GEOLOGY AND SEISMICITY OF THE AREA AROUND RAJPUR, DEHRADUN DISTT., U.P.

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

SUBMITTED By
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ROORKEE (U.P.)
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CERTIFICATE

CERTIFIED that the dissertation entitled GEOLOGY AND SEISMICITY OF THE AREA AROUND RAJPUR, DEHRADUN DISTT., U.P. being submitted by Sri Prem Murti Jalote 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 22, 1966.

(R.S. Chaturvedi)
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P R E F A C E

During the past hundred years, Himalayan belt has been the scene of nearly 40 major earthquakes. In the course of various five year plans of the country, a number of projects have been located and others envisaged in the region. In order to get a proper appraisal of the seismic activity of the Himalayan regions, it would naturally be necessary to decipher the geological and structural features of the various areas in sufficient detail.

In view of the above, a project was jointly sponsored by the School of Research and Training in Earthquake Engineering, Roorkee and the Department of Geology and Geophysics, University of Roorkee. The specific objective was to assess the seismicity of the Mussoorie-Rajpur region of Uttar Pradesh, which would involve detailed geological and structural mapping. The area was divided into four sectors and Sarvasri Bhupendra Singh, S.M. Salpaka, Gopalji Singh and the author were allotted separate sectors.

The dissertation covers a short account of the geological set-up, the lithological characters, the structure and tectonics, the major landslides and the seismicity of the area. A number of interesting observations were made and it is hoped that future work will further elucidate many unsolved problems.

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

The author is grateful to Professor R.S.Mithal, Head of the Department of Geology and Geophysics, University of Roorkee for suggesting the problem and offering valuable guidance from time to time. He also wishes to express indebtedness to Prof. Jai Krishna, Director, School of Research and Training in Earthquake Engineering, for the financial assistance and all other help given during the course of investigations.

I express my sincere gratitude to my supervisor, Sri R.S. Chaturvedi, for his valuable advice while carrying out the field work and the laboratory studies. His constructive criticism, based on his experience of Himalayas, was of great help in the preparation of the dissertation. The trouble he has taken in correcting the the manuscript has been of immense help in giving the present shape to the dissertation.

I am grateful to Dr. K.K.Singh, Reader in Geology, for the critical discussion, both in the field and in the laboratory, and to Sri L.S. Srivastava, Reader in Applied Geology of the School of Research and

Training in Earthquake Engineering, for the help rendered particularly in the discussion of the seismicity of the region.

The help given by the other members of the teaching staff and by my colleagues is gratefully acknowledged.

The boarding and lodging facilities provided by the Shahanshahi Ashram, Rajpur and transportation facilities by the local quarry managers are thankfully acknowledged.

In the end I would like to thank Sarvasri R.C. Sharma, O.P. Varma and R.C. Punj for their help in typing, drafting and section cutting.

C O N T E N T S

CHAPTER I

T H E A R E A

LOCATION

The area investigated is enclosed by latitudes 30° 8' 5" and 30° 26' 5" and longitudes 78° 2' 38" and 78° 8' 5" lying in the topo sheet No. 53 J/3.

Approximately nineteen square miles of foot hill region in the Dehradun District - extending from Baldi river in the east to Bhitarli in the west, was taken up for detailed investigations. Dehradun-Mussoorie road passes through the region revealing good sections from Dhakpatti which is approximately six miles north of Dehradun city. Rajpur- a suburb of Dehradun - is situated in the heart of the area (Plate No.1)

Formerly Rajpur was a very important communication centre, since the mule track connecting Mussoorie with Dehradun emerged at Rajpur. After the development of Mussoorie township and the construction of motor road between Dehradun and Mussoorie, Rajpur township was virtually deserted. Tibetan refugees have now been settled there and a sizeable population exists. In view of the scenic beauty, a number of ashrams have lately been developed around Rajpur- namely Shahanshahi, Ram Tirath and Bengali Ashrams.

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About $3\frac{1}{2}$ miles south-east of Rajpur, lies Sahasradhara- which is a famous picnic spot along the banks of Baldi river.

CLIMATE

Above 5,000 feet, the temperature remains comfortably cool but most of the area investigated lies below 5,000 feet. The climatic conditions are tropical in the months of April, May and June. At this time of the year, the densely jungle-covered river valleys are hot, humid and unpleasant. The area is visited by a heavy monsoon during late fortnight of June which extends upto July and August. The annual rainfall exceeds 60 inches. In winter, the temperature reaches below freezing point, particularly in the months of January and February. The snow fall takes place above the height of 5500 feet approximately.

TOPOGRAPHY

The area, ranging in elevation from 2500 to 5500 ft., forms the southern part of the main Mussoorie hill ranges. At lower altitudes, it represents an undulating topography which is dissected by an intricate drainage system. A number of hillocks ranging in height from 2500 to 3300 feet project out from the Dun Gravel deposits- which are gently sloping towards the Dehradun Valley.

GEOMORPHOLOGY

The rocks exposed as the part of Krol Belt and of the Siwaliks, show distinctive geomorphological characters.

The Siwalik hillocks are generally elongated in a NW-SE direction but some are trending NNE-SSW also, which might be attributed to the excessive erosion of Siwalik formation by youthful streams emerging out from the mountains. The lternating loose sandstones and clay-shale beds of Siwalik exhibit typical differential erosion as a result of which sandstone escarpments are distinctive. This is true for the entire Siwalik Ranges (Wadia, 1961) and is shown here as well. The occasional conglomerate bands within the Middle Siwalik sand rock formations project out as seen at Kiarkuli River Section. The clay-shale having been easily weathered forms cornices.

The rock types in the Krol Belt show differential geomorphological characteristics. The dominent rock types are Shale-Slate-Phyllite-Quartzite succession and massive limestone with marble.

The weathering of phyllites and slates in the Kalagad area has resulted in the formation of vertical escarps which expose sections parallel to the regio. l strike. Similar prominent escarpments are seen at Kiarkuli river and half a mile from Kothal Gate on the Dehradun-Mussoorie road. The rocks being very fissile tend to weather easily thus affecting the stability of slopes. The slates show landforms similar by Badil Nadi in Sahasradhara region and elsewhere also.

The streams have comparatively steeper gradients in higher reaches where occasional water falls and rapids mark the course. About one and a half miles N.E. of Rajpur, in the Rispana Rao, a 60 feet high water fall is seen.

Nalota river which originates at Kothal gate at Rajpur has cut its course through gently sloping terrain composed of Dun Gravels. It has been observed that the Nalota river does not have sufficient discharge. In fact, it goes underground for some part of its length. This appears to be due to:

i) the river flows through a region where a thick gravel deposit exists below the river bed-which is highly pervious in nature.

ii) The water in the stream is insufficient so as to saturate thin gravel-deposit which might be present below the river bed in order to have a constant surface flow.

The drainage system of the area feeds two major rivers of India-the Yamuna and the Ganges. In fact Bhitarli Kiarkuli and Nalota rivers in the western part of the area tend to flow towards Yamuna, while Baldi Nadi flowing in the eastern part of the area meetsthe Ganges.

As would appear clear from the drainage map of the area, there is development of dendritic pattern which might be due to different rock types present in the area and their to those of phyllites (as seen at Rajpur, Sahasradhara and Kiarkuli river areas). The more metamorphosed and less jointed slates and associated quartzites, however, sustain better slopes.

The limestones form the hill tops in the entire region. Though it does not exhibit characteristic 'karst' topography, yet at a number of places, caves are seen which are apparently due to the solution effects. In fact, near Sahasradhara, huge caves are found in the limestones at lower levels in which stalactites and stalagmites are seen. A number of springs emerge out of these caves.

DRAINAGE

The area is drained by five rivers - namely the Bhitarli, Kiarkuli, Nalota, Rispana Rao and Baldi. Originating from the southern side of the main Mussoorie hill ranges, the rivers flow southwards into the Dehradun valley. The Nalota River originates from Kothal gate at Rajpur and flows in a southward direction (Plate No. 2).

All the four rivers, except the Nalota, are young rivers as they are constantly eroding their channels even today. They have sufficient gradient to carry all the bed load brought to it by their tributaries. They flow in narrow valleys which they have cut for themselves. These streams occupy the entire floor of the valley whose sides are very steep in the mountainous regions, but flatten out as they emerge into plains, as exhibited by Badil Nadi in Sahasradhara region and elsewhere also.

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As would appear clear from the drainage map of the area, there is development of dendritic pattern which might be due to different rock types present in the area and their varying degree of susceptibility to erosion.

VEGETATION

In the area investigated, there are three dominent types of vegetation characteristic of 'Siwalik formation', 'the Jaunsar-Krol formation', and 'Subrecent to Recent formation'.

The Siwalik hills are principally covered by dense forests. The most important tree is the Sal (*Shorea robusta*), which in fact marks the presence of Siwalik formations. They are found at heights less than 3500 feet. Sal trees sometimes form almost pure forests. The other trees are Shisham (*Dalbergia sisso*), the thorny khair (*Acacia catechu*) and Bamboo (*Dandrocalamus strictus*).

In Jaunsar-Krol formation the vegetation is scanty except where layer of soil is found or in the weathered shale formations. At higher reaches, pine trees are common. Oak is the principal dominent tree in the intervening regions.

In the recent and subrecent formations there are mostly cultivated lands or gardens of Mango, 'Jamun' 'Lichi' etc. Pipal (*Ficus religosa and F. cordifolia*), Neem and Bargat trees are found near the villages.

SCOPE OF WORK

The field work entailed systematic geological mapping of the area on 6" to 1 mile scale which was ~~inlaged~~ enlarged from the original one inch topo sheet No. 53J/3. Special attention was given to the geological studies pertaining to the krol thrust region. In view of the rugged terrain it has not been possible to trace all the outcrops of individual lithologic units along the strike for long distances. A number of traverses were taken along the various streams and road sections. The outcrops were marked on the map which were subsequently correlated and joined in the field. In order to ensure accuracy, intermediate traces were checked at a number of places. For the type of work, structural mapping was also done in greater detail near the thrust zone.

The laboratory work included petrelogical examination of various representative rock types in hand specimen and under microscope. Heavy mineral studies of the Siwalik sandstones were made to distinguish the lower and middle Siwaliks.

In view of the numerous landslides in the area an attempt has been made to study them.

For the proper appreciation of seismicity of the area, data were collected on the prescribed form, for the intensity and the effects of the previous earthquakes felt in the region.

CHAPTER II

GEOLOGY OF THE AREA

A - PREVIOUS WORK

H.B. Medlicott (1864) gave the first authoritative account of a tract of the Himalaya, lying between the Ravi and Ganges rivers. His attention was confined principally to the Tertiary rocks which he classified as under:

Sub-Himalayan Series

Upper	.....	Siwalik
Middle	.....	Nahan
Lower	.....	(Kasaoli (Dagshai (Subathu

The pre-tertiary rocks were classified by him on the basis of the degree of metamorphism as:

Himalayan Series.

1. Unmetamorphic

   Krol.
   Infra Krol.
   Blaini.
   Infra Blaini.

2. Metamorphic

   Crystalline and sub-crystalline rocks.

R.D. Oldham (1883, 87, 88) published a series of papers on the geology of the hills between Simla and Chakrata and was mainly concerned with the Blaini and Infra Blaini succession. In his second paper he suggested a glacial origin for the Blaini conglomerate, renaming it a 'boulder slate'. In his fourth paper he assigned an Upper Palaeozoic age to the Krol beds.

C.S. Middlemiss (1887) mapped and described large areas of British Garhwal. A new standard of accuracy in mapping was introduced and possibility of great rock translations was foreshadowed.

Middlemiss (1890) found that the Upper Siwalik Conglomerates have over-lapped the Nahans, on to the traps of the pre-Tertiary rocks, truncating the Main Boundary Fault. This proves that the M.B.F. of Garhwal was pre-Pliocene. Middlemiss also noted that a later reversed fault in the same Gangolia locality, has brought Middle Siwaliks on to Upper Siwaliks. The thrusting must have continued over a considerable length of time.

Thomas Holland (1908) described a striated boulder from the Blaini beds at Simla, further substantiating Oldham's supposition of their glacial origin. He suggested a Purana age for the Blaini.

C.S. Middlemiss (1910) gave an account of the relative difference in elevation between Dehradun and

Mussoorie as a result of the Kangra earthquake of 1905. The earlier levelling of the year 1882 from Saharanpur to Dehradun was repeated in 1907 to note the changes, in view of the ambiguity in the height of Mussoorie (Vincent Hill) with respect to Dehradun, which was noted soon after the earthquake in 1906. On the basis of the data of levelling, he concluded that Dehradun rose by 3.28 inches relative to Mussoorie, which was considered to be stable (Appendix I and Plate No. 15)

H.C. Das Gupta (1915-18) published various papers on the age and correlation of the rocks in the Solon and Simla areas.

Pilgrim and West (1928) completed the detailed survey of the Simla hills, using the excellent two inch to one mile Punjab forest maps. Their work was confined almost entirely to the more metamorphosed rocks. They realised that the apparent simplicity of the sections at Simla was probably deceptive and, discarding the correlation of the rocks at Simla with those of the Krol hills, they suggested instead that a series of thrusts had brought rocks of different degrees of metamorphism to lie in abnormal juxtaposition. This succession is as follows:

Dagshai series	.....	Lower Miocene
Subathu series	.....	Middle Eocene to Upper Oligocene
Krol series	.....	?

Krol sandstone)
Infra krol beds)
Blaini Limestone) ...... Lower Gondwana.
Blaini conglomerate)

Simla series (Infra Blaini)..... Lower Palaeozoic.

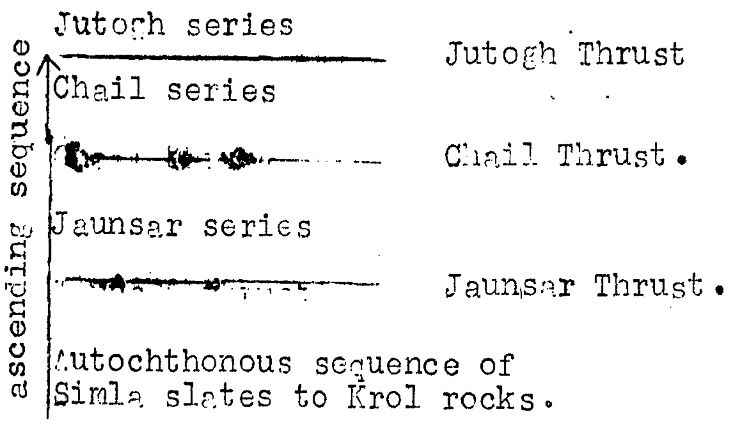
Jaunsar series ...... Purana..

Chail series ...... Purana.

Jutogh series ...... Archaean ?

Shali Limestone and slates ..... Position uncertain

The sequence of Jutogh, Chail Jaunsar and Simla series was considered as follows:



An upper carboniferous age was reintroduced for the Blaini beds.

Wadia (1928) gave an account of the geology of Poonch state and adjacent portions of the Punjab. He indicated the existence of extensive thrust planes, and of volcanic rocks in the Upper Carboniferous and Permian which was further emphasized in his later work, particularly that on the Himalayan syntaxis.

1	2	3
Lower Palaezoic and Pre-Cambrian	Simla slates with Kakarhatti limestone	Deoban limestone Simla slates.
Miocene and older	Dolerites	

Dealing with the structure and tectonics, Auden inferred that the structure of Krol Belt is that of two thrust-bound synclines of Krol rocks resting on a Jaunsar-Simla slate foundations. He has named the two synclines as :-

1. The Nigali syncline.
2. The Krol Hill-Kamli -Dhar syncline.

Discussing the Krol thrust, Auden has said that it is the "Main boundary fault" of earlier writers who have described analogous areas. From Solon to Dadahu, it brings Infra Krol 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. He mentioned that the thrust below Mussoorie is the continuation of the Krol thrust.

In the Kalsi area, the Krol thrust brings pre-tertiary rocks to rest upon Nahans. The thrust must, therefore, be of Miocene or later age. At Bilaspur the Krol limestones are seen to rest at 30° to 40° upon Upper Siwalik Conglomerates. The latest movement of the thrust here (Bilaspur) cannot be older than Pliocene. The same inference applies to the thrust at Dadhuwala which bring Middle Siwaliks to rest upon Upper Siwaliks.

J.B. Auden (1934), however, completed the most remarkable work onthe Krol Belt and mapped the Simla and Dehradun areas. His authoritative account has formed the basis of more detailed investigations by later workers. He attempted to correlate the succession of Solon area with that of Tons region and gave the following stratigraphical sequence:

<table>
<tr><th>1</th><th colspan="3">2</th><th colspan="3">3</th></tr>
<tr><td>Age.</td><td colspan="3">Solon neighbourhood</td><td colspan="3">Tons river neighbourhood</td></tr>
<tr><td>Miocene</td><td colspan="3">Nahans (only at Kalka)</td><td colspan="3">Nahans</td></tr>
<tr><td>Lower Miocene</td><td colspan="3">Kasauli
Dagshai</td><td colspan="3">Dagshai</td></tr>
<tr><td>Oligocence Eocene</td><td colspan="3">Subathu (Nummulitic)</td><td colspan="3">Subathu (Nummulitic)</td></tr>
<tr><td rowspan="2">Cretaceous and Jurassic</td><td colspan="3" rowspan="2">Absent</td><td rowspan="2">Tal</td><td colspan="2">Upper Tal</td></tr>
<tr><td colspan="2">Lower Tal</td></tr>
<tr><td rowspan="7"></td><td rowspan="7">Krol Series</td><td rowspan="5">Krol Lime-stone</td><td>Krol E</td><td rowspan="7">Krol Series</td><td rowspan="3">Krol lime-stone</td><td>Upper Krol Limestone</td></tr>
<tr><td>Krol D</td><td>Red shales</td></tr>
<tr><td>Krol C</td><td>Lower Krol Line stone</td></tr>
<tr><td>Krol B (Red shales)</td><td colspan="2" rowspan="4">Infra Krols</td></tr>
<tr><td>Krol A</td></tr>
<tr><td colspan="2">Krol sand stone</td></tr>
<tr><td colspan="2">Infra krol</td></tr>
<tr><td>Upper Carboniferous</td><td colspan="3">Blaini</td><td colspan="3">Blaini</td></tr>
<tr><td>Devonian and Silurian</td><td colspan="3">Jaunsar with possible Mandhali</td><td colspan="2">Nagthat stage
Chandpur stage
Mandhali stage</td><td>Jaunsar Series</td></tr>
</table>

(Continued...)

