (1952) in the case of Co-Donegal area.

(b) Folds

Folds form an important structural feature of the area under reference and have developed the following types :-

i) Flextural slip folds

ii) Slip or shear folds

(b) Chevron folds

iii) Flow folds

Grigg and Handin (in Wynne Edwards, 1963) have suggested three ways in which rock flow may take place (a) by cataclasis and intergranular movement (b) by intergranular gliding and twinning and (c) by melting solution and diffusion. Due to the interplay of above processes which are caused mainly by stress and diffusion of the rocks individually or collectively, ~~have produced~~ has taken place folding in this area.

(i) Flextural slip folds

These are the commonest folds developed in the area. A flextural fold indicating an anticline is indicated in Plate 8, Fig. 2. Flextural folding is the main mechanism which has resulted in the formation of these folds. It has been described by many authors Billings (1954); Badglay (1965) and Naha (1965). This type of folding has resulted in the bending of more competent layers under tangential forces and the sliding of beds past one another.

ii)a Slip or shear folds

Among the schists shear ~~or slip~~ folds are very common. They are produced by differential slip along closely spaced parallel planes. According to Turner and Verhoogen (1960) and Badgley (1965), these are also named as slip folds. The shear planes are marked by schistosity roughly parallel to the axial planes of the folds. These slip folds are similar, each layer having

the same configuration and radius of curvature and are intermediate between shear and flow folds.

(b) Chevron folds or oblique shear folds

These are sharp angular folds ~~and have developed slip~~ cleavage and are ~~as is~~ indicated in the case of Bhata schist near Bhuba (Plate 8, Fig. 3).

Badgley (1965) has explained such chevron folds in the Hudson river area. Chevron folds are formed when a marked difference in competence exists between adjacent layers, this slip movement is accentuated to the point when the folds become disharmonic in shape as chevron folds (De-sitter, 1959).

The mechanism of formation of such similar folds have been explained by Ramsay J.G. (1967) as follows :-

> " The only mechanism that has been suggested to explain satisfactorily the geometrical form of perfect similar folds is that of slip, shear or flow across a set of layers or beds. The layers act as reference surfaces or markers and points on each layer become differentially displaced with respect to each other and so the layer takes up a folded form".

iii) Flow folds

Flow folds have been developed in high grade schists near the gneisses at elavated temperatures and are observed near Jagota, north of Dehra (Plate 11, Fig. 2) and at Dharara. Flow folds are produced by flow along closely spaced laminae parallel to their axial planes (Wynne Edwards, 1963).

(c) - Faults

The area under reference is dissected by ~~three~~ two sets of faults ~~in all. Small regional faults have developed in the E-W~~, which are generally oriented in the N-S and SSW-NNE directions.

On the western flank of the river Chenab high angle normal faults have developed which are recognised by the following features:-

i) Presence of steep scarps; and

ii) by the presence of warped terraces on both flanks of the river Chenab.

Normal faults have been located as follows :-

(a) At Bhabor and on the opposite spur of Badraon on Udainpur stream; here the schists are abutting against the gneisses.

(b) Steep scrap at Koti on the upper reaches of Doda stream indicates normal faulting.

(c) above Jodhpur near Buttle; here the schists are seen in contact with the gneisses along the fault plane.

(d) A high angle fault has been observed in Doda city area, where schists have been displaced from Heinshwa to Malwas. Along this fault plane Doda landslide had taken place.

On the left flank of the river Chenab faulting on small scale has been observed. The various faults observed here are as under :-

i) Strike slip faulting in S E N W direction is observed near Doda bridge area, here fault line scarp is indicated by the presence of triangular facet at the end. New Doda bridge site which marks obsequent fault line scarp. Further displacement of Adamellitic Muscovite gneiss has thrown it parallel to schist.

ii) A minor dislocation has been observed near Bhala. This dislocation is clearly noted between Kattu-di-Khadi and Dalah along normal fault. The presence of fault is indicated by the prominent fault scarp at Kattu-di-Khadi, which is situated ~~east~~ south of Malothi.

iii) A normal fault has been observed along the Bach Nalla near Khaleni in N-S directions which is clearly indicated by the shifting of various rock types along the fault line scarp.

IV - Deformational and Metamorphic History

Detailed and systematic mapping of the area under study has revealed vast variation in planer and linear structures. Analysis of structures of all scales has led to the recognisation of three episodes of deformation.

D_1 is the first phase of the deformational episode caused by the load metamorphism of the sediments in a gradually sinking geosyncline and has resulted in the formation of phyllosilicates. It has further resulted in the formation of flextural foldsmx marking F_1 phase of folding striking N-S and is indicated by the development of schistosity S_1. F_1 is recognised by the ~~preserved~~ relict hinges of the torn off intrafolial folds. According to Saurindernath Sen (1971) intrafolial folds are rootless structures produced as a result of shearing a plane parallel to the axial, surface S_2.

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D_2 is the second phase of deformation and has resulted in coaxial refolding (F_2) of the F_1 axial planes forming S_2 on a tract on regional scale. It has resulted in the formation of flextural slip folds striking E-W in a major part of the area.

These flextural folds are highly inclined-folds with north easterly dipping axial planes. D_2 has resulted in a group of regional folds showing cummulative transport at right angles to that of the first. This deformation mxk marks the peak period of metamorphism . F_2 has resulted in the formation of garnets (almandines) - the neosilicates - in the paratectonic stage. The crystallization of almandine started during the accentuation of the foliation (S_2) by interplaner slip. This is evidenced by the rotation of almandine with S-shaped S_i trails (Plate 16, Fig. 2 and Plate 27) wraping of garnet porphyroblasts by mica flakes and

presence of muscovite, biotite and quartz inclusions.

D_3 indicates the last phase of deformation where schists have developed intense crinkling and strain slip cleavage (S_3), in which the muscovite has recrystallised along the foliation planes. Development of chevron folds and puckers indicates such a deformation. Formation of puckers is followed by re-crystallisation of sillimanite, staurolite at their apices by the development of " garnet in garnet" as also shown by Das and Pande (1964) and Das (1971) in the metamorphic rocks of Kumaon and Almora respectively. This recrystallisation proves that the thermal peak of metamorphism was attained just after the development of axial plane schistosity (S_2) .

Thus the texture and structure alongwith mineral paragenesis of the rocks of the area indicate that metamorphism, ~~granitisation~~ and deformation are closely related. Here it needs also to be mentioned that the retrogressive metamorphism in the area has taken place after the thrusting. Such a deformational phase ~~have~~ has also been observed in Jutoghs of Simla by Ray and Naha (1971) and around Rajgarh in Central Rajasthan by Saurindranath Sen (1971) and at Kishtwar by Wakhaloo et, al. (1972).

CHAPTER IV

STRATIGRAPHIC AND GEOLOGIC SETTING WITH A BRIEF NOTE ON THE GEOLOGY OF THE ADJOINING AREAS

I. Geologic setting

II. Startigraphy

III. Geology of the adjoining areas

CHAPTER IV

STATIGRAPHIC AND GEOLOGIC SETTING WITH A BRIEF NOTE ON THE GEOLOGY OF THE ADJOINING AREAS

I Geological setting

The area under reference is an integral part of the Himalayas. Near Doda bridge, the important off shoots of the Lesser Himalayas in the locality; viz. Siraj Range, ~~Bapso~~ Barsu Range, Gadiare Range and Galihan Range; coalesce to form a mountainous knot (Plate 2 & Plate 5, Fig. 1).

The Archaeon metamorphic rocks together with their granitic intrusions are also found out cropping in north, north west, north east and are doubtless are the continuation of the similar rocks of this area. It is only towards south and south west that it is bounded by mostly proterozoic rock types which consist both of crystalline and sedimentary ~~types~~ ones.

In accordance with the stratigraphical nomenclature, the Archaeon constitutes the Salkhalas whereas the proterozoic rocks are indicated by the Dogra Slates.

As already mentioned in the previous history of the area, it is in recent years that some of the geologists, of the Geological Survey of India, have found in the adjoining Bhalesa and Bhaderwah areas sedimentary deposits forming complete sequence of palaeozoic and lower Mesozoic rocks overlying the oldest formations, viz; the "Salkhalas" and the Dogra Slates, which from the basement for them.

The kaplash anticlinal flexture separates the Kashmir synclinal basin from the Chamba one and is an important structural feature.

The Geologic setup of the Doda area is illustrated in Plate 3 and the relevant formations are reproduced in the following Tables I

and II. The geologic sequence in N, NW, ~~xx~~ E and SE of the adjoining areas is as follow :-

TABLE I
SHOWING THE SEQUENCE OF FORMATIONS TOWARDS N, NW, E AND SE DIRECTIONS

Tiasic Limestone	Triassic	Mesozoic
Zewan series	Permian	
Gangamopteris beds and Panjal Traps	Permo-Carboniferous	Upper Palaeozoic
Agglomeratic Slate	upper Carboniferous	
Fenestalla shales	Middle Carboniferous	
Syringothyris limestone ...	Lower Carboniferous	
Muth quartzites	Devonian	Lower Palaeozoic
Cambro-Silurian shales and slates	Cambro-silurian	
Dogra slate	Late Precambrian to early Cambrian	Proterozoic
Salkhala schists and gneisses	Precambrian	Archaeon

TABLE II
SHOWING THE SEQUENCE OBSERVED IN SOUTH AND SOUTH-WEST OF THE AREA

FORMATION	AGE
Murree series	Middle Miocene
_____ Murree Thrust _____	
Autochthonous Zone	Nummulitic limestone (Eocene) with palaeozoic rocks in its core
—— Panjal Trap ——	
Dogra Slates	Late precambrian to L. Cambrian
Salkhala schists and geneisses	Precambrian

II Stratigraphy

The area under study is comprised of only Salkhalas. These show wide extension towards Bhaderwah, Bhalesha and Chamba in the east and south-east directions and towards Thathri, Padar and Kishtwar in the north, north-east and north-west directions.

The types of rocks encountered are :-

Marble, quartzite, graphitic phyllites, biotite schist, Almandine-mica schist, staurolite schist, kyanite-biotite-schist, sillimanite schist, migmatite, garnetiferous-mica gneiss, Augen-gneiss and Granitic gneisses invariably intruded by stocks of granites. Apart from these there are sills and dykes of pegmatites, aplites and amphibolites. The lithological units are well depicted in the geologic map (Plate 49). The schists and gneisses which form the most prevalent rock types are highly folded and show the presence of flextural slip folds. Puckers and chevron folds are also present (Plate 8, Fig. 3).

Among the schists, almandine-mica-schists and biotite schists are commonly developed. Other types of schists show meagre development. Migmatites and gneisses show great variation in their kind and grain size. Some of the important gneisses are streaky gneiss, banded gneiss, garnetiferous mica-gneiss, augen gneiss, Potash granitic gneiss, adamellitic gneiss and granodiorotic gneiss. There is an intimate relationship of progressive grade of metamorphism with synkinematic granitization. The gradual gradation of schists to gneisses, presence of relict bands of schists and marble in gneisses, and inhomogenity of granitic gneisses, all go to prove granitization. The rise of migmatic solutions from deep seated portions of the earth crust, in shape of Wegmann's migmatic fronts are responsible for the metamorphic changes. According to the facies

conception the rocks can be grouped into (I) Green-schist facies; (II) epidote-amphibolite facies; (III) amphibolite facies and (IV) amphibolite-granulite transition facies.

These rocks units can very well be correlated with their Salkhala equivalents in other parts of Jammu & Kashmir State as has been described by Wadia (1931, 1934 & 1953); Misch (1949) and Sharma (1973). It further corresponds to Jutogh series of Simla; Vaikrita series of Central Himalayas and Darjeeling series of Nepal and Sikim (Wadia, 1931, 1935 & 1953) and Sharma, (1973). Since the normal order of superposition of the various lithological units is highly disturbed because of structural elements, it is difficult to arrange them in stratigraphical order. The help of lithology, structure and grade of metamorphism has been taken into account to arrange them according to order of super-positions given in the Table III. The apparent lithological succession of the crystalline rocks from north to south is shown in Plate 50.

TABLE III

	Granites and amphibolites	Age not determined
	Pegmatites, aplites and quartz veins	
	Marble	
	Graphitic phyllite	
	Quartzite	
Salkhala schists	Biotite schist	Pre-cambrian
	Almandine-mica schist	
	Staurolite schist	
	Kyanite-biotite schist	
	Sillimanite schist	
Migmatites and Gneisses	Banded and streaky gneisses	
	garnetiferous augen gneisses	
	coarse grained granitic gneisses	

The gneisses and schists are the oldest rocks of the area and form the basement complex for Chamba-Bhaderwah-Doda area as indicated by their lowest stratigraphical position and relatively highest grade of metamorphism.

These are overlain in adjoining areas by unfossiliferous crystalline rocks of Dogra slates of the late Pre-cambrian to early Pre-cambrian age. Salkhalas can be distinguished from the overlying Dogra slates by their exhibiting intenser grade of regional metamorphism, higher degree of plications and considerable lithological variations as indicated by the presence of graphitic phyllites and schists associated with quartzite and marble. According to Chakravarty at al. (1971) :-

> " The salkhala series is characterised by limestone and graphite-phyllite and also by gypsum".

In this respect the series is similar to Shumar series in Bhutan towards the other end of the Himalayas (Nautiyal et al. (1964).

FIELD OCCURRENCES OF ROCK UNITS

(1) Marble

It occurs in shape of bands or pockets, south of the study area, in Khaleni. There are two major occurrences of marble which show marked differences in colour. At Kilota west of Khaleni, it is of whitish colour, whereas at Bhanan (33°6' 59" & 75°30' 50") and at Chibban it is of ~~dark~~ blackish colour. The mode of their occurrences is also different. In the first mentioned locality there is an outcrop of it found between granite and graphitic phyllite.

At other localities it occurs as pockets ~~associated with gneisses~~ amidst different kinds of rocks, at Bhanan it is present between gneisses and the ~~graphitic phyllite~~ schists; whereas at Chibban it is present as relict in the stocky gneisses. It is also observed that black marble near Bhanan has secondary white marble vein in it (Plate 11, Fig. 3) due to plastic flow, indicating its post-crystalline nature.

(2) Graphitic phyllite

There are two main bands of graphitic phyllite occurring in the south and west directions of the study area. One band is present near Khaleni area which extends from Kilota to Dedan (a part of band is outside the study area) in south direction and then takes a turn to north-east which continues upto Kaleh. Second band is present towards south-east of study area, at Seri-Danda area. Both these bands are conspicuous due to their lustrous appearance, dark black colour and fine grained texture. The foliation of these phyllites coincides with the foliation of pelitic schists which varies from 45° to 65°.

The phyllites of Khaleni area are highly foliated and show the development of puckers. Pyrrhotite and pyrite are associated, with these graphitic phyllites of Khaleni, in the disseminated form. The phyllite at Seri is of compact type and has shades of dark and grey colour.

(3) Quartzite

Quartzite is present, in the shape of a lenticular mass at Malnai (33° 5' 58" : 75° 35' 25"). This is the only outcrop observed and is found associated with the schists. Due to its steep dip slope and resistant nature it stands as a prominent ridge (Plate 10, Fig. 5). It is observed in these quartzites, that there is alternation of dirty white layers with pinkish ones, which indicate the relict stratification. It shows an angle of dip = 55°.

SCHISTS

The schists are predominently developed covering almost half of the study area. The colour varies from grey to light brown to dark brown and the schistosity is well developed. The schists are highly contorted and show the common development of flextural slip folds. Puckers and chevron folds are also developed in the schists. These

are of different varieties and are described as under :-

i) Biotite schist

Though it is scattered ~~through all parts~~ over the entire study area, it is quantitatively not important, as is apparent from the geological map (Plate 49). It is present as small outcrops pockets and bands. Its prominent exposers are as follows :-

(a) Balasu (33°7' 02"; 75°37' 10"). This outcrop is indicated in Plate 10, Fig. 6.

(b) Between Barasu (33°6' 12"; 75° 37' 20") and Batholi (33°3' 30" ; 75°35' 41").

(c) Near Bhagratta (33° 4' 18" ; 75°37');

(d) Bontra (33° 5' ; 75°34' 15");

(e) Gujot (33° 4' 40" ; 75° 35' 15");

(f) Kaile (33° 6' 40" ; 75° 35' 15");

(g) Between Kishora (33° 8' 35" ; 75° 32' 55") and It was (33° 8' 25" ; 75° 36' 52"); and

(h) Groundi (33° 3' 40" ; 75° 33' 40").

As biotite schists are easily weathered and eroded among the various types of schists, small streamlets are carved out of these due to differential erosion. The amount of foliation dip varies from 45° to 55° in these.

ii) Almandine mica-schist

Almandine mica schist is the most prevalent rock Type which is present, in almost the whole area of study, as is apparent from the geological map (Plate 49). ~~These~~ It covers an area of about 50 sq. km. out of total 136 square km. and is ~~under study. These~~ are predominently developed on the ~~eastern rather than on the western side~~ left flank of the river Chenab in the area. The prominent exposures of these schists ~~are as follows:-~~ occur at the following places:-

(a) Seva (33° 7' 45" ; 75° 34' 53");

(b) Bhadra (33° 7' 35" ; 75° 33' 50"); (Plate 6, Fig. 4)

(c) Kakrasu (33° 7' 09"; 75° 36' 16");

(d) Between Kaile (33° 6' 40"; 75° 35' 15"); and
Sindra (33° 6' 18"; 75° 35' 55");

(e) Buttle (33° 9' 20" ; 75° 35' 10");

(f) Between Drasu (33° 5' 42"; 75° 39' 30"); and
Chhatra (33° 3' 20"; 75° 40');

(g) Between Thalsera (33° 3' 40"; 75° 35' 45") and
Banjoi (33° 4' 43"; 75° 35' 40");

(h) Bhagretta (33° 4' 18"; 75° 34')

(j) Sangra (33° 4' 30"; 75° 35' 40");

(k) Between Auth (33° 5' 15"; 75° 34' 50") and
Maisri (33° 5' 42"; 75° 34' 30");

(l) Between Pranu (33° 5' 02"; 75° 39'); and
Trawn (33° 5' 15"; 75° 34');

(m) Bigotha (33° 1' 10"; 75° 3' 20") and
Naligondi (33° 7' 14"; 75° 34' 10");

(n) Khaleni (33° 8' 15" ; 75° 30' 40");

(o) Badaron (33° 9' ; 75°35' 30");

(p) Between Beoli (33° 9' 39"; 75° 32' 30") and
Gat (33° 6' 50" ; 75° 34' 30");

(q) Jodhpur (33° 8' 20"; 75° 33' 15"); and

(r) Jigot (33° 9' 30" ; 75° 33' 20").

These are characterised by the conspicuous presence of the red almandine garnets which range in size from 0.5 mm. to 3 mm. in diameter. These schists vary in colour from greyish white, brownish to dark grey colours at various places. Puckers and chevron folds are also commonly developed. The foliation dips of these schists

vary markedly
~~vary strongly~~ from 27° to 80° as is clear from the geological map (Plate 49). These directions of their strike ~~is~~ are variable. These are traversed by quartz veins near Pranu.

iii) Staurolite schist

These are found only in three outcrops in the study area as is clear from the geological map (Plate 49). The outcrops of these schists are developed at :-

(a) Badraon (33° 9' ; 75° 36');

(b) Lal Dharaman (33° 9' ; 75° 30');and

(c) Doda bridge area.

These schists are of greyish white to dark colour and are highly puckered. These are found between almandine mica schists and sillimanite schists at Doda bridge, between almandine-mica-schist and kyanite schist at Lal Dharaman and between almandine-mica-schist and gneisses at Badraon. The staurolite is conspicuous mineral in these schists and is recognised with the help of microscope. These schists have foliation dip varying from 45° to 65°.

iv) Kyanite biotite schists

A very small outcrop of kyanite-biotite-schists has been found near Lal Dharaman. In these schists, kyanite can only be recognised, under microscope. A good outcrop of these has also been found at Puneja, north east of the study area, near Dehra.

v) Sillimanite schist

These schists are developed as thin bands mostly at the contacts with the gneisses and granites and have reached the highest grade of metamorphism amongst schists. These schists are of reddish brown colour. The conspicuous mineral of these schists is sillimanite, which has been recognised under microscope, where it is found as thin

needles or as fibrous mass. These schists often show the presence of puckers. These are prominently developed at the following localities :-

(a) Dharara (33° 50" ; 75° 33' 34");

(b) Sewa (33° 7' 45"; 75° 34' 58");

(c) Sindra (33° 9' 10" ; 75° 35' 55");

(d) Malnai (33° 5' 58" ; 75° 35' 25"); and

(e) Lal Dharaman (33°11' ; 75° 30' 45")

The foliation dips of these schists vary from 55° to 65°.

vi) Migmatites

Migmatites are developed at many places as is apparent from the geological map (Plate 49). These show gradational contacts with the schists. These are present mainly as streaky and banded gneisses. Migmatites indicate the presence of alternate white bands of granitic composition with the dark bands comprising of palaeo-some and melanosome (Plate 9, Fig. 1). The prominent outcrops of banded and streaky gneisses are met in the following localities :-

(a) Beoli (33° 9' 39" ; 75° 32' 30");

(b) Barshal (33° 9' 41" ; 75° 33' 15");

(c) Bubha (33° 6' 50" ; 75° 33' 50");

(d) Doda bridge (33° 8' 25" ; 75° 32' 30");

(e) Chibban and Krara

The foliation dips of these migmatites vary from 45° to 65°.

vii) Gneisses

The gneisses are predominently developed in the metamorphic complex of Doda and come next only to almandine-mica-schists in distribution as is apparent from the geological map (Plate 49).

Migmatite and high grade schists show gradual contact with gneisses in general. These form prominent hillocks, wherever they are present, and are readily recognisable by their greyish colour and typical gneissose structure. The composition, texture and structure often show considerable variation and hence can be distinguished under three main groups :-

(a) Garnetiferous augen gneiss

(b) Muscovite gneiss

(c) Porphyritic granitic gneiss

(a) Garnetiferous augen gneisses

These show typical gneissose structure. These are named as augen gneisses, as felspars occur in the shape of "lenses" or "eyes", in these. These also contain almandine garnets in them, in most of the places. Their foliation dips are between 55° to 65°. The prominent outcrops of them are present in the following localities :-

i) Heinshowa range;

ii) between Nalva and Shai Pot;

iii) between Bhabor and Hanch;

iv) Below Doda city;

v) east of Mundella; and

vi) a big outcrop extending from Krara through Jindani, Dehra, Agreka to Dharara.

(b) Muscovite gneiss

This gneiss is present only at two outcrops around Doda bridge (33° 8' 25" ; 75° 33' 35") and below Doda city. It is of greyish white in colour and possesses gneissose structure.

(c) Porphyritic granitic gneisses

These gneisses are found, mainly in the east and south of the study area, and show a great deal of change in the mineral and

chemical composition. Megascopically the minerals do not clearly exhibit prefered orientation (Plate 13, Fig. 1). Their foliation dips coincide with that of the pelitic schists and range in amount from 33° to 55°. These have sharp contact with the granite intrusions. Their prominent exposures are present in the following localities :-

i) between Saura (33° 4' 10" ; 75° 37') and Kungle in Bapso range.

ii) between Saras and Khol in Galihan range, and

iii) between Kummiari and Duga.

INTRUSIVES

(1) Granites

Granites are present in the shape of stocks at :-

a) Bhala (33° 3' 51" ; 75° 36' 35")

b) Mundella (33° 4' 11" ; 75° 37' 12")

c) Dedni granite developed at Padri. Their distribution is shown in Plate 49. These are intruded into the surrounding schists and gneisses and show sharp contacts with them.

Bhala-Mundella granites are of greyish colour, whereas Dedni granite is of brownish colour. They show typical holocrystalline, coarse grained and hypidiomorphic texture. At Mundella granodiorite is also developed.

(2) Pegmatites

A large number of pegmatite veins are found scattered in the area. Their distribution is shown in the geological map forming Plate 49 of the thesis. There are two types of pegmatites present:-

(a) Muscovite and tourmaline bearing pegmatite

(b) Kyanite bearing pegmatite.

Muscovite and tourmaline bearing pegmatites form almost all the pegmatite veins except one. Muscovite is present in all the pegmatite veins of this type and attains the maximum size of 9 cm. in length. Tourmaline is typically developed in these at

Thallela and Saye. The prominent pegmatite veins are present in the following localities :-

i) The best development of veins is at Thallela. Here the thickness of veins is varying from 4 ft. to 8 ft. The veins are present as sills and dykes in the gneisses.

ii) Two pegmatite veins of 4 ft. thickness are present below Doda city.

iii) A pegmatite vein of 4 ft. thickness was observed inbetween migmatite and schists at Lal Dharaman.

iv) Two pegmatite veins of 2 feet thickness are present at Buttle. The veins are present as dykes in schists and gneisses.

v) Two pegmatite veins of 2 feet thickness are present in the tourmaline permeation gneiss at Saye.

KYNITE BEARING PEGMATITE

It is only localized at one place - Bhabor (33° 8' 50" ; 75°35'35" It is present in the shape of sill between almandine-mica-schist and gneiss. Kyanite which forms typical mineral in it, has bladed form and has large grains measuring upto 10 cm. x 7 cm.

(3) Aplite

Aplite veins are present in the south-east at Saras (Plate 10, Fig. 2) and Khabral. These are present in the shape of dykes cutting across gneisses and are recognised by their reddish brown colour and fine grained texture.

AMPHIBOLITES

These are present as sills and dykes and make sharp contacts with the surrounding metamorphic rocks. The common thickness of these amphibolites is 4 feet. These are usually of dark greenish colour. The mineral orientation of prismatic crystals of hornblende does not

coincide with the country rocks. These, in usual, exhibit a banded appearance, due to the alternation of melanocratic and leucocratic bands, comprising of felspar and quartz and the hornblende crystals respectively. It appears that banding is in response to metamorphic differentiation. Amphibolites occur prominently in the following localities :-

i) Seja
ii) Jodhpur
iii) West of Seva
iv) Barshal
v) West of Kumiari

III GEOLOGY OF THE ADJOINING AREAS

The various formations present in the adjoining region have been depicted in the Plate 3. Their brief account is given as under:-

SALKHALAS OF THE ADJOINING AREAS

Salkhala series has been named after a little hamlet situated on the bank of Kishenganga in Muzaffrabad by Wadia (1928 & 1934). This series is of wide occurrence in Jammu and Kashmir State and has been described by Wadia (1931, 1934, 1953); Misch (1949) and Sharma (1973).

Wadia (1931), has vividly described the rocks of this series as comprising of " Wavy crystalline schists and phyllites, carbonaceous slates generally altered to graphitic phyllites and schists, as a rule pyritous; associated with carbonacous or grey or white limestone often dolomitic; and calcareous slates which are frequently altered to sachroidal marbles and calc-schists respectively. Igneous instrusions are notable constituents of this series". According to him, it indicates the oldest sedimentary deposits of N.W. Himalayas laid down over the fundamental gneisses which constitute the basement complex.

Recumbent folding, isoclinal folding and flextural slip folding

constitute the important structure in the series. Intensive minor folding, is also characteristic. The Salkhala series is characterised by the presence of a graphitic phyllites and schists associated with limestone and quartzites; by high degree of foliation and intensive regional metamorphism.

Chakravarty, et al. (1971) have indicated Salkhalas of Kashmir as of Precambrian age and have correlated them with Jutogh and Vaikrita in Simla and U.P. Himalaya, Bhimphedis of the Nepal Himalaya; Darjeeling series of Darjeeling area, Darjeeling and the Thimpu and Paro series of Bhutan. They further believe that crystalline schists and gneisses of the extra-peninsula Pre-cambrian area are derived by metamorphism and graintigation of the earlier sediments.

DOGRA SLATES

Wadia (1928) has named these rocks as Dogra slates after the Dogra country, the home of valient Dogra Rajputs, which lies between the valleys of Jhelum and Ravi. The name has reference to the fact that these slates are significant lithological types in the Lesser Himalayas. Salkhalas are overlain by them without apparent sharp break. In the adjoining areas these are well developed ~~[illegible]~~ north of Assar ~~and in the west~~ towards Ramban area. These are also developed in the Kishtwar area and near Bhaderwah town which are towards north and east ~~south~~ south directions respectively from the present study area. Towards the ~~south~~ north and west these slates together with that of underlying Salkhalas are thrust over the formation of the autochthonous zone and the boundary, as such, on these sides is well demarcated in these directions. These rocks have more or less uniform composition, indicated by the presence of black shales and grey phyllites in which quartzite partings are invariably present. Dolerite intrusions and quartz veins are sometimes met with. Their thickness is 2500 meters.

These are considered to be homotaxial equivalents of Simla slates in the Punjab and Kumoun region and also of Attock slates in Hazara district of Pakistan.

Their age is Late Precambrian to Early Cambrian. These slates alongwith the underlying Salkhalas indicate deep geosynclinal deposits of Precambrian which changed gradually into shallower deposits with the beginning of the Palaeozic.

CAMBRO-SULURIAN ROCKS

These rocks show conformable passage over Dogra slates. Good outcrops of these have been found in the south beyond Bhaderwah and Balesha and in the north east towards in the Kishtwar. In south-east these are encountered towards Pangi, Chamba and Lahoul.

These are slaty shales of variegated colours banded sandy shales and oolitic limestone (algal), and show rare development of with annelid sandstone.

MUTH QUARTZITE

It has been recorded in Wardwan valley of Kishtwar in the north-west. It has typical white colour and is devoid of fossils. It is correlated with Muth quartzite of Spiti.

Upper Palaeozoic and Mesozoic formations are well developed, in the north-west direction at Marbal and Banihal. The complete sequence of these formations as indicated by Hazra & Prasad (1963), at Banihal is as follows :-

	Jurassics
	Triassics
.....	fault .....
Upper Palaeozoic formations	Zewan beds
	Gangamopteris beds
	Panjal Traps
	Agglomeratic slates
	Fenestella shales
	Syringothyris limestone
.....	Thrust fault .....
Precambrian	Older slates

Syringothyris Limestone

There is a development of thick strata of syringothyris-limestone 700 - 1000 meters in thickness. It is equivalent to Lipak Series of Spiti. It is composed of grey limestone and quartzite rocks. It has typical presence of Lower Carboniferous index fossil Syringothyris cuspidata. Products and Athyris are also present in the limestone.

Fenestella shales

Overlying the above mentioned Syringothyris Limestone is a bed of Fenestella Shales, which is equivalent of Po-Series of Spiti. It is composed of dark coloured shales and interbedded quartzites. Fan-shaped fenestella, protorepora ampla, productus, spirifer and pecten are important fossils, present in it. Its age is middle - carboniferous. However, Tiwari & Singh (1967) have indicated its age to be Upper Carboniferous on the basis of microfossils.

Agglomeratic Slates

They consist of massive or rudely laeminated and cleaved tuffs, looking like slaty graywacke, in which are sparsely distributed fragments of angular quartz grains, quartzite, sandstone, grit, shale and conglomerate. Tillite is also associated with the slates at various places. They are mostly devoid of fossils but fragments of spirifer from the upper parts of the formation in Banihal area has been reported by Hazra & Prasad of G.S.I. (1963).

In few localities in Kashmir, important discovery of Eurydesma has also been reported by Bion & Middlemiss (1928). Recently at Singpore, north-west of the area under study and Kishtwar Cordaites have been discovered in them by Wakhaloo et al. (1968) and have established their age to be Permo-carboniferous. However, K

Fuchs & Gupta (1971) have indicated their age from Middle - Carboniferous to Lower Permian.

As regards their origin, Wadia (1928 & 1953) and Krishanan (1956) have shown these rocks to be the products of explosive volcanic action combined with ordinary subarial deposition and have established that large parts of this formation are pyroclastic. Hazra & Prasad (1964) have quoted Middlemiss about their origin and have described them to ~~be~~ have "originated from the deposition of tuff in shallow water or subaerially deposited with pyroclastic sediments as well as due to glacial agency, the angular pieces and grains being frost-weathered debris, and transported by floating ice masses to lakes at a later stage". Wakhaloo et al (1968) have ascribed glacial origin to these rocks developed at a Singhpore locality lying north-west of Kishtwar. Ahmad, F(1961) and Fuchs & Gupta (1971) have also supported the glacial origin for these rocks.

Panjal Trap

Panjal trap lies over the Agglomeratic Slates every-where with a transitional contact. The composition of lava flows is that of Augite Andesite. It shows phenomenon of epidotization which ~~here~~ has given greenish colour to most of the rock formation. The rocks are massive. Amygdaloidal structure is also commonly observed. Its primary constituents are plagioclase and augite, developed in a fine grained semicrystalline groundmass, with magnetite and ilmenite as important accessories. The maximum thickness attained is 1066 meters. The volcanic activity in Kashmir commenced in permo-carboniferous. It ceased in Permian in Eastern Kashmir though it continued in areas towards north west like Guris upto Upper Trias.

Gangamopteris beds

The Panjal Traps are overlain by a compact chert like white or cream coloured rock known as "Novaculite", which forms the base of these. Novaculite has been derived by the metasomatic silicification of preexisting limestone.

Gangamopteris beds are composed of carbonaceous shales of yellow, buff and grey colours and sands interbedded with thin bands of conglomerates. The presence of conglomerates at the base clearly indicates the conditions which were prevalent at the beginning of the Gondwana formation everywhere. Gangamopteris Kashmirensis, Glossopteris Communis, Vertibraria Indica, Noeggerathiopsis and Taeniopteris form important plant fossils(Hazra & Prasad,(1957). This flora indicates that these beds are of Permo-carboniferous age.

Zewan Series

Gangamopteris series is overlain by Zewan series. However, their voluminous development is in the upper Sind and Lidar valleys. It is mainly comprised of limestone and shale outcrops. These are of small thickness and in their linear extent are much crushed and sheared between Panjal Trap and the Trias. The fossils commonly present are products, spirifer, chonetus, marginifera, lyttonia, eurydesma and protoretepora.

Triassic limestone

It is mainly composed of compact, bluish or greyish limestone which is sometimes dolomitic in composition. The rocks are prominently folded and have developed isoclinal folds. It is poorly ~~xxxxifer~~ fossiliferous. Only few corals and crinoidal stems have been observed at Banihal. Besides, Panjal Range it has shown ~~wide~~

wide development at Wadwin, Sind, Lidar and Gurais valleys. It, further, finds its extension from central Ladakh to Karakoram.

Jurassics

They are present as small outcrops, it consists of variegated quartzitic sandstones, grey limestones and shales.

Upper Palaeozoic formations alongwith Trias have also been observed ~~in~~ towards the east and south-east of ~~the study area~~ Doda in Bhalesha area by G.S.I. personnel. Recently ~~in~~ according to the News Magazine (C.S.I.) (1970), these formations have been reported as under :-

"Adjoining te Himachal Pradesh in Bhalàsha area, Doda district, Jammu & Kashmir State, a sequence of rocks closely resembling in lithology and faunal content to the Agglomeratic slates, Zewans, Panjal Traps and Lower Trias of Kashmir valley, has been recorded. Permian fossils found in the slates include Eurydesma cordatum, Morris var. Compressa Reed, Productus (Taeniotherus) permixtus Brion, ~~Kitchin~~, Neospirifer rajah, Protoretepora etc. and the Lower Triassic fossils are represented by Calaria sp. and Glyptophiceras. Slates with ill preserved plant fossils exposed near Masha Ghatti gali are considered to be representative of the Gondwanas".

In the south-west direction, the Dogra slates together with underlying Salkhalas have been thrust over autochthonous zone which is represented by Eocenes with f Palaeozoic rocks in its core.

EOCENES

Wadia (1934) has described Nummulitic limestone of the Eocene as the youngst formation of the Himalayan Geosyncline and is well represented in the autochthonous belt of much disturbed rocks of the foreland.

These are mainly composed of shaly phyllites, carbonaceous phyllites, limestone and quartzites. Numerous folds and minor faults are present in the formation.

Wadia has described these to be Eocene with the help of nummulitic fossils - Nummulite and Assilina - which are found in the north-western extension of these beds.

MURREES

In the south and south west of Eocene formation are Murrees. Nummulitic limestone is overthrust over Murrees at Chakwa Nalla near Batote, forming Murree thrust. These are of Middle Miocene age.

The Murrees are mainly composed of hard grey standstone with red and purple clays and shales. Their thickness is about 6000 feet. Leaf imprints of di- and mono-cotyledons are occasionally met with.

The landslides frequently occurring in this formation upsetts the traffic on the Jammu and Kashmir Highways especially in monsoon months and I have had an occasion of undertaking thorough studies about their origin and prevention (Didwal, 1960 & 1967).

CHAPTER - V

PETROLOGY OF THE CRYSTALLINE ROCKS

1. MARBLES

2. PHYLLITES

3. QUARTZITE

4. SCHISTS

5. MIGMATITES AND GNEISSES

6. POSTKINEMATIC GRANITES

7. AMPHIBOLITE

CHAPTER V

PETROLOGY OF THE CRYSTALLINE ROCKS

The geological setting and distribution of the rocks of the area have already been mentioned by me in Chapter IV and the present chapter deals with the petrography and petrogenesis of the various rock types. The nomenclature of the rocks has primarily been based on their structure and further subdivisions have been made by taking into consideration their mineralogical composition. The various types of the rocks present are given in the following table :-

TABLE IV

1. MARBLES

   i) White marble
   ii) Black graphitic marble

2. QUARTZITE

3. GRAPHITIC PHYLLITE

4. SCHISTS

   i) Biotite schist
   ii) Almandine mica schist
   iii) Staurolite schist
   iv) Kyanite biotite schist
   v) Sillimanite schist
   vi) Felspathic schist

5. MIGMATITES AND GNEISSES

   i) Migmatites
   ii) Garnetiferous augen gneiss
   iii) Granitic gneisses

      a) Potash granitic gneiss
      b) Adamellitic gneisses

         i) Muscovite gneiss
         ii) Augen gneiss of Bhalla-Mundella area

      c) Granodioritic gneisses

         i) Grey granodioritic gneiss
         ii) Hornblende biotite granodioritic gneiss

iv) Tourmaline permeation gneiss

6. POSTKINEMATIC GRANITES

I Granites

(a) i) Granite of Bhalla-Mundella area
ii) Dedni granite
iii) Granodiorite

(b) Xenoliths as inclusions in granites

II Pegmatite

i) Muscovite and Tourmaline bearing pegmatite
ii) Kyanite bearing pegmatite

III Aplite

IV Quartz veins

7. AMPHIBOLITE

1. MARBLES

Marble is present at Khaleni in two varieties as :-

i) White marble
ii) Graphitic black marble

i) White marble

Megascopically it is saccharoidal, fine grained and has granulose structure. Its specific gravity is 2.72.

Under the microscope it shows typical development of granoblastic texture (Plate 14, Fig. 1). It is mainly composed of calcite though other prominent minerals developed are diopside, tremolite and actinolite with grossularite. The accessories present are sphene and magnetite.

Significant properties of minerals are as under :-

1. Calcite:- Its average grain size is 0.7 mm. in diameter, but occasionally one comes across grains whose diameter is 1.4 mm.

It shows the development of rhombohedral cleavages and shows polysenthetic twinning lamellae (Plate 14, Fig. 1). Its birefringence is 0.172.

2. Diopside : Its largest grain is 0.3 mm. in diameter. It shows the development of double primatic cleavages. It is non-pleochroic and shows birefringence = 0.031. Its extinction angle is 45°.

3. Tremolite: It occurs as elongated primatic grains. It is colourless with perfect cleavage. Birefringence = 0.027. Its extinction angle is 15°.

4. Actinolite : It ~~has few grains~~ is occasionally met with and is recognised by its pale green colour and slight pleochroism. It has extinction angle of 12°.

5. Grossularite : It is of light brownish colour and is isotropic.

6. Accessories:

(a) Magnetite: It is the common accessory. It is black and opaque ~~and [illegible]~~ and exhibiting steel grey colour in reflected light.

(b) Sphene: It occurs as rhombic grains of yellowish brown colour. It is highly pleochroic with X = colourless, Y = pale yellow and Z = reddish brown. Birefringence = 0.14.

TABLE V

MODAL ~~ØK~~ ANALYSIS OF WHITE MARBLE ~~AT~~ OF KILOTA

Calcite	93.00%
Diopside	2.20%
Tremolite - Actinolite	1.53%
Other minerals	3.27%
	100.00%

ii) Black graphitic marble

Under the megascopic study, graphitic marble shows typical granulose structure. It is of black colour and its specific gravity is 2.62.

Under the microscope, it is comprised of calcite, graphite and diopside with haematite as an important accessory. The important properties of its constituents are described as under :-

1. Calcite : It is the largest component of the rock. It is colourless and has developed rhombohedral cleavages. Birefringence=0.172.

2. Graphite : It has tabular shape with crinkly margins. It is of black colour and is opaque and isotrppic.

3. Diopside : It has prismatic sections with double cleavage. It is non-pleochroic. Birefringence = 0.031. Its extinction angle is 45°.

Haematite occurs as an important accessory. It is of reddish colour, and is opaque.

Origin of graphite in marbles

Diversified theories have been putforth to explain the origin of graphite in marbles. Some of these are set out below :-

1. The origin of graphite in Ceylon, where it occurs in the form of veins, in metamorphic rocks, has been attributed to the process of sublimation of the hydrocarbons by Johnnes Walther(1890).

2. Dunn (1929), while working in northern Singhbhum, has suggested that fumerolic activity results in the breaking of complex hydrocarbons into C, CO_2 and CO. This carbon has later on changed to graphite.

3. Wadia (1943), while working in Ceylon has suggested that it is primarily of igneous origin or is a product of the interaction

of magmatic gases from igneous bodies with limestone. Limestone, at high temperatures yields carbon in two stages as under :-

$$Ca\ CO_3 = Ca\ O + CO_2$$
$$4\ CO_2 = 2\ C + 2CO + 3\ O_2$$

4. Rozen, Sideorenko & Blizyuchenko (1972-73) have advanced organic origin to the graphitic material present in the graphitic phyllites and marbles of Kazakhstan (U.S.S.R). According to these scientists, the large scale deposition of organic material in Precambrian rocks in Kazakhstan (just like the deposition of sapropelic ooz in the sediments of the present time) has been responsible for the formation of graphite by conversion under reducing conditions.

They have, in this reference, received support from the observation of Petola (1969) and Marmo (1970), who have indicated that graphitic phyllites of the Precambrian of Finland have sapropelic ooz as the possible source of carbon in the rock.

This leads me to believe that the intrusion of granite has given rise to CO_2 by its interaction, with limestone and this later on has dissociated into carbon (in the form of graphite) and oxygen. This view is in accord with the ~~reference~~ inference drawn by Wadia (1943) about the origin of graphite in Ceylon.

2. QUARTZITE

Quartzite, under the megascopic study, shows granulose structure, there is seen an alternation of dirty white layers with pinkish ones which indicates the relict stratification. Tyrrell(1952) has indicated the presence of lines of heavy minerals like magnetite and zircon in Perthshire quartzite formations, which according to him mark the original bedding. Its specific gravity is 2.65.

Under the microscope, it shows granulose structure. There is

typical development of mosaic texture with planer contacts (Plate 14, Fig. 2).

As is apparent from the Modal Analysis of the rock given in Table IV, it is mainly composed of quartz grains. The average grain size is 0.1 mm. x 0.1 mm.

Small amount of biotite flakes ~~produces a slight foliation~~ are also present. ~~It is~~ There are of brownish colour, ~~and has subhedral flakes with~~ have frayed ends ~~and~~ and ~~It is~~ There are highly pleochroic according to the scheme Z = Y = reddish brown, X = light brown, ~~where~~ with absorption ~~is~~ Z = Y ⩾ X. Birefringence = 0.04. In some sections it shows ~~alteration to~~ the presence of reticulated rutile needles.

Hornblende occurs as prismatic crystals and is highly pleochroic, according to pleochroic scheme, X = ~~x~~ pale green, Y = green and Z = dark green, ~~where~~ and the absorption is Z ⩾ Y ⩾ X. Its extinction angle is 12°; birefringence = 0.022. It shows replacement by biotite at the margins as is shown in Plate 14, Fig. 2.

K-Feldspar is present in very minute quantity and shows the development of microperthite in some sections.

The plagioclase feldspar is mostly oligoclase showing very thin twinning lamellae.

Zircon is the most common accessory. It is comprised of rounded anhedral grains arranged in linear position (Plate 14, Fig. 3).

Almandine is of pinkish colour and is isotropic.

Rutile, magnetite and haematite are other accessories.

TABLE VI of
MODAL ANALYSIS OF QUARTZITE AT MALNAI

Quartz	96.45%
Plagioclase	0.16%
K-felspar	0.23%
Biotite	1.14%
Hornblende	0.58%
Accessories (Zircon, Almandine, Rutile&Haematite)	1.44%
	100.00%

3. GRAPHITIC PHYLLITE

Under megascopic study it shows schistose structure. Strain-slip cleavage is developed at places. It is of black colour and shows micaceous sheen on the surface. Its average specific gravity is 2.5. It is also associated with pyrite and nickeliferous pyrrhotite at Khaleni which exist either in disseminated form or as stringers.

The description of the various constituents is as follows :-

1. Quartz : Its largest grain measures 0.5 mm. X 0.14 mm. These grains are elongated and are arranged in parallel bands or lenses parallel to micaceous minerals.

2. Biotite : It is present as large porphyroblasts (Plate 14, Fig. 4) measuring upto 2.4 mm. X 0.4 mm. in size. It is of brownish colour though few sections indicate greenish brown colour. It has many inclusions of magnetite and zircon. The pleochroic formula is

Z = Y = Deep brown

X = Ligh brown

absorption is Z = Y > X.

But in case of few greenish brown flakes the colour corresponding to Z vibration direction is deep green. Birefringence = 0.038.

These porphyroblasts indicate a slightly more advanced grade of metamorphism. The occurrence of such large porphyroblasts in phyllites has also been mentioned by Moorhouse (1964).

3. Chlorite : It is of light greenish colour and has perfect cleavage. It is feebly pleochroic; birefringence = 0.011. It shows straight extinction.

4. Sericite : Small sericite flakes are found arranged parallel to quartz grains in some cases and in other cases as clusters. It is comprised of tiny flakes of white colour having low R.I. These show rainbow interference colours of 2nd order.

5. Graphite : It is either present in disseminated form or as clusters of tabular crystals with crinkly margins. It is recognised by its black colour having metallic lustre under reflected light.

6. Pyrrhotite : It has bronze yellow colour, slight pleochroism and ~~strong birefringence~~ and feeble anisotropic characters.

7. Pyrite : It has brass-yellow colour; non-pleochroic and opaque ~~isotropic~~.

Small number of accessories comprising of bluish tourmaline, rutile needles, zircon and magnetite are also present.

Nickeliferous pyrrhotite and pyrite are present in graphitic - phyllites near the Dedni granite. The sulphide mineralization appears to have been caused by the moblization and transportation of sulphide matter by heated water vapours and gases from the magmatic chamber of Dedni granite.

