GEOLOGY OF THE AREA SOUTH & WEST OF MUSSOORIE WITH A NOTE ON SEISMICITY

A DISSERTATION
SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENT FOR THE DEGREE OF
M. Sc. Tech.
IN APPLIED GEOLOGY

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C E R T I F I C A T E

Certified that the dissertation entitled GEOLOGY OF THE AREA SOUTH AND WEST OF MUSSOORIE WITH A NOTE ON SEISMICITY being submitted by Sri SATYANARAYANA MURTY SALAPAKA 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 23rd March, 1966

(R.K. Goel)

LECTURER

Department of Geology & Geophysics,

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PREFACE

The area herein described is a part of Mussoorie Rajpur region allotted to the Author and his colleagues for geological and structural mapping and for collection of seismic data. This project was jointly sponsored by the Department of Geology and Geophysics, University of Roorkee and the School of Research and Training in Earthquake Engineering C.S.I.R. This entire region was split up into four sections and the author and his three other colleagues worked out one portion each in detail.

The area South and West of Mussoorie was mapped by the author in June and October 1965. In the field various lithological units were traced and their contacts marked mainly by employing pace and compass method.

The accessible regions were visited and the structural and lithological data collected in the field. The approach was not always easy as is to be expected in the mountaineous country and visit to several places had to be abondoned on account of thick forests of vegetation.

From Snowdon upto the power house mapping was done on the 8"-1 mile guide map of Mussoorie. The Western portion, that is cloud end, Hathipaon Banog section is mapped on a 6.5"-1 mile map enlarged from the toposheet 53 J/3 of Survey of India. Finally in the laboratory the 6.5" map was enlarged to 8" and the lithological and structural data were filled.

The various units marked in the field are Infra-Krols, Krol A, Krol B, Krol C, Krol D and the intrusive bodies.

In the laboratory microscopic studies of various rock types were carried out and the limestones were chemically analysed. The microscopic studies support the designation of the intrussive bodies as mela monzonites. The results of the Chemical Analyses are listed in Table No. 4.

Date: 23rd March, 1966

Sm Salapaka
(S.M. SALAPAKA)

A C K N O W L E D G E M E N T

I take this momentous opportunity to thank Prof. R.S. Mittal, head of the Department Geology and Geophysics for his constant advice and encouragement and for allowing me all the facilities to work in the field and laboratory.

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I am much indebted to Dr. K.K. Singh, and Mr. R.S. Chaturvedi, who introduced me to the geology of difficult Himalayan terrain and to Dr. B.B.S. Singhal who helped me in carrying out the petrographic work.

My sincere thanks are due to my colleagues Messrs Gopalji Singh, Bhupendra Singh and P.M. Jalote who helped me time to time while carrying out the field work.

I thank Mr. P.C. Punj, Section Cutter and Mr. Deen Dayal the typist for their considerate attitude.

Date : 23rd March, 1966. (S.M. Salapaka)

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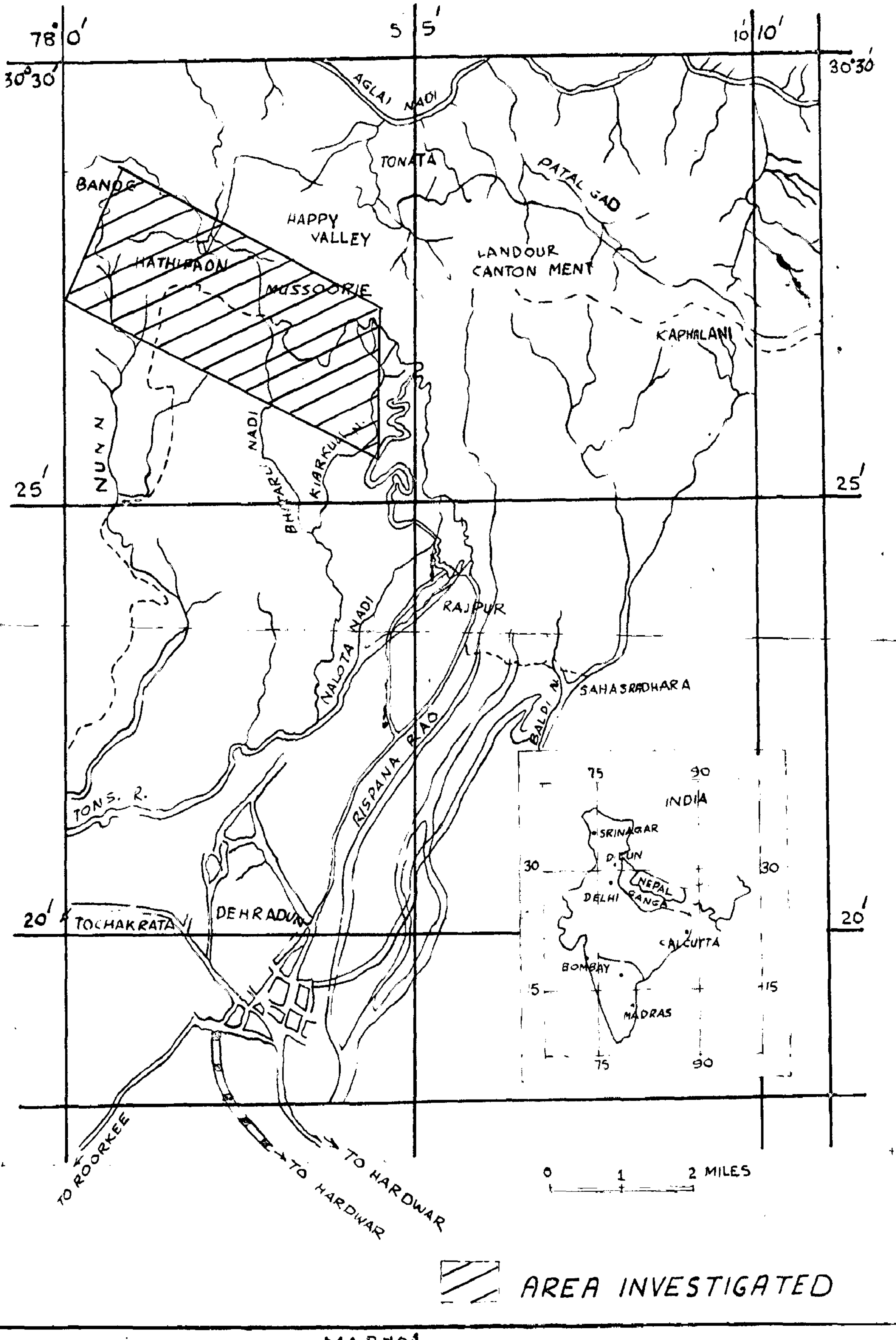
LOCATION MAP



MAP NO.1

CHAPTER I

INTRODUCTION

The area under investigation by the present author forms a part of the South Western Mussoorie, and is situated in the toposheet 53 J/3 of Survey of India. It lies between 30°26' and 30°28' 30" lattitudes, and, 78° - and 78°4' 30" longitudes, and covers roughly an area of about 6.5 square miles. Mapping and field work has been restricted to the cloud end and Banog hills in the North West and the electric power house in the South East.

Mussoorie is situated at a height of 64,00 ft above the mean sea level and is a comfortable summer resort for the people from plains. The temperature of Mussoorie ranges between 23°F in the winter to 78°F in summer. The annual rainfall of the area varies from 90 to 120 inches. In the winters snow fall is quite frequent.

Most enjoyable and convenient months for the field work in the neighbourhood of Mussoorie are the months of May and June. During these months the weather is pleasant and the skies are clear. From July onwards the sky is almost always overcast. After the end of monsoons gradually the temperature goes considerably down, so much so that in December and January very frequent snow falls occur. From March onwards the rigorous cold begins to dissipate and the life and activity comes back to this queen of hills.

Mussoorie is negotiable all through the year by road from Dehradun which is about 22 miles away. Dehradun is a terminus of the Northern Railway and is very well connected with the other parts of the country by rail and roads. At Mussoorie there are abundant lodging facilities.

Physiography

The area assigned to the author is almost 6,000 ft in height above the M.S.L. Excepting the Southern most portion near Kiarkuli power house which is situated at 3300 ft only. Most of the hills in this area particularly in the North West namely Banog, cloud end, Blucher, Hathipaon, Lochletter and craig top, are above 7,000 ft in height but the Sianti Tibba lying in the South is only 6000 ft. The highest of all is Banog hill (7, 429 ft.). Hathipaon and Banog hills represent anticlinal hills, which is an indication of the immaturity of the terrain. Southward close to the power house a very big escarpment facing East is noticed where the land fall is striking.

The valleys in this area are narrow and are almost always covered with vegetalion. Big blocks of lime stone (not insitu) occur all along the way making access to the valleys difficult.

Excepting the summit of the Blucher and Craig top hills and the eastern flanks of Banog hill rest of the area is thickly vegetated. The tops of the Blucher, Craig top and Banog hills aredevoid of any vegetation. The rolled down and displaced blocks of lime stone give a rugged appearance to the area.

Narrow caverns about 3 ft wide and extending 10 to 15 ft deep are observed along the new circular road. Everywhere in this region aragonitic stalactites are common. The aragonite is seen formed along joints as well. At places lime stone is not hard and compact but crumples like soft clay on exposure.

Along the stream valleys big boulders consisting of shales, lime stones and basic rock fragment are found. These boulders are due to the concretionary affect of lime stone.

Except for the Mackinnons khad Bhitarli and Kiarkuli rivers which are more or less perennial, in this area others are mainly seasonal.

Here the main drainage pattern is of radial type. The hill range extending from Lochletter Abbey to Craig top and further east acts as the water shed. From here Mackinnon's khad flows towards north west and Bhitarli nadi towards south. Kiarkuli nadi starts from the eastern most portion of the area and flows down. It broadens as it goes down the power house where it emerges on a comparatively plain region. Below the power house the Kiarkuli nadi cuts into the Nagthat quartzites which are beautifully exposed on either side. In the West, cloud end and Banog hills also acts as the source areas of the streams and streamlets.

The Kiarkuli, Bhitarli nadis and the Mackinnon khad with their tributaries form dendritic pattern of drainage. Most of the streams and streamlets in this area flow down the mountain flanks and meet together to give a general dendritic pattern of drainage.

The Bhitarli nadi and Dauru khala give a typical example of a sort of annular drainage associated with the radial drainage flowing down from the Sianti Tibba.

Though the drainage forms mainly dendritic pattern in this area local parallelism in the streams and the streamlets can be observed in the drainage map which shows the adjustment of streams to local structural features.

Water falls of any significance in the region are Hardy falls and Kiarkuli falls. Hardy falls is situated at the point where the Dauru khala meets Bhitarli nadi. This name is given to a combination of several narrow rapids. The Kiarkuli fall is comparatively small and occurs South of Kiarkuli village.

There are several springs in the area. On the Mackinnons cart road itself there are two springs one near Bansigarh and the other opposite to Sianti Tibba. The new spring road owes it name to the John Mackinnons spring.

CHAPTER II

PREVIOUS WORK

Krol belt in general and that of Mussoorie in particular has drawn the attention of geologists since the second half of the 19th century. First person to publish an authoritative account of the rocks comprising the Krol belt was H.B. Medlicott (1864). His work was followed by that of R.S. Oldham, C.S. Middlemiss, Thomas Holland, H.C. Das Gupta, C.E. Pilgrim, D.N. Wadia, W.D. West, J.B. Auden and several others.

Mussoorie area became the subject of detailed investigation since the time, the deposits of white marble were noticed by J.B. Auden (1935). His work was supplemented by that of Alladdin (1939) in locating further deposits of marble. Later Auden (1942) continued his work and gave a full report on the marble formations around Mussoorie. R.S. Mehta and others (1959) of geological survey of India have further worked on these deposits. The directorate of Geology and Mining (Uttar Pradesh) has been actively engaged in studying the workable marble deposits of this area ever since its inception and they (1960) published a detailed report on their investigations.