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Auden(1937) gave a further account of the Krol Belt and discussed in detail the areas lying east of 77° longitude. The succession as enumerated for this area is given below.

Formation		Unconformities	Approximate maximum thickness in feet.	Probable age.
Siwalik			16,000	Upper Miocene to Pleistocene
		?		
Murrel (almost absent east of longitude 78°			?	Lower Miocene
		?		
Nummulitic			?	Eocene
		~~		
Tal limestone and Calc grit			200	Upper Cretaceous ?
		~~		
Tal	Upper Tal quartzite		4,500	Cretaceous } ?
	Lower Tal shales		2,000	Jurassic
		~~		
Krol	Upper Krol Dolomities limestones and shales		3,000	Trias } ?
	Krol Red shales		} 1,000	Permian
	Lower Krol limestones and shales			
Infra Krol Slates			} 2,000	Talchir?
Upper Blaini boulder-bed and dolomite.				
		~~		
Blaini slates				
Lower Blaini boulder bed				
		~~		
Nagthats			3,000	Devonian ?
		~~		
Chandpur			4,000 ?	Lower Palaeozoic and Precambrian ?
Dolerites				Late Tertiary

5. Granite zone - consists of paragneisses and schists.

6. The Tethys zone of fossiliferous sediments- The relationship of this zone to granite and para gneiss was considered obscure.

Krol Thrust-its Age and Movements

The maximum age of the Krol thrust was established by the presence below it of Nummulitic and Dagshai rocks. This thrust cannot therefore, be older than Burdigalian.

He said that some of the movements along the Krol thrust are more recent than Helvetian which is proved by the frequent juxtaposition of pre-Tertiaries upon Nahans between the Jumna river and north of Bengal. Further in places even the Upper Siwalik conglomerates are involved in over thrusting of pre-tertiaries. Ten miles north west of Dehradun, the boulders of these conglomerates are so shattered that it is impossible to obtain hand specimen of them. Similar overthrusting occurs at Bilaspur on the Sutlej river. These movements were considered to be of lower pleistocene or even later age. He found it difficult to believe that major horizontal movements of the Krol and Garhwal nappes over a distance of several miles should take place as late as this. By lower Pleistocene times, the upper nappes had already been worn away into outliers. The formation of these upper nappes could only have taken place before erosion. These outliers would be unable to translate the stress, as unit.

Auden suggested a classification of the Krol Belt on the basis of topography and structure which is given below.

Topographical Zones

1. Siwalik range and Dun

2(a). Outer lower Himalaya, with an intricate network of spurs and rivers.

(b) Inner lower Himalaya with simpler topography.

3. Main Himalayan range with its deep scarp slopes facing towards the plains and gentler dip slopes facing Tibet.

4. High peaks north of the Main Himalayan Range with irregular disposition.

Tectonic Divisions (for the Garhwal Himalayas)-

1. Authochthonous unit- The base of this unit is probably the Simla slate series, overlying which occur Numulitics, Murrees and Siwaliks. Thrusts occur with this unit but do not seem to be of premier magnitude. The most important thrust is that-which has long been called the Main Boundary fault. This autochthonous unit appears to occur within the Himalayas.

2. The Krol Nappe- thrust upon the autochthonous unit and corresponding to the Krol Belt.

3. The Garhwal Nappes- thrust upon the Krol Nappe. The main Garhwal Nappe may have its root in the main Himalayas range.

4. The Main Himalayan range- with elements common to the Garhwal Nappes and the distinct group of para-gneisses and schists.

5. Granite zone-- consists of paragneisses and schists.

6. The Tethys zone of fossiliferous sediments- The relationship of this zone to granite and para gneiss was considered obscure.

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Auden explained the folding in Krol and Garhwal nappes as a result of the resistance offered by the floor upon which the movement was affected. The movements along these thrusts took place before the river dissections had reached the present pronounced stage.

Concluding, Auden observed "...... there has been more than one period of movements, the stronger movements perhaps during the Helvetian and the later movements during the Siwalik and post Siwalik ".

Auden (1942, a) while dealing with the geological investigations of tunnel alignment for Jamuna Hydel Scheme has discussed the regional geological set-up which is as follows.

European time scale		Indian terms	
Tertiary	Pliocene	Nahans	Youngest
	Eocene-Miocene	Subathu-Dagshai series.	
Palaeozoic to Precambrian	Upper Carboniferous	Blaini series	
	?Lower Palaeozoic to Pre-cambrian	Mandhali series.	Oldest

He maintained the glacial origin of Blainis and described the glacial tillite to be 200,000,000 years old. Regarding Mandhalis he felt that their position was very uncertain in the time scale. Its age was inferred to be older than the Blainis. Tectonically the Mandhalis and Blainis have been thrusted over the Subathus and Dagshai formations (Krol thrust) which in turn have been thrusted over the younger Nahan formations (Nahan thrust). Both the thrusts dip Northwards.

In the violent Kangra earthquake of 1905 though the main epicentral region was situated between Kangra and Dharamshala, a minor region of intensity greater than isoseismal VIII was present in the Dun valley (Plate No.14).

He has described that the focal plane of the earthquake was associated with one of the boundary thrusts present in the Kangra valley, along which Murree rock had been thrusted against the Siwaliks. This thrust is homologous to the Nahan thrust of the Giri-Tons area. The region of high isoseismal around Dehradun was probably connected with either Nahan thrust or the Krol thrust, because the long axis of the ellipse representing isoseismal VIII is shown to lie between Rajpur and Kalsi. Considerable damage and collapse was suffered by houses in Dehradun, Mussoorie and bazar of Chakrata.

Auden concluded that the zone of landslips on the south side of the Giri river and north side of the Jumna running from Bakan to Danda (53 F/10, 53 F/14) was connected with a past earthquake of great violence. This zone is demarcated by a chain of lakelets and depressions as is well seen at Bakan. In view of their parallel alignment to the Nahan thrust, he felt that they had developed consequent to the repeated movements along Nahan or Krol thrusts.

Krishnan and Swaminath (1959) referred to the earlier work of V.H. Boileau on the Simla Hills, completed during 1948 to 1952. Stratigraphic and tectonic problems in the sub-Himalayas were discussed and a new interpretation of the relationships of the formations and correlations was suggested. The Khaira Quartzites of Dharamshala, Mandi and Bilaspur areas were correlated by him with the Tanakki quartzite of Hazara- which occurs below the Sirban limestone and with the Blaini boulder beds. Though the Blaini Boulder Beds were earlier regarded equivalent to the Talchir Boulder Beds, V.H. Boileau suggested that they were approximately equivalent of the Kaimur series of the Vindhyans. With this as the basic idea, Boileau has suggested a correlation of other sub-Himalayan formations including Krol series as shown in the table:

(Part of V.H. Boileau's Tentative)
Correlation

Suggested age	Peninsular India	Simla-Garhwal Krol belt
Carboniferous	--	Tal series Upper Krols
?	Bhander	Krol red shales.
?	Rewa	Lower Krol
Ordovician	Kaimur	Blaini (? Mandhali)
Middle Cambrian	Rohtas stage	
	Tirohan movements	
	Kheinjua stage	
	Porcellanite stage	Deoban limestone
	Malani Igneous activities.	Nagthat.

Continued .../

Auden (1942,b) investigated the cause of the Kalagad landslip on Dehradun-Mussoorie road. According to him gradual flooding of the Kalagad ravine with gravel is due to perennial landslip which operates at the head of the nala. Protective measures were first started in 1928. He also reported that the filling up of the Kalagarh ravine has been taking place even before 1913-1914.

In the year 1941-42 for a distance of 2960 feet below the bridge, the average gradient was 5°. From the bridge upto the toe of the slip, the gradient was 10°. Finally the average gradient of the slipped hill rose to 36°, the height of the slip zone was 686 feet.

During the monsoon of 1941, a heavy down pour on the night of August 21-22, caused the flooding of 400 feet of the motor road with gravels to a depth of 4 feet.

He felt that no protective measures would be useful in view of the slope being 36°, which is considerably in excess of the stable slope of 25° for sheared and jointed slates.

Auden (1942,c) reported on the workability of the marble deposits for their use in the manufacture of calcium carbide, giving details of the chemical analyses and a map of the marble band.

Ravi Prakash (1958) gave a further note on the marble of Bhatta near Mussoorie.

D.R.S. Mehta and Narayan Murty (1959) gave an account of the high grade limestone deposits of Dehradun-Mussoorie area.

Krishnan and Swaminath (1959) referred to the earlier work of V.H. Boileau on the Simla Hills, completed during 1948 to 1952. Stratigraphic and tectonic problems in the sub-Himalayas were discussed and a new interpretation of the relationships of the formations and correlations was suggested. The Khaira quartzites of Dharamshala, Mandi and [illegible] Bilaspur areas were correlated by him with the Tanakki quartzite of Hazara- which occurs below the Sirban limestone and with the Blaini boulder beds. Though the Blaini Boulder Beds were earlier regarded equivalent to the Talchir Boulder Beds, V.H. Boileau suggested that they were approximately equivalent of the Kaimur series of the Vindhyans. With this as the basic idea, Boileau has suggested a correlation of other sub-Himalayan formations including Krol series as shown in the table:

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	Kheinjua stage	
	Porcellanite stage	Deoban limestone
	Malani Igneous activities.	Nagthat.

Continued .../

Suggested age	Peninsular India	Simla-Garhwal Krol belt
Lower Cambrian	Basal stage	Bhimtal Volcanics
	Erinpura porogeny	
Precambrian	Ajabgarh	Chandpur
	Alwar	Chamoli
	Rialo	Tojam

P.N. Mehta (1962) while describing the regional geology of Yamuna Hydel Project region considered Krol thrust as the 'gravitational glide plane'. The contact of Mandhalis, Chandpurs and Nagthats have been described as thrust plane as shown in the table below:

Devonian	Nagthat series
	——Thrust——
	Chandpur series
	—— Thrust ——
Silurian	Mandhali series
	——Krol thrust — (or the Krol gravitational glide plane)
Eocene	Subathu-Dagshai series
	——Thrust —(or overfold)
Middle Miocene	Nahan

In his view, there does not seem to be any positive evidence to suggest that future shocks will necessarily be connected with the Krol or Nahan thrust. He believed that the rocks of the area have been translated over long distances and now they form autochthonous unit separated from its root area due to gravitational gliding. He felt that all the stresses, to which the rocks may have been subjected to in the past, were likely to have been released during the process of translation from their original place of deposition. Thus thrust plane need not necessarily be considered as offering foci for any earthquakes in future.

In the end he concluded "..... The Krol-Tons thrust plane may not be a plane of continuing stress accumulation, so as to serve as possible focal plane for future earthquakes. However, if there is any accumulation of compressional stress along the Nahan thrust, (which lies close to the Krol thrust) there may be a release of this stress by movements along the thrust".

Krishnaswamy (1962), while discussing the structure and tectonic features of Punjab-Himachal Pradesh Tertiary rentrants with the pattern of seismicity of the region, concluded that Satlita thrust was possibly the most likely tectonic feature involved in the origin of the Kangra shocks.

S.P. Jalote (1962) undertook investigations relating to the seismicity of the Satlita thrust in the Beas Dam project region, established subrecent and recent movements along the

Satlita thrust in the vicinity of dam site.

Raina (1963), dealing with the correlation problems of Simla Hills has correlated the Mandhalis with Blainis, rather than recognising the existance of two different boulder beds of widely different ages. He further mentioned that the Jaunsar-Simla Slate junction is a thrust plane.

Ahmad (1963,a), dealing with the age and correlation of the glacial deposits of the Himalayan region has correlated the Blaini Boulder Bed with Talchir Boulder bed of the Peninsula and has recognised four distinct periods of refrigeration in Himalayas.

Ahmad (1963, b) while discussing the epiorogenic activity in the Himalayan region, has drawn attention to a number of perched river terraces which are often not even mildly tilted. He considered that they may have been formed by a vertical uplift that might have been going on since the Pleistocene period. He said that there are also distinct evidence of strong orogenic activity in the region and believed that both could co-exist.

Hukku and Akhtar (1963) described the structure and tectonics of the Krol thrust in the vicinity of the Sundernagar Sutlej tunnel, Mandi and observed some bar faults and drag folds in the over-thrust and under-thrust sheets, indicative of folded thrust sheets.

Raju (1963) indicated the heavy mineral characteristics of the tertiary formations lying between Jammu and Western Nepal. He observed that the Subathu and Dharamsala are characterised by simple mineral assemblage consisting of tourmation garnet, zircon with occasional epidote and flooding of barite in certain horizons. The Lower Siwalik sequence is characterised by the incoming of Staurolite and epidote, which are persistant throughout. Addition of kyanite to the above assemblage marks the Middle Siwalik suite. Upper Siwaliks are characterised by hornblende and sillimanite with local occurrence of Andalusite and sphene.

Ranga Rao (1963), while describing the traverses in Himalayas of U.P., has discussed the probability of Krol Belt as autochthonous unit. This conclusion is based on the fact that in upper reaches of Bhagirathi-Tons area he observed Deoban limestone occurring in normal stratigraphic contact with Simla slates. He believed that there were five cycles of sedimentation in the Krols.

Wadia and West (1964) gave an account of structure of Simla Garhwal area. They considered Dun gravels of east of Ganges as of Pleistocene age where Palaeozoic and Mesozoic rocks directly abut against them. Regarding the orogenic movements in the region, they concluded-

"There were more than one period of orogeny. The earliest is pre-Eocene, as Subathu sediments are found resting unconformably on the strata of palaeozoic and mesozoic ages in different areas in this region. A large scale post-subathu movement resulted in the translation of sheets of rocks southwards along low-angle thrusts in a series of nappes, possibly with abundant intrusions of granites in the root zone. This movement cannot be precisely dated but it is likely to have taken place at the beginning 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 Himalayas. 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 the foot hills trough. The latter 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 moved further southward at this time, coming to rest directly against Siwalik sediments in places. Subsequent movement has been largely of a vertical nature due presumably to isostatic and oustatic adjustments."

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. These 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 recumbant nappes".

B- PRESENT WORK

XXXXXXXXXXXXXXXXXXXXXX

GEOLOGICAL SET-UP IN THE GIVEN AREA

The area forms a part of the main Krol belt comprising of Jaunsar-Blaini-Krol-Tal sequence, folded in the form of a major syncline, whose axis trends NW-SE approximately. The Krol Nappe is thrusted over the Siwaliks in the south with Mandhalis and Chandpurs over-lying them. The thrust is dipping between 28° to 35° in a direction N 40 E to due E (discussed in Chapter IV).

The age correlations given in the table have been taken from earlier work, considering the Blaini boulder bed to be the equivalent of Talchir boulder bed. This marker horizon has been recognised by Gansser (1964) as well, and the earlier correlation by V.H. Boileau quoted by Krishnan and Swaminath (1959), has not been included.

On the basis of the field and laboratory investigations, structural relationships of the various formations, and based on the earlier work, the geological succession has been prepared and is given on the next page.

Age Correlation	Raipur Area			Approximate thicknesses (in feet)
Recent	Recent gravels			-
Upper pleistocene	Dun gravels.			-
Mio-pliocene	Siwalik System	Middle Siwaliks	Loose Sandstone and clay-shales	-
Middle Miocene.		Lower Siwaliks	Sandstones and clay shales	
Carboniferous-	Krol Series	Krol D and E	Limestone and shale.	
		Krol C	Upper- crystalline limestone Lower-Calcareous siltone and shales	1000
		Krol B	Purple shales.	500
		Krol A	Limestone and slaty-shales	850
Upper Carboniferous	Blaini Series		Infra Krols-Slaty-Shales	700
			Blaini boulder bed	100
Devonian	Jaunsar Series		Nagthat stage-Quartzite.	1500
Lower palaeozoic and pre-cambrian			Chandpur stage-Phyllite.	-
			Mandhali stage-Quartzite.	-

The above mentioned sequence is represented in the area investigated, by the following:

1. Mandhali Stage: Mandhali stage is thrusted over the Siwaliks in the Bhitarli river section. Lithologically it is represented dominantly by pale greenish fine grained quartzites and argillites. Laterally, it grades into Chandpur phyllite which are seen well exposed in the Kiarkuli River

section.

2. Chandpur Stage: The Chandpur stage is characterised by the presence of thin bands of phyllites associated with quartzite. They are thrusted over the Siwaliks from the Kiarkuli section east-wards. The phyllites and associated quartzites show puckering and crinkles.

3. Nagthat stage: Chandpur stage is overlain by Nagthat stage in the area without any evidence of unconformity or thrust. The Nagthats are mostly pale greenish and light purple coloured quartzites with subordinate slaty-shales (seen in the Baldi Nadi section). They contain lenses of conglomerates comprising of pebbles of vein quartz, quartzites, purple and green slates and phyllites.

4. Blaini Series: The Nagthat stage is overlain by Blaini series which consists of Blaini boulder bed and Infrakrol slates.

(a) Blaini Boulder bed- This forms the marker horizon for the stratigraphy of the region. It comprises of very diverse associations of rock types. There is no typical development since no two exposures agree in character. The typical boulder bed dies out laterally and sometimes slates-which are lithologically identical to the Infrakrol slates-overly the Nagthats. In the area, the Blaini boulder bed pinches out laterally at a number of places (e.g. in Bhitarli River section and near the Toll on the Mussoorie road where the Infra Krols directly overlie the Nagthats.

(b) Infra Krols- Infra Krols-overlying the Blaini boulder bed--are dark slaty-shales interbedded with very thin bands of quartzite. They are traversed by numerous veins of quartz and calcite criss-crossing each other. The dominent veins follow the foliation. Being rather incompetent rocks they have been folded and faulted.

5. Krol Series: The Krol series overlies the Infra-krols conformably and has been divided into four stages, namely- the Krol A, Krol B, Krol C and Krol D and E in the ascending order. Krol A, B and C are distinctive lithologic units but for Krol D and E no satisfactory field distinction is possible.

