GEOLOGY OF NORTHERN AND EASTERN PARTS OF MUSSOORIE WITH

A NOTE ON THE SEISMICITY OF THE AREA

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

SUBMITTED BY
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C E R T I F I C A T E

Certified that the dissertation entitled GEOLOGY OF NORTHERN AND EASTERN PARTS OF MUSSOORIE WITH A NOTE ON THE SEISMICITY OF THE AREA being submitted by Sri BHUPENDRA SINGH in part 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.

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P R E F A C E

The dissertation presents a concise account of the field and laboratory investigations carried out during the session 1965-1966, on the Northern and Eastern parts of Mussoorie Hills. The work was done under a scheme jointly sponsored by the Department of Geology and Geophysics and the School of Research and Training in Earthquake Engineering with the object of evaluation of Geology and the seismicity of the Dehra Dun-Mussoorie region. The entire area was divided into four sectors and each sector was assigned separately to the present writer and colleagues Sri Gopalji Singh, Sri S.M. Salapaka and Sri P.M. Jalote.

It has been endeavoured to include all the important and useful informations available but their presentation is subjected to the limitations set by time. It is hoped that further investigations in the area will unravel the unsolved complexities.

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

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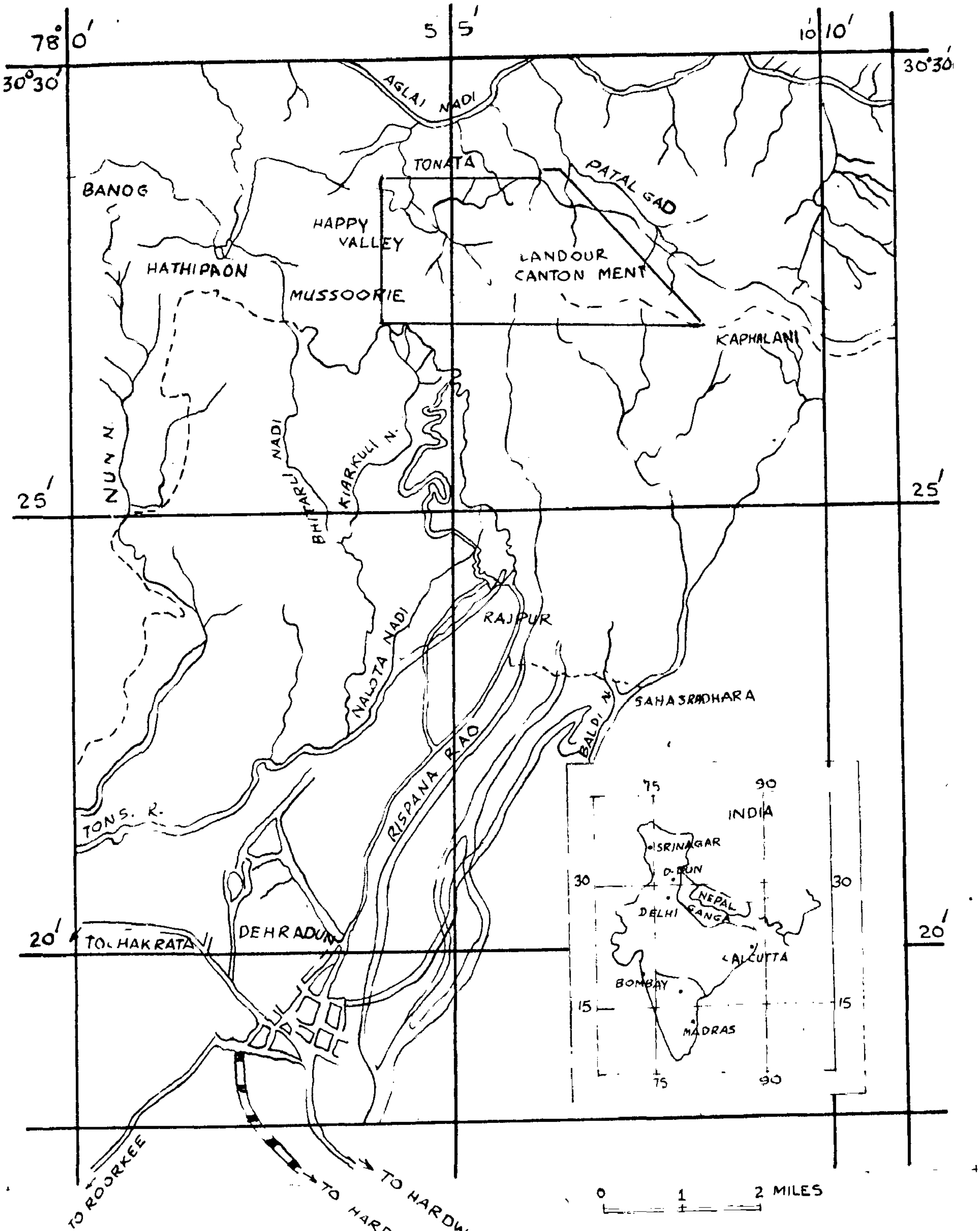
Fig 2

LOCATION MAP



AREA INVESTIGATED

ABSTRACT

The area, comprising of Northern and Eastern parts of Mussoorie is represented by the formations of the Upper Krol series and the Tal series. Upper Krols are mainly exposed on the Eastern most and Western side of the allotted area, structurally it represents the core of the main Mussoorie syncline running NW-SE.

Upper Krols are generally limestones, intercalated with shales in various colours in the lower part and porcellaneous limestones in the upper parts. The porcellaneous limestone is generally microcrystalline and of cream colour and probably corresponds to the Krol E stage of the type area. The intercalated grey coloured limestone is fine grained to medium grained and often calcite and aragonite have formed in the cavities. These limestones show various types of deformations on the Kempty fall Road. The limestones dolomitic in composition have formed by replacement of lime-rocks. These are generally devoid of fossils though some doubtful algal structures were witnessed.

Overlying the Krols is the Tal series. The Tal series is represented by shales of various varieties e.g. calcareous, carbonaceous, siliceous and arenaceous in the lower parts. The lower Tals grade upward into red siltstones and quartzites of shallow water origin representing Upper Tals. In

Upper Tals sometimes are found vein like masses of grey-wacke rock, showing cross-cutting relation with the host siltstone rock. This gray-wacke contains fragments of various other rock types found in the area.

Mineralization in the area is represented by barite and pyrite. Occurrence of barite in veins in the Upper Krol limestones is discovered for the first time from this area. One major barite vein runs parallel to a fault plane running roughly NW-SE.

Pyrite from Upper Krols and Tals occuring as thin veins and lenses were studied in detail under the ore microscope and certain textures of typical hydrothermal origin were observed. Based on these studies hydrothermal activity in the area is postulated.

Krol-Tal contact is faulted in Company Khad, Tehri Road. This contact is generally regarded as disconformable, but the investigations in the present area showed the possibilities of its being a tectonic contact.

Landslides in the area are frequent and generally confined to shales of the Lower Tal. This phenomenon in this part is generally governed by the slopes, structure, climate and the rock compositon.

The area is seismic and the minor shocks are frequent. Collapse of possible under ground caves may be a cause to these frequent minor shocks.

CONTENTS

CHAPTER I

INTRODUCTION

Location :

The area under investigation lies mainly North and East of Mussoorie. The region covers an area of nearly 12 Sq. miles lying between the parallels of 30° 27' 0" and 30° 29' 06" North and the meridians 78° 2' 33" and 78° 9' 27" East, around Mussoorie. The area is depicted on the Topo sheet 53 $\frac{J}{3}$ and is situated at a height of 6400' above mean sea level. West-easterly a strech from Library on The Mall Road to Masrana on the Tehri Road (Map 1) fixes the Southern limit of the area. On the Northern side it extends upto Ledar village. Mussoorie is an important hill station of Uttar Pradesh and is connected with on all weather metalled road to Dehra Dun.

Climate :

The area enjoys a pleasant climate during Summer (April to July) and severe cold during winter (November to March). The average temperature during summers is around 25° C and during winters is about - 5°C. Snow falls during winter season are common. The average annual rainfall is about 220 cms (nearly 90") to 300 cms (nearly 120") and mostly confined between July and September. Often preceding or succeeding the rains the atmosphere becomes cloudy, causing a poor visibility, sometimes as low as three meters.

Topography:

The area is a rugged tract, made up entirely of mountains. These mountains have their tops in the South of the area and slopes steeply North-wards and South-wards. This Southern margin of the area is made up of three main hills. The topography is mainly governed by the structure and the rock composition in this region.

(i) If a traverse from West to East be made it will be found that the hill first encountered trends roughly N-S and has its highest point Gun hill (7029').

(ii) East-wards next hill having its highest point Lal Tibba (7459') has a regional trend of NW-SE. In this hill the slope of the NE side continues for greater depth (vertical fall from top 2000') while slope on the SW side dies relatively soon.

(iii) Further East-ward the hill with Deo Ki Dhang (Deo Ka Tibba 7699') as the highest point trends partly

E-W and partly NE-SW.

(iv) There are no long streches of level ground except those of man made playing ground and few agricultural fields. There are number of culminating points, from which main ridges and side spurs with intervening streams, streamlets, and water courses grow from one another like the branches of a tree. The streams are in youthful stage of their development and so no terrace deposits of any significant thickness have formed.

(v) Regions made up of Krol D and E limestones have a very undulating topography and the escarpments are very common. The slopes are generally bare, but sometimes small bushes scattered here and there can be seen. These dolomitic limestone bodies on weathering stand out very prominently giving rise to a rugged scenery and barren cliffs. The weathered rock surfaces look like elephant skin when viewed from a distance. Small caves somethimes are also present.

The shales having a thin soil cover form gently undulating hills dotted with forests and agricultural lands Quartzites form very steep slopes, sometimes even vertical and rising many meters vertically. It is generally in quartzites that the highest points of the area are located (Map 1 and 3).

Geomorphology:

Under the influence of various agents of denudation, such as heavy rains, snowfalls, wide range of temperature difference during day and night time, the rock minerals are either disintegrated or decomposed.

(i) The limestones are easily soluble in water and thus taken into solution. The steep slopes, hand in hand, with heavy rainfalls in jointed limestone masses cause rapid denudation and quick removal of the material, leaving behind bare mountain hills and slopes. Camel's Back Hill forms a typical landscape in limestone. The collapse of solution cavities formed along the joint planes ultimately result in the origin of caves (Fig. 5).

(ii) Landscape in the shales, which occupies the Eastern side of the area is characterized by less undulating hills. These shales are well bedded and at some places carbonaceous also, thus very susceptible to weathering agencies. The water absorbing character of these shales aided by vegetation results in frequent landslides on Tehri Road, particularly where these are more arenaceous and carbonaceous. A heavy load of rock debris of shales is brought by the perennial streams.

(iv) Quartzites are generally less hospitable to the weathering agencies, except where they are heavily jointed. Big blocks of various cubic feet in volume, with sharp straight edges comes with the stream load.

Valleys:

Both erosional and tectonic valleys are present in the area.

(i) A readily recognizable tectonic valley is the Company Khud which follows the strike of a recent fault. Khaksiana Khala passing through Toneta Forest, in the vicinity of the Krol-Tal contact+

+See Chapter III

runs parallel to it. This Khaksiana Khala is a longitudinal stream flowing North-Westerly parallel to the mountain strike (Map 2).

Patal Gad, a Khala on the North-East limb of the major syncline also runs North-westerly, in the vicinity of the Krol-Tal contact. Both Patal Gad and Khaksiána Khala meets North-ward in to Aglar Nadi.

(ii) With the exception of above mentioned valleys there are number of erosional valleys. The curve of erosion of these valleys, which are in the youthful stage of their development are most irregular and abounds in many equalities. These erosional valleys for a greater part of their course are longitudinal, but sometimes adopt transverse courses also.

Geomorphologically the area is in the initial stage of its development. Denudation is extensive and the streams are deepening their courses with a V-shaped valley.

Drainage Pattern:

There are two main water divides (i) running East-West and (ii) subsidiary water divide running NE-SSW. Number of streams and innumerable rills, present a very typical study of geomorphology. Most of the tributries form a NE-SW pattern i.e. perpendicular to the trend of the synclinal axis. The number of streams emerging from the axial part are comparatively few. It is the axial part of the river, in the vicinity of which two sets of streams with initial down streams due NE and SW originate. A combined picture of all these streams will show a Sub-Trellis Drainage Pattern, Characteristic of strongly folded and highly dipping rocks (~~sheet~~ Map 2.).

Springs:

Springs in the area are very few and mainly confined to shales on the Landour Khattapani foot-track. Small intermittent streams occur along hill sides where small nalas have cut gullies below ground water level. These streams show fluctuation with the rain-fall. Carbonaceous beds on Tehri Road are generally moist and at places water seeps out of the...

Vegetation:

The flora is characteristic of cold humid hilly type of vegetation. There are varieties of plants. The nature of the flora is marked by the altitude and the lithological differences of the surface rocks. The following are the main type of plants:

Deodar (Pinus longifdia and Cedrus deodara) Maples (Acer pictum and Acar oblongum) Birch (Betula acaminata), Banj (Quercus incana), Karshu (Quercus Semicarpifolia) tilonj (Quercus dilatata), riunj (Quercus lanuginosa) and Rhododendron.

Common fruit trees are : Chestnut, Kaphal, cherry, Medlar, apples, Peaches, plum, fig, apricot, and Blackberry. Flowers are also commonly sown in the gardens and private bunglows.

Hardly 5% of the area forms cultivated lands. On the hill slopes and occassionally on the limited flat floor of the valleys, terrace farming is done. Vegetables, potato and maize are the common crops. The cultivated fields are mainly confined to shales.

The lithological contrast has controlled the growth and density of plants in a particular area. The slopes on the shales are clothed with a thick dense growth of forest vegetation, while the quartzites and limestones (except those of Camel's back Road and Public Garden Road) are too preciptious and bare (Fig 26 and 27). The scanty vegetation in limestones is due less to the absence of soil than to the lack of water, Rich as is the rainfall the water quickely disappears either along the slopes in the nalas or into the rock mass via joints and fissures, where it transfers its circulation and a part of its geologic action to the interior of the mountain mass.

Quartzites ~~is~~ are devoid of any soil cover and are very scarcely vegetated.

Altitude plays an important role in governing the kind of plants. At higher altitudes within the shales Pine trees have grown, while at lower levels Maples (Acer pictum) and Banj (Quercus incana) are the common variety. Shales weather easily forming a soil cover and have high water retaining capacity thus supporting luxuriant growth of vegetation.

<u>Present Work:</u>

The area was visited by the writer for the first time during the month of June, 1965. The field work was done till the burst of the monsoon which made any further work impossible. The writer visited the area again in October, 1965 to complete the remaining part of the work and for confirmation and correction of the details. The present study was made to map the different lithological units and the structure with a view to assess the geology and seismicity of the area.

The survey map of the region is available on a scale of 1" = 1 mile (Sheet No. 53 $\frac{J}{3}$). A part of the area on a scale 8" = 1 mile is also present in Guide map of Mussoorie and Landour. Apart from these two sheets mapping of eastern parts was done on 6.5" = 1 mile (enlarged by epidioscope from 1" sheet). The details on the map were filled by traversing along the nala cuttings, roads and foot tracks. Even on these large scale maps it was not possible to show the different rock types of a single stratigraphic unit. Sections and diagrams of various important lithological and structural features were prepared.

The main formations mapped are the parts of the Upper Krol series and the Tal series. The Upper Tals are mainly limestones, corresponding to Krol D and E stages of the type area. But in the field it was not possible to delineate between these two stages and so both were mapped as a single unit.

Questionnaire forms related to the periodicity and magnitude of the tremors were filled with enquiries made from the local people.

More than 100 representative specimens of various rock types were collected and out of these 30 specimens were examined in thin section. Limestones of the Upper Krol and the Tal series were analysed by Edta Titration method. A few pyrite samples collected from the area were studied under ore microscope. The entire geology and the drainage pattern of the area were transferred on a map of scale 4"= 1 mile.

The available literature on the geology of the area were consulted and an attempt has been made to discuss the various geological problems. The dissertation represents an account of the studies carried out in the field and laboratory with necessary illustrations.

CHAPTER II

PREVIOUS WORK AND REGIONAL GEOLOGY

As mentioned earlier the area is mainly composed of the Upper Krol series and the Tal series. Where-ever these formations have been described by previous workers little mention has been made about the formations of this area. It would be evident from a following brief review of the previous work carried out on these formations. This has greatly helped to understand the regional geological set up and to correlate the formations of the present area.

The name Krol, derived from Krol hills near Solon (Simla), was given by Medlicott (1864) to rock formations composed of limestones and quartzitic sandstones. He mainly worked between the Ravi and Ganges and classified the formations into two broad groups as follows:-

TABLE 1

Sub Himalayan Series (Siwaliks)

Himalayan Series	(Unmetamorphics	(a) Krols
		(b) Infra-Krols
		(c) Blainis
		(d) Infra-Blainis
	(Metamorphics	

Oldham (1883-1888) based on his work in Simla and Chakrata area suggested the Blainis to be of glacial origin and assigned them Upper Paleozoic age.

Middlemiss (1910, 1885) worked in Tehri Garhwal and Hazara area. He described an elevation difference between Dehra Dun and Mussoorie as a result of the Kangra Earthquake.

Holland (1908) supported Oldham for the glacial origin of the Blainis of Simla area but assigned them to the Purana group. Dass Gupta (1915-1916) worked on the age and correlation of the rock types in Simla area.

The first substantial work on the Krols from the Simla hills was carried out by Pilgrim and West (1925). They suggested that series of thrusts have brought rocks of different degrees of metamorphism to lie in abnormal juxtaposition and advocated upper carboniferous age for the Blainis. They gave the following succession in their area.

TABLE 2

Lower Miocene	–	Dagshai Series
Middle Eocene to Upper Oligocene	–	Subathu Series
?	–	Krol Series
		(Krol Sandstone
Lower Gondwana	–	(Infra Krol beds
		(Blainis Limestone

Contd ...

Lower Paleozoic	-	Simla Series (Infra Blainis)
Purana	-	Jaunsar Series
Purana	-	Chail Series
Archean	-	Jutogh Series
Uncertain ?	-	Shali Shales

But the sequence of Jutogh, Chail, Jaunsar and Simla Series was considered as follows:-

Jutogh Series

——— Jutogh Thrust.

Chail Series

——— Chail Thrust.

Jaunsar Series

——— Jaunsar Thrust.

Autochothonous sequence of Simla slates to Krol rocks.

Pilgrim and West (1928) suggested tha Krol series to be a nappe enclosed by two thrust planes namely the Krol thrust and the Giri Thrust (Fig 3). The Krol series structurally made up of two inverted synclines which upwards grades into one broader syncline composed of the Tal series. In a normal succession the Krol series overlies the Blainis series. As the latter was regarded to be upper conboniferous, in age the Krol series was assigned the age ranging from Permian to Triassic.

Auden (1934-1942) presented a detailed account on the Krol Belt in Simla and Garhwal regions. He described the Krol nappe in Garhwal area to be enclosed between the Krol Thrust and the Garhwal Thrust (Fig. 4).

The following table represents the stratigraphic succession in Dehra Dun - Mussoorie region as suggested by Auden.

TABLE 3 - STRATIGRAPHIC SUCCESSION IN DEHRA DUN-MUSSOORIE (AFTER AUDEN)

KROL NAPPE	Tal Series	(Upper Tal quartzites (Lower Tal shales and slates
	Krol Series (Permo-carboniferous)	(Upper Krol Limestone (Krol Red shales (Lower Krol Limestone
		(Infra Krol slates
	Blaini Series (Upper carboniferous)	(Upper Blaini boulder beds and Limestones (Blaini slates (Lower Blaini boulder bed
	------------- Unconformity -------------	
	Jaunsar Series (Devonian and Silurian ?)	(Nagthat Quartzites (Chandpur slates (Schistose phyllites and quartzites
	------------- Krol Thrust -------------	
	Lower and Middle Siwalik, (Autochthonous with minor Thrust)	

In the type area he divided the Krol Series into five sub-divisions.

<u>Krol E</u> Massive cream coloured limestone, calcareous sandstone and brown shales.

<u>Krol D</u> Cherty limestones, dark limestone, Bleached shales and quartzites.

<u>Krol C</u> Massive crystalline limestone often sulphurous.

<u>Krol B</u> Red and green shales with dolomitic limestone.

<u>Krol A</u> Thin bedded blue limestone, shaly limestone, Calcareous and carbonaceous shales.

Auden (1937) gave the following classifications of the Krol Belt based on topography and structure.