TABLE VII

MODAL ANALYSIS OF PHYLLITE AT SERI (32 C)

Quartz	34.17 %
Biotite	38.41 %
Sericite	11.80 %
Chlorite	14.02 %
Other minerals*	1.60 %
	100.00 %

* Other minerals include graphite, pyrrhotite, pyrite, tourmaline rutile, zircon and magnetite.

4. SCHISTS

1) Biotite Schist

It is scattered in all the areas of study as is apparent from the geological map (Plate 49).

In hand specimen it shows typical schistose structure and has average specific gravity of 2.72. Due to the abundance of biotite flakes in it the rock is dark coloured and the resulting soil is also of the same hue.

In the form of thin sections, under microscope, it shows crystalloblastic texture and owing to the presence of biotite, which has imparted schistosity to the rock, the texture is remarkably lepidoblastic (Plate 15, Fig. 1).

The various constituents of the rock are described as under :-

1. Biotite : It is subhedral in form and shows frayed ends. It is usually of light brown colour, and occasionally shows alteration to chlorite which is of greenish colour. It is highly pleochroic, according to the scheme

Z = Y = Reddish brown

X = Light brown

Where absorption is Z = Y > X

Birefringence = 0.04. It occurs in two generations. The biotite of second generation makes an angle to that of first generation. There are few flakes of muscovite intergrown with it. Occasionally we come across porphyroblasts of biotite in the schistose matrix, and these invariably exhibit the presence of poikiloblastic texture owing to the presence of inclusions of quartz, zircon and magnetite in them. The ~~biotite flakes vary in size from 1.35 to 0.075 mm.~~

2. Quartz : It is very abundant and varies in amount from

54.72 % to 85.70 %. It occurs as elongated grains parallel to schistosity. It rarely shows undulose extinction.

3. Albite : It occurs as subhedral grains and has maximum symmetrical extinction angle of 16°. It shows albite type of twinning.

4. Accessories :

(a) Magnetite : It is a very common accessory. It has black colour and is opaque.

(b) Rutile : It is present in shape of needles of brownish colour showing very high birefringence.

(c) Zircon : It is present in shape of rounded grains of greenish colour, showing birefringence = 0.061.

(d) Epidote : It is present as yellowish green anhedral grains. It is pleochroic and shows birefringence = 0.041.

(e) Chlorite : It is of light greenish colour and is slightly pleochroic. Birefringence = 0.044.

TABLE VIII
MODAL ANALYSES OF BIOTITE SCHISTS

Locality Slide No.	Balasu 3C	Dalah 17D	Below Seva 3B
Quartz	79.35 %	88.70 %	54.72 %
Albite	9.21 %	2.55 %	9.56 %
K-feldspar	0.98 %	-	7.56 %
Biotite	9.22 %	7.17 %	1.68 %
Muscovite	1.22 %	0.14 %	25.89 %
Accessories*	0.02 %	1.46 %	0.65 %
	100.00 %	100.00 %	100.00 %

* Accessories are, magnetite, rutile, zircon, epidote and chlorite.

ii) Almandine mica schist

It is the most prevalent rock, which is present in almost all the areas of study as is apparent from the geological map(Plate 49).

Under megascopic study it shows typical schistose structure. Almandine, quartz, feldspars and muscovite can easily be recognised in it. The rock, in general, shows greenish white colour but dark greenish black and reddish brown coloured varieties are also present. The weathered rock produces greenish to dark brownish coloured soil. Segregation layering of muscovite and biotite flakes has produced alternate white and black layers in the schist at Badraon and north of Doda bridge. This layering is due to metamorphic differentiation. It shows the development of puckers (Plate 11, Fig. 1).

The average specific gravity of rocks is 2.71.

Under the microscope it shows typical schistose structure. The schistosity is defined by preferred orientation of biotite or muscovite flakes arranged with their C (001) pinacoids parallel to the foliation. In case of schists showing puckers, schistosity is defined by the preferred orientation of biotite flakes which are arranged with their longer ones parallel to main foliation (S_2) and rude foliation (S_1) is also observed by whisps of muscovite and chlorite which runs oblique to the main foliation. Sometimes the schistosity (S_2) is modified in microfolds with the development of strainslip or crenulation cleavage (S_3). Further it shows crystalloblastic texture and owing to the presence of mica flakes which have imparted schistosity to the rock the texture becomes remarkably lepidoblastic.

The constituents are described as under :-

a) Quartz : It is the largest constituent of the rocks

and varies in amount from 66.56 % to 35.53 % in these schists as is apparent from the Table IX. The average grain size varies from 1 mm. to 0.5 mm. in diameter.

b) Oligoclase (An_{13} to An_{20}) : It is the most common feldspar. It has subhedral form and is white in colour. It has polysenthetic twinning of albite type. The average grain size varies in diameter from 1.5 mm. to 0.5 mm.

c) K-Feldspar : K-Feldspars are either untwinned or show ghost twinning. In some sections helicitic structure is present. The largest grain size is 2 mm. X 0.7 mm.

d) Almandine : It is the typical mineral of the schists and varies in amount in these schist from 9.35 % to 2.2 %. It is of pinkish colour and has euhedral hexagonal crystals outlines (Plate 16, Figs. 1, 2 & 3); It shows poikiloblastic texture (Plate 15, Fig. 3; Plate 16, Figs. 1&2 and Plate 27). It shows spiral arrangement of the inclusions consisting of comprising of quartz, biotite and magnetite are usually spirally arranged indicating snow-ball structure with complete continuity of Si and Se surfaces as indicated in Plate 16, Figs. 1, 2 & 3 and Plate 27. Such a relationship has also been indicated by Fairbrain, (1948); Spry, (1963) and Sexana, (1964). Some garnets also show mildly rotated Si trails which are discordant to Se (Plate 15, Fig. 4). Zonary structure has also been observed in some of them (Plate 15, Fig. 3 & Plate 16, Fig. 1). In very rare cases garnet consists of an inner core containing finer and lesser inclusions and an outer rim containing coarser and abundant inclusions mostly of quartz and magnetite (Plate 16, Fig.2). It is similar to " Garnet in Garnet" of Das & Pande (1964) and Das (1971);and has been earlier described by these authors in Almora and Kumaon Districts of Utter Pardesh. All of these varieties are

isotropic and vary in grain size from 2 mm. to 0.5 mm. in diameter

e) Biotite : It is the common mica present and varies in amount 23.64 % to 6.44 % and is of brownish colour with abundant inclusions of magnetite and zircon. It shows pleochroism which is indicated by the formula

Z = Y = Reddish brown
X = Light brown

and the absorption is obviously Z = Y > X. Its extinction angle is 3°, birefringence = 0.037. It shows negative biaxial interference figure in case of basal sections exhibiting dispersion r > v. The size of the flakes varies from 0.8 mm. to 0.1 mm. ~~in diameter~~.

f) Muscovite : It varies in amount from 14.92 % to 0.94 % and is subhedral white mineral with abundant inclusions of zircons which form pleochroic haloes. It shows birefringence = 0.04. The size of flakes varies from 1.5 mm. to 0.075 mm. ~~in diameter~~.

g) Accessories : Large number of accessories are present which are described as under :-

i) Tourmaline : It has brownish to bluish coloured grains and is highly fractured. It is strongly pleochoric showing maximum pleochroism in the NS vibration direction of the cross wire, birefringence = 0.04. In case of almandine mica schist at Bhabor, zoned tourmaline is present, which has greenish centre with brownish border.

ii) Zircon : It is a very common accessory. In most schists it is anhedral but schists bodering Bhabor have euhedral grains. These are of white or pinkish colour and show very high birefringence = 0.06.

iii) Pennine : It is present in sheafy form of green colour. It is pleochroic in shades of green to nearly colourless. It shows "Berlin - blue" anomolous interference colours.

iv) Chlorite : It is present in light greenish colour and occurs in anhedral form. It shows slight pleochroism and grey interference colours.

v) Magnetite : It is very common accessory. It is black and opaque. ~~and isotropic~~.

vi) Epidote : It occurs in granular form. It is pleochroic. Birefringence = 0.04.

vii) Apatite : It is present in shape of needles of white colour showing high R.I. and has first order interference colours.

viii) Rutile : It occurs as reddish brown coloured grains with high R.I. Interference colours are of very high order.

ix) Sphene : It occurs as euhedral angular rhombic grains of yellow colour. It is highly pleochroic with X = colourless, Y = pale yellow and Z = reddish brown. Birefringence = 0.14.

TABLE IX
MODAL ANALYSES OF ALMANDINE MICA SCHISTS

Locality	Doda bridge	Badraon	Mundella	Mundella	Doda bridge	Khabrel
Slide No.	5	10B	3	2	1F	26D
Quartz	65.00 %	54.24 %	50.55 %	55.13 %	66.56 %	35.53 %
K-Feldspar	-	1.91 %	1.83 %	-	-	15.27 %
Plagioclase	12.46 %	6.77 %	7.40 %	0.39 %	11.26 %	27.59 %
Biotite	6.44 %	22.36 %	23.64 %	20.59 %	-	14.48 %
Muscovite	9.57 %	7.15 %	7.98 %	2.56 %	14.92 %	0.94 %
Almandine	5.45 %	7.19 %	7.52 %	7.53 %	2.22 %	4.68 %
Accessories* & other minerals	1.03 %	0.38 %	1.08 %	13.80 %	5.04 %	0.51 %
	100.00 %	100.00 %	100.00 %	100.00 %	100.00 %	100.00 %

*Accessories (Zircon, apatite, epidote, tourmaline, sphene & rutile).
Opaques ... (magnetite)
Secondary minerals (Chlorite).

iii) Staurolite schist

It is developed only at few localities in the area as is depicted on the geological map (Plate, 49).

Under the megascopic study it shows schistose structure. It also shows sharp puckers. It is of greyish white colour to dark colour. At different places quartz, muscovite, biotite, almandine and feldspar are easily recognised. The average specific gravity is 2.76.

In the form of thin sections, under the microscope, it shows crystalloblastic texture. Owing to the presence of micas, which have imparted schistosity to the rock, the texture is typically lepidoblastic (Plate 16, Figs. 4 &6).

Following is the description of the constituents :-

1) Staurolite : The largest grain size is 1 mm. X 0.2 mm. ~~It is the index mineral of the rock and~~ It has typical golden yellow colour. It is mostly anhedral, though one section at Doda bridge shows euhedral form with the development of pseudohexagonal cross sections ~~as short prismatic cross-section~~. It is poikiloblastic with abundant inclusions of quartz and magnetite (Plate 16, Fig. 4 & Plate 17, Fig. 1). Pleochroic formula is

Z = Orange yellow
Y = Pale yellow
X = Colourless

~~where~~ with absorption Z > Y > X; birefringence = 0.012.

2) Quartz : Its grain size varies from 2.25 mm. to 0.07 mm. in diameter. It shows wide variation in its amount in schist varying from 68.7 % to 14.4 % as is apparent from the Table X. It is mostly present as anhedral grains though some sections show tendency towards becoming idiomorphic. These grains are oriented parallel to the schistosity.

3) Feldspars : Both K-Feldspar and plagioclases are present as untwinned grains in most cases. These feldspars were differentiated from each other by applying staining tests. The rock slide was

dipped first in concentrated HCl and then in Cobalt Nitrate solution which has imparted golden yellow colour to the K-feldspar whereas plagioclases remained unaffected. Feldspars showing twinning are described briefly as under :-

Plagioclases : These shows albite type of twinning in some sections and have got maximum extinction angle of 9°, which indicates their composition to be An_{27}, and helps to recognise these as oligoclase.

K-Feldspars: These occur as subhedral grains and in most cases show grey colour due to the alteration into kaoline. Sections show ghost twinning.

4) Muscovite : It is very common in case of Badraon, where it constitutes 31. 72% of the total constituents. Muscovite flakes show preferred orientation and are arranged with their longer axes parallel to the main foliation S_2. A rude foliation S_1 is alsc observed which is marked by whisps of muscovite and biotite flakes. It has an abundant inclusions of zircon and magnetite. Pleochroic haloes are common around zircon grains; birefringence = 0.037. The size of flakes varies from 1.6 mm. X 0.6 mm. to 0.1 mm.X0.01 mm.

5) Biotite : The size of flakes varies from 0.75 mm. X0.045 mm. It is of brownish colour and has abundant inclusions of zircon and magnetite. Pleochroic haloes are present around zircon grains. It is highly pleochroic with pleochric formula

Z = Y = reddish brown
X = light brown

where absorption is Z = Y > X; birefringence = 0.04. In case of basal sections efforts were made to find optical sign which is found to be -ve.

6) Almandine : The largest grain is 1.76 mm. X 0.7 mm. It is of pinkish colour and occurs as anhedral grains; It is poikiloblastic

and has abundant inclusions of quartz, magnetite and biotite, which are arranged in a spiral manner indicating the presence of snow ball garnets (Plate 16, Fig. 3).

7) Ottrelite (Chloritoid) : In case of Lal Dharaman staurolite schists, the presence of ottrelite is typical. It has subhedral form and shows bending (Plate 16, Fig. 4). It shows greenish grey colour and perfect cleavage. It is pleochroic and shows straight extinction. Birefingence = 0.016.

Among the accessories tourmaline, chlorite, magnetite and ilmenite are present.

TABLE X

MODAL ANALYSES OF STAUROLITE SCHIST

Locality	Badraon	Lal Dharaman
Slide No.	6B	1B
Quartz	14.40 %	68.70 %
Oligoclase	31.40 %	10.08 %
K-feldspar	4.02 %	0.31 %
Biotite	3.64 %	5.89 %
Muscovite	31.72 %	2.75 %
Staurolite	3.76 %	3.05 %
Almandine	10.73 %	8.47 %
Other minerals *	0.33 %	0.80 %
	100.00 %	100.00 %

* Other minerals are, Chlorite, tourmaline, magnetite and ilmenite.

ii) Kyanite biotite schist

It is very rarely developed in the study area, and is present only at Lal Dharaman, though wide occurrence of it has been located at Puneja in the adjoining area, north east of Dehra.

Under the megascopic study it shows schistose structure. It is present in dark coloured rocks. The average specific gravity is 2.86.

Under the microscopic study it shows schistose structure and crystalloblastic texture. The schistosity is defined by the preferred orientation of biotite flakes which are arranged with their longer axes parallel to the main foliation (S_2).

The study reveals the presence of quartz, biotite, staurolite, almandine, K-feldspar, kyanite and magnetite. Kyanite is an important varietal mineral.

Specific properties of minerals are as under :-

1. Kyanite : The largest grain is 1·4 mm. X 0·34 mm. in size. It is colourless and occurs in elongated plates parallel to (100) (Plate 17, Fig. 1). Its extinction angle is 30° on (100). Frequent twinning is present.

2. Quartz : Its largest grain is 2 mm. X 0.08 mm. in size. It is the largest constituent of the rock and constitutes 70.7% of it as revealed by ~~the rock constituents according to~~ modal analysis as shown in Table ~~XI~~ XI. It ~~has~~ is mostly anhedral ~~grain having~~ and has abundant linear inclusions.

3. Biotite : Its largest flake is 0.8 mm. X 0.25 mm. in size. It is deep brownish colour and has subhedral form with frayed ends. It has many inclusions of magnetite and zircon. It is pleochroic according to the scheme

Z = Y = Reddish brown
X = Light brown

where absorption is Z = Y > X; birefringence = 0.035. Well developed basal sections show optical sign which is -ive.

4. Almandine : The largest grain is 1 mm. X 0.45 mm. in size. It is poikiloblastic and has abundant inclusions of magnetite, quartz and epidote. It has outer margin highly fractured but central portion is quite massive.

5. Staurolite : The largest grain is 1 mm. x 0.15 mm. in size. It is recognised by pale yellow colour and abundant inclusions of quartz, and magnetite are present in it. It is highly pleochroic according to the scheme Z = orange yellow Y = Pale yellow and X = colourless Birefringence = 0.012.

6. K-Feldspar : The grain size varies from 0.6 mm. X 0.075 mm. It occurs mostly as clusters of slender primatic crystals. It is recognised by applying staining test which consists of first dipping the slide in conc. HCl and then treating it with Cobalt Nitrate solution which imparts golden yellow colour to the grains.

7. Magnetite : It is black and opaque and shows steel grey colours under reflected light.

TABLE XI

MODAL ANALYSIS OF KYANITE BIOTITE SCHIST OF LAL DHARMAN

Quartz	= 70.70 %
K-Feldspar	= 9.39 %
Biotite	= 7.89 %
Almandine	= 8.47 %
Staurolite	= 1.87 %
Kyanite	= 1.03 %
Magnetite	= 0.65 %
	100.00 %

V-SILLIMANITE SCHIST

It is usually present in contact with the gneisses. Under megascopic study, the rock shows the development of puckers in the specimens obtained from Kothi and Jagota (Plate 11, Fig. 2). These are mostly reddish brown in colour due to the presence of reddish brown biotite. Apart from biotite, muscovite, quartz and feldspar are easily recognised. Average specific gravity of the rock is 2.77.

Under the microscope, it shows crystalloblastic texture and schistose structure. The schistosity is defined by the preferred

orientation of biotite and muscovite flakes running parallel to each other and are interleaved, but rude foliation due to biotite, muscovite, and sillimanite is also present.

1. Sillimanite : Its grains size varies from 0.04 mm. X 0.01 mm. ~~It is the index mineral and shows the development of needle like~~ According to the Barrowian classification of the metamorphic grades, it is the index mineral of the highest grade. It occurs in kyanite crystals (Plate 17, Figs. 2 & 3). It has traversed fractures. Birefringence = 0.02. It shows parallel extinction. Its fibrous variety (fibrolite) is also developed in some sections (Plate 17, Fig. 4).

2. Biotite : The largest flakes is 1.6 mm. X 0.04 mm. in size. It is of brownish colour and has many inclusions of magnetite and zircon. It is pleochroic according to the formula

Z = Y = reddish brown
X = light brown

where absorption is indicated by Z = Y > X; birefringence = 0.04. In case of basal sections efforts has been made to determine optical sign which is found to be -ve sign.

3. Muscovite : The largest flake is 1.6 mm. X 0.03 mm. in size. It varies in amount in these rocks from 2.5% to 7.00%. It is present as subhedral sections with abundant pleochroic haloes around zircon inclusions; birefringence = 0.037. In case of basal sections -ve optical sign has been determined.

4. Quartz : The grain size varies from 1.2 mm. X 0.01 mm. in length. It is the most common mineral in the rock and varies in amount from 53% to 62.5%. It is mostly anhedral. It has inclusions of quartz and apatite.

5. K-Feldspar : Mostly it is untwinned, but few sections show ghost twinning and some showing contact twinning. Extinction angle is 12°.

(An 30)

6. Oligoclase/: The grain size varies from 0.5 mm. to 0.1 mm. in length. It mostly occurs as subhedral grains. It shows albite type

of twinning and ~~shows~~ the maximum symmetrical extinction angle determined is of 12°.

7. Almandine : The largest grain is 3 mm. x 2.5 mm. in size. It is of pinkish colour and shows poikiloblastic structure and has abundant inclusions of quartz and magnetite, which are arranged spirally to indicate the formation of ' snow-ball' garnets. It is isotropic.

Among the accessories, zircon and apatite are very common, though apatite and blue tourmaline are also present in small amounts.

TABLE XII
MODAL ANALYSES OF SILLIMANITE SCHISTS REVEALS THE COMPOSITION AS UNDER

Locality	At Doda bridge Koti area		Malnai	At Singarhi	Doda
Slate No.	4 B	2 B		7 B	
Quartz	62.56%	53.00%	72.09%	56.05%	29.07%
K-Feldspars	19.44%	11.51%	4.96%	11.18%	8.54%
Olligoclase	10.70%	20.08%	1.58%	3.58%	20.97%
Biotite	1.58%	5.08%	14.56%	20.80%	37.77%
Muscovite	2.50%	4.02%	5.01%	7.10%	1.33%
Sillimanite	1.09%	3.21%	1.01%	1.28%	1.97%
Almandine	1.84%	2.42%	-	-	-
Other minerals*	0.29%	0.50%	0.79%	0.01%	0.33%
	100.00%	100.00%	100.00%	100.00%	100.00%

* Other minerals are, Zircon, Apatite and Tourmaline which occur as accessories.

VI FELSPATHIC SCHIST

Felspathic schist has been typically observed at Dhera (33° 7' 12", 75° 39' 35") near the granitic gneisses. Under megascopic study, the rock shows porphyroblastic texture, where large fully crystallised felspar grains are surrounded by mica flakes (Plate 11, Fig. 4). Its specific gravity is 2.56.

Under microscopic study the rock shows porphyroblastic texture. Myrmekitic texture is also developed. Biotite and muscovite are interleaved and show the development of microfolds (Plate 16,Fig.5).

1. Oligoclase (An_{19}) : The largest grain size is 4.6mm.X3 mm. It is highly fractured and weathered along fractures (Plate 17, Fig. 6). It has abundant inclusions of quartz, muscovite, biotite and irom ores in it. Sericitization is also very common.

2. Biotite : The largest flake is of 0.50 mm. X 0.02 mm. It is present as anhedral flakes of brownish colour. Mostly these are basal sections and are therefore non-pleochroic. It is slightly birefringent.

3. Muscovite : Its largest flake measures 1.2 mm. X 0.22 mm. Being colourless it is non-pleochroic but shows the presence of pleochroic haloes which are found surrounding the inclusions of zircon. Few flakes show lamellar twinning indicating their first stage of alteration to plagioclase. The extinction angle of muscovite flakes is $\pm 2^{\circ}$.

4. Quartz : The grain size varies from 1.4 mm. X 1.1 mm. to 0.1 mm. X 0.02 mm. It occurs as anhedral grains though some euhedral grains are also present. It invariably shows overgrowth over earlier formed quartz grains.

Magnetite, rutile and zircon are present as accessories.

TABLE XIII

MODAL ANALYSIS OF FELSPATHIC SCHIST OF DEHRA

Quartz	29.89 %
Oligoclase	57.47 %
Biotite	7.40 %
Muscovite	4.84 %
Accessories*	0. 40 %
	100.00%

*Accessories are rutile, magnetite and zircon.

The schists have been formed from the pelitic material, originally deposited in the subsiding troughs by recrystallisation. The recrystallisation has taken place under the orogenic movements which have caused dynamic stresses of great magnitude, resulting in bringing about the parallel orientation of the flakes of micaceous minerals, which are abundantly found in these rocks.

5- MIGMATITES & GNEISSES

The intensity of metamorphism increases across the strike and then is manifested by the presence of migmatites, garnetiferous-gneisses and granitic gneisses.

Granitic permeations in metamorphites have resulted in the formation of streaky migmatites or banded migmatites or garnetiferous gneisses. These by gradual influx have resulted in the granitic gneisses, by the process of granitisation.

Phenomemon of granitization of such gneisses have been reported in Nanga Parbat by Misch (1949), in Ranikhet area by Merh & Vashi (1968); Dhauladhar Range by Gupta (1969) Didag area of Himachal Pradesh by Kanwar (1969) and Kishtwar area by Wakhaloo et al. (1971).

All the gneisses of the study area are synkinematic, which is borne out by the following factors :-

1) The gneisses show concordant relationship to felspathic - schist from which they are derived.

2) The relicts of schists are present in the gneisses showing their parallel arrangement with the regional development of schists.

3) Relicts of marble have sometimes been formed in the centre of gneisses, for example, at Chibban. It is due to their refractory nature that marbles have been left unaffected during synchronous metasomatism.

4) The inclusions of schists are invariably to be found in the porphyroblasts of feldspars and microcline perthites showing thereby that these have grown by the metasomatic replacement of the schistose rocks. Sometimes these inclusions are oriented in 'S' patterns revealing thereby that during their growth diastrophic movements had also been active.

5) The augen gneisses are synkinimatic as is shown by the elongation and alignment of the porphyroblasts which have acquired the augen-structure during their recrystallization followed ~~crystallographic growth and~~ by cataclastic deformation. The porphyroblasts have suffered at places where movement outlasted the growth as is observed by Misch (1949).

The formation of the gneisses by the process of grantization is revealed by the following factors :-

1) It has been commonly observed that felspar and quartz porphyroblasts observed in mica-schist go on gradually increasing in size and number as schists grade into gneisses.

2) There is heterogeneous distribution of granitic gneisses with their concordant relationship and irregular gradition from one rock to the other from mica schists.

3) Gneisses have vast areas of regionally metamorphosed rocks around it which have been effected by the high temperature and by migmatic fronts bringing out metasomatic changes in the surrounding schists forming smooth and graditional contacts with the schists.

4) In case of banded gneisses there is the presence of palaeosomes of intermediate composition between leucosome and melanosome indicating metasomatic changes (Plate 12, Figs. 1,2&3).

5) The formation of porphyroblasts of K-feldspars clearly indicates the addition of potash into the metasediments. Misch(1949),

has indicated that increase of potash in augen gneisses ~~by the~~ is connected with the widening shape of bands of rock material between the porphyroblasts.

6) The granitic fluids soaked the metasediments with them and large scale metasomatic changes resulted in the formation of gneisses. So the theory of granitization, clearly solves the space problem; which would have otherwise arisen ~~in case of magmatic intrusion.~~ were we to substantiate the magmatic hypothesis.

These gneisses show some important textures, structures and other peculiar features which have also great significance in revealing the process of granitization and their development. These may be summed up as under :-

a) Clouding of feldspars,

b) Progressive enrichment of the rocks with microcline and other K-feldspars;

c) Formation of albite rims;

d) (i) Myrmekitic and (ii) Perthitic textures; Development of

e) Occurence of three forms of quartz; and

f) Sagenitic structure.

A brief note on each of the above is referred below :-

(a) Clouding of feldspars

Clouding of feldspars is a common feature of gneisses and granitic gneisses as is exhibited in Plate 22, Figs. 1,2,3&4.

The features responsible for it are the presence of inclusions of quartz, muscovite, biotite, apatite, sillimanite, magnetite and zircon; whereas in plagioclases apart from the presence of these inclusions, there has taken place the phenomenon of the saussuritization also on vast scale.

Another important feature of these feldspars is that in some cases they show rotational nature of inclusions also, indicating the recrystallisation of feldspars over long period, through which

there have been diastrophic movements. 61

Many theories have been put forward to explain the clouding of feldspars and their complex nature indicates that more than one factor has been responsible for their development

(i) According to Cornelius (1935) the "stuffed" plagioclases which have abundant particles of clinozoisite and muscovite have been explained as occurring diaphthoretically in the feldspars.

(ii) Pitchmuthu (1959) has believed that some of the clouded plagioclases may be formed by palingenesis (or rheomorphism).

(iii) Stern (1964) has suggested the preferential clouding of plagioclases could be explained by persistors which permit easy diffusion of foreign matter.

(iv) According to Rao (1964) clouding in some plagioclases is neither of exsolution origin nor of extraneous source but represent a by-product in the metamorphic replacement of biotite and hornblende by plagioclases.

In the study area clouding in most cases is due to synkinematic development of feldspars by the process of recrystallisation during metamorphic replacement. The rate of elimination of impurities - which later on are retained as inclusions-is not keeping pace with the process of recrystallisation of feldspars. In plagioclases it is due to saussuritization in which the lime component is divorced from the sodium one. The lime part forming minerals such as [illegible], epidote and calcite. The sodium component forms albite and paragonite.

(b) Progressive enrichment of the rocks with microcline and other K-feldspars.

The development of potash feldspar porphyroblasts commonly showing microperthitic texture is controlled by foliation of metamorphites, which imparts them a linear direction.

The growth of porphyroblasts of K-feldspars is a later stage development as has been shown to be the case by several authors. Anderson (1934); Reynold (1944); Harme (1949); Walker & Mathias (1947); Leedal (1952); Pitcher (1953); Harry (1954) and Gupta (1969) have noted similar phenomenon regarding the development of potash feldspars dub to replacement.

(c) Development of albite rims around feldspars

Albite rims surrounding the perthites and microperthites have frequently been observed.

According to Drescher-Kaden (1948) formation of the albite rims takes place in three stages :

i) increase of acidity on margins with retention of twin lamellae;

ii) reversal and extinction of twinning lamellae; and

iii) finally complete homogenization of the marginal zone of altered region.

This view has been supported by many authors working on the gneissose rocks of the Himalayas. Gupta (1967 & 1969) has indicated that albite rims are genetically connected with the perthites and are of late stage development. He has shown the increase of acidity on the margins of the perthites in Dhauladhar Range. The present author also holds the same view.

(d) (i) Development of Myrmekitic texture

Myrmekitic texture has been abundantly developed in the granitic gneisses of the study area (Plate 21, Figs.1,2&3). It is met with the gneisses of Koti (Latitude 33°10' 22"; Long. 75° 33' 34") Bhabor (Latitude 33° 8' 50" ; Long.75° 35' 10") and Bhala (Latitude 33° 5' 10"; Longitude 75° 36' 34").

According to Drescher-Kaden (1948) it is developed due to replacement. He has shown that the plagioclase is corroded along "smekal defects" by the solutions which give the orthoclase of granites and granitized rocks. The solutions deposit silica, while the removed cations fill empty spaces in the lattice of plagioclase. This theory has further been supported by Voll(1960) and Augustithis (1962).

In the area under reference this texture is developed in the granitic gneisses at the contact of K-feldspars and plagioclases and is the result of metasomatic replacement.

(d) (ii) Perthitic texture

It has been commonly observed in microperthites present in the gneisses of the area (Plate 22, Fig. 5).

Anderson (1923) has pointed out that the replacement of microcline by albite is effected by circulating solutions.

Gupta (1968 & 1969) has explained a type of replacement perthite in Dhauladhar Range where idiomorphic plagioclase is present as inclusions in the microcline. He has indicated acidic rims around these included plagioclases which may be due to the replacement caused by sodic material brought from external sources, in a liquid state.

The perthites with inclusions of plagioclase are common feature of the gneisses (Plate 22,Fig.5).These plagioclases at the margins show replacement features caused by the sodic solutions brought from external sources.

(e) Occurrence of three forms of quartz

Quartz is encountered in three forms which are as follows :-

i) Quartz I exhibits granoblastic texture and occurs on the margins of feldspar porphyroblasts. During felspathization entire amount of silicon dioxide which has been discharged from the original material ~~them~~ shows sutured contacts with original rocks and has recrystallised as quartz grains.

ii) Quartz II occurs ~~with periphery of porphyroblasts of feldspars~~, in the interspaces of plagioclase and microcline or microperthite, in the form of stringers and streaks. This type of quartz appears to have been formed due to the replacement of microcline by plagioclase as is the case with the development of myrmekitic texture on a microscopic scale.

iii) Quartz III is yet another modification of quartz which shows sutured contacts with feldspars. This form is evidently connected with the welding process, at the time of the original rocks being subjected to considerable heat and pressure.

(f) Presence of sagenitic structure

Sagenitic structure is developed in the biotites of garnetiferous banded gneisses at Doda Bridge (Plage 20, Fig. 2) and in some granodioritic gneisses. It shows the relict cleavage of hornblende in biotite from which it is derived. This structure is depicted by rutile needles making an angle of 56° with each other in biotite flakes. Rutile needles show weak pleochroism with O = light yellow and E = light brown. During alteration of hornblende into biotite, TiO_2 has been separated and has deposited alongwith relict cleavages of hornblende which have offered the least paths of resistance. It has also been recorded at Kishtwar by Wakhaloo et al. (1968) and at Dhauladhar Range by Gupta (1969).

(i) Migmatites

These are observed in the field as banded garnetiferous gneisses and streaky gneisses. The banded gneisses, under megascopic study indicate the presence of alternate white bands of granitic composition with dark bands comprising of palaeosome and melanosome (Plate 12, Figs. 1 & 2). However, streaky gneisses show alternate irregular bands (Plate 12, Fig. 4). These rocks indicate gneissose structure and are coarse to medium grained. Feldspar, quartz, biotite and almandine can easily be recognised in hand specimen. Size of biotite flakes and almandine increases appreciably especially in case of Beoli banded gneiss. The size of euhedral garnets, observed in Beoli banded gneiss, has reached upto 60 mm. X 40 mm. (Plate 11, Fig. 6). These bigger almandine grains show shattering effect with quartz, magnetite, tourmaline and biotite flakes fitting the fractures. The average specific gravity of these rocks is 2.71.

Under the microscope gneissose structure is indicated. The typical structure in case of banded gneisses is banded structure, (Plate 18, Figs. 1&3). This study has revealed the presence of K-feldspar, quartz, oligoclase, biotite and almandine with accessories comprising of magnetite, muscovite, chlorite, zircon and apatite.

Characteristic properties of the constituent minerals are as under :-

(1). K-Feldspar : The largest grain size is 1.4 mm. X 0.6 mm. It is mostly untwinned except in case of one grain of orthoclase. It is highly poikiloblastic and has inclusions of biotite, muscovite, quartz, apatite and zircon. These inclusions have been incorporated during the growth of porphyroblasts. Gliding planes are developed.

(2) Oligoclase (An 18) : It is commonly developed and shows twinning on albite law in most cases and on pericline law in some cases. The maximum symmetrical extinction angle is 6°.

(3) Quartz : The grain size varies from 1.6 mm. to 0.5 mm. in diameter. It has abundant inclusions of magnetite, apatite, quartz of earlier formation and zircon. It shows undulose extinction and granulation of grains (Plate 19, Fig. 2), due to stress factor.

(4) Almandine : The largest grains measure upto 1.8 mm. X 1.4 mm. When studied under microscope, All the almandine grains are poikiloblastic having inclusions of biotite, magnetite, tourmaline, quartz and chlorite. The Si of the inclusions in the almandine garnets are not continuous with Se of the constituents of the rock. Two varieties of almandine garnets are present. Firstly, layered garnets indicate the parallel arrangement of inclusions of biotite flakes. At places these flakes have altered to chlorite also. Secondly, zoned almandine garnets are observed indicating snow-ball phenomenon in the inner core with a periphery of massive garnets. The outer periphery shows fractures which do not penetrate into the core (Plate 18, Fig. 2). These are highly fractured and in some of these quartzo-felspathic veins have been intruded. The above factors suggest that the metamorphism outlasted the granitization in this area.

Such garnets have also been found in the metamorphites of Dhauladhar, Simla and Darjeeling areas.

(5) Biotite : It is of reddish brown colour. It is pleochroic with Z = deep brown, Y = yellowish brown, X = light brown; where absorption is Z = Y > X. Birefringence = 0.033. Basal sections show -ve biaxial interference figures.

(6) Accessories :

i) Magnetite : It is very common accessory which has black colour and is opaque ~~and isotropic~~.

ii) Tourmaline : It is of brownish colour, highly pleochroic. Birefringence = 0.022.

iii) Apatite : It is present in the shape of elongated needles, showing high R.I. and 1st order interference colours.

iv) Chlorite : It is light greenish in colour. It shows weak pleochroism and has 1st order interference colours. It mostly occurs as massive variety, though in some cases pennine variety at the margins of garnet is also developed.

v) Sillimanite : It occurs as fibrolite.

TABLE XIV AND STREAKY
MODAL ANALYSES OF BANDED/GARNETIFEROUS GNEISSES

Locality	Doda Bridge	Chibban
K-feldspar	18.27 %	30.77 %
Oligoclase	5.37 %	9.63 %
Quartz	47.00 %	48.75 %
Biotite	7.69 %	7.78 %
Muscovite	0.30 %	1.62 %
Almandine	20.78 %	Traces
Other minerals*	0.89 %	1.45 %
	100.00 %	100.00 %

*Other minerals are accessories comrising of Magnetite, tourmaline, apatite, chlorite and sillimanite.

PETROGENITIC INTERPRETATION

The petrogenitic interpretation of streaky and banded gneisses as revealed by field and laboratory studies is as follows. These have been formed by the infiltration of migmatic fluids into the metasedimentary rocks in their sheared zones, which by metasomatism have caused granitization.

The granitization of these gneisses can be established by the following evidences :-

(1) In the field, these gneisses show concordant relations to the schists from which these gneisses are developed.

(2) In these gneisses, apart from white bands there are bands intermediate in composition and colour to the dark coloured bands (Plate 12, Figs. 1, 2 & 3).

Banded gneisses have been studied by Misch (1949) in Nanga - Parbat. He has established that the banded gneisses owe their origin to infiltration and replacement of the country rocks.

(ii) Garnetiferous Augen Gneiss

The rock under megascopic study shows gneissose structure with typical development of augen structure. It shows porphyroblastic texture. / ~~These~~ the specimens of such a rock are mostly grey in colour, but some as those of Zaginda are of pinkish hue which may be due to the influx of iron - oxide from biotite as is shown by Mc Mohan (1884) in his description of rocks from the summit of Chor mountain near Simla.

Under the microscope, it shows typical porphyroblastic texture in which ~~the development of~~ large porphyroblasts of feldspars are commonly observed surrounded by biotite flakes. Myrmekitic texture is also ~~developed~~.

Specific properties of the minerals / ~~present~~ exhibiting into its composition are as under :-

(1) Oligoclase (An_{25}) : Its largest grain is 3 mm. X 1.2 mm. in size. It occurs in subhedral form, and shows clouding due to the presence of quartz and biotite. It shows albite type and combined albite-carlsbad type of twinning.

(2) K-Feldspars : Among the K-feldspars are present (a) Orthoclase (b) Microcline and (c) Microperthite.

(a) Orthoclase : Its largest grain is 1.8 mm. X 1.35 mm. in size. It is commonly developed form of ~~among~~ K-feldspars. It occurs as

subhedral grains which show sericitization in small patches. It shows typical carlsbad type of twinning.

(b) Microcline : It is subhedral in form and is recognised by cross-hatched twinning.

(c) Microcline - microperthite : These are present as patch - perthites and have inclusions of plagioclase grains in it.

(3) Quartz : Its largest grain is 1.2 mm. X 0.1 mm. in size. It is present as anhedral grains and has abundant linear inclusions. It shows highly strained effects.

(4) Biotite : It is of brownish colour and is highly pleochroic, according to the following scheme

Z = Y = dark brown

X = light brown

Some sections are of greenish colour and have the pleochroic scheme

Z = Y = brownish green

X = yellowish brown

The absorption in both cases is Z = Y > X; birefringence = 0.041. It shows the development of magnetite at the margins. The largest flake is 0.8 mm. X 0.2 mm. in size.

(5) Muscovite : Its largest flake is 0.7 mm. X 0.6 mm. in size. It is subhedral with frayed ends. It is not infrequently exhibiting of bent lamellae. Birefringence = 0.037.

(6) Almandine : The largest grain size is 0.2 mm. X 0.1 mm. It is of pinkish colour. It shows strained effect and is highly fractured. It is poikiloblastic and has abundant inclusions of magnetite, biotite and quartz. Rotational form of fractured - almandine forms S shape (Plate 20, Fig. 1). However, some almandine garnets are laminated owing to the development of garnets by metasomatism having bands of biotite and chlorite in it

Among the accessories tourmaline is well developed but there are others comprising of zircon, rutile, epidote and magnetite.

TABLE XV

MODAL ANALYSIS OF GARNETIFEROUS GNEISS AT ZAGINDA (30 C)

Quartz	25.85 %
K-Feldspar	34.48 %
Plagioclase	31.28 %
Biotite	4.62 %
Muscovite	3.27 %
Almandine	0.23 %
Accessories*	0.27 %
	100.00

* Accessories are tourmaline, zircon, rutile, epidote and magnetite.

These garnetiferous augen gneisses have been formed by the combined effect of deformation followed by potash metasomatism. Formation of similar augen gneisses have been explained by Carnnon (1964) in the Batica Assemblage of British Guinea.

iii) Granitic gneisses

These granitic gneisses show a great deal of change in the mineral and chemical composition wherever they are developed. This is borne out by the modal analyses shown in Table XVI which have revealed the presence of

(a) potash granitic gneiss

(b) Adamellite gneiss and

(c) granodiorite gneiss

(a) Potash granitic gneiss

It is of grey colour and show the development of large sized porphyroblasts of K-feldspars comprising of (i) orthoclase (ii) microcline and (iii) microperthite.

Megascopically these are coarse grained gneisses and show

well developed foliation (Plate 13, Figs. 1,2 & 3). They show porphyroblastic texture. The size of K-feldspar ranges upto 14 cm. X 6 cm. at Duga and its porphyroblasts become euhedral which are surrounded by biotite flakes.

The granitic gneisses show gneissose structure under the microscope. Myrmekitic texture is also well developed (Plate 21, Figs. 1,2 & 3).

It seems to be composed of orthoclase, microcline, oligoclase, biotite and muscovite. Among the accessories zircon, epidote and tourmaline are present. The modal analyses is given in Table XVI. The description of the various constituents, is as under :-

(1) K-feldspars

(a) Orthoclase : It shows well-developed carlsbad type of twinning. Its largest grain is 6 mm. X 4 mm.

(b) Microcline : It is recognised by cross-hatched twinning.

(c) Microcline - microperthite : It is very common and forms large porphyroblasts measuring 4.6 mm. X 4 mm. It has tendency to form subhedral to euhedral grains. String perthite is commonly developed and it has inclusions of plagioclase, biotite and quartz (Plate 22, Fig. 5).

(2) Oligoclase : It is present in small amounts and shows albite and carlsbad albite type of twinning. It is highly clouded with sericite, epidote and quartz, indicating sericitization due to replacement (Plate 22, Fig. 6). Its composition is An_{25-30} as judged by the maximum symmetrical extinction angle.

(3) Quartz : It is present in the form of sutured grains and show signs of progressive development from minute grains. It occurs as porphyroblasts as well as small sized grains varying

TABLE XVI
MODAL ANALYSES OF GRANITIC GNEISSES

Locality	Granitic gneiss of Bhala	Granitic gneiss of Mundella	Granitic gneiss of Duga	Potash Hornblende and biotite gneiss at Seja	Adamellite gneiss near Niru bridge	Adamellite gneiss Doda bridge	Augen gneiss Mundella	Granodioritic gneiss at Kummari	Granodioritic gneiss at Basti	Granitic gneiss at Malnai
Slide No.	45D Percent	2D Percent	1F Percent	A Percent	Y Percent	A Percent	B Percent	13C Percent	2A Percent	Z Percent
Quartz	37.997	54.541	39.432	20.66	20.14	36.67	35.12	20.21	37.00	42.24
K-felspar (orthoclase)	50.375	23.804	58.566	19.26	42.97	27.05	43.02	4.60	1.00	39.74
Oligoclase	5.730	6.022	1.537	41.63	29.10	29.72	20.12	68.02	43.88	9.55
Biotite	2.812	2.953	-	11.20	0.08	0.48	0.36	6.00	12.00	2.82
Muscovite	2.993	12.679	0.078	0.75	6.86	5.96	1.38	0.10	4.72	4.34
Hornblende	-	-	-	-	0.75	-	-	0.02	-	-
Accessories*	0.093	0.002	0.189	6.50	0.15	0.12	0.01	0.05	1.40	1.31
	100.000	100.000	100.000	100.00	100.00	100.00	100.00	100.00	100.00	100.00

*Important accessories are, Almandine, zircon, sillimanite, magnetite, epidote, tourmaline and apatite.

from 2.6 mm. to 0.02 mm. in diameter. There is a general tendency for these to get elongated parallel to the direction of the foliation. These at places show granulation due to the effect of stress.

(4) Biotite : It is of dark brownish colour and is highly pleochroic according to the scheme

Z = deep reddish brown

Y = brown

X = light yellow

where absorption is Z > Y > X; birefringence = 0.041. At the margins it breaks up into sillimanite needles (Plate 20, Fig.3). In case of basal sections it shows -ve biaxial interference figure.

(5) Muscovite : It is present interleaved with biotite. Pleochroic haloes are common in its flakes around zircon grains; birefringence = 0.037.

Accessories are present in very small amount and are comprised of zircon, magnetite, tourmaline and epidote.

(b) Adamellite gneisses

In the study area, gneisses are of adamellitic nature as is clear from modal analyses, which are reproduced in Table XVI, these however can be broadly divided into two following type :-

(i) Muscovite gneiss

(ii) Augen gneiss of Bhala-Mundella area

(i) Muscovite gneiss

Under megascopic examination it shows gneissose structure. It is of greyish white colour, where foliation is marked by muscovite flakes. The easily recognisable minerals are feldspars, quartz and muscovite. Its sp. gravity is 2.67.

The microscopic examination of a thin section of it shows porphyroblasts of K-feldspar (4 mm. X 1.8 mm.) and oligoclase (3 mm. X 1.4 mm.), with marked poikiloblastic texture (due to the inclusions of muscovite, zircon, epidote and apatite), are well developed, whereas at the contact of both the feldspars myrmekitic texture is met with. The various minerals present in the rock are described as under :-

1. K-feldspars

They occur in the following three varieties :-

(a) Orthoclase : It is recognised by well developed carlsbad type of twinning (Plate 22, Fig. 3).

(b) Microcline : It shows cross hatched twinning.

(c) Perthite : It is very common among the K-feldspars. It is present in number of varieties as string perthite, patch - perthite and vein perthite. Patch perthite have inclusions of plagioclase grains and biotite in it (Plate 22, Fig. 5).

2. Oligoclases (An_{25-30}) : ~~It~~ These shows normal albite type of twinning. ~~It is~~ These are highly fractured where fractures are healed by quartz.

3. Quartz : It varies in grain size from 1.6 mm. to 1 mm. in diameter. It commonly shows well developed sutured boundary in most cases, though some grains occur as mosaic in granulated form. It has inclusions of muscovite and earlier formed quartz grains. It shows preferred orientation.

4. Muscovite : The largest ~~grain~~ flake is 1 mm. X 0.5 mm. in size. It occurs is subhedral flakes with frayed ends. It has abundant pleochroic haloes due to the presence of zircon grains. Birefringence = 0.037.

5. Biotite : It is present as basal sections of deep brown colour with inclusions of magnetite. It shows negative biaxial

interference figure.

6. Accessories :

i) Almandine : It occurs as anhedral grains which are slightly birefringent.

ii) Sillimanite : It occurs as needles with cross-fractures. Birefringence = 0.023.

iii) Epidote : It is greenish yellow in colour with high R.I.; birefringence = 0.04.

iv) Zircon (v) Apatite and (vi) Magnetite are other accessories, which are present in small amounts.

(ii) Augen gneiss of Bhala-Mundella area

In hand specimen it shows the typical development of Augen-structure and porphyroblastic texture. It is of light greyish colour. Its sp. gravity is 2.70.

Under microscopic study it shows porphyroblastic texture in which the development of large porphyroblasts of microcline - microperthite (3.4 mm. X 2.3 mm.) and are surrounded by biotite and muscovite flakes.

Microcline-microperthite mostly occurs as string perthite and composite perthite. Besides this the various other constituents present are described as under :-

2. Oligoclase (An_{25}) : Its largest grain is 1.6 mm. X 0.9 mm. in size. It occurs as subhedral grains. It shows commonly normal type of twinning - albite type and pericline type. Few grains show combined albite - carlsbad type of twinning. Sericitization at the margins of the grains indicate hydrothermal activity. Gliding planes in it indicate role of stress factor.

3. Quartz : It varies in size from 0.39 mm. to 0.004 mm. in diameter. It varies from large porphyroblasts to small strained

grains. The large porphyroblasts are mostly sutured and show preferred orientation. It has abundant inclusions of earlier grains of quartz, biotite and muscovite.