(a) Krol A Stage- They overlie the Infrakrols and are thinly bedded limestone and slaty-shales. The bands vary in thickness from 1 to 4 inches. The limestone is dominent and slaty-shales are subordinate. The slaty-shales are jointed and traversed by veins of calcite. They assume various patterns e.g.square, rhombohedral and rectangular (Plate No.18 Photo No.2). They are universally present in the area but are best developed above the Jud village near Rajpur.

(b) Krol B stage- This stage consists of variegated shales of purple and green colour which are quite uniform in their distribution. The shales are closely jointed and sheared, rendering it difficult to obtain proper hand specimen. The cleaved faces show irregular patterns.

(c) <u>Krol C stage</u>- It overlies the Krol B purple shales and comprises of dark blue coloured crystalline limestone which gives sulphurous smell on striking. It overlies a bed of calcareous siltstone and black shales which vary in thickness from 50 to 100 feet. It has been mapped as a separate rock unit within Krol C, as it is underlying the massive crystalline limestone in the entire area.

There are gradation of colour and chemical quality of limestones laterally from Sahastradhara-where it is dark and crystalline to Bhitarli-where it is light grey and white. It is a very high grade limestone but the carbonate content slightly decreases towards Sahastradhara. In the area, a marble band extends from Rispana Rao in the east to Kiarkuli and further west also. Pockets of dolomitic limestone, occur within the crystalline limest ne, showing oolite structure.

There is a sporadic occurrence of Galena in association with the white dolomitic limestone. The galena occurs as fillings and no consistent bed is known. It is found from one of the limestone quarries near Rajpur.

5. Krol D and E: There is no satisfactory field distinction possible between the Krol D and Krol E in the area and they have been mapped together as one unit. They comprise of alternations of shales and siliceous limestones with the dominance of the latter. The shale beds can not be traced laterally for long distance and usually grade into the limestone facies. In the present area this is found further upstream of Sahasradhara in the Baldi Nadi Section up to Chamsari village.

Gypsum occurs as veins and fracture fillings within Krol D and E limestone at Majhera where it is quarried.

6. Siwaliks - The Siwaliks, which are thrusted over by the Chandpurs and Mandhalis, are mainly sand stone and clay-shales alternations. The lower Siwalik is more compact sand stone with subordinate clay-shales as seen under the bridge over Kalagad on the diversion road for Mussoorie, while middle Siwaliks are loose sand rock with dominent clay-shales. The sand rocks occasionally contain rounded pebbles of quartzite of varying size but are confined to a few horizons only.

7. Dun Gravel - The dun gravels are widespread in the area and gently slope towards south. These deposits have been subsequently cut up by streams which expose good sections. At places even 200 feet vertical faces are exposed in the stream cuttings. From the study of these stream cuttings it has been observed that, Dun gravels have a great variation in size,

shape and lithological constituents at various stages. They contain pebbles and boulders which are mostly sub-angular to subrounded. They are mainly made up of quartzites, slates, limestones and phyllites. In lower part these are well cemented while in the upper they are loose.

8. <u>Recent Gravels</u>- Occasionally the Dun gravels are overlain by about 50 feet or more thick recent gravel and terrace deposits which are somewhat different in nature than the Dun gravels. There is one typical isolated outcrop of gravel deposit resting on Chandpur near Ambica Devi Temple (Rajpur). Unlike the horizontality of other similar gravels, it shows tilting towards south-west. They show different composition and grading at different places. Three different exposures were thus studied around Rajpur as per details given below. Their locations have been given in Plate No.3.

(a) Exposure No. X_2- In the Lispana nadi Section S-E of Ambica devi temple,Rajpur.

(b) Exposure No. X_3- 300 yards SE of exposure No.X-2.

(c) Exposure No.X_4 - Near the Jud village.

(a) <u>Exposure No.X_2</u> - In the Lispana Nadi Section an isolated triangular-shaped gravel terrace, which is resting on Chandpur, is seen. At the base of the deposit there is a 10 feet thick yellow clay layer which rests on crushed and powdery Chandpur phyllites. The deposit shows very well marked layerihg of clay and pebble bands. The terrace shows tilting towards S-W. (Plate No.20 Photo No.2)

The pebble lineation is 35° in a direction S 60 W.

This gravel deposit is quite different to the Dun gravels. It contains clay interbedded with uncemented pebbles, unlike Dun gravels which do not contain any definite clay layers. It differs in the degree of compaction and cementation from the adjoining Dun gravels—only 10 ft. away — which occur at practically the same elevation. On the basis of field relationship it is felt that this gravel deposit is possibly younger than the Dun gravels and has been tentatively assigned Recent age.

(b) <u>Exposure No. X_3</u> : This gravel terrace comprising of boulders of quartzites, slates and limestones is nearly at a height of about 15 to 20 feet from the nearby river bed level of the Rispana Rao. Highly crushed and powdery Chandpur phyllites are observed resting over these. The contact between the two is sharp and dips 30° in a direction N 40 E.

(c) <u>Exposure No. X_4</u>: The exposure occurs on the right bank of the stream cutting near Jud village. Here the terrace gravels comprising of boulders of quartzite, slates and limestone are observed resting under the Chandpur phyllite which are crushed (Plate No.22). The contact between the two is distinct and dips 20° in a direction N 60° E. The terrace is found at an higher elevation than the terrace of exposure No. X_3. The terrace deposit is underlain by another deposit which is well sorted and comprises of small flakes of phyllites and slates only, and is thus quite distinctive.

They are horizontally bedded and have practically no tensile strength. This deposit is underlain by the Dun gravels (Plate No. 5) having the usual character described earlier.

CHAPTER III

LITHOLOGY

1. MANDHALI STAGE :

QUARTZITE (J/53) – They are fine to medium grained pale greenish coloured siliceous quartzites which appear to have been subjected to crushing and break easily.

On microscopic examination it shows dominence of quartz which exhibits undulose extinction. Orthoclase, albite and tourmaline are the other constituents present in minor quantities, in the order of abundance. The quartz grains are cemented together by very fine quartz, sericite and chlorite grains.

2. CHANDPUR STAGE :

PHYLLITE (J/8, J/3, J/5, J/6)– In hand specimen, the phyllites show typical satiny appearance and seem to predominate over the thin intercalated quartzite bands. At places, however, the pure quartzite bands are even 7 to 8 cms. thick. The phyllites show imperfect foliation, and puckering is common.

On microscopic examination, the quartzite bands appear to be in excess of phyllite bands. These bands show clear foliation. Four thin bands of quartzites were recognised in the slide.

The quartzite bands consist mainly of medium, rounded grains of quartz which show undulose extinction. The phyllite bands show preferred orientation of minerals with chlorite and associated sericite lying in parallel flakes. The texture is fine grained though the grains are identifiable.

An interesting case of a quartz vein (J/55), parallel to the foliation was studied. It showed development of chlorite and siderite at the contact with phyllite. The margins of chlorite and quartz show corrugations-indicative of the possible replacement of chlorite by quartz.

3. NAGTHAT STAGE :

a) QUARTZITE (Medium grained) (J/20, J/61)

The quartzite is pale purple and green coloured traversed by quartz veins. It is fine grained consisting dominently of quartz. The colour is due to the presence of chlorite.

Under microscope, these show generally equigranular, granoblastic texture. The grains are subangular to subrounded showing good interlocking of grains. They generally range in size from 0.1 to 0.2 mm. Most of the quartz grains show undulose extinction. At some places they are cemented by fine grained chlorite and sericite. A few grains of plagioclase (albite), potash-felspar and tourmaline are also present in minor quantities.

b) ORTHOQUARTZITE (Coarse grained) (J/15, J/63).

These are gritty, orthoquartzites of purple and grey colour. They consist dominantly of quartz and the cementing material is also quartz. At places, however, iron oxide is the cementing material. On the surface it is friable, though the core is very compact and siliceous. There are a number of veins of calcite and quartz.

Under microscope, they are equigranular, ranging in size from 0.5 mm to 2 mm. The fragments are angular to subrounded. Interlocking of quartz grains is poor and cement is invariably present. The main mineral constituent is quartz through plagioclase (albite) and detrital calcite grains are also present in smaller quantities. Quartz shows undulose extinction. The cement, which is extremely fine grained is both calcite and quartz. Chlorite and sericite are also present in minor amounts as cementing material. Pyrite is found in the intergranular spaces and also as separate grains.

C) CONGLOMERATE (J-59)

The conglomerate shows rounded pebbles and gravels ranging in size from approximately 2 mm to 3 cm. The pebbles are those of quartzites, vein quartz and limestone. The slate and phyllite fragments are flaky.

In microscope, a part of the conglomerate (J/59) was studied which shows the presence of detrital quartz and calcite grains and metamorphic rock fragments. A number of oolites were also observed associated with a calcite vein. Most of the quartz grains show undulose extinction. The grains are cemented together by calcite. In the oolites, detrital quartz usually occurs as nucleus. (Plate No.19, Photo No.2)

4. BLAINI BOULDER BED:

CONGLOMERATE (J/24, J/69, J/68)-- Boulder conglomerate is light to dark grey coloured, consisting of subrounded and rounded pebbles in heterogeneous matrix of various sizes. The matrix is clayey and gritty with calcareous cement. The boulder conglomerate is sometimes sheared, in which case the pebbles become flattened. Striation on the pebbles was seldom seen. The pebbles are generally of the following rock types:

Dark slates, greenish quartzites, pale quartzites, vein quartz and lime stone.

Microscopic studies of parts of the boulder conglomerate were made in a number of thin sections. The pebbles and gravels in these are subrounded to rounded and are set in fine grained clayey and carbonate matrix.

It comprises of pebbles of quartzites, phyllites and quartz in the order of abundance. In addition to these, calcite, felspars and biotite are also found. Secondary sericite occurs in laths. Some pyrite specks were also found in small quantities.

5. INFRA KROL STAGE:

SILTY-SHALES (J/71)

These are dark coloured thinly laminated shales, which show imperfect development of slaty cleavage, as a result of which they tend to split easily along the foliation.

Slaty shales on microscopic studies, consists of mixture of sericite and quartz occurring as very fine grains. Some iron oxide and pyrite is also seen, though in very small quantities. There is a calcite vein which is bent and broken due perhaps to the secondary stresses. The criss-cross pattern seen in hand specimen is not clearly observed in thin sections.

6. KROL-A STAGE:

a) LIMESTONE (J/37, J/38) It is greyish brown coloured, massive and very fine grained limestone which effervesces with difficulty due perhaps to the higher doloritic content.

b) SLATY-SHALE(J/38): It is brownish black thinly laminated shale showing slaty cleavage transforming into 'pencil-slates' It gives slow effervescence due to the small quantity of carbonate present.

On microscopic examination it shows a mixture of very fine grained sericite quartz and calcite. Iron oxide is found in small quantities.

7. KROL B STAGE:

VARIEGATED SHALES:

They are purple and green coloured shales with closely spaced foliation and a net work of jointing. They are very soft and crumble easily. They are very fine grained and no minerals could be recognised in hand specimen. In view of their characteristic colour, however, they are easily identifiable.

8. KROL C STAGE

a) LIMESTONE (J/41, J/93).

It is mainly bluish grey finely crystalline limestone which gives suphurous smell on striking. The greyish white variety resembles the typical bluish grey limestone. The fracture surface of both is subconchoidal.

The greyish white coloured limestone was studied under microscope. It shows dominent crystalline calcite but some oolites were also seen. The nucli of the oolites are generally dolomite, calcite and siderite. The oolitic rims are made up of fine grained calcite. This oolitic structure is characteristic of greyish white limestone only.

b) MARBLE:

These are fine grained crystalline limestone of of white colour showing typical sachharoidal texture. They are highly jointed and the joints are very closely spaced, often seen even in hand specimens.

c) CALCAREOUS SILTSTONE:

They are fine grained silt stones giving efforvesence with dil Hcl. At places they are extremely rich in carbonate.

Under microscope, it shows thinly banded character. They are fine grained and grains are equigranular showing better sorting. They consist of finely crystalline calcite and a mixture of silt and clay with disseminated iron oxide. At places, some chloritic material is seen.

9. KROL D AND E STAGE (J/49):

It comprises of alternating beds of shale and limestones which often integrade into one another. A specimen of thinly bedded shale and limestone was chosen for study.

SHALE AND LIMESTONE-

There are alternating bands of shales and limestone ranging between 5 mm to 1 cm in thickness. The shales are dark coloured, while the limestone is greyish. Both are very fine grained and limestone tends to be massive.

On microscopic examination it shows even closer banding, about 1 mm, of shales and limestone. The limestone band show fine grained calcite disseminated in it. The shale bands are very fine grained and comprise essentially of clay.

10. SIWALIKS:

Siwaliks in the area investigated are represented by sandstone (friable and compact) interbedded with thin clay-shales belonging to the lower and middle Siwaliks. An attempt has been made to distinguish the lower and middle Siwalik sandstones on the basis of heavy mineral analysis.

The lower Siwalik sandstones, which are generally more compact, are known to be characterised by the presence of staurolite and epidote which is persistent throughout and the addition of kyanite marks the middle Siwalik (Raju 1963). The middle Siwaliks are more friable and clay-shale bands are numerous.

The data of heavy mineral analysis for three chosen specimens of sandstones is tabulated below:

No	Specimen No.	Locality	Wt.% of heav -ics	Heavy mineral frequencies							
				G	K	T	E	S	Z_r	Ch	L
1.	J/104	Near the bri -dge on dive -rsion road, Kalagad section.	0.4	AA	-	AA	RR	R	-	-	C
2.	J/102	200 yards from the Kal -agad bridge near Ambica Devi Temple	1.10	AA	AA	C	RR	R	C	A	CC
3.	J/48	1/2 a mile NW, of Punk-ul village in the Kiar-kuli section	1.8	AA	AA	A	C	R	R	CC	C

Index: I. G=Garnet, K=kyanite, T = Tourmaline, E=Epidote, S=staurolite, Zr= Zircon, Ch=Chlorite, L=Leucoxene

II. AA=Abundant, A = Fairly abundant, CC=Very common, C=Common, RR=Rare, R = Very rare.

From the foregoing table, it would appear that specimen no. J/104 collected near the bridge on the diversion road is characterised by the absence of kyanite and will thus be part of lower Siwalik. The other heavy minerals present support it further. Specimen No.J/102 and J/48 collected from Kalagad section near the bridge close to Ambica Devi Temple and from Kiarkuli river section, are characterised by the presence of abundant kyanite indicative of Middle Siwalik. The other heavy minerals also lend support to this.

These evidences further corroborate the hand specimen studies made earlier.

11. DUN GRAVEL:

Dun gravel is mainly made up of the boulders and pebbles of quartzite, slate, limestone and phyllites. They are mostly subangular to subrounded, and vary at various horizons and also laterally. Average size range is from 2" to 3" but at places they are as large as 2 ft. The cementing material in most of the cases is fine grained of sand size range-yellowish in colour and calcareous, Gravels also acts as cementing material. The cement is fairly indurated.

12. RECENT GRAVELS:

The Recent gravels are quite distinctive from Dun Gravels and have been studied and distinguished at three sections particularly. They are of hetrogeneous size, shape and composition at these places as indicated below.

(a) Exposure No. X2- The terrace is made up of alternate uncemented layers of gravels and silty material. The gravel layers contain rounded to subrounded pebbles of quartzite, slates and limestone, embedded in sandy and uncemented matrix. The maximum size of the gravel is 2" but on an average they are less than 1/2".

(b) Exposure No. X_3: The gravel deposit is uncemented in nature. The maximum size of pebbles in the gravel deposit is 2 feet and average size is 9 inches. They are mainly of quartzite limestone and slates.

(c) Exposure No. X_4: The upper horizon is characterised by pebbles and gravels of quartzite and limestones with maximum size of 1 ft, the average size is 6 inches. They are not cemented. The lower horizon contains mostly flakes of phyllites and slates embedded in fine grained brownish green matrix. The maximum size of these flakes is 1/2" and the deposit is well sorted.

CHAPTER IV

STRUCTURE AND TECTONICS OF THE AREA

1. REGIONAL STRUCTURE

As mentioned earlier, Auden (1934) has described the structure of the Krol belt on the regional basis as that of two thrust bond synclines of Krol rocks, resting on a Jaunsar-Simla slate foundation (Plate No.8). He attributed the folding of Krol and Garhwal Nappes as a result of the resistance offered by the floor upon which the movement was effected.

2. STRUCTURE OF THE AREA

In the area investigated in Dehradun-Mussoorie region, the Jaunsar-Krol succession is folded as a major syncline, whose axis tends N-W to S-E approximately and passes through Batamad (30° 27', 78° 7'), which lies further NE of the area. It is thrusted over the Siwaliks generally and at places even on the Dun gravels in the southern part of Mussoorie hill ranges. The structural data has been plotted on the Geological map of Rajpur Area (Plate No.3). The main structural features are described here.

These have fairly consistent amounts and directions of dip. The amount varies from 50 to 85 degrees and the direction is persistently N 5° E. The general strike of the formation in the entire area is N 85 W - S 85 E.

(B) FOLIATION:

Foliation planes are often seen in Chandpur phyllites and Infra krol slaty-shales. In phyllites, the foliation planes are very feebly developed near the thrust zone but are distinctly seen further away from it (e.g. in the Rajpur area and in the Kiarkuli river sections). The amount and direction of dip of foliation coincides with the bedding planes of Nagthats and Krols. The foliation planes are fairly closely spaced. They dip generally 40° in the direction of N40E and the strike is N50W-S50E.

The foliation planes of Infra Krol slaty-shales are very closely spaced. In fact, Auden (1934) has remarked that it is difficult to distinguish them as a formation from a distance, thus mistaking it to be scree material. The Krol A slaty-shales show marked cleavage often closely spaced but quite distinctive from the underlying Infra Krols.

(C) JOINTS:

The joints are quite common in almost all the rock formations of the area, but are developed well in restricted horizons only.

The Chandpur phyllites are highly jointed and crushed. The joints are clearly seen in Kiarkuli river section where three major sets were noted (60°, N40W, 58°, S60E and 42°, N50E). The Nagthat quartzites also generally show three sets of joints. The joints are widely spaced (Plate No.18, Photo No.1). Infra Krol slaty-shales and Krol B purple shales are so closely jointed that it is difficult even to take any hand specimen. They show the extreme case of shearing.