<u>Topographical zones</u> :

1. Inner lower Siwalik range and Dun.
2. Outer lower Himalayas, with an intricate net work of streams and rivers.
3. Main Himalayan Range with its deep scarp slopes facing towards the plains and gentle dip slopes facing Tibet.
4. High peaks North of the main Himalayan Ranges with irregular disposition.

<u>Tectonic Divisions of Garhwal Himalayas</u>

1. <u>Autochthonous units</u> : It is a folded belt

and lies well within the Himalayas. The sub-stratum is of Simla slates series over which lies the Nummulitics, Murrees and Siwaliks. The most important thrust is the familiar Main Boundry fault.

2. The Krol Nappe :- Thrusts on the authochthonous unit and the Nummulitics and Dagshai.

3. The Garhwal Nappe :- Thrusts upon the Krol nappe the main Garhwal Thrust may have its roots in the main Himalayan range. The rocks of the Krol nappe completely surround the metamorphic rocks of the suprincumbent nappe.

4. The Great Himalayan Range :- of phyllites and schists with a distinct group of para-gneisses and intrusive granites.

5. The Tibetan zone :- It contains fossiliferous sediments ranging in age from Cambrian to Cretaceous. The relationship between (4) and (5) is still obscure.

According to Auden some of the movements along the Krol Thrust are more recent than Helventian. It is because of the over-riding of the Krol Belt on Nahans and even upper Siwalik conglomerates. These movements were considered to be of lower Pleistocene age or even later. Concluding, Auden observed

"There has been more than one period of movement, perhaps during the Helvetian and the later movements during the Siwaliks and the post Siwaliks". In his opinion folding in the Krol and the Garhwal nappe has resulted because of the resistance offered by the floor upon which the movement took place.

Auden (1942a) while working for the tunnel alignment for Jamuna Hydel Scheme maintained the glacial origin for the Blainis and the Mahdhalis were inferred older than the Blainis.

Auden (1942b) investigated the cause of the Kalighad land-slip on Dehra Dun-Mussoorie Road and felt that no protective measures would be useful.

Auden (1942c) submitted a "Report on the marble formations around Mussoorie as a source of Chemical lime for the manufacture of calcium carbide".

Ravi Prakash (1958) published a "Note on the Chemical analysis" of marble of Bhatta near Mussoorie.

Mehta and Narayan Murthy (1959) gave an account of the High Grade Limestone deposits of Mussoorie-Dehra Dun area.

Krishnan and Swaminatha (1959) referred to the earlier work of Bolieau (1948-1952). Stratigraphic and tectonic problems in the Sub-Himalayas were discussed and a new interpretation of the relationships and correlation was put forward. The Khaira quartzites are correlated with Tanakki quartzites of Hazara which occur below the Sirban limestone, and with the Blaini boulder bed Bolieau regarded the Blainis to be equivalent of the Kaimur series of the Vindhyans. With this basic idea he correlated the Sub-Himalayan formations with that of Peninsula.

PART OF BOILEAU'S TENTATIVE CORRELATION

TABLE No. 4

Suggested Age	Peninsula India	Simla-Garhwal
1	2	3
Carboniferous		Tal Series Upper Krols
?	Bhander	Krol Red shales
?	Rewah	Lower Krol
Ordovician	Kaimur	Blainis (? Mandhalis)
Upper Cambrian	-	-
Middle Cambrian	Rohtas stage	-
..	Tirohan movements	-
-	Kheinjua stage	-
..	Porcellanite stage	..

Contd ----

1	2	3
	Malani Igneous activity	Deoban limestone
Lower cambrian	Basal stage	Nagthat and
	Erinpura orogeny	Bhim Tal
		Volcanices
Precambrian	Ajabgarh	Chandpur
	Alwar	Chamoli
	Raialo	Tejam

Mehta (1962) described Krol Thrust by the mechanism of gravitational gliding. He postulated that the contacts between Mandhalies, Chandpurs and Nagthats are thrusts (Table No. 7).

Krishnaswamy (1962) while discussing the tectonics of Kangra concluded that the Satlitta thrust may be the possible cause of the Kangra earthquake of 1905.

Jalote (1962) established subrecent-recent movements along the Satlitta Thrust in the vicinity of Beas Dam site.

Raina (1963) has correlated the Mandhalis with Blainis in the Simla area.

Ahmad (1963a) correlated glaciated deposits of the Himalayan region - Blaini boulder beds with the Peninsular Talchir beds. He suggested four periods of refrigeration in Himalayas.

Ahmad (1963b) published "Epeirogenic Activity in Himalayan Region" in which attention was focussed on the nature of the perched river terraces. These terraces are not even mildly tilted, and it is thought that these have formed by a vertical uplift which might have been going on since the Pleistocene period. Thus the idea of strong orogenic activity in the region was proposed.

Hukku and Akhtar (1963) worked on the structure and tectonics of the Krol Thrust in the vicinity of Sunder Nagar-Sutlej Tunnel, Mandi district. Some tear faults and drag folds in the under-thrust and overthrust sheets are postulated.

Ranga Rao (1963) has described the probability of the Krol Belt as autochthonous unit. This conclusion is based on the fact that in the upper reaches of the Bhagirthi-Tons area, Deoban limestone is found in normal stratigraphic contact with Simla slates. He suggested five cycles of sedimentation in the area.

Srivastava (1963a) reported the presence of a lamellibranch fossil, Posidonia cf Oranti quenst from Lower Tal Carbonaceous shales of Mussoorie.

Srivastava(1963b) described some semi-circular to partly rounded crustacean forms. He recognised the species as Estheria marginata and cited the possibility that Lower Tal beds may range from jurassic to lower cretaceous.

Wadia and West (1964) based on their earlier works discussed the structure of Himalayas. They suggested four periods of orogeny in the Simla-Garhwal area.

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

REGIONAL GEOLOGY

The normal succession of the Krol nappe as proposed by Auden has been given earlier (Table 3), The nappe includes the Krol series together with the Blainis and Jaunsar formations below and the Tals above. The Krol andthe Tal outcrops of the Mussoorie syncline stretch from Mussoorie south-east-ward to the Huil river in Tehri Garhwal. This entire Krol nappe of the older stage overlies the younger Siwaliks. In order to understand the regional geology a short account of these stratigraphic units is being described.

Jaunsar Series:- Pilgrim and West applied the name Jaunsars for Conglomeratic phase underlying the Chails which have thrusted over it in the Simla area. Downward the Jaunsars are restricted by Simla slates. These unfossiliferous formations having an average thickness of 500 meters are assigned to later section of Purana (Devonian ?) by the later workers.

The Jaunsars of Garhwal are regarded as made up of three stages. The bottommost Mandhali stage is followed upward by the Chandpur series and the Nagthat series.

In Dehra Dun - Mussoorie area, the Jaunsar series is represented by two suites of rocks known as the Chandpur slates and the Nagthat quartzites. The chandpur stage comprises thin bedded alternations of quartzites and phyllites. They are associated with green chloritized tuffs which show polygonal jointing.

The Nagthats are represented by purple to green coloured sandstones, arkoses, quartzites, grits, conglomerates, clay slates and phyllites. In the eastern parts of Dehra Dun they are thrusted over Nummulitic and younger Tertiary beds. Both the Chandpurs and the Nagthats show a marked increase in metamorphism from South-west to North-east.

Blainis Series:- The series consists of Lower Blaini boulder beds succeeded upward by Blaini slates, Upper-Blainis boulder bed and limestone and Infra Krol slates. Auden (1934) traced the interrupted ribbons and patches of the Blaini stage south-east-ward across the Upper Jamuna in Dehra Dun district. Between Jamuna and Dehra Dun the Lower boulder bed has not been observed. It appears this formation is overlapped by the Upper Boulder beds and the limestones which unconformably overlie the Jaunsars.

Lithologically the boulder beds are represented by rounded, sub-rounded and angular boulders of varying sizes embedded in a clayey matrix. The boulders are mainly formed of slates, quartzites, shales and limestones. The boulder bed is usually 3 meters to 30 meters thick and the average thickness of the limestone is 5 to 6 meters. The thickness of Blainis slates in Dehra Dun may be anything upto about 230 meters. These formations have been regarded by many workers to be of glacial origin. There is usually a tillite facies and a lime-slate facies.

The Infra-Krol (thickness 150 meters) is the youngest member of the Blaini-s series and is made up of a thick series of carbonaceous shaly slates alternating with limestone bands. These rocks show different degrees of metamorphism at different places, from shales to well cleared slates and schistose rocks. Close folding and small scale faulting are common. A few micro-fossils believed to be of Lower ondwana affinities have been found in these formations.

Pascoe (1959) has classified the Blainis series into two stages-the Blainistage and the Infra Krol stage. The thickness of the Blaini stage is variable within a wide range and the sequence is frequently incomplete.

<u>Krol Series</u>:- The succeeding series lying over the Infra-krols consists of a thick group of massive blue limestones and shales and is known as Krol series. It is overlain by the Tals. The lithology and nature of these formations

indicate that these are of shallow water and epicontinental origin. Auden (1963) established the following sequence in Solon and Tons River areas.

TABLE - 5 (AFTER AUDEN)

	Solon area			Tons river area
Krol Series	(Upper Krol (Limestones	(Krol E (Krol D (Krol C	Krol Series	(Upper Krol (Limestone
	(Red shales	(Krol B)		(Red shales
	(Lower Krol (Limestone	(Krol A)		(Lower Krol (Limestones
	(Krol sandstone	(Local)		

The Krol series is unfossiliferous and it is difficult to account for the conspicuous absence of fossils, though the conditions for their growth and preservation were quite favourable. Mittal and Chaturvedi (1963) have reported the possible algal structure in upper Krol limestone.

The Krol series shows a normal contact with underlying Upper Carboniferous Blaini series, and hence these have been assigned an age from Permian to Triassic. The upper limit of series has been fixed Triassic because, the Lower Krol limestone has many features in common with the Infra-Triassic Limestones of Kashmir.

Lower Krol Limestone (Krol A)

These are thin bedded, hard, flaggy limestone, always high in magnesia, and often approaching dolomitic in composition. It shows alternations of shaly limestone and a calcareous shales or slates. These alternations are either in parallel layers or consists of lenticular pillows of limestone surrounded by calcareous shales. The thickness of this stage varies from 90 meters to 230 meter.

Krol Red Shales (Krol B)

This stage comprises mainly of variegated purple or red shales with thin laminations, streaks, blotches and intercalation of green shales, There are also thin bands of dolomitic cherty limestone. These formations of red shales at times pinches out a-long the lower and upper Krol contacts. The maximum thickness is upto 90 meters.

Upper Krol Limestones (Krol C, D and E)

Krol C are mainly limestones, pure calcareous and magnesian or dolomitic, with intercalations of shale. Bedding planes are almost absent . When freshly broken it gives sulphurous smell. The pure massive blue coloured limestone grades into white coloured bands locally called marble. The pure limestone is quarried for various purposes.

The stage D comprises alternations of cherty limestone and black, red, green and orange shales. Their minimum thickness is about 200 meters. Conglomerates with pebbles of vein quartz and chert are rare, but some of the limestones show penecontemporaneous brecciation. In several localities pockets of gypsum have been noted as replacing the limestone. Patches of carbonaceous limestone are also present in the vicinity of the contact of stages C and D.

In the normal succession Krol E overlies Krol D stage. The Krol E are well bedded microcrystalline limestones with grey to cream-white banding. They attain a minimum thickness of about 170 meters. The pale coloured limestone has a porcellaneous appearance on fresh surface and thin veins of calcite stands on the surface even after weathering. At places it grades into arenaceous limestone. Ripple marks are seldom present. On weathering it forms rugged topography popularly known as elephant skin weathering.

In Dehra Dun Mussoorie area the Krol D and E stages are difficult to differentiate in the field and have been treated in present work as a single-unit.

Tal Series:

The Tals were originally discovered by Medlicott (1864) in the Tal valley east of Ganges. This series is exposed in two synclines in the Mussoorie-Garhwal area surrounded by the Krols. These formations have been divided into two groups , Upper Tals and Lower Tals (Auden 1934). The Lower Tals are soft dark shales graywackes and carbonaceous shales passing laterally into slates. The slates resemble those of Infra-Krol slates, but are more massive and associated with graywackes. Srivastava (1963) has reported the occurrence of phosphatic nodules from Lower Tals of Mussoorie.

Tewari (1963) also found such nodules from Garhwal area. From the fossil evidence Srivastava (1963) suggested fluvodeltaic conditions of deposition for the Lower Tals and proposed an age range from jurassic to Lower Cretaceous.

The Upper Tals are mainly pebbly quartzites with shallow water markings like ripple marks. Some intercalations of micaceous shales and some sandy limestone are always present. The Tal limestone in Garhwal shows broken shells in a few places but are unidentifiable. The thickness of Upper Tals are about 650 meters

CHAPTER III

GEOLOGICAL SET UP AND STRUCTURE OF THE AREA

Based on the earlier works and on the field and Laboratory investigations carried out by the present worker the following stratigraphical succession has been established in the area.

TABLE No. 6

Age	Designation		Lithology	Correlation with Simla	Average Thickness
Triassic Cretaceous	Tal Series	Upper Tals	Dark Grey and red limestones, Black and red siltstone, Pebbly and arkosic quartzites, Quartzites with thin micaceous bands.	Upper Tals	90 meters (300 feet)
			CONTACT GRADATIONAL		
		Lower Tals	Micaceous shales grading upwards into quartzites, Well bedded carbonaceous shales, Black Cherty bands Calcareous shales	Lower Tals	600 meters (2000 feet

Contd ..

Age	Designation	Litholoty	Correlation with Simla	Average Thickness
		------------- DISCONFORMABLE ? AND FAULTED CONTACT ------		
Permian (Triassic)	Upper Krol Limestone (Dolomitic)	Massive porcellaneous grey to cream coloured dolomitic limestones.	Krol E	--
		Grey massive dolomitic limestones with intercalations of the thin bedded shales (D and E limestones)	Krol D	--
		Krol 'C' Limestone	Krol C	

A concise account of the field character and probable age of various formations met in the area is being given in the following paragraphs.

UPPER KROL LIMESTONES (D and E)

The upper Krol limestones are represented by the Krol D and E stages of the type area. In the present work these have been considered together as it was not possible to distinguish and demarcate these limestones. These limestones are mainly exposed on the eastern and Western parts of the area representing the two limbs of the Mussoorie Syncline. The regional strika is NW-SE with an average dip of 30° to 35°.

In the lower part the limestones are dolomitic massive and grey coloured. On weathering they show typical elephant skin weathering giving rise to a rugged scenery and barren cliffs. Where limestones are well jointed caves have formed (Fig.5) Complex folding at places is very common.

Calcite sometimes has formed in small cavities. Thin coating of aragonite has formed from the percolating water solutions along the joint planes.

Upwards the limestones become more and more massive, cherty and porcellaneous in appearance. At the contact with the Lower Tal Series the bedding planes are practically obliterated. The intercalation of shales are not observed in the upper parts. Barite and pyrite veins are found in these limestones near the Krol-Tal contact.

With the exception of probable algal structure (Fig 38) the limestones are devoid of fossils and so no definite age can be assigned. Previous workers on the basis of its conformable contact with underlying carboniferous Blain Series have suggested an age of Permian (-Triassic ?).

TAL SERIES

Upper Krol limestones are overlain by the Tal series. The Krol Tal contact seems to be an erosional plane representing a probable disconformity. This contact is faulted in the Landour area. Possibility of a thrusted Krol-Tal contact is discussed later (see structure). On the basis of lithological characters this series is divided into two stages.

LOWER TALS:

The Lower Tals are represented by shales of varying composition such as calcareous, cherty, carbonaceous, micaceous and arenaceous. These shales show overturned folds in the vicinity of the Krol-Tal contact, where it is very much crushed. Minor local thrusts and small faults are common. At Ledar village slaty cleavage sometimes has developed in the folded shales (Fig 11).

The Lower Tal shales which are calcareous in the lower parts e.g. in the Landour market area gradually becomes cherty and carbonaceous, and ultimately grades into arenaceous variety. This gradation can be very well seen along Tehri Road. Small lensoid bodies of pyrite have developed along the bedding planes in Company Khad. On the NE limb small cubes of pyrite disseminated in carbonaceous shales can be located at few places (near Tibri).

Fossils are generally absent but some unidentifiable fragmentry forms were found in the calcareous and cherty shales near the Masrana village.

Srivastava (1963) has described _Estheria marginata_ from the carbonaceous shales and thus assigned a probable age range from jurassic to Lower cretaceous.

UPPER TALS:

The Lower Tals gradually passes upwards into more arenaceous upper Tals, thus showing a gradational contact. They are found in nearly a 1 mile long tract along Tehri Road from Ashton Court and Cottage to Tibri. Upper Tals from the core of the Mussoorie syncline. The regional strike is NW and SE and dip 25° due NE. East of Batagad the direction of dip becomes reverse and beds start dipping due SW. Minor faults with a general trend NE-SW are common. Sometimes drag folds have produced due to local thrusting as near Batagad (Fig 14). Upper Tal formations are generally well jointed. The quartzites are more resistant to weathering and thus stand in elevated ridges with almost vertical slopes.

Upper Tals which now occupy most of the highest points and serve as the water divide between two systems of streams running South to North and North to South. (Map. 2).

The bedding planes in quartzites are quite regular and sharp. Individual beds range in thickness from tens of cms to hundred of cms. At places these are interbedded with thin micaceous laminae. Sometimes quartzites become gritty and even pebbly showing repeated graded bedding (Fig 15).

Red siltstone is found in alternating bedding units with white quartzites and the individual bedding units range in thickness from few meters (at Batagad) to several tens of meters. The red colour of the siltstone sometimes grades into yellow. These have developed distinct fissility planes parallel to the bedding. Pockets of aragonite are found within red siltstone 1/2 mile NE of Childer's cottage on mule track going to Leadar village.

The red siltstones grades into red limestone. Lensoid bodies of about 1 meter thickness are enclosed within siltstones. Fragments of white limestones are found within this red variety.

An interesting exposure of a dirty greenish grey rock showing cavities on the surface was located on Tehri Road just few meters East of Ashton Court and Cottage on Tehri Road. It shows cross-cutting relation with the host red siltstone, and is discussed in the chapter on "Petrography".

STRUCTURE

Auden (1934, 39) gave a detailed account on the Krol belt in Simla and Garhwal region. According to Auden the Mussoorie area is occupied by a large syncline of Krol nappe rocks. The rocks of Krol nappe are again overlain by klippes of more metamorphosed Garhwal rocks brought in position by the Garhwal nappe. This Klippe is exposed in Banali area in Garhwal and is known as Banali window (Fig 4). Pilgrim and West (1928), who worked together in Simla area suggested that the Krol series is a nappe enclosed by two thrust planes the Krol Thrust and the Giri Thrust (Fig 3).

The present area is located on the central part of the Mussoorie syncline. Below is given an account of various structures found in this area.

Planer Structure

Bedding planes in Krol D and E limestones often contain intercalations of thinly bedded shales in the lower parts. The bedding planes in limestones are not well preserved particularly in the upper parts. Two sets of joint planes running NE-SW and NW-SE are common. Spacing of joint planes varies from spot to spot but as a generalization they are closely spaced in limestones intercalated with shales. Caves have formed along the joint planes (Fig 5).

Lower Tal shales are well bedded in the lower parts and individual beds are 3 cms to 6 cms thick. Thickness of beds go on increasing upwards. Bedding planes show variable dips on the Krol-Tal contact on SW limb. The shales show symmetrical folds with the development of slaty cleavage (Fig 12). Shales near the contact are very closely jointed and even shows the effect of crushing. Two sets of joints running NW-SE and NE-SW are common. Bedding joints were also observed. Upper Tal quartzites and siltstones are interbedded and the thickness of individual beds is variable. Beds of quartzites are commonly 50 cms thick and sometimes contain thin laminae of micaceous material.

Folds:

Dip relations on regional scale show that the major fold in the area is a syncline, the axis of which runs NW-SE (Map. 3) and passes through Batagad. The limbs have an average dip of 25°–30° (Section along A B). The limbs of the Mussoorie syncline are folded into local anticlines and synclines with their axes parallel to the axis of major syncline. Such foldings are very prominent in the Krol D and E limestones exposed on the newly made Kempty Fall road. Incompetent nature of the intercalations of shales in limestones have given rise to folds of varied types (Fig 7, 8, 9, 10 and 33).

Lower Tal shale show both symmetrical and overturned type of folds (Fig 11, 12). Folds are not so much common in Lower Tals as they are in the under-lying Krol limestones. Folds in Upper Tals are rare. Minor drag folds have developed in the siltstone beds because of local small thrusts (Fig 14).

