Sedimentological Studies of the Rock Units of the area between Jangal Gali and Salal, (J & K State)

By

SATISH KUMAR CHADHA

Professor of Geology

Govt. G. M. SCIENCE COLLEGE, JAMMU.

(Thesis Submitted in fulfilment of requirements for the Degree of Doctor of Philosophy of the University of Jammu, Jammu)

Post Graduate Department of Geology

University of Jammu,

J A M M U.

July, 1978.

2nd. Copy

Sedimentological Studies of the Rock Units of the area between Jangal Gali and Salal, (J & K State)

By

SATISH KUMAR CHADHA

Professor of Geology

Govt. G. M. SCIENCE COLLEGE, JAMMU.

(Thesis Submitted in fulfilment of requirements for the Degree of Doctor of Philosophy of the University of Jammu, Jammu)

Forwarded.

31.7.1978

Professor & Head of the Graduate Deptt. of Geology, The University of Jammu, JAMMU, (J & K State)

Post Graduate Department of Geology

University of Jammu,

JAMMU.

July, 1978.

ROCKS

180700

179716

552.509545
C345

C E R T I F I C A T E

Satish Kumar Chadha, who was registered for the degree of Ph. D. under my supervision, has completed his work. The title of his thesis is "Sedimentological Studies of the Rock Units of the Area Between Jangal Gali and Salal (J&K State)".

I certify that he has worked under my supervision and the work done is original and worthy of consideration for the award of the degree of Ph. D. I further certify that :-

(a) the thesis embodies the work of the candidate himself

(b) the candidate worked under me for the period required under rules

(c) the candidate was registered under the category of teachers and has fulfilled all the statuary formalities to submit his thesis.

(T.R.Bhatia)
Supervisor
Reader in Geology,
University of Jammu.
JAMMU

C O N T E N T S

	Preface	(i)-(v)
	Introduction	1-9
Chapter		
	1. Historical Resume of the Previous Work	10-16
	2. Stratigraphy and Structure	
	Stratigraphy	17
	(a) Geological set up of the area within the broader framework of the Himalaya	18
	(b) Stratigraphic Sequence	19
	i) Trikuta Formation	22
	ii) Eocene Formation	29
	iii) Murree Formation	34
	Structure	35
	(a) Major and Minor Structures	36-40
	(b) General discussion of the tectonics	41-53
	3. Petrography of the Trikuta Limestone	54-102
	4. Jammu Eocenes	
	(a) Petrography of the Bauxites	106-133
	(b) Petrography of the Coal	134-153
	(c) Petrography of the Nummulitic Limestone	154-170

5. Petrography of the Murree Formation 171-198

6. Depositional history of the Coal Belt 199-208

7. Summary and Conclusions 209-218

List of Plates 219-222

List of Tables 223-225

Bibliography 226-245

PREFACE

PREFACE

This work pertains to the sedimentological investigations leading to basin analyses of the eastern part of the Jammu Coal Belt. Ever since the discovery of coal in this area number of investigations have been made by eminent geologists to find out the total reserves and the quality of coal available in the belt. No attempt, however, has been made by any one so far to work out the nature of the basin and its depositional environs in which coal was deposited. This work fulfils these objectives. In order to achieve this aim, the whole sequence of rocks from base to top has been studied. This involved the studies of both clastic and non-clastic rocks which are found in different units. These have been studied by modern sedimentological techniques.

The whole sequence has been sub-divided into three main formations viz. the Trikuta Limestone, the Jammu Eocenes and the Murrees. The formations have been further classified into smaller units depending upon the textural, structural and compositional aspects. These studies provided sufficient data to work out their provenance and depositional environments which have halped further to understand the evolution of the basin.

As a result of this study, it was found that the Trikuta Limestone acted as basement rocks of the coal basin. This limestone represents tidalite deposits mostly supratidal which might have been deposited in a

lagoon like basin, the modern analogue of which we find at Coorong in the south Australia. The Jammu Eocenes in which the coal is found at the base represent open marine sea in which limestones and shales were deposited in a cyclic manner. The gradual shallowing of this sea by the emergence of rocks ultimately gave rise to esturine and deltaic conditions in which the Murrees were formed.

All possible endeavours have been made to work out each and every detail of the subject and to interpret the data on the lines of modern thought but the frontiers of science are unlimited. This work may, therefore, be viewed as a humble beginning in this direction. Much more further detail work is required on each formation before reaching any final verdict. New techniques might be developed in future by the aid of which future workers might study them from different angles.

Most of the work has been carried out in the sedimentological laboratory of the Post-Graduate Department of Geology, University of Jammu, Jammu. However, some work the facilities of which were not available has been got done in different laboratories of the country. In this regard I wish to express my sincere thanks to Dr. M.D.Karkhanawala, Head Chemistry Division, Bhaba Atomic Research Centre, Trombay (Bombay), Prof. K.S.De, Chairman, analytical laboratory, Indian Institute of Technology, Kharagpur and Dr. E.R.Saxena, Head, Mineral Products and

Inorganic Chemicals Division, Regional Research Laboratory Hyderabad (A.P.), Head, Division of Soil Science Agricultural Chemistry, I.A.R.I., New Delhi and University of Agricultural Chemistry, Bangalore, for their help in D.T.A. work. Thanks are due to Dr. V.K.Verma, Professor and Head, Department of Geology, Delhi University, Delhi, Dr. S.Varadarajan, Delhi University, Delhi, Dr. B.Rama Rao, Head, X-Ray Group, Regional Research Laboratory, Hyderabad, Dr. A.R.Vasudeva Murthy, Department of Inorganic and Physical Chemistry, Indian Institute of Science, Bangalore, Director General, G.S.I., Calcutta, for providing facilities for X-Ray investigations. The spectrochemical analyses were got done from National Geophysical Research Institute, Hyderabad and the Chemical analyses of coal were got done from the Coal Survey Laboratory, Jammu. My thanks are also due to all those who inspired, encouraged, guided and helped me in my research work.

I express deep gratitude to my supervisor, Dr. T.R.Bhatia, of the Post-Graduate Department of Geology, University of Jammu, Jammu for his inspiring guidance, unfailing encouragements, constructive suggestions, unstinted and unwearied assistance in all phases of my work, without his help the completion of this study would have been well nigh impossible. I am also grateful to Dr.T.R.Sharma, Professor and Head, Post-Graduate Department of Geology, University of Jammu, Jammu for placing all the necessary laboratory and library

facilities at my disposal.

Finally, I am grateful to University Grants Commission, New Delhi who provided me financial assistance to complete the field work of the present research project.

Satish Chadha

Jammu-Tawi,
July, 1978.

(Satish Kumar Chadha)

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

(i) Statement of the problem

(ii) Area of Study

(iii) Approach to the area

(iv) Physical features of the area

& (v) Nature of the present work

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

(i) Statement of the problem.

Within the sub-Himalayan zone of Jammu hills, there exists a coal belt (Plate No. I) which extends from the Jangal Gali (Lati $33^{o}01'15"$ N : Long. $75^{o}01'25"$ E) in the East to the Kalakot (Lat. $33^{o}12'$- $33^{o}15'15"$ N : Long. $74^{o}23'30"$- $74^{o}26'30"$ E) in the west. This coal belt flank the northern part of the Trikuta Limestone in the eastern side and completely surrounds on all sides the isolated domes of the Mahowgala and the Kalakot. The limestone inliers are magnificently set within the younger Tertiary rocks.

The coal belt attracted the attention of many early workers of whom mention may however, be made of La Touche (1888), [Godwin, 1901, Mort, 1902, Hope, 1902 (Simpson, 1904)], Simpson (1904), Wright (1906), Middlemiss (1914-1929), Srivastava (1956), Mehta & Srivastava (1959), etc. The main work of these stalwarts was confined to the estimation of the quality and reserves of coal and other economic products in the various fields but no particular attention was paid to the petrogenesis of the rocks in which coal has been found.

There were certain other workers like Medlicott (1976), Wadia (1928-1937), Auden (1944), etc.; who debated certain structural and stratigraphical aspects of the rock units associated with the coal belt but they

also did not pay any serious attention to their mode of formation.

More recently, Pratap Singh (1970) has touched upon certain palaeontological aspects of the Subathus which is one of the important units of the coal belt but no serious thought has been given to the depositional environment under which the rocks were deposited.

Above mentioned contributions, though excellent in their own fields, yet have either structural or stratigraphical bias. No study of the coal belt will be complete unless it takes into consideration the depositional history of the rocks. This type of inquiry throws a lot of information on their depositional environments and also the distributional pattern of the coal seams. The present work, therefore, is an attempt to fill up the lacuna in our existing knowledge.

(ii) Area of Study.

In this study only the eastern part of the coal belt extending from Jangal Gali to Salal has been undertaken.

The area under investigation lies in the Udhampur district of Jammu, J&K State and falls between Lat. 33°01'15" to 33°10' N and Long. 75°01'25" to 74°50' E, encompassing an area of about 500 sq. km. The area studied forms part of Survey of India topographic Sheet Nos. 43 k/16, 43 L/13, 43 O/4 and 43 P/1, on a

scale 1 : 63, 360. (Plate No. II).

The area has moderate climate with fairly hot summers and tolerably cold spell. Mercury rises as high as 102°F during April to June and falls as low as 30°F during December to January. The mean average rainfall is 1050 mm. The vegetation at higher altitudes include long leafed conifers while the low altitude areas support deciduous trees, small leafed accacias, wild shrubs and thorny bushes. The chief crops are Maize, Bajra, Wheat Paddy and Pulses. The terrain is hilly and not densely populated.

(iii) Approach to the area.

Jangal Gali (Lat. 33°01'15" N and Long. 75° 01'25" E), the eastern most part of the coal belt, is hardly 16 km from Tikri (Lat. 32°56'30" N : Long. 74° 57' E) which is at a distance of 45 km from Jammu on the Jammu Srinagar National Highway.

Salal (Lat. 33°10'00" N and Long. 74°50' 00" E), an important village in the western part of the area lies at a distance of about 105 km from Jammu via Katra. A link road also connects Katra town with Tikri.

(iv) Physical features of the area.

The area has low relief, rugged and mature topography. The Jammu (Lat. 32°44' N : Long. 74°52' E) hills in the north range in altitude from 600 m to 2800 m, while in the south is a vast plain with an

elevation of 300 m. The higher hills in the north have gigantic escarpments and dip slopes separated by broad longitudinal strike valleys. The offshoots of the ranges run parallel to one another for considerably longer distances and are called by the natives as DHARS. The Chief "Dhars" are SAROLI DHAR (2511 m), DEVI DHAR (2708 m), BASINDA DHAR (2498 m), etc. The TRIKUTA (Atharvaveda-Trikakud" or "Trikakubh" meaning three peaked mountains) is the highest peak (2710 m) in the area. Its glimps can be had even from the far off places of Jammu. Within these mountain ranges are the passes locally known as GULLIES or GALLAS such as Sukhwal Gali (2103 m), Batal Gala (1028 m), Panchari Gully (1888 m), Sarli Gali (1577 m), etc. The gradient in the higher Jammu Hills is 5° while in the lower hills it is about 3°. The hill slopes according to Savigear's principle can be classified into CREST, MID and FOOT slope.

The Chenab ("Asikni" of the Vedas and "Acesines" of the Greeks) is the only major river fed by several ephermal tributary streams such as the Anji, ~~the Burr~~ the Bhurru, the Jalwan, the Kotri, the Mari, the Pei etc. Among the perennial tributaries, mention may, however, be made of the Ans, the Balan and the Rad. All these flow north to south and join the Chenab near Arnas (Lat. 33°11'30" N : Long. 74°59' E), where the Chenab takes an abrupt syntaxial or "Knee shaped" bend of

about 80°. The flow which is initially east-west now becomes north-south. The "Chenab re-entrant" is probably due to certain sub-crustal structural dearrangement. The loop which the Chenab makes (Plate No. III) at Dhiangarh (Lat. 33°08'25" N : Long. 74°48' E) has conveniently been employed for the construction of a rock fill dam. Taking the advantage of the narrow saddle here, it has been proposed to make a spilway on the right side and a power houses at the toe of the left abutment saddle. The river makes a typical deep "V" or "I" shaped Valley at Salal. The tributary streams make mini Valleys locally called as KHADS such as the Anji Khad, the Mari Khad, the Pei Khad, the Samat Khad, etc. Most of these are the strike valleys through which the streams flow.

Among the minor streams draining the eastern sector of the area, are the Dadda, the Kala Gabbar, etc. No stream has been observed to flow East to West in the area and the drainage pattern, as a whole, is that of the "Radial Type".

The overall bifurcation ratio is 5.3 and the drainage density in the area is 2.6. This low drainage density reflects the mature topography.

(v) Nature of the present study.

The present work consists of an extensive study of rocks in the field supplemented with their investigations in the laboratory.

I. Field Work.

It includes mapping, measurement of some important sections and systematic sampling.

(a) Mapping.

The mapping was done mostly during the period of 1973 to 1977, as and when the opportunities for visiting the various areas arose.

Mapping on 1 inch : 1 Mile was done of the whole area but certain areas, e.g., the Jangal Gali-Sukhwal Gali, Reasi-Salal etc. were mapped on a larger scale i.e. 4 inch : 1 Mile. In all, an area of about 500 sq. km. was mapped.

(b) Sampling.

Samples were collected from the measured sections at an interval of 2 metres from all the horizons.

II. Laboratory Work.

The following laboratory techniques were used to study various types of samples collected in the field.

(a) Limestones (both Trikuta and Nummulitic)

These were studied by the following techniques:

(i) Thin section petrography.

(ii) Chemical Analyses by E.D.T.A. methods.

(iii) Insoluble residues by the methods introduced lately.

(iv) Staining techniques as suggested by Friedman (1959) were employed to determine

the presence of calcite and dolomite. The staining was chiefly carried out by using Alizarine Red-S solution.

(v) D.T.A. of representative samples were conducted to corroborate the results derived from other investigations.

and (vi) X-Ray diffraction by powdered method was done to determine the presence of mineral assemblage in various rocks types.

(b) Chert Breccia was studied by :-

(i) Thin section petrography

& (ii) Size and Shape analyses.

(c) Bauxite was studied by :-

(i) Thin section petrography

(ii) Chemical Analyses

(iii) D.T.A.

(iv) X-Rays

& (v) Spectrochemical Analyses

(d) Coal samples were studied by the following techniques:-

(i) Study of the coal pellets by reflected light.

(ii) Chemical Analyses- both proximate and ultimate.

(e) Murrees

Sandstones were studied by the following techniques:-

(i) Thin section petrography

(ii) Size Analyses- on account of undurated and compact nature of the Murree sandstones, sieve analyses were not possible, hence, the number frequency was determined under thin sections and it was later converted to weight frequency.

The analytical data obtained from the above investigations has been put to the discipline of statistics in order to get concise results and to eliminate the chances of errors and omissions.

Chapter 1

Historical Resume of the Previous Work.

C H A P T E R - I

Historical resume of the previous work.

The area under investigation received the attention of a large number of scientists on account of its economic potentialities as good reserves of limestone, bauxite, coal, clays, etc. are present here. The area also received consideration on account of its complex tectonic adjustment within the inner Tertiary belt of Sub-Himalaya of Jammu. The following is a brief resume of the previous work carried out on different rock units exposed in the area.

Medlicott (1876) was probably the first geologist who made a mention of the stratigraphy and economic potentialities of the area under investigation. In his contribution titled "Note upon the Sub-Himalayan Series in the Jamu (Jamoo) Hills", he gave a very vivid picture about the great inlier of old limestone within the Tertiary area, which forms the basement of the Subathu formation in which coal is found and of other younger Tertiary rocks. According to him, the great inlier is not a continuous one but represents a chain of isolated small patches all running parallel to the main trend line of the mountains from east to west. The eastern most patch known as the Reasi inlier is the biggest one, as he writes, "the principal mass of

limestone is at the south east end, where for a length of thirty miles it forms a lofty picturesque ridge, through the very centre of which the Chenab has cut a precipitous gorge, just north of Reasi".

This limestone according to Medlicott is succeeded by the Subathu group of rocks, the bottom most beds of which constitute the pisolitic clays which at places become highly ferruginous. These are, according to him overlain by coaly bands on which the nummulitic limestone rests. He also mentioned about the siliceous breccia under the Subathu in which iron ore is extensively mined at Sangar Marg ridge. Medlicott (1876) believed this rock to be a shattered condition of a sandstone band that often occurs at the top of the "Great Limestone series". According to him, the iron ore is a cellular limonite occurring in nests and stringes through the breccia. It is probably derived by decomposition and infilteration from the coaly band of the Subathu Group.

The relation of the Subathu group to the Great Limestone mass is most uniform one and on account of the unfossiliferous nature of the latter, he could not find any special points of resemblance in it to the Krol group of the outer Himalaya.

Regarding the quality, Medlicott considered the formation as unfossiliferous, dense, cryptocrystalline

thin bedded, locally cherty and has intercalated bands of siliceous slates and flags. This is in sharp contrast to the Subathu limestone which he described as compact, earthy and highly fossiliferous with fossils of nummulites.

La Touch (1888), [Godwin, 1901, Mort, 1902 and Hope, 1902 (Simpson, 1904)] also made simple reference to the area and briefly described the rock groups, while prospecting for the economic minerals like coal etc., but did not discuss any rock group in detail.

Simpson (1904) was the first person who used the term "Jammu coal belt" for the area under investigation and elaborated in detail the geological setting, and further classified the rock units especially the Sabathus described earlier by Medlicott (1876). He prepared the geological map of the entire coal belt extending from Jangal Gali to Kalakot and described all the important sections. Within the area of present study, he described in detail two Coalfields viz. the Ladda and the Salal. He calculated for the first time the coal reserves of the coal belt and described in detail the physical and chemical aspects of the coal. According to him the Ladda coal is extremely friable, slightly bituminous and shows no regular bedding planes but has a strongly foliated character. The coal is bright and lustrous along the foliation planes. It burns with little flame or

smoke. The ash content is almost invariably high. Apart from its high ash content, it is highly friable. This crumbling nature is due to earth movements from the north east to which these rocks have been subjected and being brought to the surface .The coal is only occasionally of a caking quality.

Middlemiss (1917-1929) made a comprehensive study of the various aspects of the whole coal belt extending from Jangal Gali to Kalakot and published his findings in the form of various reports published by the Mineral Survey Deptt. of Jammu & Kashmir Govt. From the study of these reports, his contribution to the geology of the coal belt can be summarised as follows:-

1. He retained almost the same sequence of formations as introduced by Medlicott and Simpson. The tectonic set up was also discussed by him. He stated that the Jammu Coal Measures occur on the NE and SW flanks of the elongated domes. These coal bearing strata are inclined for the most part at moderate to steep angles outwards from the axes of the domes. They present old massive limestones and other rocks protruding through and among the Sub-Himalayan zone of younger Tertiary rocks.

2. Although he worked out the geology of the Western part of the coal belt, viz; Kalakot, Metka, Mehowgala, etc., yet he made a reference to the Ladda

Coalfield as well. An interesting part of his report on coal is that he and his colleagues discovered the "Lower Coal Measures" in addition to the "Upper Coal Measures" as recorded by Medlicott and Simpson. But this discovery was reported only in the Kalakot, Metka, Mehowgala and some other Coalfields in the western sector and not in the Ladda and Salal areas. He also established the higher rank and the quality of the "Lower Coal Measures" as compared to the upper one.

3. In his report on the bauxite deposits of Jammu & Kashmir, he surveyed and mapped the bauxite spreads at Jangal Gali, Salal, Panhassa and Chakkar areas and worked out the economics of these deposits. He sub-divided the "Bauxite series" into pisolitic, semi-pisolitic, non-pisolitic and Kaolinitic horizons. He discussed the physical and chemical properties of rock types belonging to different horizons. He established that a definite relationship exists between the silica percentage and the specific gravity. He also worked on the mode of occurrence and the genesis of the bauxite deposits.

4. In his reports on the metallic and non-metallic minerals of Jammu & Kashmir State, he gave a comprehensive account of the sulphide mineralisation in the "Great Limestone" and also worked out the occurrence and mode of formation of the ore deposits.

Pratap Singh (1970, 1973) contributed much to

the study of the Subathus, while working on the smaller foraminifera of the Jangal Gali area. On the basis of rich foraminiferal assemblage, he assigned a Lower Eocene age to the Subathus. He also made an attempt to correlate this formation to the Subathus of Dharmsala and Simla areas. He sub-divided the formation into four groups, i.e., the Jangal Gali Formation, the Beragua Formation, the Kalakot Formation and the Arnas Formation. He further established in it three "Biostratigraphical zones and gave a sketchy account of each zone.

Chapter 2.

Stratigraphy & Structure

I. STRATIGRAPHY

(a) Geologic set up of the area within the broader frame work of the Himalaya.

(b) Stratigraphic sequence

i) Murree Formation;

ii) Eocene Formation;

& iii) Trikuta Formation.

II. STRUCTURE

i) Folds;

ii) Faults & Thrusts;

iii) Joints;

iv) Unconformities;

v) General discussion of the tectonics.

I. STRATIGRAPHY

(a) Geologic set up of the area within the broader framework of the Himalaya.

The area under investigation embraces only a section of the Sub-Himalaya of Jammu. Longitudinally, it falls in the outer Himalaya and latitudinally, it forms a constituent unit of the Punjab Himalaya. The higher Jammu hills including the picturesque Trikuta (2700 m) form the northern boundary of the area. The hills run in narrow parallel ridges with their strike persistently in the NW to SE direction separated by narrow valleys of longitudinal streams and deep gorges of their secondary and tertiary branches. On the south, are the vast plains of Jammu, where the altitude does not exceed 300 m above the mean sea level. The northern limit is probably less defined while the southern limit is sharp, well defined and changes the direction gradually. The eastern boundary is marked by the streams such as the Dadda, the Kala Gabbar etc., while the river Chenab forms the western limit of the area.

Within such a framework lies a coal belt known as Jammu (or Ladda) coal belt. It is fringed and flanked by younger rocks of Tertiary age. The Chenab divides this belt into two parts i.e. the eastern and the western. The present study is confined only to the eastern part which has three formational units with

marked lithological and structural characters.

(b) Stratigraphic Sequence

The stratigraphic succession of the area has been worked out by Medlicott (1876), Simpson (1904) and Middlemiss (1929) etc. Their classifications are almost identical but differ in minor details only. Broadly speaking, the rock units have marked variation in lithology from top to bottom (Plate No. 50). The oldest unit is thick, unfossiliferous, dolomitic limestone, the base of which has not been exposed in the area. On this dolomitic limestone rest the younger Tertiary rocks consisting of the Eocenes and the Murrees of Eocene to Middle Miocene age. The unconformable junction between the limestones and the Eocenes (or Subathus) is marked by beds of Chert Breccia and Bauxite.

Many workers have tried to classify the formational units of the area based on lithostratigraphy and constituted the stratigraphic column. Their efforts were no doubt very rewarding but do not suit the need of present work. In this direction, an attempt has been made to improve upon the earlier classifications and to reconstitute the stratigraphic column. The broader units have further been sub-divided on the basis of their sedimentological characters. The oldest limestone unit has been sub-divided into three parts i.e. the

lower, the middle and the upper. Similarly, the Jammu Eocenes (or the Subathus) have been sub-divided into the lower, the middle and the upper and the Murrees have been considered as one major unit. In this effort, care has been taken to retain the old stratigraphic terminology wherever possible but a compelling necessity has been felt to incorporate some new terms to bring clarity in the matter. A generalised view of the stratigraphic column of the area is given in Table I.

T A B L E - I

Stratigraphical Column of the Area

Group	Formation	Member	Lithology	Thickness	Age
Tertiary	Murree Formation	-	Dark grey and purple sandstones interbedded with purple shales.	UNKNOWN	Middle Miocene oligocene -
Tertiary	Eocene Formation or Jammu Eocenes	Upper Member	Splintery grey shales.	2-4 m	E
			Limestones with fossils and bands of shales.	6-12 m	O
			Shales	6-10 m	
			Nummulitic Limestone with bands of shale.	3 to 100 m	C
			Shales	4 m	
		Middle Member	Upper Coal Measures	4-6 m	E
			Pyritous and Hematitic shales.	2-4 m	N
			Ironstone shales, at places carbonaceous.	6-10 m	E
		Lower Member	Lower Coal Measures		Eocene
			Bauxite beds comprising pisolitic, semi-pisolitic and non-pisolitic horizons.	3-4 m	Upper Cretaceous
			U n c o n f o r m i t y		
Palaeozoic or Proterozoic(?)	Trikuta Formation	Upper Member	Chert Breccia	5-30 m	
			Hematitic Chert quartzite, Cherty.		Permian or Upper Pre-Cambrian
		Middle Member	Limestone with bands of oolites.	Unkown	

Lower Member	Dense, Cryptocrystalline or massive, flaggy, dolomitic limestone, replaced at places to magnesite with bands of stromatolites. (Thickness unknown).

BASE NOT EXPOSED

Trikuta Formation

It is an oldest formation in the study area and consists of a thick pile of magnesian limestone. It is exposed in the vicinity of Katra and Riasi within the younger Tertiary rocks. Starting from Jangalgali in the east, it extends to Salal and further west to Chakkar, it reappears in the form of isolated domes at Mahowgala, Metka, Kalakote, etc. The formation has a very striking stratigraphic significance both from the abruptness of its relief and from much worn serrated aspect of the steep limestone crags protruding through soft sandstones and clays of Tertiary age.

In the literature, the formation has been known under various names such as "Great Limestone" Medlicott (1864), Wynne (1872), Lydekker (1876) and Simpson (1904), "Sirban Limestone" Wright (1906), Middlemiss (1924-29), Waishno Debi Limestone Rao, et.al. (1968), etc. Each name has its own

significance and merit but for the present work the name "Trikuta Formation" is proposed on account of the "Trikuta hills" - a most picturesque topographic feature that dominates in the relief of the area.

The formation is in the form of a dome having a length of about 80 km and a breadth varying from 8 to 20 km with the strike of the rocks being NW to SE. The domal character has been established on the basis of fluctuations in the amount and direction of dip of the rocks. The rocks in the east have a general strike of N 75°W - S 75°E, dips being 52° due N15°E. On the west, the strike of the beds is WNW-ESE, with dips being 25° to 60° due NNE.

The outcrops of the formation have been exposed at Muttal and Jangalgali in the east (Plate No. 51) at Katra, and at Riasi-Salal (Plate No. 52) in the north west of Jammu. The strike at Jangal Gali is N 60° W - S 15° E to N 30° W - S 30° E with dips ranging from 50° to 78° due north. At Salal, the strike varies from N 70° W to S 70° E to N 80°E to S 80° W with dips 30° to 50° due north.

The Trikuta formation is almost wholly composed of limestone which has been dolomitised to a much greater extent. In outward appearance, the limestone rock is greyish blue to greyish white in colour, hard, compact and microcrystalline in texture. In thin sections, almost all the varieties show a strong tendency towards crystallisation due

to dolomitisation. This transformation of limestone to dolomite has resulted in the development of new textures and microstructu Many of the structural features associated with the various types of rocks have been discussed in detail but at their relevant places.

The part of the limestone has also been subjected to silicification which is mostly confined to the upper portion of the formation. The silicification has both concordant and discordant relationship with the main body and it appears in the form of Chert bands, nodules, stringes, veins and lenaes of various shapes and sizes.

Another interesting feature of the limestone is the presence of some oolitic and stromatolitic bands in certain horizons. At places, the upper part of the formation consists of pelletic material mostly slates of calcareous composition.

The upper most part of the formation is brecciated. Early workers considered it a separate stratigraphic unit altogether but in the present work evidences have been collected to prove that the brecciated horizon conventionally known as CHERT BRECCIA belongs very much to the limestone formation itself

The limestone has been highly mineralised at places. The ores of lead, zinc, copper and iron have been developed in the shear zones at a number of places like Darabi (Lead, Zinc, etc.), Doga (Copper), Panhasa (Cobalt, Nickel etc.), Sersandu (Lead, Zinc, Copper, iron, etc.), Gainta (Copper, etc.),

Matah (Iron, etc.) etc. Though the total reserves do not encourage their economic exploitation yet their presence has aroused considerable academic interest.

A part of the limestone has also been transformed into magnesite which occurs in Sizeable dimensions near Painthal (Lat. 32°59' 30"N: Long. 74°59'E), Katra (Lat. 32°59' 30" N: Long. 74°56'E), Adkanwari (Lat. 33°0' 31"N: Long. 74°56' 51"E), Pei-khad & Salal (Lat. 33°10'N: Long.74°50' E). Keeping in view their outward appearance, physical characters and field relationship, the magnesite can be sub-divided into three categories viz. fine grained, coarse crystalline, compact and massive with a characteristic saccharoidal texture. All the varieties show characters which strongly suggest replacement origin.

The joint planes in the limestone carry veins of variable dimensions which are impregnated with the minerals like calcite, barytes, dolomite, siderite, etc.

The total thickness of the Trikuta formation can not be estimated on account of the fact that its base has not been exposed anywhere.

The limestone is totally unfossiliferous and excep for a few algal structures, no trace of life has been reported so far by any scientist.

The age of the Trikuta formation still poses a baffling problem on account of two above mentioned factors, i.e.

the unfossiliferous nature of the limestone and an unexposed base. References to age starting from Jurassic (Medlicott, 1864) and Permian (Wadia, 1937) down to Pre-cambrian (Raha and Sastry 1973, Raha, 1975, Raha et.al. 1978, etc.) have been made but no final verdict has been given so far.

No attempt worth recording has so far been made to classify the Trikuta formation into various distinct units. All that has beeh done upto date is to recognize some litho zones based on superficial petrographic characters. Recently Gundu Rao (1973) has made an attempt to classify this limestone into seven units but in this work, however, an attempt has been made to subdivide the formation on its inherent characters and as such the formation has been divided into three units i.e. the upper, the middle and the lower. The chief characteristic features of each unit are as under :-

Lower Member

The lowermost member of the Trikuta Limestone is typically exposed near Dhiangarh dam site, Anji (Lat.33°04' 30"N Long.74°53' E), Katra, Hansal (Lat. 32°59' 50" N : Long.74°56' 30" E), Namal (Lat. 33°8' 30"N : Long. 74°45' 30" E), Purana Daruhar (Lat.33°N : Long. 74°57'E), etc. Much of the Trikuta formation belongs to this member and in all the localities, it consists of hard, massive and greyish black coloured limestone. This limestone differs from the limestone of other members on account of a fairly higher percentage of magnesia. The magnesite

alteration of the limestone is also located within this unit. The chief characteristic feature of this unit is the dominance of algal structures which appear either in the form of various laminated bands or stromatolitic nodules of various shapes, and sizes. Previously these nodules were reported at a few places but in this work number of additional localities have been discovered (Chadha, 1975) in the present study area. In addition to stromatolites, a few oolitic bands have also been discovered (Chadha, 1976a, 1977) at Dhiangarh and Katra.

An interesting feature of the lower member is the metalliferous mineralisation. The occurrence of ores of lead, zinc, copper, iron, cobalt, nickel, etc. are known since long. The control of mineralisation is mainly structural, while lithology has only played an insignificant role. The principal structural controls are bedding planes and contacts, induced cavities, bedding thrust and faults, Joints (Plate No. 19), etc. Most of the deposits are either telethermal or hydrothermal in character.

Middle Member

This member conformably overlies the lower member and exposed near Salal. No clear line of demarcation can be marked between the lower and the middle members of the Trikuta limestone. There is much interfingering between the two. However, certain well defined characters help to differentiate the middle member from the Lower, Firstly, the middle member is markedly more

silicified than the lower member. Although even in the lower member the silicification has affected the limestone but it certainly dominates in the middle portion where silicification has resulted in the formation of chert. The bands of chert are either interbedded with the limestone or cutting across the bedding planes in disorderly manner. Secondly, the percentage of magnesia is slightly lesser and a few beds of limestone almost magnesia free have been found at Salal, Malatha village, Riasi east, Garan (Lat. 33° 05' N: Long. 74° 58' E) etc. Thirdly, Stromatolitic laminations do occur but in a much reduced degree. Magnesitic alterations are totally missing.

The uppermost part of the middle member is more pelletic in character although identical in composition. This pelletic portion appears in the form of flaggy slates and the outcrops of such rocks have been observed at a number of places such as Devi Dian Pinddian - North of Painthal (Lat. 32° 59' 30"N: Long. 74° 59' E), Mari (Riasi), etc. Wadia (1937, P. 162-173) observed the same rock near the village of Sumlar, below the ruined Fort of Devigarh and thought it to be a representative of "Agglomeratic Slate Series" of the Panjal Volcanic group of the Pir Panjal Range and he wrongly thought it to be of Permo-Carboniferous age. In this work it has been established beyond doubt that these slates belong very much in composition to the general character of the limestone itself and they are not of volcanic origin.

Upper Member

The proposed member of the Trikuta Formation in this work is chert breccia. Previous workers have considered it to be a distinct unit resting over the limestone. An effort has been made to collect evidences to prove that the fragments of breccia are the result of desiccation cracks which have been cemented together to form a distinct rock and therefore, belongs very much to the the limestone itself. This unit forms a uniform blanket over the limestone and has been evenly distributed in the study area. The fragments are mostly angular or sub-angular of the nature of Chert and limestone and cement is mostly siliceous. At places, the pore spaces of the breccia are mineralized. The thickness of this unit varies from 5 to 30m everywhere.

Eocene Formation

The rocks of Eocene age are exposed all along the area starting from Jangalgali-Sukhwalgali to Salal and beyond fringing the Trikuta Formation. The outcrops occur as a discontinuous strip along the northwest to south East margin of the Riasi dome (Plate No. 50).

La Touche (1888) was probably the first to use the term Subathu for the Eocene rocks exposed between Sangar Marg and Mehowgala. Later workers such as Simpson (1904), Wright (1906), etc., also retained the same terminology for Eocenes of Jammu Coal belt. Wadia (1926 pp.377-378) explained that there

is wide variation in the lithological characters of the Subathus of the two regions. The Subathus of Simla are more arenaceous while those of Hazara are more calcareous whereas those of Jammu show characters inbetween these two. The sand beds in case of Jammu Subathus are confined either at the top or at the bottom of the Coal seams. The limestone and coal being the predominant while the arenaceous matter occurs in subordinate amount.

Pratap Singh (1973) sub divided the Subathu group into four lithologic formations i.e., the Jangal Gali, the Beragua, the Kalakot and the Arnas. He sub-divided the Jangal Gali Formation into two sub-divisions i.e. the Khargalla Chert Breccia member and Lain Bauxite members According to Middlemiss (1929) and early workers, however, both Breccia and Bauxite are mainly residual rocks derived from the exposed surfaces and edges of the Trikuta Limestone and their age, "must be something between Gault and Eocene". The term Subathu however has been restricted by Simpson (1904) and Middlemiss (1929) for younger Eocene rocks ranging in age from upper Laki to Lower Kirther and it is, therefore, not understandable how Partap Singh has included Breccia and Bauxite horizons in Subathu more particularly when they happen to be unfossiliferous.

Wadia (1926, p. 377-378), however, considered that basal beds of Eocene of Jammu are highly aluminous clays, pisolitic limonites and bauxite alongwith the overlying coal Measures. Middlemiss (1929) recognised two horizons of Coal Measures, Lower Coal Measures being equivalent to Bauxite while

the upper Coal Measures being an integral constituent of the Subathus.

In the present work, an attempt has, therefore, been made to use the term "Jammu Eocene" for Subathus and the following sub-divisions have been proposed :-

Lower Member - it consists of bauxite and Lower Coal Measures.
Middle Member - it consists of Upper Coal Measures alongwith the associated ironstones and shales.
Upper Member - it consists of alternate bands of limestones and shales.

The chief characteristics features of each member are as under :-

18760

Lower Member

The base of the Subathus are composed of residual deposits of aluminous clays, laterites and pisolitic bauxites having a variable thickness from 2m to 9m. The bauxite at places also gets mixed up with coal. In the area under investigation the best outcrops of bauxite have been exposed at Salal (Plate No. 21). The bauxite beds show same structural attributes as are found in the overlying and the underlying formations. It is the largest outcrop known and rests over Chert Breccia with a vertical thickness of about 9 metres. Outcrops have also been observed in the Jangalgali-Sukhwalgali area resting over the Chert Breccia with the usual position. Excellent outcrops have been located near Lain. The spreads of bauxite at Lain are less coherent than those found at Salal.

The bauxite is variable in its composition besides having non-pisolitic (or Kaolinitic) varieties, it has got semi-pisolitic and pisolitic material of varying composition and colour

Middle Member

Bauxites of the lower member are conformably overlain by a mixture of ferruginous, Carbonaceous and arenaceous meterial having a thickness of a few hundred metres. The ferruginous material is developed in the form of iron nodules often of septarian type, ferruginous shales, ironstone bands, nodules and lenticles. There is a sharp contrast between bauxite and this material. In ancient days this limonite ore was used for the extraction of iron in local industry. The ironstone shales have a thickness of about 10 metres.

Ironstone shales in turn pass into carbonaceous shales and within these are found beds of coal. The thickness of the coal bands is variable from a few centimetres to a few metres. At Lain (Lat. 33° 00' N: Long. 75°5' E), the maximum thickness of Coal seam is 6 metres. The coal is highly crushed and friable and due to intense tectonic activity, its rank has been raised to that of semi-anthracitic variety. Those of the Coal seams which are associated with Ironstone shale have been designated as upper Coal Measures, while those associated with bauxite have been named as Lower Coal Measures. All the Coal seams exhibit different physical and Chemical properties. In the area under investigation Lower coal measures have not been located anywhere though they have been excellently developed

in the west at Kalakot, Metka, Mahowgala, etc. Associated with the coal beds are arenaceous bands known popularly, as siliceous grit which acts as a roof or base of coal mine.

Commencing from Muttal, the south eastern point of the Riasi dome, a recognisable coal outcrop is first noticed along the nala at Lain. Passing up the slope from the Lain, the outcrops are exposed at Doodar nala, Jungal ravine, at places between Jangal Gali and Sukhwal Gali (Lat. 33°2' N : Long. 75°4' E). From Sukhwal Gali the ground descends to the bed of the Anji stream and scattered and patchy outcrops of coal have been observed all the way down to a village of Santrani Kund (Lat. 33°2' N : Long. 75°3' E) about 1.6 Km. from the crest. At Santrani Kund the coal seam is about a metre thick and dips north east at an angle of 30°. In the Anji bed, the outcrops of coal become obscured by debris. Another seam of coal appears at Kotri (Lat. 33°4' N : Long. 75°3' E) just across the stream and continues until the Anji stream is re-crossed 5 km below, at Bowli (Lat. 33°4' N : Long. 75°3' E). Some outcrops have been observed in an area between Anji and the Chenab Valleys.

The outcrops of coal have also been observed at several places between Mootal (Lat. 32°59' N : Long. 75°4' E) and Sandrani (Lat. 32°59'00" N : Long. 75°00'00" E) but nowhere the thickness of the coal seams exceeds a few centimeters.

Upper Member

It is constituted of distinct limestone bands

alternating with olive shales. Both the limestones and shales are profusely laden with micro fossils of foraminifera. The greater number of species belong to the larger foraminifera eg., Nummulites and Assilina, while a fairly good number belongs to the smaller foraminifera more especially of the species Rotalids, Miliolids, etc.

Some of the bands especially the uppermost ones are rich in the fossils of lamellibranchs and those bands lying below these contain a rich assemblage of echinoids.

The limestone is dark in colour and argillaceous in composition. There as as many as five distinct bands of limestones. The middle band contains nodules of phosphorites. The rocks of this member are typically exposed at Salal and Sukhwal Gali-Jangal Gali area.

Murree Formation

All along the area of study, the Eocene group of rocks are succeeded by a thick pile of clastic sediments of many hundred metres in thickness which are known in the literature as MURREE FORMATION. The junction between the two formations is apparently a conformable one.

The main constituents of Murrees are hard sandstones and claystones arranged in an alternating beds. The shales are of red chocolate colour while sandstones are greyish white to greenish. The sandstones are orthoquartzites to protoquartzites in composition whereas some of the claystones

contain the greenish mineral glauconite. Ripple marks of various types are very common in this formation along with small scale cross bedding. Sabal major is the most dominant plant fossil in these rocks although at places some dicotyledon leaves have also been found. Ranga Rao (1971) has found vertebrate fossils from the similar rocks at Kalakot. From all the available evidences, this formation appears to have been formed under deltaic environments.

This formation follows the same domal trend as that of Subathus and underlying Trikuta Limestone except in the southern side where it has been cut by a series of reverse faults. The easternmost exposure of this formation, has been located near Lain where it is seen on the right side of the Do-Khadda stream (Plate No.51) where it has been thrown into complex folding. This easterly trend takes a turn towards west near Sukhwalgali and continues upto Salal and further extend to Chakkar (Lat.33°11'. N : Long. 74° 39' E) where it again takes a swing towards south. The only remnant of the formation in the southern side is seen near Katra where Murrees are exposed along the Subathus.

II. STRUCTURE

The tectonics of the study area has been discussed in detail by Medlicott (1876), Simpson (1904), Middlemis (1928, 1929), Wadia (1937), Rao et.al (1968) etc. The basic featur is the exposure of oldest formation of Trikuta Limestone through the younger Tertiary rocks in a domal form. An interesting feature

of the dome being that the main trend of the Trikuta Formation is an arcuate one. Starting from Jangalgali in the east which mark the easternmost limit of the Trikuta outcrops, it swings towards north west from Sukhwalgali. This trend continues upto Chakkar where the outcrops again swing towards south (Plate No.50). The younger Tertiary rocks of Eocene and Murree age encircle the Trikuta Formation in the same fashion except on the southern side where it is faulted. The faulting has brought limestone in contact with the still younger Tertiary rocks of Siwalik age.

The direction and amount of dip varies with structure. The strike in the Jangalgali area is N 60° W - S 60°E, with dips being 50° due N 30° E while in the Salal area, the strike varies from N 70° W - S 70° E to N 80° E - S 80° W, with dips varying from 30° to 50° due north.

The following structural features are discernable in the study area :-

(i) Folds

No doubt the main exposure is of domal form but within it various features show complexity of fold patterns.

In the Trikuta Limestone, the folds are simple, broad with complex curvatures of anticlines and synclines (Fig. 4 Plate No. 19). Near Katra, the limbs of anticlines and synclines are tightly appressed to produce reclined folds (Raha, 1975b pp.522-524). On the eastern side,

most of the fold patterns have an easterly plunge. On the west, folds are westerly plunging and are almost parallel to the general trend of the outcrops.

The Subathus show recumbent type of folding. Due to folding (Plate No. 5) the Eocenes have been squeezed and their continuity along the direction of dip and strike has been lost. The thickness of the coal seams has been reduced and consequently the rank has been increased. The various minor structures developed reflect the trend of major structures.

Murrees are marked by high dips and show isoclinal folds. The upper parts of the Murrees are characterised by open, broad folds weathered into strike ridges and valleys with a succession of escarpments and dip slopes, while the lower parts show tight isoclines and overfolds with repeated local faulting.

(ii) Faults and Thrusts.

The constituent units of the dome show different types of faults. Some of these are low angled reversed faults. Majority of the faults run either parallel to the strike or run across the strike of the rocks.

The only thrust of importance whose reference has been found in the literature is known as 'Main Boundry Fault' (Wadia, 1926, p.7, 232). It is an important feature of the structure of outer Himalaya. It is not a single fault(Plate No. 5

but consists of a series of more or less parallel faults among the Tertiary zone of the outer Himalaya, all of which show same tectonic as well as stratigraphic peculiarities. The term "Jammu Fault" has been used by Gansser (1964) for it. The fault in the study area has been given the name "Waishno Devi Thrust" by Rao et.al (1968). On the eastern side of the area it is named as "Muttal Thrust" (Plate No. 51). It has a south easterly direction and it bifurcates at about 1.6 Km. to the west of Muttal, one running ENE bringing Murrees in contact with the Trikuta Formation and the other running to the south east bringing the Siwaliks against Murrees. The thrust continues further east of the village of Chirai (Lat. 32°59' N : Long. 75° 01' E) where it is named as "Chirai Thrust". As a result of thrusting, the Carbonaceous shales are seen dipping under the Trikuta Limestone.

Near Thalwal (Lat. 33°3'30" N: Long.74°59' E) the thrust has totally obliterated the Bauxite member of the Subathus and the sequence starts with the Nummulitics which overlie the Trikuta Limestone. The fault planes are covered with either talus or with wild shrubs. The thickest fault plane of the "Muttal Thrust" is near Banganga (thickness 300 metres) and thinnest near Samunderaini (thickness 50 m).

The western extension of the thrust has been given different names at different places such as "Riasi Thrust", "Nahoti Thrust"; etc. In case of Riasi Thrust (Plate No.52), the fault plane is almost vertical as it has been observed near

Mari nala. Further norhwest of Riasi near Nahoti the thrust has brought upper Murrees over the Lower Siwaliks and here it goes by the name of "Nahoti Thrust". Several faults or fractures emerge out from this thrust and one of these faults at Chinkah (Lat. 33° 11' 15" N: Long. 74° 48' E) has created a sharp deflection in the strike of the structure from NNW - SSE to East-West. This syntaxial bend of 80° has changed the direction of the river Chenab from NNE to SSW near Salal (Plate No. 52).

West of Chenab the thrust takes a westerly trend and starts disappearing near Paoni (Lat.33° 5' N : Long 74° 41' 30" E). All the thrusts in the study area are genetically related to the "Main Boundary Fault" (Plate No. 50). This fault has an important structural bearing on the southern flank of the dome where the Trikuta Limestone has come in contact with the younger Siwaliks. This phenomenon of Middle Siwaliks dipping under the Trikuta Limestone is known as " stratigraphic inversion".

(iii) Joints

Joints of diverse patterns have been observed in the following lithological units :-

1. Trikuta Formation

The pattern of joints in the limestones (Fig.1 & Fig.2 Plate No. 19) is either parallel to the bedding or at right angles to the bedding or striking at an angle to the beds. The important sets of joints in the Jangal Gali area are :

(a) N 60°W - S 60° E, dipping 65° towards N 55° W.

(b) N 45°W - S 45° E, dipping 60° towards N 50° W.

and (c) N 35°E - S 35° W, dipping 75° towards N 55° W.

The important sets of Joints in the Salal area are :

(a) N 50°E - S 50° W, dipping 35° towards S 40° E.

and (b) N 20°E - S 20° W, dipping 50° towards S 70° E.

2. Eocene Formation

Of all the constituent units of the Eocenes, Joint have mostly been observed in the bauxites. Three sets of Joints have been found to run NE - SW, SE - NW & East-West. At places, minor Joints have been observed to run parallel to the major Joint

3. Murree Formation

The important sets of Joints are of the following patterns :

(a) N 8° W - S 8° E, dipping 58° towards S 82° W.

and (b) N 12° W - S 12° E, dipping 50° towards S 80° W.

(iv) Unconformities

Several unconformities both of local and regional importance have been encountered within the formations of the area under investigation.

The"Trikuta Formation" being an oldest unit is

unconformably overlain by the "Bauxite ~~to~~ Series". Middlemiss (1928, p. 4) referred to the Chert Breccia bed as a stratigraphic break in between the older Trikuta Formation and the overlying Bauxite Bed. Wadia (1949, p. 43) stated, "The Chert Breccia marks an erosional unconformity". Srivastava (1956, 1959) referred to the unconformable junction between the Trikuta Limestone and the Bauxite Bed and further suggested that the unconformity is a faulted one.

In the Ladda area, a local unconformity exists between the Trikuta Limestone and the overlying Coal Measures. This unconformity is also a faulted one. In the same area, the Bauxite Bed is unconformably overlain by the Shales.

The contact of the Eocenes with the overlying Murrees is apparently a conformable one.

v) General discussion of the tectonics

Varied views have been expressed from time to time regarding the structural disposition of various formational units found in the study area (plate No. 50). The points which need clarification are :-

1. The structural form of the massif;
2. The mechanism of the emplacement of the massif;
3. The structural relationship of the massif with the younger formations;
4. The relationship of the structures found in the massif vis-a-vis with structures found in other formations;

5. The cause of structural complexity towards east as compared to the west;

and 6. The structural evolution of the area.

1. The structural form of the massif.

The various views expressed by the early workers regarding the structural form of the massif are :-

(a) Middlemiss (1929) referred to the form as an elongated upheaved anticlinal dome, round which on the NW, NE & SE the younger formations appear concentrically dipping away from the central dome of the limestone. Faulting on the south west of the dome has dropped the Siwaliks in juxtaposition with the limestones. He stated that the fault is of the reverse type and is an extension of the MAIN BOUNDARY FAULT.

(b) Wadia (1937, 1949) considered it to be an anticline with a system of folding with broad and open types of anticlines and synclines without any considerable compression. He writes, "these inliers are exposed as the cores of faulted anticlinals in the Murree Series, north limb of which shows an apparently conformable passage of Eocene into Murrees, while the south limb is generally missing as the result of strike faulting".

(c) Auden (1944) stated this structure to be in the form of an assymmentrical dome and the southern units of the "Great Limestone" are tectonically eliminated along the contact of the thrust.

(d) Banerjee (1959) could not get any evidence in favour of domal structure. He writes, "none of the makrker horizons show any repetition on a large scale and the dome concept can only be upheld on the assumption that the thrust zone marks the axial part of the hypothetical dome".

Mehta and Srivastava (1959) strongly supported the non-domal form of the massif as suggested by Banerjee.

(e) Gupta & Kapoor (1960) considered this massif to be a WNW plunging anticline, the southern limb of which is traversed by a thrust. Gupta & Dhall (1962), Dhall and Srivastava (1964a & 1964b) also supported this view.

From the foregoing discussion it has been found that there are broadly speaking two schools of thought, firstly those who believe it to be a dome and secondly, those who advocate for its doubly plunging anticlinal form. The points which support its domal structure are :-

(i) Bead like shape of the structure;
(ii) The radical type of drainage in the area;
(iii) The younger formations which cover and flank the older limestone are exhibiting the same circular plan as exhibited by the oldest limestone formation;

(iv) Deeper roots of the rocks in the dome;

(v) Arcuate trend of the strike;

& (vi) The younger formations appear concentrically dipping away from the central dome.

The points which go against the domal structure are :-

(i) Absence of repetition of marker horizons around the structure;

(ii) Absence of radial, concentric and tangential cracks in the younger formations;

(iii) Abbence of limestone matter in the overlying younger formations;

(iv) Presence of thrusts on the southern side of the structure;

(v) Presence of synclinorium inbetween the massifs;

(vi) The limestone is thrust over the Neogene fold and fault structures (Riasi Boundary Thrust);

(vii) The Riasi boundary thrust is itself thrust over by the Udhampur thrust which dies out NE of Riasi;

& (viii) Most of the fold structures with broad and open types of anticlines and synclines have plunging ends.

The field observations have proved beyond doubt that it is not a symmetrical dome but an elongated upheaved anticlinal dome as suggested by Middlemiss (1929).

2. The mechanism of the emplacement of the massif.

The sudden apparition of a large massif of pre-Cambrian to early Palaeozoic (?) rocks amidst a zone of considerably younger stratigraphic units needs explanation.

(a) Raina (1964, P. 59) while working on the structure of Shali and Krol Limestones of the Sub-Himalaya of Simla referred to the limestone massif of Riasi and thought it to have formed in the same manner. Raina considered it to represent a Klippe which has been formed either due to erosion or gliding or detachment of the mass from the original nappe. Since such structures have not been reported in the Murree zone of the entire outer-Himalaya and moreover the complete absence of field evidences of translatory movement and the deep roots of the limestone clearly reject the idea of its being a Klippe.

(b) Valdiya (1964, P. 16) while discussing the structure of the Krol thought it to be a "Tectonic Window" like the windows in the Nappes of Simla but there the younger rocks have been exposed whereas in the area under study the older rocks have been laid bare and as such

there seems to be no identity in the structure of the two areas.

(c) Rao et.al (1968) while considering the frame work of the Chenab re-entrant thought it to be a parautochthon (named also Waishnodevi parautochthon) exposing the older limestones, the Eocene and the Lower Murrres.

(d) An autochthonous mass diapirically or otherwise pushed through the younger cover rocks and with the marginal parts of the resultant dome thrust over its neighbours

(e) A massif consisting of allochthonous rock units pushed over the younger rocks through gravity or recumbent fold nappe process and later infolded with the surrounding sediments posterior to its emplacement.

An autochthonous position needs following clarifications :-

(i) The loci and magnitude of such vertical uplifts in areas and in periods known for lateral rock translation;

(ii) Absence of field evidences of such uplifts over the cover and neighbourly rocks;

& (iii) The ultimate tie up with other fault structures like Murree and "Panjal Thrusts".

The allochthonous position requires following clarifications :-

(i) The root zone of these allochthonous masses and their tectonic transport through gravity or other processes.

& (ii) The infolding and marginal thrusting of these masses posterior to their emplacement.

Again considering the autochthonous position, the diapiric uplift is not possible because it fails to explain :-

(i) The absence of radial, concentric and tangential cracks in the overlying younger formations;

(ii) The complete absence of intruding matter within the cracks of the cover rocks;

(iii) The restricted aereal distribution of loci of uplifts in an area of complex thrusts eg; the Waishnodevi thrust, Udhampur Thrust, etc., which could offer opportunity for the diapiric uplifts;

(iv) The absence of sills of limestones within the Murree sandstones;

(v) The absence of sharp truncation of the edges of younger formations which flank the limestone massif. On the other hand, they have got themselves folded along with the massif;

(vi) The absence of structures like "Salt piercement Dome", which afe generally associated with the diapiric uplifts.

Having been proved that the diapiric uplift is an improbability, the other possi bilities of its being in present position are :-

(i) The emplacement of the limestone massif might have taken place under the principle of piercement of salt dome;

(ii) The massif might have occupied its present position through tectonic uplift connected with Himalayan Orogeny which finally underwent a uniform dextral drag along the postulated Chenab re-entrant;

(iii) The massif might have found its present position through sliding over the folded Neogenes and hence obliterating and masking the Neogene structure. This has further been supported by Dasarathi (1968,p.24), who writes, " the lateral rock translation had possibly

never operated to the extent as imagined by Wadia and others, many of the thrust structures are actually vertical to steep dipping faults with marginal incurving at shallow levels ..... recent geophysical investigations suggested the continuation of the Riasi Limestone under the Tawi Valley Neogenes of Jammu area. Consequently, it is presently thought that the Sawalkot massif is linked with the Riasi Belt under the Neogene cover and the whole complex, as a single unit has been strongly imbricated into a set of isoclines with their inverted limbs sheared off along huge thrust planes. The complex structures of Neogene exposed between the Sawalkot and Riasi massifs have developed due to free and secondary gliding of the cover elements along the north dipping contact planes between the limestone substratum and the cover. This is a secondary phenomenon that took place after the coming into being of the limestone upthrusts".

The above mentioned facts lead to a conclusion that the present position of the limestone massif is due to over riding of the limestone substratum over the folded Neogenes. Subsequent to its emplacement, the massif suffered tensional and peripheral faulting.

3. <u>The structural relationship of the massif with the younger formations</u>

Regarding the relationship of the massif with the younger formations, it has been found that a thin strip

of Eocenes unconformably encircle the Trikuta Limestone on all sides except on the south and southwest where the contact is faulted one. As a result of faulting, the limestones have a contact first with the Murrees and then with the Siwaliks. This relation has been termed as a "Stratigraphic Inversion".

The younger Murrees conformably overlie the Eocenes and swing around the older formations in the same fashion.

4. <u>The relationship of the structures found in the massif vis-a-vis with structures found in other formations</u>.

In this regard, the following observations have been made :-

(i) The limestone formation exhibits fine folding with broad synclines and tight anticlines. The axis of the fold run along NW to SE direction. The younger formations, on the contrary, show either recumbent folds (as observed in Subathus) or isoclinal folds (as observed in Murrees) etc.

(ii) The limestone massif is characterised by normal and reverse faults. Most of these faults have developed along the axes of the anticlines. At places, these faults have further been activated and developed into thrusts along which considerable horizontal movement took place often overlapping the synclinal axes. The Waishnodevi Thrust

is one of such thrusts which has developed along a pre-existing anticlinal axis. This thrust brings the limestones against the Sivaliks. Wadia (1926, P.7, 232) referred to the Main Boundary Fault and the various thrusts including the Vaishno Devi Thrust observed in the area are the offshoots of it.

(iii) The limestone massif has well developed joints running at right angles to the bedding while the joints in the younger formations are far less developed.

(iv) The relative ease with which the younger rocks have been denuded sharply distinguishes them from the older limestones.

(v) The limestone massif has bold and rugged features while the younger formations have smoother and more rounded outlines.

5. <u>The cause of structural complexity is more towards east as compared to the west</u>.

The complexity of the structure towards east is due to following factors :-

(i) Thrusts that separate the Sivalik and the Murree belts east of the Chenab are not present west of it.

(ii) This absence of thrusts coincides with the cropping out of the limestone.

& (iii) It is also possible that there is a change in the basement composition east of the massif. The swing in the strike near Salal could also be due to the change in the basement composition. Greater complexity has been caused by the moulding of the structures around this resistant part of the basement.

6. Structural evolution of the area.

The structural evolution of the area is closely related to the Himalayan Orogeny which in turn have evolved from the Tethys. The Himalayan uplift took place in three distinct and widely spaced revolutions.

In area under investigation, the thin patch of the Eocene Nummulitic Limestone which is covering and flanking the Trikuta limestone is probably the last record left by the Tethys before it, vanished. The successive upheavals which had preceded the final phase are difficult to trace in the area. The synsedimentary folding in the younger formations remained in operation with the result that broad synclines and tight anticlines formed, faults developed along the axes of the anticlines. These faults activated and developed into thrusts eg. Waishno Devi Thrust, Udhampur Thrust, etc., along which considerable movement of the old massif took place. The Waishno Devi Thrust has been given different names at different places

in the area and is clearly exposed on the left bank of the Aghar Nala, in the Mari Nala and in the Duglla Nala. The Chief evidences of this thrust are :-

(i) Tilting of the boulder beds at high angles on either sides of the thrusts;

(ii) River terraces (eg. Katra Terraces, Riasi and Bidda Terraces, etc.);

& (iii) Over riding of the limestones on the scree and boulder terraces.

The Waishno Devi Thrust disappears on the south-west of the massif and coincides with the cropping out of the limestones. Subsequent to its emplacement by over riding of the limestone substratum over the folded Neogenes, the massif suffered tensional and peripheral faulting. Greater structural complexity resulted due to swing in the strike which in turn may be due to dextral tear fault in the basement. Having experienced all these structural changes the area under study came into being and adjusted itself within the frame work of Jammu Hills.

Chapter 3

Petrography of the Trikuta Limestone.

Chapter 3

Petrography of the Trikuta Limestone

The Trikuta Limestone is an oldest formation exposed in the study area. Number of workers have studied this formation laying emphasis mostly on its stratigraphy, structure and economic potentiality. Pertaining to petrography only two papers have been published (Sharma & Krishnaswami, 1970 and Gundu Rao, 1976). In the former, only a few micro structures and some chemical analyses have been described while in the latter, a few petrographic types have been given. But for these two papers no other standard work is available in which the use of petrography has been made to interpret the depositional environment of this most interesting formation. Even in these papers the systematic variation of petrographic types both in vertical as well as in horizontal directions have not been discussed. The petrographic studies are of considerable importance not only in classification but also in understanding the milieu in which these rocks were formed.

In this work an attempt has been made to study in detail the compositional, textural and structural features, of these limestones to understand their genetic history and depositional environments. To achieve this goal some 500 representative samples were collected all over the area and put to various tests. On the basis of the results derived from the laboratory and field investigations, it has been found possible to divide the

formation into three parts i.e. the Lower, the Middle and the Upper. The lower part is hard, dense, cryptocrystalline, microcrystalline or crystalline and greatly transformed to dolomite. The middle part is intensely silicified and contains lenses and nodules of chert. The upper part is non-carbonate mostly of the nature of chert Breccia.

Petrography of the Lower & the Middle Trikuta Limestone

Chemical Composition

The chemical characters including the chemical analyses, spectrochemical analyses, etc., have been conducted of a large number of samples from all horizons to make an assessment of their petrographic characters.

Chemical Analyses

Representative samples were collected by trench and open cuts at an interval of five metres and subjected to chemical analyses by modern methods for the determination of Cao, Mgo, R_2O_3, acid insolubles and loss on ignition. An attempt was made to find the percentage of $CaCo_3$ and $MgCo_3$ and also the relationship of Calcite and dolomite. The various rock types have been recognised and represented by triangle methods (Plate No.6). The detailed results of chemical analyses are given in tables II to VII. In these tables analyses of only the lower and the middle horizons have been given. The upper group is more of chert

Table X-II

Chemical Analyses of the Lower Trikuta Limestone

Area	Sample Nos:	CaO%	MgO%	R_2O_3%	Acid Ins Silica%	Loss on ignition	$CaCO_3$%	$MgCO_3$%	Sp. Gr.	Calcite	Dolomite	Rock Type
Jangal Gali Backslope	CH=131	29.53	18.60	1.26	10.82	39.59	52.73	39.06	2.86	52.73	36.45	Impure dolomitic Limestone.
"	CH=128	28.04	19.46	1.31	6.86	42.29	50.07	40.86	2.88	50.07	43.07	Dolomitic Limestone.
"	CH=127	31.50	21.45	0.85	5.96	40.26	56.07	45.04	2.89	56.07	37.97	"
"	CH=126	30.60	19.81	1.12	4.74	43.53	54.64	41.60	2.89	54.64	40.62	"
"	CH=125	29.77	18.92	1.48	7.60	42.20	53.16	39.73	2.88	53.16	39.24	"
"	CH=123	30.12	19.51	1.50	8.94	39.89	53.78	40.97	2.88	53.78	37.28	"
Jangal Gali	CH=220	30.87	20.10	1.26	5.24	42.52	55.12	42.21	2.88	55.12	39.64	"
"	CH=138	28.38	19.87	1.22	5.90	44.59	50.67	41.72	2.86	50.67	43.43	"
"	CH=137	27.90	18.92	0.93	7.29	44.93	49.82	39.73	2.86	49.82	42.89	"
"	CH=136	27.96	18.86	0.92	7.40	44.73	49.92	39.60	2.85	49.92	42.68	"
"	CH=135	30.76	19.40	1.50	3.95	44.31	54.92	40.74	2.88	54.92	41.13	"
Jangal Gali-Gogalta	CH=133	29.53	20.47	1.91	4.45	43.59	52.73	42.98	2.88	52.73	42.82	"
"	CH=132	29.10	20.86	1.07	3.98	40.91	51.96	43.80	2.88	51.96	44.06	"
"	CH=4	29.34	22.12	1.12	0.25	47.16	52.39	46.65	2.87	52.39	47.36	"
" Lain	CH=36	27.91	19.61	1.00	7.76	43.68	49.83	41.18	2.88	49.83	42.41	"
"	CH=32	29.04	20.32	1.10	4.70	44.78	51.85	42.67	2.87	51.85	43.45	"
"	CH=31	29.15	19.83	1.02	3.86	46.11	52.05	41.64	2.88	52.05	44.09	"

Contd.....

