GEOLOGY OF SOUTH-- EASTERN PARTS OF MUSSOORIE WITH A NOTE ON THE SEISMICITY OF THE REGION.

DISSERTATION
IN PART FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF
M Sc. Tech. DEGREE IN APPLIED GEOLOGY

SUBMITTED BY
GOPAL JI SINGH. B. Sc.

DEPARTMENT OF GEOLOGY AND GEOPHYSICS,
UNIVERSITY OF ROORKEE
ROORKEE (U.P.)
1966

Photo-1 A view of a huge creeping escarp on the right bank of Kiarkuli Nadi 2 furlong N.E. of Electric Power House. Photo taken from a place near Bhatta on Mussoorie-Rajpur Motor Road.

CERTIFICATE

CERTIFIED that the dissertation entitled GEOLOGY OF SOUTH-EASTERN PARTS OF MUSSOORIE WITH A NOTE ON THE SEISMICITY OF THE REGION being submitted by Sri GOPALJI SINGH in partial fulfilment for the award of the Degree of M.Sc. Tech. in Applied Geology of University of Roorkee is a record of student's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other Degree or Diploma.

Dated March, 23, 1966.

Dave

(V.K.S. Dave)

Reader,
Geology Department,
University of Roorkee,
Roorkee.

ACKNOWLEDGEMENTS

The author is thankful to Prof. R.S. Mithal, Professor and Head of the Department of Geology and Geophysics for arranging and encouraging the progress of the present work. He is indebted to Sri L.S. Chaturvedi for the pains, he has taken at various stages of this work and the help rendered to the author. His thanks are also due to Dr. V.K. S. Dave, under whose general guidance the present work was carried out and presented in this form. The author also thanks to Dr. K.K. Singh, who has not only taken a keen interest in this work, but has provided all possible helps in field as well as in the laboratory.

The author sincerely thanks to Prof. Jai Krishna, Professor and Director, School of Research and Training in Earthquake Engineering for providing necessary financial help by sponsoring the present research programme of the Department of Geology. He is indebted to Sri L.S.Srivastava, Reader in Applied Geology, School of Research and Training in Earthquake Engineering for the help and valuable discussions regarding the regional seismicity. The author also thanks to his fellow-workers, Sri S.N. Salapaka, Sri P.N. Jalote and Sri Bhupendra Singh for their cooperation at various levels. The author also acknowledges with thanks the helps rendered by Sri Naresh Chandra and Sri Gangadharan for typing the dissertation and for preparation of the tracings required for ammonia prints.

Gopal ji Singh
(Gopalji Singh)

Department of Geology and
Geophysics,
University of Roorkee,
ROORKEE(U.P.)

Dated March 23rd, 1966.

PREFACE

The present work embodies the result of investigations which were carried out by the author to study the geology and seismicity of the south-eastern part of Mussoorie as a part fulfilment of the requirements of the award of the degree of M.Sc.(Tech) in Applied Geology of the University of Roorkee. The program was jointly sponsored by the department of Geology and Geophysics and School of Research and Training in Earthquake Engineering with a view to assess the seismicity of Mussoorie-Rajpur region. The entire region was divided in four sectors, the writer being deputed in the south-eastern parts of Mussoorie. The other three sectors were distributed amongst Mr. P.M. Jalote (Rajpur), Mr. Salapaka (Western Mussoorie) and Mr. Bhupendra Singh (Northern Mussoorie).

The association of the orogenic belts and earthquakes is a well established fact in geology. The origin and effect of the seismic phenomena is related with the crustal disturbances which are manifested by the geological structures. Under the various development plans of our country, many under-developed hilly regions are now being provided with industrial units and seismic factor is one of the important consideration for deciding the size and the design of such projects. A proper investigation of the seismicity of a region is, therefore, a necessary part of the development programmes of our country. Any study relating to the seismicity of an area, however, has got to start with the geology and structural investigations. The present work may be regarded therefore, an attempt towards this end.

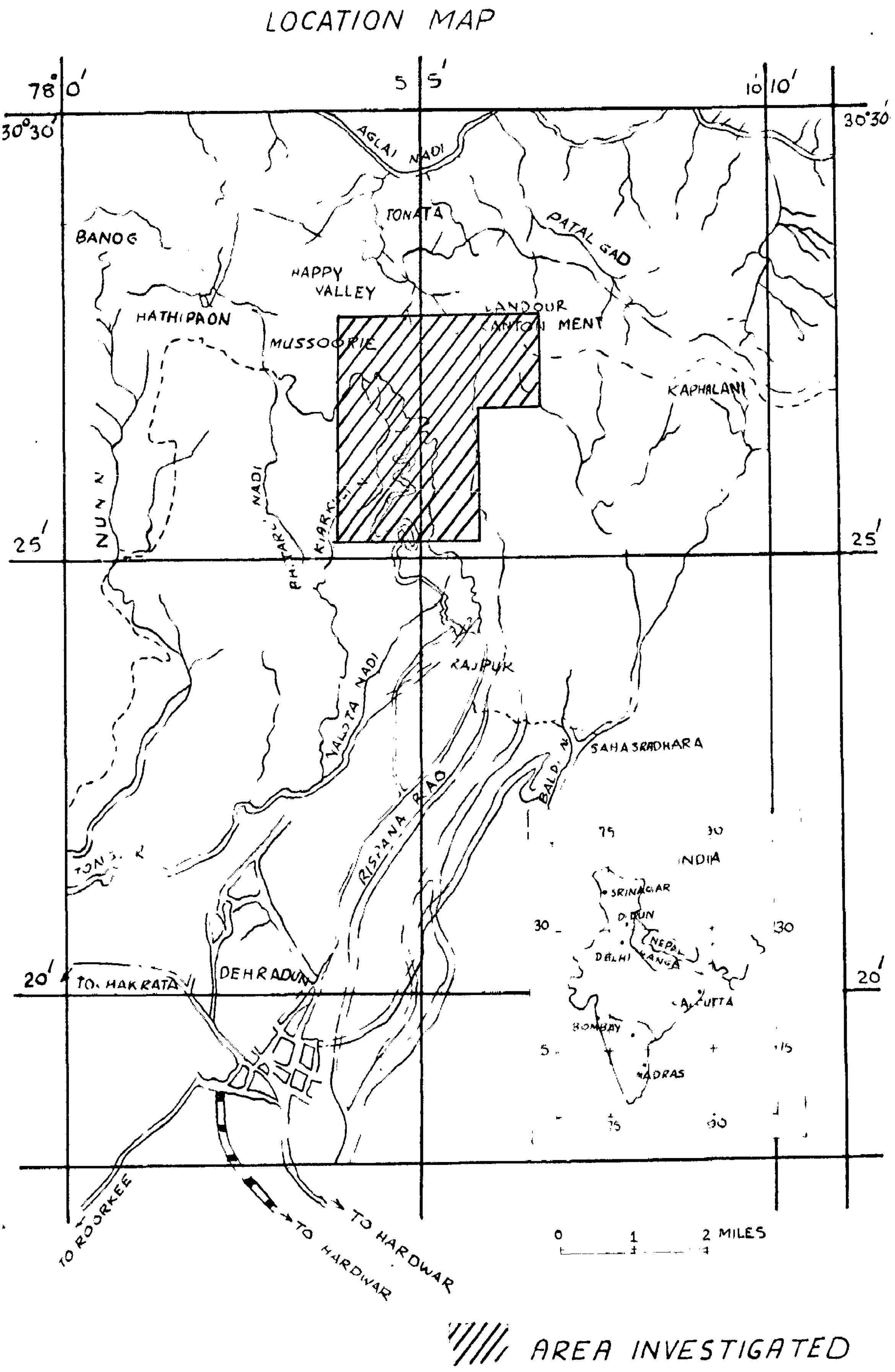
CONTENTS

List of Illustrations.

<u>PHOTOGRAPHS</u> <u>FRONT PAGE</u>

.-.-.-.

MAP-1


LOCATION MAP
78° 0'
5 5'
10 10'
30°30'
30°30'
AGLAI NADI
TONATA
PATAL GAD
BANOG
HAPPY VALLEY
HATHIPAON
LANDOUR CANTONMENT
MUSSOORIE
KAPHALANI
NUN N.
25'
25'
KIARKULI
RAJPUR
SAHASRADHARA
BALDI N.
RISPANA RAO
INDIA
SRINAGAR
DELHI
NEPAL
BOMBAY
MADRAS
30
30
20'
20'
TO CHAKRATA
DEHRADUN
TO ROORKEE
TO HARDWAR
TO HARDWAR
0 1 2 MILES
AREA INVESTIGATED

CHAPTER I

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

THE AREA

SITUATION, CLIMATE AND HISTORY:

The area herein included in the present work, constitute the S-E portion of Mussoorie and is situated between north latitudes 30° 25' 15" - 30° 27' 33" and east longitudes 78° 01' 15" - 78° 06' 45". It is nearly 22 miles north of Dehradun and lies in Survey of India, one inch sheet No. 53J/3. The area is located in the map 1.

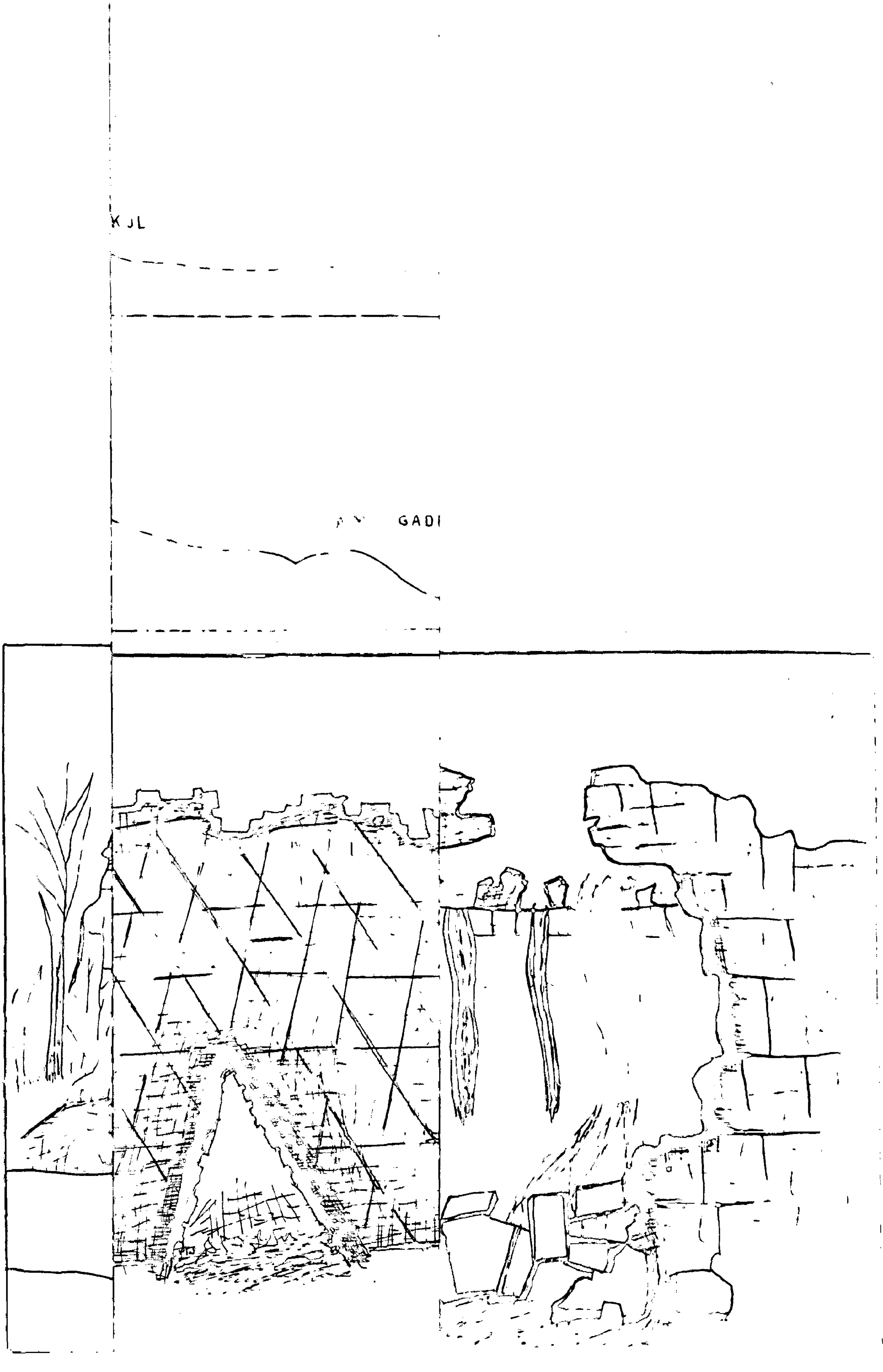
The area has a healthy and bracing climate throughout the year. The temperature ranges between 23°F (-5°C) in the winter to 78° F (25°C) in summer. Monsoon is copious, the total rainfall is being 70" to 90" per annum. The monsoon starts with the advent of July and continues throughout the months of August and September. During this period rain is continuous for days together. Temperature begins to fall in November, January and February are very cold, and there are frequent snow falls these days. From second week of March the weather begins to change and becomes warmer. The months of May and June may be considered as the best season for visiting as well as for geological expedition of the area. During these months the temperature ranges between 25°c and 10°c.

The original name of Mussoorie was Mansuri, probably because the area was supposed to be the hide-out of a big out law chieftain named Mansur. However, Mussoorie came into prominence after the Survey of India offices were established by Col. Everest in 1832. By the end of last century Mussoorie had carved out an important place for itself amongst the the Indian hill stations. Its development and attraction increased subsequently and now it is popularly known as the "Queen of Hills".

COMMUNICATION, ACCOMMODATION AND OTHER AVAILABLE FACILITIES:

For visiting Mussoorie from any part of the country, the journey by rail has got to be terminated at Dehradun which is a terminal railway station of the Northern Railway. There is a regular bus service running between Mussoorie and Dehradun. During season the bus service is also introduced between Mussoorie and Delhi. Within the town hand pulled rickshaw dandies and ponies are the only means of conveyance.

In addition of three Dharamshalas, there are a large number of hotels in Mussoorie where accommodation is available on reasonable rents. For investigation of the area under consideration of present thesis, staying either in Landhour or


GADI

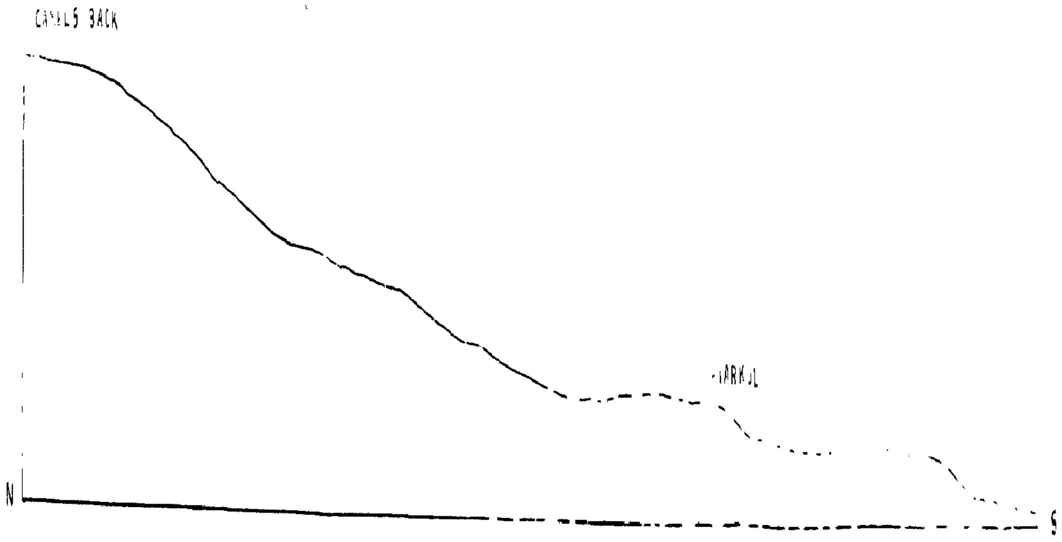


Fig.1(a)

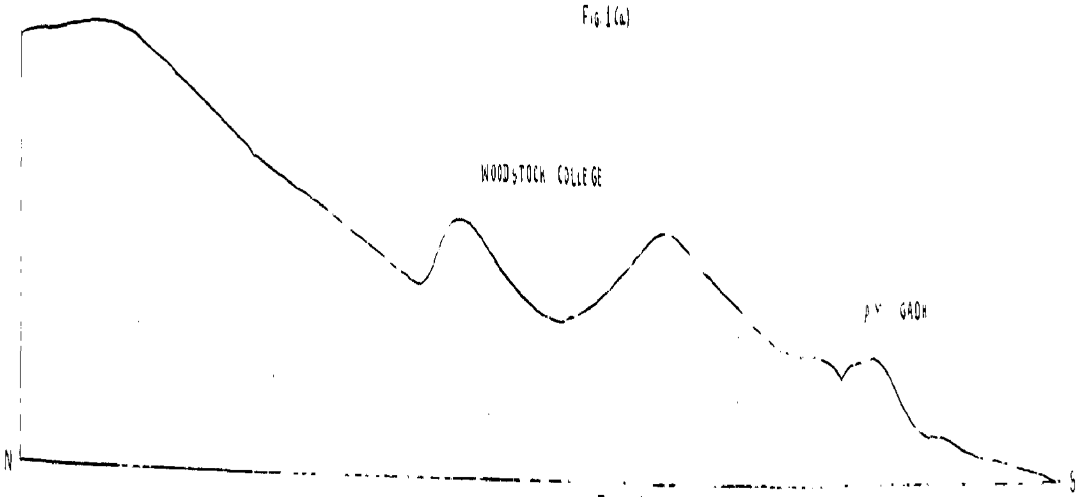
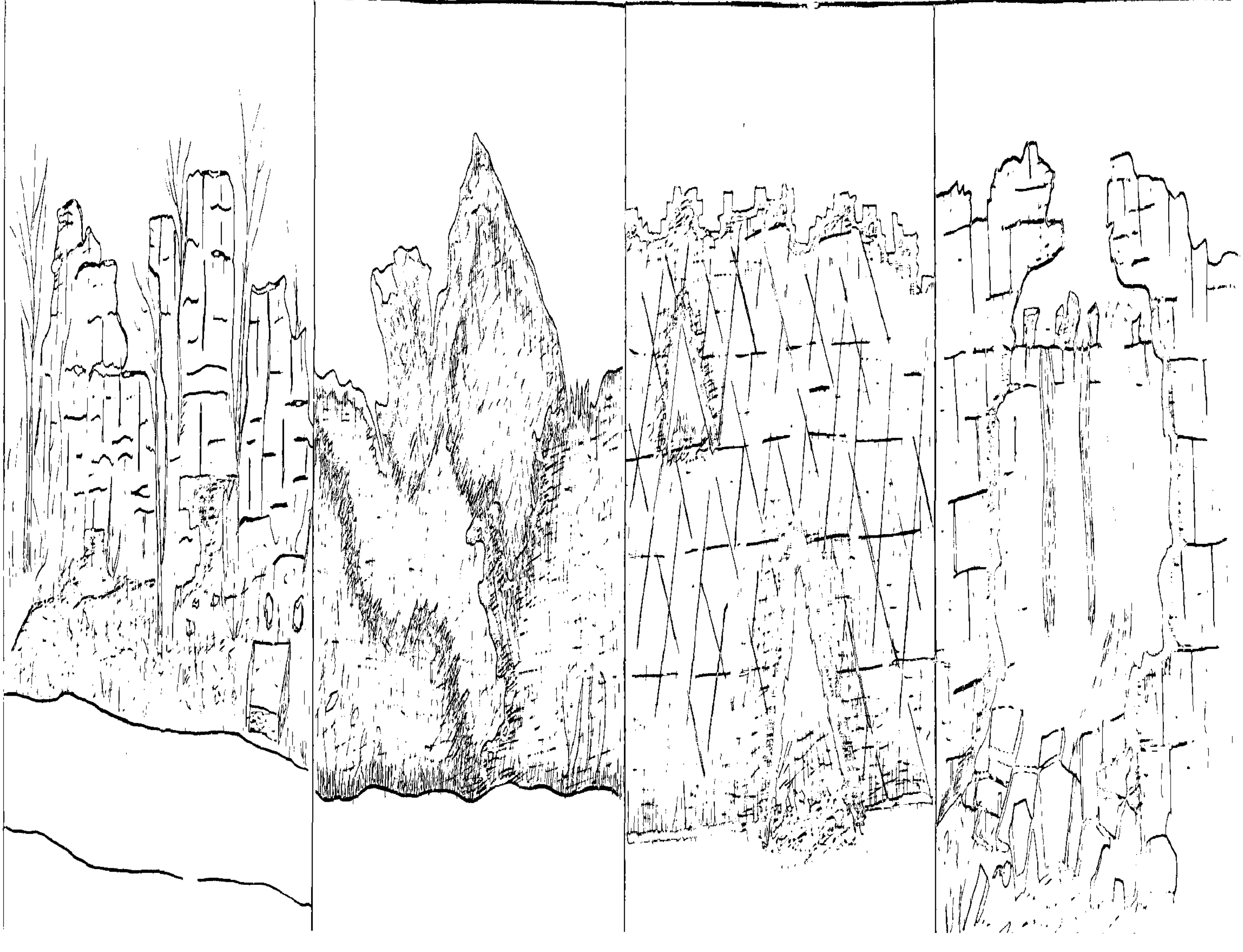


Fig 1(b)



Kulri Bazar is most suitable. All modern amenities of entertainment and shopping are available.

PHYSIOGRAPHY

Topography

The area represents a hilly terrain. Northern part of the area is highest and three prominent hills are the Gun hill, Castle hill and Lal Tibba. Lal Tibba has the highest altitude of the area and is 7459' above the means sea level. The eastern portion is also comparatively higher and is composed of numerous highlands being separated by inter-running valleys (fig. 1(b)). The western part of the area is less undulating and to a greater extent has a gradual slope (Fig. 1(a)). The SW corner of the area forms its lowest land and is represented by a major valley (Kiarkuli Nadi) which ultimately opens up in the Dun valley.

Geomorphologically the area is in initial stage. Denudation is extensive. Streams are deepening their channels regularly. Several of them are flowing turbulently through steep-walled gorges with V shaped cross section. Land slides are frequent along the walls of these gorges.