Faults:

In the Company Khal on Tehri Road the contact between the upper Krols and the Tals is effected by a recent fault. Here it strikes approximately in N-S direction (N170-N350) and Southwards takes a turn in SE direction. Lower Tal shales dips at 30° due N20E. There is a 15 cms thick zone of gouge along the fault plane (Fig 32). Along this fault plane runs a nala in which some pieces showing slicken sides can be seen. It is a normal fault having a throw of nearly 50 meters.

Local faults and thrusts are very common in Krol limestones (Fig 6) and Tals (Fig 11). The general trend of these faults is variable within NNW-SSE and NE-SW,

KROL-TAL CONTACT

In the present text Krol-Tal contact has been regarded as a disconformable contact, but in the area this contacts on the SW limb is faulted for a considerable distance. This Krol-Tal contact is usually very much disturbed. The shales in the vicinity of contact on both limbs are comparatively much faulted, folded and jointed. Looking at the different aspects of this contact plane and the regional structu-re it is possible that it is a tectonic contact. But any conclusion to this problem will require further work on the regional basis. The present studies are too limited to describe the entire Krol-Tal contact to be a thrusted contact, but the various evidences in its support, as available from the present field investigations are discussed below. The following field evidences suggest that the contact between the Krols and Tals is not a normal contact.

(i) If the pattern of outcrop of Lower Tal formations be studied on the map (3 and section along AB), it will be found that there are two major outcrops separated by an exposure made up of Krol D and E limestones. This intervening portion of limestone is not due to topography. The study of the contacts of these Tal formations brings to light some interesting features.

(a) Western outcrop (Castle Hill)

The contact plane show inward dips. The regional dip of this outcrop is generally small -15° due NE. There is sudden increase in the amount of dip at the eastern contact. The rocks at the contact are very much crushed and sometimes seepage of water also takes place.

(b) Eastern outcrop (Landour cantonment):

The regional dip here is about 25°. In the vicinity of the contact the shales have rolling dips. The shales at the contact are very much deformed and small overturned folds traversed by thrusts can be well seen on Tehri Road (Fig 11). Shales just near the contact on main Tehri Road is heavily crushed in a patch of nearly 15 meters running roughly E-W.

(ii) The major streams passing in the vicinity of the Krol-Tal contact on both limbs of the syncline runs very much parallel to these contacts. The streams which again are parallel to one another are the major streams in this area.

(iii) From the map pattern on a regional basis, the axis of the Tal synclinal mass appears to be non-coincident with the axis of the Mussoorie syncline.

(iv)Mineralization has taken place within limestones in the vicinity of the contact.

The above factors when combined together will site possibility of a Tectonic contact between Upper Krol limestones and Lower Tals.

This **thrusting** can be explained by the phenomenon of gravitational gliding. When the Krol nappe was still moving SW, the relative movement of the Tal series took place in NE direction. This movement which would have been governed by the forces of reaction from the Krol Thrust and the topography of that period resulted in the development of present Krol-Tal contact.

CHAPTER IV

PETROGRAPHY

A brief petrographical account of the study of various rock types has been presented in this chapter. Based on the field and laboratory investigations a note on the sedimentary history of the area has been added. In the end occurrence of barite and pyrite has been discussed under Mineralization.

UPPER KROL LIMESTONES (Krols D and E)

The upper Krol limestones are dolomitic in composition containing lenticular intercalations of shales.

(a) Dolomitic limestones (sp-k_6, W_1 To_5, B_5)

It is a consolidated grey coloured dolmitic limestone in which calcite and aragonite sometimes have crystallized in cavities. In the lowerpart the dolomitic limestones are medium to fine grained, massive and mostly grey coloured. Cracks and cavities are common in which aragonite and calcite have crystallized, the former often showing typical colloform structure. Some specimens show stromatolytic structure. In the upper parts the limestones show grey to cream colour and is of porcellaneous appearance. Some specimens show irregular, curved, rectangular fragments of grey limestone with white crystalline borders (sp B_5).

In thin section (slide AO_1), these are fine to medium grained with grain size ranging from .08 mm to 2 mm. The main constituent minerals are dolomite and calcite, both of which possess perfect rhombohedral cleavage. Calcite sometimes show pseudo-pleochroism and interference colours are usually of fifth order. Thin twin lamellae in dolomite show first order, interference colours. A few detrital quartz grains are observed at places. Secondary crystallization of the carbonate along fractures are seen in some sections.

The specimen having (sp K_6 slide K_6) stromatolytic structure shows dark and light coloured regular and irregular bands, the thickness of which varies from 2 millimeters to a fraction of a millimeter. The bands are arcuate and lobate (Fig 38). Some times the lobes are closed giving a concentric lamellar pattern.

Generally the centre of these structures are composed of crystalline calcite, which is fairly euhedral and coarse grained. The bands surrounding the core are composed of fine and fibrous aragonite, the fibers being oriented perpendicular to the bands. At places columnar aragonite is also seen. The growth of aragonite columns normal to the walls of the innermost bands have given rise to characteristic comb structure.

Mittal and Chaturvedi (1962) have reported similar structures from this area and suggested these to be possible algal structures. In their opinion the fine laminae of rectangular square-shaped or fibrous calcite arranged normal to the arcuate laminae may be indicative of possible cellular structure. They have identified these structures broadly as stromatolytic probably belonging to collenia. Such structures can also form by inorganic processes. Due to the lack of time, detailed work could not be done on these structures and it is difficult to give any definite conclusion on their origin.

A representative sample of the dolomitic limestone was analysed by Edta. Titration method. The results of this analysis are given below :

Constituents	Percentage
$CaCO_3$	52.8 %
$MgCO_3$	43.4 %
Fe_2O_3 and Al_2O_3	0.3 %
Residue insoluble in 50 % Hcl	3.5 %
	100.0

$$\frac{MgO}{CaO} = .699$$

(b) Shales (sp KC_2)

These shales are fine grained argillaceous rocks with distinct fissility generally parallel to the bedding. These exhibit various colours like blue, red, voilet and crown. Pink and red shales are the most common.

In the thin section (slide K O_2) shales are mainly composed of very fine grained clay minerals, which at places along the bedding planes have crystallized into lenticular bodies of fine mica and chlorite. A few detrital grains of quartz, feldspar and flakes of mica are also observed.

LOWER TALS

The Lower Tals are represented by various types of shales such as cherty, black and arenaceous shales.

(a) Cherty Shales (sp F_5, B_7 slide F_5)

These are fine grained dark coloured rocks with greasy feel and porcellaneous appearance resembling hornstone. These are very much fractured and crumpled. The rock is traversed by a number of quartz veins cross-cutting one another.

In thin section much of the portion is opaque. At few places clays and cryptocrystalline cherts are the main consituents. The rock is traversed by thin quartz veins (Fig 45) showing reticulate pattern. The vein quartz is fine to coarse crystalline and some of the veins are displaced. Coating due to the leaching of iron oxide is quite common.

(b) Black Shales (sp P_3 slide P_3)

It is fine grained black coloured compact and massive rock. Weathered surface is generally brownish.

In thin sections the main ground mass is composed of finely crystalline clay. Fine grains of detrital quartz, feldspars and mica flakes are distributed randomly. Fine opaque grains of iron oxide are well distributed in the rock.

Feldspars

Bigger grains of feldspar does not show twinning, while the smaller grains show ill preserved repeated twinning. Few grains of microcline showing cross hatched twinning are also observed.

Micas

Muscovite is present as flakes and are comparatively small in size as compared to the other detrital minerals.

(c) Black Arenaceous Shales (sp To_1 slide To_1)

These are dark black compact shales and along joint planes and fractures thin veins of calcite have formed. The weathered parts exhibit grey colour with brown tinge.

In thin sections these show very fine clay matrix in which large amount of detrital grains of quartz, feldspar, chlorite and mica flakes are distributed. The clay and the detrital grains are nearly equal in amount. The average grain size of these detrital constituents is 0.04 mm. Fine grains of magnetite and hematite are disseminated throughout the matrix.

Quartz:

It is most dominant mineral after the clay matrix. The individual grains are of various shapes with angular edges.

Mica:

Small muscovite flakes are randomly oriented. At some places they are elongated parallel to the bedding planes.

Feldspars:

Few grains of unweathered feldspars are observed.

UPPER TALS

Upper Tals are represented by a variety of rocks such as siltstone, quartzites, limestones and graywacke.

(i) Siltstones (sp T_8, T_9 slide T_9)

These are very fine grained rocks of red and black colour. At places the red siltstone show lateral variation into green shales. Fissility planes are well developed and the only recognizable mineral in hand specimen is muscovite. Black siltstone gave chemical test of Manganese (sp C-3).

In the thin section the principle clastic grains are angular to sub-rounded quartz grains, and altered feldspars. The cementing material is generally ferruginous but sometimes clay also serves as binding material. Particles are usually of siltsize and have a very narrow range of size variation. Usually the grain boundries are smooth but sometimes crenulated.

Quartz:

It is the predominating mineral showing wavy extinction and strained effect, thus indicating its derivation from some metamorphic source.

Feldspars:

Few of the feldspar grains are quite fresh and show repeated twinning. These plagioclase feldspars are of albitic composition. Twinning in most of the grains have obliterated. Occassionally grains of microcline showing cross-hatched twinning are observed.

Muscovite and Biotite:

Mica flakes are generally bent and deformed by compaction of the sediments. They do not show any preferred orientation but generally occur at the interstices between quartz grains. Biotite flakes showing pleochroism from faint green to green colour are seldom present.

Tourmaline:

Small grains of tourmaline are present. These are pleochroic from light yellowish green to turbid green. The grains are rounded to sub-rounded in shape and traversed by characteristic cracks.

(i) Quartzites (sp T_{17}, T_{12} slide T_{17}, T_{12})

Quartzites are generally coarse grained, gritty and even sometimes pebbly. Some varieties show very poor sorting and quartz grains of various colours such as violet, white and grey etc.

Pebbly quartzites also occur as rhythems within fine variety. The pebbles show preferred orientation and the long axis of the pebbles are as much as 3 cms long. The matrix of this indurated rock is very fine grained and pebbles derived from vein quartz are also present.

In the pebbly variety the cementing material is generally fine grained clay but otherwise silica is the main cementing material. Quartz, feldspar and other heavy minerals are the main constituent of the rock. The general composition of the rock is in the range of ortho-quartzites.

Quartz:

Quartz grains have a very wide range of size distribution. Authigenic growth around the detrital grains has taken place. The adjacent quartz grains have grown together to form an inter-locking aggregate of anhedral individuals, in which it is very often no longer possible to distinguish the original grains from their secondary rims. Sometimes a single quartz grain shows extinction of variable degrees in its different portions but elongated and parallel to the elongated side of the grains. This exhibits the pressure distortion of the quartz lattice and indicates its metamorphic nature.

Feldspar:

In some sections feldspar is quite abundant and occurs as big grains (particularly coarse grained varieties) while in some other fine grained varieties it is wanting. Feldspar grains are generally quite fresh. Twinned (albite law) feldspars are generally albitic in composition. Some untwinned feldspars show one set of cleavage and almost straight extinction. Grains of microcline are found mostly in gritty quartzites.

Staurolite:

The grains are anhedral and show pleochroism from yellow to yellowish brown. The effect of extinction is generally obscured by quartz grains. It shows interference colours yellow and red of first order.

Tourmaline:

The shape of the grains are generally angular to sub-rounded. It shows high relief and pleochroism from light blue to sky blue and sometimes from pale yellow to dark yellow with characteristic cracks.

Zircon:

It occurs as elongated long grains with some opacity developed along the cracks. Under crossed nicols it shows high order interference colours.

Mica flakes:

Muscovite usually forms very short flakes, located between quartz grains. These flakes are moulded along the quartz grains and show second order interference colours.

Iron oxide:

It is an opaque mineral.

Rock Fragments:

Of phyllites, Limestone and fine grained quartzite are sometimes present.

(iii) Calcareous Rocks:

The calcareous rocks are mainly grey and black limestones and calcareous siltstones. Such rocks are generally found in the axial part of the Mussoorie syncline.

(a) Grey Limestone : (sp P_6 slide P_6)

It is grey coloured partly crystalline

limestone with thin veins of calcite.

In thin section the rock is mainly made up of calcareous material which sometimes has crystallized to calcite (dolomite). The main mass is turbid under the microscope and quartz is the only detrital constituent.

It shows oolitic structure under the microscope. Oolites (dia. 0.5 - 0.8 mm.) of fine grained calcite are found in a coarse grained matrix of calcite. The core of oolites is sometimes made up of quartz around which the growth has taken place. The oolites are turbid because of their immature crystallization. Sometimes calcite forming the core is much crystalline than the rims. The oolites do not show any concentric growth or radiating character. Calcite shows pseudo-pleochroism.

Detrital grains:

Quartz and muscovite flakes are the main detrital constituent. A representative sample of the grey limestone was analysed by Edta Titration method and following results were obtained.

Constituents	Percentage
$CaCO_3$	32.01
$MgCO_3$	39.70
Residue	21.57
Solubles	6.72
Total =	100.00

$$\frac{MgO}{CaO} \doteq 1.002$$

(b) Black Limestone (sp To_4)

It is very finely crystalline black coloured limestone.

In thin section much of the characters are same as that of (a). Oolites owing to replacement have lost their original structure and show only a crystal mosaic of calcite. Chemical test performed showed that it contains Mn in small amounts.

(c) Calcareous Siltstone and Red Limestone

The red coloured calcareous siltstone is very compact and resembles to the red siltstone of upper Tals. The specimen from Tabore village in Landour shows some detrital fragments of calcite and aragonite.

Some varieties contain Pellets, the concretionary bodies, flattened parallel to the bedding planes. The pellets are of red colour and ellipsoidal in shape and the long diameter of these ranges from 0.3 to 0.7 mm in hand specimen.

Under the microscope very minute grains of calcite are found as aggregates in a fine matrix of iron oxide and clay (Fig 41).

Detrital grains:

Fine grained quartz but coarser than calcite is sometimes present. Mica flakes present do not show any preferred orientation. Tourmaline pleochroic from pale blue to blue is found as inclusions within bigger grains of quartz.

Pellets (sp P_9 slide P_9)

Pellets of ellipsoidal shape are found in a matrix of calcareous siltstone. These pellets show concentric growth lines with alternating layers of fine grained clay and calcite. Broken pieces of irregular shapes are scattered in the ground mass (Fig 41).

James (1954) described the formation of these pellets by " .... slight current or wave action on a fine grained precipitate". The sizes of these pellets is quite big as compared to the main ground mass. The lack of sorting shown by the finer grades means that these sizes were coagulated and deposited as floccules at the time of deposition.

Grey-wacke rock:

It occurs as veins in red siltstone striking N-S. This set of parallel veins (Fig 13), vary in thickness and some veins pinches upward. On weathering this rock shows porous texture and contains well rounded nuts of limestone.

The rock is greyish green in colour and very fine grained. Angular chips of some foreign rock and spherical nuts of limestone are included within the rock mass. On weathering it shows porous texture.

Under the microscope it shows pseudo-porphyritic texture, phenocrysts of quartz, feldspar, tourmaline, magnetite and various rock fragments of quartzites, limestones and phyllite. The matrix consists of some fine grainded turbid mass of chlorite and muscovite (Fig. 40).

Quartz:

Quartz is the most predominant mineral and occurs in various shapes and sizes. The grains are generally angular to sub-rounded with smooth margins. Chlorite occurs as occassional vermi-intergrowth in the quartz. Cherts and microcrystalline varieties are sometimes present.

Feldspar:

Feldspars are generally quite fresh. Varieties perthite and microcline are often observed. Other feldspars show polysynthetic twinning but generally it is obliterated.

Tourmaline:

Few grains of tourmaline are present. It shows pleochroism from yellow to dark colour. Individual crystals are rectangular with rounded edges and traversed by parallel cracks.

Rock Fragments:

Crystalline limestone fragments are very common.

Sometimes a portion of such fragments is coarsly crystalline while the rest of it is crysptocrystalline. Commonly coating of iron oxide on the rims of limestone is found.

There are two varieties of quartzites' fine grained and coarse grained. In the coarse variety calcareous material which has crystallized to calcite and dolomite has served as matrix.

Phyllites and shale fragments are very fine grained.

From the textural and mineralogical studies the rock falls simply in the categories of graywacke. But gray-wacke is a rock with tuffaceous matrix and brought about by sedimentary processes or in other words their bedding should be in parallelism with the country rock. One argument which could be forward for such a field occurrence is to think of the filling of open joint volumes, simultaneously with sedimentation, by the rock fragments and fine grained matrix material, but it will not explain pinching of these veins.

SEDIMENTATION

Dolomites are generally regarded to be formed by replacement of limestone. Replacement may take place in the environment of deposition. In the area the stratigraphic persistance of many beds of dolomitic limestones, extending over many square miles indicates that the dolomitization is the result of reaction of lime-carbonate sediments and Mg bearing sea-waters.

Overlying these limestones are the Lower Tal shales showing a faulted and disconformable (?) contact. Theoritically under conditions of peneplation, little other than ionic and colloidal materials should be removed from the land area and reach the basin of deposition. Under such conditions iron and silica might have migrated and accumulated at favourable sites to form chemical deposites of cherty shales. These cherty shales would then correspond to the reducing environment of deposition.

Black shales lying above cherty variety are comparatively more aluminous and contain grains of other detrital minerals. Upwards the proportions of these detrital grains go on increasing until they grade into rocks of upper Tals.

The continued depostion in the basin resulted in the shallow-ness of the basin of sedimentation. Thus oxidising environment would have prevailed. Such was the probable nature of the sedimentary basin in which the rock of upper Tals were deposited.

Upper Tal quartzites are generally coarse grained and have a wide range of grain size distribution. The coarse grained nature of the sediments, and the poor sorting with angular grains is indicative of the shallow water nature. It also suggests that the source area of these sediments was not very far away. The presence of thin laminae of micaceous material in white quartzites near Jhabharkhet Tal Bar may be attributed to the seasonal changes representing the period of dry winter when the site of deposition received light mica particles. (Fig. 16).

In siltstones at Alyndale near Chiller's Lodge Tal Bar are found beds of intraformational conglomerate (Fig 18) These conglomerates display intricately folded laminae suggesting that the deformation occurred during or shortly after deposition. Sub-rounded green coloured fragments of siltstones are embedded in red coloured siltstone. Such conglomerates are generally found to occur in shallow marine environments, where partially consolidated materials are torn up by strong waves and re-deposited in the strata of nearly contemporaneous age. Variegated colours, ripple marks (Fig 36), rhythmic bedding, mud cracks (Fig 17) and Pellets (Fig 41), all-together are suggestive of shallow water and oxidizing condition of deposition for the Upper Tals. The absence of fossils in this area throws some more light on the conditions of deposition. It is believed that the environment of deposition could not have been that of normal, shallow marine waters because under such conditions sufficient organic matter would have been included to reduce the iron and eliminate the red colour. The red colour of the sediments could only have been retained under conditions of such rapid deposition as to prevent the colonization of the bottom by organisms, thus limiting the quantity capable of incorporation in the sediments. The strong wave action which frequently prevails in shallow water produces great wear on everything that enters and so the fragmentary fossils result (Reported by [illegible] from Sill[illegible] and Ri[illegible]arh).

MINERALIZATION IN THE AREA

Mineralization in the area has taken place both in the Tals and the Krols and is represented by Pyrite and Barite. Pyrite is found both in the Tals and the Krols while the Barite is restricted only within upper Krol limestone of this area. Pyrite and Barite both were studied under microscope.

Pyrite of upper Krol limestone is found in Company Khad in irregular veins and pockets which show pinch and swell (Fig 25, 24). Sometimes a very thin sheet of gypsum is found on either side of the concentrated pyrite, which may be formed by the alteration of calcium of host rock.

Pyrite of the lower Tals is found as small lensoid masses in the bedding planes but is not very widely distributed. (Fig 21).

Pyrite in the Upper Tal quartzites is found as small pockets. These small pockets are distributed at random ly. Beyond Bat[illegible] at some places localized pockets of pyrite containing quartz of different character than the quartz of host rock is found. An individual pocket sometimes may weigh as much as 2 Kms.

<u>Microscopic characters:</u>

Pyrite associated with Krol limestone under the ore microscope shows the following textures:

(i) porphyritic texture, (ii) disseminated texture, (iii) island texture, (iv) colloform texture (v) pseudo-myrmekitic texture.