Area	Sample Nos:	CaO%	Mgo%	R_2O_3%	Acid Ins Silica%	Loss on ignition	$CaCo_3$%	$MgCo_3$%	Sp. Gr.	Calcite	Dolomite	Rock Type
Jangal Gali-Gogalta												
" Muttal	CH=30	29.89	20.84	0.80	2.98	45.44	53.37	43.76	2.88	53.37	43.65	Dolomitic Limestone.
"	CH=29	29.15	19.98	1.28	3.94	45.85	52.05	41.95	2.88	52.05	44.01	"
"	CH=21	29.41	19.43	1.08	4.58	45.50	52.51	40.80	2.88	52.51	42.01	"
"	CH=11	29.15	19.18	1.15	4.18	46.34	52.05	40.27	2.88	52.05	43.77	"
Painthal	CH=11	27.64	19.48	1.08	8.96	42.80	49.35	40.90	2.90	49.35	41.69	Dolomitic Limestone.
"	CH=34	27.85	18.42	1.68	5.02	46.91	49.71	38.68	2.90	49.71	45.27	"
"	CH=260	27.82	19.83	1.18	9.24	41.90	49.67	41.64	2.84	49.67	41.09	"
Painthal Devi Dian Pindial	CH=326	28.62	19.88	1.64	6.84	43.00	51.10	41.74	2.85	51.10	42.06	"
"	CH=1002	27.33	22.80	1.30	1.19	48.95	48.80	47.88	2.90	48.80	50.01	"
"	CH=1010	30.40	20.90	0.51	1.37	46.80	53.64	42.18	2.89	53.64	44.99	"
"	CH=1011	28.55	22.80	0.72	1.25	46.42	51.00	47.88	2.89	51.00	47.75	"

Table III

Chemical Analyses of the Lower Trikuta Limestone

Area	Sample Nos:	CaO%	MgO%	R_2O_3%	Acid Ins Silica%	Loss on ignition	$CaCO_3$%	$MgCO_3$%	Sp. Gr.	Calcite	Dolomite	Rock Type
Painthal (D.D.P.)	CH=1018	4.20	43.80	1.15	0.13	51.08	7.50	91.98	3.00	7.50	92.37	Dolomite being altered to Magnesite.
"	CH=1019	5.13	42.74	1.04	0.24	50.83	9.16	89.75	3.01	9.16	90.60	Dolomite "
"	CH=1020	4.19	44.18	1.16	0.19	50.26	7.48	92.77	3.01	7.48	92.33	" "
"	CH=1021	6.20	41.34	1.81	0.34	50.29	11.07	86.81	3.01	11.07	88.59	" "
"	CH=1022	7.12	40.39	1.32	0.78	50.37	12.71	84.81	3.00	12.71	86.51	" "
"	CH=1023	9.04	40.16	0.98	0.46	49.34	16.14	84.33	2.99	16.14	83.40	" "
"	CH=1024	5.18	42.88	1.91	0.39	49.62	9.25	90.04	2.99	9.25	90.36	" "
CH "	CH=1025	4.16	43.76	1.16	0.42	51.43	7.42	91.89	2.99	7.42	92.16	" "
"	CH=1026	4.19	43.64	1.31	0.62	50.21	7.48	91.64	3.00	7.48	91.90	" "
"	CH=1030	5.11	42.91	1.40	0.34	50.23	9.12	90.11	3.00	9.12	90.54	" "
Katra	CH=1	29.68	20.60	1.00	3.04	44.60	53.00	43.26	2.88	53.00	43.96	Dolomite Limestone.
"	CH=11	29.89	20.84	0.80	2.98	45.44	53.37	43.76	2.87	53.37	43.65	"
"	CH=17	27.46	18.53	1.12	10.62	42.24	49.03	38.91	2.83	49.03	40.35	"
"	CH=19	30.64	20.75	1.26	0.96	46.37	54.71	43.57	2.88	54.71	44.33	"
"	CH=23	30.42	20.32	1.12	0.82	46.56	54.32	42.67	2.85	54.32	44.86	"
"	CH=28	30.70	19.83	1.12	4.80	43.54	54.89	41.64	2.86	54.89	40.31	"
Katra-Banganga	CH=3	Traces	45.03	1.90	2.80	50.00	Traces	94.56	2.87	Traces	97.20	Dolomite being altered to Magnesite.
"	CH=14	29.55	23.85	0.84	0.85	43.50	52.76	50.08	2.88	52.76	46.39	Dolomite Limestone.
"	CH=3000	0.96	45.57	2.26	1.29	49.54	1.71	95.69	3.01	1.71	97.00	Dolomite being altered to Magnesite.

Contd.....

Area	Sample Nos:	CaO%	MgO%	R_2O_3%	Acid Ins Silica%	Loss on ignition	$CaCO_3$%	$MgCO_3$%	Sp. Gr.	Calcite	Dolomite	Rock Type
Katra-Banganga	CH=3001	0.40	46.30	2.15	1.34	49.81	0.71	97.23	3.00	0.71	97.95	Dolomite being altered to Magnesite.
"	CH=3002	0.54	44.95	2.02	1.56	50.95	0.96	94.39	3.00	0.96	97.48	"
"	CH=1016	0.70	43.30	1.74	6.10	48.00	1.25	90.93	3.00	1.25	92.65	"
Purana Darm	CH=46	30.38	21.16	0.94	2.48	45.06	54.25	44.43	2.87	54.25	43.27	Dolomite Limestone.
Charan Patika Trikuta(N)	CH=1	30.21	20.91	0.62	2.18	45.93	53.94	43.91	2.87	53.94	43.88	"
"	CH=1(A)	29.91	20.84	0.98	2.80	45.40	53.41	43.76	2.88	53.41	43.79	"
"	CH=2	30.45	21.24	0.69	0.90	46.54	54.37	44.60	2.88	54.37	44.73	"
"	CH=2(A)	29.00	19.05	1.51	6.06	44.02	41.78	40.00	2.87	41.78	52.16	Calcareous Dolomite.
" (E)	CH=5	27.89	18.93	1.40	11.96	39.80	49.80	39.75	2.87	49.80	38.24	Impure Dolomite Limestone.
"	CH=10	28.62	19.32	Traces	6.36	45.72	51.10	40.57	2.84	51.10	42.54	Dolomite Limestone.

Table IV

Chemical Analyses of the Lower Trikuta Limestone

Area	Sample Nos:	Cao%	Mgo%	R_2O_3%	Acid Insol Silica%	Loss on ignition%	$CaCo_3$%	$MgCo_3$%	Sp.Gr.	Calcite	Dolomite	Tock Type.
Trikuta Hills	CH=11	29.36	20.86	Traces	1.98	47.80	52.42	43.80	2.88	52.42	45.60	Dolomitic Limestone.
	CH=128	28.68	20.97	0.46	2.90	46.00	51.21	44.03	2.89	51.21	45.89	"
	CH=34	28.12	19.29	0.48	6.02	46.08	50.21	40.50	2.88	50.21	43.77	"
	CH=79	28.32	20.19	1.34	4.44	45.70	50.70	42.39	2.88	50.57	44.99	"
	CH=83	29.17	17.66	1.42	3.82	47.92	52.08	37.08	2.88	52.08	44.10	"
	CH=84	30.32	20.73	1.74	1.22	45.90	54.14	43.53	2.89	54.14	44.64	"
	CH=135	30.13	21.36	1.48	1.35	45.66	53.80	44.85	2.89	53.80	44.85	"
	CH=143	30.04	20.94	0.64	2.88	45.50	53.64	43.97	2.88	53.64	43.48	"
	CH=227	29.17	20.85	0.35	5.18	44.46	52.08	43.78	2.88	52.08	42.74	"
	CH= 3	29.16	20.56	0.84	3.68	45.76	52.07	43.17	2.88	52.07	44.25	"
Trikuta(Hansal)	CH=323	29.18	20.59	1.25	2.64	46.34	52.10	43.23	2.87	52.10	45.26	"
"	CH=328	29.78	20.88	1.98	2.70	44.58	53.17	43.84	2.89	53.17	44.13	"
Riasi(Talwara)	CH=3	30.41	21.36	0.26	0.96	46.56	54.30	44.85	2.88	54.30	44.74	"
" (12th Km post on Riasi-Salal Road)	CH=206	28.56	20.60	1.84	2.80	45.80	51.00	43.26	2.89	51.00	46.20	"
"	CH=207	29.54	18.80	0.64	3.04	48.41	52.75	39.48	2.88	52.75	44.21	"
	CH=284	27.40	18.43	0.55	9.76	43.86	48.92	38.70	2.86	48.92	41.32	"
	CH=285	29.42	20.49	0.81	4.98	44.30	52.53	43.02	2.87	52.53	42.49	"
	CH=1222	27.81	20.02	4.10	4.23	43.82	49.66	42.04	2.88	49.66	46.11	"
"(Mari)	CH=1223	28.82	20.60	Traces	4.84	45.70	51.46	43.26	2.88	51.46	43.70	"
"	CH=1224	28.98	20.43	Traces	4.36	46.25	51.75	42.90	2.89	51.75	43.89	"

Contd.....

Area	Sample Nos:	Cao%	Mgo%	R_2O_3%	Acid Insol Silica%	Loss on ignition%	$CaCo_3$%	$MgCo_3$%	Sp.Gr.	Calcite	Dolomite	Rock Type
"	CH=1225	29.48	20.84	Traces	2.12	47.40	52.64	43.76	2.89	52.64	45.24	"
"(Aghar)	CH=1227	29.68	21.10	Traces	1.78	47.40	53.00	44.31	2.88	53.00	45.22	"
	CH=1229	27.58	19.98	0.40	5.58	46.40	49.25	41.95	2.88	49.25	45.17	"
	CH=1231	30.40	21.38	Traces	1.40	46.82	54.28	44.89	2.88	54.28	44.32	"
	CH=1236	30.10	20.91	1.97	0.94	46.08	53.75	43.91	2.88	53.75	45.31	"
"(Anji)	CH=318	28.98	19.88	1.34	3.42	46.38	51.75	41.74	2.88	51.75	44.83	"
"(Bidda)	CH=7	29.95	21.20	Traces	0.86	47.95	53.48	44.52	2.88	53.48	45.66	"
	CH=8	30.83	21.26	Traces	1.87	46.03	55.05	44.64	2.88	55.05	43.08	"
	CH=13	29.95	21.20	Traces	1.09	47.75	53.48	44.52	2.88	53.48	45.43	"

Table V

Chemical Analyses of the Lower Trikuta Limestone.

Area	Sample Nos:	CaO%	MgO%	R_2O_3%	Acid Ins. + Silica %	L.O.I.%	$CaCO_3$%	$MgCO_3$%	Sp.Gr.	Calcite	Dolomite	Rock Type
Riasi(Bidda)	CH=14	28.74	20.80	Traces	5.74	44.69	51.32	43.68	2.88	51.32	42.94	Dolomitic Limestone
	CH=26	29.66	20.81	Traces	1.21	48.34	52.96	43.70	2.89	52.96	45.83	"
	CH=29	29.54	20.45	Traces	1.51	48.45	52.75	42.94	2.89	52.75	45.74	"
Dhiangarha Dam Site area	CH=1/77	30.52	20.80	0.83	0.50	45.78	54.50	43.68	2.89	54.50	45.00	"
"	CH=101	29.50	20.51	0.63	0.44	47.10	52.67	43.07	2.89	52.67	47.33	"
"	CH=222	32.30	18.13	0.04	4.05	45.19	57.67	38.07	2.86	57.67	38.28	"
"	CH=228	31.80	21.00	0.35	0.20	45.68	56.78	44.10	2.89	56.78	43.02	"
"	CH=244A	30.24	22.00	0.35	0.53	46.46	54.00	46.20	2.88	54.00	45.47	"
"	CH=252	30.06	21.03	0.24	0.22	47.05	53.67	44.16	2.89	53.67	46.11	"
"	CH=254	30.24	21.80	0.74	0.87	45.80	54.00	45.78	2.88	54.00	45.13	"
"	CH=255	29.54	18.80	0.64	3.04	48.41	52.75	39.48	2.89	52.75	44.21	"
"	CH=255A	30.40	20.13	0.84	1.54	46.35	54.28	42.27	2.87	54.28	44.18	"
"	CH=261	33.28	18.18	0.02	1.71	46.62	59.42	38.17	2.88	59.42	38.87	"
Salal	CH=01	30.07	20.09	0.63	0.10	47.04	53.59	42.18	2.89	53.69	46.21	"
"	CH=102	29.35	21.24	0.54	0.84	46.80	52.41	44.60	2.89	52.41	46.75	"
"	CH=505	28.09	22.07	0.48	0.26	47.05	50.16	46.34	2.89	50.16	49.58	"
"	CH=511	27.53	20.52	1.58	0.32	49.53	49.16	43.09	2.89	49.16	50.52	"

Table VI

Chemical Analyses of the Middle Trikuta Limestone

Area	Sample Nos:	CaO%	MgO%	R_2O_3%	Acid Insol. + Silica %	Loss on ignition%	$CaCO_3$%	$MgCO_3$%	Sp.Gr.	Calcite	Dolomite	Rock Type
Jangal Gali (Lain)	CH=17	24.88	16.65	1.44	19.68	37.29	44.42	34.91	2.86	44.42	35.90	Impure Dolomitic Limestone
Jangal Gali	CH=134	21.58	15.02	1.14	27.48	44.78	38.53	31.54	2.79	38.53	33.99	" "
" Backslope	CH=130	27.08	22.41	1.02	20.14	29.33	48.30	47.10	2.85	48.30	31.56	" "
Backslope	CH=129	25.16	17.43	1.29	17.32	39.78	44.92	36.60	2.85	44.92	37.76	" "
"	CH=122	29.41	18.36	2.04	12.42	37.72	52.51	38.55	2.87	52.51	35.07	" "
"	CH=121	29.40	18.37	2.04	16.80	33.37	52.50	38.57	2.86	52.50	30.70	" "
Painthal	CH=14	24.98	18.70	1.68	18.62	36.00	44.53	39.27	2.89	44.53	36.85	" "
"	CH=46	25.90	18.40	1.30	13.90	40.47	46.25	38.64	2.89	46.25	39.35	" "
"	CH=49	23.83	15.85	1.06	23.56	35.70	42.55	33.28	2.87	42.55	33.89	" "
"(D.P.)	CH=327	25.66	18.62	0.93	17.82	36.94	45.82	39.10	2.87	45.82	36.36	" "
"	CH=328	25.46	18.90	0.91	17.19	37.52	45.46	39.69	2.84	45.46	37.35	" "
Katra	CH=13	30.57	11.09	5.12	16.22	36.96	54.58	23.28	2.85	54.58	29.20	" "
"	CH=13/77	24.36	17.60	2.19	16.57	38.42	43.50	36.96	2.86	43.50	39.93	" "
"	CH=15	24.96	17.93	1.38	19.84	36.14	44.08	37.65	2.86	44.08	36.08	" "
"	CH=16	18.04	12.80	0.79	40.18	28.12	32.21	26.88	2.81	32.21	27.61	" "
"	CH=18	25.30	17.86	1.32	16.94	38.58	45.17	37.50	2.86	45.17	37.89	" "
"	CH=20(?)	23.36	16.54	0.23	23.82	35.70	41.71	34.73	2.79	41.71	34.47	" "
" (B.G.)	CH=1	25.62	18.8	1.77	15.41	39.05	45.75	37.96	2.86	45.75	38.84	" "
"	CH=9	22.86	16.89	0.65	24.66	34.66	40.82	35.46	2.79	40.82	34.52	" "
"	CH=1603	24.52	16.53	2.72	18.27	37.22	43.78	34.71	2.86	43.78	37.95	" "

Contd.....

Area	Sample Nos:	CaO%	MgO%	R_2O_3%	Acid Insol. + Silica %	Loss on ignition%	$CaCO_3$%	$MgCO_3$%	Sp.Gr.	Calcite	Dolomite	Rock Type	
" (C.P.)	CH=27	25.62	18.16	1.46	16.18	38.56	45.75	38.13	2.87	45.75	38.07	"	"
"	CH=34	24.33	17.29	0.94	19.35	38.00	43.44	36.30	2.86	43.44	37.21	"	"
"	CH=41	24.12	17.34	1.33	20.65	36.56	43.07	36.41	2.86	43.07	36.28	"	"
"	CH=52	25.46	17.83	1.85	18.62	36.20	45.46	37.44	2.86	45.46	35.92	"	"
"	CH=57	23.83	16.76	1.21	21.99	36.24	42.55	35.19	2.87	42.55	35.46	"	"
Waishno Devi(E)	CH=3	25.46	18.96	1.00	15.60	38.92	45.46	39.81	2.86	45.46	38.94	"	"
"	CH=6	23.40	16.81	0.90	23.80	35.12	41.78	35.30	2.79	41.78	34.42	"	"
"	CH=9	17.96	12.87	0.88	36.16	32.10	32.07	27.02	2.78	32.07	31.77	"	"
"	CH=15	27.46	18.53	1.12	10.62	42.27	49.03	38.91	2.87	49.03	40.35	"	"

Table VII

Chemical Analyses of the Middle Trikuta Limestone.

Area	Sample Nos:	CaO%	MgO%	R_2O_3%	Acid Insol. + Silica %	L.O.I.	$CaCO_3$%	$MgCO_3$%	Sp.Gr.	Calcite	Dolomite	Rock Type
Waishno Devi(W)	CH=78	18.90	13.47	1.46	37.06	29.09	33.73	28.28	2.85	33.73	29.21	Impure Calcareous Dolom
"	CH=320	25.77	18.38	1.27	15.34	39.20	46.01	38.59	2.86	46.01	38.65	Impure Dolomitic Limestone
"	CH=321	26.56	18.78	Traces	12.86	41.82	47.42	39.43	2.86	47.42	39.72	" " "
"	CH=326	24.76	19.99	1.36	18.40	35.50	44.21	41.97	2.85	44.21	37.39	" " "
Riasi	CH=279	21.40	15.49	1.67	22.84	38.59	38.21	32.52	2.79	38.21	38.95	" " "
"	CH=280	37.44	6.88	1.10	20.14	34.44	66.85	14.44	2.86	66.85	13.01	" " "
"	CH=281	36.88	5.18	1.06	17.84	39.03	65.85	10.87	2.79	65.85	16.31	" " "
"	CH=282	32.94	8.91	0.60	19.94	37.60	58.82	18.71	2.81	58.82	21.24	" " "
"	CH=283	31.50	13.49	1.48	14.70	38.81	56.25	28.32	2.85	56.25	29.05	" " "
Garan	CH=1304	29.90	3.64	1.24	32.70	32.52	53.39	7.64	2.56	53.39	13.91	" " "
"	CH=1320	26.74	8.52	1.06	28.40	35.20	47.75	17.89	2.56	47.75	23.85	" " "
MARI	CH=1022	24.50	17.40	Traces	15.52	42.58	43.75	36.54	2.86	43.75	40.73	" " "
"	CH=1226	20.44	15.48	1.73	25.00	37.38	36.50	32.50	2.78	36.50	38.50	Impure Calcareous Dolomite
AGHAR	CH=1228	24.36	16.95	0.40	15.58	46.44	43.50	35.59	2.86	43.50	40.92	Impure Dolomitic Limestone
"	CH=1230	26.36	18.88	0.84	10.46	43.40	47.07	39.64	2.86	47.07	42.47	" " "
Anji Valley	CH=316	24.32	17.43	1.36	19.44	37.45	43.42	36.60	2.85	43.42	37.14	" " "
"	CH=317	28.13	19.47	1.42	16.88	34.10	50.23	40.88	2.86	50.23	32.89	" " "
"	CH=319	24.66	17.37	Traces	16.46	41.51	44.03	36.47	2.86	44.03	39.51	" " "
Bidda	CH=9	29.45	19.28	Traces	9.50	41.75	52.58	40.48	2.86	52.58	37.92	" " "
"	CH=11	26.18	18.66	Traces	11.78	43.35	46.75	39.18	2.86	46.75	41.47	" " "
Dhiangarh	CH=102	22.90	18.27	0.95	23.40	33.67	40.89	38.36	2.81	40.89	35.71	Impure Dolomitic Limestone
Damsite	CH=243	37.22	6.85	0.62	11.73	42.91	66.46	14.38	2.80	66.46	21.81	" " "

Contd.....

Area	Sample Nos:	CaO%	MgO%	R_2O_3%	Acid Insol. + Silica%	L.O.I.	$CaCO_3$%	$MgCO_3$%	Sp.Gr.	Calcite	Dolomite	Rock Type
SALAL	CH=4/77	29.53	18.60	1.26	10.82	39.49	52.73	39.06	2.87	52.73	36.45	Dolomitic Limestone
"	CH=101	26.65	4.72	1.11	45.09	20.55	47.58	9.91	2.71	47.58	7.33	Impure Dolomitic Limestone
"	CH=535	28.16	6.20	Traces	32.66	32.97	50.28	13.02	2.69	50.28	17.06	" " "
"	CH=536	22.10	4.34	Traces	32.41	41.12	39.46	9.11	2.65	39.46	28.13	" " "
"	CH=541	32.73	3.14	Traces	24.45	39.67	58.44	6.59	2.66	58.44	17.11	" " "
"	CH=544	36.56	3.84	Traces	27.74	31.84	65.28	8.06	2.62	65.28	6.98	" " "
"	CH=3534	38.50	4.16	Traces	25.96	31.34	68.75	8.73	2.62	68.75	5.29	Impure Limestone.

Breccia and hence can not be included in these tables. The chemical analyses have led to the following observations :-

Calcium Content

The normal range of Cao in the Lower Trikuta varies from 0.40% to 33.28%. While in the Middle Trikuta, it varies from 17.96% to 38.50%. It appears that the content of Cao increases from the Lower to the Middle Trikuta Limestone.

Magnesium Content

The normal range of Mgo in the Lower Trikuta is between 3.14% to 46.30% while in the Middle Trikuta, it varies from 3.14% to 22.41%. The ratio of Mgo decreases from the Lower to the Middle group.

Relationship between Cao% and Mgo%

In case of the Lower Trikuta Limestone the content of Mgo is far greater than that of Cao as has been shown in plate No. 7, whereas in case of the Middle Trikuta, the ratio of Mgo is far lesser than that of Cao. From this relationship, it has become obvious that the lower part of the Trikuta Limestone has greatly been transformed to dolomite.

Impurities

The content of acid insolubles and silica incase of the Lower Trikuta varies from 0.13% to 11.96% while in the Middle Trikuta the percentage is between 9.50 and 45.09. From these figures, it appears that the content of impurities in the Middle Trikuta is far greater than that of the Lower Trikuta Limestone.

Loss on ignition.

There is a great variation in the L.O.I. content of the limestones belonging to the Lower and the Middle Trikuta groups. In case of the Lower Trikuta, the L.O.I. varies from 39.59% to 51.43%, while in the Middle Trikuta, the percentage varies from 20.55 to 46.44. It is thus obvious that there is greater loss on ignition in the lower group than in the middle one.

Insoluble Residues

The insoluble matter varies from 6% to 8% of the total weight of the rock. The percentage is higher in the middle group as compared to the lower one. The various insolubles examined are given in the following table :-

Table - VIII

Showing Various Insoluble Residues in the Trikuta Limestone.

Group	Quartz.	Ferruginous matter.	Clay minerals.	Others	Total
The Middle Trikuta	60%	30%	6%	4%	100
The Lower Trikuta.	10%	10%	25%	55%	100

Relationship between Insoluble Residues & Mgo

There exists a definite direct relationship between the content of Mgo and insoluble residues. It has been observed that where the content of Mgo is greater the percentage of the insoluble residues is sufficiently less as in case of the Lower Trikuta group, shown in plate No.8. On the other hand, where the content of Mgo is lesser, the ratio of the insoluble residues is sufficiently great, as shown in plate No.8 for the middle Trikuta Limestone.

Spectrochemical Analysis

The spectrochemical analysis of about half a dozen samples from the lower and the middle horizons were got analysed from the Atomic Mineral Division, Department of Atomic Energy, Hyderabad (A.P.). This was done to make an assessment of the trace elements within the limestones. While conducting the analyses, the densities were compared with the prepared standard solutions. The percentage of elements have been given in the table I-IX.

Table I - IX

Showing quantitative spectrochemical Analyses of Limestones.

Sample No.	Locality	Horizon	Major Elements (above 1%)	Minor Elements (0.1 to 1%)	Trace Elements (Below 0.1%)
CH=2030	Salal	Middle	Mg, Ca.	Si, Fe.	Al, Ti, Mn, Cu.
CH=14	Katra	Middle	Mg, Ca.	Al, Si, Fe.	Mn, Ti, Cu.
CH=1601	Katra	Middle	Mg, Ca.	Si, Fe.	Al, Mn, Cu, Ti.
CH=9	Katra	Lower	Mg, Si, Ca.	Al, Fe,	Mn, Ti, Cu.
CH=1010	Painthal	Lower	Mg, Ca.	Al, Si, Fe.	Mn, Ti, & Cu.
CH=3	Gogalta-Jangal-Gali.	Lower	Mg, Ca.	Si, Fe.	Mn, Ti, Nb, & Cu.

Mineralogical Composition.

The mineralogical composition has been thoroughly investigated by the help of D.T.A., X-Ray powder diffraction, X-Ray diffractograms and thin sections of rocks from different horizons. Staining techniques have also been employed to test the presence of calcite and dolomite.

D.T.A.

The D.T.A. of about 25 samples were got done from Indian Institute of Technology, Kharagpur (West Bangal), Chemistry Division, Bhaba Atomic Research Centre, Trombay (Bombay), Regional Research Laboratory, Hyderabad (A.P.), Division of Soil Science, Agricultural Chemistry, I.A.R.I. New Delhi and the University of Agricultural Chemistry, Bangalore. The investigations were conducted upto a temperature of 1160°C with a rate of temperature of 10°C/Min. The powdered samples were heated in the platinum crucibles under static air. The experiments have produced high, moderate and low amplitude, double or triple endothermic curves from 780°C to 940°C with peak temperatures from 800°C to 920°C but some of the samples have exhibited small endothermic curves with temperatures ranging from 140°C to 220°C indicating the presence of some impurities in the limestones. It has been observed that the samples from the lower horizon mostly contain dolomite as a major constituent while the

Data of
Showing D.T.A. Curves of the Trikuta Limestone.

Table X

Sample Nos:	Locality	Horizon	Amount Taken	Nature and Number of Endothermic Curves.	Nature & Number of Exothermic Curves.	Mineral Composition Major	Minor	Traces	Remarks, if any.
CH=13	Katra	Middle	100 mg.	Sharp peak at 877°C & another at 920°C.	A small peak at 112°C.	Dolomite,	Calcite	Nil	Dolomitic Limestone
CH=511	Salal	"	"	A small peak at 877°C & another prominent peak at 925°C.	-	Dolomite,	Calcite	-	"
CH=5/78	"	"	"	A small peak at 877°C & another at 920°C	-	Dolomite,	Calcite	-	" CH=6/78 & CH=7/78 also show identical results
CH=101	"	"	50 mg.	A conspicuous peak at 840°C.	-	Dolomite	-	-	Not represented.
CH=102	Dhiangarh	"	0.50 mg	Two acute endothermic peaks Ist at 800°C and second at 905°C.	-	Dolomite	-	-	-
CH=9/77	Katra	"	0.5 mg.	Two acute, sharp peaks, Ist at 810°C and second at 920°C.	-	Dolomite ,	Calcite	-	CH=7/78, CH=8/78 and CH=9/78 all show identical results.
CH=235	Mari	Lower	100 mg.	Long, narrow and acute peak at 877°C and another at 933°C.	An acute curve at 125°C.	Dolomite,	Calcite,	Felspar	
CH=254	D.D.Site	"	"	First long & prominent peak at 867°C & second at 933°C.	A conspicuous peak at 112°C.	"	"	-	Dolostone.
CH=244A	"	"	"	A sharp and acute curve at 850°C and another at 913°C.	A prominent smaller peak at 112°C.	"	"	Felspar	CH=2/78 shows similar results.
CH=255	"	"	"	A long acute and sharp peak at 845°C & another prominent peak at 918°C.	An insignificant peak at 112°C.	Dolomite,	Calcite	-	Dolostone.
CH=244	"	"	"	Two prominent peaks, Ist at 846°C & another at 933°C.	A smaller peak at 110°C.	"	"	-	Dolostone.
CH=224	"	"	0.5 mg.	Two sharp peaks, Ist at 800°C and second at 935°C.	-	"	"	-	"
CH=1010	Painthal	"	0.5 mg.	Two prominent peaks, Ist at 800°C and second at 925°C.	-	"	-	-	"

Table XI

Showing Data of D.T.A. Curves of the Trikuta Limestone

Sample Nos:	Locality	Horizon	Amount Taken	Total Wt. Loss.	Nature & Number of Endothermic Peaks.	Nature & Number of Exothermic Peaks.	Wt.Loss for $MgCO_3$ (Ist peak)	Wt.loss for $CaCO_3$ (2nd peak).	Ratio of $MgCO_3$ + $CaCO_3$.	Mineral Composition Major	Minor	Traces	Remarks
CH=3/77	Muttal	Lower	0.5gms.	-	Two very sharp & acute peaks, Ist at 805°C & another at 930°C.	No peak formed.	-	-	-	Dolomite	-	-	Dolostone
CH=1/77	DoKhadda	"	0.5gms.	-	Two prominent peaks, Ist at 800°C & second at 910°C.	"	-	-	-	"	-	-	CH=3/78 & CH4/78 show identical results.
CH=2006	Salal	Middle	100gms.	-	The only important long & sharp curve at 1100°C.	Two peaks, first at 1000°C and second at 1160°C	-	-	-	Silica (Quartz)	Clay	-	CH=29/78 & CH=30/78 show identical results.
CH=2005 M	Salal	"	100gms.	-	Long, Narrow & sharp curve at 800°C.	Two peaks, Ist at 1000°C & second at 1100°C.	-	-	-	Dolomite, Quartz, Clay			CH=28/78 shows identical results.
CH=2002	Salal	Lower	490gms.	198gms.	Two peaks, Ist at 790°C and second at 900°C.	-	3.80%	4.28%	1:1.12	Dolomite, Calcite		-	-
CH=2003	Salal	"	560gms.	270mgs.	Two peaks, Ist at 780°C and second at 910°C.	-	4.82%	4.82%	1:1	"	"	-	-
CH=2004	"	"	450gms.	224mgs.	Ist peak at 780°C and second at 900°C.	-	5.12%	4.90%	1:0.95	"	"	-	-
CH=2005 L	"	"	530mgs.	250mgs.	Long narrow and acute peaks, Ist at 800°C & second at 920°C.	-	4.72%	4.72%	1:1	"	"	-	-
CH=4/77	Jangal-Gali	Lower	50gms.	-	A conspicuous peak forms at 800°C.	-	-	-	-	Dolomite	-	-	Not represented.
CH=104	Mari	"	"	-	An acute peak at 790°C.	-	-	-	-	"	-	-	"
CH=254/2	D.D.Site	"	"	-	Sharp and acute peak at 800°C.	-	-	-	-	"	-	-	"
CH=255/2	"	"	"	-	An acute peak at 790°C	-	-	-	-	"	-	-	"
CH=103	Salal	"	"	-	Sharp peaks at 800°C, at 840°C and at 910°C.	-	-	-	-	"	Calcite		"

middle horizon has dolomite and/or calcite as the major elements. The minor constituents included quartz, clay, etc. The results have been given in the table X to XI and D.T.A. curves have been shown in plates No. 9 to 14.

X-Ray Studies.

The identification of the mineral assemblage in the rocks was done by the help of x-ray investigations. The X-ray powder diffraction of about a dozen representative samples from the lower and the middle horizons were got done from the Geological Survey of India, Calcutta and the X-ray Division of the Regional Research Laboratory, Hyderabad (A.P.). Most of the X-rays have been taken by Rigaku Camera with a diameter of 11.46 cms. in Cu Kα radiation using Fe filter. Each X-ray photograph was given a time exposure ranging from 2 to 11 hours. The 'd' values were calculated and compared with standard ASTM cards and the mineral species present in the rocks were identified and the results have been given in the tables XII to XIII.

About 12 X-ray diffractograms were taken with the help of Phillips Diffractometer, PW1130/00 Holland Type, using Cu Kα radiations (γ=1.5418A^{o}) with nickal filter at 40 KV and 20 MA. The samples were run from 20° to 60° (2θ) at the scanning speed 1°/Min and paper speed of 100mm/Min. These investigations were conducted at room temperature (25°C). Most of the samples were run at 1X10^{3}C CPS range but in certain cases the range was kept 2X10^{3} CPS.

Table XII

X-Ray diffraction Powder data for samples of the Trikuta Limestone

Quartz (SiO_2)		Dolomite $CaMg(CO_3)_2$		Ankerite $Ca(Mg, Fe)(CO_3)_2$		CH=5 Jangal Gali Horizon Lower Dolostone		CH=228 D.D.Site Area Horizon Lower Dolostone		CH=235 Mari Horizon Lower Dolostone		CH=239 D.D.Site Area Horizon Lower Dolostone		CH=244(A) D.D.Site Area Horizon Lower Dolostone		CH=511 Muttal Horizon Lower Dolostone		CH=781 D.D.Site Horizon Lower Dolostone		CH=1002 D.D.Site Area Horizon Lower Dolostone		CH=13 Katra Horizon Lower Dol. Limestone	
d	int.	d	int.	d	int.	d(A°)	I/I_I	d(A°)	I/I_I	d(A°)	I/I_I	d(A°)	I/I_I	d(A°)	I/I_I	d(A°)	I/I_I	d(A°)	I/I_I	d(A°)	I/I_I	d(A°)	I/I_I
4.252	(35)																					4.252	vw
		4.029	(15)																				
				4.04	-							4.04	mw										
				3.704	3			3.705	vw	3.701	vw	3.701	mw										
		3.690	(100)											3.695	mw	3.694	vw	3.695	1			3.693	w
3.343	(100)																					3.537	w*
										3.339	vw					3.350	vw	3.33	3			3.353	mw
								2.902	vs											2.901	vs		
		2.886	(500)	2.896	100	2.886	vs			2.886	vs	2.889	vs	2.892	vs	2.891	vs	2.87	10			2.891	vs
																2.701	w						
		2.670	(50)	2.685	3	2.697	w*	2.694	mw	2.677	w	2.676	w					2.65	4	2.680	w	2.681	mw
						2.661	w																
		2.540	(40)	2.552	2			2.542	mw	2.547	w	2.540	mw	2.542	mw	2.551	mw	2.53	4	2.538	w	2.554	mw
						2.467	w*																
		2.405	(50)	2.411	3			2.412	mw	2.416	mw	2.412	m	2.419	mw	2.415	ms			2.412	w	2.417	ms
																		2.39	4				
						2.302	mw													2.283	ms		
								2.205	ms					2.200	ms					2.207	s		
		2.192	(150)	2.199	1	2.195	s			2.199	s	2.198	ms			2.196	s	2.18	7			2.205	vs
		2.066	(25)	2.067	1			2.073	w	2.071	w	2.069	w	2.074	w	2.066	w	2.06	2	2.073	vw	2.078	vw
		2.015	(75)	2.020	3	2.021	ms	2.023	ms	2.029	ms			2.023	ms	2.021	ms	2.01	6	2.025	m	2.018	s
		1.848	(25)	1.852	1			1.846	vw	1.868	mw*	1.852	w	1.856	w	1.857	w	1.84	3			1.854	w
1.817	(17)	1.804	(100)	1.812	6	1.809	s	1.805	ms	1.810	ms	1.809	s	1.811	s	1.813	s	1.80	6	1.811	ms	1.813	vs(b)

Quartz	Dolomite		Ankerite		CH=5		CH=228		CH=235		CH=239		CH=244(A)		CH=511		CH=781		CH=1002		CH=13	
	1.786	(150)	1.792	6	1.792	S	1.793	ms	1.791	ms	1.786	S	1.789	S	1.789	S	1.78	6	1.795	ms	1.794	S
	1.781	(150)																				
			1.751	1																		
	1.567	(40)	1.569	1			1.569	W	1.572	W	1.568	mW	1.570	mW	1.572	mw	1.57	1				
	1.545	(50)	1.548	2			1.550	mw	1.550	m	1.547	m	1.550	m	1.549	ms	1.54	4	1.551	mw	1.551	m
																	1.53	w				
			1.501	<1																		
	1.496	(10)									1.492	mw	1.490	mw								
	1.465	(25)	1.468	2			1.476	mw	1.471	m	1.463	vw			1.472	mw	1.47	4	1.473	w	1.474	mw
	1.445	(20)	1.449	3			1.449	vw					1.450	vw								
			1.436	1			1.440	mw			1.435	vw	1.435	vw	1.435	vw					1.437	w
	1.431	(50)													1.417	vw						
	1.413	(20)	1.416	<1																		
			1.391	1							1.391	ms	1.392	mw	1.394	ms	1,39	4	1.393	w	1.396	ms
									1.382	m												
	1.389	(75)	1.381	-																		
			1.341	1	1.341	mw	1.339	mw	1.340	mw	1.337	mw	1.339	mw	1.341	mw			1.339	w	1.340	mw
	1.335	(40)																				
			1.300	<1																		
					Major=Dolomite Traces=Feldspars		Major=Dolomite		Major= Dolomite Traces= Quartz		Major= Dolomite		Major= Dolomite		Major= Dolomite Traces= Quartz		Major= Dolomite Traces= Ankerite		Major= Dolomite		Major= Dolomite Traces= Quartz + Feldspars	

ASTM-S-490 After Howie & Broadhurst; (1958)

Table XIII

X-ray diffraction powder data for Samples of the Trikuta Limestone.

Sample Nos:	Locality	Horizon	Mineral Assemblage.
CH=2006	SALAL	MIDDLE	MAJOR= Dolomite
			MINOR= Quartz
			Traces= Feldspar
CH=434/13	KATRA	LOWER	MAJOR=Dolomite

These diffractograms were got done from the Geology Department, Delhi University, Delhi. The X-ray diffractograms have been reproduced in plate No.15(1) and plate No. 15(2).

The X-ray investigations have thrown sufficient light on the mineral assemblage in the rocks from the lower and the middle horizons. Dolomite is the major mineral in the Lower horizon while the middle horizon contains Calcite and/or dolomite and some minor constituents such as quartz, feldspar and AnKerite (?) etc.

Thin section petrography.

The thin sections of the Trikuta Limestone have been examined and it has been found that the rocks of the group on the whole have undergone widespread dolomitisation. The transformation is so perfect that it has left no trace of the original depositional texture and the trace of the most of the allochems have also been obliterated. The few rock types which can be identified on the basis of their microscopic studies are as under :-

1. Saccharoidal Dolostone.
2. Pellet Dolostone.
3. Oolitic Dolostone.
4. Algal Dolostone.

& 5. Highly Cherty Dolostone.

Saccharoidal Dolostone

Most of the carbonate rocks of the Trikuta Limestone belong to this type. This type is characterized by its hypidiotopic texture, typically known as saccharoidal texture. The rocks are equigranular, sub-idiotopic and are congealed in a mosaic like form. Some of the grains show single cleavage and higher order of interference colours. There are two sub-divisions i.e. the fine grained and the coarse grained, the limit being kept for demarcation as 0.2 mm. Although most of the sections are granular in appearance but the development of a few microstructures are helpful in recognising more sub-types. These are as under:-

(a) Bird's Eye Dolostone

In this rock type, small lensoid of calcite are found in an otherwise dolomitic rock. The size of the lensoid varies from 0.3 mm to 0.4 mm.

(b) Stylolitic Dolostone

In this rock type, a stylolitic surface formed by the interpenetration of the two sides resembles a suture and runs parallel to the bedding. The trace of the stylus is due to the secondary replacement of calcite by cherty matter.

(c) Veined Dolostone

Some dolostones are traversed by veinlets of varied sizes having diverse relationship with each other. Some are straight while others are undulating. A few of the sections have shown veins of cimplex meandering nature. Some veins have sharp walls while others show numerous borders. Where more than one vein is present which is more often the case, these veins show diverse relationship. In some cases they are sub-parallel while in others they even criss cross each other as shown in figures 1 and 2 plate No. 16. Both in length and width they also show wide variation. Some veins traverse the whole rock from one corner to the other while in others they end abruptly half way. In width also a few of the veins have size of a few microns while in others the width is as much as 0.2 mm. Internally also in some of the veins crystals grow perpendicular to the walls developing a comby structure while in others they have radiating patterns. The dolostones having veins of these types are thus named as vein dolostones.

2. Pellet Dolostone

This type of rock as shown in figures 5 and 6 plate No. 17 is named on account of the presence of varied amount of pellets of different sizes and shapes which are cemented by dolomitic limestone. The pellets are oval bodies somewhat deformed having no

internal rings or branches. Their size varies from 0.4 mm to 0.6 mm. Some of the pellets are even smaller. The percentage of the pellets varies from 35 to 50.

3. Oolitic Dolostone

In the lower horizons of the Trikuta Limestone a distinct facies of rocks have been formed which are wholly composed of minute rounded grains of oolites. The intervening space between the oolites have been filled up with siliceous cement. Most of the oolites are tangentially in contact with each other. The ratio of the grains to cement is 90:10. The oolites are almost of equal size, and exhibit good sorting. The largest oolite is not more than 0.3 mm in size. Most of the oolites are rounded but some are elliptical as well as shown in Figure 1 plate No. 17. Due to dolomitic replacement in most of the oolites the trace of rings, nucleus etc. have been obliterated (Figure 2 plate No. 17) but in some of these rings numbering two to three are still present as shown in Figure 1 plate No. 17. In most of the cases, the second ring exhibits radial pattern whereas the other ring which is thin has concentric lines. In some of the oolites replacement is so intense that no trace of rings has been left and what is left of them is a rounded lump like structureless body.

The outer shape of the oolite is controlled by the inner shape of the nucleus which though completely replaced has still retained its original shape.

In one portion of rock two or three oolitic grains have been enclosed. The rock has also a vein which is dolomitic in composition.

The interesting feature of these rocks is the compositional difference in grains and cement. The dolomitic composition of the grains clearly point out that the replacement of the grains was carried out first and cementation took place at a much later stage.

Although this rock is found at most of the localities in the study area but its prominent exposures are found near Dhiangarh Dam site area, Known as Salal Hydel Project.

4. Algal Dolostone.

A few of the sections show no recognizable structures other than the very thin, film like laminae. The laminations are composed of comparatively coarse and fine grains of calcite. In the former case, the blades of the crystals are arranged perpendicular to the trend of the lamination while in the latter grains are randomly oriented. Dolomite rhombs can be frequently observed in these laminations. The distribution of silica is patchy or along the laminations that probably have acted as weaker

planes through which injection of silica took place. Silica invariably shows inclusions of carbonates including many dolomite crystals of appreciable size.

5. Highly Cherty Dolostone

The rock is named so because it carries layers of Chert along the grains of calcite and/or dolomite. The chert is present in the form of stringers, lenses, veins or irregular nodules. The sections are mostly microcrystalline. consisting of inequal sized grains of dolomite, calcite and chert. The grains of dolomite are idiotopic and are of the size of 0.1 mm. The chert appears to be composed of 10 to 50 micron size areas of chalcedonic silica. In some, the grains of dolomite and calcite are interspersed with cryptocrystalline chert layers. Veins of chert run across the whole section and bifurcate into number of branches. The width of the veins vary from 0.1 mm to 0.3 mm and their internal boundary shows "comby structure". The junction between the chert and the non-cherty matter is very sharp. In a few sections very thin laminae of black chert showing slightly tortuous disposition alternate with fine grained or partially recrystallised layers.

Textures and Microstructures.

The carbonate rocks show a variety of textures but hypidiotopic texture is seen in most of the rocks. The textural variations depend upon grain size, pore filling, mineralogy, porosity and permeability.

The microstructures observed in the rocks are the result of mode of sedimentation, chemical transformations before and after the sedimentation and selective dissolution and precipitation.

Of the varied structures observed in the rocks the following are the important ones.

(i) Algal mat structure.

Some of the rocks from the lower Trikuta consist of fine, parallel and wavy laminae on a mm-cm scale. The separation of layers is marked by a dark residue. The thicker laminae have been ruptured at places and some minor brecciation structures have been formed.

(ii) Algal Structures.

These have been observed in the algal rocks and are produced by the trapping and binding of detrital sediments by an algal film. These are mound like masses of varied forms. The mounds stand a few centimetres to many metres above the contemporary depositional interface and are having discordant relationship with the bedding planes.

Some of the types in these algal structures have been noticed in the study area which are as under :-

Type A

It includes columnar structures and have been observed at Do-Khadda (Jangal Gali area) and 3 kms SW of Waishno Devi. The laminae are often domed towards the top and incurved around the edges, the space between the laminae is filled with calcareous cement. These are 6 cm to 10 cm in diameter at the base and expand upto 16 cm at the top and their height varies from 12 cm to 20 cm. Majority of the columns are vertical but those exposed at SW of Waishno Devi are oblique. In these, height varies from 6 to 15 cm, width 1 to 6 cm and the laminae are very fine. These forms closely correspond to LIH-C structures of Logan et.al (1964), as shown in figure 1 plate No. 20.

Type B

It includes non-columnar structures and these have been observed in the stromatolitic dolostones exposed at Banganga (Katra), near Bidda ($33^{\circ}07'$ N : $74^{\circ}49'30''$ E), Do-Khadda (Jangal Gali) and Dhiangarh ($33^{\circ}08'$ N : $74^{\circ}50'$ E) Dam site area. In such structures as shown in figures 3 and 4 plate No. 20, the laminae is thin, smooth or crenulated, grows perpendicular to the surface, convex to the top and finally descend down abruptly at the margins.

At Bidda the sub spheroidal forms have alternate fine and coarse laminae. The structures have a height of 20 to 35 cm and a width varying from 10 cm to 20 cm. In the Dhiangarh area, the laminae is closely spaced, unlinked at the margin or in certain cases linked at the margin with the just preceding or succeeding laminae.

Type C.

This type includes spheroidal structures as shown in figure 2 plate No. 20. Such algal structures have been noticed near Painthal (32° 59' 30" N: 74° 59' E) and Bidda backslope. In these, each dome is made up of alternate layers of dolomite and Chert. The laminae are moderately convex centrally and abruptly convex marginally. The height of the dome varies from 12 cm to 25 cm while the width varies from 8 cm to 15 cm. The transverse sections are circular in outline. The black coating in some of the domes is due to organic carbon derived from the algae.

Some of these structures look like a loaf or an inverted bowel as shown in Fig. 6 plate No.20. Each mass consists of irregularly alternating fine and coarse lamellae.

Type D.

It includes discrete forms as shown in Figure 5 plate No.20. Such algal structures have been observed at Sanji

Chhatta north of Katra. It includes Ovoidal, oblong, ellipsoidal, and fan like forms. The fan like forms have a height of 8 to 12 cm with a laminae having variable basal radii and they grow from the same level. In certain structures the laminae is less closely spaced and smooth. These are flattened centrally and convex at the top and then descend downward abruptly along the margins.

(iii) Bird's Eye Structure

This structure has been observed in most of the rocks. The laminated fenestral fabric present in the rocks have a distinctive, reticulate, fissure pattern, parrallel or perpendicular to the bedding. The rocks with such structures are dark in colour than the host rock.

(iv) Laminated Structure

This structure has been observed in laminated dolostones exposed in the Katra-Riasi area. The lamination is developed by the presence of cryptocrystalline to microcrystalline calcite and/or dolomite; chert, etc. The laminae in certain cases is uniformly thick while in others the laminae are extremely thin, smooth and fairly regular. The quartz laminae acts as divisional planes between the various laminae. Leaving aside cases of even laminae, there are roiled or contorted laminae. In most of the rocks the thickness of the laminae varies from a fraction of mm to as

much as 10 mm. Wherever the laminae are disturbed by minor cuts, they give rise to "Cut and Fill" structures.

(v) Grumous Structure

It has been observed in some of the rocks from the Lower Trikuta in which the pervasic recrystallisation has produced patches of coarsely crystalline carbonates in an otherwise fine grained cement.

(vi) Oolitic and Spherulitic Structures

These structures as shown in Figures 1, 2 & 4 plate No. 17 have been observed in oolitic dolostones - a distinct facies associated with the Lower Trikuta Limestones. In these, both radial and concentric rings have been observed. The radial structures, in many cases, are seen to cut across the concentric rings, these are probably due to diagenetic changes (Cayeux, 1935).

(vii) Veins and Vugs

Veins of different types have been found to traverse some dolostones. In many cases as shown in Figures 1 & 2 plate No. 16, they are simple or compound, straight or undulatory, branching or criss cross each other. Both in length and breadth they show great variations. They may be composed of cryptocrystalline or microcrystalline carbonate minerals or Cherty matter.

In certain cases, veins are connected with vugs. The vugs are of diverse characters and are often

impregnated with cryptocrystalline to microcrystalline carbonate minerals or quartz or chert, etc.

(viii) Microstylolitic Structure

An important microstructure observed in certain dolostones of lower horizon. It represents a surface marked by interlocking or mutual interpenetration of the two sides. The teeth like projections of one side fit into sockets of like dimension on the other as shown in Figure 5 plate No. 16. The stylus is parallel to the bedding and is often due to a secondary replacement of the limestone by chert, subsequent to the development of the stylolite.

Diagenetic Changes

Like all the ancient carbonates, the Trikuta Limestones have undergone a fair degree of diagenetic changes including cementation, compaction, solution, recrystallisation, crystal inversion, replacement, mineralisation and deformation. Some of the diagenetic changes noticed in the Lower and the Upper Trikuta Limestone are as follows:-

i) Replacement of calcimicrites to dolomicrites.

ii) Recrystallisation of the ancient carbonates, has reduced the grain size typically producing saccharoidal texture in the dolostones.

iii) Decrease in porosity- due to compaction.

iv) Decrease in density eg; Aragonite (2.94) to calcite (2.71) in case of oolitic dolostones.

v) Reduction in volume by about 13% of the total

volume. The volume reduction has caused the development of shrinkage, polygonal cracks and microcracks, fissures and their microequivalents.

vi) Recrystallisation of aragonite to calcite and further to dolomite and conversion of colloidal silica gel to chert.

~~vii~~ vii) Formation of veins and veinlets of microcrystalline silica within the rocks.

viii) Formation of vugs. These occur either independently or connected with veins.

ix) The presence of cryptocrystalline calcite within the cherty matter suggests that either some calcite has formed during silicification of the dolomite or it has escaped replacement by dolomite and silica.

x) The increase in size of pseudo-oolites, development of RADIAL TEXTURE and superimposition of radial texture over the concentric rings of the oolites are some of the important diagenetic changes in the oolitic dolostones.

Mechanism of Dolomitisation

The Trikuta Limestone is all dolomitic materials and nowhere an evidence of any replacement has been found. Inspite of best efforts no original remnant of the limestone has been recorded. The presence of oolites, stromatolites and "birds eye" texture of shinn (1968) and

desiccation cracks give an indication of supratidal environment. Even in this environment we find a fairly widely ranging hydrodynamic energy conditions, as reflected in the considerable variety of composition, texture and structure. But no such gradations have been observed in the study area. Under these circumstances, it has become difficult to explain as to what was the exact nature of the basin in which the sediments might have been deposited. Gundu Rao (1973) while conducting the time trend analyses of dolomite variation in the Sirban Limestone of Riasi expressed that the topmost unit of the rocks is a "flysch" like repetition of thin limestone and shale. Later, he contradicted his own views and stated (1976) the existence of Sabakha type of conditions in which supersaline water had replaced the original limestone. He stated that under such environments with higher values of PH, Eh and Co_3 ionic concentration, the original limestone had been replaced by dolomite and anhydrite. While considering such evaporitic conditions for the formation of dolomite and anhydrite, he failed to account for the absence of "red beds" and also the association of siliceous and calcareous shales with the biostromes. The theory becomes untenable also on account of the total lack of gypsum in these deposits. The same difficulty crops up if we consider it a Bahama Type of conditions. Bahama's Bank is a submerged plateau off the coast of Florida constructed of

Pleistocene limestones on Tertiary and Cretaceous limestones and dolomites covered with a film of Recent Carbonate sediments. In this environment too, besides oolitic and pelletic material we find coralgal reef types of solid rocks which are completely missing in case of the Trikuta Limestone although the presence of stromatolites, oolites, pellets, etc., indicate a very close similarity.

Another area which answers the possible living analogue of the Trikuta Type of environment may be Coorong area of South Australia. This region abounds in Playa Lakes and ephermal lagoons in which varied group of carbonate sediments are accumulating. An interesting part of this environment is that among various minerals like Dolomite, Calcian Dolomite, Magnesian Calcite and other minerals like Magnesite and Hydro-magnesite are also being deposited although their mode of formation is not very clear. This environment differs in many important and interesting ways from that of the Sabakha of the Persian Gulf.

Petrography of the Chert Breccia

The upper part of the Trikuta Limestone which acts as a cap over the underlying rocks has a uniform behaviour in all the outcrops. The rocks are hard, dense, and reveal the same structural attributes as are exhibited by the middle and the lower members of the Trikuta Limestone. The lower horizons have a comparatively greater thickness and show different physical and chemical characteristics. On these very basis, the early workers considered it to be a separate formation and designated it by different names such as Siliceous Breccia (Medlicott, 1876), Siliceous grit (Simpson, 1904), Brecciated quartzitic grit (Middlemiss, 1928), Brecciated Limestone zone (Bhat and Nanda, 1957), Brecciated quartzitic grit (Gupta and Kapoor, 1960), Brecciated quartzite (Dhall and Srivastava, 1964), Tectonic Breccia (Dhall and Srivastava, 1964), Glacial till (Wakhaloo and Shrma, 1970) etc. Each name has its own merit and significance but for the present work the term "Chert Breccia" has been proposed and it has been found to be an integral part of the Trikuta Formation.

The Chert Breccia is exposed in the entire area between Jangal Gali and Salal.

The outcrops are more conspicuous on the northern side than on the southern side of the dome, where the rocks are missing due to faulting. In the eastern part of the study area, the chert breccia is unconformably overlain by Bauxites of the Eocene Formation while on the west, the rocks directly underlie the olive shales and sandstones of the Eocene Formation. The thickness of this member ranges between 5m to 30m. The outcrops that pinch and swell have uniform petrological characters. The formation has little heterogeneity in the upper part and more brecciation in the lower part. It acts as a stratigraphic break between the Trikuta Formation and the Jammu Eocenes. Middlemiss (1928, pp.4) while discussing its stratigraphic set up stated, " whatever be the age of the Breccia and its associated finer textured beds, it clearly marks a great stratigraphic break". Wadia (1949, p. 43) stated, "the Chert Breccia marks an erosional unconformity". Srivastava (1956,1969) referred to the unconformable junction between the Trikuta Formation and the Bauxite Bed of the Jammu Eocenes. He further stated that the unconformity is a faulted one. Gupta and Kapoor (1960) also expressed that " the Breccia Bed of Sangar Marg and Chakkar indicates a subaerial erosional unconformity between the Nummulitics and Sirban Limestone".

Petrography

The petrography of the Chert Breccia has been made with reference to physical characters, microscopic features and chemical composition.

Physical Characters

In physical appearance the rock is dark grey to black but occasionally it is dark reddish grey. The rock is clastic, medium to coarse grained typically showing brecciated structure. The phenoclasts are mostly angular or sub-angular of varying sizes. Most of them are 3 to 4 cm in length and 2 cm in thickness. Majority of the phenoclasts are of chert, quartzite, quartz, dolomite etc., impregnated with siliceous cement. The specific gravity varies from 2.67 to 2.84. At places, the pore spaces of the breccia are mineralised. Marked colour differences between adjacent breccia fragments suggest slight differences in their minor constituents, probably due to the mixing of source materials. Minor chert aggregate occur in the matrix.

Thin section petrography

The rock under microscope is coarse to medium grained typically exhibiting porphyroclastic structure. The porphyroclasts of chert, quartzite, quartz, carbonate etc., are impregnated by siliceous cement. The clasts of quartz are sub-angular or sub-rounded, varying in size from 0.1 mm to 0.24 mm. They show wavy extinction, sub-parallel

fractures and some have gas or air bubbles as the inclusions in them and some contain Chert as the inclusions. In many cases, the quartzite grains appear to have evolved from the Chert. The accessory minerals include Feldspars, Carbonates, tourmaline, magnetite, zircon, etc., within the siliceous and/or calcareous cement. Of all the clasts, those of the Chert and quartzite are longest and are angular to sub-angular and vary in size from 0.36 mm to 0.65 mm. The pattern of distribution of various grains in the matrix is variable either clustered together or sparsely distributed.

In another section as shown in Fig. 1, plate No. 18, rock has an inequigranular mosaic of quartz grains varying in size from 0,36 mm to 0.65 mm. The grains of quartz either show overgrowth or microstylolitic contacts. The grains in the cement include those of quartz, Chert quartzite, etc. A few accesories include calcite and/or dolomite. The cryptocrystalline Chert has at places been recrystallized into microcrystalline quartz.

Chemical Composition

The chemical characters have been studied by conducting the chemical analyses of a large number of representative samples. An attempt was made to determine Cao, Mgo, Fe_2O_3, R_2O_3, Loss on ignition and acid

insolubles. The results have been reproduced in the table No. XIV. These analytical investigations have led to the following conclusions :

Calcium Content.

The normal range of Cao in the samples varies from 19.68% to 40.12%. In case of the Lower Trikuta, Cao content varies from 0.40% to 33.28% and in case of the Middle Trikuta, it varies from 17.96% to 38.50%. It appears that the content of calcium oxide increases from the Lower to the Upper Trikuta group.

Magnesium Content.

The normal range of Mgo in the rocks varies from 4.61% to 21.16%. In case of the Lower Trikuta, it is between 3.14% to 46.30% and in the Middle Trikuta, it varies from 3.14% to 22.41%. The content of Mgo thus decreases from the Lower Trikuta to the Upper Trikuta group.

Impurities

The content of acid insolubles and silica varies from 15.41% to 46.10%. In case of the Lower Trikuta the impurities vary from 0.13% to 11.96% while in the Middle Trikuta these vary from 9.50% to 45.9%. It is thus obvious that an overall percentage of silica and acid insolubles increases from the lower to the upper Trikuta group.

Table XIV

Chemical Analyses of the Trikuta Limestone

Horizon - Upper.

Sl.No.	Sample Nos:	Locality	Cao%	Mgo%	F_2O_3%	Al_2O_3%	R_2O_3%	Silica + Acid insol%	L.O.I.	Sp.Gr.	Remarks, if any.
1.	CH=31	Muttal	21.01	14.91	1.04	0.11	2.00	30.38	30.55	2.72	Chert Breccia.
2.	CH=39	"	24.31	16.31	1.31	0.07	2.15	25.18	30.36	2.75	"
3.	CH=43	"	21.14	18.21	0.11	0.05	3.37	30.98	26.14	2.73	"
4.	CH=44	"	28.12	19.34	0.21	0.13	2.19	21.54	28.67	2.84	"
5.	CH= 71	Chimiara	30.32	20.73	Traces	0.05	4.13	20.14	24.53	2.84	"
6.	CH=73	"	30.48	18.41	0.14	0.71	6.39	29.34	14.52	2.74	"
7.	CH=74	"	24.13	16.19	0.15	0.09	5.81	34.16	19.47	2.70	"
8.	CH=79	"	12.68	18.34	0.09	Traces	2.78	46.10	13.93	2.66	"
9.	CH=119	Katra	25.62	18.08	1.04	0.05	1.77	15.41	38.03	2.86	"
10.	CH=121	"	25.42	19.14	1.02	Traces	2.15	19.22	33.05	2.86	"
11.	CH=131	"	22.19	18.36	1.14	-	4.16	24.14	30.01	2.75	"
12.	CH=139	Talwara	40.12	4.61	1.31	0.35	0.41	18.63	34.56	2.86	"
13.	CH=140	"	31.90	11.39	1.94	Traces	2.20	26.15	26.42	2.76	"
14.	CH=156	Riasi	27.81	20.02	1.28	0.50	4.10	24.23	22.06	2.74	"
15.	CH=158	"	24.34	21.16	1.39	0.41	5.78	20.94	26.28	2.86	"
16.	CH=159	"	28.34	18.14	0.94	Traces	4.64	28.44	20.50	2.73	"
17.	CH=219	SALAL	24.22	17.23	0.07	"	2.99	19.44	36.05	2.86	"
18.	CH=220	"	21.19	16.17	0.09	-	5.18	22.18	35.18	2.85	"
19.	CH=231	"	29.16	17.61	0.49	0.09	3.14	25.29	24.22	2.76	"
20.	CH=242	"	28.11	13.90	1.31	Traces	6.16	21.93	28.57	2.86	"

Loss on ignition

In case of the upper Trikuta limestone the content of L.O.I. varies from 13.93% to 38.03%. In case of the lower Trikuta, it varies from 39.59% to 51.43% and in the upper Trikuta the percentage varies from 20.55 to 46.44. It is thus apparent that the L.O.I. considerably falls from the lower to the upper Trikuta Limestones.

Insoluble Residues

The insoluble matter in the Chert Breccia varies, from 6.5% to 9.5% whereas the percentage in case of the Lower Trikuta ranges from 5 to 6.5 and in case of the Middle Trikuta the insoluble matter varies from 6.5 to 8.5. It is thus clear that the percentage of insoluble residues considerably increases from the Lower to the Upper Trikuta group.

Nature of the Chert Breccia

Diverse opinions have been given regarding the nature of the Chert Breccia. Of the many mention may however be made of Dhall and Srivastava (1964) who thought it to be a "Tectonic Breccia" but the typical "pinch and Swell" character of the rock rejects this idea. Wakhloo and Sharma (1970) thought it to be a tillite but the following points go against it :

1. The phenoclasts are of uniform composition except chart fragments and limestone fragments no other rock is found in these breccias showing thereby that the fragmentation has resulted from the limestone mass itself and these have not been transported by any other agency from outside the area. Till deposits are very hetrogenous in nature in which number of rock types are found among coarser fraction. Hence tillite nature of the Chert Breccia is totally ruled out.

2. In pure tillites all the grains are not anguler, only 10 to 20% grains are angular to sub-angular while others are all rounded but in the Chert Breccia under review no rounded grains at all have been observed showing thereby that it can be anything but tillites.

3. Wakhaloo and Sharma (1970) have correlated these tillites to the Talchir Boulder Bed and mentioned that this tillite was formed during widespread glaciation of upper Carboniferous times. In this regard, it may be mentioned that the age of the Trikuta Limestone is still controversial. Although some recent workers are inclined to consider it Pre-Cambrian but majority of them still believe these to be of Permian age. The Tillite represents the uppermost horizon of the Trikuta Limestone Formation. If the

limestone is of the Permian age, it is not understandable how the Talchir Boulder Bed could deposit its material when the main body of the limestone was not in existence.