The topographical configuration of the terrain has been influenced by the nature of the rocks. In areas composing of shales, grits and quartzites (Tals), the landscape is different as compared to that of Limestone and dolomite areas (Krols). Tals have formed gently undulating or flat topped

Photo-2

Photo -3

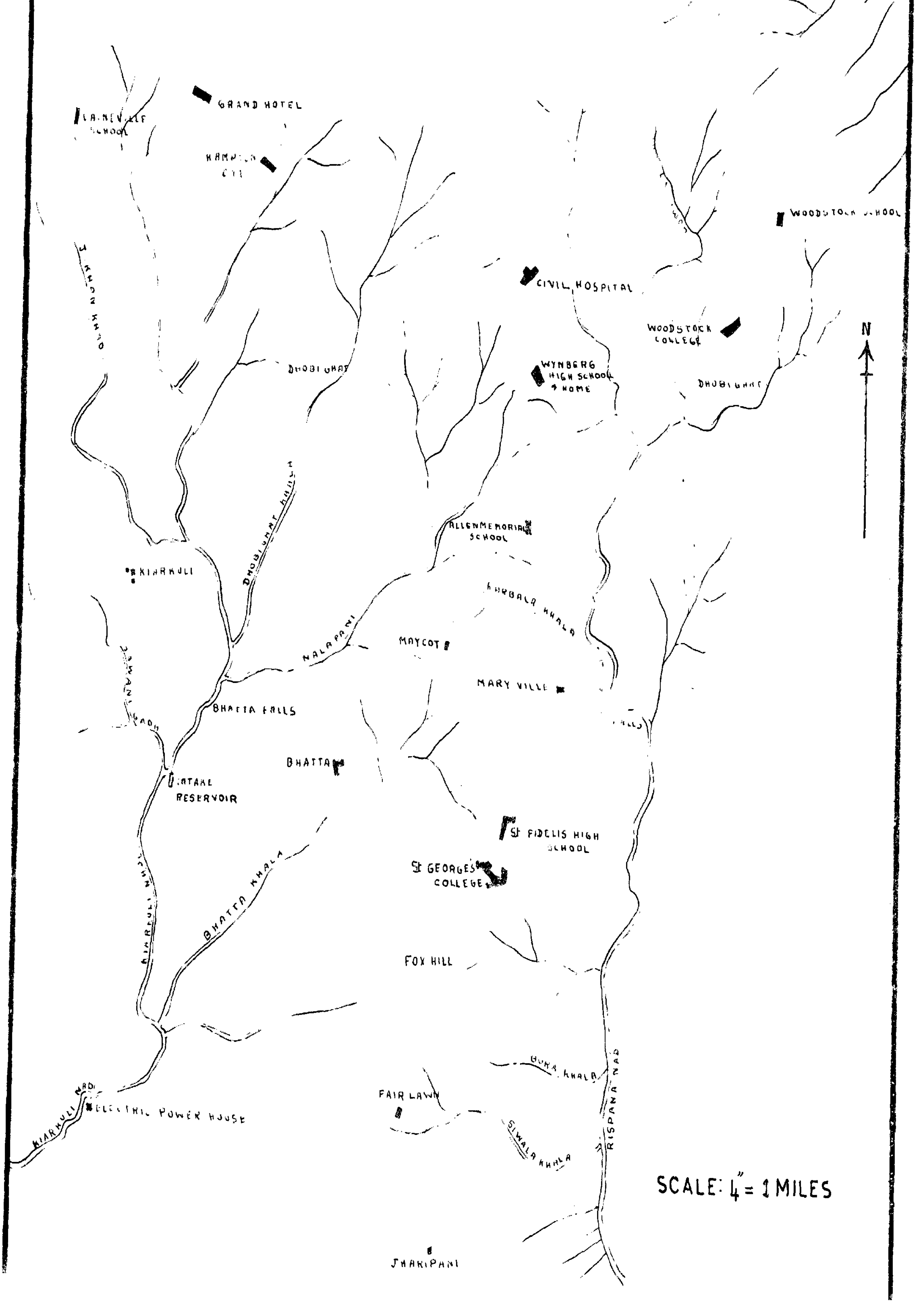
Photo-4

hills. On the other hand, the limestone bodies, both high grade and dolomitic stand out very prominently giving rise to a rugged scenery and almost barren cliffs and precipices, often hazardous to climb. In fact a more or less a Karst topography has developed in the area constituting of the Krol limestones. Some of the characteristics of Karst topography have been well represented in this region. These include pitted, grooved and rugged surface (photo 2) solution channels, hums (fig. 2) and caves etc. Some outcrops of bare limestone have been carved into fantastic natural architectural forms. Most peculiar of them is the Camel's Back Hill. It is just N-W of Gun Hill and looks much like a sitting camel when viewed from a distance. (Fig.3). The other attracting physiographic features met within the Krol formation are a number of caves founded at various places. Some of them are huge in dimension (photo 3). Caves seen along the Kincraig road are prismatic in shape with triangular cross section (Fig.4). This shape has been acquired due to erosion of the rock along 3 sets of joint planes traversing the rocks.

Drainage:

The main Mussoorie ridge acts as a watershed, dividing the drainage in two groups. Those streams which are in north of Mussoorie flow in a northerly direction and those which in south, flowing in a N-S direction. With the exception, therefore, of a small portion in the northern side, the drainage of the major part of the present area is from north

DRAINAGE PATTERN OF THE AREA



to south. Through sheet run-off, gullies, ravines, nalas, seepage and springs, the entire body of effluent surface water is chained ultimately into either of two major streams- the Kiarkuli Nadi and the Rispana Nadi. Both of these are consequent streams.

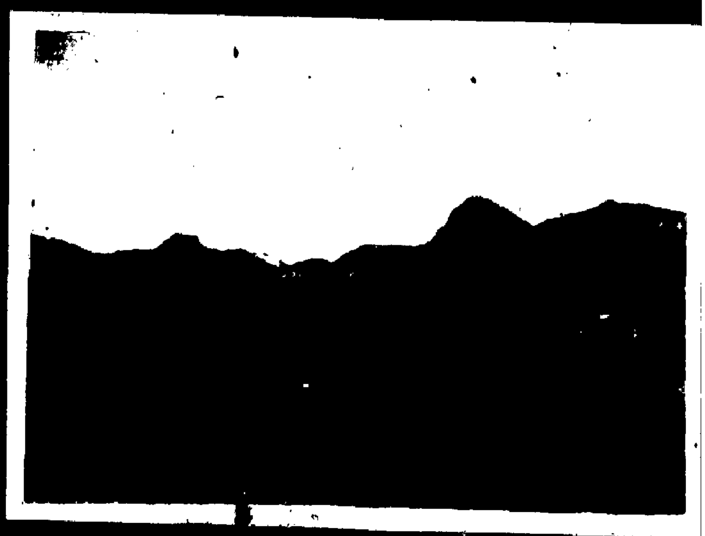
Kiarkuli Nadi

The western half of the region acts as the catchment area of Kiarkuli Nadi. This stream is developed as a result of the confluence of several large gullies, known locally as Khalas or Khad or Gadh. The chief Khalas are, from west to east, Kukhankhad, Kiarkuli Khala, Dhobighat Khala and Nalpani Khala. The first two flow in NNW-SSE to N-S directions. The Dhobighat Khala flows in a NE-SW direction and Nalapani Khala in roughly ENE-WSW direction. Each Khala is joined by several small channels and nalas. These Khalas join together to form a revulet known as Kiarkuli nadi. Just south of the junction with Nalapani Khala this rivulet passes through a series of short falls, known as Bhatta falls. Moving further south, at a place 2 furlong N.E. of electric power house, this rivulet is joined by Bhatta-Khala and Siwala Khala ~~and~~ ~~Bhalas~~. Both of these Khalas as well as the above mentioned Nalapani khala are structural stream-flowing through anti-clinal valleys. Near the meeting point of Kiarkuli Nadi and Bhatta khala there is a steep creeping scarp (Photo 1 and 4). At this place Kiarkuli Nadi changes its course from S to S-W. Further S-W of Mussoorie Kiarkuli Nadi is

Photo-5

Photo-6

Photo-7 a



Phogot 7 b

added with several streams and ultimately discharges its drainage into Tons river.

Rispana Nadi

This stream flows in eastern region of the area and is developed on a similar pattern as Kiarkuli nadi. The initial channel, the Company Khadh, flows along a fault valley, roughly in north-south direction. It is joined by a number of tributary channels along its course.

About 2 furlongs south of Wynberg High School this khala passes through a steep and narrow gorge and forms a number of step falls, known as Mossy falls. Moving two furlongs south of the Mossy falls the stream is joined with Sivala Khala and becomes a rivulet known as Rispana Nadi. The Rispana nadi continues to flow south wards and ultimately merges into the Suswa Nadi at Clement Town, Dehradun.

Water Falls:

The streams in the limestone formations have given rise to numerous rapids, cascades and at many places to magnificient water falls (Photo No.5 and 6). The most picturesque falls met within this area are Mossy falls and Bhatta falls.

Mossy falls-

At a distance of about two miles SSE of Landhour, Clock Tower, the Rispana Nadi passes through a number of step falls. The highest of them is 15' in height. Water discharged is small and cause only a narrow stream during low water period. The country rock is limestone, which is highly jointed. The most prominent set of jointing is running in the direction N 40-220. This direction is parallel to the ledge of the fall. Therefore, it indicates that the fall has been caused by the removal of a rock-block along the above mentioned joint plane. Similar removal of other blocks, along this set of parallel joint-planes, might have given rise to the series of step falls.

The scarplet across which the stream course is falling is 15 feet in height and 25 feet in width. The water falling vertically downward has corroded the wall-rock along its course. Three such vertical cuttings are seen on the wall of the scarplet indicate the shifting of the fall at different stages.

Another notable feature of Mossy fall is that the side-walls of the down as well as the upper channel are in the form of an arch (Fig.5). It seems that previously this channel was an underground cavern, whose roof has now fallen to form an open valley. . ... .. similar

Bhatta Falls

A series of similar small step falls is located nearly a mile and a half west of Bhatt toll checking barrier and is known as Bhatta falls. These falls have also been caused by the removal of the rock blocks along joint planes. The falls though not very high are extremely spectacular. The water from these falls is used for producing hydro-electricity.

PLAN OF THE PRESENT WORK AND ITS CONTRIBUTION

The object of the present work was to study in detail, the geology of the south-eastern Mussoorie area and on its basis and on the basis of other available data, to assess the seismicity of the region. The problem was tackled in a three-fold manner viz. a large scale mapping of the area, the study of the rock specimens in the laboratory and collections of data regarding the commencement of earthquakes in the Mussoorie-Rajpur and surrounding regions.

The geological mapping of the area was carried out on 'Eight Inch Mussoorie and Landhour Guide Map' prepared by the Survey of India in 1946.

The total field work was of two months duration and was carried out in two stages, each time followed by laboratory studies.

Maximum field data were collected within the limited time allotted for the field work. Emphasis has been given to mark the various lithological boundaries with the greatest possible accuracy. Over 300 rock specimen were collected during the field work.

More than 25 thin sections of the rock specimens were studied under the microscope. A few polished sections were examined under the ore microscope to study the metallic minerals present in a few rocks. The MgO/CaO ratio of 15 dolomite and limestone specimens were determined by the method of EDTA titration. Modal analyses of two basic rock samples were carried out by Swift Point Counter method.

During the stay at the field, the author collected information regarding the recent earthquakes felt in the area. The information obtained from the natives of Mussoorie were taken down on a tabulated form supplied by the School of Research and Training in Earthquake Engineering. These works done during the present investigation resulted the following contributions to the previous geological works made in the area.

(1) It gave a large scale mapping of S-E Mussoorie area which differs, essentially in few respect, from the existing geological maps of the area by Auden and other subsequent workers.

(2) The Krol-Tal contact which was considered so far as a plane of unconformity, has been found to be contact of dislocation at least in the present area.

(3) A revision was made in respect of the hitherto known "Upper Krols" and this formation has now been divided into two stages the Upper Krol limestone and the Upper Krol Dolomites. In addition to the field characteristics MgO/CaO ratio of the rock was found to be the most satisfactory basis for

this classification.

(4) The occurrence of barytes is being reported for the first time in the area. These barytes occurrence though probably not economical because of its small size and poor quality, may be interesting from academic point of view in respect to its genesis.

(5) The true nature of the igneous intrusive was worked out in the field and it was found to be a trasgressive sill.

(6) The structural and the available seismic data were correlated and it was concluded, on this basis, that the seismic factor has to be considered as an important factor during the designing and construction of any major structure in this region.

CHAPTER II

PREVIOUS WORKS IN MUSSOORIE AND OTHER GEOLOGICALY RELATED AREAS

The lower Himalayas have been drawing the attention of the geologists since past several decades owing to their structural complexities. A number of expeditions have been made in several parts of this region including the area under investigation. An additional geological interest in Mussoorie-Rajpur area has been due to the presence of high grade limestone and marble deposits. As a result, a number of geological works have been carried out in the area.

Medlicott (1964) was the pioneer worker in the lower Himalaya, who studied the geology between Ravi and Ganga rivers. He has made a passing reference to the Mussoorie-Dehradun area.

He classified the pre-tertiary formations of lower Himalayas into two broad groups and gave the following sequence:

Himalayan Series	Unmetamorphics	Krol Infra Krol Blaini Infra Blaini.
	Metamorphics-	crystalline and sub-crystalline rocks

Oldham (1883,1888) carried out geological investigations in the Chakrata Tahsil of Dehradun district and in region extending upto west of Tons river. He was concerned chiefly with the Blaini rocks to which he suggested a glacial origin and showed its equivalence to Talchir series.

Middlemiss (1887, 1890) carried out detailed survey in several parts of lower Himalayas and established the sequence given in the following table.

TABLE II (a)

	Sub-Himalayas
Outer Formations	Nummulitic
	Tal
	Purple slate
	Volcanic Breccia
Inner Formations	Schistose series
	with intrusive
	Gneissic Granite

Middlemiss noted the presence of "older schistose rocks with intrusive gneissic granite (older rocks) capping the higher mountains, surrounded on all sides and at a lower level by unmetamorphosed (younger) rocks, including limestone and dipping towards and under the schistose series " . But he was unable to give any satisfactory, explanation for this relation between 'Inner' and 'Outer' formations.

Pilgrim and West (1928) carried out a detailed survey of Simla area. They demonstrated for the first time, the presence of nappe structure and overthrust with inversion of the strata between Simla and Chakrata. They classified Krols into six stages and Tals into two stages.

Auden J.B. (1934,35,37,42) - The work of Pilgrim and West was subsequently continued by Auden (1934,1935, 1937,1942) to cover the lower Himalayas between Gambhar and Jamuna rivers. His famous work on the Krol-belt was published in the year 1934. Soon after he published another paper (1935) on the structure of Garhwal Himalayas. These works of Audenn described the structure of Garhwal Himalaya. He showed that this region consists of two nappes-the Krol-Nappe and the Garhwal-Nappe, which have been thrust over the younger rocks in the south-west.

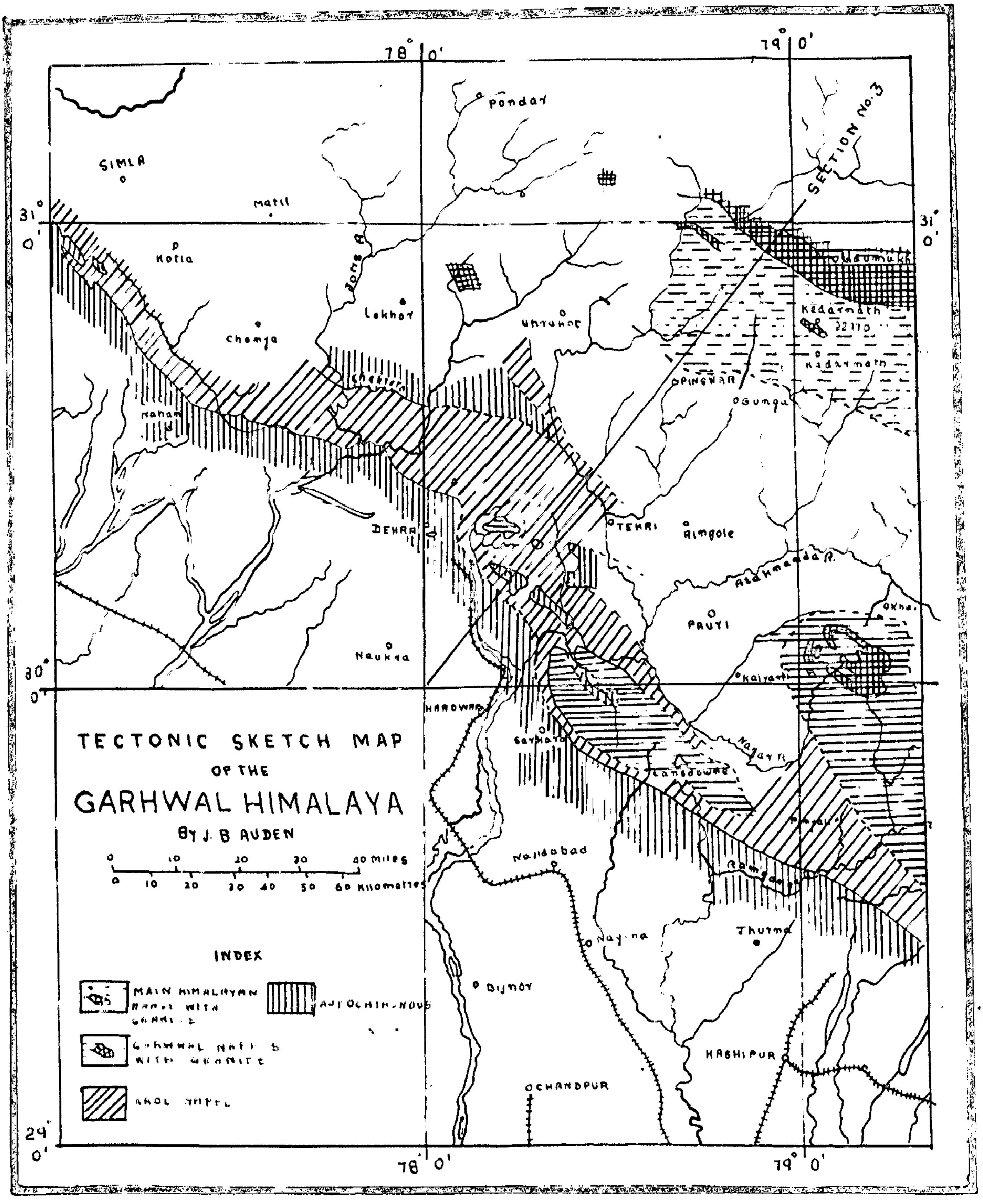
Following table shows the lithological sequence of lower Garhwal Himalayas, east of longitude 78°E as worked out by Auden.

TABLE II (b)

Formations		Unconformity	Approximate maximum thickness.	Probable age.
Siwalik			16,000 ft.	Up Miocene to Pleistocene
Murree almost absent east of long. 78°				Lower Miocene
Nummulitic		~~~		Eocene.
Tal limestone and Calcgrit.		~~~	200 ft.	Up Cretaceous?
Tals	Up. Tal quatzite.		4,500 ft.	Cretaceous?
	Lr. Talshale.	~~~	2,000 ft.	Jurassic.
Krol	Up. Krol-Dolo-mites L.St and Shales		3,000 ft.	Trias.
	Krol red shales Lr. Krol L. St. and shales.		1,000 ft.	Permian.
Blaini	Infra Krol slates.			
	Up. Blaini Boulder bed and dolomite.	~~~	2,000 ft.	Talchir (Uraliam)
	Blaini slates.			
	Lr. Blaini boulder bed	~~~		
Nagthats.		~~~	3,000 ft.	Devonian?
Chandpur.			4,000 ft.	Lower Palaeozoic and Pre-cambrian.
Simla slates (possibly equivalent to the Chandpur series although different in lithology.				
Dolerite.				Late Tertiary.

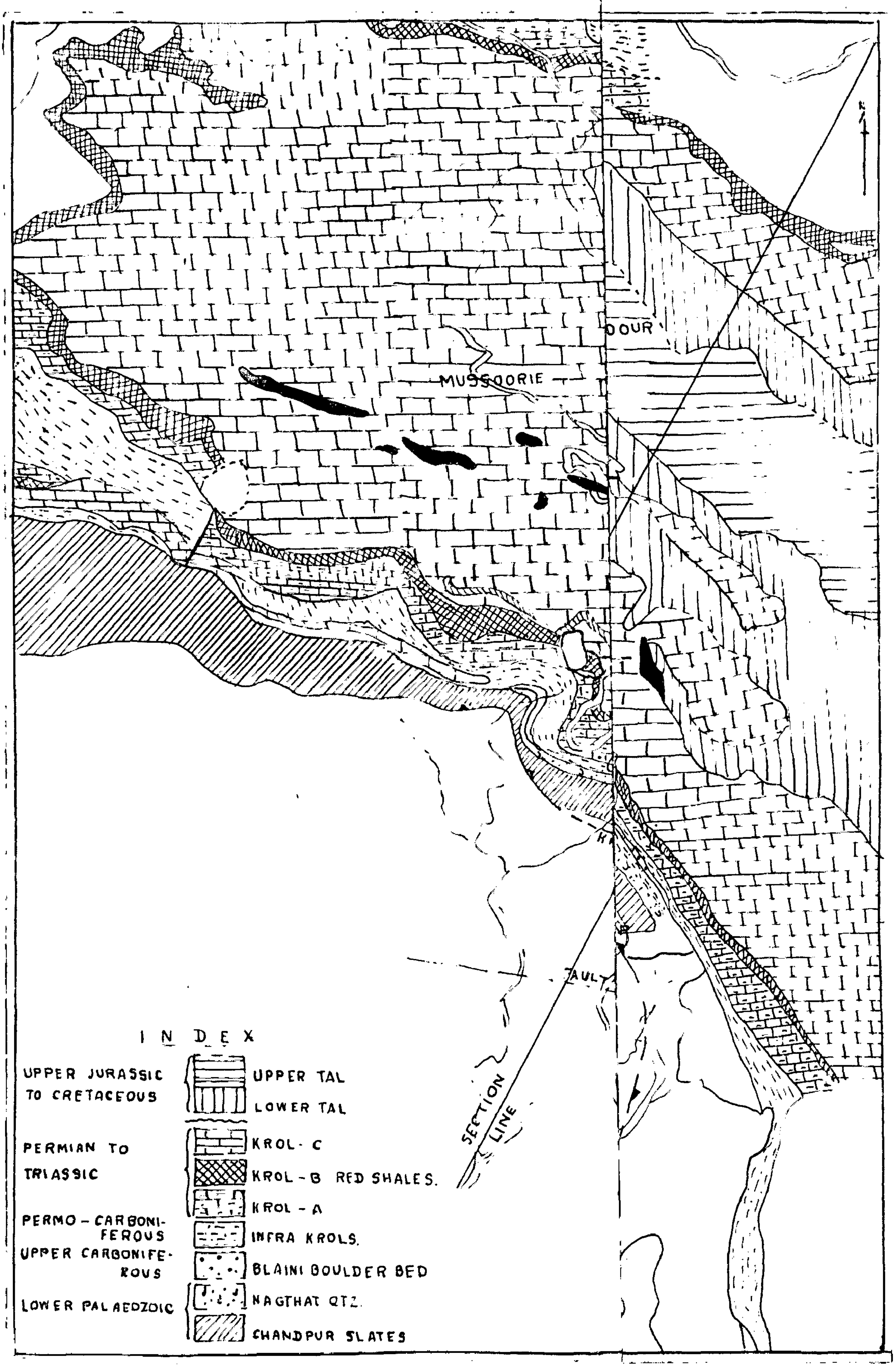
Note ———— = Non conformity. ~~~~ = Unconformity

MAP- 3


78° 0'
79° 0'
31° 0'
30° 0'
29° 0'
SECTION No. 3
SIMLA
Kotla
Chamja
Lakhor
Nahan
DEHRA
TEHRI
Rimgole
PAUTI
Naukra
HARDWAR
Lansdowne
Bijnor
KASHIPUR
CHANDPUR
Thurma
Kedarnath
TECTONIC SKETCH MAP
OF THE
GARHWAL HIMALAYA
BY J. B AUDEN
0 10 20 30 40 Miles
0 10 20 30 40 50 60 Kilometres
INDEX

Map 4

GEOLOGICAL MAP OF DEHRA DUORIE (After AUDEN)



Auden has classified the lower Garhwal Himalaya into three tectonic units viz.