In recent years oil and Natural Gas Commission has done considerable work on the geology of Mussoorie area, but most of this undoubtedly interesting work remains unpublished to this day and is therefore not available for reference. However, the only paper available namely studies on the Krol limestones from Mussoorie by A.T.R. Raju and S.N. Bhattacharya (1962) is worthy of description.

Regional Geology

H.B. Medlicott (1864) described a tract of Himalaya between Ravi and Ganges rivers covering about 7000 sq. miles in area and extending in length upto 250 miles. His work was mainly concerned with tertiary rocks but his observations on pretertiary rocks have formed the basis of all the later work on Krol belt. He classified the tertiary rocks which he called as sub-Himalayan series into three units, lower, middle and upper. The pre-tertiaries are classified by him into unmetamorphics and metamorphics and were named togther as Himalayan series. The Krol, Infra-Krol, Blaini and Infra-Blaini were included in unmetamorphics and crystalline and sub-crystalline rocks in metamorphics. The unmetamorphosed rocks of Krol hills are considered by him as equivalent to crystalline schists, tremolite schists, and recrystallised quartzites at Simla.

R.D. Oldham (1883-1888) was the next person to work on the Krol belt. He contributed several papers, on the geology of the hills between Simla and Chakrata. He concerned himself mainly with Blaini and Infra-Blaini rocks and suggested a glacial origin to the Blaini conglomerate and renamed it as boulder stage. He assigned upper paleozoic age to these beds.

C.S. Middlemiss (1885) mapped and described large areas of Garhwal Himalaya and his paper on the physical geology of the West British Garhwal is most significant, since this tract is South-East and in strike continuation with the Krol belt. His accurate mapping fore shadowed the possibility of great rock translations. Middlemiss paid much attention to the metamorphic conditions, noticing transitions between rocks of widely different metamorphic grades.

Holland (1908) described a striated boulder from Blaini beds and on this evidence supported the glacial origin as earlier given by Oldham, but ascribed purana age to the Blainis.

Prof. H.C. Das Gupta (1915-18) of presidency College Calcutta lead several parties to Simla and Solon areas and has published several papers on the age and correlation of the rocks in this area.

G.E. Pilgrim and W. D. West (1925) conducted a detailed survey of the rocks of Simla hills. Their work was almost entirely confined to the more metamorphosed rocks. They realised that the simplicity of sections at Simla was probably deceptive and discorded the correlation of rocks at Simla with those of Krol hills. They suggested that a series of thrusts had brought rocks of different degrees of metamorphism to be in abnormal juxtaposition.

J.B. Auden (1934) continued the work of Pilgrim and West and mapped the area between Gambhar river which flows from Simla to meet the Sutlej and Jumna river which delineate the boundary between Chakrata Tehsil and Tehri Garhwal state. The correlation as given by him for Simla and Chakrata hills is as shown in table No. 1

Table No. 1

Age	Solan neighbourhood	Tons river, neighbourhood
1	2	3
Miocene	Nahans (only at Kalka)	Nahans
Lower Miocene	(Kasauli (Daghsai	Dagshai
Oligocene to Eocene	Subathu (Nommulitcs)	Subathu (Nummulitics)
		Never in contact
Cretaceous ?and Jurassic	Absent	Tal (Upper Tal Tal (Lower Tal
	Krol E	
?Permian	Krol D	Upper Krol L.St.
Carboniferous	Krol series — Krol limestone — Krol C	Krol series — Krol limestone
	Krol B Red shales	Red shales
	Krol A	Lower Krol L.St.
	Krol sandstone	
	Infra-Krol	Infra-Krol
Upper Carboniferous	Blaini	Blaini

Contd ---

1	2	3
Devonian ? (Silurian)	Jaunsar with possible Mandhalis	Nagthat stage) Chandpur stage) Jaunsar series Mandhali stage)
Lower paleozoic ? and pre cambrian	Simla slates with Kakahatti limestone	Deoban limestone Simla slates
? Miocene and older	Dolerites	

For the area East of 78° longitude including Mussoorie and the neighbourhood, J.B. Auden (1937) has given the following geological succession.

Table No. 2

Formation	Unconformity	Approximate maximum thickness	Probable age
1	2	3	4
Siwalik		16,000'	Upper Miocene to Pleistocene
	?		
Murree			Lower Miocene
	?	?	
Nummulitics			Eocene
	.___ .___.___.	?	
Tal limestone and Calcgrit		200	Upper cretaceous ?
	.___.___.___.		

Contd ...

1	2	3	4
Tal Series (Upper Tal quartzite		4,500'	Cretaceous) ?
(Lower Tal Shales		2,000'	Jurassic)
	-.-.-.-		
Krol Series (Upper Krol Limestone and shales		3,000'	Triassic) ?
(Krol Red shales	)		)
(Lower Krol limestone and shale	------------)	1,000'	Permian)
Blaini series (Infra-krol slates	)		
(Upper Blaini boulder bed and dolomite	)		
	-.-.-.-.-.-)	2,000'	Talchir (uralian) ?
(Blaini slates	)		
(Lower Blaini Boulder bed	)		
	-.-.-.-.-.-		
Nagthat		3,000'	Devonian ?
	-.-.-.-.-.-		
Chandpur		4,000'	Lower paleozoic and pre-cambrian ?
Simla slates			
Possibly equivalent to Chandpurs, although different in lithology			
Dolerites			Late tertiary ?

Note:- Conformity, --- unconformity -.-.-

Krishnan and Swaminathan have referred in their paper (1959) an earlier work of V.H. Boileau wherein, Boileau has suggested that the Blaini boulder bed was equivalent to the Kaimur series rather than to the Talchir boulder bed as believed earlier. With this as the basic idea Boileau suggested correlation of other Himalayan formations including Krols with the peninsular formations.

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

In Mussoorie area a marble zone of 40 ft thick is present in Krol C stage. It runs from Jharipani upto cloudend hill. Auden (1935-36) was first to notice these deposits. He (1942) surveyed these deposits further and estimated the total reserve to be of the order of 34,000,000 tons. He found the marble to be extremely low in silica, and sesquioxide and found magnesia to be variable. A metasometic origin was given by him to these deposits.

Recent authoratative work on the marble deposits is that of R.S. Mehta (1959) of the Geological Survey of India and R.P. Mathur (1960) of the Directorate of Geology and Mining Uttar Pradesh. They traced a continuous band of marble from Jaripani to cloudend, and analysed several samples of this high grade limestone.

Various Krol lime stones of Mussoorie area were analysed by A.T.R. Raju and S.N. Bhattacharya (1962) of the Oil and Natural Gas Commission. According to their analyses Krol C residues are dominated by fluorides, those of Krol D by detrital sands and authigenic euhedral felspar, while chert and mud stones flood in Krol E. Upper part of Krol D however resembles Krol E in its residue. Their Geochemical study of the degree of dolomitization based on Mgo/cao ratios suggests that Krol A limestone and the upper Krol sequence has two distinct groups. Krol C is dolomitized lime stone while both Krol D and E are magnesian dolmites. Though basal part of Krol D sequence resembles Krol C in such ratios no distinction can be made between Krol D and E by this method.

In upper Krol limestones R.S. Mittal and R.S. Chaturvedi (1963) indicated the presence of probable algal structures.

The basic intrusive rock occuring in this area was described by Auden (1934). He identified plagioclase (oligoclase to Andesine), Quartz, Augite, Magnetite and Apatite in this rock and named it as leucophyre.

Regional Structure

Auden (1937) devided the Garhwal Himalaya into the following tectonic divisions:

Autochthonous Unit: The base of this unit is probably the Simla slateo series. Nummulitics, Murrees and Siwaliks overlies the Simla slates. Thrusts occur in these units but they do not seem to be of primary magnitude. The important thrust is the main boundary fault. This Autochthonous Unit appears to occur well within the Himalaya, some twenty miles at least from Dehra Dun.

Thekrol Nappe : This is thrust upon the Authochthonous unit. This corresponds to the krol belt.

The Garhwal Nappes: These are thrust upon the Krol Nappe. The main Garhwal Nappe may root in the main Himalayan range.

The main Himalayan range: It appears to be made up partly of elements common to one of the Garhwal Nappes and partly of a distinct group of paragneisses and schists.

The granitic zone : To the North of main Himalaya, granite intrusives occur in paragneisses and schists.

The Tethys zone : This zone consists of fossiliferous tertiary sediments.

In the area East of 78° longitude which includes the Mussoorie syncline, the tectonic succession of Jaunsar, Blaini, Krol and Tal rocks by the same Author is as follows:-

TABLE No. 3

+Garhwal Nappes	Chandpur's (metamarphosed) Thrust Nagthat) Little metamor- Chandpur) phosed Boulder beds, shales and lime stones of uncertain strati- graphical horizon occur in one outlier below metamorphosed Chandpur's.
+Garhwal thrust	
Krol Nappe	+Nummulitics Tal Krol Blaini Nagthat) metamarphosed and Chandpur) unmetamarphosed
Krol thrust	
Autochthonous	+Dagshai, Nummulitic / Siwalik Simla slates

N.B. Formations marked with asterisks were not observed in the area investigated in the neighbourhood of Mussoorie.

Between Jamuna and Ganges rivers the main structure is an anticline in the Siwalik range, a syncline forming the Dun valley, and to the North East an over-turned anticline which is truncated on the North side by the main boundary fault and the krol thrust. The base of the Siwalik rocks is presumed to consist of Nummulitics with attenuated Dagshai rocks resting on Simla slates. Originally the term main boundary fault was used by Medlicott, denoting the thrust which separates Siwaliks from older tertiaries. East of 78° longitude, that is, in Mussoorie area, the Dagshai rocks are seldom seen. Here the krol thrust has brought pre-tertiaries to directly rest upon Siwaliks. In these rocks numerous thrusts and faults occur but they are of less magnitude.

The krol Nappe is having a thickness of the order or 20,000 ft. The succession here is a normal one. Numerous exposures of current bedding in the calc-grit of the Tal lime stone, and in the Tal and Nagthat quartzites, show that these particular stages are not inverted and therefore the whole succession is in correct order. The most convencing evidence for the existence of Nappe East of 78° longitude is the occurrence of two windows disclosing Nummulitics and Simla slates. The windows occur along the anticlinal axis which separates the Mussoorie syncline of Nagthat-Blaini-Krol-Tal rocks from the Garhwal syncline lying to the South and enechelon with it. Simla slates occur in the centre of the windows. Nummulitics overlie Simla slates some times as isolated cappings. More typically, the nummulitic shales and lime stones are found together bordering the windows along with blocks of highly shattered quartzite. Unmetamorphosed facies of Chandpurs of Krol Nappe occur above the Nummulitics. According to Auden the nummulitics were deposited on the peneplained surface of Simla slates and were over thrust by the Chandpur series of Krol Nappe.