4. Biotite : It occurs as basal sections of coffee brown colour. It has inclusions of magnetite and zircon. However, some sections are subhedral with perfect cleavage. Its pleochroic scheme is

Z = coffee brown

Y = brown

X = pale yellowish brown

and the
~~where~~ absorption is Z > Y > X. It breaks into sillimanite at margins (Plate 19, Fig. 3).

5. Muscovite : Its largest flake is 0.44 mm. X 0.4 mm. in size. It has subhedral flakes with well developed perfect cleavage. Extinction angle = 3°, birefringence = 0.038.

Almandine, sillimanite and tourmaline are important accessories.

Augen gneisses at Bhala-Mundella area are present in a dislocation zone, where deformation during orogeny explains their origin. Tyrrell (1952) has explained the formation of such gneisses due to deformation, feldspars being resistant minerals only break into lenticular eye like forms whereas other minerals are crushed into granular aggregate, the pre crystallisation of which results in the formation of such augen gneisses.

(c) <u>Grey granodioritic gneisses</u>

These gneisses are commonly developed at the marginal zones of gneiss massifs in the area under reference. Their composition ~~presence~~ is indicated by the Modal Analyses as shown in Table XVI.

Under megascopic study, they reveal gneissose structure and porphyroblastic

texture. The easily recognised minerals in the rock are feldspars, quartz, biotite and muscovite. Feldspars are well developed and in certain cases porphyroblasts of feldspar have acquired rectangular shape. Presence of rectangular plagioclases have also been reported by Das (1971) in case of porphyroblastic gneisses of Chaubattia - Ranikhet area in Almora. Its specific gravity is 2.71.

Under the microscope the following minerals are observed :-

1. Oligoclases(An_{21-26}): These occur as porphyroblasts of very large size (8 mm. X 2.2 mm.). These indicate clouding with abundant presence of the inclusions of biotite, muscovite, quartz, zircon, epidote and sericite (Plate 22, Figs. 1,2&4). The presence of abundant gliding planes in them indicate the effect of strain. Reverse zoning in few grains is observed with varying anorthite content from An_{26} to An_{21} inwards. Reverse zoning indicates a response to increasing temperature (Barth, 1951) i.e. it developed during progressive metamorphism. These commonly show albite type of twinning (Plate 22, Fig. 2) though rarely combined albite -calsbad twinning has also been observed (Plate 22, Fig. 1).

2. Microcline : Its largest grain size is 2.2 mm. X 1.8 mm. It is recognised by the cross-hatched twinning. It also shows the development of gliding planes. Few grains of microcline-microperthites are also developed.

3. Quartz : The grain size varies from 1.6 mm. to 0.1 mm. It is invariably present in the form of sutured grains and shows preferred orientation.

4. Biotite : It is oriented in different patterns. Its pleochroic scheme is

Z = coffee brown
Y = brown
X = pale yellow

where absorption is Z > Y > X; birefringence = 0.04.

It breaks into garnet at the margins (Plate 20,Fig. 4).

5. Hornblende : Few grains of green hornblende are present with perfect cleavage. Its pleochroic schme is

Z = dark green

Y = green

X = yellow brown

with absorption ~~where~~ Z > Y > X. It shows extinction angle of 12°, birefrengence=0.20.

Accessories :

i) Muscovite : Only few flakes are present which show bending. Birefringence = 0.037.

ii) Sillimanite : It is present in shape of needles with high R.I. and birefringence = 0.021. Few grains of sillimanite are of fibrolite variety.

iii) Zircon : It shows typical tetragonal form with high R.I. It typically shows development of zoning. It occurs as inclusions in feldspar and biotite. However, some grains are of subhedral and anhedral nature.

iv) Tourmaline : It is of bluish colour with high R.I. It is highly pleochroic. Birefringence = 0.025.

v) Apatite : It is present as thin needles.

vi) Magnetite : It is black in colour and opaque ~~and isotropic~~.

vii) Chlorite : It is of greenish colour formed after the alteration of biotite.

(ii) <u>Hornblende granodioritic gneiss</u>

Hornblende granodioritic gneiss is observed along a streamlet between Seja and Dhrara on Kishtwar road. Under megascopic study it is of dark grey colour with abundant biotite flakes. Biotite, feldspars, quartz and almandine can easily be recognised.

Under microscopic study the rock shows gneissese structure. The various minerals recognised under microscope are

K-felspar, quartz, oligoclase, albite, biotite, hornblende and accessories comprising of epidote, almandine, sphene, zircon, rutile, tourmaline, magnetite, muscovite and chlorite.

~~1. K-Feldspar~~ Characteristic of its various constituents are as under.

1. K-feldspar It is mostly untwinned and fractured. It shows the presence of gliding planes. The cracks have been filled with veinlets of quartz and sometimes by biotite and chlorite. It also shows clouding and has inclusions of epidote, quartz, magnetite and zircon. The grain size varies from 1.05 mm. to 0.222 mm. in diameter. Here and there a few ~~grains~~ grains of orthoclase are met with which show carlsbad type of twinning.

2. Oligoclase : It measures 0.01 mm. to 0.9 mm. in length. It is mostly altered to sericite with the concurrent development of quartz at the margins. It is mostly fractured which are mainly healed by the veinlets of biotite and chlorite. It shows albite type of twinning.

3. Quartz : The grain size is 1.05 mm. to 0.01 mm. in diameter ~~across~~. It occurs as elongated grains which are euhedral to anhedral in shape. The important inclusions that are found in it are those of magnetite and biotite. It is highly fractured and shows the effect of strain.

4. Biotite : The ~~grain~~ size of the flakes varies from 0.9 mm. to 0.01 mm. It is of coffee brown colour and is abundantly developed. It shows magenitic texture. Pleochroic haloes are present. It is highly pleochroic with Z = Y = dark brown, X = light brown and has a birefringence of 0.037. Some basal sections are present which show -ve biaxial interference figure. Dispersion r 7 v.

5. Hornblende : It is of greenish colour and occurs in prismatic form (Plate 20, Fig. 5). It is pleochroic in shades of

greenish brown and deep green with absorption Z > X > Y. It has the extinction angle of 16° , birefringence = 0.022.

Accessories :

i) Almandine : It has euhedral outline and is of pinkish colour. It shows the phenomenon of snow-ball garnets where inclusions of quartz, biotite and muscovite are present in S pattern.

ii) Epidote : It is of pale greenish colour. It is pleochroic in shades of pistachiogreen and yellowish green. Birefringence=0.04.

iii) Tourmaline : It has bluish colour. It is highly pleochroic with maximum absorption at right angles to the vibration direction of the polarizer. Birefringence = 0.022.

iv) Zircon : It occurs as euhedral grains.

v) Magnetite (vi) Rutile and (vii) Chlorite are other accessories.

The hornblende - biotite gneiss is formed by the permeation of granitic material with abundant alkalic solutions which have effected amphibolite and formed biotite at the margins of amphibolite by potash metasomatism. Such gneisses have been reported by Saxena (1961) from Kabrai area of Bundhelkhand in Uttar Pradesh.

(iv) Tourmaline permeation gneiss

Under megascopic study it is of greyish white colour and has a specific gravity of 2.66. The quartz and feldspar are preponderant mineral. Tourmaline occurs mostly as subhedral grains but in one case at Sarsi it is also found as radiating prismatic needles.

The microscopic study reveals porphyroblastic texture. It is mainly composed of quartz, oligoclase, K-feldspar and tourmaline together with a few accessories.

1. Quartz : It ranges in size from 2.4 mm. to 0.8 mm. in diameter. Most of the grains are surrounded by a zone of secondary growth of silica which is in optical continuity with the inner core. The grains show preferred orientation and are highly fractured.

2. Oligoclase (An_{24}) : The largest size of its porphyroblast is 3.8 mm. X 3.00 mm. in size. It shows albite type of twinning in some grains but other grains show complex twinning in the shape of carlsbad - albite type and albite - percline type. It shows maximum symmetrical extinction angle of 7°.

3. K-feldspars : The largest grain is 1.6 mm. X 1.4 mm. in size. It is mostly untwinned and highly fractured. It is poikiloblastic and has abundant inclusions of muscovite, biotite and quartz.

4. Tourmaline : The largest grain size is 1.6 mm. X 1.00 mm. It exists as subhedral grains of bluish and brownish colour which are invariably fractured (Plate 21, Fig. 4). It is highly pleochroic with maximum absorption at ~~high~~ right angles to the vibration direction of the polarizer. Birefringence = 0.025.

Among the accessories almandine, muscovite, biotite and magnetite are met with.

PETROGENETIC INTERPRETATION OF GRANITIC GNEISSES

Petrogenetic interpretation of granitic gneisses based on field and laboratory studies is given as under.

The potash granitic gneisses, adamellitic gneisses and granodioritic gneisses of the area have been formed by large scale granitization.

Granitization has taken place by a process of metasomatism wherein at any given moment only small amounts of rocks are formed in a molecular disperse state in the medium of solutions, gases and possibly even by currents of ions migrating by diffusion within the intergranular spaces (Mehnert, 1968). The metasomatism to cause granitization is brought out in disperse state by diffusion of ions. According to Barth :

> " The only potential that will create diffusion is difference in the chemical activity of the several rock forming elements at different places in space. Every chemical species will try to reach a place where its activity is low after being dispersed where its activity is great".

There are two schools of thought " dry " and " wet " supporting respectively diffusion in the solid state and soaking by fluids as an operative process.

The idea of dry diffusion of ions has been supported by Perrin & Roubault (1937 & 1939); Bugge (1946); Buckland (1946) and Reynolds (1947). According to Reynolds (1947), solid diffusion takes place through spaces in crystal lattice from one lattice point to another within the crystal mesh and along the boundaries of closely packed crystal grains. Migration of ions is faciliated by lattice disorder, substitution and lattice deformation. The idea of soaking of country rocks by granitic fluids is supported by Barrois (1884); Michel Levy (1893); Lacroix (1899 & 1900); Termier (1904 & 1912); Sederholm (1907, 1913, 1923 & 1926); Wegmann (1935 & 1936); Barth (1952); Read (1956); Mehnert (1968); Pande et al. (1968) and Wakhaloo et al. (1971).

Turner and Verhoogen (1960) and Pande et. al (1968) after critically reviewing the process of diffusion have come to the conclusion that though dry diffusion may be effective through small distances. It cannot be applied to the problems of origin

of large masses of granitic rocks. Further large amount of feldspar present in the granitic rocks show that material required for its formation could not have been derived from the metasediments themselves but must have been introduced from outside in the form of fluids.

In the area under study, the above mentioned idea of Turner & Verhoogen (1961) and Pande et al. (1968) holds good where granitic fluids have played a major role in the process of granitization of these gneisses. The granitization in this area has mainly taken place with the help of granitic fluids.

These granitic fluids comprising mainly of K, Al and Si named as 'Ichors' or 'granitic juices' of Sederholm and "filter colones" by Triemer or "emanations" by Read are formed by anatexis which refers to the selective fusion of rocks. The idea of anatexis to form fluids has been supported by many writers like Saderholm (1907, 1913, 1923 & 1926); Barth (1952); Read(1957); Mehnert (1968); Pande et al. (1968) and Wakhaloo et al. (1971).

By this process minerals having low melting points like that of quartz and feldspar form a melt which can penetrate into the upper portion of sedimentary rocks.

The fluid is accelerated by the capillary action through which the lighter ions of K, Na, Si move up against the force of gravity. These waves of granitizing fluids may also cause migmatization in the country rock.

The tourmaline permeation gneiss at Saye has also been formed by the process of granitization caused by large scale influx of migmatic solutions, containing abundant boron constituents, into the country rock.

There appears to be a zonal distribution of the various types

of gneisses in the area. In the central portion, these are of granitic composition involving preponderance of K-feldspars over that of oligoclases and it is surrounded by gneisses of granodioritic composition with more of plagioclases than orthoclase. Such distribution is also found in other fold regions and can be explained on the basis of Mehnert's view point (1968), which takes into consideration the lightness of sodic ions as compared to potassic ions thereby making the former concentrate towards the marginal area.

According to Reynolds ([illegible], 1943, 1944, 1946 & 1947), the process of granitization takes place in the form of waves which allow first to dispell the heavier constituents of ferromagnesian minerals from the country rocks, in order to make room for lighter ions involved in the formation of granite. The basic constituents create a basic front which always moves in advance of the main wave of granitization. This can be explained by the formation of basic zone showing concentration of biotite, garnet, amphibole and magnetite.

Granitization is further proved by K-feldspathization in granitic gneisses above Duga. K-feldspars of the area showing porphyroblastic texture are conspicuously large and are idiomorphic. These large crystals are known in French as 'dents-de-chevals' (Horse's teeth). In the outer rim of these, plagioclase disappears or becomes quite less but biotite is highly enriched in front of growing crystal.

The formation of 'dents-de-chevals' due to permeation of fluids is quite logical. Mehnert (1968) has clearly elaborated the process by visualizing that granite has been formed by one type of granitic fluids, whereas later attack of K-rich and water-rich fluids which are very mobile can react to other minerals

K-rich fluids in later case show mobility because of different geochemical and P.T.X. conditions affecting them. The fluids, are, therefore, to migrate relatively far afield and when present in excess are able to felspathize the granitic gneisses around them.

These gneisses along with associated schists are formed due to regional metamorphism and indicate the presence of Wegmann's "zone of detachment" in the study area.

6. POSTKINEMATIC GRANITES

The acid intrusives of postkinematic origin in the area under study are (i) granites (ii) pegmatites and (iii) aplites. These bodies occur as stocks, sills and dykes.

Such post-kinematic intrusives can be differentiated from the associated granitic gneisses of synkinematic origin by the discordant nature of these.

I GRANITES

Granites are found to be typically developed at Bhala (33° 3' 51" : 75° 36' 35"); Mundella (33° 4' 11":75°37'12") and Dedni granite developed near Padri as depicted in the Plate 49. These show discordant relationship to surrounding gneisses and schists.

The granites of Bhala-Mundella show some features different from those of the Dedni area and this is made clear from the following description of these.

(a) i) Granites of Bhala-Mundella area

Under the megascopic study these are of light grey colour and are coarse grained and holocrystalline (Plate 13, Fig. 4). The leucocratic minerals consist of quartz and feldspar and ferro-magnesian mineral is mostly biotite. Its specific gravity is 2.65.

TABLE XVII
MODAL ANALYSES OF GRANITES

Locality	Granite near Bhala	Granite at Mundella	Granite at Bhala	Granite near Mundella	Granite away from Brahampur	Granite ofMun-della	Granite away from Mundella	Grano-diotite at Mun-della	Grano-diorite near Munde-lla	Granite of Duga
Slide No.	41D	1972	2 E	9 C	8 E	16	3 E	1 E	7 E	2 G
Quartz	38.54%	13.64%	11.54%	15.34%	21.99%	38.42%	33.28%	46.23%	22.47%	39.44%
K-feldspar	39.04%	75.40%	74.63%	79.60%	47.89%	38.62%	46.08%	8.92%	30.93%	58.56%
Plagioclase	9.55%	6.00%	3.47%	-	17.06%	7.87%	8.15%	27.53%	40.69%	1.73%
Biotite	7.82%	3.06%	3.14%	0.32%	4.26%	7.47%	6.37%	10.39%	2.38%	-
Muscovite	4.34%	1.85%	7.12%	4.17%	7.89%	7.58%	6.09%	6.80%	3.52%	0.08%
Hornblende	0.26%	-	-	0.05%	-	-	-	0.05%	-	-
Accessories*	.45%	0.05%	0.10%	0.52%	0.91%	0.04%	0.01%	0.08%	0.01%	0.19%
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

* Accessories are zircon, magnetite, tourmaline, epidote and apatite.

Under the microscopic study these show holocrystalline and hypidiomorphic texture. Modal analyses is given in Table XVII.

Following are the constituents present in the rock :-

1. K-feldspars : The largest grain is 8 mm. X 6 mm. in size. These are mostly microperthite but occasionally one comes across a few crystals of microcline - microperthite and microcline and orthoclase.

a) Microperthite is mainly composed of string perthite and has inclusions of euhedral quartz grains (Plate 24, Fig. 4). It also shows typical contact twinning overshadowing the perthite (Plate 24, Fig. 1).

b) Microcline - microperthite : It is mostly present as string-perthite (Plate 25, Figs. 2,3&4) and ~~else~~ rarely as film perthite. It shows corroded margins.

The above mentioned conditions indicate their origin due to exsolution at high temperature. Similar perthites are commonly found in Adirondock granites of New York in U.S.A., which are of magmatic origin.

c) Microcline : It is recognised by cross-hatched twinning. Clouding is very common ~~and has~~ due to inclusions of muscovite, biotite, zircon and magnetite. Large scale sericitization is due to the action of hydrothermal solutions.

d) Orthoclase : It is developed as euhedral grains and shows typical carlsbad twinning. The grain size varies from 4.2 mm. X 1.6 mm. to 0.8 mm. X 0.3 mm.

2. Oligoclase (An_{21-30}) : ~~Their~~ largest grain measures upto 4 mm. X 3 mm. ~~It~~ These show large variety of twinning pattern. The normal type indicated by albite and pericline type of twinning, whereas the complex type is marked by the combination of albite - carlsbad type of twinning. However some grains are untwinned. Efforts have been made

to construct the ~~MNK~~ U A C diagram (Plate 44) in order to ascertain their mode of origin. On the basis advocated by GORAI (1951) it has been ascertained that they are of magmatic origin. In Bhala area there is also the presence of orbicular structure (Plate 23, Fig. 5). According to Tyrrell (1952) orbicular structure can be explained as a special case of reaction of granitic magma with accidental xenolith. The formation of this structure in the study area is also due to this factor.

3. Quartz : The largest grain of quartz is 2.4 mm. X 1.6 mm. in size. It shows tendency towards becoming euhedral with hexagonal boundaries. It contains zircon, apatite and micaceous minerals as inclusions. In certain cases its margins are corroded (Plate 24,Fig.5).

4. Biotite : The largest flake measures 1.8 mm. X 0.6 mm. It is mostly yellowish brown in colour and has abundant inclusions of euhedral zircons surrounded by pleochroic haloes. Some of the flakes are riddled with magnetite inclusions. Some of the flakes show bending. Its scheme of pleochroism is

Z = Y = reddish brown

X = light brown

and the
~~where~~ absorption is Z = Y > X; birefringence = 0.04.

5. Muscovite : The largest flake is 1.4 mm. X 0.4 mm. in size. It occurs in subhedral form with abundant inclusions of zircons forming pleochroic haloes around them. Birefringence = 0.041.

Among the accessories euhedral zircon, magnetite, sillimanite, rutile, apatite and tourmaline are present.

(ii) <u>Granodiorite of Mundella</u>

Under the megascopic study it shows holocrystalline and coarse grained texture. It is of greyish colour and its specific gravity is 2.71.

Under the microscopic study it is hypidiomorphic. Myrmekitic-texture is also developed (Plate 25, Fig. 1).

Modal analyses of them are is given in Table XVII. The various minerals present in the rock are described as under :-

1. Oligoclases (An_{25-30}) : The largest grain size is 3.2 mm. X 2.2 mm. ~~in xixx it~~ These have vast variety of twinning patterns. The simple type of twinning is indicated by albite law and pericline law (Plate 23, Fig. 2) whereas the complex type of twinning is marked by combined carlsbad - albite type of twinning and by the penetration twins. Zoning is present occasionally. However, some grains are untwinned. These have been plotted on the U A C diagram as shown in the Plate 44, on the lines advocated by GORAI, it indicates magmatic origin for these.

2. K-feldspars : Among the K-feldspars, microcline, and microcline - microperthite are commonly developed.

i) Microcline : Its largest grain size is 2 mm. X 1.6 mm. It shows tendency towards idiomorphism. It is recognised by cross-hatched twinning.

ii) Microcline - Microperthites : Its largest grain is 6 mm. X 2.2 mm. It contains abundant inclusions of muscovite, biotite and plagioclase.

3. Quartz : Its grain size varies from 2 mm. X 0.6 mm. to 0.2 mm. X 0.2 mm. in size. It is developed as large elongated grains which are highly fractured. Most of the quartz grains are free of inclusions, but some contain inclusions of apatite, zircon and muscovite.

4. Biotite : The largest flake is 2.6 mm. X 4.0 mm. in size. It is of deep brownish colour and has inclusions of euhedral zircons which form pleochroic haloes around them. Pleochroic scheme is Y = Z = deep brown, X = brown ~~where~~ with absorption Z = Y > X.

5. Muscovite : It shows tendency towards idiomorphism in some sections but other sections are subhedral. It shows perfect cleavage and has inclusions of zircons in it which have pleochroic haloes around them; birefrengence = 0.04.

6. Hornblende : It has few grains of greenish colour. It is pleochroic according to the scheme

Z = deep green

Y = green

X = yellowish brown

where absorption is Z > Y > X; birefringence = 0.022. Its extinction angle = 12°.

Among the accessories euhedral zircon, tourmaline and apatite are present.

(iii) Granite of Dedni area

Under the megascopic study it is holocrystalline and fine grained. It is of brownish colour and its specific gravity is 2.60.

Under the microscope it shows granitoid texture. Micrographic texture is ~~also~~ typically developed (Plate 23, Fig.3 & Plate 25, Fig. 3). Myrmekitic texture is also developed (Plate 24, Fig. 2). It is composed of the following minerals :-

1. Oligoclase : It shows normal albite type of twinning in common, though complex carlsbad - albite type of twinning is also observed in few grains. Maximum symmetrical extinction angle is 8°. It also shows zonary structure (Plate 23, Fig. 4).

2. K-feldspars : These are present as (a) Orthoclase (b) Microcline and (c) untwinned K-feldspars.

(a) Orthoclase : It is of subhedral form and shows typical carlsbad type of twinning (Plate 23, Fig. 1).

(b) Microcline : It ~~has~~ shows cross-hatched twinning and has extinction angle = 5°.

(c) Untwinned K-feldspar : It shows large scale sericitization.

3. Quartz : It is mostly present in granulated form and occurs as mosaic of euhedral grains. Some grains show overgrowth over the earlier ones and have inclusions of muscovite and biotite.

4. Biotite : It mostly occurs as basal sections and is of deep brownish colour. It shows -ve biaxial interference figure. However some flakes are subhedral with perfect cleavage. Its pleochroic scheme is

Y = Z = deep brown

X = brown

with absorpition Z = Y > X; birefringence = 0.04.

5. Accessories :

(a) Epidote : It is of pinkish colour and is highly fractured. It occurs as rounded grains. Birefringence = 0.04.

(b) Zircon : It occurs as perfectly euhedral grains and shows very high birefringence.

(c) Tourmaline : It is of blue colour and is highly pleochroic.

(d) Zoisite : It is colourless and shows blue anamolous interference colours.

(e) Almandine : It is of pinkish colour and is highly fractured. It is isotropic.

(b) <u>Xenoliths in granites</u>

These have been abundantly found in the granites of Duga (33° 3' 28" : 75° 36' 15"); Malnai (33° 5' 38" : 75° 35' 25") and Dragga (33° 6' 25" : 75° 33').

Under megascopic study these are elliptical in shape (Plate 10, Fig. 6 & Plate 13, Fig. 5). It ranges in size from two centimeters to twelve centimeters in size. These are of black colour and are medium grained.

Under microscope typical granoblastic texture is observed (Plate 25, Fig. 5). The various minerals developed in xenoliths are described as under :-

1. Biotite : The largest flake is 1.6 mm. X 0.5 mm. in size(Plate 25, Fig. 6) and is developed at the margins of xenoliths. It is of dark brownish colour and has abundant inclusions of magnetite, zircon and allanite. Pleochroic haloes are present around zircons. Its pleochroic scheme is

Z = Y = dark copper brown

X = light brown

and the ~~where~~ absorption is Z = Y > X; birefringence = 0.041. Some sections show undulatory extinction.

2. Quartz : Its grain size varies from 0.8 mm. to 0.02 mm. in diameter. It is the next important mineral and is invariably granoblastic in texture. It is free of all the inclusions.

3. K-Feldspar: It is present as mostly untwinned grains. It is recognised by staining tests. The slide when first dipped in conc. HCl and then cobalt nitrate gave golden yellow colour to these grains.

4. Oligoclase (An_{25}) : Few grains are present and showing subhedral form and albite type of twinning.

5. Accessories : A large number of accessories are present as is indicated below :-

(a) Almandine : It is present as small rounded grains of pink colour, which are isotropic.

(b) Cordierite : It is colourless and is seen in large plates with irregular outlines. It has abundant inclusions of zircon. It shows sector twinning.

(c) Sillimanite : It is mostly present as fibrolite. It is formed owing to the breaking of biotite which can be explained by the reaction advocated by Shalley (1968)

$$K_2Fe_5Al(OH)_4Si_5Al_3O_{20} + 2\,SiO_2 = Al_2SiO_5 + K\,Al\,Si_3O_8 + 2\,H_2O + 5FeO$$
(Biotite) (Quartz) (Sillimanite) (Orthoclase)

(d) Anthophyllite : It is of pale ~~brownish pink~~ colour and occurs as fibrous patches with serrated margins, replaced internally and at the borders by tuffs and bunches of fibrolites.

(e) Spinel : The xenoliths at Dragga contain spinel in addition to other accessories. It is greenish coloured mineral and is isotropic.

Other minor accessories are comprised of (f) zircon (g) brown allanite (h) muscovite (i) apatite (j) Magnetite (k) tourmaline (l) epidote (m) ilmenite and (n) leucoxene.

TABLE XVIII OF
MODAL ANALYSIS OF XENOLITH AT DUGGA

Quartz	39.70 %
K-feldspar	3.26 %
Oligoclase	1.40 %
Biotite	43.70 %
Muscovite	0.46 %
Sillimanite	3.21 %
Cordierite	4.06 %
Other minerals*	4.21 %
	100.00 %

*Other minerals are Almandine, Anthophyllite, spinel, allanite, zircon, muscovite, apatite, magnetite, tourmaline, epidote, illimenite and leucoxene.

These are formed due to the incorporation of rock material into the magma during its injection. The fragments of the country rock which were engulfed in the granitic melt, were subjected to thermal metamorphism which resulted in the formation of such minerals as cordierite, sillimanite, spinel etc. This view is supported by Tyrrell (1952) and Mehnert (1968).

Petrogenetic interpretation of granites based on their field and laboratory study.

In all probablity the granites of the area have originated by the processes of anatexis, which is operative at considerable depth. The low melting fractions, comprising of quartz and feldspar, are the first mineral constituents to be melted with the release of pressure by any diastrophic movement resulting in the formation of magma. This is in agreement with the observations of Lacy (1960), who on the basis of laboratory investigations on granitic melts, has dealt with the structure, properties and behaviour of such melts. According to him

> " Granite liquid originates at depths of 28 to 30 Kms, that the initial water content is in the order of 2% by weight, and that the geothermal gradient is in the order of 32°C per km. The temperature of magma formation under these conditions, indicated by the data of Tuttle & Bowen, will be about 925°C".

He further mentions that the portion of strata above the generation of the melt, acquires plasticity in response to elavated temperatures and the tectonic stresses involved in the orogeny create an upward buldge below which the granitic melt arises in a diapiric fashion. The rise of granitic magma is further faciliated by the presence of dislocation zone on the outskirts of granite which, in the area of the present study are to be met with in the form of faults and existence of mullion structures (Plate 9, Fig. 2). Though Bhala-Mundella granite and

and Dedni granite appear at the surface to be two different stocks but down below they appear to have a common source.

The process of anatexis responsible for the formation of granites is further confirmed by the complete absence of other plutonic rocks such as diorites, gabbro and peridotite and also their corresponding volcanic equivalents.

That the granitic rocks in the area have originated by crystallization from a melt can be interpretted from the field and laboratory observations.

In the field, one cannot fail to notice the zone of thermal metamorphism, surrounding the main seat of intrusions of main granitic mass, like that of Dedni granite, where the limestone has been recrystallized to diopside bearing marble.

Secondly, the rocks surrounding the intrusive masses are sufficiently deformed which is evidenced by the presence of faults and mullion structures in the vicinity of these.

Thirdly, there is a contact zone of granite at Duga which has "dents-de-chavals" mostly consisting of perthitic feldspar.

Lastly, there are pieces of country rocks which have been caught up as xenoliths in the body of main granitic mass. These xenoliths are haphazardly distributed which indicate their incorporation during the injection of magma.

Regarding the microscopic criteria it has been observed that i) plagioclase shows the normal type of zoning in which the core is richer in anorthitic content than the periphery.

ii) The plagioclase feldspars show beside albite and pericline type of twinning, the combined carlsbad - albite type of twinning and interpenetration twinning.

iii) There is presence of orbicular structure (Plate 23,Fig.5) in some of the granitic rocks which is due to post-magmatic growth of ~~microperthitic~~ zones over the earlier formed crystals. These zones are to be ascribed to the development of these feldspars of different intensity.

iv) The euhedral development of K-feldspars and plagioclases is to be connected with the crystallization from the melt.

v) Micrographic texture as is shown in Plate 23, Fig. 3 and Plate 24, Fig. 3, indicates the simultaneous growth of quartz and orthoclase at the eutectic ratio of the magmatic melt.

vi) Presence of bipyramidal grains of quartz inclusions in feldspars (Plate 24, Fig. 4) indicates high temperature conditions.

vii) Presence of euhedral zircons with their elongation ratio slightly more than 2/1 indicates their magmatic origin of granites.

II PEGMATITES

Pegmatites are formed in the area under reference in the shape of sills and dykes. There are two types of these:-

i) Muscovite and Tourmaline bearing pegmatite;

ii) Kyanite bearing pegmatite

Their distribution is shown in the Geological Map forming Plate 49 of this thesis.

i) Muscovite and tourmaline bearing pegmatite

It is the most common variety met with in the study area. Under megascopic study it shows very coarse grained texture with pegmatitic structure. It is of white colour. Its weathered outcrops show spangles of muscovite which are scattered all around.

This rock has typical development of muscovite, whose flakes

are upto 9 cm. in size. Some flakes are euhedral and as is common with such a mineral it shows the development of percussion - figures when pressure is applied to it with a blunt point. Besides muscovite, feldspar, quartz and black tourmaline grains are also easily recognisable. Its specific gravity is 2.67.

Under microscopic study it shows holocrystalline and hypidiomorphic texture (Plate 26, Fig. 1).

It is composed of K-feldspar, oligoclase, quartz, muscovite, tourmaline and accessories of zircon and magnetite. Their important optical properties are set out as under :-

1. K-feldspar : It indicates the presence of both orthoclase and microcline and also perthitic feldspar.

(a) Orthoclase : Its largest grain is 2.4 mm. X 1.6 mm. in size. It has abundant inclusions of quartz, biotite and muscovite. Its extinction angle is 12°. It shows typical carlsbad type of twinning.

(b) Microcline : It is present in subhedral form and shows perfect cleavage. Its extinction angle is 15°. It shows typical cross-hatched twinning and has gliding planes as are indicated in Plate 26, Fig. 2.

(c) Perthite : It is present in the shape of film perthite.

(2) Oligoclase (An_{28}) : Its largest grain is 4.4 mm. X 3.8mm. It has abundant inclusions of quartz, muscovite and biotite. It shows twinning on albite law and has thin twinning lamellae. It also shows the development of gliding planes.

(3) Quartz : The largest grain is 3.6 mm. X 2 mm. in size. It mostly occurs in anhedral form but in some cases it has acquired euhedral form. It shows abundant inclusions of earlier formed grains quartz and muscovite.

(4) Muscovite : It is present as large flakes showing the development of perfect basal cleavage and has inclusions of zircon and magnetite abundantly distributed in it. Pleochroic haloes are present around the zircon grains. Birefringence=0.037. Simple twinning is observed in some sections. Some of the interference figures have been studied in basal sections for the determination of the optical sign and it has been found that they are optically negative.

5. Tourmaline : Its largest grain is 1.4 mm. X 0.8 mm. in size. It is present as bluish coloured grains ~~and~~ which are highly fractured (Plate 26, Fig. 1). It is highly pleochroic with maximum absorption at right angles to the vibration direction of the polariser. Birefringence = 0.015.

(ii) Kyanite bearing pegmatite

It is localized at only one place, Bhabor($33^{\circ}8'$ 50":$75^{\circ}35'35"$) It lies between almandine mica schists and the gneisses in the shape of a sill.

The kyanite attains grain size ~~of grains~~ upto 10 cm. X 7 cm. and shows typical bladed forms (Plate 13, Fig. 6). Besides kyanite, other minerals recognised megascopically are feldspar, quartz and biotite. Its specific gravity is 2.65.

Under microscope it shows holocrystalline and hypidiomorphic texture (Plate 26, Fig. 3). The various minerals present in it are described as under :-

1. Kyanite : It is the dominant mineral in thin sections. It is colourless and occurs as broad elongated plates parallel to (100). It has abundant inclusions of staurolite, rutile, quartz, muscovite and epidote. It has perfect double cleavage which ~~and~~ shows cross partings at angles of 85°. Birefringence = 0.016. Its

extinction angle = 30°. on (100). Frequent twinning is also present. It is highly fractured and shows the development of gliding planes. The fractures have been healed by muscovite flakes (Plate 26,Fig.4). Under convergent light biaxial interference figure is observed. It is optically -ve. Dispersion r > v. Some sections also show the presence of bent grains (Plate 26, Fig. 5).

2. Oligoclases (An_{27-30}) : Their largest grain is 3 mm. X 1 mm in size. These occur as subhedral grains and have abundant inclusions of sericite and quartz. The maximum symmetrical extinction angles vary from 9° to 12°.

3. Quartz : Its grain size is 4 mm. X 1 mm. It is present in shape of bipyramidal grains but in some grains there is granulated form.

4. Biotite : It is of brownish colour and has abundant inclusions of magnetite and zircon. It is highly pleochroic, according to pleochroic scheme

Z = Y = reddish brown

X = light brown

where absorption is Z = Y > X; birefringence = 0.041 and its extinction angle = 3°.

5. Sillimanite (fibrolite) : It is developed parallel to kyanite grains and is the outcome of the breaking of biotites. It has brownish colour and occurs as bundle of fibres. Birefringence = 0.021.

6) Accessories:

Among the accessories magnetite, rutile, staurolite and zircon are present.

(a) Magnetite : It is black and opaque.

(b) Rutile : It is of reddish brown colour with high refractive index and very high interference colours.

(c) Zircon : It is present as euhedral grains which are birefringent.

TABLE XIX

MODAL ANALYSIS OF KYANITE BEARING PEGMATITE OF BABHOR

Quartz	20.12 %
K-feldspar	2.40 %
Oligoclase	16.34 %
Biotite	0.37 %
Muscovite	0.90 %
Kyanite	58.90 %
Sillimanite	0.85 %
Other minerals*	0.12 %
	100.00 %

* Other minerals are magnetite, rutile, staurolite and zircon.

Petrographic interpretation of Pegmatites from the field and laboratory study

Pegmatites are formed by the migration of ions from the surrounding country rocks into the fissure and other such openings. These openings which have been formed by shear and tear of solid rocks in the course of deformation and have provided the enough space for the development of such veins.

Ramberg (1964) has explained that at the local places of low free energy of growth, the conditions are somewhat supersaturated where the pegmatites grow slowly.

Barth (1952) has explained the growth of pegmatites by dispersion, diffusion and consolidation of individual chemical species of the solid rock.

In orogenic areas, as a result of fracturing, mechanical pressure gradients are immediately set up which in turn create corresponding gradients in the chemical activities. So consolidated particles in the rocks will disperse and migrate towards the crack and then consolidate in shape of new minerals.

In this way every molecular seam that opens will be filled with minerals until the mechanical pressure in the rock becomes evenly distributed.

(iii) APLITE

Under megascopic study it is of brownish colour and is fine grained. Its specific gravity is 2.6. Near Dedni, galena is associated with its vein in disseminated form(Plate 11, Fig. 5).

Under microscopic study it shows holocrystalline and xenomorphic granular texture (Plate 26, Fig. 6).

Following are the constituents present in it :-

1./ Quartz : It mostly occurs as sutured grains though few grains show granulation due to the effect of strain during their formation. It shows clouding and has inclusions of biotite, clinozoisite and tourmaline.

2. K-feldspar : It is commonly present in untwinned form. Few grains of microcline with typical cross-hatched twinning are also present.

3. Oligoclase : Few grains of it are present showing subhedral form. It shows thin twinning lamellae with maximum symmetrical extinction angle of 9°.

4. Biotite : It is of brownish colour and is highly pleochroic according to pleochroic scheme

Z = Y = reddish brown

X = light brown

and the
~~where~~ absorption is Z = Y > X; birefringence = 0.041.

5. Hornblende : It is of greenish colour with perfect cleavage and is highly pleochroic. Extinction angle is $Z \wedge C\ 12^{\circ}$.

6. Galena : It is recognised by its black colour which

is white by reflected light. It has cube shaped grains which are opaque, ~~and isotropic~~.

7. Accessories :

(a) Tourmaline : It is of bluish colour and is highly pleochroic with maximum absorption at right angles to the vibration direction of the polarizer; birefringence = 0.025.

(b) Pyrrhotite : It occurs as irregular masses of reddish brown colour. It is recognised by having bronze colour in reflected light, weak pleochroism and feeble anisotropic character.

(c) Magnetite : It is black and opaque ~~and isotropic~~.

Petrogenetic interpretation of the origin of aplites from the field and laboratory studies

Raguin (1965) has described the formation of aplite as under :-

" The residual magma of granitisation should consolidate in the form of aplite".

The aplites of the area under reference have a similar origin. These have been consolidated from granitic fluids under stress in the joints which got opened by shear and tear of solid rocks in these orogenic areas, ~~from granitic fluids~~. Raguin(1965) has emphasized that in their formation ~~of~~ stress is an essential feature.

Its formation indicates late stage of differentiation of residual magmatic material.Sudden relief of pressure results in the formation of fractures which communicated the aplitic magma.

The association of galena and pyrrhotite indicates magmatic source of their mineralization.

(iv) QUARTZ VEINS

They are of white colour and are scattered through schists as dykes (Plate 10, Fig. 1). The common thickness of

these veins is 4 feet except one at Kumari, which occurs at the margin of granitic gneiss, is 25 feet thick and have considerable longitudinal extension.

An interesting feature of Pranu quartz veins is that these veins have cores comprising of transparent quartz crystals, which crystallise in hexagonal shape and occur as Twins. Occasionally here and there radiating tourmaline needles are observed in some of these veins.

The quartz veins, with cores of transparent quartz and the presence of tourmaline needles in some veins, indicate a hydrothermal stage of fluids which has been reached at the last stages of permeation. These hydrothermal solutions have moved through fractures and shear zones and consolidated in the openings to form these veins.

7. AMPHIBOLITES

Amphibolites are present as sills and dykes and make sharp contacts with the surrounding metamorphic rocks.

The rocks comprising them are usually medium grained and are of dark greenish colour but in case of Kummiary, it is fine grained. Their average specific gravity is 3. They exhibit a banded appearance due to alternation of melanocratic layers of amphiboles and leucocratic ones of feldspar and quartz. It appears that this banding is in response to metamorphic - differentiation.

Under the microscope it shows typical decussate (Plate 19, Fig. 5), nematoblastic (Plate 19, Fig. 6) and glomeroblastic textures (Plate 19, Fig. 4). The last mentioned term has been coined by Goodspeed (1937) to demonstrate the aggregate recrystallization of hornblende.

Following are the important constituents present :-

1. Hornblende : Its largest grain is 3.8 mm. X 1 mm. in size. The hornblende crystals usually are poikiloblastic containing innumerable inclusions of epidote and magnetite (Plate 19, Fig. 4). It is a prominent constituent and varies in amount from ~~25.67%~~ 85.76% to 53.04%. It mostly occurs as subhedral grains and has well developed amphibole cleavages. Its refractive indices are α = 1.64 and γ = 1.67. Its pleochroic scheme is

Z = deep green

Y = green

X = greenish yellow

where absorption is Z > Y > X. In one case the colour corresponding to Z vibration direction is bluish green. Birefringence = 0.022. Its extinction angle Z $\wedge$ c is 22°. Optical sign is biaxial -ve.

2. Andesine (An_{38}) : Its largest grain is 0.6 mm. X 0.5mm. in size. It is present upto 10.95% and is the next important constituent of amphibolites. It occurs as subhedral grains and has abundant inclusions of quartz and magnetite. The maximum symmetrical extinction angle is 20°. It shows albite type of twinning.

3. Quartz : It is present as xenoblastic grains and has its inclusions arranged in linear positions. It amount varies from 8.03% to 1.5% in various sections.

4. Accessories :

(a) Epidote : It is the most common accessory. It is yellowish green in most sections though other sections are colourless. The coloured grains are strongly pleochroic. Birefringence = 0.041.

(b) Biotite : Few flakes of brownish colour with

perfect cleavage are present. Its pleochroic scheme is Z = Y = deep brown X = light brown, where absorption is Z = Y > X; birefringence=.037.

(c) Tourmaline : It is present as small grains of bluish colour, showing high degree of pleochroism where maximum absorption is at right angles to the direction of the polarizer. Birefringence = 0.029.

(d) Magnetite : It is black and opaque ~~and isotropic~~.

(e) ~~Ilmenite~~ Ilmenite : It is brownish black in colour with metallic lustre in reflected light.

(f) Sphene : Few euhedral grains of yellowish brown colour occur in shape of rhombic cross sections. Birefringence =0.04.

TABLE XX

MODAL ANALYSES OF AMPHIBOLITES

Locality	Seja	Jodhpur	Thalsera
Slide No.	4C	16D	36D
Honrblende	85.76 %	53.04 %	63.57 %
Andesine	10.95 %	25.53 %	23.00 %
Quartz	1.56 %	3.73 %	8.03 %
Biotite	-	3.56 %	-
Muscovite	-	1.41 %	-
Other minerals*	1.73 %	12.73 %	5.40 %
	100.00 %	100.00 %	100.00 %

* Other minerals are comprised of magnetite, ilmenite, epidote, sphene and tourmaline.

The amphibolites are of ortho_type which is indicated by the following evidences :-

1. In case of Doda amphibolite J, Niggli value mg was plotted against c (Plate 43, Fig. 2) and observed that its trend line was similar to Karoo dolerites ~~trend~~ trend (Walker & Poldervaart, 1949) ~~(1954)~~, which indicates that amphibolite is ortho_type.

Leake (1963) and Orville (1969) in case of Adirondack - amphibolites and Wakhaloo et al. (1969) in case of Kishtwar amphibolites have got a similar trend which indicates their nature to be orthotype.

2. It shows blasto-ophitic texture as is indicated in case of amphibolite at Thalsera.

3. The development of glomeroblastic texture is typical of the rocks developed by the metamorphism of Igneous rocks (Goodspeed, 1959). The glomeroblastic texture (Plate 19, Fig.4) has been observed in case of amphibolite at Seja. This represents an intermediate stage of crystalloblastic growth where the groups are merely aggregates of crystals. These are irregular in shape with sharp re-entrant angles resulting from the growing together of several individual crystals.Haung(1962), has supported this view. To quote him,

> " Plug shaped bodies lacking mineral orientation represent ortho-amphibolites".

4. The presence of sufficient amount of andesine favours their origin from basic igneous rocks.

5. Abundance of magnetite and ilmenite in these indicates their origin from basic igneous rocks as magnetite and ilmenite are uniformly present in the basic lavas.

6. Absence of diopside and presence of quartz and biotite in minor amount also indicates that these are not of sedimentary origin.

CHAPTER VI

DESCRIPTION OF THE MINERALS ENTERING INTO THE COMPOSITION OF METAMORPHIC ROCKS

1. QUARTZ
2. CHLORITE
3. MUSCOVITE
4. BIOTITE
5. ALMANDINE
6. HORNBLENDE
7. STAUROLITE
8. KYANITE
9. SILLIMANITE
10. PLAGIOCLASE
11. K-FELSPARS
    - (a) ORTHOCLASE
    - (b) MICROCLINE
    - (c) UNTWINNED K-FELSPAR
    - (d) PERTHITE
12. MYRMEKITE
13. ACCESSORIES
    - (a) ZIRCON
    - (b) EPIDOTE
    - (c) TOURMALINE
    - (d) APATITE
    - (e) MAGNETITE

CHAPTER VI

DESCRIPTION OF THE MINERALS ENTERING INTO THE COMPOSITION OF METAMORPHIC ROCKS

The nature of minerals, their properties and their sizes vary in various rocks according to their phase of metamorphism. Such changes and their mode of formation under varying P T conditions and chemical environment have been also attempted.

1. QUARTZ

Quartz is the commonest mineral which ranges from 20% in the pelitic rocks to more than 95% in case of quartzite. In low grade metamorphic growths, it almost occurs as anhedral grains with sutural or plane contacts with feldspars or with the quartz grains. In the high grade metamorphic rocks, gneisses and schists, there is a tendency in it to form hexagonal crystals with pyramidal terminations.

In granites and pegmatites it is more euhedral and forms "dihexahedra" form of crystals within felspars as inclusions (Plate 24, Fig. 4). The hexagonal symmetry is regarded as the high temperature form of quartz and is thus taken as a proof for a formation above 573°C i.e. the inversion temperature of high/low quartz (Mehnert, 1968).

The grain size of these is dependent on the grades of metamorphism. In low grade metamorphism, like phyllites, these are 0.004 mm. x 0.003 mm. whereas in pegmatites their size goes upto 4 mm. x 1 mm.

In quartzite the quartz grains show planer contact and annealing effect is visible (Plate 14, Fig. 2). The average grain size is 0.1 mm. x 0.1 mm.

In the greenschist facies its grain size increases to 0.9 mm. x 0.5 mm. With the increase of metamorphism its grain size

goes on increasing. In the epidote - amphibolite facies, its grain size is 1 mm. x 0.5 mm. which in amphibolite facies ~~the grain~~ increases to 1.35 mm. x 1.05 mm. In the higher grades, it has undergone recrystallisation with concomitant increase in grain size and in addition much has been developed by the release of SiO_2 in reactions taking place during metamorphism.

In case of gneisses the grain size of quartz grains still further increases by its growth over earlier existing smaller grains. The largest grain size met in gneisses is 2.1 mm. x 1.1 mm.

In case of magmatic granites, however, the largest grain size observed is 2.4 mm. x 1.6 mm.

Some of its grains show abundant of clouding due to the presence of earlier inclusions of quartz, over which the growth has taken place, and also due to the presence of inclusions of magnetite and apatite.

In some of the rocks it shows preferred orientation owing to the elongation of these parallel to the pucker axis and is particularly observed in the almandine - mica schists and the felspathic schist.

The quartz grains show evidence of post-crystallisation deformation which is indicated by the presence of marginal granulation (Plate 19, Fig. 1); deformational lamellae (Plate 19, Fig.2) and strong undulatory bands (Plate 24, Fig. 6). The deformation is mainly observed near local shears which show the development of local cracks.

The deformational quartz has been abundantly found in the marginal granites and granodiorites of Bhala-Mundella area.

2. CHLORITE

It is commonly found in the phyllites, though it is also observed in small scales in the biotite schist and other high grade schists as a result of partial chloritization.

It is usually met as anhedral flakes of deep green clour. It is pleochroic, anisotropic and gives first order interference colours having birefringence = 0.011.