Euhedral grains of pyrite are disseminated into a fine ground mass of calcareous shales (Fig 1[illegible], 42). Individual crystals have remarkably straight geometrical boundries. The four sided crystals generally appear as squares (can be well seen in thin section) but triangular crystals are also common. It is remarkable that the pyrite grains do not show any tendency to form aggregates but occur as individual crystals in the ground mass. They are of uniform size of (.05 mm.). Pyrite sometimes has altered to goethite with which it shows emulsion and colloform texture.

Pyrite of the Lower Tals shows a group of Textures:

(i) colloform texture, cockade texture, pseudo-myrmekite texture, emulsion texture, comb texture, septarian texture and porphyritic texture.

Bigger crystals of pyrite as phenocrysts are generally associated with veins of quartz. Alteration of pyrite into goethite has given rise to a variety of secondary textures mentioned above. Pyrite at the boundry with host Tal shales shows the bending of the cleavage. Square shaped pseudomorph of goethite have interrupted the continuity of these bent cleavages (Fig 43).

Microscopic examination of Pyrite from upper Tal quartzites brings to light some interesting features. The following textures are dominant:

Cement texture, porphyritic texture, brecciated texture and rim and vein texture.

Pyrite in this case occurs most commonly as cementing material for quartz grain (Fig 46). Quartz grains are of no definite shape and show commonly sub-rounded boundries. Neighbouring grains seems to be counter part of one another.

<u>Paragenesis</u>:

From the field character and the microscopic studies of these, a probable paragensis can be derived.

Disseminated texture with euhedral grains of pyrite probably indicates to the porosity of the shales which governed the replacement of the latter by the former. Disseminated pyrite in field is found in the immediate neighbourhood of the concentrated lensoid masses of its own. Field and microscopic characters maybe explained by Bold Face advance Replacement (Fig 19). Thus the concentrated pyrite has resulted from the continued growth and coalescence of innumerable centers of replacement.

Bending of cleavages of shales (Lower Tals) at the margin may be formed due to the growth of pyrite. Replacement of shales by pyrite can be argued on the basis of cleavage character and the presence of pseudomorphs of pyrite into goethite as interuptions in the continuity of cleavage. Thus there is reason to believe that there had been a small feeding channel along which the sulphide solutions came and became accumulated along the bedding planes as small lensoid bodies.

Cement texture of the pyrite of Upper Tal quartzites shows the replacement phenomenon. It also indicates that quartz grains must have been ones the only major constituents of the quartzites. Later this rock would have been attacked by up-rising solutions with a greater force to disintegrate it and make accomodation for those which gave rise to pyrite. Few of the quartz grains which would have been subsequently attacked in their individual capacity did not fully break but formed a hinge crack and the open space then occupied by pyrite.

If the Upper Tals were deposited under oxidizing conditions as they appear to be, the concept of uprising sulphide solutions holds good. This concept is also supported if the relative grain size of the host rock pyrite pockets be taken into account.

Pyrite in all the three varieties show the secondary replacement by goethite.

BARITE

At the beginning of the Tehri Road, (near Company Khad) by the side of the road two veins of Barite can be seen, one of which is nearly 6 cm thick and the other about 60 cm. Both veins are nearly vertical and strike due NE-SW . The thick vein was traced for about three furlongs along Company Khad. It is worth mention that this Khad is along a fault plane striking approximately NE-SW and which brings Krols and Tals in contact with each other. In the branch of this nala due South a vein in section as much as 100 cm thick was seen. Some small pockets of the barite can be located near Wyn-berg High School and below Arya Samaj in the nala cutting. Very thin and localized pockets can be seen at the gate of Claremount by the side of the road. Barite NE of Lancer Lodge shows pinching and swelling structure. Barite vein of 30 cms thickness can be located on the Landour-Khattapani mule track near the contact between the Lower Tal shales and the Upper Krol limestone.

Barite is generally medium to coarse grained and is of milky colour. The main features of this barite can be summarized as below.

(i) The barite is restricted to Krol D (including E) limestone and is found in the neighbourhood of the Krols and Tals contact. This contact at Tehri Road is a faulted contact.

(ii) Irregular veins cut each other forming box-work pattern.

(iii) Barite is universally associated with Calcite and often the ratio $\frac{BaSO_4}{CaSO_4}$ varies within wide limits.

(iv) It does not show wall alterations. Pinch and Swell structure is common.

(v) Upper Krol limestone (E) contains considerable amount of detrital barite. Raju and Bhattacharya (1962) have reported that the insoluble residues obtained by dissolving Krol E limestone in 10% Hcl contains 90% barite.

(vi) Chemical analysis done from one sample shows the following percentage of the ingredients.

Calcium	...	46%
Barium	...	44%
Lead	...	1.1%
Sulphur	...	7%
Impurities including O_2	...	1.9%
Total	=	100.0

(vi) Specific gravity of barite varies between 4.3 - 4.4.

(vii) Pyrite found in the neighbourhood of these barites show textures representative of replacement phenomenon. But pyrites associated with barite could not be found.

It is generally considered that the barite is formed from hot solutions. But here in this case the lack of wall alteration of limestone - a most susceptible rock to hot solutions, and the absence of any essentially hydrothermal mineral in the barite association makes the problem complicated. The only igneous body of any significant values are the transgressive sills in the Kral-D limestone, but these are located at such a long distance from the barite vein that their genetic relationship can be doubted. Further these intrusives though have penetrated in limestones but could not develop any hydrothermal deposit in the near vicinity.

Barite has been reported from various oxidation zones. Zuffardi and Solvadori (1964) believe that there is solid solution between the barite and the anglesite. They suggested this origin for the barite of Monterecchio Mines. Zuffardi concluded that the Barite in this area is of supergene origin and it was deposited by percolating ground water solutions which may have brought barite form some other source.

If Raju and Bhattacharya's results of 90% of detrital barite in the residue, are correct then the above genesis can be applicable to some extent in the above problem.

As mentioned previously that pyrites under the microscope shows texture typical of hydrothermal replacement. Small veins of pyrite and its disseminations are located in the same nala cutting where Barite vein is found. Further significant is the fact that barite veins tend to occur in the near vicinity of the Krol-Tal contact, which in company Khad is faulted one.

To assign any particular origin to these barite is a matter of further studies. Systematic sampling of limestones near the barite vein and their chemical and microscopic examinations may throw light on its genesis.

Economics:

A systematic estimation of the total reserve may probably indicate its feasibility for economic exploitation. If profitable reserves are proved other requirements for exploitation such as labour, roads for transportation, Power and Water etc. are within easy reach.

CHAPTER V

LANDSLIDES

1. GENERAL GEOLOGICAL AND TOPOGRAPHICAL SET UP :

From the view point of landslides the Upper Tal siltstones and quartzites are least susceptible. The massive Krol limestone formations are fairly safe though the slopes are rugged with ocassional landslips. The shales of Lower Tals and fissile varieties of siltstone and quartzites of Upper Tals, are the most susceptible and perennial landslides are numerous.

Landslides are generally frequent on Tehri Road and particularly in the vicinity of Wood-stock School. Special emphasis has been laid on the study of that part of Tehri Road which lies within the Municipal limits of Mussoorie No major landslide is seen though occassionally a few landslips develop soon after the rains. For proper appreciation of the landslide phenomenon in the area weaker planes were studied and their possible effect on the future landslides anticipated.

Between Ivy Cottage and Jhabarkhet Toll Bar on Tehri Road the rock type is dominantly shales of Lower Tal which have an average dip of 15°-30° in the direction NE with bedding planes only 6 cms apart at the Krol-Tal contact and further widely spaced in the regions near the landslides. The slopes on a average are inclined 50°-55° towards the road which trends E-W, with the adjoining hills as high as 300 meters from the lowest bed level of the nala and nearly 150 meters above the road level. The joint planes are often present but not very closely spaced. Three sets of major joints were noted.

J_1 - Vertical, striking NE-SW

J_2 - Dipping 50° - 55° in a direction NE

J_3 - Dipping 50° - in a direction SW.

The Lower Tal shale which are carbonaceous and siliceous in the lower part grades upwards into more arenaceous type. The black coloured shales are quite compact when fresh but are traversed by very thin calcite infillings which have developed along the joint planes. Along these weak planes, leaching of pyrite has also taken place, with the probability of its decomposition products reacting on the hydrocarbons of the carbonaceous shales.

The Lower Tal shales here are clad with dense vegetation of trees locally Known as Banj and Chir (Pine), the roots of which penetrate deep into the solid rock through the joint planes. The rock is covered with a thin blanket of top soil which varies in thickness from place to place.

2. <u>DISCUSSION</u> :

There is no singular cause of landslides in this region but a number of factors to-gether cause the landslides.

The rocks near the second major bend on Tehri Road are very closely jointed and intensely sheared. The bedding planes are 25cms to 35cms apart and rocks are more argillaceous and carbonaceous. It is owing to the local thrusts and joints that lines of movement have developed along which shattering and grinding of the rock has taken place. The following agencies appear to be mainly responsible for the loosening of strata.

(i) VEGETATION - As mentioned earlier the Lower Tal shales support dense vegetation, whose roots extend into the joint planes. The expansive forces exerted by these cause the opening up of the joint planes with ultimate disaggregation. They are further aided by biochemical action resulting in the greater loosening of the strata and subsequent development of landslides on lubrication by water during rainy season.

(ii) CLIMATE -

(a) Action of Water : The climate is humid for most part of the year and so rainfall is very heavy. The percolating rain waters through the joint planes causes decomposition of iron pyrites and formation of acidic solutions. In view of the dips towards the hills, the acidulated waters will be contained inside and reach the underlying dolomitic limestones of Krol D and E stage. If this process is deemed to have withstand long, the solution cavities could be existing below.

When lubrication by water overcomes the coefficient of friction of weathered product-lump clay, landslides could occur in view of the favourable slopes. The coefficient of friction of wet clays is about 1.0, corresponding to an angle of repose of 45°. Slipping is further accentuated by deposition of thin clay bands, derived by percolating waters from the overlying argillaceous siltstones at the contact with the shale beds.

(b) Frost Action: As the area experiences occasional snowfall during winter, the inevitable effects of frost action are experienced. The rocks being highly jointed, aid frost action when the water in the joints freezes and expands in volume. This expansion further helps in the loosening of the joints - already affected by water action during the preceding rainy month.

(iii) <u>TOPOGRAPHY AND STRUCTURAL FACTORS:</u>

As already mentioned, the slopes on the side of the Tehri road are 50° in a Southward direction with the dip of beds being 15 to 30° in a direction NE. There is a dominant factor, the dipping of the joint plane in the same direction as the slope of the hill with practically the same inclination. This would be the dominant factor in initiating the landslides particularly as the rocks are closely jointed in other direction as well. The fractured rock will thus be susceptible to landslide by itself and more so when aided by other factors already enumerated. The joints are steeply dipping than the bedding planes and would result in the formation of wedges of various size and shapes.

In view of the foregoing, it would appear that the hill slopes ot Tehri Road at places are quite prone to landslide in future also. In fact, some of the slides are already perennial and offer great hazards. Preventive measure e.g. construction of retaining walls, do not seem to offer any permanent remedy and the road is thus not usable during the rainy season. At places, the road has already sunk and new alignments are given after each major landslide.

CHAPTER VI

A NOTE ON THE SEISMICITY OF THE AREA

Earthquakes are sudden movements due to Volcanic or Tectonic processes. Earthquake which generally occur in regions of marked instability of the crust are often responsible for great damage and destruction to life and property.

A large number of earthquakes have occurred around Mussoorie and neighbouring regions in the Northern parts of India, and Table 8 gives some of the important earthquakes occurred in the region during the last two centruries. In the Garhwal-Kumaon earthquake of 1803, two hundred to three hundred lives were lost with great damage to the buildings. In 1809 another strong earthquake in Garhwal blocked the Vishnu Ganga river. Mussoorie-Simla area experienced a severe earthquake in 1842, which caused destruction of houses. In 1843 there was again a sharp earthquake in Mussoorie (Landour area) which was felt upto Meerut and Delhi.

In the present century a devastating earthquake occurred in 1905 at Kangra. During this Kangra earthquake, a secondary epicentral tract with an intensity of isoseismal 8

(Rossi-Forel Scale) was observed in Mussoorie and Dehra Dun area (1200 sq. miles). The Kangra-earthquake was responsible for great destruction to life and property in the Kangra Velley, Dharamshala and the hilly tracts of Mandi and Kulu. Considerable damage also occurred at Dehra Dun Mussoorie, Chakrata and other towns. The dome of the Roorkee University building was damaged and had to be rebuilt. Cracks in buildings and other minor damage was noted in Lahore, Amritsar, Jullundur and Saharanpur. As much as 20,000 human beings are estimated to have perished.

In 1937 an earthquake with its epicenter at U.P. Himachal Pradesh Border was very strongly felt in Dehra Dun and Ambala and strongly in Mussoorie and Roorkee. No record of damage to property or life is available.

Local enquiries show that people in the eastern parts of Mussoorie i.e. Landour area experience moderately strong shocks frequently during the present times. Development of cracks in the buildings near Ledar village was also reported. The shocks are more frequent during the monsoon seasons.

TECTONIC FRAME WORK:

Mussoorie is located in the lesser Himalayas within the Krol Belt. The Himalayan belt shows the presence of several thrust planes along which slices of crust have moved considerable distances in order to adjust themselves to the compressive forces. Jutogh, Chail, Giri and Krol thrusts, and Main Boundry Fault have been established in the neighbouring Simla area (Fig 3). Krol thrust and the Main Boundry Fault on the east are noted in the Dehra Dun and Tehri Garhwal regions, where Garhwal nappe has thrusted over the Krol Belt (Fig 4).

The isoseismals of the Kangra earthquake show a NW-SE elliptical trend parallel to the Himalayan structural alignment of the hills. The isoseismals show a gradational decline towards the south-eastern direction. As a consequence of the 1905 earthquake Dehra Dun rose 5.26" relative to Mussoorie and this movement of the southern tract appears to have extended from the main epicentral track along the Nahan and Krol thrust.

The tectonic sequence as worked out by Auden (1951) and later modified by Mehta (1962) at Jamuna Hydel site is given as follows:-

TABLE 27

		Nagthat Series	Quartzites with slates
	Devonian	---------- Thrust ----------	
Paleozoic		Chandpur Series	Slates with minor quartzites
		---------- Thrust ----------	
	Silurian	Mandhali Series	Boulder beds, slates, quartzites and limestones
----------	KROL THRUST OR KROL GRAVITATIONAL GLIDE PLANE -------		
Tertiary	Eocene and Lower Miocene	Subathu-Dagshai Series	Crumpled red shale and siltstone, black plastic clay with gypsum, some red limestone
	----------	THRUST (overfold)	----------
	Middle Miocene	Nahan Series	Sandstone claystone and siltstone

If the regional geological map (Fig 27) is seen it will be found that Tertiary formations in parts of the Punjab, H.P. and U.P. (Dehra Dun), occur as two large, roughly crescent-shaped embayments of sedimentary rocks bounded by the Pre-Tertiary formations of sub-Himalaya of Northern India.

According to Krishnaswamy (1962) these tectonically called "re-entrants" because of their inflections are the main sources which caused the earthquake of 1905.

The crecentric margin of the Kangra re-entrant extends along the arc for a total distance of some 80 miles, with a chord distance of approximately 60 miles. The Dehra Dun re-entrant spreads over an area of some 7,500 sq. miles and the cresentric margin of this embayment extends along the arc for a total distance of 70 miles and along the chord for a total distance of 60 miles. The relative dimensions of the Kangra and Dehra Dun re-entrant probably indicate the relative magnitude of the inflection and compression in plan sufferred by the two areas, the former one being compressed more than that of Dehra Dun. This indicates that there are possibilities of accumulation of tectonic strain and their release in future either in the form of regularly felt minor shocks or some earthquakes,

Local enquiries made in Mussoorie indicate that the shocks are often felt within the Landour area made up of Tal formations. These shocks appear to be due to local disturbances and are probably due to collapse of limestone caverns in the Krols along the Tal-Krol junction of due to thrusting and slippage along the Krol-Tal contact, along which movements appear to have occurred as discussed in Chapter III.

POSSIBILITY OF FUTURE EARTHQUAKES:

The fore-going discussions indicate that Mussoorie is a seismic area. Krol thrust, the Great Boundry Fault and the Krol-Tal contact are the main active zones in and around the area. A recent fault of considerable displacement located at the Krol-Tal contact indicates to the seismic activity of this area. There is no regular periodicity of the major earthquakes in this region though minor shocks appear almost in every monsoon.

No large earthquakes have occurred in the area, though minor shocks have been felt and occur frequently. The maximum felt intensity at Mussoorie was 8 (Rossy For/el scale). Thus it can be safely assumed that no earthquake to produce an intensity more than 8 (Rossy For/el) will occur in the area in the near future. However this may be quite catastrophic for the buildings located on slopes and other unstable areas. Therefore buildings should be designed properly to resist these forces and the stability of the slopes should be evaluated carefully.

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TABLE 8

Date (1)	Location (2)	Intensity (3)	Remarks (4)
1505, 6th Jul.	Agra	Severe	Great Damage
1669, 22nd Jun.	Kashmir	Violent	Large fissures in ground
1720, 15th Jul.	Delhi	Severe	Great Damage
1803, 1st Sept.	Muthra	Very Violent	Felt up to Calcutta, Great Damage
1803	Garhwal-Kumaon	Violent	200-300 killed, Great Damage
1809	Garhwal	Strong	Landslide blocked Vishnuo Ganga.
1816, 26th May	Gangotri	Severe	Landslides and rock falls
1825, 8th Jan. C.45 P.M.	Lucknow	--	—
1825, 22nd Mar.	Delhi	Sharp	—
1828, 6 and 15th Jun.	Kashmir	Very severe	1000 killed, 1200 houses destroyed

Contd...

TABLE Contd..

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

Contd ...

[illegible]BLE Contd.

(1)	(2)	(3)	(4)
37,20th Oct.	U.P. Himachal	6.0	Felt very strongly in Dehradun and [illegible], strongly in Mussoorie before Roorkee.
1956,1st Oct.	Khurja Bulandshahar	6.75	23 killed in Bulandshahr and slightly injured in Delhi.
1960,27th Aug.	Delhi Gurgaon	6.0	50 injured and minor property damage at New Delhi.