Krol A limestones show fairly close jointing assuming various patterns (e.g. square and rhombohedral). The inter-bedded shales have three dominant sets of joints which have been subsequently filled by calcite. It appears that two sets of joints are older while the third is younger. (Plate No.18 Photo No. 2).

The joints in Krol C limestone are at places closely spaced while elsewhere it is widely spaced. The associated marble shows extreme fracturing and the joint planes are numerous and closely spaced.

(D) FOLDS:

(i) <u>Major</u> a) Jaunsar-Blaini-Krol Succession. As already described the Jaunsar-Blaini-Krol Succession in the area forms the southern limb of the Mussoorie syncline trending NW-SE, extending for about 22 miles. The syncline shows its closure near Banog and Cloud End (west of Mussoorie township).

b) Siwaliks- The lower and middle Siwaliks are interpreted as isoclinally folded near Rajpur, its axis trending E-W. The Siwalik sandstones have a general strike of N85W-S85E and at all places they dip by an amount of 80° in the same direction i.e. N 5° E.

On the basis of heavy mineral analysis, the Siwalik sandstones were distinguished into lower and middle Siwaliks. The lower Siwalik forms the core of the anticline around Suri Devi. The Middle Siwaliks further south are covered by Dun gravel but are seen in the north in the Kiarkuli section. In view of the folded nature of the Siwaliks it is reasonable to hope that they are isoclinally folded in the area (Plate Nos.3 and 4).

(ii) Minor folds- Puckering and small scale folds are very common in Chandpur phyllites and are seen in almost all the road sections. They are, however, best seen developed near Rajpur at exposure No. X_1. Minor folding of comparatively greater magnitude is seen in Krol C and Krol D and E. In Krol D and E, they are well seen in Baldi Nadi section. The lime-stone and shales are folded as plunging anticlines and synclines (Plate No.3). The plunges are mostly 25° due E. The anticlines and synclines, both asymmetrical and symmetrical types, are seen. At places even minor isoclinal folding is also seen.

E) FAULTS:

(i) Major Fault- In the area one major fault has been interpreted in the Baldi Nadi section at Sahasradhara where Krol A is conspicuously missing and Krol B directly rests on Infra Krols which are highly sheared. It is a strike fault hading 65° , NE with a throw of more than 500 ft. Shearing in both the Infra Krol slaty-shales and the Krol B purple shales is clearly seen at their contact. It may be noted that the Krol A limestone and associated slaty-shales are persistent throughout the area under investigation and no pinching has been observed elsewhere, even by earlier workers. The lateral extent of the fault is about one mile trending N25W-S25E approximately.

(ii) . Minor Faults- Minor faults are very common in the phyllites, Infra Krol, Krol A and Krol C along the road and nala cuttings of the area. They are of both the normal and reversed type and their extent is seldom more than 10 feet. A number of micro faults were recognised in the Infra Krol slates under microscope.

3. KROL THRUST

Auden (1934) named the Krol Thrust and indicated that it extends below Mussoorie. Between Baken and Kalsi (Plate No.11) two thrusts have been recognised namely, the Krol Thrust-which brings Krol Belt rocks over Subathu and Dagshais and Nahan Thrust-which brings Sabathu and Dagshais over the Nahans (Plate No.11). East and South-east of Kalsi the two thrusts appear to have coalesced together. At Mussoorie the Krol Thrust has brought the rocks of Krol Belt over the Siwaliks and at places even over the Dun Gravels(?).

The Krol thrust was mapped in the area wherever it was possible (Plate No.3). In the Lajpur area, it appears that the Krol thrust has exceeded the uppermost limit of the Great Boundary fault (or the Nahan Thrust) and come over the Siwaliks and even Dun Gravels (Plate No.4). While the thrusting of Mandhalis and Chandpurs over the middle Siwalik is clear in the Bhitarli and Kiarkuli river sections respectively, there is some doubt of its relationship in the east which is discussed later. The general trend of the Krol thrust is WNW-ESE and at places N-S, NW-SE, E-W trends are also seen.

4. CHANDPUR PHYLLITE OVERLYING THE DUN AND RECENT GRAVELS

A detailed investigation was carried out to ascertain the lateral extent of the Krol thrust where it brings the Chandpur phyllites over the Dun and Recent Gravels. The various other possibilities are also discussed here. The following evidences have been analysed and tentative conclusions arrived at. These observations are confined to the area east of Punkul village, Lajpur.

(i) Chandpur phyllites are found to occur resting above Dun Gravel deposits, the contact between them is very sharp and dips at about 30° in a direction NE (Plate Nos. 5 and 21). This disposition appears to have developed due to the thrusting of Chandpurs over the Dun gravels.

(ii) Near the thrust the Chandpur are highly crushed , as a result of which the general foliation in the adjoining Chandpur phyllites has become obscure.

(iii) The intensity of crushing in the Chandpur phyllites decreases as one moves away from the thrust and ultimately the Chandpur phyllites show well developed foliations which coincides with the general trend in the area.

(iv) In the stream cuttings south east of the Mussoorie Toll at Rajpur (exposure No.X), the crushed Chandpur are observed to occur over Dun gravel deposits for about 150 yards. This appears to be the minimum shift of Chandpur over the Dun gravels, on account of thrusting.

(v) The above mentioned over-thrusting has been observed in almost all the streams which flow across the thrust wherever the Chandpurs are in contact with the Dun gravels for a length of about $3\frac{1}{2}$ miles east of Punkul village.

(vi) The pebbles of Dun gravels show a preferred orientation parallel to the thrust (Plate No.21). Elsewhere in Dun gravels and recent gravels, there is no lineation seen.

(vii)The presence of highly plastic 2 to 6 inches thick clay bands along the thrust seems to have been developed due to the movement along the thrust.

The anomalous occurrence of Chandpurs over the Dun gravels has been considered in the foregoing to be due to the over-thrusting of the former over the latter. The various other explanations could be the following, which have been discussed in their relevant details.

i) The deposition of Dun gravels took place in the overhung portions of the Chandpur phyllites,

ii) This could be due to the gliding of Chandpur phyllites over the Dun gravels.

Both the above mentioned arguments do not stand to reason in the area in view of the following:

i) The Chandpur phyllites are generally crushed and powdery with hardly any tensile strength and thus would be incapable of standing any overhang for even a minimum of 300. ft.

It seems unlikely that the plane of the under-cut, which is an erosional surface, could be a straight one inclined at 25°. It should infact, have been an irregular and curved surface.

The development of clayey, plastic material along the thrust and the preferred orientation of pebbles could not be explained as erosional features.

Since the Chandpurs overlie the Dun gravels for nearly $3\frac{1}{2}$ miles in the area, it is very unusual that an undercut overhang has existed for such a long distance and subsequently got filled by Dun gravels.

ii) The over-riding of Chandpur phyllites over the Dun gravels could have taken place by the development of a major slip due to the base-failure. The possible successive stages have been illustrated in Plate No. 10.

In the cases cited above, there should be development of major slip scarps in Chandpur phyllites and a distinct variation of the dip of beds lying in the glided block with that of the parent block (Plate No.10). In case slip scarps were noted, the crushed and clayey mass should have been present near the plane of slip. No such features were noted during the course of the present investigations.

Moreover, it is very unlikely that the trace of a major slip plane should have exactly coincided with the Krol thrust in the region east of Punkul village (Plate No.3).

INFERENCE:

A similar thrusting over the Pleistocene Dun gravels has been noted in the areas east of Rishikesh (Wadia and West, 1964) and in the earlier work, Auden (1934) had inferred a subrecent movement along the Krol thrust at different places in Krol belt.

In view of the foregoing arguments and on the basis of earlier work, it seems more likely that there has been thrusting of Chandpur phyllites over the Dun gravels in the present area east of Purkul village. This could possibly be attributed to the later movements along the Krol thrust.

5. TECTONIC HISTORY AND MOVEMENTS ALONG THE KROL THRUST

It was Auden (1934) who envisaged two nappes in the area, the Krol and Garhwal nappes, which were considered to have been thrusted forward over the younger rocks. The movement of the Krol belt southwards took place on the Simla slates of Garhwal which acted as the autochthonous floor. In the trough of the large Mussoorie syncline is the klippen of the more metamorphosed Garhwal rocks. Thus, the Simla slates and other metamorphosed Garhwal rocks occur both as autochthonous floor and as klippen (Gansser, 1964), unlike the Simla area, where the Giri thrust brings Simla slates over the Krol belt.

It was surmised that the Mussoorie syncline—a part of which has been investigated—was consequent to the translation of Krol belt. Development of folds and faults could thus be quite natural in the limbs of the syncline.

Regarding the age of movements, it had been thought that the earliest movement took place in the Burdigalian times (Auden, 1934) and some of the movements may have taken place even earlier than Helvetian. The geological evidence suggests more than one period of orogeny and Wadia and West (1964), mention that the earliest orogeny is in the pre-Eocene times, though the large scale translation of sheet of rocks along low-angle thrusts in a series of nappes, took place at the beginning of middle Miocene times. The movement has not been precisely dated yet. Auden (1937) observed that there has been more than one period of movement along the Krol thrust and imagined that the stronger one took place in Helvetian and the later movements during the Siwalik and post-Siwalik. Auden (1942) mentioned about the chain of lakelets and depressions in the Achhugan-Bakan area (15 miles east on Nahan, Plate No.11) and considered them to have been formed as a result of recent activity along the Nahan and Krol thrusts.

On the basis of the investigations carried out in the Rajpur area, and on the basis of foregoing, the following three possibilities of movements have been interpreted for the area in addition to the earlier movements.

i) The Krol thrust has brought the Mandhalis and Chandpurs over the Middle Siwaliks in the part of the area, indicating a movement younger to the Middle Miocene times.

ii) The undoubted occurrence of Chandpurs over the Dun gravels in the eastern part of the area, indicates the possibility of a movement later than the upper Pleistocene times.

iii) Analogous to Auden's (1942) observations in the Bakan area concerning the formation of lakelets due to the recent activity along the thrust, some evidences have been analysed in the present area also.

The tilting of recent gravels at exposure No.X_2 and of the gravels underlain by Chandpur phyllites at Exposure X_3 and X_4, indicate a possibility of movement later than the movement involving the Dun Gravels. These evidences are as yet paltry and no definite conclusions could be drawn at this stage.

CHAPTER NO V

MAJOR LANDSLIDES IN THE AREA

i) Geological and Topographical Set-up:

In the southern flank of the Mussoorie ranges, particularly east of Kiarkuli river section, Chandpur phyllites--highly sheared and jointed--are exposed in their strike sections. The scarp faces all along have caused unstability conditions and a number of landslips have taken place, wherever the streams cut across these formations. In fact, some of the local streams originate from these slopes and it is these, which have caused the major landslides. The landslips have been triggered by the shocks of the earlier earthquakes.

ii) Vegetation: The vegetation is quite scanty on the hillslopes, and wherever trees are present, their roots, in the jointed Chandpur and allied formations, have caused expansive forces which have opened up the joints. Small shrubs usually act as protective measures to keep the scree together but are absent, particularly on the steeper slopes.

iii) Action of Water: The precipitation is heavy during rainy and winter seasons and water percolating through these jointed phyllites acts as a lubricant and helps in the sliding of material.

iv) Structural Relationships: The foliation of Chandpur phyllites is close and dips northwards with gentler dips. The joint pattern is intricate with numerous joint directions and minor close folding and faulting further aid in the disintegration of already soft phyllites.

In view of the above mentioned factors, it would be reasonable to expect numerous landslides, particularly in the southern reaches of the Mussoorie hill ranges i.e. in the area investigated.

A number of landslides-- both perennial and seasonal types--were observed, whose detailed discussion follows. Greater emphasis, however, was laid on the Kalagad landslip.

2. KALAGAD LAND SLIP

At the time of the construction of the Dehradun-Mussoorie road, the problem of landslide was particularly noticeable. For a small stretch, the road had to pass over the Kalagad ravine near Rajpur and a bridge was constructed in 1919.

Though the landslide at Kalagad had existed even before, it assumed greater dimensions in the years to come and eventually in the summer of 1965 , the bridge was observed to have been completely filled up by scree material (Plate No.9).

Auden (1940) investigated this landslip and suggested an alternative alignment of the road. He mentioned that the gradual flooding of the Kalagarh ravine with gravels is due to a perennial landslip operating at the head of the nala. Though the flooding had started earlier, the protective measures were taken up in 1928, which did not help matters.

The landslip is taking place in the black and dark green slates and phyllites of Chandpur stage which are overlain by purple coloured quartzites. Both these, as mentioned earlier, are very closely jointed and sheared.

In the year 1941-42, for a distance of 2,960 ft. below the bridge, the average gradient was 5°. From the bridge upto the toe of the slip the gradient was 10°. Finally the average gradient of the slipped hillside was 36° and the height of the slip zone was 868 ft.

The average slope of the hill there was 36° which was 11° steeper than the angle of 25° which can be considered a safe slope for sheared and jointed slates. The slope between the bridge and the slipped hill gradually rose to 25°.

<u>Discussion:</u>

The stage in which the Kalagad landslip is present now, it would seem that any future triggering of the unstable slope by earthquake movements would cause complete inundation of the existing bridge. The slopes of the slipped material are gradually exceeding the critical angle of repose and it could well be expected that on a future date, there would be development of a secondary slip surface within the scree material. This possibility can be envisaged in view of the likely effects of shock in the area. The present position of the scree material in the nala is indicated in Plate No.9, with the earlier levels of gravel given by Auden (1942).

3. OTHER LANDSLIDES.

In addition to the main Kalagad landslip, there are some other major slides in the area as indicated below:

i) 1/2 a mile from Kothal Gate on the Dehradun-Mussoorie road.

ii) Near Power House in the Kiarkuli river.

iii) A number of landslips are seen adjacent to the limestone quarry faces.

i) In some respects, the slide near the Kothal Gate on the Mussoorie road is similar to the one observed in the Kalagad ravine. The river bed level is, however, considerably more steeper than that of Kalagad. The rocks at the head of the stream is the same phyllite-slate sequence which is jointed and sheared and could pose similar problems. In view of the steeper gradient of nala, however, no flooding of scree material has taken place nor one is likely in the future.

The distance between the bridge and the toe of the slip is only 50 yds. and the slope of the slipped hill is about 60° towards the downstream side. The landslip has thus not progressed very far and protective measures have already been taken up.

ii). The landslip in Kiarkuli, which appears in the earlier Survey of India top sheet No. 53 J/3, is in the nature of a vertical scarp in the Krol C limestones. The limestone is otherwise quite compact but the slip appears to have taken place along one of the major structural weak planes opened up by the Kiarkuli river.

iii) Similar to the slip in the Kiarkuli section, a number of other landslides were observed near the quarry faces but no detailed investigations were made there.

CHAPTER [illegible]

SEISMICITY OF THE AREA

1. GENERAL

An idea of the seismicity of the Himalayan belt could be had from the fact that, during the past hundred years, this has been the scene of nearly 40 major earthquakes. Although, earthquakes of this nature must have been occurring in this belt from times immemorial, yet the first scientific study of this subject was undertaken as late as 1883 by Dr. T. Oldham the first Director of the Geological Survey of India.

The seismicity of the Indo Gangetic plain of the Himalayan thrust is closely related with their tectonic history and they are structurally related with each other. The development of Indo-gangetic plains and the lofty mountains of the Himalayas is complimentary to each other. The thrusts and the strike of the formation in the Simla-Garhwal are at right angles to the Aravalli-Delhi strike-extensions of the peninsular shield which are likely to be extending below the Himalayas (Gansser, 1964).

The area around Rajpur, Dehradun district, has been affected by many earthquakes. In fact, the 1905 Kangra earthquake which had one of its auxiliary epicentre in this region brought about considerable damage in the area. Though a number of earthquakes have occurred in the neighbouring regions earlier, which might have affected the Rajpur area also, no reliable record is available of the extent of damage done in the 19th century and earlier.

The Ganga basin, south of Simla-Garhwal region is western Uttar Pradesh, is bounded by Moradabad fault on its south eastern margin, Delhi ridge on the western and the Himalayan thrusts along its northern border. This triangular block has shown activities all along its margins. The northern part had the Kangra earthquakes as the biggest earthquake during the recent times.

The list of some of the important past earthquakes that originated in the neighbourhood of Dehradun district during the period 1905 to 1962, which could have affected the Dehradun region also, are given as Appendix II. It also gives an idea of the activity of the region since 1500 A.D. during which period, several large earthquakes have occurred and may have done considerable damage.

2. KANGRA EARTHQUAKE:

The Kangra earthquake has been considered by various workers to be connected with the great boundary fault

(Middlemiss 1910, Auden 1942). It had a magnitude of about 8 (Richter magnitude) and some of the earlier earthquakes must have had similar magnitudes but had not been recorded, as instrumental seismology had not developed at that time. However, some estimates of the intensity in the epicentral region of earthquake could be made from the scanty description of the damage described in the historical records. It would, however, not be possible to estimate their intensity at Rajpur, before the Kangra earthquake. The intensity of damage of the Kangra earthquake in Rajpur area was Rossi-Forrel VIII.

The chief vibrations appeared to have been horizontal and could be divisible into two or three main shocks which lasted from 25 secs to 2 minutes. The effects of the shocks were:

1. Moaning and rattling sounds.
2. People standing or walking lost their balance.
3. Buildings showed serious damage-chiefly fissures and cracks.
4. Loss of life was insignificant.

C.S. Middlemiss (1910) discussed the relative heights of Mussoorie and Dehradun on the basis of the surveying carried out from Saharanpur in cold weather of 1906-1907, soon after the Kangra earthquake. He concluded that consequent to the Kangra earthquake, Dehradun rose by 5.28 inches relative to Mussoorie. The details appear as Appendix I and in Plate No.15.

The damage in Rajpur region during the earthquake was probably due to the connected movements along the thrust from the epicentral region of Kangra (Auden 1942).