In few garnetiferous biotite schists the formation of penni/te has been observed which is recognised by having green colour, long prisms of tabular habit occuring in sheafy form, perfect cleavage and showing slight pleochroism. It is typically recognised by optical anomaly by having Berlin blue colour.

Feeble retrogressive chlorite is also met within higher grades which is altered from garnet at its margins. Such chlorite has also been reported by Billings (1937); Harker (1939) and Naha (1965).

In the green schist facies chlorite is met with large flakes of biotite. Biotite and aluminium rich chlorite have been formed from an aluminium poor chlorite and muscovite as is indicated by the following reaction :-

$$5\,Mg_3Si_2O_5(OH)_4 + 3KAl_3Si_3O_{10}(OH)_2 = 3KMg_3Si_3O_{10}(OH)_2 + 3Mg_2Al_2SiO_5(OH)_4 + 7SiO_2 + 4HO_2$$

(Antigorite) (Muscovite) (Biotite) (Amesite)

.....(Tilley, 1924); Harker, 1939; Barth, 1952; Naha, 1965 & Winkler, 1967).

3. MUSCOVITE

It is found in the area nearly in all type of rocks from low grade schists to high grade schists, gneisses and pegmatites.

It shows remarkable uniformity in optical characters in all grades. It is found as elongated flakes with rare medium sized plates in schists and gneisses. Large flakes of muscovite are met within pegmatites. When pressure is applied, with a thin nail on a large flake, percussion figure is obtained. It is recognised by its white colour, medium R.I. and abundant inclusions of magnetite and zircon. Pleochroic haloes are commonly developed around zircon grains. Birefringence = 0.041. Some flakes having basal sections, show biaxial interference figure, Disperson is r > v. Large sized individuals of undeformed muscovite are present at the fold crest of the puckered schists forming polygonal arcs, which indicate its crystallisation during D_3 episode.

It occurs in a wide range of regionally metamorphosed rocks of the area. The size of the flakes has increased with the increase in grade of metamorphism.

In case of phyllites the ~~grain~~ size of the flakes is the smallest which measures 0.01 mm. x 0.005 mm. With the rise of metamorphism the size of its flakes gradually increases in schists. ~~The size of its flakes~~ Its size in case of biotite schists ranges from 1.35 mm. to 0.75mm; in case of almandine - mica schists it varies from 1.5 mm to 0.075mm; in case of staurolite schists it varies from 1.6 mm. to 0.1 mm. and in case of sillimanite schists it varies from 1.6 mm. to 0.3 mm. along its length.

In case of gneisses and pegmatite the size of flakes still further increases. The largest flake observed in case of gneisses is 1.35 mm. x 0.1 mm. in size.

However, their larger size as observed under megascopic study is 9 cm. x 3 cm. in pegmatites, where flakes occur as books of muscovite sheets and possess hexagonal boundary.

It is commonly met with in the schists of both epidote - amphibolite facies and amphibolite facies. It remains an important constituent of gneisses also throughout though decreased in amount, indicating that its upper stability limit has not been exceeded.

4. BIOTITE

Biotite is the most common and widely distributed constituent of the schists and gneisses of the study area. The size of the biotite flakes increases from very fine to highly coarse size, with the increase in the grade of metamorphism.

It is mainly sub-hedral, though anhedral sections are also met with in some rocks. It is mainly present in coffee brown, deep brown and light brown colours though in some metamorphic rocks light green coloured biotites are also met with. It has abundant inclusions of zircon and magnetite. It shows pleochroic haloes around zircons. Its brown varieties are pleochroic according to the following scheme:-

Z = Y = Redish brown
X = Light brown

In case of greenish biotite pleochroism takes place as under:-

Z = Y = Grass green
X = Bronish yellow

The obsorption in both the case is Z = Y > X.

Green biotite has commonly met with in phyllites, biotite schists and Xenoliths present as inclusions in granite. Birefringence = 0.04 and extinction angle is 3°. Some of its flakes show twinning. However, Basal sections show -ve biaxial interference figure exhibiting ~~where~~ dispersion is of r > v. Its size varies from the largest flake measuring 3 mm.x0.4mm. to the minimum size measuring 0.01 mm. x 0.005 mm. It is generally undeformed, ~~where~~ biotite superindividuals, tracing the puckered schistosity, ~~and with the individuals~~ are also undeformed even at fold hinges,

It is commonly met in biotite schists and biotite -sericite-schists of the greenschist facies. Here increase of biotite flakes is marked by decrease in chlorite and muscovite. Its formation has taken place according to the following reaction:-

$$5\ Mg_3Si_2O_5(OH)_4 + 3KAl_3Si_3O_{10}(OH)_2 = 3KMg_3AlSi_3O_{10}(OH)_2 + 3Mg_2Al_2SiO_5(OH)_4 + 7SiO_2 + 4H_2O$$

(Antigorite) (Muscovite) (Biotite) (Amesite)

....(Tilley, 1924; Harker, 1939; Barth, 1952; Snelling, 1957 & Naha, 1965).

Association of biotites with chlorites is a common feature and points towards this fact. It is also a stable mineral in epidote - amphibolite facies, amphibolite facies and amphibolite - granulite facies. It has been noted that the colour and refractive-indices of biotite show a gradual change from low grade to high grade rocks. The biotite of greenschist facies is paler and shows lesser refractive index($n\beta$ = 1.645) than in amphibolite facies ($n\beta$ = 1.658). The biotite in amphibolite facies is of reddish brown colour due to higher TiO_2 content. Consequent upon the increase in grade of metamorphism. (Ramberg, 1952).

Alteration products of biotite.

It is rich in alteration products comprising of chlorite, rutile, quartz, orthoclase and sillimanite which have been developed as under :-

(a) Conversion to chlorite

Alteration of biotite to chlorite has been explained by Chayes (1955) due to addition of silica as follows :-

Biotite + quartz --⇒ chlorite + orthoclase .....(1)

Partial chloritisation of biotite has been explained by

Wakhaloo, et. al. (1968) by the addition of aluminium silicate in the presence of steam as follows :-

$$2(OH)_2\ 2KFe_3+2AlSi_3O_{10}+2H_2O = (OH)_8Fe_3+2Fe\ Al\ +3Si_3O_{10}+KAlSi_3O_8+K \quad ..(2)$$

(Fe Mica) (Fe Chlorite) (Orthoclase)

As the rocks of the area are partially chloritized the second equation explains the formation of chlorite.

(b) Separation of quartz

Ramberg (1952) has explained that during the alteration of biotite to muscovite quartz gets separated according to the following reaction :-

Biotite + Al-chlorite = muscovite + Fe Mg chlorite + Silca.

During the transformation silica is leached out to form quartz.

(c) Separation of rutile needles

Separation of rutile needles in these have produced sagenitic structure. This structure has also been observed by Wakhaloo et al. (1968) in Kishtwar area and by Gupta L.N.(1969) in Dhauladhar Range. The rutile needles are developed along the relict cleavage traces of hornblende (Plate 20, Fig. 2) from which biotite has developed. It has been concluded that they are directly connected with the deposition of TiO_2 as rutile along these very planes of resistance.

(d) Development of almandine from alteration of biotite

Almandine has been obtained during the higher stages of regional metamorphism(Plate 16, Fig. 6) and (Plate 20, Fig. 4). Ramberg (1952) has suggested the following reaction :-

$$(OH)_2KFe_3AlSi_3O_{10}+(OH)_2KAl_3Si_3O_{10}+3SiO_2 = 2KAlSi_3O_8+Fe_3Al_2Si_3O_{12}+2H_2O$$

(Fe-biotite) (Muscovite) (Orthoclase) (Almandine)

This reaction also holds good in case of granodiorites and granites.

(e) Conversion to sillimanite

In the sillimanite schists and gneisses, biotite alters to sillimanite (Plate 17, Fig. 4; Plate 19, Fig. 3 & Plate 20, Fig. 3). This formation can be explained according to the following reaction advocated by Shelley (1968) :-

$$K_2Fe_5Al(OH)_4Si_5Al_3O_{20} + 2SiO_2 = Al_2SiO_5 + 2KAlSi_3O_8 + 2H_2O + 5FeO$$

(Biotite) (Quartz) (Sillimanite)

(f) Conversion to orthoclase

Turner (1968) has given the following reaction to explain it:-

$$KAl_2(AlSi_3O_{10})(OH)_2 + SiO_2 = KAlSi_3O_8 + Al_2SiO_5 + H_2O$$

(Al-biotite) (Orthoclase) (Sillimanite)

5. ALMANDINE

The almandine variety of garnet is predominently developed in the epidote-amphibolite facies of metamorphic rocks. Its specific identification is based on the determination of its refractive index which varies from 1.782 to 1.800.

Secondly the specific gravity of the garnets of the various schists and gneisses varies from 3.88 to 4.2. The range of specific gravity is also typical of almandine variety (Read, 1947).

Thirdly, the X-ray studies of garnets extracted from garnetiferous banded gneiss of Beoli and garnetiferous - mica-schist of Bahadara have indicated the same cell constant - A° = 11.5251 in both the cases. It is indicated in case of Beoli garnet in the Plate 28, Figs. 1 & 2. The cell constant falls within the range of garnets representing almandine variety.

Fourthly in order to understand the chemistry of these garnets, an chemical analysis was made after their separation from

the banded garnetiferous gneiss of Beoli. The complete analysis is given in the Table XXI as follows :-

TABLE XXI
CHEMICAL ANNALYSIS OF GARNET AT BEOLI

SiO_2	37.16%
$Al2O_3$	22.35%
Fe_2O_3	1.62%
FeO	28.74%
TiO_2	1.46%
CaO	2.38%
MgO	5.12%
Na_2O	0.10%
MnO	1.00%
	99.93%

The chemical analysis has been worked out in the Table XXII as given below :-

TABLE XXII

SiO_2 60	TiO_2 80	Al_2O_3 102	Fe_2O_3 160	FeO 72	MgO 40	CaO 56	MnO 71	
-	.019	-	-	-	-	-	-	
.011 (.030-.019)	-	-	.010	-	-	.030	-	Andradite
.013	-	.004	-	-	-	.013	-	Grossularite
.014	-	.005	-	-	-	-	.014	Spessertite
.128	-	.043	-	-	.128	-	-	Pyrope
.399	-	.133	-	.399	-	-	-	Almandine
.565 + .019		.185	.010	.399	.128	.043	.014	
.584		.195			.584			

The excess of alumina (.219 - .195 = .024) can be explained due to substitution of ferromagnesium content by alumina.

The calculations from above table indicate the composition of garnet as follows :-

Almandine	=	62.23%
Pyrope	=	17.29%
Spessertite	=	2.48%
Grossularite	=	1.80%
Andradite	=	5.08%

So abundance of almandine content in it clearly proves that it is almandine variety of garnet.

Under megascopic study it is of deep red to reddish brown in colour. When fully developed it shows dodecahedral form (Plate 11, Fig. 6), as is observed in the porphyroblasts developed in the banded gneisses of Beoli. These garnets of Beoli show shattering effect with quartz, magnetite and biotite flakes, filling the fractures. Almandine shows considerable variation in size from 60 mm. x 40 mm. to 2 mm. x 1 mm. in various gneisses and schists.

Under the microscope it shows pinkish to light brown colour though some grains in gneisses are colourless. It is poikiloblastic (Plate 15, Figs. 3 & 4; Plate 16, Figs. 2 & 3 and Plate 27), and has abundant inclusions of quartz, biotite, magnetite, tourmaline etc. Sometimes almandine consists of an inner core containing finer and lesser inclusions and outer rim containing coarser and abundant inclusions of quartz and magnetite (Plate 16, Fig. 2), rotational garnets also have developed S forms. The development of chlorite in it in the garnetiferous mica-schist indicates retrogressive metamorphism. In majority of cases it is isotropic though few grains found in granitic gneisses are birefringent.

Following three types of almandine garnets have been recognised :-

(1) Normal garnets

These garnets are light brown to pinkish in colour, having hexagonal crystalline outline in most of the cases. These show poikiloblastic texture and have abundant inclusions of quartz, biotite and magnetite in it. However some of these are "snow-ball" garnets in which spiral arrangement of the inclusions indicate that so many diastrophic movements have taken place during their growth (Plate 16, Fig. 3 & Plate 27).

(2) Laminated garnets

In some schists and gneisses garnet porphyroblasts show lamination. The laminations are mostly marked by mosaic of the biotite flakes. According to Wakhaloo et al (1969), the laminations in Kishtwar garnets are the relict structures of the parent rocks. These have abundant inclusions of quartz, magnetite and biotite forming poikiloblastic texture.

(3) Zoned garnets

These show zoning phenomenon by having core which has abundant inclusions surrounded by periphery free of inclusions (Plate 16, Fig. 1 & Plate 18, Fig. 2). Their outer priphery is well defined and can be marked from the central core by having conspicuous development of fractures. These indicate two stages of the growth which are marked by later overgrowth around core showing spiral Si. Different views have been expressed about their origin in different areas as under :-

(a) Saxena & Kanwar (1962) have described the overgrowth to be the result of metamorphic differentiation accompanied by metamorphic diffusion and segregation.

(b) Das and Pande (1964) observed that the outer garnet layer in them is formed during the period of migmatization around the nucleus of the core garnet and for this purpose it drew part of its material from the felspathizing solutions.

(c) Saxena & Janardhan (1966) have described the outer overgrowth in these garnets to be the result of later phase of deformation and metamorphism.

(d) According to Wakhaloo et al. (1969) these are formed due to changes in chemical composition brought out by differential migration of iron, molecules and atoms in peripheral and core parts of the garnets. They have justified it by the differences in refractive indices of these two parts of the garnet.

I believe that their presence in the banded gneisses at Doda bridge (Plate 18, Fig. 2) and in garnetiferous mica-schists at Lal Dharman (Plate 16, Fig. 1) and their presence in them of quartzo-felspathic veins at Beoli is due to the fact that during migmatization zoned garnets at its outer perphery drew part of their material from the felspathic solutions and changed their outer part; this process has resulted in the migration of iron molecules and atoms from the periphery of these garnets.

The following S_i - S_e fabric relationships have been observed :-

(a) Planer S_i parallel to S_e;

(b) Planner S_i athwart to S_e at various angles;

(c) Wraped S_i continuous with S_e at the margin of the porphyroblast; and

(d) Wraped S_i discontinuous/to S_e and is at various angles to the latter.

These S_i - S_e relations in these garnets, including zoned

garnets, indicate the early to late tectonic history of their formation. These show synkinematic crystallization with respect to development of schistosity and foliation and post-crystallization rotation and fracture in relation to thursting.

Occurrence of Almandine

Almandine which is the common garnet, is found in different rock types as is clear from the following :-

1. Almandine in the pelitic schists

It mostly occurs in idiomorphic form (Plate 15, Fig. 3; Plate 16, Figs. 1&2 and Plate 27). It possesses reddish brown to pinkish colour. The grain size varies in these schists from 2 mm. to 0.5 mm. These mostly occur in the mica flakes and have all the types of garnet present in them.

2. Almandine in garnetiferous gneisses

In massive garnetiferous gneisses and banded gneisses, these show various types and sizes. It shows considerable range in size from 2 mm. X 1 mm. to 60 mm. X 40 mm. ~~in size~~. The large porphyroblasts have been observed in Banded Gneiss at Beoli (Plate 11, Fig. 6). The formation of large garnets is a case of metamorphic differentiation. According to Ramberg (1952) its formation can be explained as under :-

> " The zone is supersaturated with the chemical constituents of the garnet. A few nuclii are formed at some favourable sites. Supposing that the activation energy of nuclear formation is rather high, the degree of supersaturation may be great without rapid formation of new nuclii. In this case the increased pressure in and closely around the few growing garnets, can be rather appreciable before the growth stops, garnets start to grow in intergranular space and continue to grow mainly by supply of material from the supersaturated zone, via intergranular path partly replacing the elements of minerals in the immediate surrounding and partly by pushing them aside".

These gneisses usually have the presence of zoned garnets (Plate 18, Fig. 2). Their grains are mostly idiomorphic in shape and possess reddish brown to pinkish brown colour.

(3) Almandine in the gneisses

The almandine grains are rounded and are colourless. These are birefringent. These resemble with the garnets of Sutlaj Valley as described by Col. Mc Mohan (1884). Rotational garnets occur in shape of S forms (Plate 20, Fig. 1).

(4) Almandine in granite

It is present in the shape of an accessory in granite. It has anhedral grains of pinkish colour showing isotropism.

It is a typical ~~an index~~ mineral of garnetiferous-mica schists formed by the regional metamorphism of argillaceous sediments in the epidote-amphibolite facies.

There are individual changes in chemical composition of garnets with the increase in the grades of metamorphism. The study of Miyashiro (1953) has shown that with increasing grade of metamorphism ~~the~~ Fe ++ content increased and that of Mn decreased. Engel & Engel (1960) have indicated that in Adirondack paragenesis complex Mg, Cr and Ti content are present with increasing grade of metamorphism and with complementary decrease in Fe^{+++} and Mn.

Formation of almandine in the almandine mica schist can be explained by the following reactions :-

(1) Fe Mg - chlorite+SiO_2 = Fe-Mg garnet+H_2O ...(Ramberg, 1952)

(2) Chlorite+muscovite+quartz with some iron ores taking part = garnet+water ...(Tilley, 1926; Harker, 1939 and Naha, 1965).

(3) Fe-Mg-chlorite+quartz = almandine+Mg chlorite ... (Winkler, 1967).

Deer et al.(1962) have given the reaction to show the formation of almandine with kyanite from staurolite, with the increase of metamorphism as follows :-

$$6(OH)_2Fe_2Al_9Si_4O_{22} + 11\,SiO_2 + 1\tfrac{1}{2}O_2 = 4Fe_3Al_2Si_3O_{12} + 23Al_2SiO_5 + 6H_2O$$

(Staurolite) (quartz) (almandine) (kyanite)

In the advance grade of metamorphism it is produced by the breakdown by micas with which it is mostly associated. It is explained by the following reaction given by Deer et al.(1967):-

$$(OH)_2KAl_3Si_3O_{10} + (OH)_2K(Fe^{+2}Mg)_3Al\,Si_3O_{10} + 3\,SiO_2 = 2KAl\,Si_3O_8 + (Fe^{+2}Mg)_3Al_2Si_3O_{12} + 2H_2O$$

(Muscovite) (biotite) (quartz) (orthoclase) (almandine)

Harker (1960) has discussed the presence of almandine in the granitic bodies. He has explained it, due to the dissociation of biotite due to ample supply of water and other volatiles by the mangma. The potash part of the biotite is used up in the formation of orthoclase in the presence of sillimanite or other aluminous silicate and the ferromagnesian part gave rise to a garnet.

6. HORNBLENDE

It is mainly met with amphibolites (Plate 19, Figs.4,5&6) though few grains have also been observed in gneisses and granites. Its refractive indices, as determined by a [redacted] refractometer, have been observed as $\alpha = 1.635$ and $\gamma = 1.670$. It is generally found in green colour though few bluish green sections are also present. It occurs as mostly subhedral grains and has well developed amphibole cleavage. It is poikiloblastic and has many inclusions of magnetite, epidote and quartz (Plate 19, Fig. 4). It is highly pleochroic having the following scheme of pleochroism :-

Z = deep green; Y = green and X = greenish yellow

and the obviously
where absorption is Z > Y > X.

Birefringence = 0.022.

Optical extinction angle Z∧c = 22°.

It is biaxial - ve and shows dispersion r > v. The largest grain met with is 3.8 mm. x 1 mm.

It is typical mineral of amphibolite facies. It is commonly met in amphibolites, alongwith plagioclase and quartz, and forms bulk of the rock.

Its formation from pyroxene can be explained by the following reaction mentioned by Wakhaloo et al. (1969):-

Pyroxene + anorthite + water = hornblende + quartz

7. STAUROLITE

It is a critical mineral for the onset of amphibolite facies. It is commonly found associated with quartz, biotite, muscovite and almandine in schists. At Badraon, it occurs in highly puckered schists. It mostly occurs in the shape of anhedral grains and has typical yellow colour. It has abundant inclusions of quartz and magnetite (Plate 16, Fig. 4 & Plate 17, Fig. 1). It shows strong pleochroism in golden yellow shades where Z = orange yellow; Y = pale yellow and X = colourless with absorption Z > Y > X. Birefringence =0.012. The grains are length slow. Its grain size varies from 0.95 mm. x 0.44 mm to 1 x 0.075 mm.

Change of almandine to staurolite is well exhibited as spiral trails of almandine continue into the staurolite as straight trails (Plate 16, Fig. 3) which provide evidence of paratectonic crystallisation of almandine and the development of staurolite in D_3 episode as is observed in case of Badraon staurolite schist. However, in case of Lal Dharaman staurolite schist, it indicates

that quartz and iron ore trails are straight, and are at an angle with the S_2 trends (Plate 16, Fig. 4) proving static crystallisation after the development of schistosity S_2 and post crystalline rotation with mica layers wrapping around them. Post crystalline deformation is commonly met with. It is indicated by the intergranular rotation with lenses and ovoids covered with mica flakes and the puckering of the schistosity against staurolite grains (Plate 16, Fig. 4).

Staurolite indicates the beginning of amphibolite facies. It is found only at few localities viz. Lal Dharaman, Doda bridge and Badraon. According to Deer et al. (1962) the rarer development of staurolite as compared with garnet and biotite is the result of its restricted temperature and pressure conditions. It is mostly found in rocks rich in alumminium and FeO and deficient in K_2O (Turner, 1968).

In different localities, it has different association of minerals with it, which indicates the different stages of their formation in this sub-facies. At Lal Dharman it has been found with chloritoid which indicates the lower stage of this staurolite - almandine sub-facies. To quote Deer et al. (1962),

> " At the lower temperature limit of the stability field staurolite is often found associated with chloritoid and in many regionally metamorphosed areas, the two minerals show an antipathic relationship to each other, the amount of chloritoid decreasing and that of staurolite increasing with increasing grade of metamorphism".

According to Winkler (1967), the chemical compositions from which staurolite is generated may be similar to chloritoid and has explained its formation due to the following reaction :-

Chloritoid + chlorite + muscovite = staurolite + biotite + almandine + water.

But the following reactions, by Tilley, 1925; Harker, 1939 and Naha, 1955, can also explain its formation as under :-

i) Chloritoid + quartz = staurolite + garnet

ii) Chloritoid + muscovite + quartz = staurolite + biotite+water

iii) Chloritoid = staurolite + quartz + iron oxide + water

At Badraon, it is found associated with abundant of mica flakes and almandine. According to Naha (1965) it is formed from mica layers leaving the excess of quartz. Besides this, its formation can be explained by the following reaction of Winkler (1962):-

Fe-rich chlorite + muscovite = staurolite + biotite+almandine + H_2O

8. KYANITE

It is found in the shape of large crystals in the pegmatite veins near Bhabor (Plate 11, Fig. 6), light blue colour with a flexture on (100) plane and has variable hardness at various faces of crystal, varying from 4 to 7.The maximum size of these crystals is 10 cm. x 7 cm.

Under the microscope it occurs as broad elongated plates which are parallel to (100) and have perfect cleavage with cross-parting at an angle of 85° (Plate 26, Fig. 4). It has many inclusions of staurolite quartz, rutile, muscovite and epidote which show its development at their expenses. Birefregence = 0.016 and extinction angle = 30°. Frequent twinning is present. It shows -ve biaxial interference figure, ~~where~~ exhibiting dispersion r 7 v. Undulose extinction is also present. Few grains are bent (Plate 26, Fig. 5). It shows the development of fractures and glinding planes, which have been healed by muscovite (Plate 26, Fig. 4).

It is found as cluster of large grains in the pegmatite of Bhabor. It is also met in very small amounts, associated with staurolite at Lal Dharaman. It is also the case with other parts of the world indicating the higher grade of metamorphism in the paragenesis. Its formation can be explained according to the

following reaction of Deer et al. (1962) :-

3 Staurolite + 2 quartz = almandine + 5 kyanite + 3 water

Its rarity in metamorphites may be due to the absence of very high pressure, which is according to Winkler (1967) is essential for its formation.

9. SILLIMANITE

It is commonly found in the high grade schists (Plate 17, Figs. 2, 3 & 4) though it is observed in gneisses also due to breakdown of biotite (Plate 19, Fig. 3 & Plate 20, Fig. 3).

It is met as thin needles or as fibrous mass. Needle like grains have common cross fractures. It is length slow. Birefringence = 0.023Main deformational effects are manifested by puckering around needles.

It indicates the highest grade of metamorphism, arrived in the amphibolite facies by the regional metamorphism of pelitic rocks. Its formation can be explained by the following reaction mentioned by Turner and Verhoogen (1960 :-

Staurolite + quartz = sillimanite + almandine + H_2O.

It is a typical reaction of sillimanite - almandine - muscovite subfacies.

At higher grades it is formed due to the breakdown of muscovite and biotite (Francis, 1956). This view has further been supported by Winkler (1967) who has referred that muscovite, biotite and quartz react with each other and yield almandine alongwith K-felspar and sillimanite. He has further mentioned that it can co-exist with muscovite, if the temperature remains well within the stability range of muscovite, which is the case with the study area.

10. PLAGIOCLASE

Among the plagioclases, albite, oligoclase and andesine are present. These are anhedral in lower grades but become subhedral in higher grades. However, in case of granites, these even become euhedral (Plate 23, Fig. 2) and often show orbicular structure (Plate 23, Fig. 5). These are poikiloblastic (Plate 22, Figs. 1 & 2) and show large scale clouding due to the presence of muscovite, quartz, biotite, apatite, zircon and magnetite as inclusions. These inclusions often show rotational features. These show both simple and complex type of twinning. Simple twinning is present on albite law (Plate 22, Fig. 2 & Plate 23, Fig. 2) and pericline law, but complex twinning is indicated by combined carlsbad - albite type of twinning (Plate 22, Fig. 1) and also in case of interpenetration twins.

Some grains are also untwinned.

A large variation is observed in the grain size of plagioclases in different rocks. The largest grain size observed in these is 8 mm. x 2.2 mm. while the minimum size observed is 0.1 mm. x 0.08mm. Plagioclases in the puckered mica schists show the presence of the cracks and ruptures which give the evidence ofpostcrystalline deformation.

The nature and composition of plagioclase felspars in metamorphic rocks is related to the grade of host rock as follows :-

i) In the lower grades of regional metamorphism indicating greenschist facies only albite is present. Here anorthite content is zero (Turner, 1968).

ii) In the epidote - amphibolite facies both oligoclase and albite are present and these show twinning on albite and pericline law (Harker, 1939; Turner, 1951 & Naha, 1965). Anorthite content in case of oligoclase varies from An_{20} to An_{26} and in case of albite

it is from An_3 to An_7 , but plagioclases of inbetween composition are absent in the schists. According to Deer (1962) the sharp break can be correlated with the unmixed constitution of plagioclases in the compositional range An_3 to An_{22}.

iii) In the amphibolite facies, plagioclases of the composition An_{25} to An_{30} are commonly met with in schists but in amphibolites it has developed andesine (An_{38}).

iv) In the amphibolite - granulite transitional facies oligoclase is the common plagioclase and has anorthitic content An_{27} to An_{30}. It shows twinning on albite and pericline laws.

v) In case of granite, both simple and complex twinning is present. A-twins show albite and pericline type of twinning whereas C-twins show complex type of twinning. The complex twinning is mainly marked by combined albite-carlsbad twins and interpenetration twins. The factor which controls the formation of C-twins is related to crystallization of plagioclases from a melt (Gorai, 1951 & Turner, 1951). Some grains are also untwinned.

Efforts have been made to construct the UAC diagram (Plate 44), in order to ascertain their mode of origin in granites. On the basis advocated by GORAI (1951), it has been ascertained that these are of magmatic origin.

11. K-FELSPARS

Potash felspars are represented by (a) orthoclase (b) microcline (c) untwinned K-felspars and (d) perthite.

(a) ORTHOCLASE

It is mainly formed in granites where it is developed as euhedral grains. Pegmatites and gneisses contain subhedral grains. Few grains are also present in sillimanite schists.

It shows perfect cleavage along (001) less perfect cleavage along (010) and imperfect parallel to (110). It shows abundant clouding by having inclusions of muscovite, biotite, quartz, apatite, magnetite and zircon (Plate 22, Fig. 3).

It shows maximum extinction angle of 12° on (010) and shows straight extinction on (001). It shows typical carlsbad type of twinning (Plate 22, Fig. 3& Plate 23, Fig. 1). Its largest grain observed is in granites and is 4.22 mm. x 1.6 mm. in size.

It is also present as large grains showing carlsbad - twinning overshadowing the perthite in granite (Plate 24, Fig. 1). However, the granitic gneiss at Duga, adjoining to granite stocks, has also similar K-felspars in shape of"Dents-de-chevals". The maximum size obtained by these is 14 cm. x 6 cm.

(b) MICROCLINE

It is commonly met with in shape of subhedral grains. In microscopic study it is recognised by having perfect cleavage parallel to (001) and imperfect cleavage parallel to (010). It has abundant inclusions of quartz, muscovite, biotite, zircon and apatite. Its extinction angle on (001) is 15° whereas on (010) it is 5°. It shows typical cross-hatched twinning. The largest grain size observed is 8 mm. x 4 mm.

(c) UNTWINNED K-FELSPARS

Untwinned K-felspars are abundantly found in felspathic - schists of high grade metamorphism. These are also met with streaky-gneisses and granites. These are differentiated from untwinned plagioclases by staining method; K-felspars give golden yellow tint when the slide is dipped first in conc. Hcl and then dipped in cobalt nitrate solution.

K-felspar is commonly found in granites and as porphyroblasts in schists and gneisses especially where these rocks are in proximity to granites. The porphyroblasts are formed due to local concentration of potassium from migrating granitic fluids. It is a stable product of high grade regional metamorphism, therefore, does not occur in rocks of lower metamorphic grades. Its formation in high grade metamorphic rocks is largely due to the instability of micas in the PT environment for which the following reactions are suggested by Deer et al.(1967):-

(a) $2K(Mg\ Fe)_{1-5}Al_2Si_3O_{10}(OH)_2 + 3SiO_2 = KAlSi_3O_8 + (Mg\ Fe)_3Al_2Si_3O_{12} + 2H_2O$
(siderophyllite) (quartz) (orthoclase) (almandine & pyrope)

(b) $K\ Al_3Si_3O_{10}(OH)_2 + SiO_2 = KAlSi_3O_8 + Al_2SiO_5 + H_2O$
(muscovite) (quartz) (orthoclase) (sillimanite)

(d) PERTHITES

These are the common features of the granites and the granitic gneisses of the area under reference and are commonly found in microperthites and microcline -microperthites. Based upon their different textural patterns as described by Anderson (1928); Barth (1969), and Wakhaloo et al. (1970), the various varieties are mentioned below :-

(1) String perthite

The strings are elliptical shading into lenticular forms. These lie parallel to (010) forming an angle of 73° with (001), (Plate 25, Figs. 3 & 4).

2. Film perthite

Films of plagioclase are much thinner which never exceeded in thickness to .01 mm. They lie normal to (010) and at an angle of 73° to (001).

(3) Vein perthite

The veins are about 0.1 mm. thick often running parallel to (001) but frequently in other directions.

(4) Patch perthite

In these perthites square shaped soda plagioclases are present in K-felspar. The twin lamellae of albite are sharply defined and these do not show any continuity and are present as isolated remnants in the K-felspar.

ORIGIN OF PERTHITES

The large varities of perthites mentioned above are due to the many factors as given below :-

(1) Perthites due to exsolution

The theory of exsolution has been mentioned as one of the main cause of the formation of many perthites by various authors, Harker, 1909; Alling, 1921; Spencer, 1930, 1937 and 1938; Laves, 1951 & 1952; Spry, 1969/ and Barth, 1969. Their formation is explained by the physico-chemical fact that felspar forms extended series of solid solutions at elavated temperatures; at lower temperatures these become unstable and exsolve to the ~~constituents~~ constituent components. Laboratory investigations have indicated that potash rich felspar can hold in solution upto 52% soda rich felspar, but normally does not retain more than 10% at ordinary temperatures (Dittler & Kohler, 1925 & Spencer, 1930, 1937 & 1938). Perthites in granites mostly occur in shape of film perthite and string perthite in the area under reference and their formation can be explained due to exsolution

2. Perthites due to replacement by Deuteric processes

Colony, 1923; Alling, 1932; Goldrich & Kinser, 1939; Robertson, 1959 & Wakhaloo et al. 1970, have described deutaric process as one of the cause for their formation. According to

Robertson (1959), perthites are formed by the reorganisation of albite from other plagioclase as a consequent of potash metasomatism and he has quoted perthites of Boulder Batholith as an example.

Further in the formation of perthites the importance of stress factor has also been laid down by Phemister, 1926; Chayes,1952; Gates, 1952; Smith & Mackenzie, 1959/ and Wakhaloo et al. 1970.

At Mandella, perthites in granite(Plate 25, Fig. 3) are formed by exsolution followed partly by replacement caused by deuteric agencies, under the condition of stress. This process can well be explained in the various varieties of perthites in this rock k and their lying in juxtaposition with each other.

3. Perthites due to replacement

Perthites formed due to replacement of microcline by sodic solutions has been explained by Anderson (1928) and Gupta (1968&1969). Perthites present in the gneisses of the area have inclusions of plagioclase (Plate 22, Fig. 5) which indicates replacement relationship with the microcline. The acidic rims around included plagioclases in microclines may be explained due to replacement caused by sodic solutions brought from external source in a liquid state.

12. MYRMEKITE

Myrmekite is an intergroth of quartz and plagioclase where quartz occurs as blebs, drops and in vermicular shapes within the felspar.

Myrmekite is typically developed in granites and granitic-gneisses of the area. The typical sections indicating their formation are from Koti (33°6' 22" : 75°33' 34"); Babhur (33°8' 50":75°35' 10") and Bhala (33°3' 51" : 75°36' 34"), though a small scale myrmekite formation is common in all areas where granitic gneisses are present.

The most abundant shape in which it occurs is of the plug shape occuring at the margins of K-felspar (Plate 21, Figs. 1 & 2; Plate 24, Fig. 2). Even this structure with plug shape is found as inclusions in the K-felspars (Plate 25, Fig. 1) indicating two stages of grantization in folded area as has been described by Shelley,1964. In most cases, especially in plug shaped bodies, the quartz has vermicular shape.

It has also been observed that it is surrounded by strained quartz and at places where complete recrystallisation of quartz has taken place. In general it has been met with as under :-

i) at the margins of K-felspars;

ii) between K-felspar and plagioclase;

iii) within K-felspar; and

iv) between K-felspar and perthite.

ORIGIN OF MYRMEKITE

Its origin has been attempted by various scientists;-

i) Becke (1908) has suggested that potash in orthoclase was replaced by soda and lime of late magmatic solutions, the lime setting free quartz in the process.

ii) According to Schwantke (1909), it is formed due to exsolution forming plagioclase and quartz from high temperature potash felspar at the interface of already existing plagioclase.

iii) Drescher-Kaden (1948) has shown that the plagioclase is corroded along "smekal defects" by the solutions which give the orthoclase of granites and granitized rocks. The solutions deposit silica, while the removed cations fill empty spaces in the lattice of plagioclase. This theory has been supported by (Voll, 1960 and Augustithis, 1962).

iv) Sarma & Raja (1959) believe that myrmekite is the result of a breakdown of unstable portion of plagioclase to form epidote and quartz under conditions of stress.

v) Shelley (1964) has stated in his theory that exsolution of albite from orthoclase is responsible for its formation. Exsolution of albite from orthoclase is generally accepted as a common process (e.g. Gates, 1953; Voll. 1960) Tuttle & Bowen (1958) have supported the contention that albite migrates to the grain boundaries of orthoclase by exsolution.

The statement of the exsolution theory of Shelley is quoted as under :-

> "Albite, exsolved from orthoclase, will grow on a plagioclase seed in a cataclastic texture, or grow in structural continuity into a neighbouring plagioclase crystal. As far as the immediate environs of the myrmekite are concerned, the albite is growing in volume (in the solid state) while the quartz is not and will exert a confining pressure on any quartz which is changing its form due to recrystallisation. The growth is towards the source of the albite, so that plug like forms will be convex towards the orthoclase, and the confined quartz will develop as rods in this direction".

Most of the workers Eskola (1914); Gilluly (1933); Chatterjee (1954) and Shelley (1964) have stressed the importance of granulation in its formation.

vi) Govinda Rajulu & Nagaraja (1967-68) have indicated that the formation of myrmekite in Jamkhandi granite of Mysore State is due to the incorporation of deuteric silica in felspars. ~~This idea supports its presence in the granodiorite of Mundella.~~

vii) Gupta (1970) has indicated that the myrmekites which are not associated with the crushing are developed by the replacement process at Mandi on Mandi-Kulu Road. To quote him :-

> " The sodic solutions left over after the crystallisation of the K-feldspar, replace the microcline metasomatically resulting into myrmekite".

viii) Bhattacharya (1971) has suggested that potash felspar at its contact with already existing plagioclase ~~gixing~~ gives rise to myrmekite at high stress.

ix) Recently Phillips, Ransom & Vernon (1972); Ashworth(1972) and Phillips & Ashworth (1973) have widely supported the exsolution theory for their formation. These scientists have suggested the following reactions to explain the ~~theory of exsolution~~ formation :-

(a) Potash felspar + sillimanite + fluid = muscovite + quartz & plagioclas

..... Ashworth,1972.

(b) $3\ KAlSi_3O_8$ (Alkali felspar) + $CaAl_2Si_2O_8$ $NaAlSi_3O_8$ (calcic plagioclase) + H_2O = $CaAl_2Si_2O_8$ $2NaAlSi_3O_8$ (more sodic plagioclase) + $6SiO_2$ Quartz

myrmekite

* ~~Kxixixix~~ + $KAl_2(Al,Si_3)O_{10}(OH)_2 + K_2O$
(muscovite)

..... Phillips et al., 1972.

(c) $3xKAlSi_3O_8$
$y\ Na\ Al\ Si_3O_8$
$z\ Ca\ O\ (Al\ Si_3O_8)_2$
(alkali-felspar)
$+ x\ H_2O = x\ K\ Al_2(Al,Si_3)O_{10}(OH)_2$
(muscovite)
$+y\ Na\ Al\ Si_3O_8$
$z\ Ca\ Al_2Si_2O_8$
(plagioclase) $+(6x+42)\ Si\ O_2$ (Quartz

(myrmekite)
$+x\ K_2O$

..... Phillips et al., 1972

According to these scientists myrmekite is mainly formed due to exsolution of plagioclase and quartz at high temperature from the high temperature potash felspars. Hence potash felspar having formed at relatively high grade become unstable with respect to exsolution.

I understand that myrmekites in granites of the area under reference have been developed due to the release of albite exsolved from K-felspars (Plate 24, Fig. 2). The released albite has migrated towards the margins of K-felspars and has enclosed granulated quartz grains with which free energy have produced to form myrmekites.

This type of myrmekite is associated with shearing forces which have developed granulated quartz at the margin of felspar.

While myrmekites of two generations can be explained by two stages of migmatization. In the first process myrmekite-I was developed at the margins of K-felspar by mixing of exsolved albite with granulated quartz. This stage was further followed by the growth of K-felspar, which at later stage again exsolved to albite to get mixed with sheared quartz to form myrmekite II.

In granitic gneisses of the area it has been typically developed betwee n K-felspars and plagioclases and is the result of the replacement of K-felspars by soda solutions.

13. ACCESSORIES

The most common accessories are discussed as under :-

(a) ZIRCON

It is the common accessory of all the rock types and occurs in various shapes from euhedral to anhedral grains in different rocks. These grains are mostly colourless to grey in colour, though pink varieties have also been observed in some rocks. Birefringence = 0.062.

It is mainly found as inclusions especially in biotites and is usually surrounded by pleochroic haloes.

The study of various rocks has revealed that different shapes and colours of these are present in different types of rocks:-

i) Zircons in quartzite

These are of rounded and anhedral shape arranged in parallel bands at Malnai (Plate 14, Fig. 3), which indicates their derivation from detrial sediments.

ii) Zircons in schists

These are of white to greyish in colour and occur as anhedral grains.

iii) Zircons in megmatites and gneisses

These are of white to grey in colour. These occur in anhedral to euhedral forms, which indicates that granitic juices were responsible for their paragenesis from metasedimentary rocks.

iv) Zircons in granites

These are very commonly found in granites. In order to study them in detail, these were separated from the granitic rocks. The separation has been done by crushing the granite to 100 mesh size. The material was then treated with dilute HCl 15% for about 30 minutes. After washing, the sample was dried in an oven at 100°C. This clean and dry sample was treated with bromoform to acquire heavy mineral separation. Then Isodynamic Separator was used to separate the zircons from other material.

The zircons obtained are of pink colour and are idiomorphic in shape. Some grains also show zoning. However some section show overgrowths in which core of zircons is also idiomorphic. In case of Bhala Mundalla granite, the elongation ratio observed is typically 2/1 as is indicated by the following study of grain size

TABLE XXIII
SHOWING VARIATION IN SIZE AND ELONGATION RATIO OF VARIOUS ZIRCON GRAINS

Length	Bfeadth	Elongation ratio	
0.048	0.024	0.048/0.024	2/1
0.04	0.02	0.04/0.02	2/1
0.028	0.014	0.028/0.014	2/1
0.02	0.01	0.02/0.01	2/1
0.024	0.012	0.024/0.012	2/1
0.016	0.008	0.016/0.008	2/1

From the above elongation ratio of 2/1 it can very well be inferred that granite is derived from magma. According to Mehnert, 1968, the elongation ratio of zircons in magmatic granites amounts to 2/1 or slightly more.

(a) EPIDOTE

It is a common mineral and is found as accessory in rocks, varying from low grade schists to gneisses and even in intrusive granite of Dedni. In granites and gneisses, it depicts pink colour whereas in schists and amphibolite greenish colour is met with. It mostly occur as anhedral grains. It is highly pleochroic. Birefringence = 0.045. It is found in the early stages in the amphibolite facies where it is formed as a result of the following reaction as mentioned by Wakhaloo et al. (1969) :-

$$\underset{\text{(Hornblende)}}{Ca_2(Mg\ Fe)_3Al_4Si_6O_{22}(OH)_2} + 1/2\ K_2O + X\ Si\ O_2 + H_2O = \underset{\text{(dissolved schists)}}{\quad}$$

$$\underset{\text{(biotite)}}{K(Mg\ Fe)_3Al\ Si_3O_{10}(OH)_2} + \underset{\text{(Epidote)}}{Ca_2Al_3Si_3O_{12}(OH)}$$

(c) TOURMALINE

Tourmaline occurs from euhedral to anhedral grains in various types of rocks. It occurs in two colours of blue and brown shades. Irregular fractures are commonly present (Plate 21, Fig. 4&Plate 26, Fig. 1). Its grains are highly pleochroic which show maximum absorption in the vibration direction at right angles to the polarizer. Zoned tourmaline with greenish blue centre and brown border has been observed in the almandine mica schists surrounding the kyanite bearing pegmatite at Bhabor. Birefringence = 0.04 and the crystals are length slow. Perfect idiomorphs of tourmaline are also met with in the schists present in shear zones. It is met as accessory in all types of rocks varying from granites pegmatites to gneisses and also seen in schists adjoining the granitic bodies which indicates the formation of tourmaline mainly from granitic fluids.

(d) APATITE

It is present in the shape of minute grains in schists and in the shape of needles in case of granites and gneisses.

It occurs from euhedral to anhedral grains. It is non-pleochroic. Birefringence is weak and gives grey interference colours of first order. The acicular apatite needles in granites are euhedral in shape and show inclusions in their centre which according to Mehnert K.R.(1968) is a high temperature magmatic stage of their crystallization. These have elongated ratio of 5/1 which is typical for granites of magmatic origin (Mehnert, 1968).

(e) MAGNETITE

Magnetite is a common accessory and varies in size from tiny specks to 0.4 mm. x 0.16 mm. It mostly occurs as anhedral grains. It is black in colour, opaque [redacted]. It shows steel grey colours under reflected light.

CHAPTER VII

PETROCHEMISTRY

CHAPTER VII

PETROCHEMISTRY

In order to know the composition of the original material and the possible changes in overall composition of rocks during metamorphism of the area under study, Chemical Analyses of selected rock samples of schists, gneisses, migmatites, pegmatites, and amphibolite have been done.

The chemical analyses of these rocks have been done according to the conventional methods outlined by Washington (1930) and/later reviewed by Shand (1951). SiO_2 , R_2O_3 and CaO were determined gravimeterically as oxides and MgO as pyrophosphate. Total Fe (as Fe_2O_3) and FeO were determined by titration with potassium - permanganate. TiO_2 and MnO were determined colorimetrically. The value for Al_2O_3 was obtained from R_2O_3 by difference from the sum total of Fe_2O_3, TiO_2 and MnO. Total alkalies K and Na were first determined as chlorides and from it K_2O was estimated by forming potassium chloroplatinate and Na_2O was determined by difference from the total.

The nature of original sediments of the area which have been transformed to metamorphic rocks can be acquired by the method employed by Butler (1965) in respect of correlating the Moine rocks with other rocks of Ardnamurchan area in Scotland. A variation diagram (Plate 30) has been constructed by using molecular percentages of SiO_2 as abscissa and Al_2O_3 as ordinate. Majority of values fall well within the limits delineated by Butler (1965, Fig. 5) but in other cases values are quite divergent which indicate varied composition of the original sediments. The variation diagram indicates the presence of the

TABLE XXIV

CHEMICAL ANALYSES OF SCHISTS, QUARTZITE AND GARNET

S.no.	1	2	3	4	5	6	7	8	9	10	Q 11	G 12
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
SiO_2	86.84	84.40	82.72	67.74	65.78	63.10	47.86	65.57	67.24	76.01	83.02	37.16
Al_2O_3	5.00	5.03	5.94	16.24	19.77	23.76	22.66	16.80	16.24	13.96	5.79	22.35
Fe_2O_3	0.18	3.44	2.53	0.72	1.02	1.49	2.01	3.22	0.91	0.72	2.38	1.62
FeO	4.32	2.16	2.89	4.02	4.01	2.01	10.12	7.26	1.71	3.08	3.02	28.72
TiO_2	0.30	0.40	0.64	0.36	0.34	0.74	2.58	0.29	0.30	0.50	0.22	1.46
CaO	0.10	0.24	0.14	2.63	1.17	0.58	3.51	0.11	2.31	0.58	0.13	2.38
MgO	0.95	0.86	0.91	0.05	1.04	1.00	7.71	0.02	0.71	0.82	Traces	5.12
Na_2O	0.21	0.45	0.50	4.15	3.24	3.11	1.04	2.83	2.54	1.05	1.29	0.10
K_2O	1.94	1.86	3.12	1.87	2.33	3.48	0.64	3.02	7.01	2.45	2.39	-
MnO	-	-	-	-	-	-	-	-	-	-	-	1.00
$+H_2O$	0.48	0.30	0.54	1.10	1.10	1.01	1.38	0.84	1.26	0.70	0.74	-
$-H_2O$	0.06	0.09	0.08	0.82	0.34	0.36	0.72					
	100.38	99.73	100.01	99.70	100.14	100.54	100.23	100.14	100.23	99.37	99.43	99.91

No. 1 Quartz - Biotite schist
Nos. 2-5 Almandine - mica schist
No. 8 Staurolite - Biotite schist
Nos.6,7 & 10 Sillimanite schist
No. 9 Felspathic schist

G = Garnet
Q = Quartzite

Localities of the analysed samples are indicated in the Map No. 49.