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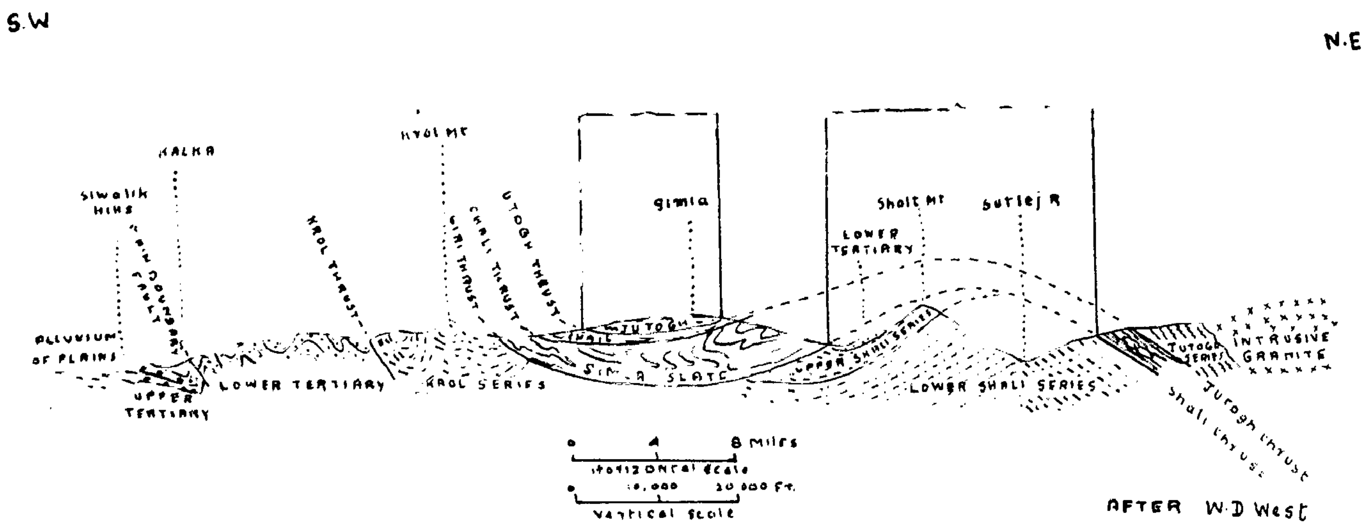
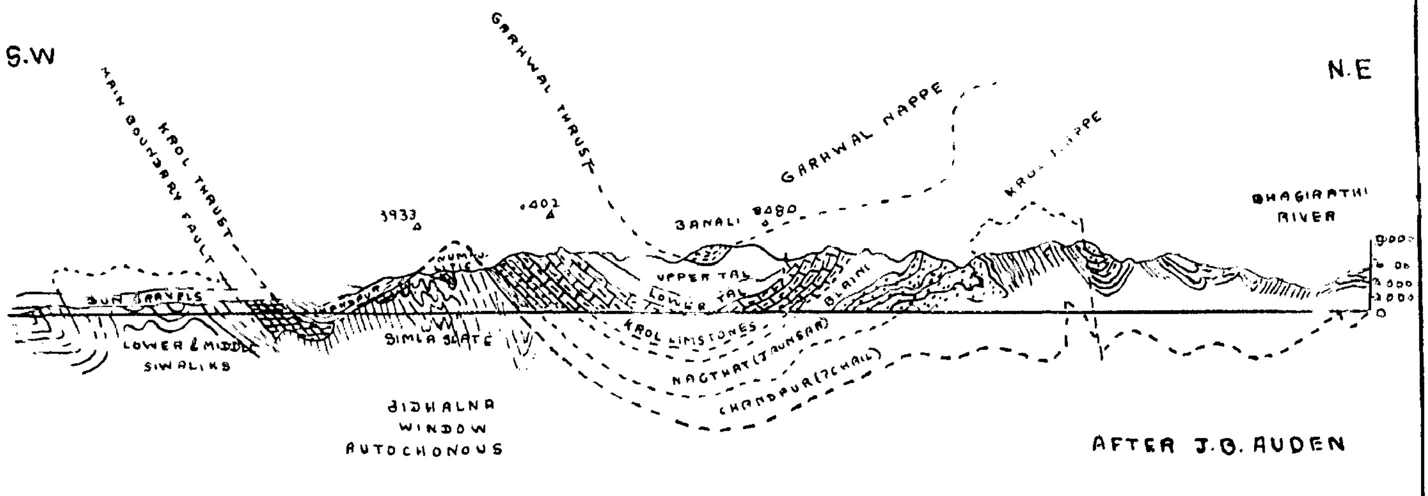
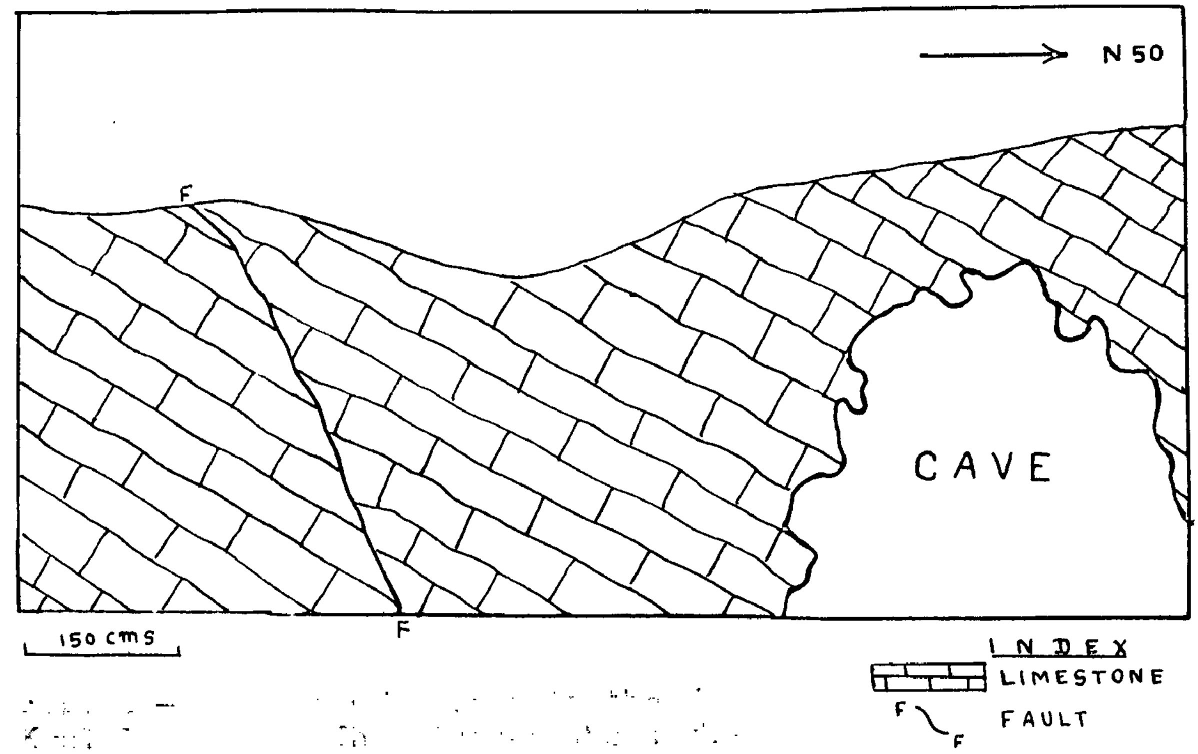


AFTER W.D West



AFTER J.B. AUDEN



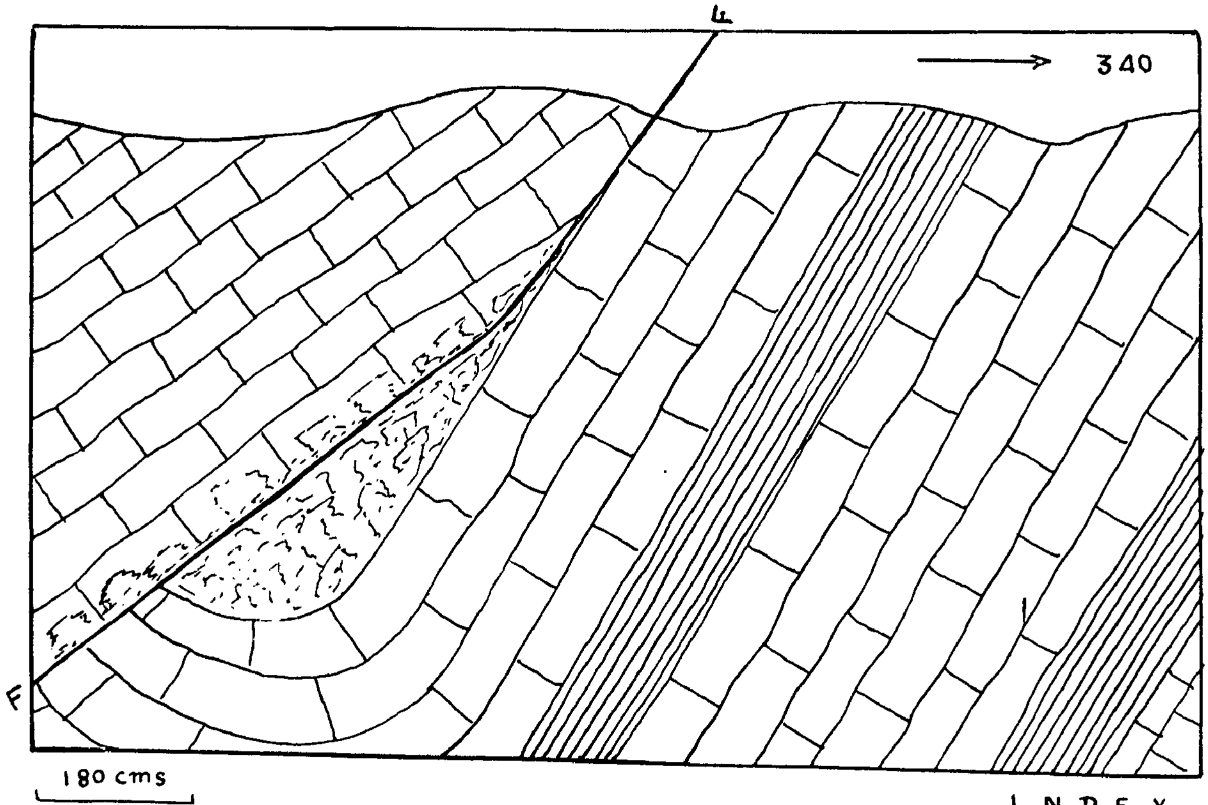
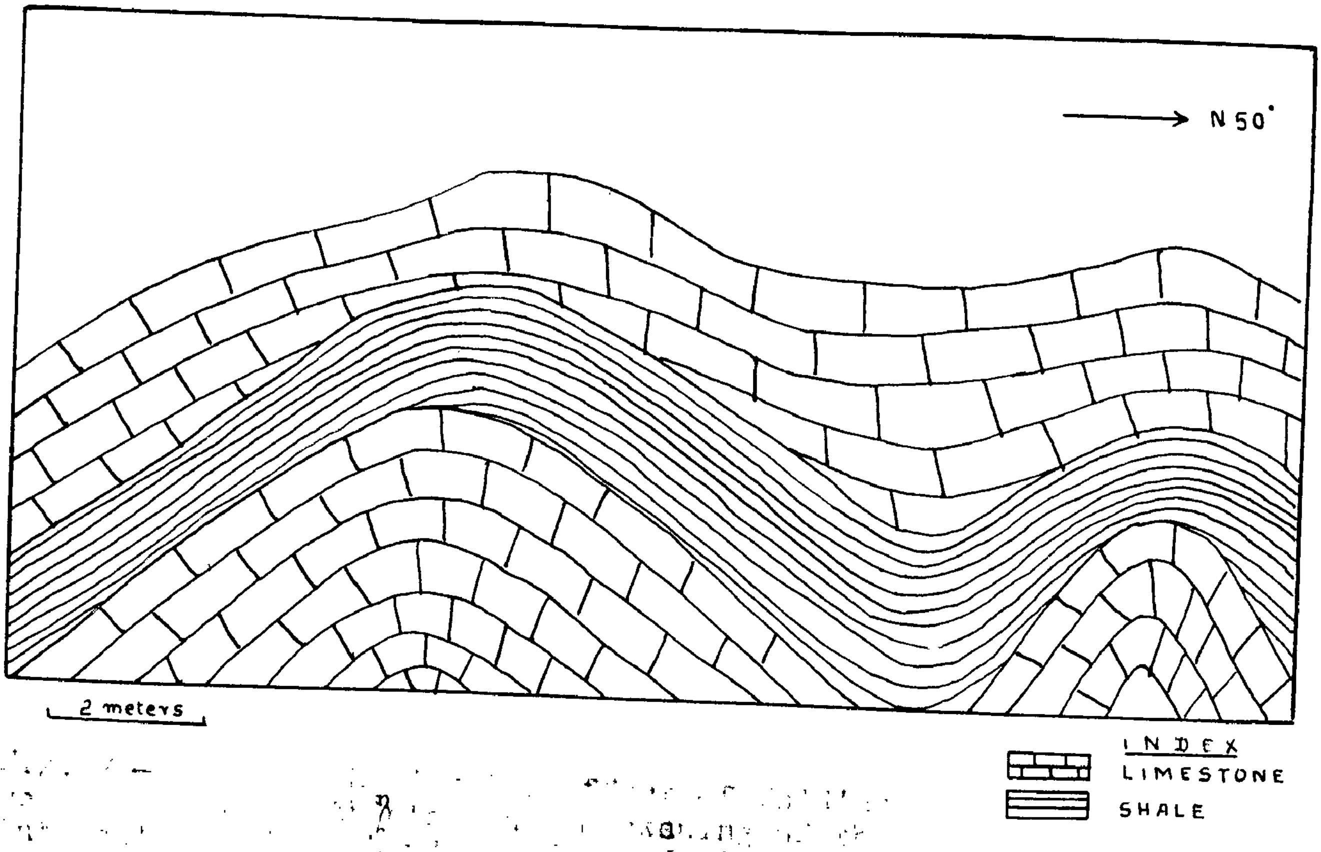
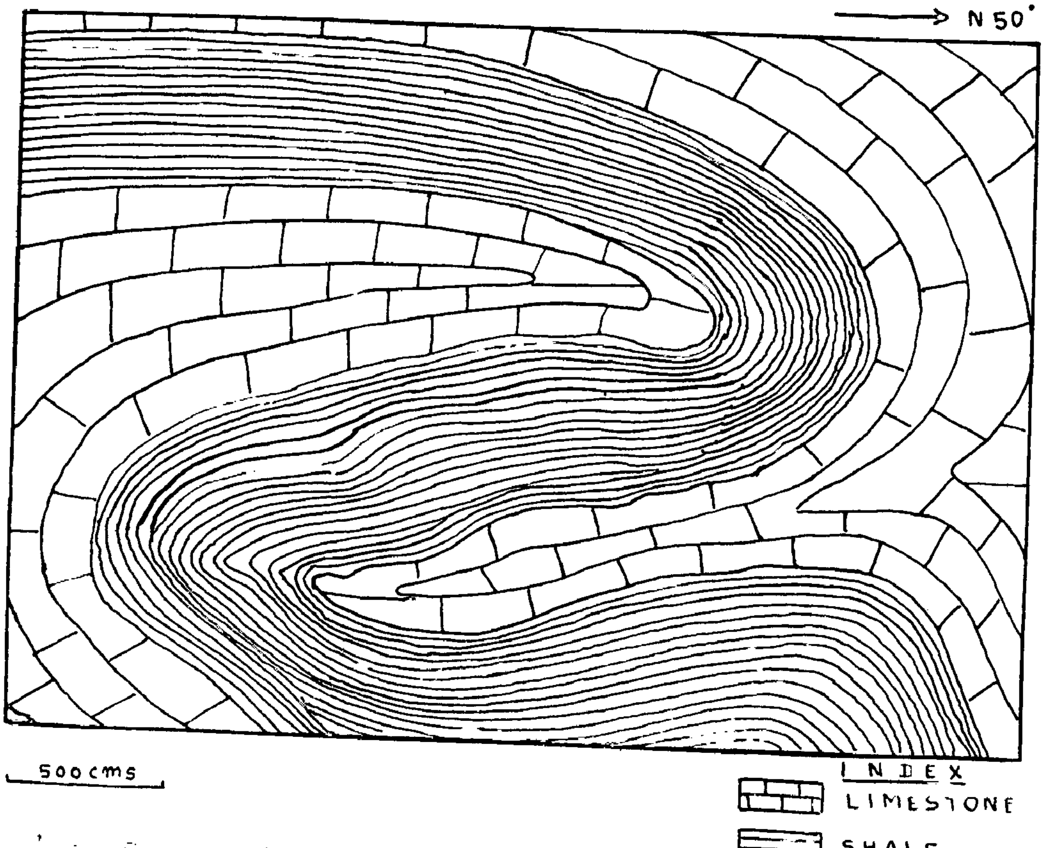
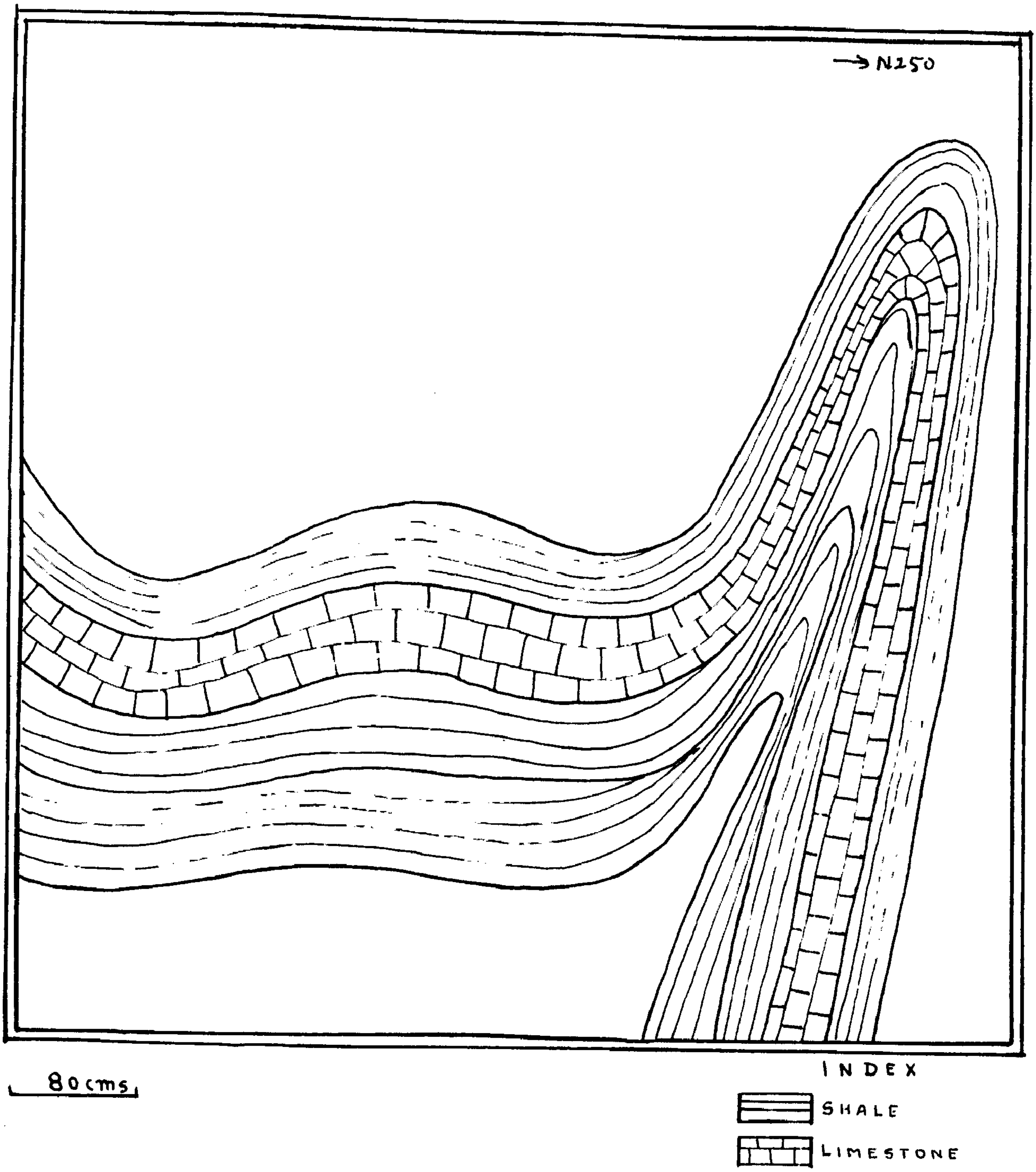


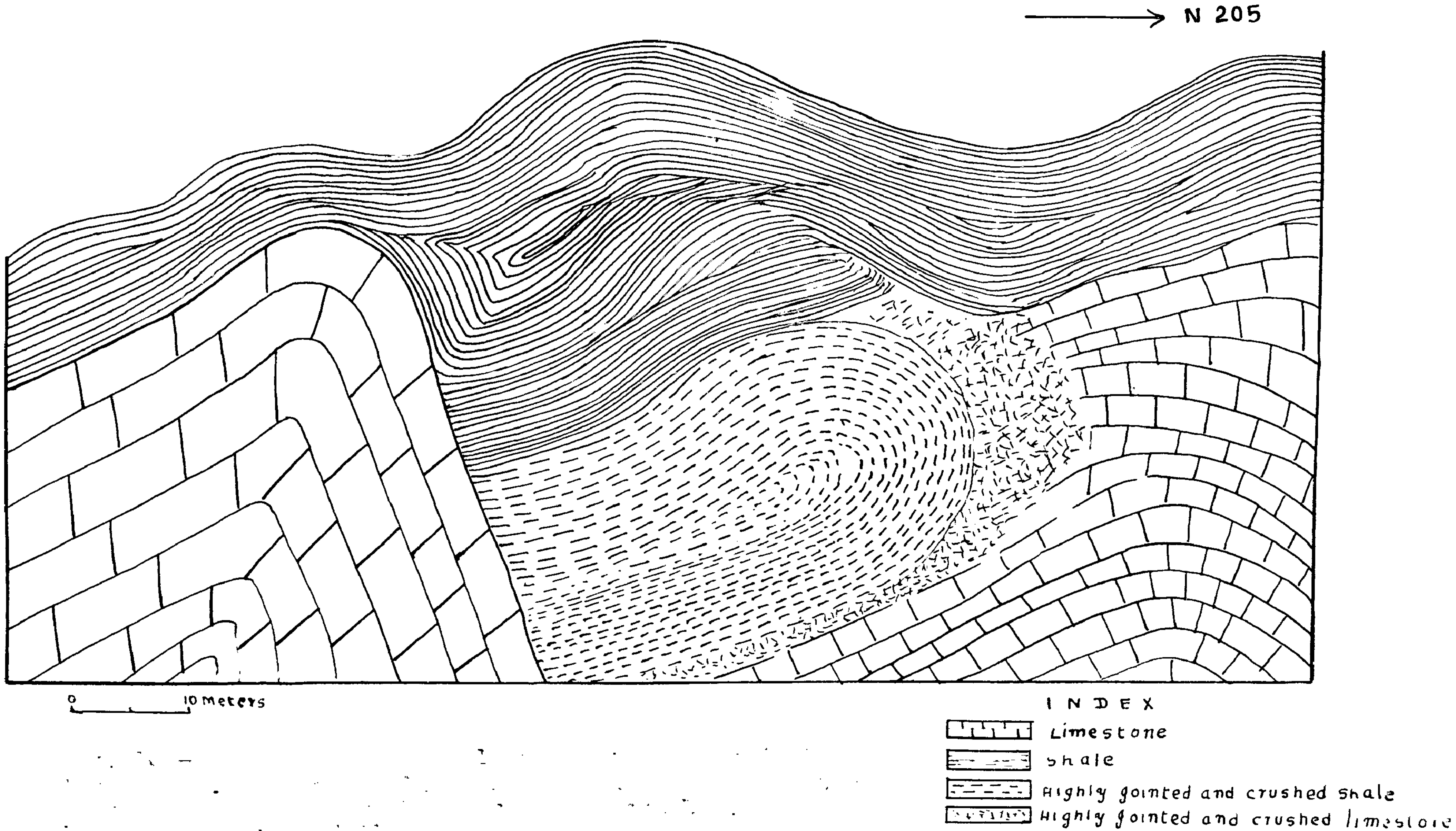
Fig. 6 – [illegible] and [illegible] faulting [illegible] [illegible] [illegible]

