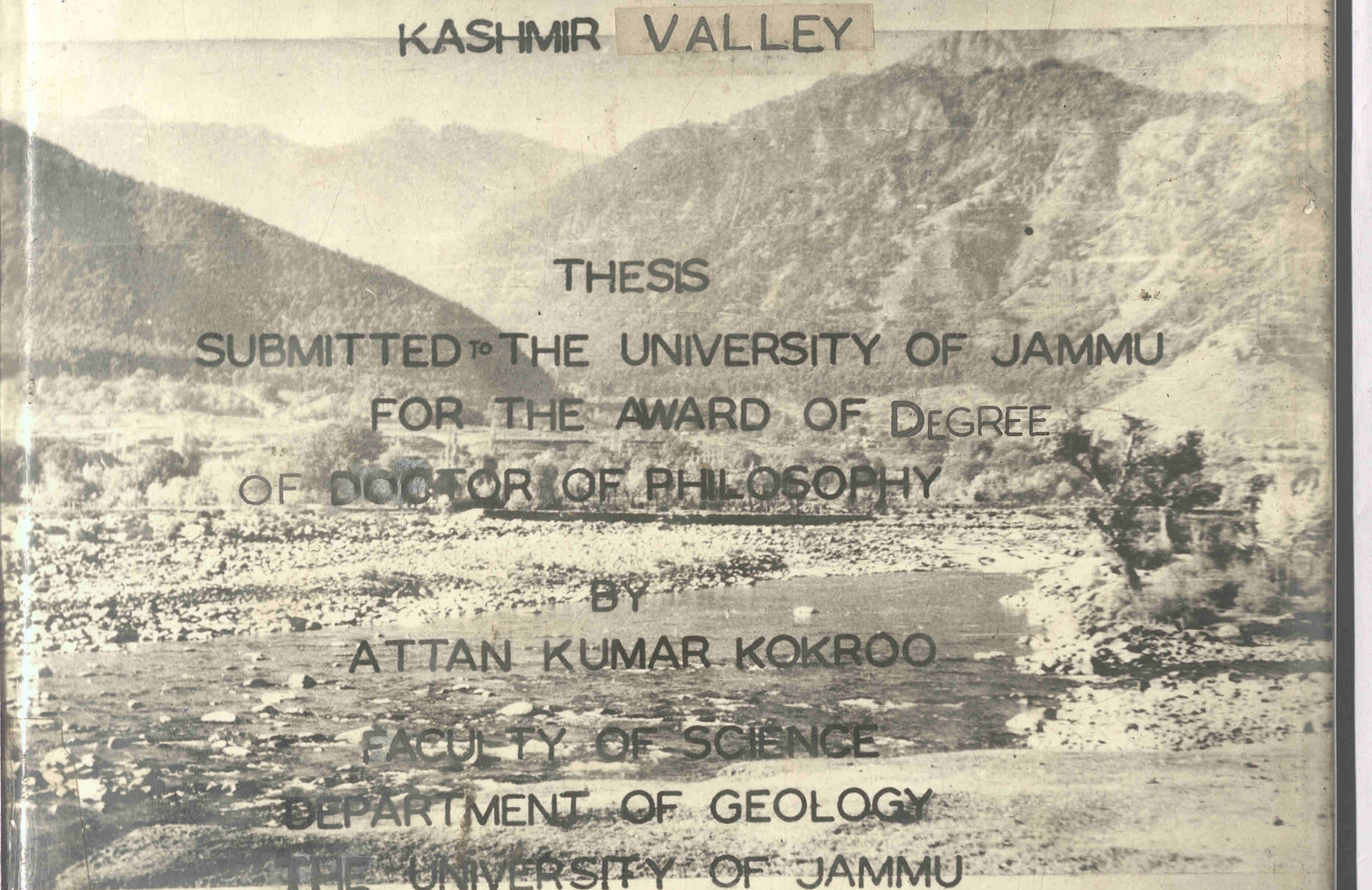
SEDIMENTOLOGICAL STUDIES OF THE PALAEOZOIC ROCKS OF ANANTNAG DISTRICT, KASHMIR VALLEY



THESIS

SUBMITTED TO THE UNIVERSITY OF JAMMU

FOR THE AWARD OF DEGREE

OF DOCTOR OF PHILOSOPHY

BY

ATTAN KUMAR KOKROO

FACULTY OF SCIENCE

DEPARTMENT OF GEOLOGY

THE UNIVERSITY OF JAMMU

JAMMU 180001

1978

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STRATIGRAPHIC GEOLOGY

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To my parents

C E R T I F I C A T E

Mr Attan Kumar Kokroo was registered as a regular research scholar in the department of Geology, University of Jammu, Jammu for the degree of Doctor of Philosophy in August, 1974 under my supervision and has completed his work.

The title of his thesis is:

Sedimentological studies of the Palaeozoic rocks of Anantnag district, Kashmir Valley.

I certify that he worked under my supervision and the work is original and worthy of consideration for the award of the degree of Doctor of Philosophy.

I further certify:

(a) the thesis incorporate the work of the candidate himself;

(b) the candidate worked under my supervision for the period required under rules; and

(c) the candidate has put in the required attendance in the department during this period.

(T. R. BHATIA)
Supervisor.

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CHAPTER-I

INTRODUCTION

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

The Himalaya conj-ures up the image of gentle colours shrouded in mystery. Over the ages, man has endeavoured to prove its secrets; be it philosophical, geographical or geological. At present we know but the rudiments of its intricate history and the enigma still abides.

Kashmir forms a part of the Himalaya which has been the result of the movement of the Indian landmass towards the Tibetan or the Asian one, which started around hundred million years ago, squeezing up and folding the sediments present in the enormous ocean which was known as " Tethys ". The movement was slow and continues even to-day. During the successive orogenies which followed the initial "lift " of the Himalaya, the part of Kashmir got its birth with north Kashmir range towards its north and Pir Panjal towards its south.

Amongst the rocks of almost all ages, in Kashmir, the rocks of Palaeozoic period are most noteworthy, as these have entombed in them a prolific assemblage of faunal wealth (Silurian to Carboniferous), which hitherto has not been found in any part of India. The best exposures of such rocks are found towards the southeastern part (Anantnag district) of Kashmir valley.

PURPOSE OF STUDY

This work pertains to the sedimentology of the Palaeozoic rocks (below the Panjal lava flow) of Anantnag district of Kashmir Himalaya. The fossiliferous rocks of Kashmir, according to Wadia (1959), are found in the form of elongated ellipse shaped patches in and around the valley, stretching from north west of Hundwara to the south east end of the Kashmir sedimentary basin. Palaeozoic rocks are also exposed in the Basmai anticline of the Sind valley between Sonamarg and Kolhoi. Similar rocks are also exposed in a large synclinal basin extending from Wular lake to Titwal. Out of all these localities, where Palaeozoic rocks are exposed, the exposures of southeastern Kashmir of Liddar valley and Naubug valley are most spectacular and complete.

In sharp contrast to this basin, the development of Palaeozoic rocks in northwestern Kashmir is almost blank, with the exception of small patches of Muth quartzite, the Silurian system of Kashmir.

The exposure of Palaeozoic rocks of the Liddar valley is in the form of denuded anticlinal flexure in which the

whole of the Palaeozoic rocks are exposed. The denudation has exposed in the central part of this anticline, a broad oval outcrop of Cambrian and Ordovician flanked in its two sides successively by thinner bands of the younger formations Silurian, Devonian and Carboniferous. Similarly, in the Naubug valley older Cambro-Silurian rocks are exposed in the form of a denuded anticline near Gauran and Durderman flanked by younger rocks. (Plate – 51).

The geology of the Palaeozoic rocks of Anantnag basin is well established through the writings of Lydekker (1978-1883), Middlemiss (1910), Gupta (1964-1971) and many others, who have laid down the solid foundation of geology of these rocks. Their work, however, deals mainly with stratigraphical and palaeontological problems. No earlier worker has worked on the sediments of these rocks, except a paper by Ganju and Srivastava (1961), on Agglomeratic slates of Bren, and by Bhatia and Kokroo (1977-78), on the Syringothyris limestone.

The sedimentological studies, these days are very important in understanding not only the characters of the sediments, but also are essential in palaeogeographic reconstruction, such as in understanding the nature of the basin, the direction of the paleocurrents, delineations of paleo-slopes, inferring the trend of the shore line,

location of the margin of the depositional basin, location of the areas supplying the material and depositional environments in which sediments were deposited. No information was previously available on these aspects. The present work has, therefore, been undertaken to fulfil the existing gap in our knowledge. This study was, therefore, designed to solve some of the outstanding problems which are as follows:

1. The basement rocks of the Palaeozoic sequence consist of undifferentiated assemblage of shale, slate, greywackes etc. which are referred by Middlemiss (1910), as Cambro-Silurian slates. Gupta (1967-68) and Pal (1977), on the basis of presence of graptolites, attempted to classify these rocks, but due to indeterminable nature and very sporadic occurrence of these fossils, the classification proposed by them is difficult to apply.

2. The nature and position of the Passage beds is still a geological riddle. The quartzo-sandstones of Muth-quartzite, Syringothyris limestone and of Passage beds look quite alike in the field.

3. The nature of the Fenestella shales and its relationship with the overlying Agglomeratic slates is still obscure. According to Wadia (1959), some of the black shales being crowded with pyroclastic and glaring debris, crystals of

feldspar, quartz, etc.

4. The Agglomeratic Slate in itself, is a very problematic formation. According to Wadia, " its mode of origin is not easy to understand and that such a rock could not have been the product of any simple process of sedimentation, whether subaerial or submarine, is quite clear."

5. The nature of the Syringothyris limestone is still not clear. Recently, Bhatia and Kokroo (1978) noted distinct dolomitization in the upper part and described a few types, but their detailed studies are needed with respect to facies types and depositional environments.

To solve all these problems, a combined stratigraphic, sedimentological and petrographic approach was needed and this work embodies the outcome of this effort.

AREA OF STUDY

The present area is confined to the Palaeozoic rocks, exposed in the southeastern parts (Anan-tnag district) of Kashmir valley, J-ammu and Kashmir state and is covered by the Survey of Indian Toposheets: 43 O/1, 43 O/2, 43 O/5, and 43 O/6. The study area is restricted within the latitude: 33° 35' to 33° 55'; Longitude: 75° 15' to 75° 30'. The total area covered under this study is roughly 700 sq. kms.

The nearest town from where the area can be approached

easily is Anantnag (33° 48' : 75° 12'), which lies on Srinagar-Pahalgam road. Anantnag is only 54 kms. south-east of Srinagar. With respect to Anantnag, the area of study can be roughly subdivided into northern and southern sides. Southern side of the area can also be approached via Verinag (33° 32' 30" : 75° 14' 50"), which is linked by 2 km road with the National Highway near Munda. The inner parts of the area are covered by fairweather roads and the higher reaches are connected by mule and footpaths (Plate- I). The important localities on the higher reaches include Batkot (33° 56' 40" : 75° 18'), Gugaldar (33° 50' 46" : 75° 21') in Liddar valley and Lihhinwan (33° 43' 58" : 75° 26'), Margan Pass etc. in the Naubug valley.

The area is drained by two important rivers. In the northern area, the famous Liddar river flows, forming the famous Liddar valley; while the southern side is drained by river Bring forming Naubug valley. Both these valleys are surrounded by high hills on eastern and western sides. The geological field work in the area is possible only upto the month of October, after which it becomes snow covered and remains so till April.

PHYSIOGRAPHY

The area of study has typical topography, characteristic of Lesser Himalaya, in having narrow erosional valleys, surrounded by high mountain ranges. The minimum altitude of the peaks in the area of study is 1899 m, while as the maximum altitude of the hill tops does not exceed 4409 m. Some of the prominent peaks include that of Borsar (4409 m), Kindraz (3852m), Desu (2464m), Hoksar (4300m), Khiram (2636m) and Tsokilpur (1452m) (PLATE 3)

There are number of mountain ranges traversing the area, some of which are as under:-

1. Saribal Range: It is a continuous range stretching in north-south direction and has maximum slope towards Wardwan river. It has an average elevation of 3500m. This range is parallel to Borsar range and number of valleys have been carved out due to stream erosion. The Saribal range is dissected into labyrinth of hillocks and valleys; the crusts of ridges are broken by notches, which in some cases appear to allign with each other from ridge to ridge and with portions of courses of streams that now flow far below them in the valleys. There is dense vegetation on number of grassy lands called as "Margs".

2. Tsuru- Pantsal Range: It is another important range in the study area, stretching in north-west direction. This range has maximum elevation (3455m) on northern side and minimum elevation (2600m) on southern side and has gentle slope towards

Liddar. It constitutes a number of as-ymetrical valleys on either side, which is due to exercise of climate and slope form. The soil varies from alluvial deposits (deposited by streams) near basins and fluvioglacial at higher elevations.

3. Desu-Kindraz Range: Kindraz Range is towards southeast of Anantnag and runs almost in the direction southwest-northeast, with the maximum elevation near Kindraz (3852m) and has steep slope.

4. Other Minor Ranges: There are number of minor ranges falling between Saribal Range and Tsuru-Pantsal Range like Astanba Range, Drinyan Range and Desu-Kindraz Range. All these ranges almost run parallel to each other and in between them, there are number of valleys carved out by the trientries of Bring,Liddar and Arbat rivers. Astanba Range traverses in the middle of the study area and has mean elevation of about 2,500 m, towards west of Chaturgal, it makes a sort of loop due to valley erosion. The drainage pattern in this range is different from that of other ranges due to variation in rock types and structures.

DRAINAGE

The area is drained by two large rivers viz., Liddar and Bring along with their numerous tributaries. The overall drainage pattern is that of dendritic type. The main features of these rivers are as follows:-

1. Liddar River: It takes its source at the base of the Kolhoi and Sheshnag snow fields and bifurcates into two streams: east Liddar and west Liddar, which unite at Pahalgam. After passing from Pahalgam downstream, Liddar enters into the open plains of Liddar valley, where it further bifurcates into numerous streams, forming what is known as "Outwash Plain". Basin characters of Liddar river are shown in Table-I below (After Moonisraza, 1978).

Table-I

Stream order	No. of streams.	Bifurcation ratio	Length of segments in each order as % of the cumulative Length	Percent	Mean length of the segments.
1.	215	4.09	412.0	60.68	1.91
2.	52	4.72	152.0	22.39	2.92
3.	11	5.50	58.0	8.55	5.27
4.	2	2.00	25.0	3.68	12.50
5.	1		32.0	4.70	32.00
	Total 281	AVERAGE 4.07	Cumulative length 679.00		

2. Bring River: It comes from the snow-melt from over a wide area in the Pir Panjal. The Bring has two main tributaries which unite at the village Wangom called the Bring. This stream then takes a west-northwest course, flowing for some kilometers upto south of Anantnag, where it unites with the Sandran river. The density of the Bring is high, as compared to that of Liddar

and the Arapatkol and medium to high texture, with a dendritic type of drainage. The other characters of this river are given in Table-II.

Table-II

Stream Order	No. of streams	bifurcation Ratio	Length of segments in each order as % of the cumulative		Mean Length of the segments. (Km.)
			Length (Km.)	Percent	
1	140	5.0	215.0	67.82	1.53
2	28	4.66	58.0	18.29	2.07
3	6	3.0	31.0	9.79	5.16
4	2		13.0	4.10	6.50
	Total 176	Average 4.22	Cumulative Length 317		

3. Arapat Kol: This river flows from northeast to southwest direction in the area of study. Before merging with the Sandran, the Bring receives waters of the mountain torrent known as Arapat Kol, draining the Kuthiar valley having gentle slope. It has moderately high texture and comparatively medium to high density, (0.70). The number of stream segments is 96 in which the first order streams are 72, second order as 18, third order 5 and fourth order 1 in number. The average bifurcation ratio is 4.20. The total area of this river is 362 sq.kms with cumulative length as 255.00 kms.

CLIMATE

Contrary to usual four seasons in a year, Kashmir valley and its adjoining areas have six seasons, each one of a duration of two months. These are :(i) Spring (mid-March to mid-May), (ii) Summer (mid-May to mid-July),(iii) Monsoons (Mid-July to mid-September),(iv) Autumn (mid-September to mid-November), (v) Winter (mid-November to mid-January), (vi) Severe cold (mid-January to mid-March). Overall, the valley has very less summer season, in which the mean daily maximum temperature in July is as high as 31.8°C, with a diurnal range of 12.05°C. The total rainfall received during the southwest monsoon period is only three fifth of the Spring rains. The summer rainfall is almost highly erratic and unequal within the different parts of the valley. The rainfall exceeds 300 mm during this period in the district of Anantnag, and is about 200 mm in Srinagar and its adjoining areas. In winter, by the end of December, snow is almost universal for two months upto February and the area remains under the grip of cold wave.

FAUNA AND FLORA

Within the study area, Alpine forest type of trees, firs and Kail are found, while Deodar, Walnut, Willow, white birch are found on the higher reaches. Among the wild animals, black beer is very common, alongwith the domestic animals like goats, sheep, horses, cows, etc. The river Liddar is famous for having special type of fish known as "Trout."

METHODS OF STUDY

This study consists of field mapping, collection of representative samples, their sedimentological studies and determination of paleocurrents by the study of directional sedimentary structures. The sedimentological studies pertain to textural, compositional and structural features of the sediments. Besides this, there lateral and vertical variations were also studied. The available evidence from these observations was utilized in determining provenance, transport direction, mechanism of deposition and depositional environments.

FIELD WORK

Field work consisted of mapping, systematic sampling, compiling paleocurrent data from directional sedimentary structures etc. In all seven months were utilized in four years time from 1974-1978. A geological map was prepared on a scale of 1" = 1 mile.

The area contains varied types of rocks ranging from slates, sandstones, Agglomerates to limestones. These rocks have been studied by various sedimentological techniques which are as follows:-

Primarily, thin sections were made for all the rock types. For the study of sandstones, the standard thickness of 0.03 mm of the sections was used, while for carbonate rocks, slightly thicker sections were made. Oriented sections for sandstones

were also made for fabric and paleocurrent studies.

The sedimentological techniques both for carbonate and non-carbonate rocks followed in this study are as under:-

CARBONATE ROCKS

These rocks were studied with respect to their geochemical tests, differential Thermal Analysis, staining and insoluble residue studies.

Chemical Analysis: In order to have qualitative and quantitative results from the representative samples, these were chemically analysed by conventional methods. The CaO and MgO weight percentages were determined by EDTA titration after complete extraction of the iron oxides. K_2O and Na_2O percentages were obtained from the silica free solutions (tri-acid-digestion) on the Flame Photometer (EEL Model) by Evans Electro-Selessium Limited, Essex, England.

Differential Thermal Analysis: This analysis was carried out on portable Eberbach D.T.A. apparatus. The samples were first dried, weighed and then kept in a dessicator for 24 hours. The powdered sample was then filled in the left hole of the crucible, while the known reference material (fused alumina) in the other hole of the crucible for the temperature resistance. The apparatus was operated upto 1000 degree Centigrade temperature to record different deflections at different temperatures from the galvanometer. The deflections below the base line

are considered to be endothermic peaks, whereas the deflections above the base line as exothermic. These peaks were recorded with the time interval of 20 minutes. The readings recorded from the galvanometer were plotted on the inch cross section paper. The results obtained were confirmed by the chemical analysis and staining tests.