ANNEXURE XXV

C.I.P.W. NORMS AND BRAMMAL'S RATIOS OF SCHISTS AND QUARTZITES

S.No	1	2	3	4	5	6	7	8	9	10	Q
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
C.I.P.W. NORM											
Q	73.87	72.78	65.34	23.08	31.56	28.32	14.46	35.72	19.72	55.80	63.62
Or	11.12	10.56	18.35	11.12	13.34	20.57	3.41	17.79	41.14	15.01	16.68
Al	1.53	3.67	4.19	35.11	27.25	26.20	8.91	23.53	20.96	8.33	9.96
An	0.56	1.11	0.56	12.79	5.84	3.06	17.51	0.56	11.40	2.78	0.56
C	2.54	2.24	1.53	3.67	9.76	13.77	13.37	3.67	0.41	3.67	0.61
Hyn (En	2.40)	2.40)	(2.30	0.10	2.60	2.50	19.30	0.10	1.80	3.50	-
(Fs	7.26)	0.66)	(2.77	6.20	6.07	1.32	12.41	10.16	1.53	4.36	3.17
Mt	0.23	4.87	3.44	0.93	1.39	2.09	3.02	4.64	1.62	0.93	3.63
Il	0.61	0.76	1.22	0.76	0.61	1.37	5.02	0.46	0.61	0.91	0.46
Q	76.03	77.25	69.58	31.44	35.57	32.43	16.13	37.52	20.36	60.71	68.52
L	13.46	15.73	22.32	60.90	53.37	60.29	38.79	48.64	73.84	30.43	26.10
M	10.46	7.02	8.10	7.66	11.06	7.28	45.08	13.84	5.80	8.86	5.38
BRAMMAL'S RATIO											
Or+c =	51.79	47.33	61.03	19.80	34.54	48.31	20.45	40.12	52.41	53.17	49.51
Ab =	6.00	13.58	12.42	50.48	40.76	36.86	10.71	35.75	26.43	18.81	28.52
An+fm=	42.21	39.09	26.55	29.72	24.70	14.83	68.84	24.13	21.16	28.02	21.97

TABLE XXVI

NIGGLI VALUES OF SCHISTS AND QUARTZITE

	1	2	3	4	5	6	7	8	9	10	Q
al	21.9	29.5	29.6	45.0	54.8	59.3	33.9	41.5	42.8	52.1	31.7
fm	40.1	53.4	48.5	17.3	17.7	15.8	53.0	22.4	14.6	27.6	40.0
c	27.8	2.3	1.0	13.0	5.9	2.8	9.6	1.0	11.0	3.8	1.1
alk	10.2	14.8	20.9	24.7	21.6	22.1	3.5	35.1	31.6	16.5	27.2
si	642.9	795.4	700.0	320.1	311.1	264.9	121.1	269.2	302.5	485.0	765.0
k qz	+502.1	+636.2	+516.4	+221.3	+124.7	+76.5	+7.1	+28.8	+77.1 +70.1	+319.0	+556.2
mg	0.25	0.29	0.29	0.02	0.31	0.43	0.58	0.01	0.38	0.36	0.0

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TABLE XXVII

CHEMICAL ANALYSES OF GNEISSES, PEGMATITE AND AMPHIBOLITE

S. No.	A	B	C	D	E	F	H	I	J
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
SiO_2	73.42	62.490	67.63	62.90	71.46	64.72	69.62	72.80	47.16
Al_2O_3	15.89	17.904	14.72	16.58	12.74	19.42	16.28	16.67	15.01
Fe_2O_3	1.16	2.280	2.59	0.39	0.53	0.45	1.23	0.50	4.12
FeO	1.16	3.110	2.40	6.10	2.20	3.71	2.10	1.02	8.50
TiO_2	-	0.205	0.29	0.37	0.47	0.82	0.24	0.21	2.01
CaO	1.46	0.140	0.92	0.27	1.15	3.51	1.91	1.17	10.50
MgO	0.21	Traces	0.21	0.06	2.82	0.50	0.90	0.15	7.80
Na_2O	1.30	3.257	2.64	4.31	3.11	5.16	5.96	4.92	0.93
K_2O	4.33	9.038	8.16	6.56	4.25	1.62	0.90	1.47	1.27
$+H_2O$	1.10	1.330	0.74	1.41	1.36	0.66	1.07	0.89	1.78
	100.03	99.754	100.30	98.95	100.09	100.57	100.22	99.80	99.08

No. A to ~~H~~ = Gneisses and Migmatites
I = Pegmatite
J = Amphibolite

Localities of the analysed samples are indicated in the Map No. 49.

TABLE XXVIII

C.I.P.W. NORMS AND BRAMMAL'S RATIOS OF GNEISSES AND PEGMATITE

	A	B	C	D	E	F	H	I
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Quartz	45.29	7.44	18.18	6.84	28.98	18.12	25.26	44.48
Orthoclase	25.58	53.38	47.82	38.36	25.02	9.45	5.56	8.90
Albite	11.00	27.25	22.01	36.15	26.20	43.49	49.78	41.39
Anorthite	7.23	0.56	4.45	1.11	5.56	17.51	9.45	5.56
Corundum	6.43	2.55	-	2.14	1.02	2.75	2.04	5.00
Hyp. Enstatite	0.50	-	0.50	0.10	7.50	1.20	2.30	0.40
Fs	1.06	3.30	1.72	10.16	3.04	5.02	2.38	1.96
Magnetite	1.86	3.25	3.71	0.72	0.70	0.70	1.86	0.70
Ilmenite	—	0.46	0.61	0.76	0.76	1.52	0.46	0.46
Q	49.97	8.75	20.56	9.45	31.27	23.07	27.26	47.51
L	47.25	85.29	74.29	78.63	55.01	68.57	65.92	50.45
M	2.78	5.96	5.24	11.92	13.72	8.36	6.82	2.04
Brammal's Ratio								
Or + c =	59.65	61.63	62.61	45.37	36.11	15.08	10.30	21.92
Ab. =	20.50	30.03	28.82	40.40	36.34	53.74	67.42	65.27
An + m =	19.85	8.34	8.57	14.33	27.55	31.18	22.28	12.81

TABLE XXIX

NIGGLI VALUES

S.No.	A	B	C	D	E	F	H	I	J
al	54.8	44.3	40.2	51.5	33.8	44.9	47.0	55.0	20.9
fm	12.6	17.7	19.6	22.4	31.2	16.5	15.2	6.1	47.0
c	9.1	0.5	4.5	1.0	5.7	14.9	10.0	6.7	26.6
alk	23.5	37.5	35.7	35.1	27.3	23.7	27.8	32.2	5.5
si	427.3	262.3	313.1	269.2	341.3	245.8	340.0	490.0	413.1
qz	+234.3	+112.3	+70.3	+28.8	+132.0	-245.2	+128.8	+261.2	+231.1
mg	0.2	0.02	0.1	0.01	0.29	0.80	0.40	0.21	0.61

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following chemically distinct types :-

1. Rocks derived from Pelitic material where in some cases the Al_2O_3 content is very high. Their argillaceous nature is further clear from high K_2O values in majority of rocks.

2. Rocks derived from psammites.

3. Rocks derived from greywacke like material.

Alkali values of pelitic and psammitic schists and gneisses shown in Plate 31 in line with Mehnert (1968) also indicates the presence of both pelitic and psammitic schists and gneisses. The presence of the abundance of Na_2O content in some rocks also indicates their derivation from greywacke like material.

Such vast variation in chemical composition is typically observed in the Main Rocks by Butler (1965). This vast variation in chemically composition indicates that the metamorphic rocks of the study area are derived from rocks of composition different from that of Kishtwar as described by Wakhaloo et al (1971).

I. PETROGENESIS OF THE GNEISSES AND MIGMATITES

There can only be three possibilities regarding the origin of gneisses :-

i) that the gneisses are of magmatic origin;

ii) that the gneisses are formed by anatexis; and

iii) that the gneisses are products of granitization.

The very first possibility of the magmatic origin or their formation by bodily injection of the granitic material into the country rocks is ruled out. This is borne out by the field relation, laboratory and chemical data taken together.

The field study indicates that there is continuity in parallelism of the foliation of migmatites with the schistosity planes of the schists, which does not favour bodily injection of

granitic liquids. The absence of xenoliths in them also proves this.

This idea is further supported by Brammall's diagram (Plate 33) in which normative values of orthoclase + corrundum, albite and anorthite + femic constituents were plotted; which indicates the presence of almost all the gneisses in the metamorphic field and thus their igneous origin is rules out. However, the presence of some values across Brammall's diagram (1933) boundaries, as found by him, may be explained either due to composition variation from the parent rock by the process of chemical weathering and mechanical sorting, or due to granitization at a later date involving mostly the addition of Na_2O, K_2O and SiO_2 which has resulted in the formation of hornblende biotite gneiss (F) from the pre-existing amphibolite dyke.

That the gneisses are not of igneous origin is further substantiated by plotting the normative values Q, Ab, Or of the gneisses as shown in triangular diagram (Plate 32, Fig. 2) in which the points of cotectic minimum are shown by solid circles. The cotectic minimum composition, for Ab/An ratio was determined by Tuttle and Bowen (1958). Later Winkler (1967) and Von Platen(1965) have demonstrated in their experiments on anatexis that the cotectic minimum composition is dependent on Ab/An ratio of parent rock. With decreasing Ab/An ratio the cotectic minimum moves towards quartz-orthoclase line in the diagram. In Plate 32, Fig. 2, the normative values of Q, Ab, Or of the gneisses is also plotted. Their Ab/An ratio ranges widely from 1.5 to 36, therefore, cotectic minimum of Ab/An 1.8 to ∞ is considered for the paragenesis of these gneisses. The normative composition of the gneisses lies either towards the quartz side of the diagram or below the trough towards the albite side and are always away from the trough in

relation to Ab/An ratio. So, conclusively, the bodily injection of granitic magma in the rocks to form these gneisses and migmatites is ruled out.

It can be argued that the gneisses are formed from anatectic melt but the chemical evidences are against such an origin.

Winkler (1967), by his experimental work has shown that at a temperature of more than 700°± 40°C and P H_2O = 2000 bars, an anatectic melt is formed. At water pressure greater than this there is considerable lowering of the temperature of the formation of melt (Tuttle & Bowen, 1958). Winkler (1967) has further mentioned that by the process of anatexis a rock splits into a melt fraction which consists essentially of feldspar and quartz and into a crystalline residue enriched in MgO, FeO, $Fe_2O_3$and Al_2O_3, thus resulting in the migmatite or a banded gneiss, but he observed in such a case that the bulk composition of the crystalline residue and the melt fraction remains unchanged. The chemical analyses of schists, migmatites and gneisses of the area (Table XXIV & XXVII) show that the gneisses are richer in K_2O, Na_2O,CaO and poorer in FeO, MgO and H_2O as compared to schists. This indicates that PT conditions during regional metamorphism of the rocks were below the temperature at which the process of anatexis takes place. The PT conditions required for the formation of anatectic melt as shown by Winkler (1967) and Turner (1968), is attained in the upper part of the amphibolite facies, where muscovite becomes unstable and breaks down by the following reaction-

Muscovite + quartz = Orthoclase + sillimanite + water

According to Evans (1965) and Seki and Kennedy (1965) the temperature for the reaction lies somewhere between 605°to 640°C at 2 K bars and 665° to 700°C at 4 K bars water pressure.

In the study area, the microscopic study has revealed the presence of muscovite in the gneisses containing sillimanite and K-feldspar. It clearly indicates that the upper stability limit of muscovite has not been exceeded.

The rocks, therefore, seem to be formed by the third alternative that is granitization which is amply proved by the chemical data, Graphically represented in Von Wolff's Triangular diagram. The Q, L and M values of Von Wolff have been plotted in the triangular diagram (Plate 32, Fig. 1). In this diagram, the granitic cotectic minimum composition has also been given for comparison. This has been calculated from the experimental data of Tuttle & Bowen (1958) on quartz - albite - orthoclase system at 4-8 K bars water pressure using normative Ab/An ratios of average granite of Daly (Smith, 1964). It is observed that the field of gneisses and migmatites of the area lies in intermediate position between the fields of schists and granitic cotectic minimum composition. The changes in Q L M components from phyllites and schists to gneisses clearly show an enrichment of L (Leucocratic component) value which is also evidenced by increase of feldspars as observed under microscope. The slight decrease in Q(Quartz) and M(Melanocratic components) values could only be due to the replacement of quartz and mafic minerals by feldspars. Though majority of the gneisses conform to the above conclusion, the value of E is slightly away from the Q L line which is due to the fact that these gneisses contain garnet in it, which is richer in iron content.

Engel & Engel (1958) have shown on the basis of detailed geochemical work that a granitic melt developed in the granulite facies of the Adirondack mountain of the rocks were the source of

granitic sol-ution responsible for the granitization of the rocks of amphibolite facies in the area. On the other hand the rocks of the granulite facies show degranitization and relative enrichment of ferromagnesium constituents. Thus, it is probable that the granitic melt of cotectic minimum composition may have developed at depth in Precambrian times where the rocks of the area were metamorphosed in upper amphibolite and granulite facies.

This Von Wolff's diagram has been used by Reynolds (1946) to illustrate the geochemical changes causing granitization; by Harry (1954) to describe such an origin of Ardgour gneisses; by Butler (1965) to describe the rocks of Ardnamurchan & Moin rocks, by Lal (1969) to discuss the origin of the gneisses of Almora district lying east of Masi Bazar; by Das (1971) to discuss the origin of Ranikhet area gneisses by granitization, and by Kashyap (1972) to explain the formation of migmatites of Ramgarh area by granitization.

So it is clear from the study that the area is comprised of different rocks or metamorphites of heterogeneous nature. On granitization, rocks of distinct granitic composition have been developed from different rock types of heterogeneous nature, depending upon the type of parent material involved in the process. The following table shows the migmatites and gneisses which are derivatives of different country rocks after transformation. Table XXX shows the country rocks and their derivatives as follows :-

TABLE XXX

Country rocks	Migmatic derivatives
Mica schists	Streaky migmatite, banded gneisses or migmatites, granodioritic gneisses, adamellitic gneisses and potash granitic gneisses.
Quartzites & quartz mica schists	garnetiferous gneiss, augen gneiss and tourmaline permition gneiss.
Amphibolite	Hornblende biotite gneiss

The metamorphosed equivalents of pelitic and semipelitic rocks were granitized first because they are chemically more like the gneisses than the other rocks like quartzite and amphibolites (Mehnert, 1968).

When the pelitic schists get converted into granitic gneisses many excess constituents become available for the granitization viz. Al_2O_3. Hence the mineralogical and chemical changes brought out in case of pelitic schistose rocks are dealt first, followed by quartzites and amphibolites.

Samples 5, 7, A & Y were selected in the Doda bridge area to study the mineralogical and chemical changes in the pelitic schistose and gneissose rocks. The micrometeric and chemical analyses of these rocks as given in Tables IX, XII, XVI, XXIV and XXVII respectively.

Results of micrometeric analyses as given in Table IX XII & XVI have been plotted in Plate 34. The results of chemical analyses of samples 5, 7 and A and their Niggli values have been plotted in Plate 35 & Plate 36 respectively.

Initially the change from garnetiferous mica schist to biotite schist is in the nature of biotite enrichment along with increase in feldspars, quartz, muscovite and the accessories have been decreased. At this stage the rock is molecularly desilicated relatively to bases present. This desilication is due to increase in Fe_2O_3, FeO and MgO and decrease in silica. The increase in plagioclase shows that SiO_2 and Al_2O_3 released from muscovite have been utilized in the formation of plagioclase by the addition of Na & Ca ions from circulating solutions (Cheng, 1943, Saxena, 1961, Kanwar, 1969 & Gupta, 1969). The rise in TiO_2 makes the geochemical culmination, Reynolds, 1946. The material lost in the transformation accounts for the development of biotite rich

zone (Ma, 1948 & Kanwar, 1969).

Later the schistose material is replaced by a sizeable extent of felspathic material and the rock assumes the adamellitic character. This change has been described as ~~desilicification~~ desilication by felspathiz-ation (Reynolds, 1946).

In the next stages there is a marked decrease in the quartz so that the rock contains only 20% at the last stage. In the initial adamellitic gneisses near the Doda bridge plagioclase dominates, whereas in the end product orthoclase predominates. Potash felspar is the last to crystallize indicating that in the last stage K_2O has increased. The ~~xxxdy~~ steady rise of feldspar curve coincides with the declining curve of biotite forming gneisses approaching granitic composition. It is probable that feldspar is formed by the destruction of biotite. The accessories like apatite, rutile etc. also decrease sufficiently.

The changes throughout the transformation were essentially of the nature of metasomatic replacement. The desilication change in the transformation of the rock has taken place by the combination of desilication by basification and by felspathization. The transformation indicates that in the beginning the fluids were more sodic and in the later phases they became more potassic.

From the chemical analyses and the Niggli values of schist and adamellitic gneisses as shown in Plate 36, it is evident that the changes involve/~~can~~ indicate increase in al and alk and decrease of fm c and si. These results are diagrammatically shown in the Plate 37.

Secondly the mineralogical and chemical changes involved in the transformation of quartzite and quartz-mica schists to form gneisses ~~is~~ are studied. Representative samples along the strike were collected from Malnai and Mundella lying ~~east~~ south of the area. The

mineralogical variations are represented diagrammatically with respect to distance along the strike (Plates 38 & 39).

Three rocks of Mundella area viz. 2,3 and B, are chemically analysed and the Niggli values are calculated, the results of which are diagrammatically represented in Plates 40 & 41 respectively.

The changes are gradational. The steady rise of K-feldspar curve is parallel to the decrease in quartz curve. Biotite first increases and then decreases gradually. The decrease in muscovite, biotite and quartz is compensated by the increase of K-feldspar.

The changes in the transformation of these rocks are chemically speaking of the nature of felspathization. The felspathization is due to the alumina set free by the mica schist. The source of potash in the later stages may be traced from the schistose rocks. K_2O released from the breaking of biotite and muscovite of schists and left unconsumed (Cheng, 1943) and circulated in the circulating fluids already contaminated with potassic molecules have also been responsible for the formation of potash feldspars in the later phases(Saxena, 1961 & Gupta, 1969).

With the decrease of si, fm and c; the al and alk increases as plotted in Plate 41 which have been provided by the circulating fluids. The results of possible mineralogical and chemical change are diagrammatically shown in Plate 42.

Thirdly the chemical transformation of amphibolite into granodiorite is observed below Dharara. The granitic material has permeated the amphibolite along the foliation plane and has replaced the rock. The sodic fluids have played an predominant role in bringing out the transformation. The addition of Na_2O and SiO_2 has brought the main change by transforming amphibolite to granodiorite.

II PETROCHEMISTRY OF GRANITES

The field and petrographic studies of granites, as indicated in Chapter V, have already proved that these are of igneous origin, which is further confirmed by studying their petrochemistry.

The samples of granites from Bhala and Dedni (Sadri) have been chemically analysed. The results of such granites alongwith their C.I.P.W. norms and Niggli values are presented in Tables XXXI, XXXII and XXXIII given below :-

TABLE XXXI
CHEMICAL ANALYSES OF GRANITES

	I (Dedni granite)	II (Bhala granite)
SiO_2	67.96 %	72.10 %
Al_2O_3	15.33 %	14.12 %
Fe_2O_3	2.08 %	0.62 %
FeO	1.87 %	1.27 %
TiO_2	0.35 %	0.15 %
CaO	2.46 %	1.58 %
MgO	1.85 %	0.82 %
Na_2O	3.01 %	2.05 %
K_2O	4.69 %	6.84 %
H_2O	0.45 %	0.31 %
	100.05 %	99.86 %

TABLE XXXII
C.I.P.W. NORM (%)

	I	II
Quartz	24.00	28.86
Orthoclase	27.80	40.03
Albite	12.51	17.29
Anorthite	12.51	8.06
Corundum	0.71	0.41
Hypersthene	5.79	3.58
Magnetite	3.02	0.93
Ilmenite	0.67	0.30

TABLE XXXIII
NIGGLI VALUES

	I	II
si	291.05	380.50
al	28.37	42.40
fm	25.06	14.46
c	11.51	9.12
alk	25.06	33.02
k	0.51	0.68
mg	0.50	0.48

The chemical analyses (Table XXXI) confirm the petrographic observations that the specimens are granites, as the projected analyses which are shown in (Plate 45, Fig. 4) lies well within the granite intrusion.

Harker's variation diagrams (Plate 44, Fig. 2) showing the weight percentages of the major oxides on the ordinate against SiO_2 on the abscissa have been prepared. From the graph it is clear that as SiO_2 content increases there is a decrease in CaO, MgO, FeO + Fe_2O_3 and Al_2O_3. An increase in the total alkalies content is noticed with the increase in SiO_2, the variation between K_2O and Na_2O is reciprocal. From this diagram a clear picture of the chemical changes that occurred during the crystallization of the magma can be inferred.

Similar variation diagram for the al, fm, c and alk values against si is also prepared.

Plate 45, Fig. 1 shows al, fm, c, alk values plotted as ordinate against si as abscissa. It is evident from the graph that with the increase in the si value there is rise in al and alk values and fall in fm and c values respectively, which

indicates igneous origin.

The plot of Niggli values mg against k shown in Plate 45, Fig. 2 (after Burri and Niggli, 1945) also leads to same inference.

Further al, c and alk Niggli values have been plotted in Triangular diagram (Plate 45, Fig. 3), which indicates that granites are confined to igneous field, thus confirming magmatic origin.

III PETROCHEMISTRY OF DODA AMPHIBOLITE

The origin of amphibolites, whether para or ortho, is a controversial subject. The metamorphism of calcareous or dolomitic shales forms para-amphibolites whereas the ortho-amphibolites are the result of basalts, meta dolarites and basic tuffs.

In order to distinguish between two groups of amphibolites, the chemical method indicated recently by Leake (1963, 1964) has been utilized in which the nature of trends of variation in the amounts of elements and their relationship in known basic igneous or sedimentary trends have been followed.

Leake (1963, 64) has plotted Niggli mg against c for the Karroo dolerites (Walker & Poldervart, 1949) and for mixtures of pelites and limestones or dolomites. In case of Karoo dolerites, when he plotted mg against c, he got a particular trend, similar to one observed in case of basic igneous rock, and hence he regarded them as ortho-amphibolites.

He has also plotted a triangular diagram with 100 mg, c and (al-alk) recalculated to 100 as its parameters which has revealed that the line joining dolomite and typical pelite and semipelite runs at right angles to the trend of variation shown by typical basic igneous rocks.

Orville (1969), in case of Adirondack - amphibolites and

Wakhaloo and Dhar (1969)& Dhar (1972) in case of Kishtwar amphibolites observed that the plotted values of mg and c on these diagrams lie close to the trend observed in basic igneous rocks and have, therefore, regarded them as orthoamphibolites.

In case of Doda amphibolite J, when mg plotted against c in similar diagrams (Plate 43, Figs. 1 & 2) it indicated a trend similar to one which indicates an igneous origin.

Doda amphibolite are present as Sills and Dykes, which implies that their magmatic stress-es were high resulting in the forceful penetration of the magma (Ramsay and Sturt, 1970).

Taking into consideration the mode of occurrence, their simple composition, as described in Chapter on petrography, and the petrochemistry it can be inferred that these amphibolites had resulted from the transformation of igneous bodies. The primary phase of the emplacement of basics has been followed by a subsequent phase of metamorphism in which "Cafemic" elements liberated during the granitization of mica schists got fixed up in the previously existing basic rocks and caused "amphibolitization".

CHAPTER - VIII

METAMORPHIC FACIES

I - Metamorphic facies indicating progressive grades of Metamorphism.

(1) - Greenschist facies

(2) - Epidote - amphibolite facies

(3) - Amphibolite facies

(4) Amphibolite - granulite transition facies

II - Retrogressive Metamorphism or Diaphthoresis

CHAPTER - VIII

METAMORPHIC FACIES

The minerological and textural features in metamorphic rocks have been indicated by various scientists under the following three concepts :-

(1) Grubenmann's depth zone concept

(2) Barrow's zonal concept

(3) Eskola's facies concept

Firstly, Grubenmann (1904) has explained the presence of the following three depth zone :-

(a) Epizone

This zone is developed at low temperature and high non-hydrostatic pressure. The typical minerals developed in this zone are Chlorite, Chloritoid, epidote and carbonate.

(b) Mesozone

In this zone, the metamorphic rocks are developed at moderate temperature and pressure conditions. The typical minerals developed are muscovite, biotite, almandine, staurolite and kyanite.

(c) Katazone

In this zone high temperature and pressure play an important part in the forming of metamorphic rocks. The important minerals of this zone are potash-feldspar, calcice plagioclase and sillimanite. This zone has been named as hypozone by Niggli(1924).

Secondly Barrow (1912) by working in Scottish Highlands gave the zonal concept of progressive regional metamorphism by laying emphasis on certain index minerals/- chlorite, biotite, almandine, staurolite, kyanite and sillimanite - formed under particular temperature and pressure conditions in a definite zone.

Thirdly Eskola (1915) gave the facies concept which has now come to hold its own and is universally applied. As the final outcome of mineralogical changes is controlled by P T conditions and the original composition of the bulk material, this facies concept is the true scientific approach. In the area under reference, metamorphism has effected various kinds of rocks argillaceous, siliceous, calcareous and basic igneous intrusives. It is, therefore, metamorphic facies concept which can better explain the constant relation between mineral composition and chemical composition of the rocks.

A - Metamorphic Facies indicating progressive grades of metamorphism

The following facies have been met with in the study area, indicating the increase in the grade of metamorphism with the development of their critical mineral assembalages :-

I. Greenschist facies,

II. Epidote - amphibolite facies

III. Amphibolite facies

IV. Amphibolite - granulite transitional facies of Turner(1968)

The limits of the above mentioned metamorphic facies have been shown in the Plate 46. The range of various minerals developed in these facies is indicated in Plate 47. The detailed study of these facies is given in the following pages, which clearly gives the idea of progressive grades of metamorphism with the increasing P T conditions.

I Greenschist facies

This facies is represented by biotite schist and biotitic phyllite. The development of large flakes of biotite in phyllite is a common feature in the area under reference. The temperature range for the formation of various assemblages in this facies

varies from 200°C to 250°C (Barth, 1952).

The pelitic rocks give the following assemblages :-

1. Chlorite - sericite - biotite - graphite - quartz

2. Muscovite - biotite - epidote - quartz - albite

The important reactions explaining the formation of above assemblages are as follows :-

(a) 5 Antigorite + 3 muscovite = 3 biotite + 3 amesite
(Prochlorite) (Al-rich Chlorite)

$+ 7\ SiO_2 + 4\ H_2O$.

....(Tilley, 1924; Harker, 1939; Barth, 1952; Snelling, 1957; Naha, 1965 and Winkler, 1967).

(b) Another reaction, which holds good for assemblage (1) alone, is given by Ramberg, 1952 :-

Muscovite + ferromagnesian chlorite + silica = biotite

+Alumino - Chlorite.

The assemblage No. 2 shows close resemblance to the greenschist assemblages of the pelitic rocks of Vermon Hampshire described by Lyons (1955), Abukama plateau of Japan described by Miyashiro, 1961 and at Kishtwar by Wakhaloo et, al. (1971).

II Epidote - amphibolite facies

This facies covers nearly 40% of the total area under study. It is characterized by the presence of oligoclase epidote and almandine. Oligoclase has anorthitic content upto 30%, as excess of it is replaced by epidote. The upper boundary of this facies is determined by Barth to be 400°C by the stability relation as under:-

Oligoclase $\xrightarrow{400^\circ C}$ epidote.

In dealing with this sub-facies rocks can be grouped into two classes viz.,

(A) Rocks of original pelitic composition
(B) Rocks of original quartzo-felspathic composition

Mineral assemblages are the following :-

(A) Pelitic assemblages :-

(1) Almandine - biotite - muscovite - plagiolase -epidote - quartz

(2) Almandine - biotite - Oligoclase - K-felspar - quartz

(3) Almandine - biotite - muscovite - epidote - Oligoclase - quartz

(4) Almandine - muscovite - Oligoclase - epidote.

(B) Quartzo-felspathic assemblages :-

Almandine - muscovite - biotite - microcline - Oligoclase - epidote - quartz

The above mentioned assemblages can be explained by the following reaction by Winkler (1967).

Fe Mg Chlorite + quartz = almandine+Mg chlorite

The assemblages of this facies show close resemblance to the assemblages of this facies in Kishtwar area described by Wakhaloo et. al. (1971)& at Dudatoli area in Almora described by Das and Pande (1973).

III Amphibolite facies

The mineral assemblages of this facies mainly consist of plagioclase felspar, which is a basic variety and hornblende. This assemblage is taken to correspond to the zones of staurolite - kyanite and sillimanite in the Scotish Highlands. According to the typical minerals present, three sub-facies can be recognised in order of the increasing grade of metamorphism :-

(a) Staurolite - almandine sub-facies

(b) Kyanite - almandine sub-facies and

(c) Sillimanite - almandine - muscovite sub-facies

Above division is in accordance with the sub-facies encountered by Francis (1956) while working in Grampian Highlands.

(a) Staurolite - almandine subfacies

The first appearance of staurolite introduces the amphibolite facies. In dealing with the subfacies, rocks can be grouped into two classes viz. (A) rocks of pelitic composition (B) rocks of basic igneous rocks which are present in the form of dykes and sills. Mineral assemblages are the following :-

(A) Pelitic assemblages :-

(1) Staurolite - almandine - chloritoid - biotite - - Oligoclase - quartz

(2) Staurolite - almandine - muscovite - biotite - Oligoclase - quartz

(B) Basic assemblage :-

Hornblende - andesine - epidote - quartz

Assemblage of No. 1 of the pelitic rocks can be explained by the following reaction by Winkler (1967) :-

Chloritoid + chlorite + muscovite = staurolite + biotite + almandine + H_2O .

Assemblage No. 2 of the pelitic rocks is explained by the following reaction of Winkler (1967) :-

Fe - rich chlorite + muscovite = staurolite + biotite + almandine + H_2O.

The basic assemblage of Group B can be explained according to a reaction mentioned by Wakhaloo et. al. (1969) as under :-

Pyroxene + anorthite + water = hornblende + quartz

Some of the epidote and biotite could have formed from the transformation of hornblende according to the following reaction by Wakhaloo et. al. (1969) :-

$$Ca_2(Mg\ Fe)_3\ Al_4\ Si_6O_{22}\ (OH)_2 + \tfrac{1}{2}\ K_2O + XSi\ O_2 + H_2O$$

(Dissolved sillicates)

$$= K\ (Mg\ Fe)_3\ Al\ Si_3O_{10}(OH)_2 + Ca_2\ Al_3\ Si_3O_{22}(OH)$$

(Biotite) (Epidote)

(b) Kyanite - almandine subfacies

The pelitic schists at Lal Dharaman have developed kyanite-bearing almandine subfacies indicating the following assemblage :-

Kyanite - staurolite - almandine - biotite - quartz

The formation of kyanite can be explained according to the following reaction of Deer et, al. (1962) :-

3 Staurolite + 2 quartz = Almandine + 5 kyanite + 3 water

Presence of kyanite in a small zone in the metamorphites is due to the fact that operating high pressure required for its formation is not reached. It has been clearly shown by Winkler(1967) with his kyanite - sillimanite equilibrium curve that higher pressure is the essential feature for the formation of kyanite.

(c) Sillimanite - almandine - muscovite subfacies

This facies is developed at very high temperatures and has developed the following classes :-

(A) Representing the rocks of original pelitic composition

(B) Representing rocks of calcareous composition

Mineral assemblages are the following :-

(A) Pelitic assemblages

(1) Sillimanite - almandine - biotite -muscovite -Oligoclase - quartz

(2) Sillimanite - staurolite - almandine - biotite - - muscovite - Oligoclase - quartz

(B) Calcareous assemblagex :-

Calcite - diopside - tremolite

The pelitic assemblages can be explained by the following reaction by Turner & Verhoogen (1960) and Winkler (1967) :-

Staurolite + quartz = sillimanite + almandine + H_2O

At the formation of this subfacies the temperature remained

within the stability range of muscovite, hence muscovite and sillimanite can co-exist in this subfacies.

(b) Calcerous assemblage

The calcerous assemblage has been recorded in the marbles near Khelani at Kilota. This calcareous assemblage has also been recorded by Misch (1964) in Nanga Parbat area. [redacted]. The calcareous assemblage in which diopside is present can be developed by the reaction of some calcite with tremolite in the presence of $Si\ O_2$ present as impurity.

Ramberg (1952) has given the following reaction to explain the formation of this assemblage :-

$$\underset{\text{(Calcite)}}{3\ Ca\ Co_3} + \underset{\text{(Tremolite)}}{Ca_2\ Mg_5\ Si_8\ O_{22}\ (OH)_2} + \underset{\text{(Quartz)}}{2\ Si\ O_2} = \underset{\text{(Diopside)}}{5\ Ca\ Mg\ Si_2O_6} + 3\ CO_2 + H_2O$$

IV Amphibolite - granulite transition facies

In recent years, banded gneisses and granitic gneisses have been included under the Amphibolite - granulite transitional facies by Engel & Engel (1953); Buddington (1963) and Turner (1968). These scientists have indicated that during granitization both granitic material and metasedimentary rocks got mixed. In this process biotite and hornblende together or alone, begin to dehydrate in the presence or absence of phases such as quartz or plagioclase, the resulting transformation is a gradual one, probably spread over a significant interval of temperature at any given pressure. Hence there is justification to call this period of transformation as a transitional zone between amphibolite and granulite. Formerly, Barth (1952) & Turner & Verhoogen (1960) alongwith other scientists by taking the literal meaning have included these gneisses under the heading of comprehensive granulite facies. As the granitization has resulted the formation of gneisses

I propose to enclose these under the heading of Amphibolite - granulite transitional facies.

The following assemblages have been recorded :-

(1) Perthite - biotite - muscovite - plagioclase - quartz

(2) Perthite - Oligoclase - muscovite - quartz

(3) Perthite - ~~xiiiii~~ sillimanite - almandine - oligoclase - quartz

(4) Perthite - oligoclase - muscovite - biotite - quartz

(5) Orthoclase - perthite - oligoclase - biotite - muscovite - quartz

(6) Orthoclase - perthite - oligoclase - biotite - muscovite - - hornblende - quartz

(7) Orthoclase - oligoclase - biotite - muscovite - quartz

The presence of muscovite in gneisses containing sillimanite and K-feldspar indicates that the upper stability limit of muscovite has not been exceeded.

Widespread presence of almandine and definite presence of staurolite, kyanite and sillimanite in schists, presence of perthite and oligoclase in gneisses and presence of amphibolites indicates that these rocks have been recrystallised under the environment of almandine - amphibolite facies of Winkler (1967) and Amphibolite facies of Turner (1968).

The mineral assemblages present in the different rocks of the area reproduced in table ~~XXXIV~~ given below :-

Schists :-

(1) Chlorite - sericite - biotite - graphite - quartz

(2) Muscovite - biotite - plagioclase - quartz

(3) Almandine - muscovite - chlorite - plagioclase - quartz

(4) Almandine - epidote - muscovite - microcline - - plagioclase - quartz

(5) Almandine - biotite - plagioclase - quartz

(6) Almandine - muscovite - biotite - epidote - plagioclase - quartz

(7) Staurolite - almandine - chloritoid - plagioclase - - biotite - quartz

(8) Staurolite - admandine - muscovite - biotite - plagioclase - quartz

(9) Kyanite - staurolite - biotite - quartz

(10) Sillimanite - muscovite - plagioclase - quartz

(11) Sillimanite - almandine - muscovite - biotite - - plagioclase - quartz

(12) Sillimanite - staurolite - almandine - biotite - plagioclase - quartz

Gneisses

(13) Perthite - plagioclase - muscovite - quartz

(14) Perthite - plagioclase - muscovite - biotite - quartz

(15) Perthite - almandine - biotite - muscovite - plagioclase - quartz

(16) Perthite - sillimanite - muscovite - plagioclase - quartz

(17) Perthite - Orthoclase - muscovite - biotite - plagioclase - quartz

(18) K-felspar - hornblende - plagioclase - quartz

Marble

(19) Calcite - diopside - tremolite

~~(20)~~ Amphibolite -

(20) Hornblende - andesine - epidote - quartz

In assigning the various minerals to constitute an assemblage, as is commonly the practice, amount of minerals has not been taken into consideration since this varies considerably according to the heterogeneous presence of rock types formed from different bulk compositions. The accessory minerals do not feature in the mineral assemblages because being refractory these are

liable to have resisted the physiochemical changes. Effort has been made to depict prominent mineral assemblages present in schists and gneisses in A K F diagram (Plate 29), from the chemical analyses of some of these rocks. In constructing this diagram position of garnet be fixed from its assemblages, while the positions of muscovite and biotite have been taken from the ideal compositions as is available from the published analyses of these. As is apparent, the analyses of schists (represented by circles) in the diagram lies above the ideal muscovite - biotite line, while those of gneisses (represented by solid triangles) is below the muscovite - biotite line. Further analyses of staurolite and sillimanite schists falls in the field above the muscovite - almandine line, while the composition of garnetiferous mica schists is below this line and above muscovite - biotite line, since these are deficient in Al_2O_3 as compared to staurolite - sillimanite bearing rocks which contain excess amount of Al_2O_3. This is in accord with the observations of Winkler (1967) & Turner (1968), who have mentioned that the staurolite, kyanite and sillimanite have developed in more aluminous pelitic assemblages. The staurolite bearing assemblage has indicated a higher FeO/FeO + MgO and Al_2O_3/ FeO + Mg O ratio as compared to assemblages free from these minerals. This is evidenced from the analyses reproduced in the table XXIV. In confirmity of the ideas expressed by other authors the chemical composition of the rocks has played an important role in the development of staurolite in mineral assemblages apart from the physico-chemical conditions of temperature and pressure.

(B) Retrogressive Metamorphism or Diaphthoresis

The main episode of regional metamorphism was followed by some retrogressive changes.

Both high grade schists and gneisses of this area have been effected. The effect of retrogressive metamorphism on schists have been typically observed at Khabrel (33° 4' 20" : 75° 30' 30") and at Lal Dharaman (33° 11' : 75° 30'). At Khabrel, almandine has altered on the margins to chlorite whereas central portions have remained unstable relict due to low velocity of retrogression. At Lal Dharaman, presence of altered sillimanite schist indicate retrogressive metamorphism by the presence of following features :-

(a) Mosaic of granular quartz with twinning lamellae in lenticular forms;

(b) by the presence of chlorite and sericite from biotite;

(c) by the formation of muscovite from sillimanite; and

(d) breaking of almandine to biotite and iron oxide at the margins (Plate 17, Fig. 5).

In general, the retrogressive metamorphism is indicated at other places by the presence of chlorite within almandine and iron ores around the margins of biotite. Such retrogressive features have also been mentioned by Wakhaloo et, al. (1972) in Kishtwar area.

It is mainly due to the decline of temperature and stress conditions promoted by activity of water content within the rock. The mineral assemblages which attained equilibrium at high grade at the early stages of progressive metamorphism exhibit alteration to the minerological assemblages which will be confirmable with the reduced temperature and pressure conditions as is common with such a process. This phenomenon is particularly proved by the alterations of such minerals as garnet, sillimanite etc.

CHAPTER IX

CORRELATION AND COMPARISION OF THE ROCK UNITS WITH THE PRECAMBRIANS OF OTHER PARTS OF HIMALAYAS AND OF THE PENINSULAR INDIA

I MINERALOGICAL AND PETROLOGICAL CORRELATION OF THE ROCK UNITS WITH THE PRECAMBRIAN OF THE REST OF THE HIMALAYAS

Himalayan regions

(a) Nanga Parbat and adjoining areas of Chilas & Kaghan;

(b) Kishtwar and Atholi in Pader;

(c) Dhauladhar Range;

(d) Lahaul and Spiti;

(e) Kulu District;

(f) Simla Region;

(g) Dudatoli-Almora area in Central Himalayas;

(h) Nepal;

(i) Darjeeling Region; and

(j) Bhutan.

II MINERALOGICAL AND PETROLOGICAL RESEMBLANCE OF THE ROCK UNITS WITH THE PRECAMBRIAN OF PENINSULA

Peninsular Regions

(a) Rajasthan;

(b) Bihar;

i) Gaya, Hazaribagh, Manbhum and Palamau districts;

ii) Northern and eastern Singhbhum area;

(c) West Bengal - Kuilapal area of Purulia District;

(d) Orissa - Gangpur series of Sundergarh and Sambalpur Districts; and

(e) Madhya Pradesh and Maharashtra Dharwars.

CHAPTER IX

CORRELATION AND COMPARISION OF THE ROCK UNITS WITH THE PRECAMBRIANS OF THE PENINSULAR INDIA

The rock units can be correlated mineralogically and petrologically with the Precambrian of Nanga Parbat, Kishtwar, Dhauldhar Range, Lahaul, Spiti, Kulu, Simla, Almora, Nepal, Darjeeling and Bhutan in extra-peninsular area and the Precambrian of Rajasthan, Bihar, West Bengal, Orissa, Madhya Pradesh and [redacted] Maharashtra.

The principal criteria employed for correlation of Salkhala series with Precambrian of other areas are as follows :-

(1) The presence of graphitic phyllites interbedded with diopside-grossularite marble. To quote Chakravarty et al. (1971) :-

> " The Salkhala series is characterised by limestone and graphite-phyllite and also by gypsum"

(2) The presence of meso - to hypo - grade schists comprising of biotite schists, almandine-mica schist, staurolite schists, kyanite schists and sillimanite schists, alongwith intercalations of quartzites and amphibolites.

(3) The very common development of high degree plications.

I - MINERALOGICAL AND PETROLOGICAL CORRELATION OF THE ROCK UNITS WITH THE PRECAMBRIANS OF THE REST OF THE KIRKRAKE HIMALAYAS

Chakravarty et al. (1971) have correlated the Salkhala rocks of Kashmir with Jutoghs and Vaikrita in Simla and Vakrita of U.P. Himalaya; Bhimphedis in Nepal Himalaya; Darjeeling series in West Bengal and Thampo and Paro series of Bhutan.

The correlation of the rock units, in general and on mineralogical and petrological basis in particular, can be made with the Precambrian rocks of extrapeninsula of various regions mentioned below.

(a) Nanga Parbat and the adjoining areas in Chilas & Kaghan

The rocks of the area under reference can well be correlated with Nanga Parbat and its surrounding areas of north-western Kashmir and Hazara, where Salkhalas are well developed. The Nanga Parbat area has been described by Wadia (1932) and Misch (1949). Both areas can be correlated as under :-

(1) The graphitic phyllites of Khaleni can be compared with outer bands of similar rocks occurring south of Nanga Parbat, Babusar and north Kaghan.

(2) Saccharoidal white marble ~~of~~ at Kilota in Khaleni area can be compared with marbles occurring on the slopes of Tarshing Cliffs above Thalichi and Bunar valley of Nanga Parbat.

(3) Sulphide mineralization in shape of pyrite, pyrrohotite in graphitic phyllites resemble with that of Kaghan area in Hazara.

(4) Biotite schists in both areas show great resemblance.

(5) Garnetiferous-mica-schists are the most dominant schists in the study area covering Gadiara, ~~Banso~~ Barsal, Galhian and Siraj Ranges. These schists can very well be compared with the garnetiferous - mica schists of Nanga Parbat and the areas north of Kaghan between Narang and Babusar.

(6) The sillimanite schists of both the areas contain sillimanite on microscopic scale.

(7) Banded biotite gneisses of Doda bridge, near Beoli, Barshal and near Khelani can well be compared with the banded-gneisses of Garkot; Bunji and Hattu-Pir.

(8) Granitic gneisses show resemblance with the central gneisses at Nanga Parbat.

(9) Muscovite gneisses at Doda bridge can be compared with that of Perri and Leycher lying south of Nanga Parbat.

(10) Tourmaline and Muscovite bearing pegmatites are common in both areas.

(11) Metamorphism is differential or patchy in both cases.

(b) Kishtwar and Atholi in Padar

The Precambrian of Kishtwar has been described by Lydekkar (1978 and 1983); Wakhaloo (1968) and Wakhaloo et al. (1971). There is mineralogical and petrological resemblance in both areas as indicated below :-

(1) There is close resemblance between the mica schists and garnetiferous-mica schists of both areas. These also show prevalent development near Atholi.

(2) Amphibolites are present [redacted] in both areas.

(3) The migmatites are commonly met in both areas and are represented by banded gneisses.

(4) Granitic gneisses, garnetiferous mica gneisses and augen-gneisses are also common feature of both areas.

(c) Dhauladhar Range

It has been described by Gupta L.N. (1969) and shows resemblance as under :-

(1) The biotite schists and almandine-mica schists of both areas are similar.

(2) Tourmaline Permeation gneiss at Saye show resemblance to tourmaline permeation gneiss of Dhauladhar Range.

(3) Migmatites and granitic gneisses in both areas show great resemblance and are formed as a result of granitization.

(4) Aplite and pegmatite veins are present, as common feature.

(d) Lahoul and Spiti

Precambrian of Lahoul and Spiti has been described by Oldham (1888); Gansser (1964); Saxena and Pande (1968) and Gupta et al.(1970)

show close relation with the area under reference as follows :-

(1) The graphitic phyllites at Khaleni show resemblance to that of low grade metamorphics of Lahoul area.

(2) High grade metamorphic schists comprising of garnetiferous mica schists, staurolite schists in both the areas show great resemblance.

(3) The migmatites and gneisses of the area show resemblance with the rocks developed along the course of the river Chenab in and around Rohtang.

(4) Both areas have highly contorted schists.

(5) Both the areas are overlain by cambro-silurian rocks and hence they are definitely of Precambrian age.

(e) Kulu District

Jutoghs of Kulu district have been mapped and studied in detail by Sharma V.P (1972). This area can be correlated with the area under reference on the following lines :-

(1) The graphitic phyllites of both areas are similar.

(2) The schistose rocks in both areas comprise of biotite schists, almandine-mica schists, kyanite schists and sillimanite schists.

(3) Streaky gneisses in both areas resemble with each other.

(4) There is abundant ~~places~~ presence of pegmatites.

(f) Simla Region

The Precambrians of Simla area has been described by Pilgrim and West (1928) and Pascoe (1965). The resemblance in both the areas is as follows :-

(1) Jutogh series of Simla shows the presence of graphitic-phyllite with marble as is observed at Khaleni.

(2) Garnetiferous - mica schist and staurolite schist of Jutogh show resemblance with the schists of the area under study. The occurrence of Puckers is also very common in both area.

(3) Amphibolites in the area under reference show typical resemblance to the amphibolites of the Chor area in Simla. Pale green hornblende with basic andesine, quartz and iron ore are the common constituents of the amphibolites of both the areas.