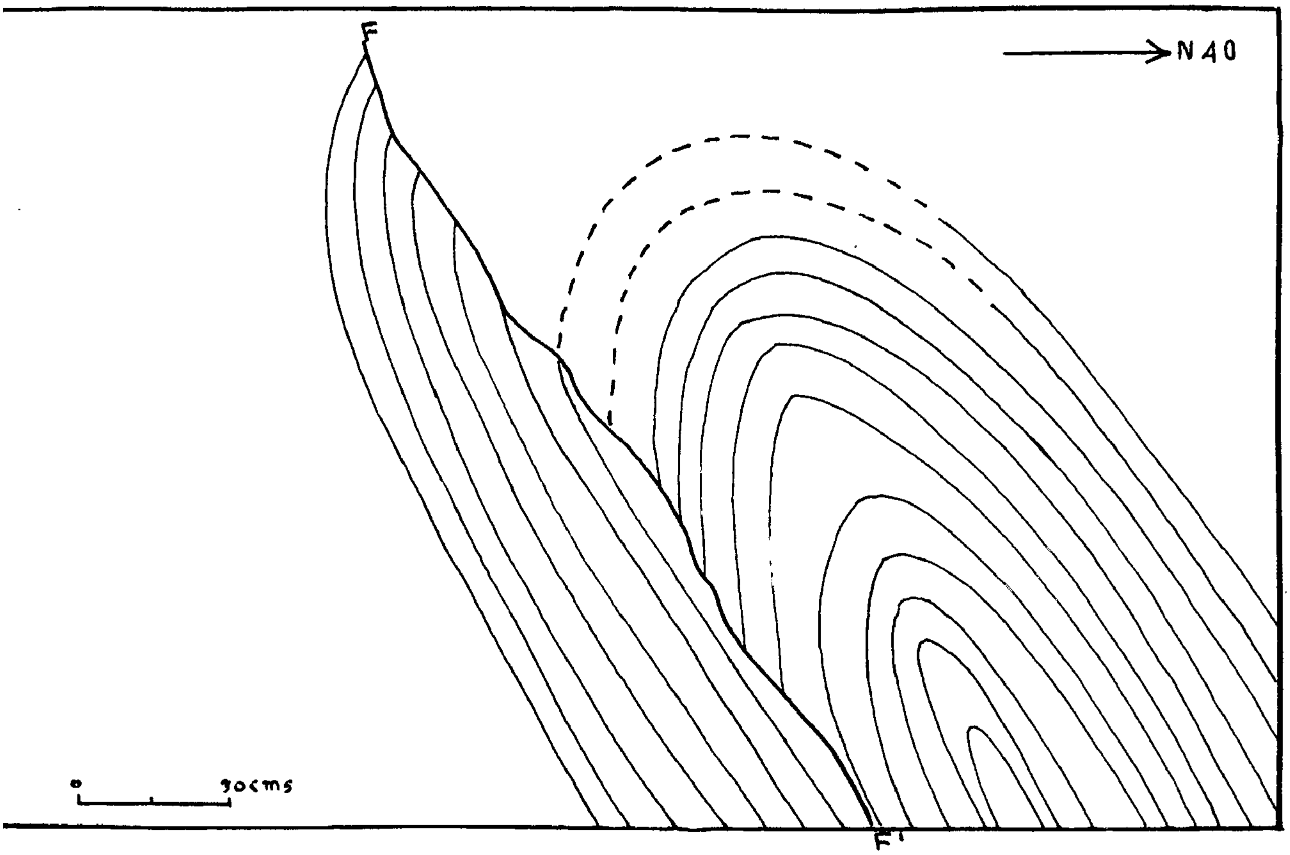

N 50°
2 meters
INDEX
LIMESTONE
SHALE

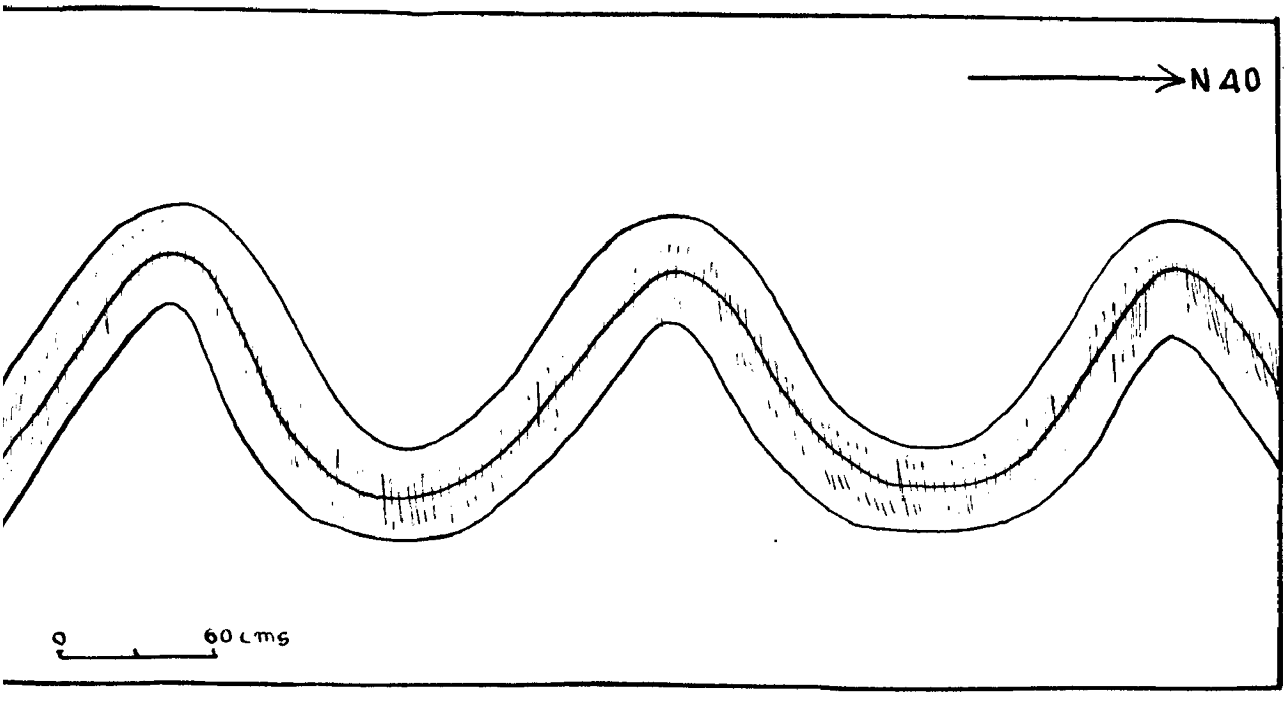

N 50°
500 cms
INDEX
LIMESTONE
SHALE



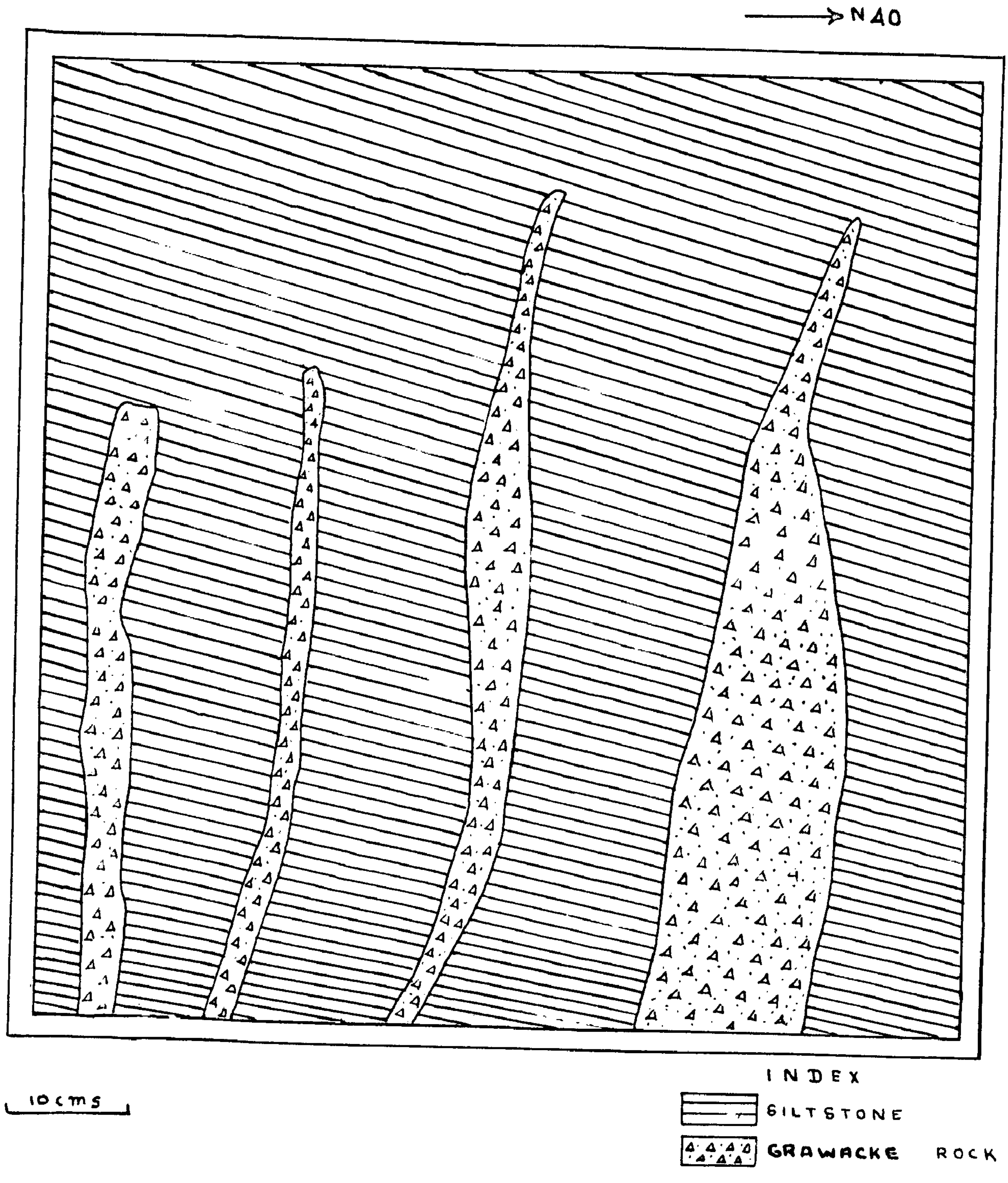
— Section showing the overturned folding in the Upper [illegible] limestones interbedded with shales. The [illegible] limb of a symmetrical syncline abruptly bends to form [illegible].

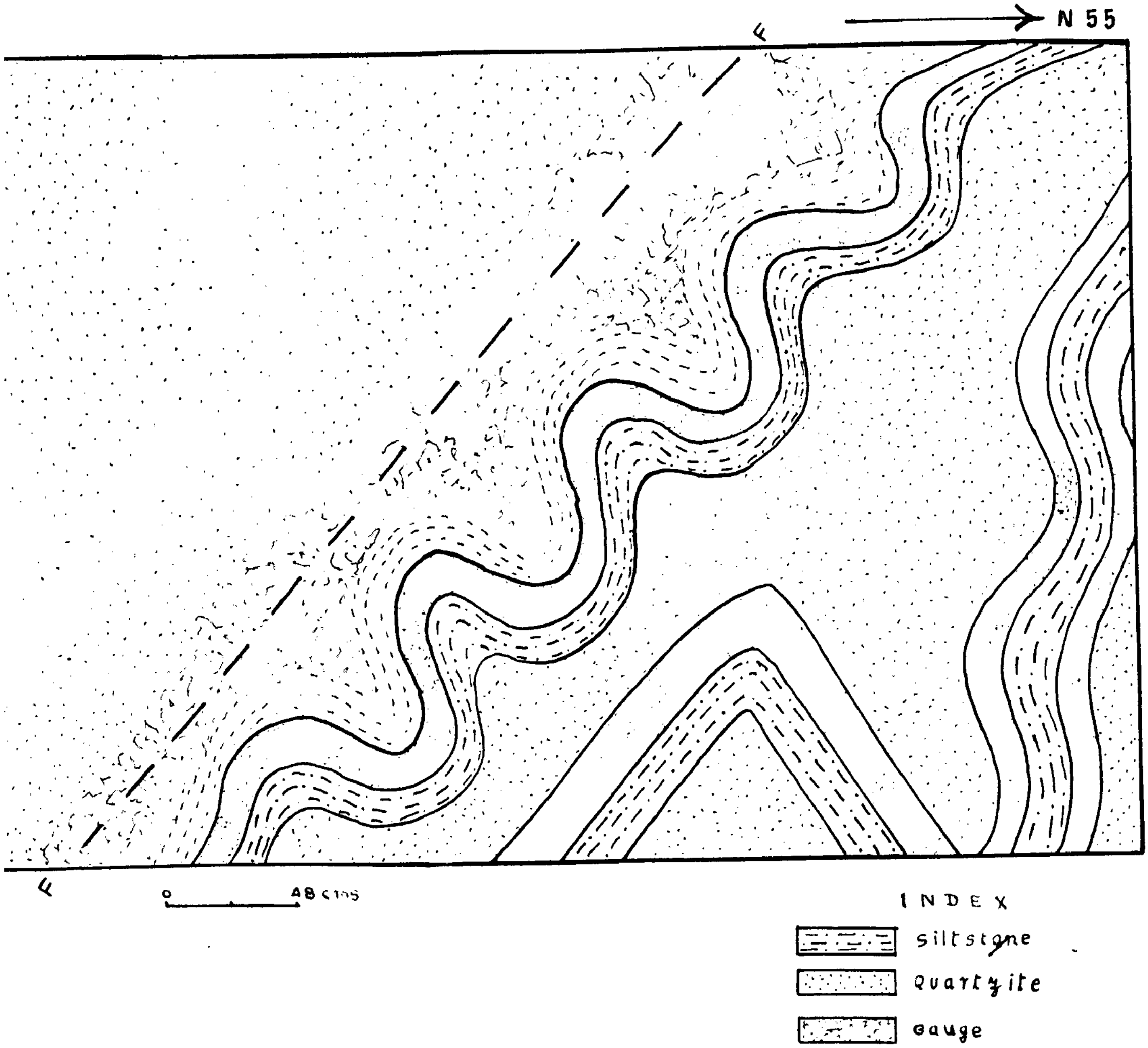

N 205
0
10 Meters
INDEX
Limestone
Shale
Highly jointed and crushed Shale
Highly jointed and crushed limestone

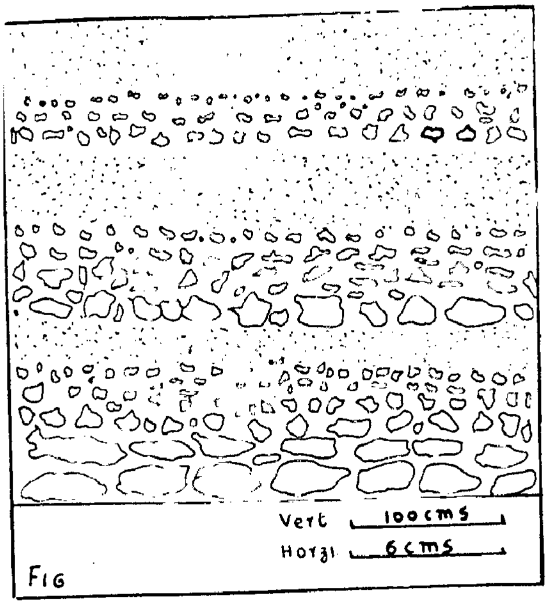




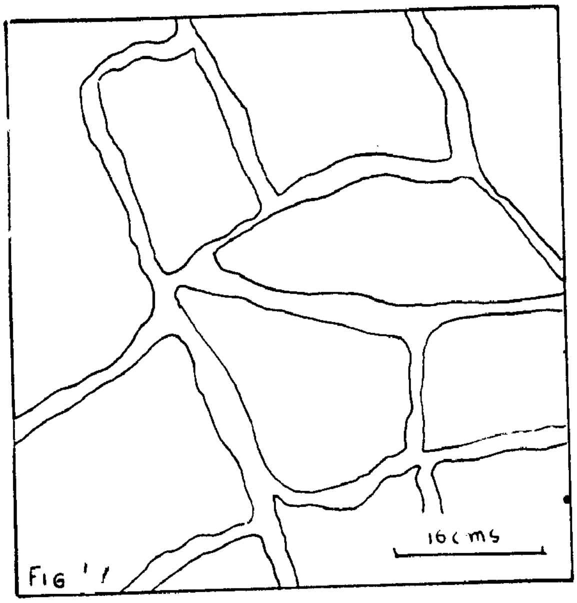
[illegible] laty cl[illegible]avage [illegible] es in lower [illegible]


N 40
10 cms
INDEX
SILTSTONE
GRAWACKE ROCK


N 55
F
F
0
48 cms
INDEX
siltstone
Quartzite
Gauge



FIG



FIG

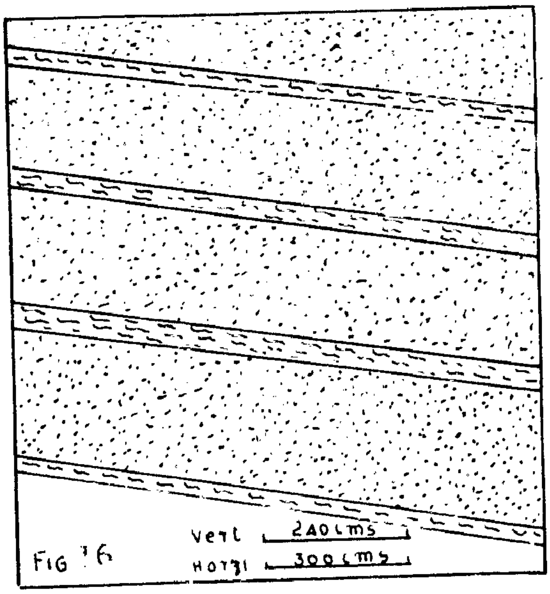


FIG 6

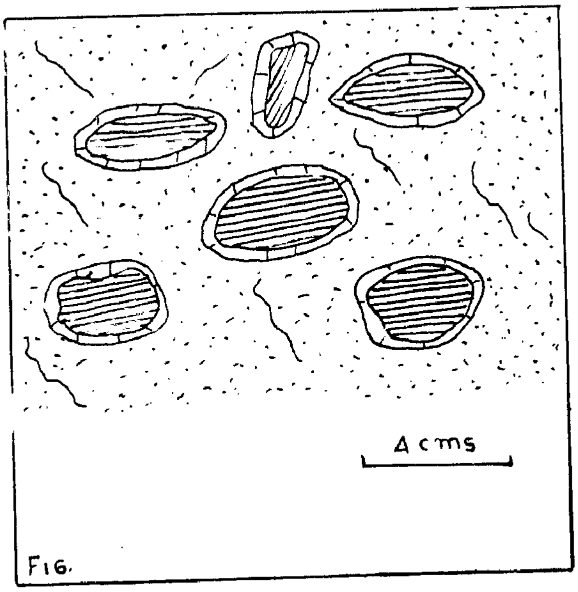
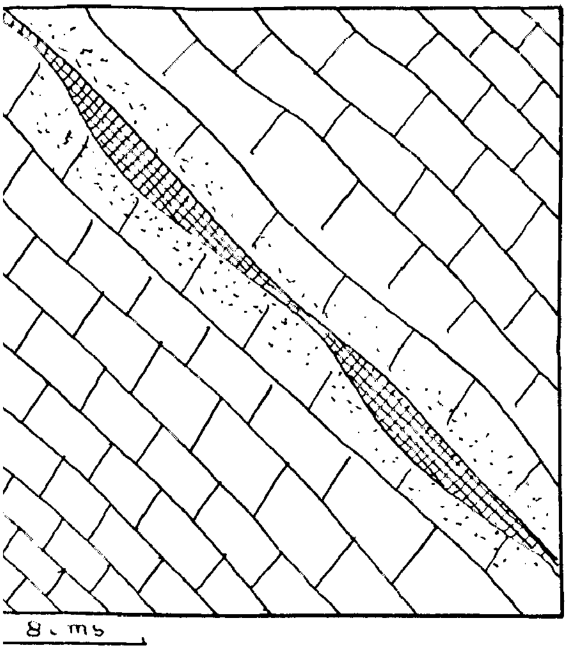
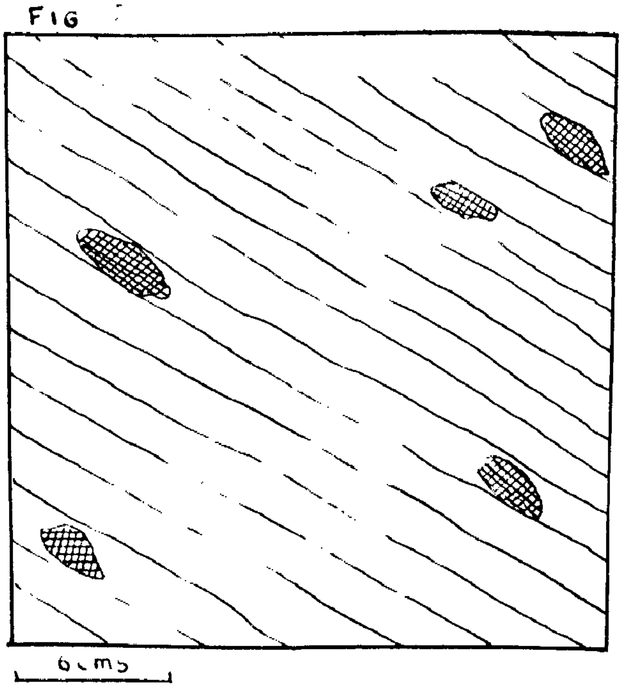


FIG.