4. Size analyses and fabric studies also ruled out the possibility of its being tillite.

5. Most of the phenoclasts are discoidal in outline and none of the fragments have shown any rod shaped or slender form. This fact is very significant as in tillites all form of pebbles are rod shaped but those formed by shringake cracks the discoidal form is most dominating one.

Depositional Environment of Trikuta Limestone.

Regarding the depositional environment of the Lower and the Middle Trikuta it has been found that the sediments consisted of carbonates precipitated in the plays lakes or in ephermal lagoons like the ones that now exist in the Coorong area of south Australia. The salinity of waters on these playas was variable but probably high at all times except during flooding. Under such environments various minerals like dolomite, calcian dolomite, magnesian calcite, magnesite and hydro-magnesite were formed. Thin biostromes and oolites also formed in this environment. The presence of microcrystalline to

~~be~~ fine crystalline dolomites containing abundant vugs suggests possible biostromes. The sediments were deposited on the algalmat covered surfaces of the playas. The basin being characterised by extremely slow subsidence, did not permit any of these algal structures to develop into thick bioherms (or biostromes). The oolites which are confined to the Middle Trikuta Formation formed in agitated waters, where the supersaturated waters first broke and lost carbon dioxide. The oolites are made of concentric layers of calcium carbonate built around a central nucleus of aggregate grains of lime or faecal pellets.

Regarding the depositional environment of the upper Trikuta, it may be stated that it is genetically related to the limestones of the Lower and the Middle Trikuta Limestones. Between times of inundation, desiccation produced cracks of diverse types in upper layers of the sediment. Sediment below the zone of mud cracking underwent desiccation, degassing and internal shringake and developed vugs and planar oriented shrinkage cracks and voids. ("Bird's eye" texture of Shin, 1968 and " dismicrite" of Folk, 1962). Desiccation, reworking and fragmentation of the phenoclasts of chert by siliceous cement produced a true clastic rock designated as Chert Breccia. These rocks result from rather restricted local conditions and are likely to reflect individual characters with regard to lithology, variability and lateral impersistence.

Chapter 4

JAMMU EOCENES

A. Petrography of the Bauxite;

B. Petrography of the Coal and

C. Petrography of the Nummulitic Limestone.

Chapter 4

JAMMU EOCENES

Introduction

The Jammu Eocenes (or the Eocene Formation) unconformably overlie the upper member of the Trikuta Limestone Formation and forms an important litho unit in the stratigraphical column of the area under study.

The outcrops of the Eocene Formation occur all along the Riasi dome. The rocks are fringing the older limestones of the Trikuta Formation and exhibit the same structural attributes as are shown by the underlying and the overlying formations. A discontinuous and thin strip of the Eocenes make its appearance in Jangal Gali- Salal and beyond in the north west across the river Chenab.

The Jammu Eocenes are further sub-divided into three members i.e. the lower, the middle and the upper. The lower member comprises of bauxites, aluminous clays and lower coal measures. The middle member consists of ironstone-shale types of rocks with thin seams of coal. There is a sharp contrast between the lower aluminous and bauxitic matter and the mixture of ferruginous and carbonaceous matter of the middle part. The upper member is undoubtedly marine consisting of limestone and olive shale sequence with mega and micro fossils of foraminifera,

echinoids and lamellibranchs. The limestone is dark in colour and more argillaceous in composition. Some bands of limestone also contain nodules of phosphorites. A few such bands are excellently exposed in Sukhwal Gali-Jangal Gali area and at Salal village.

Much has been written about bauxite [Middlemiss (1928, 1929), Abbas (1964), Roy Chowdhury (1965), Singh (1969), Chakraborty (1972), etc.], Coal [Medlicott (1876), La Touche (1888), Simpson (1904), Ganju (1956), Srivastava (1958), Mehta & Srivastava (1959), etc.] and fossil assemblage [Singh (1970, 1973), Tewari and Singh (1966) etc.] from the limestone-Shale sequence but no work has been done on the petrography of the limestone, nature of its facies and depositional environements.

In the present work an attempt has been made not only to study in detail the bauxite and coal but also the limestone, its composition, textures, structures, petrographic types and mode of origin. This study was very essential to understand the evolution of the basin in which coal seams were formed. The three main components of the JAMMU EOCENES viz. Bauxite, Coal and Limestone- Shale have been separately studied and the results are as follows:

A Petrography of the Bauxite

Introduction

Bauxites and related residual deposits form an integral unit of the Jammu Eocenes. They are confined to the Lower part and lie Scattered over an Uneven and irregular denuded edges of the upper member of the Trikuta Limestone. The outcrops are in the form of outliers lying stranded on the gently dipping slopes of the older formations. Their typical Knobby or pisolitic structure has been retained only where differential erosion has not acted upon or where they lie in the synclinal troughs of the folds. The deposits though lying in a pell mell manner yet show an ESE to WNW alignment. The rocks are hard, dense and reveal the same structural attributes as are exhibited by the underlying and the overlying formations. The rocks are overlain by Nummulitic Limestones and underlain by Chert Breccia- the upper member of the Trikuta Limestone. The bauxites mark an unconformable junction between the older and the younger formations. Number of workers such as Abbas (1964), Roy Chowdhury (1965), Chakraborty (1972), etc. have made a brief reference to the bauxites and the petrographic account has only been given by Middlemiss (1928) and Singh (1969) but that too in a fragmentary manner.

The outcrops of bauxites have been found at a number of places but excellent exposures are as under :-

Jangalgali-Sukhwalgali Outcrops.

The outcrops that pinch and swell in this area stretch over a length of eight Kilometres. In the Sukhwalgali area, the outcrop emerge out of the COAL MEASURES with a fairly uniform slope. This outcrop is of the size of 1.6 Km x 0.25 Km. The rocks on the eastern part of the outcrop are hard, dense, pale brown coloured with a typical Knobby texture and hardness varying from 4.5 - 6.5. The central part has rocks with specific gravity about 3.04 while the rocks from the western portion are greyish white, hard with a specific gravity of about 3.03.

The bauxite deposits on the west of the village Jangal are of pisolitic chacrater, pale or brown coloured with a specific gravity about 3.05. The rocks with non-pisolitic character are poorer in stuff with a far lesser specific gravity of 2.54.

Further south east at Lain (Lat. 32° 59' 30"N: Long. 75° 2' 00" E), the thickness of the beds is about 6 metres with an inclination of about 75° in ESE direction. The outcrop has various grades of bauxites.

Salal Outcrop

The Salal (Lat. 33° 10' N : Long. 74° 50' E) outcrop (plate No. 21) forms the northern limb of the Riasi dome. The deposits are far more Coherent than those of the Jangalgali-Sukhwalgali area. The deposits have a fair continuity, greater concentration and good grade. The continuity of the outcrop, whereever lost , is either due to differential erosion or due to their structural set up.

Petrography.

The bauxites have three distinct and well marked horizons. They vary from each other on the basis of their physical, textural, chemical and mineralogical characters.

Physical Characters.

The top horizon acts as a cap to the underlying horizons and shows a uniform behaviour in all the outcrops. The lower horizons have a comparatively lesser thickness and exhibit different physical characters.

Colour.

There is a wide variation as far as the colour of the bauxites and related rocks is concerned. The samples from the pisolitic horizon are mostly mottled grey, brown or white with an occasional staining of iron.

The cream coloured varieties are par excellence with a highest content of alumina. The rocks from the semi-pisolitic horizon are cream coloured and those from non-pisolitic horizon are either grey or drab coloured. The rocks are smooth with a delicate soapy touch. Some of the rocks are splintery, scaly or flaky and these quickly break up into smaller splinters. The white coloured varieties often rich in Kaolin have been washed off. The base of the non-pisolitic horizon has grey coloured varieties with a fairly good amount of the mineral Kaolinite. Some of these also contain balls of Clay.

Specific Gravity

The specific gravity of the bauxites vary from 2.42 to 3.68 depending entirely on their composition. The rocks from the top horizons have a higher specific gravity than those from the bottom horizons. The average specific gravity of the pisolitic bauxites vary from 3 to 3.68. while from the semi-pisolitic horizons, the bauxites have a specific gravity of from 2.76 to 2.99 and the non-pisolitic bauxites have a gravity of about 2.42 to 2.74. There is a specific relationship between Sio_2 and specific gravity as shown in plate No. 22. The specific gravity rises where the percentage of Sio_2 drops. This progression is irregular as regards individual analyses, but fairly regular when groups are considered.

Hardness

The rocks with rough appearance and typical pisolitic texture have hardness about 6.5, it is about 4.5 in the semi-pisolitic varieties and far less in the non-pisolitic varieties. Some of the rocks from the bottom horizons are scratched with the nail of finger or with a delicate touch of Knife.

Texture

It is another important physical character to establish variation in different grades or varieties of bauxitic rocks. The rocks from the top horizons are characterised by their peculiar PISOLITIC or Knobby appearance. The pisolites are often closely packed but in others they are closely placed and loosely packed. The individual grains are only detachable from the weathered surfaces. The pisolites vary in their shape and size between wide limits as shown in the following table.

Table XV

Showing shape, size and general characters of pisolites.

Sl. No.	Variety	Shape	Size	General characters, if any
1.	Black-Bauxite	Spherical	<5 mm	The pisolites have white lenses of varying characters.
2.	Brown-Bauxite	Lenticular	5 mm to 2 cm	The pisolites have a yellow staining due to limonite mineral.
3.	Grey-Bauxite	Pea-Shaped	5 mm to 1 cm	Pisolites are sparsely distributed.
4.	White-Bauxite	Pea-Shaped	75 mm to 1 cm.	Iron coated pisolites with white Kernals.

The rocks underlying the top horizons are characterised by SEMI-PISOLITIC texture while those from the bottom horizons show NON-PISOLITIC or massive texture. Some of these are soft, powdery and fine grained in texture. On the basis of texture, three horizons have been recognised both in Jangalgali-Sukhwal Gali sector as well as in Salal sector. The aggregate thickness of different horizons in both the sectors is as shown in the table XVI.

Table XVI

Showing an aggregate thickness of different horizons in different sectors.

Sl. No.	Horizon.	Sukhwalgali-Jangalgali	Salal
1.	Pisolitic (Top)	0.25m to 1.2m(or 47")	0.25m to 3m(or 117")
2.	Semi-pisolitic (Middle)	0.07m to 1.6m(or 62")	0.05m to 4.4m(or 171")
3.	Non-pisolitic (Bottom)	0.06m to 1.3m(or 50")	0.05m to 3.4m(or 133")

Chemical composition

The chemical characters including the chemical composition and Spectrochemical investigations have been conducted of a large number of samples from all the horizons to make an assessment of their petrographic characters.

Chemical Analyses

Representative samples were collected by trench and open cuts at an interval of five metres and subjected to chemical analyses by conventional methods for the determination of SiO_2, Fe_2O_3 and loss on ignition. The results are shown in the tables XVII to XXII.

The chemical analyses have led to the following observations:-

Al_2O_3

The normal range of Al_2O_3 is between 38.12% to 57.28%. The range in the Sukhwalgali-Jangal Gali area varies between 38.44% to 74.45% while in the Salal area, it is between 20.92% to 72.30%.

Relationship between Al_2O_3 and SiO_2

It has been observed that the ratio of Al_2O_3 goes on decreasing from pisolitic to non-pisolitic varieties whereas the content of SiO_2 goes on increasing from pisolitic to non-pisolitic horizons. The relationship between SiO_2 and Al_2O_3 has been shown in plate No. 23.

Table XVII

Chemical Analyses of Bauxites Sukhwal Gali - Jangal Gali Area
Horizon - Pisolitic.

Sample Nos:	Sp.Gr.	L.O.I.	SiO_2%	Al_2O_3%	Fe_2O_3%	TiO_2%	Total
CH=14J	3.18	11.72	5.30	74.45	4.32	3.59	99.28
CH=785A	3.17	14.54	5.91	72.47	3.21	3.87	100.00
CH=785	3.17	14.70	5.98	72.06	3.16	4.10	100.00
CH=783A	3.17	14.56	5.99	72.74	3.93	2.78	100.00
CH=13J	3.16	14.01	6.10	73.37	3.49	3.01	99.98
CH=13	2.16	14.01	6.16	73.31	3.49	3.03	100.00
CH=324	3.15	17.45	7.05	69.50	2.40	3.35	99.75
CH=25L	3.15	17.44	7.06	69.40	2.50	3.40	99.74
CH=25	3.15	16.44	7.06	69.40	3.50	3.44	99.84
CH=24	3.14	14.70	7.98	70.34	3.14	3.84	100.00
CH=326	3.13	9.81	9.00	73.34	3.34	3.51	99.00
CH=328	3.12	12.90	9.51	70.41	3.04	3.54	99.40
CH=325	3.12	15.49	10.20	67.50	3.01	3.14	99.34
CH=203	3.11	14.84	11.83	62.71	6.10	3.52	100.00
CH=203L	3.11	14.80	11.83	69.57	0.96	2.52	99.68
CH=394	3.10	11.01	13.08	69.71	2.04	3.51	99.35
CH=328L	3.09	14.90	14.51	64.01	3.04	3.54	100.00
CH=223	3.08	14.52	15.60	57.84	8.02	4.02	100.00
CH=129A	3.08	14.74	15.79	56.16	7.98	4.98	99.65
CH=130A	3.08	14.52	15.84	56.81	8.71	4.01	99.89
CH=123	3.08	14.60	15.89	56.83	8.64	4.04	100.00

Table XVIII

Chemical Analyses of Bauxites
Sukhwalgali-Jangalgali Area.

Horizon - Semi-pisolitic

Sample Nos:	Sp.Gr.	L.O.I.	SiO_2%	Al_2O_3%	Fe_2O_3%	TiO_2%	Total
CH=224	2.99	14.01	17.48	57.28	7.13	4.11	100.00
CH=102	2.79	17.50	27.70	46.40	6.20	1.70	99.50
CH=104	2.78	15.91	28.12	48.05	6.25	1.70	100.03
CH=93	2.78	14.26	28.14	51.79	2.88	2.77	99.84
CH=124A	2.78	14.40	29.00	46.18	16.88	3.54	110.00
CH=125A	2.78	14.30	29.25	46.30	6.55	3.60	100.00
CH=124B	2.78	14.53	29.48	47.57	4.48	3.94	100.00
CH=127A	2.78	14.50	29.51	47.52	4.53	3.93	99.99
CH=126A	2.77	14.47	29.88	46.92	4.21	4.12	99.70
CH=85	2.77	14.62	31.50	34.73	16.96	1.51	99.32
CH=58	2.76	13.68	33.36	42.48	7.20	2.02	98.74

Table XIX

Chemical Analyses of Bauxites
Sukhwalgali-Jangalgali Area.

Horizon - Non-pisolitic

Sample Nos:	Sp.Gr.	L.O.I.	SiO_2%	Al_2O_3%	Fe_2O_3%	TiO_2%	Total
CH=83	2.66	14.06	37.08	40.19	4.80	2.01	98.14
CH=59	2.65	13.62	38.96	36.58	7.80	3.02	99.98
CH=84	2.64	15.14	39.24	39.37	4.32	2.01	100.08
CH=2	2.63	17.70	40.25	36.80	3.01	2.24	100.00
CH=81	2.63	13.30	40.40	35.53	8.96	1.51	99.70
CH=57	2.62	14.20	40.56	40.91	1.12	2.77	99.56
CH=783	2.62	14.30	40.99	40.89	1.28	2.54	100.00
CH=6	2.61	14.41	41.10	39.69	2.76	2.02	99.98
CH=1	2.61	13.27	41.60	40.70	2.43	2.00	100.00
CH=56	2.60	13.58	41.85	39.62	2.94	2.01	100.00
CH=20	2.60	17.70	41.86	36.28	2.44	2.72	100.00
CH=82	2.59	13.92	43.20	39.73	0.96	1.52	99.33
CH=60	2.59	13.99	43.26	37.11	2.67	2.52	99.55
CH=3	2.58	12.34	44.00	39.14	2.79	2.03	100.00
CH=5	2.56	11.53	45.00	38.44	2.91	2.12	100.00

Table XX

Chemical Analyses of Bauxites
Salal Area

Horizon - Pisolitic

Sample Nos:	Sp.Gr.	L.O.I.	SiO_2%	Al_2O_3%	Fe_2O_3%	TiO_2%	Total
CH=5016	3.16	16.10	6.14	72.30	2.44	2.99	99.97
CH=5002	3.16	15.48	6.91	73.14	1.43	3.02	99.98
CH=5015	3.16	16.38	6.98	72.40	2.14	2.03	99.93
CH=5005	3.15	13.78	7.91	73.14	2.62	2.52	99.97
CH=5018	3.15	12.19	7.99	73.01	3.56	3.09	99.84
CH=5014	3.15	15.40	7.99	72.12	2.44	2.04	99.98
CH=5004	3.14	12.01	8.02	73.15	2.34	3.66	99.18
CH=5008	3.14	12.01	8.03	73.44	2.64	3.76	99.98
CH=5009	3.14	12.80	8.05	70.48	3.46	3.80	98.59
CH=5013	3.14	16.30	8.12	70.50	2.40	2.54	99.86
CH=5011	3.14	14.55	8.15	70.74	2.29	3.46	99.19
CH=5001	3.13	16.13	8.24	71.24	1.40	2.98	99.99
CH=5017	3.12	12.70	8.70	73.01	2.99	3.01	100.41
CH=5006	3.11	16.50	9.04	68.42	2.10	3.92	99.98
CH=5010	3.11	12.78	9.07	72.53	1.99	3.35	99.72
CH=5012	3.11	16.01	9.55	68.42	2.41	3.10	99.48
CH=5003	3.10	14.50	10.06	68.42	2.11	3.91	100.00
CH=5007	3.10	14.60	10.50	70.40	2.04	2.40	99.94
CH=5019	3.09	10.14	15.40	63.14	7.50	3.15	99.33
CH=5020	3.09	13.78	15.50	62.11	6.57	2.35	100.31

Table XXI

Chemical Analyses of Bauxites
SALAL AREA

Horizon - Semi-pisolitic

Sample Nos:	Sp.Gr.	L.O.I.	SiO_2%	Al_2O_3%	Fe_2O_3%	TiO_2%	Total
CH=502	2.84	14.34	21.47	50.64	9.78	3.77	100.00
CH=508	2.83	14.34	21.90	50.72	9.88	3.16	100.02
CH=500	2.82	14.44	21.97	50.43	10.04	3.12	100.00
CH=5022	2.82	12.44	22.88	51.76	9.14	4.16	100.38
CH=526	2.81	18.01	23.22	42.44	9.15	6.96	99.78
CH=5021	2.81	10.12	23.44	52.11	10.51	4.54	100.72
CH=5023	2.81	11.50	23.60	50.90	8.94	4.56	99.50
CH=525	2.79	17.40	24.44	41.52	8.95	5.94	99.25
CH=5025	2.78	18.00	25.00	40.00	9.00	8.40	99.40
CH=500A	2.78	15.45	27.80	47.70	7.10	1.60	99.65
CH=524	2.69	16.12	35.10	38.12	9.00	2.65	100.99

Table XXII

Chemical Analyses of Bauxites
SALAL AREA

Horizon - Non-pisolitic

Sample Nos:	Sp.Gr.	L.O.I.	SiO_2%	Al_2O_3%	Fe_2O_3%	TiO_2%	Total
CH=2001	2.65	14.59	38.83	46.54	7.28	2.76	110.00
CH=503	2.65	14.50	38.80	39.52	4.38	2.80	100.00
CH=504	2.65	14.51	38.89	36.96	7.41	2.86	100.63
CH=566	2.65	14.31	38.90	40.60	4.03	2.16	100.00
CH=506	2.65	14.46	38.94	38.92	3.10	2.72	98.14
CH=2008	2.63	14.02	39.57	39.77	4.32	2.32	100.00
CH=2002	2.62	13.83	41.62	40.93	1.12	2.50	99.97
CH=2007A	2.58	14.37	43.30	36.52	3.74	2.07	100.00
CH=2007	2.58	14.42	43.36	37.42	2.84	1.96	100.00
CH=2017	2.58	14.39	43.41	38.30	2.61	1.29	100.00
CH=2027	2.58	14.42	43.46	37.32	2.84	1.96	100.00
CH=2037	2.58	14.32	43.49	37.37	2.80	2.02	100.00
CH=2002A	2.57	13.83	44.62	37.93	2.50	1.12	100.00
CH=2012	2.56	13.80	45.65	37.90	2.51	1.14	100.00
CH=2003	2.29	3.60	70.56	20.92	4.08	0.84	99.90

Relationship between Al_2O_3 and Specific Gravity

There is definite relationship between the content of Al_2O_3 & Specific Gravity. As the ratio of Al_2O_3 increases from non-pisolitic to pisolitic bauxites, the specific gravity decreases as has been shown in plate No. 24.

Relationship between Al_2O_3 & L.O.I.

The content of Al_2O_3 & loss on ignition are also very closely related. As the ratio of Al_2O_3 increases from non-pisolitic to pisolitic horizon, the loss on ignition also increases.

Relationship between Al_2O_3 & Fe_2O_3.

The content of Al_2O_3 & Fe_2O_3 have a definite relationship. The greater the content of Al_2O_3 lesser is the content of Fe_2O_3. These are a few exceptional cases in the non-pisolitic horizons where the content of Al_2O_3 & Fe_2O_3 show simultaneous fall.

Fe_2O_3

In case of samples from Sukhwalgali-Jangalgali area, the content of Fe_2O_3 varies from 16.96% to 1.12% while in Salal area, the content varies from 10.5% to 1.12%. This variation is even greater than the

variation in Al_2O_3. The content of Fe_2O_3 varies inversely to the content of Al_2O_3. The higher percentage of Fe_2O_3 has been observed only in the ferruginous varieties of pisolitic horizons.

SiO_2

The SiO_2 content of bauxite in the Sukhwalgali-Jangalgali area varies from 5.3% to 45% while in the Salal area, it varies from 6.14% to 70.56%. The SiO_2 content is higher in semi-pisolitic & non-pisolitic varieties while it is highest in the highly aluminous clays. The superior pisolitic varieties have the lowest content of SiO_2. The content of Al_2O_3 varies inversely to that of SiO_2. The higher the gravity and lower the content of Fe, the better will be the grade of bauxite. There is a close relationship between SiO_2 & the specific gravity. As the amount of SiO_2 increases, the specific gravity decreases & vice versa. This relationship has been shown graphically in plate No. 22.

Loss on ignition.

There is a great variation in the L.O.I. content of different varieties of bauxites. In the non-pisolitic horizons, it varies from 11.53% to 17.70% (Jangal Gali sector) and 3.60% to 14.59% (Salal sector).

In the semi-pisolitic horizons, it varies from 13.68% to 17.50% (Jangal Gali sector) and 10.12% to 18.00% (Salal sector), and in the pisolitic horizons, it ranges from 9.81% to 17.45% (Jangal Gali sector) and 10.14% to 16.38% (Salal sector). Loss on ignition increases with an increase in the Al_2O_3 content and decrease in the Fe_2O_3 content. An increase in L.O.I. with an increase in the Al_2O_3 content indicates that the loss relates mostly to the water associated with the aluminous minerals - such as Diaspore ($Al_2O_3 . H_2O$), etc.

Relationship between the top & the bottom beds.

There exists a definite relationship between the top and the bottom beds of bauxites. The content of Al_2O_3 & loss on ingition increases from bottom to top whereas the content of SiO_2 & Fe_2O_3 decreases from bottom to top. The ratio of Al_2O_3 with respect to the thickness of the beds has been shown in plates No. 25 & No. 26.

Spectrochemical Analyses

The spectrochemical analyses of about ten samples of bauxites from different horizons were got done from the National Geophysical Research Institute, Hyderabad (A.P.), to make a detailed study of trace elements.

Table XXIII

Quantitative Spectrochemical Analyses of Bauxites.

Sample Nos:	Locality	Horizon	Co.	Ni.	V.	Cr.	Cu.	Ga.	Pb.	Ge.
1. CH=783	Lain (Muttal)	Pisolitic	<10	<10	150	190	110	158	>1000	120
2. CH=785	Lain (Muttal)	Pisolitic	24	<10	92	112	<10	218	>1000	59
3. CH=123	Kund	Pisolitic	-	11	84	75	<10	40	190	50
4. CH=185	Goggalatta	Pisolitic	82	<10	40	27	<10	24	<10	37
5. CH=124A	Lain (Muttal)	Pisolitic	11	<10	105	46	14	245	620	88
6. CH=124	Lain (Muttal)	Pisolitic	72	<10	125	57	<10	29	86	54
7. CH=500	Salal	Semi -pisolitic	14	<10	110	32	<10	96	64	88
8. CH=10	Goggalatta	Non-Pisolitic.	41	<10	53	28	<10	17	18	74
9. CH=7	Goggalatta	Non-pisolitic.	19	<10	270	118	40	70	11	115
10. CH=4	Gourimitti	Non-pisolitic.	<10	<10	92	60	20	84	13	115

In these analyses, the densities were compared with the prepared standard solutions and the results have been given in parts per million. Of all the traces elements, the ratio of Cobalt, Chromium, Gallium and lead goes on increasing from non-pisolitic horizons to pisolitic horizons while the ratio of vanadium, Copper and Germinium decreases. The content of nickel remains constant. The results are given below in table XXIII.

Mineral Composition

The mineralogical composition has been thoughly investigated by the help of differential thermal analyses, X-rays and thin sections of bauxites.

D.T.A.

The D.T.A. of about two dozen representative samples have been conducted. Sample Nos. CH=784, CH=1244, CH=7, CH=8, CH=3124, CH=3126, CH=21/64, CH=11/78 and CH=3500 were got done from the Indian Institute of Technology, Kharagpur (West Bengal) while the rest of the sample Nos., CH=124, CH=43P/1 and CH=500 were got done by the Chemistry Division, Bhabha Atomic Research Centre, Trombay (Bombay). The investigations had been conducted upto a temperature of 1200°C with a rate of temperature of 10°C/per minute. The powdered samples were heated in the platinum crucibles under static air. The experiments have produced high,

Table XXIV.

Data of
Showing D.T.A. curves of Bauxites.

Sample Nos:	Location	Horizon	Amount of sample.	Amount of Wt. loss.	Nature & Number of Endothermic peaks.	Nature & Number of Exothermic peaks.	Range of Endo. peaks with Wt. loss.	Range of Exp. peaks with Wt. loss.	Mineral present.	Remarks.
CH=784	Lain	Pisolitic	500mg.	95mg.	A broad but poorly defined peak at 540°C.	A small & poorly defined peak formed at 380°C.	500°C to 600°C Wt. loss = 75mg.	300°C to 480°C Wt. loss = 25mg.	Kaolinite Boehmite	Sample No. CH=1244 shows similar results.
CH=124	Lain	-do-	100mg.	-	First peak at 285°C Another small & poorly defined, peak developed at 560°C.	First peak at 85°C & other smaller & poorly defined peak developed at 1020°C.	-	-	Diaspore + Boehmite	CH=12/78 shows identical results to it.
CH=3126	Lain	-do-	500mg.	195mg.	First peak at 560°C. It is a sharp & well defined peak. Another poorly defined peak developed at 930°C.	A small & poorly defined peak has formed at 460°C.	i) 500°C to 650°C Wt. loss= 650mg. ii) 900°C to 960°C.	-	Boehmite	CH=11/78 shows same results.
CH=43/1	Lain	-do-	100mg.	-	Only one important Curve formed at 560°C.	An indistinct peak formed at 85°C.	-	-	Boehmite	Sample CH=200 shows same results.
CH=3124	Lain	-do-	500mg.	185mg.	Ist peak at 540°C & another acute & sharp peak developed at 580°C.	A small & poorly defined peak formed at 980°C.	500°C to 700°C.	900°C to 1000°C.	Diaspore + Boehmite.	CH=21/64 shows identical results.
CH=2944	Lain	-do-	500mg.	185mg.	Ist peak at 540°C & second at 580°C. It is very acute peak.	A poorly defined peak formed at 980°C.	500°C to 700°C	900°C to 1000°C.	Diaspore + Boehmite.	CH=1468, CH=1469 & CH=1470 show identical results.
CH=3500	Lain	Semi-Pisolitic.	500mg.	185mg	A small & poorly defined peak formed at 540°C & another a bit broad & less defined peak formed at 580°C.	A broad & less developed peak at 960°C.	480°C to 700°C. Total Wt. Loss= 175mg.	900°C to 980°C. Wt. loss= 185mg.	Diaspore + Kaolinite	CH=7 & CH=8 show almost identical results.
CH=500	Salal	-do-	100mg.	-	A shallow & poorly defined peak formed at 325°C and another at 580°C.	Only one small and poorly defined peak developed at 100°C.	-	-	Kaolinite + Traces of Albite.	CH=12/78 & CH=13/78 show similar results.

Table XXV

Showing Data of D.T.A. Curves of Bauxites.

Sample Nos:	Location	Horizon	Amount of sample	Amount of wt. loss	Nature & Number of Endothermic Peaks.	Nature & Number of Exothermic Peaks.	Range of Endo. Peaks with Wt. loss.	Range of Exo. Peaks with Wt. loss.	Mineral present.	Remarks.
CH=2001	Salal	Non-Pisolitic.	100mg	-	A sharp & well defined peak at 800°C & another at 1100°C.	First small peak appeared at 60°C, second at 600°C and the third at 1120°C.	-	-	Boehmite + Kaolinite.	-
CH=2003	"	"	"	-	A smaller peak formed at 800°C & another symmetrical peak at 1150°C.	A smaller & poorly defined peak developed at 970°C.	-	-	Quartz Illite	Not represented.
CH=2007	"	"	100mg	"	An acute & sharp peak formed at 700°C & another at 1100°C.	First peak formed at 820°C and second well defined & sharp peak at 1170°C.	-	-	Kaolinite	CH=204/78 and CH=205/78 show identical results.
CH=2008	"	"	100mg.	-	First peak developed at 880°C and second long and acute peak at 1100°C.	First sharp, and acute peak formed at 800°C and second at 1150°C	- -	-	Kaolinite	-

N.B.

1) Heating rate = 10°C per Min.
2) Span= ⇔ To 1 mv/cm
   T2mv/cm.
3) D.T.A. conducted at 1000°C under static air.
4) Crucibles=Platinum.
5) Thermocouple= Cr.Al.

moderate, and low amplitude, double or triple endothermic and exothermic curves. The range of temperature of various curves vary from 380°C to 1170°C. The temperature of various smaller endothermic and exothermic curves is about 100°C or so, indicating thereby the presence of certain impurities in the bauxites. The D.T.A. results have shown the presence of the mineral boehmite in the top horizon, boehmite and diaspore in the semi-pisolitic horizon while the bottom horizon is rich in the mineral Kaolinite with traces of quartz and albite.

The data obtained from the D.T.A. investigations has been given in the table XXIV & XXV, and D.T.A. curves have been shown in plate Nos. 27 to 30.

X- Ray Studies.

The X-ray diffraction of about eight samples were got done from the Geological Survey of India, Calcutta and from the X-Ray Division of the Regional Research Laboratory, Hyderabad (A.P.). The X-rays were taken by Rigaku Camera with a diameter of 11.46 Cm. in Cu Kα radiation using Fe filter. Each X-ray photograph was given a time exposure of 2 to 11 hours. The "d" values were calculated and compared with standard values to identify the mineral species. The data has been given in table XXVI.

Six X-ray deffractograms were taken with the help of Phillips Diffractometer PW 1130/00 Holland type using Cu. Kα radiations (λ=1.5418A°) with nickel filter at 40 KV and 20 MA. The samples were run from 20° to 60° (2Q) at the scanning speed 1°/Min. & paper speed of 10mm/min. These investigations were made at room temperature (25°C). Most of the samples were run at $1X10^3$ CPS range. The X-ray diffractograms were got done from the Geology Department, Delhi University, Delhi. The X-ray diffractograms have been reproduced in plate No.31.

The X-ray studies have shown that there is a fair amount of boehmite in the pisolitic varieties of bauxites, boehmite and diaspore in the semi-pissolitic and the mineral Kaolinite in the non-pisolitic bauxites. The minor constituents include quartz, anatase, albite, illite, etc.

Thin Section Study

Thin sections of bauxites from the upper horizons of the bauxite profile exhibit pisolites of dark colour in a cement of light coloured argillaceous and siliceous matter. The pisolites are either spherical or sub-spherical as shown in Fig.1 & 3 plate No.32 and range in size. Most of the pisolites are of the size of 1mm.

Table XXVI

X-Ray diffraction powder data for Bauxites

Sample CH=500 (Semi-pisolitic) SALAL.				Sample CH=1122, Lain (Semi-pisolitic)		Sample CH=1506, Lain (Semi-pisolitic)		Sample CH=1513, Jangal Gali (Semi-pisolitic)		Sample CH=1520, Kund (Pisolitic)	
I/I_I	d in A°	Kaolinite	Albite	I/I_I	d in A°	I/I_I	d in A°	I/I_I	d in A°	I/I_I	d in A°
S	7.194	7.15(100)		5	6.80	5	7.1	5	7.96	S	3.862
m*	6.227		6.4(20)	10-B	6.14	W	6.02	8	7.12	W	3.516
W	4.390	4.36(50)		2	4.43	V.W	4.71	3-B	4.71	V.V.W	3.334
V.S	4.157	4.17(60)		4	3.98	3	4.48	7	4.44	V.S	2.567
m.s	3.762	3.73(20)		5	3.51	W	3.98	8	4.01	S	2.347
S	3.557	3.57(100)		8-B	3.16	8	3.97	9	3.56	V.S	2.143
S(b)	3.165	3.14(20)	3.20(100)	4-B	2.58	10	3.57	3	3.25	V.S.	2.087
ms	3.092	3.09(20)		10-B	2.35	W	3.14	4	2.83	V.V.V.W	1.999
m	2.565	2.55(70)		3	2.13	5	2.56	8	2.57	V.W	1.716
ms	2.501	2.486(80)		2-B	2.05	8	2.50	6	2.49	S	1.640
S	2.360	2.374(70)		1	1.97	9	2.33	10-B	2.33	W.S	1.471
m	2.319	2.330(90)		10-B	1.85	V.W	2.13	1	2.20	W	1.429
m*	1.866			2	1.77	W	2.10	7	2.14	W	1.380
S	1.834	1.834(40)		3	1.67	V.V.W	1.86	7	2.08	V.V.W	1.344
ms	1.665	1.659(80)		3	1.63	V.W	1.66	1	1.99	V.V.V.W	1.296
ms	1.495	1.489(80)		2	1.61	W	1.64	1	1.90	V.V.V.W	1.254
m	1.457	1.464(10)		3	1.53	8	1.49	3	1.81	V.V.W	1.180
	1.352		1.35(14)	3-B	1.49	V.V.W	1.45	3	1.72	V.V.W	1.46
				4	1.45	V.V.W	1.42	8	1.64		
				1	1.44	W	1.31	4	1.62		
				2-B	1.38	V.W	1.29	1	1.53		
				8	1.32			9-B	1.49		
Inference:	Kaolinite with traces of Albite & some unidentified mineral.			Inference: +Kaolinite	Diaspore	Inference: +Kaolinite	Diaspore	Inference: Diaspore with traces of anatase.		Inference:	Diaspore +Boehmite.

Table XXVII

X-ray diffraction powder data for Bauxites.

Sample Nos:	Locality	Horizon	Mineral Assemblage Major	Minor	Remarks.
CH=2003	Salal	Non-pisolitic	Quartz	Illite	-
CH=2007	"	"	Kaolinite	-	-
CH=2008	"	"	Kaolinite	-	-
CH=2/77	Lain (Jangal Gali)	Semi-pisolitic	Diaspore	Kaolinite	-

Some of the pisolites show an alternating arrangement of limonite and boehmite, embedded in a fine grained boehmite matrix. The outer shells rich in iron and are partly replaced by matrix. The fragments of quartz or Chert form the nuclei of most of the pisolites.

Thin sections of semi-pisolitic varieties as shown in Fig. 4 plate No.32 exhibit less developed pisolites within a cement of varied chafacters. In cement, the feldspars are identified and are differentiated from the grains of quartz which have a characteristic lower order of interference colours or sometimes by undulose extinction.

Thin sections of non-pisolitic bauxites as shown in Figs. 2, 5 & 6 plate No. 32 are composed of a mixture of the mineral limonite, uncrystallised alumina hydroxide and clayey matter. The mineral Kaolinite and quartz form the bulk of the cement.

Some of the thin sections show incomplete, deferrification and fissure fillings by limonite (see Figs 2, 5 & 6 plate No. 32).

Origin of Bauxite

The origin of the Jammu bauxite is similar to the Mediterranean bauxites. The lack of intercalations of clastic sediments, fossils and other means of correlation render palaeogeographic reconstructions difficult,

ambiguous or even impossible. The complexity of their late history renders the interpretation of distributive provinces and original sediments difficult. The genetic history of the bauxites, however, requires a detailed study of

1. The Source Material;
2. The Mechanism of Bauxitisation and
3. The Diagenetic Changes.

1. <u>The Source Material</u>.

There are three possibilities

(a) The source material may be an allochthonous cover on the Trikuta Limestone;

(b) Parautochthonous residual clays and

(c) Bauxitisation of residual clays in Situ.

Since there are no detrital or clastic minerals hence the source material can not be an allochthonous. The parautochthonous character can only be possible for pre-bauxitic sediments. There appears to be only one possibility and that is about its autochthonous character. This has further been confirmed by the presence of fine stratification within the bauxitic sediments and also the presence of certain relict textures.

2. The Mechanism of Bauxitisation.

The process of bauxitisation in the area commenced when allitic sediments were subjected to subaereal meteoric agencies under warm, humid climate with plentiful and well distributed rainfall and good drainage. There was leaching of silica during dry season and formation of Al_2O_3 and Fe_2O_3 during the wet season. The uniform and well distributed rainfall reduced the ferritic matter and thus left behind a hard dense residue rich in aluminium hydroxides. Wherever the drainage was poor, the mineral Kaolinite was formed while diaspore was formed in areas of optimum drainage. The drainage basin had often been affected by movements connected with the Himalayan Orogeny.

It appears that at first bauxite with boehmite pisolites developed, later, diaspore formed in the centre and at the same time boehmite formed in the marginal parts because of the fluctuating conditions of the drainage basin. The marginal boehmite pisolites grew bigger, but those in the centre transformed into diaspore. Some of the pisolites were deformed and elongated while the sediments were still in the plastic stage.

This diasporic bauxite of Jammu is characterised by low silica and iron values and a fairly high alumina content and is solid, massiv or pisolitic. Laterally the diasporites change into clay seams.

It is thus obvious that the desilicification of large spreads of clays was graded from non-pisolitisation via semi-pisolitisation to pisolitisation.

3. The Diagenetic Changes.

The diagenetic changes in the chemical and mineralogical composition commenced with

(a) desilicification-transformation of clay minerals into Al-hydroxide hydrates;

(b) dehydration - transformation of Al-hydroxides into hydrated Al-Oxides and Al-Oxides;

(c) Partial removal of iron-this probably took place last of all; and

(d) basal enrichment of certain trace elements (see table XXIII).

The diagenetic change in texture commenced with

(a) Formation of pisolites - this was during early stages of diagenesis; and

(b) Lithification.

The diagenetic changes in textures and mineralogical composition were contemporaneous and these gave rise to the formation of different facies in the vertical profile of the bauxite.

B. Petrography of the Coal

Introduction

In the Jammu Coal belt (plate No.1) the eastern part of which forms the subject matter of present study, coal seams of varying thickness appear at a number of places and are confined to two horizons.

The lowermost horizon known as Lower Coal Measures, which correspond with bauxite and is of Pre-Eocene age (may be Jurassic or Cretaceous - Middlemiss; 1929) has been developed in the western sector only most probably at the expense of bauxite and has not been recorded in the eastern sector. In the Jangal Gali and Salal areas the bauxite has been well developed and, therefore, the Lower Coal Measures are missing. All the coal pockets which have been exposed on either side of the river Chenab belong to Eocene age and lie above bauxites and below the Limestone - Shale sequence in association with ferruginous beds.

Much has been written on this coal Medlicott (1876), La Touche (1886), Godwin - 1901, Mort - 1902, Hope - 1902 (Simpson - 1904), Simpson (1904), Srivastava (1956), Mehta and Srivastava (1959), Srivastava (1959), etc. concerning its total reserves and chemical analyses but no systematic petrographic account is available except

a brief paper by Ganju (1956, pp. 30-37) in which a study of the few coal blocks and thin sections was made. None of the early workers has explained the depositional environments of this coal. In this work, therefore, an attempt has been made to discuss the petrographic aspect of the coal and its bearing on the depositional environment of the associated beds in general and coal in particular.

Coalfields of the Eastern Sector

There are two important coalfields i.e. the Jangal Gali Coalfields and the Salal Coalfields.

Jangal Gali Coalfields

The early workers have referred to it as Ladda Coalfields. The coal bearing area is divided into a number of blocks. Starting from the south east of the village Muttal the coal is exposed at Lain (32° 59' 30" N: 75° 2' E), Thakar Sui (33° 00' N: 75° 2' 30" E), Gugalta (33° 00' 20" N: 75° 2' 15" E), Kund (33° 00' 30" N: 75° 2' 00" E), Gouri Mitti (33° 3' 34" N: 75° 3' 51" E), Jangal Gali Top (33° 01' 00" N: 75° 01' 30" E), Jangal Gali Back slopes (33° 01' 10" N: 75° 01' 30" E), Sukhwal Gali (33° 02' 30" N: 75° 00' E), etc. The coal seams in all these areas are confined to the upper Coal measures alone. All the outcrops appear as lenticular patches. Due to disturbed character of the area, the beds

of coal have squeezed in and punched out at a number of places. The abrupt increase in the thickness of the seams in the direction of strike is probably due to reverse faulting. A remarkable feature of the disturbances has been the crushing and shearing of a compact coal into a powdery state. Some of the bands have been graphitised though retaining their glossy lustre.

In the Jangal Gali coalfields the upper coal measures have in all three seams. Excepting the middle seam, which is somewhat hard coal, the coal belonging to the top and the bottom seam is soft, powdery but lustrous. The outcrops of two such well defined coal seams of thickness varying from 0.62 to 2.1 metres and separated by 1.5 to 4.3 metres of grey and carbonaceous shales are found to occur. But at Lain, the thickness of the coal seams has swelled to over 12 metres on account of disturbed character of the area. It is again due to structural set up that at several places two seams have merged together to form one seam.

Number of Seams & their thickness.

The information regarding the nomenclature of the seams in the different areas of Jangal Gali Coalfields is incomplete. However, three separate i.e. the top, the middle and the bottom seams have been identified in the Lain Block. In other blocks only one

seam whose identity is not established except in Jangal Gali Top area, has been identified. The average thickness of the seams lie between 1 & 2 metres except in Sukhwal Gali where the thickness appears to have been reduced. In the whole area the behaviour of the seams is highly erratic both with regard to their number as well as their thickness.

Salal Coalfield.

The Salal Coalfield, which derives its name from the Salal village, is the western part of the Ladda Coalfields. Here only one seam has been observed whose identity is not known and whose thickness varies from a fraction of a metre to as much as 2 metres. Like Jangal Gali coal seams, it has also shown evidence of disturbance, and at a number of places the seam either shows pinching and swelling or lenticular character. The base of the seam lies on the hard band of ironstone shales and ironstones which are present persistently throughout and they can conveniently be regarded as the datum line for the deposition of coal. As we proceed towards north west of Salal the seam splits and near Chinkah it has three parts and in all the parts the coal is of the same character.

Physical Characters

In physical appearance, the coal is bright and lustrous. The well known laminated structure of the Gondwana coal is missing.

The extra-ordinary brilliance in certain samples may be due to shearing and compression to which this coal has been subjected. The coal from different blocks has been found to be either greyish black or jet black in colour and has hardness varying from 2 to 2.5. The hardness decreases where shearing or compression increases. The harder varieties often show a brownish black streak and sub-metallic lustre.

The fracture, like lustre, also helps in recognising the rank of the coal. The coal samples often show earthy fracture but compact varieties show uneven fracture.

The specific gravity varies from 1.31 to 2.12 and it increases with the ash in coal but the increase is not proportional because the percentage of fixed carbon, moisture, and volatile matter may have a slight effect on the gravity. The gravity usually increases with the moisture content. In this regard, it may also be stated that the chemical character of the ash is a factor i.e. an aluminous ash will have a lesser gravity than an ash high in iron. The non-coherent varieties of coal also have a higher specific gravity. The relationship between the content of ash and the specific gravity of the coal has been

graphically represented in plate Nos. 33 and 34. It has been observed that an overall percentage of ash in the Jangal Gali coals is fairly high.

Another interesting feature is the presence in varying proportion of VITRAIN, FUSAIN, CLARAIN AND DURAIN bands. The durain bands appear dark grey to black, finely granular and show innumerable shining specks uniformly dispersed in the bands. The sporadic strips of vitrain are often traced within the durain bands. The layers and lenticles of fusain occur abundantly and thin strips of charred wood are exposed if coal is split along fusain bands.

The less banded varieties have only a few thin layers of vitrain with the bulk being constituted of durain anda fairly good amount of fusain.

Chemical Composition

Chemical analyses of the coal have been carried out by a large number of workers more especially by the scientists working in the Coal Survey Laboratory, located in the premises of the Regional Research Laboratory, Jammu. The results of the analyses appear in their unpublished reports. They have made proximate and ultimate analyses, determined the calorific value, softening points fusion range, screening tests and the Caking Index. Inspite

of their large number of analyses no attempt has been made to correlate the results with the petrological constitution of the coal. Since the chemical properties of coal are closely related to its petrological constitution, it was, therefore, felt necessary to determine to what extent variations in chemical properties of these coals could be attributed to the changes in their petrological constituents. To attempt an accurate correlation, it is necessary to know the percentage of the proximate and ultimate constituents of these coals. For this work, therefore, representative samples from different blocks were taken and both the proximate and ultimate analyses were got done in the Coal Survey Laboratory Jammu. The results are produced in the tables XXVIII to XXX.

Moisture

It has been observed from the tables of results of chemical analyses that the content of moisture in case of Jangal Gali coals is rather uniformly low ranging from 0.3 to 3.3%. In the Lain Block where all the three seams of coal have been found, the percentage of moisture varies from 0.5 to 1.1 in the top seam, 0.5 to 8 in the middle and 0.5 to 6 in the bottom seam.

In case of Salal Coalfield, the content of moisture varies from 1.3 % to 5.4%.

Table XXVII

Chemical Analyses of Coal, Jangal Gali (Ladda) Coalfields.

Sample Nos.	Seam	Sample	PROXIMATE ANALYSES As Analysed Basis (%age) M	V.M	Ash	F.C.	Dry Ashless Basis(%age) V.M	C	Calorific value K.Cal/kg. A.A.B	D.A.B	ULTIMATE ANALYSES As Analysed Basis (% age) M	Ash	C	H	S	N	Co_2	P	Cl	Calculated on dry Ashless Basis(%age) C	H	S	N	O	Colour of ash	Sp.Gr.	Caking Index
CH=30	Top	Channel	1.1	9.7	67.1	22.1	12.6	87.4	2285	8875	1.1	67.1	23.2	1.4	2.0	0.4	0.05	0.03	-	-	-	-	-	-	Brownish Grey.	1.94	<5
CH=33	"	"	0.8	14.4	31.5	53.3	14.2	85.8	5610	8755	0.8	31.5	57.1	3.0	5.3	0.9	0.23	0.02	0.03	91.4	4.7	0.5	1.4	2.0	Cream tinged pink.	1.57	9
CH=34	"	"	1.0	11.2	53.4	34.4	13.4	86.6	3545	8720	1.0	53.4	36.3	2.0	3.9	0.5	0.03	0.01	0.04	92.1	5.2	0.6	1.5	0.6	Biscuit tinged pink.	1.88	<5
CH=76	"	"	0.6	13.4	47.7	38.3	16.1	83.9	4075	8615	0.6	47.7	42.4	2.2	4.2	0.7	0.60	0.02	0.01	91.6	4.9	1.0	1.5	1.0	Light Grey.	1.89	6
CH=78	"	"	0.5	13.1	47.9	38.5	16.2	83.8	4060	8590	0.5	47.9	42.3	2.1	3.1	0.5	0.53	-	0.02	90.9	5.0	-	1.1	3.0	Drab Coloured.	1.89	6
CH=150	"	"	0.5	13.8	42.6	43.1	17.1	82.9	4610	8695	0.5	42.6	47.5	2.6	1.8	0.6	0.41	0.01	Traces	90.9	4.8	-	1.1	3.2	Pink	1.76	5
CH=151	"	Pit	0.6	12.6	48.1	38.7	17.1	82.9	4085	8645	0.6	48.1	42.1	2.2	2.0	0.8	0.50	-	"	90.4	4.5	0.5	1.5	3.1	Biscuit tinged Pink.	1.68	<5
CH=152	"	"	0.6	13.3	45.7	40.4	16.2	83.8	4260	8640	0.6	45.7	44.3	2.2	3.0	0.7	0.42	-	0.01	91.2	4.6	0.7	1.4	2.3	Mauve	1.67	<5
CH=153	"	"	0.5	13.5	44.7	41.3	17.1	82.9	4375	8645	0.5	44.7	45.1	2.5	2.6	0.7	0.61	0.01	0.01	90.6	5.0	0.61	1.5	2.3	"	1.67	9
CH=154	"	"	0.7	12.4	48.2	38.7	16.1	83.9	4065	8695	0.7	48.2	41.8	2.2	2.4	0.5	0.45	-	0.02	90.7	4.7	1.3	1.1	2.2	Biscuit tinged pink.	1.68	<5
CH=155	"	"	0.7	13.0	45.5	40.8	16.2	83.8	4295	8675	0.7	45.5	44.2	2.2	2.6	0.6	0.53	-	0.01	90.5	4.8	0.5	1.2	3.0	Mauve	1.67	5
CH=275	Middle Stack		0.7	14.6	37.3	47.4	17.2	82.8	5075	8690	0.7	37.3	52.3	2.6	3.7	0.6	0.43	-	-	91.3	4.5	0.6	1.2	2.4	White	1.59	10
CH=276	"	"	0.6	14.5	43.8	41.1	18.4	81.6	4425	8615	0.6	43.8	46.0	2.2	3.3	0.5	0.53	-	-	91.2	4.9	0.3	1.0	2.6	Greyish	1.76	8
CH=277	"	"	0.8	14.4	39.3	45.5	17.6	82.4	4925	8755	0.8	39.3	51.1	2.4	3.1	0.7	0.49	0.01	0.01	92.1	4.7	0.7	1.3	1.2	Cream tinged pink.	1.61	9
CH=278	"	"	0.7	14.0	44.4	40.0	17.3	82.7	4350	8610	0.7	44.4	45.5	2.1	3.7	0.6	0.45	-	-	91.5	4.7	0.3	1.2	2.3	Mauve	1.76	6
CH=279	"	"	0.8	13.2	50.0	36.0	18.3	81.7	5050	8685	0.8	50.0	41.2	2.3	2.6	0.6	0.39	0.02	0.01	-	-	-	-	-	Cream tinged pink.	1.70	<5
CH=280	"	"	0.5	14.2	39.1	46.2	17.6	82.4	4875	8500	0.5	39.1	50.7	2.6	1.9	0.7	0.54	0.01	0.01	90.3	4.7	0.2	1.5	3.3	"	1.61	10
CH=281	"	"	0.6	13.0	43.4	43.0	16.5	83.5	4490	8600	0.6	43.4	46.2	2.3	2.9	0.7	0.49	-	0.01	91.0	4.5	0.7	1.4	2.4	Brick red	1.76	6
CH=282	"	"	0.5	14.4	43.9	41.2	18.4	81.6	4420	8610	0.5	43.9	46.0	2.1	3.4	0.5	0.53	-	-	91.2	4.9	0.3	1.0	2.6	Light grey	1.76	8
CH=284	Bottom Pit		0.6	13.1	50.1	36.2	18.4	81.6	3900	8665	0.6	50.1	40.0	2.2	2.2	0.5	0.61	-	0.01	90.0	5.0	0.5	1.2	3.3	Cream colour	1.72	5
CH=285	"	"	0.5	14.4	37.1	48.0	18.4	81.6	5220	8805	0.5	37.1	52.4	2.8	1.8	0.8	0.02	0.01	0.28	89.2	4.9	0.6	1.1	4.2	White	1.59	10

Table XXIX

Chemical Analyses of Coal Seam(?) of Jangal Gali (Ladda) Coalfields.

Blocks : Thakur Sui, Gogalta, Jangal Gali Top, Jangal Gali Back Slope and Sukhwal Gali.

Sample Nos.	Block	Samp-el	PROXIMATE ANALYSES As Analysed Basis (%age)				Calculated on dry ash less Basis		Calori-fic value K.cal/kg		ULTIMATE ANALYSES As Analysed Basis (percentage)									Calculated on dry ashless basis(%age)					Colour of ash.	Sp. Gr.	C.I.
			M	V.M	A	F.C.	V.M.	C	AAB	DAB	M	A	C	H	S	N	Co_2	P	Cl	C	H	S	N	O			
CH=348	Thakur Sui	Pit	0.3	13.4	50.0	36.3	15.4	84.6	3910	8775	0.3	50.0	39.8	2.1	5.3	0.6	0.10	-	-	92.4	4.8	0.6	1.2	1.0	Cream tinged pink.	1.70	7
CH=349	"	"	0.5	14.4	33.4	51.7	14.1	85.9	5440	8745	0.5	33.4	54.7	3.0	7.3	0.6	0.13	0.07	0.01	91.0	5.0	0.6	1.2	2.2	Pale Buff	1.53	8
CH=350	Gogalta	"	0.7	12.2	50.8	36.3	15.2	84.8	3750	8555	0.7	50.8	39.5	1.9	2.9	0.5	1.31	0.05	-	92.0	4.3	9.4	1.3	2.0	Cream tinged pink.	1.70	-
CH=351	"	"	1.5	12.5	45.4	40.6	15.4	84.6	4220	8620	1.5	45.4	44.3	2.1	3.0	0.6	0.69	-	-	91.9	4.4	0.8	1.2	1.7	Mauve	1.67	-
CH=358	Jangal Gali Top	Pit	0.6	16.0	30.3	53.1	18.1	81.9	5795	8795	0.6	30.3	58.8	3.3	3.6	0.9	0.37	0.01	0.03	90.5	5.2	0.4	1.5	2.4	Cream tinged pink.	1.56	-
CH=360	"	"	1.6	11.2	37.2	50.0	11.6	88.4	4980	8650	1.6	37.2	52.8	2.2	3.2	0.6	0.22	0.02	0.01	93.0	4.2	0.5	1.1	1.2	White	1.59	-
CH=367	"	"	0.6	18.3	23.7	57.4	20.0	80.0	6440	8830	0.6	23.7	65.2	3.9	4.0	1.1	0.33	0.02	0.03	90.8	5.4	0.2	1.5	2.1	Light Grey.	1.45	-
CH=476	"	"	0.7	17.6	26.5	55.2	20.1	79.9	6120	8745	0.7	26.5	62.0	3.4	3.5	1.0	0.72	0.01	0.02	89.4	5.4	0.9	1.4	2.9	Pale Mauve	1.49	-
CH=478	Jangal Gali Back Slope	Chann-el	1.4	20.0	7.6	71.0	20.1	79.9	7930	8820	1.4	7.6	80.0	4.2	3.2	1.1	0.08	0.00	-	89.8	4.9	0.3	1.1	3.9	Pale Mauve	1.31	22
CH=479	"	"	3.3	10.8	48.7	37.2	14.2	85.8	3740	8555	3.3	48.7	39.9	1.7	2.2	0.6	0.44	0.04	-	92.2	4.4	0.8	1.3	1.3	Pink	1.68	<5
CH=480	"	"	0.6	12.4	54.4	32.6	17.4	82.6	3495	8730	0.6	54.4	36.8	1.7	2.2	0.5	0.53	0.03	-	-	-	-	-	-	Cream tinged pink.	1.89	<5
CH=501	"	"	0.7	16.7	15.2	67.4	18.2	81.8	7310	8830	0.7	15.2	75.0	4.0	2.1	1.2	0.20	-	-	91.1	4.9	9.6	1.5	1.9	Pale Mauve	1.44	14
CH=504	"	"	0.5	13.6	40.1	45.8	15.2	84.8	4875	8860	0.5	40.1	50.2	2.5	4.6	0.7	0.70	0.03	0.02	-	-	-	-	-	Cream tinged pink.	1.60	5
CH=506	"	"	0.8	13.6	38.4	47.2	16.2	83.8	5040	8835	0.8	38.4	51.5	2.7	2.8	0.8	0.83	0.01	-	91.6	4.8	0.1	1.3	2.2	Light Grey	1.60	8
CH=508	"	Pit	0.6	13.0	45.0	41.4	15.6	84.4	4345	8685	0.6	45.0	44.7	2.1	3.5	0.7	0.99	--	--	91.1	4.6	0.1	1.3	2.9	Light Brick red.	1.67	6
CH=510	"	"	0.7	14.6	33.6	51.1	16.2	83.8	5510	8875	0.7	33.6	56.2	2.8	4.1	0.8	0.73	0.01	0.01	92.0	4.9	0.6	1.2	1.3	White	1.62	12
CH=512	"	"	0.4	16.7	31.4	51.5	20.2	79.8	5645	8675	0.4	31.4	58.3	3.1	3.3	1.0	0.45	0.01	-	90.6	4.9	0.9	1.3	2.3	Cream tinged pink.	1.51	17
CH=514	"	"	0.8	13.6	38.5	46.1	14.4	85.6	4925	8740	0.8	38.5	51.0	2.5	5.7	0.7	0.27	--	--	92.8	4.8	0.8	1.2	0.4	White	1.60	9
CH=515	"	"	0.6	18.6	16.3	64.5	20.0	80.0	7130	8770	0.6	16.3	73.3	4.2	2.2	1.1	0.64	0.01	0.05	90.8	5.1	0.3	1.5	2.3	Pale Mauve	1.45	21
CH=518	Sukhwal Gali	"	2.2	7.0	55.1	35.7	1.1	98.9	3095	8280	2.2	55.1	34.3	1.1	5.3	0.4	0.05	--	--	95.2	2.9	3.2	--	--	Cream colour	1.89	<5
CH=519	"	"	2.0	6.3	47.0	44.7	0.9	99.1	3840	8295	2.0	47.0	43.4	1.1	4.5	0.4	0.05	--	--	--	--	--	--	--	Pale Mauve	1.67	<5
CH=520	"	"	2.2	14.2	46.6	37.0	22.0	78.0	3765	7925	2.2	46.6	40.8	2.1	0.9	0.6	0.05	--	--	85.9	4.5	1.1	1.2	7.3	Cinnamon Drab.	1.68	<5

Table XXX

Chemical Anslyses of coal - Salal Coalfield.

Block : Salal

Sample Nos:	Seam	Nature of sample.	As analysed Basis 6 Percentage M	V.M.	A	Dry Ashless Basis(%age) F.C.	V.M.	C.	CAL.VALUE K/CAL/Kg. A.A.B.	D.A.B.	As Analysed Basis (Percentage) M.	A	C	H	S	N	Co2	P	Cl.	Calculated on Dry Ashless Basis (%age) C	H	S	N	O	Colour of Ash	Sp.gr.	Caking Index.
CH=542	?	Pit	4.8	12.8	32.7	49.7	15.2	84.8	5160	8695	4.8	32.7	53.7	2.5	2.6	0.8	0.15	0.03	-	91.6	4.3	0.4	1.4	2.3	Light Brick red	1.52	16
CH=543	"	"	4.2	11.9	42.8	41.1	14.6	85.4	4335	8360	4.2	42.8	45.0	2.0	3.0	0.6	0.21	-	-	93.6	4.2	0.5	1.2	0.5	Pink	1.76	10
CH=548	"	"	5.4	14.5	54.2	25.9	14.2	85.8	5610	8755	5.4	54.2	35.6	2.0	2.2	0.4	0.14	-	-	91.2	4.4	0.4	1.3	2.7	Biscuit tinged pin pink.	1.88	-
CH=564	"	"	4.3	11.8	51.1	33.0	14.4	85.6	4340	9700	4.3	51.1	38.8	2.0	3.0	0.5	0.20	0.01	-	93.4	4.6	0.4	1.3	0.5	Saffron pink	1.70	-
CH=565	"	"	3.9	11.2	51.8	33.1	14.2	85.8	4450	9750	3.9	51.8	38.7	2.2	2.6	0.7	0.12	-	-	92.2	5.5	0.4	1.2	0.7	Saffron pink	1.70	-
CH=566	"	"	1.5	12.5	49.3	36.7	18.1	81.9	3700	8205	1.5	49.3	39.8	1.9	1.6	0.6	0.04	-	-	88.8	4.2	1.4	1.3	4.3	Biscuit tinged pink	1.68	/5
CH=567	"	"	4.6	12.2	72.3	10.9	15.2	84.8	5165	13050	4.6	72.3	18.7	2.0	1.8	0.6	0.01	-	-	88.4	4.6	1.3	1.4	4.3	Light Brick red	2.12	-
CH=568	"	"	4.7	12.9	32.7	49.7	15.2	84.8	5165	8695	4.7	32.7	53.8	2.5	2.5	0.9	0.15	-	-	91.8	4.2	0.3	1.5	2.3	Light Brick red	1.52	16
CH=569	"	"	4.2	11.9	42.8	41.1	14.4	85.6	4340	8865	4.2	42.8	45.0	2.0	3.0	0.7	0.21	-	-	93.4	4.6	0.3	1.2	0.5	Pink	1.76	16
CH=570	"	"	1.3	11.2	58.7	28.8	14.0	86.0	3060	8875	1.3	58.7	31.6	1.5	3.3	0.4	0.64	0.56	-	89.8	4.9	0.3	1.1	3.9	Pale Mauve	1.45	/5

N.B. : Abbreviations used:

O = Oxygen
H = Hydrogen
S = Sulphur
N= Nitrogen
Co_2=Carbon dioxide.
P=Phosphorus
Cl= Chlorine
M=Moisture
V.M.= Volatile Matter
F.C.= Fixed carbon.
C= Carbon
A.A.B.= As Analysed Basis.
D.A.B.= Dry Ashless Basis.

Volatile Matter.

The content of volatile matter, on an analysed basis generally ranges between 6.3% and 20.0%. There is an indication of gradual rise in the amount of volatile matter from the top seams to the bottom ones. In the Jangal Gali Coalfields, the percentage in the upper seams varies between 9.7% to 14.4%, in the middle 13% to 14.6% and in the lower seams 13.1% to 14.4%. The higher percentage has only been recorded in the samples from Jangal Gali Top and Jangal Gali backslope areas where the percentage varies from 11.2 to 18.3 and 10.8 to 20.0 respectively. On dry ashless basis, the values range between 0.9% to 22.0%.