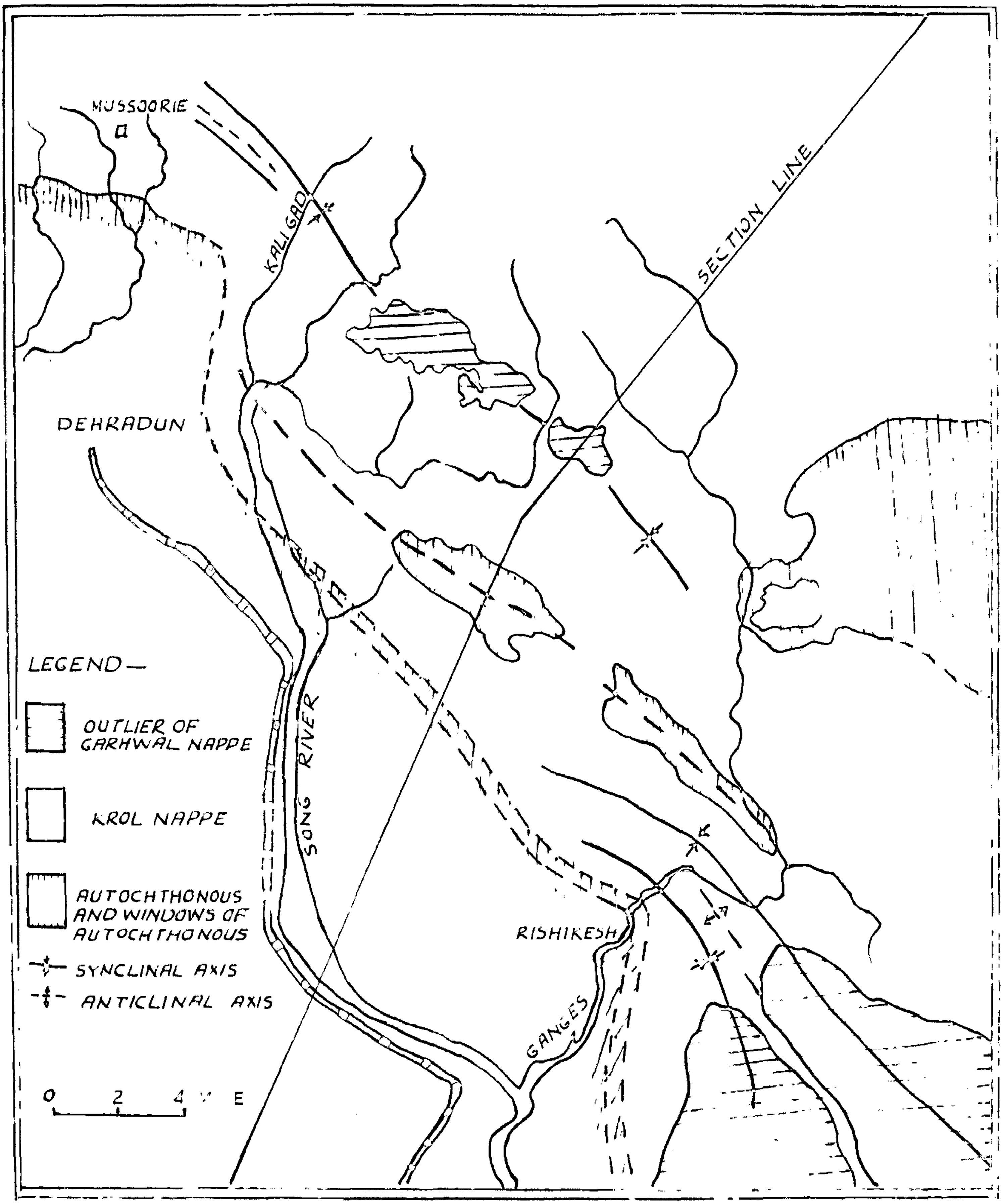
The Krol thrust from Solon to Dadahu brings Infra-Krols and Blaini rocks against Subathu, Dagshai and Kasauli stages. Further East, Blaini, Jaunsar and Mandhali rocks override Subathus and eventually come to lie upon Nahans.

The presence of Dagshais and Nummulitics put the thrust younger or equivalent to Burdigalian. In places even the upper Siwalik Conglomerates are involved in overthrust by the pre-Tertiaries. These movements therefore must be lower pleistocene in age or later.

D.N. Walia and W.D. West (1964), admit more than one orogeny in Simla-Garhwal area. According to them the earliest is pre-eocene as subathu sediments are found resting unconformably on the strata of paleozoic and mesozoic ages in different areas in this region. A large scale post-Subathu movement resulted in the translation of rocks Southwards along low angle thrusts in a series of Nappes, possibly with attendant intrusions of granites in the root zone. This movement cannot be precisely dated, but it is likely to have taken place at the begining of lower Siwalik (Middle Miocene) times, when a significant change in the nature of deposition in the tertiary belt took place, the main source area being the lower Himalaya. The folding of the thrust sheets probably took place at the end of Middle Siwalik (Upper Miocene) times giving rise to a change in deposition from arkoses to Conglomerates containing Krol belt pebbles in foot hill trough. The later was affected by the final orogenic activity at the end of upper Siwalik (Lower pleistocene) times, and folded and faulted into the structures seen at the present time. The Nappe belt also moved further Southwards at this time, coming to rest directly against Siwalik sediments at places. Subsequent movement has been largely of vertical nature due presumably to isostatic and eustatic adjustments.

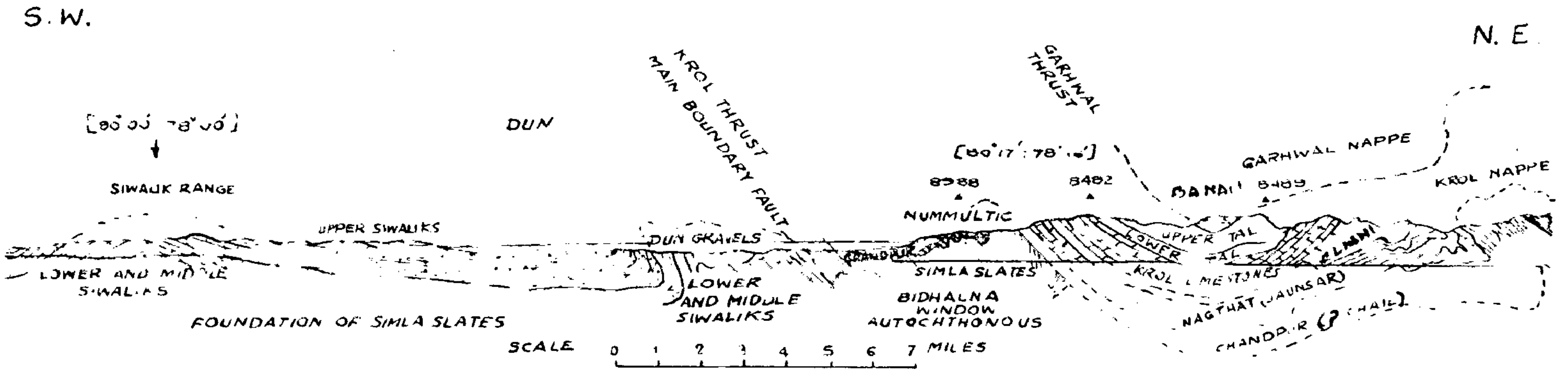
FIG. NO. 2.1

DISTRIBUTION OF TECTONIC UNITS DEHRADUN-RISHIKESH AREA



AFTER (Chand, S. 1971)

SECTION ACROSS SIWALIK RANGE AND LOWER HIMALAYA



AFTER AUDEN (1937)

FIG NO 2·2

CHAPTER III

PRESENT WORK

Geology of the Area

The area investigated by the present author is a very small portion of the main Krol belt and forms the South Western portion of the major Mussoorie syncline consisting of Jaunsar, Blaini, Krol and Tal rocks. In the area mapped by the author, the rocks of Krol series and the Infra-Krol slates belonging to the Blaini series are present.

The geological sequence of the rocks in the area is as follows:-

Lithological unit		Name after Auden	
Mela monzonite transgressive sills	--	Dolerite dykes	KROL Series
+ Massive limestone and shales	-	Krol D and E	
Marble, Bluish black limestone and calcareous shales	--	Krol C	
Purple shales	--	Krol B	
Lower limestone and shales	-	Krol A	
Slates and shales	-	Infra-Krol	Blaini Series

(+ Since Krol D and E are not easily distinguishable as two separate lithic units in the field the author has been consequently obliged to consider them together as Krol D).

In the South East of this area Infra-Krol rocks are traced below the Kiarkuli power house, in its neighbourhood, and, between Bulat and Pandai villages in the North-West. These rocks overlie the Blaini boulder bed. These are dark slaty shales interbedded with very thin bands of quartzite. Numerous veins of quartz and calcite irregularly traverse these formations. The foliation planes of these rocks being weak planes the veins generally follow them. The Infra-Krols are very incompetent and are found intricately folded and fractured. South of cloud-end between Bulat and Pandai Villages, they are folded through out.

The Infra-Krol rocks in the area are overlain by the rocks of Krol **A** stage both in the South-East and the North-West. These rocks are characterized by thin bands of limestone and slaty shale. The bands of limestone vary in thickness from 1 to 4 inches. The shale bands are subordinate and are traversed by the veins of calcite along the joints. These limestones are considerably hard to break. The thickness of this stage is 600' at power house and about 700' at cloud end.

The Krol **A** limestone is overlain by Krol B purple shales. The Krol B formation is not a regular one, varying largely in width and extent from one place to another. It may appear very broad and distinguishable at one place but may gradually pinch out to ultimately disappear completely. The Krol B formation consists of green and purple shales of variegated nature. These shales are much jointed and sheared making it difficult to get a hand specimen. Near kiarkuli power house the Krol B shales are clearly visible on the scarp face. Both in the South-East and the North-West of this area the KrolB formation is considerably thick (400').

The Krol B purple shales are overlain by the calcareous shales belonging to the basal portion of Krol C stage, which in turn is overlain by the bluish black crystalline limestone. The calcareous shales underlying the crystalline limestone occur both at Kiarkuli and South of cloud end. These shales are 40 to 50 ft thick earthy brown in colour and are traversed by calcite veins along the joints. The bluish block limestone overlying these shales gives sulphurous smell on breaking. Many fine irregular calcite veins traverse this massive limestone. Calcite is also seen developed along the cavities.

The upper layers of this limestone are purely white and crystalline for about 15 ft and are referred to as marble but the total high grade limestone is over 40 ft thick. From the Krol C stage quarrying is done for three varieties of lime stones, the top most pure white marble, the middle grey limestone and the Lower black limestone. The limestone in this area is quarried at Kiarkuli, Bhitarli, Hathipaon and cloud end by private companies. At Bhitarli the marble is particularly good being light grey to white in colour where as it is bluish grey elsewhere. Too many closely spaced joints, sometimes even 1/2" to 2 inches apart render it useless for building purposes, though not in the manufacture of calcium carbide, in sugar factories or in the manufacture of bleaching powder and glass. The Krol C stage is thick both at Kiarkuli and cloud end but its extra ordinary thickness at Bhitarli has probably been caused by folding. The usual thickness of Krol C stage is 700 to 800 ft.

The Krol C stage, through out the area is overlain by 100 ft. thick black sooty limestone and shales belonging to Krol D stage. These limestones are Dolomites in nature, which confirms their inclusion in Krol D stage. They consist of carbon and argillaceous material which is some times as high as 30%. The rest of the Krol D formation is massive lime stone with 10 to 15 ft thick green and red bands of shale. These thin shale bands cannot however be traced laterally for long distances, as they usually grade into lime stones. The Krol D lime stone near the library khala consists of small amount of of quartz and felspar grains and along the veins in it, Calcite and satin spar-a-variety of gypsum are developed. Structures comparable to stramatolites caused probably by algal agencies are observed in the Krol D lime stone near Lions Paw on the new circular road. In higher reaches, that is, near Chandal Garhi the Krol D lime stone is pale and highly jointed.

The Krol D lime stone in the area is traversed by several transgressive sills. These are in concordance with the country rock but at places are seen cutting across the shale bands into the Lime stone. As regards the mutual relationship of these sills, the author does not however possess enough evidences to prove whether these separate basic bodies belong to one major intrusive sill or they indicate different un-connected ramifications. In this area the trend of the sill is in the North-West South-East direction. There are two parallel series of sills in this area. One goes from library Khala upto the bifurcation of Mackinnon road from the main motor road and further continue outside the area upto Dhobi ghat. The other series of sills occur at Krishna mandir, Bansi garh, Snowdon, wishing well, and cloud end. Their thickness at these places ranges from below 100 ft (at cloud end and Wishing Well) to Well above 500' (Snowdon). At Snowdon a discontinued patch of the sill occurs in the North South direction.

The sill in the area is usually much sheared especially at Bansigarh Snowdon and Wishing well. Irregular fractures traverse these rocks in various directions. At Wishing Well the rock is so weathered that it has taken a loosely friable and almost powdery aspect. In contrast to these intrusive bodies the sill at the bifurcation of Mackinnon road running upto library Khala is fresh and perfect joints running parallel to the regional strike are observed in ~~them~~ it.