Staining: The staining tests were employed to distinguish between the calcite and dolomite. The reagents used were Alizarin Red 'S' , Ferric chloride, Ammonium sulphide, Copper nitrate, Harrishaematoxylene etc. The Alizarin Red S and the copper Nitrate solutions were found most effective in which the mineral dolomite remained uneffected and calcite turned red. The inferences obtained by the reagents is given in Table-III.

Table-III

Reagent	Stain	
	Calcite	Dolomite
1. Alizarin Red S (0.1 gm) in 1000 ml, with 0.2 % Hcl.	Red	Uneffected
2. Harrishaematoxelene (50 ml) ,3 ml of 10 % Hcl and 90 ml water.	Purple	White
3. 2.5 % Ferric chloride and Ammonium Sulphide	Brown Black	Colourless
4. 225 gm of hydrated Copper Nitrate diluted to 1000 ml.	Green or bluish green	Colourless.

Insoluble Residue: This was obtained by the careful Hcl digestion. After complete digestion of the residue, the decantation was followed to get the clay and silt percentages from the total residue. The material was dried upto 110°C, and constituents weighed separately to get the respective percentages, finally subjected to microscopic studies using Polarizing Microscope, AMPLIVAL POL -D and Binocular Microscope. In the study of insoluble residue Ireland(1947) method was followed.

CLASTIC ROCKS

The clastic rocks were studied with respect to the following methods:

Size Analysis: The sandstones of the area being hard and welded could not be disaggregated by any of the methods and as such size analysis was carried out by thin section studies. In this study, number frequency so obtained, was converted into weight percent frequency by plotting the cumulative curves on Friedman's chart (1958). In each section 200 grains were measured by calibrating micrometer with eye piece.

From the cumulative curves, the following textural parameters were statistically calculated;-viz., mean size, sorting, skewness and kurtosis. These parameters proved very sensitive in the environmental interpretations. These textural parameters were calculated by Folk and Ward formulae(1957).

$$\text{Mean Size} = \frac{\phi 16 + \phi 84 + \phi 50}{3}$$

Sorting $= \frac{\phi 84 + \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$

Skewness $= \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 95 + \phi 5 - 2\phi 50}{2(\phi 95 - \phi 5)}$.

Kurtosis $= \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$

Modal Composition: The volume percentage of these rocks was calculated by the ELICO Point Counter, Calcutta. In this study, atleast 10 vertical and horizontal traverses were taken to get over all mineral composition of the rock. The volume percentages were later on converted into the weight percentages and the results plotted in the equitriangular diagrams.

Morphometric studies: These studies pertain to determination of form, sphericity and roundness of both coarse and fine particles.

Coarse fraction: The form and sphericity of particles coarser than 2 mm were determined by plotting b/a and c/b ratios on Krumbein (1941), sphericity Chart, which in addition to sphercity, determine Zingg (1935), shape classes.

Roundness was determined by comparing the outlines of the pebbles with the silhoutes of pebbles drawn by Krumbein (1941) and thus assigning the proper roundness values.

Fine fraction: The sphericity was determined by Riley method (1953). In this method the grains were projected on a screen

upto a maximum of 7 cms, and sphericity was thus determined by the following formula:-

$$\text{Sphericity} = \frac{di}{Dc}$$

where di, represents maximum diameter of the inscribed circle and Dc the diameter of the smallest circumscribed circle.

Roundness of these particles was determined by the Wadell's formula (1935):

$$pd = \frac{\Sigma r_1 / R}{N}$$

where r_1, is the radius of the individual corner, R, the radius of the maximum inscribed circle, N, is the number of corners and edges of a grain and further it was visualised by Powers Scale (1953).

PALEOCURRENT STUDIES

For paleocurrent determination, both sedimentary structures and grain orientation studies have been used. Among sedimentary structures, paleocurrents have been determined from ripple marks and cross bedding. In the former case, it is done by measuring the ripple crest direction from both symmetric and asymmetric ripples, while in the latter, the Azimuth and inclination of foreset bedding has been taken into consideration. Grain orientation studies have also been made on thin sections from elongated tear drop grains. In case of Agglomeratic slates, the Azimuth of the grains/crystals coarser than 2 mm was determined by polishing the blocks. The data so obtained was graphically represented

in the form of rose diagrams and subjected to Tukey's Chi square test to determine the direction of preferred orientation.

HEAVY MINERAL SEPARATION

The separation of heavy minerals was carried out by the simple gravity separation methods, using heavy liquid Bromoform (Sp.Gravity = 2.89) and a mixture of bromoform and CCL_4 (Sp.Gravity = 1.58) was also used to separate some minor accessories at 25 ^{o}C (Krumbein and Pettijohn, 1938). These grains were mounted on thin sections and studied under polarising microscope. Lastly, the percentage of different heavy species was estimated on Point Counter.

The data so obtained from all the formations, was put to the discipline of statistics, in order to get concise and accurate results. These calculations were made on D.C.M. portable Calculator (MOSCAL-1400).

CHAPTER - II

HISTORICAL REVIEW

HISTORICAL REVIEW

The geology of the valley of Kashmir and its adjoining area, is well known through the writings of Stoliczka (1866), Godwin Austin (1866), Lydekker (1878-83), Middlemiss (1910), Wadia (1928-34). These stalwarts, not only enhanced the geological knowledge of the area under study, but presented a wider framework of the geology of the whole of the region of Kashmir, within which extensive researches were taken by latter workers to solve certain regional and local problems.

The Palaeozoic stratigraphy of Kashmir with which the present work is concerned, has attracted the attention of geologists for more than a century.

The earliest reference on Palaeozoic rocks of Kashmir is made by Stoliczka (1866), in his Memoir on " Geological sections across the Himalayan Mountain " and by Godwin Austin (1866), on geological notes on parts of the northwest Himalaya and also on the carboniferous rocks of the valley of Kashmir together with notes on the brachiopods by T. Davidson and by Vernewal (1867), who reported a few Palaeozoic fossils from the Kashmir valley.

The first mention of the geology of the area under study was made by Lydekker (1878), on the geology of Kashmir, Kishtwar, and Pongi. He described a number of sections from this area,

from Islamabad to Amarnath and Pahalgam to Sind valley northwest Kashmir. He has given the geological sequence at Aishmuqam areas as under:-

Carboniferous	I	Slates and sandstones with Fenestella, Productus and Spirifer.
	I	Sandstones and dark blue limestones with corals.
Silurian	I	Blue or green slates and amygdaloids.

He regarded slate series as Silurian age, and further mentioned that Carboniferous rocks of Aishmuqam have the same relationship to the Panjal series as have the Kiol series of the outer hills.

In another section from Kashmir to Maru-Wardwan and thence to Kishtwar, he mentioned about the carboniferous rocks in the village Naubug and also the presence of quartzo-sandstones on and near the Margan pass having beautiful broad ripples. The rocks between Naubug and Margan pass consist of Traps mingled with slates. Regarding their structure, he mentioned about the anticlinal axis to the south of Naubug which runs through the Panjal rocks at the synclinal axis at a short distance to the northwest of Margan pass.

Lydekker (1883), grouped all the stratified formations of Kashmir and divided broadly the Kashmir stratigraphy into

five systems, viz,(i) Panjal system, (ii) metamorphic system ,(iii) Zanskar system,(iv) Tertiary system and (v) Alluvial system. Panjal system include the lower Palaeozoics, metamorphic system constitutes gneisses and other metamorphics which range from Archaean to Lower Palaeozoic and the Zanskar system comprises upper Palaeozoic and Mesozoic rocks.

Middlemiss (1910) published his monumental work about the present area of study in his Memoir " A Revision of the Silurian-Trias Sequence in Kashmir " , in which he gave a detailed account of stratigraphy and structure of the present study area and located important fossil horizons. He divided the Silurian-Trias sequence into two main divisions: A and B, which are as follows:-

A Division	B Division
6. Fenestella Series	11. Upper Triassic
5. Passage beds	10. Muschelkalk
4. Syringothyris Limestone	9. Lower Trias
3. Muth Quartzite	8. Zewan Series
2. Upper Silurian	7. Gangamoptris beds, Panjal Volcanic flows and Agglomeratic Slates.
1. Lower Silurian ?	

He described in detail the distribution of all these horizons with respect to lithology, faunal assemblage, structural features, exact location of the fossiliferous zones and prepared a geological map showing the localities

and also some important sections of Liddar valley anticline northeast of Martand-Naubug valley and Wardwan.

Hayden (1910), in his paper " Fenestella bearing beds of Kashmir", besides, describing the nature of Fenestella beds of Kashmir, discussed the age of Muth Quartzite and regarded them as partly Silurian and partly Devonian.

Reed (1915), found some fossil genera of Brachiopods, Trilobites, Gastropods from the Naubug beds and assigned it Lower and Middle Silurian age.

Burrard and Heron (1934), in their work on " A sketch of the geography and Geology of the Himalayan mountains and Tibet", made a mention of the Palaeozoic rocks of Kashmir and suggested the age of Muth quartzite and Fenestella shales as Devonian and Carboniferous respectively.

Gupta (1964-1973), by way of number of discoveries of new fossils improved upon the Palaeozoic stratigraphy of the southeastern part of the valley and on the basis of fresh fossil collections, proposed a new classification of the Palaeozoic rocks of the area.

Some of his important discoveries on these rocks are as follows:-

Gupta (1964), discovered a rich assemblage of fossils from intermediate units of Muth quartzites, hitherto considered unfossiliferous near Naubug in the Anantnag district of Kashmir. The fossils include the representatives of

Brachiopods, Corals, Gastropods, Pelcypods and Cephalopods. The fauna according to the author has definitely a Devonian aspect. The presence of Schizophoria and Athyris Spiriferoids support a middle Devonian age, whereas the presence of Cyrenia heteroclita confirms a middle Devonian age.

Berry and Gupta (1966-67), discovered and described graptolites from the Silurian and the Ordovician rocks of the study area. The species include Clinograptus sp. Didymograptus sp, Glossograptus etc. According to the authors, this fauna had connections with the American-Australian and Asian Ordovician Graptolites rather than with British, European fauna. From the Hapatnar beds they found different species of Monograptus at three stratigraphical levels, the lower horizon yielded Monograptus Colonus type and Monograptus Vulgaris types. Three feet stratigraphically above this horizon, they discovered M.Meintwar dinesis, M.Duvris and M.Uncinatus types and in the third horizon also, M.Colonus and M.Vulgaris. These Graptolites are suggestive of an early and possible middle Ludlow age for the Hapatnar beds.

Gupta (1967), reported a well preserved assemblage of Conodonts from a sample of siliceous limestone, collected from locality near Lutherwan, Anantnag district. The strata yielding Conodonts lie just below the Muth quartzites which

has been assigned middle to upper Devonian age.

Gupta and Denison (1967), described a few specimens of Devonian Dipterus fishes from Margan Pass in a dark calcareous shales that overlie Naubug beds and underly the Muth Quartzites.

On these fossil finds, Gupta described in detail the Ordovician-Silurian and Devonian Systems of Indian sub-continent (1969a-1971a, 1967e) and discussed the problems of Silurian and Devonian boundary of Kashmir Himalaya(1969b). Gupta (1969c) classified the Cambro-Silurian succession of Anantnag district, Kashmir as follows:-

Muth Quartzite	Middle and Upper Devonian
Naubug Beds	Higher upper Silurian to middle Devonian.
Hapatnar beds	Upper Silurian
Unfossiliferous shales	Lower to middle Silurian.
Gauran beds	Upper Ordovician.

Gauran beds have been named by Gupta(1969), from the village Gauran in the Naubug valley of Anantnag district to the fossiliferous beds overlying the lower Ordovocian rocks. These beds contain fossils like Diplophyha, Orthisprasopora etc. These fossils are closely allied to those from the Naungkangyi beds (Ordovician) of northern Shan States, Burma.

Hapatnar beds of Gupta are fossiliferous mudstones and shale containing Graptolites of upper Silurian age. The Naubug beds have been named after the village Naubug while as unfossiliferous and fossiliferous strata overlying the Hapatnar beds have been named as such.

According to Gupta (1969b), these beds are important in that the demarcation of Silurian-Devonian boundary can be drawn between the lower and upper stratigraphic levels found within these beds.

Gupta (1971 1), on palaeontological and stratigraphical grounds has classified Syringothyris Limestone into three zones, viz.,(i) Syringothyris zone, (ii) Productus zone, and (iii) Coralline zone. The first two are best exposed in the Kotsu hill, whereas the upper one is exposed near Ichmar. The Syringothyris zone is of Tournaisian age and has characteristic fossils like Syringothyris cuspidata, Chonates etc. The productus zone have productus semireticularis and Productus lineatus which are of late turvaisian to early Visśean age, while the Coralline zone has yielded a rich assemblage of Rugosa corals such as Nemistium,Palaeoinelia, Lophophyllum etc. This fauna is suggestive of Visean age.

Shah (1972), in his paper " Stratigraphic studies of lower Palaeozoic sequence of Anantnag district,Kashmir "

classified the Palaeozoic rocks of this area into three formations viz., Chaturgal mudstone, Lihinwan sandstone and Margan shales. Most of these formations according to him are composed of splintry shales, pyritous slates, greywackes, calc-arenites and siltstones. From the litholo-gical divisions made by him, only the Margan shales are fossiliferous. According to Shah, these deposits are flysch-like sediments and extra cratonic in nature.

Bhatia and Kokroo (1976), for the first time observed the dolomitization in Syringothyris limestone which is most significant in the western limb of the Liddar valley anti-cline at Kotsu. These observations were based on thin section petrography, differential thermal analysis, staining tests of these limestones. The environments of deposition of this part of limestone has been suggested to be as supra-tidal.

Bhatia and Kokroo (1978), in their paper " Petrographic studies of Syringothyris limestone, Anantnag district, Kashmir " have discussed chemical and mineralogical nature, petrographic types and depositional environments. According to them, the limestones belonging to the lower part are mostly of pure limestone type, whereas the upper part is mainly of dolomitic nature. Within these limestones, they established three main textural types viz., grainstone and packstone, wackestone and mudstones, and sub-varieties like

encrinite, biosparite, biomicrite, pelmicrite, oomicrite; limestones having high percentage of MgO are mostly dolosparites, dolobiosparites and doloocosparites. On the basis of limestone types, sedimentary structures, chemical composition, three main facies viz., tidal flat facies, shallow sub-tidal and deep sub-tidal facies were found. On these evidences, it is concluded by the authors that the limestones were deposited in a shelf type of basin, having three zones viz., X-zone (open sea), Y-zone (barrier), and Z-zone (lagoonal and Sab-kha). These three zones represent three stages of shore to open sea gradually.

Bhatia and Kokroo (1978), on " Sedimentological studies of Agglomeratic Slates, Anantnag district, Kashmir, " discussed in detail the petrography and origin of these rocks. According to them, rocks of this series are mostly welded tuffs, which have been mostly altered , devitrified and metamorphosed. The three types of tuff, viz., vitric, crystal and lithic tuffs have been found, but majority of them belong to intermediate type. There is a gradual progression from vitric to lithic at the base to the conglomeratic one at the top. They have further observed that upper parts of the Fenestella shales have the same nature as that of Agglomeratic slates, as it is also composed of fine vitric type of tuff. Regarding their origin, they have found that the results of the grain size and the morphometric studies

constituting these rocks are comparable to the tuffaceous material of the other regions of the world. They are not at all comparable to Blaini boulder beds, however, some evidences of glacial origin have been witnessed as suggested by Middlemiss (1910).

Pal (1977), during the course of systematic sampling and section measurements in the year 1976, collected for the first time rich assemblage of graptolite fauna from the entire upper Cambrian to lower Devonian rocks of Kashmir. In this work, the assemblages are represented by numeous genera, which helped in the clasification of the hitherto unclassified Cambro-Silurian slate-phyllite -greywacke sequence of eastern Kashmir. In Liddar valley, graptolites were obtained by him from both the southern and northern limbs at Gugaldar, Shumhal sections representing the Liddar valley anticline. These sections were found to contain Dictyonena-bryeograpta (Upper Cambrian to Lower Ordovician) and Dicronograptida- Basiograptide etc. in upper Ordovician.

Pareek (1977), in his paper " Agglomeratic Slates and Panjal Traps in the Jhellum ,Liddar and Sind valleys Kashmir", considered the Agglomerate series as representing the pyroclastic nature of the volcanism, in which the constituents were blown up into the atmosphere inflated by gas. The deposit was under the influence of gravity and the resulting product compacted and solidified to form Agglomerate, glassy rocks and welded tuffs. According to him, the Agglomerates show coarse banding, well rounded iron ore rich grains with or without glass, or devitrified

in many cases.

Shah (1978), in his paper " Facies pattern of Kashmir within the tectonic framework of Himalaya" described Liddar valley section in addition to other areas of Kishtwar, Poonch,and Hundwara and Shamasbari sections, where these rocks are exposed. According to him, the facies variation in these areas indicate a lateral interfingering between the Tethyan and the Himalayan facies with the basin in Devonian and Carboniferous.

Besides these important contributions, which deal directly with the present area of study, there is other relevant literature on the Palaeozoic rocks of the adjoining areas of the Himalaya, which is as under;-

G-reisbach (1891), in his paper " Geology of Central Himalayas" made a mention of Muth Quartzites and considered these as Carboniferous in age.

Middlemiss (1911), made a detailed study of the Pir Panjal and Sind valley. His observations were markedly different from those of Lydekker (1883). He described sections along the Nil Nag- Tatakuti and Gulmarg -Aparwhat lines of route and also along the Gulabgarh pass which was examined by him in the year 1909. As a result of this study, he found that the central high peaks which formed water shed are composed of varieties of Panjal Trap or Agglom-eratic

slates on the younger Gondwana series. Formations of lower Gondwanas, Permo-Carboniferous limestones, and shales and upper Triassic limestone were observed along the north-east slope.

Bion and Middlemiss (1928), described the fauna of the Agglomeratic Slate series of Kashmir and discussed at length its faunal affinity with other Provinces. On the basis of this fauna, they suggested its age as Muscovian for the lower part.

Wadia (1928), on the geology of Poonch area referred about the great Palaeozoic unconformity. According to him this regional unconformity is not seen in Kashmir on the other side of the Pir Panjal, it being represented there by a unique development of all the Palaeozoic systems, Silurian, Devonian, lower and Middle Carboniferous. But towards the northwestern Kashmir and Hazara, this unconformity brought Panjal volcanic series above the Silurian. According to Wadia, this unconformity point out the existence of Panjab-Kashmir Hazara land mass during the Dravidian Era. In this work, Wadia has also advocated the pyroclastic nature of the Agglomeratic slates.

Wadia (1934), gave a comprehensive account of the geology of northwestern Kashmir, in which he has shown the total absence of Palaeozoic rocks due to mid-Palaeozoic

unconformity of northwest Kashmir. According to him with the exception of small patches of Muth quartzite, the Silurian rocks are succeeded by the Panjal Volcanic series.

Ganju (1957), in his paper "Physiography and geology of the area around Gulmarg" described the succession of rock formations from Precambrian to Pleistocene, giving a detailed account of the Salkhala series, Dogra slates, Tannawal series, Agglomeratic slates, Triassic and Kerawas.