(4) Banded gneisses, garnetiferous gneisses and grey granitic gneisses show typical resemblance in their composition to such gneisses occuring in the Chor area of Simla.

All the above observations lead to conclusion that Salkhalas of the study area are equivalents of the Jutogh in Simla.

(g) Dudatoli-Almora area in Central Himalayas

The Dudatoli-Almora schist has been studied in details by Gansser (1964); Tewari & Mehdi (1964); Pande & Power (1968) and Das & Pande (1973). The description of Dudatoli area makes a close resemblance with the Salkhalas of the area as is indicated below :-

(1) Both areas have the development of graphitic schists, garnetiferous-mica schists, staurolite schist and sillimanite schist.

(2) Psammitic rocks like quartzite and quartz-biotite schist are present in both the areas.

(3) Tourmaline permeation gneiss of Saye is like that of Almora tourmaline permeation gneiss.

(4) The gneisses of both the areas have variable grain size and texture. Large porphyroblasts of perthites are developed in the granitic gneisses of both the areas. These also show variable ratio of plagioclase, perthites and K-felspars.

(h) Nepal

The rocks of the study area can well be compared with the Sanguri section of Khumbu Nappe of lower Himalayas of eastern Nepal described by Gansser (1964) as under :-

(1) The mica-schists of both areas contain garnet, staurolite and large flakes of muscovite, at contacts of gneisses due to granitization.

(2) The granitic gneisses, garnetiferous gneisses, augen-gneisses and banded gneisses are prominently developed in both the areas. These also show close resemblance to Barun gneiss and Makalu-gneiss of the Everest Region.

(3) Tourmaline pegmatite of Thellela and Saye can be correlated with the tourmaline pegmatites of eastern Nepal.

(i) Darjeeling Region

Most of the area in the Salkhalas of the study area is similar to Darjeeling series except small south western corner which can well be compared with the Daling series, in the Tista valley. The Daling and Darjeeling series are well represented along the Darjeeling-Siliguri road. These series have been described by Gansser (1964) & Ghosh (1971). Both the areas show great resemblance as is indicated below :-

(1) The phyllites and biotite schists with marble of the Khaleni area can be correlated with the Daling of Tista valley.

(2) Salkhalas mainly indicate meso-to Kata grade of metamorphism which is well represented by biotite schists, garnet mica schist, sillimanite schists, garnetiferous gneisses and mica gneisses and which can well be compared with Darjeeling series.

(3) Tourmaline-muscovite pegmatites of Thallela and Lal-Dharaman are similar to the pegmatites of the Darjeeling area.

(j) Bhutan

Precambrian of Bhutan has been described by Chakravarty et al. (1971) and can be correlated with the Precambrian of the study area as under :-

(1) In both areas phyllites show pyrite mineralization and are associated with marble bands.

(2) Thampu and Paro series in Bhutan show close resemblance by having large development of garnetiferous mica schists.

(3) Para gneisses in both the areas show the development of sillimanite in them.

II - MINERALOGICAL AND PETROLOGICAL RESEMBLANCE OF THE ROCK UNITS WITH THE PRECAMBRIANS OF PENINSULA

The correlation of the rock units on mineralogical and petrological bases have been made with the Precambrians of Peninsula in the various states.

(a) Rajasthan

The Precambrian of the Mewar region in central Rajasthan has been described in detail by Heron (1953) and inSirohi district described by Coulson (1933). They show close resemblance as under :-

(1) The graphitic phyllites of Salkhala at Kilota - Dedan - Kaleh area show resemblance with the phyllites in Mewar region of Udaipur.

(2) Phyllites with marble band at Kilota are developed in a similar manner to that of Mewar region.

(3) The mesograde to hypograde schists of Salkhalas comprising of muscovite - biotite schist, garnetiferous mica schist, staurolite-kyanite schist and sillimanite schist show resemblance to the schists of central Rajasthan in Mewar region.

In Sirohi district, near Sirohi hills of Selwara, biotite schists

and garnetiferous mica schists show resemblance to Salkhala schists.

(4) The heterogenous assemblage of gneisses with schists, where islands of schists are present in them, is a common feature of both areas.

(5) Banded gneisses of Beoli, Doda bridge, Barshal and Khaleni can also be compared to the banded gneisses complex of Mewar region. In both areas the gneisses show large scale development of perthite among the felspars. ~~as the predominant feature.~~

(6) Augen gneisses of the study area can be compared with the Khamnor augen gneisses developed near Haldi Ghati in Mewar as is personally observed by me.

(7) Muscovite and tourmaline bearing pegmatites are also commonly met with in both the areas.

(b) BIHAR

1) Dharwars of Gaya, Hazaribagh, Manbhum and Palamau districts

Dharwars of these areas have been described by Pascoe(1965) and Jana & Panéey (1972) and these show resemblance with the Salkhalas of the study area as under :-

(1) Biotite schists, garnetiferous-mica schists, staurolite schists ~~show~~ of the study area ~~show great resemblance~~ are similar to the schists of Gaya, Hazaribagh, Ranchi and Palamau districts.

(2) Hundley (1954) has indicated, in Manbhum, a zone containing a pelitic suite ranging from sericitic phyllite to mica schists, garnet mica schists, graphite schists, sillimanite schists which show wide resemblance to the Salkhalas of the area.

(3) Biotite gneisses and granitic gneisses show petrological resemblance to the gneisses in Maubhum district of Bihar.

(4) Pegmatites of both the areas have muscovite and tourmaline as ~~an~~ important constituents.

ii) Northern and eastern Singhbhum

The Precambrian of Northern and Eastern Singhbhum as described by Dunn (1929); Dunn & Dey (1942) and Naha (1965) & shows resemblance to the ~~Precambrian~~ Salkhalas of the area as under :-

(1) Carbon phyllites, developed south and south ~~east~~ west of Khaleni show typical resemblance to carbon phyllites of Gobarghushi, north of Dalma syncline in eastern Singhbhum and between Gangoko che and Kudda in northern Singhbhum. Just like Khaleni area, iron pyrite is also associated with carbon-phyllites in Eastern Singhbhum.

Further carbon bearing phyll-ites associated with light coloured grey phyllites, chloritic phyllites and red phyllites ~~xxx~~ of Leorth to Dugli, above Bhala, resembles with the area occurring south of Dalma syncline in eastern Singhbhum. Also phyllites are associated with schists, therefore, can be correlated with the Iron Ore Series of Eastern Singhbhum.

(2) Salkhalas can very well be correlated with the Chaibasa stage of Eastern Singhbhum. The biotite schist, muscovite schist, garnet-mica-schist, staurolite schist, sillimanite schist are developed in both the areas.

(3) The association of biotite schist and amphibolite near Seja typically resembles with that of Singpura area and south west of Bhatin area of Eastern Singhbhum.

(4) Bladed kyanite met at Lapsu Baru of northern Singhbhum shows great resemblance to the kyanite crystals developed at Bhabur.

(5) Banded gneisses near Doda bridge, Beoli & Barshal can well be compared with the banded gneisses near Hathia and south-west of Indura.

(6) Pegmatite with muscovite and tourmaline found at Thallela and at Saye resemble with the pegmatite of Kumar near Phuljari in

northern Singhbhum and also show resemblance to those of Eastern Singhbhum.

(7) Quartz veins ~~and quartz veins with tourmaline~~ developed in mica - schists and phyllites resemble with that of Northern Singhbhum veins.

(c) West Bengal - Kuilapal area of Purulia district

The Precambrian of Kuilapal area has been described by Dunn & Dey (1942) and Ghosh (1959) and this area shows resemblance with the study area as under :-

(1) Both the areas have the presence of biotite schists, garnetiferous-mica-schists and staurolite schists. Staurolite schist is highly contorted and puckered in ~~both~~ the areas.

(2) At Seja, biotitization of amphibolites at the margins is seen which is similar to the rocks of Kuilapal area.

(3) The gneissic complex is also similar. Banded gneisses, augen gneisses and granitic gneisses show typical resemblance.

(4) The ghost ~~topography~~ stratigraphy, represented by schist relict, have been observed in the gneissic complex of both the areas.

(d) Orissa - Gangpur series of Sundergarh & Sambalpur districts

The Salkhalas of the area under reference show resemblance to the Gangpur series of Sundergarh district (former Gangpur), which is described by Banerjee (1964); Pascoe (1965) and Kanungo & Mallik (1972), both areas show resemblance as under, as follows :-

(1) The graphitic phyllites and marbles of Khaleni area can well be compared with those of Gangpur series.

(2) Muscovite-biotite-schist, garnetiferous-mica schist, staurolite schist of the area can be correlated with the Gangpur series of Sundergarh and Sambalpur districts of Orissa.

(e) Madhya Pardesh & Maharashtra Dharwars

The Salkhala series of the area can very well be correlated with the Sausser series and Sakoli series in Chhindwara, Nagpur, Bhandara and Balaghat districts of Madhya Pradesh and Maharashtra. The rocks of epigrade, Meso-grade and hypograde are developed in both the areas. The Precambrian of Madhya Pardesh and Maharashter has been described by Srivastava and Sharma (1964); Pascoe (1965) and Pichamathu (1967). The petrological and mineralogical resemblance is made as under :-

(1) The graphitic phyllites of the area under reference can be correlated with the Sakoli series of the Southern Nagpur and Bhandara Districts.

(2) The meso and high-grade schists of the Salkhala series, comprising of biotite schist, muscovite-biotite schist, garnetiferous-mica schist, staurolite schist and sillimanite schists can very well be correlated with the Junawani stage of the Sausser series of the Nagpur, Chhindwara and Chilka - Sitasaongi area of Bhandara district.

(3) The pink mica schists with garnet and sillimanite can be correlated with Mansar stage of Sausser series of Mansar - Kandari Mine area and Balaghat District.

(4) Further felpathic mica schist of Dhera can well be correlated with the Sitasaongi stage of Sausser series in Bhandara district.

(5) Marble, ~~Sw of Khaleni~~ at Lalbet, shows mineralogical resemblance to Bichua stage of Sausser series.

(6) The banded and streaky gneisses and augen gneisses of the study area near Beoli, Birshal and near Doda bridge, can be correlated with Tirodi gneisses and streaky gneisses of Nagpur and Bandhara area.

CHAPTER - X

SUMMARY AND CONCLUSIONS

CHAPTER X - SUMMARY AND CONCLUSIONS

The detailed geological studies of the Doda area, Jammu and Kashmir State falling between latitude 33° 3' to 33° 10' N and longitude 75° 30' to 75° 40', E have been undertaken for the first time. Such studies were considered to be very vital as the area provides a link between the stratigraphical formations of the lesser Himalaya, of Himachal Pradesh in the east with those of Kashmir in the south - west. Kaplash anticlinal flexture forms an important structural feature which separates the Kashmir synclinal basin from that of the Chamba one. The mapping has been conducted on a scale of 4 inches = 1 mile.*

It needs hardly be mentioned that the area was almost a virgin one since no published geological map existed. This has been one of the main reasons for selecting it for the present research work. Apart from a few brief abstracts, embodied in the records of the Geological Survey of India about the work undertaken by some of the personnel of that august body in recent years, no detailed reference is available.

The topography of the area is that of hogbacks and cuestas with strike valleys in between them. Differential erosion has been the main factor in carving the present landscape. The altitude ranges from 3000 feet above mean sea level to 11000 feet. The drainage which, is radial one, with typical dendritic pattern (Plate 48), is captured by the river Chenab.

The foliation and schistosity of these rocks do not maintain a constant direction and their dips too vary in amount from 27° to 80°. The

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*Since the Topographical Sheets of the Geological Survey of India were available on a scale of 1" to a mile, it was not possible to resort to metric system of linear measurements.

development of puckers, chevron folds, slip folds and lineation indicate that the major direction of movement was from NE to SW. Joints are commonly developed in the rock units. In gneisses and granites these are developed in three directions whereas the adjoining schists show their development in two directions. Faults developed are mainly high angle normal faults though a strike-slip fault is also observed along the course of the river Niru.

The Archaean metamorphics together with their granite intrusions are found outcropping in north, north-west and north-east direction and they doubtless are the continuation of the similar rocks of the area. However towards south and south-west these are bounded by Proterozoic rock types. Towards east there is a well developed succession of Palaeozoic and lower Mesozoic (mainly triassic) rocks overlying the Proterozoic ones and this warrants me to believe, as has also been pointed out by Sharma et.al. (1973), that the crystallines comprising of Salkhala and Dogra Slate formations are autochthonous and do not seem to have been transported.

The region under the present study is comprised only of Salkhalas as is clearly exhibited by their having witnessed high grade of metamorphism and high degree of plications. Besides there is a considerable lithological variations as indicated by graphitic phyllites and schists associated with quartzite and marble.

These are correlated mineralogically and petrologically with the Precambrian of Nanga Parbat, Kishtwar, Kulu, Lahoul and Spiti ~~districts~~, Simla, Almora, Darjeeling, Nepal and Bhutan in the extrapeninsula and with the precambrian of Rajasthan, Bihar, Orissa, West Bengal and Madhya Pardesh in the peninsula.

The rock units encountered are marble, quartzite, graphitic-

phyllites, schists and gen gneisses invariably intruded by stocks of granites. Apart from these there are dykes and sills of pegmatites, aplites and amphibolites.

Marbles of both white and black colours are present as small litho-units. The graphite of the black marbles is believed to be associated with the intrusion of granite, which has given rise to CO_2 by its interaction with limestone and this later on has dissociated into carbon (in the form of graphite) and oxygen.

The sulphide mineralization in the phyllites, which occurs in the shape of minor disseminations of nickeliferous pyrrhotite and pyrite in these at Khaleni, appears to have been caused by the mobilization and transportation of sulphide matter by hydrothermal agencies emanating from Dedni granite.

In so far as schists are concerned, there are widespread litho-units of these, and have been classified into biotite schist, almandine-mica schist, staurolite schist, kyanite schist, sillimanite schist and felspathic schist, depending on the presence of a characteristic mineral. From the description of metamorphic facies, petrographic studies and chemical analyses, it has been concluded that these schists are the metamorphic products of such original rocks which were both argillaceous and arenaceous (Chapters V, VII and VIII).

The migmatites and gneisses of the area are synkinematic and are classified as streaky gneiss, banded gneiss, garnetiferous mica gneiss, augen gneiss, potash granitic gneiss, adamellitic gneiss and granodioritic gneiss. The heterogeneous distribution of these gneisses in the field, their concordant relationship and ~~ir~~regular gradation from one rock type to another suggests that ~~rocks~~ they have been formed by granitization. It is further proved by the presence of ghost stratigraphy in the field where relicts of schists show

concordant relationship to the gneisses.

In the laboratory studies the significant points contributing to the process of granitization are :-

i) the presence of clouded feldspars;

ii) progressive enrichment of the rocks with K-feldspars;

iii) formation of albite rims around feldspars; and

iv) the development of myrmekitic and perthitic textures.

The processes helpful in granitization, as outlined in the body of the thesis, are the following :-

(a) infiltration of migmatic fluids along shear zones as in the case of banded and streaky gneisses;

(b) gradual increase in the influx of migmatic fluids which have given rise to granitic gneisses;

(c) the enrichment of such migmatic fluids with boron vapours as have given rise to tourmaline permeation gneisses;

(d) the zonal distribution of various types of gneisses, where granitic gneisses are present in the central portion and those of granodioritic composition at the margins, can be explained on the basis of Mehnert's view point (1968) which takes into consideration the lightness of sodic ions as compared to potassic ions, thereby making the former concentrate towards the marginal area; and

(e) the formation of "dents-de-chevals" in the shape of large porphyroblasts in the granitic gneisses can be explained by large scale influx of water rich and K-rich fluids at a later date.

The petrochemistry of these migmatites and gneisses has further confirmed the conclusion that these are the result of granitization.

There are, however, the magmatic granites of Bhalla-Mundella and Dedni areas which are postkinematic as is apparent from (i) the presence of xenoliths of country rocks in them and (ii) the development of contact aureole around these intrusives. Their igneous origin is confirmed by the study of thin sections under a microscope which has revealed the presence of normal type of zoning in plagioclases

together with their complex twinning; the development of micrographic texture; orbicular structure; the presence of euhedral grains of quartz in feldspars as inclusions and the presence of euhedral zircon grains. The generation of this granitic magma is apparently connected with the process of anatexis which has been operative at considerable depths.

Pegmatites of the area are formed by the process of secretion which involves the migration of ions of lighter elements.

Amphibolites are of orthotype and have been formed by the metamorphism of igneous intrusions.

The rock units have been classified into various metamorphic facies as under :-

I) Green schist facies;

II) Epidote-amphibolite facies;

III) Amphibolite facies; and

IV) Amphibolite - granulite transition facies of Turner (1968).

These facies indicate a progressive grade of metamorphism.

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ILLUSTRATIONS

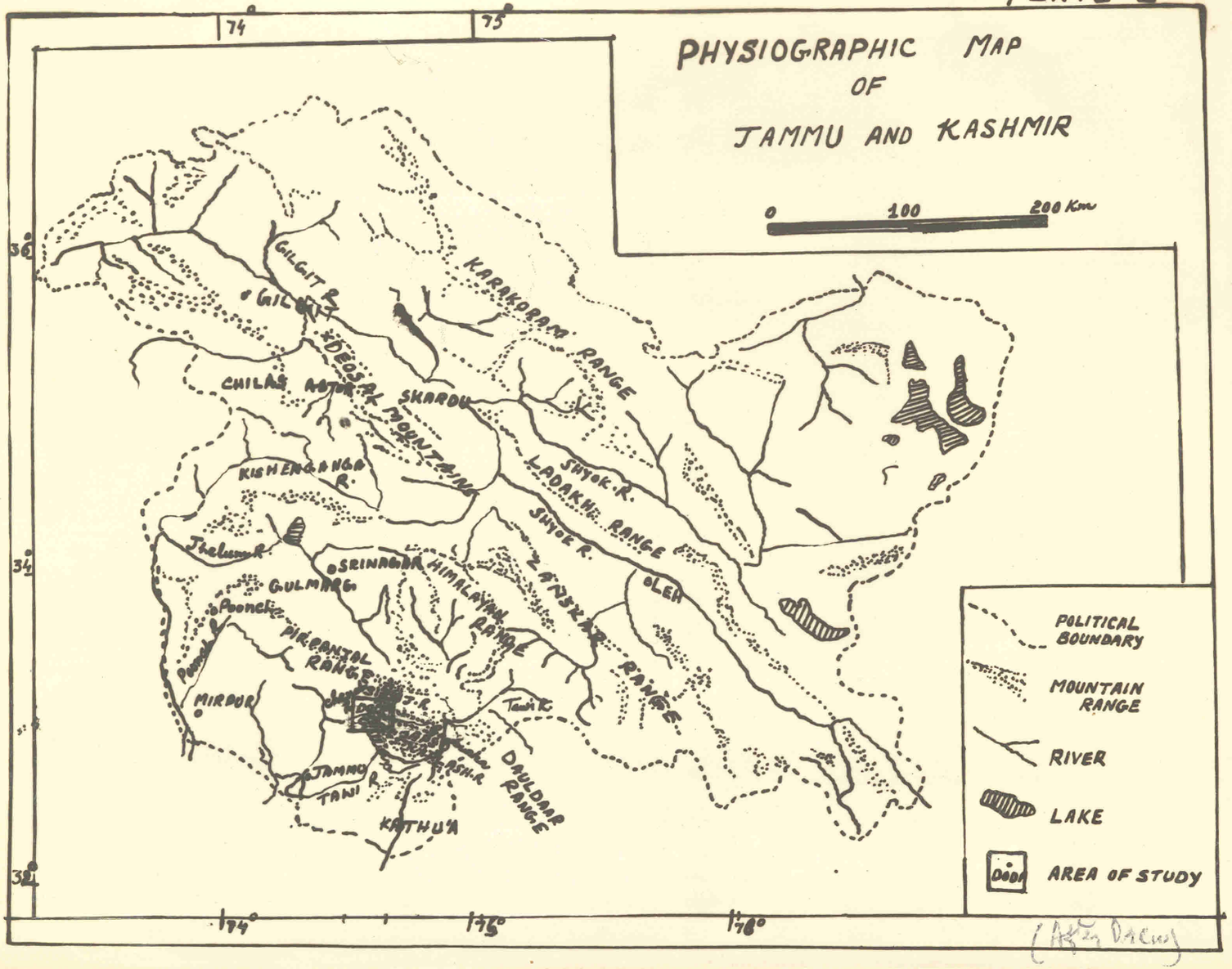
(Plate-1 to Plate - 50)

PLATE NO. 1



LOCATION MAP

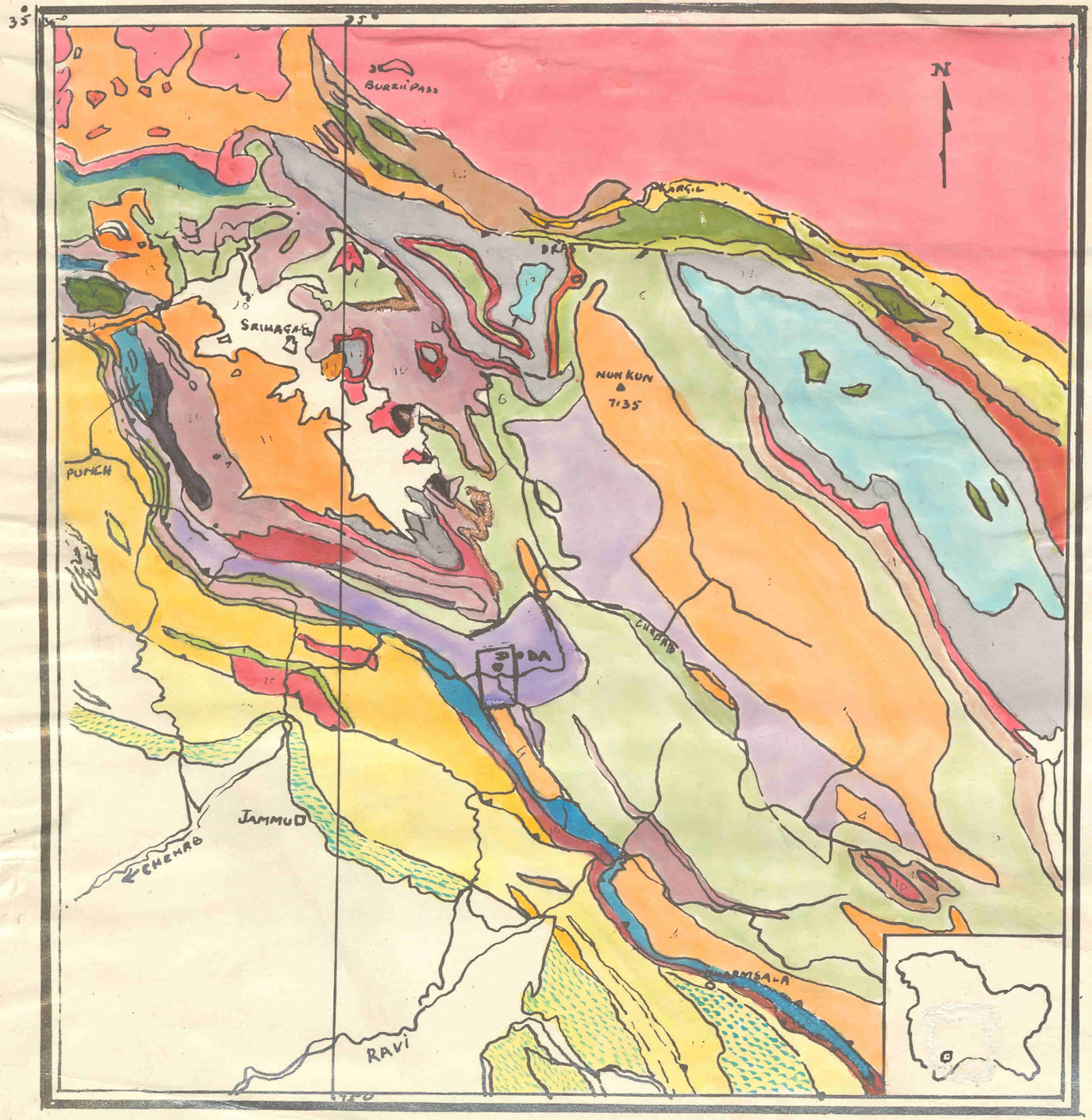
PLATE-2



(After Dasgupta)

GEOLOGICAL SET.UP OF DODA AREA

PLATE – 3.



INDEX

- RECENT
- KAREWA S
- SIWALIK S
- MURREE S
- EOCENE S
- INDUS FLYSCH
- JURASSICS
- TRIASSIC S
- PERMIAN S
- PANJAL TRAP
- AGGLOMERATIC SLATE
- MUTH QUARTZITE
- CAMBRO SILURIAN
- DOGRA SLATE
- SALKHALA S
- GRANITE and GRANITIC GNEISS
- INDUS OPHIOLITES

(After Gansser)

EXPLANATION OF THE PLATE - 4

Snow clad peak of Khol, forming extension of Kaplash Range.

FIELD PHOTOGRAPH. PLATE - 4.



EXPLANATION OF THE PLATE - 5

Fig. 1 - Photogra[illegible]aic map indicatin[illegible]arious ranges of the part of Himachal - Pardesh and Jammu & Kashmir State.

Fig. 2 - Malhori Landslide.

PHOTOGRAPHS. PLATE—5.

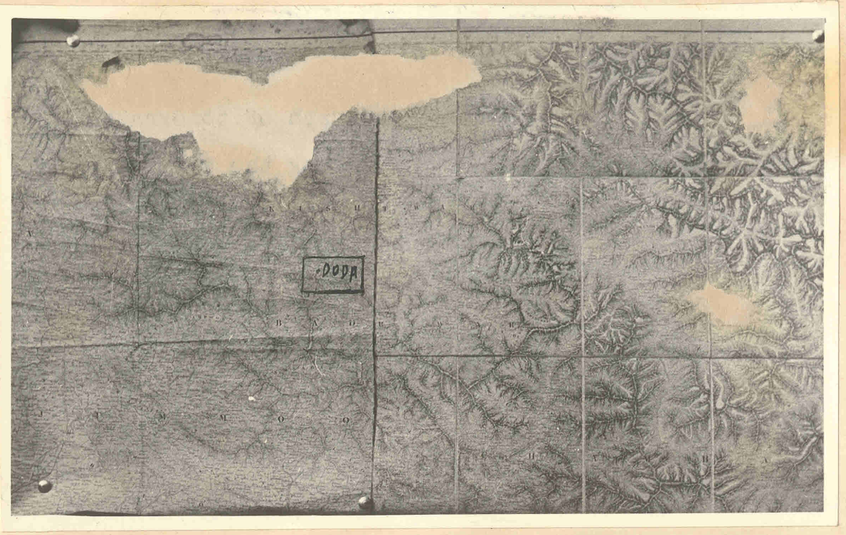


FIG. 1.

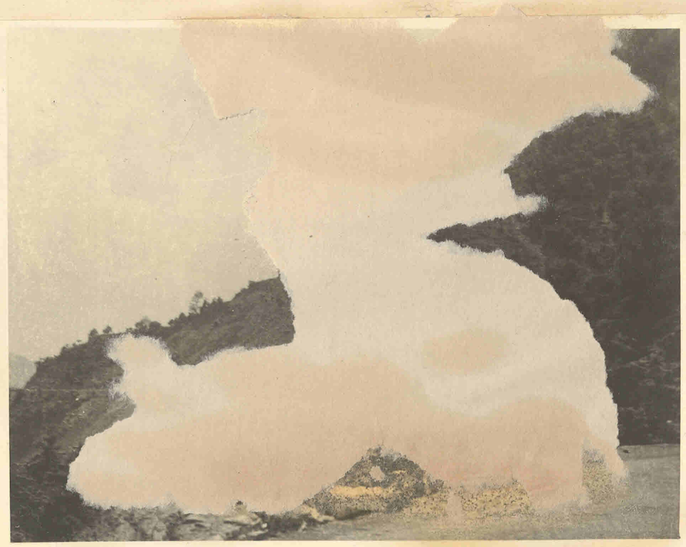


FIG. 2.

EXPLANATION OF THE PLATE - 6

Fig. 1 - A view of the Trawn Valley. Camera facing south direction.

Fig. 2 - Picture depicting the meeting place of Dhauladhar Range and the Panjal Range near Doda bridge. Camera facing north.

Fig. 3 - The river Chenab flowing near Doda in a zig-zag manner which is due to alternate high and less resistent rock types. In this picture river Chenab also depicts the gorge cut by it.

Fig. 4 - The river Cher[illegible]long garnetifero[illegible]ear Bahadra.

Fig. 5 - Picture depic[illegible]g the sharp contrast of topography, climate and vegetation between the Dhauladhar Range and the Panjal Range. Camera facing north.

Fig. 6 - Glaciated boulders of gneisses in the Bhallela stream near Bhal[illegible]

FIELD PHOTOGRAPHS. PLATE - 6.

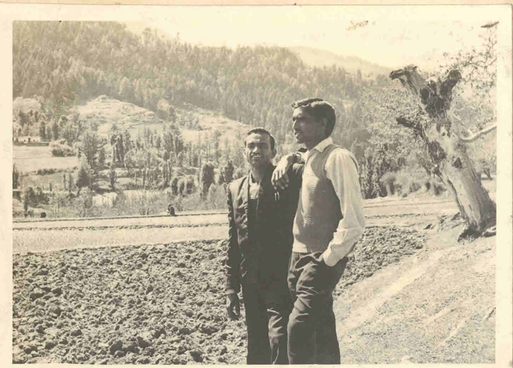


FIG. 1.



FIG. 2.



FIG. 3.

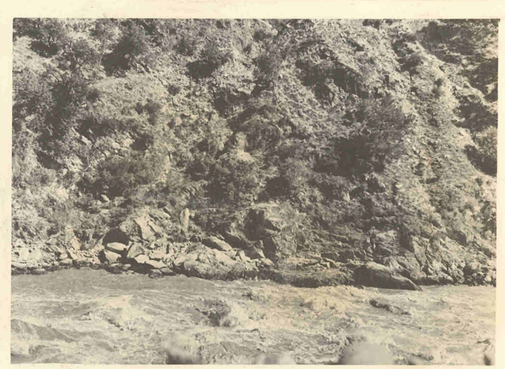


FIG. 4.



FIG. 5.



FIG. 6.

EXPLANATION OF THE PLATE - 7

Fig. 1 - Cascades made by Jodhpur stream indicating the youth stage of the valley formation.

Fig. 2 - A small waterfall near Khaleni.

Fig. 3 - Niru stream flowing through the schistose rocks.

Fig. 4 - Picture depicting the exfoliation and the jointing system present in granite, at the top of Padri.

FIELD PHOTOGRAPHS. PLATE – 7.

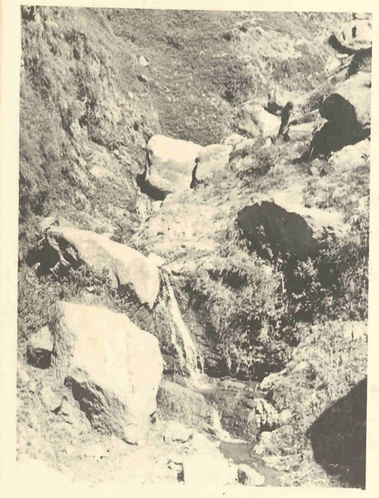


FIG. 1.



FIG. 2.

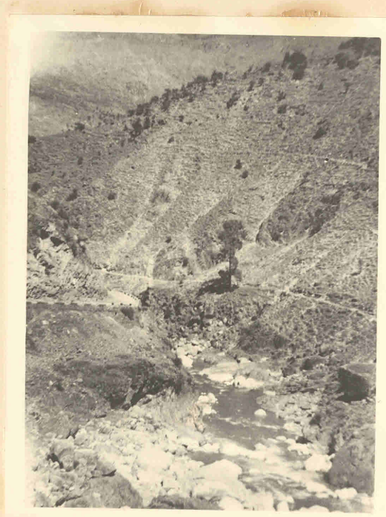


FIG. 3.

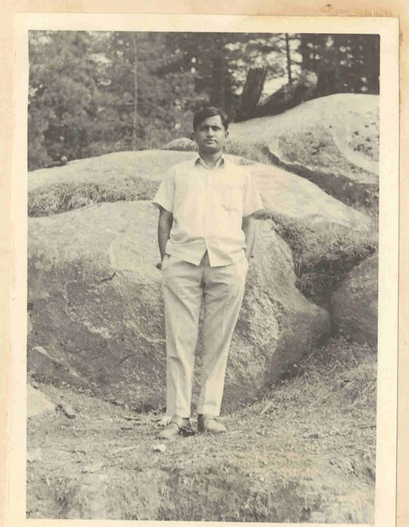


FIG. 4.

EXPLANATION OF THE PLATE - ~~VIII~~ 8

Fig. 1 - A view of the Seva Hillock.~~x~~ Camera facing north-east.

Fig. 2 - Anticlinal flexture in gneisses below Doda.

Fig. 3 - Chevron folds developed in schists near Bhuba.

Fig. 4 - Picture depicting the jointing in gneisses below Doda.

Fig. 5 - Jointing in granites observed on the side of quarry for galena deposits near Khabrel.

Fig. 6 - Picture depicting joining in granites at Dragga.

FIELD PHOTOGRAPHS. PLATE – 8.



FIG. 1.



FIG. 2.



FIG. 3.



FIG. 4.



FIG. 5.



FIG. 6.

EXPLANATION OF THE PLATE - 9

Fig. 1 - An outcrop of streaky gneisses near Khaleni depicting foliation. Puckers are also seen in the figure.

Fig. 2 - Mullion structure observed near Teson.

Fig. 3 - Synclinal flexture depicted at the lower portion of the figure at Kaile.

Fig. 4 - Picture depicting almost vertical cliffs with high dip angles near Doda.

FIELD PHOTOGRAPHS. PLATE – 9.



FIG.1.



FIG.2.



FIG.3.

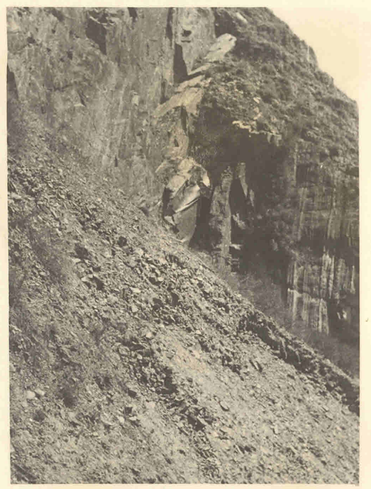


FIG.4.

EXPLANATION OF THE PLATE - 10

Fig. 1 - An outcrop indicating the presence of Quartz vein at the top of Malnai.

Fig. 2 - Picture depicting Aplite dyke in the Dedni granite near Dragga.

Fig. 3 - An outcrop of amphibolite near Thalsera.

Fig. 4 - Picture depicting the presence of a xenolith in gr[illegible] at D[illegible]

Fig. 5 - An outcrop of quartzite at Malnai.

Fig. 6 - An outcrop of biotite schist nea[illegible]alasu.

FIELD PHOTOGRAPHS. PLATE – 10.



FIG. 1.



FIG. 2



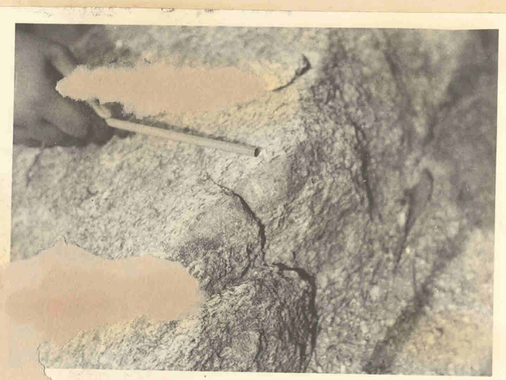


FIG. 4.



FIG. 5.



FIG. 6.

EXPLANATION OF THE PLATE - 12

Fig. 1 - A handspecimen of banded gneiss from Beoli indicating the presence of white neosome, black melanosome and palaeosome bands of intermediate shade.

Fig. 2 - A specimen of banded gneiss from Krara indicating the wide presence of palaeosome of intermediate composition formed during gra[illegible]tion.

Fig. 3 - [illegible]gmatite in handspecimen.

Fig. 4 - [illegible]aky gneiss in handspecimen [illegible]th white irregular streaks of quartzo - felsp[illegible].

PHOTOGRAPHS. PLATE – 12.



FIG. 1.



FIG. 2.

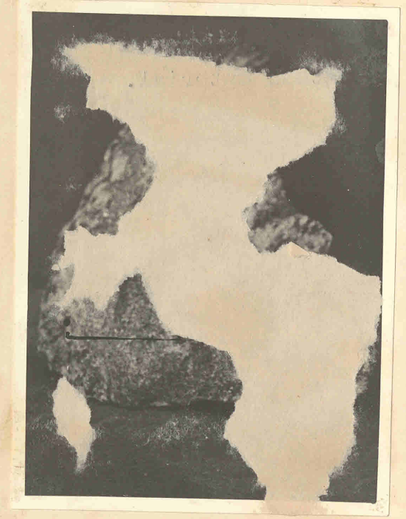


FIG. 3.

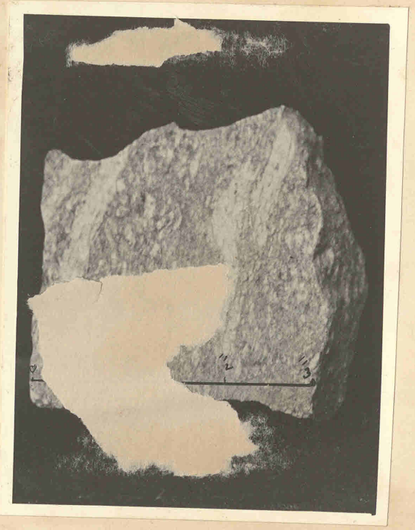


FIG. 4.

EXPLANATION OF THE PLATE - 13

[illegible] - Granitic gneiss in handspecimen.

Granitic gneiss showing au[illegible]
tructure in handspecimen.

F[illegible] - A gneiss near Mundella showing
augen structure in handspecimen.

Fig. 4 - Granite in handspecimen.

Fig. 5 - A handspecimen of granite
dicating the [illegible]resence of
[illegible]k xenolith a[illegible]

[illegible]dar[illegible]

Fig. 6 [illegible]handspecimen of pegmatite
depicting kyanite in bladed form.

PHOTOGRAPHS.

PLATE – 13.



FIG. 1.

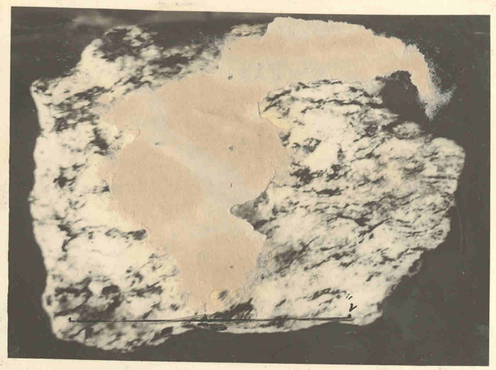


FIG. 2.

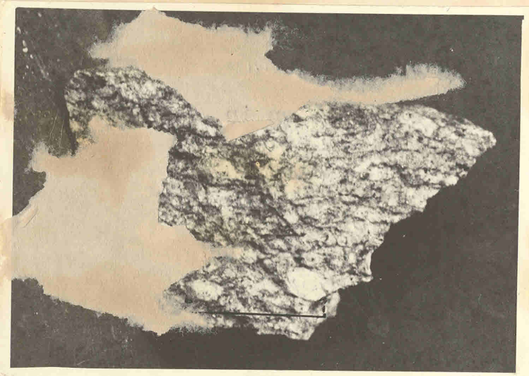


FIG. 3.

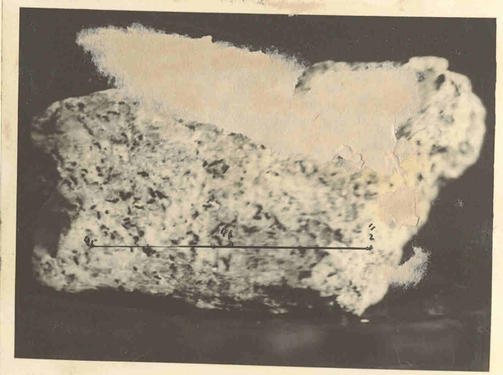


FIG. 4

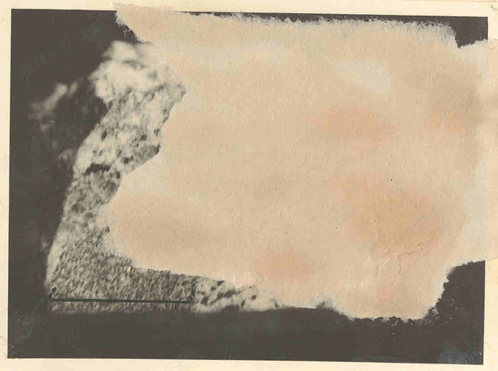


FIG. S.



FIG. 6.

EXPLANATION OF THE PLATE -14

Fig. 1 - [illegible]rble at Kilota. Calcite d[illegible]

[illegible]al

[illegible].

[illegible]z

[illegible]e [illegible]yer of

[illegible]ons is present.

Cross [illegible] (X 16).

Fig. 4 [illegible]

Nicols (

PHOTOMICROGRAPHS. PLATE — 14.

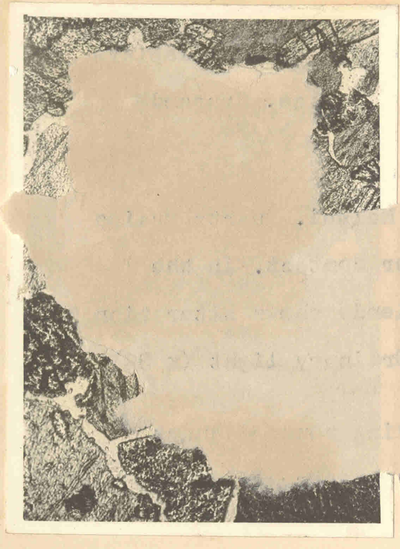


FIG. 1.



FIG. 2.

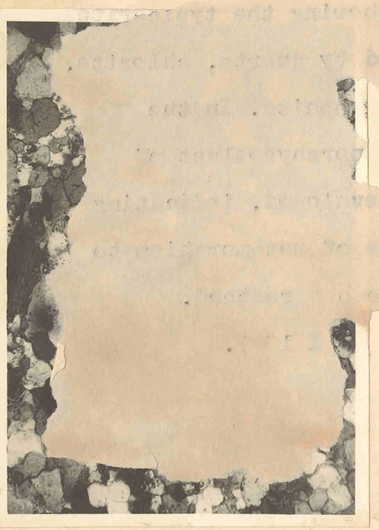


FIG. 3.

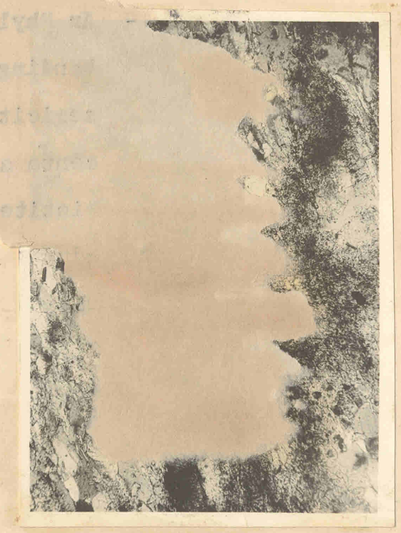


FIG. 4.

EXPLANATION OF THE PLATE - 15

Fig. 1 - Biotite schist at [illegible] In the centre of the [illegible]tite indicates its [illegible], rutile needles. Ordinary light (X 16).

Fig. 2 - Almandine biotite schist at Khaleni. Almandine is studded in the foliation of biotite flakes. Ordinary light (X 16).

Fig. 3 - Almandine mica schist at Badraon. Poikiloblastic almandine present amongst quartz, feldspar and micas. Ordinary light (X 16).

Fig. 4 - Almandine mica schist [illegible]r Mundella. Rotational almandine is seen in the centre. Ordinary light (X 16).

PHOTOMICROGRAPHS. PLATE— 15.



FIG. 1.

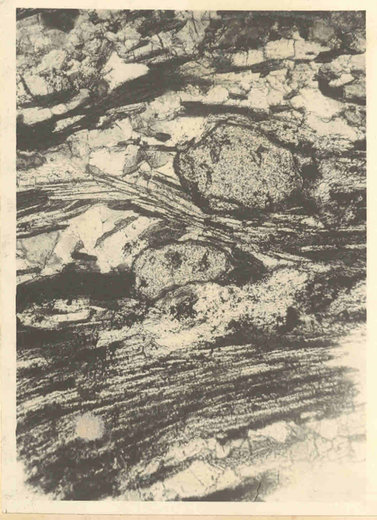


FIG. 2.



FIG. 3.



FIG. 4.

EXPLANATION OF THE PLATE - 16

Fig. 1 - Zonary almandine developed in the almandine mica schist of Lal Dharaman. Ordinary light (X 16).

Fig. 2 - "Garnet in Garnet" present in the almandine mica schist of Doda bridge area indicating its formation in the D_3 episode. Ordinary light (X 16).

Fig. 3 - Almandine (A) transforming to staurolite (St) at the margins, in the staurolite schist of Badraon. Ordinary light (X 16).

Fig. 4 - Staurolite schist at Lal Dharaman indicating the presence of poikiloblastic staurolite (St), occurring in the arcs of puckers. At the margin Otterlite (O) of dark shade is also visible. Ordinary light (X 16).

Fig. 5 - Microfold developed in the schist. Ordinary light (X 16).

Fig. 6 - Staurolite schist at Badraon where staurolite (St) shows its development in the puckers marked by mica flakes. Ordinary light (X 16).

PHOTOMICROGRAPHS. PLATE – 16.



FIG. 1.

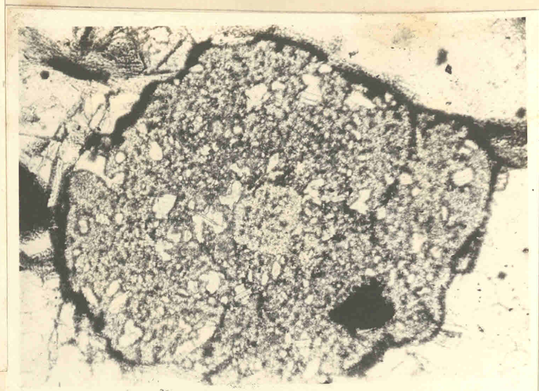


FIG. 2.

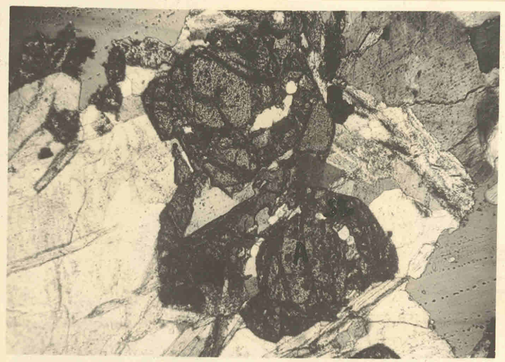


FIG. 3.