This intrusive sill is fine to medium grained and melanocratic. On the basis of the petrographic studies this sill is named as mela monzonite. In the lime stones the contact effect due to this intrusion is very meagre, though at places lime stone is observed very greatly baked. At Bansigarh the contact effect is seen upto about a foot only but talc and asbestos are seen developed at the junction of the intrusive sill and the limestone. This meagre contact effect may be due to the shallow intrusion with less over burden which caused great loss of heat. Along the joints in the sill thin coatings of serpentine are observed which may be due to later hydrothermal solutions.

Opposite vincent hill Schools on the new circular road a small isolated occurrence of very different shale formation hardly 20 to 25 ft thick and extending for roughly half a forlong is very interesting. These shales lie unconformably over the Krol D lime stone and are highly jointed. They do not resemble the normal Krol D shales but agree well in apperance with the Tal shales exposed in the neighbouring area. This abnormal occurrence of these shales at this place leads one to speculate some important structural disturbance.

Structure of the area

The area under investigation forms a part of the South Western limb of the Main Mussoorie syncline. This limb is itself seen folded into several minor anticlines and synclines, their axes being more or less parallel to the axis of major syncline. The Hathipaon and Banog hills in the North-West, which are anticlinal hills are themselves obvious manifestations of these foldings or bucklings of the synclinal limb in this area. In the field, it is, however, very difficult to determine the exact nature of the plunge and other characteristics of the folds due to difficult terrain and thick vegetation.

The regional dip of this area, that is the dip of the major synclinal limb is in the North East direction. The dip direction varies from NNE to NE and the dip amount varies from 35° to 55°. Near Kiarkuli power house the formations are seen dipping 45° to 50° due Nort-East. Further West at Bhitarli the beds dip very steeply, their dip being 70° due Nort-East. At Bhitarli the Krol C stage exhibits unusually great thickness which may have been caused by folding.

South of cloud end the formations dip due North-East with an angle of 40°. The Infra-Krols at this place occur at ...bly higher level than elsewhere and are observed ... incompetent. Fractures run parallel to the ...lds. Below the cloud end hill the ...fra-Krol rocks are observed. ...bout a mile South of

Bulat, the author has found the repetition of Krol A, Krol B and Krol C rocks dipping 40° due NE. This shows that this area consists of a major isoclinal anticline and this is apparently the main reason for the unusual width and elevation of the Infra-Krols. Thus the beds South of cloud end are forming the Norther limb of the Bulat anticline and the Southern limb of the cloud end syncline, whose Northern extension is the Banog anticline.

In the area, Hathipaon and Banog hills are anticlinal hills as already stated above. The Hathipaon hill is consisting of Krol C stage. Its plunge is towards East. The Banog hill is an anticline as North of it, beds dipping due North-East are clearly visible from Hathipaon tollbar and the Southern flanks of which are seen folded again . This hill can thus be called a minor anticlinorium.

In Krol D stage the beds are observed either dipping due North-East or South-West. The dip amount of these beds vary from 20° to 60° though normally the general dip ranges between 35° to 55°. The North-Easterly and South-Westerly dips clearly suggest the minor folds in this stage.

The main joints in the area run parallel to the strike of the bedding planes. Their dip varies from 20° to 90°. Vertical joints are also observed striking North-East South-West. The marble formations show closely spaced rhombohedral joints some of these are as close as 1/2" to 2" apart.

In Krol D stage the intercalated shales are observed assuming non-uniform types of folding. Because of the presence of shale bands the limestones lying above and below are folded independant of each other and the shales adjust themselves accordingly (Fig 3.3 a and b).

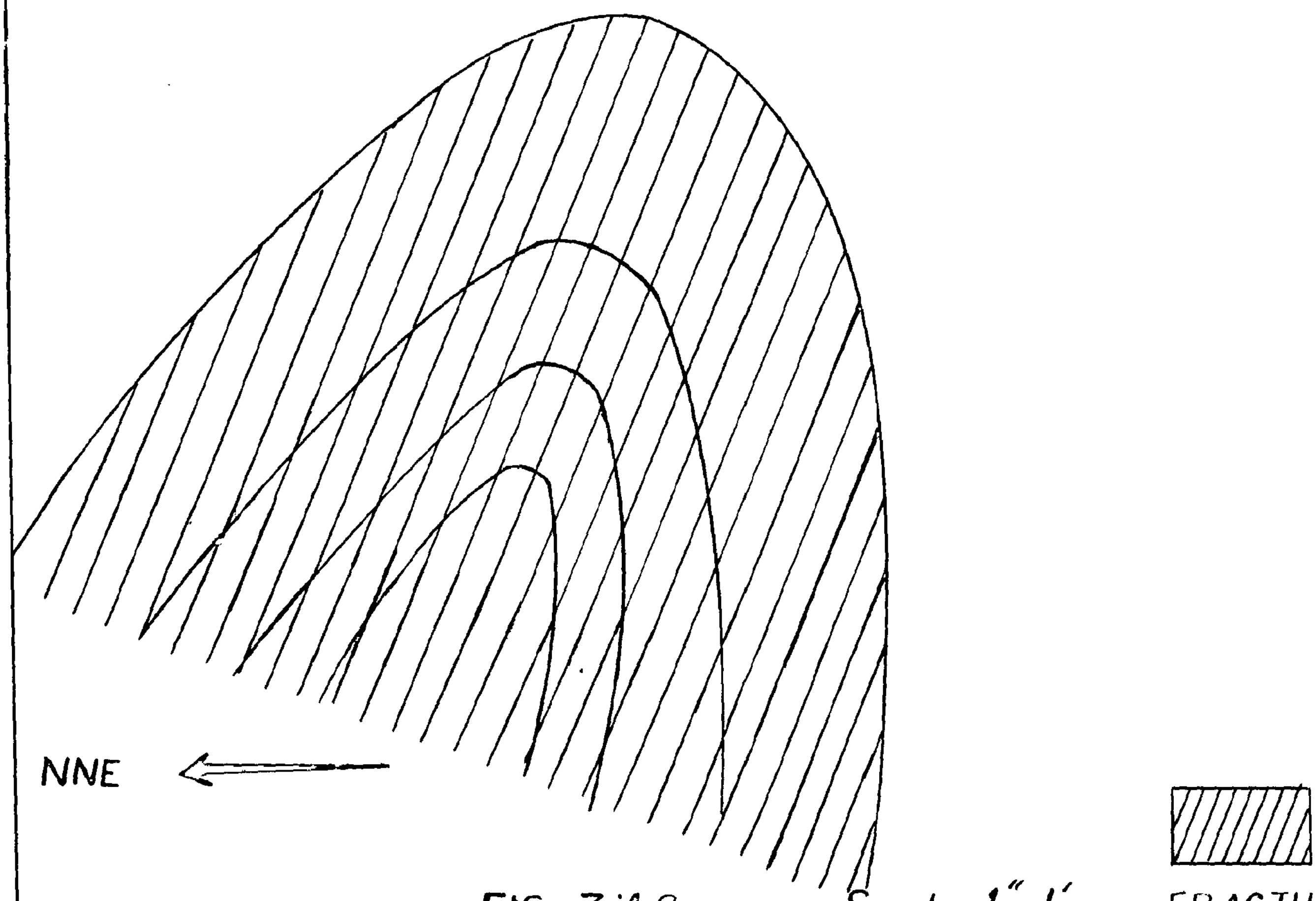
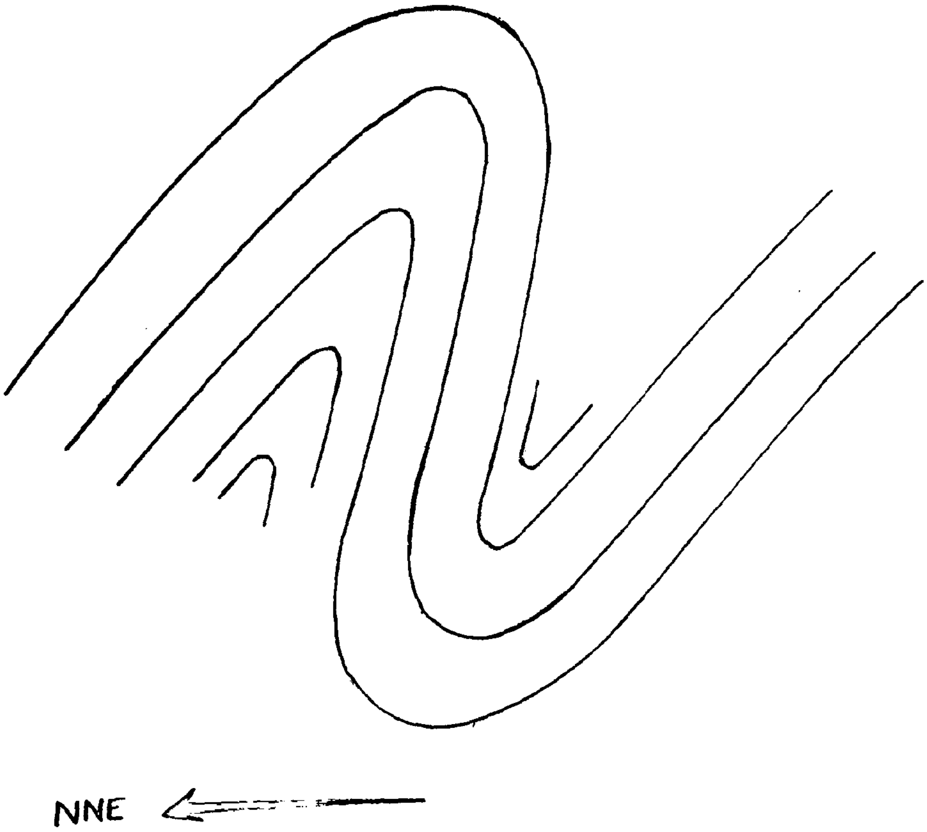


FIG. 3.1a Scale 1"-1'



Scale 1"-1'

FIG. 3.1b

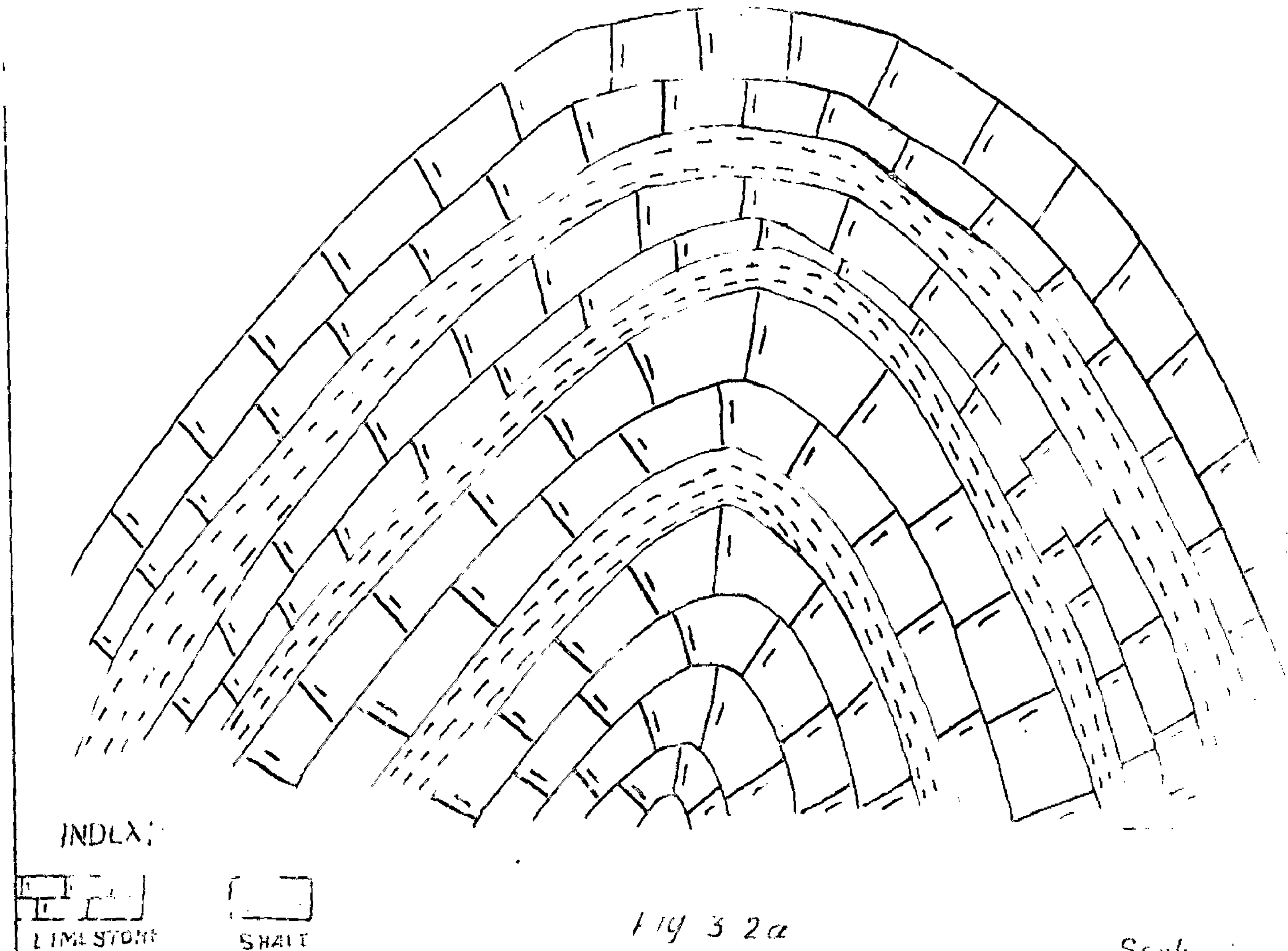


Fig 3.2a

Scale :