3. ACTIVITY OF KROL THRUST

P.N. Mehta (1962) felt that there was no positive evidence to suggest that future shocks would necessarily be connected with the Krol thrust. The observation of most of other workers , however, tend to show that the Krol thrust has given evidences of recent activity. In the present work, evidences were analysed which corroborate the above view, and it seems quite possible that this thrust may even become reactivated later. (Details in Chapter IV).

Minor earthquakes of the region which are being recorded at the Seismological Observatory of the Indian Metreological Department, located in the Survey of India office, show that many of the epicentres are clustered along the thrust zone, though they are fairly distributed in the whole region (personal communication from Dr. A.N. Tandon, Director, India Meteorological Department). Some of these clusters, associated with the Krol thrust alignment support the view that the Krol thrust is still active. Local enquiries reveal that minor shocks are felt by the people in the Rajpur area periodically but no damage has been caused.

4. POSSIBILITY OF FUTURE EARTHQUAKES

The foregoing description indicates that the area around Rajpur is fairly susceptible to earthquakes. The maximum intensity of damage in the area during the Kangra Earthquake was of the order of VIII Rossi-Forrel. Minor tremors are being recorded every week, a few of them are even felt by the people. This indicates that strain build-up is taking place in the region and part of it is released frequently. The residual strains which are building up could cause a major earthquake in the region, but in the absence of well documented and well recorded data, the likely magnitude of future earthquakes cannot be forecast with confidence. Besides, as the activity of this region is connected with that of the whole crustal block bounded by the Moradabad fault and Delhi ridge in the south along which earthquakes of high magnitude with higher intensities have occurred--the activity of the Rajpur region is likely to be influenced by the movements of the entire block.

The maximum magnitude so far observed in the neighbouring regions are Richeter's magnitude 8 (Kangra, 250 kms. from Dehradun), 6.0 to 7.0 (Almora and Kumaon, 200 kms) and 5.0 to 6.75 (Delhi 210 km.). The observed magnitudes indicate the potentialities of development of similar earthquakes in the Rajpur region as well.

Most of the known earthquakes in the Indo-gangetic plain and foothills of Himalayas, generally show shallow depths of foci-ranging from 20 to 30 kms, which indicate that they are mostly due to the release of strain within the crust above the Moho-discontinuity. These may be atributed to minor isotatic adjustments.

Conclusion: In view of the foregoing, it can be safely assumed that no major earthquake is likely to occur in the area, though recurrence of minor shocks will be common. The Krol thrust zone is an active zone and any future earthquake along it is likely to be of low magnitude. The future structures in the area, therefore, can be designed to stand an intensity of 8 (Rossi-Forrel) or (9 (Modified Mercally). The minor shocks will, however, affect the stability of slopes, specially in the region near the thrust zone where the rocks are already highly jointed and crushed.

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APPENDIX I

(Extract from Memoir, Geol. Surv. Ind., Vol.38, pp.348-349)

VARIATION OF LEVELS BETWEEN SAHARANPUR, DEHRADUN AND MUSSOORIE

The facts are that in 1882 the line between Saharanpur and Mussoorie was first levelled. This was repeated in 1904 (the year before the earthquake), so far as the portion between Dehradun and Mussoorie is concerned. Again in 1905 after the earthquake the later portion was again levelled with the object of seeing if any change could be detected, and a demunition of about 4 inches was found in the difference of height between the two places with proportionate dimunitions at points on the way. These last two experiments were carried out in May of these years, but the results were ambigues in as much as they might be interpreted as either a rise of Dehra or a sinking of Mussoorie. To settle this point, and also to verify the whole thing, sanction was obtained, and the whole line relevelled from Saharanpur to Mussoorie in the cold weather of 1906-07. The results corroborated the 1905 levelling and established the fact that it was Dehradun and the Siwaliks which had risen and not Mussoorie which had sunk. As it must have taken place between May 1904 and May 1905 it is conjectured that it happened during the earthquake.

It may be mentioned that the greatest care was taken in levelling over such a long and mountainous tract, the reliability of the staves and the comparison of them with a standard steel unit kept at Dehradun being attended to. It is also necessary to emphasise the fact that in the last levelling along the whole line the results agree so closely over much of it.

The following is the tabular statement of these measurements and a section is shown. (Plate No.15)

Table showing the results of levelling between Saharanpur, Dehradun and Mussoorie

Names of point	Heights determined in 1862 (in feet)	Heights determined in 1906-07 (in feet)	Difference (in feet)	Remarks
G.T.S.Embedded B.M. at Saharanpur.	907.25	907.25	---	Accepted as origin
Standard B.M. at Saharanpur	---	902.728	---	---
G.T.S. Embedded B.M. at Mohand	1489.400	1489.730	+0.330	---
G.T.S. Embedded at Mohabewala.	2096.56	2096.925	+0.365	-- --
E.End of Dehradun Base Line.	1959.07	1959.464	+0.394	---
Iron Plug at Trigl. Branch Survey Office at Dehradun.	2229.132	2229.576	+0.444	---

Height of Bench Mark at Vincent's Hill, Mussoorie, determined in May 1904, accepting Dehradun as correct	... 7,129.315
Height of Bench Mark at Vincent's Hill, Mussoorie determined after earthquake in May and October 1903, accepting Dehra as correct.	... 7,128.897
Height of Bench Mark at Vincent's Hill, Mussoorie, taking the new value of Dehra determined in 1906-07, accepting Saharanpur as correct.	... 7,129.341

APPENDIX II

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-July 15	Delhi	Severe	Great damage.
1726-July 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.

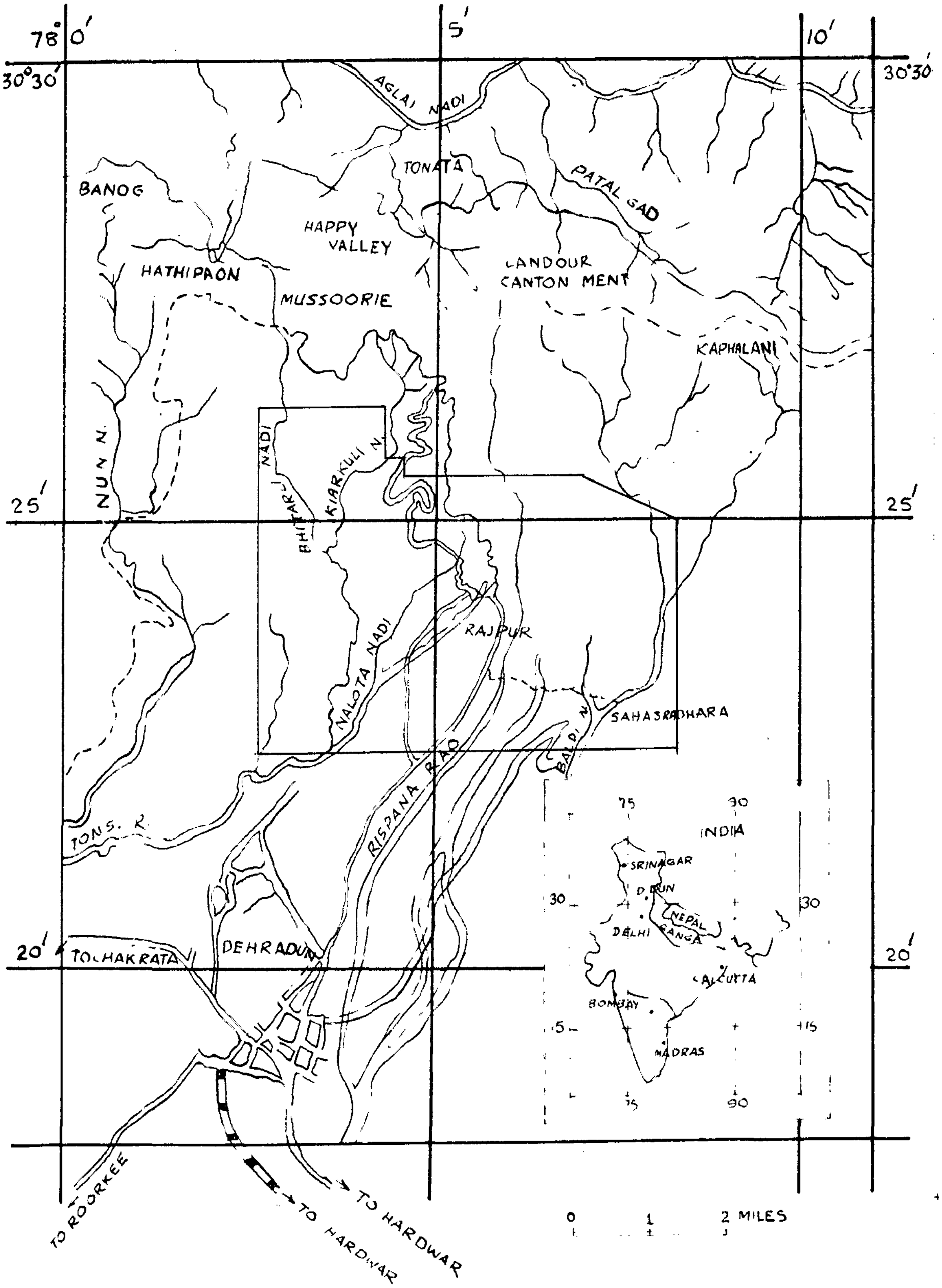
Date	P Arrival	Position	
1	2	3	
	h.m.s.		
1956–Oct.	——	——	Felt at Roorkee.
1958–Dec.	—	——	Felt at Hissar, Simla, Bareilly and Roorkee at 5 h. 37 m with intensities V,V, VII, VIII respectively
1961–July 13	07,13,30	25.8–81.5	Moderate Intensity well recorded all over India

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.

PLATE NO 1

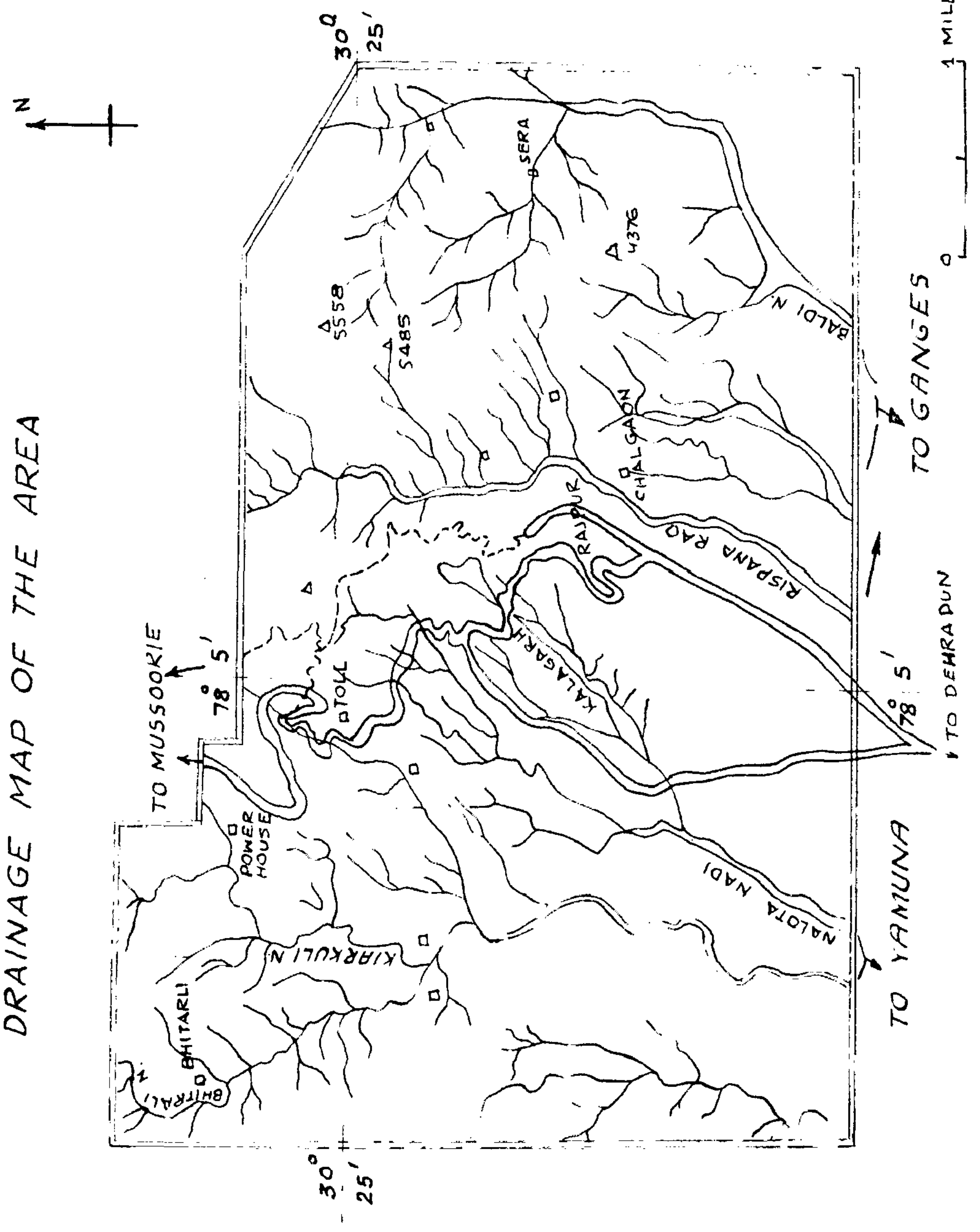
LOCATION MAP



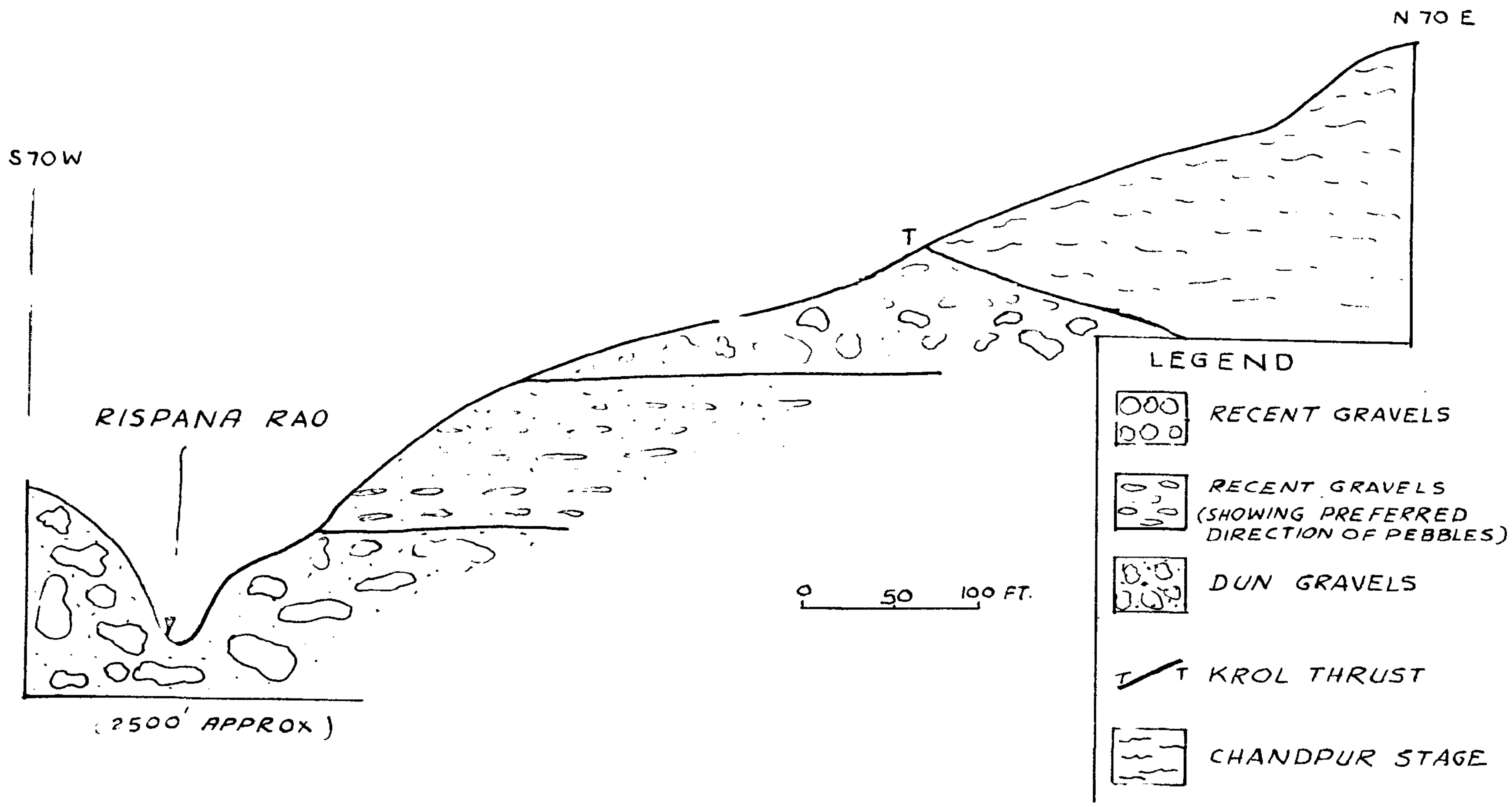
AREA INVESTIGATED

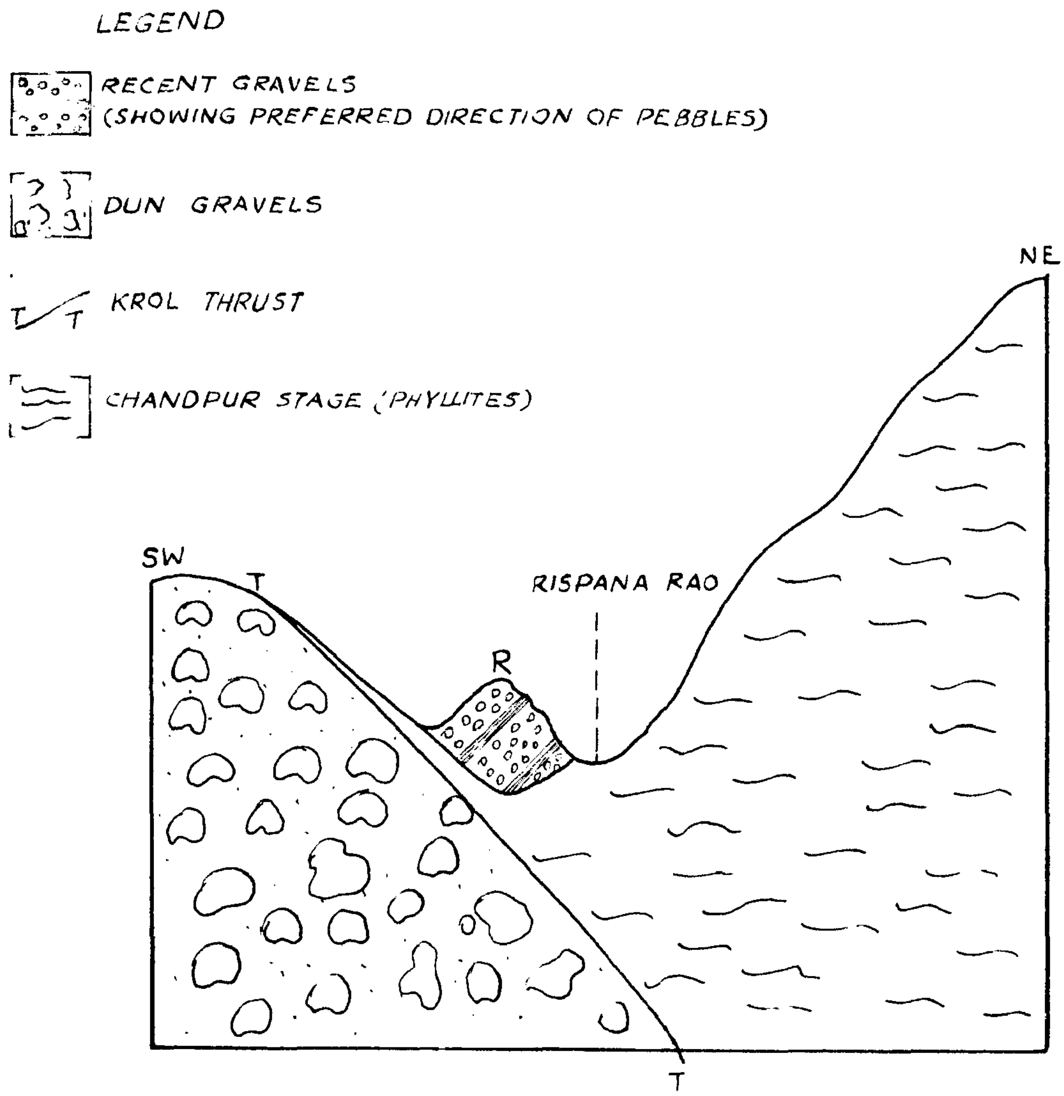
PLATE NO 2.