In case of Salal, the content of volatile matter varies from 11.2% to 14.5% and on the dry ashless basis, values vary between 14.0% to 18.1%.

Ash.

The coal samples from the area under study show a variation in the content of ash from 7.6% to 67.1%. At Lain, the top seam has an ash percentage from 31.5% to 67.1%, the middle seam samples show a content of ash varying from 37.3% to 50.0% and the bottom seam samples have a content of ash varying from 37.1% to 50.1%. From the data obtained from the samples from Jangal Gali top and Jangal Gali backslope, it appears that the quality of coal in these areas is far better

than that of Lain. The content of ash in Jangal Gali top and Jangal Gali backslope areas varies from 7.3% to 54.4%. This shows that an overall variation is not very great.

In coal samples from Salal area, the content of ash varies from 32.7% to 72.3%.

Calorific Value.

The calorific value for Jangal Gali samples with less than 50% of ash generally falls between 3740 and 5795 K.Cal/Kg. In the samples from the Lain block, the Calorific Value varies from 2285 to 5610 (top seam), 4350 to 5075 (Middle seam) and 3900 to 5220 (bottom seam). On dry ashless basis, the general range of Calorific Value lies between 8590 and 8845 K.Cal/Kg.

In case of Salal, the calorific value on an analysed basis varies from 3060 to 5610 and on dry ashless basis, it varies from 8205 to 13050 K.Cal/Kg.

Sulphur.

In the Lain block of Jangal Gali Coalfields, the content of sulphur lies between 1.8% & 3.7%. The percentage is comparatively high for coal from other blocks, eg. Thakar Sui (5.3% to 7.3%), Jangal Gali top (3.2% to 4%) and Jangal Gali backslope (2.1% to 5.7%).

In coal samples from Salal, the content of sulphur varies from 1.6% to 3.3%.

Phosphorus, Chlorine and Carbonate Co_2.

In the ultimate analyses, it has been observed that the content of phosphorus is low in almost all the samples i.e. not more than 0.01%. Like Phosphorus the percentage of chlorine is also very high ranging between traces & 0.38%.

The content of carbonate carbon dioxide in all the samples from Jangal Gali and Salal Coalfields has been found to be below 1% (with an exception of 1.31% found in a coal sample from Gugalta block).

Carbon and Hydrogen.

The content of carbon calculated on dry mineral matter free basis in the proximate analyses has been found to lie between 78.0% and 99.1% in case of Jangal Gali Coal samples while in case of Salal, the content of carbon lies between 81.9% and 85.8%.

In the ultimate analyses, the content of carbon as calculated on dry ashless basis falls between 85.9% and 95.2% in case of Jangal Gali samples and between 88.4% and 93.6%, in case of Salal samples.

Caking Index

The caking index of all coal samples both from the Jangal Gali Coalfields as well as from the Salal Coalfield falls between 5 & 22. With an exception of a few samples which have shown a caking tendency all others are non-caking type.

Rank.

The coal of the enture Ladda area is highly matured, low in volatile content, of the bituminous to semi-anthracitic rank. It has been reported to belong to group VI of the Indian Standard Classification and most of the samples fall under ISI Code rank No. 770-870.

Relationship between Ash & Volatile Matter.

From the proximate & ultimate analyses of coal samples, it has been found that there is a close relationship between the content of ash and volatile matter. It has been noticed that wherever the amount of ash increases the content of volatile matter decreases as has been shown graphically in plate Nos. 35 to 37.

Relationship between Calorific Value & Ash

The calorific value (on an ahalysed basis) is closely related to the content of ash. It has been found that with a decrease in the calorific value there is an increase in the percentage of ash, as shown graphically in plate Nos. 38 & 39.

Relationship between Volatile Matter & Calorific Value.

There appears to be a definite relationship between the calorific value and the volatile matter. As the percentage of volatiles increases the calorific value of the coal also increases as has been shown in plate Nos. 40 & 42. On the dry ashless basis also the same relation has been noticed and graphically represented in plate Nos. 41 & 42.

Microscopic Characters.

The microscopic investigations was got done on polished surfaces of the pellets in reflected light under oil immersion. All attempts to obtain thin sections met with no success. This is chiefly because of the friable nature of the coal.

An attempt has been made to study the maceral composition which has a close relationship with the chemical composition. Of the different macerals, telinite and collinite of the vitrinite group, fusinite, micrinite and sclerotinite of the inertinite group and alginite of the exinite group are present in varying proportion.

The low rank constituents like sporinite, resinite, cutinite and cerinite of the exinite group are absent in these coals.

The components of vitrain do not show any structures in the polished surfaces of the coal pellets owing to the fact that the cell cavities are impregnated with a pale coloured substance which has almost the same reflectance as that of the cell wall. The reflectance of vitrain components is considerably lower than those of fusain and vitro-fusain materials with the result that vitrinite bands appear less bright. The fusain and vitro-fusain components are largely composed of woody tissues.

The durain is compact and mostly devoid of low rank tissue of vitrain, spore, exines and resin bodies. The mineral matter is found sparsely distributed.

The fungal bodies occur in large number and have played vital role in the destruction and disintegration of the woody tissues. Fusinised matter is in abundance and is closely associated with the fungal bodies.

Origin of Coal.

The origin of Jammu coal needs consideration of the following points :

1. Source Materials;
2. Mechanism of decay of vegetable matter; and
3. Mode of carbonisation.

Source Materials.

As known the mother substance from which coal is derived are compounds of definite and well known chemical nature, some of them very reactive e.g. the non-nitrogenous, celluloses and the lignins of constructive tissue and the nitrogenous protein contents of the living cells, the more resistant compounds of protective tissue e.g. cut in of cutcles, the spore exines and suberin of cork together with excretory substances such as resin, or reserves such as fats, waxes, starch and sugar. All these liable to decay and

bring abuut complete transformation, under suitable conditions of temperature and pressure.

But the basic question is whether the mother substance was of insitu character or drifted from other areas. The conformity of the strata; the occurrence of marine fossils e.g. Foraminifera in the coal bearing succession in a given section at a definite horizon; the gradual passage of the coal seams to the carbonaceous shales and then to coal; the presence of clay or seat earth below every coal seam; etc. all strongly support the fact that the material was drifted and came from a forest covered land far to the north and the entire vegetable debris had been transported by streams or other water bodies and deposited in a swampy basin, which opened southwards of the upper Eocene Sea.

2. Mechanism of decay of vegetable matter.

The plant debris got transformed under mild temperate to sub-tropical climate, with moderate to heavy rainfall well distributed throughout the year. There were two main processes responsible for the transformation of the plants into coal, firstly, the humification and secondly, the fusinization. The humification was the conversion partly by bacterial agencies, probably anaerobic into brown colloidal substances soluble in alkalis called

humic acid. They were toxic to the micro-organisms when they reached a certain concentration. The biochemical changes thus liberated oxygen, hydrogen and concentrated the carbon. The bacteria were most active near the surface. The kind of bacteria and the duration of bacterial action controlled the quality of humus.

The fusinisation on the other hand was another process by which wood tissue survived. It was converted into material which closely resembled to charcoal, now termed as FUSAIN.

Carbonisation.

The change in the rack was the result of carbonisation. There could be three probable causes.
First - due to the depth of cover and the rise in temperature and pressure gradients associated with it;
Second - due to higher temperature produced from igneous instrusions; and
Third - due to the activities of bacterial and fungal organisms.

As far as the first cause is concerned, the overburden over the vegetable debris was negligible when compared with the over burden of the Gondwana coals. An over burden of a few tens of metres, therefore, could not be the cause of carbonisation.

There are no igneous intrusions to indicate the carbonisation due to higher temperature produced from igneous intrusions.

The carbonisation was probably only due to the "thrust movements" associated with the Himalayan Orogeny, as a result of which the vegetable matter was carbonised. These disturbances not only helped in carbonisation but also raised the rank of Jammu coals though made them friable. In this carbonisation some part was played by bacterial and fungal organisms, as has been established by the presence of fungal bodies alongwith the decomposition products of the fusain materials.

C. Petrography of the Nummulitic Limestone

Introduction

The upper member of the Eocene Formation (or the Jammu Eocenes) consists of alternating bands of limestone and shale in a sequence known as Limestone shale sequence. The total combined thickness of this sequence does not exceed 50 metres. Within this sequence, there are four to five distinct bands of limestone. The average thickness of the limestone bands, varies from 2 to 3 metres. The limestone is profusely laden with nummulitics and other foraminiferal tests (Figure Nos. 3, 4 plate No. 44 and Figure Nos. 1, 3 and 5 plate No. 45) and as such it is known as NUMMULITIC LIMESTONE.

A fairly good detail of the micro and mega fauna contained in these limestone bands is well known through the work of Tewari and Singh (1966, p. 27-28) and Pratap Singh (1970) but no petrological account has been given of these limestones.

In this work, therefore, a detailed petrographic description has been given which includes the study of insoluble residues, sedimentary structures and facies relation. On the basis of these features a depositional environment of the limestones have been worked out.

The details are as follows:-

The Nature of the Limestone Bands

The nummulitics comprise at the top limestones interbedded with two lamellibranch zones of limestones and is underlain by thin limestone bands interbedded with grey shales. These are followed by a zone of grey shales. The thickness of the shale bands does not exceed 12 metres. Then comes a zone which comprises two nummulitic bearing bands of limestones interbedded with grey shales. Further below there is a zone of grey shales, the lower part of which includes the upper coal horizon.

The upper coal horizon comprises one or two thin bands of coal varying in thickness from 0.3 to 2.5 metres separated by 1 to 4 metres thick grey carbonaceous shales. Below the upper coal horizon there occur some grey shales. All these are highly crushed and sheared.

The limestone bands in the middle part of the limestone shale sequence carry nodules of phosphates varying in diameter from 1 to 4 cm. These nodules contain a very little content of P_2O_5 and are sparsely distributed. Since the encrustations of the phosphatic material are neither persistant nor do attain sizeable thickness and hence these are of no economic significance.

Chemical Composition

The chemical characters including the chemical analyses, differential thermal analyses and insoluble residues have been conducted of a large number of samples from different horizons in the study area. These investigations have helped to understand the petrographic characters of the rocks.

Chemical Analyses

Representative samples were collected from all the bands of limestones and subjected to chemical analyses by modern methods of EDTA for the determination of Cao, Mgo, etc. and conventional methods were employed for the determination of R_2O_3, acid insolubles and loss on ignition. An attempt was also made to calculate the percentage of $CaCo_3$ and $MgCo_3$ and the relationship between calcite and dolomite. The detailed results are given in the table Nos. XXXI and XXXII. In these tables specific gravity of the samples has also been given. The analytical investigations have led to the following observations:-

Calcium Content

The normal range of Cao in the middle bands of

Table No. XXXI

Chemical Analyses of Nummulitic Limestones

Horizon : Upper Bands

Sample Nos.	Locality	Loss on ignition %	Silica + Acid Insol%	R_2O_3	Cao%	Mgo%	$CaCo_3$	$MgCo_3$	$CaMg(Co_3)_2$	Sp.Gr.
CH=21	Thalwal west	39.52	7.62	3.34	48.04	1.40	85.78	2.94	6.60	2.70
CH=23	"	39.54	7.12	3.54	48.44	1.36	86.05	2.85	6.83	2.70
CH=34	"	39.50	7.62	3.34	48.04	1.50	85.78	3.15	6.60	2.69
CH=36	"	38.99	7.50	3.78	48.64	1.09	86.85	2.28	5.65	2.69
CH=41	"	39.42	7.16	3.24	48.39	1.79	86.41	3.75	6.43	2.69
CH=42	"	38.94	7.08	3.78	48.40	1.80	86.42	3.78	6.50	2.69
CH=201	Kothari	36.88	12.04	6.83	42.84	1.40	76.50	2.94	11.46	2.66
CH=202	"	36.88	12.64	6.13	42.73	1.62	76.21	3.40	11.15	2.66
CH=203	"	36.40	12.50	6.40	42.96	1.74	76.71	3.65	10.79	2.67
CH=204	"	36.98	12.60	6.90	42.06	1.46	75.10	3.06	13.30	2.67
CH=205	"	36.14	11.94	7.46	42.56	1.90	76.00	3.99	12.06	2.67

Sample Nos.	Locality	Loss on ignition %	Silica + Acid Insol. %	R_2O_3	Cao%	Mgo%	$CaCo_3$	$MgCo_3$	$CaMg(Co_3)_2$	Sp.Gr.
CH=214	Rahot Kot	39.45	7.49	3.28	48.34	1.44	86.32	3.02	6.19	2.69
CH=219	"	40.12	10.32	1.44	46.94	1.18	83.82	2.47	5.86	2.67
CH=223	Salal Village	39.47	7.94	2.96	47.88	1.75	85.50	3.67	6.56	2.70
CH=224	Kanthan	40.46	5.13	3.09	49.88	1.44	89.07	3.02	5.80	2.71
CH=231	"	40.91	5.88	3.19	48.24	1.78	86.10	3.73	8.02	2.71
CH=234	"	37.34	11.34	5.16	44.36	1.80	79.21	3.78	9.45	2.67
CH=239	"	38.56	9.76	3.88	45.96	1.84	82.07	3.86	8.17	2.68
CH=240	"	39.76	6.92	3.10	48.88	1.34	87.28	2.81	5.80	2.71
CH=251	"	37.43	11.36	6.12	43.25	1.84	77.23	3.86	11.41	2.69

Table No. XXXII

Chemical Analyses of Nummulitic Limestones

Horizon : Middle Bands

Sample Nos.	Locality	Loss on ignition %	Silica + Acid Insol. %	R_2O_3 %	Cao%	Mgo%	$CaCo_3$ %	$MgCo_3$ %	$CaMg(Co_3)_2$	Sp.Gr.
CH=9	Lain	41.13	10.46	1.03	46.12	2.16	82.34	4.53	7.19	2.71
CH=10	"	23.44	17.15	2.35	34.66	2.40	61.89	5.05	20.96	2.63
CH=74	"	38.54	10.29	1.84	46.76	2.57	83.50	5.39	6.21	2.67
CH=79	Thakur Sui	38.87	7.10	3.06	48.96	2.01	87.42	4.22	5.48	2.74
CH=81	"	38.54	10.29	1.84	46.76	2.56	83.50	5.37	6.21	2.69
CH=82	"	38.33	10.33	1.96	46.84	2.54	83.64	5.33	6.03	2.67
CH=93	"	37.08	11.16	1.32	45.56	2.50	81.39	5.25	7.50	2.7
CH=94	Kuldd	38.00	10.17	1.99	47.34	2.50	84.53	5.25	5.30	2.69

Sample Nos.	Locality	Loss on ignition %	Silica + Acid Insol. %	R_2O_3 %	Cao %	Mgo %	$CaCo_3$ %	$MgCo_3$ %	$CaMg(Co_3)_2$	Sp.Gr.
CH=96	Kund	38.42	10.36	2.10	45.96	3.16	82.07	6.63	7.57	2.64
CH=98	"	38.75	10.33	1.29	47.19	2.44	84.26	5.12	5.41	2.70
CH=99	"	33.72	24.56	1.83	40.27	3.23	71.90	6.78	3.54	2.63
CH=121	Gouri Mitti	39.44	6.48	2.94	47.81	3.33	85.37	6.99	8.15	2.71
CH=122	"	39.94	7.36	2.64	47.92	2.14	85.57	4.49	7.07	2.70
CH=136	Jangal Gali	40.14	6.10	3.02	47.91	2.83	85.55	5.94	8.35	2.70
CH=139	"	37.60	10.80	4.76	44.84	2.00	80.07	4.20	9.13	2.67
CH=140	"	37.42	9.83	5.12	44.63	3.00	79.69	6.30	9.51	2.68
CH=152	"	36.49	8.62	3.43	48.74	2.72	87.03	5.71	4.35	2.69
CH=154	"	38.41	8.32	3.56	47.52	2.19	84.85	4.59	6.83	2.69

nummulitic limestone varies from 34.66% to 48.96% while in the samples from the upper bands, it varies from 42.06% to 49.88%. It is thus obvious that the content of Cao increases from middle to upper bands.

Magnesium Content

The normal range of Mgo in the middle bands of limestone varies from 2.00% to 3.33% while in samples from upper bands, it varies from 1.09% to 1.90%. There is a clear indication that the content of Mgo decreases from middle bands to the upper ones.

Impurities

The content of acid insolubles and silica in case of limestone samples from the middle bands varies from 6.10% to 24.56% whereas in samples from the upper bands, it varies from 5.13% to 12.64%. From these observations it is very much clear that the content of impurities in the middle bands is far greater than those in the upper bands.

Loss on ignition

There is a great variation in the L.O.I. content of the limestone from the middle bands as well as from the upper ones. In case of samples from the middle bands, the

the content of L.O.I. varies from 23.44% to 41.13%. While in the upper bands, it varies from 36.14% to 40.91%. It has been observed that the percentage of loss is quite less in the limestones from the upper bands.

Insoluble Residues

The insoluble residues were studied qualitatively by dissolving 10 gms of each limestone sample. The insolubles were found to form 6% to 8.5% of the total weight of the rock. Those of the limestone samples from the upper bands which are associated with argillaceous matrix, the content of insolubles varies from 6% to 9.5% of the total weight of the rock.

The minerals which form the bulk of the residue matter are, quartz, chert grains, limonite, pyrite, clay, minerals and carbonaceous matter.

Differential Thermal Analyses

The differential thermal analyses of more than half a dozen samples were got done from the Regional Research Laboratory, Hyderabad (A.P.) to study the mineral assemblage in these limestones. The D.T.A. studies also throw light on the type of the limestone. The studies were conducted at a temperature of 1000°C with a rate of temperature of 10°C/Min. The powdered

samples were heated in the platinum crucibles under static air. The experiments have produced high, moderate and low amplitude single or double endothermic curves from 910°C to 980°C with peak temperature from 936°C to 980°C. The single endothermic curve with peak temperatures referred above indicates a fairly good percentage of calcium. A few of the samples have produced small endothermic curves between 60°C to 180°C with peak temperatures between 60°C to 100°C, which is an indicative of the presence of minor clay impurities within the limestone samples. The results of D.T.A. have been graphically represented in plate No. 43. It has been found that the samples from all the horizons carry normal calcium percentage, which is given in the table XXXI and table No. XXXII.

Petrographic Types

In outer appearance nummulitic limestone is greyish white in colour having numerous smaller sized foraminifera tests but on freshly broken surface it is greyish black in colour. Megascopically, on the basis of sedimentary structures, fossil content, it is possible to recognise a few petrographic types, such as:-

a) Stylolitic Limestone.

b) Cone-in-Cone Limestone.

c) Lamellibranch Coquina Limestone

d) Nummulitic Limestone

but their true nature is revealed under microscope alone.

Thin Section Petrography

As a rule these limestones are composed of very fine limy mud as such most of the types are restricted to Mudstones and Wackstones in Dunham's (1962) terminology. The uppermost lamellibranch bearing beds are packstones and Boundstones. In Folk's (1959, p. 1-38) classification most of these may be classified as Biomicrites as all the allochems in these limestones are fossils. It is very significant to record that except fossils no other allochems such as oolites, pellets or interclasts are found in these limestones. Fossils besides foraminifera are lamellibranchs and echinoids.

Textures and Microstructures

Wide range of textures and microstructures have been observed in the limestones. Most of the textural variations depend upon grain size, pore filling,

porosity, permeability and mineralogy.

The microstructures studied in the rocks are the product of mode of sedimentation, chemical transformations before and after the sedimentation and also selective dissolution and precipitation.

Of the varied structures and microstructures following are important ones.

i) Microstylolites

A microstylolitic seam is marked by interpenetration of the two sides. The teeth like projections of one side fit into sockets of like dimensions on the other (Fig. 6, plate No. 45). In cross section, the microstylolitic surface resembles an oscillogram (or suture).

The microstylolites do'nt have any particular orientation with respect to bedding planes, branching is most common while some microstylolites intersect each other. The vertical and lateral extent varies from 1.06 mm and 0.01 mm to 0.03 mm respectively. Generally they cut across the grains (see Fig. I, plate No. 44), but in certain cases they occur at grain boundaries. At the point of junction most often we notice either argillaceous or ferruginous matter.

The stylolitic or microstylolitic structures are most often the result of replacement of limestone by chert.

ii) Cone-in-Cone Structure

In some samples of nummulitic limestone cone-in-cone structure is very well developed. The limestone containing this structure is greyish coloured and is composed of nested and interfering cones. Individual cones range from 4 to 8 cm in height. Apical angles range from 25° to 75° and the shorter cones have the larger apical angles. The clay films separate individual cones and cone segments and are striated. The orientation of the cones differ from place to place. Most of the cones have their apices directed down while in some cases they are directed upward.

Cone-in-Cone bearing limestone differs from other nummulitic samples in the fact that instead of composed of muddy limy matter, it is mainly composed of microgranular and fibrous calcite. The grains of calcite are less than 0.05 mm in long diameter. The fibrous calcite is relict in form as in thin sections it is found as stringers of elongate inclusions in the relatively short cones.

Regarding the development of cone-in-cone structure number of theories have been propounded. Gresely (1894) attributed the growth of cone-in-cone structure to pressures induced by the concretionery growth of calcium carbonate. Tarr (1922) considered this structure to be produced by the conversion of aragonite to calcite. More recently Gillman and Metzger (1967) suggested that cone in cone structures in calcareous materials are of early diagenetic origin. According to Frank (1969) cone structures are the product of the growth of cone shaped plumose aggregates of fibrous calcite in argillaceous sediment. As most of our nummulitic limestones are muddy lime hence the theory of Frank is most plausible one for the growth of cone in cone structures.

Diagenetic Changes

Nummulitic limestone has undergone very little diagenetic changes except composition as is evident from the muddy nature of the limestone, no sign of recrystallisation has been observed in any sample. The development of cone in cone structure in calcareous materials are also due to early diagenetic changes (Gilman and Metzgar, 1967). The effect of solution

however is quite evident in these rocks with the development of stylolitic seams. The compaction has decreased porosity. In some samples the dolomite rhombs have been observed along with incipient dolomitisation. This may be due to replacement of the limestone by mg. solution.

The tests of the larger foraminifera in the limestone do show various diagenetic changes. These changes commence with a change in the pigmentation of the parts of the tests. The fan like projections of fibrous calcite initiate from the axial plane and the calcite fibres exhibit brush extinction. In the advanced stage of diagenesis, the chambered structure and the internal skeletal architecture of the tests is totally destroyed. In certain cases, the ghosts of the original septae continue through the brushes of fibrous calcite.

Depositional Environment

The upper member of the Jammu Eocenes which mainly comprise of limestone-shale types of rocks appears to have been deposited in a clear, shallow, linear, epicontinental sea. This open sea was vast extending

from north west to south east, opening towards Jammu. This sea sustained fauna which are represented in fossil forms within the limestone shale sequence of the Eocenes. The shallow nature of the basin has further been established by the fossils of larger foraminifera e.g. Assilina Granulosa etc. and ostracods (Bhandari and Aggarwal, 1966). The basin was an active geosyncline whose depth did not exceed epineritic dimensions. The basin was also protected from strong waves creating thereby conditions for the development of marshes in which muddy limy matter accumulated which later on compacted to form bands of limestones.

The complete absence of thick arenaceous sediments in the lower part and the presence of streaks and lenses of carbonaceous matter within the argillaceous units suggests the presence of ridges along the basin floor. These ridges partially isolated some parts of the basin and raised the effective wave base thereby creating conditions for the accumulation of argillaceous material with streaks and lenses of carbonaceous matter.

The rate of sinking kept pace with that of deposition for long interval of time so as to form a thick pile of mixed sediments. Local fluctuations of

depth were prevalent in this basin, involving possible reworking and winnowing of the sediments as a result of considerable reduction in depth.

Under such environmental implications a sequence of rocks with alternating bands of limestone and shale was formed to constitute the upper member of the Jammu Eocenes.

Chapter 5

Petrography of the Murree Formation

Chapter 5

Petrography of the Murree Formation

Overlying the Subathus is a thick succession of clastic sequence consisting of alternating beds of sandstones and clay rocks which is known in the literature as Murree Formation. They are regarded as being equivalent to Dagshais and Kasaulis of Simla area and to the Dharmsalas of Kangra area. Although no petrological account of these rocks is available but a few papers on Dagshai and Kasauli rocks (Ganju and Srivastava 1961, pp. 138-147) and Dharmsalas (Raiverman, 1964) have been published giving a preliminary account of the rocks. Raiverman (1964, pp. 27-30) has considered them to be of turbidite nature whereas Ganju and Srivastava (1961) feel that these represent beach deposits.

Murree Formation in the study area have surrounded the Sabathu outcrops and follow the same trend and pattern. The good exposures are seen on the opposite side of the Do-Khadda nala, near Muttal, at Thalwal ($33^{o}03'30"$: $74^{o}59'00"$), Kothri ($33^{o}05'00"$: $74^{o}59'00"$), Balada ($33^{o}07'40"$: $74^{o}54'30"$), Arnas ($33^{o}11'30"$: $74^{o}50'00"$), etc.

No previous worker has undertaken sedimentological studies of these rocks. Such studies are very essential and vital to understand the evolution of the Tertiary basin

in which these rocks and the underlying Subathus were deposited. Hence a detailed study of these rocks comprising their textural, compositional and structural features have been undertaken. The results are as follows:-

Textural Studies

Textural studies which have been undertaken for the present work include their grain size, sphericity and roundness.

Grain Size

The grain size studies have been undertaken for sandstones only. The clay rocks, silt rocks and shales are too fine to be of any use. These studies are partly helpful in understanding the domain of sedimentation although due to diagenetic effects which these rocks have undergone their reliability is somewhat doubtful. The Murree sandstones are tough and hard and separation of the individual grain was not possible hence their grain size studies were mainly done in thin sections only. Some representative thin sections taken and with the help of automatic point counter the length of 200 grains per section were measured and their Cumulative curves were drawn. In order to convert number frequency

Table XXXIII

Textural Analyses of the Murree Sandstones

Sample Numbers	Mean size (Mz)	Sorting (P_1)	Skewness (SKG)	Kurtosis (KG)
CH=131	3.37	0.64	0.62	1.12
CH=132	3.43	0.56	0.68	0.68
CH=137	3.43	0.53	0.68	0.97
CH=138	3.9	0.48	0.50	1.9
CH=210	3.70	0.68	0.55	1.20
CH=211	2.70	0.40	0.37	0.17
CH=214	3.46	0.42	0.62	1.36
CH=278	4.03	0.57	1.62	1.65
CH=301	3.13	0.50	1.05	4.30
CH=302	3.53	0.63	0.80	1.12
CH=311	3.93	0.46	0.69	0.77

percentage to weight percentage, the technique of Friedman (1961) was used. In order to calculate mean size (Mz), Sorting (P_1), Skewness (Skg) and Kurtosis (KG), the $\phi 5$, $\phi 16$, $\phi 50$, $\phi 84$, $\phi 95$ percentile were calculated from these curves. The calculations were made by Folk and Ward method (1957, pp. 3-26). The results are given in table No. 33.

Mean Size

The mean size of a sediment depends upon the size distribution of the material found in the source area and Kinetic energy of the depositing medium. The Murree sandstones are somewhat fine grained having an average grain size ranging between 3.13 to 4.03 ϕ. In no case the grains are lesser than 2.70 ϕ size. It is inconceivable that in the source the particles were so fine as to give rise to this size distribution. The Kinetic energy of the depositing medium appears to be the sole agency responsible for this type of uniformity of the grain size.

Standard Deviation

It indicates sorting of the sediments. The average value of the sorting of the Murree sediments is 0.45 ϕ. In no case greater than 0.64 ϕ and lesser than

0.40 ϕ. It indicates very good sorting which is characteristic of beach sediments as according to Friedman (1961) deviation values ranging between 0.35 ϕ to 0.5 ϕ are found within marine sands.

The relationship between standard deviation and mean size has graphically been represented in plate No. 46.

Skewness

Skewness indicates the symmetry of the modal class with respect to coarse and fine fraction. It may be normal or Skew towards coarser side or finer side when the distribution is said to have negative skewness or positive skewness respectively. In case of Murree sandstones the values are ranging between 0.37 to 0.80 ϕ. Only in two cases the value exceeds 1 i.e. 1.62 ϕ and 1.05 ϕ. It shows that most of the samples are symmetrically distributed which again is a characteristic feature of beach sand.

The relationship between standard deviation and Skewness has graphically been represented in plate No. 47.

Kurtosis

Kurtosis refers to peakedness of the modal class. The sediment may be platykurtic (.68, .77 and .97), Mesokurtic (1.12, 1.20 and 1.36), or Leptokurtic (4.30, etc.) depending upon the values shown against each. In case of Murree sandstone the minimum is 0.17 ϕ while the maximum goes upto 4.30 ϕ. It shows that the samples belong to all the three categories referred above. However, the majority is that of mesokurtic.

Roundness and Sphericity

Both sphericity and roundness of the quartz grains were determined from thin sections only. The Murree sandstones are so hard that it is not possible to separate an original grain without breaking its boundaries. For this work sphericity is determined by Riley (1953) method. In this method sphericity is calculated by the formula-Riley Projection Sphericity $fr = \frac{di}{dc}$.

Where dc= diameter of the smallest circumscribing circle;

And di= diameter of the largest inscribing circle.

In this method the transparency of thin sections were projected on a screen and the outlines of the grain drawn to draw circles inside and outside the grains.

Similarly the roundness of the grain was also determined from the same grain outline by Wadell (1935) formula

$$Pd = \frac{\Sigma r/R}{N}$$

where, pd= Degree of roundness

Σr = Curvature radius of individual curves

N= number of corner radii including corners whose radii is zero.

R= Radius of maximum inscribed circle.

This method was only used for check purposes as it is very time consuming. In most of the cases the roundness was determined by Powers (1953) method. Powers presented the size classes of roundness and two classes of sphericity as grain photographs.

The results of the investigations have been given in the table 34.

Table XXXIV

Sphericity- Roundness values of Murree Sandstones

Sample Nos.	Sphericity		Roundness	
	Mean	Standard Deviation	Mean	Standard Deviation
CH=13	0.591	0.113	0.642	0.01
CH=14	0.622	0.197	0.531	0.13
CH=15	0.721	0.046	0.590	0.11
CH=19	0.531	0.021	0.623	0.21
CH=20	0.692	0.094	0.663	0.19
CH=21	0.584	0.002	0.557	0.15
CH=41	0.590	0.073	0.692	0.001
CH=43	0.662	0.112	0.710	0.223
CH=44	0.553	0.044	0.583	0.041
CH=48	0.711	0.011	0.677	0.033

The sphericity values of Murree sandstones vary from 0.721 to 0.531 and 0.197 to 0.002. These values indicate that the grains have moderate sphericity.

The roundness values of Murree sandstones vary from 0.710 to 0.531 and 0.223 to 0.001. These values indicate that the grains are sub-angular to sub-rounded.

Thin Section Studies

Thin sections were made of the representative samples from number of places in the study area. Thin sections were subjected to modal analyses (table XXXV) by automatic point counter. The percentage of matrix were separately determined and also the percentage of quartz and feldspar, the rock fragments and cement were determined. The quartz and feldspar, rock fragment ratio was also determined from the framework constituents. On this basis the sandstones were classified according to the nomenclature suggested by Gilbert. This classification takes into consideration many fundamental things such as provenance factor, maturity factor, fluidty factor, etc., and is best suited for the classification of sandstones of the Murree Formation. From the percentage of matrix which is more often very little in these sandstones, it is thus obvious that in these rocks all the sandstones belong to

arenite group. The chief characteristics of these rocks are as follows:-

i) Quartz Arenite

As shown in figures ~~shown~~ in plate Nos. 48 & 49, majority of the samples belong to this category. These rocks have intact framework showing more or less good sorting. Rocks are medium grained and have higher roundness and sphericity value.

The main feature of these rocks is the higher percentage of quartz which goes upto 95%. The quartz grains are mostly monocrystalline but in some coarser varieties even some polycrystalline grains are found. The majority of the grains are inclusionless although in some acicular inclusions probably of rutile have been noticed. Majority of the grains have non undulatory extinction. Quartz grains are cemented by clear calcite cement which in certain cases replaced some of the quartz grains. Typical sections of these sandstones have been shown in plate Nos. 48 & 49.

ii) Sub-lithic Arenite

There are however some varieties which contain minor amount of rock fragments in addition to quartz in the framework of the sandstones. The rock fragments

are of quartzites, trap rocks and some grains of gneisses and schists. The amount of the rock fragments is 10%. These grains are comparatively bigger than the quartz grains and are somewhat more rounded. In other textural details the rock is similar to the quartz arenite showing good sorting, having uniform grain size, sub-rounded to well rounded quartz etc. This rock is similar to one described by pettijohn as Proto-Quartzite.

iii) Lithic Arenite

A few varieties having rock fragments upto 25%. have also been noticed in these rocks. The rocks are similar to one described by Pettijohn as sub-Graywacks. These rocks have moderate sorting. The quartz grains are similar to the previous varieties except in one respect that there is a little higher percentage of grains showing undulatory extinction and in place of inclusion less quartz grains in these rocks all grains of quartz having inclusions arranged in linear pattern likewise there is also an increase of polycrystalline grains of quartz. A few grains of green glauconite has also been observed. Elongated flakes of mica which have been bent under pressure of the quartz grains have also been noticed. Increase in the percentage of calcite

cement has led to the replacement of the quartz grains due to which in some cases poikitopic type of texture due to which the contact of the grains have been lost is developed.

Thin Section Studies of
Siltstones and Shales

These rocks under microscope appear as a fine grained sandstone having lot of clayey matrix in which quartz grains are scattered like pepper grains in the salt. The rocks, therefore, have a disrupted framework and the grains have no contact with each other. Sorting is very good as the rocks appear as equigranular and the grains are sub-angular to sub-rounded.

As a rule these rocks are entirely composed of quartz grains with a few flakes of muscovite and biotite. Here and there the quartz grains are monocrystalline, having linear inclusions and almost all of them showing non-undulatory extinction.

The matrix which consists of red coloured fine granular mixture of clay and minute quartz grains contain patches of calcite at places. Sometimes these patches are circular in form probably representing the transverse section of the small twigs and branches of which have been replaced by calcite. The typical

Table XXXV

Showing Modal Analyses of Murree Rocks

Sample Nos.	Quartz					Feldspars			Rock Fragments				Matrix	Cement	Total	Remarks, if any.
	Mono Mineralic	Poly Mineralic	Undulatory Extinction	Non-undulatory Extinction.	Total	Altered	Unaltered	Total	Igneous	Sedimentary	Metamorphic	Total				
CH=149	64.4	2.6	-	3.4	70.4	4.7	-	4.7	-	1.8	0.4	2.2	2.0	20.7	100.0	Quartz Arenite
CH=150	60.2	2.1	-	1.9	64.2	3.6	0.4	4.0	1.2	0.3	0.8	2.3	1.6	27.9	100.9	"
CH=153	63.0	2.6	-	1.7	67.7	2.6	1.0	3.6	0.2	1.0	0.2	1.4	1.9	25.4	100.0	"
CH=154	64.2	2.5	-	2.7	69.4	2.4	0.5	2.9	-	0.7	0.2	0.9	1.8	25.0	100.0	"
CH=158	58.8	2.2	1.6	1.9	64.5	2.9	0.2	3.1	0.6	0.4	0.3	1.3	2.1	29.0	100.0	"
CH=159	57.4	1.9	-	2.1	61.4	2.2	0.3	2.5	0.7	0.6	0.4	1.7	3.0	31.4	100.0	"
CH=213	33.6	3.4	2.4	4.8	44.2	3.1	1.1	4.2	5.2	2.6	3.4	11.2	3.4	36.8	100.0	Sub-Lithic Arenite
CH=214	40.1	2.7	1.3	2.8	46.9	2.9	1.0	3.9	3.7	2.1	4.8	10.6	4.2	34.4	100.0	"
CH=218	40.6	4.3	2.2	1.0	48.1	3.2	1.1	4.3	2.6	4.6	3.9	11.1	3.9	32.6	100.0	"
CH=221	40.2	4.1	0.6	3.0	47.9	3.0	1.6	4.6	4.0	3.8	2.6	10.4	3.2	33.8	99.9	"
CH=224	36.7	4.6	1.3	2.9	45.5	4.0	0.9	4.9	4.0	2.9	3.4	10.3	4.3	35.0	100.0	"
CH=318	0.5	18.0	4.2	1.3	24.0	3.2	1.2	4.4	9.1	7.9	8.4	25.4	6.0	40.2	100.0	Lithic Arenite
CH=319	6.0	19.4	1.4	-	26.8	4.0	1.3	5.3	8.4	9.2	7.4	25.0	4.3	38.6	100.0	"
CH=321	3.7	24.2	1.3	0.9	30.1	4.6	2.6	7.2	5.9	11.4	7.6	24.9	3.4	34.4	100.0	"
CH=334	3.6	27.4	1.1	1.3	33.4	3.1	1.8	4.9	7.6	9.4	8.3	25.3	5.4	30.9	99.9	"
CH=381	10.2	4.0	-	1.4	15.6	4.2	4.2	8.4	4.0	18.4	3.9	26.3	11.4	38.2	99.9	Siltstone
CH=382	16.0	2.0	1.2	1.6	20.8	6.4	3.3	9.7	1.0	19.2	1.3	21.5	7.8	40.6	100.0	"
CH=384	15.9	2.1	1.7	0.9	20.6	4.5	6.9	11.4	0.6	18.1	1.0	19.7	5.9	42.4	100.0	"
CH=416	11.4	3.2	1.2	0.6	16.4	11.4	4.0	15.4	1.7	9.0	-	10.7	5.9	51.6	100.00	Shale
CH=417	12.2	2.5	-	1.0	15.7	10.6	3.3	13.9	1.4	10.0	-	11.7	9.4	49.4	99.8	"
CH=420	13.1	1.0	-	0.5	14.6	9.6	2.2	11.8	2.1	14.1	-	16.2	8.9	48.6	100.1	"
CH=431	11.2	1.2	-	1.0	13.4	7.1	2.1	9.2	1.1	8.9	0.3	10.3	9.4	57.7	100.0	"

section is shown in photomicrograph No. 5 of plate No. 48 and Fig. No. 5 of plate No. 49.

Mineral Studies

Besides thin sections, it was also considered appropriate to study individual light and heavy minerals present in these rocks. The heavy minerals of the cleaned samples were separated by Krumbein and Pettijohn (1938, pp. 343-344, Fig. 153) using bromoform of specific gravity 2.87 as the separating medium. After the separation was conducted both the heavy and light fractions were washed, weighed and stored separately. The light and heavy minerals were mounted in Canada balsam for a detailed optical study. Such studies are useful not only in correlation but also in determining the provenance, the lithological characters of the source rocks and even the climatic vicissitudes if any. No doubt both the light and heavy minerals have been studied but more emphasis was laid down on the nature and percentage of heavy minerals.

Light Minerals

The main characteristic features of light minerals present in the rocks are as under:-

i) Quartz

The quartz grains were studied with respect to

form, inclusions and extinction. The elongation ratio of quartz grains indicate that these have been derived both from igneous and metamorphic source. The grains of quartz are sub-rounded to sub-angular. Majority of the grains are either inclusionless or show smaller black particles arranged in a linear fashion. Most of the grains do not show any undulatory extinction, only a few grains with undulatory extinction have been noticed.

Certain sections show grains of quartz which are fused with one another and some contain gas inclusions. A few grains have exhibited an outgrowth or overgrowth, which might have occured during diagenetic re-organisation while the cementation was in progress.

iii) Feldspar

In some sections the percentage of feldspars goes upto 8 which otherwise is not so abundant in Murree sandstones. Both potash and alkali feldspars are present and majority of these are altered to Kaolin, sericite, etc. In certain sections, the grains of feldspars are clouded with sericite alteration products. Most of the

feldspar grains are rounded indicating thereby the maturity of the sediments.

iii) Glauconite

In a few quartzo- sandstones, this mineral is present in the form of green coloured grains and shows marked polarisation colours. Its size range is identical with that of quartz showing thereby that it is detrital and not authigenic. The lack of anastomosing cracks also corroborate this fact.

Heavy Minerals

The weight percentage of heavy minerals found in various rock samples, their frequency and individual characteristic features were determined. The results of these investigations are as follows:-

Percentage of Heavy Minerals

The percentage by weight of the heavies in various samples have been tabulated in table No. 36.

Table XXXVI

Percentage by weight of Heavy Minerals

Serial Nos.	Sample Nos.	Localities	Weight percentage
1.	CH=133	Do-Khadda	1.258
2.	CH=134	Samol	3.124
3.	CH=135	Kothari	2.250
4.	CH=136	Thalwal	2.570
5.	CH=188	Basua	1.440
6.	CH=189	Yabu Khad	1.963
7.	CH=190	Baladda	2.451
8.	CH=303	Kansar	1.683
9.	CH=304	Arnas	3.210
10.	CH310	Arnas	2.865

The results reveal certain interesting trends. Firstly, these indicate that only in two samples the heavy minerals exceed 3 percent while in others the percentage is still lesser and secondly, the results indicate that a considerable fall in the percentage of the heavies is due to the high maturity of the sediments.

The study of the table No. 36 indicates that the percentage of the heavies vary from 1.258 to 3.210.

The heavy mineral assemblages are zircon, tourmaline, rutile, garnet, epidote, biotite, chlorite, apatite, and opaques. The opaques include ilmenite, magnetite, pyrite, etc. The percentage of the various heavy minerals have been given in table No. 37.

Table XXXVII

Showing Heavy Mineral Percentage

Sample Nos.	Locality.	Zircon	Tourmaline	Rutile	Garnet	Epidote	Chlorite	Apatite	Biotite	Opaques
CH=133	Do-Khadda	25	15	0.5	8.0	0.5	-	-	-	51.0
CH=134	Samol	17	10	1.5	2.0	2.5	1.4	-	0.5	65.1
CH=135	Kothari	22	13	-	3.0	2.2	-	-	-	59.8
CH=136	Thalwal	20	10	1.5	5.0	-	1.5	-	0.5	61.5
CH=188	Yabu Khad	20	18	0.9	5.0	2.9	-	-	-	53.2
CH=189	"	18	14	1.4	7.0	-	-	1.0	-	58.6
CH=190	Balada	18	12	1.0	9.0	1.0	-	-	-	59.0
CH=303	Kansar	20	15	-	6.5	5.0	-	0.5	-	53.0
CH=304	Arnas	19	10	1.2	-	2.2	0.4	-	1.2	66.0
CH=310	Arnas	21	11	-	3.0	-	1.5	-	0.5	63.0

The chief characteristic features of some of these minerals are as under:-

i) Zircon

The percentage of zircon varies from 15 to 20 of all the heavies in these rocks. Both colourless and pinkish varieties of zircons are met with but majority of them show light pinkish colour. Most of these are rounded but in certain samples the percentage of euhedral grain is increased. None of the zircon grains has shown zoning.

ii) Tourmaline

Except a few isolated blue grains of tourmaline, all others are brown in colour. Some of these have been rounded like disc while in a few a prismatic form is very characteristic. The percentage is lesser than the zircons and has been found to vary from 10 to 15% but in a very rare case their number exceeds that of the zircons.

iii) Garnet

The percentage of garnet varies from 2 to 9. The grains are irregular or sub hedral in outlines. The grains are pinkish but colourless varieties have also

been observed. The grains have high refractive index which become isotropic under crossed nicols. The garnet grains are present only in a few rock samples but in others they are completely absent.

iv) Epidote

In most of the samples the percentage of epidote does not exceed 5. However, the percentage varies from 0.5 to 5.0. The grains typically show greenish yellow colour and feeble pleochroism. Some green coloured grains show compass needle interference figures and are undoubtedly recognised to be of epidote while the others are of doubtful character. Most of the grains are irregular in outline.

v) Rutile

A few isolated grains having deepred colour and prismatic form are interpretted to be of rutile.

vi) Apatite

Occasionally a grain or two of the mineral apatite have been found in some of the samples. The grains are colourless and often sub-rounded in outline.

vii) Opaques

The bulk of the heavy minerals recovered from the Murree rocks belong to this category. Their percentage varies from 51.0 to 65.1. In ordinary light, their identity is indeterminable but under reflected light these appear to be a group consisting of magnetite, ilmenite, pyrite, etc.

Z.T.R. Index

The zircon, tourmaline and rutile index as calculated and shown in table No. 37 is 50 : 30 : 20.

Sedimentary Structures

The Murree rocks in the study area have a development of wide variety of sedimentary structures (table No. 38) which have offered an interesting and vital information regarding their depositional environments.

Some of the important sedimentary structures found are as follows:-

1. Bedding Types

Although coarse and fine beds which maintain their unifirmity both in vertical and horizontal

direction. The individual beds however are unequal in thickness. The bedding is log normal.

2. Internal Organisation

Raiverman (1964, pp. 27-33) observed graded bedding in Dharmsalas which are equivalent to Murrees but no where this structure has been found. In the study area no where large scale cross bedding has been observed. At places, however, small scale planar cross bedding has been noticed.

3. Bedding Plane Features

(a) Ripple Marks

Ripple Marks of various types have been observed within the sandstones and siltstones. At Do-Khadda, Samol, Basua, and Arnas current ripple marks have been observed.

(b) Sole Marks

Although flute casts which are the widespread sole marks have not been seen but at places such as Thalwal, Yabu Khad, Samol, Kansar, and Arnas, very small scale tool marks much like skip mark, broad mark, etc., have been seen and recorded.

Provenance

Number of sedimentological features have been

Table XXXVIII

194 Showing Comparison of Sedimentary Structures of Known environment with that found in the Murree Sediments

Sedimentary Structure	Do-Khadda	Samol	Kothari	Thalwal	Basua	Yabu Khad	Kansar	Arnas	Probable environmental Significance	Remarks, if any.
Even Uniformly thick bedding	*							*	Aqueous, tidal flat,	Bedding Types
Crude Cut & fill stratification									Beach and deltaic.	"
Rhythmic lamination									"	"
Disturbed Stratification		*		*		*			Tidal flat, beach etc.	"
Crude bedding									"	"
Cross stratification lenticulated									"	"
Planar Cross stratification			*						Aqueous, fluvial	"
Cross stratification laminar								*	Beach, tidal flat, etc.	"
Ripple stratification									"	"
Cross bedding							*		Tidal flat, beach.	Internal Organisation.
Oscillation Ripple Marks (pointed crest$)							*		"	Bedding plane features.
Oscillation Ripple Marks (flat topped)									"	"
Current Ripple Marks	*	*		*				*	Aqueous, quiet water	"
Rhombic Ripple Marks									Beach	"
Load Casts									Turbidites	Sole Marks
Flute Casts									Turbidites	"
Groove Casts									Turbidites	"
Tool Marks									Turbidites	"
Skip Marks				*		*			Deltaic	
Broad Marks							*		Deltaic	
Mud Cracks								*	Aqueous, quiet water, beach etc.	
Worm Trails										

observed in these rocks which proved useful in interpretting not only the nature of rocks present in the source area which produced the sediments but also the climatological and topographical features.

The deep maroon colour of the sediments indicate an area having rocks rich in iron. Under tropical climate the iron bearing sediments produce red soil which can remain so if the oxidation reduction potential is favourable. The paleogeography of Indian sub-continent during the Lower Miocene times when these rocks were deposited was such that the bulk of the material could only have been supplied from the southern side.

The high textural and compositional maturity of the sediments also indicate a highly tectonically stable area which could only be the peninsular side which can fulfil the condition.

These rocks also indicate low relief of the source area where profound and protracted weathering, sorting and abrasion can produce highly matured type of rocks as we find in the Murree Formation. However, the heavy mineral assemblages within the Murrees as zircon, rutile, tourmaline, garnet, epidote, etc. indicate that they have been derived from all types of rocks in the source

area. There is a possibility that a very minor amount of sediments also came from the newly rising Himalayan Mountains having still low relief.

Depositional Environments

Number of views have been expressed regarding the depositional environments of the Murree sediments. Of the many early workers mention may, however, be made of Middlemiss (1890) who thought Murree sediments to be of brackish water origin. Krishnan (1940) strongly supported the view of Middlemiss in considering them as deposited in a lagoon. Ganju and Srivastava (1961) who worked on Dagshai Sandstones near Barog Simla Hills considered these rocks as representing beach environment. Raiverman and Seshavataram (1965), who worked on Dharmsala sediments which are equivalent to the Murrees, considered them to be turbidites.

In this work number of evidences have been collected to establish their true mode of sedimentation.

1. No where within the area of study any turbidite features such as graded bedding, sole marks, ripple cross lamination etc., have been found to justify hypothesis of their being turbidites.

2. These deposits are mostly maroon red coloured indicating oxidising conditions within the basin of deposition. Such conditions are not possible in a lake or lagoon as postulated by Middlemiss (1890) and Krishnan (1940).

3. There is a gradual passage of the Subathus to the Murrees indicating thereby a gradual change from marine conditions to those of fresh water.

4. The presence of plant fossils, in situ roots, bones of mammalian fossils found in these rocks indicate fluviatile type of environment.

5. The standard Deviation values of the Murree sandstones alongwith roundness and sphericity values indicate close proximity to the marine shore where these rocks were deposited.

6. The presence of glauconite in the sandstones also supports the same view that the sand was deposited near the marine conditions.

Taking into consideration the above mentioned facts which indicate both fluviatile and marine environment for these rocks it may be inferred that the Murree sediments were deposited in a mixed type of

environment where there was an influence of both land and ocean currents. This environment may be, therefore, of deltaic or tidal flat type. The presence of interference types of ripple marks found in these sediments indicating opposing current direction corroborate this view.

Chapter 6

Depositional History of the Coal Belt

Chapter 6

Depositional History of the Coal Belt

The detailed stratigraphical and petrological works carried out in this study and incorporated at the relevant places in the foregoing chapters indicated many changes in the nature and kind of the basins which were existing from time to time, nature and organisation of their sedimentary fill, relation of the sediment to the source land and fluctuations in environmental patterns. The data collected in this study has been synthesized to achieve this purpose. These details have also been worked out in the case of the Trikuta Formation which forms the basement of the JAMMU COAL BELT. The details are as follows:

I. Trikuta Limestone

Nature of the Basin

The Trikuta Formation consists of exclusively carbonate rocks which are of the nature of dolostones. The complete absence of unaltered limestone bands, the presence of laminites, general prevalence of saccharoidal (or hypidiotopic) texture, etc. all point to either the penecontemporaneous alteration or their primary character. In addition to this, the nature and configuration of the

outcrops of these limestones as isolated domes within the Murrees indicated the existence of interconnected lagoons which had a link with an open sea of the Salt Range, most probably somewhere in the Pre-Cambrian times which deposited huge salt deposits alongwith Neobolus shales and Magnesian Sandstones. It appears that there was an overall congenial climate for the deposition of evaporites as indicated by Salt deposits and gypsum and anhydrite deposits on the western and the eastern side of the Trikuta Dolostones under reference which occupy central position.

The observation referred above is further corroborated by the fact that all the deposits have an alignment in a linear belt extending from west to east within a distance of 1000 kms. Again while the geological age of the salt deposits of the Salt Range and gypsum deposits of Assar and Bhaggar in the Doda district of Jammu has been confirmed as Pre-Cambrian, the latest stromatolite finds by Raha (1972), Raha & Sastry (1973), Chadha (1975), etc. also point out that the dolostones are also of Pre-Cambrian age. More recently the age of the dolostones has been established as Pre-Cambrian (Raha, et.al, 1978) on the basis of lead isotopic analysis

of galena found within these dolostones at Sersandu (Riasi-Jammu).

Regarding the nature of the lagoon, it is assumed that it occupied an elongated basin having NW-SE trend & appears to have a close similarity with the physiographic conditions as we find to-day in the coorong area south west of south Australia where in the present times six minerals are forming in and around the coorong eg., aragonite, magnesian calcite, calcian dolomite, magnesite and hydro-magnesite (Bathurst, 1971). The coorong lagoon is connected with the southern ocean and the area abounds with ephermal lakes and lagoon itself is about 100 km. long.

In this study, it has been found that the mechanism of dolomitisation of coorong is well applied to the Trikuta dolostones and therefore, it is assumed on very safer grounds the similarity between the two.

Provenance

Regarding the source land which supplied the material for these carbonate rocks, it may be mentioned that the Trikuta Formation does not contain any terrigenous material from base to top. Even the breccia

which occupy the upper horizons is Oligomictic and does not contain any other material except the intraclasts of underlying rocks. This indicate an absence of any major topographic feature in the relief of the surrounding areas which could have supplied its denuded products through rivers or other agencies in the basin of deposition.

The presence of exclusively of carbonate rocks also indicate quite conditions and absence of any major diastrophic disturbance.

The sequence of lithology and sedimentary structures called by Pettijohn (1957) as LITHOLOGIC PACKAGE indicate as tidal flat environment. There were fluctuations, however, from supratidal to intertidal zones as indicated by lithology and structures. Whereas the presence of desiccation cracks, stromatolites indicate supratidal conditions, evidence of some algal mats and well laminated sediments provide distinctive criteria for the recognition of intertidal sediments. Similarly fluctuation in high energy conditions to low energy conditions as indicated by the presence of oolites (Chadha, 1976a, 1977), pellets. The absence of ripples and other structures point out high energy episodes. The presence of these structures indicate low energy conditions.

II. Eocene Formation

The Eocene Formation consists of broadly speaking two contrasting facies of deposits. The lower part consists of carbonaceous and pyritous shales with the associated coal seams while the upper part consists of highly fossiliferous limestones and green shales.

Nature of the Basin

According to Weller (1928) the lower facies was deposited in a comparatively narrow trough created between the newly uplifted Himalayan mountains on the north and Indian landmass on the south under lacustrine and fluviatile conditions. The upper faces, on the contrary, was deposited in a narrow gulf formed by the encroachment of the sea. This sea was extending from Baluchistan to eastern Afghanistan and thence along the southern boarders of the Himalayan area as far as Nainital.

Bhandari and Aggarwal (1966) also believed in the existence of a shallower linear epicontinental sea extending from Nepal northwards and opening towards Jammu.

According to these authors below the basin floor

of this sea ran a series of low parallel ridges formed due to folding and erosion which partially isolated the basin and raised the effective wave base creating highly euxinic conditions in which lower facies of the Subathus were deposited.

Krishnan and Aiyengar (1940) believed that the Jammu Eocenes which are equivalent to CHARRAT were deposited in isolated basins produced by the first upheaval of the Himalayas breaking up the earlier Eocene sea.

In this study, it has been observed that both the facies were deposited in the same basin. The varied environmental conditions gave rise to different types of deposits. The basin was of the nature of elongated longitudinal trough in which the depositional strike corresponded with structural strike.

Depositional Pattern

During the deposition of the two facies of Eocene Formation the trough was filled up with rain water and by small consequent streams from the northern side and slow and sluggish rivers from the southern side. The water had no outlet producing thereby marshy and highly euxinic conditions. Under such environments when zero Eh surface

was much above than the depositional interface, H_2S was abundant and oxygen was absent, pyrite was formed and at places pyritous shales were deposited. The vegetable matter within the marshes could not be completely oxidised and converted into peat which latter converted into semi-anthracite when involved in the earth movements connected with the rise of the Himalaya. The first stage in the formation of a normal coal is the attack of plant tissue by microbial agencies and the differences in the type of coal depends upon the depth to which the material was submerged during the period of decomposition.

The upper facies represents marine shelf environment with no influx of terrigenous sediments. The limestone - shale sequence was deposited in a more open sea. The deposition took place both near the shore as well as in the deep basin. The low input of terrigenous sediment was due to low run off and low relief of the source area. It shows that the Himalayan mountains still were not very high and could not contribute much. The shales are grey or green in colour, often highly calcarrous and contain thin white calcilutite bands. Internally the shales are laminated. The lamination and fine grain size of this facies indicate deposition out of suspension in a low energy environment. The

fossil suggest a range of salinity from normal marine to brackish one. These conditions point out deposition in a deep water below effective wave base. Lime mud was also deposited under low energy conditions presumably below wave base.

III. Murree Formation

It consists of a thick succession of clastic sediments. The entire sequence comprises of alternating beds of sandstones and clays. Most of the sandstones are of quartz- arenite type and the grains are highly matured and well sorted.

Nature of the basin

There are number of evidences to believe that the Murree Sedimentation also took place in and around the same basin in which the Eocene Formation was formed with the only difference that there was an increased amount of influx of terrigenous sediments brought by rivers into the sea which resulted in the formation of sandstone- shale facies. Among the evidences is the presence of interfingering of both Eocene and Murree types of rocks towards Simla area although in the area under study there is a perfect gradation and superposition of one upon another.

Environmental Pattern

The sediments exhibit coarsening upward type of sequence. This resulted either under deltaic or linear shore line conditions. Deltas are formed where rivers bring more sediments into the sea than can be reworked by marine current. On the other hand, where marine currents are strong enough to redistribute land derived sediments, linear shore lines probably of the nature of the alluvial coastal plain are formed which grade into tidal flats, swamps and lagoons.

Chapter 7

Summary and Conclusions

Chapter 7

Summary and Conclusions

In this work sedimentological aspects of the eastern part of JAMMU COAL BELT has been studied in detail in order to interpret the basin geometry, depositional environments, provenance and palaeotectonics.

The oldest formation exposed in the area under study is Trikuta Limestone. It has been further sub-divided into three units viz. the lower, the middle and the upper. Each unit has been studied separately. The lower and the middle units are composed of dolostones while the upper one is essentially composed of Chert Breccia. The dolostones are completely unfossiliferous but contain bands of stromatolites, oolites, pellets and other algal structures from base to top. The upper part of the middle unit however, is Cherty and siliceous while the topmost beds exposed near Mari (Riasi) have thin laminated marly slates.

These dolostones exhibit a variety of textures and microstructures such as stylolites, vugs and veinlets, Bird's eye texture, grumous texture but hypidiotopic and saccharoidal textures are the most characteristic ones.

The chemical analyses of a large number of representative samples have revealed the normal range of Cao from 0.40% to 33.28% in case of the Lower Trikuta Limestones and 17.96% to 38.50% in case of the middle Trikuta Limestones. It indicates

that the values of Cao in the lower unit are less. Similarly the normal range of Mgo in the samples from the lower unit is between 3.14% to 46.30% and in the middle unit the normal range of Mgo varies from 3.14% to 32.41%. The ratio of Mgo decreases from the lower to the middle group. The relationship of Cao and Mgo in the different samples from the lower and the middle units have been graphically represented in the plates.

Since the content of insoluble residues does not increase in accordance with the increase of Mgo, hence the relationship between Mgo and insoluble residues could not be established.

The results of chemical analyses also carroborate with the data obtained from other investigations such as DTA, X-Rays, staining etc. The DTA endothermic Curves at 780°C and 940°C, characteristic of dolomites and calcites have been recorded in almost all the cases.

The X-ray analyses have also proved the presence of the mineral dolomite and calcite both in the lower and the middle units.

No true limestones have been found from bottom to top. Thin section petrography has revealed different rock types such as oodolosparite, peldolosparite, dolomicrites, etc. which have been discussed and described. The microscopic investigations of the limestones have revealed

several diagenetic changes such as decrease in porosity, reduction in volume, recrystallisation, formation of veins and veinlets of microcrystalline silica within the rocks, formation of vugs, increase in the size of ooids, development of RADIAL TEXTURES and the superimposition of radial textures over the concentric rings, etc.

The depositional environments of the limestones and the possible mechanism of dolomitisation has been worked out. The cooring model of dolomitisation appears to be the most plausible one as far as these dolomites are concerned. The upper unit of the Trikuta Formation consists of Chert Breccia. It has been studied with respect to chemical composition, thin section petrography and morphometry of the coarser clasts. The results of all these investigations have shown it to be an intraformational Breccia and the possibility of its being a tillite has totally been ruled out.

The coal seams are found in the Jammu Eocenes which unconformably overlie the Trikuta Limestones. The Eocene Formation is also sub-divided into three units i.e. the lower, the middle and the upper.

The lower member consists of aluminous clays and bauxites. The Lower Coal Measures which form an important

part of this unit are not exposed in the study area but make their appearance at Kalakot, Metka, Mahowgala, etc. i.e. the western wings of the Jammu Coal Belt.

The outcrops of the bauxites have been encountered both in the eastern as well as in the western sectors of the study area and everywhere all the three well marked horizons have been recognised. The horizons differ from each other on the basis of their physical and chemical, textural and structural and mineralogical characters. The bauxites are composed mostly of diaspore and boehmite. This has been confirmed by D.T.A, X-Rays and chemical analyses. The source material of these bauxites is the residual clays originated from the dissolution of the limestone deposits on which these rest.

The middle member is composed of a mixture of ferruginous and carbonaceous shales with seams of coal of varying thickness. These coal seams are designated as upper coal Measures. The outcrops are best developed at Salal and Jangal Gali. In Sukhwal Gali- Jangal Gali area, there are three seams in all. The top and bottom seams are soft, powdery but lustrous. In Salal area, only one seam has been recognised which shows pinching and swelling character. In physical appearance the coal is bright and lustrous but the well known laminated structure of the Gondwana coal is

absent in these. The coal is highly matured, low in volatile content, the values ranging from 6.3 to 20.0% on analysed basis and 0.9% to 22.0% on dry ashless basis in case of Jangal Gali coals and 11.2% to 14.5% on analysed basis and 14.0% to 18.1% on dry ashless basis in case of Salal coals, high in ash content i.e. 7.6% to 67.1% (Jangal Gali) and 32.7% to 72.3% (Salal) and the calorific values ranging from 3740 to 5795 K.Cal/kg on analysed basis and 8590 and 8845 K.cal/kg on dry ashless basis in case of Jangal Gali coals and 3060 to 5610 K.cal/kg on analysed basis and 8205 to 13050 K.cal/kg in case of Salal coals.

The cell structure of most of coals has been destroyed by the fungal bodies. Sulphurous impurities are mostly in the form of pyrite crystals which appear to have been developed from the iron rich sediments that came most probably from the south. The coal is of higher rank but highly friable.

The upper part of the Eocenes is composed of alternating bands of limestones and shales. The aggregate thickness of the entire sequence does not exceed 50 metres. There are five distinct bands of limestones while the lower bands are profusely laden with mega and micro fossils of foraminifera, the upper one is full of shells of

pelecypods and is of Coquina type. The middle bands contain varied types of phosphatic nodules. These limestones are essentially mudstones and wackstones and have undergone very little diagenetic changes although at places structures like stylolites and cone-in-cone have been developed.

The chemical analyses of these limestones have a high percentage of cao i.e. values ranging from 34.66% to 48.88% and low Mgo, i.e. the values ranging from 1.09% to 3.33%, and insoluble residues varying from 6.1% to 9.5% of the total weight of the rock. These results have further been confirmed from the D.T.A. analyses.