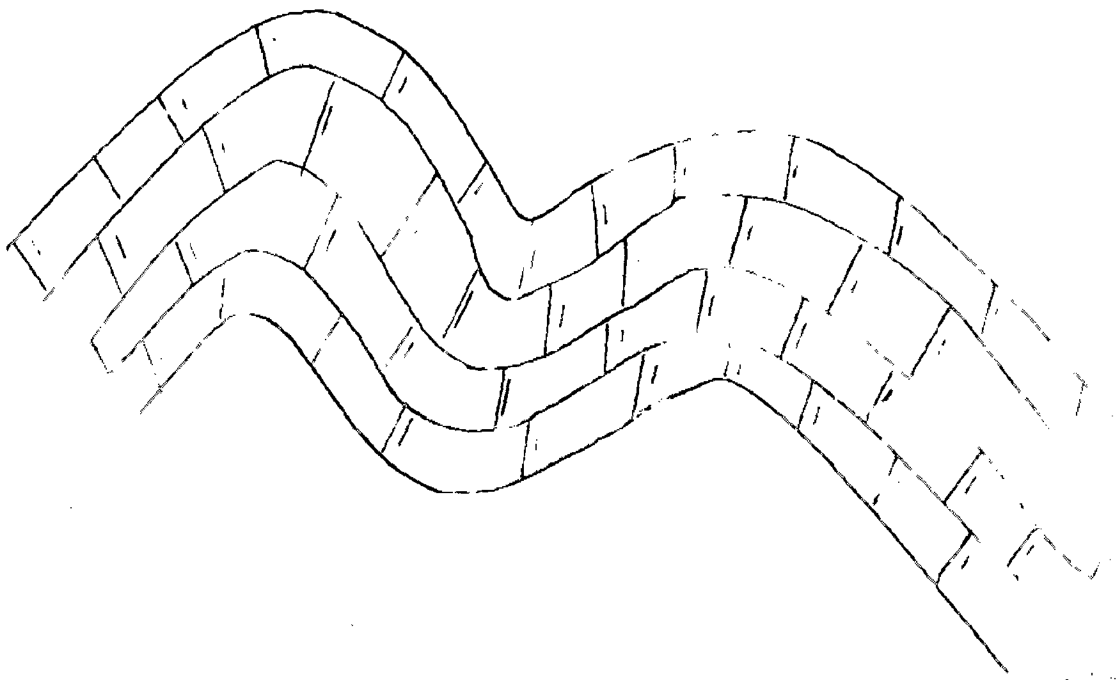


Fig 3.2b

Figure 3.3a : Non uniform folding in shales. The lime stone lying above and below the shale bands are folded independent of each other (Lower park road).

Figure 3.3b : Non uniform folding in shales (Lower park road).

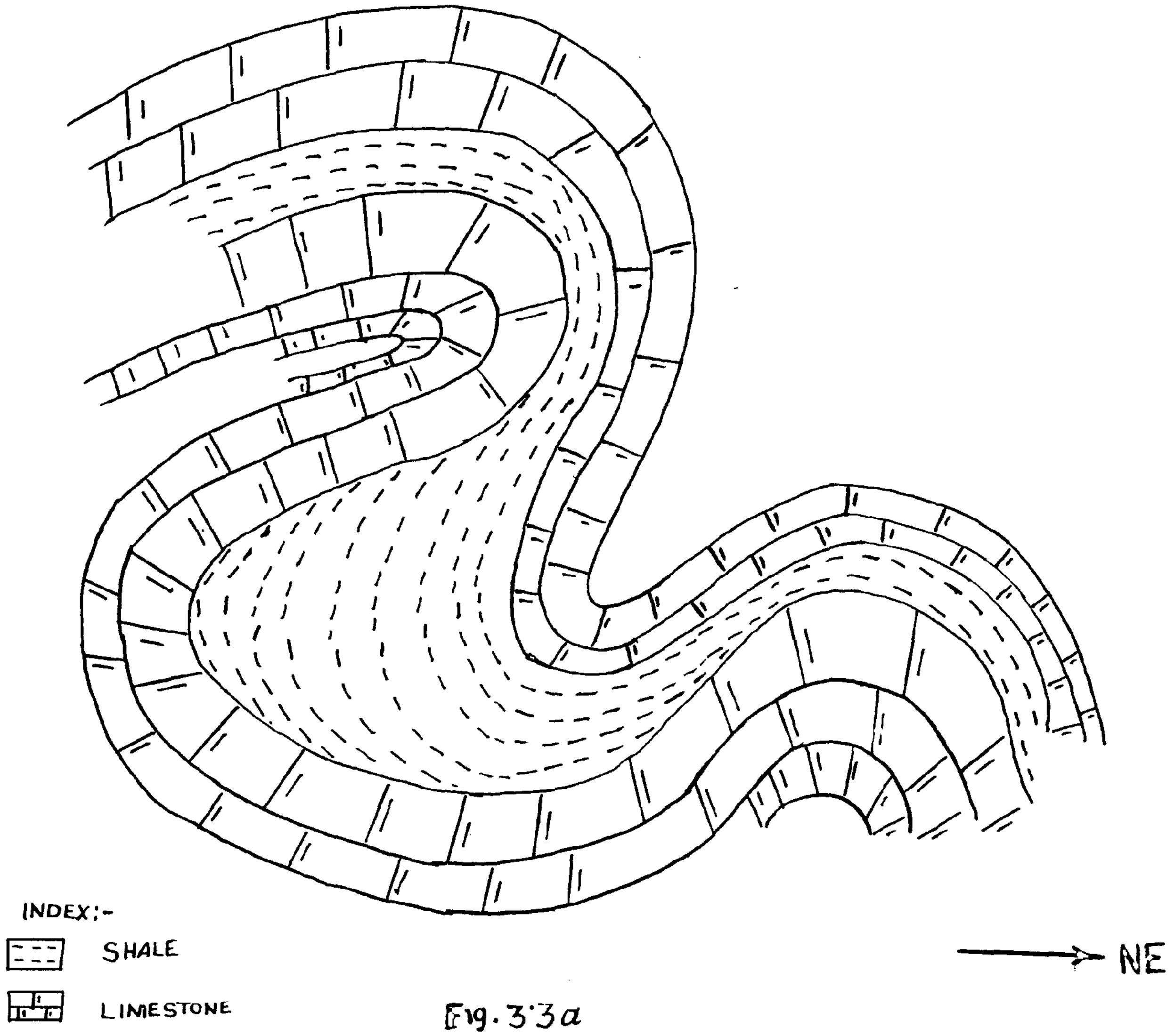


Fig. 3'3a

Scale 1"-3"

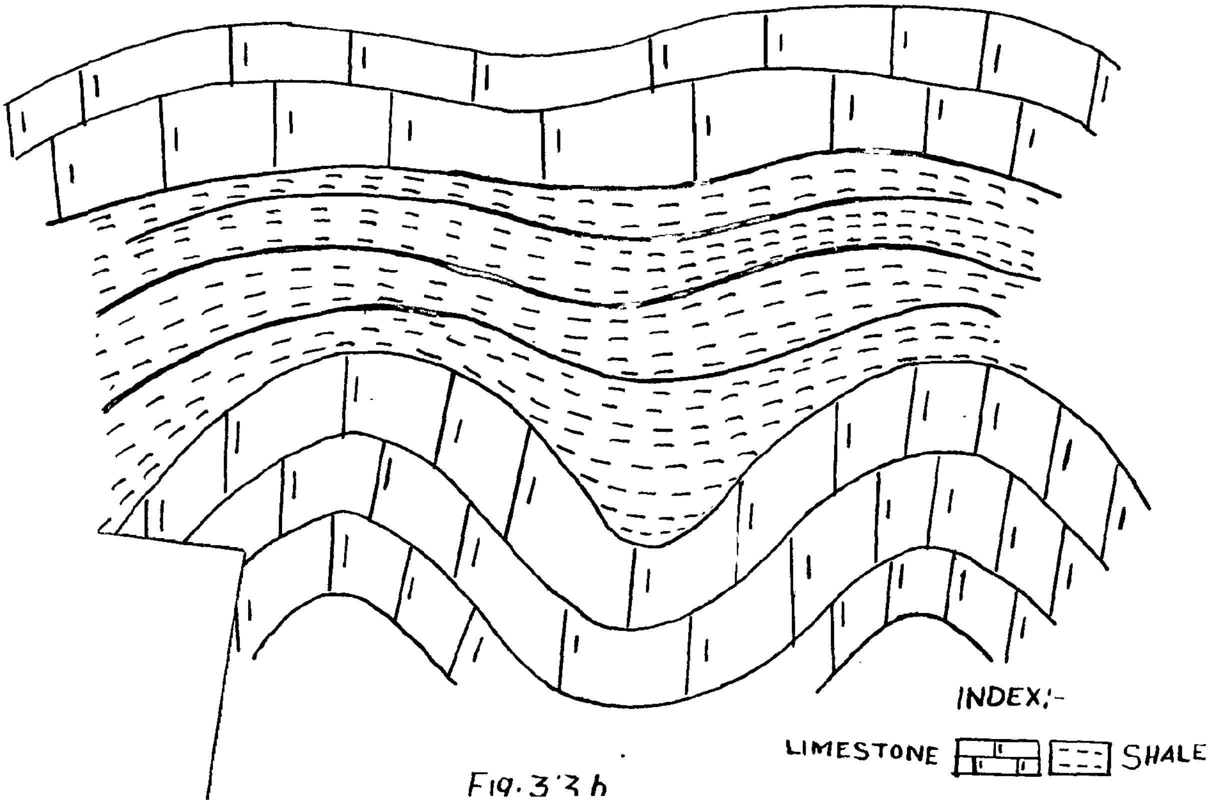
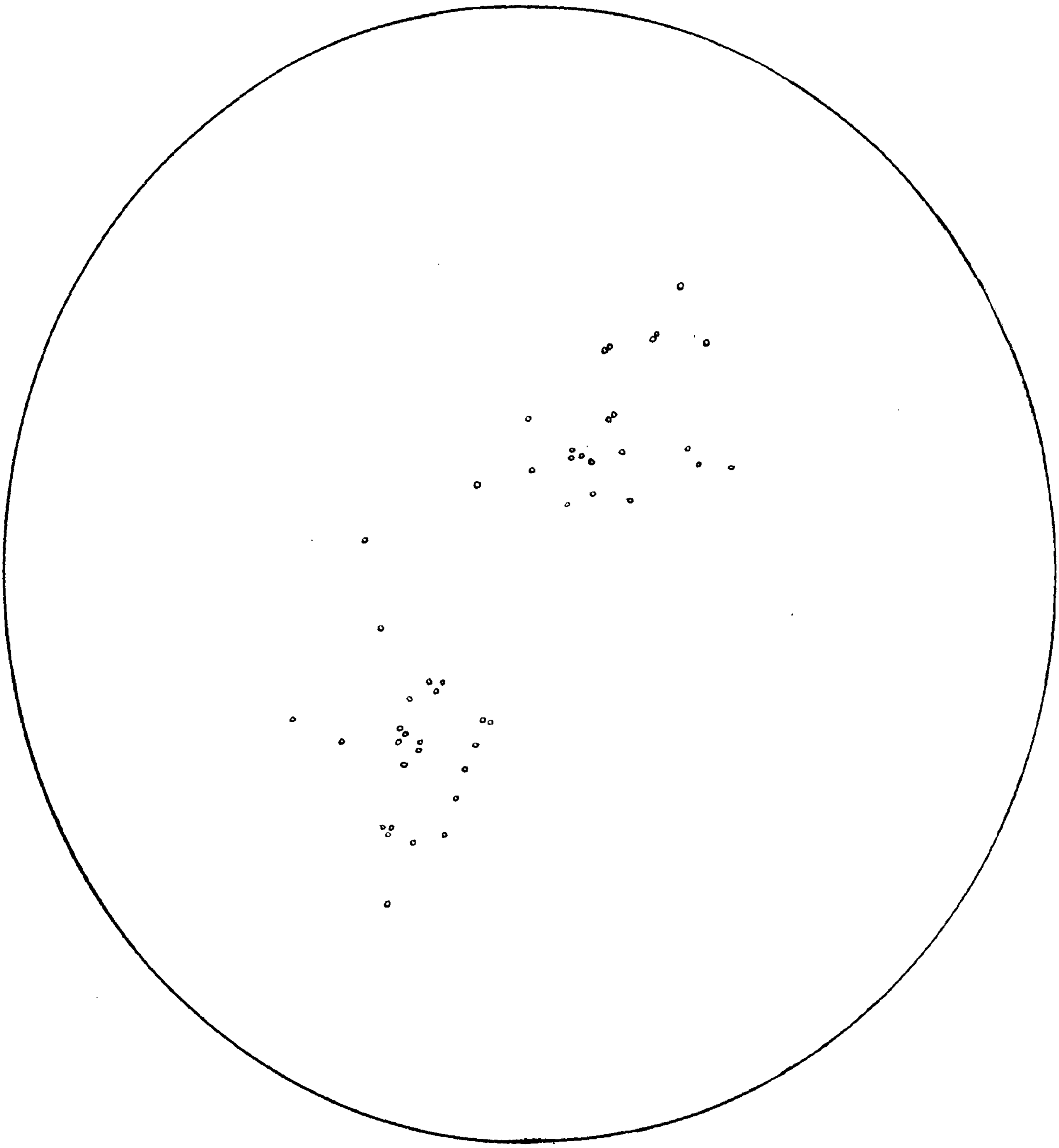