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Ganju and Srivastava (1961), studied Agglomeratic slates near Bren, Kashmir and found two types viz., coarse grained and fine grained. Their coarse grained varieties compose of unsorted angular debris consisting of quartz, feldspar and rock fragments, which lie in an abundant devitrified glassy matrix. The fine grained variety is predominantly glassy and contains numerous dark , lensoid patches of partially devitrified glass, which probably represents the drawn out and collapsed pumice lapilli. The presence of glass in cracks in quartz grains indicate that the tuffaceous debris was very hot and mobile at the time of formation. On the basis of these characters, they suggested that the rocks were originally rhyolitic crystal vitric welded tuffs, which have been subsequently metamorphosed, devitrified and altered to a feldspathic quartz sericite slate.

Das Gupta (1971), published a paper entitled " On textural characteristics of the Muth quartzite of Spiti

and Kuti regions, Central Himalaya. " in which he has shown the presence of supermature quartz arenite with a special bimodal distribution , which according to him is typical of deflationary dessert flats. On this basis, he has inferred an Aeolian origin for the upper member of Muth-quartzite.

CHAPTER -III

STRATIGRAPHY

S T R A T I G R A P H Y

GEOLOGICAL SET UP OF THE AREA WITHIN THE BROADER FRAMEWORK OF HIMALAYA

The area of study forms a part of Kashmir Himalaya, which is divisible into three distinct tectonic zones, viz., the Foreland Zone, Autochthonous Zone and the Nappe Zone. It is within this Nappe Zone (Kashmir Nappe, Wadia, 1928), that the area under present investigation lies. The Kashmir Nappe consists predominantly of Precambrians which form the floor of the Himalayan Geosyncline, that has been forced up and thrusted forward in a big recumbent fold. On this old basement, lies the synclinal basin, consisting of rocks of almost all the ages upto Recent.

The rocks of the area form a part of the famous Palaeozoic sequence of Kashmir, developed along the southeastern part of Kashmir valley. The valley itself lies between the Great Himalaya and the most westerly range of the Lesser Himalaya, Pir Panjal (Plate - 2). It is an ellipse shaped patch, where the fossiliferous Palaeozoic rocks are exposed. The long axis of the ellipse is northwest to southeast, which corresponds to the axis of the broad anticlinal flexure; in which the whole series of the Palaeozoic rocks are folded. The typical exposure is near Kotsu-Aishmuqam, where the most ancient fossiliferous rocks of Kashmir-the Cambrian and Ordovician have been exposed in the central

part of the denuded anticline, flanked on its two sides successively by thinner bands of the younger formations, Devonian and Carboniferous rocks. The sedimentary basin of Kashmir merges into the Spiti basin where similar rocks are exposed.

STRATIGRAPHIC SEQUENCE

Since Lydekker (1883), classification of Palaeozoic rocks of Himalayas, number of attempts have been made to classify Palaeozoic rocks of present area of study (Middlemiss, 1910, Gupta, 1969, Shah, 1972). Middlemiss classification of these rocks is most outstanding and classic one and later workers suggested further sub-divisions within the broader framework of his classification. He subdivided these rocks into two major divisions, viz., A and B (A, below the Panjal Volcanics; B, above the Panjal volcanics.). The subdivision of the formations below the Panjal volcanics, within which the present area of study is concerned, is as follows:-

Division A

6. Fenestella Series
5. Passage beds.
4. Syringothyris limestone
3. Muth Quartzite.
2. Upper Silurian
1. Lower Silurian ? Cambrian.

Gupta (1967-69) on the basis of fossil collection of fish, further classified the Silurian-Devonian rocks into Gauran beds (Upper Ordovician), Hapatnar beds (Silurian) and Naubug beds— demarcation of Silurian-Devonian Boundary. He also classified the Muth Quartzites into lower, middle and upper parts and suggested middle Devonian age for the middle division. For Syringothyris Limestone Gupta proposed three divisions, viz., (i) Syringothyris Zone,(ii) Productus Zone and (iii) Coralline Zone.

These classifications have primarily been made on the basis of palaeontological wealth found in these rocks and have been useful in the interpretation of geological structure of the area, demarcation of various biostratigraphic units and in the correlation of local faunal assemblages, with that of other Palaeozoic Provinces. No attempt was made to classify Palaeozoic rocks of Anantnag district on the basis of lithostratigraphy.

In this work,however, a lithostratigraphic classification has been proposed in which the Palaeozoic rocks of Anantnag district have been divided into three main groups. Each group is further subdivided into few formations and members. The grouping of the sequence has been made on the basis of facies principle, so that even rocks dissimilar to each other but having similar consanguine^ous relationship

TABLE-4

LITHOSTRATIGRAPHIC CLASSIFICATION OF PALAEOZOIC ROCKS OF ANANTNAG DISTRICT, KASHMIR.

GROUP	PROPOSED FORMATION	MEMBER	LITHOLOGICAL CHARACTERS	EXISTING NOMENCLATURE	AGE
VOLCANIC CLASTIC GROUP	Batkot formation	Upper	Rudaceous type predominates and consisting of conglomerate and breccia types.		Upper Carboniferous
		Middle	Partly altered lithic tuff predominates	Agglomeratic slate	
		Lower	Altered crystal tuff and vitric tuff with alternating bands of shales.		
	Yenner formation		Consisting of fine grained altered vitric tuff with quartzites and shales, and also some basic intrusives.	Fenestella shale	Middle Carboniferous
Orthoquartzite-carbonate Group.	Cindermar Gali Formation		Unfossiliferous quartzites and shales	Passage beds	Carboniferous-Devonian.
	Aishmuqam formation.	Upper	Grey to dark coloured, hard, flaggy, limestones and dolostones with intercalated shales and quartzites.	Syringothyris limestone	
		Lower	Grey to greyish black, hard, flaggy limestones intercalated with shales, and quartzites.		
	Gurderman formation		Hard, white to greyish quartzites with bands of siliceous limestones.	Muth Quartzite	
Shale-slate-greywacke group.	Hapatnar formation	Upper	Siltstones, slates, mudstones and associated with thin bands of quartzites.		Cambro-Silurian
		Lower	More argillaceous, with slates, phyllites mudstones and claystones etc.		
	Gauran formation	Upper	Phyllites, siltstones and greywackes.		
		Lower	Shales, greywackes, siltstones and phyllites.		

have been grouped together. The chief merits of the proposed lithostratigraphic classification are as under:-

1. The specific formation or a particular unit of a formation even in the absence of fossils can be recognized and correlated on the basis of lithological characters. In the lower Palaeozoic rocks especially fossils are few and unequally distributed. This lithostratigraphic classification is, therefore, useful in recognizing specific horizons.

2. Each group is based on certain specific physical, chemical and tectonic set up and each member within it has a consanguineous relationship indicating similarity in depositional environments.

3. The successive groups with distinct depositional environments in a vertical sequence ultimately point out the evolution of the basin, in which these rocks were deposited and are thus helpful in reconstructing palaeogeography.

The following is the stratigraphic sequence proposed in this work:- (Table-4).

1.SHALE- SLATE - GREYWACKE GROUP

The lowermost portion of Palaeozoic sequence of eastern Kashmir essentially consists of semi-metasediments consisting of slate, shale, phyllite, and greywackes, etc. Although

the rocks are not totally unfossiliferous, but the fossils are quite indeterminable and very erratically distributed. Middlemiss (1910), broadly considered this division as " Older Silurian and Cambrian ? " and did not further subdivide the sequence. Gupta (1966-69), on the basis of discovery of graptolites and other fossils subdivided the Cambro - Silurian sequence into Gauran, Hapatnar and Naubug beds. According to him, Gauran beds are referred to fossiliferous shales of Ordovician in age, Hapatnar beds to Silurian beds, Naubug beds to strata, demarcating the Silurian -Devonian boundary between the lower and upper stratigraphic levels.

Shah (1972), subdivided the Cambro-Silurian sequence of Kashmir on the basis of lithostratigraphy, into three divisions viz., Chaturgal mudstone (200 m) , Lihhinwan sandstone (2370 m) and Margan shales (555m). According to him Chaturgal mudstone is the oldest unit in the entire area consisting of mudstone and shales well exposed in the Haribal valley and also near Khyar in Hapatnar valley. Lihhinwan sandstone unit is composed of greywackes and sandy phyllites, whereas the Margan shale unit consists essentially of shales. He further says that it is the only formation containing determinable fossils and the Hapatnar beds, Naubug beds and the Gauran beds of Gupta (1966-1971), seem to refer to various parts of this formation and that these names have been applied on the basis of local lithology and the faunal assemblages.

Pal (1977), discovered a rich graptolite assemblage in the Cambro-Silurian sequence of Liddar valley area and on this basis he classified these rocks. The Graptolite genera reported by him are Dictyonema, Bryograptus, Didymograptids , Dicranograptida- Basiograptid, Monograptus Cyrtograptus- Linograptus marked the position of the upper Cambrian, Lower Ordovician, upper Ordovician and Lower to middle Silurian respectively.

In this work, the subdivisions have been made on lithological basis, as fossils in these rocks are restricted to a few pockets only and are not equally distributed. The basis of subdivisions for this group is on sand-shale ratio, nature of the sandstones and the textural-cum -structural features and degree of metamorphism. On this basis, it has been found possible to subdivide this group into two main units, viz., Gauran Formation and Hapatnar Formation.

GAURAN FORMATION

This Formation has been named after the village Gauran located northeast of Qusba Naubug on the left of the river Bring, passing through the Naubug valley (Plate-51). It is equally well represented in and around the village Lihhinwan extending upto Hangalpao and the basal parts of the village Hapatnar. In this Formation, two members have been recognized

(i) Lower Gauran Formation and (ii) Upper Gauran Formation. The detailed lithological characters of these members are as follows:-

(i) The lower member of this Formation is characteristically composed of interbedded sandstone with sandy phyllites and shales. The most important sandstone type present in this Formation is the greywacke, which is grey to greyish black in colour and massive at places. The graded bedding, cross lamination and the sole marking is the characteristic feature of these sandstones. The intermixed phyllites, sandy phyllites and shales are highly metamorphosed/ foliated with low foliation angles. The foliation pattern is almost parallel to the anticlinal axis. The greywacke type of sandstones are chiefly composed of quartz, feldspar , rock fragments(metamorphic and igneous) and the matrix composed of sericite and quartz material.

This Formation is exposed in the village Gauran and adjoining Lihhinwan in the Naubug valley and extends upto Hangalpoa southeast of Shumhal,Liddar valley which forms the core of the Liddar valley anticline. Near Mathihundu some siliceous bands of limestone are also present. The fauna present in the patches near Gauran are: Orthis (Dalmanella, Flexical-ymene - stubblefieldi etc.).

(ii) The upper member of this Formation is slightly different in having higher percentage of shales and phyllites as compared to lower member. In addition, some sandstones of wackestone types alongwith siltstones are also found. In this member, sandstone bearing turbidite structures like cross, lamination, graded bedding, etc. are less well developed as compared to the lower part. Quartz and rock fragments are the chief constituents of these rocks, but the distribution of quartz varies from type to type. Quartz present in the wackestone type of sandstones is high, whileas it decreases from shale to Siltstones. This member of Gauran Formation is exposed both in the Naubug and Liddar valleys. It extends upto lower and middle parts of the Hapatnar and Gugaldar in Liddar valley, whereas in the Naubug valley, it extends from the upper portions of village Mathihund and the lower parts of the Gauran and Margan pass. The nature of the bedding, i s highly jointed and foliated in the Naubug valley. Gupta (1966), on the basis of fossils of Brachiopods and Trilobites fixed the age of this member as Ordovician.

HAPATNAR FORMATION

The younger Formation of the shale-slate-greywacke group lying over Gauran Formation overlain by Muth Quartzite is named as Hapatnar Formation from the village Hapatnar (33° 50' 56" ; 75° 20' 52"). Gupta (1966), also used the same nomenclature for Graptolite bearing beds of Hapatnar (Silurian).

This formation is, however, more argillaceous in character, such as muddy siltstones, mudstones, slates, phyllites are dominating with partings of sandstone. On lithological basis Hapatnar formation is further divided into lower and upper members.

(i) Lower Member: The lower member consists of mudstones, siltstones, phyllites and slates showing some turbidite features. It is more muddy with fine grained shales, siltstones which have entombed in them the graptolite fauna (Gupta, 1966; Pal, 1977). Associated with them are phyllites and slates. The phyllites are very much metamorphosed and have copper encrustation at Shumhal and show gradual contacts with the slates.

(ii) Upper Member: The upper part of this formation has been located with some gradual, abrupt contacts of sandstones and protoquartzites intermixed with thin bands of shale, slate and phyllites. The slates are mostly fine grained with chloritic matrix. The sandstones of this member are clearly distinguishable than the greywackes of the Gauran formation.

The Hapatnar formation is exposed in the Liddar valley near Hapatnar, Shumhal, Reitang and towards south of Gugaldar. In the Naubug valley, it is exposed along the northeastern part of Lihhinwan, Margen etc. and extends upto Hapatnar towards south-eastern part on the village Mathihund to Reitang in Liddar valley.

On the basis of the fauna reported by the earlier workers Gupta (1966), Pal (1977), upper Silurian age has been delineated.

ORTHOQUARTZITE -CARBONATE GROUP

Shale-slate greywacke group of rocks are overlain by a thick pile of sequence, consisting of quartzo-sandstones of various types, intercalated with limestone beds, characteristic of a stable shelf or of a plateform facies. These deposits represent a definite stratigraphical horizon, not only in the Palaeozoics of Kashmir, but have been found occupying the same position in the adjoining Spiti basin and eastern Himalayan region. This group is well represented in the present area of study, especially in the Liddar valley, although some good exposures of quartzites have been found in the Naubug valley as well. Surprizingly, this group is not well represented in the northwestern Kashmir (Wadia, 1934), where Tannawal type of rocks have been developed at their expanse. Middlemiss (1910), classified these rocks into (i) Muth Quartzite, (ii) Syringothyris Limestone, (iii) Passage beds. Gupta (1971), also retained the same nomenclature but further subdivided these formations into different zones. In the present work, the same scheme has been followed, although local formational names have been suggested, such as Gurderman formation, Aishmuqam formation and Cinderman Gali formation. In a deposit of such a long aerial extent , local facies characteristic features are bound to develop and the suggested formational names represent these local characters. The chief characteristic features of these deposits are as follows;-

MUTH QUARTZITE (GURDERMAN FORMATION)

The term 'Gurderman formation' is a local term suggested for the Muth Quartzites of Anantnag district, after the village Gurderman (33°40' 33"; 75° 23' 25") in the Naubug valley, where it is typically developed. Gupta (1964), discovered a rich assemblage of invertebrate fauna from the same locality in these deposits, which were hitherto considered unfossiliferous.

This formation is wholly composed of a thick sequence of quartzites and quartzo-sandstones, with thin shale partings at places. The quartzites are mostly hard, massive, having snowwhite colour. The white colour predominates , but at places, there are spots and patches of ferruginous material. Most often, this material is in the form of pyrite cubes of various sizes, which have been altered into limonite. Though apparently uniform, many varieties and types of rocks have been found in these quartzites, depending upon their textural and compositional peculiarities. Most of these quartzites have interlocking arrangement of grains due to diagenetic growths. Bimodal distribution of grain fequency is another characteristic feature of these quartzites, which led certain workers (Das Gupta, 1971), to believe them to be of Aeolian derivation. The heavy minerals like Zircon, Tourmaline, and rutile are found in very minor amounts. The primary sedimentary structures found in these rocks include well developed

ripple marks, planar and herringbone type cross bedding etc. Gupta (1964) discovered a number of fossils, which include representatives of Brachiopods, corals, Gastropods, Pelcypods, Trilobites and Cephalopods. These fossils were collected from the locality (SW GURDERMAN 33°.44': 75°.23'E) from the intermediate units, while the lower and the upper units of these quartzites are unfossiliferous. Prior to Gupta (1964), Hayden (1910), also considered them of Devonian age, while other workers like Stoliczka (1866), Griesbach (1891) and Middlemiss (1910), assigned ages ranging in between Upper Silurian to lower Carboniferous.

Gurderman Formation is exposed in both the Naubug and the Liddar valleys. In Liddar valley, it is exposed in Gugaldar and upper parts of the Hapatnar in the form of a very prominent cliffs and precipices at the surface making a distinct topographic feature in the area. The thickness becomes maximum near Gugaldar. In the Naubug valley, the Gurderman formation, is extended towards south, though much reduced in thickness, and passes into the Margan Pass.

SYRINGOTHYRIS LIMESTONE (AISHMUQAM FORMATION)

The Muth Quartzites are overlain by Aishmuqam formation which represents Syringothyris Limestone of Liddar valley. This formation is typically developed in an isolated hillock in Kotsu village (33° 50' 58": 75° 14' 05") 20 miles, north west of Anantnag and towards the left bank of the river Liddar

at Aishmuqam (33° 52' 05" : 75° 17' 22") as two limbs of the Liddar valley anticline.

Syringothyris Limestone is not wholly composed of limestone, as the name indicates, but it is frequently interbedded with quartzites and shales. The proportion and position of these quartzites and interbedded shales differ in different sections. (Sharma and Sehgal, 1976) have reported a thick pessage zone of quartzite and shales, which occur in between the Muth Quartzites and the Syringothyris limestone from Aishmuqam-Ayunu-Chander Nar Gali area. It is on account of these local characters of Syrongothyris limestone which vary from place to place, the term Aishmuqam Formation has been used in purely local sense.

The limestone constituting this formation, occurs in many bands. The uppermost band is more than 300 feet thick, whereas the central and the basal limestone bands are comperatively thinner. Gupta(1971), on the basis of fossils, has divided the Syringothyris Limestone into three distinct zones: (i) Syringothyris zone, (ii) Productus zone and (iii) Coralline zone. In this work, however, it was found convenient to divide the limestone into two distinct units, lower and upper, purely on lithological considerations. The main difference between the two units, is their degree of dolomitization. The rocks of the lower unit show incipient to partial dolomitization, while as the upper unit has undergone almost

almost complete transformation. On the basis of varied types of allochems present in these rocks, various types of limestones such as biosparite, oosparite, encrinite, micrite and biomicrite have been recognized in the lower unit; While the upper unit have types like dolosparite, dolomicrite, dolo-oosparite,etc.

The sandstones and quartzites associated with these limestones, though apparently similar to Muth Quartzites differ considerably in their textural and compositional peculiarities. Interlocking type of grain packing so characteristic of Muth Quartzites,is no more found in these sandstones. Bimodal distribution of grain frequency is also lacking. There is , however, lesser amount of quartz and higher amount of cement/ matrix, in these sandstones associated with Syringothyris Limestone. The sedimentary structures observed in these quartzites like cross-bedding, ripple marks, sun cracks , tail and tracks are quite similar to that of Muth Quartzite.

Syringothyris limestone has yielded a rich invertebrate fauna like Brachiopods,Corals, Crinoids and Lamellibranchs. Among these, Syringothyri-s, Productus ,Athyris etc. represent Brachiopods; Caninophyllum, Lophophyllum,Pseudocaninia and Caninia belong to Corals. According to Gupta (1973), these forms are of lower Carboniferous affinity and the fauna is suggestive of Visean age for the upper part of the Syringothyris Limestone.