FIG. 4.

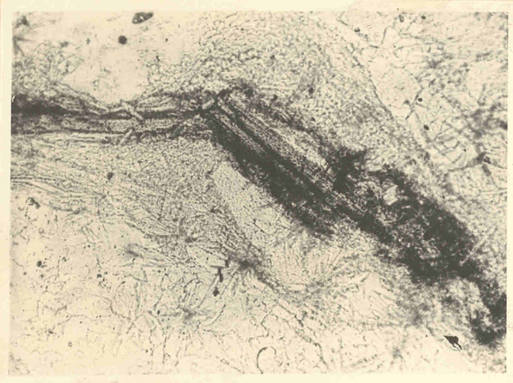


FIG. 5.

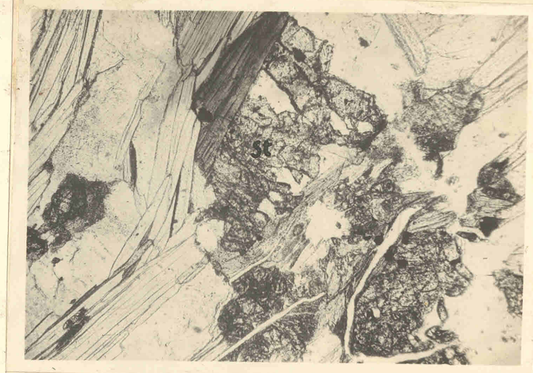


FIG. 6.

EXPLANATION OF THE PLATE - 17

Fig. 1 - Kyanite schist of Lal Dharaman indicating the presence of kyanite (K) inbetween poikiloblastic staurolite (St) and almandine (A). Ordinary light (X 16).

Fig. 2 - Sillimanite schist at Seva. A large sillimanite needle (S) is depicted in the centre. Crossed Nicols (X 16).

Fig. 3 - Sillimanite biotite schist depicts the presence of needle like sillimanite (S) at Sindra. Mica flakes, quartz, feldspar and garnet are also present in the schist. Crossed Nicols (X 16).

Fig. 4 - Sillimanite biotite schist at Koti. The picture depicts the breaking of biotite at the margins into fibrolite. Ordinary light (X 16).

Fig. 5 - Schist at Lal Dharaman showing diaphthoresis. Picture depicts garnet (G) breaking into chlorite, magnetite and biotite at the margins. Ordinary light (X 16).

Fig. 6 - Felspathic schist at Dehra. Feldspar(F) is prominently depicted. Cross Nicols (X 16).

PHOTOMICROGRAPHS. PLATE – 17.

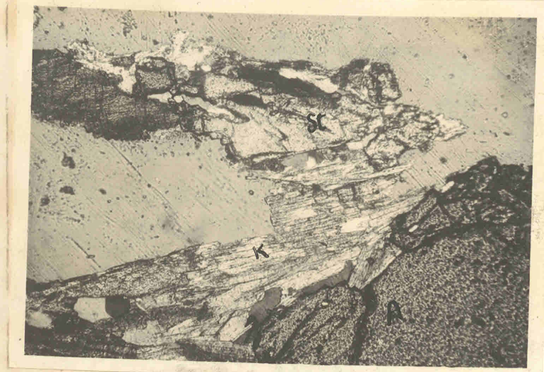


FIG. 1.



FIG. 2.



FIG. 3.



FIG. 4.



FIG. 5.



FIG. 6.

EXPLANATION OF THE PLATE - 19

Fig. 1 - Banded gneiss at Krara depicting granulation of quartz. Crossed Nicols (X 16).

Fig. 2 - Streaky gneiss of Chibban depicting undulose extinction in quartz (Q). Crossed Nicols (X 16).

Fig. 3 - Augen gneiss at Mundella depicting alteration of biotite flakes to sillimanite needles at their ends. Ordinary light (X 39).

Fig. 4 - Amphibolite at Seja depicting glomeroblastic hornblende. Hornblende is also idioblastic. Crossed Nicols (X 16).

Fig. 5 - Amphibolite at Thalsera depicting deccusate texture. Crossed Nicols (X 16).

Fig. 6 - Amphibolite at Jodhpur depicting nematoblastic texture. Hornblende, quartz, plagioclase, biotite and iron ore are present as important minerals in it. Crossed Nicols (X 16).

PHOTO MICRO GRAPHS. PLATE-19.



FIG. 1.



FIG. 2.



FIG. 3.



FIG. 4.



FIG. 5.



FIG. 6.

EXPLANATION OF THE PLATE - 20

Fig. 1 - Garnetiferous Augen gneiss at Zaginda depicting rotational garnet having S-form. Ordinary light (X 16).

Fig. 2 - Garnetiferous banded gneiss near Doda bridge depicting at the centre sagenitic structure where biotite shows the presence of rutile needles in it. Ordinary light (X 16).

Fig. 3 - Granitic gneiss near Malnai depicting the breaking of biotite flake into sillimanite needles at its margins. Ordinary light (X 39).

Fig. 4 - Granodioritic gneiss at Kummiari depicting the alteration of biotite (B) to Garnet (G). Ordinary light (X 39).

Fig. 5 - Augen gneiss at Mundella depicting abundant presence of sillimanite needles. Ordinary light (X 39).

Fig. 6 - Hornblende biotite granodiorite at Seja showing the presence of quartz, plagioclase, hornblende and biotite. Crossed Nicols (X 16).

PHOTOMICROGRAPHS. PLATE – 20.

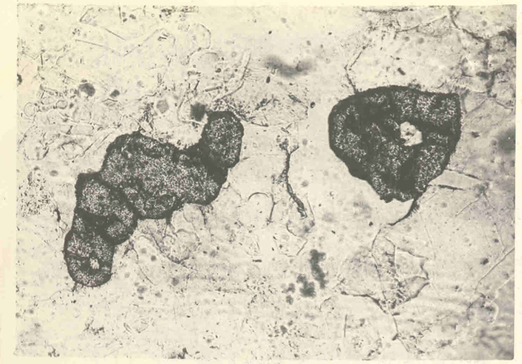


FIG. 1.

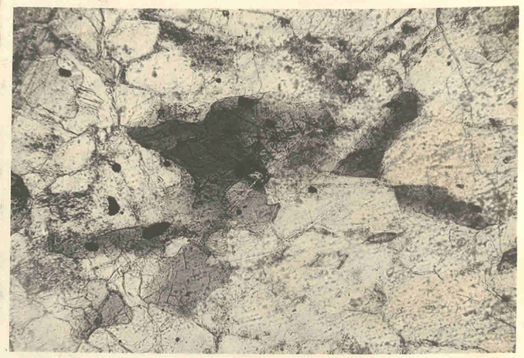


FIG. 2.

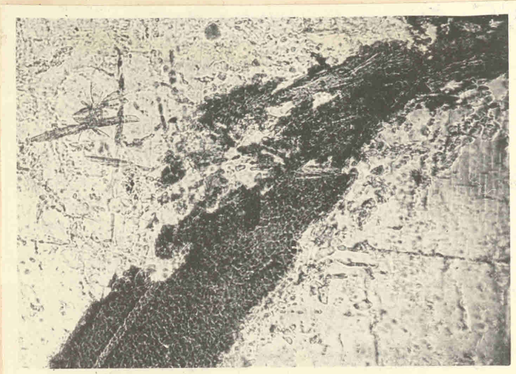


FIG. 3.

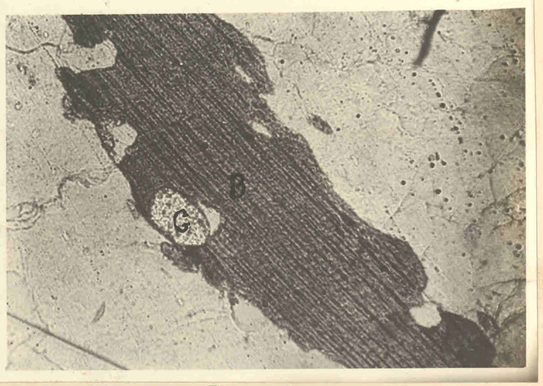


FIG. 4.

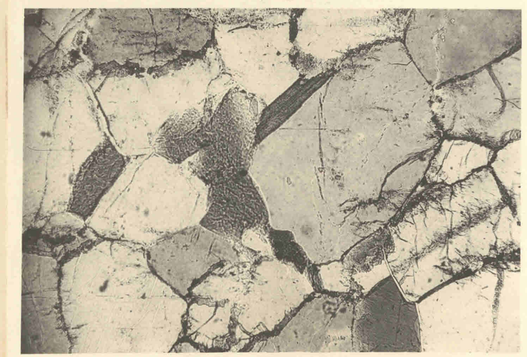


FIG. 5.

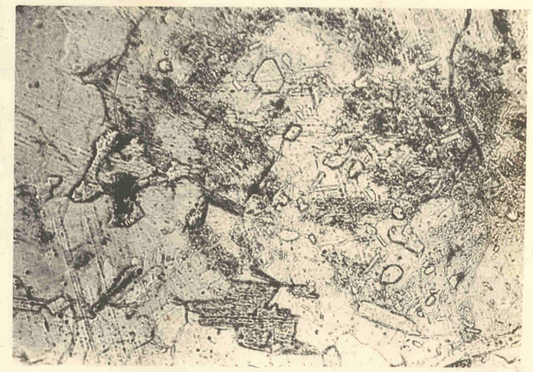


FIG. 6.

EXPLANATION OF THE PLATE - 21

Fig. 1 - Myrmekite developed in the granitic gneiss, Ordinary light (X 39).

Fig. 2 - Myrmekite in granitic gneiss of Bhala showing the replacement of K-feldspar. Crossed Nicols (X 39).

Fig. 3 - Myrmekite, in the granitic gneiss of Koti, shows its development at the margins of K-feldspar. Crossed Nicols (X 39).

Fig. 4 - A large grain of tourmaline in Tourmaline Permeation gneiss of Saye. Ordinary light (X 16).

PHOTOMICROGRAPHS. PLATE — 21.



FIG. 1.



FIG. 2.



FIG. 3.



FIG. 4.

EXPLANATION OF THE PLATE - 22

Fig. 1 - Plagioclase in granitic gneiss showing combined carlsbad - albite type of twinning. It also indicates large scale clouding. Crossed Nicols (X 39).

Fig. 2 - Plagioclase, in granitic gneiss of Thellela, albite type of twinning. Large scale clouding is also depicted. Crossed Nicols (X 16).

Fig. 3 - Orthoclase developed in the muscovite gneiss at Doda bridge. Large scale clouding is depicted. Crossed Nicols (X 39).

Fig. 4 - Granitic gneiss at Shai-Pot indicating the presence of quartz inclusions in feldspar. Crossed Nicols (X 39).

Fig. 5 - Composite perthite in granitic gneiss having inclusions of plagioclase indicating the process of replacement. Crossed Nicols (X 39).

Fig. 6 - Granit[illegible] scale replacement [illegible]y plagioclase. Crossed Nicols (X 39,

PHOTOMICROGRAPHS. PLATE. 22.

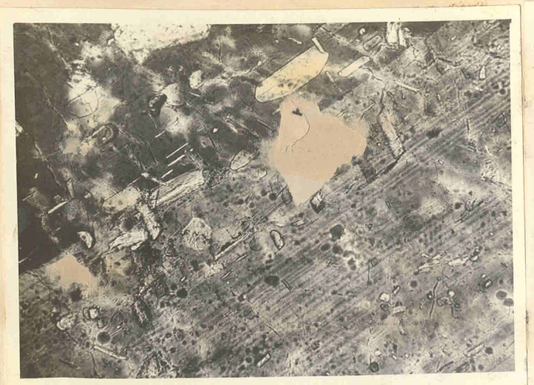


FIG. 1.

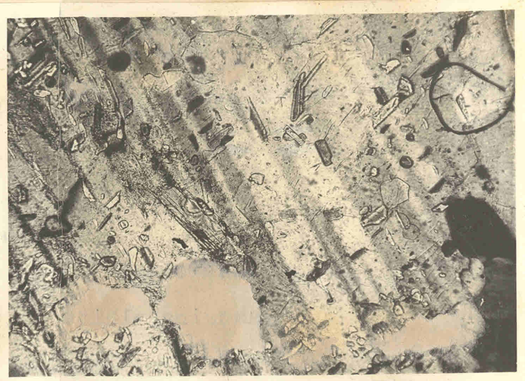


FIG. 2.

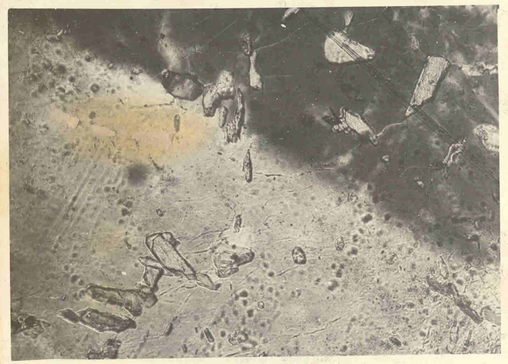


FIG. 3.

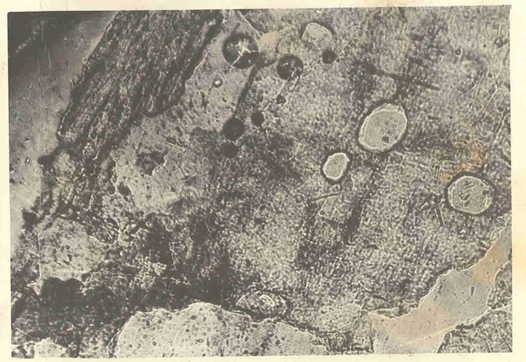


FIG. 4.

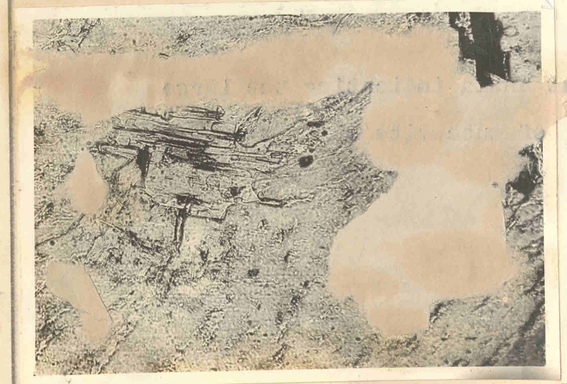


FIG. 5.



FIG. 6.

EXPLANATION OF THE PLATE - 23

Fig. 1 - ...nite showing the development of orth... ...e with ty... ...g. Crossed Nicols (X 16

Fig. 2 - Granodi... ...te at Mundell... ...ral plagioclase showing albite type of twinning is prominently developed. Ortho... ...g bevano type of twinning and anhedr... ...rtz are also seen. Crossed Nicols (X 16).

Fig. 3 - Dedni granite at Saras depicting the presence of micrographic texture. Crossed Nicols(X 16).

Fig. 4 - Feldspar, in Dedni granite, indicating zonary structure. Crossed Nic... ...16).

Fig. 5 - Feld... ...ing the dev... ...ment ...16).

PHOTOMICROGRAPHS. PLATE - 23.



FIG. 1.

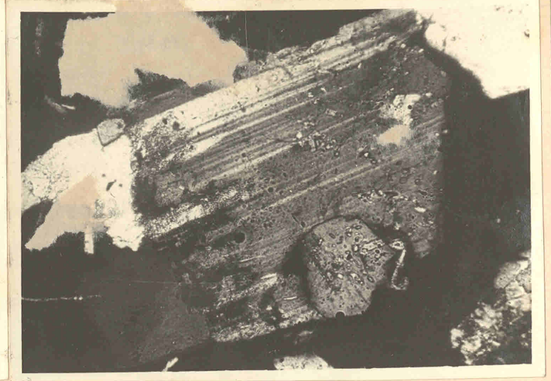


FIG. 2.



FIG. 3

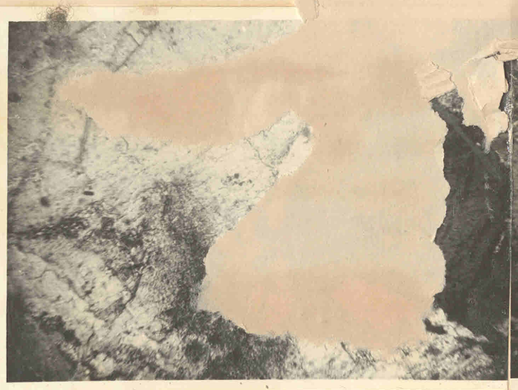


FIG. 5.

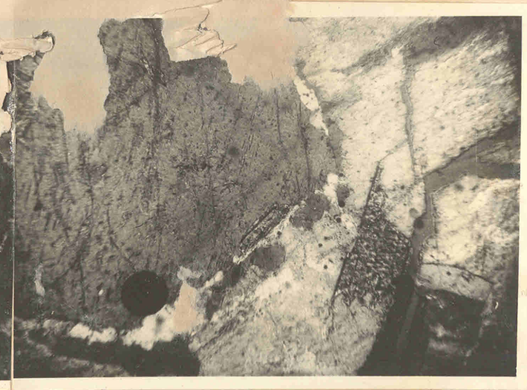


FIG. 6.

EXPLANATION OF THE PLATE - 24

Fig. 1 - Orthoclase of depicting carlsbad twinning, which overshadows the perthite, in Mundella granite. Crossed Nicols (X 16).

Fig. 2 - Myrmekite developing at the margin of K-feldspar in Dedni granite. Crossed Nicols (X 16).

Fig. 3 - Micrographic texture developed in Dedni granite is depicted. Crossed Nicols(X 16).

Fig. 4 - Dipyramidal quartz, developed in the perthite grains of Bhala granite, is depicted in the centre. Crossed Nicols(X 16).

Fig. 5 - Corroded quartz grains in the Mundella granite are depicted. Zircon (Z) is also seen in the centre of quartz grains. Crossed Nicols (X 16).

Fig. 6 - Undulose twinning lamellae is depicted in quartz of the Mundella granite. Crossed Nicols (X 16).

PHOTOMICROGRAPHS. PLATE — 24.

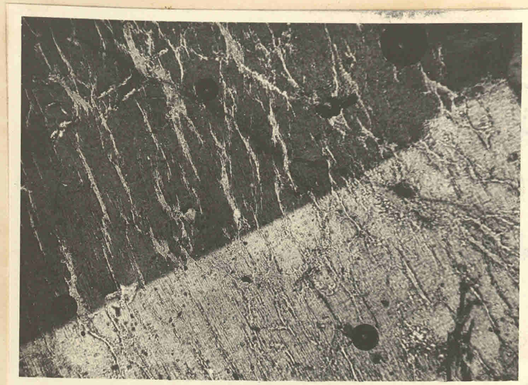


FIG. 1.



FIG. 2.



FIG. 3.

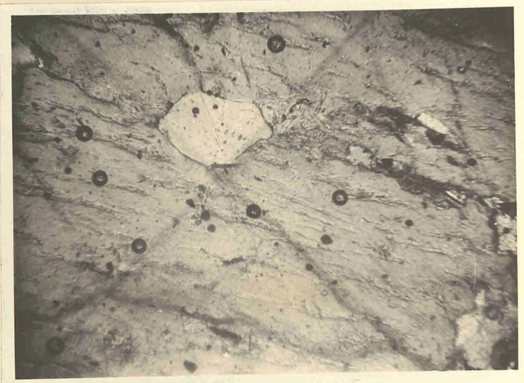


FIG. 4.

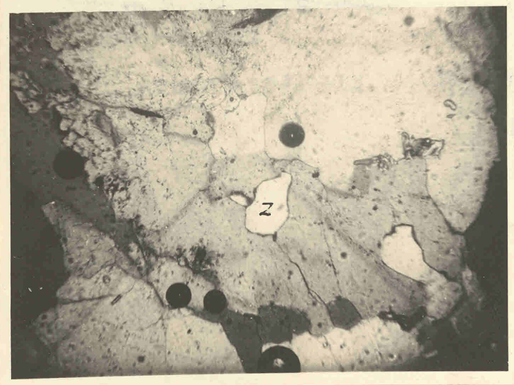


FIG. 5.

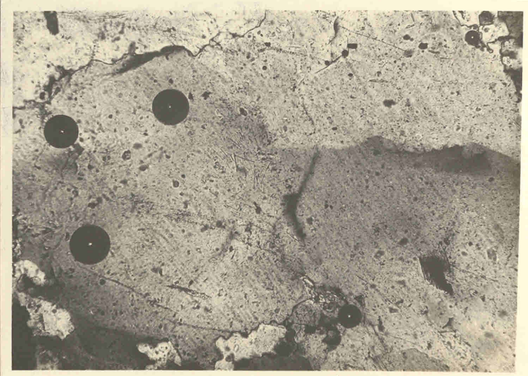


FIG. 6.

EXPLANATION OF THE PLATE - 25

Fig. 1 - Granodiorite at Mundella showing the development of Myrmekite. Crossed - Nicols (X 39).

Fig. 2 - Granite at Mundella showing the development of string perthite. Crossed - Nicols (X 16).

Fig. 3 - Granodiorite at Mundella showing the presence of microcline - microperthite, ...pe of string perthi... ...formation by deutric proces... Nicols (X 39).

Fig. 4 - A broader view of string perthite in microcline microperthite of Mundella granodiorite. Crossed Nicols (X 39).

Fig. 5 - Hornfelsic xenolith showing granoblastic texture. It is mainly comprised of biotite flakes (dark shade) and quartz grains (light shade). Crossed Nicols (X 39).

Fig. 6 - Porphyroblast of biotite developed at the outer rim of xenolith showing poikiloblastic-texture with abundant inclusions. A grain of euhedral zircon (Z) is also seen. Ordinary-light (X 39).

PHOTOMICROGRAPHS. PLATE — 25.



FIG. 1.



FIG. 2.



FIG. 3.

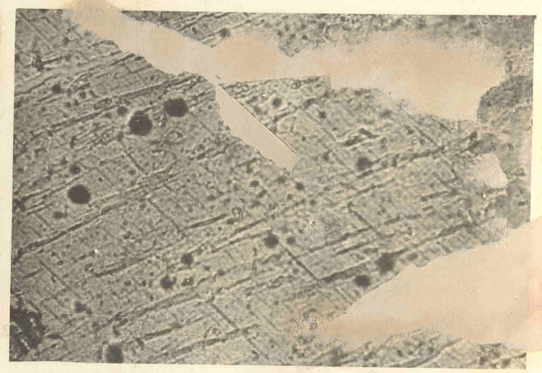


FIG. 4.

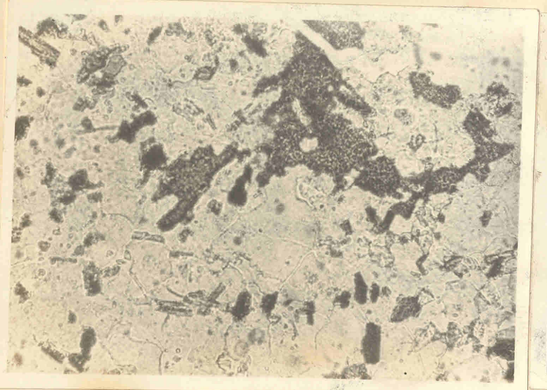


FIG. 5.



FIG. 6.

EXPLANATION OF THE PLATE - 26

Fig. 1 - Tourmaline - muscovite bearing pegmatite at Thallela. It depicts highly fractured tourmaline, muscovite, quartz and feldspar. Ordinary light (X 39).

Fig. 2 - M[illegible]line with gli[illegible]es in t[illegible]matite of Thellela, is depicted. [illegible] 39).

Fig. 3 - Staurolite schist at Bhab[illegible]epicting the bending and rotation of [illegible], Ordinary light (X 16).

Fig. 4 - Kyanite developed in [illegible]gmati[illegible]., depicting gliding planes which are filled with quartz. Ordinary light (X 16).

Fig. 5 - Bendi[illegible]g of kyanite grain in the pegmatite of Bhabor. Ordinary light (X 16).

Fig. 6 - Aplite near Khabrel with sufficient grains of square shaped black opaque galena. [illegible]o shows the presence of quartz, felds[illegible], myrmekite and biotite. Crossed Nicols (X 16).

PHOTOMICROGRAPHS. PLATE—26.



FIG.



FIG. 2.



FIG. 3.

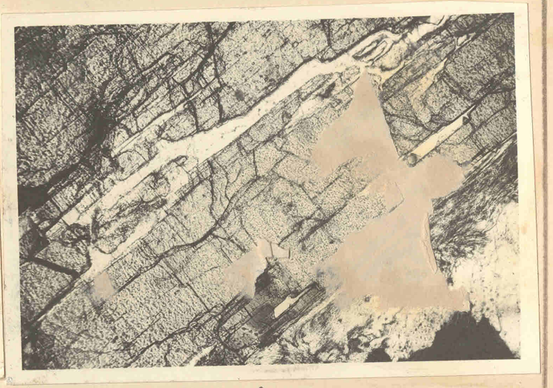


FIG. 4.

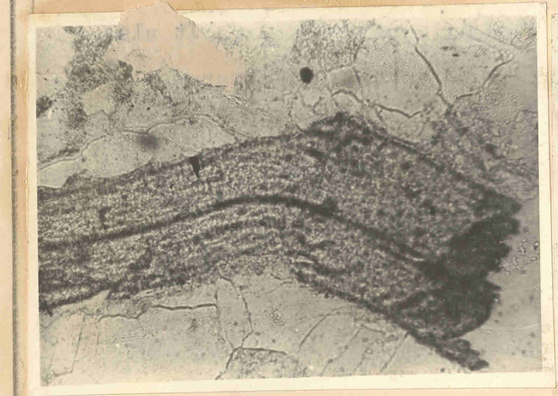


FIG. 5.



FIG. 6.

EXPLANATION OF THE PLATE - 27

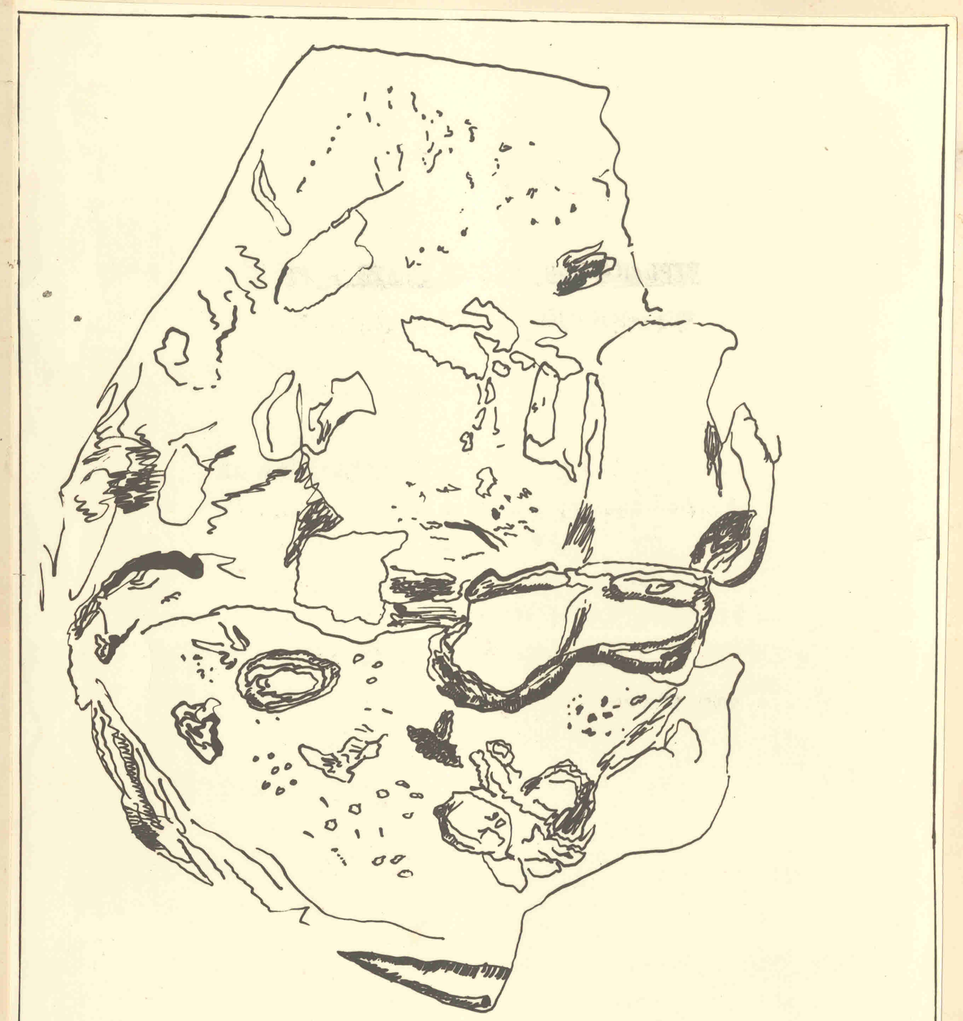
Camera Lucida drawing of almandine in

almandine - mica schist of Bhadra

showing enlargement to ~~XXXXXXXX~~

100 times.

PHOTOMICROGRAPH. PLATE — 27.



Camera lucida Drawing of Almandine Porphyroblast in Contorted Sillimanite Schist at Koti near Doda.

EXPLANATION OF THE PLATE - 28

Fig. 1 - X-ray diffraction photograph of the almandine. Each diffraction line in photograph represents the reflection from a particular plane.

Fig. 2 - It p represents the enlarged view of the forward reflection region.

X- RAY PHOTOGRAPHS. PLATE – 28.

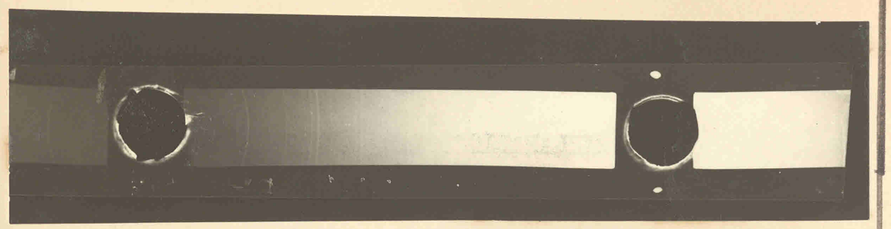


FIG. 1.

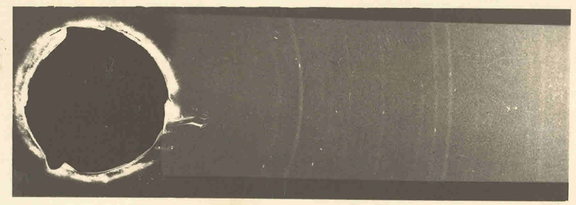
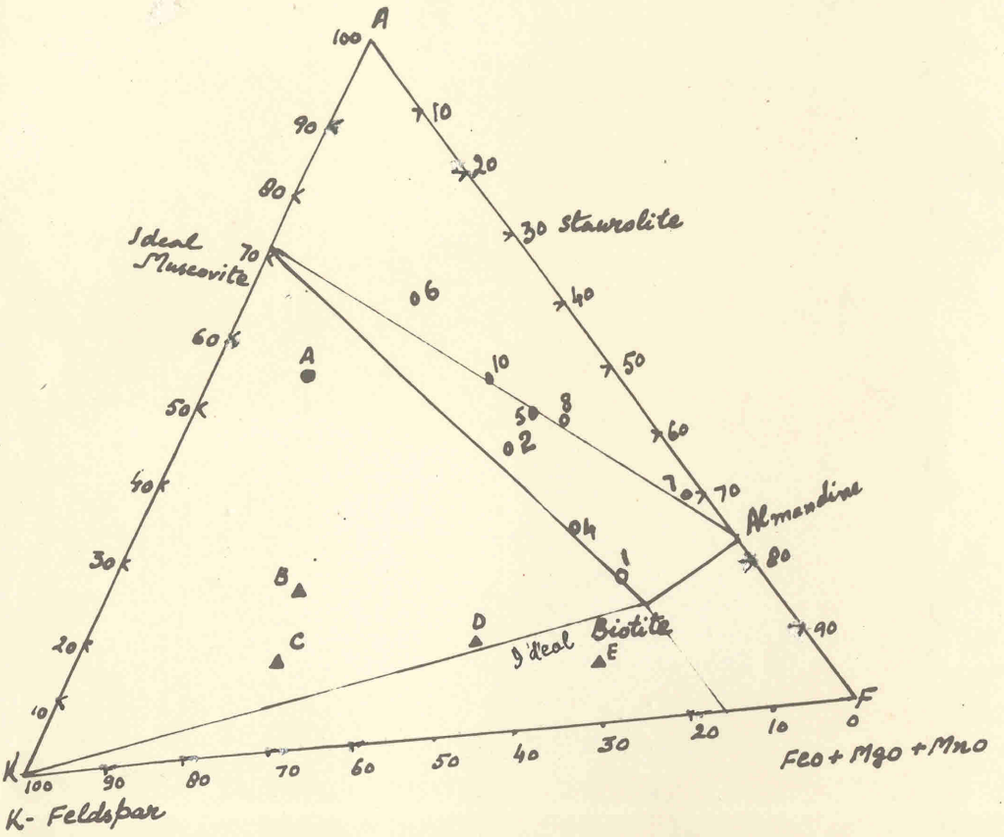


FIG. 2.



AKF diagram ($A = Al_2O_3 - (\frac{K_2O}{2} + \frac{Na_2O}{2} + CaO)$, $K = \frac{K_2O}{2}$, $F = FeO + MgO + MnO$, in mol %) showing mineral assemblages of schists (open circles), gneisses and migmatites (solid triangles) of Doda Area.

1 = Biotite – Muscovite 2 to 5 = Biotite - Muscovite - Almandine

6 = Biotite – Muscovite – Sillimanite

7 = Biotite - Sillimanite

8 = Biotite - Almandine - Staurolite

A = Muscovite - Perthite, B - Muscovite - Biotite - Perthite

C = Biotite - muscovite - Almandine - K- Feldspar

D = Biotite - Perthite E = Biotite - muscovite - almandine - K-feldspar

Analyses of Rocks & Garnet given in tables.

PLATE – 30.

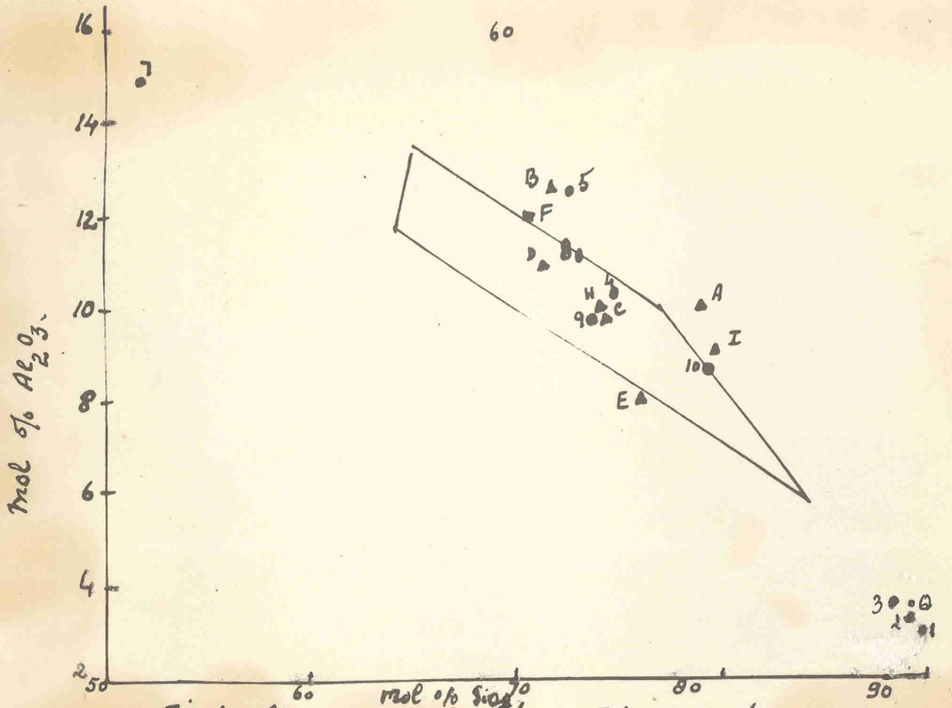
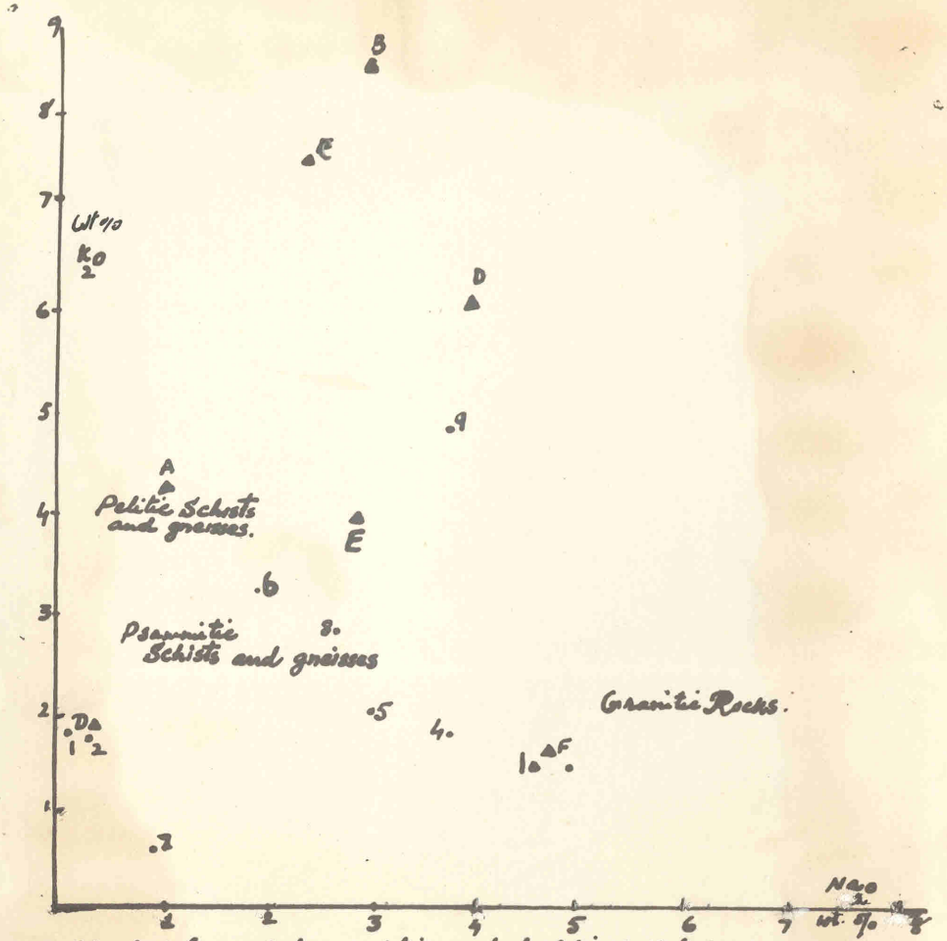


Fig 1. Al_2O_3 : SiO_2 Variation Diagram for analysed Soda Rocks from Tables XXII & XXVI Field of continuous line indicates Bullen's [1965, Fig 5] limits. Circles indicate schists and triangles gneisses.

PLATE – 31.



Alkali values of psammitic and pelitic schists (Solid circles) and gneisses (triangles) are interpreted as the products of metasomatising alkali fluids. (After Mehnert, 1968).

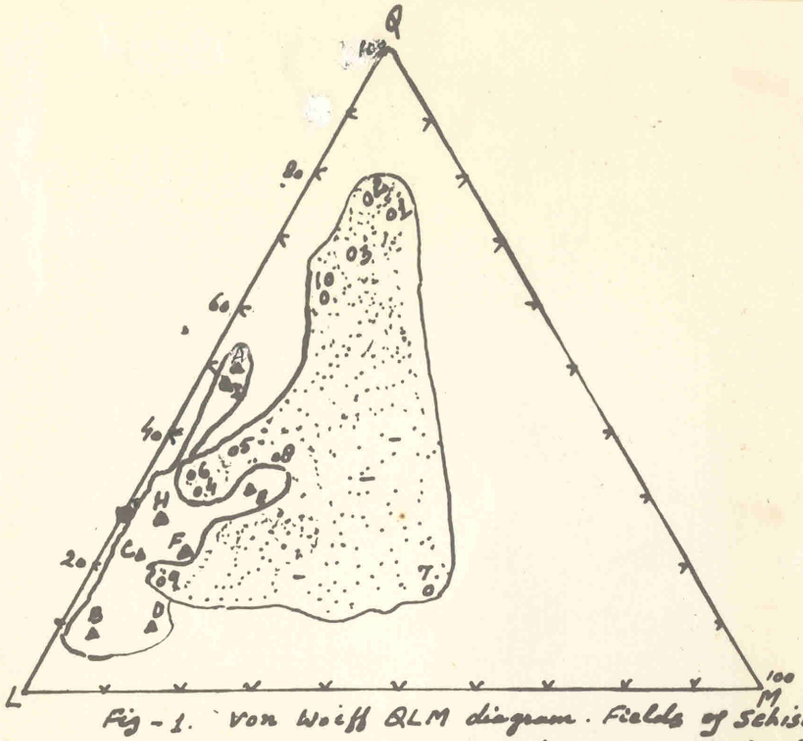


Fig – 1. Von Wolff QLM diagram. Fields of schists of Doda. (Stippled) and gneisses (Horizontal lines Numbers refer to analysed samples of thin rocks in tables XV & XXVIII Solid Square - granite eutectic minimum Composition.

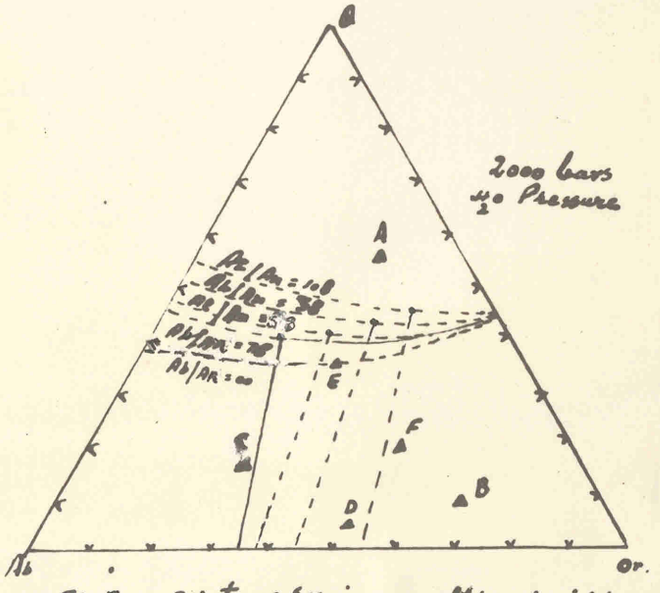
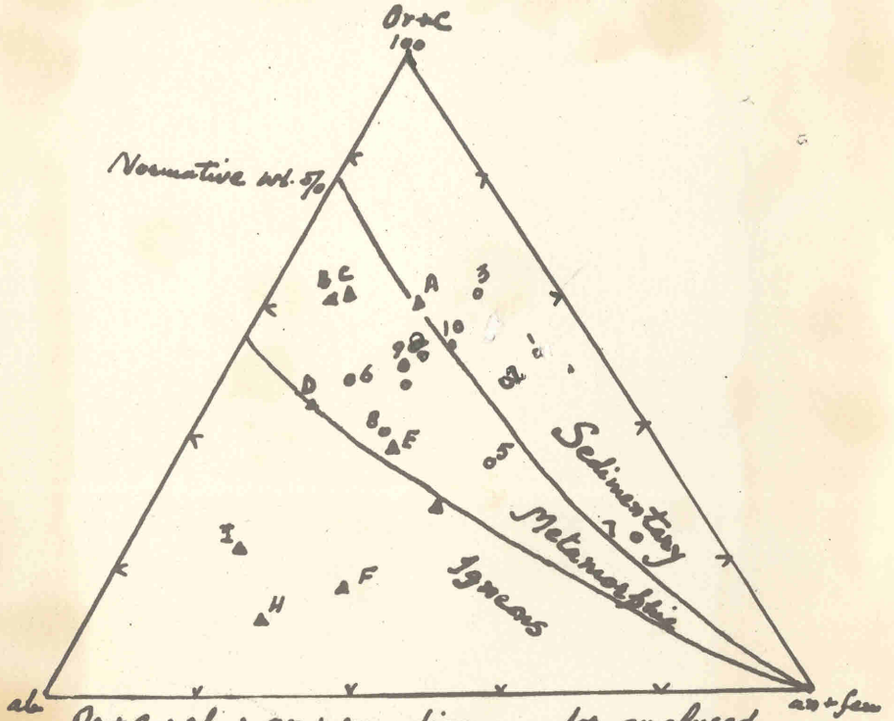


Fig-2:- Points of 'Minimum melt' Composition and eutectic lines of Sections through the System Q - Ab - An - Or - H_2O, with Various Ab/An ratios, at P_{H_2O} = 2000 bars.

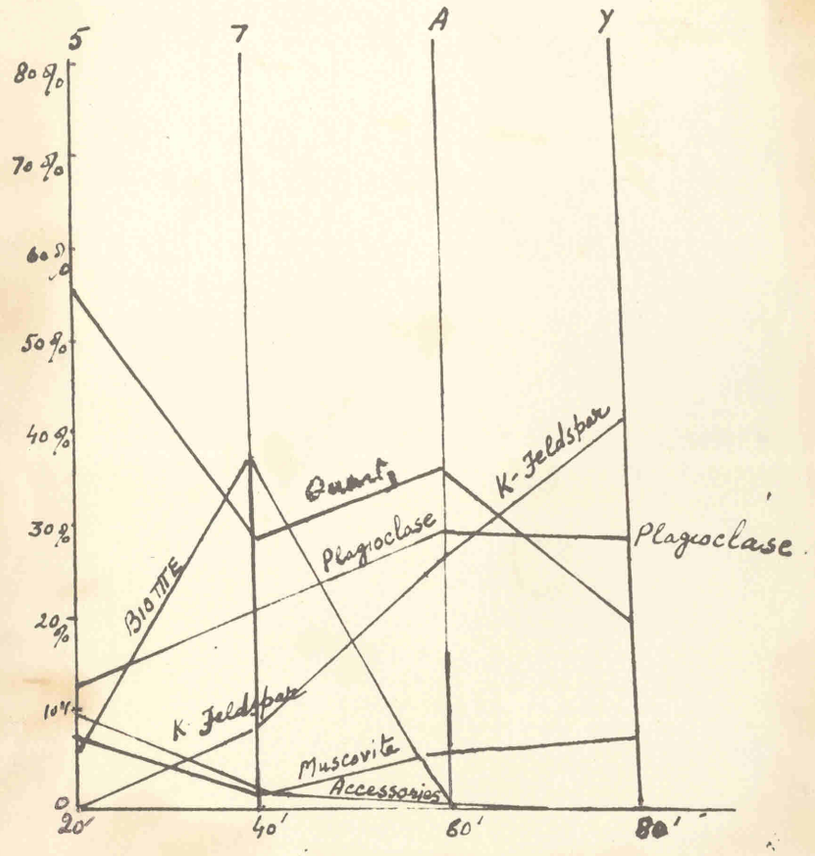
PLATE–33.