Fig. 3'3b

Figure 3.4 : Point diagram of the 50 bedding plane dips in Krol D limestone and shales. The diagram indicates the North easterly and South Westerly dips of the beds in this area.

POINT DIAGRAM



CHAPTER IV

PETROGRAPHY

The area under investigation consists mainly of limestones and shales. In the Upper Krols mela monzonite intrusives are common in the form of transgressive sills

The oldest rocks occuring in this area are dark slaty shales which belong to Infra Krols. They are carbonaceous in nature and at places consist of quartzite bands. They are very fine grained and even under microscope it is difficult to determine their mineral constituents.

The Krol A stage which overlies the Infra-Krols is composed of interbedded earthy brown shales and limestone. Shales have calcite veins traversing them. Under the microscope the thin sections (slide No. S/7) show fine grained anhedral calcite crystals in the limestone. The shale bands are very fine grained and it is very difficult to distinguish various minerals. However, quartz and feldspar are observed to lie in good amount along with clay. The calcite veins in the shales consist of anhedral and bigger grains of calcite. From these veins smaller off shoots are seen traversing the shales. It is very difficult to infer the composition of Krol A lime stone from microscopic examination only, but chemical analyses as listed in Table 4 confirm their inclusion in dolomitised limestones.

The Krol B shales occurring above the Krol A lime stone consist of green and purple shales. In hand specimen these shales are very friable and jointed. The thin section (Sl No. S/30) study of green shales show that they are composed of quartz, chlorite, calcite and sericite. Under the microscope these shales show several micro joints filled with calcite veins.

The Krol C stage which overlies the Krol B stage consists of calcareous shales, black lime stone and marble. The calcareous shales in the hand specimen are earthy in colour with several calcite veins. The Krol C limestone is bluish black in colour, in these lime stones calcite is seen as veins and in cavities. The thin sections (Sl. No. S/8) under the microscope reveal medium sized anhedral grains of calcite. Calcite shows twinning and high order polarisation colours. Its interference figure is uniaxial negative with many rings. Within the medium sized anhedral grains there are few coarser grains showing perfect twinning parallel to the shorter diagonal of the rhomb. These may be the grains of dolomite. Though from the thin sections it is very difficult to judge the nature of the lime stone, it can be inferred from the table No. 4 that this lime stone is a dolomitized lime stone. The upper horizon of Krol C contains white marble. The thin sections of the marble (Sl. No. S/8b) show finely crystalline, anhedral grains of calcite.

The Krol D stage which overlies the Krol C stage, consists of several varieties of limestones and shales. The limestone near the library is dark fine grained and is traversed by coarse grained calcite veins. Quartz is present in varying amount along with calcite in these veins. Under the microscope (Sl. $27/1_0$) it is observed that the calcite in the veins is much coarser. Along with calcite quartz is also seen to develop in the veins. At few places the quartz grains are seen concentrated as pockets. The ground mass of mainly calcite consists of scattered grains of muscovite, plagioclase quartz and iron oxides.

Specimens S/13, S/13a, S/13b show probable stromatolitic structures both in hand specimen as well as under the microscope. In hand specimen these samples show fine arcuate and lobate bands varying less than a fraction of a millimeter ~~of~~ to 2mm. The thin sections of these samples show fibrous aragonitic bands bordering the coarse grained dolomite. These bands are recognized as cellular structures by R.S. Mittal and R.S. Chaturvedi (1963). The aragonite given a negative biaxial figure while calcite shows a uniaxial negative figure with many rings. From the chemical analysis

(Table No. 4) it is inferred that the limestones in Krol D are Magnesian Dolomites and Dolomitized limestones.

The shales in Krol D are much leached. They are very finegrained, so the microscopic studies are very difficult. The thin section (S/32) of the shale from the new circular road shows bigger grains of quartz and feldspar embedded in the fine grained shale.

The MgO/CaO ratios of the different limestones calculated by EDTA titration with Murexide and erichrome black T as indicators are as given in Table No. 4.

TABLE No. 4

Specimen number	Place	MgO/CaO	$CaCO_3$	$MgCO_3$	Remarks
1	2	3	4	5	6
S/15	Krol D (Chandal garhi)	0.808	51.9%	49.25%	Magnesian Dolomite
S/14	Krol D (Newcircular road)	0.679	53.95%	43.25%	Dolomitized Limestone
S/13	Krol D (New circular road)	0.726	42.55%	37.5%	Magnesian Dolomite
S/11	Krol D (Savoy hotel)	0.73	48.25%	41.4%	Magnesian Dolomite
S/17	Krol D (Blucher Hill)	0.79	46.6%	43.29%	Magnesian Dolomite

1	2	3	4	5	6
S/20	Krol D (Hathipaon Toll)	0.687	34.6%	28%	Dolomitized lime stone with argillaceous material and carbon
S/8b	Marble (Krol C) (Hathipaon)	0.0737	92.2	7.6	Marble
S/b	Krol C limestone (cloud end)	0.1135	83.9%	11.1%	Dolomitized lime stone
S/7	Krol A	0.1195	18.6%	1.73	Shaly limestone Dolomitized.

Basic intrusive

The basic intrusive rock in the area is melanocratic and fine grained to medium grained. Along the cracks in the rock epidote is developed. The joints in the rock show a thin coating of serpentine which may be due to later hydrothermal activity.

Under the microscope these rocks are fine to medium grained, equigranular and show hypidiomorphic texture. The main constituents of this rock are potash and plagioclase felspars, Augite, Magnetite and apatite. The potash felspar is much altered into sericite. In the slide S/1b perthitic and graphic intergrowth are observed.

The Plagioclase felspar is very fresh. It shows little or no twinning. Few grains which show albite law twinning

($S/3_b$) give an extinction angle of 16° on these twins. This indicates that the plagioclase is of $Ab_{69}An_{31}$ (Andesine) in composition. In plagioclase felspars it is noticed that these are saussoritised very much at the centre where as the the border they are fresh, this may be due to the difference in composition of the flespars from margin to the centre and such a difference is brought about by zoning.

Pyroxene occuring in the rock is augite. Basal sections of Augite show two sets of cleavage at 87° and 93°. It shows a sort brown colour in ordinary light. The maximum extinction angle with respect to cleavage is 43°. It shows second order blue, red and green polarisation colours. Mostly augite is altered into chlorite, the percentage of chlorite in the rock being more than augite. Alteration of augite into Uralite is also common.

Magnetite is the main opaque mineral occurring in the rock and it is titaniferous as determined in polished section. It is oxidized to goethite at places. Hematite and pyrite are also observed in very little amount in this rock.

The next abundant accessory mineral in the rock is Apatite occurring as needles and perfect hexagons.

In the rock biotite, and calcite also occur in little amount. Biotite occurs along with the chlorite, whereas calcite might have been released from the plagioclase and the pyroxenes (Sl. No. $S/3_a$).

The modal analysis as determined by swift point counter for specimen Nos $S/1_b$ and $S/3_b$ is as given below

TABLE No. 5

Mineral	$S/1_b$	$S/3_b$
Fresh felspar (plagioclase)	25%	19%
Altered felspar (potash felspar)	41%	42%
Augite whith chlorite and uralite	23%	25%
Magnetite	8%	9%
Apatite	3%	5%

Auden (1934) described the basic rocks in this area as dolerites. He identified plagiocolase felspar, Augite, Apatite and magnetite in these rocks. He called the altered felspar as saussuritized plagioclase and the felspar quartz intergrowth as graphic intergrowth between quartz and plagioclase. Because of the time limitation however the Author could not find out the chemical composition of the rock, but he feels that the altered felspar is potash felspar because of its typical alteration and graphic and perthitic intergrowths. On the basis of the percentages calculated the rock can be called as a monzonite but as the colour index of the rock is more that a normal monzonite, this is named here as Mela Monzonite.

Contact effect of the intrusive on the Country rock

The contact effect of the intrusive is very meagre. In lime stone tremolite and talc are seen formed at the contact. The shales from cloud end from the contact of the intrusive show the character of spotted slates. In the thin section (Sl No. S/29) recrystallization of quartz and felspar are seen as spots in the otherwise fine ground mass.

CHAPTER V

A NOTE ON THE SEISMICITY OF THE AREA

In the Indian sub-continent the Himalayan belt experienced more than forty major earthquakes in the past hundred years. The minor local shocks are a regular feature in Himalayas. These earthquake often resulted in heavy loss of persons and property and therefore not relishable happenings.

Mussoorie - Rajpur area where the author and his colleagues worked has been a scene of several major earthquakes since the beginning of the 19th century and a great many of them must have occurred even before, though their historical record is not available. In table No.6 a number of earthquakes which occurred in this and the neighbouring areas are arranged.