(i) The Autochthonous Unit.

(ii) The Krol Nappe, and

(iii) The Garhwal Nappe.

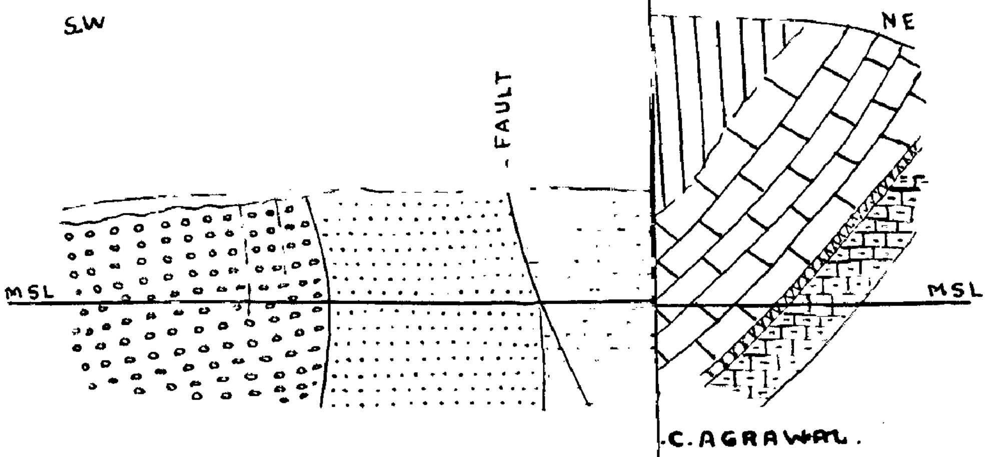
The tectonic map of a part of the Garhwal Himalaya relevant to present discussion is given herewith (Map-3). A representative section is also given (fig. 6).

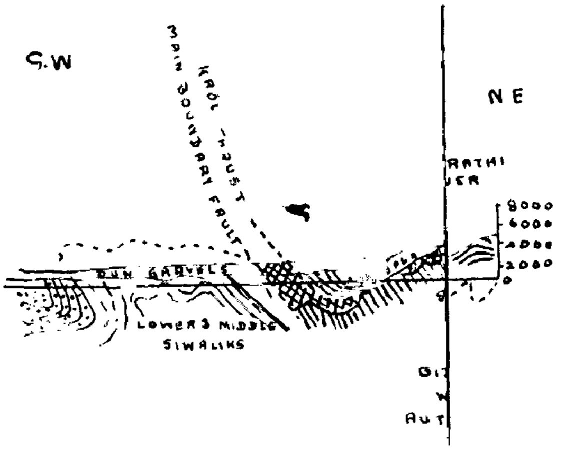
Autochthonous Unit-

The base of the Autochthonus unit is probably the Simla slates series, overlying which occur Nummulite, Murrees and Siwaliks. A series of thrusts occur within this unit most important of which is the main boundary fault. This seperates the Siwaliks from the zone of Simla slates, which underly the Nummulitic and other lower tertiary strata.

Krol Nappe-

The Krol Nappe, which in Garhwal area involves not only the Krol series but also the underlying Blaini, Nagthats and Chandpur beds as well as the overlying Tals, is made up of an uninverted sequence of over 20,000 feet (6,100 meters) of strata. It is bounded below by Krol thurst which has brought the older rock over the Autochthonus units. The Krol nappe itself is folded by later disturbances which have foliated the Krol Belt. Culminations within the Krol belt have exposed Simla slates in Bidhalna and Pharat windows


S.W
NE
FAULT
MSL
MSL
C. AGRAWAL.


S.W
NE
MAIN BOUNDARY FAULT
KRÖL THRUST
RATHI
VER
8000
6000
4000
2000
0
DUN GRAVELS
LOWER & MIDDLE
SIWALIKS
AUT

where these are unconformably overlained by marine Eocene rocks. Krol thrust, which is widely separated from the Main Boundary Fault, west of Nahan, transgresses southwards in the east and finally overlaps it.

Garhwal Nappe-

The Garhwal Nappe is superposed on the Krol Nappe, the relations being such that the rocks belonging to the underlying Krol Nappe completely surround the older Paleozoic metamorphosed schistose series of rocks of the superincumbent nappe and dips below them in a centripetal ~~Himalaya~~ manner, where the rocks are more metamorphosed and include a distinct group of paragneisses and schists.

In Garhwal the Krol-belt rocks are exposed in the form of two huge synclines with the intervening anticlinal belt exposing a complicated assemblage of Tal and Eocene marine sediments. The larger of the two synclines is the Garhwal syncline which is en echelon with the other, that is, the Mussoorie syncline.

The syncline stretches east-west between Kalsi-Chakrata and Hunil river in Tehri-Garhwal. The geological map of Mussoorie-Dehradun area, as given by Auden (1934) is enclosed herewith (Map-4). A geological section according to Agrawal (1964) is given in Fig. 7.

In the year 1939 Auden paid a brief visit to the marble deposit in upper krol limestone of Mussoorie. He estimated the reserves and discussed the utility of marbles for the manufacture of calcium carbide. He suggested metasomatic origin for these deposits. Auden continued his study afterwards and in connection with the Jamuna Hydro-electric Scheme he discussed the seismicity of the Krol belt. According to Auden (1942), the Krol thrust has been active in geologically recent past.

Krishnan and Swaminath (1959) have referred to an earlier work of Boileau, carried out in 1954 in Bilaspur-Mandi and Kangra Dharamshala areas. According to them, Boileau considered the Blaini boulder bed as equivalent to the Kainur series instead of the Talchirs as suggested by earlier workers like Oldham and Auden.

Nautial (1954) visited Mussoorie Rajpur areas in 1953 and submitted a report entitled "A Geological Report on the Mussoorie-Dehradun Marble quarries with particular reference to the hill slope". He advised that at certain places the quarring should be stopped because it is causing unstability to the slopes which may be proved hazarduous to the Mussoorie-Rajpur Motor road.

D.R.S. Mehta, Murthy and Narshimhan (1959) investigated the high grade limestone deposits of Dehradun-Mussoorie area. They have given in their work, a brief account of the physiography and geology of Mussoorie area.

Ravi Prakash (1958, 1960) revised the work of Mehta et al. and investigated the continuation of the entire marble belt.

W.Mehta (1962) has discussed the nature and origin of Krol thrust. He came to the conclusion that the Krol Nappe has been brought to its present position by gravitational gliding.

Raju and Bhattacharya (1962) have published a paper on 'The studies of the insoluble residues and other geochemical studies on the Krol rocks".

Mithal and Chaturvedi (1963) during the Symposium on Himalayan Geology held at Calcutta in October 1963 reported the occurrence of probable algal structure in the Upper Krol limestone of Mussoorie. On the basis of morphological studies. They have concluded that the structures could belong to Collonia.

Srivastava (1963) during the above mentioned symposium reported a fossil lamellibranch Posidonia from Lower Tal shales of Mussoorie and supported Auden's view regarding the Jurassic age for this bed. During the same symposium, he reported the occurrence of phosphatic nodules within the shales of lower Tal beds of Mussoorie.

Gansser (1964) while discussing the Krol-Tal succession, has observed that the Krol series is divisible into five distinct members viz. Krol A, B, C D and E. Regarding the Blaini boulder beds, he agrees with the view that they should be correlated with the Talchir boulder beds and their tillite aspect is undisputed. About the Krol-Tal relationship he has observed "After the deposition of Calcareous Krol Section, a striking change in deposition took place, and the younger beds consist exclusively of detrital, mostly quartzitic rocks.... there can be little doubt about their normal stratigraphical contact with the underlying limestones. The detrital sediments have been called the Tals,......" Dealing with the krol thrust, he has observed, "None of the Krol thrusts has actually been formed through large recumbent folds..... We actually have to deal with proper thrust sheets and not recumbent nappes."

CHAPTER III

GEOLOGICAL SETTING OF THE AREA

The area under present investigation constitutes a part of the Krol-belt. Structurally it is a part of the S-W limb of Mussoorie syncline whose axis passes through Toneta forest, Landhour Cant, and Bataghat etc. This limb of Mussoorie syncline in itself has been refolded into a number of anticlines and synclines severals of which are noted in the present area.

The rocks exposed in the area belong to Infra Krol, Krol and Tal series. The sequence as worked out on the basis of the lithological characteristics and the structural relationship of various formation, is given in the following table:

TABLE III (a)

Designation	Average thickness.	Lithology	Correlation with standard	Age (after Auden)
1	2	3	4	5
Upper Tal	Over 300' (9.15m)	Siltstone and quartzite	Upper Tal	Cretaceous.
Lower Tal	2,000 (610 m)	Calcareous , cherty and carbonaceous shales.	Lower Tal	Jurassic

——— Tal thrust ——— ~Unconformity~

continued.

1	2	3	4	5
Upper Krol Dolomites.	5,000 (1525m)	Calcareous Dolomites and shales.	Krol D)	Trias
Upper Krol limestones	600' (182 m)	Limestone and marble	Krol C)	
Krol Red shales.	250'	Purple-red shales.	Krol B)	Permian
Lower Krol	800'	Slaty shales and Limestone	Krol A)	
Infra Krol	over 200'	Phyllitic shales	Infra Krol-	Talchir (Uralian)

The lithological and structural maps of the area prepared during the present investigation and a few typical sections are enclosed in the back envelop.

The Infra Krol Series.

Infra Krol forms the base of the overlying Krol series. It consists of dark phyllitic shales with thin varve-like bands of slaty quatzite. Owing to their highly incompetent nature, these formations have suffered intensive crumpling. They are traversed by numerous veins of quatz and calcite criss-crossing each other.

The Infra Krol beds are folded together with the rocks of the krol series. The exposures of Infra Krol are, therefore, repeated in the area and occur at two places in the south-western corner of the area and again near the electric power house.

The Krol Series.

The Krol series conformably overlies the Infra Krol formation. On the basis of lithology and other field characteristics the series can be divided into four distinct stratigraphic units viz. the lower krol, krol Red-shales Krol Limestones and Krol Dolomites. First three of these units correspond to Krol A, B and C respectively. The last unit-the Krol Dolomite is probably equivalent to both the Krol D and E stages together, which due to the lack of any differentiating characteristic and gradational lithology could not be separated in this area.

Lower Krol-

This stage overlies the Infra Krol and consists of rapidly alternating bands of slaty shale and limestone. The shales are of earthy colour and calcareous while the L. St. is fine-grained, dull, bluish-dark-grey and clayey. Thickness of the bands varies from 2 cm to 10 cm. Owing to their high degree of cleavage - schistosity and the intensive jointing the shale disintrigrates into pencils and needles like fragments. Along the joints the shales have been traversed by calcite veins which have followed the joint planes and thus, give rise to square, rhombohedral and rectangular patterns. Small scale puckering is common.

The lower Krol formation is exposed all along the S-W boundary of the area, but its best exposure are found on the Mussoorie-Rajpur motor road, along which the lower krol outcrops are met twice due to the folding.

Krol Red-Shales.

The lower Krol formation is overlain by Krol Red Shales which are soft, thinly laminated, purple-red shales with blotches and intercalations of green chloritic shale. These are closely jointed and sheared to such an extent that it is difficult enough to obtain proper hand specimens. Owing to their incompetent nature of the original bedding of these shales have been obliterated.

The Krol Red Shales show the maximum effect of folding in this area. Due to the highly incompetent nature, of these shales, not only the original beddings have been obliterated, but also the beds pinch out due to the south western folding. With these shales are not exposed between Kalukhet and Mussoorie-Rajpur Motor Road, a distance of about two furlong (800 meters). The width of the outcrops increases eastward from Kalukhet as well as westward from the motor road. The maximum development of the krol red shales is seen in the vicinity of Kiarkuli Nadi, where this formation attains a thickness of over 300 feet (915 meters). Good exposures are seen on the face of the escarpment along the right bank of Kiarkuli Nadi.

Upper Krol Limestone-

Overlying the Krol Red-shales there is a sequence of black, dark grey to pale-grey limestones, weathering to large blocks with broad surfaces and very often giving a sulphurous smell on freshly broken surfaces. The limestones show varying degree of recrystallisation and are high grade limestone in composition having MgO/CaO ratio less than 0.2. Within these limestone formations, however, there are streaks and pockets of highly magnesian limestone (MgO/CaO ratio about 0.5).

In the basal part of this limestone formation there is a discontinuous shale band which is lenticular in nature and frequently show pinching and swelling behaviour. This shale band is often in direct contact of underlying Krol-Red-Shales. The shales of Lower Krol-L.St. stage resembles to a great extent with the slaty-shale of Lower krol, but are softer and have less development of cleavage schistosity. Such shale bands are exposed near the Jharipani Toll-bar as well as north-west of Kiarkuli Nadi.

The total thickness of krol L. St. stage is over 600' Thickness of the formation is nearly constant all along its strike. The top-most portion of this stage gradually grades into a crypto-crystalline white coloured marble. Chemically it is almost a pure form of calcium carbonate, and is suitable for a number of industrial purposes. It takes good polish and would have been an excellent marble for statuary purposes were it not so highly jointed. Close-spaced jointing is universal and hence it is impossible to obtain slabs or well shaped blocks. Bedding is very rarely observed in the marble, the divisional planes being joints oriented at various angles. The marble grades gradually downwards and no sharp boundary can be drawn between the marbles and the rest of the Upper Krol Limestone stage.

The marble band has been traced out from west of Kiarkuli water-fall to Jharipani along its strike. It is well exposed across the Kiarkuli Nadi, at Bhatta, and north of Kalukhet water supply. Further east-ward, after getting folded, the band starts narrowing and seems to thin out near the Oak Grove School. All along its exposure the marble together with the other pure limestone of this stage is quarried by private owners. Important quarries situated within the area are Lachhaman Das quarry at Kiarkuli, A.Deans Bhatta quarry and a Maulasa Quarry at Jaripani. The limestone and marble is quarried mainly for flooring purposes but the marble is also utilised in sugar refining.

<u>Upper Krol Dolomites-</u>

The Krol limestone stage is overlain by a thick succession of doloritic limestone beds ~~with intercealations of dolomitic limestone beds~~ with intercalations of various types of shales. The plane separating these two horizons can be sharply traced in the field as well as on the basis of MgO/CaO ratio-the ratio never exceeds .1 in Krol lime-stone whereas it is over .6 in Krol Dolomites.

Photo-8

Photo-9

Photo-10

Fig-8 An overturned fold in the dolomite and shale formations of Krol seen near the Kincrag bus stand. Sectional view

Fig-9 A fault between thickly bedded dolomite and dolorite-shale bands. Seen by the side of Mussoorie-Raipur Motor road, near Bhatta.

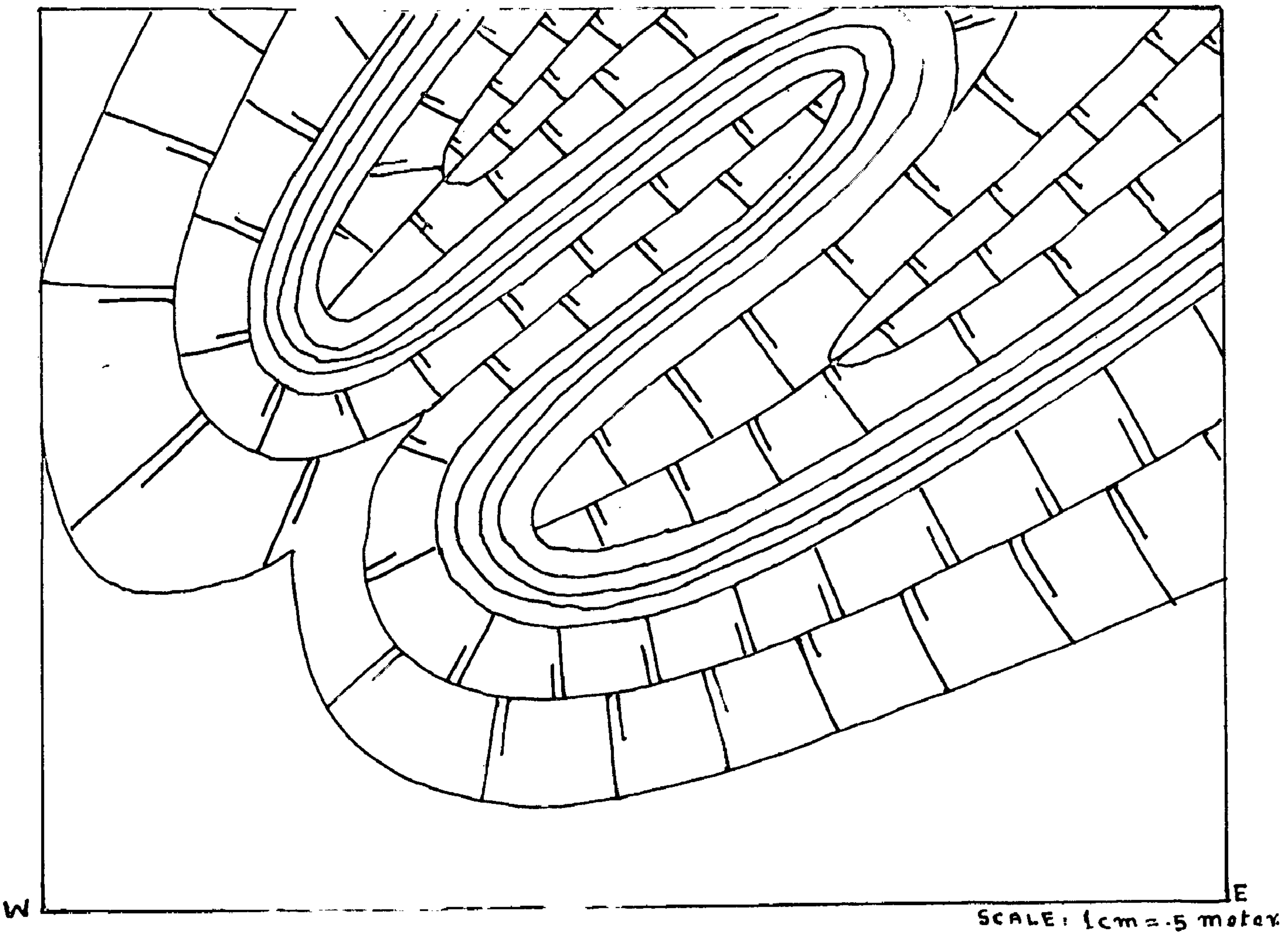


FIG. 8

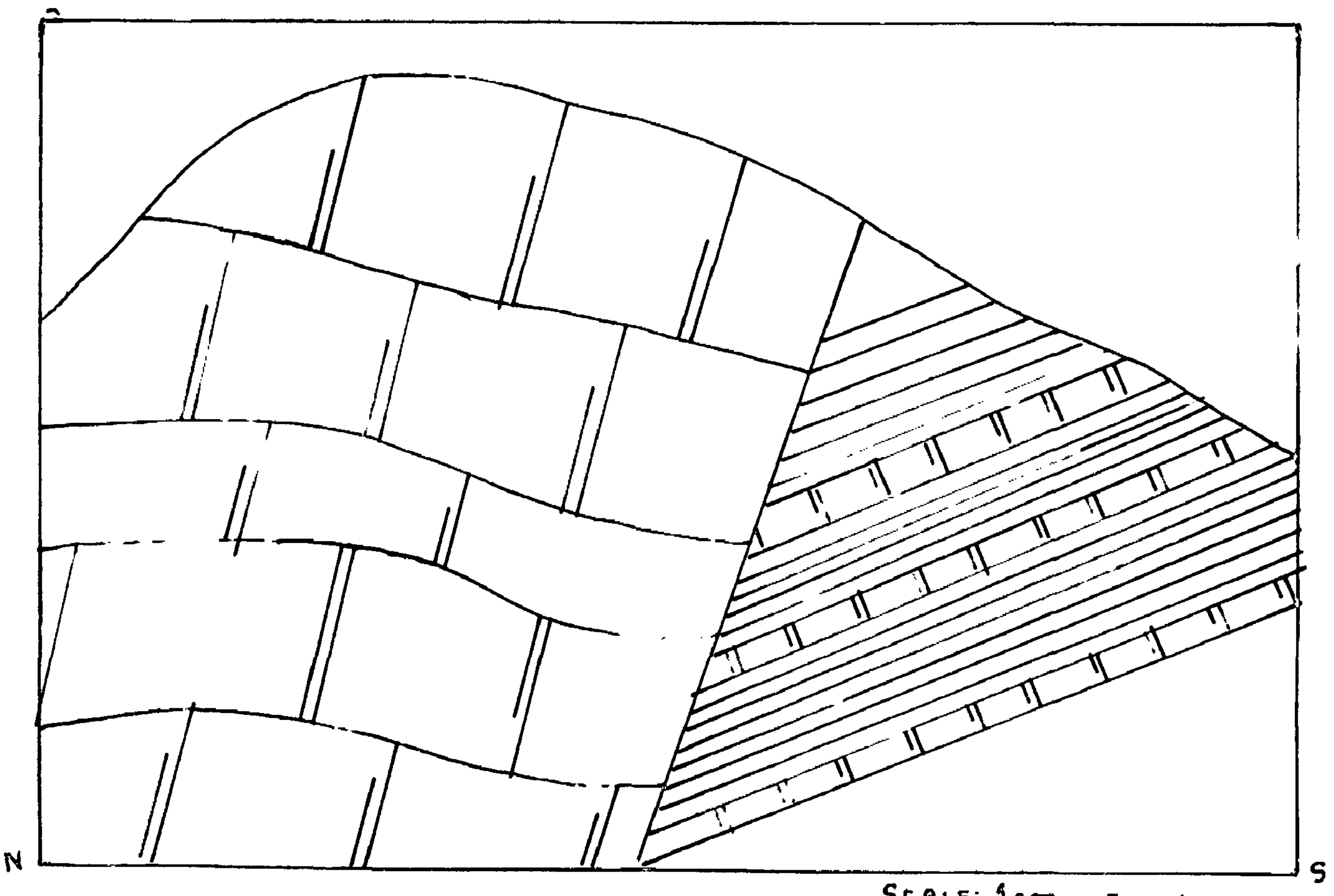


FIG. 9

The lower and upper parts of the Krol dolomites corresponds to Krol D and E stages respectively. A specimen from the lower most horizon of Krol dolomite can be distinguished from that of the upper-most part but the change is so gradual that no dividing plane can be drawn and hence it is better to recognise the whole succession as a single stratigraphic unit.