Or+C : ab : an+fem diagram for analysed Hoda rocks, fields as delineated by Brunnall, 1983.

PLATE - 34.

Linear Variation Diagram of schist and its Migmatitic derivatives by Volume Percentage.

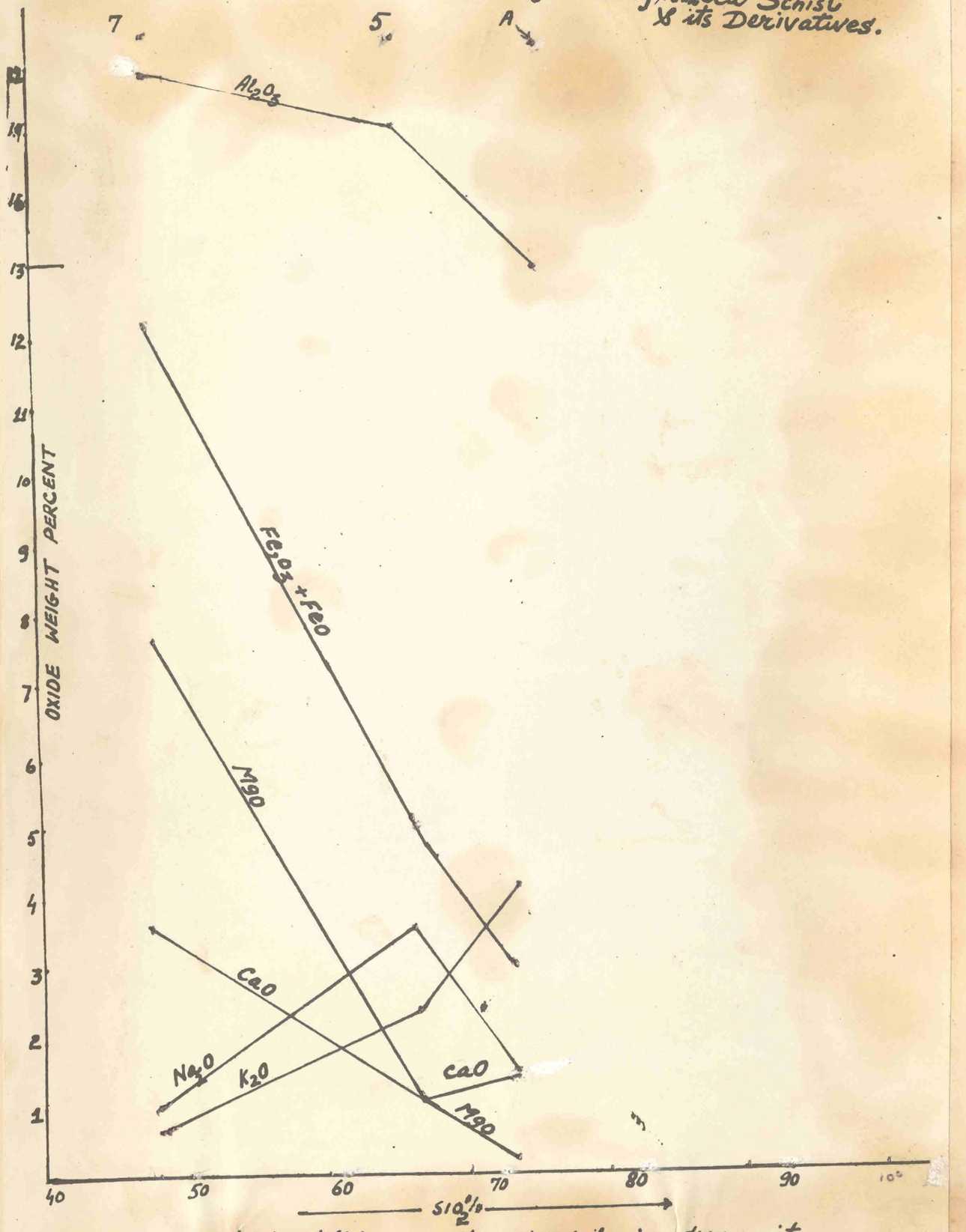


DISTANCE IN FEET

5- Garnet Mica schist ; 7- Basified schist bearing Sillimanite

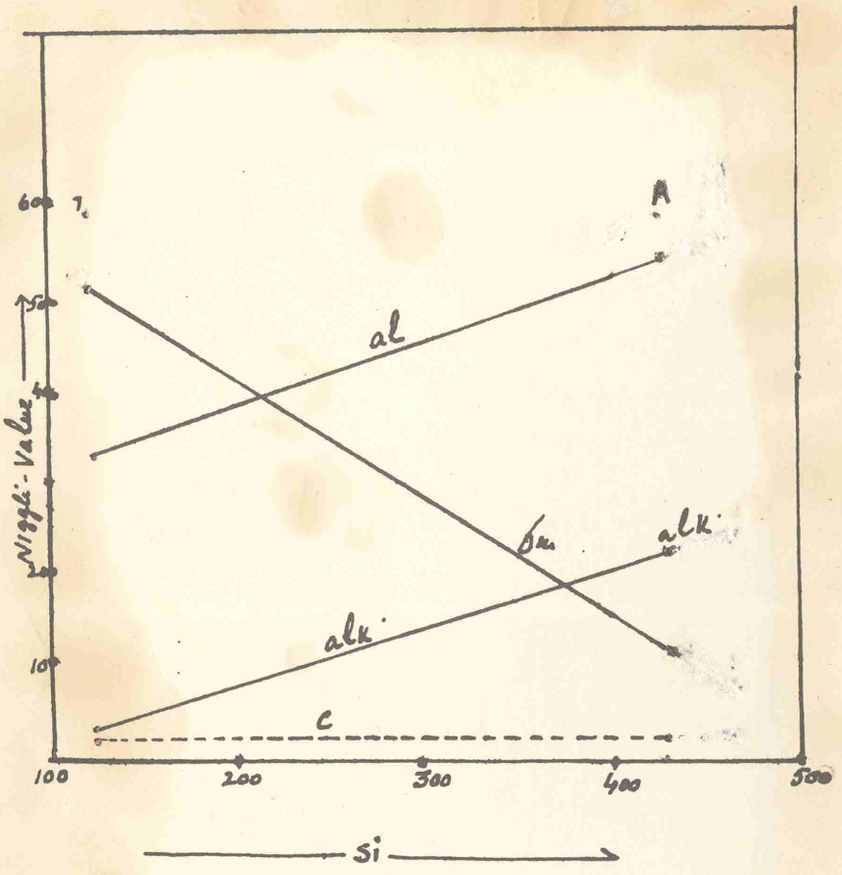
A- Muscovite sdemellite ni gneiss , Y = Muscovite gneiss leading towards granitic composition

Variation Diagram of Garnet-Mica Schist & its Derivatives.



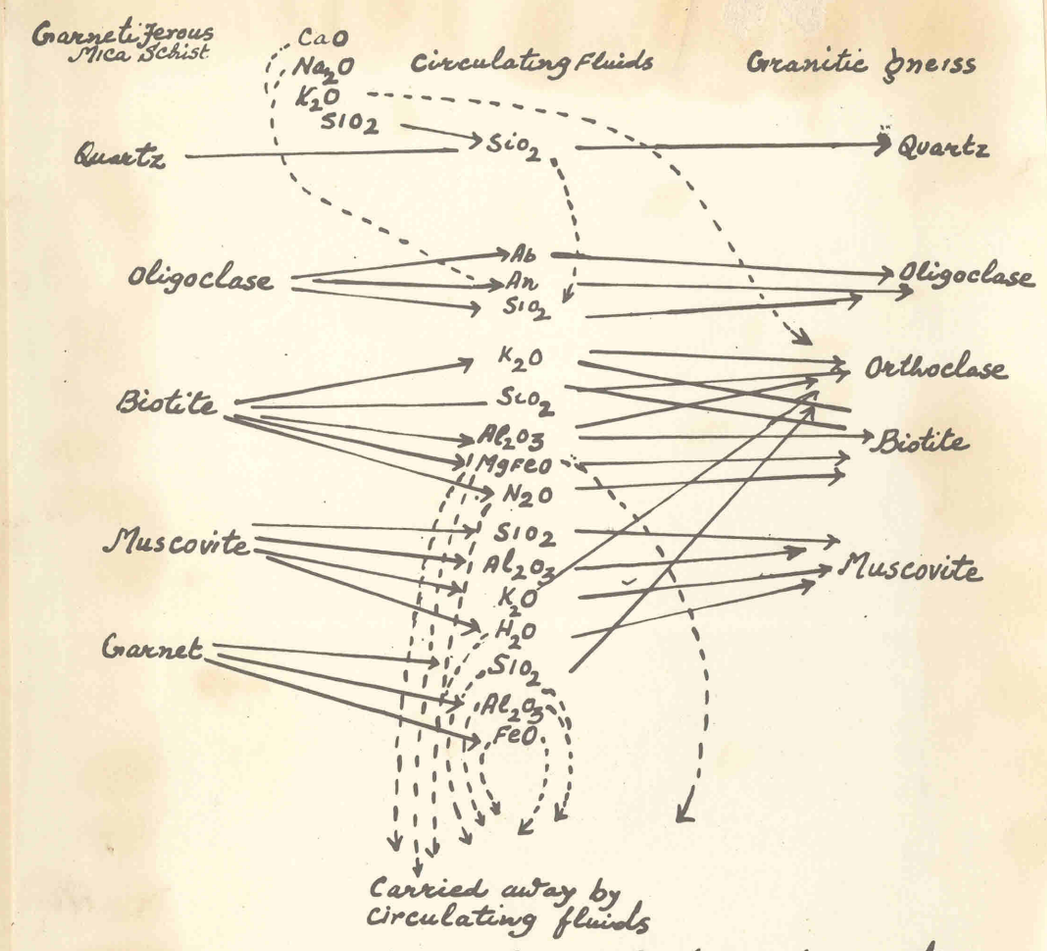
5. Garnet Mica Schist ; 7. Basified Schist bearing Sillimanite
A. Muscovite - Adamellili - gneiss.

Variation Diagram of Pelitic S. list and its Derivatives



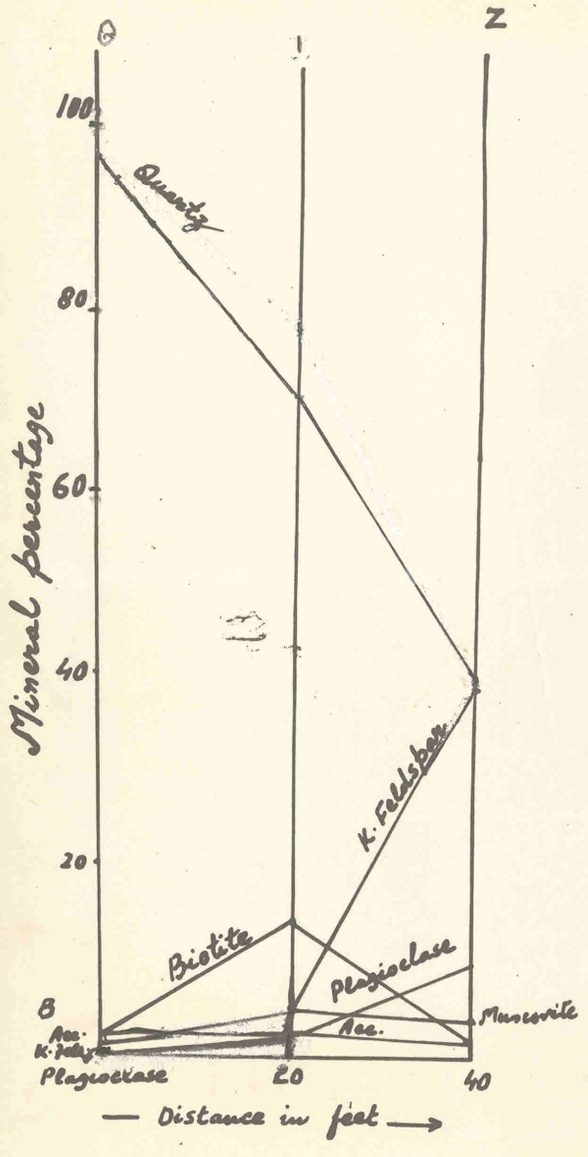
T - Sillimanite - Mica - Schist

A - Muscovite gneiss



Showing the Mineralogical transformation in the granitization of Muscovite garnet gneiss from garnetiferous Mica-Schist.

Variation Diagram of Quartzite and its Derivatives at Malrai

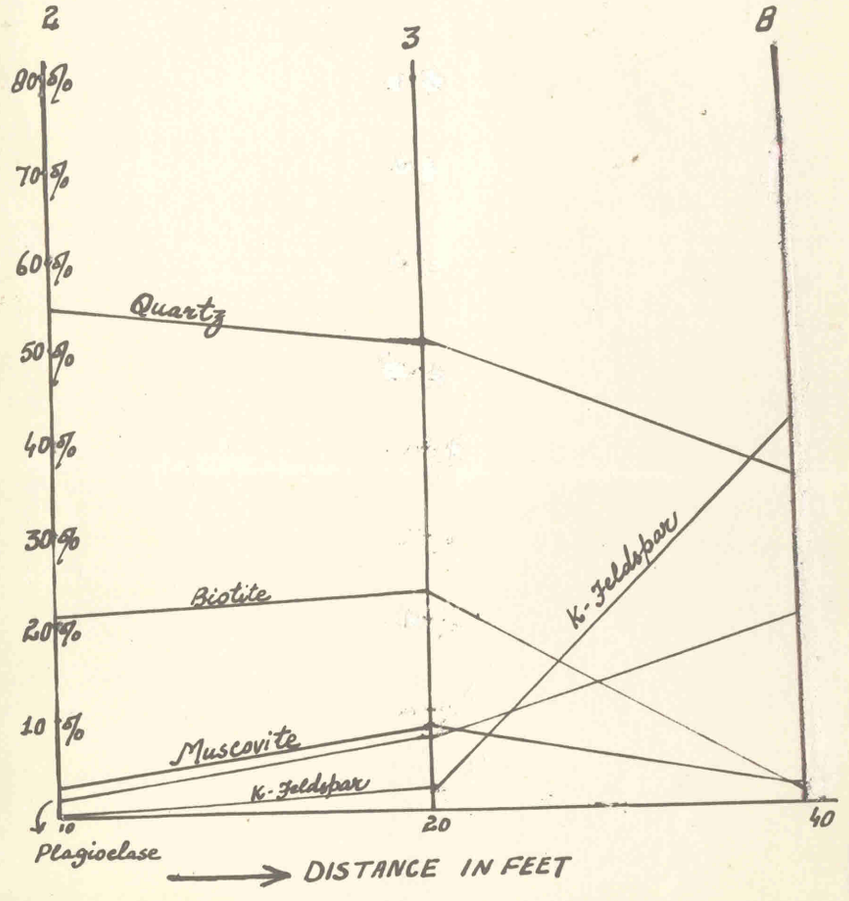


Q - Quartzite

1 - Schist with Sillimanite

Z - Augen gneiss bearing Sillimanite near Bhals.

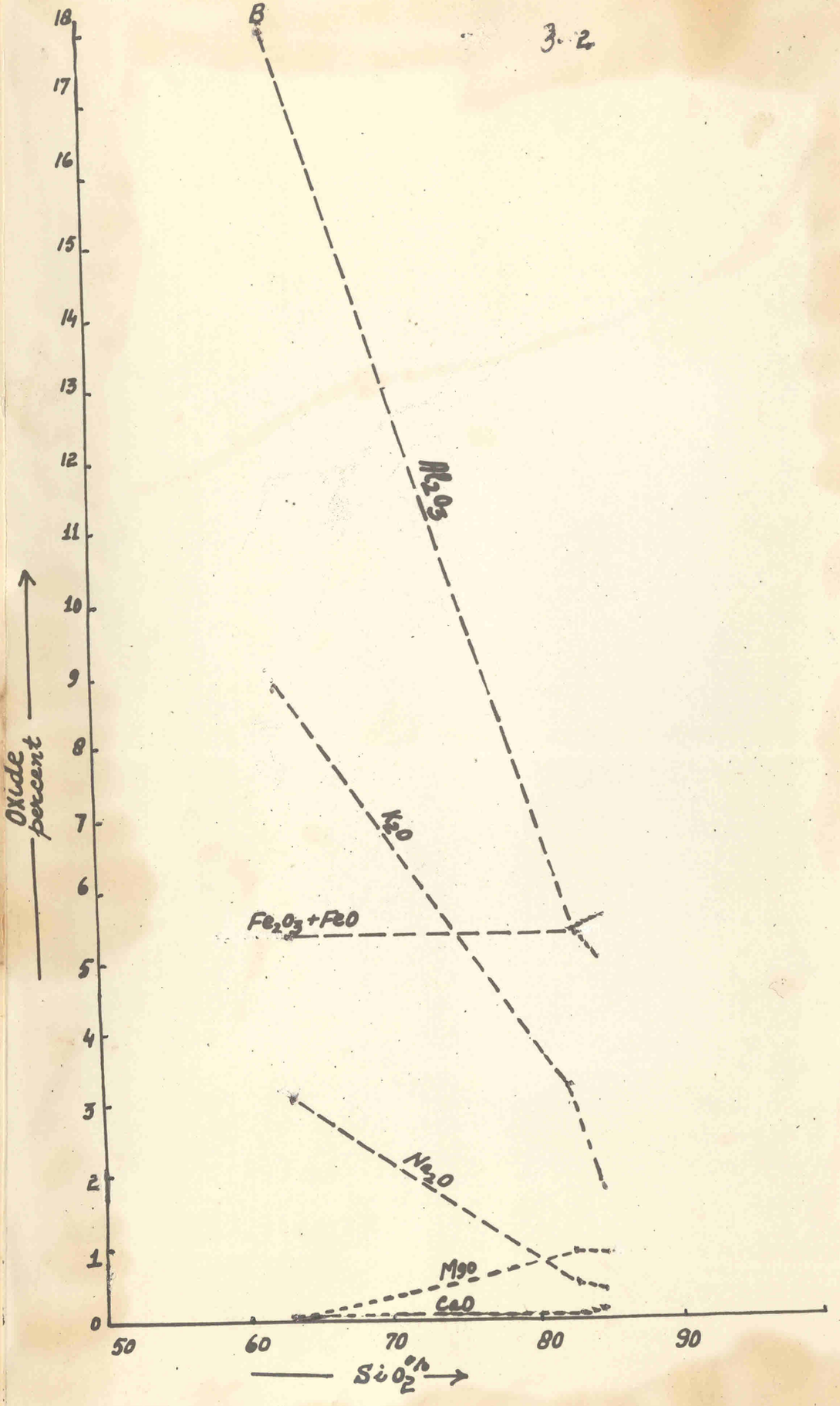
Variation Diagram of Quartz-Mica Schist & its Derivatives at Mundella.



2. Quartz-Mica schist; 3. Garneti ferous-Mica schist
B. Augen-gneiss

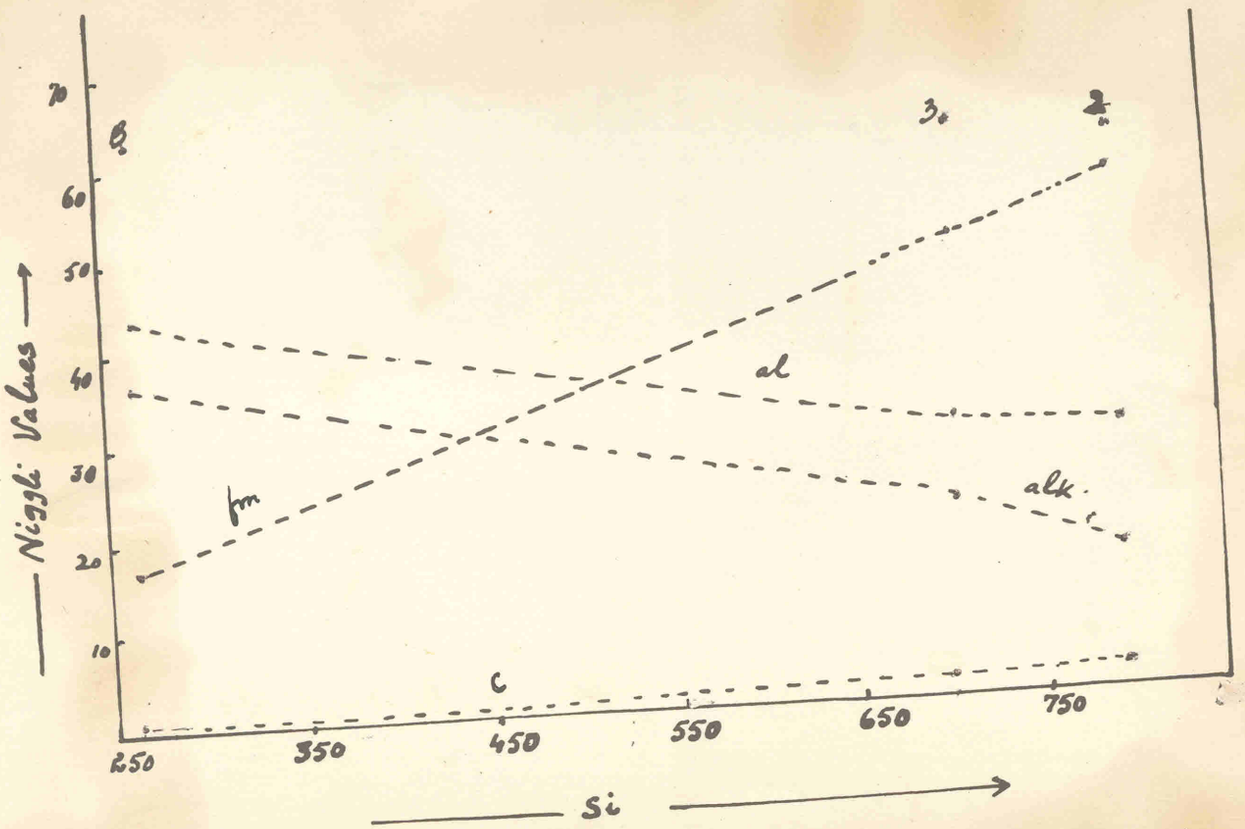
Variation Diagram of Quartz-Mica Schist and its derivatives at Mundella.

PLATE-40.

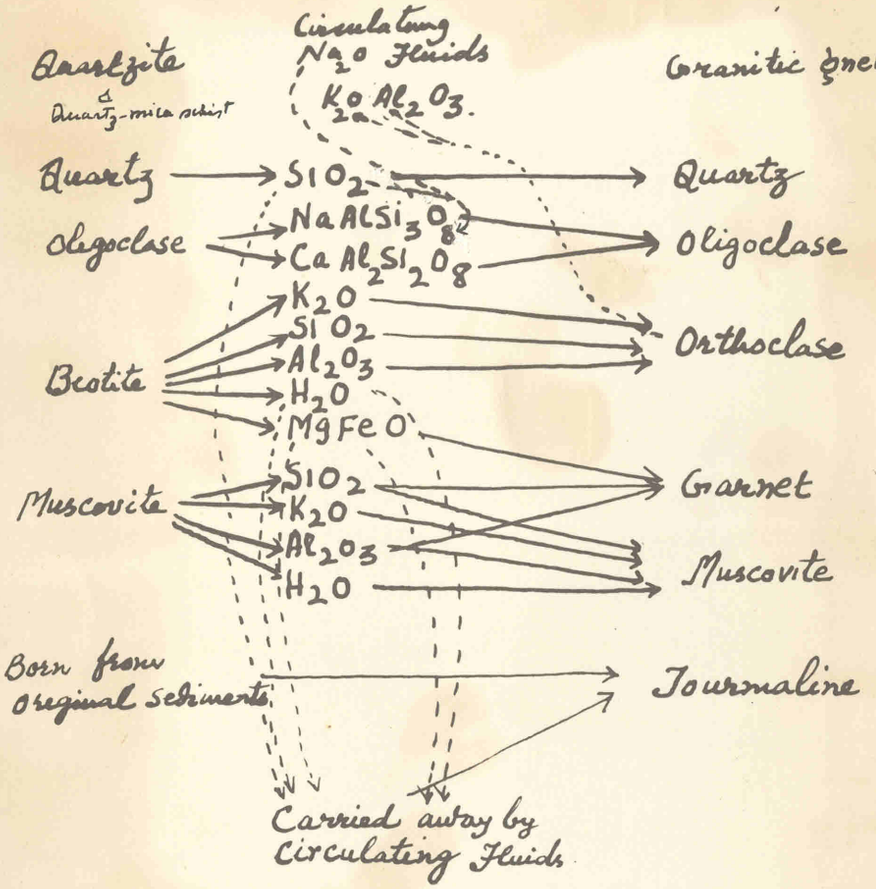


2. Quartz-Mica Schist
3. Garnetiferous-Mica Schist
B. Augen-Gneiss

Variation Diagram of Quartz-Mica-Schist and its derivatives
of Mundalla



2 - Quartz-Mica-Schist, 3.- Garnet-Zeoros Mica Schist
B - Augen Gneiss.



Showing the Mineralogical Transformation in the granitization of the quartzite and Quartz-Mica-Schists

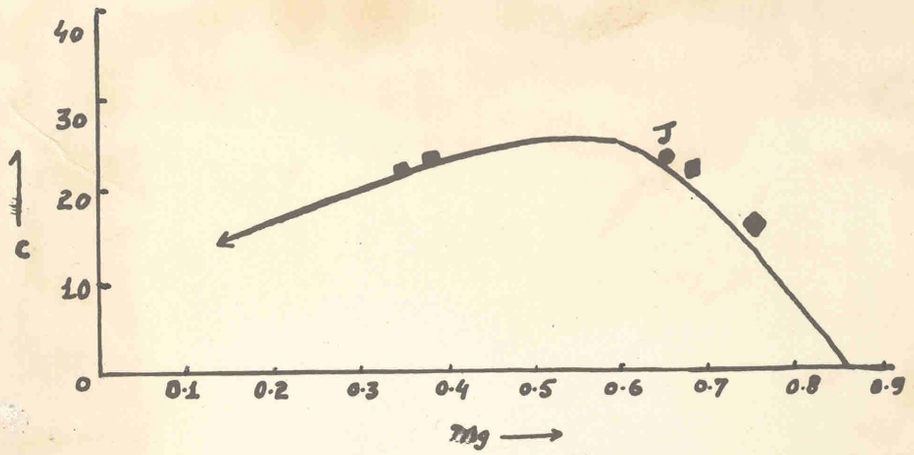


Fig-1. Plot of Niggli mg/c against of Doda Amphibolite J on trend line of Karoo dolerites. No: J Refer the analysed Sample in Table XXIX Solid circle (●) indicates the position of Doda Amphibolite and is compared to Kishtwar amphibolites (Solid squares ■)

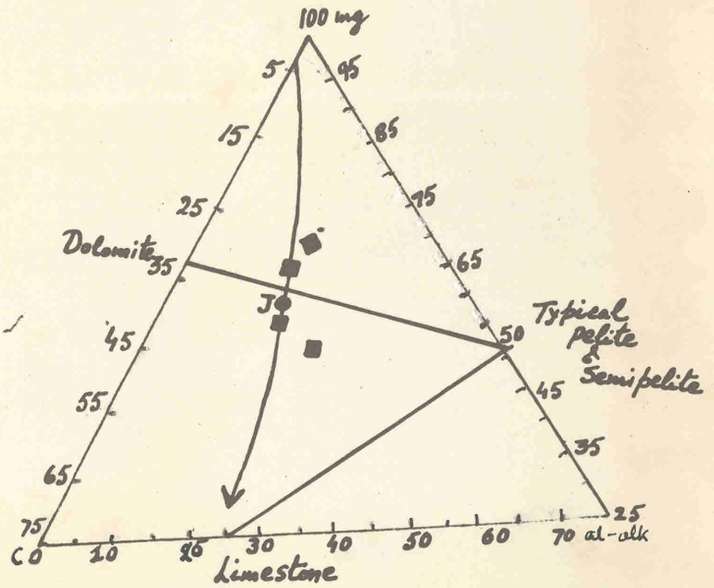
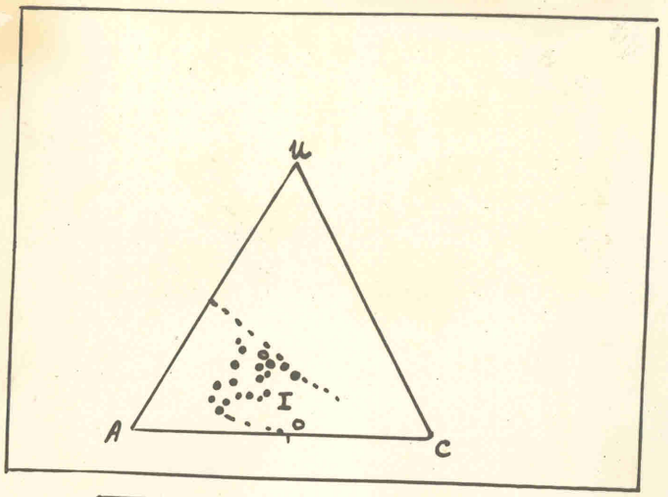


Fig 2. Part of 100 mg c (al-alk) triangle Showing these values of Doda amphibolites plotted on Karoo dolerites trend line. Solid circles indicate Doda Amphibolite and is Compared to Kishtwar amphibolites (Solid Squares).

FIG-1 GORAI'S DIAGRAM SHOWING RATIOS OF TWINNING IN GRANITES.



▲ GRANITES OF JAPAN

o GRANITES OF DODA

□ GRANITES OF ALMORA

I FIELD OF TYPICAL GRANITES ACCORDING TO GORAI

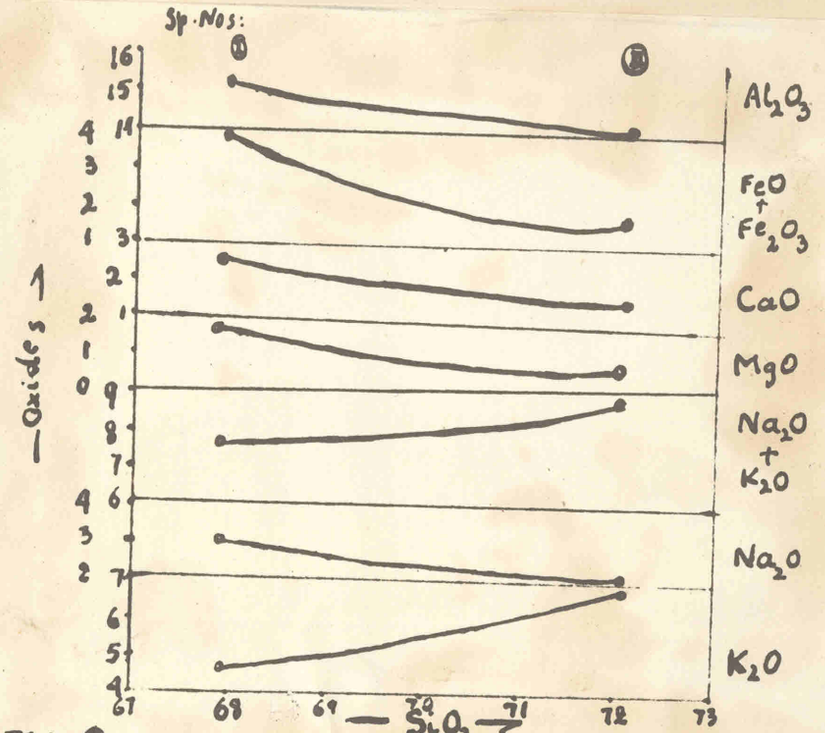


FIG. 2 Harker's SiO_2: oxides variations diagram for Doda Granites

PLATE-45

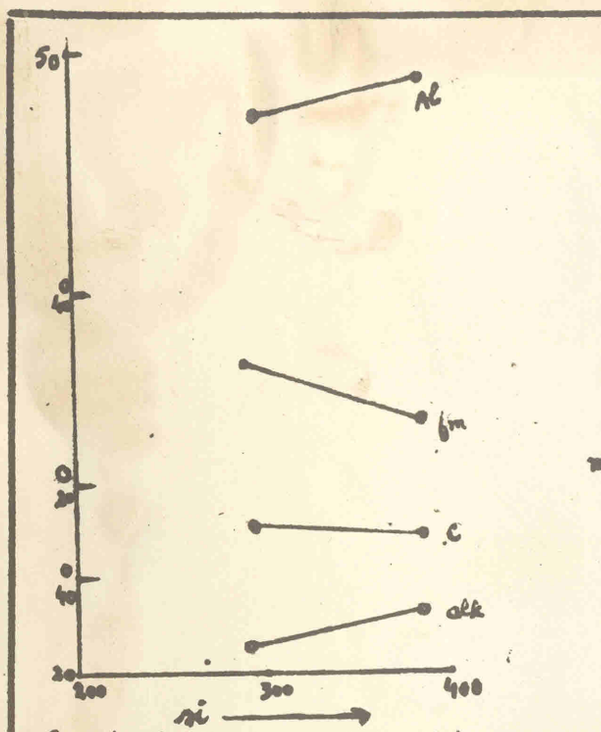


Fig 1. Variation diagram plotting Al, fm, c and alk values against increasing Si (Burri and Niggli)

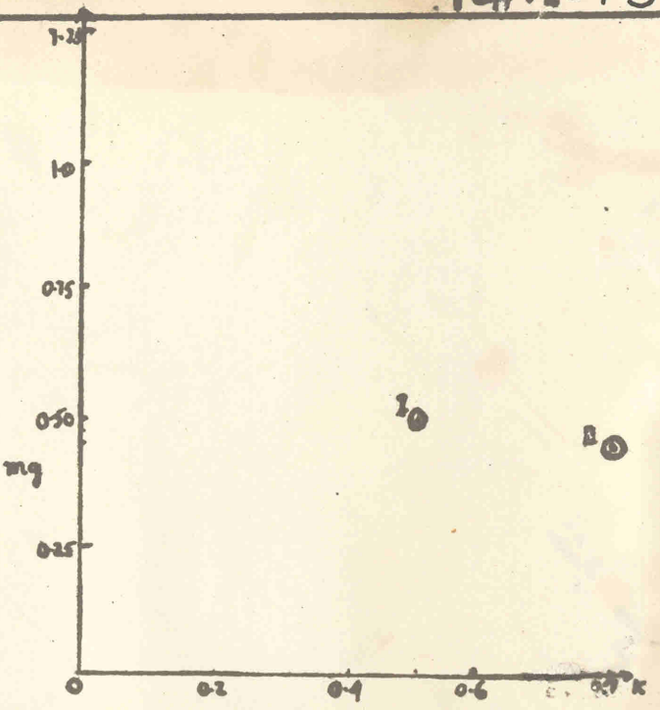


Fig. 2. Plots of mg vs K values (Burri and Niggli)

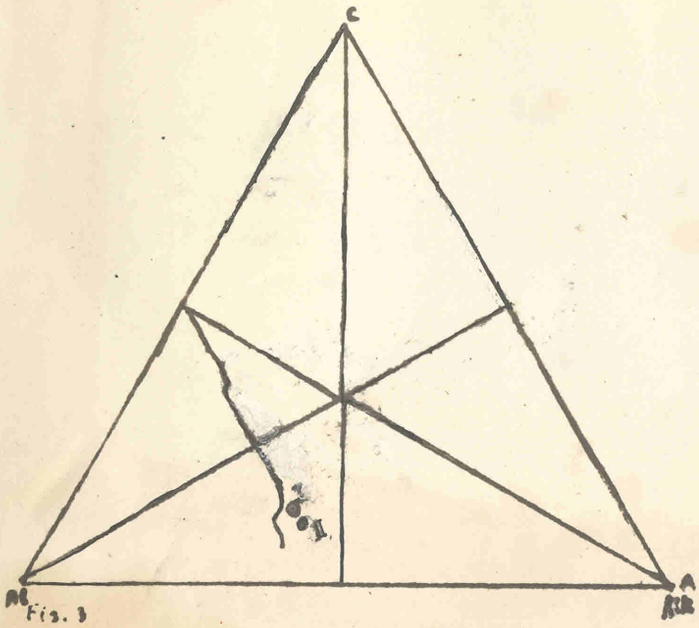


Fig. 3
Al, C and Alk diagram (Niggli) showing the confinement of the rocks to igneous field.

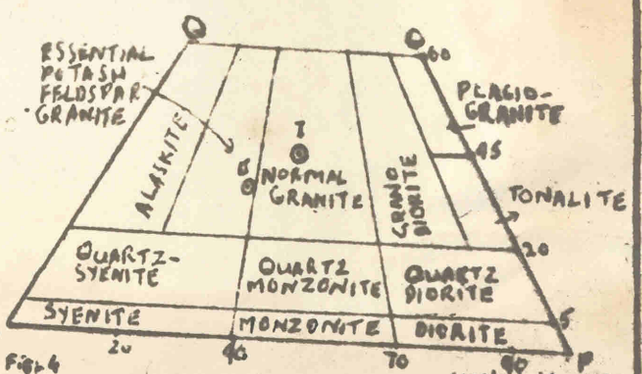
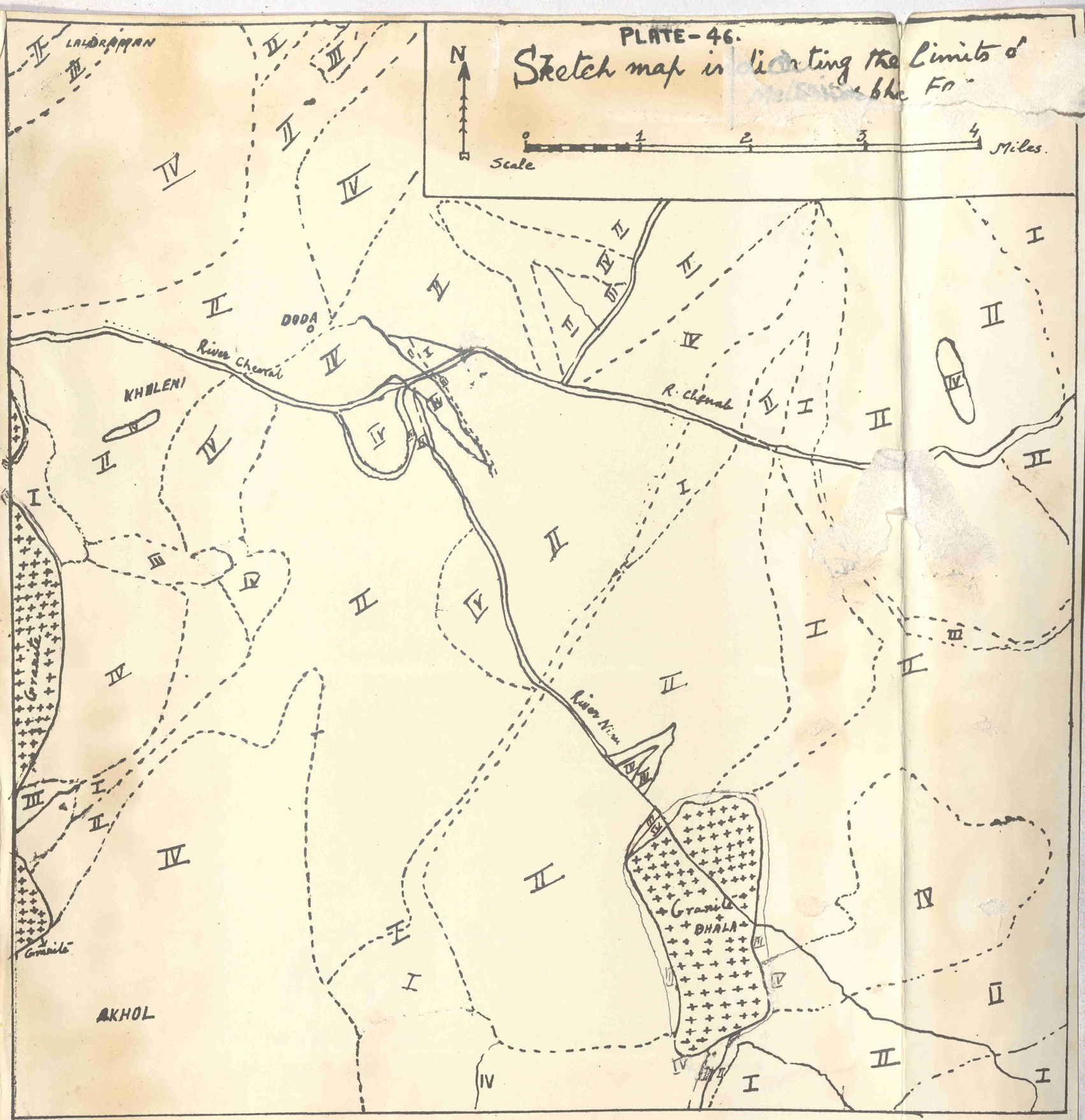


Fig. 4
Classification according to A. V. Gonsburg, S. V. Ehremova, Volarivich and G. P. Ellseeva, 1962) (After Streckeisen, 1967, p 156) Plotted analyses are I Debri granite and II Bhalu Granite (including albite)

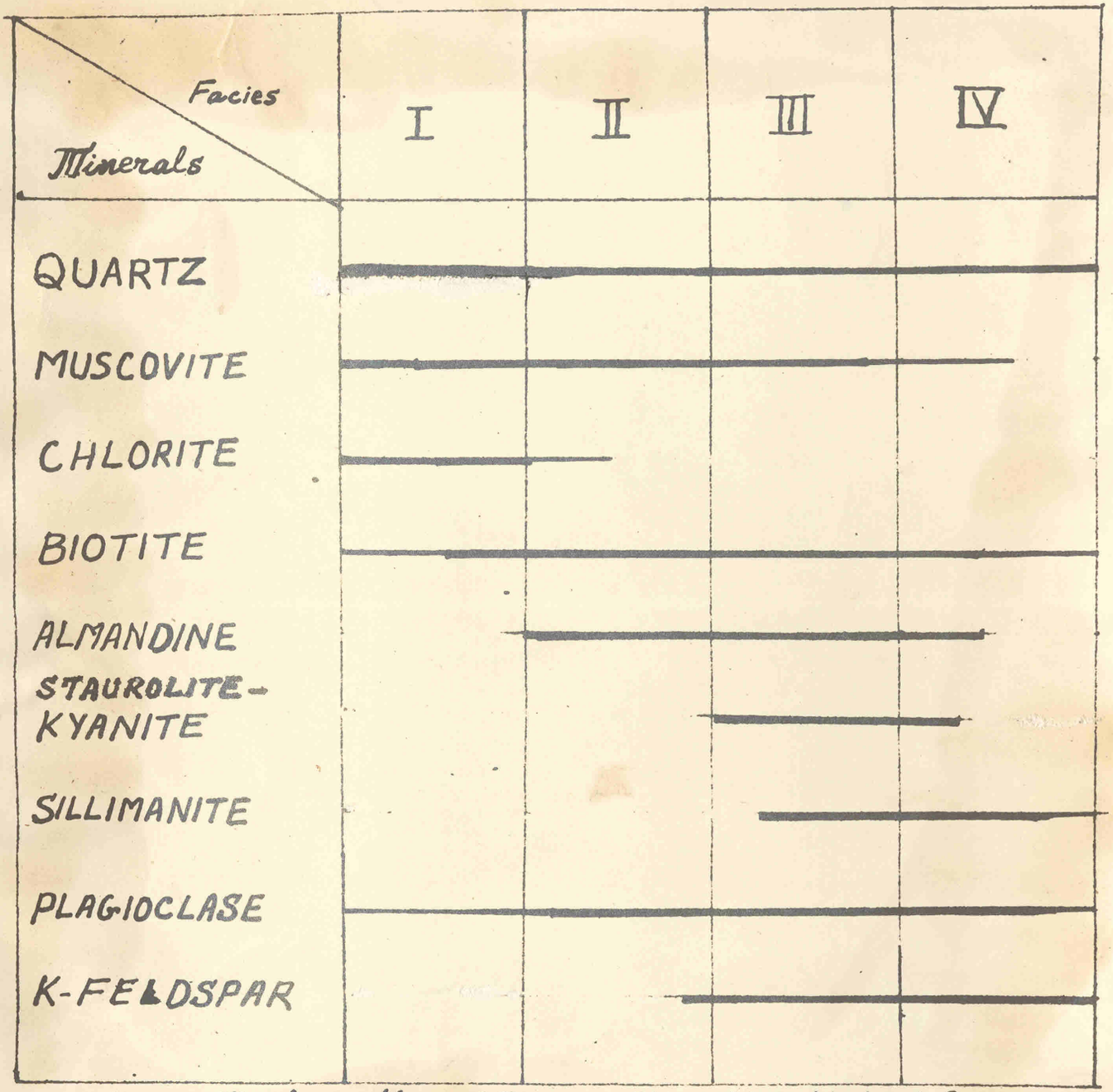
PLATE-46.



Sketch Map of Study Area Showing limits of different Metamorphic Facies

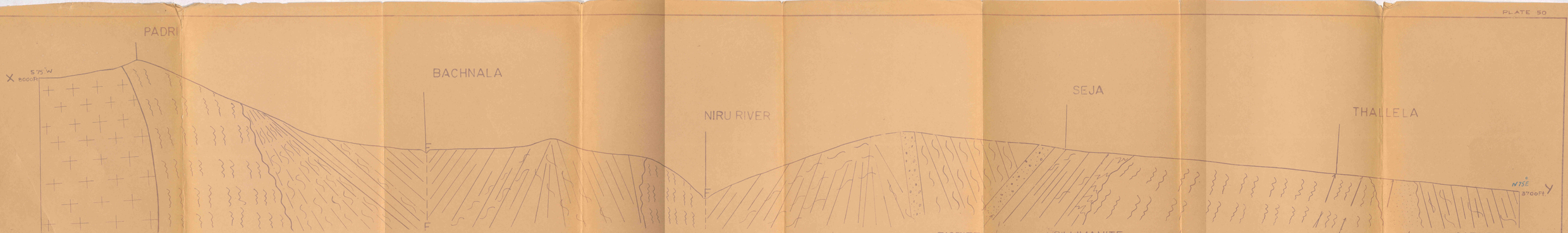
I. Green-schist Facies, II Epidote-amphibolite facies, III Amphibol

IV. Amphabalite Granulite Transition Facies of Turner, 1968.



Mineral assemblages of the various Metamorphic Facies of Doda Area.

I. Green-schist Facies II. Epidote-Amphibolite Facies III. Amphibolite Facies
IV. Amphibolite granulite Transition Facies of Turner, 1968.



SECTION ALONG X,Y PLEASE REFER PLATE NO.49

SCALE:- 4" = 1 MILE

PLATES 48 to 50

(Three numbers)