The earthquakes which affected this area severely are too many to enumerate but out of them Garhwal-Kumaon earthquake of 1803 which took 200 to 300 lives and caused great damage to property deserves particular reference. In 1809 this region was again rocked by another earthquake which blocked Vishnoo ganga river. On 5th March 1842 another earthquake occurred which had its epicentre at Mussoorie and its influence was felt upto Simla. This was followed by still another which occurred on 11th April 1843 and shook the entire area from Mussoorie to Delhi and Meerut.

The Kangra earthquake that occurred on the 4th April 1905 and which took a toll of about 2,000 lives and destroyed Dharmashala and Kangra townships had a secondary epicentral tract with an intensity 8(Rossi-Forrel) in Dehradun and Mussoorie. The two or three shocks connected with this earthquake lasted for 25 secs. to 2 minutes. The effect of these shocks at Dehra Dun were following.

1. Moaning and rattling sounds
2. People walking or standing lost their balance
3. Buildings showed various damage including fissures and cracks.
4. Loss of life (not very significant).

Middlemiss (1916) has mentioned that Dehra Dun rose 5.28" relative to Mussoorie as a result of this great earthquake.

An earthquake with an intensity 5.5 (Rossi-Forrel) occurred in the Mussoorie-Dehra Dun region on the 20th October 1937. The epicentre of this earthquake was situated at 31N and 78E. This was very strongly felt at Dehra Dun and Ambala and was considerably intense at Mussoorie and Roorkee.

The Himalaya mountains represent a comparatively recent orogenesis and the area has not yet reached its stability. The Himalayan belt is therefore very susceptible to the occurrence of earthquakes and other crustal disturbances. Several thrusts namely the Krol thrust and the main boundary fault have been recognized in the lesser Himalaya and the older pretertiary rocks have been as a consequence thrusted over the more recent Siwaliks. Along these thrusted blocks a release of tectonic strain from time to time is to be naturally expected. Moreover the Indogangetic plain forms the fore deep to the South of Himalayas. The Aravallis, Delhis and the peninsular shield continue underneath the Indogangetic alluvium with their strike perpendicular to the Himalayan range. These coming in contact with Himalayas serve further as continuing source of release of energy and cause minor shocks. Frequent minor tremors in the thrusted region of Rajpur prove that the Krol thrust is still active.

The investigations carried out by the author and his colleagues in the Mussoorie area reveal that in the North and East of Landour minor shocks are not uncommon whereas to the South and West of it only major earthquakes have been experienced. The area North and East of Mussoorie is situated on Tal Krol contact with shales forming the lower most horizon of Tals. If this Tal Krol contact is proved to be a thrusted contact, the frequency of minor seismic shocks in the region can be explained by the movement of overlying Tal rocks. Especially the frequent tremors in the rainy season can be explained by the movement of overlying

Tal rocks along the lubricated shales.

In view of the above description and analysis of the available data this is to be inferred that Mussoorie and its neighbourhood lies within the seismic zone as the activity along the Krol thrust, Krol-Tal contact and the great Boundary Fault will normally continue to be dissipated. Minor tremors have been frequently recorded in this area but many major earthquakes of higher magnitude are not likely to occur as the only earthquake of maximum intensity recorded in this area is of the order of 8 (Rossi-Forel). However even in the absence of many important earthquakes possibility of higher intensity quakes cannot be totally ruled out and the constructions are fraught with grave risks and therefore adequate precautions should be taken before heavy structures are laid.

TABLE 6

Date (1)	Location (2)	Intensity (3)	Remarks (4)
1505, 6th Jul.	Agra	Severe	Great Damage
1669, 22nd Jun.	Kashmir	Violent	Large fissures in ground
1720, 15th Jul.	Delhi	Severe	Great Damage
1803, 1st Sept.	Muthra	Very Violent	Felt up to Calcutta, Great damage
1803	Garhwal-Kumaon	Violent	200-300 Killed, Great Damage
1809	Garhwal	Strong	Landslide blocked Vishnuo Ganga.
1816, 26th May	Gangotri	Severe	Landslides and rock falls
1825, 8th Jan. 6.45 P.M.	Lucknow	-	-
1825, 22nd Mar.	Delhi	Sharp	-
1828, 6 and 15th Jun.	Kashmir	Very severe	1000 killed, 1200 houses destroyed

Contd...

TABLE 6 Contd..

(1)	(2)	(3)	(4)
1830,17th Jul.	Delhi	Severe	West of Delhi, Nausea and shaking
1842,19th Jun.	Mathura	Severe	Felt upto Mirzapur and Chunar
1842,5th Mar.	Mussoorie-Simla	Severe	Damage to houses
1842,4th Jul	Near Delhi	Violent	Rumbling Noise
1842,11th Apr.	Landour (Mussoorie)	Sharp	Felt up to Delhi and Meerut
1851, 14th Feb.	Naini tal	Light	Storm
1888,11th Aug.	Simla	light	Two shocks
1860,9th Jul	Dharma Shala	Moderate	–
1864,30th Aug.	Lucknow	Light	Two shocks
1726,15th Jul.	Delhi		
1803,22 May	Upper Ganges	–	Severe rumbling noise
1905,4th Apr.	Kangra	7.8	Great Damage, 2000 killed, Kangra and Dharmshala destroyed.

Contd ...

TABLE Contd.

(1)	(2)	(3)	(4)
1937,20th Oct.	U.P. Himachal	5.0	Felt very strongly in Dehradun and Ambala, strongly in Mussoorie before Roorkee.
1956,1st Oct.	Khurja Bulandshahr	6.75	23 killed in Bulandshahr and slightly injured in Delhi.
1960,27th Aug.	Delhi Gurgaon	6.0	50 injured and minor property damage at New Delhi.

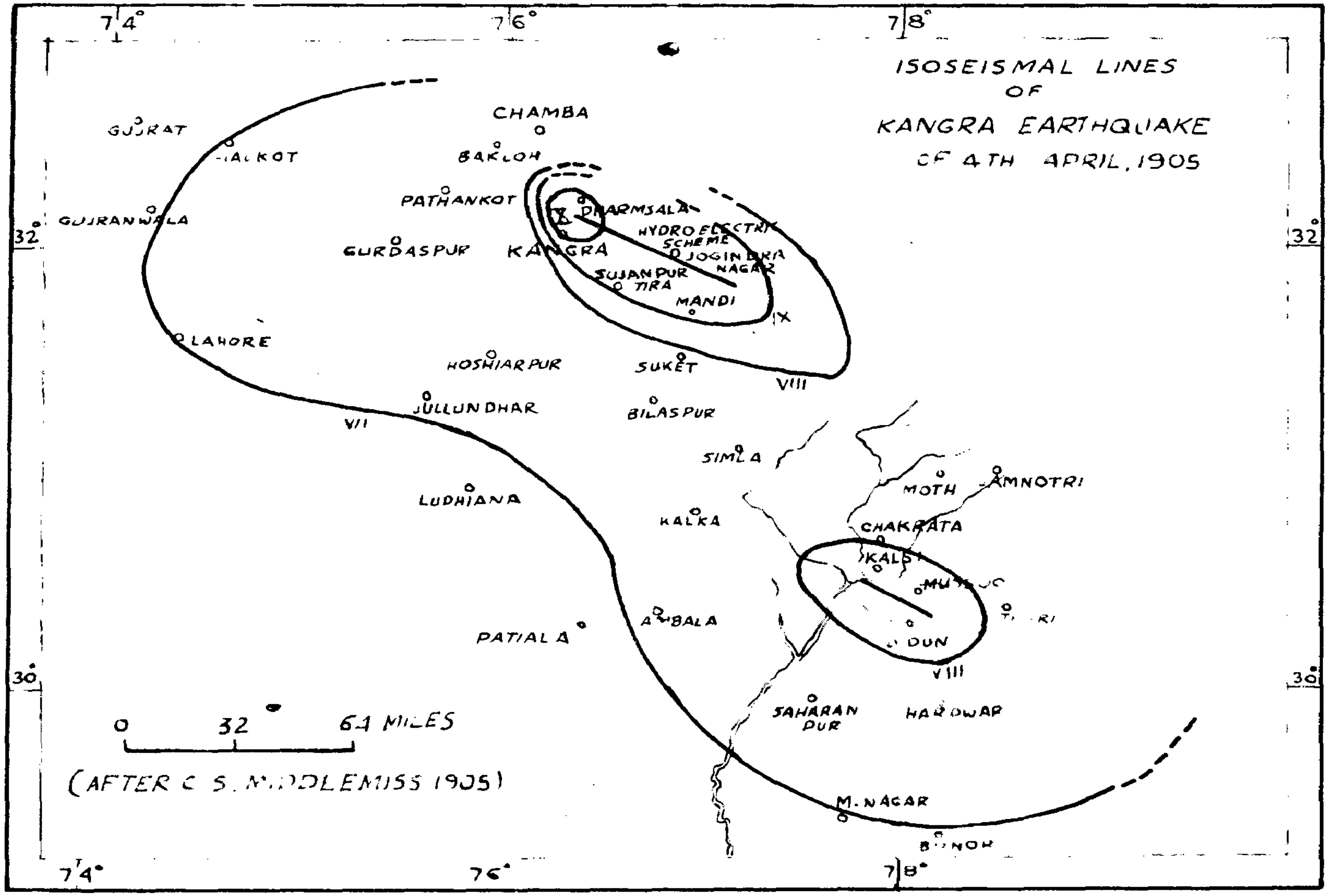

ISOSEISMAL LINES
OF
KANGRA EARTHQUAKE
OF 4TH APRIL, 1905
74°
76°
78°
32°
30°
CHAMBA
BAKLOH
PATHANKOT
DHARMSALA
HYDRO ELECTRIC SCHEME
JOGINDRA NAGAR
GURDASPUR
KANGRA
SUJANPUR TIRA
MANDI
IX
VIII
HOSHIARPUR
SUKET
JULLUNDHAR
BILASPUR
VII
SIMLA
LUDHIANA
KALKA
MOTH
CHAKRATA
KALSI
DUN
VIII
PATIALA
AMBALA
SAHARAN PUR
HARDWAR
M. NAGAR
LAHORE
GUJRANWALA
GUJRAT
0
32
64 MILES
(AFTER C S. MIDDLEMISS 1905)