This formation is exposed both in the northern and southern

parts of the study area, although it is best developed in the northern parts. In the Liddar valley, it is exposed at Kotsu in the western limb, of the Liddar valley anticline, while in the eastern limb it is exposed at Aishmuqam with a moderate north-easterly dips. It has a northwest-southeast trend and extends beyond Ichnar. On the west, of Naubug valley, it is exposed as faulted thin band showing southwesterly dip.

PASSAGE BEDS (CINDERNAR GALI FORMATION)

This formation represents passage beds of Middlemiss (1910), which according to him are intermediate rocks consisting of quartzites, sandstones and shales. It is petrologically linked with the Fenestella series above rather than with the limestone series below.

Sharma and Sehgal (1976), in their paper " Some new observations on the stratigraphy and structure of Liddar valley anticline" observed that there is no passage zone between the Syringothyris limestone and the Fenestella shales, as seen in Ayunu-Pindobal-Ziarat Section, where instead it occurs between Fenestella shales and the Agglomeratic slates. According to them, a similar situation exists in Kolur-Kollerina-Salar and Kotsu spurs. A thick passage zone also exists between the Muth Quartzites and Syringothyris Limestone, as seen in Aishmuqam-Ayunu-Chander Nar Gali area. It is, therefore, clear that passage beds as such, have no stratigraphical significance,

as unfossiliferous quartzites and shales can be found in any position from Muth Quartzites to Fenestella shales. In this work, therefore, the term 'Cindermar Gali Formation' has been used to represent a thick pile of unfossiliferous white, grey, purple quartzite with shale and slate partings occurring between Muth Quartzite and Fenestella shales. This formation has been named after the village Cindarmar (33°51' 40": 75° 20' 52") towards the northeast of Aishmuqam, where it is typically developed.

Petrologically, much similarity has been found between quartzo sandstones of this formation and that of quartzites found associated with Syringothyris limestone, whileas these are somewhat dissimilar to Muth Quartzites. On these observations, it has been inferred that quartzites of Passage zone represent simply a facies variation of Syringothyris limestone and have been developed due to local environmental conditions at the expanse of the Syringothyris Limestone.

This formation has been exposed NNE of Aishmuqam and extends upto Liwapathar (33° 54' 06": 75° 16'),Kollur (33° 54' 06" : 75° 16'), and upto Aynu (33° 51' 58": 75° 18').

VOLCANIC CLASTIC GROUP

The Orthoquartzite Carbonate group is conformably overlain by a suite of rocks which have very complex petrological characters, being composed of fragments of different rock types embodied in greywacke type of matrix. By and large

these deposits are considered to be of pyroclastic nature (Middlemiss, 1910, Ganju and Srivastava, 1961, Pareek, 1977), and, therefore, named as Agglomeratic slates. Underlying these Agglomeratic Slates are Fenestella shales, being composed of black sandy shales crowded with Fenestella alongwith Brachiopods and other fossils. There are also other evidences to prove that major part of these deposits are of similar nature to that of Agglomeratic slates, as there is much textural and compositional resemblance between the two. Even Wadia (1959), has written that " its relation with overlying volcanic Agglomeratic Slates are perfectly conformable and even transitional". Some of the black shales being crowded with pyroclastic and glassy debris, crystals of feldspar quartz etc.

In this work, therefore, both Fenestella shales and Agglomeratic Slates have been included in one group, viz., Volcanic Clastic Group.

This group is primarily well exposed on the northern side of the study area, while on the southern side, it is not so well developed. This group is subdivided into the following two formations:-

1- Agglomeratic Slate (Batkot Formation)
2- Fenestella Shales (Yenner Formation)

The chief characteristic features of these formations are as follows:-

1.FENESTELLA SHALE (YENNER FORMATION)

Fenestella shale is the name given to a 500 m thick succession of varied type of fossiliferous shales, unfossiliferous quartzites and welded tuffs. This unit is well developed in the vicinity of Yenner (33° 54' 10" : 75° 17') on the left bank of river Liddar, just 15 kms southwest of Pahalgam(34° 01' 17"; 75° 19' 04"). The term'Yenner formation' is suggested which can serve as the best local name for these deposits,as these are not wholly composed of shales.

The shales are of various colours and shades ranging from greyish white to greyish black. Most of them are composed of vitric type of tuffaceous material and some of them even show characteristic type of vitroclastic structure. These shales especially of lower horizon are crowded with Bryozoan fossil Fenestella alongwith shells of Brachiopods, Lamellibranchs and Crinoid stems. Among Brachiopods, Productus and Syringothyris are commonly associated with these shales.

The quartzites found alongwith these shales are of similar nature as that of quartzites of Passage beds. These are mostly of arkosic type. Symmetrical ripple marks with straight crests are found in these quartzites.

These deposits have been regarded as of Carboniferous in age, ranging from lower Carboniferous (Verma,1969), middle Carboniferous (Wadia, 1928),to upper Carboniferous (Burrard and Hayden,1907).

This formation is well exposed in the area of study. The formation has a northwest-southeast trend on the eastern side showing dips of about 40 to 50 north-east. The best exposures are found near Yenner (33° 54' 10" : 75° 17'), Sruchhin (33° 55' 15" : 75° 17' 15"), Gagarpather (33° 52'35": 75° 19' 10"), Salar (33° 52' 28" : 75° 15' 03"), Kullar (33° 54' 35" : 75° 15' 50"), Paran (33° 53' 22": 75° 15' 56"), Rasta (33° 53' 37" : 75° 16' 05").

AGGLOMERATIC SLATE(BATKOT FORMATION)

Fenestella shales are overlain by a hetereogenous type of deposits consisting of shale, slate, sandstone, quartzites, tillodés and conglomerates commonly named and described by Middlemiss (1910), as Agglomeratic Slates. As these deposits are best exposed near Batkot (33° 56' 22" : 75° 17' 42"), the term 'Batkot Formation' is suggested.

These deposits though apparently hetereogenous, have one com-mon feature of their being of pyroclastic in origin. It is quite evident from textural and compositional features of these deposits. There are two types of deposits ,viz., (i) Rudaceous type and (ii) fine grained type. The larger fragments are usually composed of quartz, feldspar, slate, quartzite and granitic material embodied in a greywacke type of matrix, composed chiefly of angular grains of quartz, sericite, and clay. The predominance of angular grains impart it a typical breccia-like appearance to most of the rock types.

The presence of fragments with resorption borders, vitroclastic texture and glassy shards in these deposits are some of the strong evidences of their pyroclastic origin. Most of these are welded tuffs, depending upon the predominance of various constituents. All the three types of tuffs,viz., vitric, crystal and lithic types have been found in these deposits. From base to top, a regular gradation from vitric to lithic type is seen. The deposits become more conglomeratic at the top.

Most of these deposits have been metamorphosed, divitrified and altered to a feldspathic quartz-sericite slate. In the study area, no fossil has been found in these deposits except near Prangam (33° 54' 18" : 75° 20' 22")(Gupta and Fuchs,1971), although from other localities some fossils like Fenestella, spirifer, productus, Eurydesma etc. indicating an age from middle Carboniferous to lower Permian (Gupta,1973).

This formation is well exposed in the northern part of the the study area at places like Batkot (33° 56' 22"; 75° 17' 42") Dohwat (33° 55' 41" : 75° 16' 33"), Vir Saran (33° 56' 52"; 75° 17' 36"),Prangam (33° 54' 18" : 75° 20' 22") and above Kullar (33° 54' 35" : 75° 15' 50"),while as in the southern part it is interbedded with Panjal Traps near Tangwani (33° 38' 56"; 75° 23' 12") in the village Naubug. This formation becomes gradually thinner towards the eastern parts,till the outcrops pinch with the Panjal Traps.

MAJOR STRUCTURES OF THE AREA

The area forms a part of the Kashmir Synclinorium (Palaeozoic-Mesozoic rocks), being present towards its southeast corner, where it forms a broad anticlinal flexure consisting of Palaeozoic rocks. Within this broad anticlinal flexure, of anticlinorium of(Middlemiss, 1928), are present a number of anticlines and synclines, of which a famous anticline (Liddar valley anticline- Middlemiss (op.cit.) and its complementary syncline have been noted in the area under investigation. (Plate - 51). The central parts of these structures have considerably been denuded as a result of which larger parts of these have been exposed.

The detailed structural study of the area under reference could not be covered under the present study; however, a broad description of some of the major structures noted in the area are given below:-

1-FOLDS

(a) <u>Anticline:</u> The famous Liddar valley anticline is present in the central part of the study area, showing NW-SE strike and a steep plunge towards NNW (Koul,1976). It occurs in the beds of Gauran and Hapatnar formations with overlying Ash-Muqam formation. The lower Gauran formation present towards the central part of the anticline and upper Gauran formation, lower and upper Hapatnar formations constituting its limbs respectively. The beds show an average dip of 40° towards SW and an average dip of 55° towards NE (Plate - 51).

The rocks of the Aish Muqam formation near Kotsu show a dip of 55° due SW and near Aish Muqam with an average dip of 30° NE. It is here that the anticline is plunging and dies out.

(b) Syncline: A complementary syncline of the Liddar valley anticline is recognizable near Margan pass area (outside the scope of present investigation- this area is part of Kishtwar tehsil of Doda district). Here the syncline plunges towards SE with the strike of NW-SE. Part of this synclin-e (left limb) is shown in Plate-51 . From the description given by Middlemiss (1928), it is evident that the rocks entering into the Margan valley syncline are composed of Cambro-Silurians and Muth-Quartzites and Panjal Trap present in the central part of the syncline. Its northeastern continuation has not been fully demarcated as yet, because of its being covered by perenial snow and consistent soil cover.

FAULTS

A number of faults have been recognized in the field. A major one of these is an fault running in NNE-SSW direction recognizable near Kotsu and Batkot. Most probably part of it is hidden by river Liddar, which maintains remarkably a straight course -probably controlled by this fault. As a result of this fault the younger Agglomeratic slate (Batkot formation) has been brought in juxtaposition with the older yenner shales/ quartzites in the area between Batkot and Kotsu (Plate-51). The displacement of this fault is nearly 1500 m. A lot of crushing of the rocks is noted near Ganeshpur, Yenner and Kotsu,

and some other areas close to the fault line, most probably as a result of the movement caused by this structural break.

An another fault of the smaller magnitude has been recognized near Maiteng area, running West -north-west -East south-east direction. As a result of this fault, the beds of Muth quartzite , Syringothyris limestone etc. near Treswar, have been displaced by nearly a kilometer. Parts of this fault are covered by loose material, hiding its true extension.

PETROGRAPHY OF SHALE-SLATE-GREYWACKE GROUP

The basal Palaeozoic rocks in the Anantnag district of Kashmir within the area of study constitute intermixed assemblage of undifferentiated shale, slate, phyllites and greywackes ranging in age from Cambrian to Silurian. Middlemiss (1910), designated this assemblage of rocks as Cambro-Silurian slates. Wadia (1934), expressed the similar views about the lower Palaeozoic rocks of Kashmir. Gupta (1965-69), and Pal (1977), attempted to classify these rocks on the basis of sporadic fossils particularly the graptolite fauna found in these rocks from the locality Hapatnar(33° 49' 45"; 75° 20' 55"). Gupta classified these rocks into three main divisions of each formation viz., lower, middle and upper units of the Ordovician and Silurian formations. Shah (1972), on the lithostratigraphic basis, reclassified the lower Palaeozoic rocks into three main divisions, viz., Chaturgal mudstone, Lihhinwan sandstone and Margan shales.

No earlier worker has so far worked out its mode of origin and the mechanism of deposition. In view of these facts, there is little literature available on these rock formations.

In this work, therefore, an attempt has been made to study in detail the compositional, textural and structural features of these rocks individually to determine their provenance and the environments of deposition with respect to their

petrology and to determine their facies.

The sedimentary rocks found in this group are generally considered to be representative of geosynclinal suite. These rocks are slightly metamorphosed and the rock units include epiclastic (non volcanic), siltstones, clay stones, mudstones, wacke stones and thin bands of limestones. Although these rock types merge into one another and have intertonging nature, two well defined units named as Gauran Formation and the Hapatnar Formation have been delineated. These two units are based on sand, silt and clay ratios with other textural and structural features. The Gauran Formation is more sandy, mixed with shale, while as the Hapatnar Formation is more mudy mixed with siltstones and thin layers of sandstones. These rocks have undergone slight metamorphism, but it is not uniform and there is a gradation from relatively unfoliated sedimentary rocks to slate and phyllites, sometimes even to schists.

For the purpose of petrographic description, both Gauran and Hapatnar Formations have been separately studied with respect to their composition, texture and structure; facies types and the mechanism of deposition.

The results are as follows:-

PETROGRAPHY OF THE GAURAN FORMATION

COMPOSITION

This formation consists of wackstones, sandstones intermixed with clay and phyllites. These sandstones are

hard, indurated, greenish-white to greyish-black in colour. The characteristic features of the sandstones of this formation are as follows:-

GREYWACKE TYPE OF SANDSTONES

This type of sandstone found in Gauran Formation has high percentage of matrix, typical micro-breccia texture, broken framework and floating nature of the grains, hence these are classified as Greywackes.

Pettijohn (1957), used 15 percent matrix as the defining limit between greywackes, arkosic and lithic sandstones. Recently, Pettijohn (1965), modified this limit to 20 percent. Dott(1964), however, has shown that in many sandstones certain percentage of matrix is secondary, formed due to squashing of the included soft rock fragments. Gauran sandstones, however, do not contain much soft material, hence 15 percent matrix is quite reasonable to consider them as greywackes.

The typical nature of these sandstones is shown in Plate-9 fig nos. 1 to 6, as seen under microscope. In all these photo-micrographs, sandstones have broken framework, floating nature of the grains in the matrix, poor sorting and angular to sub angular form. Angularity is more pronounced with poor sorting (Plate-9 fig 2,3,4 and 6). The micro-breccia like appearance is typical texture of these sandstones, as seen in

Plate-9 figs 3,4 and 6. However, photomicrographs (fig.1 of Plate-9) show a well developed graded bedding in which the finer fraction constitutes abundant matrix, except some minute particles of quartz.

The framework constituents include quartz, feldspar and rock fragments. Their modal composition is shown in table-5

The quartz grains constitute 30.63 to 62.36 percent of the total bulk of the rock. These are mostly angular to subangular, at places subrounded. The size ranges between 0.1 mm to 0.4 mm, and the grains less than 0.1 mm have been considered with matrix. Most of the grains are monocrystalline, but some poly-crystalline grains have also been observed. The edges of the quartz grains are often embayed or sutured, rarely the edges grade outward into the matrix. Authegenic overgrowths of these grains has not been observed in any section. Most of the grains show non-undulatory extinction, although in some cases, undulatory extinction has been observed. The quartz grains are mostly angular to subangular as tabulated in Table No. 7 .

Feldspars found in these sandstones are in the range of 1.91 to 9 percent only. Most of these grains are altered, although polysynthetic twinning is seen in some cases. Alteration has affected mostly the edges, which appear to grade into the matrix. The size of these grains is less, as compared to

quartz grains.

Rock fragments of varied sediments, usually of bigger sizes than that of quartz grains, have been seen. The size of these grains exceeds at places 0.5 mm as seen in Plate-9 fig 5. These rock fragments consist of ferruginous shales, phyllites, schists and quartzites. The percentage of these fragments varies widely from sample to sample i.e. 8 to 30 percent, whileas in most of the cases, it exceeds 15 percent. In addition, some opaque minerals like magnetite, haematite, are present, besides these constituents some significant accessory minerals like tourmaline, zircon and biotite are also present.

Regarding their types, the classification of Macbride (1963) has been followed. There are in practice several classifications of the argillaceous sandstones in terms of their nomenclature. Pettijohn (1957) used clay as one of the most important constituents, besides quartz and feldspar in the classification of these sandstones. This classification is later modified by Dott (1964), Gilbert (1954), Macbride (1963) and Cassyap (1967). In most of these classifications three end members, viz, quartz, feldspars and rock fragments are used. The advantage of adopting Macbride classification is that, in this scheme sandstone types are determined on the basis of four components. Three end members of the equitriangular diagram include M(matrix) which is the most important

TABLE- 5

MODAL COMPOSITION OF GREYWACKE

S.No:	Sample No:	Quartz %	Feldspar %	Rock fragments %	Matrix %	Mica/ Heavy minerals
1.	GU-4	62.36	9.68	12.02	15.23	0.71
2.	GU-6	61.63	3.73	8.11	26.53	-
3.	GU-8	46.19	2.83	23.22	27.56	0.20
4.	GU-9	43.53	3.90	19.27	29.31	0.99
5.	GU-18	30.63	9.58	18.93	39.30	1.56
6.	LH-3	54.13	7.06	28.32	10.31	0.18
7.	LH-6	48.80	1.91	22.36	26.33	0.60
8.	LH-11	42.00	2.77	30.91	24.16	0.16
9.	LH-8	42.13	11.23	10.04	36.20	0.40
10.	LH-13	37.33	2.21	27.27	32.66	0.54

Sr. No: 1 to 5: Left river bank of Bring (Gauran)
Sr. No: 6 to 10: In and around Lihhinwan (Right Bank)

component of the greywackes, Q(quartz) and the rock fragments. Feldspar percentage is indicated by the length of the base of each triangle plotted inside the diagram. The percentages of these framework constituents of greywackes are plotted in this equitriangular diagram (Plate-10). The modal composition of these sandstones is shown in Table-5 . In this diagram, greywackes are seen mostly falling in three categories, viz., lithic greywackes, subgreywackes and quartz-wacke. These plots clearly distinguish greywackes from sandstones of the upper Hapatnar formation.

GRAIN SIZE

A few selected samples of greywackes were subjected to size analysis by thin section method as is outlined in chapter II, page 15 . Table-6 summarizes the statistical measures of grain size distribution of these sandstones. The mean grain size values vary from 2.40 to 3.32 ϕ and the standard deviation values mostly exceed 1.00 ϕ. About 70 percent of the samples show negative skewness and mesokurtic nature, however, a few samples are platykurtic. This data was obtained from the cummulative curves, which are shown in(Plate-11 No 1,2,3 and 4). These curves are showing poor sorting at tail and the central portions, which clearly distinguishes greywackes from the sandstones of the Hapatnar formations. The grain size analysis of these sandstones also corroborates with the petrographical features observed in them.

TABLE-6

STATISTICAL PARAMETERS OF THE SAMPLES OF GREYWACKES OF GAURAN FORMATION AND SANDSTONES OF HAPATNAR FORMATION

Sr.No:	Sample No:	Mean size (MZ)	Standard Deviation (S_1)	Skewness (SK_1)	Kurtosis (KG)	Remarks
1.	GU-4	2.83	1.10	-0.119	1.11	Mesokurtic
2.	GU-8	2.48	1.01	+0.093	1.13	Leptokurtic
3.	GU-18	3.06	0.93	-0.880	0.93	Mesokurtic
4.	LH-3	3.01	1.06	-0.083	1.11	Mesokurtic
5.	LH-8	3.23	1.04	-0.055	0.88	Platykurtic
6.	H-16	2.55	0.57	-0.250	1.33	Leptokurtic
7.	H-26	2.03	0.73	-0.528	1.02	Mesokurtic
8.	H-31	2.40	0.84	+0.023	1.08	Mesokurtic
9.	H-36	2.54	0.48	+0.082	0.98	Mesokurtic
10.	HK-14	2.45	0.63	+0.431	1.10	Mesokurtic

Sr.No: 1 to 3: Gauran
4 and 5: Lihhinwan
6 to 9: Upper beds of Hapatnar
10. : Hapatkhai (Hapatnar).