Thin section petrography has helped in recognising rock types such as stylolitic limestone, cone-in-cone Limestone, Nummulitic Limestone, Lamellibranch Coquina Limestone, etc. All these petrographic types have been discussed and described.

The topmost formation in the area under study is a thick succession of clastic sequence consisting of alternating beds of sandstones and clay rocks designated as Murree Formation. Most of the Murree Sandstones belong to quartzo-arenite group although sub-lithic and lithic types have also been recognised in them.

The textural analyses have proved that the sand

grains are highly matured and well sorted. The sphericity values reflect the moderate sphericity of the grains and the roundness values indicate that the grains are sub-angular to sub-rounded. All these features are characteristic of coastal type of deposits.

In the concluding chapter of the present work all the data collected has been synthesized to reconstruct the palaeogeography of the area from time to time and the basin analyses of all the formations from base to top.

It has been found that the oldest unit i.e. the Trikuta Limestone was deposited in an isolated elongated basin having NW-SE trend. It was more or less a lagoon like basin of the cooring model type which was connected with the main sea of the Salt Range during Proterozoic era. The limestone deposited in this lagoon was converted into dolomite almost penecontemporaneously by seepage reflux mechanism. Most of the algal mats, stromatolites and other algal structures indicate a tidal flat type of environments.

The Chert Breccia was formed during subaerial exposure of the Carbonate deposits for a prolonged period resulting in the formation of intraclasts which were cemented again when covered by water.

The palaeogeographic conditions were such that for a considerable period of time (Cambrian to early Cretaceous) there was no sedimentation due to sea resession and the limestones formed earlier were exposed to subaerial erosion and subjected to processes of solution which resulted in the formation of residual clays in the smaller sink holes which on further desilicification converted into bauxites.

During early Eocenes with the initial rising of the Himalaya a narrow furrow was formed between Indian Landmass and the rising Himalayan mountains which became loci of fresh sedimentation in marshes. Newly formed rivers and streams brought vegetation from the forests of the north alongwith other sediments which later on converted into coal. The ferruginous clays associated with coal beds most probably formed from the iron rich sediments that came from the south.

The upper facies of the Eocene Formation however, undoubtedly deposited in a marine shelf type of basin in which the influx of terrigenous material was very small and both limestones and shales were deposited in a low energy environment below the wave base.

The Murree sediments exhibit coarsening upward type of sequence and appear to have experienced a mixed type of environment. It was probably of the nature of alluvial coastal plain or linear shoreline which grades seaward into tidal flats, swamps and lagoons.

List of Plates

S.No:	Description	Page No:
1.	Map of Jammu Coalfields	
2.	Location Map	
3.	A glimpse of the Chenab loop at Dhiangarh Dam Site, Salal project, Jammu.	
4.	An Outcrop of Trikuta Limestone near Salal showing nature of bedding	
5.	Folding in the Nummulitic Limestone, Do-Khadda (Muttal) area of Jammu.	
6.	Showing Calcite/Dolomite relationship in Trikuta Limestone	
7.	Showing relationship between Cao% & Mgo% in Trikuta Limestone	
8.	Showing relationship between insoluble residue% & Mgo% in Trikuta Limestone	
9.	D.T.A. Curves of Trikuta Limestone (Horizon - Middle)	
10.	-do-	
11.	-do-	
12.	D.T.A. Curves of Trikuta Limestone (Horizon - Lower)	
13.	-do-	
14.	-do-	
15(1)	X-Ray diffractograms of Trikuta Limestone	
15(2)	-do-	
16.	Photomicrographs of Veined Dolostones	
17.	Photomicregraphs of Oolitic Dolostones	
18.	Photomicrographs of Saccharoidal Dolostones	
19.	Field photographs of textures & structures of Trikuta Limestone	

20. Field photographs of Stromatolitic Dolostones

21. The Bauxite spreads at Salal (Jammu)

22. Showing relationship between SiO_2% & Sp.Gr. of Bauxites

23. Showing relationship between SiO_2% & Al_2O_3% of Bauxites

24. Showing relationship between Al_2O_3% & Sp.Gr. of Bauxites

25. Showing relationship between top & bottom beds of bauxite w.r.t.Al_2O_3% in Sukhwal Gali - Jangal Gali area

26. Showing relationship between top and bottom beds of bauxite w.r.t.Al_2O_3% at Salal.

27. D.T.A. Curves of Bauxites (Horizon - pisolitic)

28. D.T.A. Curves of Bauxites (Horizon - pisolitic)

29. D.T.A. Curves of Bauxites (Horizon - Semi-pisolitic)

30. D.T.A.Curves of Bauxites (Horizon - Non-pisolitic)

31. X-Ray diffractograms of Bauxites

32. Photomicrographs of Bauxites

33. Showing relationship between Sp.Gr. & Ash content of Coal, Sukhwal Gali - Jangal Gali Coalfields.

34. Showing relationship between Sp.Gr. and Ash content of Coal, Salal Coalfields.

35. Showing relationship between Ash% and V.M.% in the different seams of Coal in the Lain Block, Jangal Gali Coalfields

36. Showing relationship between Ash% and V.M.% in the Coal, Jangal Gali - Sukhwal Gali Coalfields.

37. Showing relationship between Ash% & V.M.% in Coal, Salal Coalfield

38. Showing relationship between Calorific Value & Ash% in Coal from different blocks in the Sukhwal Gali - Jangal Gali Coalfields

39. Showing relationship between Calorific Value & Ash% in Coal, Salal Coalfield

40. Showing relationship between V.M.% & Calorific Value in Coal, Sukhwal Gali - Jangal Gali Coalfields

41. Showing relationship between Calorific Value & V.M.% in Coal, Sukhwal Gali - Jangal Gali Coalfields

42. Showing relationship between V.S.% & Calorific Value in Coal, Salal Coalfield

43. D.T.A. Curves of Nummulitic Limestone

44. Photomicrographs of Nummulitic Limestone

45. Photomicrographs of Nummulitic Limestone

46. Showing sorting (Q) Vs Mean Size (Q) in the Muree Sandstones

47. Showing Skewness (Q) Vs. Sorting (Q) in the Murree Sandstones

48. Photomicrographs of Muree Sandstones

49. Photomicrographs of Muree Sandstones

50. Geological Map of an area between Jangal Gali & Salal, District Udhampur, Jammu, J&K State, INDIA

51. Geological Map of the Jangal Gali area, District Udhampur, Jammu (Tawi), J&K State, INDIA

52. Geological Map of Salal area, Tehsil Riasi, District Udhampur, Jammu, J&K State, INDIA

53. Geological Sections along line AB= SSW of Balganga to Jangal Gali Back slope

CD= NNW of Balganga to NNE of Anji Khad
EF= NW of Balganga to SE of Rahotkot
GH= SW of Riasi to NE of Balada
IJ= NW of Bagia to NNE of Kanthan

List of Tables

S. No.	Description	Page No.
I.	Stratigraphical Column of the area.	21-22
II.	Chemical analyses of the Lower Trikuta Limestone	57-58
III.	Chemical analyses of the Lower Trikuta Limestone	59-60
IV.	Chemical analyses of the Lower Trikuta Limestone.	61-62
V.	Chemical analyses of the Lower Trikuta Limestone.	63
VI.	Chemical analyses of Middle Trikuta Limestone.	64-65
VII.	Chemical analyses of Middle Trikuta Limestone.	66-67
VIII.	Showing various insoluble residues in the Trikuta Limestone.	69
IX.	Showing quantitative spectro chemical analyses of Limestones.	70
X.	Showing Data of D.T.A. Curves of the Trikuta Limestone.	72
XI.	Showing Data of D.T.A. Curves of the Trikuta Limestone.	73
XII.	X-Ray diffraction powder data for samples of the Trikuta Limestone.	75-76
XIII.	X-Ray diffraction powder data for samples of the Trikuta Limestone.	77
XIV.	Chamical analyses of the Trikuta Limestone, Horizon upper.	98
XV.	Showing shape, size and general characters of pisolites.	110
XVI.	Showing an aggregate thickness of different horizons in different sectors.	111

XVII	Chemical analyses of Bauxites, Sukhwal Gali-Jangal Gali area, horizon-pisolitic.	113
XVIII.	Chemical analyses, Bauxites, Sukhwal Gali- Jangal Gali area, Horizon-semi-pisolitic.	114
XIX.	Chemical analyses of Bauxites, Sukhwal Gali- Jangal Gali area, Horizon- Non-pisolitic.	115
XX.	Chemical analyses of Bauxites, Salal area, horizon- pisolitic.	116
XXI.	Chemical analyses of Bauxites, Salal area, Horizon- Semi-pisolitic	117
XXII.	Chemical analyses of Bauxites, Salal area, horizon- Non-pisolitic	118
XXIII.	Quantitative spectrochemical analyses of Bauxites.	122
XXIV.	Showing Data of D.T.A. Curves of Bauxites.	124
XXV.	Showing Data of D.T.A. Curves of Bauxites.	125
XXVI.	X-Ray diffraction powder data for Bauxites.	128
XXVII.	X-Ray diffraction powder data for Bauxites.	129
XXVIII.	Chemical analyses of coal, Jangal Gali (Ladda) Coalfields.	141
XXIX.	Chemical Analyses of Coal Seams(?) of Jangal Gali (Ladda) Coalfields.	142
XXX.	Chemical analyses of Coal-Salal Coalfield.	143
XXXI.	Chemical analyses of Nummulitic Limestone.	157-58
XXXII.	Chemical analyses of Nummulitic Limestone.	159-60

XXXIII	Textural analyses of the Murree Sandstones.	174
XXXIV.	Sphericity Roundness values of Murree Sandstones.	179
XXXV.	Showing modal analyses of Murree rocks.	184
XXXVI.	Percentage by wight of heavy minerals.	188
XXXVII.	Showing heavy mineral percentage.	189
XXXVIII.	Showing comparison of Sedimentary structures of Known environment with that found in the Murree sediments.	194

BIBLIOGRAPHY

B I B L I O G R A P H Y

Abbas, S.A.	1964	Report on bauxite deposits of Salal, publication of DGM, J&K State, (unpublished report).
Adams, J.E. and Rhodes, M.L.	1960	Dolomitisation by seepage refluxion. Bull. Amer. Assocn. Petrol. Geologists, V. 44, pp. 1912-1920.
Ahmed, F.	1960	Glaciation and Gondwanaland, Recd. G.S.I., Vol. 86, pp. 637-674.
———	1961	Palaeogeography of the Gondwana period with special reference to India. Mem.G.S.I. Vol. 90, pp. 142.
Alderman, A.R. & Skinner, H.C.W.	1957	Dolomite Sedimentation in the south west of South Australia. Am. Journ. Sci. Vol. 255, pp. 561-567.
Auden, J.B.	1944	Preliminary Geological report on Dhiangarh Dam Site, Chenab river, J&K State. (G.S.I. unpublished report).
Bannerjee, P.K.	1959	Preliminary report on the metalliferous mineralisation of the Great Limestone between Sersandu and Sukhwal Gali, Riasi, Tehsil, Udhampur District. J&K State. (unpublished report, G.S.I.).
Bateman, A.M.	1959	Economic Mineral Deposits; Asia, Pub. House, New Delhi, pp. 916.
Bathurst, R.G.C.	1971	Carbonate Sediments and their Diagenesis; Developments in Sedimentology (12); Elsevier Pub. Coy. Amsterdam, London & New York.
Beales, F.W.	1965	Diagenesis in pelletted limestones. Soc. Econ. Palaeontologists, Mineralogists Specl. Publ. V. 13, pp. 49-70.
Bhandari, L.L. & Aggarwal, G.C.	1966	Eocene (Subathu Series) of the Himalayan Foothills of North India, Pub. Centre Adv. Stdy. Geol. Chandigarh, Vol. 3, pp. 57-78.

Bhat, M.L. and Nanda, M.M.	1956-1957	Preliminary report on the suitability of limestone deposits between Muttal and Riasi for the manufacture of portland cement in Jammu Province, J&K State (unpublished report, GSI).
Bhatia, T.R. and Bhatia, S.K.	1973	Sedimentology of the Slate Belt of Ramban-Banihal area, Kashmir Himalaya, Him. Geol. Vol. 3, pp. 116-134.
Bhatia, T.R. and Kokroo, A.K.	1977a	The study of Limestone Deposits of J&K and their utilisation in Industries. University Review, Journ. of the University of Jammu; Vol. VI(10), pp. 23-35.
———	1977b	Dolomitization of Syringothyris Limestone of Kotsu, Hill, Anantnag District, Kashmir. Journ. Indi. Assoc. of Sedimentologists, Aligarh, Vol. I (in press).
———	1978	Petrographic Studies of Syringothyris Limestone, Anantnag District, Kashmir. University Review, Journ. of University of Jammu. Vol. VI(11), pp. 73-88.
Black, M.	1933a	The precipitation of calcium carbonate on the Great Bahama Bank. Geol. Mag. Mol. 70, PP. 455-66.
Carozzi, A.V.	1960	Microscopic Sedimentary Petrography. John. Wiley and Sons, London, pp. 485.
Cary, S.W.	1955	Orocline Concept in Geotectonics. Proc. Roy, Soc. Tasmania, Vol. 89, pp. 255-288.
Cayeux, L.	1935	Les roches Sedimentaires de France-Roche Carbonates, Paris, Masson & Cie, pp. 447.
Chadha, S.K.	1975	Occurrence of Stromatolites from the Great Limestone of Muttal, Udhampur District, Jammu Province, J&K State. India. Current Sci. Vol. 44(18) pp. 665-667.
———	1976a	A note on the Pseudo-oolites from the Great Limestone of Lain, Udhampur District, Jammu Province, J&K State, INDIA. Current Sci. Vol. 45(6), pp. 221-222.

Chadha, S.K.	1976b	A note on the Control of Jointing by topography between Jangal Gali and Salal, Jammu Province, J&K State, INDIA. Current Sci. Vol. 45(7), pp. 261-262.
————	1976c	Some new observation on the nature and origin of cherts in the Great Limestone formation in an area between Muttal and Salal, Udhampur District of Jamu, J&K State, INDIA. Current Sci. Vol. 45(12), pp. 458-460.
————	1976d	A note on the evoluation of phyto Karst topography in the Great Limestone formation of Jammu Province, J&K State, INDIA. Current Sci. Vol. 45(16), pp. 588-589.
————	1976e	Geomorphological expression of Soil variations in the Sedimentary terrain of Muttal & Salal areas of Udhampur District in Jammu Province of J&K State, Sci. & Cult. Vol. 42(3), pp. 172-175.
————	1976f	The geomorphological features in an area around Udhampur. The Deccan Geographer-Hyderabad, Vol. XIV(2), 42(3), pp. 145-150.
————	1977	Some new observations on the ooids from the carbonate complex in the Udhampur District of Jammu, J&K State, INDIA. Sci. & Cult. Vol. 43(6), pp. 261-262.
Chakraborty, S.C.	1972	Possibilities of the setting up of Industries based on mineral resources of J&K, D.G.M., J&K Govt. pp. 34-56.
Chowdhury, R.S.	1968	Stratigraphy of the Lower Tertiary Formations of Punjab Himalayas. Geol. Mag. Vol. 105, pp. 421-430.
————	1972	Tertiary Sediments of northwest Himalayas A Critique. Punjab Univ. Res. Bull. Vol. 23, pp. 83-99.
Cloud, P.E.	1942	Notes on stromatolites. Amer. Journ. Sc. Vol. 240, pp. 363-379.
————	1962	Environment of Calcium Carbonate deposition west of Andros Island, Bahamas; U.S. Geol. Surv. Prof. paper, 350.
Dasarathi, N.	1968	Structural Embayments of Western Himalayas, J&K Un. Review, Vol. 2, No. 2 pp. 14-18.

Dear, W.A., Howie, R.A. & Zussman, J.	1963	Rock Forming Minerals; Longman's Green & Co. Ltd. London.
Deffeyes, K.S., Lucia, F.J. and Weyl, P.K.	1965	Dolomitisation of Recent and Plio-Pleistocene sediments by Marine Evaporite Waters on Bonaire, Netherlands, Antilles. Soc. Econ. Palaeontologists Mineralogists Specl. Publ. V. 134, pp. 71-88.
Deoglas, D.J.	1946	Interpretation of the results of mechanical analyses. Journ. Sed. Pet. Vol. 16, pp. 19-40.
Dhall, B.N. and Srivastava, S.R.	1964a	Progress report on the investigation of occurrences of lead ore in Sersandu-Kherikot area, Riasi Tehsil, Udhampur District, J&K State. (unpublished G.S.I. report).
----------	1964b	Progress report on the geological mapping of the Sirban Limestone Inlier in Ghar Baba Jito-Muttal-Sukhwal Gali area, Riasi Tehsil, Udhampur District, J&K State. (Unpublished G.S.I. report).
Dryden, A.L.	1932	Accuracy in percentage representation of heavy mineral frequencies. Proc. Nat. Acd. Sci. Vol. 17, pp. 233-238.
Duane, D.B.	1964	Significance of Skewness in recent sediments western Pamlico Sound, North Carolina; Journ. Sediment. Petrol, V. 34, pp. 864-874.
Dunham, R.J.	1962	Classification of Carbonate rocks according to depositional texture. In. Ham W.E. (editor) classification of Carbonate Rocks, Amer. Assoc. Petrol. Geologists, Mem. No. 1, pp. 108-121.
Fenton, C.L. & Fenton, M.A.	1931	Algal and Algal beds in the Belt Series of glacier, National Park; Journ. Geol. Vol. 39, pp. 670-686.
Fenton, C.L.	1943	Pre-Cambrian and Palaeozoic algae. Am. Midland Naturalist, Vol. 30, pp. 83-112.

Folk, R.L.	1951	Stages of textural maturity in sedimentary rocks. Journ. Sedi. Pet. Vol. 21 No. 3, pp. 127-130.
_____ and Ward, W.C.	1957	Brazos river bar. A Study in the significance of grain size parameters. Journ. Sed. Pet. Vol. V, 27, No. I, pp. 3-26.
Folk, R.L.	1959	Practical Petrographic classification of Limestones. Amer. Assoc. Pet. Geol. Bull. Vol. 43, pp. 1-38.
_____	1962	Special Subdivision of limestone types in classification of Carbonate Rocks. Amer. Assocn. Petrol. Geologists, Mem. I, pp. 62-84.
_____	1965	Some aspects of recrystallisation in ancient limestones. In Pray D.C. and Murrey R.C. (editors). Dolomitisation and limestone Diagenesis, a symposium Soc. of Econ. Palaeontologists and Mineralogists. Spec. Publ. No. 13, pp. 14-48.
_____	1966	A review of grain size parameters; Sedimentology, Vol. 6, pp. 73-93.
_____	1968	Petrology of Sedimentary Rocks. Hemphills.
Frank, C. Paul	1969	Nature, origin & significance of cone-in-cone structures in the Kiowa Formation- Early Cretaceous, North Central Kansas. Journ. Sed. Pet. Vol. 39 No. 4, pp. 1438-1454.
Frederickson, G.M.	1959	Identification of Carbonate Minerals by staining methods. Journ. Sed. Pet. Vol. 29(1), pp. 87-97.
Friedman, G.M.	1959	Identification of Carbonate Minerals by standing methods. Journ. Sedi. Pet. Vol. 29(1), pp. 87-97.

Friedman, G.M.	1961	Distinction between dune, beach and river sands from their textural characteristics, Jorn. Sedi. Petrol, Vol. 31, pp. 514-529.
_____	1964	Early diagenesis & Lithification in Carbonate Sediments, Journ. Sedi. Pet. Vol. 34, pp. 777-813.
_____	1965	Terminology of the Crystallisation Textures and Fabrics in Sedimentary rocks. Journ. Sed. Pet. Vol. 35(3), pp. 643-655.
Friedman, G.M. and J.E. Sanders.	1967	Origin and Occurrence of dolostones chap in developments in sedimentology 9A, Carbonate rocks-origin and occurrence and classification. Amsterdam, Elsevier Pub. Co. pp. 267-348.
Fuchs, Gerhard.	1973	Contributions to the Geology of North Western Himalayas, pp. 42.
Ganju, P.N.	1955	Geology of Indian Coals, Mem. G.S.I Vol. 83.
_____	1956	The microstructure of coals from Jangal Gali, Kalakot area in the Jammu Province, Indian Acad. Sciences, pp. 30-37.
Ganju, P.N. and Srivastava, V.K.	1961	Petrology of the Dagshai Sandstones near Barog, Simla, Hills, Mahadevan Vol. pp. 138-147.
Gansser, A.	1964	Geology of the Himalayas; Inter Science, Pub. New York.
Gilman, R.A. and Metzger, W.J.	1967	Cone-in-Cone concretions from western New York. Journ. Sed. Pet. Vol. 37, pp. 87-95.
Godwin, Austin, H.H.	1864	Geological notes on parts of the north western Himalayas; Quartz Journ. Geol. Soc. London, Vol. 20, pp. 383-388.
Gresely, W.S.	1894	Cone-in-Cone How it can occur in the Pennsyl Vania (U.S.A). Q. J. Geol. Soc. London, p. 731-739.

Grim, R.E.	1953	Clay Mineralogy, MC Graw Hill, New York.
Gupta, B.D. Kapur H.M. et. al.	1960	Progress report on the investigation of Zine occurrence in the lower Darabi area, Riasi Tehsil, Udhampur District, J&K State (unpublished report, G.S.I.).
Gupta, B.D. and Dhall, B.N.	1962	Progress report on the investigation for the base metal ores in Darabi area, Riasi, Tehsil, Udhampur District, J&K State (Unpublished report, G.S.I.).
Gupta, B.D. and Kapoor, H.M.	1962	Report on the detailed geological mapping of the Riasi Sirban Limestone Inlier, west of the Chenab river, Udhampur District, J&K State. (unpublished report, G.S.I.).
Gupta, L.N. and Dixit, P.C.	1970	On the occurrence of stromatolites from the Great Limestone, north Katra (Jammu Province); Sci. & Cult. Vol. 36(3), pp. 185-186.
Gupta, V.J. and Dixit, P.C.	1971	A note on the algal stromatolites from the Great Limestone of Riasi (J&K). Sci. and Cult., Vol. 37(2), pp. 353-354.
Harry, G. Pagf.	1955	Phi-millimeter Conversion Table. Journ. Sed. Pet. V. 25, pp. 285-292.
Hatch, F.H., Rastall, R.H. and Black, M.	1938	The Petrology of the sedimentary rocks, Thomas Murby & Co. London.
Henry, D. Milner	1962	Sedimentary Petrography. George Allen & Unwin, London.
Horton, R.E.	1932	Drainage basin characteristics, Trans. Am. Geophys. Union, Vol. 13, pp. 350-361.
Howie, R.A. and Broadhurst, F.M.	1958	X-Ray data for dolomite and ankerite. A. Mineralogist, Vol. 43, pp. 1210-1214.

Illing, L.V., Wells, A.J. and Taylor, J.C.M.	1965	Pencontemporary Dolomite in the Persian Gulf. In L.C. Pray and R.C. Murray (Editor), Dolomitisation and Limestone Diagenesis, Symposium Soc. Ecol. Palaeontologists. Spec. Publication 13, pp. 89-111.
Irman, D.L.	1952	Measures for describing the size distribution of sediments; Journ. Sed. Petrol. Vol. 22, pp. 125-145.
Irwan, M.L.	1965	General Theory of Eperic Clear water Sedimentation. Bull. Amer. Assoc. Petrol. Geol. Vol. 49, pp. 445-59.
King, L.C.	1962	Morphology of the Earth, Oliver and Boyd, Edinburgh, pp. 470.
Krishnan, M.S.	1968	Geology of India and Burma, Pub. Higginbothams (P) Ltd. Madras.
Krishnan, M.S. and Aiyengar, N.K.H.	1940	Did the Indobraham or Siwalik river exist? Recd. G.S.I. Vol. LXXV, pp. 1-24.
Krumbein, W.C. and Pettijohn, F.J.	1938	Manual of sedimentary petrography. Appleton Century Crfts. Inc., New York.
Krumbein, W.C.	1941a	Measurements and geological significance of shape and roundness. Journ. Sed. Petrol. Vol. 11, pp. 64-72.
————	1941b	The effect of abrasion on size, shape and roundness of rock fragments. Journ. Geol. Vol. 49, pp. 482-520.
Krumbein, W.C. and Sloss, L.L.	1963	Stratigraphy and Sedimentation. Freeman & Co. San Francisco, California.
Krynine, P.D.	1946	The tourmaline Group in Sediments, Journ. Geol. Vol. 54, pp. 65-87.
————	1948	The Megascopic study and field, Classification of Sedimentary rocks. Journ. Geol. Vol. 56, pp. 130-165.

Kuenen, P.H.	1957	Sole Markings of Graded graywacke beds. Journ. Geol. Vol. 65, pp. 231-258.
———	1959	Turbidity Currents- A Major factor in Flysch deposition. Eclogae Geol. Helv. Vol. 51, pp. 1009-1021.
Laport, L.F.	1967	Carbonate Deposition near mean sea level and resultant facies mosaic, Manlius Formation (Lower Devonian) of New York, State, Amer. Assocn. Petroleum Geologists, Bull. 51, pp. 73-101.
———	1972	Palaeozoic Carbonate Facies of the Central Appalachian Shelf. Journ. Sed. Pet. Vol. 41, No. 3, pp. 724-740.
La Touche, T.D.	1888	Report on the Sangar Marg and Mehowgala Coalfields, Kashmir. Recd. G.S.I. Vol. 21, pt. 2, pp. 62-70.
Logan, B.W.	1961	Cryptozoon and associate stromatolites from the Recent Shark Bay, Western Australia, Journ. Geol. Vol. 69 No. 5, pp. 517-33.
Logan, B.W., Rezak, R. and Ginsburg, R.N.	1964	Classification and environmental. significance of algal stromatolites. Journ. Geol. Vol. 72, No. I, pp. 68-83.
Laydekker, R.	1876	Notes on the Geology of the Pir Panjal and Neighbouring districts. Recd. G.S.I., Vol. IX, pt. 4, pp. 155-162.
———	1877	Notes on the Geology of Kashmir, Kishtwar and Pangi, Recd. G.S.I. Vol. XI, pt. I, pp. 30-64.
———	1879	Geology of Kashmir, Recd. G.S.I. Vol. 12, No. I.
———	1882	Geology of North West Kashmir and Khagan, Ibid. 15, pp. 14-24.
———	1883	The Geology of Kashmir and Chamba territories and the British district of Khagan. Me. G.S.I. 22, pp. 1-334.
Marshal, C.E.	1936	The alteration of Coal Seams by the intrusion of some of the igneous dykes in the Northumberland and Durham Coalfield. Trans. Inst. Min.

Martin, L.R.	1965	Significance of Skewness and Kurtosis in Environmental Interpretation. Journ. Sed. Petrol. Vol. 35, pp. 768-770.
Mason, C.S. and Folk, R.L.	1958	Differentiation of the Dune and aeolian flat environments by size analysis, Mustang Island, Texas, Journ. Sedi. Pet. Vol. 28, pp. 211-226.
Matter, A.	1967	Tidal flat deposits in the ordovician of western Marryland. Journ. Sed. Pet. V. 37, pp. 601-609.
Mcke, E.D.	1957	Primary Structure of some recent sediments. Bull. Amer. Assoc. Petrol. Geologists, Vol. 41, pp. 1704-47.
Medlicott, H.B.	1864	On the Geological Structure and Relation of the southern portion of the Himalayan Ranges between the river ganges and Ravee. Mem. G.S.I. Vol. 3, pt. 2, pp. 11.
_____	1876	Note upon the Sub-Himalayan series in Jamu (Jummoo) Hills, Recd. G.S.I., IX, pt. 2, pp. 49-57.
Mehta, D.R.S. & Srivastava B.S.	1959	Progress report on the investigation in the Muttal-Lain area, Ladda (Jangal Gali) Coalfields, Jammu Province, J&K State. (unpublished report, G.S.I.).
Middlemiss, C.S.	1890	Physical Geology of the Sub-Himalayas of Garhwal and Kumoan. Mem. G.S.I. Vol. 24, pt. 2.
_____	1891	Physical Geology of the Sub-Himalayas, Geol. Mag. Vol. VIII, pp. 93.
_____	1928	Bauxite deposits of Jammu Province, Min. Surv. Reports, J&K Govt.
_____	1929	Ore deposits of lead, copper, zinc, iron and other metals in Jammu and Kashmir State; Min. Survey Report, J&K Govt. (unpublished).

Middlemiss, C.S.	1929	Possible occurrence of petroleum in Jammu Province, Recd. G.S.I. Vol. 11, pt. 44, pp. 192-213.
————	1929	Kalakot, Metka, Mahagola and other Coalfields of Jammu Province, Min. Survey report; J&K Govt. (unpublished).
————	1938	Mineral Survey Report of Jammu and Kashmir, Non-Metallic Minerals. pp. 32-37.
Miheev, V.I.	1957	X-Ray determination of minerals. State Scientific Technical Publication of Literature on Geology, Moscow.
Milner, H.B.	1962	Sedimentary petrography. 2nd Ed. Allen and Unwin Ltd. London.
Moor, E.S.	1947	"COAL", John. Wiley and Sons, New York.
Nanda, M.M.	1960	Report on the preliminary investigation of the Riasi Sirban limestone inlier in the area west of the Chenab River. (unpublished report, G.S.I.).
Pascoe, E.H.	1954	Manual of the Geology of India. Vol. 2, Manager, Publication Division, Govt. of India, New Delhi.
————	1959	A Manual of Geology of India and Burma, V. II, 3rd Edi. Govt. of India Press, Calcutta.
Perkins, R.D.	1963	Petrology of the Jeffersonville limestone (Middle Devonian) of Southeastern Indiana. Geol. Soc. America, Bull. 74, pp. 1335-1354.
Pettijohn, F.J.	1954	Classification of Sandstones. Journ. Geol. Vol. 62, pp. 360-365.
————	1957	Sedimentary rocks', Harper and Bros. New York.
Potter, P.E. and Pettijohn, F.J.	1963	Paleocurrent and basin analysis. Springer Verlag. Heidelberg.

Powers, M.C.	1953	A new roundness scale for sedimentary particles. Journ. Sed. Pet. Vol. 23, pp. 117-119.
Raaben, M.E.	1959	Columnar Stromatolites and Late Pre-Cambrian Stratigraphy; Amer. Journ. Sci. Vol. 267, No. I, pp. 1-18.
Raha, P.K.	1972	New find of Riphean Stromatolites from the Jammu Limestone, Udhampur District, J&K State. Ind. Min. Vol. 26, No. 3, pp. 68-69.
————	1975a	Magnesite in Jammu Limestone, NEWS a pub. G.S.I, Vol. 6, No. I, Feb. 1975, pp. 5-6.
————	1975b	Tightly appressed reclined folds in Jammu Limestone (Great Limestone) of the Himalayan Foot Hills of Jammu and Kashmir. Journ. Geol. Soc. Ind. V. 16, No. 4, pp. 522-524.
————	1976	Tectonic Setting of the Riasi inlier of Jammu Limestone, Udhampur District, J&K, Him. Geol. Vol. 6.
Raha, P.K. and Sastry, M.V.A.	1973	Stromatolites from the Jammu Limestone, District Udhampur, Jammu and their stratigraphic significance Him. Geol. Vol. 3, pp. 135-147.
Raha, P.K., Chandy, M.C. and Bala Subrahmanyan, M.N.	1978	Geochronology of the Jammu Limestone Udhampur District, Jammu & Kashmir State, INDIA. Journ. Geol. Soc. INDIA. Vol. 19(5), pp. 221-223.
Raina, B.N.	1964	A note on the occurrence of some detached outcrops of limestones in the Sub-Himalayas of Simla Hills. Rep. Intern. Geol. Cong. 22nd Session Ind. 11, pp. 59-78,
Raiverman, V.	1964	Clay Sedimentation in Subathu Dharmsala, Group of rocks in the fort hills of northwestern Himalayas, Bull. O.N.G.C. I, pp. 27-33.
————	1968	Petrology of the Tertiary Sediments of Sarkaghat anticline in the Himalayan Foot Hills of Himachal Pradesh. Publ. Punjab Uni. Centre Adv. Study Geology, Vol. 5, pp. 39-52.

Raiverman, V.	1964	Time Series and stratigraphic correlation of cenozoic sediments in foot hills of Himachal Pradesh. Him. Geol. Vol. 2.
Raiverman, V. & Raman, K.S.	1971	Facies relation in the Subathu sediments Simla, Hills, Northwestern Himalaya, INDIA. Geol. Mag. 108, No. 4, pp. 329-341.
Raiverman, V. & Seshavataram, B.T.V.	1965	On mode of deposition of Subathu and Dharamsala sediments in the Himalayan foot hills in Punjab and Himachal Pradesh. Quart. Journ. Geol. Min. Met. Soc. Ind.
Raju, A.T.R.	1967	Observation on the petrography of the Tertiary clastic sediments of the Himalayan Foot Hills of North India. Bull. ONGC, Vol. 4, No. I, pp. 5-16.
Ranga, Rao, A.	1971	New mammals from Murree (Kalakot Zone) of the Himalayan foot hills near Kalakot, J&K State, India. Journ. Geol. Soc. Vol. 12(2), pp. 125-134.
Rao, C. Gurdu.	1970	A note on Oolites in the Krol Series and their age significance. Pub. Cent. Adv. Geol. No. 7, pp. 127-129.
————	1973	Carbonate- clay mineral relations in the limestone inliers in the outer Himalaya of N.W. India. Him. Geol. Vol. 3, pp. 189.
————	1973	Stratigraphic Time Trend. Analysis of Dolomite Variation in the Sirban Limestone of Riasi, J&K State, India. Current Science, Vol. 42.
————	1974	Quartzine and Lutecite as evnironmental indicators in Sirban Limestone of Riasi, J&K State, Current Sci. Vol. 43, (16), pp. 513-14.
————	1976	A integrated mineralogical, petrographic and sedimentological study of the carbonate inliers in the Murree belt of J&K, Himachal States, proceedings of the Himalayan Geology Seminar held in Delhi.

Rao, R.P., Saxena, I.P. and Dhar, C.L.	1968	Tectonic framework of Chenab Re-entrant in the Sub-Himalayan region of J&K State. Pub. Cent. Adv. Study. Geol. No. 5, pp. 33-38.
Rau, T.V.M.	1931	Bauxite from Kashmir, Min. Mag. Vol. 22, pp. 87-97.
Riley, M.C.	1953	A new roundness scale for sedimentary particles. Journ. Sedi. Pet. Vol. 23(II), pp. 94-97.
Roy Chowdhury, M.K.	1965	Bauxite in India-An Assessment of reserves; Bull. Geol. Surv. India. No. 25, Series A. Economic Geology.
Roy Chowdhury, M.K., Subramanium, M.R. and Banerjee, P.K.	1960	Source bed concept in some sulphide ore bodies from the Western Himalayas. Rep. internat. Geol. Cong. 21st Session, Norden, pt. 16, pp. 138-148.
Selley, R.C.	1970	Ancient Sedimentary environments. Pub. Chapman & Hall Ltd. London.
Sharma, M.R.	1970	Study of the dolomite and limestone inliers of the Reasi region of J&K State, togetherwith their associated mineralisation; an unpublished Ph. D. Thesis of Jammu University, Jammu.
Sharma, M.R. & Krishnaswami, S.P.	1970	Petrography of the Sirban Limestone of Riasi, Jammu Province J&K State. Journ. Sedi. Pet. Vol. 39(3), pp. 1023-1031.
Sharma, T.R.	1973	Geology and Economic importance of a new gypsum deposit found in Gulabgarh area of Udhampur District, Jammu & Kashmir State, Uni. Review, Jammu, 3(6), pp. 1-7.
Shinn, E.A., Ginsburg, R.N. & Lloyd, R.M.	1965	Recent Supratidal dolomite from Andros Island, Bahamas; Dolomisation and Limestone diagenesis symp. Soc. Econ. Palaeontologists, Mineralogists Specl. Publ. 13, pp. 113-123.
Shinn, E.A.	1968	Practical Significance of Bird's Eye Structure in Carbonate Rocks. Journ. Sed. Petrol. V. 38, pp. 215-223.

Shinn, E.A. Ginsburg, R.N. & Lloyd, R.M.	1968	Recent Supratidal Dolomitisation in Florida and Bahams. Geol. Soc. Amer. Spec. Paper 82, pp. 183-134.(Abastract).
Simpson, R.R.	1904	Report on the Jammu Coalfields, Mem. G.S.I. Vol. 32, pt. 4, pp. 194.
Singh, Ashok.	1969	Contribution to the Bauxite Facies of Salal and Panhasa Area, Jammu Province, J&K, (Ind.), Conf. on Bauxite Geology, Budapest, Hungry, Sept. 1969.
Singh, Pratap.	1970	Smaller Foraminifera from the Nummulities (Subathus) of the Beragua, Jangal Gali area, J&K State, Qty. Journ. Geol. Min. and Met. Soc. of India, Vol. 42, No. 1.
Singh, P. and Vimal, K.P.	1972	Discovery of Stromatolites from the Sirban Limestone of Riasi, J&K State. Journ. Pal. Soc. India. Vol. 15, pp. 6-9.
Singh, Partap.	1973	Geology of the Subathu group of Jammu & Kashmir State, Him. Geol. Vol. 3, pp. 284-298.
Singh, S.	1952	On the Laki beds of Dharmpur Subathu region- Simla Hills; Current Science Vol. 21, pp. 335-336.
Srivastava, A.K.	1965	Report on the geological studies of the Riasi thrust Dhiangarh Hydal Project, J&K State. (unpublished report, G.S.I.).
Srivastava, B.S.	1956	Preliminary Geological Survey report of Ladda Coalfield, Jammu Province, J&K State (unpublished).
———	1958	Ibid. (unpublished report).
———	1964	Progress report on the investigation of the Nummulitics in the Area east of Magogala Coalfields, West of Ransuh Village in the Poonch & Udhampur District, Jammu Province. (unpublished report, G.S.I.).

Srivastava, B.S.	1965	Preliminary report on the investigation of Nummulitics in Arnas-Salal-Khiru area of Ladda (Jangal Gali) Coalfields, Riasi Tehsil, Udhampur District, J&K State. (unpublished report G.S.I.).
Tarr, W.A.	1922	Con-in-Cone. Amer. Journ. Sc. 5th Series Vol. IV, p. 199-213.
Tennant, C.B. & Berger, R.W.	1957	X-Ray determination of dolomite calcite ratio of a carbonate rock. Am. Min. Vol. 42, pp. 23-29.
Tewari, B.S. and Singh, Partap.	1966	Ostracoda from the Nummulitic beds of Kalakot, J&K State; Pub. Cent. Adv. Stud. Geol. Chandigarh, Abst. No. 39, pp. 27-28.
Textoris, D.A.	1968	Petrology of Supratidal, Intertidal and shallow subtidal Carbonates, Black River Group, Middle Ordovician. New York. U.S.A. XXXIII, G.C. Vol. 8, pp. 227-248.
Twenhofel, W.H.	1950	Principles of Sedimentation, 2nd edi. Pub; Mc Graw Hill Book Coy. Inc. New York. pp. 673.
Valdiya, K.S.	1962	An outline of the stratigraphy and structure of the Southern part of Pithorgarh district, U.P., Journ. Geol. Soc. Ind. V. 3, pp. 27-48.
_____	1964	The tectonic design of the Himalayas; A Survey of Structures between Indus and Brahamputra and their comparison with the Alpine structures. Himalayan and Alpine Orogeny. 22nd Int. Geol. Cong. India. pp, 16, 382-315.
_____	1968	Origin of the Magnesite Deposits of Southern Pithorgarh, Kumaon Himalaya, India, Economic Geology, Vol. 63, pp. 424-934.
_____	1969	Stromatolites of the Lesser Himalayan Carbonate formation and the Vindhyans, Journ. Geol. Soc. India. Vol. 10(1), pp. 1-25.

Valeton, Ida.	1972	Bauxites, Elsevier Publishing Coy. New York.
Vohra, C.P.		Report on preliminary investigation of Sulphide mineralisation in Panhasa-Salal area of Udhampur District, (Unpublished report of G.S.I.).
Wadell, Hakon.	1932	Volume, Shape and roundness of quartz particles, Journ. Geol. Vol. 40, pp. 443-451.
————	1935	Volume, Shape and roundness of quartz particles. Journ. Geol. Vol. 43, pp. 250-280.
————	1936	Shape and Shape position of rock fragments. Geographish Ka Annaler. pp. 74-92.
Wadia, D.N.	1926	Geology of India; Pub. Mac Millan & Co. London, pp. 7, 232-337-378.
————	1928	Geology of Poonch State (Kashmir) and adjacent portions of the Punjab; Mem. G.S.I. Vol. 51, pp. 253.
————	1932	Tertiary Geosyncline of N.W. Punjab Quarty. Journ. Geol. Min. Met. Soc. Ind. Vol. 4(3).
————	1934	The Cambrian Trias Sequence of North West Kashmir; Recd. G.S.I. Vol. 68, pp. 163.
————	1937	Permo-Carboniferous Limestone inliers in the Sub-Himalayan Tertiary Zone of Jammu & Kashmir Himalaya; Recd. G.S.I. Vol. 72, pt. 2, pp. 162-173.
————	1949	Geology of India; Mac Millan & Co. Ltd. London. pp. 43-49.
————	1961	Ibid. 1961 Edition.
Wakhaloo, S.N.	1965	Possibilities of petroleum occurrences around Lon-Ka-Pani in Udhampur District, Kashmir Science Vol. II(1-2), pp. 77-79.
Wakhaloo, G.L. & Raina K.B.	1966	Report on the investigation of flux grade limestone inlier, Reasi area, Udhampur District, J&K State. (unpublished report G.S.I.).

Wakhaloo, S.N. & Bhatia, T.R.	1968a	Studies of Zircon types in Siwalik Sediments of Jammu region. J&K Uni. Review Vol. 2 , pp. 1-9.
————	1968b	Significance of grain size parameters of Siwalik Sandstones of Jammu region Kashmir Science, Vol. V, No. 1 & 2, pp. 158-169.
————	1969	A stone axe from Jammu Siwaliks. J&K Uni. Review, Vol. II , pp. 1-3.
Wakhaloo, S.N. & Sharma, M.R.	1970	Riasi Tillites, Geology and Geography section. Indian Science Congress, 57th Session, part III, Section V, pp. 195.
Walker, T.H.R.	1962	Reversible nature Chert Carbonate replacement in sedimentary rocks. Bull. Geol. Soc. Amer. Vol. 73, pp. 237-242.
Warne, S.St. J.	1962	A quick field or laboratory staining scheme for the differentiation of the major Carbonate minerals. Journ. Sed. Petrol. Vol. 32, pp. 29-38.
Weller, J.M.	1928	Cenozoic history of the North West Punjab. Journ. Geol. Vol. XXXVI, pp. 362.
————	1930.	Cyclical Sedimentation of the Pennsylvanian Period and its significance. Journ. Geol. Vol. 38, No. 2, pp. 124.
————	1956	Argument for diastrophic control of Late Palaeozoic Cyclothems, Bull. Amer. Assoc. Petrol. Geol. Vol. 40, pp. 17-50.
————	1960	Stratigraphic principles and Practice. Harper Bros. New York.
Wells, A.J.	1960	Cyclic Sedimentation- a review; Geol. Mag. London, Vol. 97, pp. 389-403.

Wentworth, C.K.	1919	A Laboratory and Field Study of Cobble abrasion. Journ. Geol. Vol. 27, pp. 507-521.
————	1922	A field study of the shapes of river pebbles. U.S. Geol. Surv. Bull. 730-C, pp. 103-114.
Wright, C.M.P.	1906	The Dandli Coalfields; Recd. G.S.I. Vol. 34, pt. II, pp. 37.
Wynne, A.B.	1872	Geology of Sirban Hills, Mem. G.S.I. Vol. IX, pt. 2.
————	1877	Tertiary Zone and underlying Rocks in N.W. Punjab. Recd. G.S.I. Vol. X, pp. 107.
————	1879	Further Notes on the Geology of upper Punjab. Recd. G.S.I. Vol. XII, pp. 114.
————	1882	Note on Connection between Hazara and Kashmir Series. Recd. G.S.I. Vol. XV. pp. 164.
Zeller, E.J. and Wray, J.L.	1956	Factors influencing precipitation of Calcium Carbonate. Bull. Amer. Assoc. Pet. Geol. Vol. 40, pp. 122-39.

PLATE NO. I

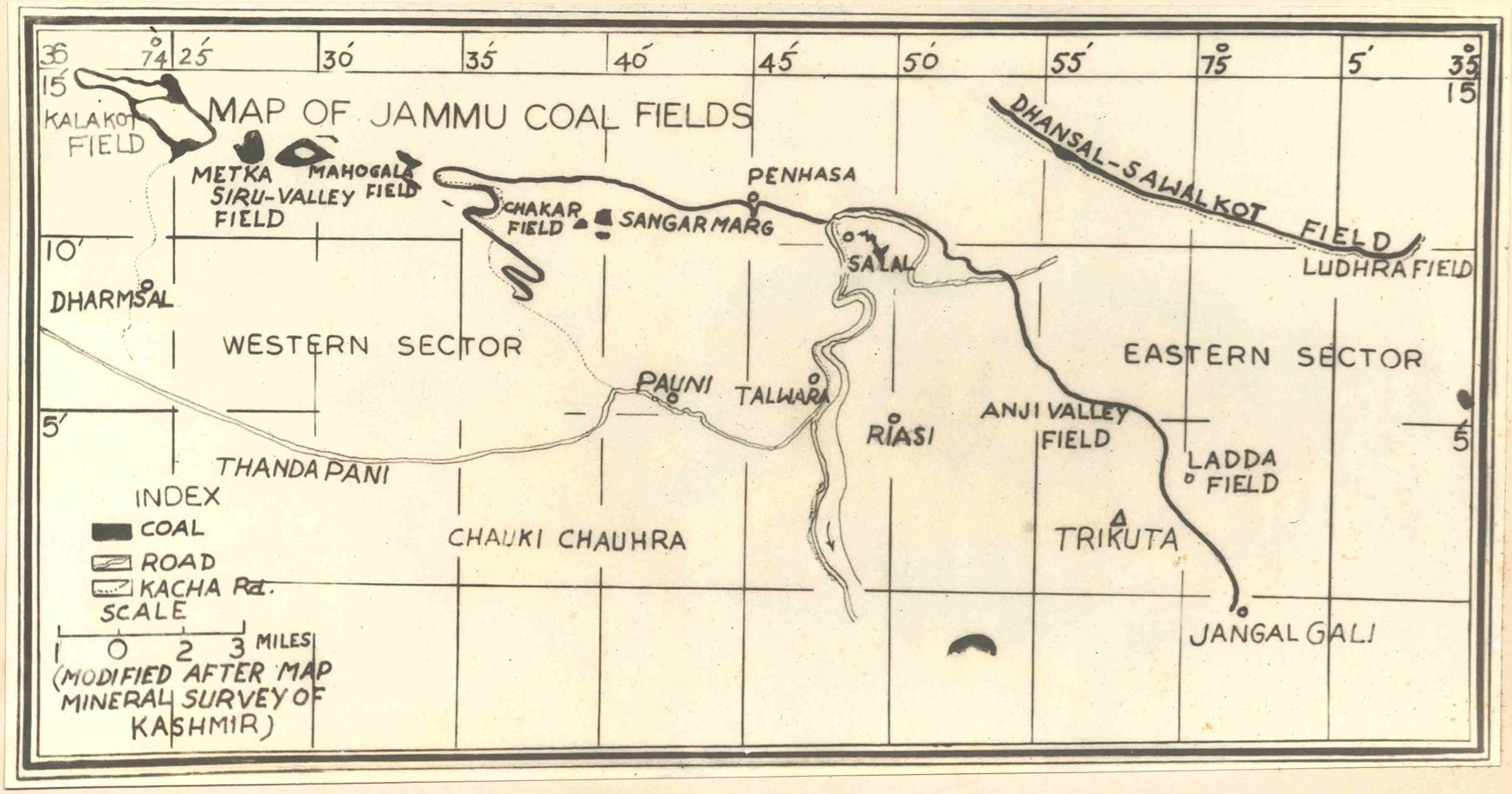
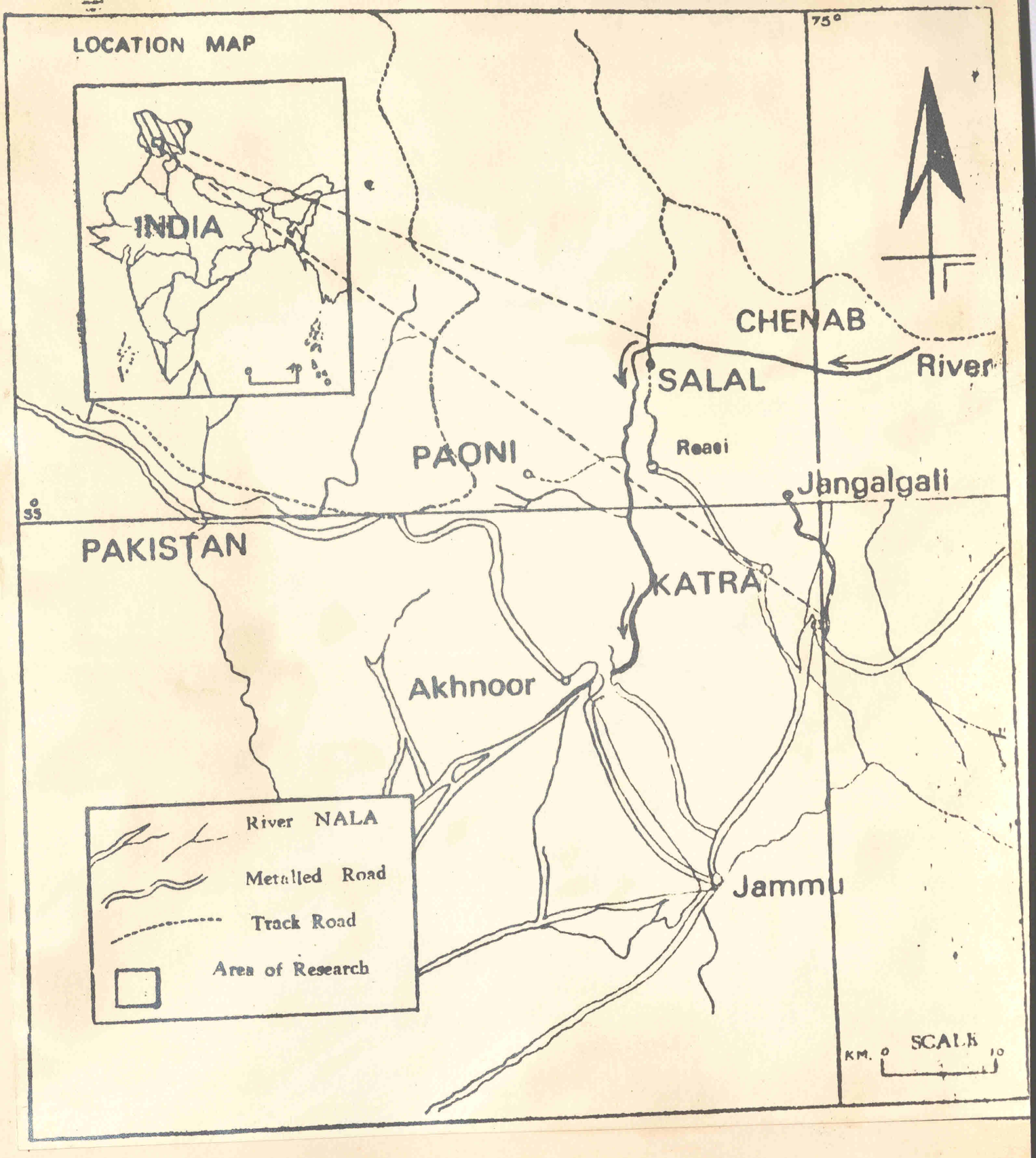
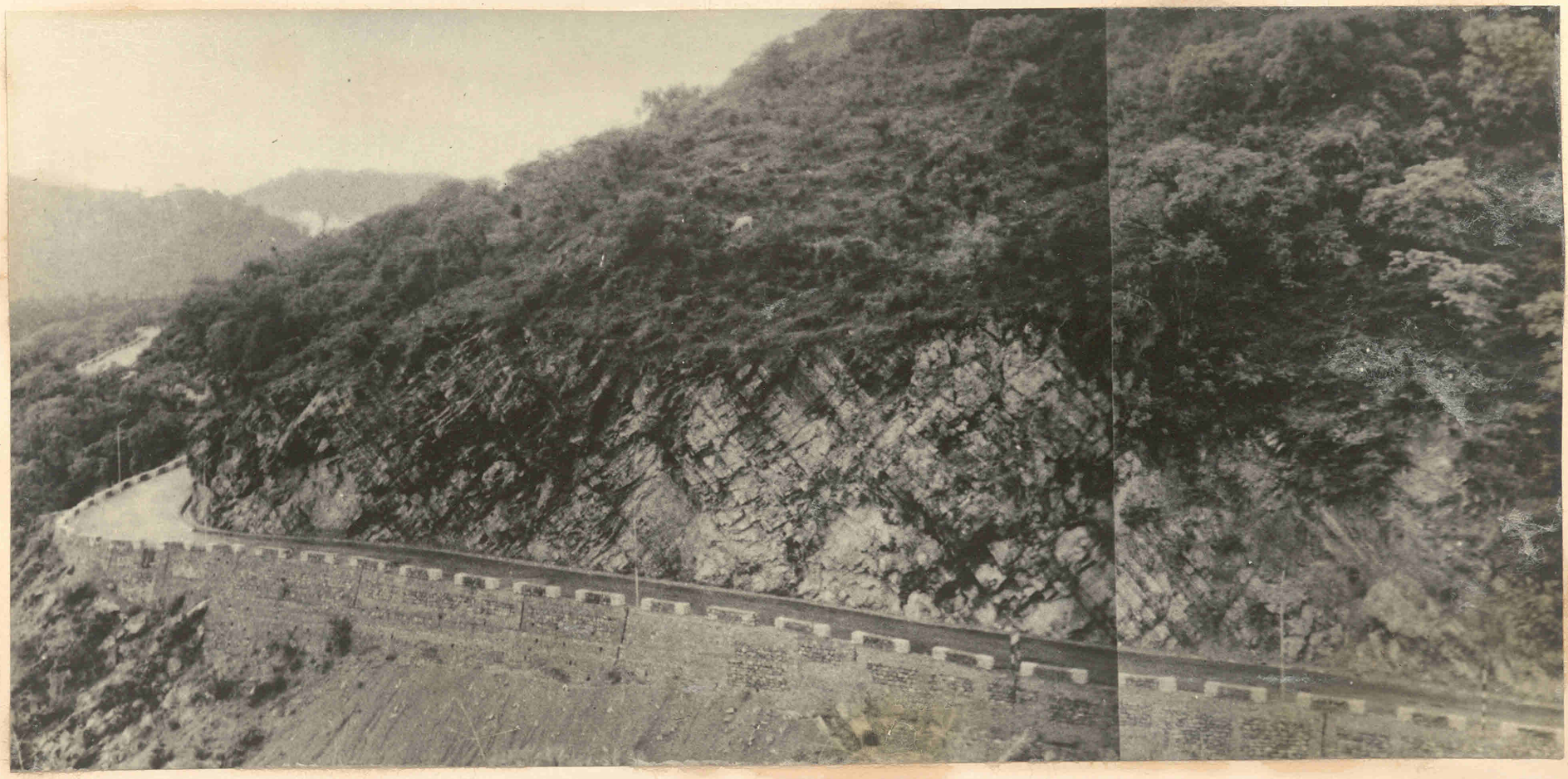

MAP OF JAMMU COAL FIELDS
74° 25′
30′
35′
40′
45′
50′
55′
75°
5′
35°
15′
10′
5′
KALAKOT FIELD
METKA
SIRU-VALLEY FIELD
MAHOGALA FIELD
CHAKAR FIELD
SANGAR MARG
PENHASA
SALAL
DHANSAL-SALWALKOT FIELD
LUDHRA FIELD
DHARMSAL
WESTERN SECTOR
EASTERN SECTOR
PAUNI
TALWARA
RIASI
ANJI VALLEY FIELD
LADDA FIELD
THANDA PANI
CHAUKI CHAUHRA
TRIKUTA
JANGAL GALI
INDEX
COAL
ROAD
KACHA Rd.
SCALE
1 0 2 3 MILES
(MODIFIED AFTER MAP MINERAL SURVEY OF KASHMIR)

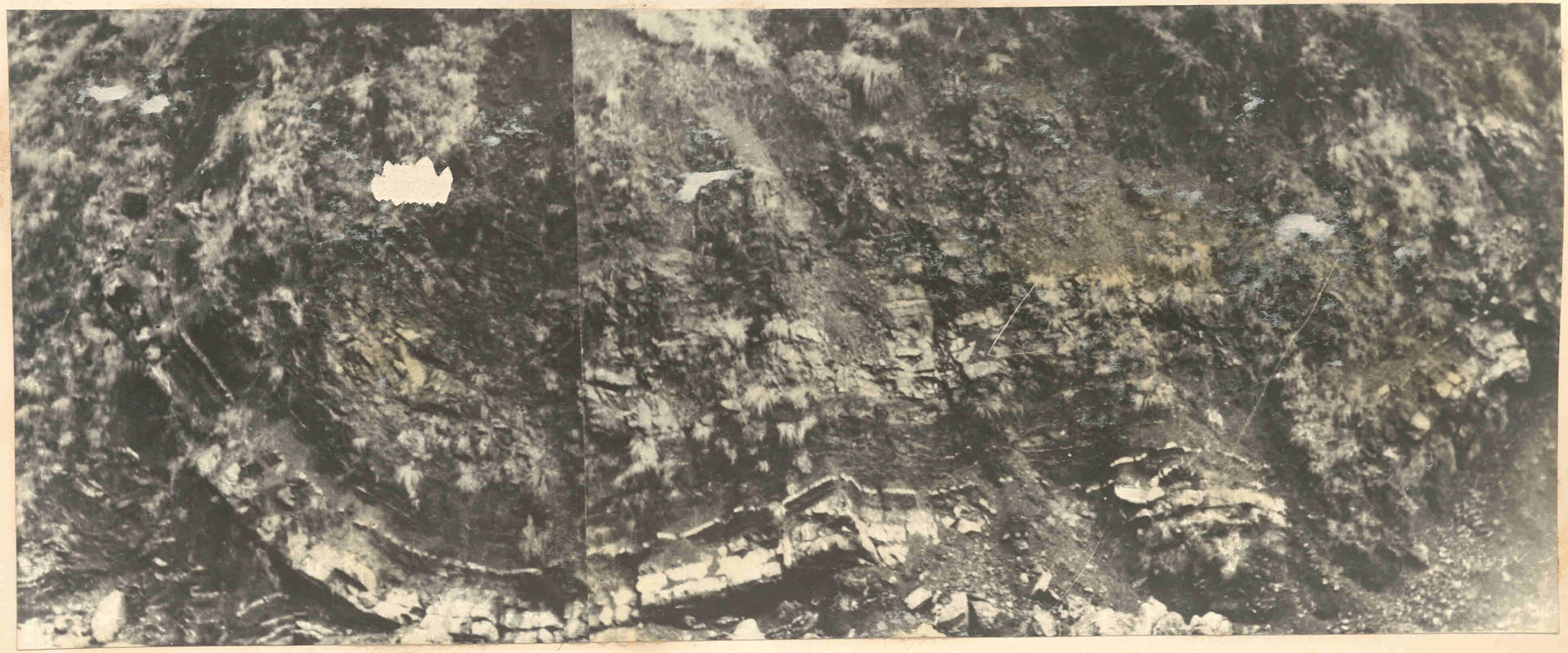
PLATE NO. 2


LOCATION MAP
INDIA
75°
CHENAB
River
SALAL
Reasi
PAONI
Jangalgali
33°
PAKISTAN
KATRA
Akhnoor
Jammu
River NALA
Metalled Road
Track Road
Area of Research
KM. 0
SCALE
10

A GLIMPSE OF THE CHENAB LOOP AT DHIANGARH DAM SITE, SALAL PROJECT, JAMMU.



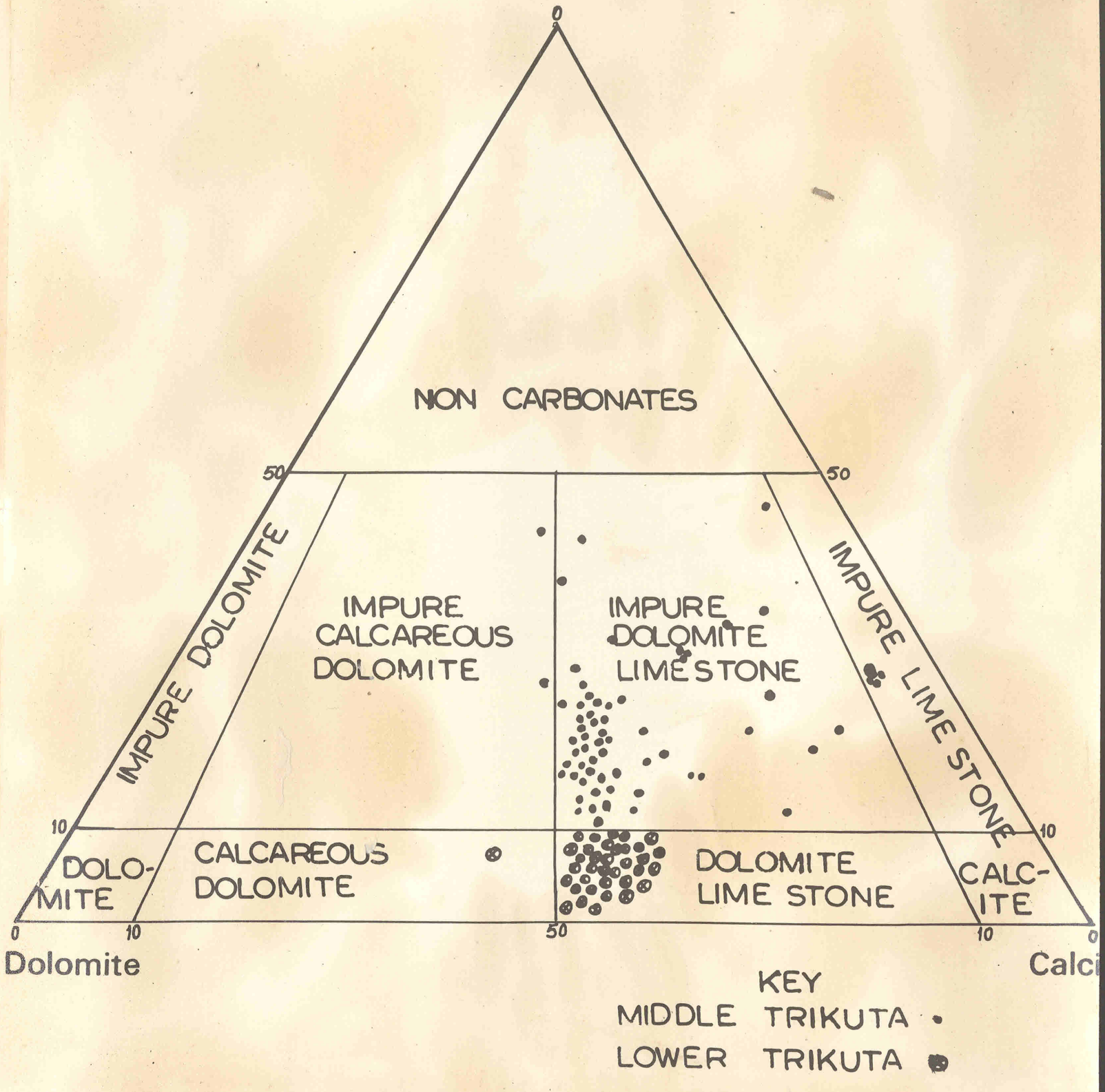
AN OUTCROP OF TRIKUTA LIMESTONE NEAR SALAL SHOWING NATURE OF BEDDING.