The lower-most portion of the Upper Krol Dolomite stage is composed of loosely consolidated fragmentary limestone together with powders carbonaceous-argilaceous material (Photo No.8). In its extension this horizon is fairly continuous outcroping all along Fairlawn, Bhatta and Kiarkuli etc. The thickness is over 80' (24.4 m) at places. The rocks have been traversed by numerous calcite veins (photo -9) and there are no traces of original beddings. Within this horizon of fragmentary dolomites, there are pockets of compact and massive dolomite which have preserved the original bedding planes. The unconsolidated loose material is quarried locally on a small scale and is used as foundation material.

This unconsolidated carbonaceous dolomite formation gradually grades upwards into a massive dolomite. Lenticular bands of various types of shales are found within this horizon. The shales are of various colours like pinkish-brown , buff, bluish-grey and red. Calcite vein filling and other cavity fillings are commonly seen within this horizon. Tiny pockets of gypsum (alabaster) is found at few places.

In the absence of fossils no exact age can be assigned to the Krol series, but since the Krol series is in conformity with the upper carboniferous Blaini series, it appears to represent the Permian and probably also the Trias. The Blaini series and the Krol Series together thus correspond to the Lr. Gondwana.

Structures in Krol Series.

The Krol series represents a huge sequence of univerted strata. The general dip of Krol formations is 30° to 60° due NE, which is the general dip direction of the S-W limb of Mussoorie syncline. Frequent inversal of dip direction have been caused due to number of folded structures in the Krol formation (including infra Krols). Among some of the important and comparatively major fold structures, met within the area, mention may be made about the followings:

1. A couple of anticline and syncline in the Fairlawn-Powai House region in the southern part of the area.
2. A couple of anticline and syncline near Bhatta.
3. A major synclinal structure due west of Barlowgunj.
4. An anticline south of white hall, and
5. An anticline north-west of Mackinans Road,

The axes of the first four foldings are normal or oblique to the axis of the main Mussoorie syncline, where as that of the last mentioned is parallel to the axis of Mussoorie syncline. Section along A-B (enclosed in the back envelop) well represents the first four of the

A peculiar stromatolite-like structure (described in Chapter IV) is found developed at a few places within these dolomites. The stromatolytic structures are seen near Brookland, St. George College, Kinaag and a few other places.

Total thickness of the massive dolomite horizon is over 2,500′ (7625 m.). The bedding planes are obscure in the massive dolomites. However, the intrecated shale bands show well preserved beddings. Joints are wide spaced and not as frequent as in other horizons of the area.

This massive dolomite horizon is well exposed all along the Brooklands, the Dhobighat village and Mackinans Road etc. This horizon shows upward gradation into a banded microcrystalline dolomite with grey to cream-white bands imparting a rather well-bedded nature to the rocks. The bands are 25 cm. to 1.5 meter in thickness. The intercalation of shales become less common. In the uppermost portion it is cherty and porcellaneous in appearance and form rugged topography.

With the exception of probable algal structure (stramatolites?) , the entire krol series was found to be completely baren of fossil. Actually it is an strange that these formations "eminently adopted to preserve any entombed organisms, are entirely barren of fossils" (Wadia, 1952). It seems that the basin of deposition was far from favourable for the habitation of organisms.

In the absence of fossils no exact age can be assigned to the Krol series, but since the Krol series is in conformity with the upper carboniferous Blaini series, it appears to represent the Permian and probably also the Trias. The Blaini series and the Krol Series together thus correspond to the Lr. Gondwana.

Structures in Krol Series.

The Krol series represents a huge sequence of univerted strata. The general dip of Krol formations is 30° to 60° due NE, which is the general dip direction of the S-W limb of Mussoorie syncline. Frequent inversal of dip direction have been caused due to number of folded structures in the Krol formation (including infra Krols). Among some of the important and comparatively major fold structures, yet within the area, mention may be made about the followings:

1. A couple of anticline and syncline in the Fairlawn-Point House region in the southern part of the area.
2. A couple of anticline and syncline near Bhatta.
3. A major synclinal structure due west of Barlowgunj.
4. An anticline south of white hall, and
5. An anticline north-west of Mackinans Road,

The axes of the first four foldings are normal or oblique to the axis of the main Mussoorie syncline, where as that of the last mentioned is parallel to the axis of Mussoorie syncline. Section along A-B (enclosed in the back envelop) well represents the first four of the above mentioned folding structures.

Folding in Southern Part.

The folding in the southern part of the area has affected all the rock formation right from Infra Krol to Upper Krol Dolomites.

The folding has affected the trend of the outcrops as shown in the geological map of the area, enclosed in the back envelop. Along the folding the Krol Red Shale formation has suffered flowage and are, therefore, missing from the area which has suffered folding.

The folded character of the rocks is well exhibited on the Rajpur-Mussoorie Road. As one moves towards Mussoorie, the dip average 30° due N 20° in the southern part of the area mainly comprising of Lower Krols. The outcrops of Krol Limestone also follow the same dip for nearly a furlong and then suddenly the dip changes to 40° due S. This reversal marks the axis of a syncline running in roughly ENE-WSW. Further north, the outcrops of Lower Krols are repeated with the similar southward dip. At a place due east of the Power House where the road cuts across the Siula Khala, the lower krols show a further reversal and are thrown into an anticlinal fold with the dip changing to 70° due N. The axis of this anticline is almost parallel to that of the syncline. The axis of the folds extend from west to east in the entire southern portion and subsequently all the Krol formation are affected.

Folding near Bhatta.

Folding near Bhatta has also caused a couple of anticline and syncline. Both of these folding structures are plunging approximately 25° ENE. The anticline has been eroded to an anticlinal valley through which the Bhatta Khala has taken its course.

Syncline west of Barlowgunj

A portion of the area west of Barlowgunj Bazar and east of the Bhatta falls is in the form of a major syncline. The limb of this syncline dips 70° due N20 whereas the northern limb dips 50° due N200. This synclinal mass has formed a highland.

Anticline south of White Hall

Further north of the above mentioned syncline, there is a plunging asymmetrical anticline. The northern limb of the anticline is dipping 70° due N20 whereas the southern limb dips only 25° due N 160. Northern limb of the fold has in itself been refolded. A portion of the anticline has been eroded and has given way to the Nalapani Khala.

Anticline near Mackinans road

The folding west of the Mackinans road has given rise to an anticlinal hill, good sectional view of which is seen along the road-cutting near milestone 3. The anticline is more or less symmetrical, with the dips of the two limb being 60° due N20 and 70° due N 200 respectively.

In addition to the above mentioned folding structures, the rocks show numerous minor foldings in the area.

In contrast to the major foldings a few of the minor structures have suffered overturned foldings. Good out-crops of such overturned folding are seen along the road cutting near Kincrag bus stand. (Fig.8).

Faulting.

There is certain to be considerable faulting with-in the Krol formations. But the mapping of the faults is not easy on account of the less litholo ical variation and the general lack of striking bands.

A fault, however, has been recognised just north of the Bhatta village. The sectional view as seen along road-cutting has been given in the figure 9.

The fault plane is dipping 70° due N. Faulting has brought two rockstypes of Krol Dolomite stage in juxta-potion with each other. On the hanging wall side there are thickly bedded dolomites bands, which are nearly horizontal. On the foot wall side are alternate bands of shales and dolomite. The throw of the fault could not be determined.

Joints.

Krol formations have suffered intensive jointing. More than one set of jointing can be seen almost at every outcrop of these formations. However, highest intensity of jointing is observed within the lower Krol, Krol Red shales and in the marble bands (Photo No.10). In these formations the spacing of jointing is as close as a fraction of a centimeter. The uppermost horizon of the Krol formation have also been extensively jointed but the intensity of jointing is moderate to low in the middle portion. The most important set of joints dip 70° to 80° due N210 to N225 other important sets are 10° to 40° due N20 to N40 (bedding joints) and 60° to 70° due N130 to N 140.

Slaty Cleavage.

Slaty cleavage is seen well developed within the shales of Lower Krol and within that of the basal part of Upper Krol limestone. At places it is also seen developed within the shales of Krol Dolomites. In most of the cases the schistosity plane (S_2) is parallel to the bedding plane (S_1), but there are cases when the strike of the schistority plane is same as that of the bedding plane, but the amount of dips vary. Such variation is, however, small and the maximum difference is 20°.

THE TAL SERIES

Krol series is overlained by Tal series - a sequence of various types of shales, siltstones and quatzites. The nature of the contact of Tal with Krol was found of much interest from structural point of view and hence is briefly

Photo 11

described below:

Krol- Tal Contact
(Tal thrust?)

The contact between the Upper Krol dolomite and the lower Tal shales does not seem to be normal. Previous workers have regarded this contact as unconformity, but the present work has indicated that this contact is more like a faulted or more correctly a thrusted contact, where there is a relative movement between Krol and Tal Formations. The fault dips 20° due N 20°E, in general, although in a portion of the area the thrust plane is folded and dips 40° due S 20° W. This folding has exposed the underlying Upper Krol dolomites in a narrow belt extending parallel to the strike of beds. There are several indication of the contact between Krols and Tals being a tectonic one. Some of the important field observations which may be sited in support are the following:

(i) Intensive crushing is noted all along the contact. Both the rocks of Krol and Tal formations have brecciated and crushed from small angular fragments to fine powder (fig.10 Photo 11). Water seepage is common along this crushed contact plane.

(ii) The contact surface is irregular. Its dip at places differs from the dip of the Tal and Krol beds. Near its south-western

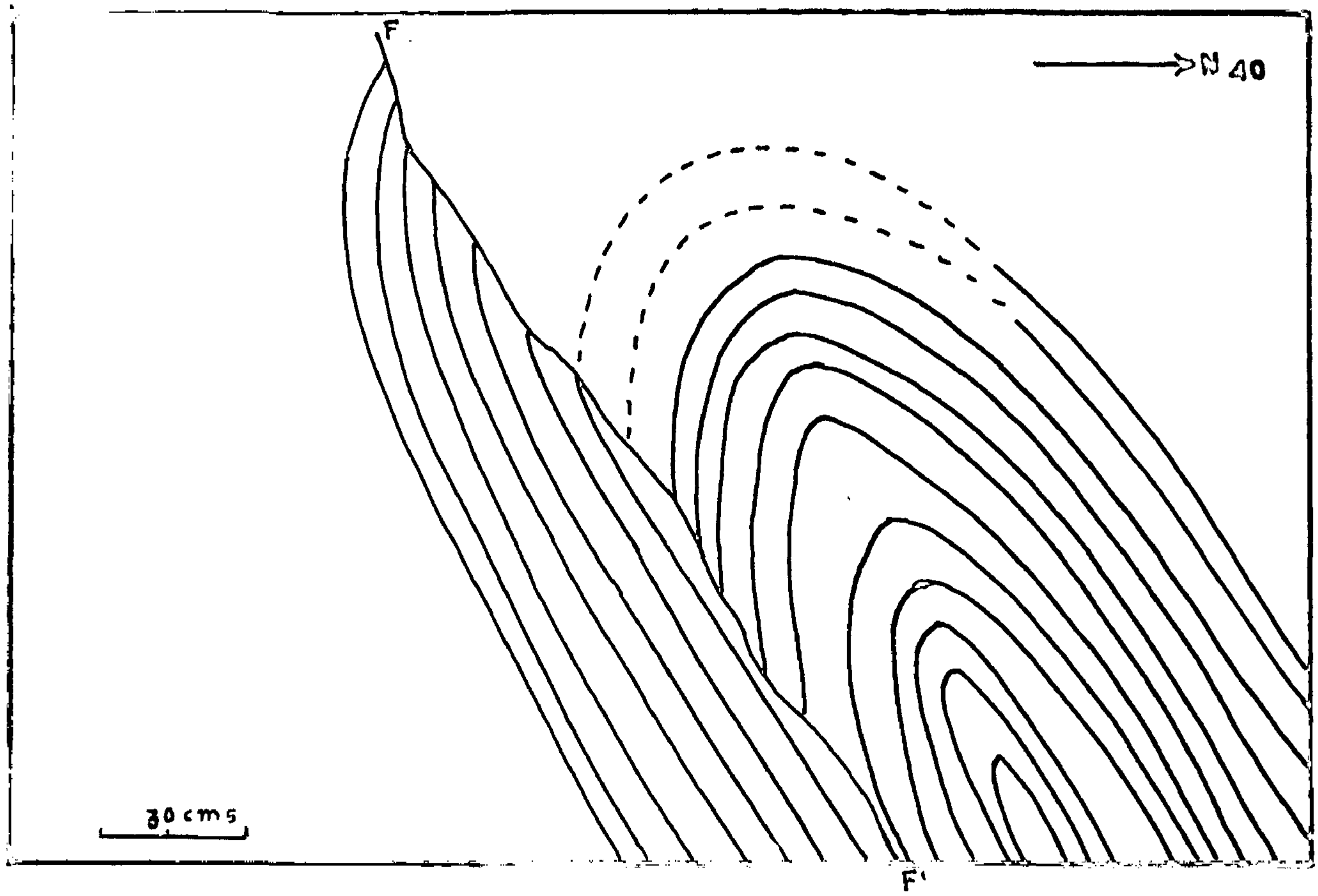


FIG. 11

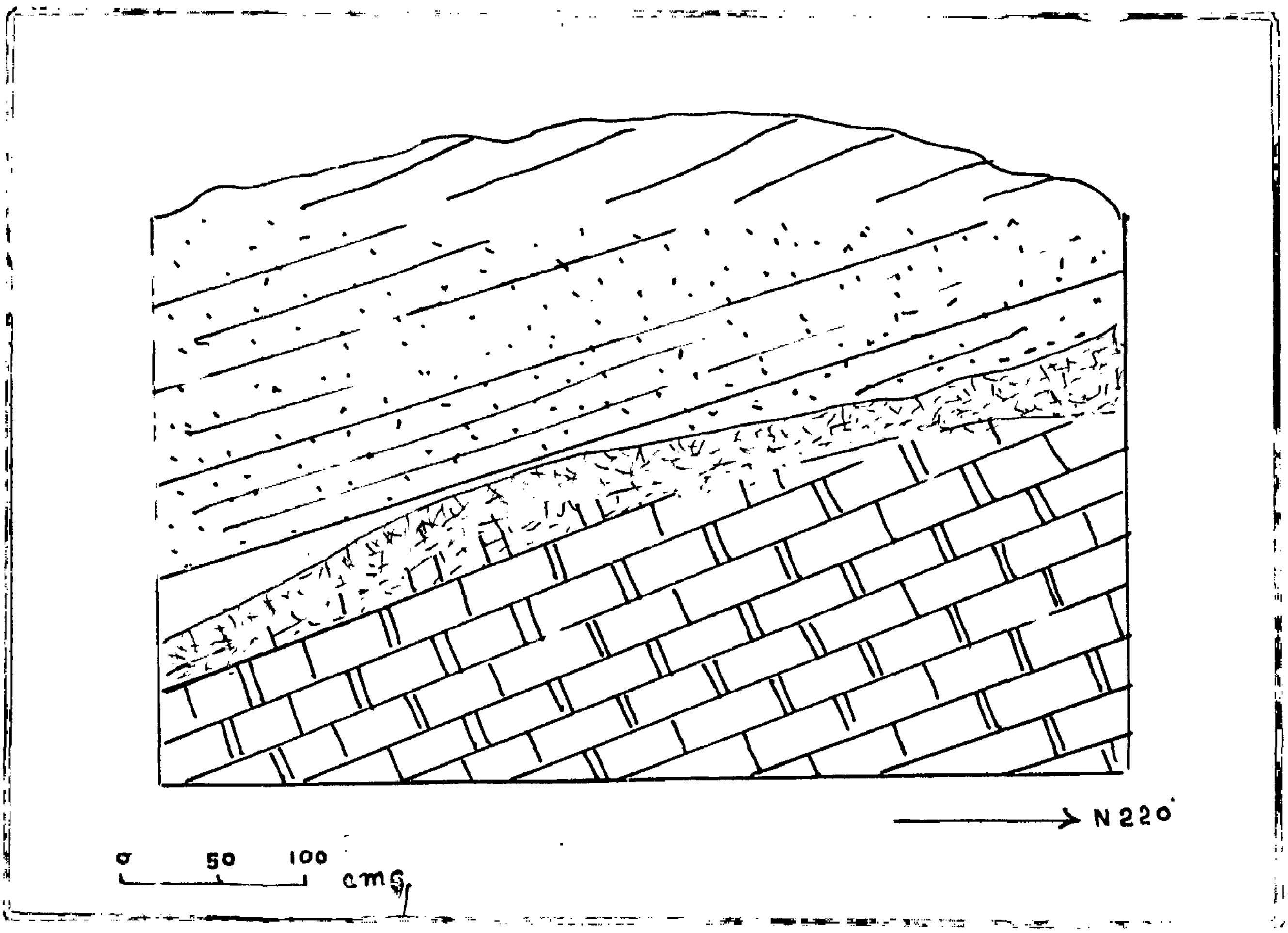


FIG. 10

extremity the contact plane has been folded into a syncline and an anticline. None of Krol and Tal formation have been affected with this folding. The crest of the anticline has been eroded exposing a narrow track of Krol formation in between the exposure of Tal Formations from Dhobighat to Woodstok College and further extending beyond Tehri Road.

(iii) At a few places where the contact plane is folded, it is noted that the beds, both below and above the contact plane have changed their original orientation near the contact. An example of such deviation from original bedding dip is seen near company Khad, sectional view of which is given in the figure No.12. This deviation suggests dragging along the contact.

(iv) Near the contact minor thrusting is common both in Tal and Krol formations. Such a minor thrust is well exposed on the Tehri Road, near Landhour Bazar (Fig. 11). The foregoing observations indicate that some movement has taken place along the Krol-Tal contact or in other words, the contact is a plane of dislocation.

extremity the contact plane has been folded into a syncline and an anticline. None of Krol and Tal formation have been affected with this folding. The crest of the anticline has been eroded exposing a narrow track of Krol formation in between the exposure of Tal Formations from Dhobighat to Woodstok College and further extending beyond Tehri Road.

(iii) At a few places where the contact plane is folded, it is noted that the beds, both below and above the contact plane have changed their original orientation near the contact. An example of such deviation from original bedding dip is seen near company Khad, sectional view of which is given in the figure No.12. This deviation suggests dragging along the contact.

(iv) Near the contact minor thrusting is common both in Tal and Krol formations. Such a minor thrust is well exposed on the Tehri Road, near Landhour Bazar (Fig. 11). The foregoing observations indicate that some movement has taken place along the Krol-Tal contact or in other words, the contact is a plane of dislocation.