These results are indicative of deep water turbidity currents.

SPHERICITY AND ROUNDNESS

Sphericity and roundness studies were thought essential in case of these sandstones because of their angular nature. In this study, low roundness values and low to medium sphericity of these greywackes was observed.

The sphericity and roundness values of the greywackes have been tebulated in Table No:- 7 . The mean sphericity values range between 0.46 to 0.66, however, the sphericity values of individual grains is comparably higher. The mean standard deviation values are also low and range between 0.012 to 0.123.

The degree of roundness varies between 0.13 to 0.33, roundness ratio from 0.08 to 0.40 and the rounding index 0.10 to 0.20, with lower values of mean standard deviation. The lower values of degree of roundness clearly indicates angular to subangular morphology of the grains, except in a few cases, where the grains are subrounded. This angularity alongwith the unsorted nature of the grains suggests very less transportation and the active turbidity currents of deeper parts of the sea.

TABLE- 7

SPHERICITY AND ROUNDNESS OF GREYWACKES OF GAURAN

S.No:	Sample No:	SPHERICITY Mean	SPHERICITY Mean S.Dev.	ROUNDNESS Mean	ROUNDNESS Mean S.Dev.	Roundness Ratio	Rounding Index.
1.	GU-4	0.53	0.073	0.19	0.049	0.10	0.20
2.	GU-6	0.56	0.134	0.15	0.068	0.09	0.10
3.	GU-8	0.61	0.119	0.27	0.036	0.19	0.20
4.	G-9	0.61	0.116	0.20	0.038	0.10	0.38
5.	G-18	0.58	0.137	0.22	0.061	0.09	0.12
6.	LH-3	0.46	0.123	0.33	0.028	0.40	0.61
7.	LH -6	0.56	0.012	0.18	0.084	0.40	0.52
8.	LH-11	0.58	0.113	0.16	0.058	0.10	0.23
9.	LH-13	0.52	0.173	0.15	0.063	0.15	0.13
10.	LH-16	0.66	0.118	0.13	0.044	0.08	0.10

Sr.No: 1 to 5: (Gauran)-Left bank of river bring) Naubug.
Sr.No. 6 to 10 (Lihhinwan-right bank of river Bring)

SEDIMENTARY STRUCTURES

NATURE OF BEDDING

One of the most significant features of Gauran Fromation is continuity of beds from a fairly long distance. The individual thickness of beds varies from base to top, but their continuity is maintained at almost all levels. The pattern of bedding also varies. In the lower part, sandstone beds are less than a meter in thickness and intermixed with mudstones of similar thickness, which are highly foliated. Sandstones invariably have abrupt basal contacts in the upper part of the Gauran Formation. These beds generally exceed one metre in thickness, while the mudstone layers are either absent or very thin.

GRADED BEDDING

This structure has been mostly found in the lower horizon where 25 to 30 percent of the beds show graded bedding. In the upper horizon also graded bedding is seen, though less frequently. Even in the thin sections as shown in Fig 1, Plate-9 graded bedding is clearly visible. Graded bedding in these rocks normally consists of an upward increase of argillaceous material, however, a decrease in grain size upward does occasionally exist. The graded beds are deposited from a waning current and which range in thickness from a centimeter or less to more than a metre. The graded bedding is more frequently observed in the greywacke type of sandstones (Pettijohn, 1957).

CONVOLUTE BEDDING

In general, the complexity of the convolutions increase from the bottom to top of the bed and is the result of drag of currents of waning strength flowing over loosely consolidated sand and clay laminae on the floor of the basin of deposition. Convolute bedding in the Gauran Formation is well developed in the siltstones and the sandstones, which is confirmed within the plannar boundaries of the bed. It is commonly associated with current lamination and suggests rapid deposition.

CROSS LAMINATION AND RIPPLE MARKS

Cross lamination, is an integral part of the graded beds. Small scale cross lamination at the top of the beds is common, rarely does it occur throughout the unit. Ripple marks are extremely rare, current direction clearly agrees with that of sole marks.

CURRENT SOLE MARKINGS

These sedimentary structures are most commonly found in the sandstones. These sole structures are caused by current erosion before the deposition of the overlying bed or by distortion, however, majority of them are created by the scouring action of currents from which material is being deposited. A variety of sole markings like groove casts, flute casts, and scour lamination etc. are displayed by the sandstones.

LOAD DEFORMED STRUCTURE

This type of structure is the result of rapid deposition of sand on a saturated mud surface, frequently resulting in gravity adjustments, creating load casts. This structure is also met with in the Gauran Formation.

LATERAL CONTINUITY

The sandstones and siltstones of this group show remarkable lateral continuity regardless of bed thickness.

NATURE OF VERTICAL SEQUENCE

In recent years, the vertical sequence (internal organisation) is considered to be the most important criteria in the interpretation of depositional environments and mechanism of deposition.

The shale-slate-greywacke group of Anantnag district exhibits varied types of cycles both on macro and micro-scale as recognized by Bouma (1962), in flysch sediments of the Maritime Alps, France. Bouma typical cycle shown in fig - 1 Plate-13 consists of five units:-

(e) Pelitic
(d) Upper divisions of parallel lamination
(c) Division of ripple cross lamination
(b) Lower division of parallel lamination
(a) graded division.

The typical vertical sequence observed in the Gauran Formation is shown in Plate-13 ,fig. A to D.

The composite cycle of Bouma(1962) was not observed in its complete form anywhere in this formation, but truncated cycles in which upper part is missing are very predominant. The most conspicuous cycles show graded bedding and lower divisions of parallel lamination,while in some cases the third unit ,viz, division of ripple cross lamination is also observed.(Plate -13 fig A+D). These divisions have been mostly found in hand specimens of a few inches thickness in vertical sequence of a few metre thick,as well as even on microscopic scale in this section.

FACIES

Using the criteria of lithology, sedimentary structures and biological features, two main types of facies have been recognized in the Gauran Formation. These are lower Gauran Facies and the upper Gauran facies. The characteristic features of each facies is as follows:-

1.LOWER GAURAN FACIES

This facies is characterized by interbedded sandstones with mudstones and siltstones. The thickness of the foliated beds are always less than a metre. The beds often have a sharp base. The two sandstone beds sometimes are perfectly amalgamated, with a change in grain size and show perfect

annealing without a change in grain size. Graded bedding is very common in these sandstones as also parallel lamination or cross lamination. The most common rock types are greywackes and shales.

2.UPPER GAURAN FACIES

This facie is slightly different from the lower one, in having thick sandstone beds, generally their thickness is more than a metre. These sandstone beds have a sharp basis, but unlike the lower facies, the amalgamation of successive beds are common. It also shows structures like graded bedding, parallel bedding, cross lamination, but these are not so well preserved as in the previous one. In this facies, the more metamorphosed, phyllites and sandy phyllites are well developed with extensive foliation and schistosity. The most common rock types presented therein are quartz wackes and siltstones.

MECHANISM OF DEPOSITION

There are majority of evidences to prove that both the lower and upper facies of the Gauran Formation are the result of turbidity currents. In this study, not only that there are evidences of their being turbidites, such as total absence of cross bedding, superimposed sets of cross lamination and symmetrical ripples, but also sandstone beds have many textural compositional and structural features, most competitible with the turbidity current hypothesis. These are further supported by the presence of sharp bases , with sole marks, parallel

sided nature of the beds, inter-bedded mudstones, presence of greywackes with graded bedding, scanty of fossils and the nature of the vertical sequence. Presence of Bouma cycle is the most important evidence of their being turbidites. In this case, although full cycle has not been found anywhere, but base-cut cycles and truncated cycles are present, which also indicate that the Gauran Formation has been deposited by turbidity currents; which were gradually slowing down during deposition.

Bouma (1962), has shown that the function of structures and period of erosion in a turbidite , depends upon velocity of the current. According to him, various stages happen in the reverse order in a turbidity current, where the current velocity decreases and the turbidity current is overloaded and the sedimentation takes place instead of erosion. Only the front of turbidity current may have an erosional influence on the underlying layers and leave its marks in clay, causing them to fill up as casts.

The upper part of the Gauran Formation consists of very thick sandstone beds and absence of silty and muddy deposition, the perfectly amalgamated junction without horizontal joints, further suggest that the time interval between successive currents was small. Also the absence of thickness of the pelitic divisions suggests that all the muds were carried further into the basin or that there was no time for it to settle out between

currents or that eroded by successive currents. All these features suggest proximal deposition for the upper part of the Gauran beds.

PETROGRAPHY OF THE HAPATNAR FORMATION

Above the Gauran Formation, within the shale-slate-greywacke group, overlies the sequence of rocks essentially composed of more argillaceous material such as muddy siltstone, mudstones, slates and phyllites with some sandstones beds essentially in the upper part of this formation. The sequence is characterized by having graptolite fauna found at some places. Although much work has been done on its faunal assemblages, no earlier worker has described the petrography in detail, therefore, this work is poineer one for these suite of rocks.

PETROLOGY OF SHALE-SLATES-AND MUDDY SILTSTONES

The dominating sedimentary rocks in this unit are generally well bedded, laminated, meta-pelite , which represent somewhat deformed and metamorphosed shale, slate,mudstone argillite and siltstones. At places,these rocks have been further metamorphosed to phyllites, composed essentially of quartz, sericite, muscovite and chlorite. These fine grained rocks may be further divided into three major groups:-

1. Medium to dark grey, blocky marine mudstone 15 to 50 cm thick.
2. An olive grey to brown obscurely bedded to well bedded siltstones.

3. A distinctive laminated argillite with individual lamillae from 0.1 to 10 mm in thickness. These laminations are regular/ uniform and persistent and are graded silt sized particles at the base, passing upward to clay sized particles.

All these pelitic rocks are essentially composed of Quartz, Feldspar, Muscovite, Chlorite, epidote, biotite; Pyrite and Magnetite being less in amount. Most of these minerals are considered to be secondary. The sedimentological features of these rocks are as under:-

MUDSTONES

These rocks occur as the host rock formations in the lower part of the Hapatnar Formation, silt and clay contents range between 20 to 58 percent. These mudstones differ from the shales in having completely mixed sand-silt and clay distribution and scattered fragments. These mudstones are intermixed with limestones and the siltstone bands which are distinguishable by their colour, greyish brown to brown. The degree of softness, clay orientation determined by the degree of mass extinction is weak or absent.

SHALES

Shales are the main rock types in this formation which are interbedded with the other rocks. Chief colours of these shales are greenish, light-olive-green and greyish-black. Clay cement present in these rocks ranges between 65 to 70 percent and the rest is composed of quartz, silt and fine

sands with some well developed Silurian Graptolites. The Cement present in these rocks is mostly chloritic in nature, and the iron ores like magnetite and haematite are also equally present. In addition, some minerals like montmorillonite and and illite etc. have also been observed. These are massive to slightly laminated in character. The silt and sand have accumulated as distinct layers from a few inches to several millimeters, but most of these layers have been mixed with clay of the host rock.

SLATES AND SILTSTONES

These are distinguishable from their framework constituents. The siltstones are fine grained, the size is almost in all the cases less than 0. 1 mm, but most of the grains are greater than 0.01 mm. Among the framework constituents, quartz is the main dominating constituent in a sort of mosaic form with sand and clay gradation. The silt particles are mostly angular to subangular, well sorted, intermixed with the mineral cement of micaceous/chloritic material. Feldspars are occasionally seen, while the rock fragments are absent. Heavy mineral species like garnet, tourmaline, zircon and epidote are frequently observed.

SLATES

These are very fine grained intermixed with chlorite matrix, with a degree of regular orientation commonly of

finer minerals as seen in microphotographs 1 and 2 (Plate-14). In most of these slates fissile property itself is evident upon the examination of the microstructures which reveals that the perfect cleavage, large part of these rocks consist of flaky and flattened elements set approximately in parallel positions. False cleavage structures also are observed in some of the slates. The main mineral components of slates and phyllites are: quartz, feldspar, chlorite, sericite, magnetite, pyrite and calcite etc.; particularly phyllites are sericite-chlorite type.

In fig 3 of Plate-14 a large rock fragment (1mm size) occurs as a lenticular body clouded with inclusions, essentially quartzitic in nature. This rock fragment is almost set in a parallel position with the finer fraction. Similarly in fig.1 of the same plate a microsandstone dyke like body is seen intersecting horizontally the host rock. The dyke itself is also fine grained with inclusions of magnetite.

Five samples of slates were chemically analysed and the results are tabulated in Table-8 . The chemical analyses of these slates reveals that in most of the samples from Shumhal area are characteristic of high percentage of calcium. The CaO percentage ranges between 6.08 to 10.53. This has been referred to as Calcic type. However, this type is rich in pyrite also as the Fe_2O_3 (Total iron) percentage is between 9.66 to

11.58, which is also evident from the thin section studies. The other type of these slates is represented by sample nos. 4 and 5, which reveal low percentage of Calcium present in them (range 2.80-3.27). This type is of chlorite-sericite type.

Table - 8

CHEMICAL ANALYSES OF SLATES

Sample No:*	1	2	3	4	5
SiO_2	58.19	53.52	62.08	58.98	62.12
Al_2O_3	15.12	15.21	12.01	17.87	17.38
Fe_2O_3(Total iron)	11.58	10.02	9.66	10.53	8.00
TiO_2	0.42	0.30	1.39	0.60	0.30
CaO	10.53	10.05	6.08	3.27	2.80
MgO	0.22	2.38	3.61	3.30	3.00
Na_2O	2.06	4.01	2.01	2.00	2.00
K_2O	0.63	1.18	1.03	0.70	2.53
H_2O (+)	1.72	2.14	1.03	1.28	1.46
H_2O (-)		1.01	1.00	1.17	0.25
Total	99.47	99.82	99.90	99.70	99.86
S.G.	2.95	2.84	2.96	2.95	2.60

Sample No: 1-2 Shumhal (Hapatmar)
Sample No: 3 Hapatkhod
Sample No : 4-5 Mathihund. (Naubug)

* Each sample represents the average of three.

SANDSTONES OF THE UPPER PART OF THE HAPATNAR FORMATION

The upper part of this formation constitute shales intermixed with sandstones. These sandstones differ from sandstones of the Gauran Formation in having lesser percentage of matrix, intact framework and most of the grains show tangential contacts. The typical photomicrographs are shown in Plate-14 figs. 5 and 6. These reveal that the sandstones of this formation are mature sandstones, as the percentage of cement is less than 5 percent and the quartz exceeds 75 percent in almost all the samples, which is the most distinguishing feature of these sandstones from that of Gauran sandstones. All these sandstone beds have sharp basal contacts with the underlying shales and slates, but have upper surface contacts that range from abrupt to gradual contacts. These beds have small scale ripples and cross lamination, but ripple marks are very rarely observed.

The framework constituents of these protoquartzites are quartz, feldspar, rock fragments and traces of mica flakes. Modal composition of the representative samples are shown in Table-9 . and the classification in equitriangular diagram (Plate-10) on the basis of its framework constituents.

The chief characteristic constituent of these sandstones is quartz, which exceeds 75 percent in all the samples. The grains range in size from 0.2 mm to 0.4 mm; both undulose and

non-undulose extinctions have been observed. The grains are subangular to subrounded(Table-10) and their boundaries are tangential and are perfectly interlocked. Interlocking is the interesting feature of these sandstones, due to which the pore space has been considerably reduced, except a few cases where it exceeds 5 percent. The matrix/ cement percentages are less than 5 percent, but in some cases it exceeds 5 percent. The quartz grains are seen with typical overgrowths which have cemented these grain junctions. The overgrowths are considered to be of secondary in origin. All these features are clue for the shallowing of the basin in the later stages of the Silurian times.

Feldspar grains are very less represented in these sandstones which range in percentage from 1.22 to 8.89 of the total. Both fresh and dull coloured feldspar grains are seen with twinning, the most distinguishing feature of these grains to that of quartz.

The rock fragments constituted in these sandstones are mostly of quartzite, slate ,schist, etc. with mica flakes less commonly observed. The rock fragments in just three samples exceed 10 percent. Besides these, some heavy mineral species like zircon, tourmaline, apatite and magnetite/ haematite among opaques are present. In all these samples, the percentage of these accessory minerals is less than 0.4 percent. The overall classification shows that these sandstones are protoquartzite / subgreywacke types.(Plate-10).

GRAIN SIZE ANALYSIS

Table-6 summarises the statistical parameters of grain size distribution of the sandstones of upper Hapatnar formation. The mean size ranges between 2.03 to 2.53 and the standard deviation values 0.483 to 1.02. The standard deviation values indicate their good sorting. The skewness values, however, show that these have a good amount of coarser fraction of the grains. Most of the samples are mesokurtic in nature. The cummulative curves are also shown in (Plate-22) . These cummulative curves reveal that these sandstones are better sorted than that of the sandstones from the Gauran formation.

SPHERICITY AND ROUNDNESS

The sphericity and the roundness values of these sandstones are summarized in Table-10 . The mean sphericity values range between 0.48 to 0.72 with standard deviation values from 0.112 to 0.196. The degree of mean roundness values are between 0.19 to 0.42, however, majority of the grains are above 0.25, with low values of roundness ratio and the roundness index. The elongation values of length to breadth range between 1.05 to 2.60. The values observed of both these variables are fairly higher to those of greywackes, owing to their good morphological characters. The results of this study also corroborate with that of thin section studies.

TABLE - 9

MODAL COMPOSITION OF SANDSTONE BANDS OF HAPATNAR FORMATION

S.No:	Sample No:	Quartz %	Feldspar %	Rock fragment %	Matrix/ Cement %	Heavies & others
1.	HK-1	93.17	1.22	4.44	1.16	0.01
2.	HK-3	78.22	3.38	11.36	6.93	0.11
3.	HK-8	88.91	3.14	6.58	1.05	0.05
4.	HK-14	91.06	2.21	4.73	1.89	0.11
5.	H-16	88.12	4.22	2.32	5.34	-
6.	H-26	76.88	4.28	6.33	12.46	0.05
7.	H-28	76.33	5.20	11.26	7.21	-
8.	H-31	81.81	2.33	9.86	5.86	0.14
9.	H-36	89.36	2.03	6.22	1.98	0.41
10.	H-40	82.16	8.89	7.76	1.19	-

Sr. No: 1 to 4: Hapatkhai (Hapatnar.)
Sr. No: 5 to 10: (upper beds of Hapatnar).