FOLDING IN THE NUMMULITIC LIMESTONE, DO-KHADDA (MUTTAL) AREA OF JAMMU.

PLATE NO. 6

Showing Calcite/Dolomite relationsh



SHOWING RELATIONSHIP BETWEEN CaO % & MgO % IN TRIKUTA LIME STONE.

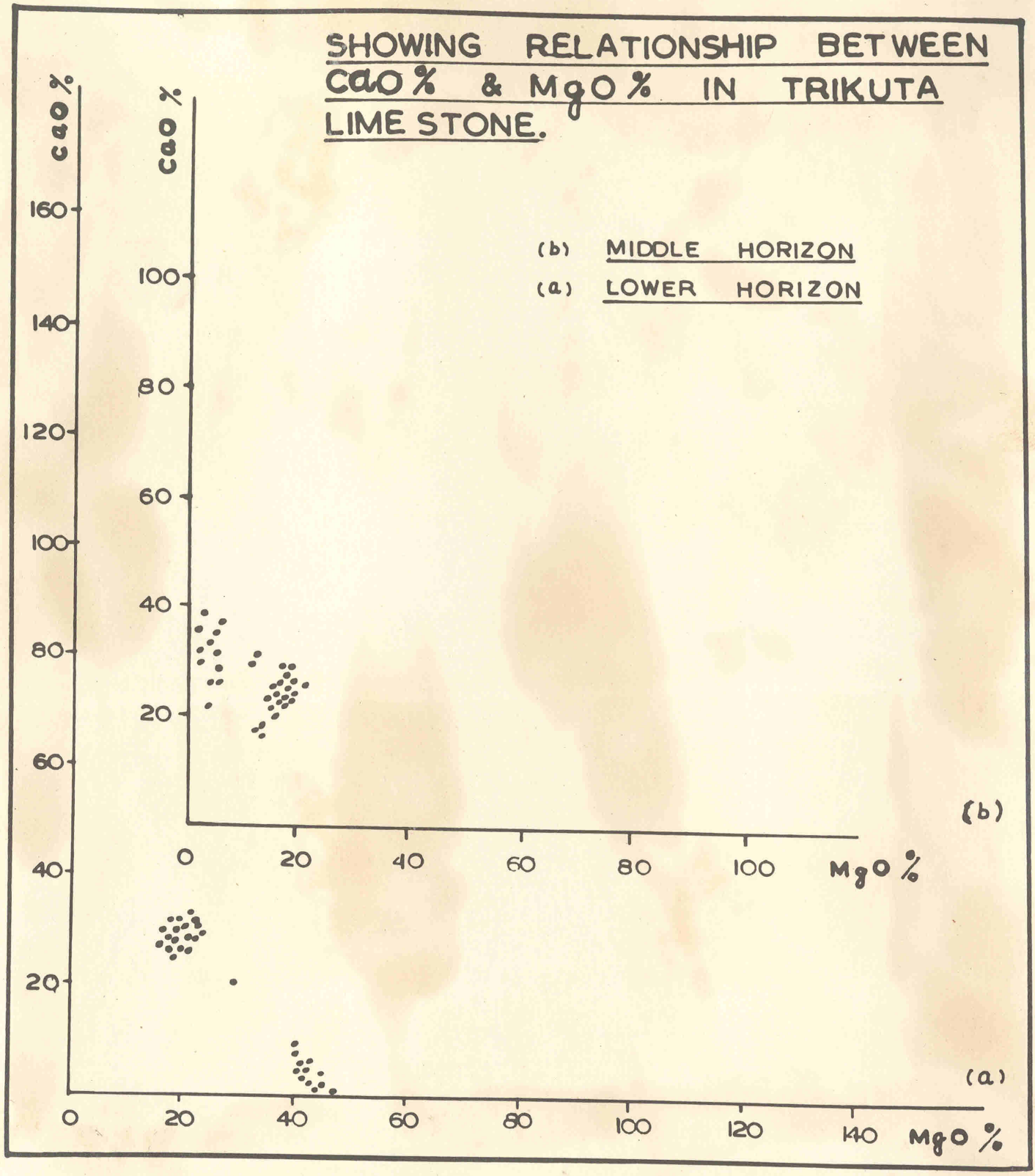


PLATE NO. 8

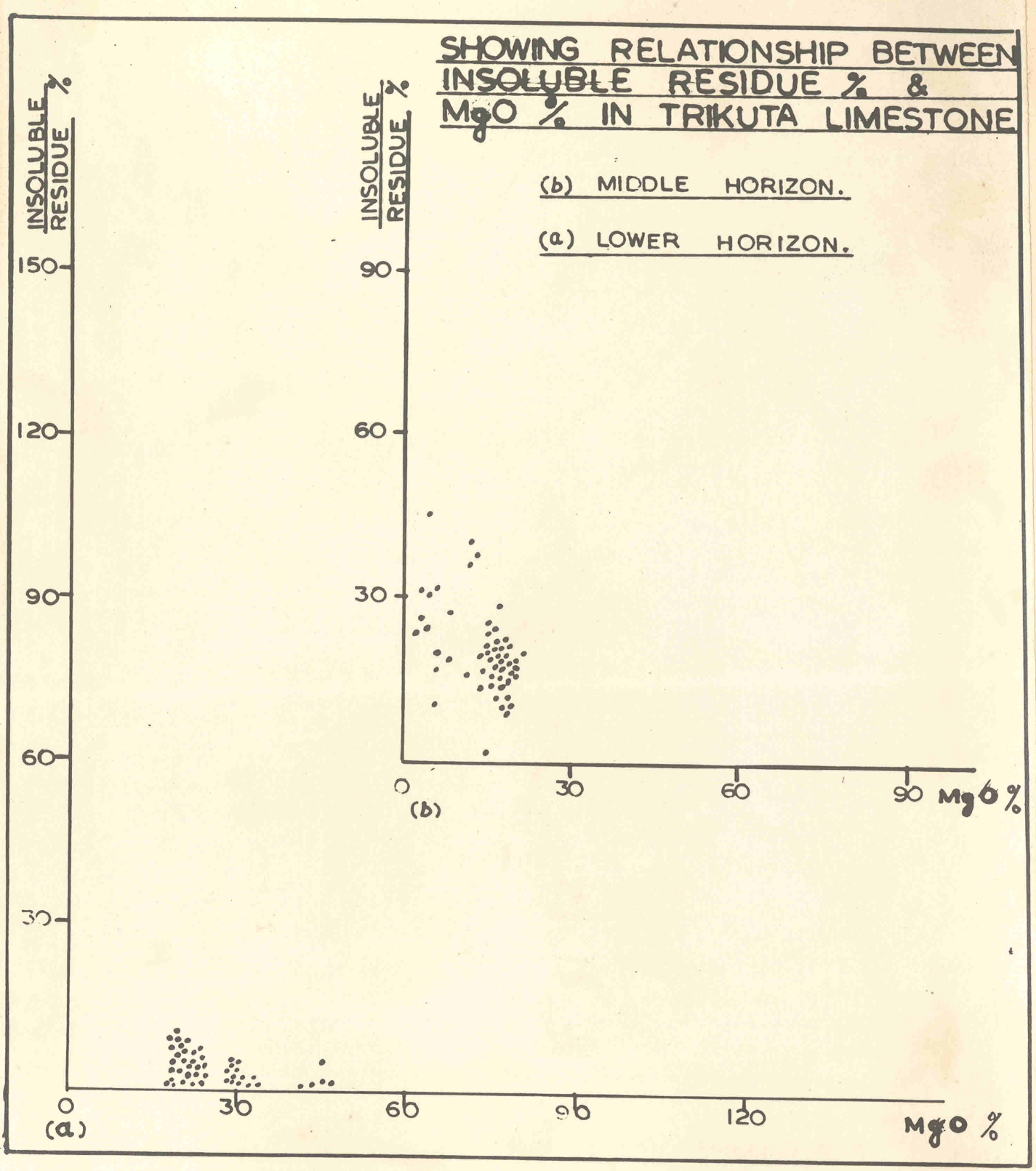

SHOWING RELATIONSHIP BETWEEN
INSOLUBLE RESIDUE % &
MgO % IN TRIKUTA LIMESTONE
(b) MIDDLE HORIZON.
(a) LOWER HORIZON.
INSOLUBLE RESIDUE %
150
120
90
60
30
0
30
60
90
120
MgO %
(a)
INSOLUBLE RESIDUE %
90
60
30
0
30
60
90
MgO %
(b)

PLATE NO. 9

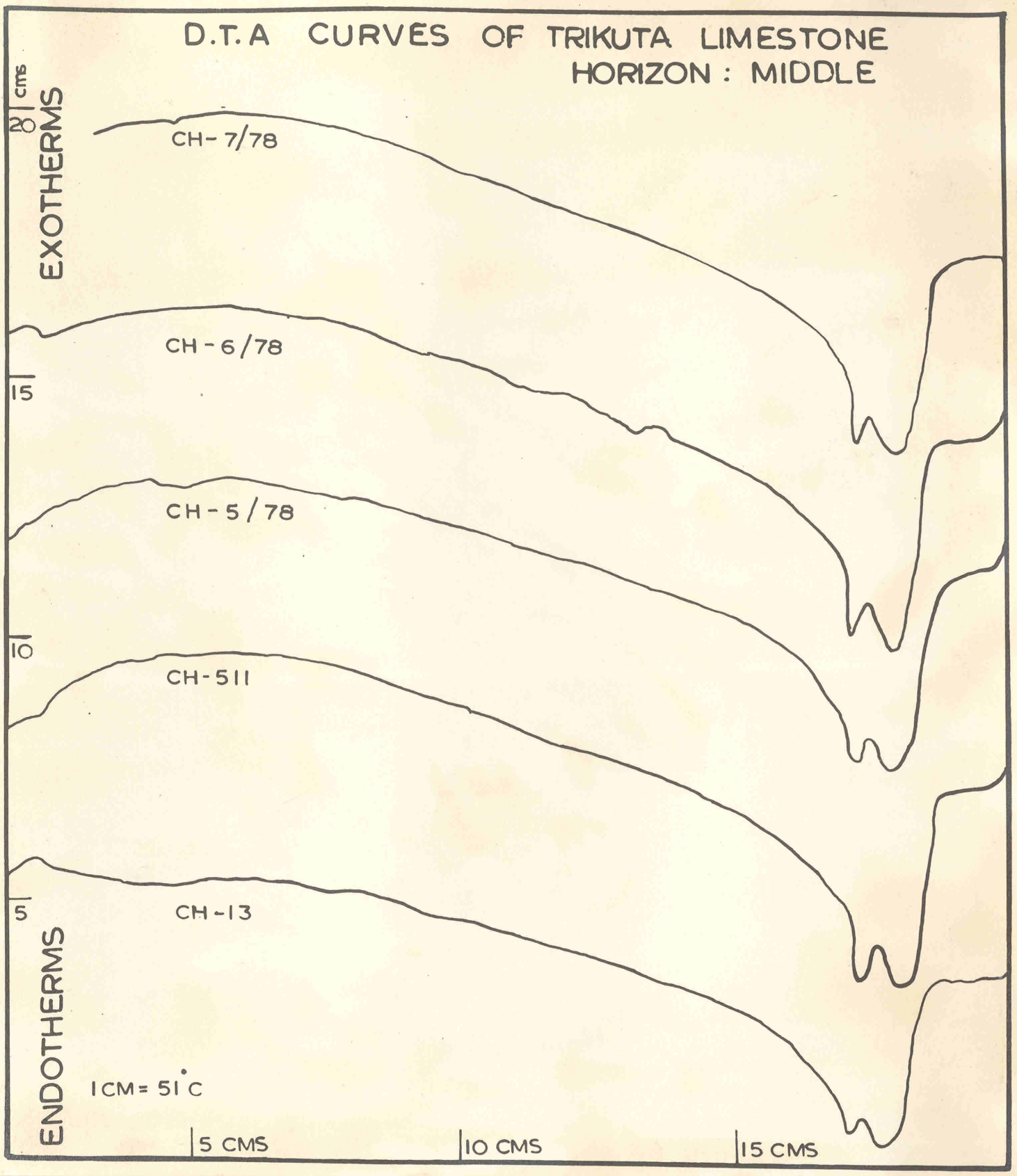

D.T.A CURVES OF TRIKUTA LIMESTONE
HORIZON : MIDDLE
20 cms
EXOTHERMS
CH-7/78
CH-6/78
15
CH-5/78
10
CH-511
5
CH-13
ENDOTHERMS
1CM = 51°C
5 CMS
10 CMS
15 CMS

PLATE NO 10

D.T.A CURVES OF TRIKUTA LIMESTONE

HORIZON = MIDDLE

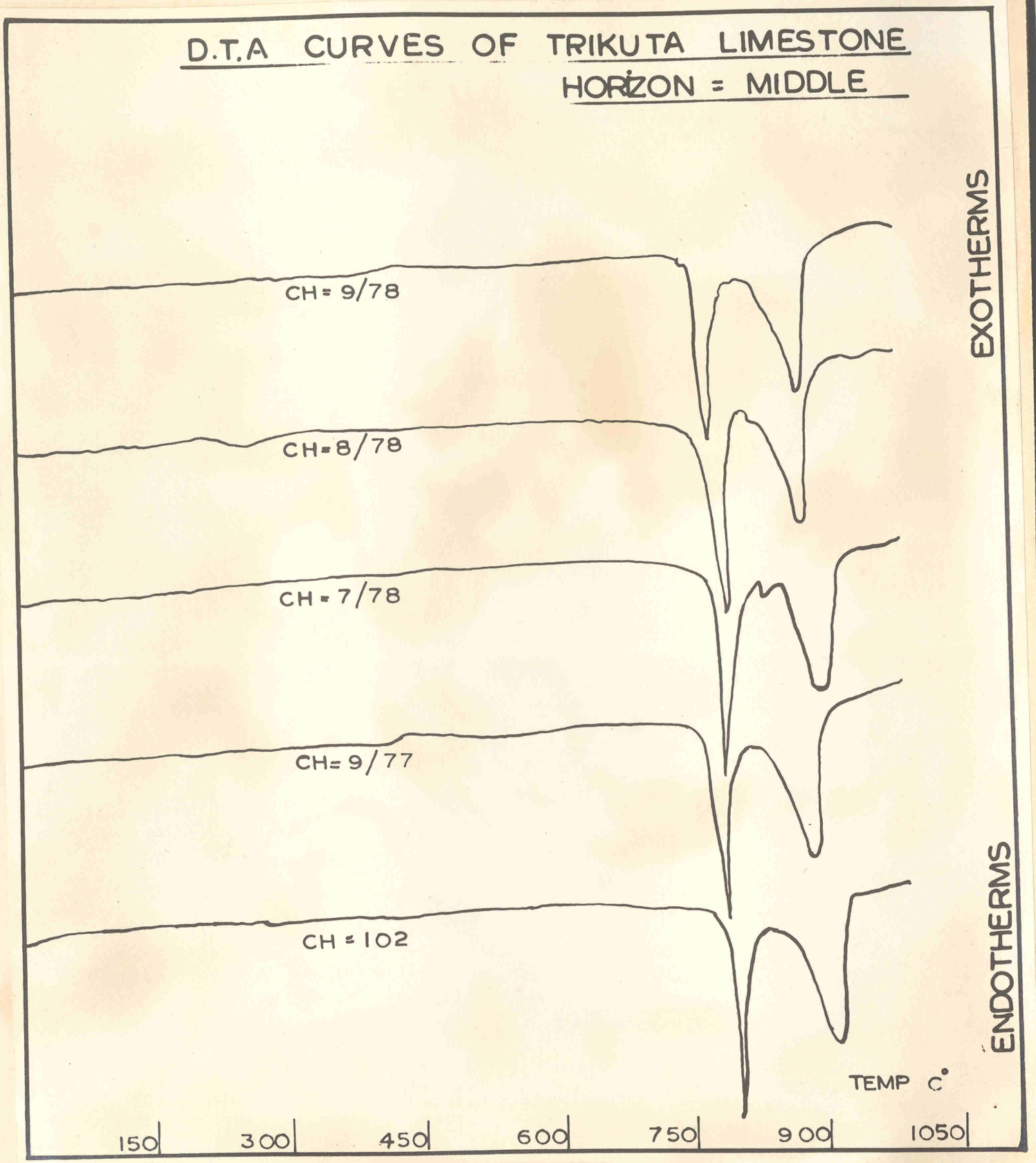


PLATE NO. 11

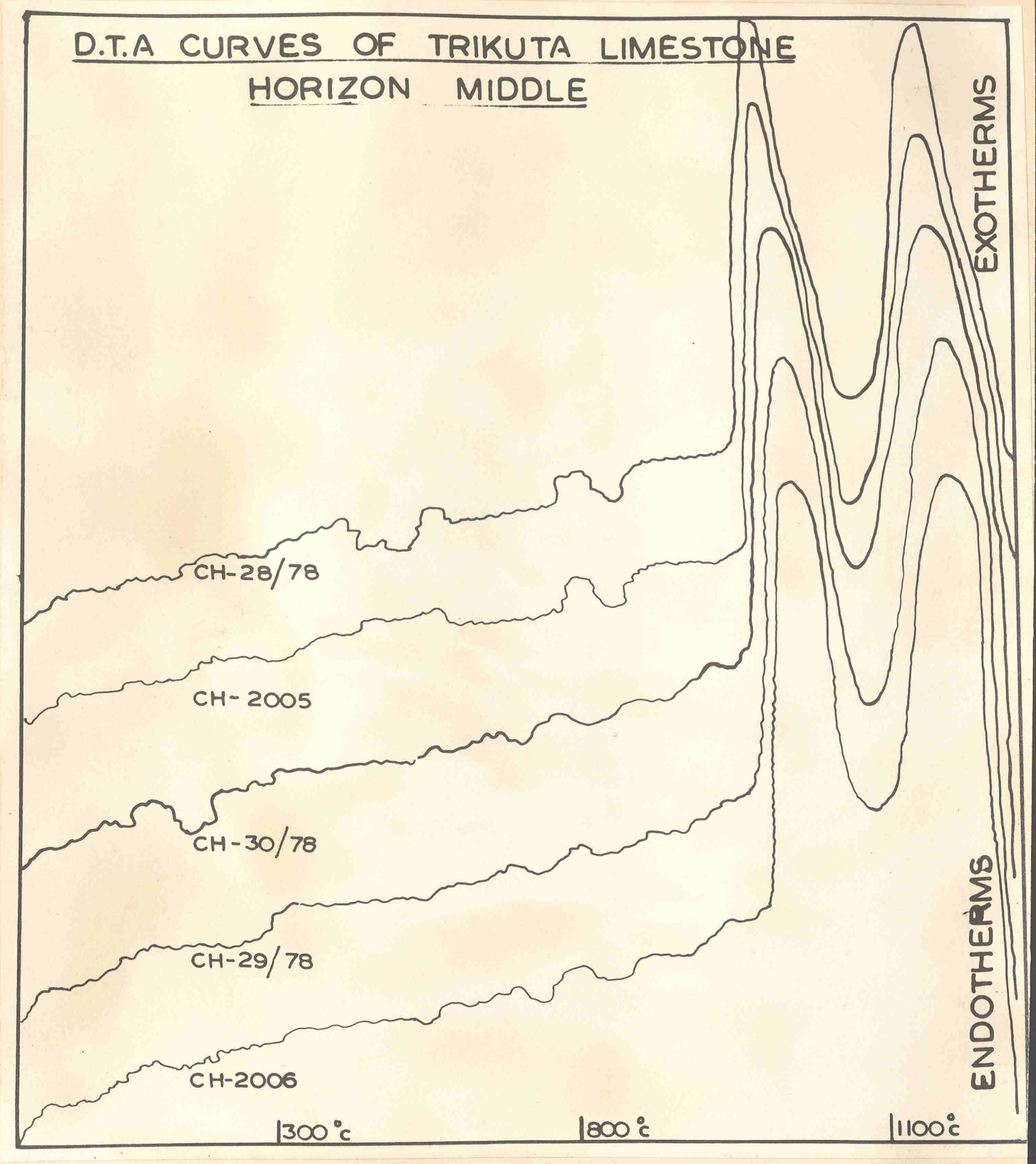

D.T.A CURVES OF TRIKUTA LIMESTONE
HORIZON MIDDLE
EXOTHERMS
ENDOTHERMS
CH-28/78
CH-2005
CH-30/78
CH-29/78
CH-2006
300 °c
800 °c
1100 °c

PLATE NO.12

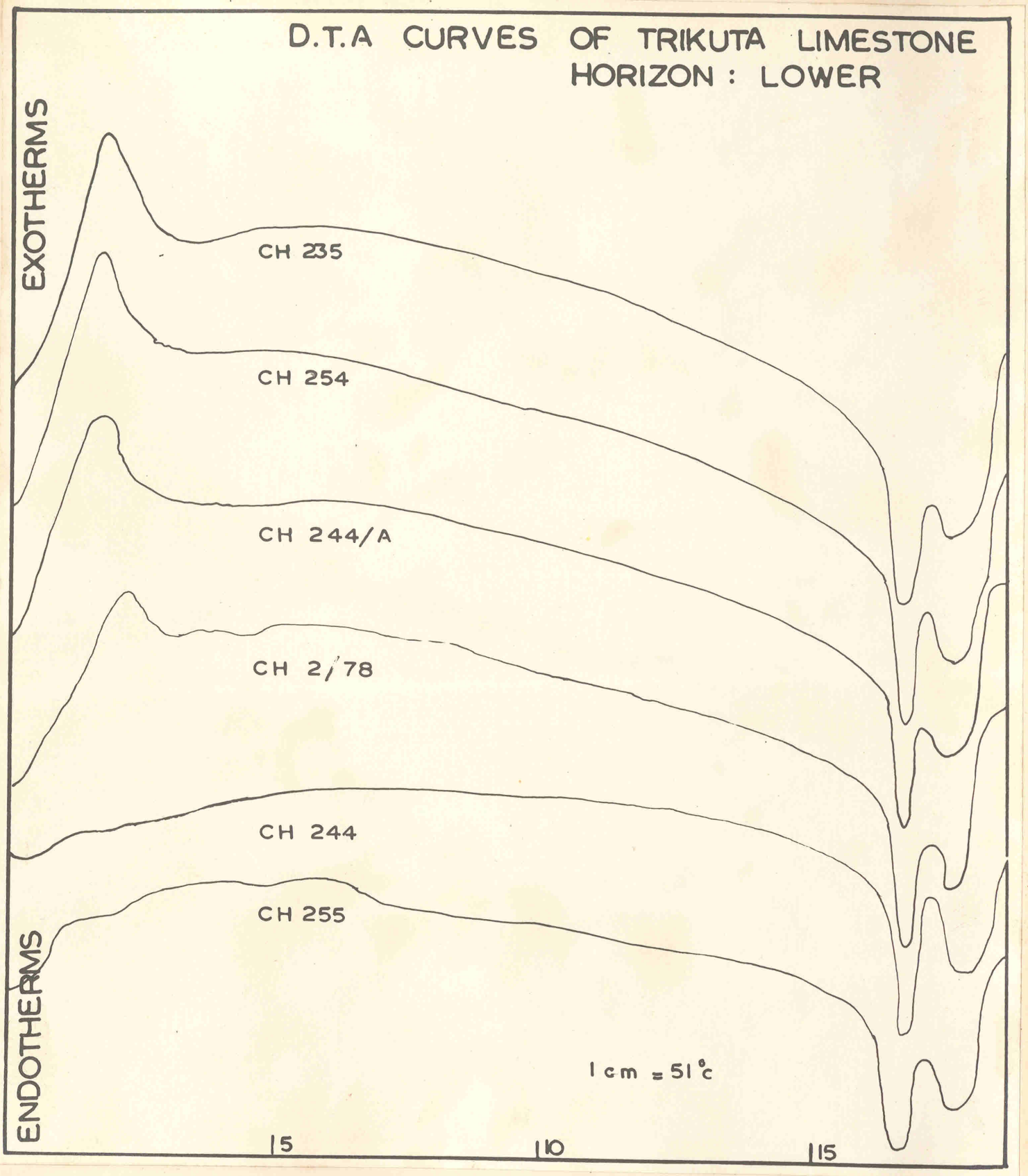

D.T.A CURVES OF TRIKUTA LIMESTONE
HORIZON : LOWER
EXOTHERMS
CH 235
CH 254
CH 244/A
CH 2/78
CH 244
CH 255
ENDOTHERMS
1 cm = 51°c
15
10
15

PLATE NO.13

D.T.A CURVES OF TRIKUTA LIMESTONE

HORIZON : LOWER

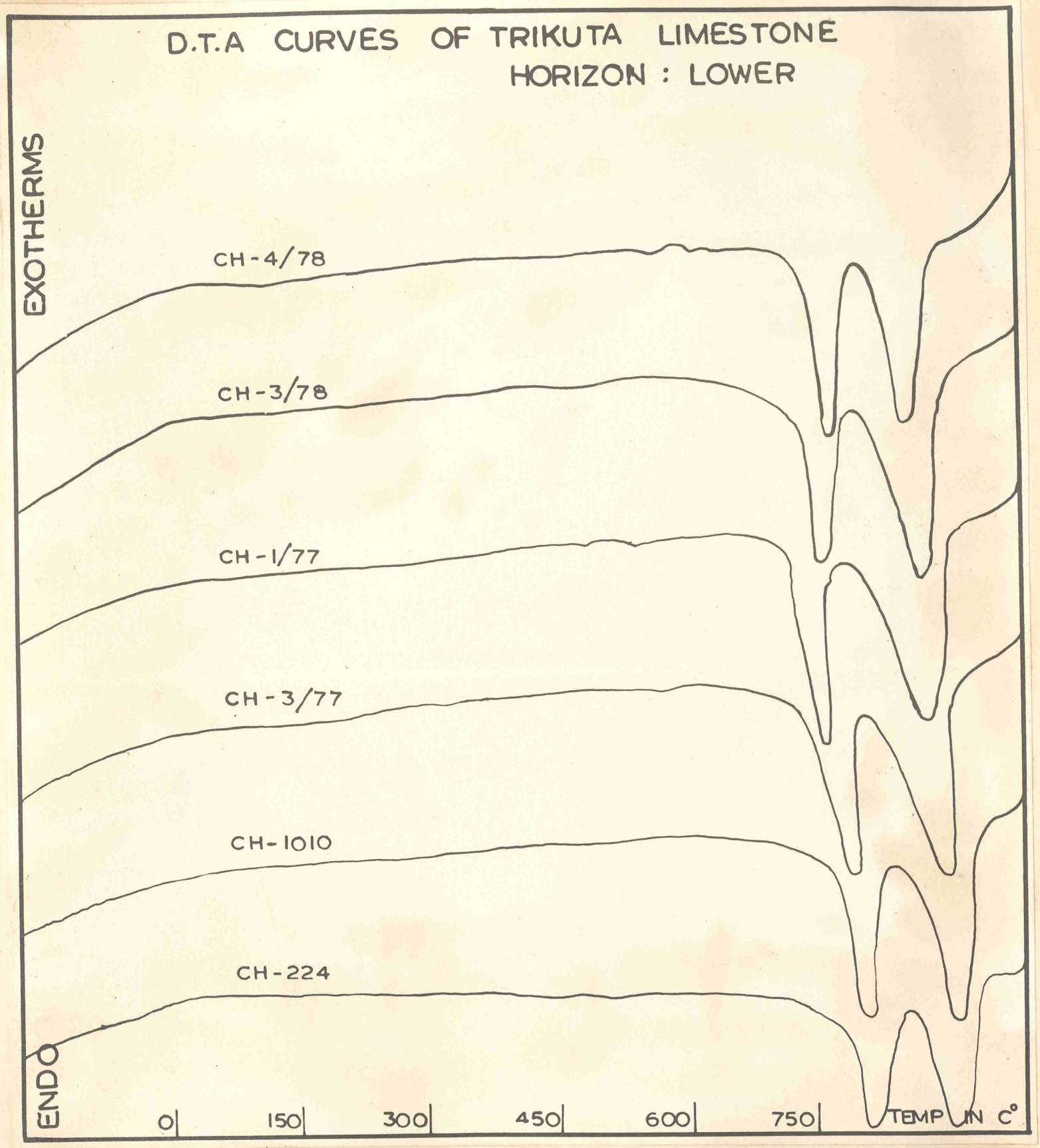
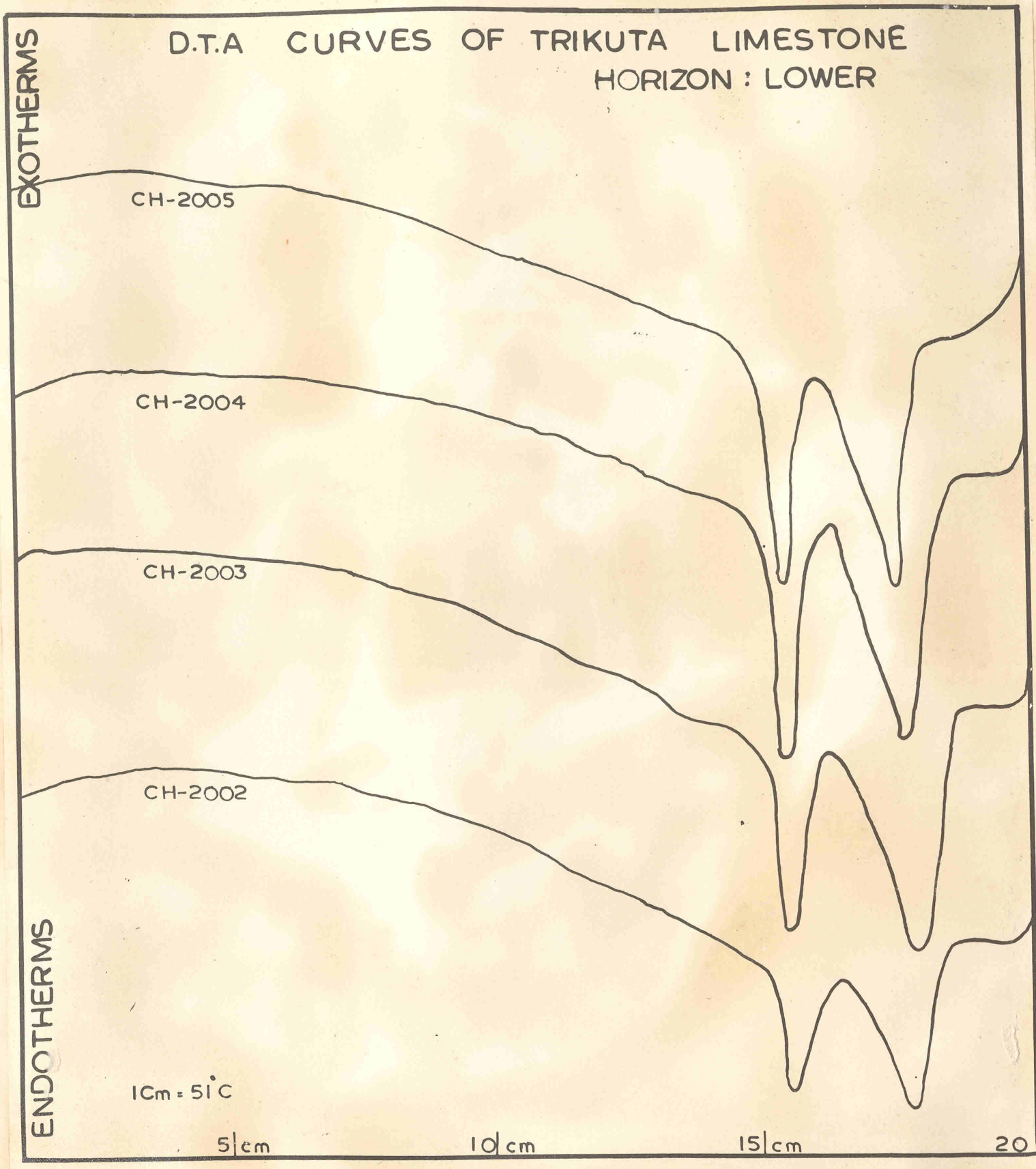


PLATE NO.14


D.T.A CURVES OF TRIKUTA LIMESTONE
HORIZON : LOWER
EXOTHERMS
CH-2005
CH-2004
CH-2003
CH-2002
ENDOTHERMS
1Cm = 5°C
5 cm
10 cm
15 cm
20

Explanation of plate No. 16

Fig. 1. Photomicrograph of dolostone showing the development of veins cutting across each other. Both the horizontal and the vertical veins show slight faulting. The bending in the veins on the right side is also due to faulting.

Locality - Jangal Gali Crossed NicolsX45.

Fig. 2. Photomicrograph of a dolostone showing veins as in fig. 1 but having slightly different pattern. One of the vein is effected by faulting.

Locality - Waishno Devi. Crossed NicolsX45.

Fig. 3. Photomicrograph of a dolostone with a vein extending NW-SE. The vein has a broader thickness in the upper part as compared to the lower one. The vein typically shows hypidiotopic texture. The same type of texture is seen on the left side of the vein whereas the right side of the vein shows micritic texture.

Locality - Katra. Crossed NicolsX45.

Fig. 4. Photomicrograph of a limestone showing alternate black and white laminae.

Locality - Muttal. Crossed NicolsX45.

Fig. 5. Photomicrograph of a dolostone showing microstylolitic structure.

Locality - Dhiangarh. Crossed NicolsX45.

Fig. 6. Photomicrograph of a dolostone with a big crystal of magnesite showing rhombohedral cleavage.

Locality - Katra. Crossed NicolsX45.

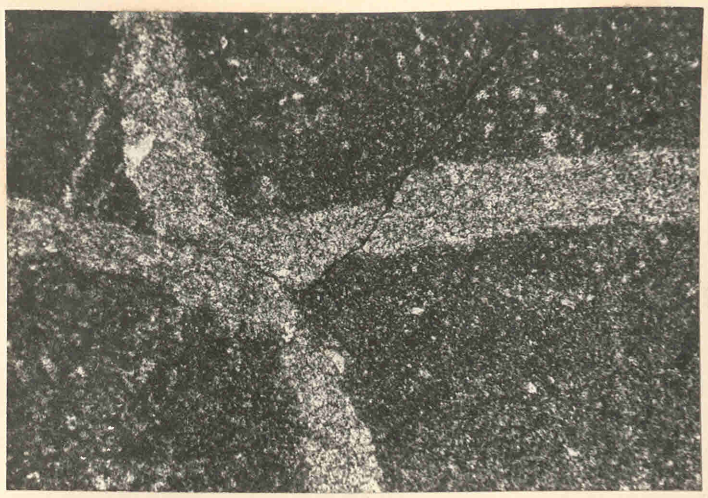


FIG. 1

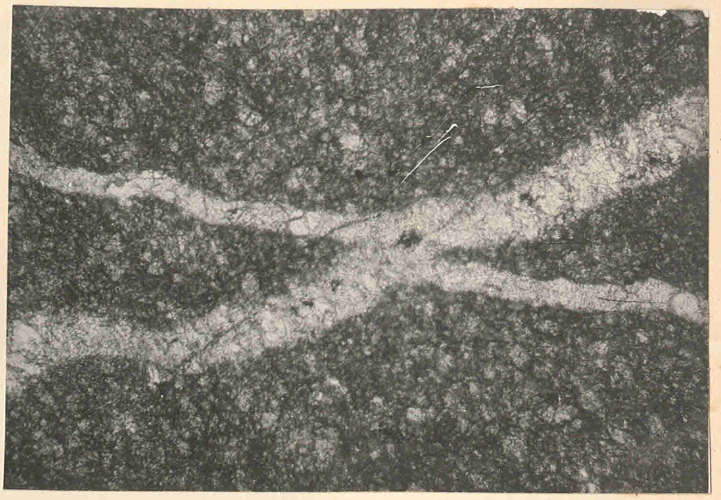


FIG. 2

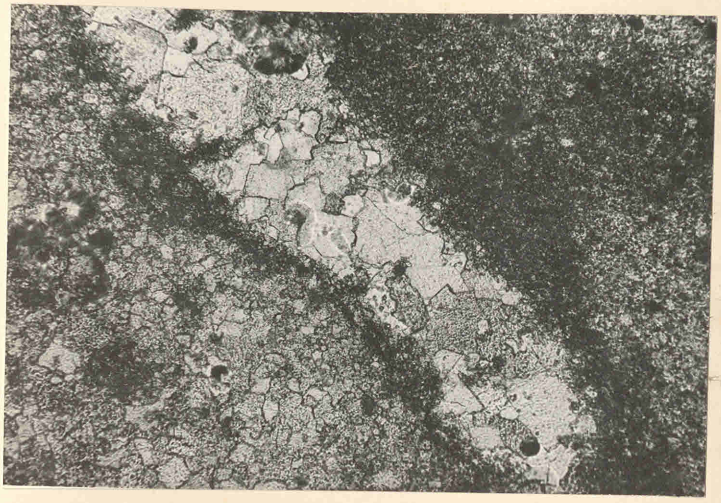


FIG. 3

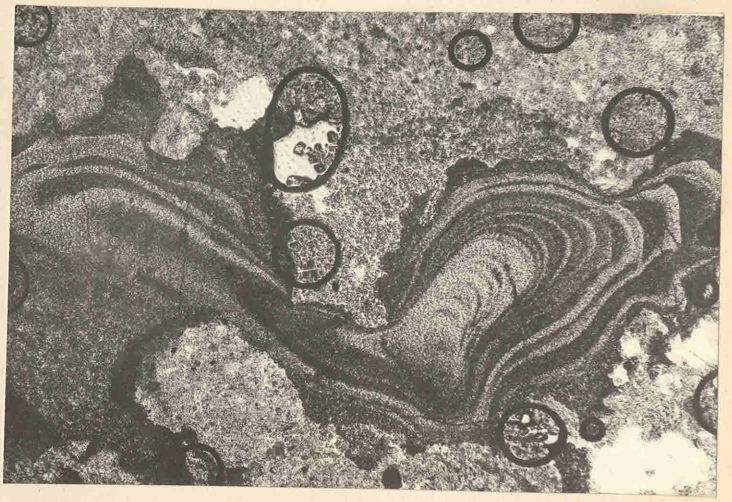


FIG. 4

FIG. 5

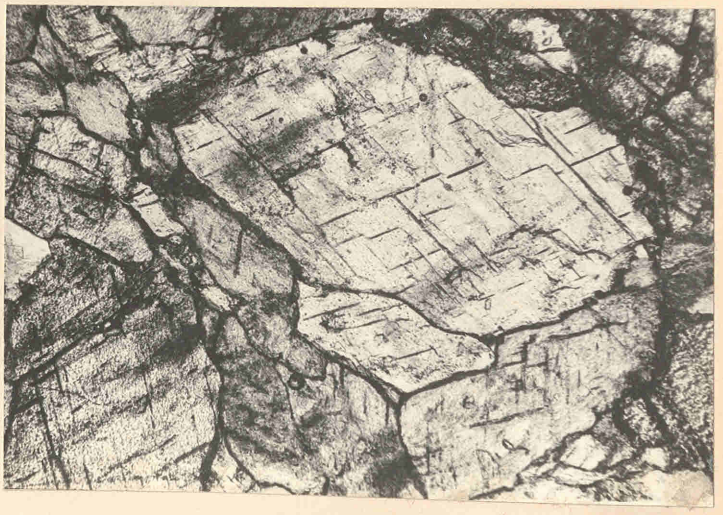


FIG. 6

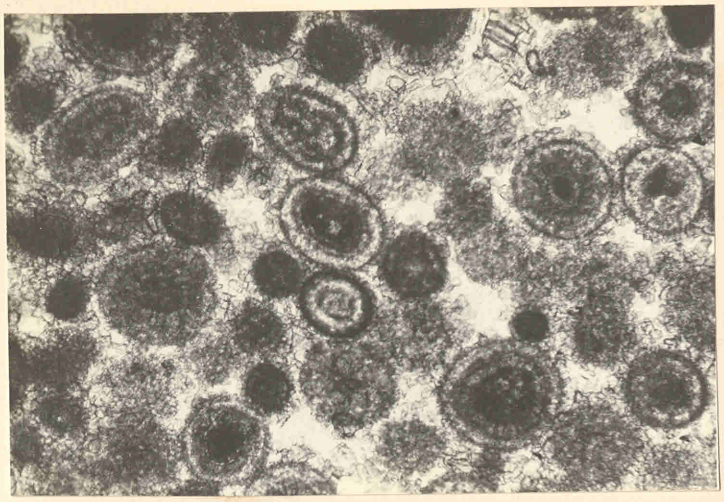


FIG. 1

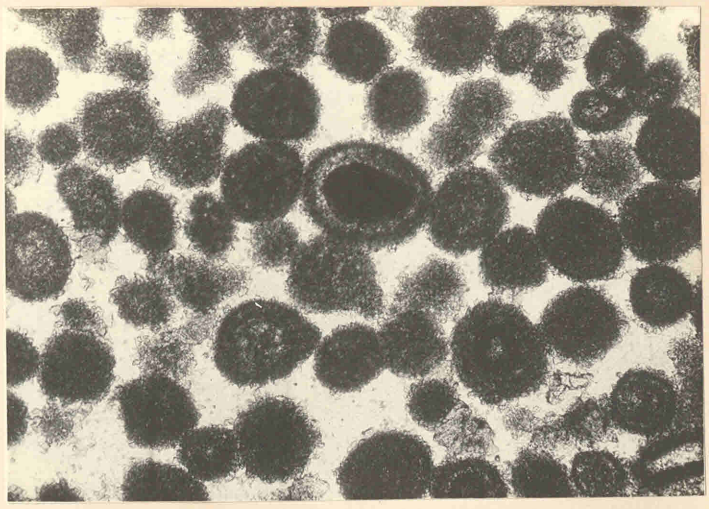


FIG. 2

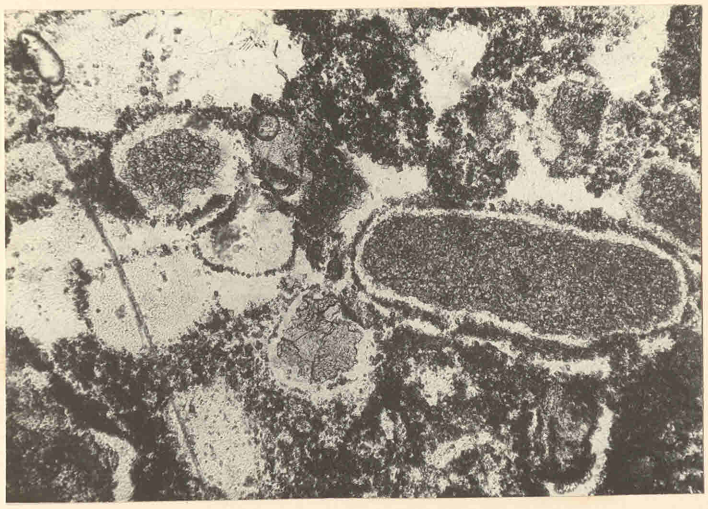


FIG. 3

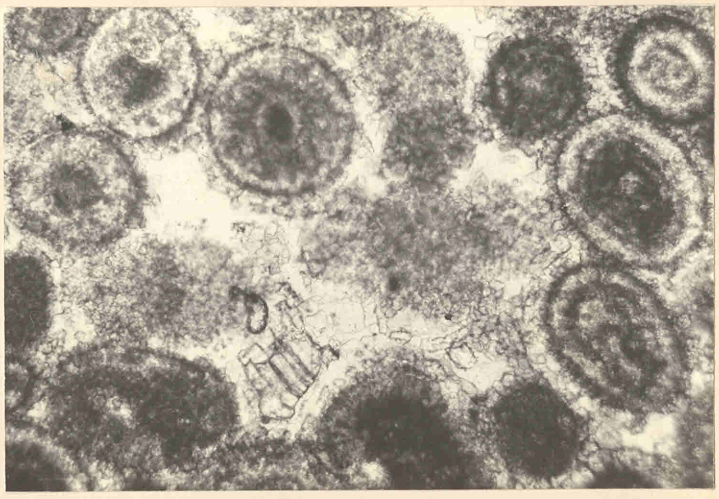


FIG. 4

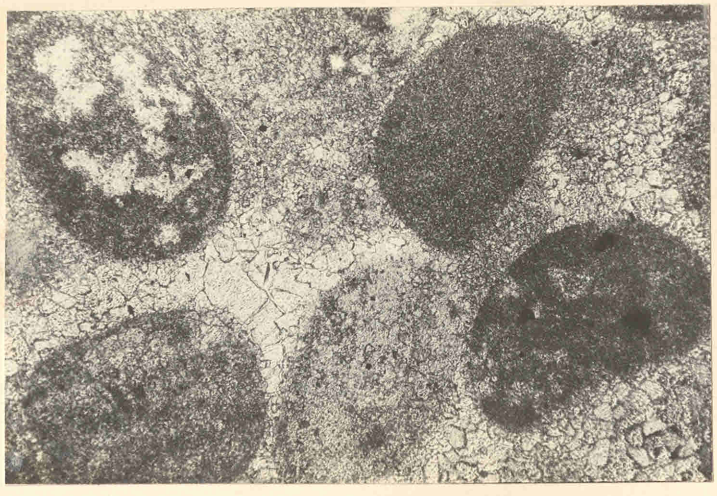


FIG. 5

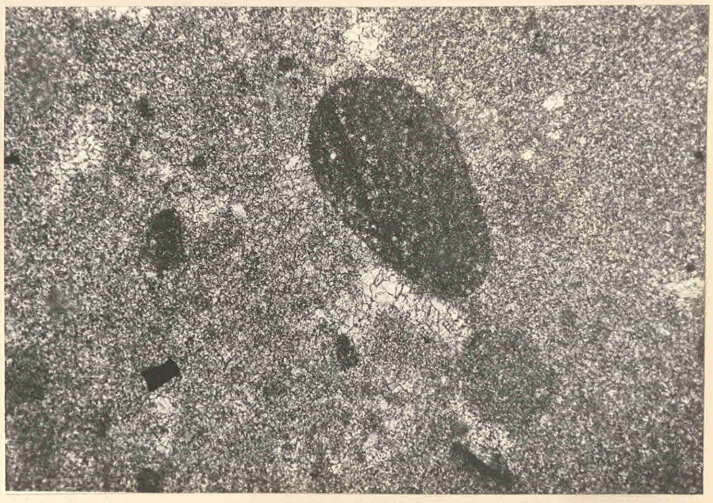


FIG. 6

Explanation of plate No. 17

Fig. 1. Photomicrograph of an oolitic dolostone. The oolites are spherical or sub-spherical. The number of rings vary from 2 to 4 and their nuclei is not seen.

Locality - Waishno Devi. Crossed NicolsX45.

Fig. 2. Photomicrograph of an oolitic dolostone with majority of the oolites spherical in shape. The rims and nuclei are not clearly seen. The intervening space between the oolites has been filled up with dolomitic cement.

Locality - Katra. Crossed NicolsX45.

Fig. 3. Photomicrograph of an oolitic dolostone. In this majority of the ooids are oval or elongated with a maximum size of 1 mm.

Locality - Katra. Crossed NicolsX45.

Fig. 4. Photomicrograph of an oolitic dolostone. The oolites are similar to those seen in fig. 1 with the difference that

(a) the size is much greater
(b) Nucleus is visible
(c) Ghost oolites are also visible which have been replaced due to dolomitisation but their outlines are still visible.

Locality - Katra. Crossed NicolsX45.

Figs. 5 & 6. Photomicrographs of dolostones showing oval shaped pellets (0.4 mm to 0.6 mm size) cemented by dolomitic limestone. In these neither the nuclei nor the rings are visible.

Locality - Dhiangarh. Crossed NicolsX45.

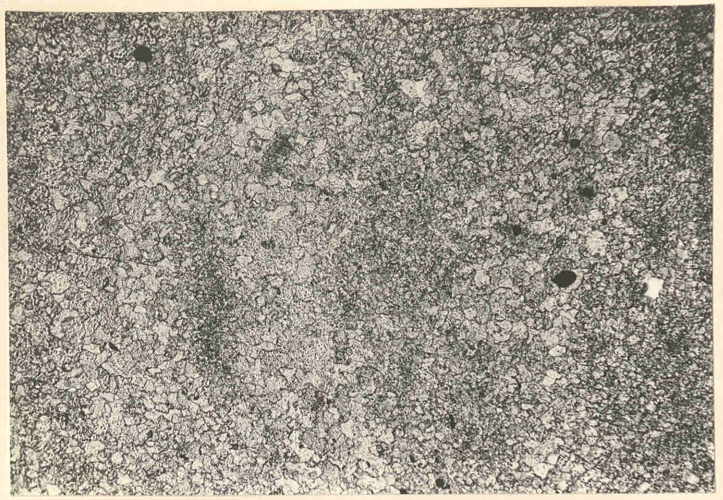


FIG. 1

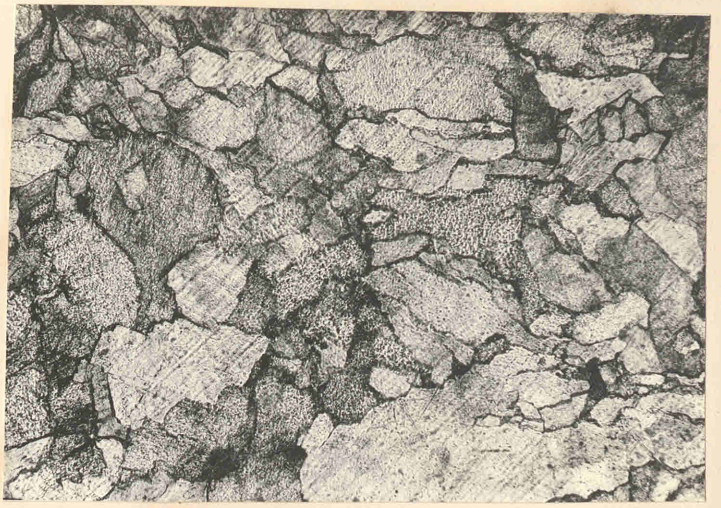


FIG. 2

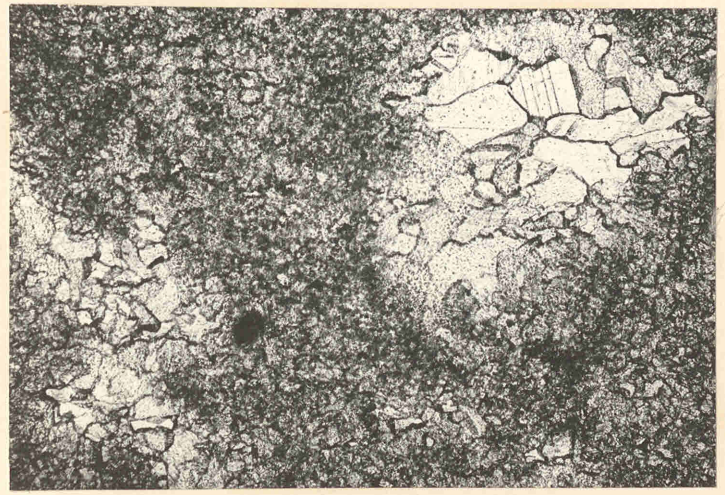


FIG. 3

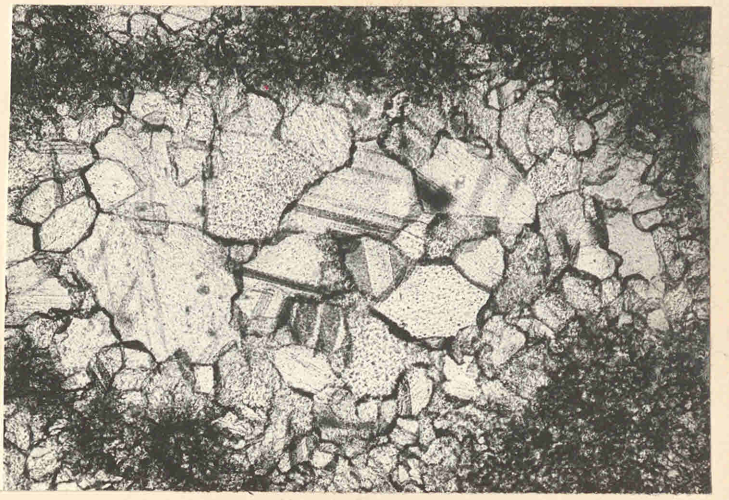


FIG. 4

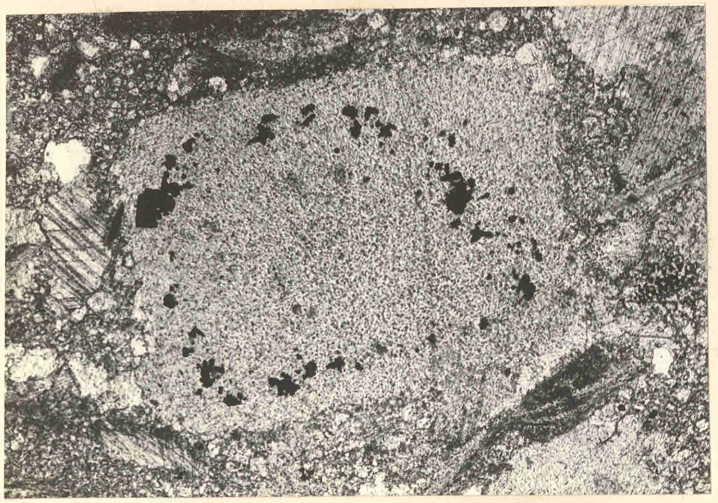


FIG. 5

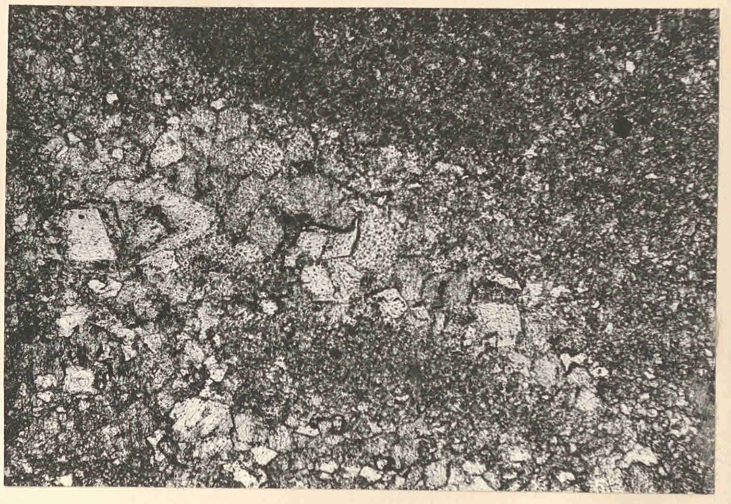


FIG. 6

Explanation of plate No. -18

Fig. 1. Photomicrograph of Chert Breccia exhibiting an inequigranular mosaic of quartz grains varying in size from 0.36 mm to 0.65 mm.

Locality - Talwara. Crossed NicolsX45.

Figs. 2 to 4. Photomicrographs exhibiting grumous structure. Due to pervasic recrystallisation there are patches of coarsely crystalline carbonates in an otherwise fine grained cement.

Locality - Dhiangarh Dam Site. Crossed NicolsX45.

Fig. 5. Photomicrograph of a dolostone with a rectangular crystal in the centre replaced by a cherty matter. The symmetrical carbonaceous inclusions are almost parallel to the peripheral margins of the crystal. It is enclosed in a mixed matrix of cherty and dolomitic nature.

Locality - LAIN C.N. X45

Fig. 6. Photomicrograph of highly Cherty dolostone exhibiting an inequigranular mosaic of chert, calcite and dolomite. The grains of dolomite are of the size of 0.1 mm while the chert grains are of the size of 10 to 50 microns.

Locality- Dhiangarh Dam Site. Crossed NicolsX45.

Explanation of plate No. 19

Fig. 1. Fieldphotograph of Trikuta Limestone exposed at Mari showing pattern of Jointing.

Fig. 3. Fieldphotograph of Trikuta Limestone exposed at Katra showing nature of bedding.

Fig. 4. Fieldphotograph of Trikuta Limestone exposed in the eastern part of the Jammu Coal Belt exhibiting the pattern of folding within the limestones.

Fig. 5. Fieldphotograph of desiccation cracks in the Trikuta Limestone exposed near Katra.

Fig. 6. Fieldphotograph showing bands of chert within the limestone exposed near the village Garan (Riasi).

FIG. 1

FIG. 2

FIG 3

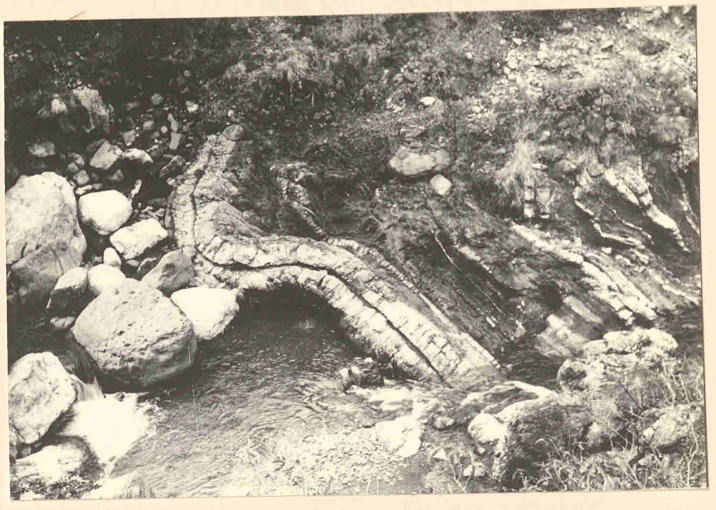


FIG 4

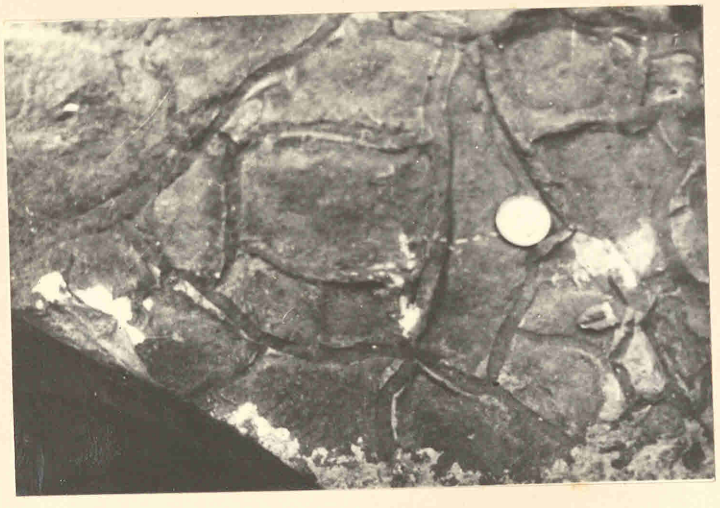


FIG. 5

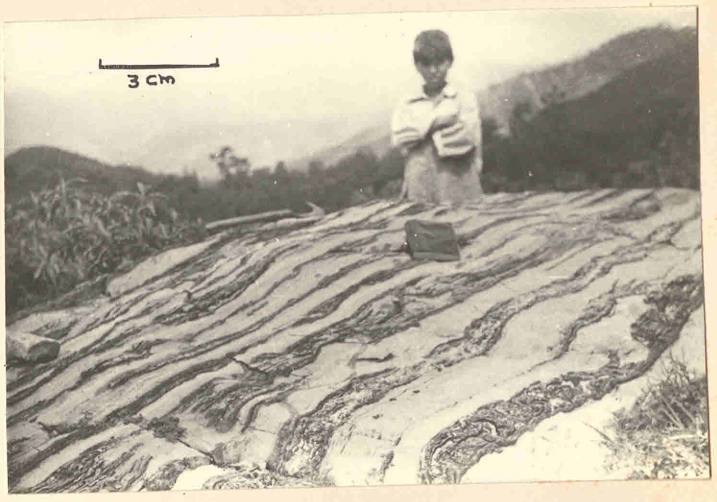


FIG 6

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG 5

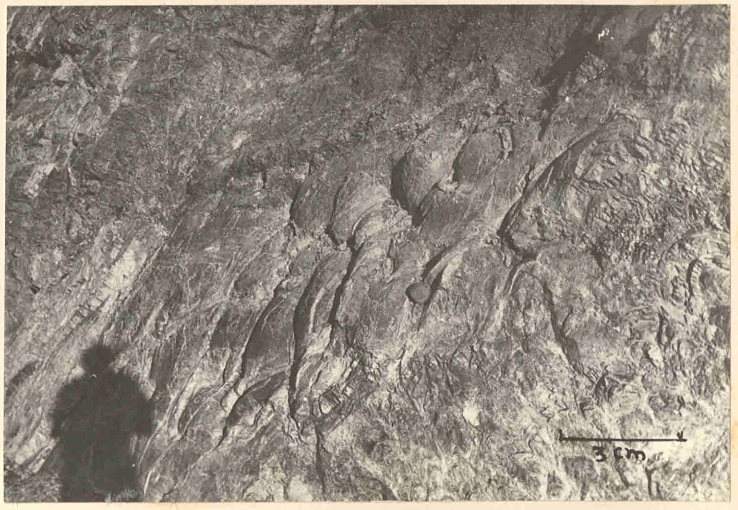


FIG 6

Explanation of plate No. 20

Fig. 1. Fieldphotograph showing columnar stromalolites near Bidda Back Slope on the Riasi-Salal Road.

Fig. 2. Fieldphotograph showing spheroidal stromatolites near Bidda Back Slope on the Riasi-Salal Road.