DRAINAGE MAP OF THE AREA



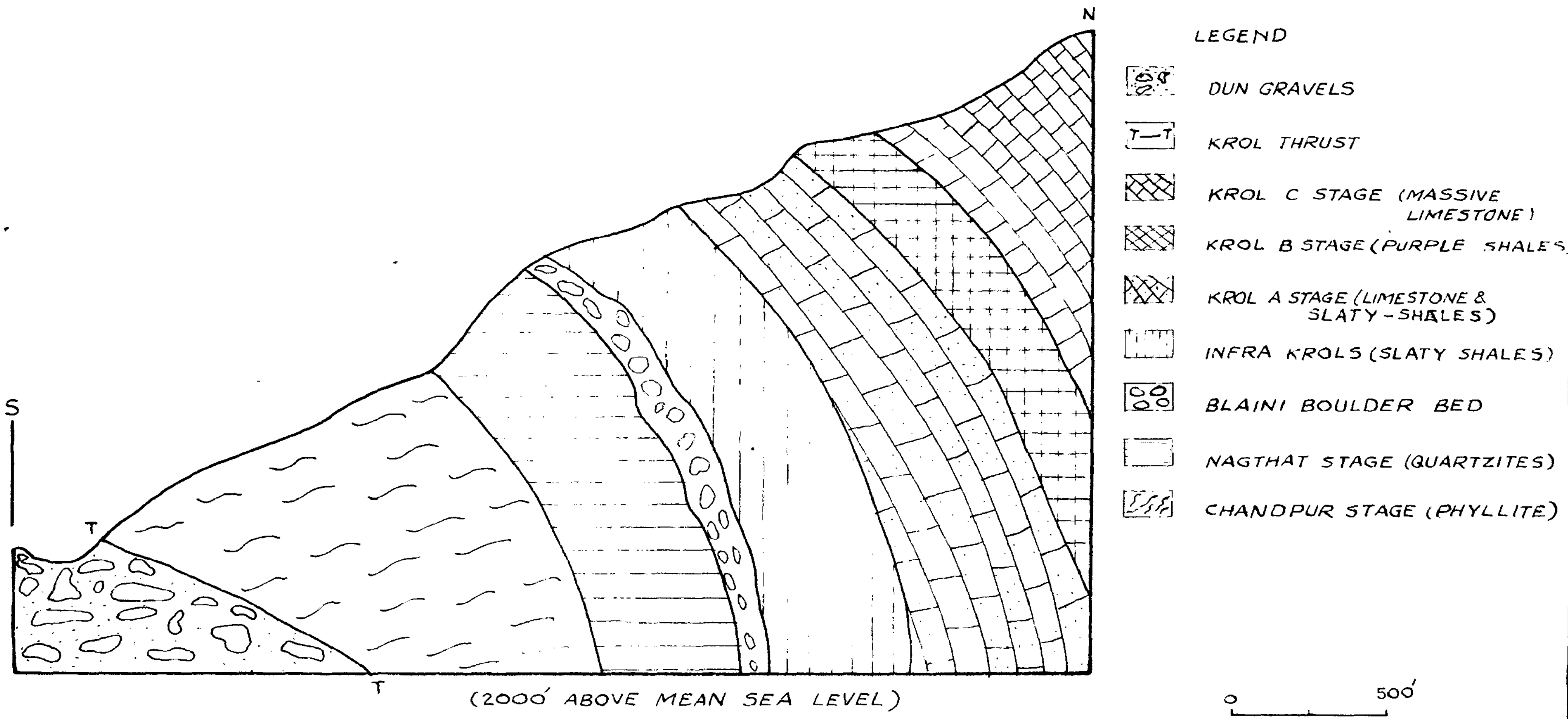
DIAGRAMMATIC SECTION ALONG STREAM No.-X4 SHOWING THE THRUSTED CHANDPUR PHYLLITE OVERLYING THE RECENT GRAVELS





SCHEMATIC SECTION SHOWING TILTING OF RECENT GRAVELS(R) NEAR AMBICA DEVI TEMPLE (RAJPUR)

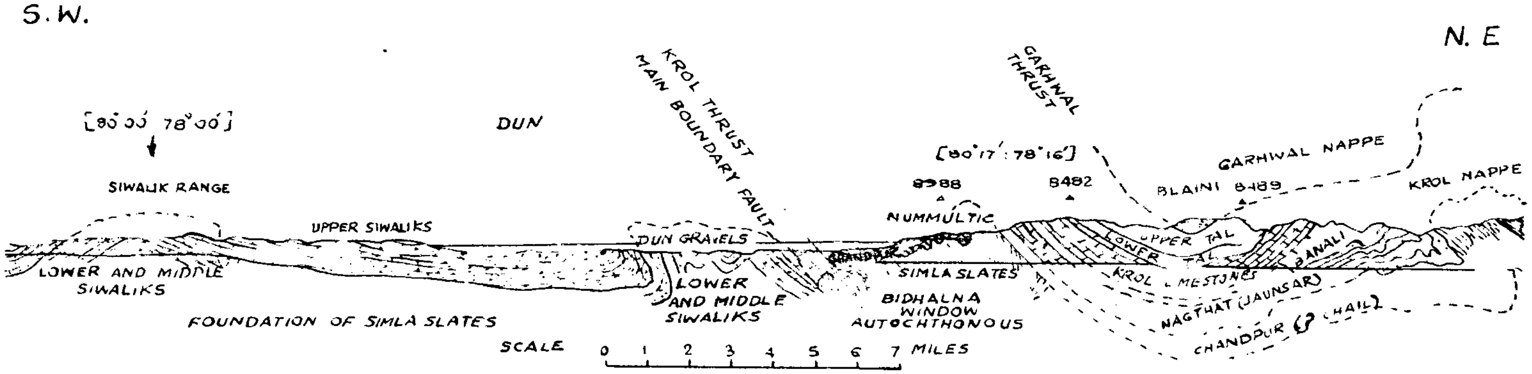
(NOT TO THE SCALE)



DIAGRAMMATIC SECTION ALONG RISPANA RAO SHOWING THE CHANGE OF DIP NEAR THE SURFACE.

PLATE NO. 8

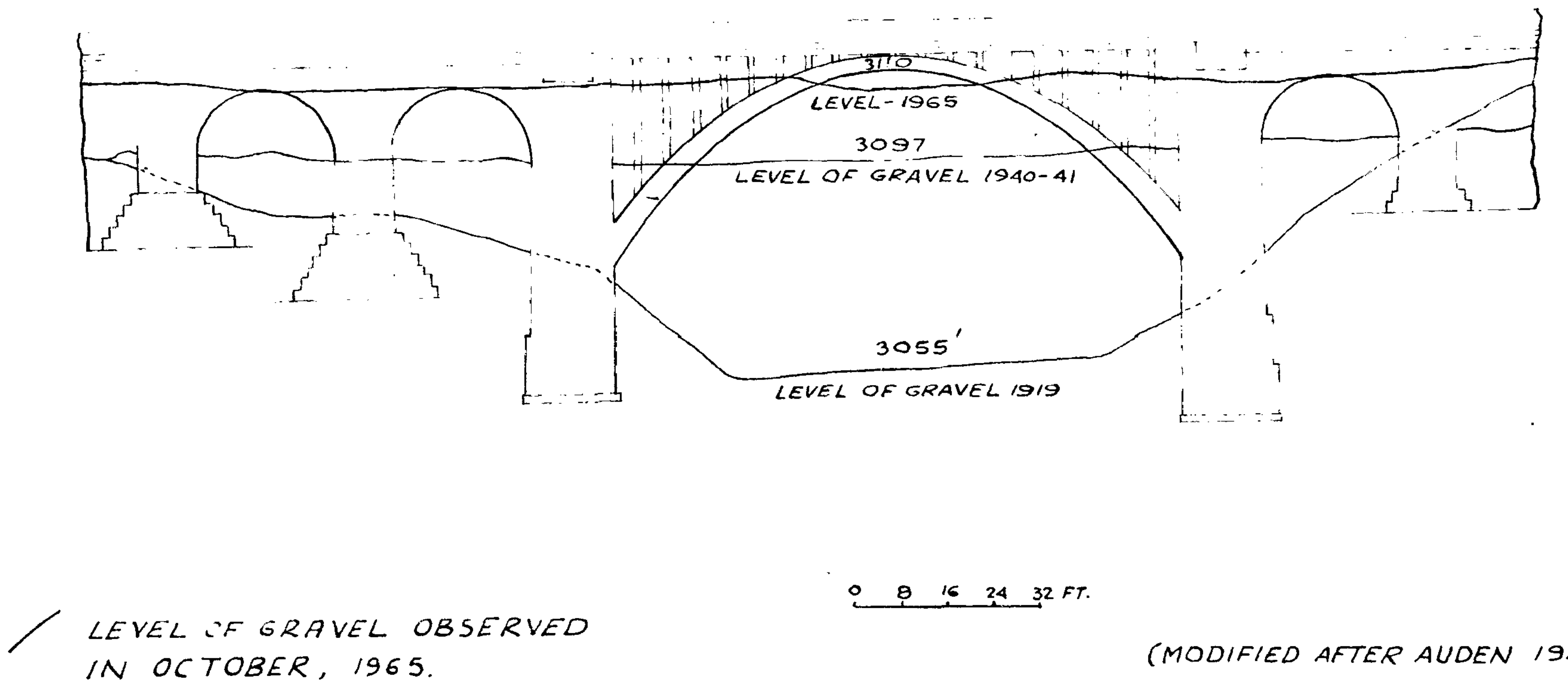
SECTION ACROSS SIWALIK RANGE AND LOWER HIMALAYA



AFTER AUDEN (1937)

BRIDGE OVER KALAGAD NALA

MUSSOORIE-DEHRADUN MOTOR ROAD



(MODIFIED AFTER AUDEN 1942)

PLATE NO 1

SCHEMATIC DIAGRAMS SHOWING THE BASE FAILURE OF CHANDPUR PHYLLITES
(NOT TO THE SCALE)

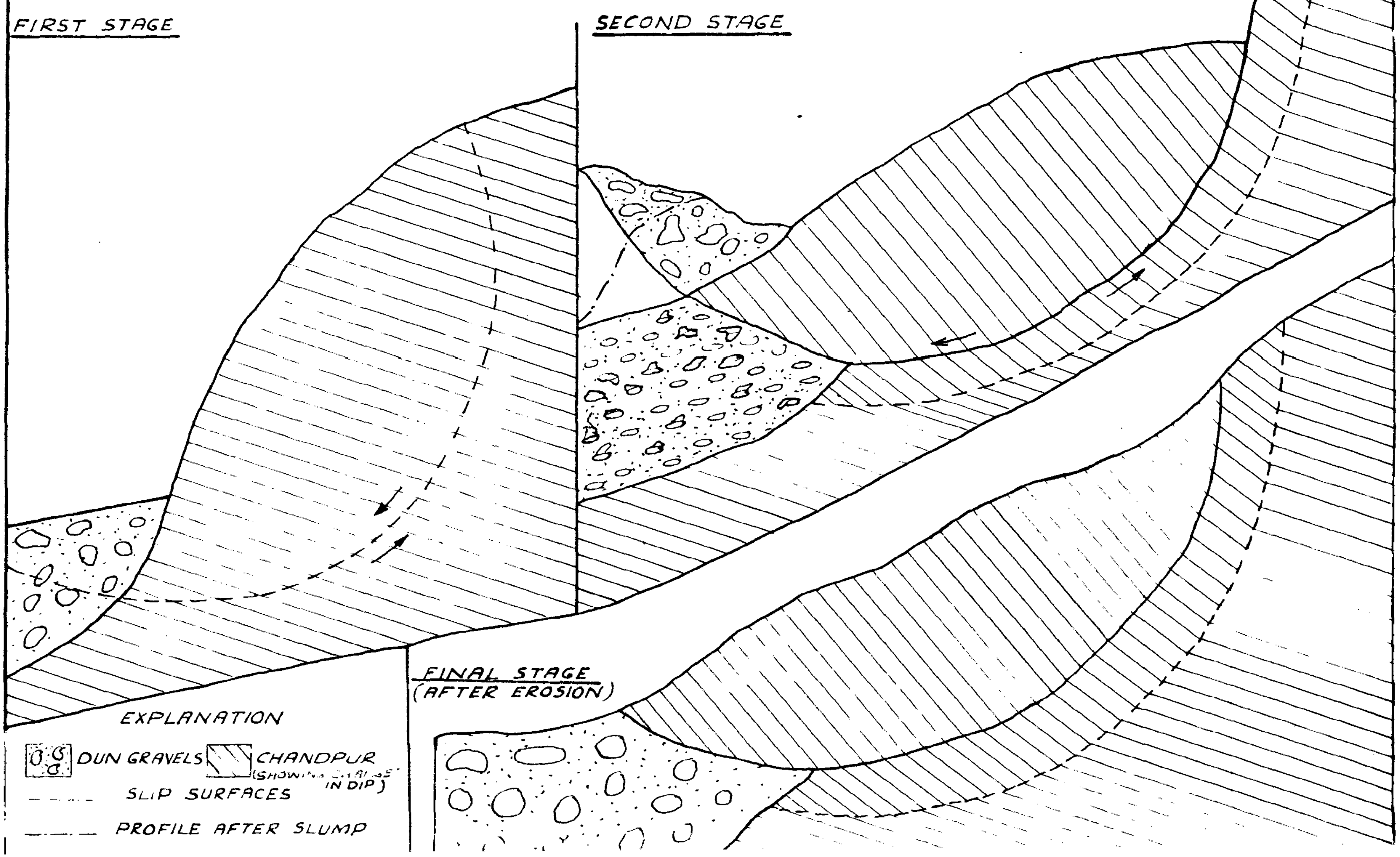
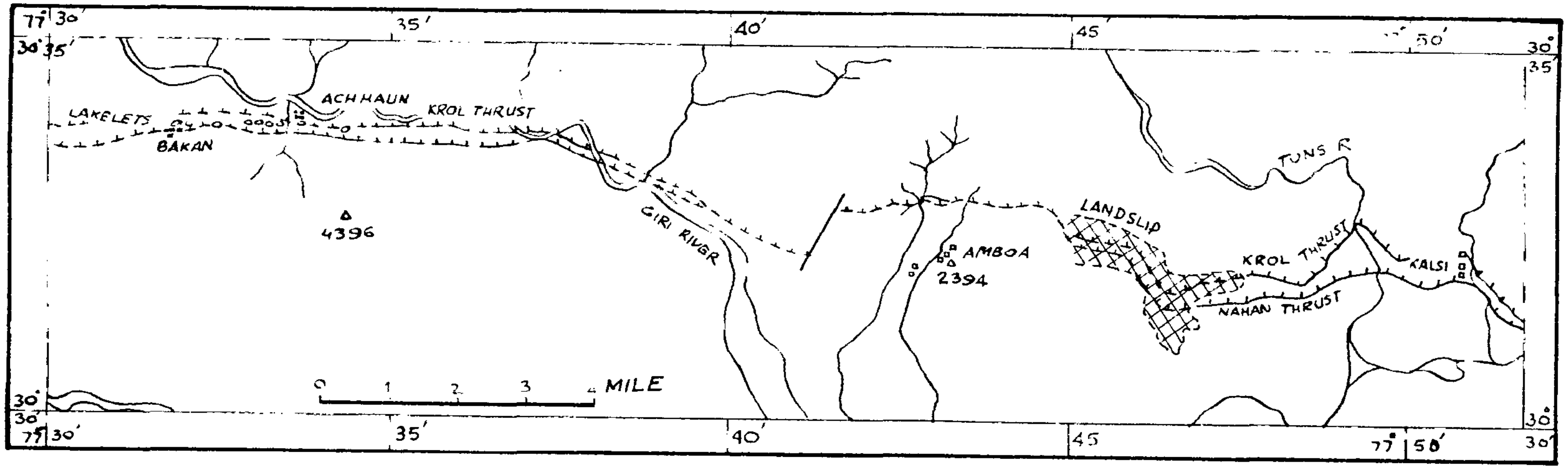