TABLE- 10

SPHERICITY AND ROUNDNESS OF SOME REPRESENTATIVE SAMPLES OF SANDSTONES OF HAPATNAR FORMATION

S.No:	Sample No:	Sphericity		Roundness		Roundness Ratio	Roundness Index	Elongation
		Mean	Mean S.Dev.	Mean	Mean S.Dev.			
1.	HK-1	0.61	0.138	0.42	0.089	0.22	0.14	1.20
2.	HK-3	0.63	0.144	0.37	0.038	0.39	0.15	1.66
3.	HK-12	0.59	0.120	0.24	0.076	0.33	0.25	2.18
4.	HK-14	0.700	0.108	0.41	0.098	0.18	0.13	1.36
5.	H-16	0.59	0.112	0.33	0.081	0.43	0.16	1.05
6.	H-26	0.65	0.158	0.27	0.076	0.18	0.13	1.40
7.	H-28	0.68	0.120	0.40	0.073	0.31	0.21	1.10
8.	H-31	0.72	0.112	0.22	0.083	0.22	0.10	2.60
9.	H-36	0.51	0.210	0.38	0.088	0.36	0.17	1.75
10.	H-40	0.48	0.196	0.19	0.063	0.13	0.16	1.78

Sr.No: 1 to 4: Haptkhai (Hapatnar)
Sr.No: 5 to 10: (Upper beds of Hapatnar)

FACIES IN HAPATNAR FORMATION

1. LOWER HAPATNAR FACIES

This facies is characterized by the presence of mudstones, siltstones , and phyllites; these rocks have acquired almost equal proportions. In sandstone beds of this formation, the graded bedding is found alongwith certain sole marks; but in the upper part of this facies, these structures are almost lacking. These features indicate that the lower part is undoubtedly of turbidity nature, whileas in the upper part, currents became ineffective and the facies was deposited above the range where they could operate.

2. UPPER HAPATNAR FACIES

This facies is characterised by the sandstone bands with burrows and tracks intermixed with mud and shale bands, but the sandstone beds increase in thickness with abrupt contacts. The sandstones of this facies are entirely different from the early Gauran Facies as there are mature quartz-arenite type of sandstones represented. In this facies, however, no current bedding, ripple marks, dessication cracks etc. have been seen indicative of very shallow depth for deposition. No sedimentary structures of shallow water have also not been found, indicating thereby that although the basin became shallower but water was still sufficiently deep to produce current dominating structures.

PROCESS OF DEPOSITION

1. Only the lower part of this formation has been experienced to be formed by the turbidity currents, while in the upper part no sedimentary structure is characteristic of turbidites.

2. No sedimentary structures indicative of shallow depth have been found in the upper part of Hapatnar formation, such as dessication cracks, trail and tracks etc.

3. There is a gradual increase in sandstone from base to top and is characteristic of totally different from the sandstones found at the base of Gauran formation, as the sedimentary structures like graded bedding, convolute bedding and cross lamination-s are totally absent from the Hapatnar formation.

4. Graptolites have been found in the lower part of the Hapatnar formation. The graptolites are generally found below nerritic zone, as they are present in the deep ocean floors, mostly preserved in the slopes of the ocean. The graptolite preservation is indicative of deep water environments. All these features indicate that the Hapatnar formation was neither deposited in the neritic zone where shallow water sedimentary structures dominate, nor on the ocean slope where generally turbidity currents operate. These deposits have, therefore, been believed to be formed somewhere between the two zones, most probably at the foot of the slope.

PALEOCURRENT STUDY

Grain orientation study was made on section-s made from oriented samples parallel to the bedding plane. In all 100 grains

were selected for measurements. The measurements were grouped into twenty degree sectors. The data so obtained has been presented in the form of rose diagrams (Plate-15). from the Azimuth of the long axis. The direction of preferred orientation was determined by Tukey's method as shown in Table // . These values indicate SE direction with some other local currents. It is possible that the sediments were transported in the SE direction.

TABLE- //

PALEOCURRENT DATA FROM GRAIN ORIENTATION

Sector No:	Number of Readings.	Preferred Orientation direction	Chi Square.
1	100	138.40	55.61
2.	160	165.36	95.31
3.	100	110.60	61.26
4.	100	179.00	26.38
5.	100	123.36	55.01
6.	100	124.24	42.93

N.B. The oriented sections were selected from Gauran, Linhinwan and Mathihund (Naubug valley) for the measurements.

DEPOSITIONAL ENVIRONMENTS OF SHALE-SLATE-GREYWACKE GROUP

The shale-slate greywacke group of rocks represents fairly a deep water environment in a geosynclinal type of basin, which was gradually becoming shallower towards the upper parts. Most of the deposition took place by turbidity currents, both proximal and distal tubidites have been found together, along with deep channels in which the material have been cut and filled by turbidity currents. This is suggestive of a submarine fan model, as applied by Walker (1966) to explain the shale grit and gridstone of shale formation (Upper Carboniferous), which have also many similar features. According to Walker, the presence of these channels in association with proximal turbidites is indicative of submarine fan. These submarine fans are formed at the foot of submarine canyons and they usually die out into rather appreon on the deep sea floor. The main characteristic features of these sands, as illustrated by Walker, are that they are cone shaped wedges of sediments with their apisces at the front of the submarine canyons and form a part of the basin appreon. The characteristic features of these fans observed in this study are as follows:-

(i) These are areas of near source deposition from turbidity currents at the first meandering of the slope.

(ii) Fan sediments consist of alternating coarse and fine beds. Lower boundaries of sand layers are sharp, several superimposed graded sand layers are sometimes present. The important

sedimentary structures found in these fans include parallel lamination, ripple cross lamination, slumping and sole markings etc.

All these features of submarine fans have been observed in the Gauran formation and, therefore, submarine fan model is fairly applicable to these rocks. It is evident that the Gauran formation was deposited from a series of laterally migrating fans. Associated with these turbidites are extensive sheet of mudstone and shales which accumulated slowly in a quiet and deep environments. These sheets are believed to have been formed at times, when the locus of turbidity current deposition had moved from neigbouring fan at the foot of the slope. Hapatnar formation also is thin turbidite at the base which becomes more sandy towards the upper part. The sand-stones present in the upper part are more clear and show better sorting indicating theirby that the basin gradually became shallower during these times. Because of this mixture of character, it is assumed that Hapatnar formation is believed to have been formed on the slope above the submarine fans.

PETROGRAPHY OF ORTHOQUARTZITE CARBONATE GROUP

Orthoquartzite carbonate group comprises all the formations from Muth quartzite to Passage beds below the Fenestella shales. Most of these formations consist of quartzites and quartzo-sandstones except Syringothyris Limestone in which thick beds of fossiliferous limestone interbedded with shales and sandstones have been found. These formations have been well studied with respect to their stratigraphic positions and fossil contents (Lydekker, 1883;Middlemiss, 1910; Gupta,1964-73;), but very little work has been done on their petrography. Das Gupta (1971), published a paper on grain size studies of Muth quartzites of Spiti area,while Bhatia and Kokroo(1978), described the petrographic characters of Syringothyris Limestone of Anantnag district, Kashmir. These papers are, however, priliminary in nature, but no other work dealing with their detailed sedimentological aspects is available. In this work, therefore, a detailed sedimentological work of both clastic and carbonate rocks constituting this group have been made. As a result of this work it has been found that all these formations,inspite of their varying nature have consanguineous relationship with each other and were deposited in a more or less similar environment.

A- PETROGRAPHY OF CLASTIC ROCKS

Among the clastic rocks found in this group, orthoquartzites and quartzo sandstones are the most dominating rock types. Muth quartzites are wholly composed of these rocks from base to top. No carbonate rocks have been found associated with muth quartzite. Syringothyris limestone too have clastic rocks associated with limestone bands, which constitute almost half of this formation in vertical thickness.

In the present area of study between Syringothyris limestone and fenestella shales, there is a thick sequence of clastic rocks known as Passage beds. These Passage beds have also been reported between muth quartzite and Syringothyris limestone (Sharma et al,1976). Most of these clastic rocks are quartzo sandstones. In outward appearance,all these sandstones from Muth quartzite-s to Passage beds are very similar with the result that it becomes exceedingly difficult to recognize the specific formation to which they belong. No one has attempted earlier to establish a separate entity of any of these sandstones. This work, therefore, constitutes a detailed textural, compositional and structural studies to find out whether any of these sandstones possess certain specific sedimentological characters, so that one could be differentiated from another. The results are as follows:-

SANDSTONES

Among the clastic rocks, sandstones are the major components constituting all the formations of the ortho/quartzite

Carbonate group. These have been studied with respect to their grain size, morphometry, thin section studies and heavy minerals.

GRAIN SIZE

Since Uden (1914), grain size studies are regarded very important for clastic rocks. Number of workers like Wentworth (1929), Otto (1939), Keller (1945), Doeglas(1946), Von Andel and Postma (1954), Inman and Chamberlain (1955), Folk (1957-66), Freidman (1961) have used these studies for the interpretation of depositional environments. Other workers like Shephard and Young (1961), Sehlee and others (1964), Gees (1965) and Sevon (1966) considered grain size studies not so important for the interpretation of depositional environments. The present concensus, however, is that although at present state of our knowledge, it is not possible to discriminate between closely related environments or agents by means of the grading curves of the sediments alone (Pettijohn, 1957), but grain size studies do serve a great purpose in establishing sedimentological characteristics of individual sand bodies. It is for this reason, that a detailed grain size studies have been undertaken for this study.

Number of methods are in use these days for grain size studies such as Sieve analysis, sedimentational analysis, pippette analysis and grain size measurement in thin sections. For this study, however, method of grain size measurement in thin sections have been found applicable, owing to their hard nature. The details of this method are given on page - 15 .

The grain size analysis was done by point counting method which is the fastest and most accurate method, by using a micrometer Ocular with cross hairs for a petrographic microscope. A grid system was set up and so the entire slide traversed. At least 200 grains per section were measured. The number percent obtained by this method was converted into weight percentage with the use of (Freidman,1958) special graph, for converting thin section frequency values to sieve equivalents.

The results so obtained were represented both graphically (histograms and cumulative curves) and by calculating statistical parameters representing various attributes of frequency distribution, such as average, sorting, symmetry and peakedness.

HISTROGRAMS

The histograms of 12 representative samples of Muth quartzite and six each of associated quartzo sandstones of Syringothyris Limestone and Passage beds are shown in Plates 16+17 .As shown in these plates, there appears to be much dissimilarity in the outer shape of the histograms from one unit to another. All the histograms (Plate-16) of Muth quartzite are more or less alike in form and are unimodal, consisting of almost four classes except histogram Nos 10 and 11 in which instead of four, there are five classes. The modal class in most of the cases represents 1/4-1/8 grade, while in others, it is in 1/8-1/16 grade. The maximum amount

of material is more than 70 percent in histogram nos. 9,10+11, 50 to 70 percent in histogram Nos 1,2,3,5,7,8 and in rest of the histograms it is between 40 to 50 percent. Most of these histograms are skewed towards finer fraction, while a few of them are skewed towards left.

As compared to these histograms, most of the histograms of Passage beds (Plate -17) do not have much material in their modal class. Out of six histograms only two have more than 50 percent material in their modal class, while in others it is less than 50 percent. The number of size grades in histogram no.1 is in three classes, while in rest of the histograms, it is in five classes. The histograms of Associated sandstones with Syringothyris Limestone (Plate -17 no. 7 -12) are much similar to that of Passage beds. However, two out of six histograms are bimodal. In other respects, such as number of classes percentage of material in the modal class and symmetry, these are in between Muth quartzites and Passage beds.

CUMMULATIVE CURVES

The cummulative curves of size frequency data of all the three units are shown in Plate 18&19. The cumulative curve is divided into separate line segments called "Components" (Harris, 1958) by inflection points. This indicate that the sample contains the mixture of more than one population (Herden, 1953), and these components are sorted more than the sample (Wagler, 1962). In many cumulative curves

the inflection point is a division between gravel bed load, sand bed load and wash load. The inflection point, therefore, indicates a change in strength of the current. The number of the inflection points correspond to number of changes in hydrodynamic conditions.

The study of these cumulative curves reveal that the size composition of these sediments range from hetereogeneous mixtures of mostly sand and silt sized material representing coarse bottom deposit to fine suspended material, fluctuation in the velocity of the transporting current. The cumulative curves of these three units have slightly seprate field, and these do not superimpose upon one another in representing different depositional conditions.

STATISTICAL PARAMETERS

The values of the statistical parameters such as Mean, Standard deviation, skewness and kurtosis calculated for all the three formations of this group are shown in Tables 12,13 & 14. The details are as follows:-

GRAPHIC MEAN

It represents the average size of the sediments and is controlled by the average size distribution of the available source material; the average kinetic energy of the depositing medium. The values of the graphic mean shown in Tables 12 to 14, are not very significant in the sense that apart from slight difference in the MZ values, there is much overlapping in these

values in all the three formations.

In Muth quartzite the MZ values range between 1.76 ϕ to 2.53 ϕ and the majority of the samples 10 out of 15 have values between 2.03 -2.53 ϕ . In Passage beds, the values range between 1.39 ϕ - 3.39 ϕ and the majority of the samples have values 2.08 - 2.88 ϕ . While in the Associated sandstones of Syringothyris Limestone, the values lie between 2.03 ϕ - 3.32 ϕ , 60 percent of the samples have the values between 2.03 -2.78ϕ .

Inspite of the similarity, as indicated above, there is a distinct trend in the MZ values which can be of some use in differentiating one unit from another. The Muth quartzites for example, have a trend towards the coarser side as five out of fifteen samples have values between 1.76 ϕ -1.98 ϕ. Similarly, in the Associated beds, this trend is towards finer size as in five samples out of fifteen, the values are between 3.17ϕ - 3.32 ϕ, while in the Passage beds, the trend is mixed one, as one sample has MZ value 3.39 ϕ and four samples have the values ranging between 1.39 - 1.98 ϕ .

It is, therefore, concluded that MZ values alone cannot help in distinguishing the sandstones of one formation from another, although the coarser or finer size trend of Muth quartzite and associated beds may be used alongwith other characteristics.

STANDARD DEVIATION

Standard deviation indicates the sorting of the sediments

and fluctuations in the kinetic energy conditions of the depositing agents. The standard deviation values show a greater similarity in all the three units represented in this group. The values of Muth quartzites range from 0.439 ϕ - 0.738 ϕ, in Associated beds sandstones of Syringothyris Limestone the values are 0.489 - 0.882 ϕ, while in the Passage beds, these values range between 0.37 ϕ 1.11 ϕ.However, the Passage beds in which some of the samples have higher values, more than 1.1 ϕ , while one of the samples having standard deviation value 0.93 ϕ . The standard deviation values of all the formations are almost similar indicating that in broader aspects the depositional environments of these formations were almost similar.

GRAPHIC SKEWNESS

It measures the symmetry of the frequency distribution and indicates the position of the Mean with respect to median. When the skewness values are negative, the mean is towards the coarser side of the median and the sample is said to be coarsely skewed; but with the positive skewnessś values, the samples becomes finely skewed and the mean goes towards the fine side of the sediment. In terms of current velocity, a coarsely skewed sample indicates that the agent has operated at a higher value than the average velocity for a greater length of time.

In Muth quartzites,9 out of 15 samples have negative values. Similarly in Passage beds, 8 out of fifteen have negative values, while in Associated sandstones, 5 of the 15 samples

have negative values. This trend of positive values in Syringothyris Limestone and negative skewness values in other units may be of some use in differentiating sandstones of these different units.

GRAPHIC KURTOSIS

Kurtosis represents the ratio between sorting in the " tails" of the curve and the sorting in the central portion. If the portion is better sorted than the tail, the curve is said to be Peaked or Leptokurtic; if the tail is better sorted than the central portion, the curve is flattened ere Platy - kurtic. For normal distribution, the kurtosis is equal to one. For series of leptokurtic samples with kurtosis greater than unity, fluctuations in the velocity of the transporting agent has more sorting effect on the central 50 percent of the size frequency distribution than on the tails. Similarly a number of Platykurtic samples reflects velocity fluctuations which effected the tails much more significantly than the central 50 percent, and thereby indicating a more erratically fluctuations in the medium of transport.

Folk and Ward (1957) and Mason and Folk (1958) gave verbal limits of kurtosis as very Platykurtic K_G values upto 0.67; Platykurtic, K_G values vary from 0.67 to 0.90; Meso-kurtic, K_G varies from 0.85 to 1.15, Leptokurtic, K_G value 1.15 to 1.50; very Leptokurtic K_G from 1.50 to 3.0 and extremely Leptokurtic; K_G value over 3.0.

TABLE - 12 STATISTICAL PARAMETERS OF REPRESENTATIVE SAMPLES OF MUTH QUARTZITE.

S.No.	Sample No.	Mean size (MZ)	Standard deviation.	Skewness (SK_1)	Kurtosis (K_g)	Remarks.
1.	N-6	1.91	0.698	-0.121	1.04	Mesokurtic
2.	N-7	2.26	0.565	-0.071	1.19	Leptokurtic
3.	N-8	1.76	0.633	+0.166	1.004	Mesokurtic
4.	N-10	1.93	0.738	+0.033	1.09	Mesokurtic
5.	NB-3	1.96	0.439	-0.054	0.82	Platykurtic
6.	NB-4	2.08	0.702	+0.119	0.93	Mesokurtic
7.	NB-5	2.31	0.624	+0.542	1.01	Mesokurtic
8.	G-1	2.23	0.723	+0.061	1.04	Mesokurtic
9.	G-2	2.42	0.587	-0.214	1.29	Leptokurtic
10.	GA-2	2.53	0.583	-0.250	1.02	Mesokurtic
11.	GA-5	2.03	0.743	-0.538	1.33	Leptokurtic
12.	H-5	2.40	0.702	-0.189	0.73	Platykurtic
13.	H-6	2.18	0.698	-0.129	1.03	Mesokurtic
14.	H-7	1.98	0.627	+0.238	1.02	Mesokurtic
15.	H-9	2.50	0.547	-0.291	1.47	Leptokurtic.

Serial No. 1 to 7: Naubug/Gurderman .
Serial No. 8 to 11: Gugaldar.
Serial No. 12 to 15: Hapatnar/ Gugaldar.

TABLE -13 STATISTICAL PARAMETERS OF REPRESENTATIVE SAMPLES OF PASSAGE BEDS.

S.No.	Sample No.	Mean Size (MZ)	Standard deviation	Skewness (SK_1)	Kurtosis (K_g)	Remarks
1.	PQ- 3	2.40	0.78	+0.117	1.19	Leptokurtic
2.	PQ-5	1.39	0.59	-0.423	1.29	Leptokurtic
3.	PQ-8	2.88	0.89	+0.118	1.10	Mesokurtic
4.	PQ-7	2.40	1.63	-0.031	0.87	Platykurtic
5.	PQ-9	2.30	0.80	-0.174	0.98	Mesokurtic
6.	PQ-10	2.63	0.51	+0.126	1.25	Leptokurtic
7.	PQ-11	2.12	0.93	-0.093	0.96	Mesokurtic
8.	PQ-14	1.83	0.69	-0.118	1.01	Mesokurtic
9.	PQ-15	2.26	1.11	+0.121	1.09	Mesokurtic
10.	PQ-16	1.98	0.72	-0.042	1.18	Leptokurtic
11.	PQ-18	2.10	0.80	+0.088	1.03	Mesokurtic
12.	PQ-19	3.39	0.43	-0.078	0.98	Mesokurtic
13.	PQ-24	1.98	0.51	-0.027	0.98	Mesokurtic
14.	PQ-26	2.13	0.37	+0.084	1.18	Leptokurtic
15.	PQ-28	2.08	0.42	+0.214	1.21	Leptokurtic.