Fig. 3. Fieldphotograph showing non-columnar stromatolites near Do-Khadda-Muttal (Jangal Gali) area.

Fig. 4. Fieldphotograph showing non-columnar stromatolites near Do-Khadda-Muttal (Jangal Gali) area.

Fig. 5. Fieldphotograph showing discrete forms of stromatolites near 13th Km on the Riasi-Salal Road.

Fig. 6. Fieldphotograph showing inverted bowel shaped stromatolites near Bidda Back Slope on the Riasi-Salal Road.

PLATE NO. 21

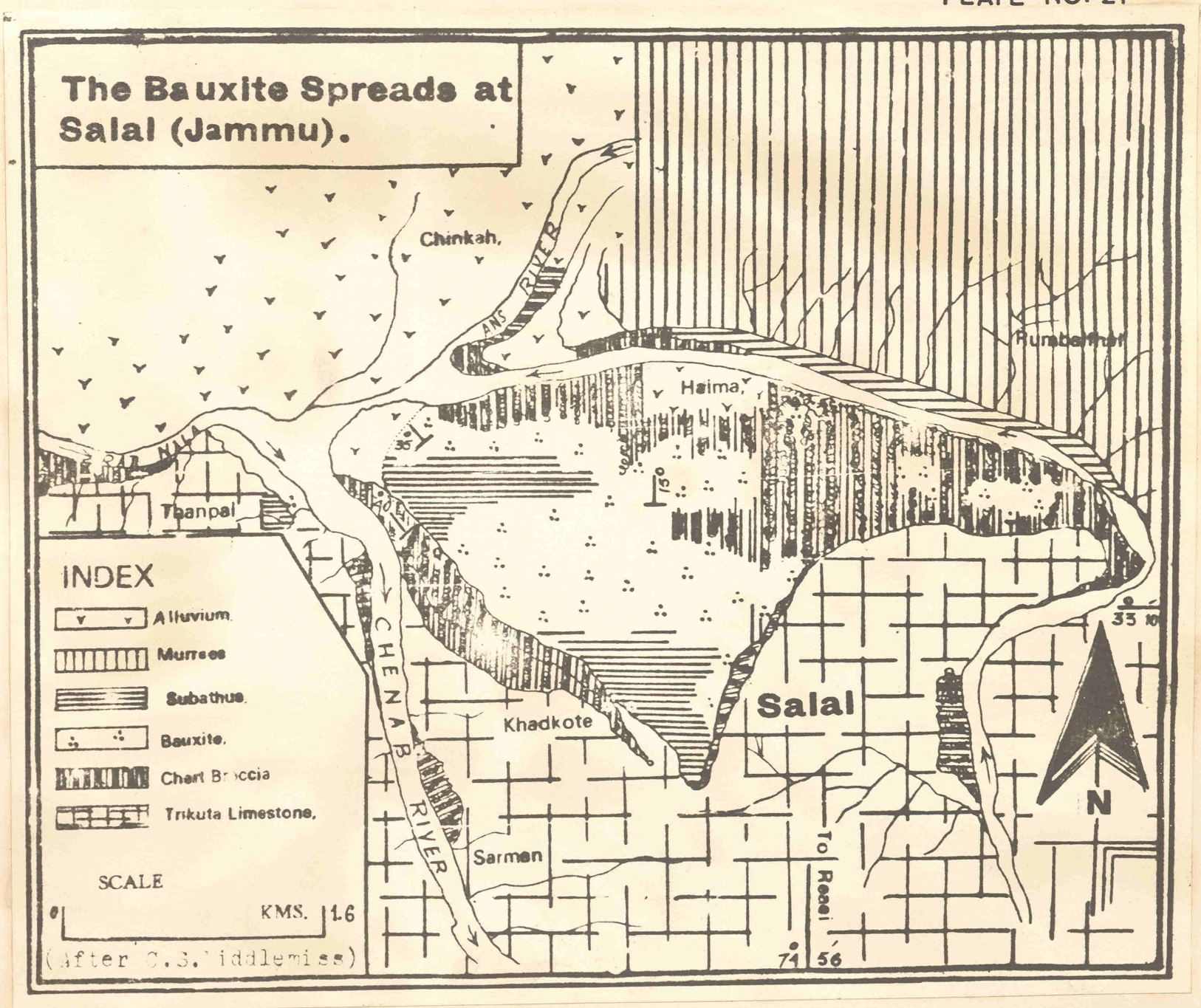
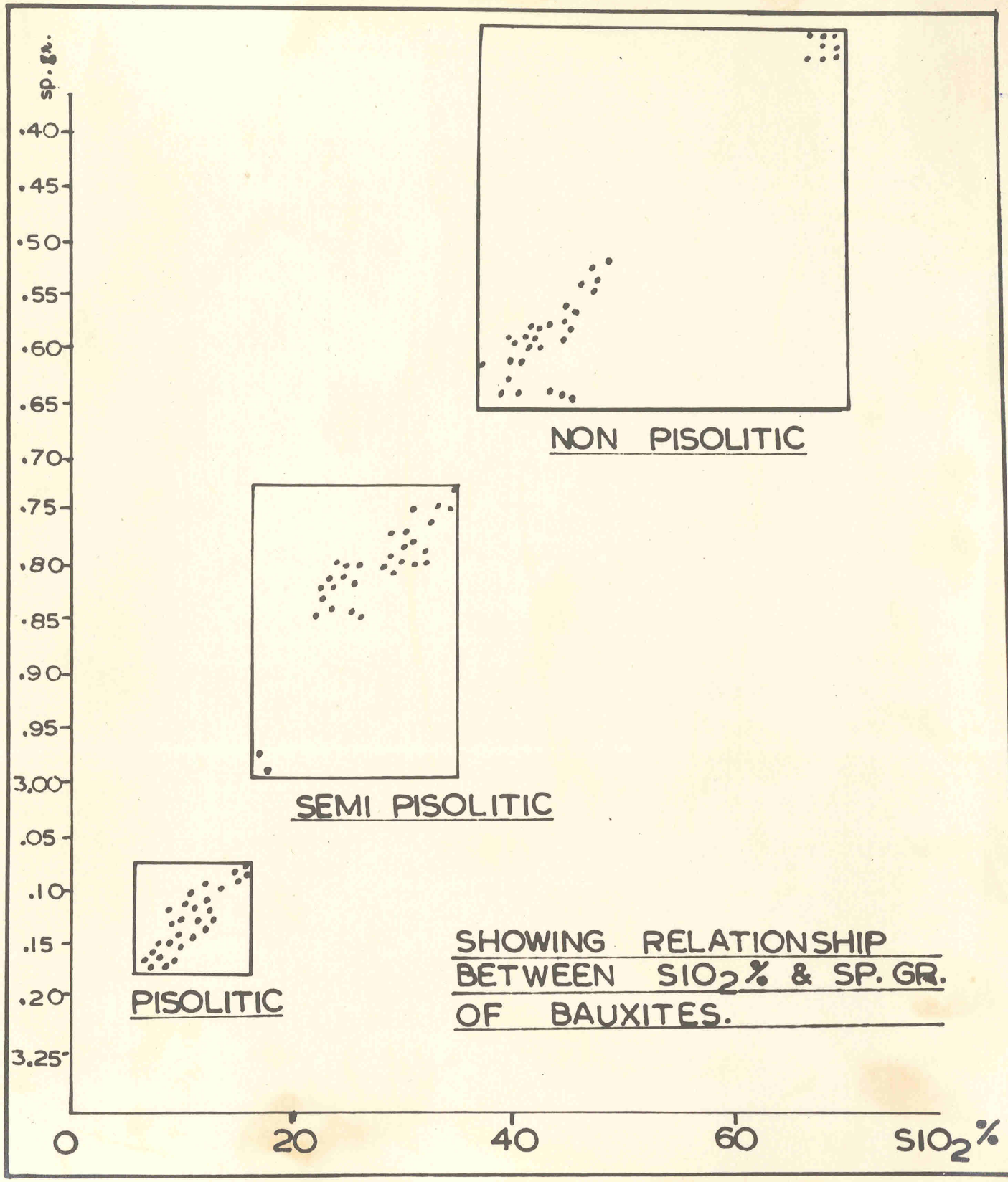

The Bauxite Spreads at Salal (Jammu).
Chinkah,
ANS RIVER
Haima,
Rumbalthal
Thanpal
CHENAB RIVER
Khadkote
Salal
Sarman
To Reasi
N
INDEX
Alluvium.
Murrees
Subathus.
Bauxite.
Chert Breccia
Trikuta Limestone.
SCALE
0
KMS.
1.6
(After C.S. Middlemiss)

PLATE NO. 22



SHOWING RELATIONSHIP BETWEEN SiO_2% & SP. GR. OF BAUXITES.

PLATE NO. 23

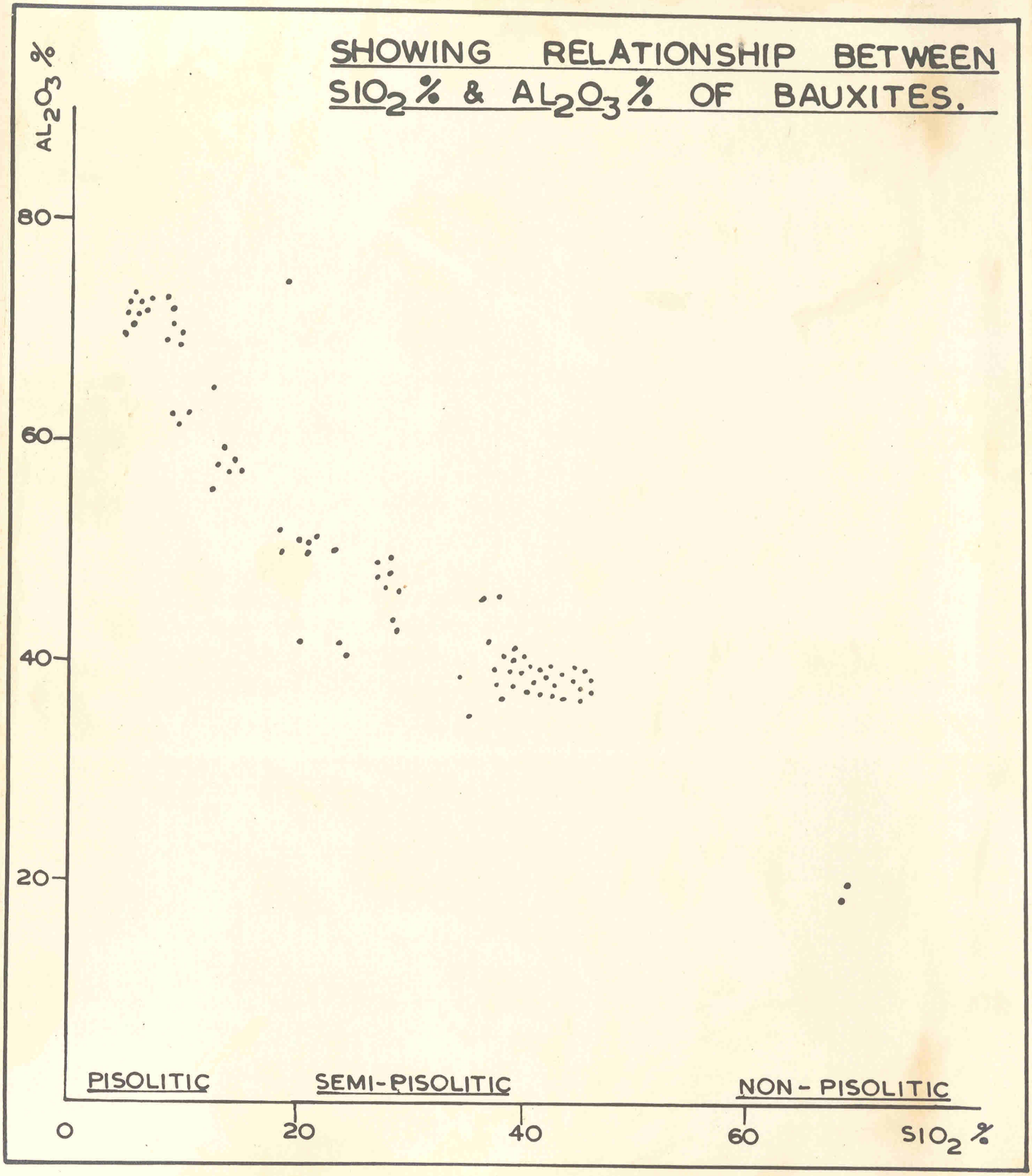
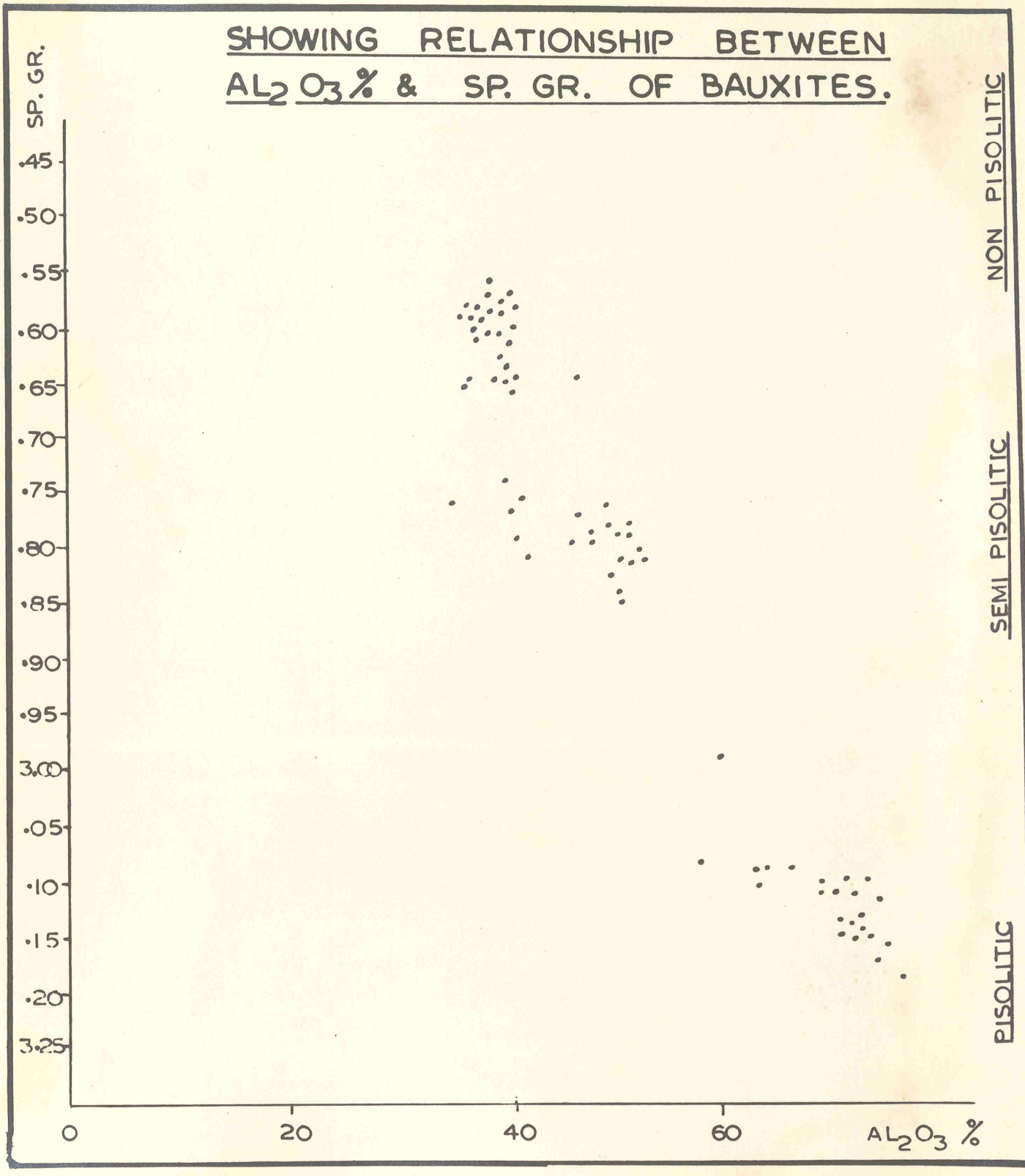
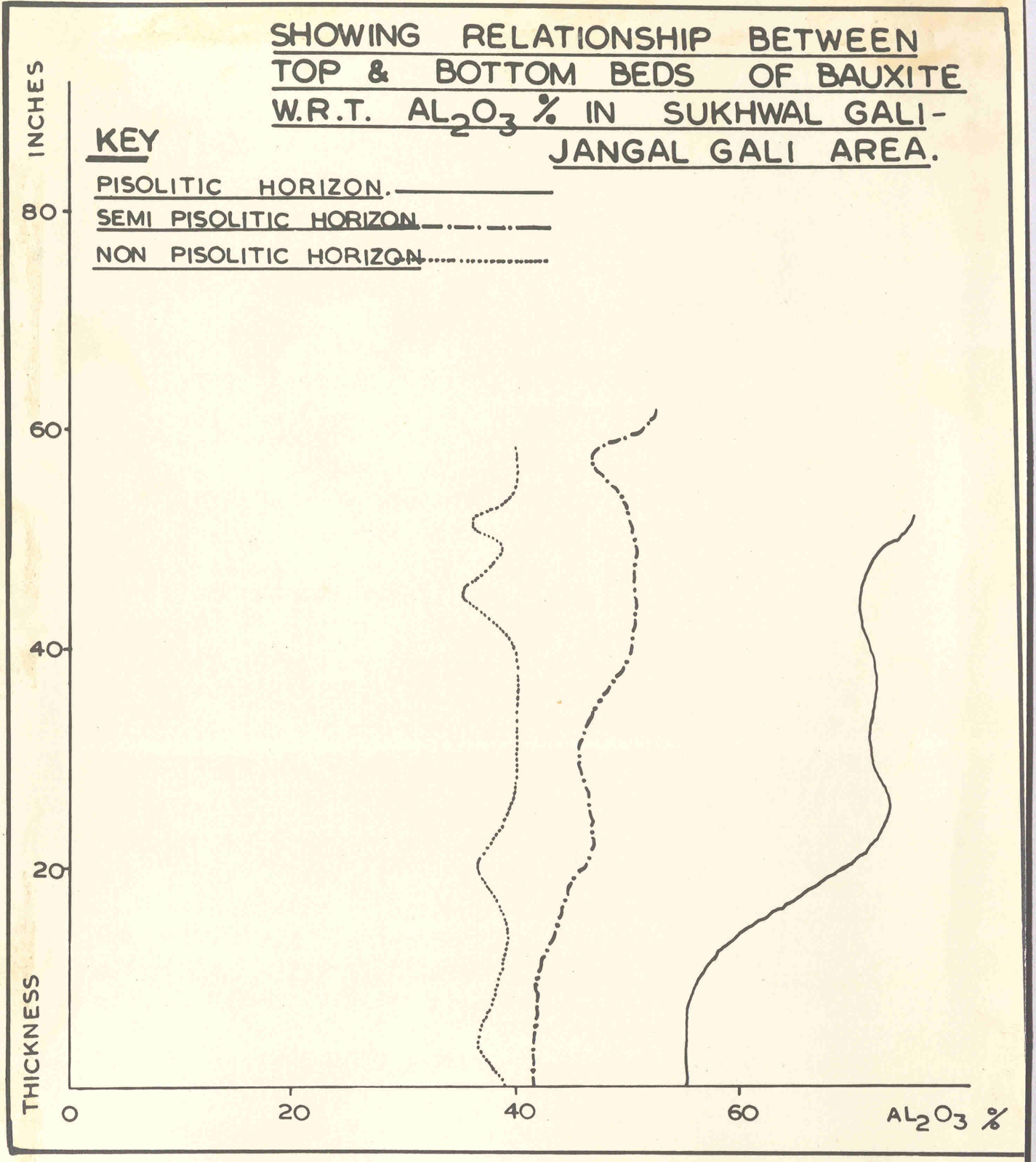

SHOWING RELATIONSHIP BETWEEN SiO2 % & Al2O3 % OF BAUXITES.
Al2O3 %
80
60
40
20
PISOLITIC
SEMI-PISOLITIC
NON-PISOLITIC
0
20
40
60
SiO2 %

PLATE NO. 24

SHOWING RELATIONSHIP BETWEEN AL_2O_3 % & SP. GR. OF BAUXITES.



SHOWING RELATIONSHIP BETWEEN TOP & BOTTOM BEDS OF BAUXITE W.R.T. AL_2O_3 % IN SUKHWAL GALI-JANGAL GALI AREA.



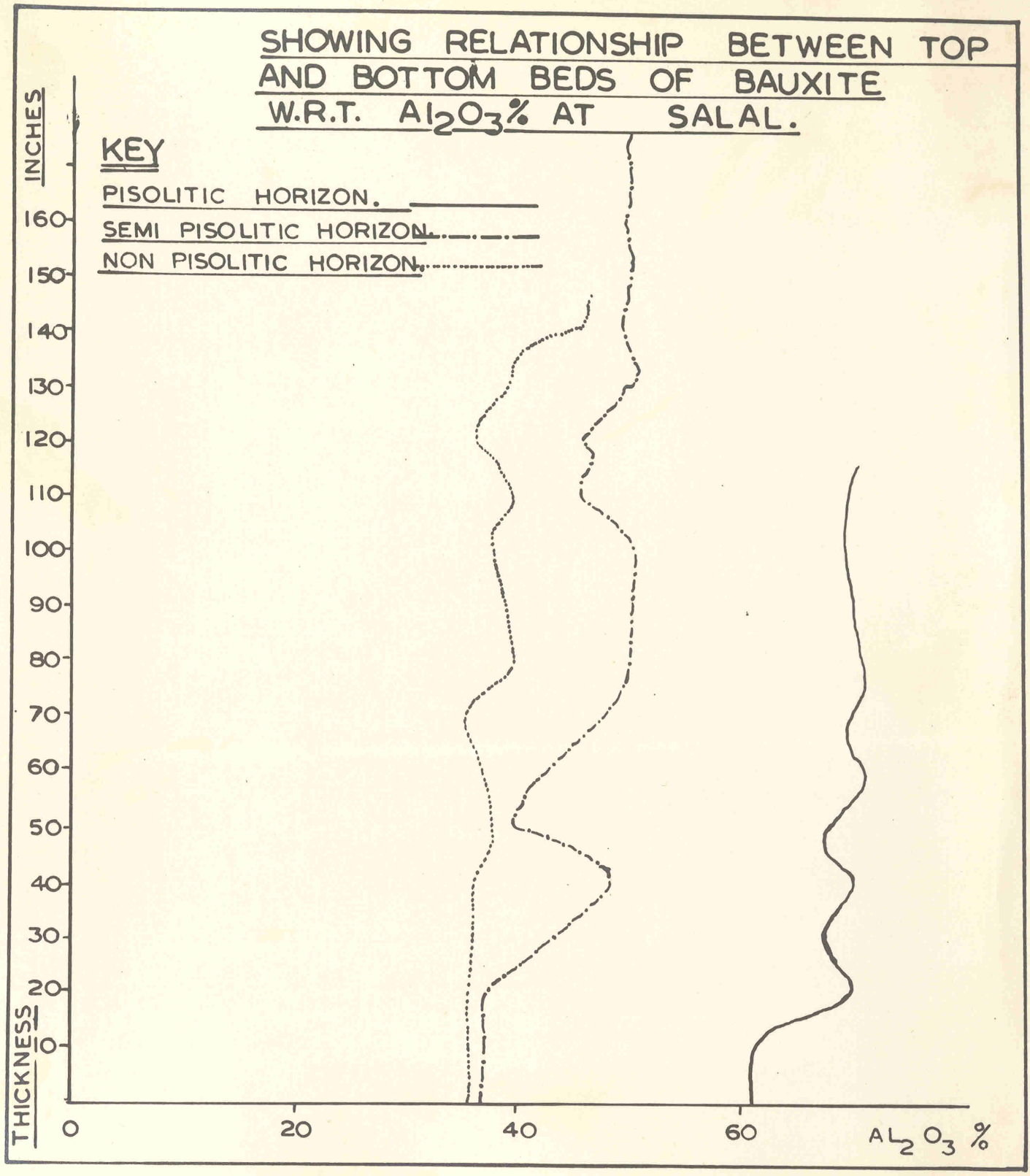

SHOWING RELATIONSHIP BETWEEN TOP AND BOTTOM BEDS OF BAUXITE W.R.T. Al_2O_3% AT SALAL.
KEY
PISOLITIC HORIZON.
SEMI PISOLITIC HORIZON.
NON PISOLITIC HORIZON.
INCHES
THICKNESS
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
20
40
60
AL_2O_3 %

PLATE NO. 27

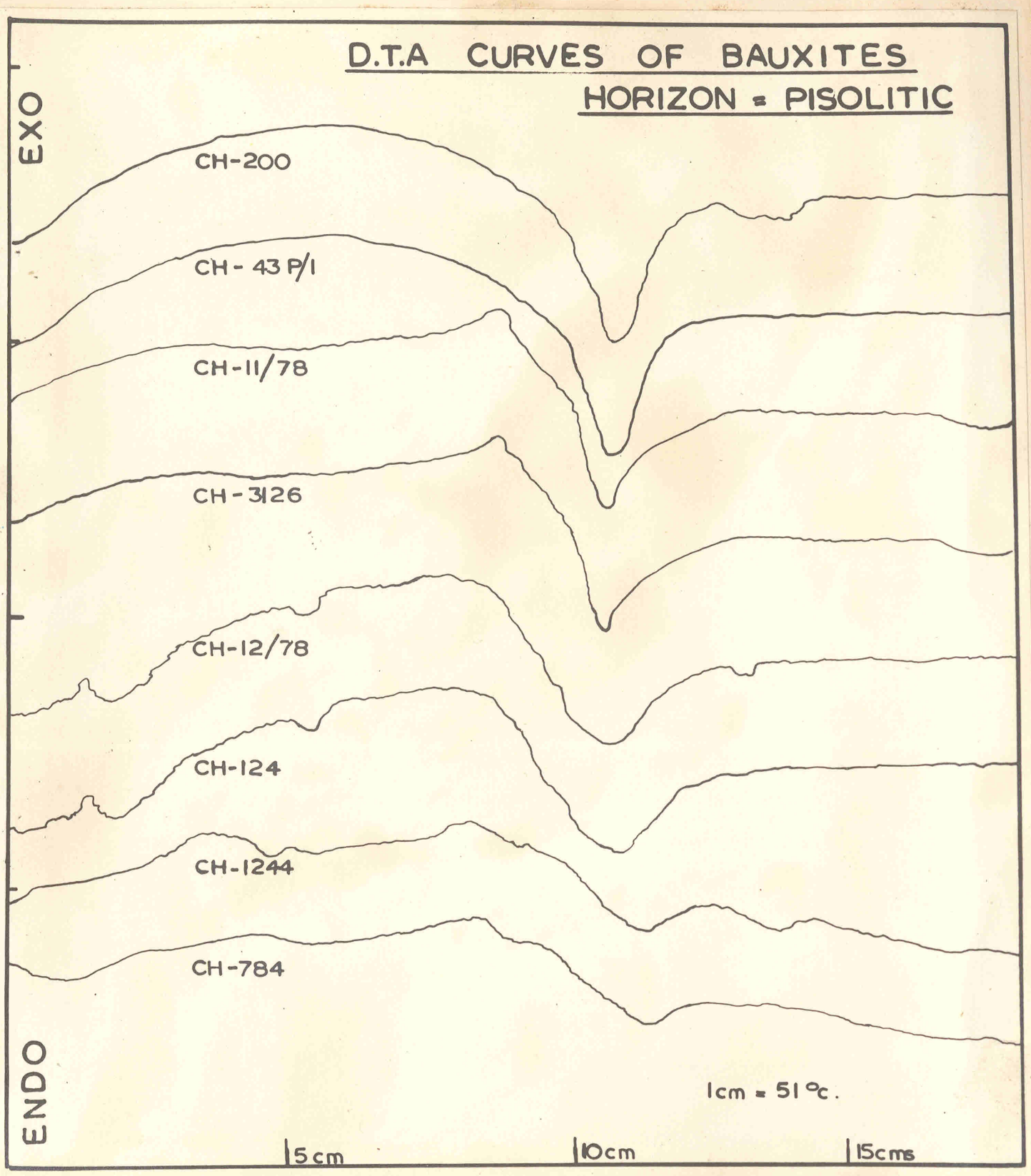

D.T.A CURVES OF BAUXITES
HORIZON = PISOLITIC
EXO
CH-200
CH-43 P/1
CH-11/78
CH-3126
CH-12/78
CH-124
CH-1244
CH-784
ENDO
1cm = 51°c.
5cm
10cm
15cms

PLATE NO. 28

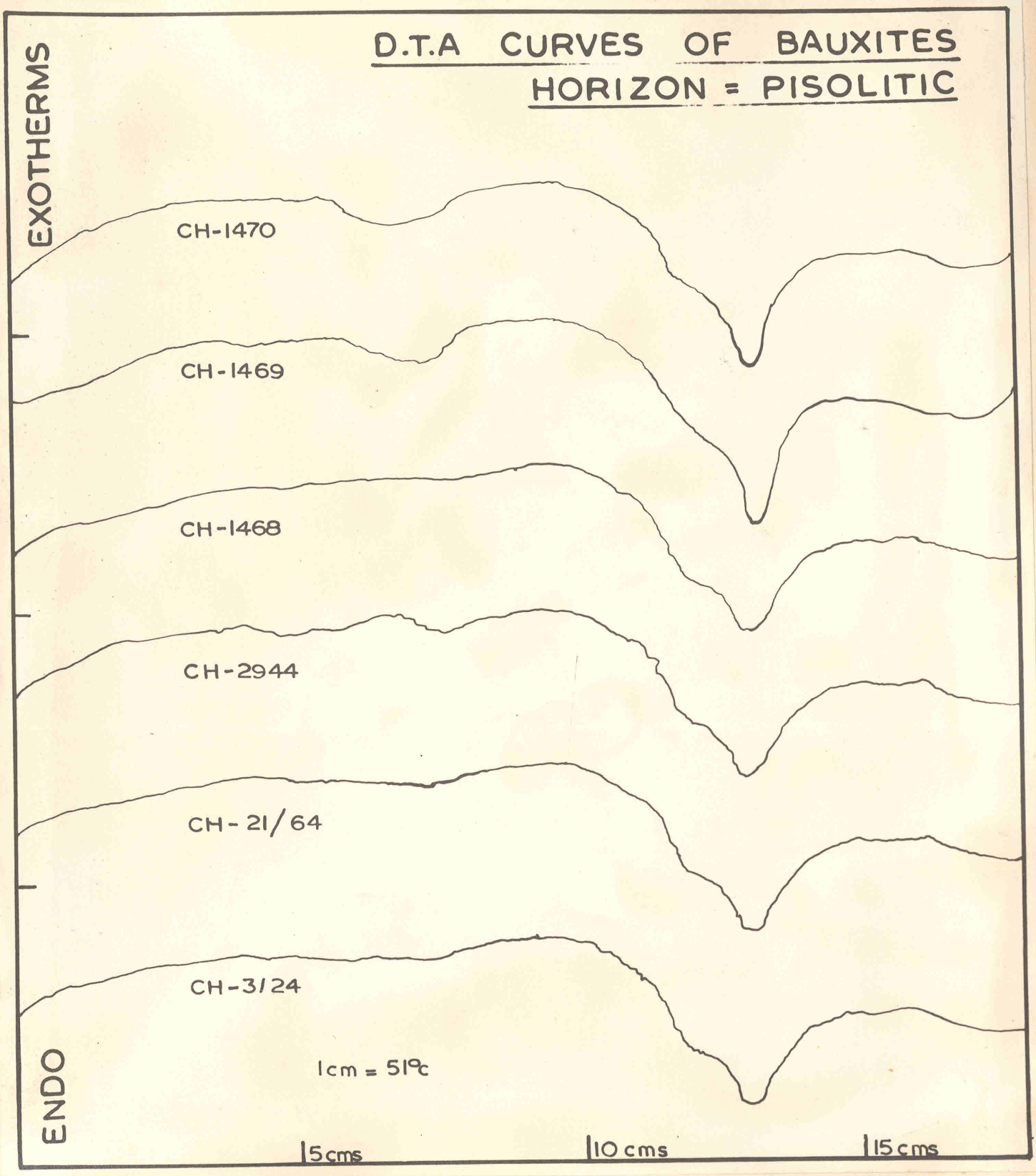

D.T.A CURVES OF BAUXITES
HORIZON = PISOLITIC
EXOTHERMS
CH-1470
CH-1469
CH-1468
CH-2944
CH-21/64
CH-3124
ENDO
1cm = 51°c
5cms
10 cms
15 cms

PLATE NO. 29

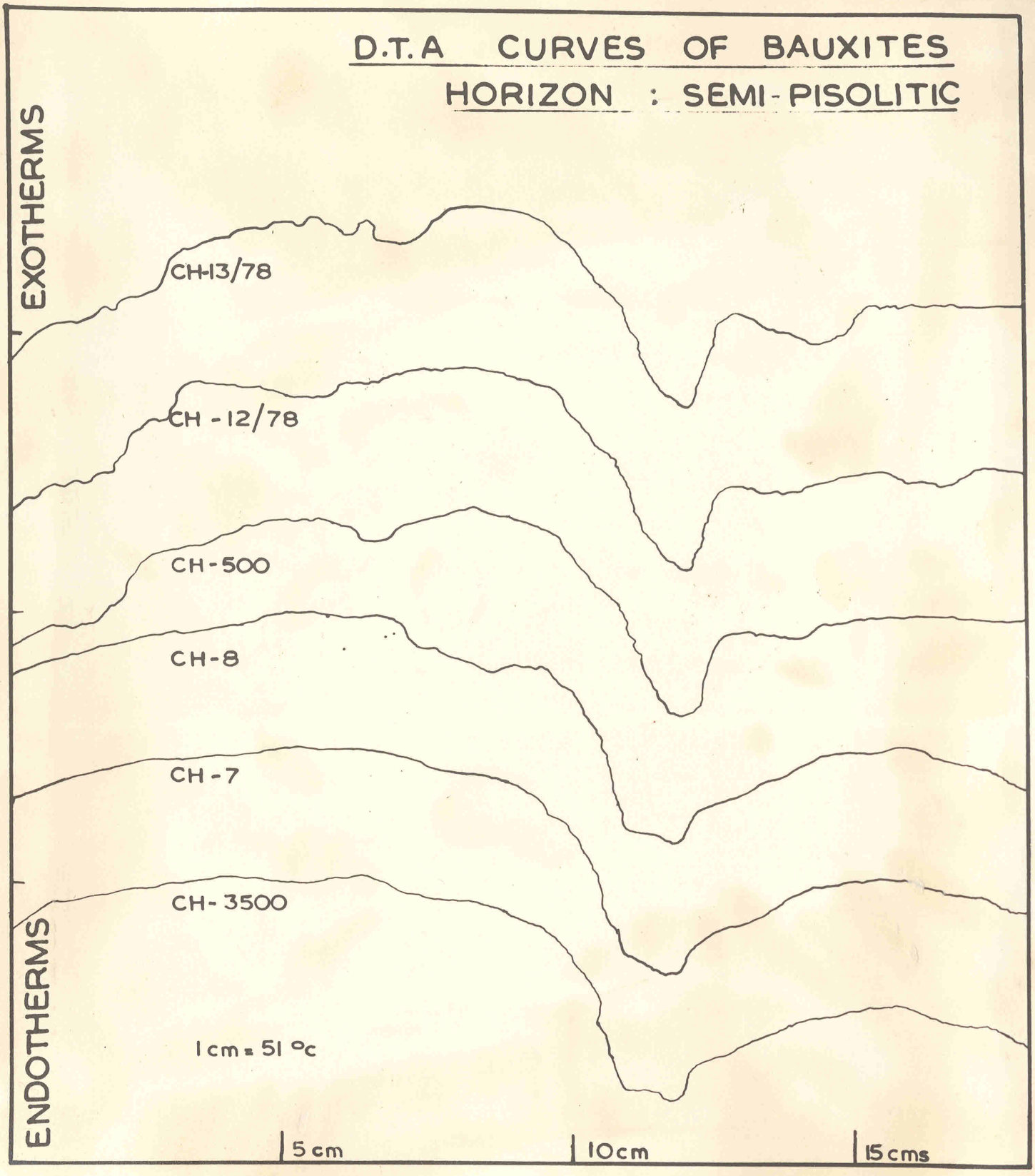
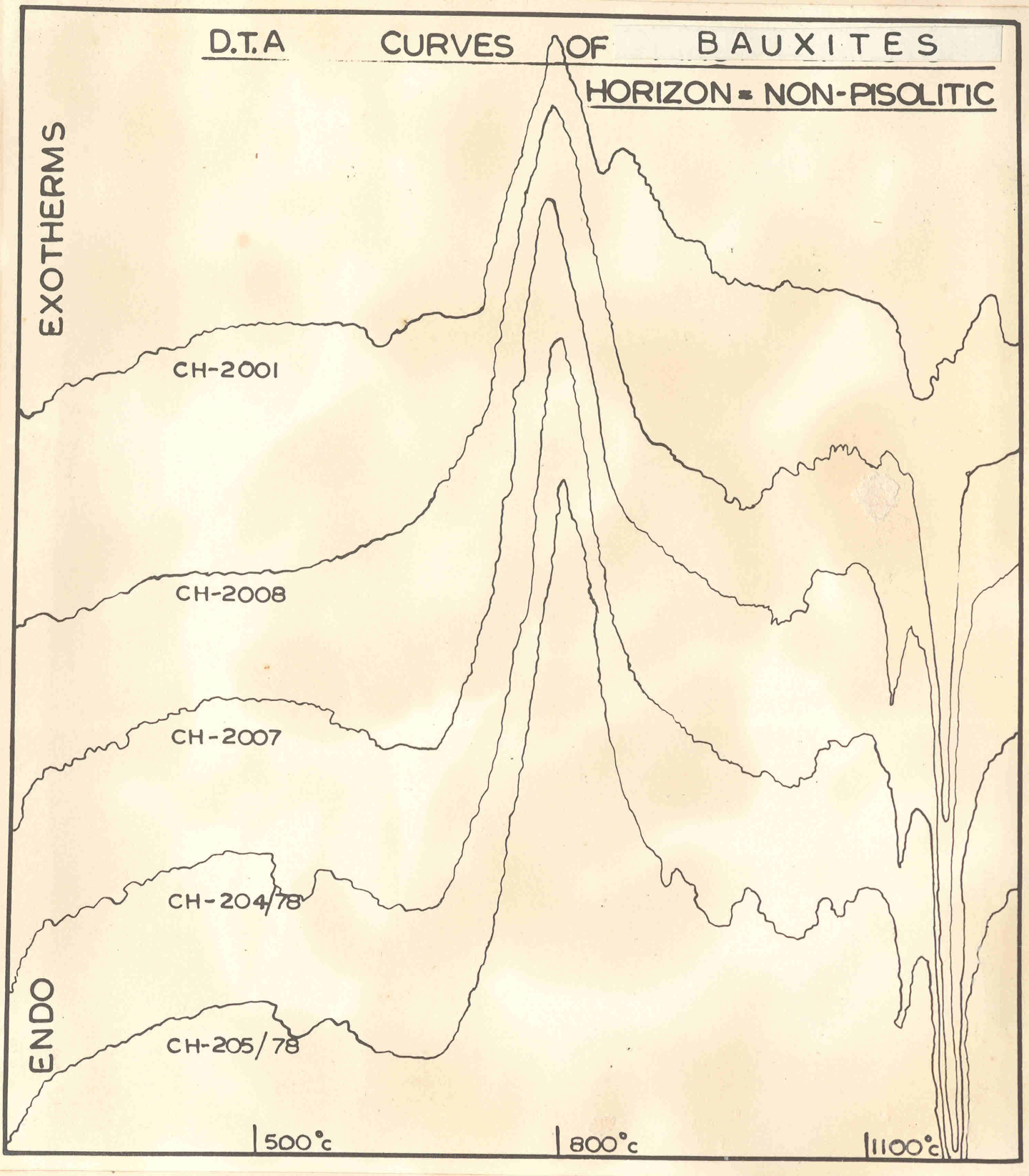

D.T.A CURVES OF BAUXITES
HORIZON : SEMI-PISOLITIC
EXOTHERMS
CH-13/78
CH-12/78
CH-500
CH-8
CH-7
CH-3500
ENDOTHERMS
1 cm = 51 °c
5 cm
10 cm
15 cms

PLATE NO. 30


D.T.A CURVES OF BAUXITES
HORIZON = NON-PISOLITIC
EXOTHERMS
CH-2001
CH-2008
CH-2007
CH-204/78
CH-205/78
ENDO
500°c
800°c
1100°c

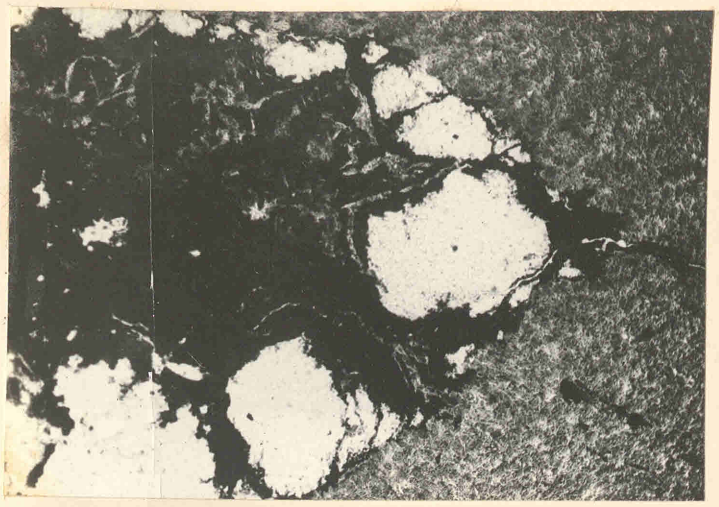


FIG. 1

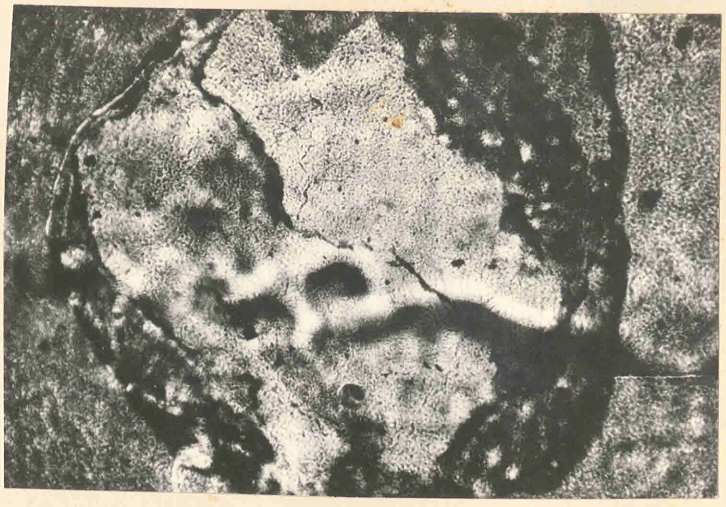


FIG. 2

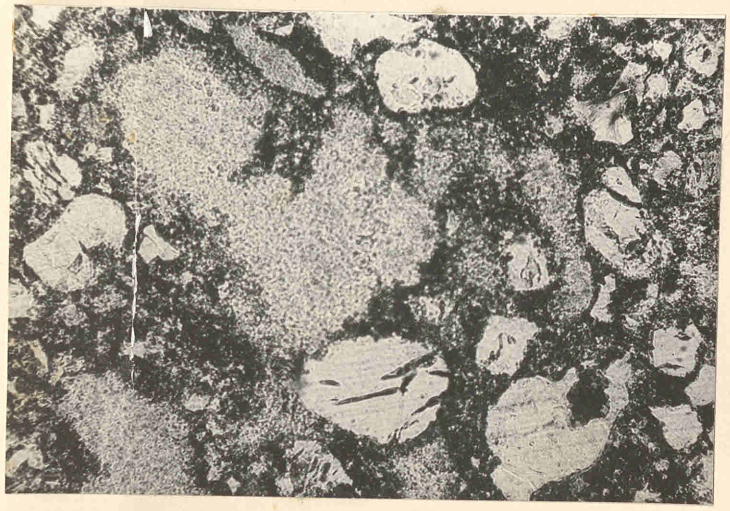


FIG. 3

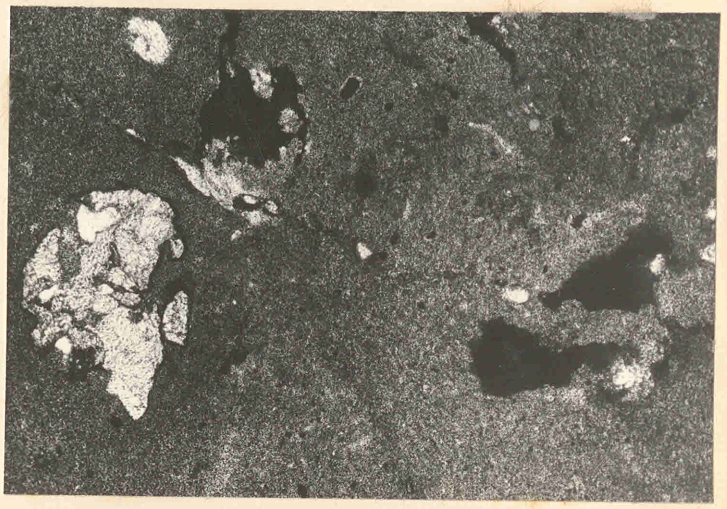


FIG. 4

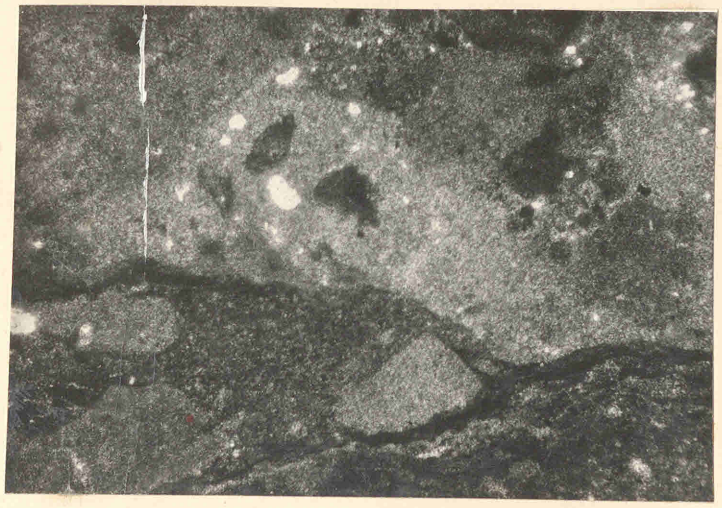


FIG. 5

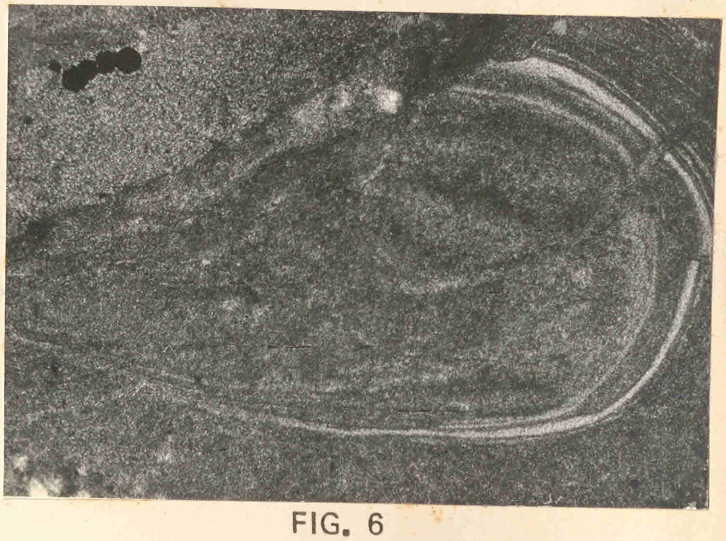


FIG. 6

Explanation of plate No. 32

Fig. 1. Photomicrograph of pisolitic bauxite showing sub-spherical dark coloured pisolites embedded in an argillaceous cement. Majority of the pisolites are of the size of 1 mm.

Locality- Jangal Gali Crossed NicolsX45.

Fig. 2. Photomicrograph of non-pisolitic bauxite showing the presence of an uncrystallised alumina hydroxide, limonite and clayey matter.

Locality - Jangal Gali Crossed NicolsX45.

Fig. 3. Photomicrograph of pisolitic bauxite showing the spherical or sub-spherical pisolites of varying size scattered in a fine grained cement.

Locality - Salal. Crossed NicolsX45.

Fig. 4. Photomicrograph of semi-pisolitic bauxite showing very less developed sub-rounded pisolites of varying dimensions within a cement.

Locality - Jangal Gali. Crossed NicolsX45.

Fig. 5&6. Photomicrographs of non-pisolitic bauxites exhibiting the presence of clayey and aluminous matter with fissures filled upwith limonite. Fig. 6 shows colloidal bands of silica within the argillaceous matter.

Locality - Lain. Crossed NicolsX45.

SHOWING RELATIONSHIP BETWEEN SP. GR. & ASH CONTENT OF COAL SUKHWAL GALI, JANGAL GALI COAL-FIELDS.

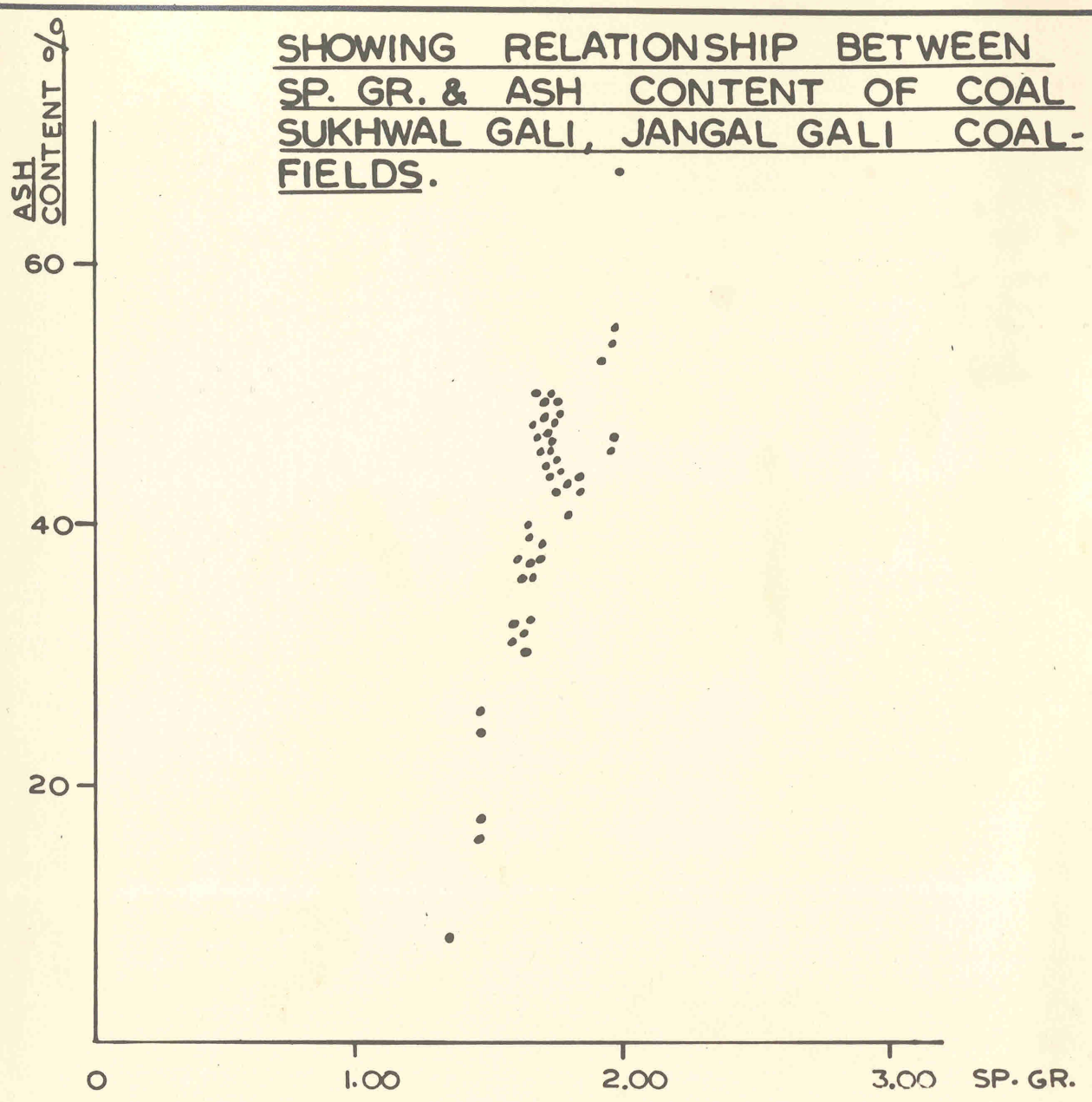
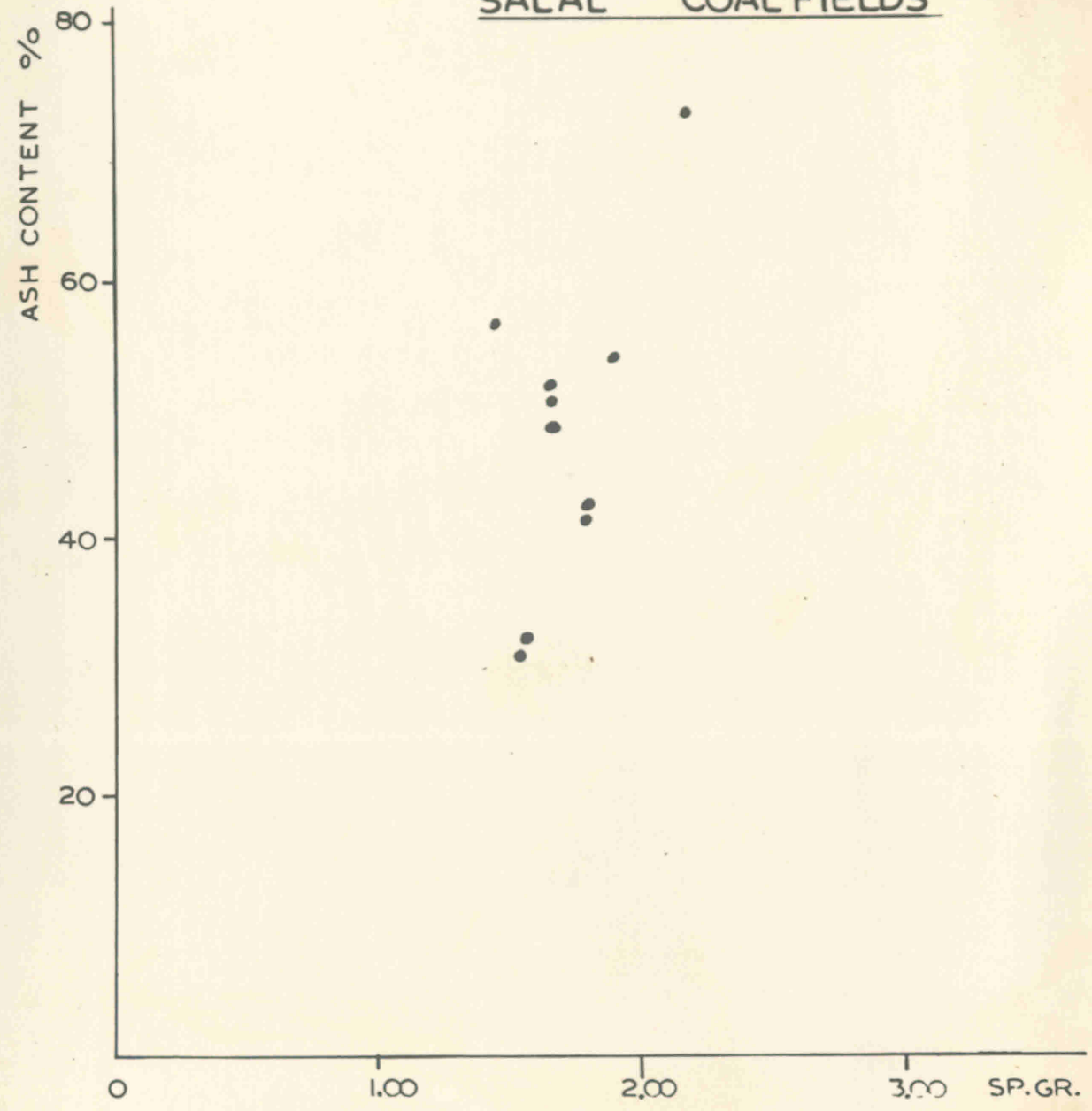


PLATE NO. 34

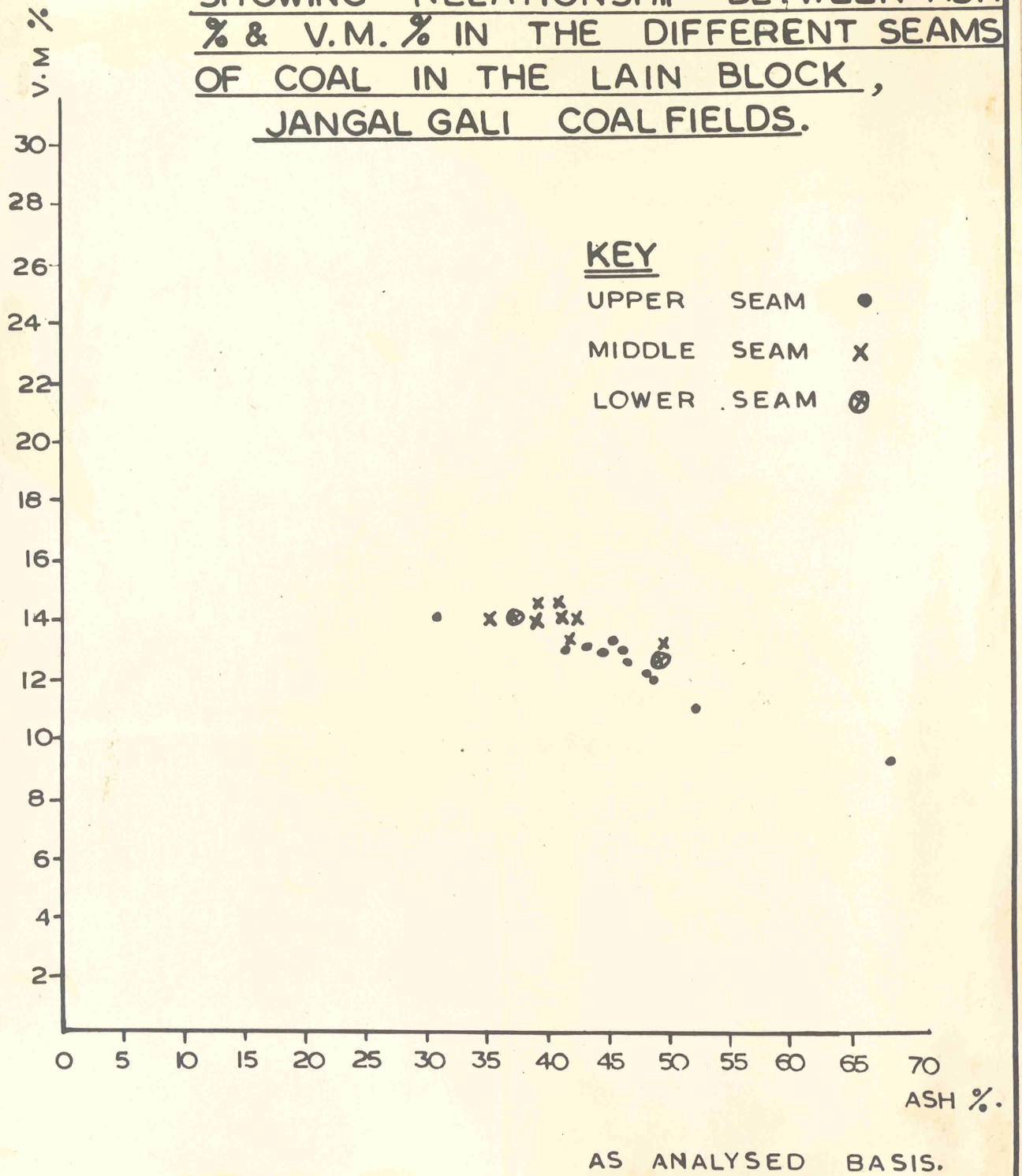
SHOWING RELATIONSHIP BETWEEN SP. GR. & ASH CONTENT OF COAL SALAL COAL FIELDS



AS ANALYSED BASIS

PLATE NO. 35

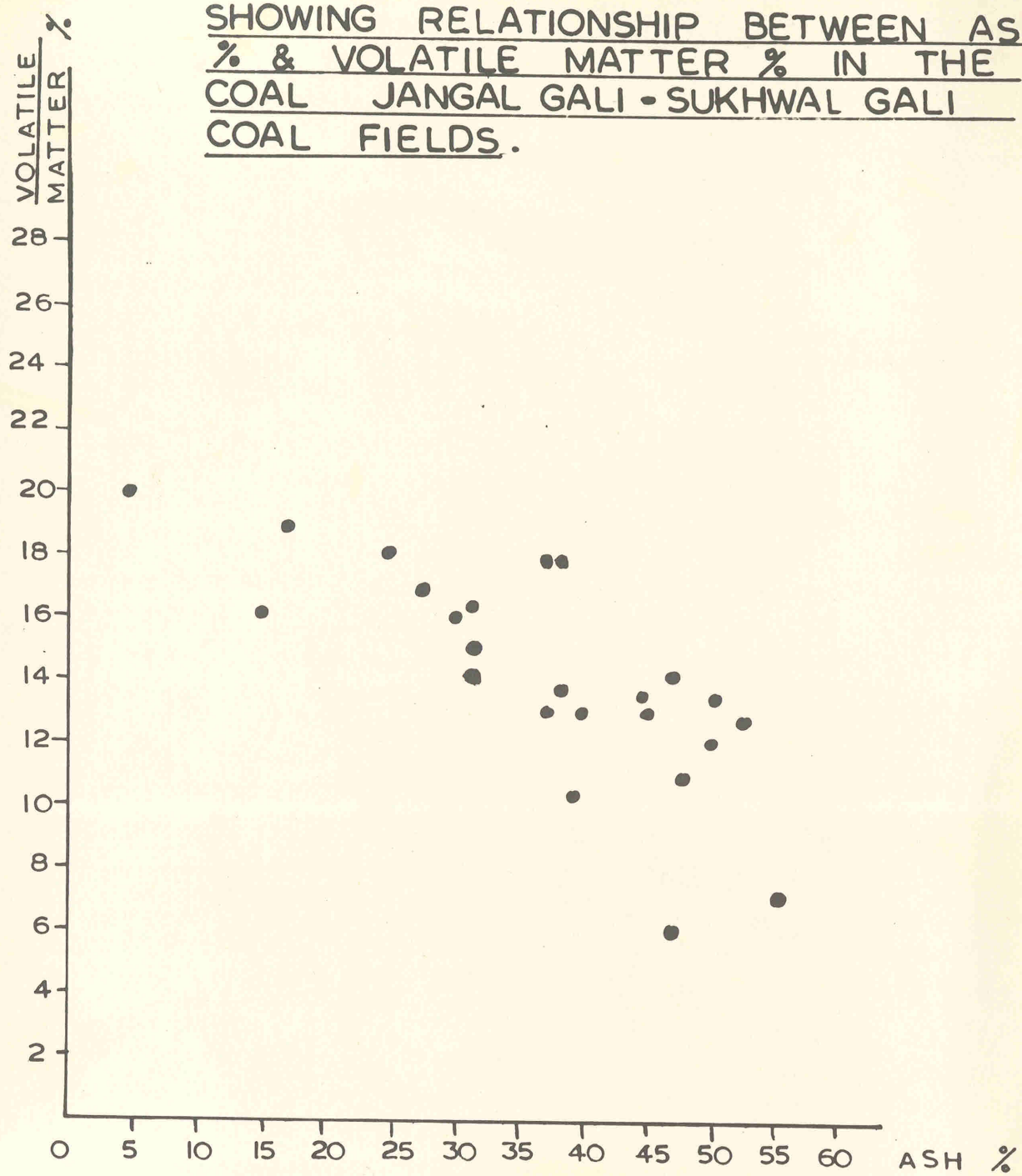
SHOWING RELATIONSHIP BETWEEN ASH % & V.M. % IN THE DIFFERENT SEAMS OF COAL IN THE LAIN BLOCK, JANGAL GALI COAL FIELDS.