A SECTION REPRESENTING NATURE OF KROL - TAL CONTACT

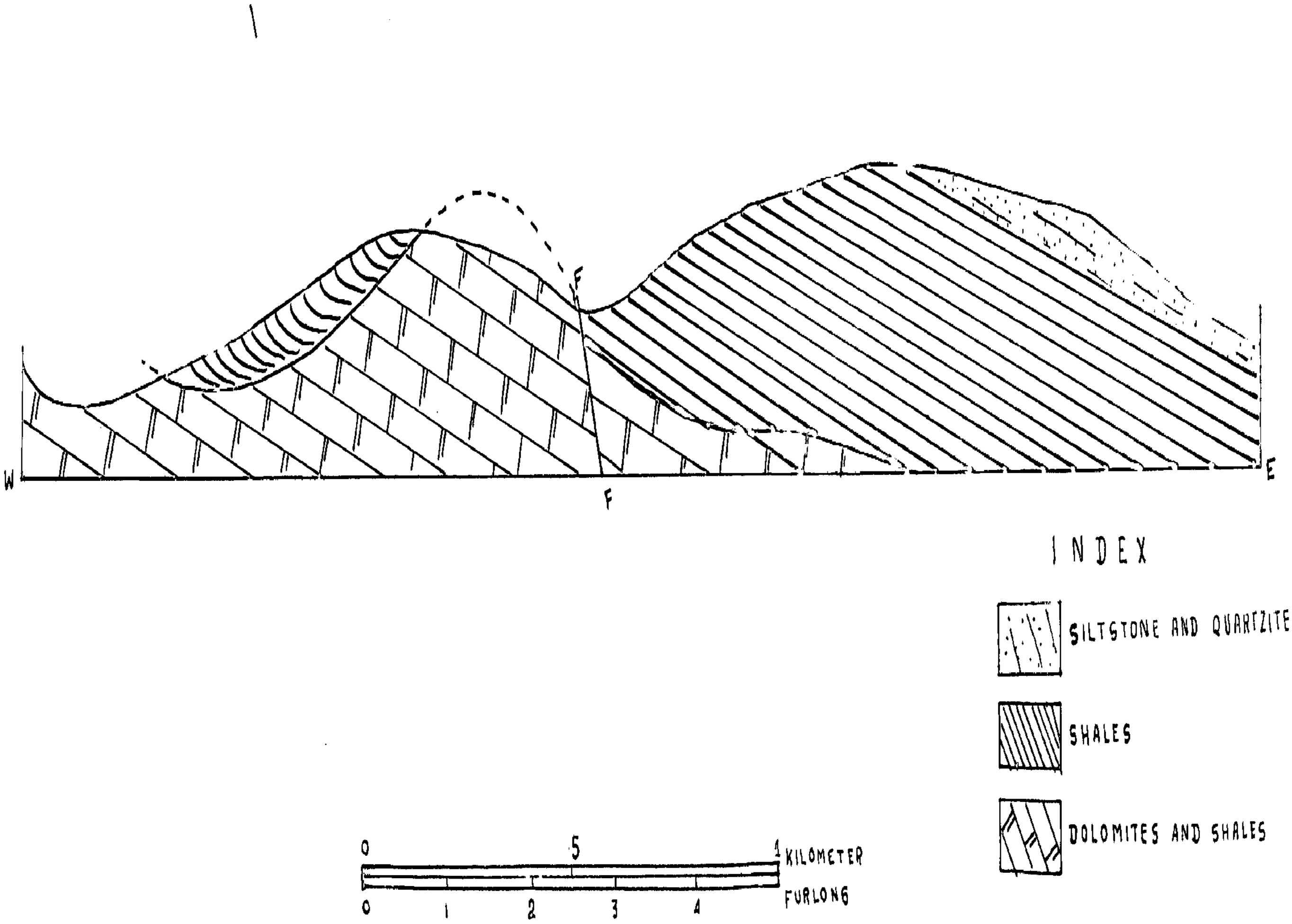


Fig. 12

Other evidences, supporting the Krol-Tal contact to be a tectonic contact, are

(1). Non-coincidence of the axes of Tal syncline and Krol Syncline.

On having a general look on the geological map of Garhwal area, prepared by Auden, it appears as if Mussoorie syncline in fact constitutes of two synclines such as if one has been kept inside the other one. The axis of Tal syncline, though approximately parallel to the axis of the underlying Krol-syncline, seems not to be coincident with it. The axis of Tal syncline perhaps lies somewhat NW of that of Krol syncline.

(2) No exposure of Tal formations on the Gun Hill-

The relation between the strike of Krol-Tal contact and the topographical contours indicate that in a normal condition if Tals are exposed near the city Hall, then they should also be found exposed on the Gun Hill. But no exposure of Tal rocks are found on the Gun hill whereas they are well exposed around the city Hall.

(3) The Landhour-Woodstock-Dhobighat Window.

As it has been mentioned previously, in the Landhour-Woodstock-Dhobighat region the Krol-Tal contact has been foled to an anticline. Erosion of the crest of this anticline, has exposed a narrow track of Krol Dolomite underneath the Tal shales. If the Krol-Tal contact is believed to be a thrust, this narrow exposure of Krol Dolomite surrounded with Tal formation will represent a small window.

All these evidences suggest thrusted nature of the contact. The mechanism of formation and the age of this 'Tal Thrust' could not be fully understood because of the limited scope of the work. However, it seems most possible that originally the Krol and Tal series were comprising a single normal stratigraphic sequence. During the Krol-thrust this whole mass together with underlying Blaini and Chandpur series was thrusted over the Tertiary formations. During this thrusting the whole nappe was rendered to folding giving rise to major synclinal structure (Mussoorie syncline). But during the last phase of the movement of Krol thrust, the rocks composing the Tal formation could not keep pace with the remaining mass of the nappe. There was therefore a relative shift between the Krol and Tal formations.

Lower Tal

The lower Tal has been thrusted over the Krol series. The stage consists of shales which are calcareous

Upper Tal-

The Upper Tal shows a gradational contact with the lower Tal shales. In its lower portion it is composed of red coloured siltstone with universal presence of ripple marks (photo No. 12). Current bedding, Mudcracks and rain prints. Within the red siltstone blotches and patches of green-siltstone are found at places. At a few places siltstone has acquired massive nature with bedding planes being unidentified but commonly this formation is well bedded.

Good exposures of siltstone are found near Woodstock school on Tehri Road.

Overlying the silt-stone there is a sequence of quatzite in which graded bedding is very common. Alternate bands of pebby quatzite, grits and massive quartzite are found. Good exposures are found near Jabarkhet.

The ripple marks, graded beddings and other sedimentary structures mentioned above show that the Tals were deposited in shallow water conditions.

No fossil could be found in the Tal formations of this area, but fragmentary mollusc shells and corals have been reported from this formation at other places. On towards the lower horizons and successively grade upwards into cherty, micaceous and carbonaceous shales. Such gradation is occasionally lateral also. The calcareous shale is a soft, earthy shale which in the lower portion has been heavily crushed due to thrusting. Its maximum thickness is over 300' (91.5 m) but at places is less than 100'. Good exposures are found along Landhour Bazar, Midlands and Wynberg High School etc.

The calcareous shale grades into a dark-coloured arenaceous shale. Its dark colour may be due to the presence of Mn-compounds. It is comparatively harder and slightly coarser than the calcareous shale. Bleaching is common. In its upper portion these shales become micaceous. Exposures are found near Tipperary on Tehri Road and near Woodstock College.

The dark arenaceous shale grades further upwards into carbonaceous shales, which are found well exposed west of Woodstock School.

The total thickness of Lower Tal stage, comprising of the calcareous to the carbonaceous shales is over 2000'.

Upper Tal-

The Upper Tal shows a gradational contact with the lower Tal shales. In its lower portion it is composed of red coloured siltstone with universal presence of ripple marks (photo No. 12). Current Bedding, Mudcracks and rain points. Within the red siltstone blotches and patches of green-siltstone are found at places. At a few places siltstone has acquired massive nature with bedding planes being unidentified but commonly this formation is well bedded.

Good exposures of siltstone are found near Woodstock school on Tehri Road.

Overlying the silt-stone there is a sequence of quatzite in which graded bedding is very common. Alternate bands of pebby quatzite, grits and massive quartzite are found. Good exposures are found near Jabarkhet.

The ripple marks, graded beddings and other sedimentary structures mentioned above show that the Tals were deposited in shallow water conditions.

No fossil could be found in the Tal formations of this area, but fragmentary mollusc shells and corals have been reported from this formation at other places. On this basis and on the basis of the fact that in Garhwal Tals are succeeded by Nummulites, it appears that Tals represents the Jurassic and Lower Cretaceous systems.

Structures in Tal Series.

The general dip of the Tal formation is 15° to 40° due N10 to N30. At a few places foldings have caused the reversal of the dips. A good example of such a folded structure is seen near the Civil Hospital. As one moves NE to SW along the Krol-Tal contact from City Hall onward, the beds at first are found dipping at average 20° due N20. Near the civil hospital there is found a sudden change in the dip, which now becomes 30° due N100. Thus an asymmetrical anticline is formed. Soon after the dip again changes to 85° due N280 giving rise to a synclinal structure. Half a furlong NE of the Midland burial ground, the dip again changes to 30° due N20, forming again an asymmetrical anticline. Erosion of the crest of this anticline has exposed the Krol Dolomite underneath the Tal shales, which looks like a loop of Krol Dolomite within the Tal shales exposure.

Faulting.

In addition of several minor faults in the Tal formations a comparatively major fault has been recognised running approximately NE-SW, coinciding with the

Photo-12

Photo-13

Krol Tal contact, extending from Tehri Road, to Woodstock College, in direction NNW-SSE. It is a normal oblique fault dipping on average 75° due N 80.(Photo 13)

Although this fault coincides with the Krol-Tal thrusted contact, yet it is very obvious and different from the later. The evidences which conform the presence of this faults are the following:

1. Presence of an escarpment all along the fault right from Tehri Road to Woodstock College.

2. Presence of fault-gouge. The fault gouge here consists of very soft clay like material found along the fault plane.

3. Presence of slickensides. These are found striated mainly over the Tal shales along the fault plane.

4. Presence of a nala (company Khad), parallel to the fault from Tehri Road to Woodstock. After the termination of the fault the Nala ((Company Gadh) takes a sudden bend near the Woodstock college (refer map.2).

5. Mineralisation in the region adjoining the fault plane.

a

Photo-14

b

6. Change in the pattern of the outcrop.
As is clear from the Geological Map (back envelope) the Krol-Tal contact is straight in the portion Tehri Road-Kaad stretch. This is because of the steep dip of the fault (photo 13).

Since the Krol-Tal thrusted contact have also been effected by this fault (fig. 12), the fault is definitely later than the thrust.

Joints.

Like the underlying Krol formations the Tal beds also, have suffered numerous sets of intensive jointing. The joints are more intensive in the lower horizon of Tal series (where their spacing is as close as one centimeter. Spacing between joint planes becomes more in the Upper Tals. However, in the Tal quartzite, though the jointings are less closely spaced, but are more prominent and more persistent. A photograph illustrating jointing in Upper Tal formations is given in Photo 14.

IGNEOUS INTRUSION

The area possesses the exposures of two basic sills being intruded into the Upper Krol Dolomites. As will be discussed in the Chapter IV the rock is probably

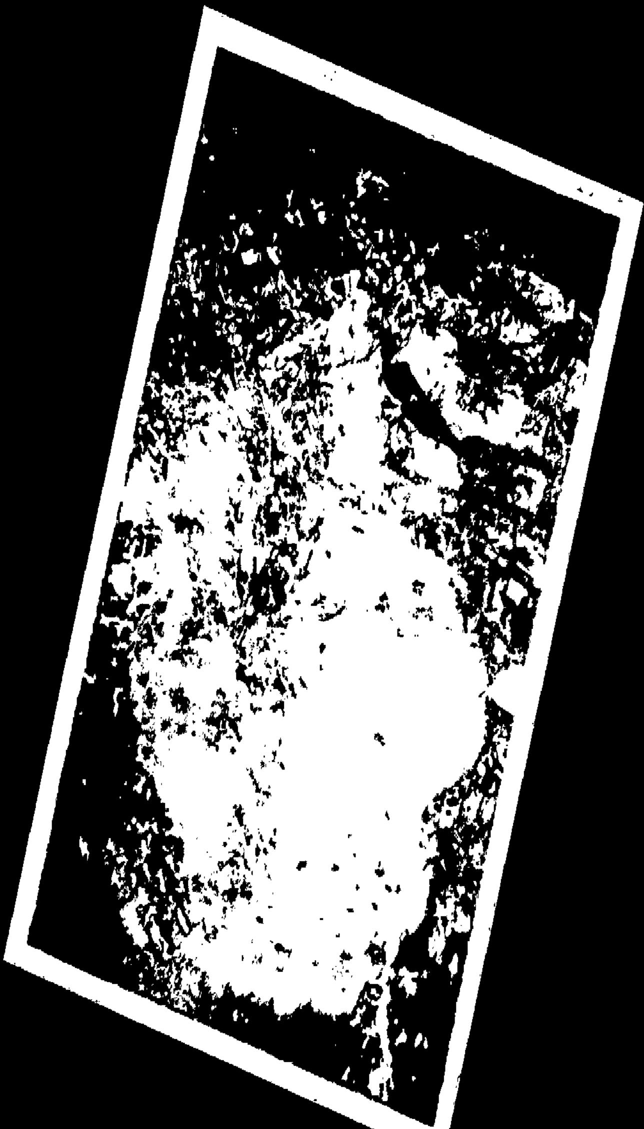


Photo 15

apatite-leucophyre. One of these apatite-leucopyre sills traverses through the Mackinons Road, Dhobighat, Airfield etc. and terminates a furlong west of the Brooklands. The other sills starts near the junction of Malorani Khala and Mussoorie-Rajpur Motor Road. It runs through May-cottage, Barlowgunj etc. and terminates half a furlong east of the Mossy falls. Near the Mussoorie-Rajpur Motor Road, a small dyke has branched out of the sill and is oriented in a direction NNE-SSW.

Average thickness of both of these sill is approximately 200'. The orientation in general is concordant with the country rocks. At places the sills have been folded also together with the intruded formations. However, at a few places these intrusive are found cutting across the alternately deposited dolomites and shales of the Up. Krol. Dolomite stage. Thus, it seems most possible that these intrusive bodies are transgressive sills which in general are parallel to the enclosing formations, but in a few portions have deviated from their normal course and have locally acquired the nature of a dyke.

<u>Mineralisation.</u>

Mineralization in the area is represented by the occurrence of barytes and pyrite. Pyrite has been found

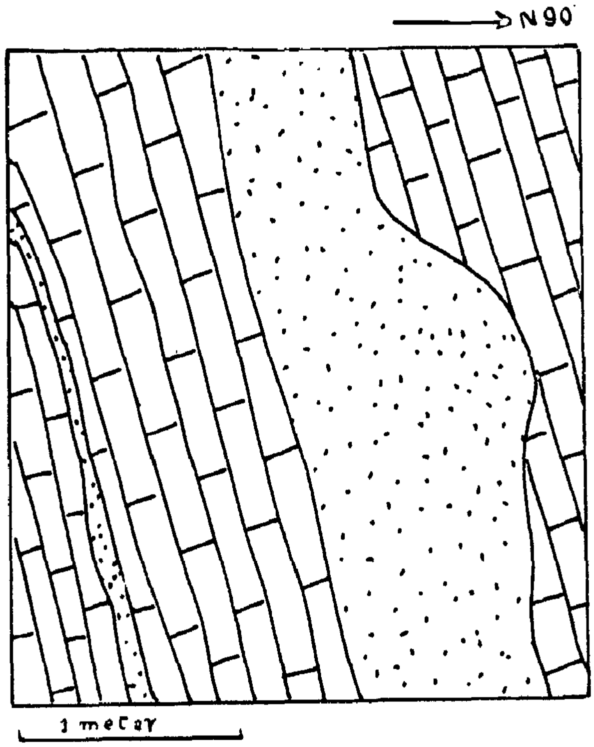


FIG. 1A (a)

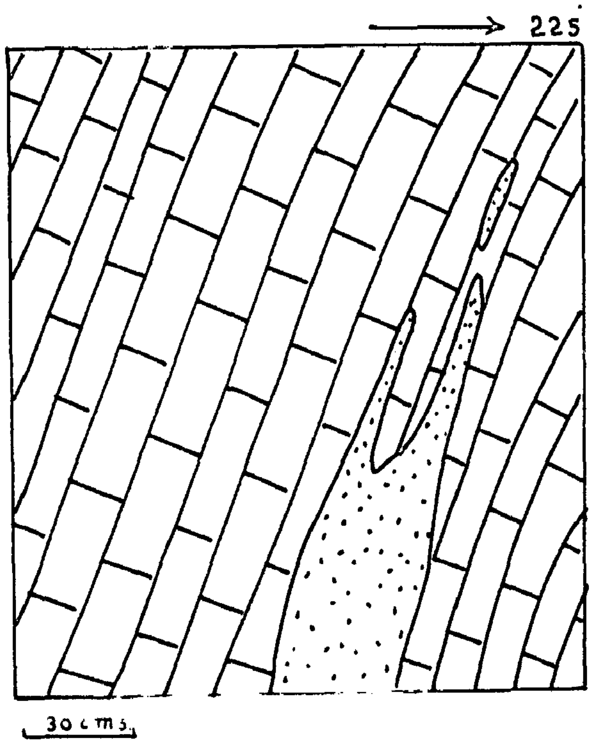


FIG. 1A (b)

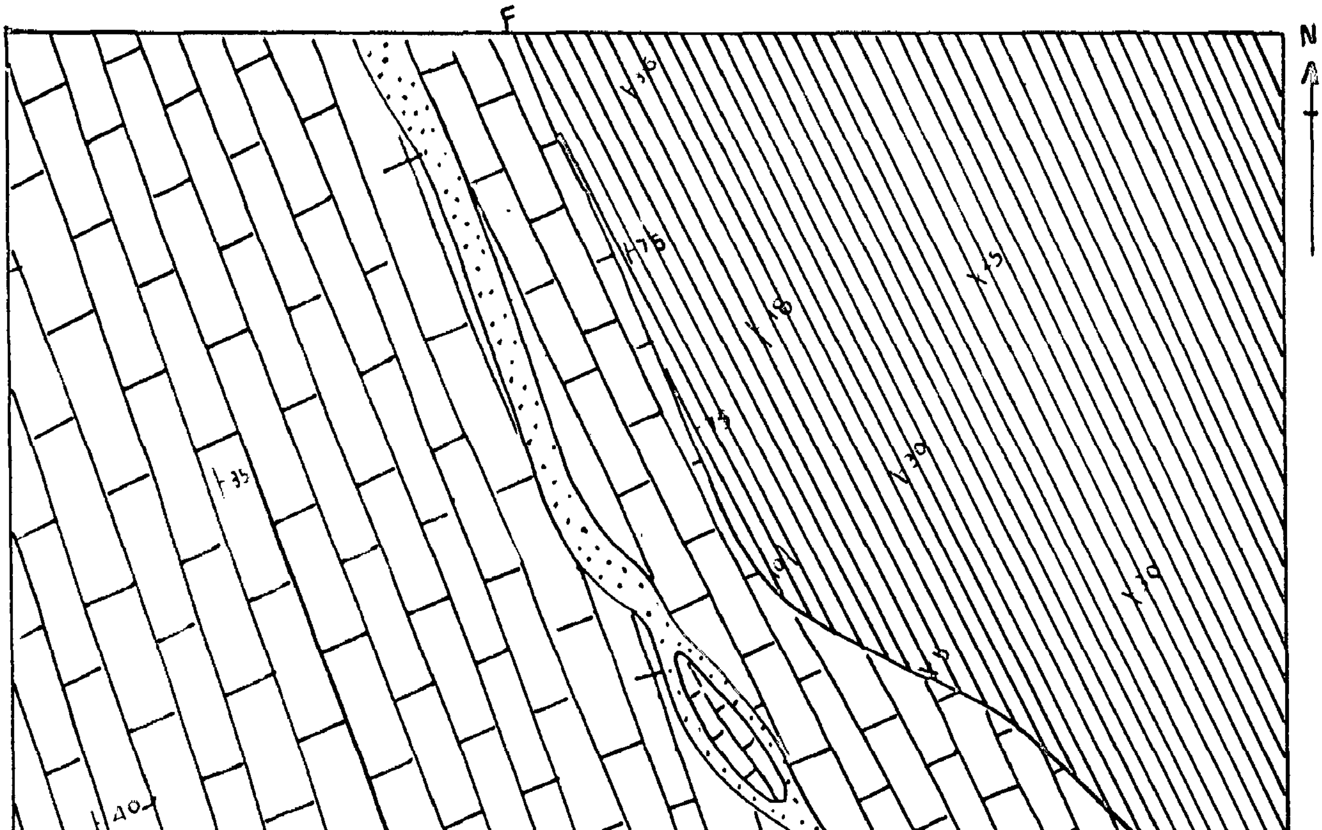


FIG. 13

both in Lr. Tal and Up. Krol formations. But occurrence of barytes is restricted only to the topmost beds of Krol Dolomites.

<u>Barytes-</u>

Barytes occur in the form of various cavity fillings. The most prominent occurrence is a fissure-vein running SW-NE from a furlong north of Wood stock college to Tehri Road (Fig. 13, Photo -15). The vein is highly dipping and has a width of .5m on average. It is fairly continuous and in the N-W portion has been subordinated by another smaller parallel vein. From Tehri Road onwards the nature of the vein becomes irregular. At times it pinches and swells and some times disappears altogether (Fig. 14)

In addition of this prominent vein of barytes there are at least two more smaller veins of barytes in the area. One of them is exposed near Municipal clerk's quarters, one furlong ENE of the kink. The other vein is one furlong S of the Civil Hospital. Both of these veins are much irregular. As one moves along these veins they pinch and swell, appear and disappear and change their orientation in a disordered manner. Each of these prominent veins are found associated with a number of thinner veinlets. These veins are irregularly oriented

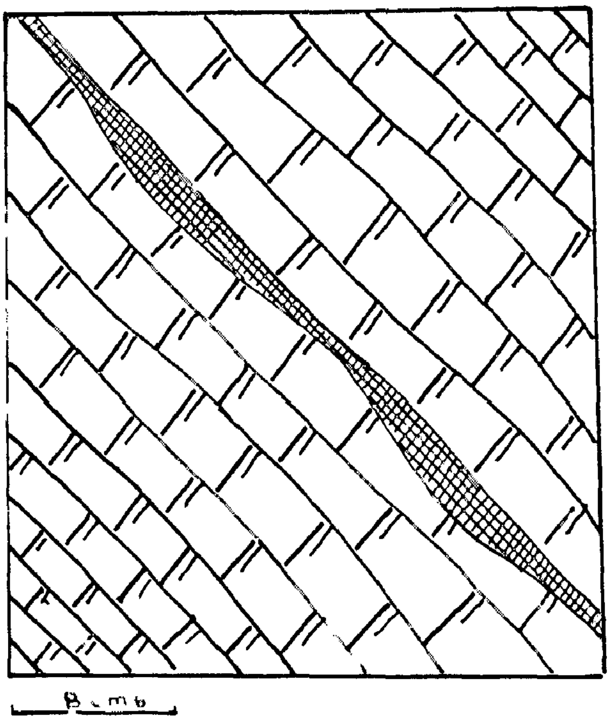


FIG. 15

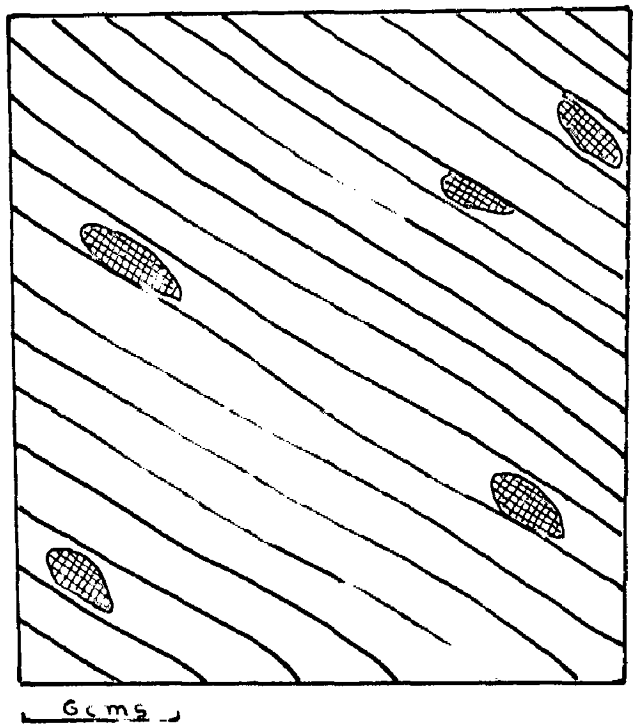
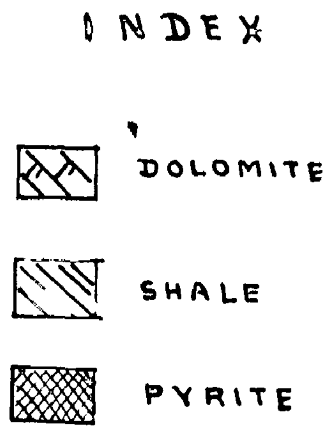


FIG. 16



criss-cutting each other and some times forming box-work like structure. By the side of the baryte vein near Tehri Road, the Krol Dolomite rocks are seen sheared and the interfragmental spaces are occupied by secondary solution fillings. It appears as if baryte is also filled in these interfragmental spaces. But on chemical and microscopic examination, the inter-fragmental spaces were found to be completely occupied by calcite, dolomite and siderite and no trace of baryte was found in these spaces.