FIG No 5-2

MAP SHOWING EPICENTRES OF PAST IMPORTANT EARTHQUAKES IN SIMLA GARHWAL AREA

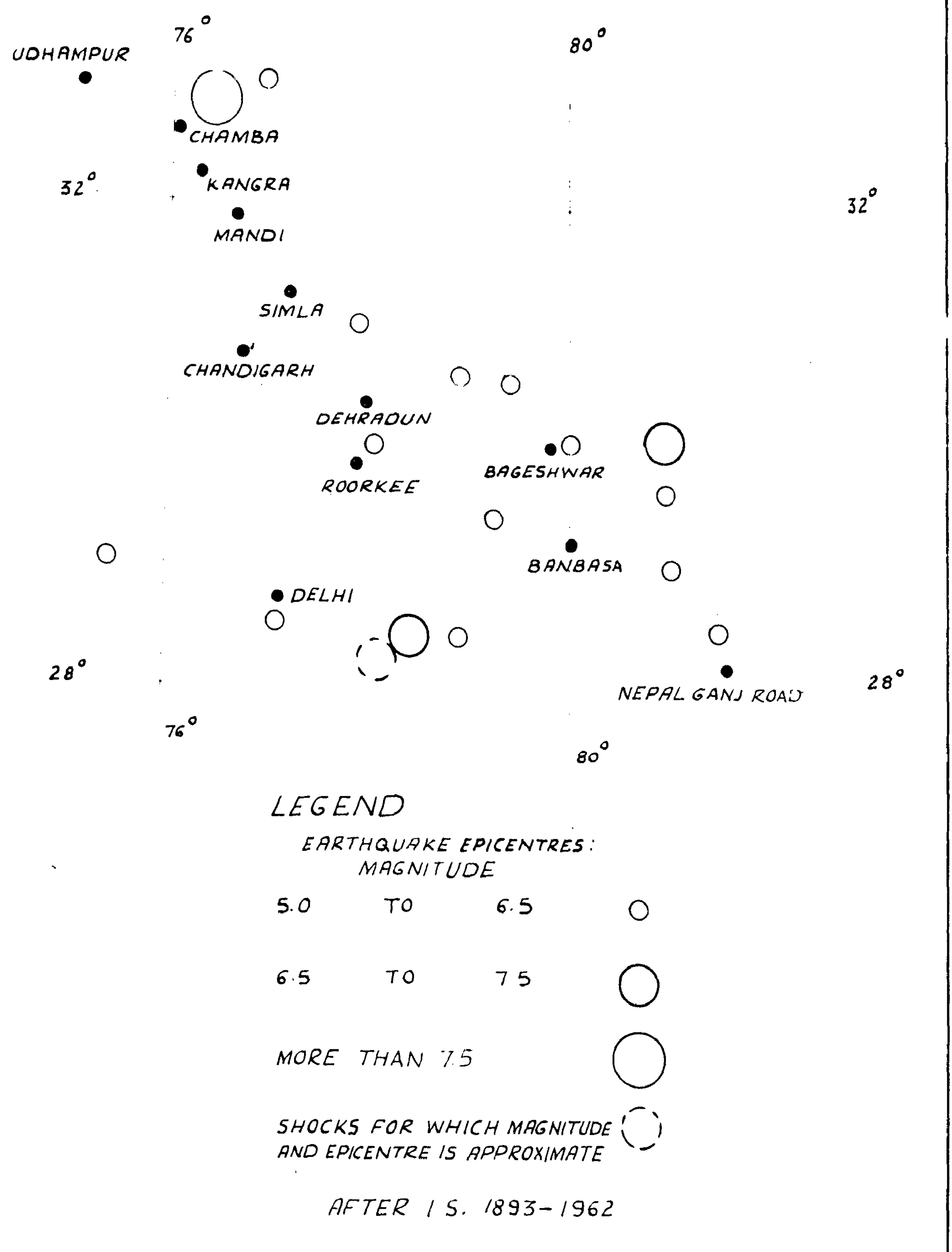


FIG NO. 3

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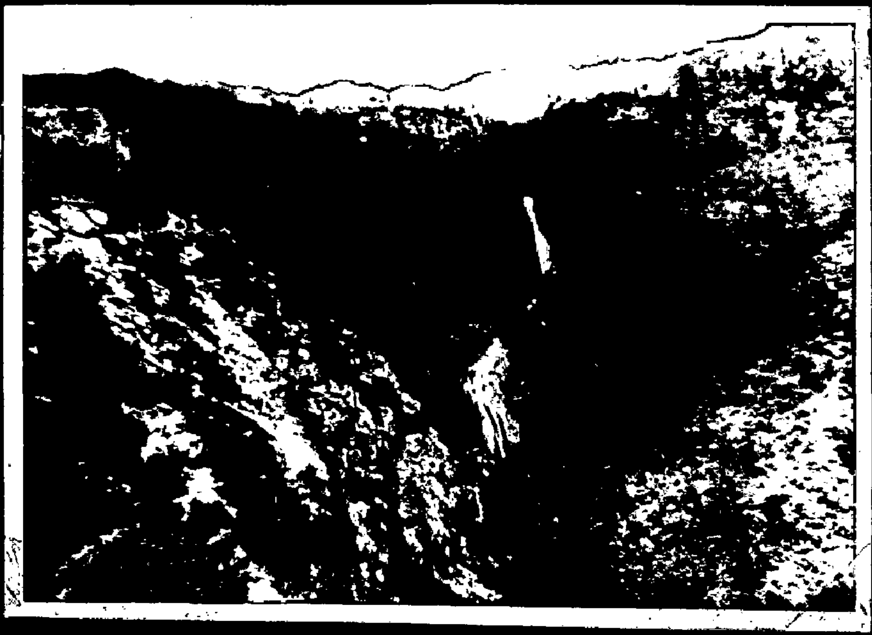

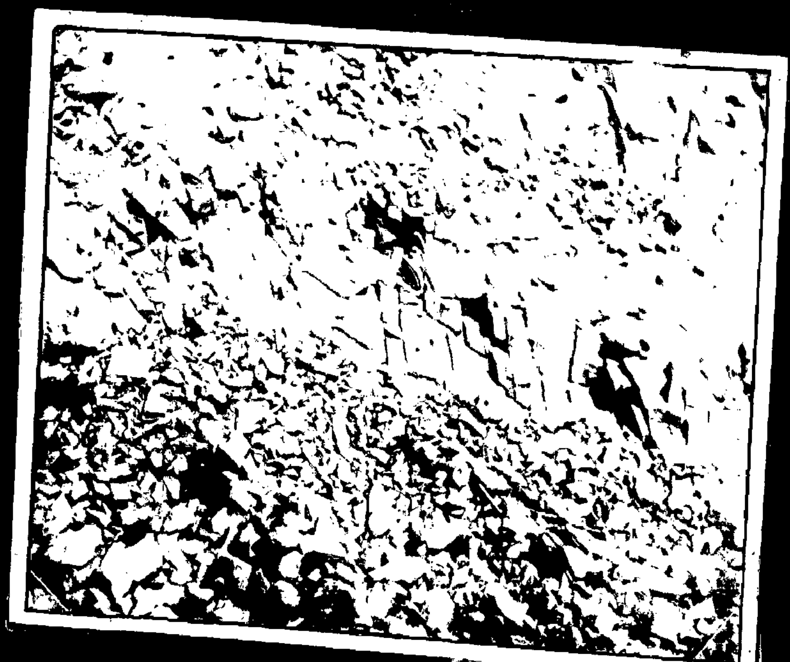

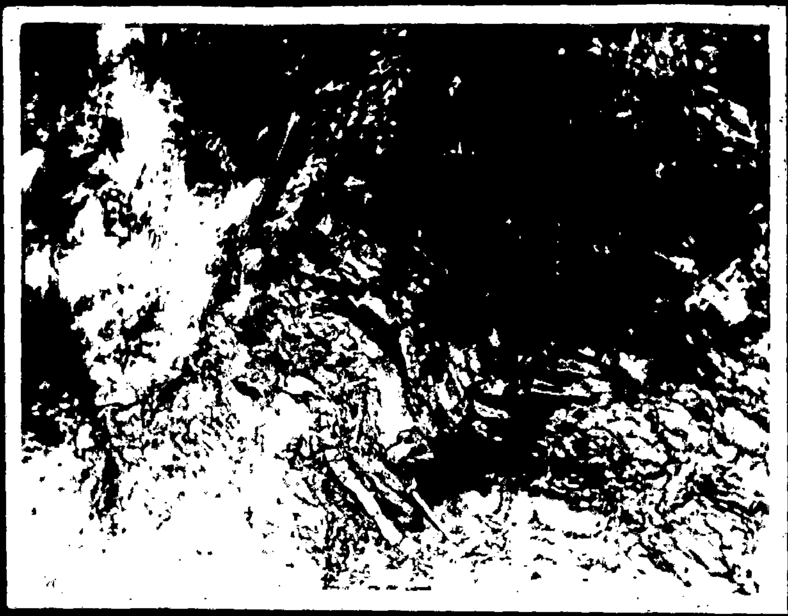

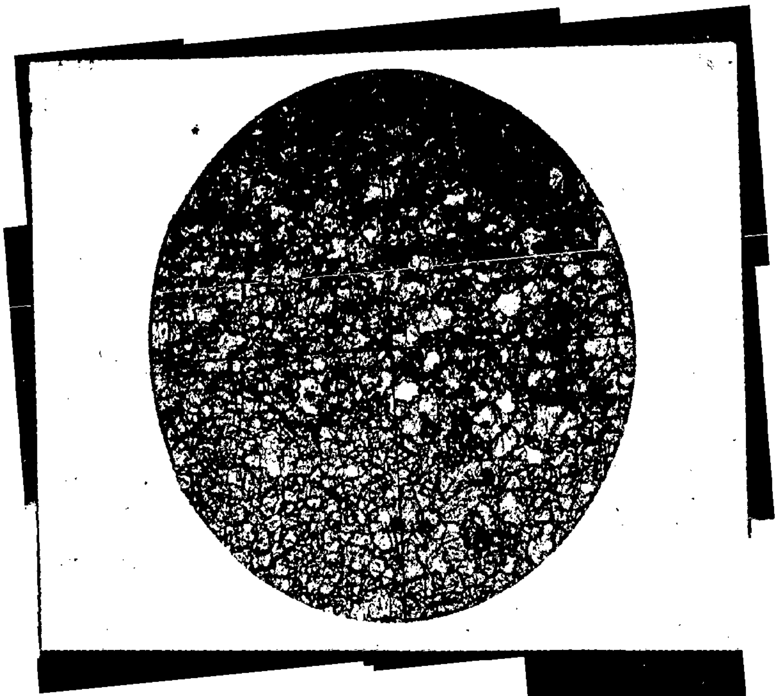

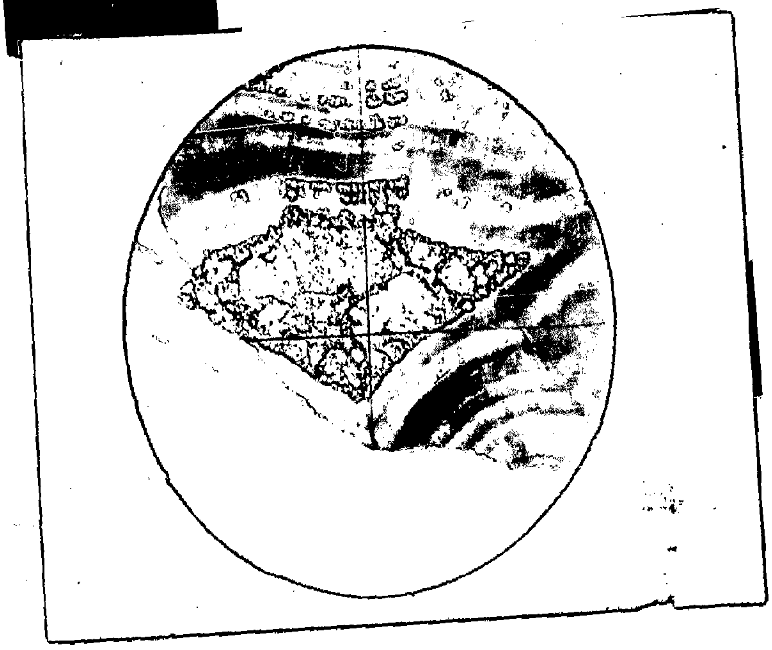

Photo 13. The mela monzonite showing augite, plagioclase potash felspar and apatite (S/1b).

Photo 14. Calcite in the melamonzonite released probably from pyroxene and plagioclase. In the slide it is sorrounded by chlorite (S/3A).

Photo 15. The slide showing asbestos developed at the contact of the sill and lime stone (B[illegible]) slide no. S/28

Photo 16. Slide showing spotted shales at the contact of the intrusive. The lighter patches are recrystallised quartz and felspar (cloud end) (S/29).

Note: The magnification of photo micrographs is 50 X

APPENDIX

50 Dips in Krol D Limestone

40° due 40	25° due 200°
30° due 220°	40° due 240°
30° due 45°	25° due 200°
20° due 220°	35° due 200°
15° due 210°	28° due 40°
25° due 200°	40° due 35°
40° due 180°	50° due 2[illegible]°
43° due 70°	40° due [illegible]°
4[illegible]° due 40°	45° due 20°
30° due 20°	50° due 30°
35° due 20°	35° due 210°
35° due 210°	40° due [illegible]°
50° due 210°	35° due [illegible]0°
35° due 4[illegible]°	20° due 1[illegible]°
30° due 15°	45° due 2[illegible]°
60° due 210°	55° due 30°
45° due 35°	45° due 20 °
52° due 20°	40° due 20°
40° due 40°	40° due 40°
55° due 30°	30° due 40°
55° due 220°	25° due 200°

65° due 25°	40° due 35°
55° due 25°	55° due 30°
45° due 200°	25° due 205°
35° due 100°	20° due 145°
25° due 210°	-