Serial No: 1 to 15: Sinder Nar -Gali Section NE of Aishmukam.

TABLE-14 STATISTICAL PARAMETERS OF THE SAMPLES OF ASSOCIATED QUARTZITES(WITH SYRINGOTHYRIS LIMESTONE).

S.No.	Sample No.	Mean Size (MZ)	Standard deviation.	Skewness (SK_1)	Kurtosis (K_g)	Remarks
1.	A-23	3.17	0.532	-0.075	0.89	Platykurtic
2.	A-25	3.20	0.882	-0.031	0.88	Platykurtic
3.	A-41	2.72	0.489	+0.066	0.92	Mesokurtic
4.	RA-6	2.32	0.736	-0.086	0.93	Mesokurtic
5.	RA-10	2.13	0.655	+0.295	0.96	Mesokurtic
6.	RA-11	2.17	0.630	+0.189	0.88	Platykurtic
7.	RA-16	3.32	0.543	+0.026	1.11	Mesokurtic
8.	RA-25	2.26	0.813	+0.112	1.15	Leptokurtic
9.	RK-1	2.78	0.683	+0.034	0.98	Mesokurtic
10.	RK-7	2.03	0.697	+0.097	1.13	Mesokurtic
11.	RK-22	2.48	0.732	+0.048	1.10	Mesokurtic
12.	RK-47	2.46	0.768	+0.112	1.23	Leptokurtic
13.	RK_2-7	2.03	0.523	-0.063	1.18	Leptokurtic
14.	RK_2-32	2.88	0.537	+0.712	1.11	Mesokurtic
15.	RK_2-37	3.20	0.613	-0.120	1.11	Mesokurtic

Serial No.1 to 8: Aishmukam.
Serial No. 9 to 15: Kotsu

Most of the samples belonging to Muth quartzites are Mesokurtic; only two samples are Platykurtic, while four are Leptokurtic. In the Passage beds almost equal number of samples are mesokurtic and Leptokurtic (seven samples each), while as only one sample is Platykurtic. In the Associated beds, out of fifteen samples, seven are Mesokurtic, five are Platykurtic and rest are Leptokurtic.

These results again point out that the values of graphic kurtosis are also somewhat similar indicating almost similar conditions in which the clastic rocks of different units of the study area were deposited.

RESULTS

In this work, size analysis was primarily done to find out:

(i) whether in terms of statistical parameters, the three units of the group possess any characteristic values, which can be used to distinguish one unit from another.

(ii) to interpret the depositional environments of these units in terms of size analysis and to correlate these results with other evidences, like sedimentary structures and the nature of the vertical sequence etc. from which the depositional environments can also be inferred.

Regarding the first preposition, it has been seen that the values of MZ , standard deviation, skewness and the Kurtosis of all the three units are more or less similar, although there are specific individual trends of these values in each unit as

for example MZ values of Muth Quartzite have a tedency towards coarser size, while that of Passage beds towards finer size. Similarly, the values of standard deviation of the sandstones of Passage beds have a tendency towards higher values and the skewness values of Muth Quartzite are 0.033-0.542, mostly negative. In terms of Kurtosis also Muth quartzite samples are usually mesokurtic, Passage beds are equally mesokurtic and leptokurtic, while sandstones associated with Syringothyris Limestone have a tendency towards Platykurtic values. These are however, many minor differences and much reliance can be paid to these minor differences to distinguish the rocks of these units individually.

With respect to depositional environments, however, the results are very significant as:-

(i) The sorting index is environmentally sensitive textural parameter. According to Friedman(1961), standard deviation values of marine sands 0.35 to 0.50 ϕ, that of river sands 0.5 - 0.8ϕ occasionally step up to 1.40 ϕ. For fluvioglacial sands the values of standard deviation exceed 1.40 ϕ. The application of this classification indicates that most of the sandstones belonging to all the three rock units composed of marine sands; although higher values of standard deviation greater than 0.5 ϕ indicate that rivers also contributed to bringing this material from the source area into the sea, which were mostly ocean currents and waves responsible for ultimately sorting the material. The

presence of marine fossils in these sandstones corroborate this conclusion.

(ii) skewness values are also environmentally sensitive (Folk and Mason, 1958), Friedman,(1962), Martin (1965). The studies of Folk (1966) indicated that these sands are normal and negatively skewed, while dune and river sands are usually positively skewed. According to Moiola and Weiser (1968), more than half of the samples,they studied from beach sands, were positively skewed. Studied of Hail and Hyot (1969), however, have shown that positive and negative values of skewness in a beach sand are possible, depending upon the position ofcupied by the deposits. They further ellaborated their statement that negatively skewed barrier sands appear to have been concentrated along the upper edge of the beach.

(iii) According to Martin (1965), kurtosis values are less sensitive to environments, than skeweness. In his studied from the sands of coastal plain of Rio Grande -do Sul, Barazil, the kurtosis values of beach sands range between 0.20 to 0.60, while that of dune sands between 0.35 to 0.55. Similarly the studies of Mason and Folk (1957)revealed that modal class becomes more peaked peaked downstream for a distance of 650 miles. In this river environment, in 20 samples, they found 10 leptokurtic values, 9 platykurtic and one mesokurtic.

In this study,however, the values of kurtosis obtained are mostly mesokurtic and leptokurtic in all the three units and only a few samples have platykurtic values.

(iv) Several combinations of textural parameters are environmentally sensitive and effective in differentiating between beach and inland dune sands, beach and river sands, river and coastal dune sands, inland dune and coastal dune sands (Moiola and Weiser, 1968). These combinations of textural parameters have also been used in this study to interpret the depositional environment of the sandstones.

(a) Friedman (1961), concluded that the plot of skewness versus standard deviation was most effective in differentiating between river and beach sands. In the present study, this combination of statistical parameter has been used (Fig 3 Plate-20). The standard deviation and the skewness values were plotted in this diagram, in which the standard deviation is represented by the abscissa and the skewness by the ordinate, from all the three units. This diagram reveals that most of the samples fall towards the left side of the dotted line which indicates the beach field. However, a few of the samples fall on the right side of the dotted line, but are very near to the demarcated line.

(b) Moiola and Weiser (1968) plotted standard deviation versus mean diamter in differentiating between river and beach sands. For this work also, this combination has been used as is shown in (Fig.1 Plate-20). In this diagram, majority of the samples fall in the beach field.

(c) Further in order to differentiate between dune and beach sand, a combination of statistical parameters of mean diameter

versus skewness as used by Moiola and Weiser (1968) has also been used as shown in fig. 4 Plate-20 . In this diagram most of the samples of Muth quartzite clustered towards the beach portion of the scatter diagram, while as majority of the samples from Passage beds and associated sandstones of Syringothyris Limestone also fall in the same field except a few samples, which fall in the dune field.

(d) Moiola and Weiser (1968) also used a combination of skewness versus kurtosis in differentiating between beach and river sands. This combination has also been tried in the study, but as seen in fig. 2 Plate-20,no clear pattern has developed. As such this combination has not been found useful for environmental interpretations. However, in fig 2 of the same plate a combination of skewness versus kurtisis in quarter phi is to some extent effective in differe n - ti- ating between beach and river sands

All the above studies pointed out that the Muth quartzite, Passage beds and the Associated beds of Syringothyris limestone are suggestive of beach environments.

2- SHAPE AND ROUNDNESS

Shape and roundness studies have been adopted by number of workers to decipher the history of the deposit of which they are composed. Wenthworth, 1919,1936; Zingg ,1935; Wadell 1935; Krumbein,(1941),Folk and Sneed (1958); Riley (1953), Russel and Taylor,(1937), Pettijohn (1957) and Verma (1965-71). These workers not only explained in detail the concept of the shape and roundness of the sedimentary particles, but also developed methods to study these important textural features and explained at length the relationship of these variables with one another and the signficance of such studies.

In this study, sphericity and roundness of the grains has been made in thin sections only. These studies have been restricted to sand sized particles, as there are no such grains exceeding 1 mm in size. In addition to sphericity and roundness elongation index has also been determined.

SPHERICITY

Number of workers have used sphericity for finding out the distance of transportation and the mechanical wear which the particles have undergone (Russel and Taylor,1937) Plumely (1948),Sneed and Folk (1958), Humbert (1968).

Sphericity is a measure of the degree of conformity of the shape of a particle to that of a sphere. Wadell (1935) defined this property as s/S, where s is the surface area of a spehere of the same volume as the fragment in question and

S is the actual surface area of the object. In view of the difficulty in computing sphericity in this way, Wadell(1935) modified the equation as dn/Ds where dn is the diameter of the sphere with the same volume as the object and Ds is the diameter of the circumscribing sphere.

ROUNDNESS

No systematic and quantitative studies of the roundness of the quartz grains of the sandstones of any of the three units has been attempted by any earlier worker. These studies are important for finding out the nature and amount of abrasion and the distance of transportation traversed by the particles before reaching the depositional site. These studies are also useful for correlation purposes.

Number of methods are in use to study roundness. Roundness was first defined by Wentworth (1919), as r_1/R, where r_1 is the radius of curvature of the sharpest edge and R is one half of the longest diameter. Wadell (1935), defined roundness as average radius of curvature of the corners of the grain divided by the radius of the maximum inscribed circle which is expressed as

$$p(\text{rho}) = \frac{\Sigma \; r_1 / R}{N}$$

where r_1 is the radius of the smallest corner, R is the radius of the maximum inscribed circle and N is the number

of the corners. Subsequent to Wadell, many other workers like Russel and Taylor (1937), Krumbein (1941), Powers (1953), Vanandel et al (1954), Pettijohn (1957) proposed different roundness scales and methods to compute roundness.

In this work, roundness of the grains was computed by Wadell method and inferred by Powers degree of roundness classes and indices. In all 60 sections were studied from these three units. In each section 50 to 100 grains were studied with respect to their mean and standard deviation, the values were statistically calculated. The results are tabulated in Tables 15, 16 & 17 .

RESULTS

The results of sphericity and roundness have been elucidated to understand: (a) the trend of variation in sphericity and roundness values from all the three units using statistical methods in drawing inferences from the data, and also the studies of elongation ratios,(b) to descipher the correlation and its significance between these two variables.

In this study, it has been observed that both the sphericity and roundness values show a decreased trend from Muth Quart-zite to Quartzo sandstones of Syringothyris limestone.

The mean sphericity values of Muth Quartzite range between 0.50 to 0.73, that of Passage beds from 0.45 to 0.65 and 0.42 to 0.61 in the Associated beds of Syringothyris

limestone alongwith the standard deviation values for all the three units from 0.012 to 0.156 and the elongation ratio (l/b) 1.03 to2.09. However, majority of the samples show the mean sphericity above 0.55.

The mean roundness values in case of Muth Quartzite range between 0.24 to 0.52;0.22 to 0.44 in Passage beds, while in associated beds from 0.15 to 0.38. The standard deviation values in all the three units is between 0.018 to 0.191.

The statistical data obtained from these formations indicate, that the grains are mostly subrounded and exceptionally subangular in the Associated beds. In particular, the coarser fraction of Muth Quartzites are well rounded and in the finer fraction the grains show less roundness; as advocated by Pettijohn (1957), that well sorted sediments show decreased roundness in finer sizes. Waksom (1958), also found relatively a little difference in roundness of the present day sands of several subenvironments of the shore zone in the Gulf coastal regions. This mixing up of grains in these formations can be referred to, as these have longer transport history either in time or space, and would, therefore, appear that the sediments are derived from more than one source, having been deposited in the shallower parts of the sea.

The elongation values have also been attempted in this work with respect to long to short axis. The results

TABLE-15 STATISTICAL SPHERICITY AND ROUNDNESS VALUES OF MUTH QUARTZITE

S.No	Sample No.	Sphericity		Roundness		Elongation
		Mean	Standard Deviation.	Mean	Standard Deviation	Mean
1.	N-6	0.59	0.118	0.42	0.085	1.32
2.	N-7	0.56	0.104	0.31	0.066	1.28
3.	N-8	0.55	0.105	0.36	0.081	1.28
4.	N-10	0.59	0.048	0.38	0.090	1.31
5.	NB-3	0.61	0.147	0.48	0.097	1.09
6.	NB-4	0.53	0.141	0.32	0.044	1.52
7.	NB-5	0.58	0.144	0.33	0.041	1.31
8.	G-1	0.64	0.129	0.37	0.018	1.42
9.	G-2	0.66	0.156	0.31	0.084	1.62
10.	GA-2	0.60	0.083	0.36	0.019	1.16
11.	GA-5	0.60	0.035	0.43	0.138	1.19
12.	H-5	0.50	0.027	0.24	0.081	1.10
13.	H-6	0.73	0.105	0.52	0.191	2.09
14.	H-7	0.67	0.051	0.45	0.020	1.65
15.	H-9	0.64	0.156	0.35	0.020	1.26

Serial No. 1 to 7: Naubug.
Serial No. 8 to 11: Gugaldar.
Serial No. 12 to 15: Hapatnar/Gugaldar.

TABLE-16 STATISTICAL SPHERICITY AND ROUNDNESS VALUES OF PASSAGE BEDS

S.No.	Sample No.	Sphericity		Roundness		Elongation
		Mean	Standard Deviation	Mean	Standard deviation	Mean
1.	PQ-3	0.46	0.012	0.21	0.064	D.26
2.	PQ-5	0.61	0.146	0.23	0.021	1.19
3.	PQ-7	0.51	0.112	0.25	0.066	1.92
4.	PQ-8	0.48	0.028	0.23	0.075	1.82
5.	PQ-9	0.45	0.061	0.25	0.063	1.41
6.	PQ-10	0.65	0.106	0.44	0.101	1.03
7.	PQ-11	0.48	0.128	0.25	0.062	1.83
8.	PQ-14	0.58	0.101	0.28	0.067	1.28
9.	PQ-15	0.50	0.096	0.38	0.068	1.39
10.	PQ-16	0.55	0.106	0.19	0.101	1.03
11.	PQ-18	0.52	0.037	0.22	0.110	1.33
12.	PQ-19	0.46	0.048	0.28	0.067	1.41
13.	PQ-24	0.59	0.126	0.38	0.084	1.32
14.	PQ-26	0.61	0.154	0.31	0.038	1.51
15.	PQ-28	0.62	0.128	0.42	0.091	1.38

Serial No. 1 to 15: Cindernar-Gali Section NE of Aishmukam.

TABLE - 17 STATISTICAL SPHERICITY AND ROUNDNESS VALUES OF ASSOCIATED QUARTZITES (WITH SYRINGOTHYRIS LIMESTONE).

S.No.	Sample No.	SPHERICITY		ROUNDNESS		ELONGATION
		Mean	Std. Deviation	Mean	Std. Deviation	Mean
1.	A-23	0.61	0.139	0.40	0.084	1.48
2.	A-25	0.53	0.144	0.32	0.073	1.32
3.	A-41	0.55	0.136	0.36	0.079	2.01
4.	RA-6	0.48	0.101	0.23	0.065	1.11
5.	RA-10	0.69	0.032	0.28	0.112	1.28
6.	RA-11	0.62	0.084	0.15	0.072	1.52
7.	RA-16	0.49	0.042	0.28	0.101	1.32
8.	RA-25	0.61	0.061	0.26	0.115	1.92
9.	RK-1	0.58	0.162	0.19	0.092	1.61
10.	RK-7	0.42	0.043	0.21	0.111	1.25
11.	RK-22	0.48	0.103	0.15	0.068	1.83
12.	RK-47	0.53	0.082	0.28	0.189	1.55
13.	RK_2-7	0.55	0.143	0.27	0.072	1.76
14.	RK_2-32	0.58	0.132	0.35	0.049	1.39
15.	RK_2-37	0.61	0.153	0.38	0.091	1.56

Serial No. 1 to 8: Aishmukam.
Serial No. 9 to 15: Kotsu.

are shown in Tables 15 to 17 . This is inconsistent with the above mentioned observations, in which the values indicate unequal abrasion. Wayland (1939), noticed that the tendency for the elongation of detrital quartz to be great in the direction of C-axis, and in particular, these grains are variable in shape and tend to be sub-spherical even in most natural sands and , however, they tend to show an elongation ratios of long to short axis between 1.00 to 2.50, generally near 1.50. The same results have been obtained in the quartzo sandstones of the Orthoquartzite Carbonate group.

Verma (1965), believed in correlation of the sphericity and roundness, and concluded that since the limiting values for both the variables are between finite numbers 0 and 1, their must be some relationship between the two. In a scatter diagram he explained that sphericity and roundness would be always an allipse , circle or any other closed curve and can never be an open curve like Parabola or hyperbola , while as Wadell (1935) believed reverse of the same.

In scatter diagram (Plate -21 fig. 1), the same results were obtained, for all the three formations of clastic group, which are closed curves having coinciding tendency.

HEAVY MINERALS

The heavy minerals are very useful in the determination of the nature of source rocks, which have supplied material from the different rock units. Due to extreme old age of the formations of the study area, most of the unstable heavy minerals, have been removed by intersititial solutions and only very stable heavy mineral species like zircon, tourmaline, rutile etc. are present. In this study, these minerals have been studied to find out:

(i) any variation in their percentage and nature in the three units of this group.

(ii) nature of the source rocks from which these minerals have been released.

WEIGHT PERCENTAGE OF THE HEAVY MINERALS

The total weight percentage of the heavies(after separation with heavy liquids) is shown in Table 18. The weight percentages of different heavies present in this group are also shown in bar diagram (Plate 21 fig.2). The minimum amount of heavies are present in Muth Quartzite, their percentage varies from 0.020 to 0.210. The percentage of heavies in sandstones of passage beds ranges between 0.160 to 0.320, while in the sandstones of Associated beds of Syringothyris limestone, it is between 0.143 to 0.402. The percentage of heavy minerals shows that, there is an increase in the heavies from Muth Quartzite to Passage beds.

The distribution of heavy mineral frequencies in various units of Orthoquartzite Carbonate group indicates that a few

heavy minerals are almost equally distributed and there is some particular trend of distribution of these minerals, which can be considered important in differentiating these three units from one another.

For determining frequency of these heavy minerals 200-300 grains per slide were counted and the data so obtained has been presented in a bar diagram (Plate 21, fig. 2) , which was further caliberated to frequency number scale, devised by Evans, Hgman and Majeed (1933) to verify the results. However, the frequency numbers in this case are in a general way logrithems of the frequency percentage determined by counting and thus the lower frequency values are emphasized. Although this scale offers little advantage over the simple statement of estimated percentages of mineral species, but it makes comparison of the data in the usual sense and tend to hide the inherent inaccuracies in the method used.

ZIRCON

Zircon is the most important heavy mineral found in all the three units of the Orthoquartzite Carbonate group. Zircon percentage varies from 35 to 80 percent of the total bulk of the heavy minerals present in these rocks. The maximum percentage has been found in Muth Quartzites, where it is around 81 percent in some samples, but decreases in some of the samples of Associated beds, going to the minimum of 35 to 40 percent. Zircon is a very important mineral as a provenance indicator (Wyatt, Michael, 1954), for the purpose of correlation and subdivision of the formations (Vitnage, 1957) and also for finding out the amount of abrasion during its original transportation (Allen , 1948 and Krynine, 1948).