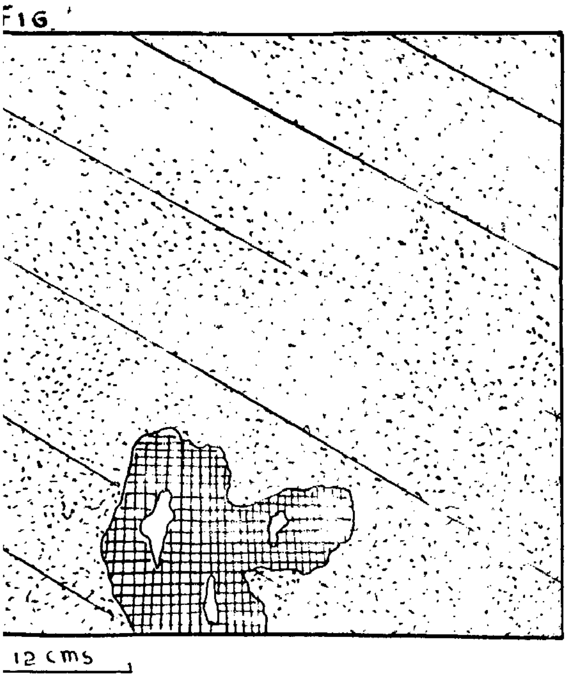
FIG



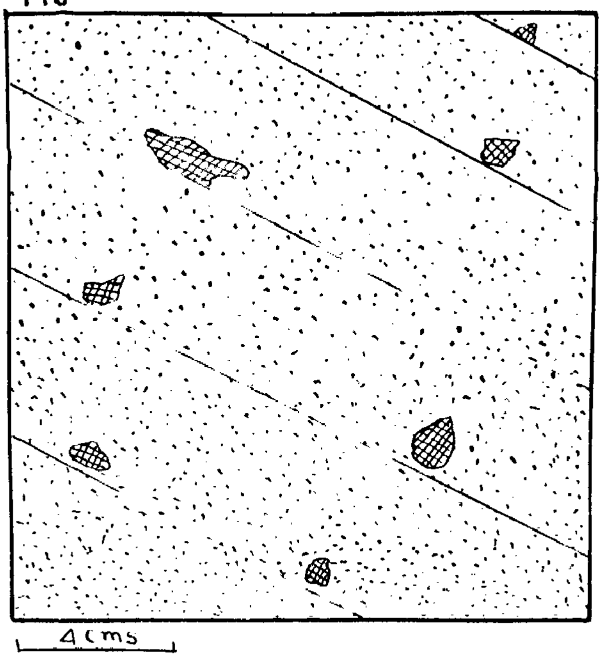
FIG



FIG



FIG

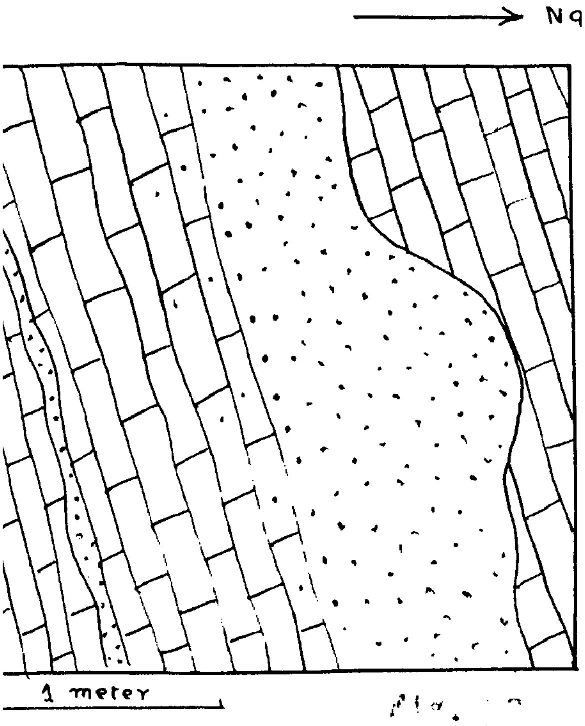


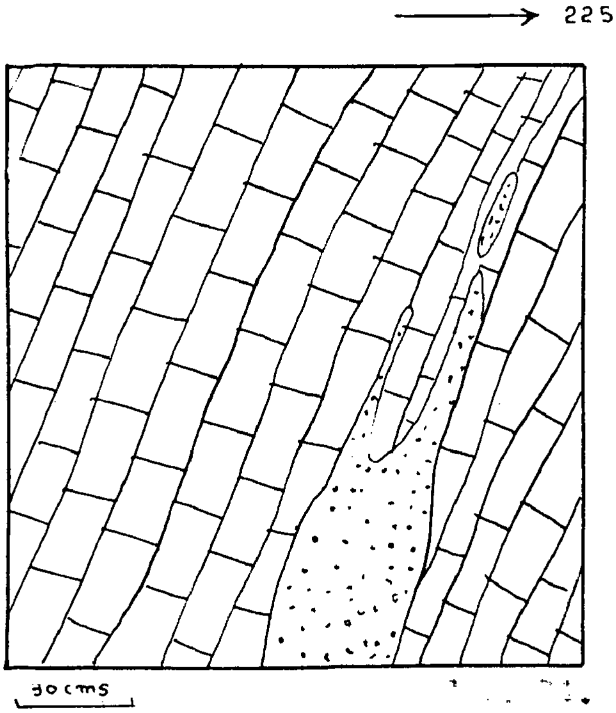
[illegible]

Fig. [illegible] — [illegible] the [illegible] bedding [illegible] Shales. [illegible] Road.

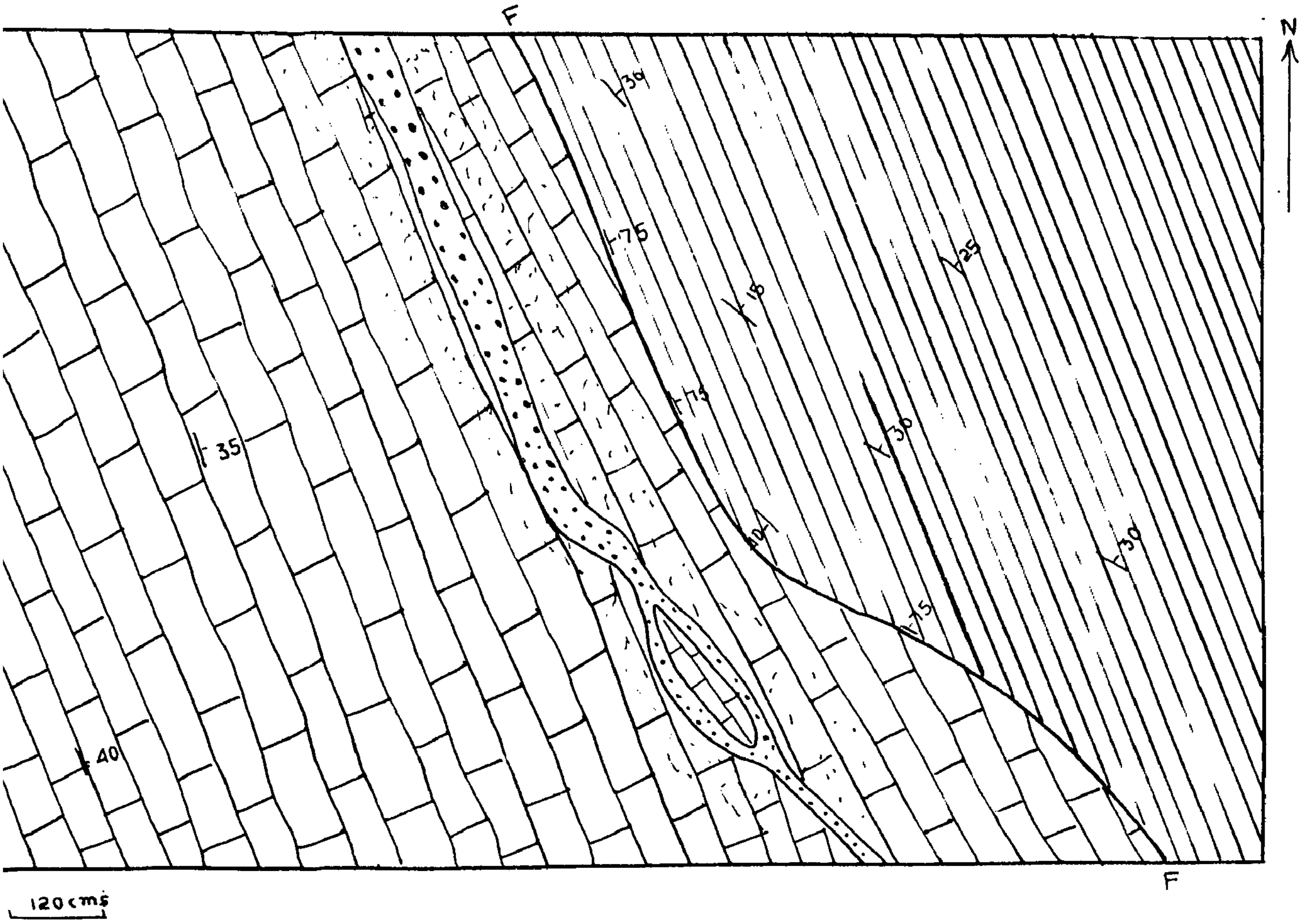
[illegible]

[illegible] showing the [illegible] of irregularly shaped [illegible] in quartzites. [illegible] — [illegible], Tehri Road.



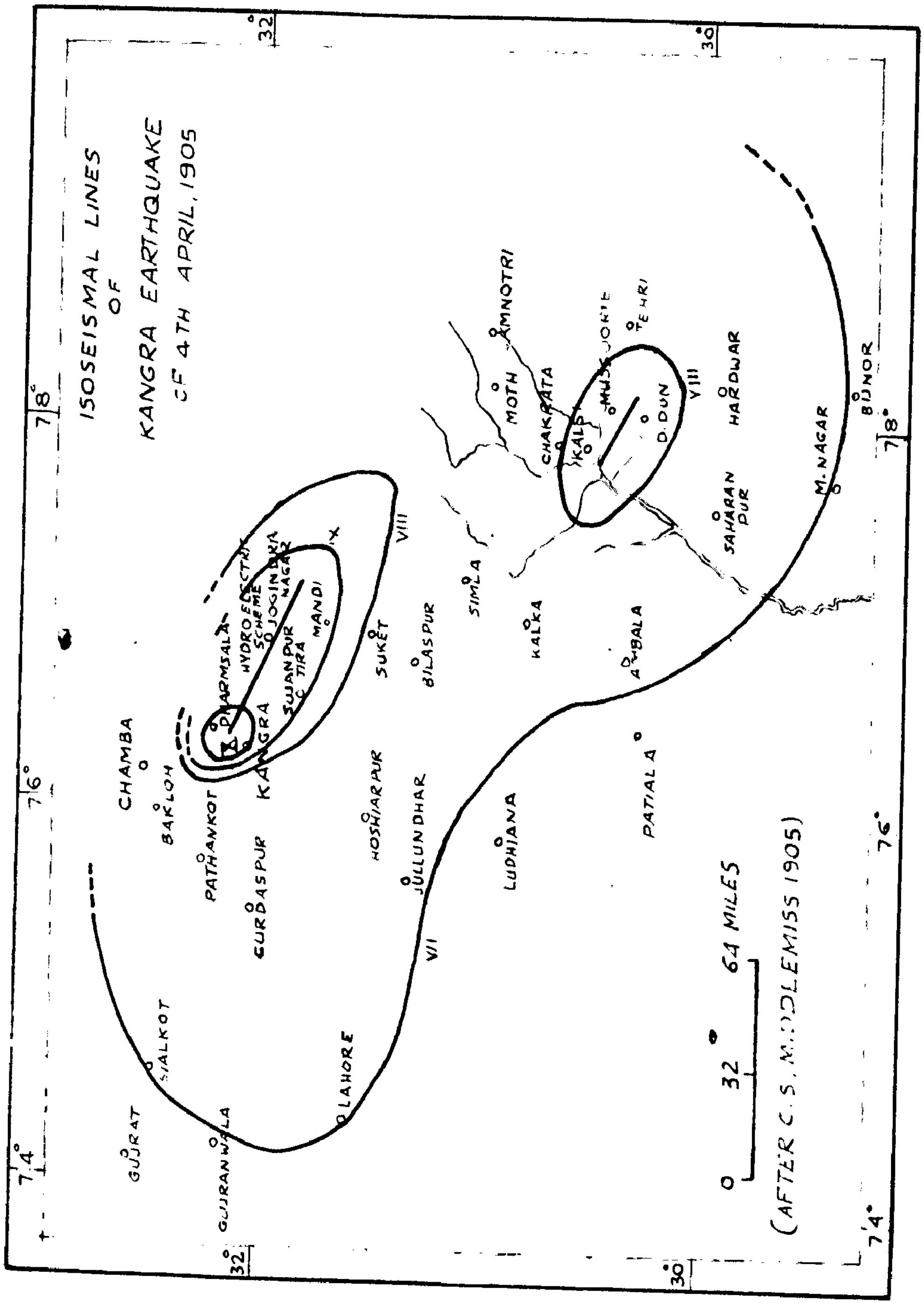


[illegible] mestones. [illegible]



[illegible]

Fig - 26



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

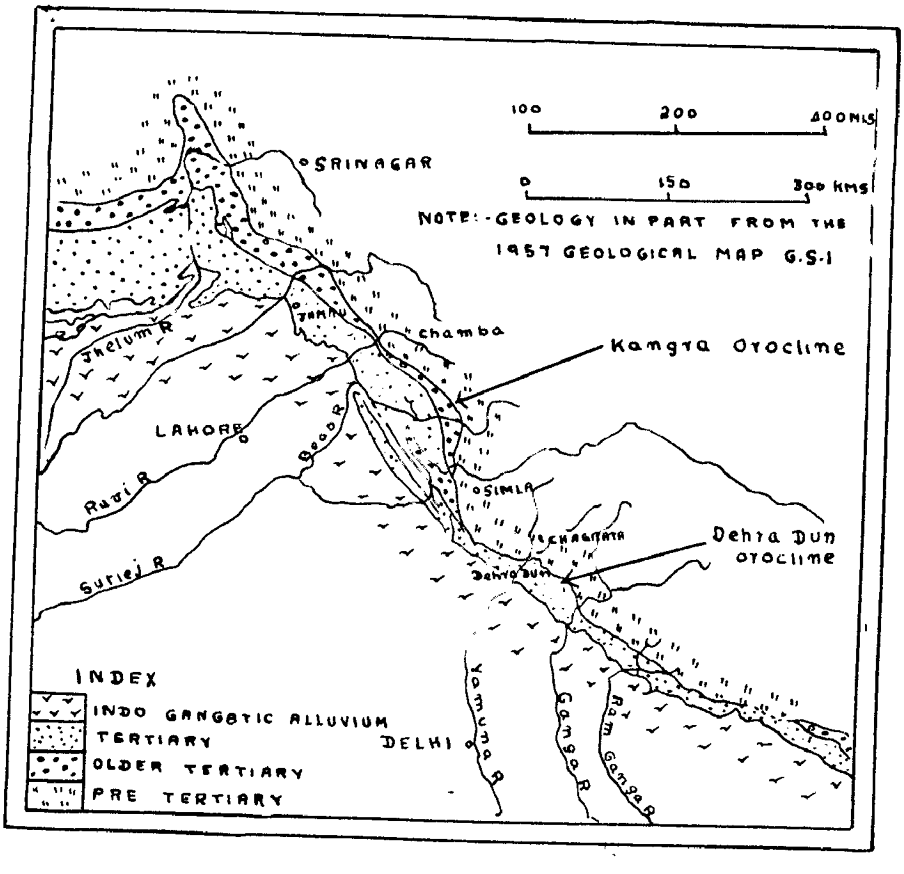

100 200 400 MLS
0 150 300 KMS
NOTE:-GEOLOGY IN PART FROM THE
1957 GEOLOGICAL MAP G.S.I
SRINAGAR
JAMMU
Chamba
Kangra Oroclime
Jhelum R
LAHORE
Beas R
Ravi R
SIMLA
Sutlej R
Dehra Dun
Dehra Dun
Oroclime
Yamuna R
Ganga R
Ram Ganga R
DELHI
INDEX
INDO GANGETIC ALLUVIUM
TERTIARY
OLDER TERTIARY
PRE TERTIARY