Pyrite:

Occurrence of pyrite is found in the form of veinlets and lenses (Fig. 15 and 16). All along the contact of Up. Krol and Lr. Tal, from Tehri Road to Woodstock School, small lenses of pyrite are found both in the Tal and Krol Rocks. Leaching and limonitization have extensively taken place but on cutting the lenses fresh pyrite is found.

Sporadic occurrence of pyrite was also found in the Up. Tal quatzites near Jabarkhet. Here it is found in the form of small pockets. As will be discussed in ChapterIV, occurrence of this pyrite represents a hydrothermal activity in the area.

CHAPTER -IV

PETROGRAPHY OF THE ROCK TYPES

The area under present investigation consists mainly of various types of shales, limestone and dolomite. The only basic rock met in the area is the transgressive silt intruded in the Upper Krol Dolomites. In the present chapter the author endeavours to present a brief petrographic description of various rock types met within the area. In addition, description of barytes and pyrite, the two epigenetic minerals found in the area is also given.

Infra Krol Rocks.

The rocks encountered within the Infra Krol series are (a) phyllitic shales, and (b) quatzites.

(a) Phillitic Shales.

The phyllitic shales are black coloured and carbonaceous. They are indurated and very thinly laminated over 15 bands being present within one centimeter thickness of the strata. Fresh surface exhibits a silky lusture.

The rocks are extremely fine grained and even under the microscope it is difficult to determine their mineral constituent.

(b) Quatzites.

Extremely thin layers of fine grained quatzite are found alternating with above mentioned phyllitic layers. The quatzite is black in colour.

Under the microscope the rock is found composed mainly of fine granules of quartz and felspars embedded in an argillaceous matrix.

This alternation of extremely fine grained phyllitic and comparatively coarse grained quartzitic lamination is probably indicative of the varved nature of these rock types. The fine phyllite and coarser quartzite layers may be representing the clay and silty sediments being deposited in a glaciated lake during the winter and summer periods respectively. The original clay and silt beds have suffered a low grade of metamorphism to give rise to the phyllite and quartzite.

Lower Krol Rocks.

The lower krol stage is composed of two rock types:

(a) slaty shale and

(b) Calcareous shale or Marl limestone.

(a) Slaty Shale.

It is an earthy brown shale with well developed cleavage schistosity and are found in alternate bands with marl limestone. Average thickness of the bands is generally 2 to 4 cms. however, beds of several decimeter thickness are also encountered. Parallel arrangement of micas and chlorite have imparted a satiny lusture to the surface of schistosity. Numerous criss-cross calcite veins are found traversing through these shales.

The very fine grained texture of these makes it difficult to recognise the individual mineral constituents even under the microscope. However, mixture of very fine grained sericite, quartz and calcite are observed to be present in good amount along with the clay minerals. Micro-veins of calcite are also seen traversing the rock. The calcite in the vein is coarse grained showing perfect rhombohedral cleavage and extreme birefringence under the microscope.

(b) Marl (or Calcareous Shale)

The Marl Lower Krol stone are fine grained, dull and dark-grey in colour. It consists mostly of clays with

$CaCo_3$ constituent seldom increasing to 30 percent. MgO/CaO ratio is 0.1795. Following table shows a partial chemical analyses of marls.

$CaCO_3$	18.60%
$MgCO_3$	1.13%
Other materials, soluble in HCl (mainly Fe and Al oxides)	19.41%
Material insoluble in HCl (mainly clay)	61.86%

Under the microscope the rock seems to be mainly composed of fine grained calcite embedded in an argillaceous matrix.

Krol Red Shale Rocks.

Rocks encountered in Krol Red shale stage are purple-red and green coloured variegated shales. Shales are soft and extremely friable, having closely spaced foliation and a net work of jointing. Fresh surfaces possess a pearly lusture which in case of green shales is more intensive.

The extreme fine grained size of the component materials makes their identification difficult. However, chlorite and biotite are well identified under the microscope, which have more or less a preferred orientation parallel to the foliation of the rock. In the green shales chlorite is more abundant.

Upper Krol Limestone Rock

Rocks comprising the Upper Krol Limestone stage can be broadly classified into four types.

(a) Shale,
(b) Limestone,
(c) Magnesian Limestone and
(d) Marble.

(a) Shale

Shales occur in the form of discontinuous bands in the basal part of the Upper Krol Limestone stage. It is earthy-buff coloured, indurated shale with moderate development of cleavage schistosity.

Under the microscope the rock is seen composed mainly of fine grained argillaceous material together with equigranular fine granules of quartz representing better sorting. They also contain finely crystalline calcite together with disseminated iron oxides. At places chloritic material is also seen.

(b) Limestones.

These rock types occur in thickly bedded form. They are black to dark grey in colour and give sulphurous smell when freshly broken. In composition they are high grade limestone having over 80 per cent $CaCO_3$ and MgO/CaO ratio as low as .063.

Following table shows partial chemical analyses of Upper Krol Limestones.

$CaCO_3$	81.4%
$MgCO_3$	2.8%
Other materials-soluble in HCl. (Mainly Fe compounds)	0.3%
Materials insoluble, in HCl (mainly carbon)	15.5%

Under the microscope they are medium to coarse grained crystalline rocks composing primarily of calcite. The crystal-size vary from 0.1 mm to 1 mm in diameter. Calcite show twinkling and perfect rombohedral cleavage. Polysynthetic twinning in various colours are some times seen even in ordinary light. These rocks are seen traversed with fine grained calcite veins (Photo 16 a). Minute pyrite grains are also seen in these rocks.

(c) Dolomitic Limestone

Occur in the form of pockets within the Upper Krol Limestones. They are greyish white in colour and are less crystalline.

Under the microscope the rock possess Oolitic structure. Oolites of calcite, showing concentric rounded structure are embedded in the matrix composing of medium grained calcite and dolomite (Photo No.17). Grains of sand are found sometimes in the nucleus of these Oolites.

(d) Marble.

These are pure white to bluish white, crystalline rocks having saccharoidal texture and vitreous lusture, and taking good polishing. The marbles are almost entirely composed of $CaCO_3$. According to Auden they are of metasomatic origin.

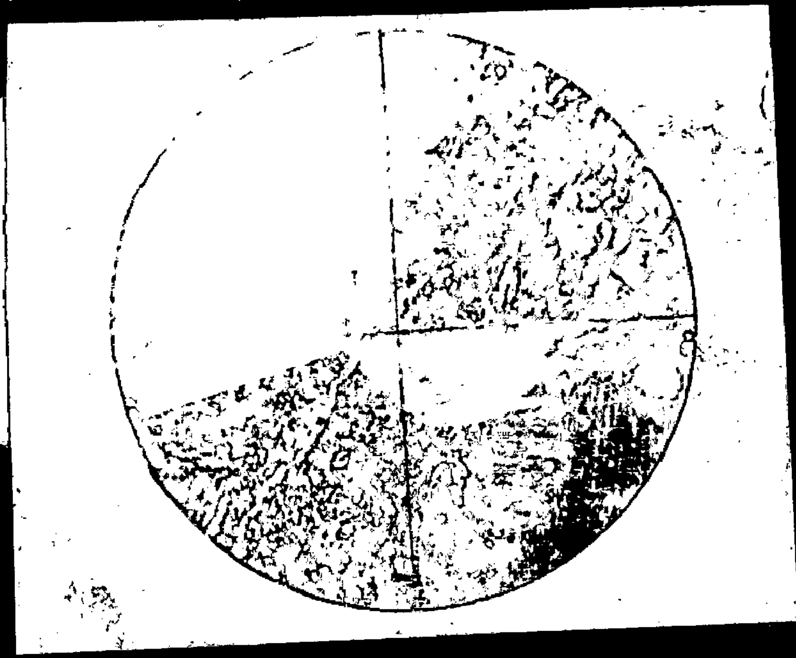
Under the microscope the rock is seen to be composed of medium grained (0.8 m.m.)equigranular, crystalline calcite. (photo 16b) The calcite crystals are sub-hedral and possess twinkling, rhombohedral cleavage and extreme briefringence with high order interference colours. Interference figure is uni xial negative with closely spaced rings.

Upper Krol Dolomite Rocks

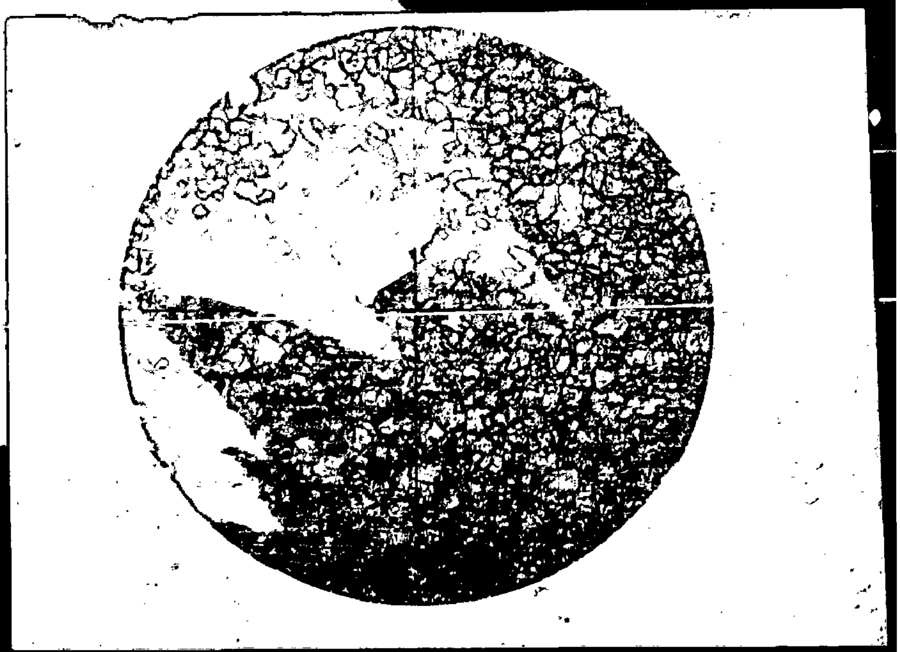
The Upper Krol Dolomite stage is found to be composed of various types of shales and dolomites.

(a) Shales.

Shales of Upper Krol Dolomite occur in the form of huge lenticular bands within the dolomites. They are of various colours like red, pinkish-brown, buff, and greenish grey. All of these are fine grained argillaceous rock with



a
Photo
b



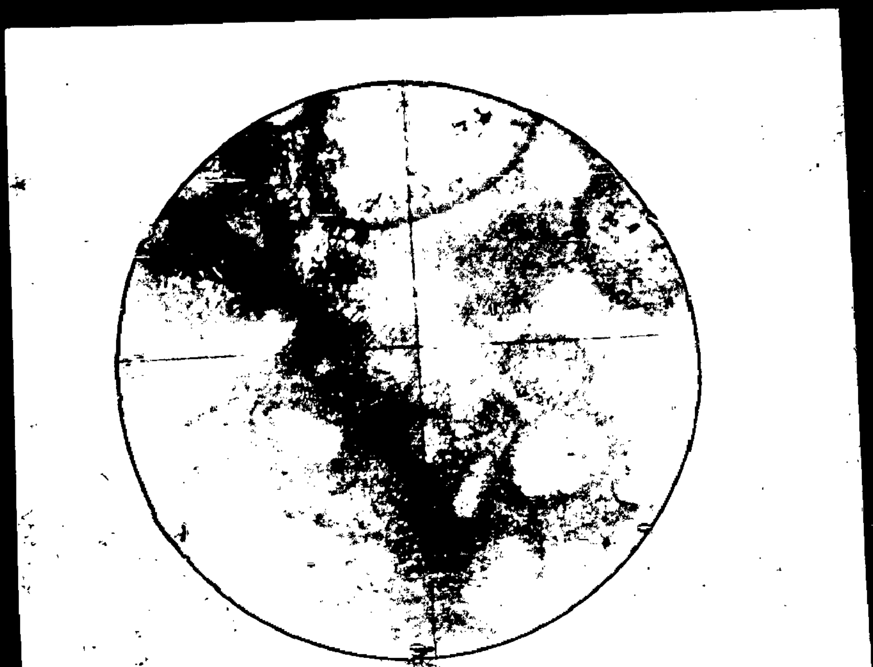


Photo-17

a distinct fissility parallel to the bedding.

Under the microscope they are found constituted mainly of extremely fine grained clay minerals, individual grains of which could not be distinguished. In association there are very small fragments of quartz, felspar, and flakes of muscovite and biotite. Next in abundance is carbonaceous material followed by calcic and dolomitic constituent. Dessimination of pyrite is some times noted, which have been much affected by leaching.

(b) <u>Dolomites.</u>

The dolomite of this stage is calcareous in general and can be broadly classified into three types:

(i) Fragmentary carbonaceous dolomite,

(ii) Massive clayey dolomite,

(iii) Well bedded crystalline dolomite.

(1) <u>Unconsolidated Carbonaceous Dolomite:</u>

This rock type occurs in the basal parts of Upper Krol Dolomite stage and also in pockets within upper horizons of this stage. It is a highly friable, loosely consolidated, concretionary rock with individual fragments, of size 0.8 to 1.5 cm. on average. The interfragmental spaces are occupied by a black carbonaceous and argillaceous powdery material. The average composition of individual fragments are

$CaCO_3$	- 50.50%
$MgCO_3$	42.70%
Other materials-soluble in HCl	.20%
Insoluble materials in HCl	6.8%

The powdery material occupying the interfragmental spaces, however, never contain more than 25% of carbonates, while its carbon constituent is always over 50%

Under the microscope the section of fragments are seen to be composed of calcite and dolomites with streaks and patches of opaque carbonaceous material.

On the basis of the composition and mineralogy it appears that these rocks were originally similar to the other dolomite rock of this stage and have later become rich in carbonaceous-argillaceous material by leaching of its carbonate constituent. It is possible that the rocks of this horizon were originally affected by shearing. The sub-surface water percolating through sheared mass must have removed the soluble carbonates and thereby increasing the percentage of carbonaceous-argillaceous material.

This postulation is supported by the fact that within this unconsolidated horizon there are found certain remanants of consolidated, massive dolomite similar in every respect to other dolomite rocks of Upper Mrol Dolomite stage. Moreover the nature, appearance and composition of the shale bands found within this horizon is exactly similar to those of other horizons of this stage.

(ii) Massive dolomite.

These rocks are light coloured consolidated dolomites. Alternating white-grey and dark-grey bands are common. They are very rich in dolomite and over 90% of the material is composed of carbonates.

The following table shows the partial analyses of dolomites.

$CaCO_3$	52.8%
$MgCO_3$	43.4%
Other soluble materials.	.3%
Insoluble materials.	3.5%
MgO/CaO ratio	.699

Under the microscope the rocks are fine to medium grained composed of dolomite and calcite.

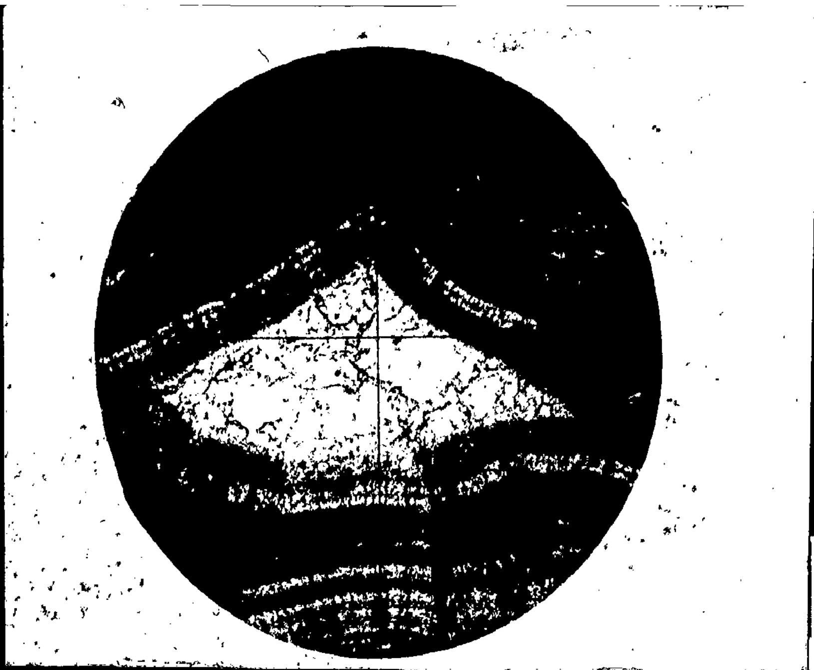


Photo-18

Photo-19

Photo-20

A few samples of this massive dolomite exhibit a peculiar stromatolite-like structure, both in hand specimen and under the microscope. (Photo 18 and 19). These structure shows dark and light coloured regular and irregular bands, the thickness of which varies from 2 mm to a fraction of a millimeter. The bands are arcuate and lobate. Sometimes the mouth of the lobes are closed which gives a concentric lammelar pattern.

Under the microscope it is found that in most of the cases the centres of these structures are composed of fine grained fibrous aragonite, the fiber being oriented perpendicular to the bands (fig. 17). The aragonite can be well distinguished from calcite because of cleavage and its biaxial interference figure. Absence of polysynthetic twinning is also one of the distinguishing characters.

At places columnar aragonite is also seen. The growth of aragonite columns normal to the opposite walls of the innermost bands have given rise to characteristic comb structure. (Fig. 18).

These "possible algal structures" have already been reported by Mithal and Chaturvedi (1962), who have identified these structures broadly as stromatolites possibly belonging to collenia.

However, the other possibility, that these structures are inorganic and are formed after the deposition of the beds, by some solution process can also not be ruled out. The well developed comb structure mentioned above may be indicative of cavity filling.

(c) Well bedded crystalline dolomite.

These are well bedded, consolidated, partly crystalline rocks with cream white colour and show porcellaneous appearance when cherty.

Following table shows the partial chemical analyses of these rocks.

$CaCO_3$	50.5%
$MgCO_3$	4?.5%
Other solubles	.22%
Insolubles.	?.73%
MgO/CaO ratio is	.7338

Under the microscope it is found composed of partly crystallised, dolomite and calcite minerals. Minor amount of siderite is also present. All these three minerals are colourless in the polarized light and possess perfect rhombohedral cleavage. Marked change in relief is noted on rotating the stage in plane polarized light. Birefringence is extreme with 5th and 4th order interference colours.

Photo-21

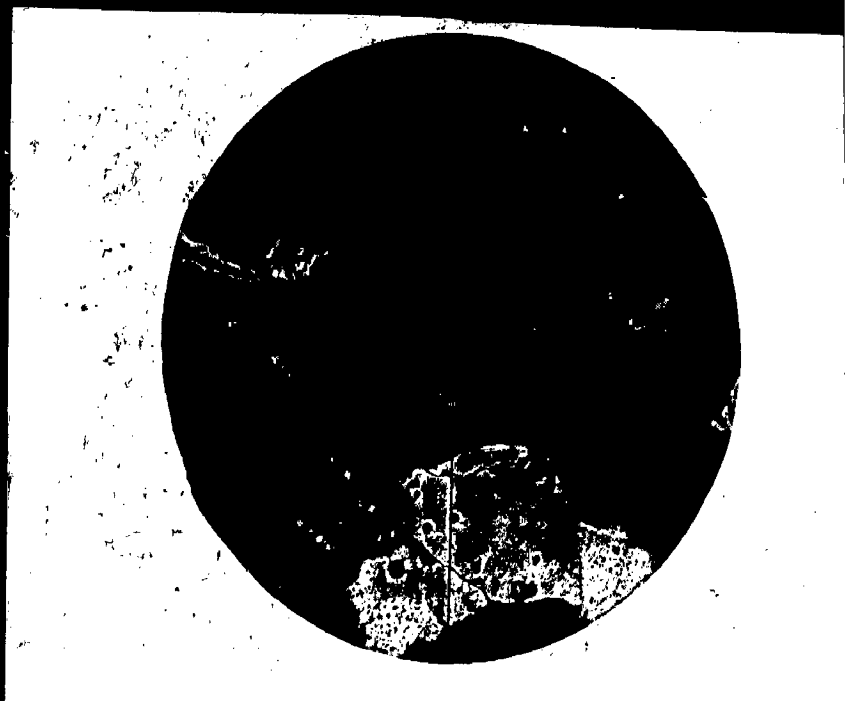


Photo-22

Under the microscope the main constituent is found to be fine grained argillaceous material with an abundance of dolomite and calcite grains. Accessory grains of quatz are also present.

(b) Cherty Shale.

It is fine grained dark coloured rock with some what greasy appearance and tough splintery to conchoidal fracture. In hand specimen it looks more or less like hornstone. It is traversed by numerous quatz vein showing cross-cutting relation with one and other.