AS ANALYSED BASIS.

PLATE NO. 36

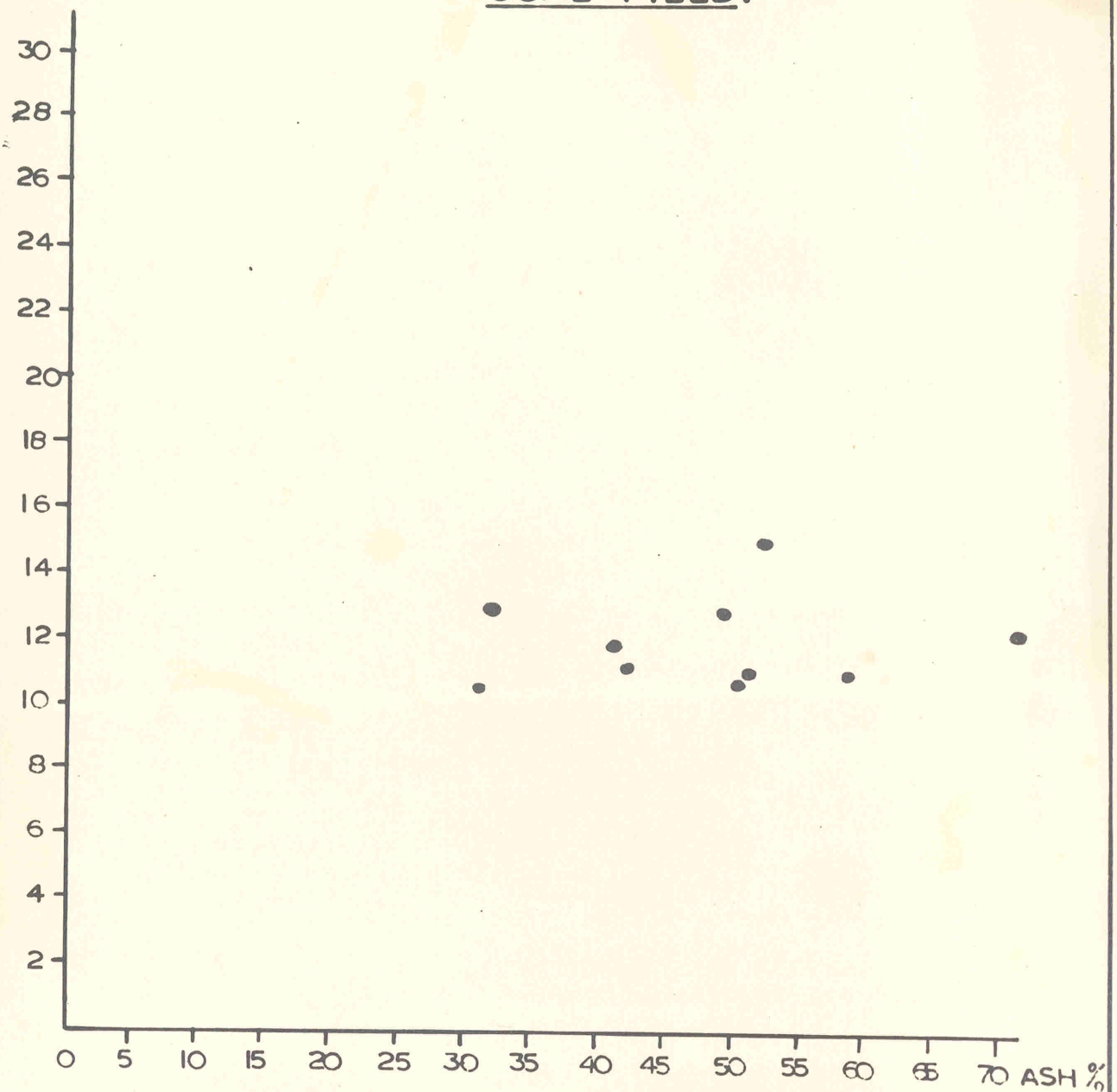
SHOWING RELATIONSHIP BETWEEN ASH % & VOLATILE MATTER % IN THE COAL JANGAL GALI - SUKHWAL GALI COAL FIELDS.



AS ANALYSED BASIS

PLATE NO. 37

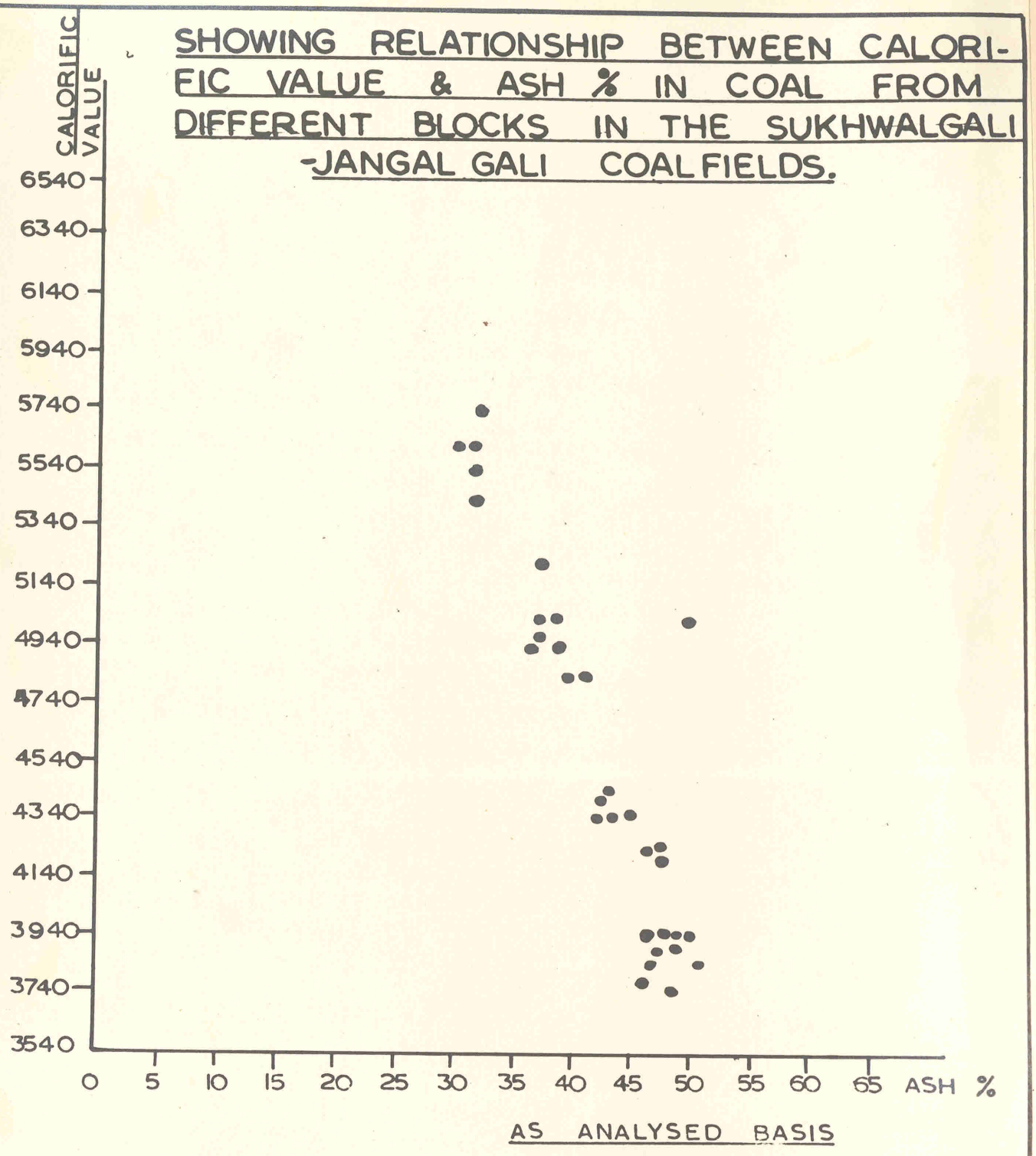
SHOWING RELATIONSHIP BETWEEN ASH % & V.M. % IN COAL - SALAL COAL FIELD.



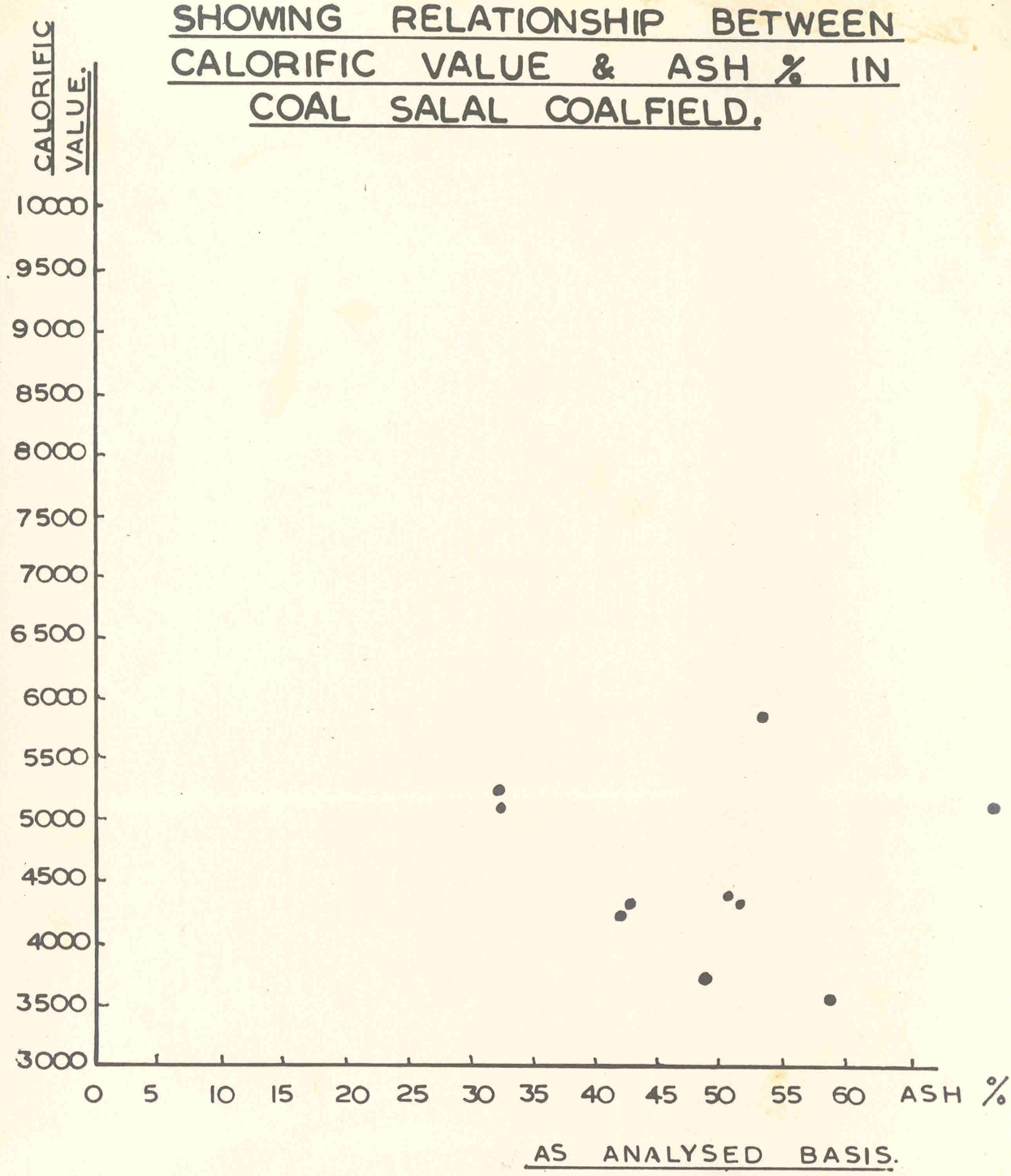
AN ANALYSED BASIS

PLATE NO. 38

SHOWING RELATIONSHIP BETWEEN CALORIFIC VALUE & ASH % IN COAL FROM DIFFERENT BLOCKS IN THE SUKHWALGALI -JANGAL GALI COALFIELDS.



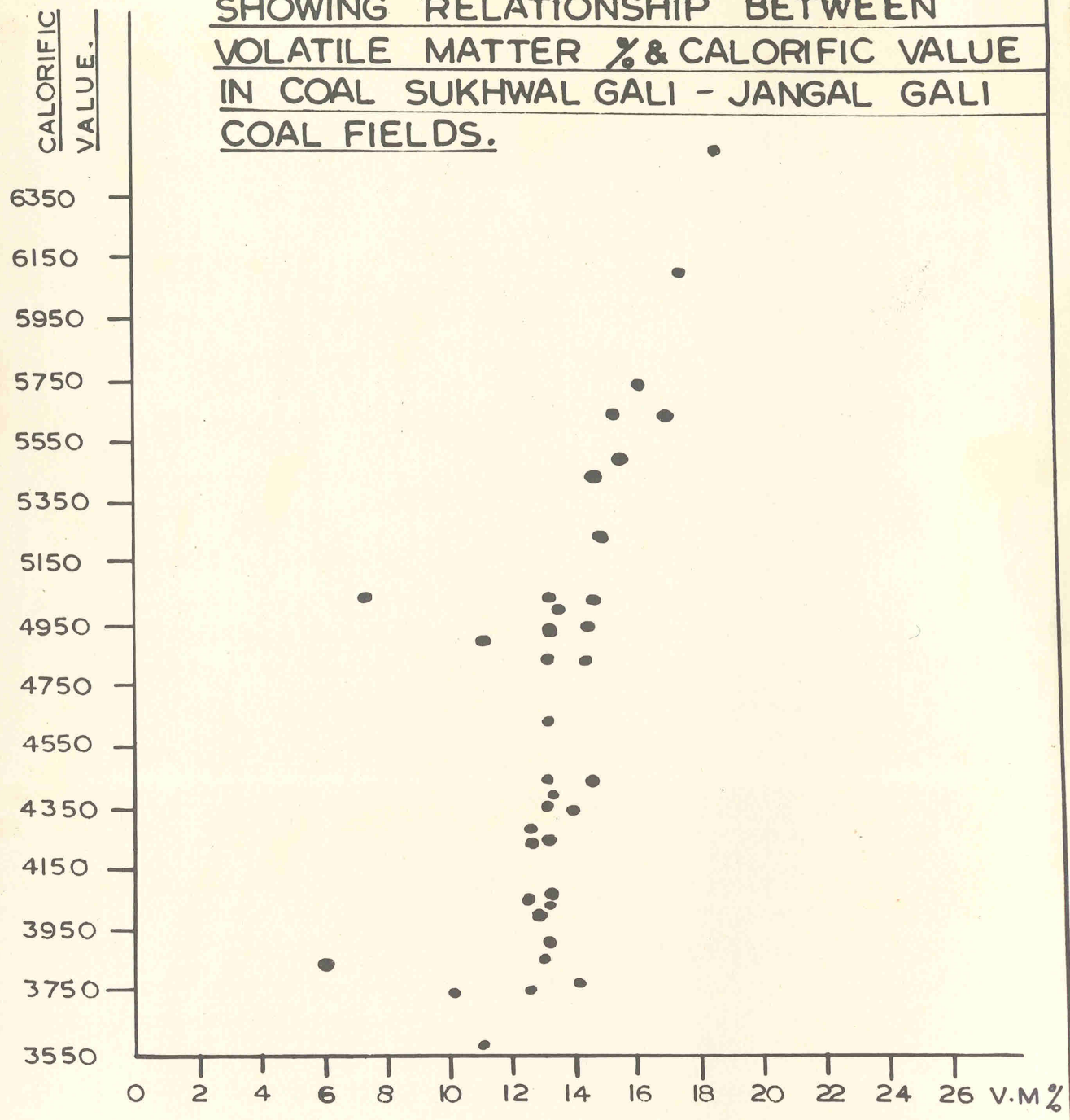
SHOWING RELATIONSHIP BETWEEN CALORIFIC VALUE & ASH % IN COAL SALAL COALFIELD.



AS ANALYSED BASIS.

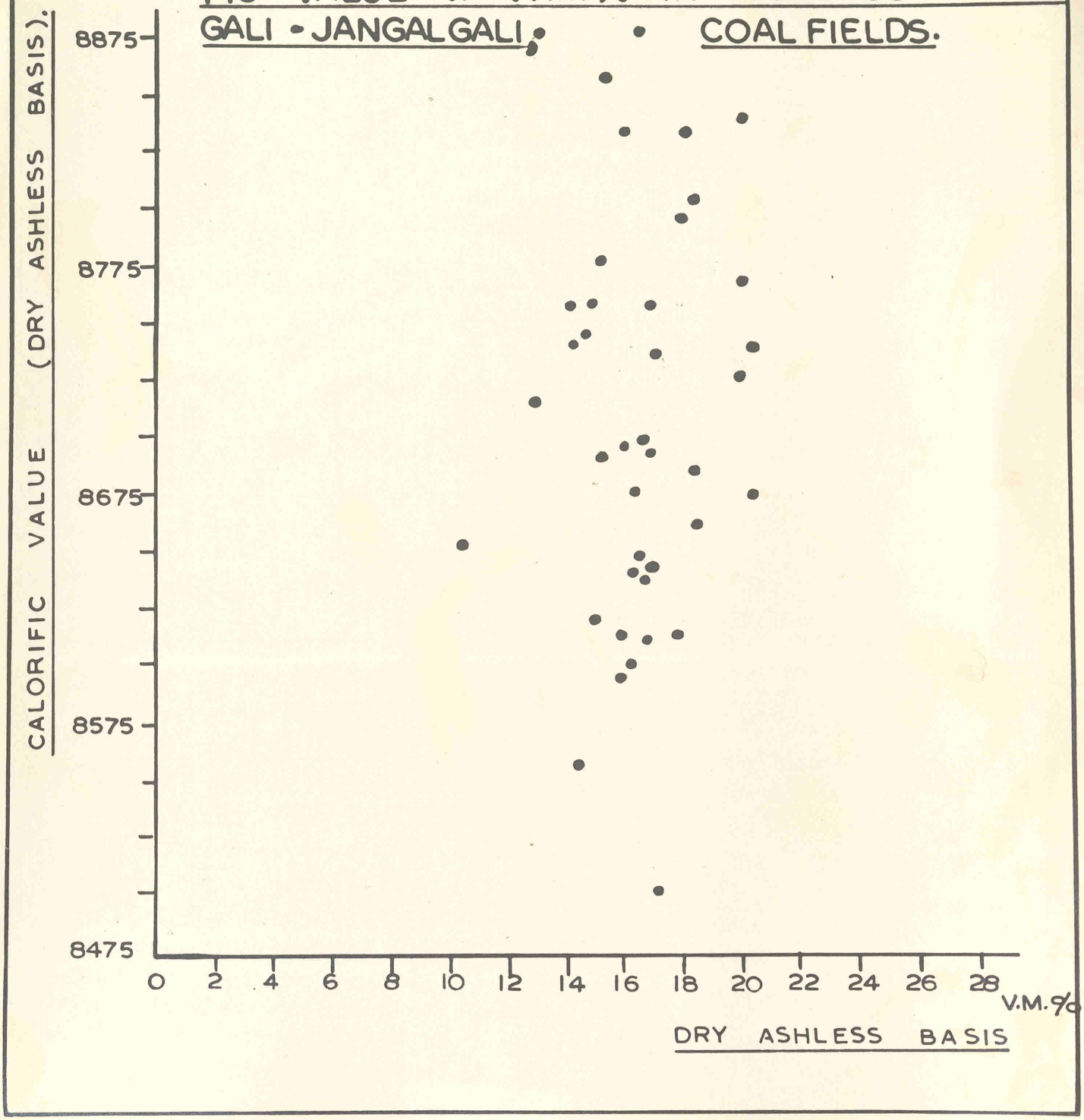
PLATE NO. 40

SHOWING RELATIONSHIP BETWEEN VOLATILE MATTER % & CALORIFIC VALUE IN COAL SUKHWAL GALI - JANGAL GALI COAL FIELDS.

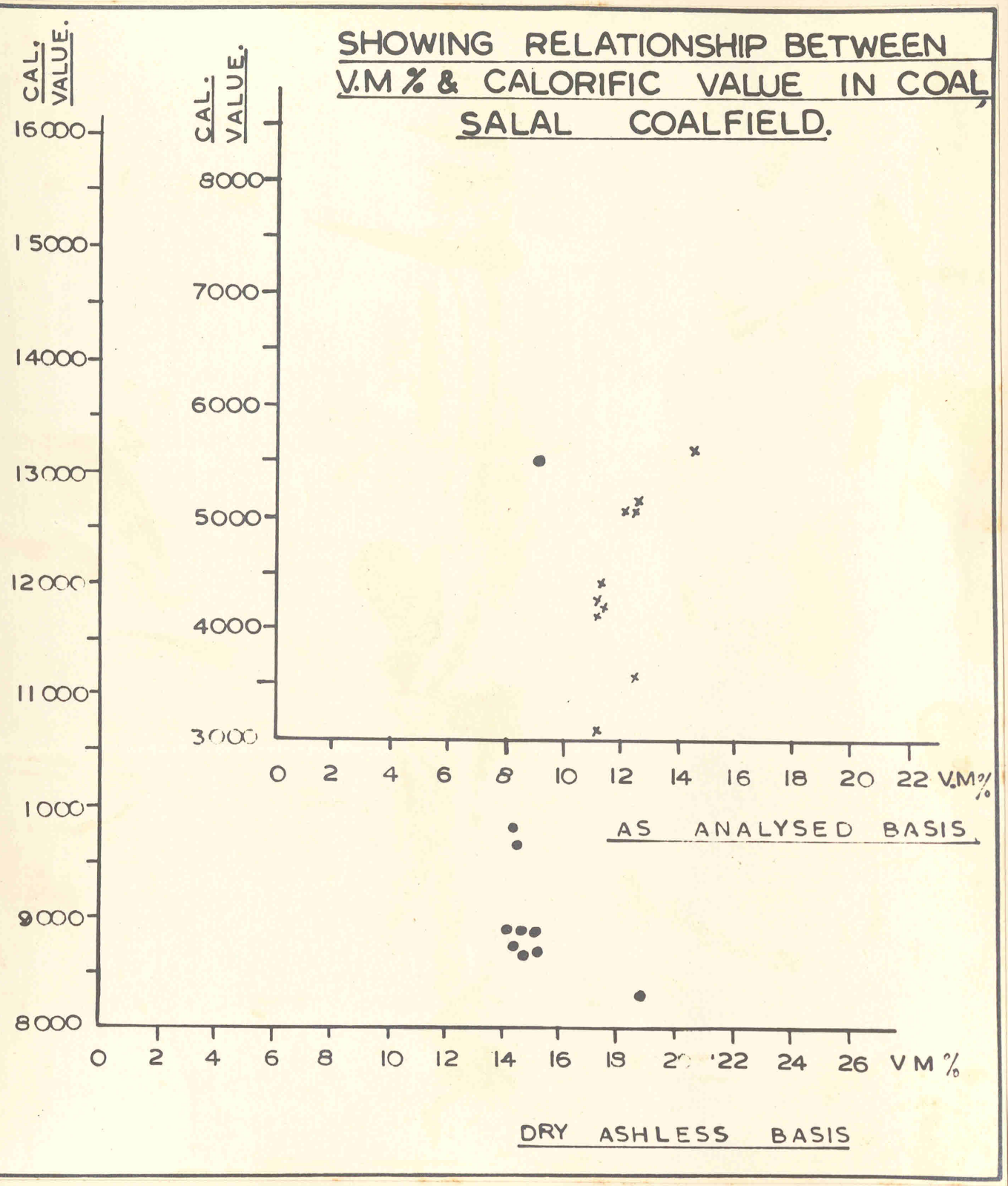


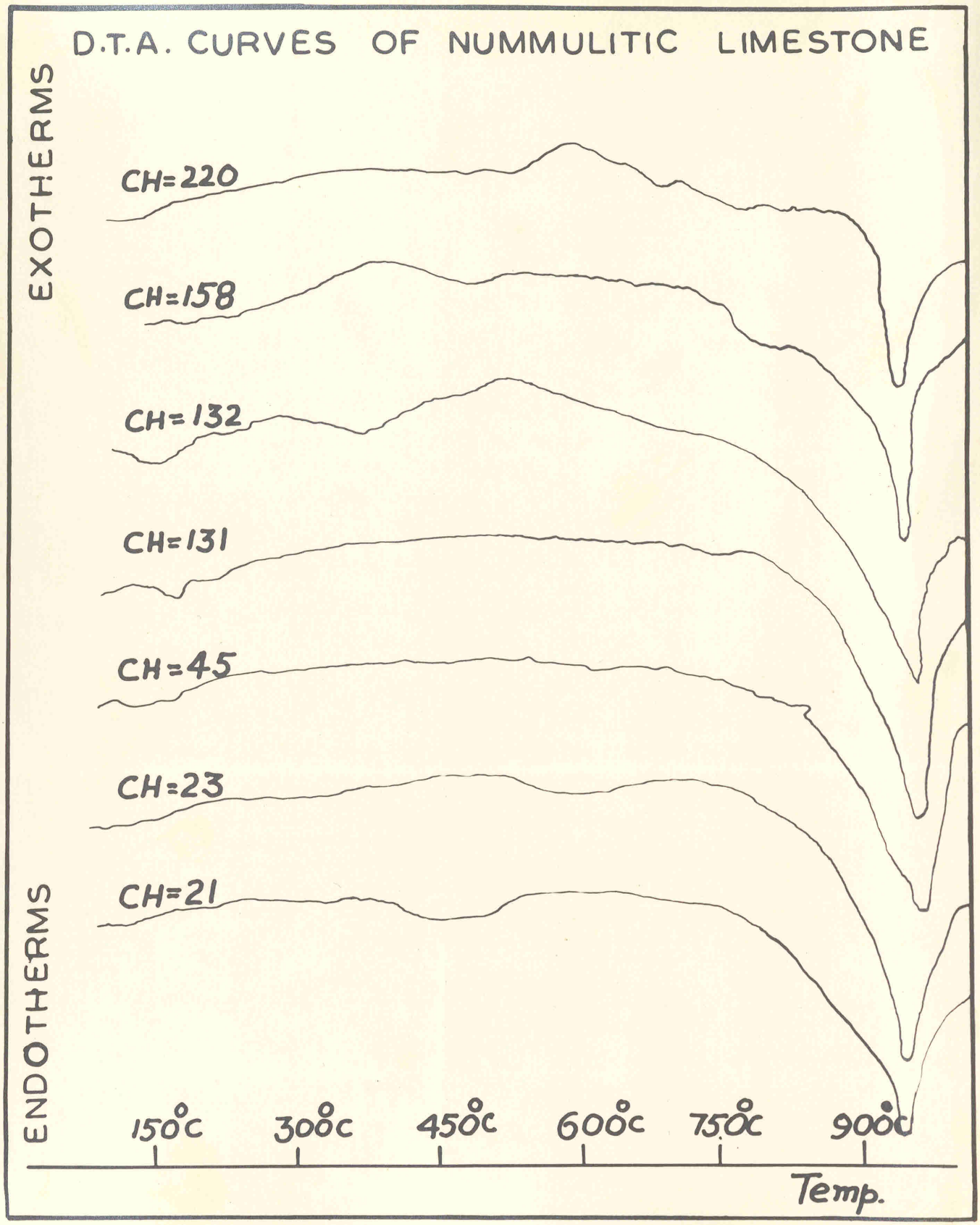
AS ANALYSED BASIS

SHOWING RELATIONSHIP BETWEEN CALORIFIC VALUE & V.M.% IN COAL SUKHWAL GALI - JANGALGALI COAL FIELDS.



SHOWING RELATIONSHIP BETWEEN V.M % & CALORIFIC VALUE IN COAL, SALAL COALFIELD.




D.T.A. CURVES OF NUMMULITIC LIMESTONE
EXOTHERMS
CH=220
CH=158
CH=132
CH=131
CH=45
CH=23
CH=21
ENDOTHERMS
150°C
300°C
450°C
600°C
750°C
900°C
Temp.

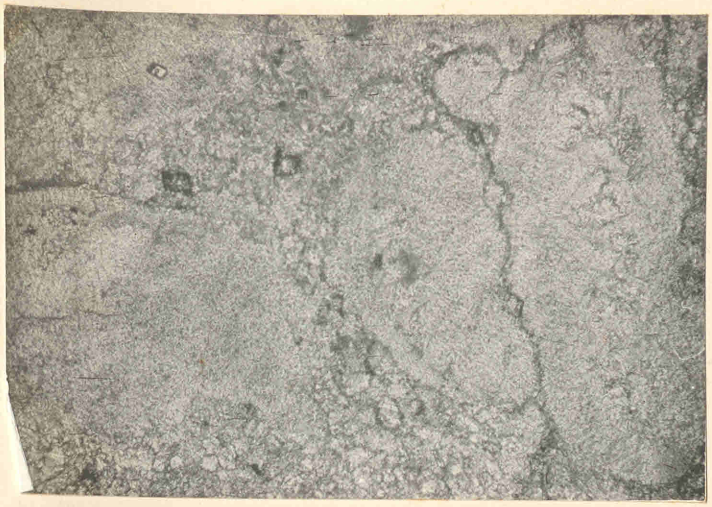


FIG. 1

FIG. 2

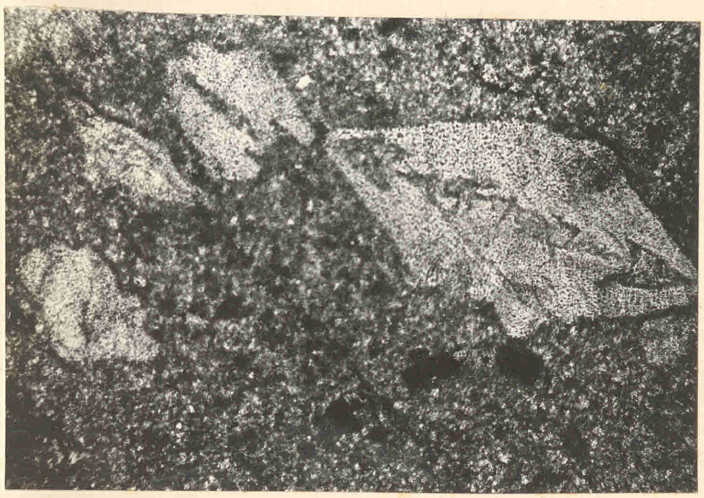


FIG. 3

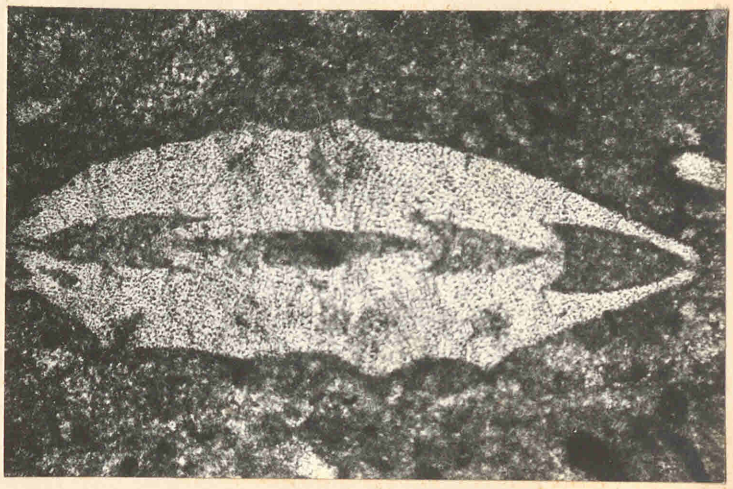


FIG. 4

FIG. 5

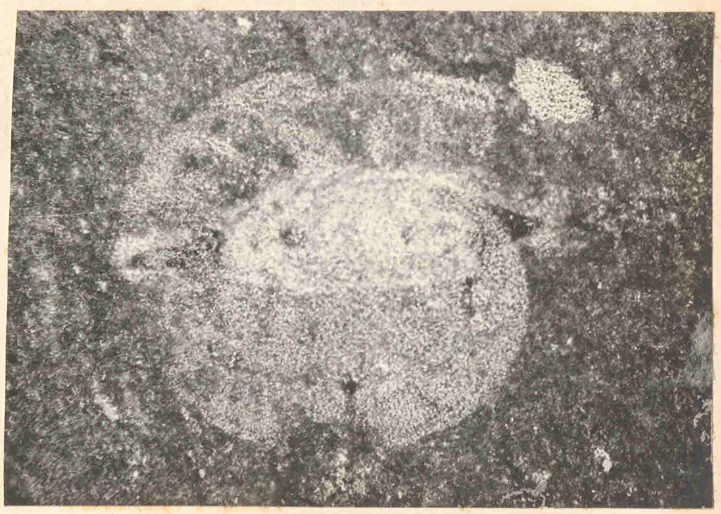


FIG. 6

Explanation of plate No. 44

Fig. 1. Photomicrograph of Nummulitic Limestone of Salal exhibiting typically microstylolitic structure.

Crossed Nicols X 45.

Fig. 2. Photomicrograph of Nummulitic Limestone of Salal area showing ghosts of the original septa making their appearance through calcareous mass.

Crossed Nicols X 45.

Fig. 3&4. Photomicrographs of Nummulitic Limestone of Jangal Gali area exhibiting diverse types of foraminiferal tests enclosed in a micritic matter.

Crossed Nicols X 45.

Fig. 5. Photomicrograph of Nummulitic Limestone of Salal area exhibiting a complete destruction of the internal chambered structures of the foraminiferal tests by diagenesis.

Crossed Nicols X 45.

Fig. 6. Photomicrograph of Nummulitic Limestone of Salal showing transverse section of a foraminifera test. Only two chamberes are visible and the septa are visible only in the outer chamber.

Crossed Nicols X 45.

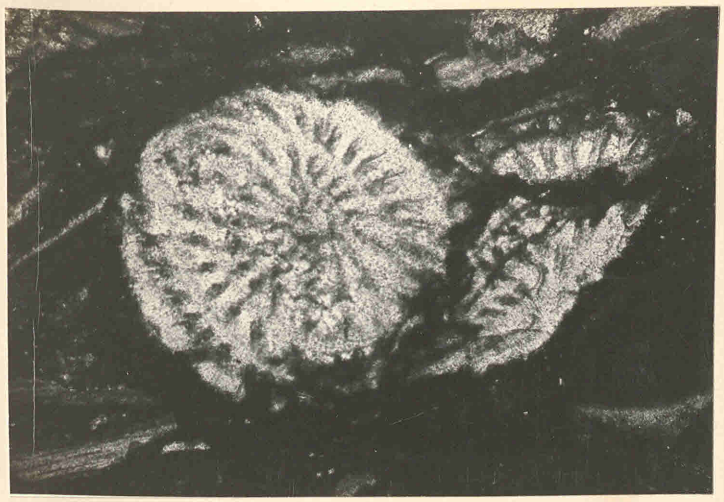


FIG. 1

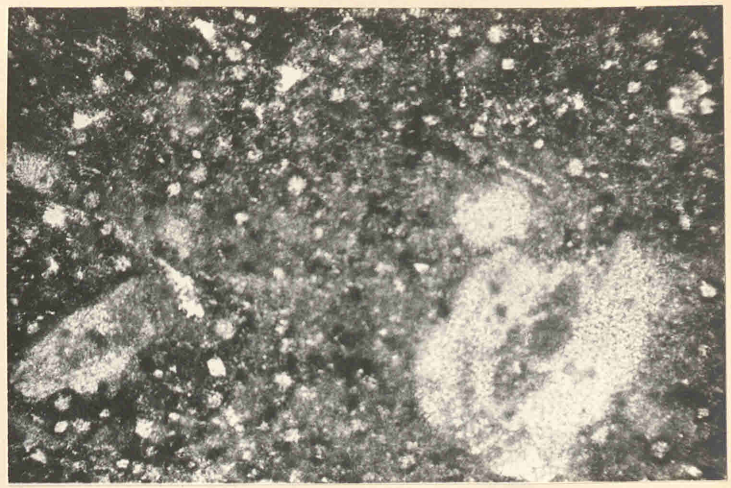


FIG. 2

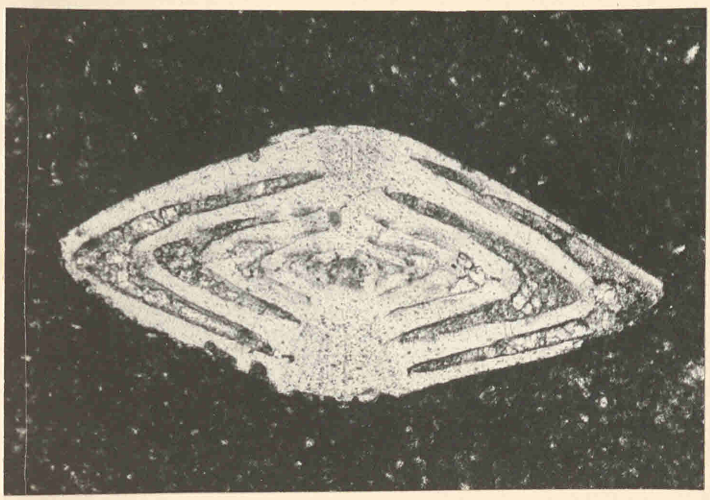


FIG. 3

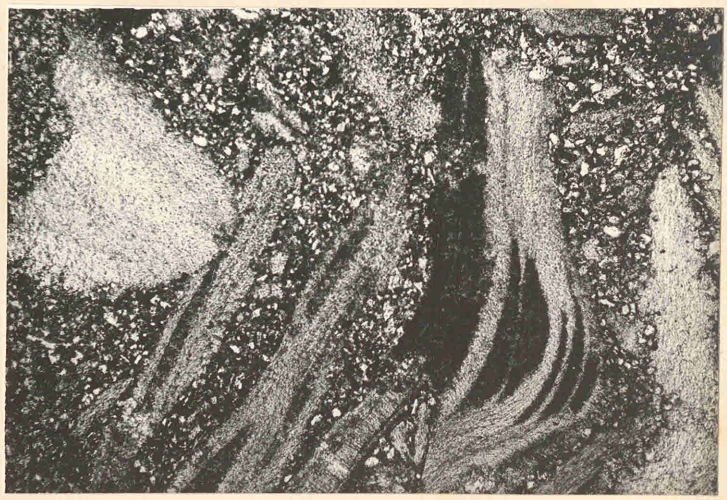


FIG. 4

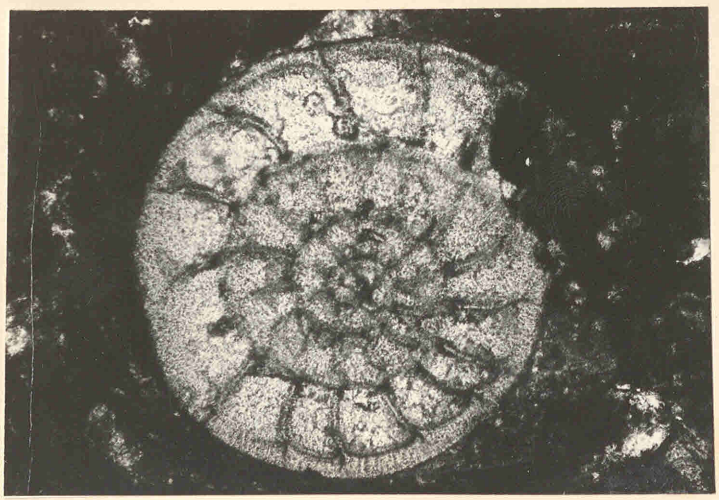


FIG. 5

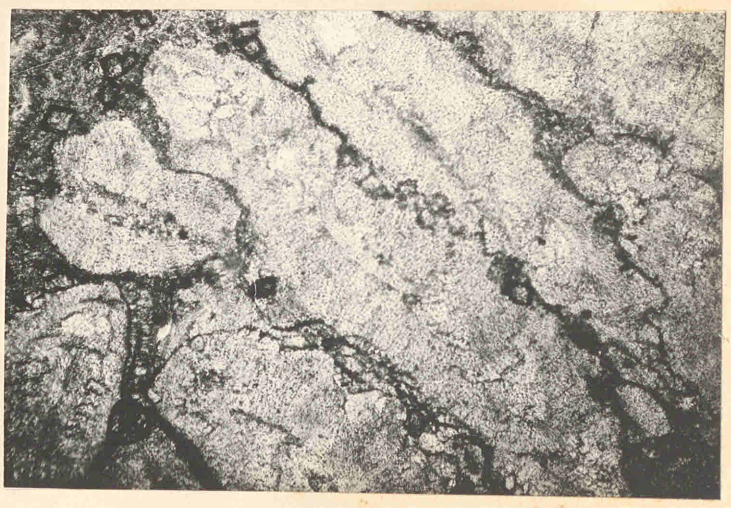


FIG. 6

Explanation of plate No. 45

Fig. 1. Photomicrograph of a limestone with a test of foraminifera. It has four chambers, the outer one is slightly eroded. The septa are prominent. Horizontal section.

Locality - Lain. Crossed Nicols X 45.

Fig. 2. Photomicrograph of a limestone with a test of foraminifera within a micritic matter. The internal chambered structure of the test has been totally destroyed.

Locality - Lain. Crossed Nicols X 45.

Fig. 3. Photomicrograph of a limestone with a typical Nummulitic enclosed in a micritic matter. The micritic matter has replaced the outer walls near the right side & the inner margins of the chambers.

Locality - Lain. Crossed Nicols X 45.

Fig. 4. Photomicrograph showing wall structures of the shells of pelecypods.

Locality - Lain. Crossed Nicols X 45.

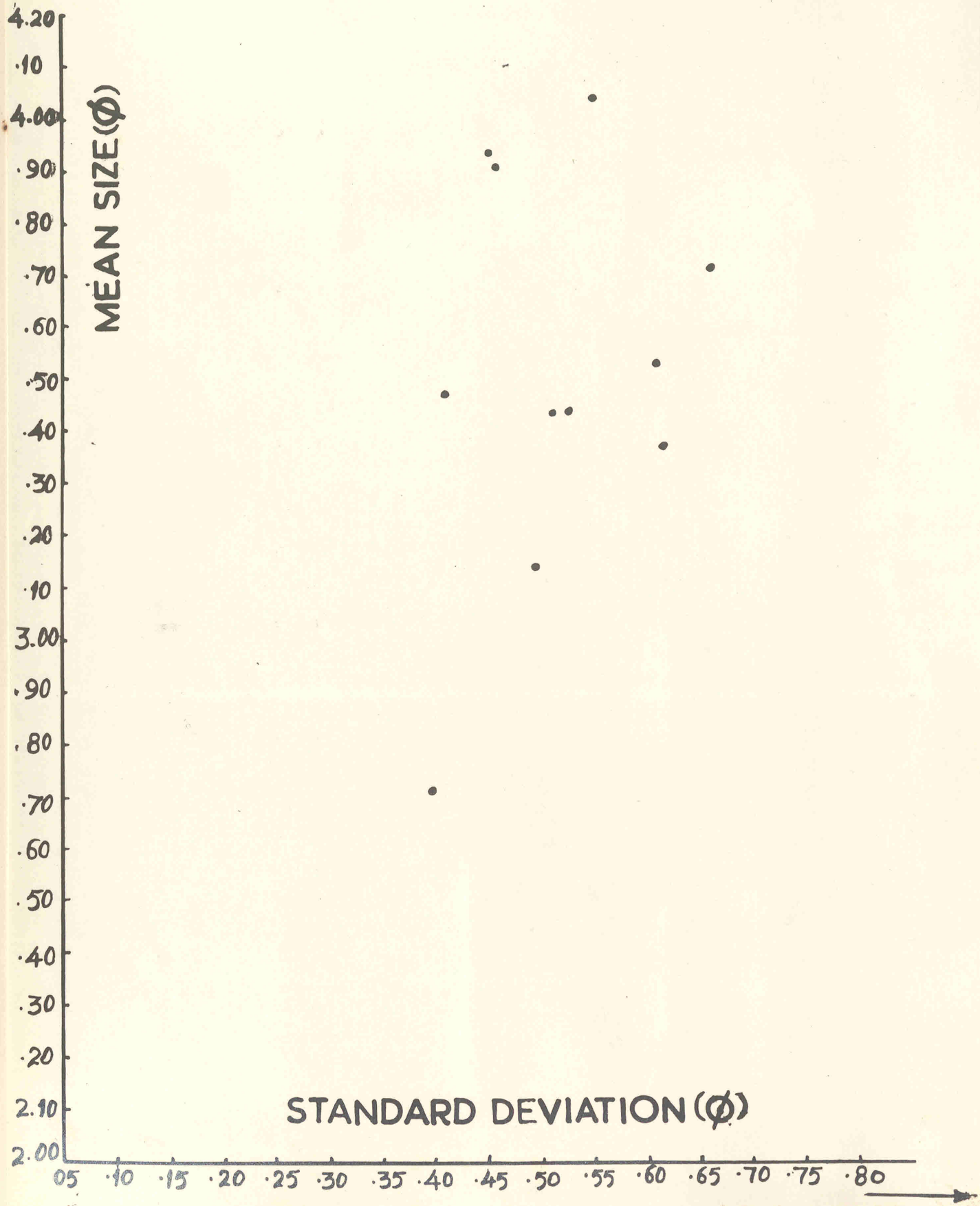
Fig. 5. Photomicrograph of horizontal section of a Nummulitic (2 mm) showing numerous whorls and a complete internal structure.

Locality- Lain. Crossed Nicols X 45.

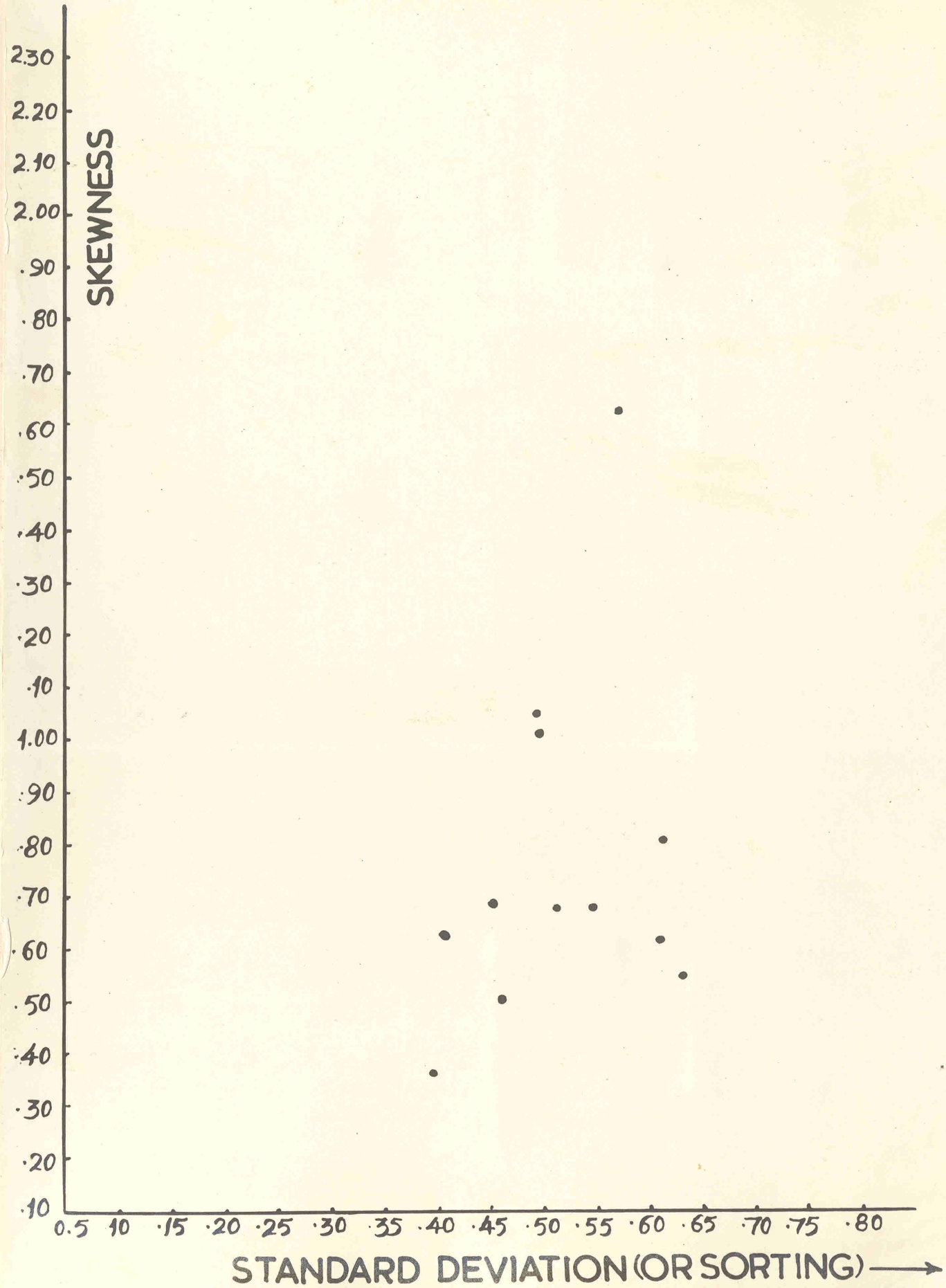
Fig. 6. Photomicrograph of a Nummulitic Limestone exhibiting microstylolitic structure.

Locality - Lain. Crossed Nicols X 45.

SHOWING SORTING(Ø) VS MEAN SIZE (Ø)



SHOWING SKEWNESS (ϕ) VS SORTING (ϕ)



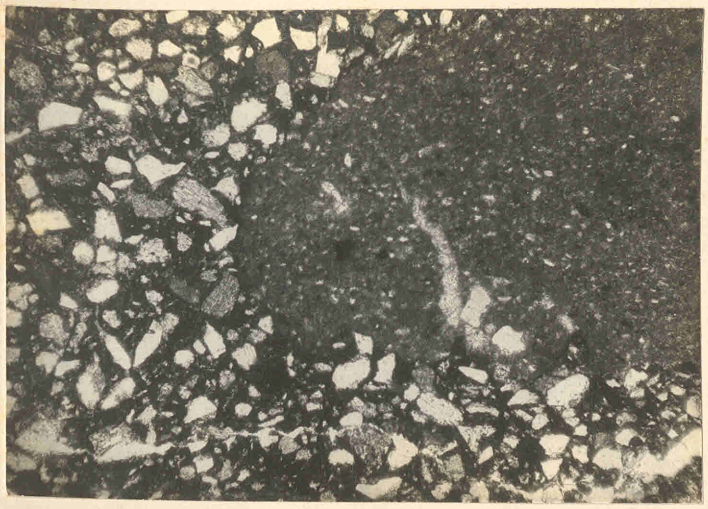


FIG. 1

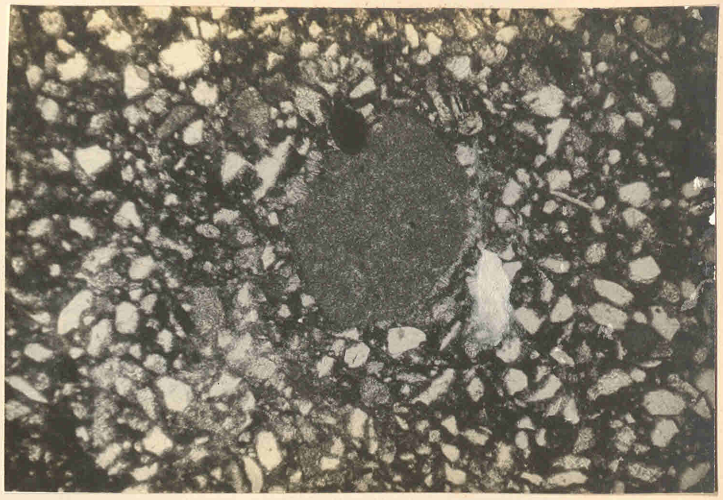


FIG. 2

FIG. 3

FIG. 4

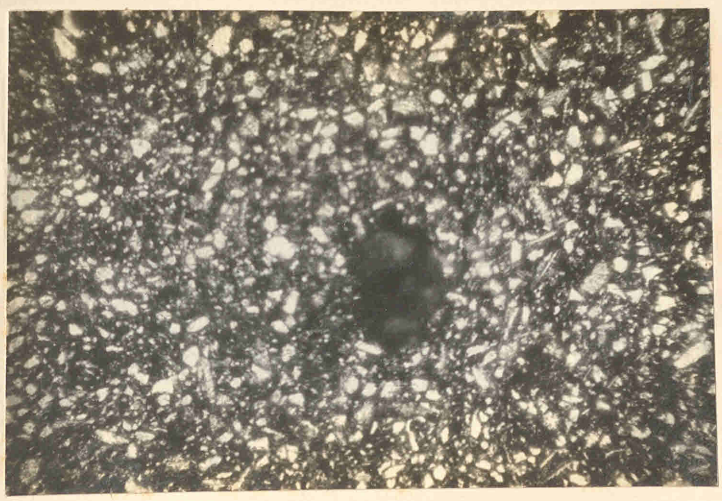


FIG. 5

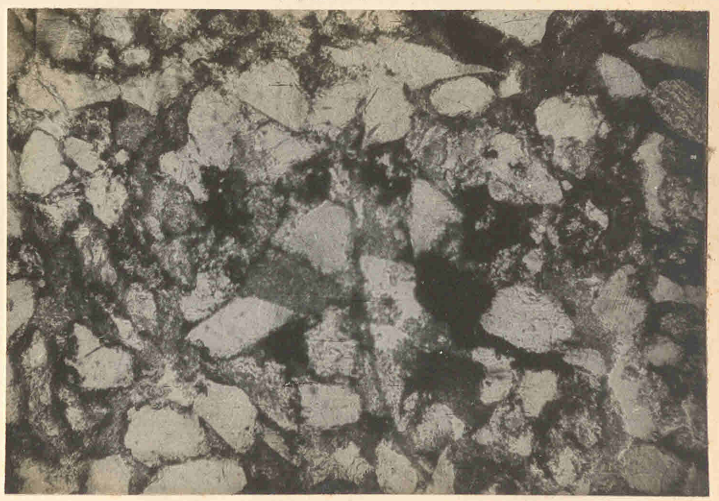


FIG. 6

Explanation of plate No. 48

Fig. 1. Photomicrograph of sub-lithic arenite showing a mosaic of sub-rounded grains of quartz which are of uniform size. A large siltstone patch can be observed on the north east of the section.

Locality - Do-Khadda. Crossed NicolsX60.

Fig. 2. Photomicrograph of sub-lithic arenite showing a rounded grain of siltstone of the size of 0.7 mm within the mosaic of quartz grains. A small feldspar grain is also present above the seltstone grain.

Locality - Thalwal. Crossed NicolsX60.

Figs. 3, 4&6. Photomicrographs of quartz Arenite exhibiting intact framework of quartz grains cemented by a calcareous cement.

Locality - Jangal Gali Crossed NicolsX60.

Fig. 5. Photomicrograph of siltstone showing very fine grained texture. The grains of quartz are sub-rounded and are cemented by marly cement.

Locality - Arnas. Crossed NicolsX60.

FIG. 1

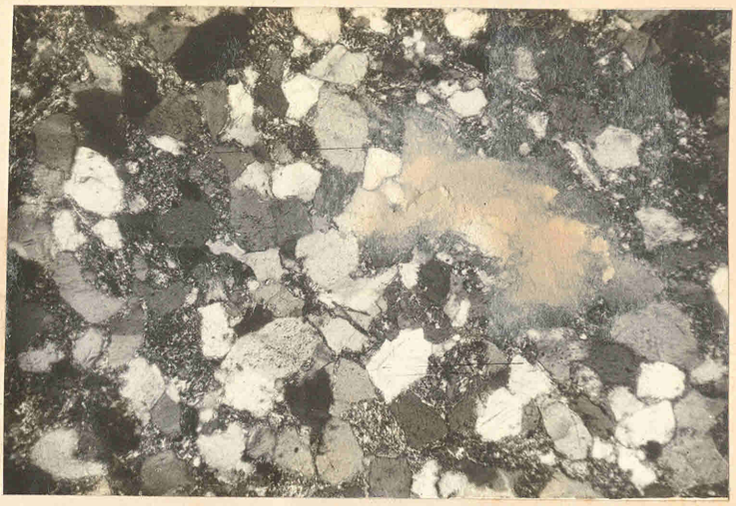


FIG. 2

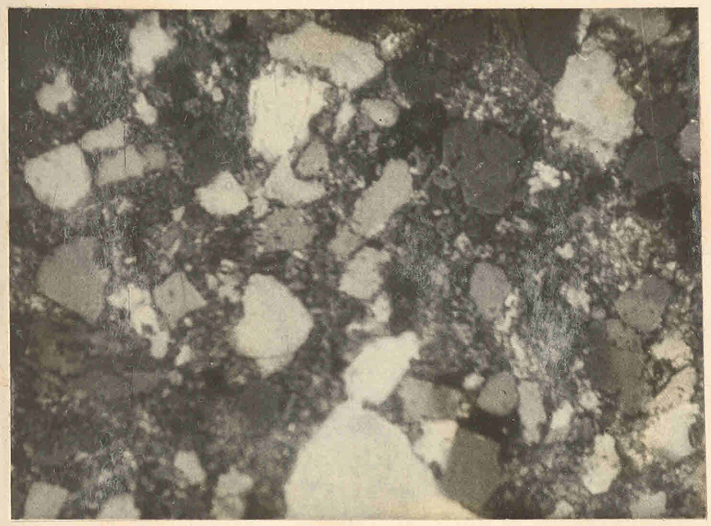


FIG. 3

FIG. 4

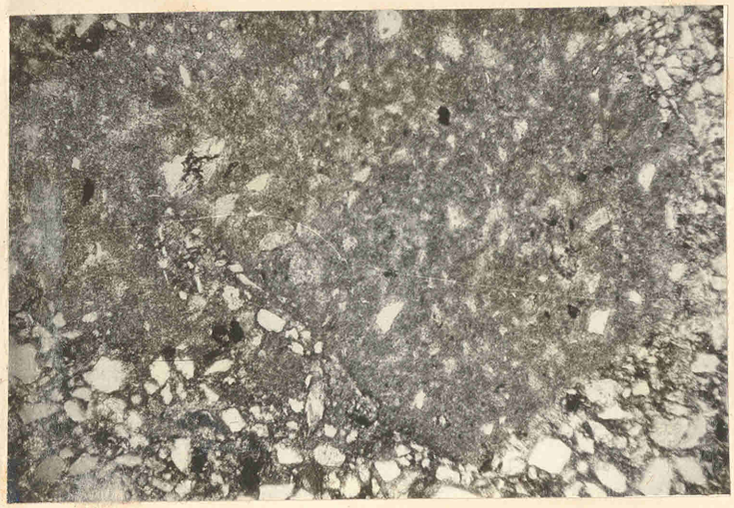


FIG. 5

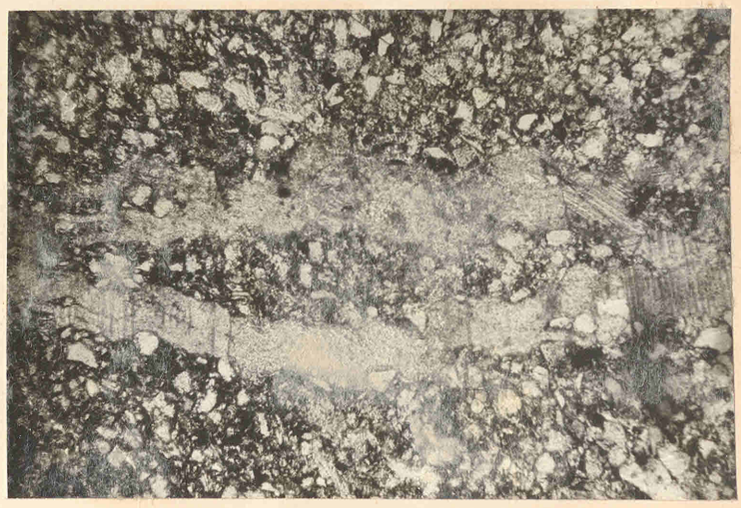


FIG. 6

Explanation of plate No. 49

Fig. 1 to 4. Photomicrographs of quartz arenites typically showing intact framework of quartz grains cemented by calcareous cement. The individual quartz grains are sub-rounded.

Locality - Jangal Gali. Crossed NicolsX60

Fig. 6. Photomicrograph of siltstone showing equigranular texture. The finer grains of quartz are cemented by a marly cement.

Locality - Arnas. Crossed NicolsX60.

Fig. 6. Photomicrograph of sub-lithic arenite showing sub-rounded grains of quartz cemented by a calcareous cement. In the centre of the section, there are twigs and branches of some plants which have been replaced by calcareous material.

Locality - Arnas. Crossed NicolsX60.