PLATE NO. 11

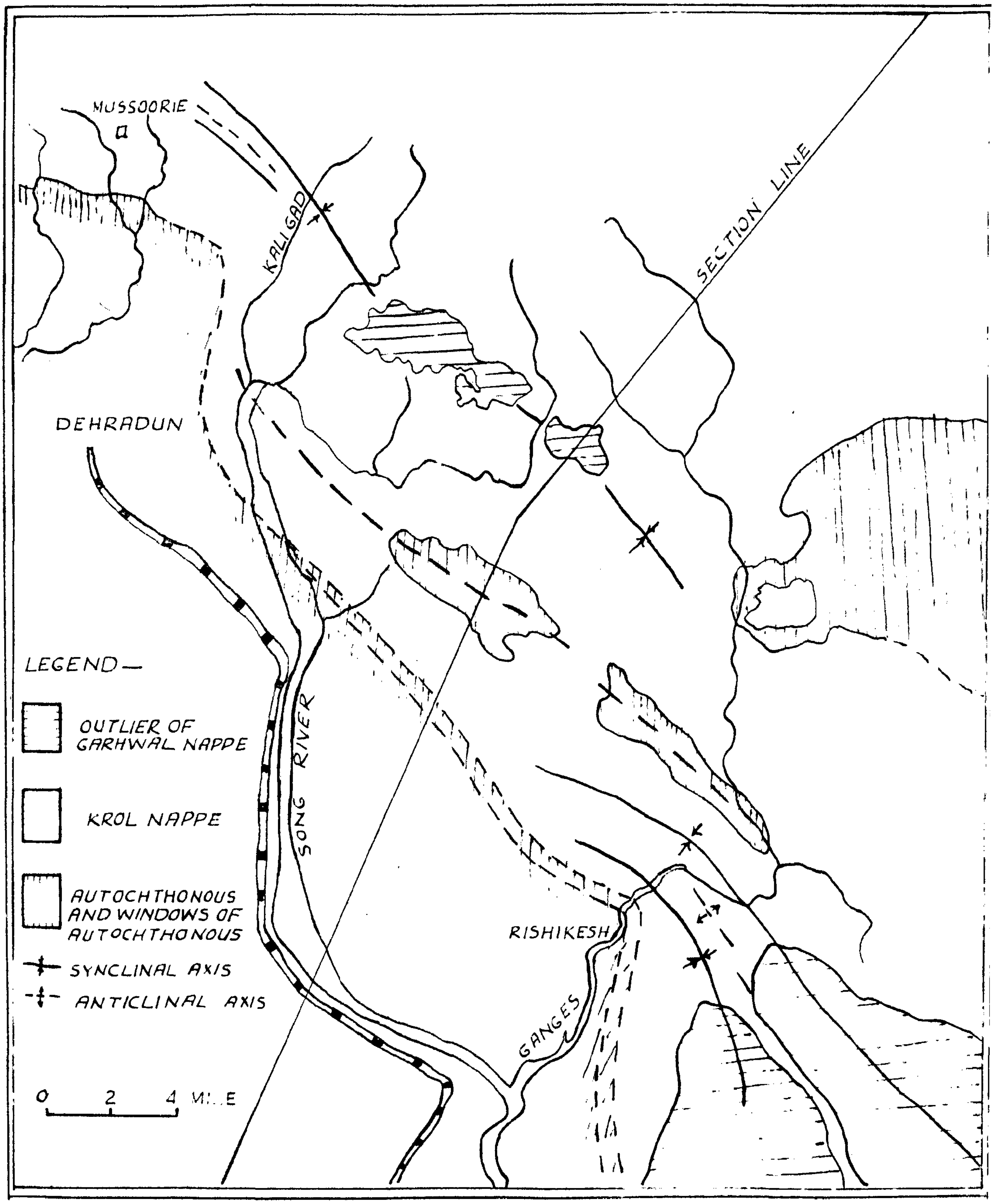
BAKAN-ACHHAUN LAKELETS



(AFTER - J.B. AUDEN 1942)

PLATE NO. 12

DISTRIBUTION OF TECTONIC UNITS DEHRADUN–RISHIKESH AREA



(AFTER AUDEN 1937)

PLATE NO. 14

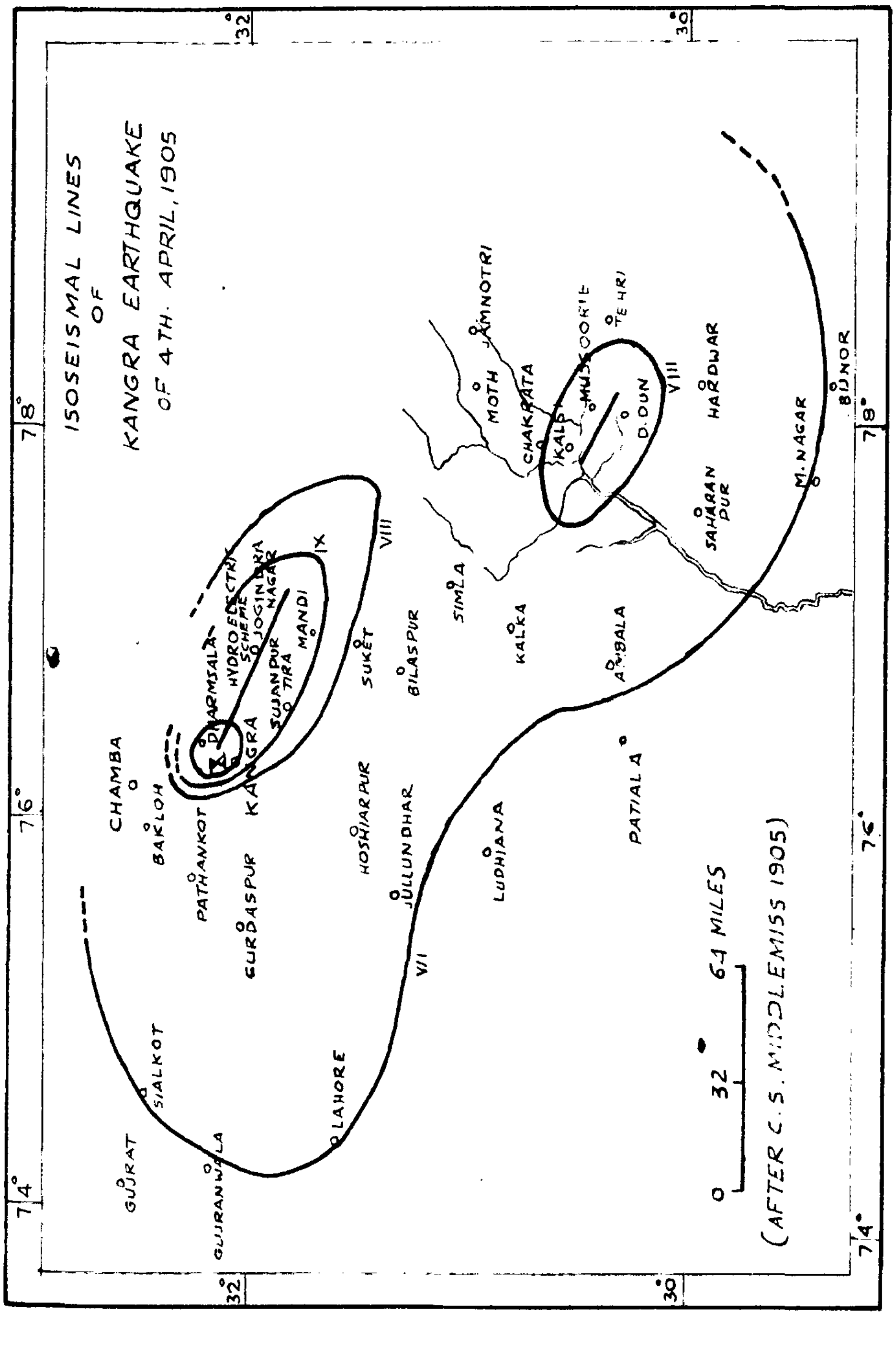
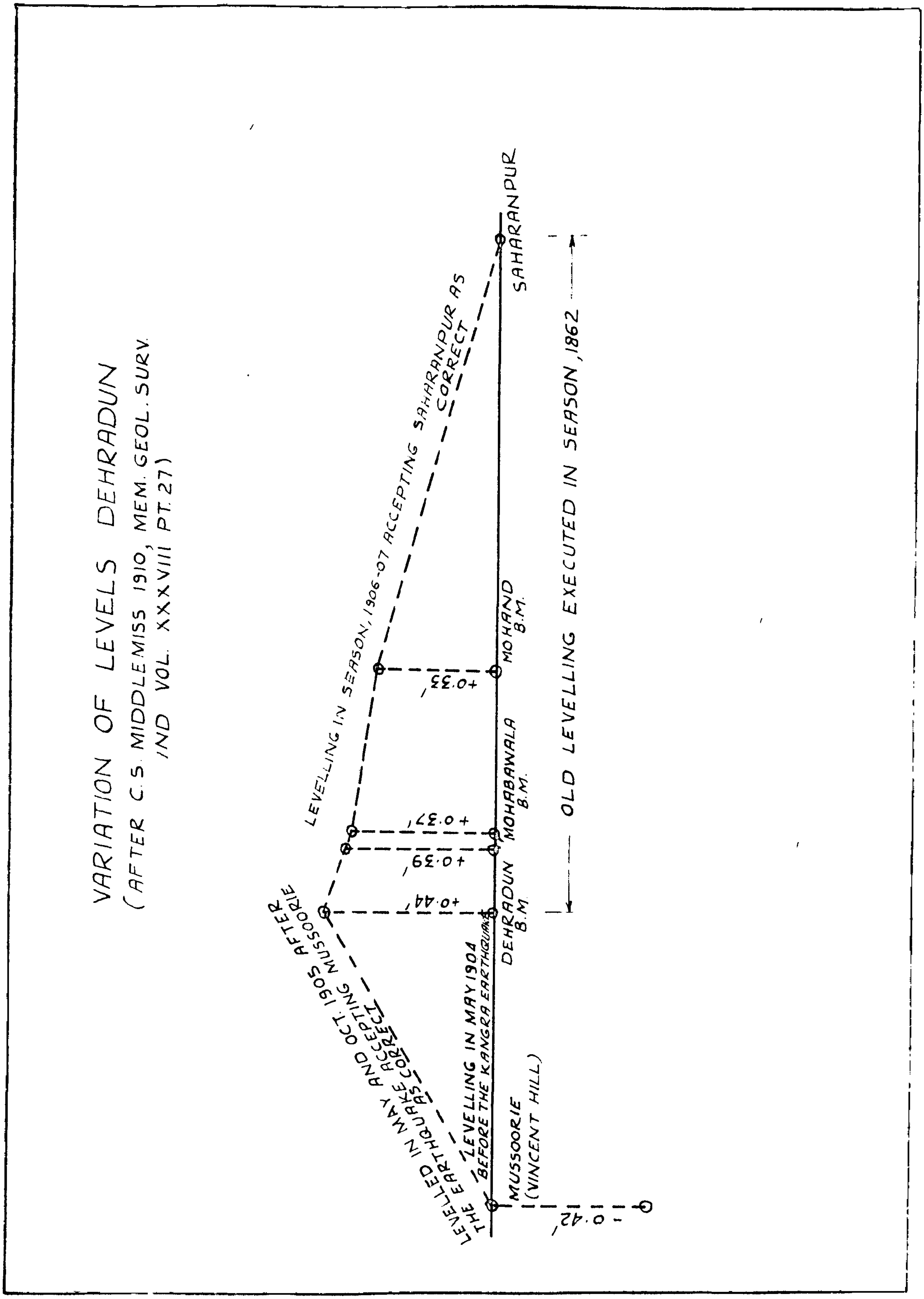
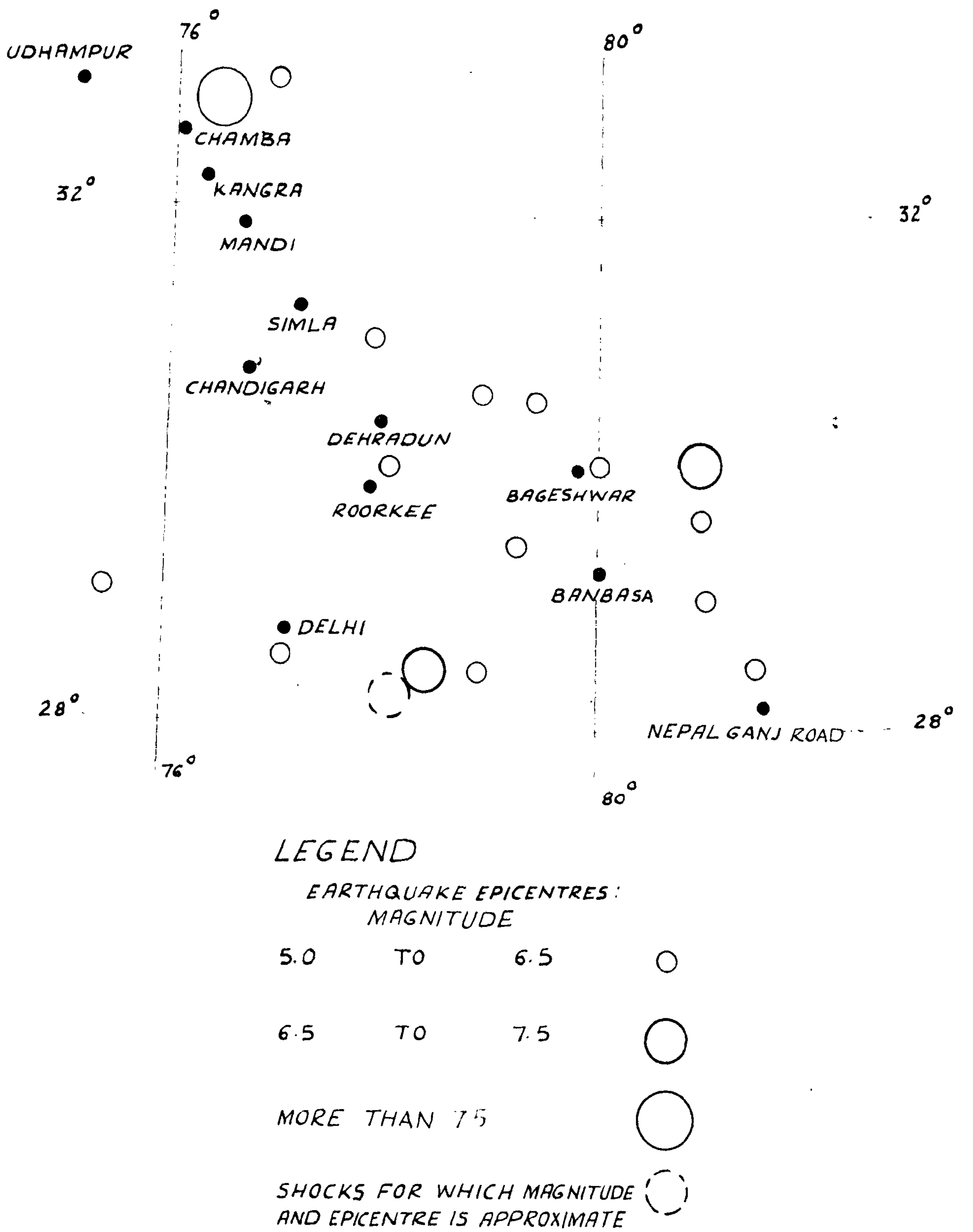

ISOSEISMAL LINES
OF
KANGRA EARTHQUAKE
OF 4TH. APRIL, 1905
0
32
64 MILES
(AFTER C.S. MIDDLEMISS 1905)
32°
30°
74°
76°
78°
CHAMBA
BAKLOH
PATHANKOT
GURDASPUR
KANGRA
DHARMSALA
HYDROELECTRIC SCHEME
JOGINDRA NAGAR
SUJANPUR TIRA
MANDI
SUKET
BILASPUR
HOSHIARPUR
JULLUNDHAR
LUDHIANA
PATIALA
AMBALA
KALKA
SIMLA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