Under the microscope the rock is found to be composed mainly of fine argillaceous material together with crypto-crystalline quatz. The main mass is traversed by quatz vein showing reticulate pattern and micro-faults (Photo 21). The quatz in the veins are granular and the average grain size is 0.[illegible]

(c) Arenaceous shale.

It is a black coloured, compact rock giving comparatively sharp edges on breaking.

In thin section the main ground mass is found composed of finely crystalline clay. Fine grains of detrital quatz and felspar and mica flakes are distributed without any preferred orientation. Fine dust of ferruginous material is found occuring as streaks and patches.

(d) <u>Carbonaceous shale.</u>

They are soft, black coloured shales with graphitic appearance. They are fissile and readily split into thin layers. In their composition high percentage of carbon has been found.

Under the microscope they are almost completely opaque.

<u>Upper Tal Rocks.</u>

The Upper Tals are represented in the area by (a) siltstones and (b) quatzites.

(a) <u>Silt Stone.</u>

They are fine grained rocks of red and black colours. The only recognizable mineral in hand specimen is muscovite. Presence of Mn was detected chemically in black siltstone.

Under the microscope the principal clastic grains are found to be angular to sub-angular quatz. Felspars are also seen in the sections, showing quadrill structur twinning, indicating the felspar to be microcline.

The cementing material is ferruginous and micaceous silt. Both muscovite and biotite are present.

(t) Quatzites.

These are generally coarse grained, gritty and sometimes pebbly. In general they are poorly shorted. In some varieties quatz grain range in size from micro-granular to grains of 3 cms. in diameter.

Under the microscope the main constituent was found to be quatz, associated with felspars (mainly micro-cline) and a few grains of staurolite, tourmaline, zircon and mica flakes. In general, the cementing material is also siliceous. However, in a few varieties they contain good amount of argillaceous material also. (Photo 22)

Intrusive Igneous Rock.

The basic igneous rock occurs in the form of transgressive sill intruded in the Upper Krol Dolomites. In band specimen the basic rock is found to be a fine to medium grained, melanocratic crystalline rock. The granutarity of the intrusive body increases from the margin to the center. No individual mineral is identified with naked eyes.

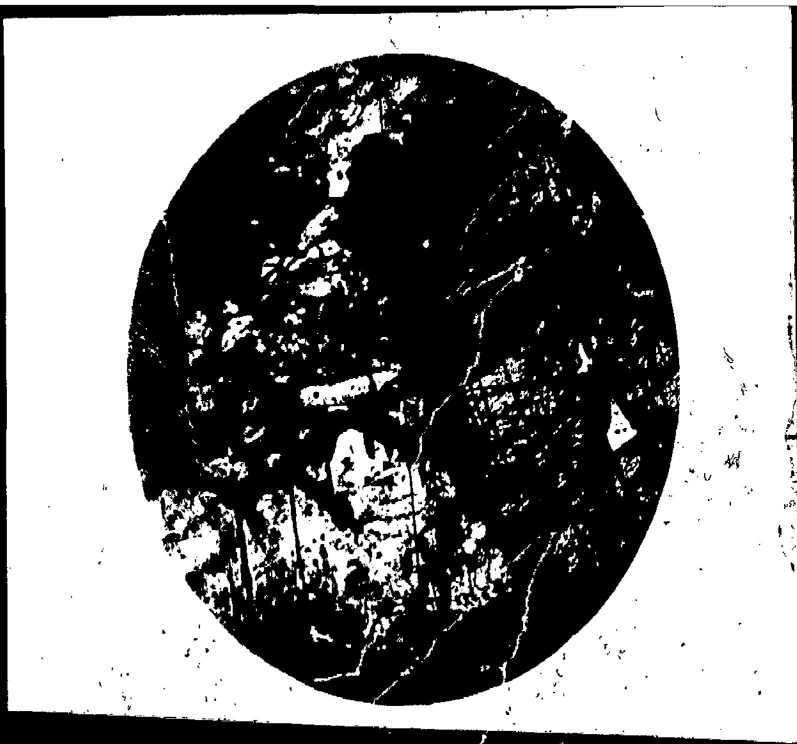


Photo-23

Photo-24

Under the microscope the rock is found to be holo-crystalline and hypidiomorphic. The most prominent constituent minerals are felspars, followed in order by augite, apatite and magnetite.(Photo No.23). Accessary quartz is also present. Secondary minerals present in the rock are chlorite, uralite, sericite, calcite, serpentine, epidolte, pyrite and hematite.

FELSPARS-

Felspars comprise two third of the total mineralogic composition of the rock. It is in the form of rather enhedral elongated crystals which are colourless under the plane polarized light and give first order grey and white interference colours. Two third of the total felspar grains are heavily altered but one third are fresh.

Altered Felspar.

A greater part of the felspar grains are altered. Such grains have generally a refractive index higher than that of Canada balsam, although a few grains show lower or nearly equal refractive index. Faint twinning is rarely observed. Generally the felspar is too clouded and thus prevents in its recognition. But since the refractive index is generally higher, and occasionally lower, it must be in the oligoclase-andesine range or may be even more calcic. The possibility that some of the heavily altered felspars may be orthoclase is remote, but nothing definite can be said in this regard, as oligoclase has a refractive index range from 1.492 to 1.513.

Fresh Felspar-

The fresh felspars have a lower refractive index than that of Canada balsam. They show parallel twinning occasionally. The maximum extinction angle with respect to twinning is 16°. This felspar is therefore albite.

An interesting feature of comparatively less altered felspars is that they are seen altered at the centre whereas at the borders they are fresh. This may be due to the difference in the composition of the felspars from margin to the centre, which might have resulted because of zoning. If this postulation is true then most of the felspar crystals in the rock will have to be throught as well zoned. This fact then will also explain the absence of twinning in the felspars. According to Emmons (1953) in plagioclase felspous zoning and twinning are mutually exclusive-a well zoned plagioclase crystal showing less development of twinning.

Augite:

Augite is found to be the next abundant mineral after felspars. In different thin sections it was found both in the form of sub-hedral phenocryst as well as in small euhedral short prismatic crystals. In colour it is pale greenish to pale purplish brown and has high relief and two sets of cleavage almost normal to each other. Interference colour in general are of first order but thick sections show second order green, yellow and purple colours also. Extinction was found varying from 35° to 40°.

Augite is highly altered into chlorite and uralite.

Apatite:

The rock is rich in apatite. In some sections the apatite was found to be over 12 percent of the total mineralogic composition of the rock. It is in the form of euhedral crystals of long prismatic habit, basal section being six-sided. Birefringence is weak with first order grey and white interference colours. Basal sections are isotropic.

Magnetite:

Magnetite was found in good amount in the rock. In thin section it is opaque. In polished section it was found to have a tinge of pinkish colour and therefore seems to be titaniferous. At places it has been altered to hematite and geothite..

Quatz-

Quatz is found occurring in minor amount. It occurs intergrown with felspar and also as separate grains. Grains are minute and xenomorphic, showing first order grey and yellow interference colours.

Chlorite-

Laths of chlorite are found as an alteration product of augite. It is dark green in colour, with development of one set of cleavage and has very low birefringence.

Uralite-

Fibrous aggregate of secondary uralite are found due to the alteration of augite.

Sericite-

Minor shreds of secondary mica having high second order interference colours are seen on the altered portions of the felspars.

Calcite

Grains of calcite having perfect rombohedral cleavage and extreme birefringence are frequently seen in the thin sections (Photo 24). They may be either contaminated or would have resulted from the liberation of calcium on the break-down of augite and plagioclase.

Serpentine-

On the shear planes within the basic rock, a coating of serpentine is found. Under the microscope it is pale green and has fibrolamellar structure. It has low relief and weak birefringence.

Epidote-

Collumnar aggregates of yellowish green epidote is found often in association with albite. It has high relief and strong birefringence.

Pyrite-

Minute grains of pyrite, disseminated within the rock are visible even with unaided eye. In polished sectioh the pyrite is found to have idiomorphic texture and brass-yellow colour.

Hematite-

In polished sections hematite and geotheite are found at the margins of magnetite grains.

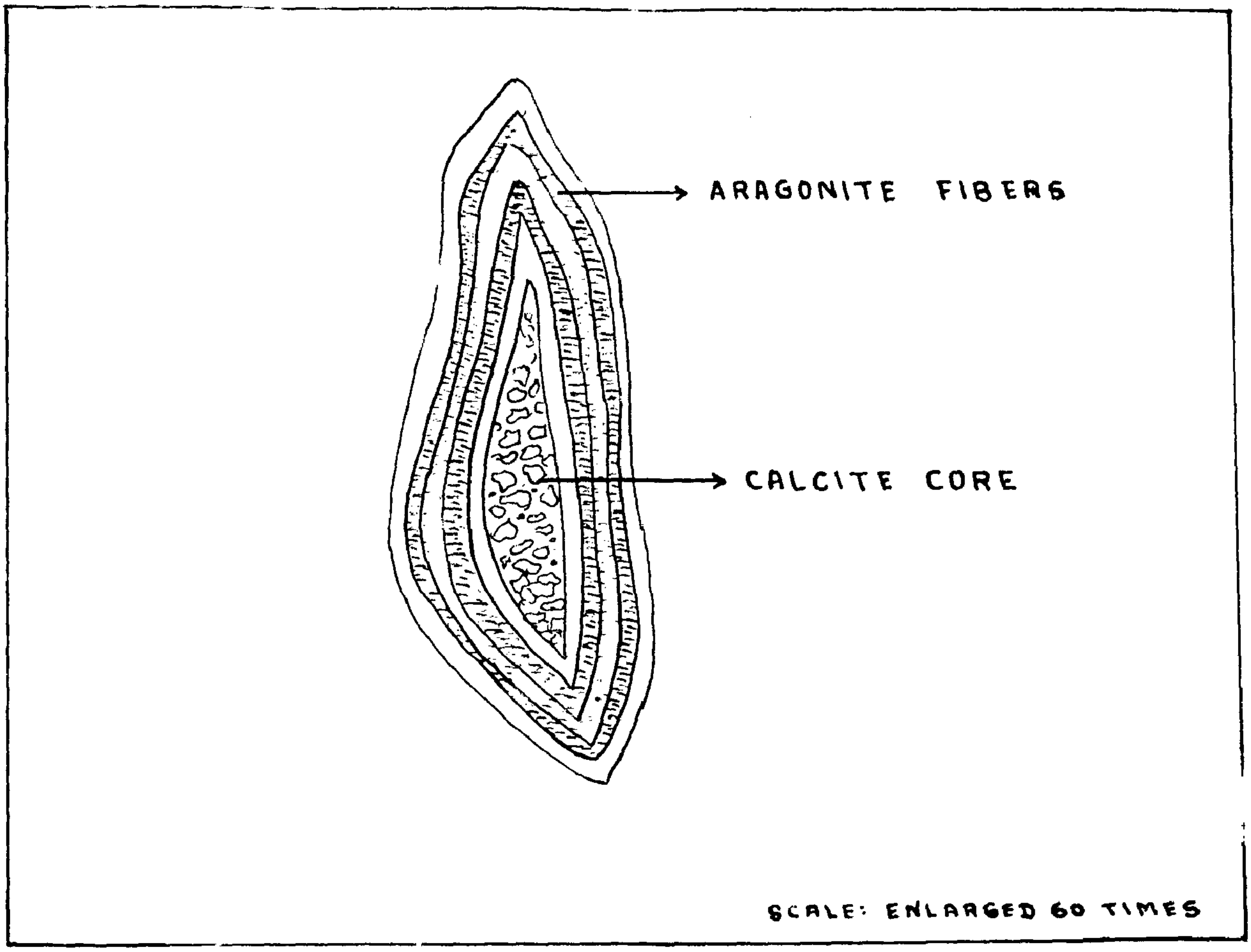

ARAGONITE FIBERS
CALCITE CORE
SCALE: ENLARGED 60 TIMES

FIG. 17.

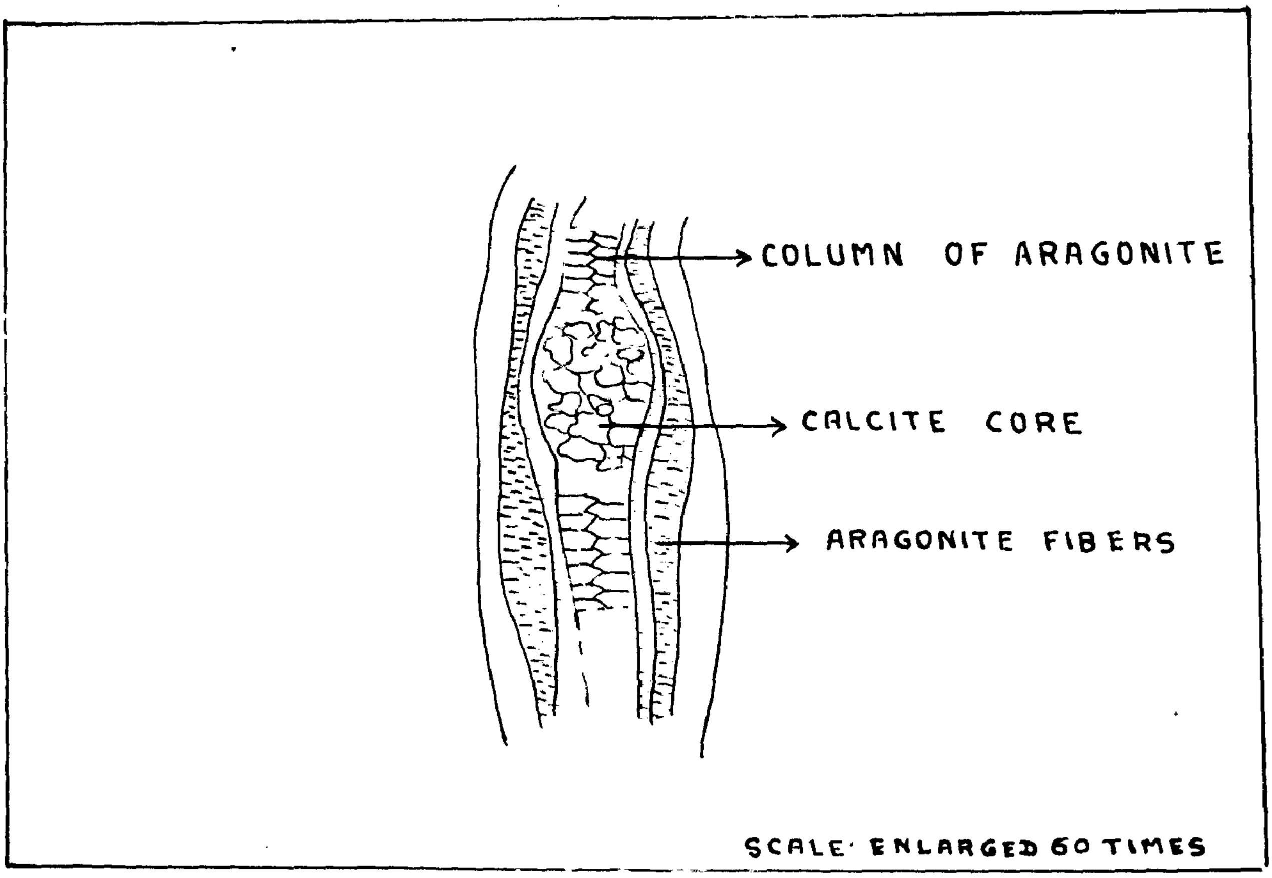

COLUMN OF ARAGONITE
CALCITE CORE
ARAGONITE FIBERS
SCALE: ENLARGED 60 TIMES

FIG. 18

The modal composition of the rock, as determined by Swift Point Counter for specimens 30/3 and 21/1 is given below.

Minerals	Percent of total mineralogical composition Sp.No.30, 3	Percent of total minerological composition. Sp. 21/1
Altered felspars.	40.7	43.5
Fresh felspars.	22.2	17.8
Augite with clorite and Uralite.	20.0	21.2
Apatite	8.2	10.0
Magnetite	3.5	5.1
Rest.	5.3	2.4

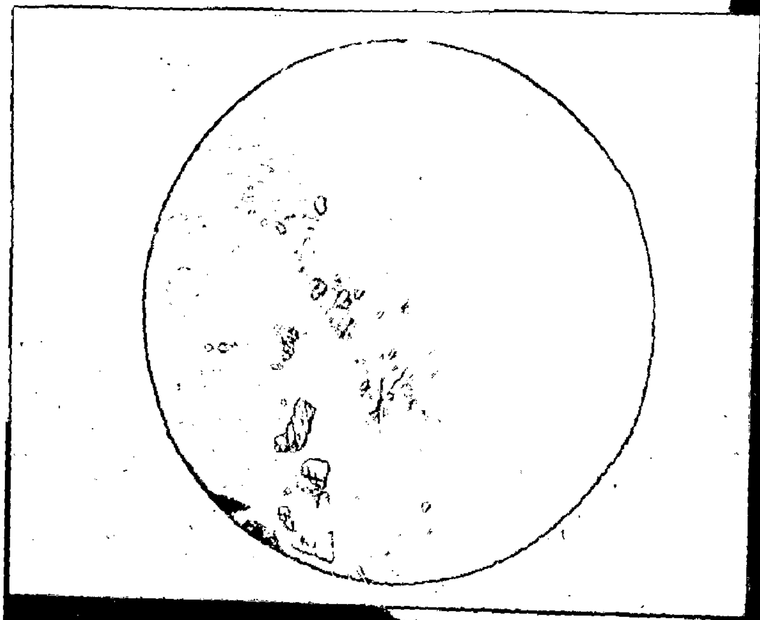
Nomenclature.

The basic intrusive rocks in Krol formation of Garhwal has been concluded by Auden (1934) as "varying from quatz-oligoclase doterite to quatz andesive dolerite". He has given the comprehensive name to these rocks as lencophyres.

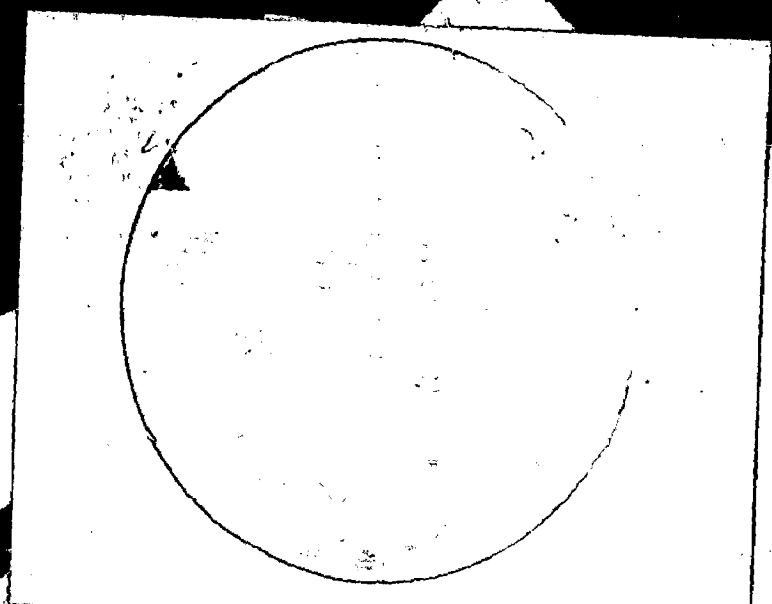
Since the rock shows heavy alteration, particularly of felspars, it is not possible to know the original composition of the rock. A chemical analysis would have been very helpful in this regard. Similar rocks have been described by Johannsen as diabase porphyry and quartz diabase, but the former contains potash rich labradorite and the latter normal labradorite. The present rock definitely shows saussuitization as is evident by the assemblage of quartz, albite, epidote, chlorite, sericite, calcite and it also shows uralitisation of augite. But these changes are not complete in the present case and hence these rocks cannot be called saussuritized gabbros. The presence of 8-10% apatite also needs an explanation, if this rock is named as metadolerite or lencophyre. The general texture of the rock is sub-optitic and the absence of clear evidence of the presence of orthoclase prevents in calling the rock as microgranodiorite or melanomonzonite. It is important, therefore, that a detailed investigation be done of these intrusines of the Krol belt, including the chemical analyses, which can throw some light on the origin and nature of these intrusive. With the work which could be done at the present instance, the present rock can be called as apatite lencophyre.

Hydrothermal minerals.

The hydrothermal minerals occurrence met within the area are those of (a) barytes and (b) pyrite.



P oto-25



P

(a) <u>Barytes.</u>

The occurrence of barytes in the Upper Krol Dolomite has already been mentioned in the Chapter III. The important points of the mode of occurrence of these barytes are that-

i) They are found in the form of veins which show pinch and swell structure and some times box-work like pattern.

ii) Their occurrence is restricted within the Upper Krol Dolomites.

iii) Their occurrence is [illegible] in the neighbourhood of Krol-Tal contact.

The barytes is greyish white in colour and has virtreous lusture. Specific gravity of various samples was found ranging between 4.2 to 4.4.

Under the microscope barytes is found to have granular aggregate and lamelar forms. It is colourless in plane polarized light and has fairly high relief and two sets of cleavage at right angle to each other. Bivfringence is weak and the maximum interference colours are of first or low second order (Photo No.25). Interference figure is positive biaxial.

The barytes is found associated with calcite, which sometimes predominates over barytes. Barytes have also been traversed by Calcite veins. The only conclusive remark regarding the genesis of these barytes can be that they are fissures and other cavity filling deposits. What was the nature of the solution which has given rise to these deposits and what were the source of Ba and SO_4 are some of the riddles which have remained unanswered due to limited scope of the present work. It has also not been possible to determine whether there is any genetic relation between the barite and pyrite met within the area.

Pyrite.

Occurrence of pyrite has been noted in both Upper-Krol Dolomites and Lower Tal Shales. In both of these formations pyrite has been found either in pockets are in veins showing swelling and pinching character. Sometimes a very thin sheet of gypsum is found on either side of the pyrite vein, which may have resulted by the reaction of host limestone rock with the pyrite bearing solution.

Under the microscope the polished sections show that pyrite is occurring both as massive and disseminated forms. When massive pyrite is generally fine grained. When disseminated they are generally in well developed crystal forms. A section of Upper Krol Dolomite rock shows disseminated pyrite crystals having remarkably straight geometrical boundaries (photo 26). Their section are square, rectangular and some times triangular also.

Both massive and disseminated pyrite is seen altered to goethite. The replacement of pyrite by goethite has given rise to several textures like coloform, island and psedo-myrmekitic.