Fig-28

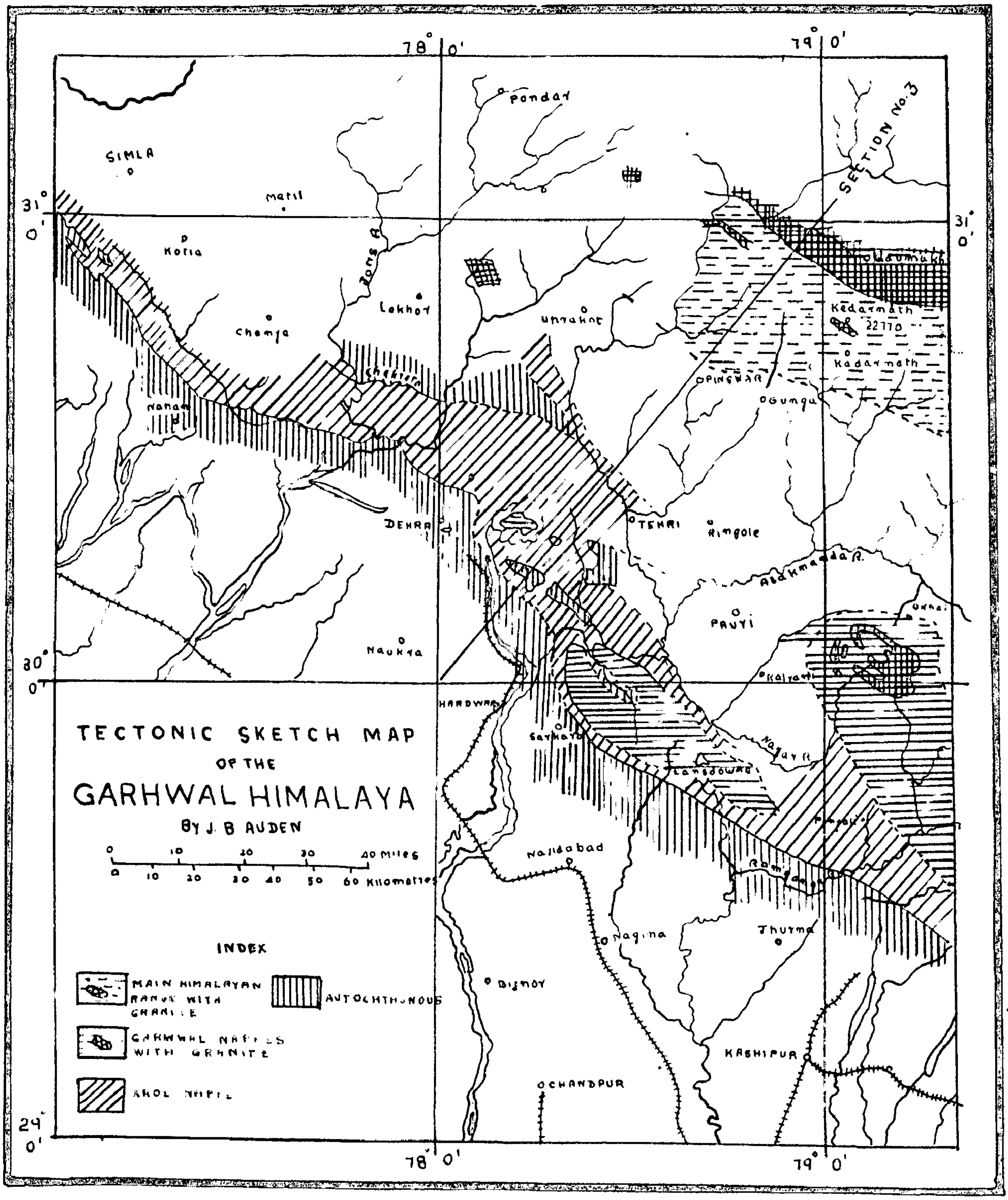
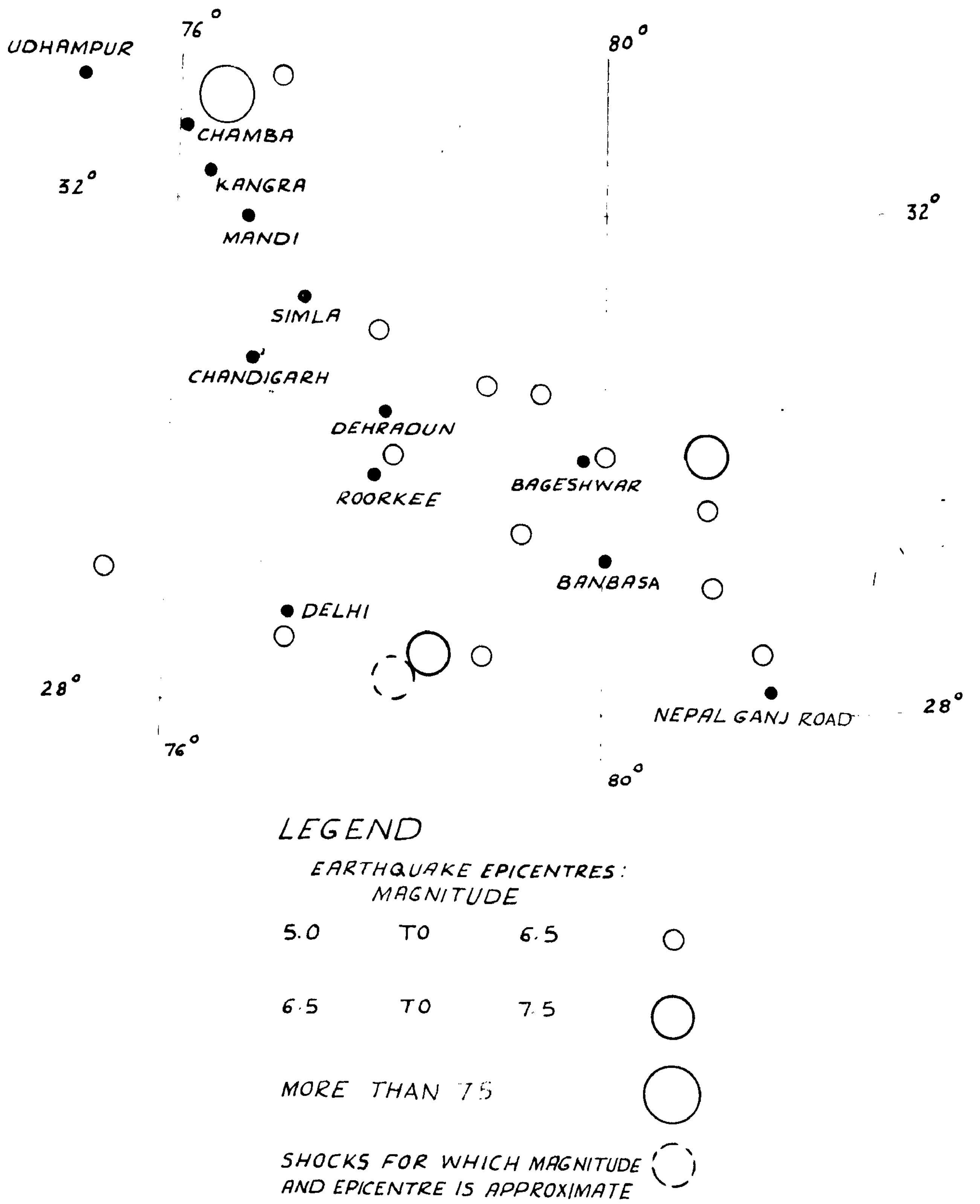

TECTONIC SKETCH MAP
OF THE
GARHWAL HIMALAYA
BY J. B AUDEN
0 10 20 30 40 Miles
0 10 20 30 40 50 60 Kilometres
INDEX
MAIN HIMALAYAN RANGE WITH GRANITE
AUTOCHTHONOUS
GARHWAL NAPPES WITH GRANITE
KROL NAPPE
78° 0'
79° 0'
31° 0'
30° 0'
29° 0'
SIMLA
Pondar
SECTION No. 3
Kedarnath
22770
Lakhot
Chamja
TEHRI
Rimgole
DEHRA
PAURI
Naukra
HARDWAR
Lansdowne
Najibabad
Nagina
Bijnor
KASHIPUR
CHANDPUR
Thurma

FIG. - 29

MAP SHOWING EPICENTRES OF PAST IMPORTANT EARTHQUAKES IN SIMLA GARHWAL AREA



AFTER I.S. 1893-1962

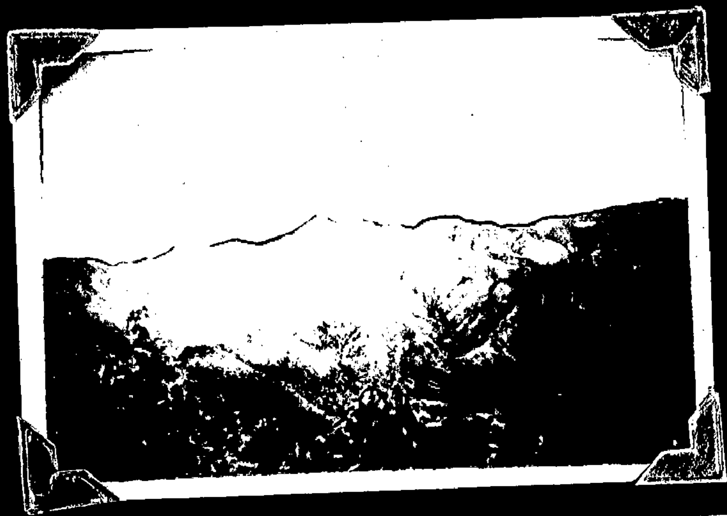


Fig.30 :- Phot graph showing barren clif s in the Up er Kr l Lim stones

Fig. 31 :- Photo raph showing contrast in vegetation of the Lower Tals and Up er Krols. Thickly vegetated hill comprises of the Tals and the barren cliffs behind represent the Upper Krols.

Fig. 32:- Hammer is located on the faulted Krol Tal contact in Company Khad. On the left are the Upper Krol limestones and on the right Lower Tal shale

Fig.33:- A synclinal fold in the intercalated limestones and shales of the Upper Krol on Kempty Fall Road.

Fig. 34:- A set of horizontal joint planes in the Upper Tal quartzites near Loti Dhar Tehri Road.

Fig. 35:- Two sets of well developed joints planes in the Upper Tal siltstones. The prominent set is dipping more than the slope inclination in the same direction indicating to its susceptibility to sliding

Fig. 36:- Photograph showing Ripple Marks in the Upper Tal siltstone near Tibri Tehri Road.

Fig.37. Photograph showing a barite vein in the Upper Krol limestone near Company Khad on the Tehri Road.

Fig. 1 :- Photograph showing two sets of well developed joint planes in Upper Tal siltstone near Koti Dhar Tenri Road.

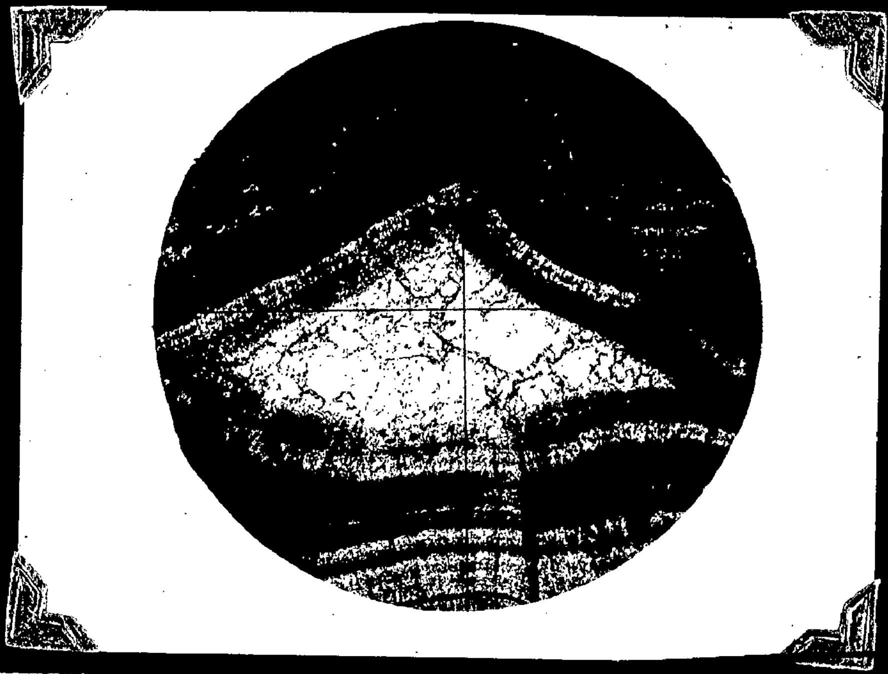


Fig.38:- Photomicrograph (50 x) showing the probable algal structure in Upper Krol limestone. The central part is calcite and surrounding rims are of fibrous aragonite.

Fig.39:- Photomicrograph (50x) showing coarse grained mass of calcite, dolomite and siderite containing pieces of fine grained Upper Krol limestone

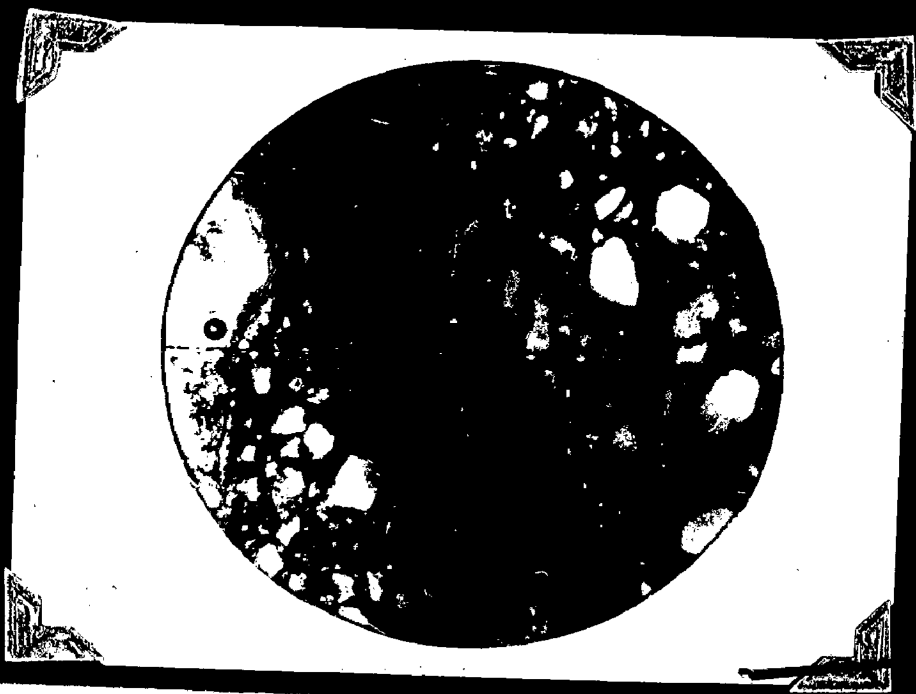


Fig. 40:- Photomicrograph (50x) of grey-wacke rock showing angular quartz grains and limestone fragments included in a fine grained matrix

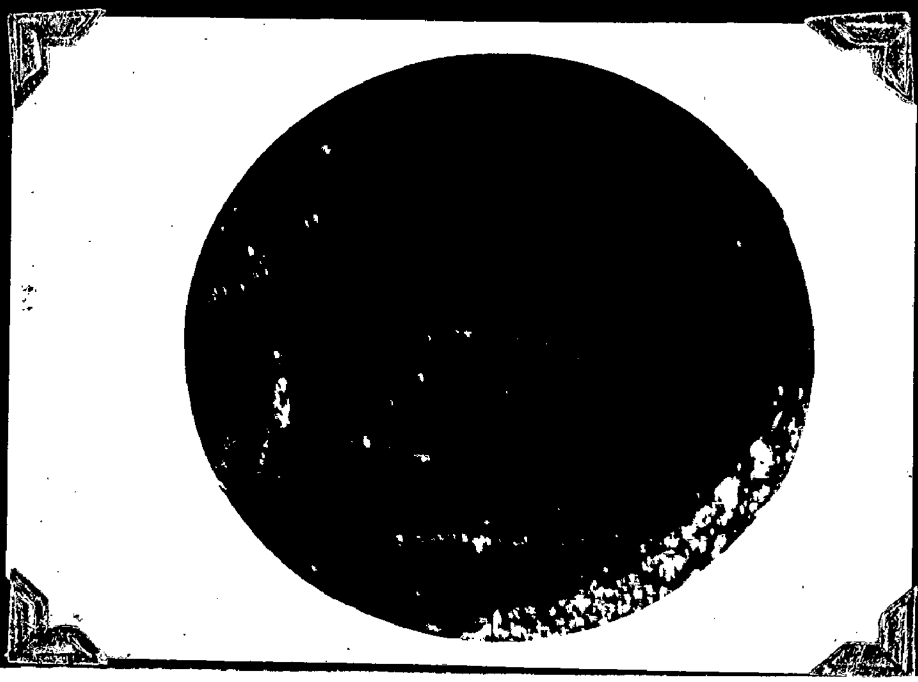


Fig. 41:- Photomicrograph (60x) of a pellet in the Upper Tal limestones. The alternative light and dark bands are of calcite (fine grained) and clay. On the right at bottom is fine grained limestone.

Fig. 42:- Photomicrograph (50x) showing euhedral crystals of pyrite in fine grained matrix of carbonaceous shales in Company Khad.

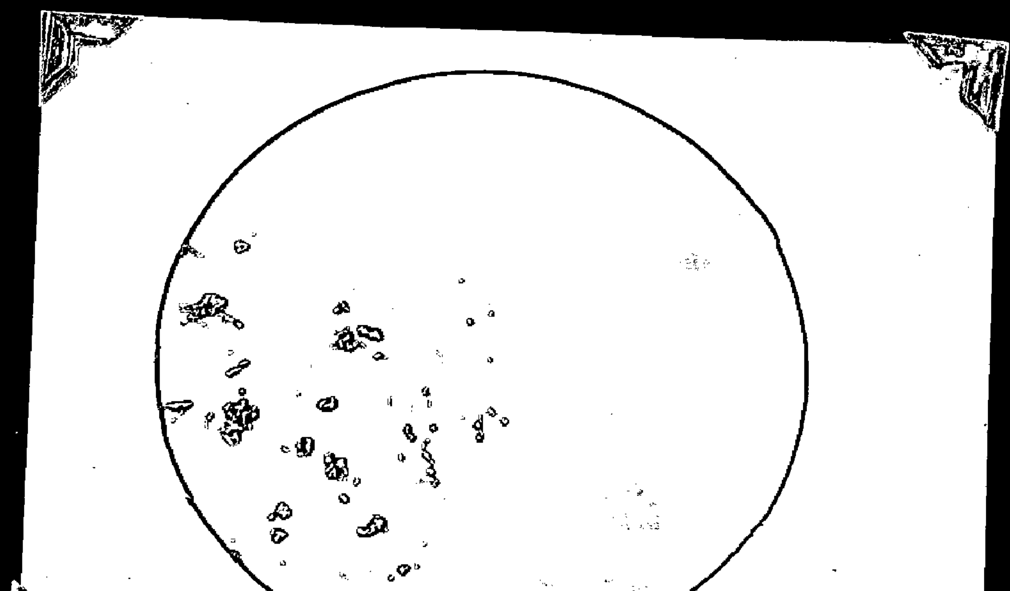


Fig. 43:- Photomicrograph ([illegible]0x) showing bending of cleavage in shales of Lower Tal. Pseudomorphs of goethite are cross cutting these bent cleavages (under ore microscope).

Fig. 44:- Photomicrograph (50x) showing relationship between barite and calcite crystals.

Fig. 45:- Photomicrograph (50x) showing reticulate veins of quartz in Lower Tal shale. The quartz is both coarse and fine grained.

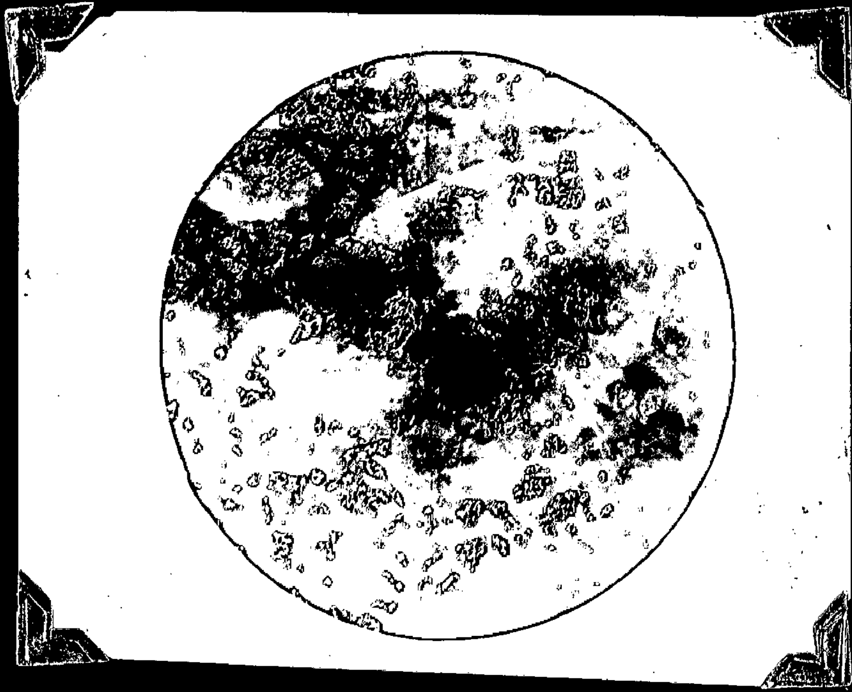


Fig. 46:- Photomicrograph (50x) of white of Upper [illegible] quartzites showing rim texture.

Fig. 47:-Photomicrograph (50x) of quartzites of Upper [illegible] showing authigenic growth in quartz.

Fig. 1 :- Photograph showing two sets of well developed joint planes in Upper Tal siltstone near Koti Dhar Tehri Road.