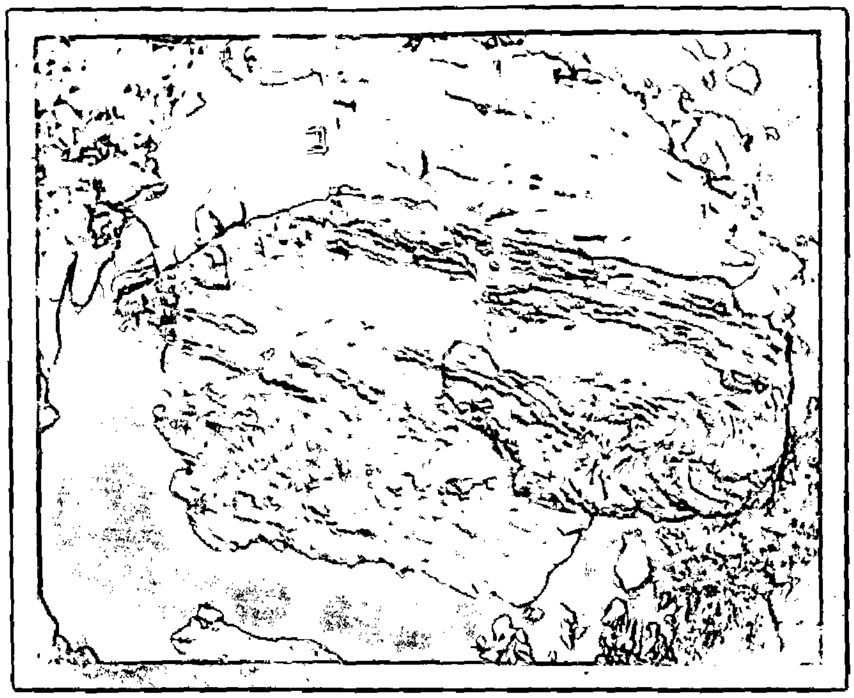
PLATE NO. I

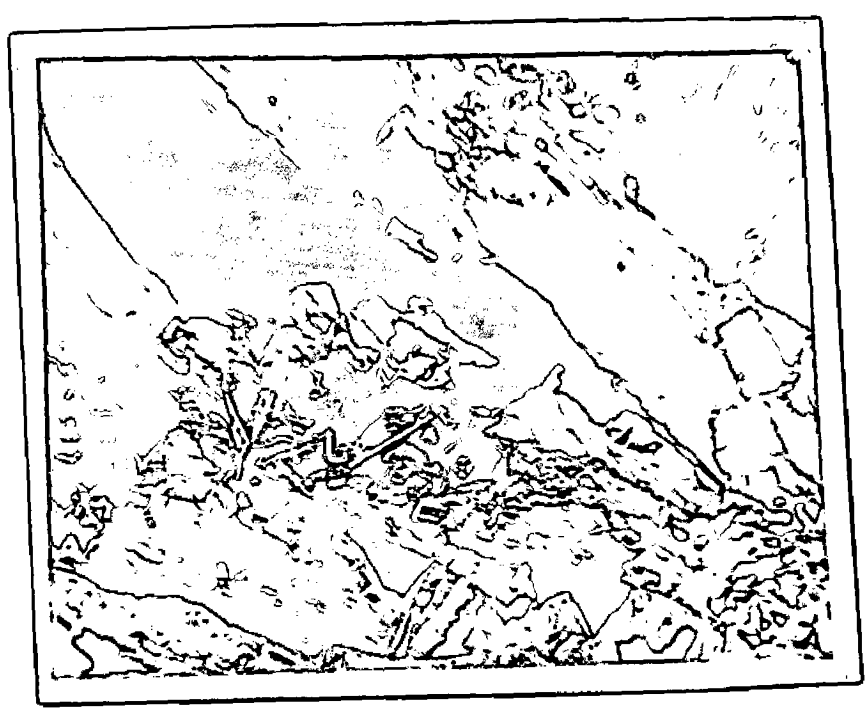

VARIATION OF LEVELS DEHRADUN
(AFTER C.S. MIDDLEMISS 1910, MEM. GEOL. SURV. IND VOL. XXXVIII PT. 27)
LEVELLING IN SEASON, 1906-07 ACCEPTING SAHARANPUR AS CORRECT
LEVELLED IN MAY AND OCT. 1905 AFTER THE EARTHQUAKE ACCEPTING MUSSOORIE AS CORRECT
LEVELLING IN MAY 1904 BEFORE THE KANGRA EARTHQUAKE
OLD LEVELLING EXECUTED IN SEASON, 1862
MUSSOORIE (VINCENT HILL)
DEHRADUN B.M.
MOHABAWALA B.M.
MOHAND B.M.
SAHARANPUR
+0.44'
+0.39'
+0.37'
+0.35'
-0.42'

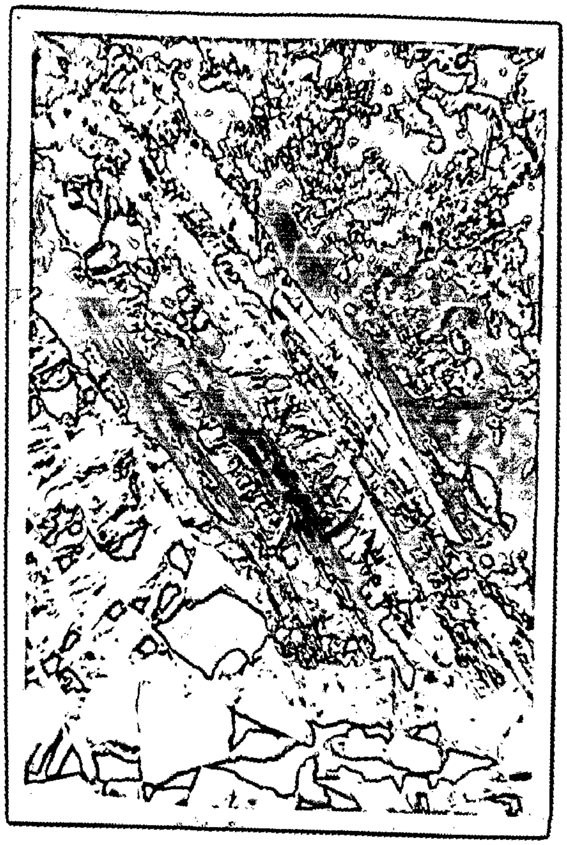
MAP SHOWING EPICENTRES OF PAST IMPORTANT EARTHQUAKES IN SIMLA GARHWAL AREA

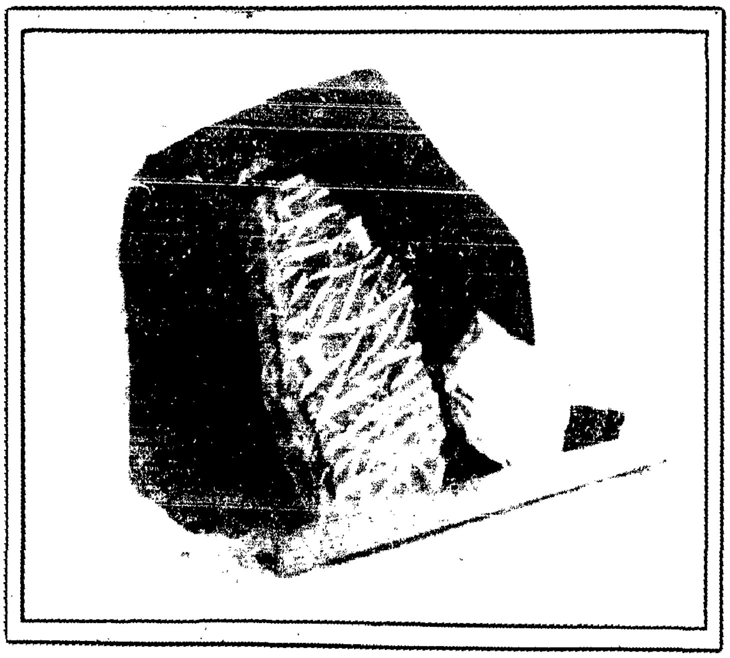


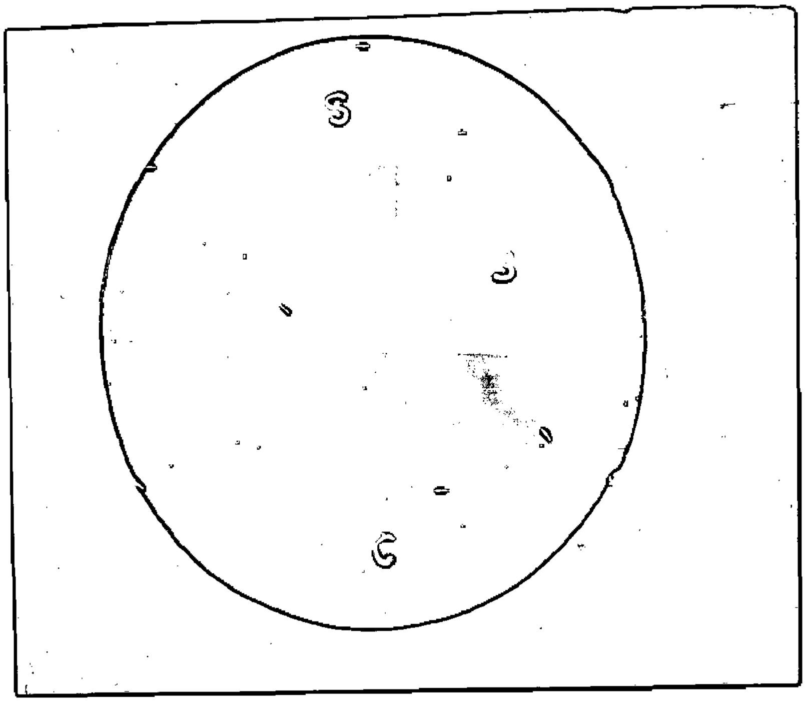
AFTER I.S. 1893–1962

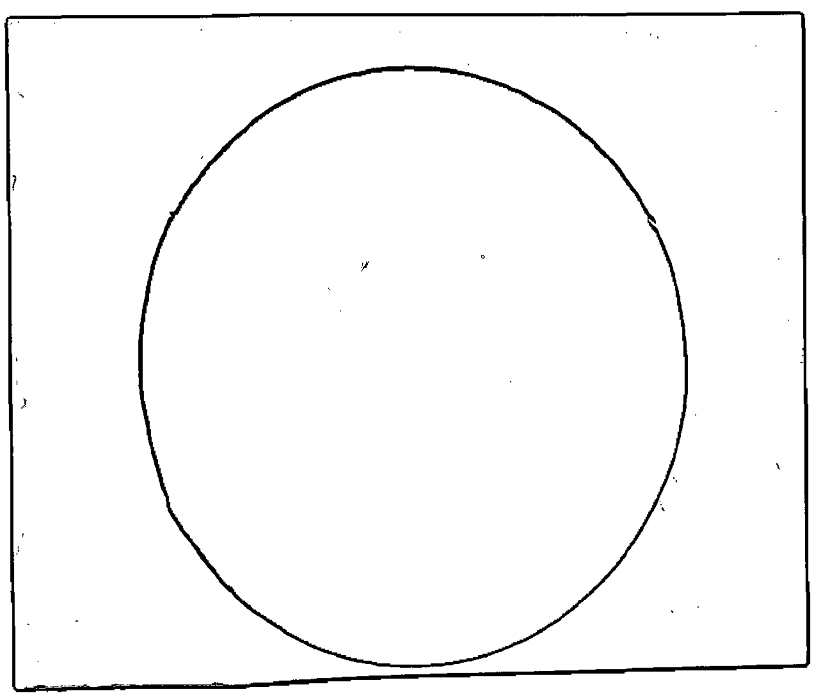


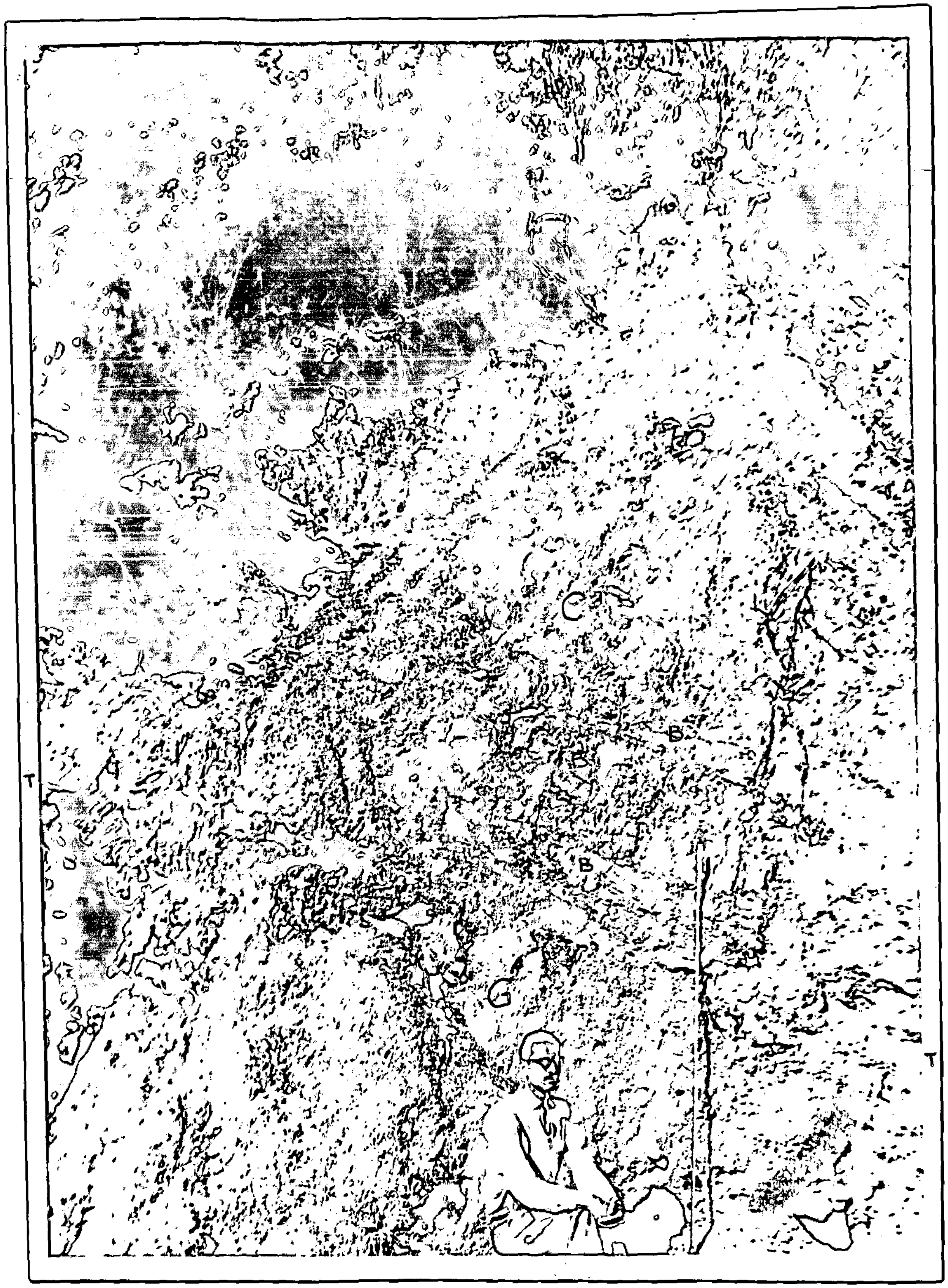






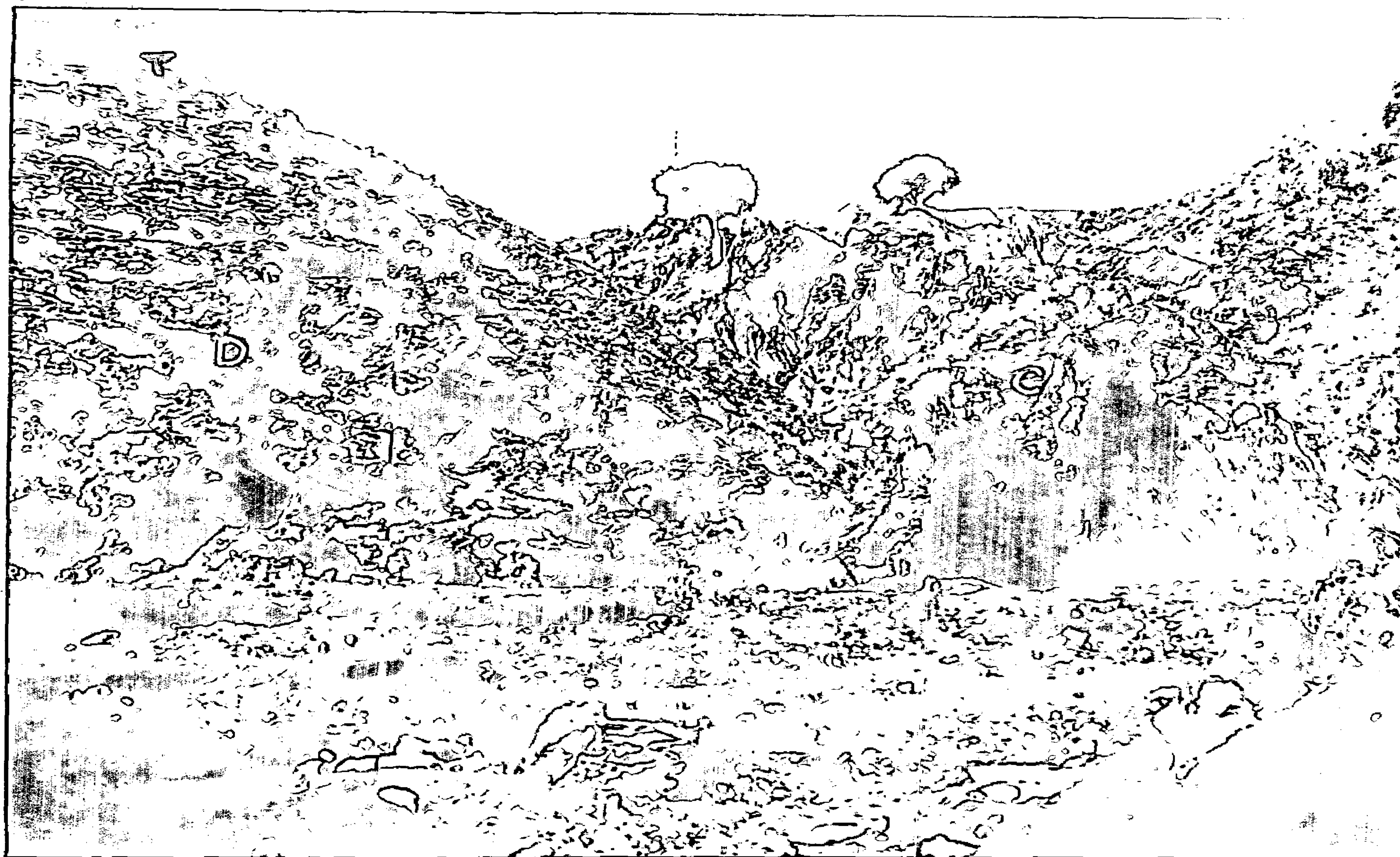






T
A
B
C
G
T

FRONTISPIECE



Photograph showing the general view of the thrusted contact of Chandpur phyllites over the Dun gravels (T—T) at exposure No.[illegible] near Rajpur. The left slope consists of Dun gravels (D) with one or two feet thick crushed or powdery Chandpur phyllites (C) showing foliation and puckerings.

Locality: Below the Rajpur Toll on the Rajpur-Mussoorie rule track.