Most probably the pyrite of this area are of hydro-thermal origin. The fault plane or the Krol-Tal thrust plane might have acted as the feeding channels for the pyrite bearing hydro-thermal solution which has deposits its pyrite constituent at suitable places both within Krol and Tal formations.

CHAPTER V

SEISMICITY OF THE REGION

HISTORICAL ACCOUNTS

Mussoorie and the adjoining regions lie within the seismic zone of India. A large number of earthquakes have occurred in the region. The table attached to the chapter represents the available record of some important historical earthquakes which occured in Mussoorie and neighbouring parts of Northern India. The epicenters of some of these earthquakes are plotted on Map.15.

Among the most important earthquakes, which have occurred in Mussoorie region during the past one and half a century, mention may be made about the following:

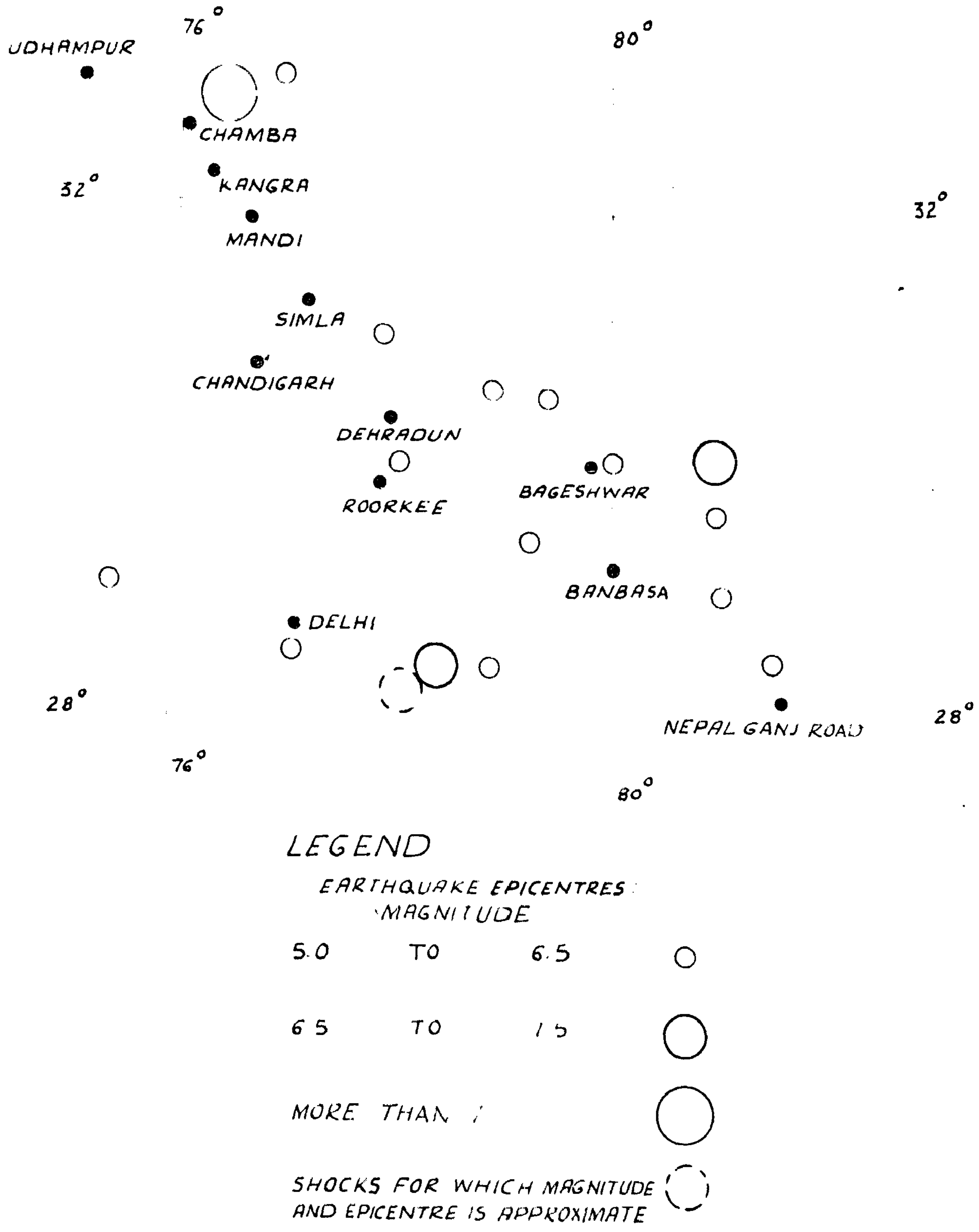
In the yea r 1803 (exact date not recorded) a violent earthquake shocked the entire Garhwal-Kumaun region. It was a disaster earthquake losting nearly 300 human lives and damaging a great number of buildings.

Soon after, in the year 1809 another strong earthquake commenced in the Garhwal area. A huge landslide, resulting due to this earthquake, blocked the course of Vishnoo Ganga river.

MAP-5

PLATE NO

MAP SHOWING EPICENTRES OF PAST IMPORTANT EARTHQUAKES IN SIMLA GARHWAL AREA



AFTER I. S. 1893-1962

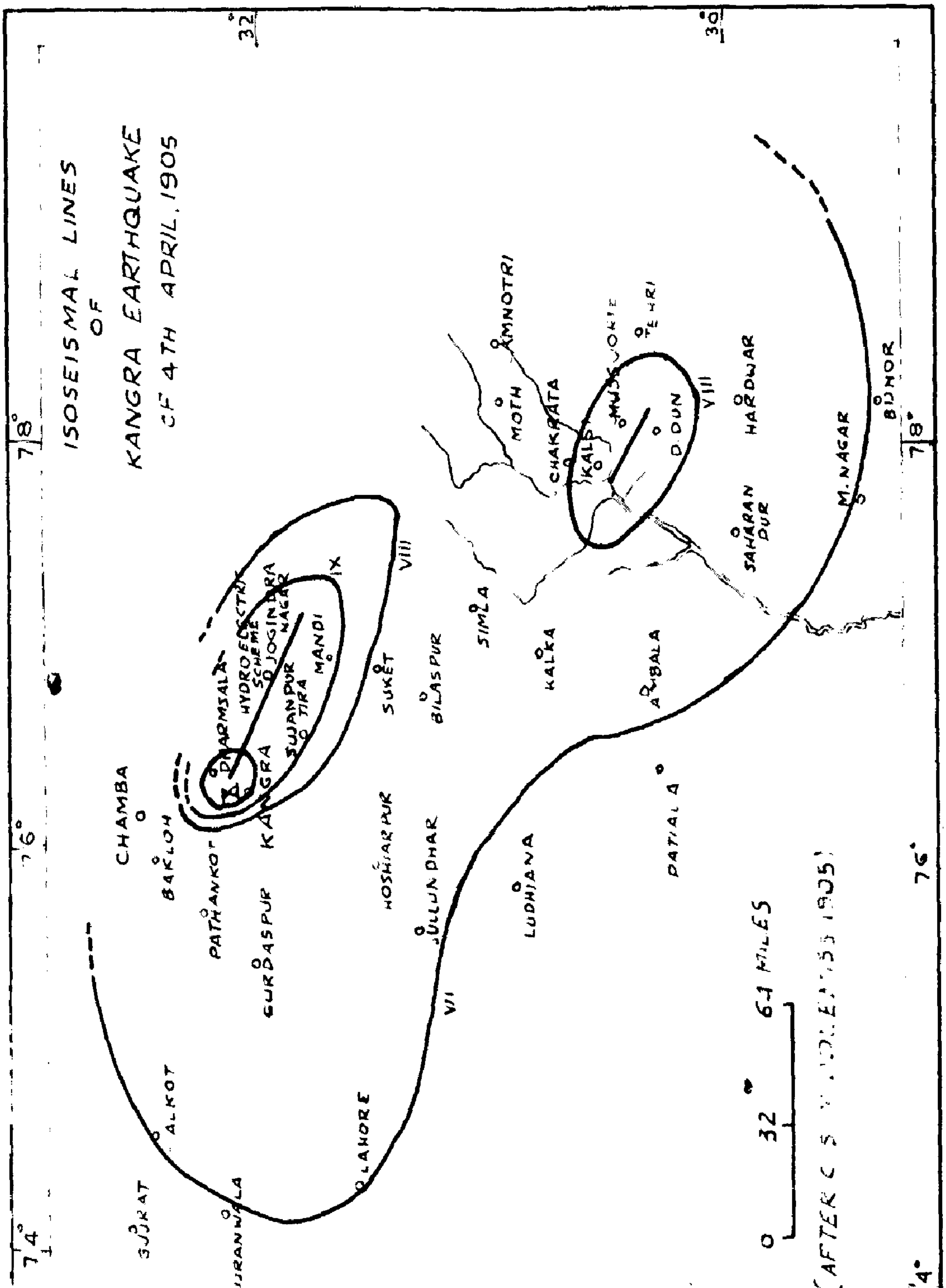
On 11th April, 1843 an earthquake of sharp intensity was felt in Landhour area of Mussoorie. This earthquake was felt in Delhi and Meerut.

On 10th January, 1842 the Mussoorie-Simla region felt a severe earthqua ke with damage to houses, but no loss of life was reported.

A violent earthquake was felt on 4th April 1905. The main epicentral region was situated between Kangra and Dharamshala, while a minor region of intensity greater than isoseismal 8 was present in Dun valley (Map. 6).

The region of high isoseismal around Dehradun was, according to Auden (1942) ,probably connected with either the Nahan or Krol thrust, because the long axis of ellipse representing isoseismal 8 is shown to lie between Rajpur and Kalsi. The earthqua ke was responsible for great destruction to life, and property. Nearly 2,000 life were lost. Considerable damage and collapse was suffered by house in Dehradun, Mussoorie and the bazar of Chakrota. Dehradun rose .44 foot relative to Mussoorie as a consequence of the Kangra earthquake. The dome of the Roorkee University building was damaged and had to be rebuilt. Cracks in buildings and other minor damage was noted in Lahore, Amritsar, Jullundur and Saharanpur. As much as 20,000 human beings are estimated to have perished.

MAP - 6


ISOSEISMAL LINES
OF
KANGRA EARTHQUAKE
OF 4TH APRIL, 1905
0
32
64 MILES
CHAMBA
BAKLOH
PATHANKOT
GURDASPUR
GUJRANWALA
LAHORE
HOSHIARPUR
JULLUNDHAR
LUDHIANA
PATIALA
KANGRA
SUJANPUR
TIRA
MANDI
HYDROELECTRIC SCHEME
JOGINDRA NAGAR
SUKET
BILASPUR
SIMLA
KALKA
CHAKRATA
MOTH
D.DUN
HARDWAR
SAHARAN DUR
M.NAGAR
BIJNOR
VIII
IX
VII
VIII
32°
30°
74°
76°
78°

On 20th October, 1937 an earthquake with its epicenter at U.P.-Himachal Pradesh Border was very strongly felt in Dehradun and Ambala and strongly in Mussoorie and Roorkee. No record of damage to property or life is available.

Local Shocks.

The enquiries made during the present investigation have revealed certain interesting information regarding the local shocks felt in Mussoorie area. According to the information given by the natives of Mussoorie, the southern parts of Mussoorie has remained seismically less active during the past 50 years. On the other hand mild to sharp tremors are occasionally felt in the Landhour, Jabarkhet and other northern parts of Mussoorie. A sharp tremor was felt in these localities on 27th May 1964. This shock which was felt for 2 or 3 seconds which caused cracking of walls of a few houses, in Landhour and Jabarkhet areas remained completely unfelt in southern parts of Mussoorie. A possible explanation will be given in a subsequent stage of this chapter.

TECTONIC FRAME WORK

The foregoing accounts indicate towards the highly seismic nature of the region. The cause of which presumably lies in the geological and tectonic set-up of this part of the country.

As it has been mentioned previously, Mussoorie is located within the Król Belt. In this region there is the presence of several thrust planes along which slices of the crust have moved considerable distances in order to adjust themselves to the compressive forces. Jutogh, Chail, Giri and Krol thrusts and Main-boundary fault have been established in the neighbouring Simla area. The Krol thrust and the main boundary faults are persistent in the Dehradun-Garhwal area also, where the Krol thrust have over-ridden the Main Boundary fault. In addition , another thrust known as the Garhwal thrust has brought the Garhwal nappe over the Krol belt.

For complete study of the seismicity of the region consideration of all these tectonic planes is necessary. But due to the limitations of the present work it was not possible to do so. A brief review of Krol thrust , however, is given below. It is because this tectonic plane is the nearest one to the area and has possibly more bearing on the seismic status of the region.

STATUS OF ACTIVITY ALONG KROL THRUST:

The exact age of Krol thrusttis not known. However, according to Auden , the thrust must have taken place over a considerable length of time. Subsequent works done by Jalote(1961, 1962), Krishnaswami (1959, 1961), and others have reveal the fact that movements have been taking place in the sub-Himalayan areas till the geologically recent times.

Author's fellow worker Mr. P.N. Jalote, while working in the Rajpur area have noted that the Chandpur phyllite have been thrusted over the Dun gravels. He has also observed tilted recent terrace deposit along the thrust. On the basis of these observations he has come to the conclusion that Krol thrust have been active during the recent past times.

POSSIBILITY OF FUTURE EARTHQUAKES

No periodic regularity could be established for the commencement of earthquakes in the Mussoorie region. Consequently, it is impossible to state when next shock may be expected in the region. However, the foregoing discussion indicate that Mussoorie lie undoubtedly in a seismic area and, therefore, the possibility of severe seismic damages can not be denied.

The present work has shown that the Krol-Tal boundary is a tectonic one. As mention has been made previously, it was noted that more earthquake shocks have been recorded in the Landhour, Jabarkhet and other areas situated above the Krol-Tal boundary, than the areas below it. It seems therefore logical to believe that the Krol-Tal boundary should be regarded as more amenable to the earthquakes than even the Krol Thrust. It is, therefore, necessary that a detailed investigation of the Krol-Tal contact be undertaken with a view to study the tectonic and seismic aspects of this part of the Himalayas.

------ X ------

TABLE V (a)

PAST RECORD OF IMPORTANT EARTHQUAKES

Important Earthquakes in and Around Dehradun

Date	Place	Intensity	Remarks.
1	2	3	4
1505- July 6	Agra	Severe	Great damage.
1669-June 22	Kashmir	Violent	Large fissures in ground.
1720-[illegible]y 15	Delhi	Severe	Great damage.
1726-J[illegible]y 15	Delhi	> 7.5	Description of damage indicates a magnitude of greater than 7.5. Great damage and large fissures in ground.
1803- May 22	Upper Ganges	---	Severe rumbling noise.
1803-	Garhwal-Kumaon.	Violent	200-300 killed, great damage.
1809-	Garhwal	Strong.	Landslide blocked Vishnoo Ganga.
1816-May 26	Gangotri	Severe	Landslides and rock falls.
1825-March 22	Delhi.	Sharp	----
1828-June 6 and 15	Kashmir	Very severe	1,000 killed, 1200 houses destroyed
1830-July 17	Delhi	Moderate	The last of three earthquakes felt during four months.
1831-October 24	Delhi	Severe	West of Delhi, Nausea and Shaking.

Continued......

1	2	3	4
1842-- June 16	Mathura .	Severe	Felt upto Mirzapur and Chunar.
1842-- March 5	Mussoorie --Simla	Severe.	Damage to houses.
1843--April 11	Landhour (Mussoorie)	Sharp.	Felt upto Delhi and Meerut.
1851-- Feb. 14	Nainital.	Light	Storm.
1888-- August 11	Simla	Light	Two shocks.
1860-- July 9	Dharamshala	Moderate.	
1905-- April 4	Kangra	Greater VIII R.F.	Great damage, 20000 killed.Kangra and Dharamsala destroyed.
1937--October 20	U.P and H.P. Border.	>V R.F.	Felt very strongly in Dehradun and Ambala, trough in Mussoorie before Roorkee.
1955-- April 14		> IV RF	Felt at Simla.
1956-- October 20	Khurja Bulandshahr	6.75	23 killed in Bulandshahr and some slightly injured in Delhi.
1960 August 27	Delhi--Gurgaon.	6.0	50 injured and minor property damage at New Delhi.

Date	P Arrival	Position	
1	2	3	
	h.m.s.		
1956--Oct.	--	--	Felt at Roorkee.
1958--Dec.	--	--	Felt at Hissar, Simla, Bareilly and Roorkee at 5 h. 37 m with intensities V, V, VII, VIII respectively
1961--July 13	07,13,30	25.8-31.5	Moderate Intensity well recorded all over India

Continued...../

1	2	3	4
	H. M. S.		
1962-July 13	05, 08, 6	30.5, 79.6	Near Almora in U.P. Felt strongly at Almora, Mukhteshwar Tel . Felt by some persons at Delhi. The shock was recorded in almost all observatories in India.
1962- July 14	15, 58, 53.7	30.4, 79.5	Near Almora, strongly felt at Almora, Mukteshwar landslides near, Joshimath, Recorded at almost all observatories in India.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The present work was carried out with a view to study the geology, structure and seismicity of the South-Eastern part of Mussoorie. The author has studied the geomorphology and its relationship with the geological set-up of the area, in Chapter I. Since the geology of the Himalayan belt is a complicated aspect, it was necessary to study the earlier works on this area and on related areas lying in the Krol belt. A general survey of the previous works is presented in Chapter II. The geology and the structure of the present area has been studied in detail in Chapter III. It was found that Mussoorie region is a part of the Krol nappe and lies on the South-Western limb of a major syncline. The formations exposed in the area range from Infra-Krols to Upper Krol dolomites conforming to Krol E of Pilgrim and West. The Krol Series is overlain by Lower and Upper Tals and the contact between the two is not normal. It has been shown that this contact is a faulted one and more of the nature of glided thrust, atleast in the present area. A petrographic description of the rocks substantiated with partial chemical analyses and modal analysis has been given in Chapter IV. The nature of the barytes and pyrite occurrances have been reported and discussed in the same chapter.

On the basis of the studies thus carried, the author has studied the seismicity of the area in Chapter V. It was found that this area lies within a definite seismic zone. It was also discussed that the regions falling above the Krol-Tal contact are more seismic than the region below it.

Certain problems have arisen during the present study, which need a further [illegible] before any final word can be written about them. Such problems are listed below:-

1. Does the Upper Krol dolomites, showing the nature of Krol D in the lower horizon and that of Krol E in top-most horizon, and showing a gradational change represents a continuity of deposition or is divisible as in other parts of the Krol belt?

2. The nature of stromatolyte-like structure found in Upper Krol dolomite needs further exploration to prove whether it is of organic origin.

3. The basal part of Upper Krol dolomite just above the Krol limestones contains a powdery carbonaceous material. What is the exact significance of such occurrence? Since the same dolomites show stromatolyte-like structure, it will be very interesting to find out whether the combination of carbon and stromatolyte-like structure indicate any possibility of life.

4. The composition of the intrusive transgressive sills needs a further study, with a view to know its exact [illegible] is [illegible]. Due to heavy alteration of [illegible] felspars, It is necessary that chemical analysis be carried out together with thorough optical investigation of the minerals.

5. What is the true nature of the Krol-Tal contact? Is it a sliding plane or a fault? What is its nature in adjoining localities. Since it has been recorded that some seismic activity has taken [illegible] of Tals, the importance of such study is obvious and imperative.

REFERENCES

Auden , J.B., 1934, Geology of Krol belt, Rec. Geol. Surv. India. Vol. 67, pt. 4.

Auden, J.B. 1935, Traverses in Himalayas Rec. Geol. Survey. India. Vol.69, pt. 2.

Auden, J.B., 1937, Structure of Himalaya in Garhwal Rec. Geol. Surv. Ind. Vol.69, pt. 4.

Auden, J.B. 1942 a, Geological Investigations of Tunnel Alignment for Jumna Hydro-electric Scheme Rec. Geol. Surv. Ind. Vol. 71, pt. 4.

Auden, J.B. 1942b, Report on the marble formations around Mussoorie as a source of chemical lime for the manufacture of calcium carbide (unpublished).

Emmons R.C. (1953)- Twin-Zone relationship in Plagioclase Felspars: The Geol. Soc. America Mem.52.

Gundu Rao, C. 1964, Pseudo-pleochroic calcite from the crystalline limestone of Krol series. Bull. Oil and Nat. Gas. Com. Vol.1

Gansser, A. 1964, Geology of the Himalayas Inter Science Publishers, John Wiley and Sons. Ltd.,

Mithal, R.S. and Chaturvedi, L.S., Possible Algal Structure in upper Krol lime stones of Mussoorie area.

Hatch, F.H., et al, 1961, The petrology of ogneous rocks Thomas Murby and Company.

Johansen, A., Descriptive petrography of the igneous rocks Volume 1, Allied pacific (Pvt) Ltd.,

Krishnaswamy, V.S., Probable Correlation of the Structural and tectonic features of Punjab-Himachal Pradesh Tertiary re-entrants with the pattern of seismicity of the region Proc. Sec. Sym. of Earthquake Eng.

Krishnan, M.S. and Swaminath, J., 1959, Great Vindhaya Basin Jour. Geol. Soc. Ind. Vol. 1, p. 20-29.

Krishnan, M.S., 1960, Geology of India, Higgin bothams (Pvt) Ltd.,

Medlicott, H.B., 1864, Mem. Geol. Surv.

Middlemiss, C.S., 1910, Kangra earthquake Mem. Geol. Surv. Ind. Vol.38 pp. 348-349.

Mehta, D.R.S., 1959, High Grade Limestone Deposits of Dehradun Mussoorie area U.P. Bull. Geol. Surv. India. Series A No.16.

Prakash, I., and Swarup, P., (1960), 'Progress Report on the investigation of Marble Deposits occurring near Mussoorie U.P. (Directorate of Geology and Mining U.P. Publication)

Pascoe, 1959, Manual of Geology of India and Burma., Publications Division , Government of India.

Raju, A.T.R. and Bhattacharya, S.N., Proceedings of the National Institute of Sciences of India, Vol.28 A No.5 1962.

Srivastava, L.S. and Mithal, R.S., 1965, Seismicity and Tectonic History of Indo-gangetic plains Bull.Ind. Soc. of Earthquake Technology. Vol.II No.2.

Wadia, D.N., 1952., Geology of India, Macmillan Co.Ltd. London.

Wadia, D.N. and West, W.D., 1964, Structure of Himalayas XXII International Geological Congress.