TABLE- 18

HEAVY MINERAL WEIGHT PERCENTAGES OF QUARTZO SANDSTONES OF ORTHOQUARTZITE CARBONATE GROUP

Sr.No:	Sample No:	Weight percentage
1.	H-5	0.020
2.	H-7	0.200
3.	H-8	0.211
4.	H-9	0.010
5.	NB-4	0.200
6.	N-9	0.112
7.	N-7	0.120
8.	G-1	0.016
9.	G-2	0.110
10.	G-5	0.102
11.	PQ-3	0.160
12.	PQ-5	0.102
13.	PQ-14	0.320
14.	PQ-16	0.160
15.	PQ-24	0.100
16.	A-25	0.014
17.	A-41	0.211
18.	BK-7	0.402
19.	BK-22	0.142
20.	BK_2-32	0.180

Sr. No: 1 to 10: Muth Quartzites.
Sr. No: 11 to 15: Passage beds.
Sr. No: 16 to 20: Associated beds. of Syringothyris Limestone.

Das Gupta (1971), reported the presence of Zircon from the Muth quartzite of Spiti area, but no earlier worker has studied this mineral in detail from any unit of Orthoquartzite Carbonate group.

In this work,a detailed study of zircon has been undertaken for all the units of the group, to find out any difference in the physical character of this mineral which might be helpful in distinguishing one unit from anohter.

The present study of Zircon is confined to morphological characters, stability, abrasion index, statistical measures of degree of elongation etc.

MORPHOLOGICAL STUDIES

Fig. 1-16 (Plate-22) represents various types of crystals of zircon found in these units; Figs. 1,3,6,12,15+16 from Muth quartzite, figs. 2,4,5,11+14 from Passage beds and from 7,8,9+10 from Associated beds.

As seen in figures,most of these have become rounded by abrasion effect, while a few have retained their original crystal boundaries. In figs 1 to 8, the original prismatic crystal outline is still seen, ,while in others,due to wear and tear of transportation, original shape and form of the crystal have been totally obliterated. On the basis of the effect of abrasion on these crystals, three types have been recognized:

(i) Euherdal grains; Fig 5 to 8 in (Plate-22) represents euhedral grains. In these grains original crystal outlines are still prominent. The prisms are terminated by pyramids and domes. Their crystal edges and corners are very slightly rounded.

These crystals belong to Muth quartzite and Passage beds.

(ii) Subhedral grains: Figs 1 to 4, (Plate-22) represent subhedral grains. In this case only, prism habit is recognizable; others are broken or rounded by the impact of transportation.

(iii) Anhedral grains: The grains which have become rounded and in which original form and shape of the crystal is totally changed, are classified as anhedral grains. Figs 9 to 16 of the same plate are anhedral grains of zircon, belonging to various units of the Orthoquartzite carbonate group.

ZIRCON ABRASION INDEX

Allen (1949), and Vitnage (1957), defined Zircon Abrasion Index as the frequency of euhedral grains, which may be used as a general index of particle shape and the amount of abrasion during transportation. The percentage of euhedral grains in each unit is shown in bar diagram (Plate-21 Fig3). It clearly shows that the percentage of euhedral grains in these sediments are very small, while most of the grains are anhedral and subhedral; The anhedral and subhedral nature of these grains can be explained by the fact that these sediments are highly mature. The roundness and spehericity studies of quartz grains also confirms the same conclusion of these sediments. In these sediments, which are the product of protracted and profound weathering, sorting and abrasion, hardly any grain could have retained its original boundary. Moreover, many of these grains must be involved in number of cycles and recycles, getting themselves under the process of abrasion number of

times. The presence of a few euhedral grains indicate, the igneous source, while as the anhedral and subhedral grains, modified with the rock transport, which is important to interpret their crystal habit in the reworked/sedi-ments as their source material. Overall, these sediments have been derived from both igneous and sedimentary sources.

COLOUR

On the basis of colour, three varieties of zircons have been found in these sediments, viz., colourless, pink and light yellowish varieties. Out of all these varieties, colourless zircons are most common in all the units. Most of the euhedral grains are pink, whileas some of the grains show double shades, in which the coresand the marginsare of different colours. No characteristic colour is restricted to any particular formation.

CLOUDING

In all the three rock types a large number of zircon grains are clouded with inclusions, which are not easily discernible. (Plate-22 figs 1,3, 5, 4+13). The cloudiness has been differentiated on the basis of types of inclusions present and their colour. The grains which are partly clouded can be well seen in Plate-22, figs 3,4+13. These are further identifiable by means of their colour, zoning; secondly alongwith the original colour of the zircon grains and the colours of the inclusions; the faces of inclusions can be easily recognized. Mostly pink varieties are inclusionless and

have euhedral form and hence these varied types of the grains are indicative of varied sources.

OVERGROWTHS AND OUTGROWTHS

Varied types of overgrowths and outgrowths have been observed in these zircon grains, which are secondary in nature. These growths are of various types:

1. Most often these are in the form of the development of pyramidal faces on some subrounded and elliptical grains.
2. Some of the grains show thread like zoning (Fig 8), which indicates that the growth has taken place by the addition of successive layers. This is further confirmed by the fact that in such grains, the colour of the original grain represents the core with different colour to that of the outer margin. These overgrowths and outgrowths are filled with dirty yellowish material, which is also indicative of their being secondary in nature.
3. Occasionally some outgrowths have been noticed which are of irregular shape.

The nature of varied types of zircon grains in which overgrowths and outgrowths have taken place are indicative of more than one cycle of sedimentation.

DEGREE OF ELONGATION

Elongation is defined as a ratio of length to breadth(l/b) Smithson(1939), — ,Vitnage (1957) on the other hand considered degree of elongation as (b/l) i.e. breadth to

length and on this basis recognized four types. These types are: (i) highly elongated grains (b/a ratio 0.10-0.35), (ii) moderately elongated (b/a ratio 0.35-0.55), (iii) equant grains (b/a ratio 0.55 -0.70) and stumpy grains (b/a ratio 0.70-1.00). According to Vitnage (1957), all these four types of zircon are characteristic of different source rocks.

In this study Vitnage elongation ratio breadth to length (b/a) has been adopted . Some 500 grains of zircons were studied in this manner. The percentage frequency of zircon types on the basis of degree of elongation is given in Table-19 . Table-19 shows that the majority of the zircon grains are either moderately elongated type or equate to stumpy in nature. However, the percentage of stumpy type dosnot exceed 10 percent in case of Muth quartzites, but in some of the samples from passage beds, it exceeds 15 percent. The percentage of moderately elongated grains are high in case of Muth quartzites to that of passage beds. The presence of different types of grains in these siliceous rocks, on the basis of elongation, show that the material containing these grains is from reworked sediments like sedimentary and other acid igneous rocks.

The study of frequency elongation histograms (Plate — 23) shows that these are of more than one pattern . Figs 1 to 3 of the same plate are unimodal and the modal class is between 0.4 to 0.5. The modal class in the Muth quartzites are almost from 0.4 to 0.5, whileas in the Passage beds it is between 0.5-0.6.

TABLE- 19

PERCENTAGE FREQUENCY OF ZIRCON TYPES, ELONGATION VALUE PERCENT FROM QUARTZO-SANDSTONES.

S.No:	TYPE-I	TYPE-II	TYPE-III	TYPE-IV
1.	12	46	34	8
2.	22	43	26	9
3.	21	38	34	7
4.	14	48	28	10
5.	16	42	52	10
6.	29	37	22	12
7.	20	48	23	9
8.	18	42	23	15
9.	14	52	20	14
10.	21	39	32	8
11.	19	63	16	2
12.	34	29	26	11
13.	30	34	22	14
14.	14	43	35	8
15.	14	43	30	13

Formations:
Sr.No: 1 to 5: Muth Quartzite,
6 to 10: Passage beds.
11 to 15: Associated Quartzites of Syringothyris Limestone.

TABLE -20 SUMMARY OF STATISTICAL DATA ON ELONGATION VALUES OF ZIRCON OF MUTH QUARTZITES

S.No.	Sample No.	Mean	Standard Deviation	Median	Mode
1.	N-6	0.5217	0.1254	0.4981	0.7651
2.	N-7	0.5115	0.1406	0.4914	0.8610
3.	N-8	0.5470	0.1265	0.4160	0.4520
4.	N-9	0.4936	0.1620	0.4700	0.8280
5.	N-10	0.4233	0.1466	0.3272	0.4130
6.	NB-3	0.4728	0.1431	0.4728	0.8181
7.	NB-4	0.5365	0.1634	0.4885	0.4812
8.	NB-5	0.4870	0.1402	0.4729	0.8280
9.	G -1	0.5165	0.1936	0.4578	0.7570
10.	G-2	0.5122	0.1661	0.3519	0.4650
11.	GA-2	0.5210	0.1538	0.4511	0.5862
12.	GA-5	0.4650	0.1365	0.5741	0.8180
13.	H-5	0.4562	0.1406	0.5170	0.7750
14.	H-7	0.4861	0.1532	0.5125	0.8126
15.	H-9	0.5840	0.1484	0.5562	0.7890

Serial No. 1 to 8: Naubug/Gurderman, No 9 to 12: Gugaldar, 13 to 15: Hapatnar./Gugaldar.

TABLE-21 SUMMARY OF STATISTICAL DATA ON ELONGATION VALUES OF ZIRCON OF PASSAGE BEDS.

S.No.	Sample No.	Mean	Standard deviation	Median	Mode
1.	PQ-3	0.5430	0.1551	0.4691	0.5431
2.	PQ-5	0.6336	0.1842	0.4950	0.8623
3.	PQ-7	0.6120	0.1812	0.5049	0.8172
4.	PQ-8	0.7642	0.2139	0.6120	0.8726
5.	PQ-9	0.5262	0.1981	0.4672	0.8162
6.	PQ-10	0.6360	0.1951	0.4650	0.8620
7.	PQ-11	0.6553	0.1258	0.6169	0.6810
8.	PQ-14	0.5218	0.1258	0.5228	0.7652
9.	PQ-16	0.5832	0.1488	0.6102	0.8926
10.	PQ-15	0.6161	0.1496	0.5153	0.5268
11.	PQ-18	0.5125	0.1403	0.4913	0.8612
12.	PQ-19	0.5641	0.1651	0.4920	0.8402
13.	PQ-24	0.4650	0.1365	0.5742	0.8173
14.	PQ-26	0.7675	0.2596	0.6140	0.8890
15.	PQ-28	0.7172	0.1987	0.5753	0.7624

Serial No.1 to 15: Sinder Nar-Gali Section NE of Aishmukam.

The elongation histograms from Passage beds and the associated beds are mostly of bimodal in nature, in case of histogram No. 7 to 11 the mode is in the 0.4 and in others it is between 0.8 to 0.9 classes.

STATISTICAL ANALYSIS OF ELONGATION DATA

The hetereogenous nature of the elongation ratios of grains indicate that the granitization of the pre-existing rocks was not uniform and the original zircon grains had different elongations. The basic elongation value data of all these formations is shown in Tables 20 to 21 . which was utilized in understanding and establishing their mean, mode, median and standard deviation. The techniques followed in this study were taken from the work of Larsen and Poldervaart (1957-59), and developed by others for the number of crystals, mean length, mean standard deviation and mean breadth etc. The results obtained from mean length varies between 0.4233 to 0.7642 and the standard deviation values between .1254 to 0.2139. The values obtained from all these formations are same, except in a few cases, while as the median and the mode values are a bit higher and varied. The results obtained from this study, indicates zircon history and explains its several sources.

TOURMALINE

Tourmaline is also to a greater extent stable heavy mineral specie and has a less effect of transport. It is found in all

the three rock units in this study with a minor variations in percentage. The morphological characters are same in all these formations, in which three main colours of tourmaline grains like brown, greenish and occasionally bluish green have been observed. The percentage of these grains increases from the Muth quartzites to associated beds. The crystal outlines are completely preserved . In some cases these are rounded and euhedral which indicate that they have passed through more than one cycle of sedimentation. These grains are clouded with some minor inclusions.

RUTILE

Rutile is found in all these formations. The grains are mostly irregular, and in a few cases their crystal outlines have been retained. In some of the grains cleavage type cracks are common. These are deep brown to blood red in colour without inclusions. The percentage of these grains is between 1 to 11 in all these formations.

OPAQUES

The percentage of opaque minerals is more in Passage beds and associated beds, as compared to that of Muth quartzites. The nature, shape, colour and the other characteristics are varied in all these formation-s. Among these opaques, magnetite pyrite cubes are clearly preserved. These are distinguished from their dark colour. However, no attempt has been made to distinguish between these varied types of opaque minerals.

THIN SECTION PETROGRAPHY

The sandstones constituting Orthoquartzite Carbonate group are hard, compact, mostly snow white coloured rocks with patches of brownish shades due to ferruginous impurities. In hand specimens, these sandstones look so alike that their distinction can not be made from one another. Under microscopic examination, however, fundamental differences, were noted in their textural and compositional features; which were of great use in differentiating sandstones of one formation from another. No earlier worker has studied the thin section petrography of these sandstones, except a paper by Das Gupta (1971), on Muth-quartzite of Spiti. In this work, more than one hundred thin sections were made in order to study their texture and composition, and more than 50 modal analyses of representative samples were made.

(i) MUTH QUARTZITE

Texture: Photomicrographs of representative samples of Muth quartzites are shown in Plate-24 figs 1-6, Plate-25 figs 1-6. In all these samples, the framwork is intact, the grains have interlocked contacts that no space is left in between them. Most of the grains are subangular to subrounded. With respect to the size of the grains, some rocks are fine grained, equigranular and show good sorting (Plate-24 fig 1.) .The size of the grains in these rocks does not exceed 0.2-0.3 mm. Some rocks, however, are coarse grained, have good sorting and

equigranular, where the grain size ranges between 0.4-0.5 mm (Plate-24 fig.4). Some of the rock types in these sandstones showing perfect bimodality (Plate-24 fig.5), in which there are two distinct sizes, fine grained and coarse grained. Each size has a good sorting, with no intermediate size in between them and the bigger sized grains are set within fine sized grains as plums in a pudding. The size of the bigger grain is about 0.7 mm and that of smaller ranges between 0.3-0.4mm. Though this bimodality is also seen in Plate-25 figs. 2,3 and 5, yet the size difference between the two is very less. Das Gupta (1971), reported this bimodality in Muth quartzites of Spiti. In this study, the bimodal distribution was, however, not seen in all the rock types. In these rocks, grain matrix ratio is very high as matrix does not exceed 5 percent in any of the sample.

Composition: The modal anal-yses of representative samples of Muth quartzites are shown in Table-22. The chief characteristic features of framework constituents of these sandstones are as follows:-

Quartz resistates: Regarding their composition, quartz is the most important framwork constituent of these rocks. As seen in Table-22, the percentage of quartz is not less than 94 percent in any case and it does not exceed 96.94 percent. The quartz grains are subangular to subrounded. Most of them are monocrystalline and rarely polycrystalline grains are noted.

GRAIN SIZE ANALYSIS

Table-6 summarises the statistical parameters of grain size distribution of the sandstones of upper Hapatnar formation. The mean size ranges between 2.03 to 2.53 and the standard deviation values 0.483 to 1.02. The standard deviation values indicate their good sorting. The skewness values, however, show that these have a good amount of coarser fraction of the grains. Most of the samples are mesokurtic in nature. The cummulative curves are also shown in (Plate-22) . These cummulative curves reveal that these sandstones are better sorted than that of the sandstones from the Gauran formation.

SPHERICITY AND ROUNDNESS

The sphericity and the roundness values of these sandstones are summarized in Table-10 . The mean sphericity values range between 0.48 to 0.72 with standard deviation values from 0.112 to 0.196. The degree of mean roundness values are between 0.19 to 0.42, however, majority of the grains are above 0.25, with low values of roundness ratio and the roundness index. The elongation values of length to breadth range between 1.05 to 2.60. The values observed of both these variables are fairly higher to those of greywackes, owing to their good morphological characters. The results of this study also corroborate with that of thin section studies.

TABLE-22 MODAL COMPOSITION OF MUTH QUARTZITES

S.No.	Sample No:	Quartz %	Feldspar %	Rock fragment %	Heavy minerals %	Others*
1.	N-6	95.61	2.30	1.52	0.211	0.36
2.	N.7	95.22	2.80	1.62	0.120	0.24
3.	N-8	94-32	2.23	2.26	0.210	0.98
4.	N-10	96.85	1.75	1.00	0.104	0.30
5.	NB-3	93.98	2.76	2.54	0.150	0.57
6.	NB-4	95.68	1.56	2.56	0.200	-
7.	NB-5	96.11	1.10	2.51	0.180	0.10
8.	G-1	94.51	2.56	2.24	0.016	0.68
9.	G-2	94.03	2.73	1.88	0.110	1.25
10.	GA-2	94.92	1.64	2.46	0.110	1.87
11.	GA-5	96.32	2.00	1.58	0.110	-
12.	H-5	96.10	2.33	1.55	0.020	-
13.	H-6	95.06	1.93	2.18	0.164	0.67
14.	H-7	96.94	0.86	1.96	0.200	0.04
15.	H-9	96.02	1.05	2.60	0.100	0.23

Sr.No: 1 to 7: Gurderman, Tangwani (Naubug).
Sr. No: 8 to 11: Gugaldar, Sr.No. 12 to 15: Hapatmar/Gugaldar.
*Others include cement/matrix.

Many of these grains are inclusionless, although gas inclusions are seen in some cases. Most of these grains show non-undulatory extinction and in a very few grains undulatory extinction is observed. In some rocks the undulatory extinction shows well marked strain shadows. The original grain outline is sutured in many cases. In many other rocks, owing to condensed framework, adjacent grains interlock along a sutured boundary. Overgrowth is a very common feature of these rocks. It usually takes place in optical continuation of the grains, ultimately resulting in the interlocking of the grains and producing condensed type of framework. Well marked overgrowths are seen along the boundaries of many grains (Fig 4 and 6, Plate-25).

Pitting and frosting also has been observed in these grains. In fig.4 of Plate-24, this feature is well displayed. The frosted a-ppearence of quartz grains may be due to incipient secondary growth. This is based on the fact that many times grains reflect light from the minute crystal faces. The pitting of the detrital grains appears to decrease progressively with increase in fineness of the grains, because pitting is visible only in the coarser grains. This pitting might have resulted in a number of ways. It may be due to solution produced at the point of contact of adjacent grains from intergrowth of secondary crystals, from some type of crust coatings produced due to solution. In most of the cases, there are very small rounded clay dots which produce pitting effect on the grains.

Feldspar: It is not a very common constituent of Muth quartzites and its percentage ranges between 0.86-2.80. It is usually present in the finer fractions, having the same size as that of the quartz grains. On the whole, it shows good rounding. Often a broken half of a rounded feldspar grain occurs, suggesting a splitting of the grain possibly during transportation. Feldspar with crossed and lamellar twinning is more common than an untwinned variety. As optically identified, feldspar with cross-twinning is microcline and that with lamellar twinning is intermediate plagioclase which may be oligoclase. Most of the feldspars are fresh, but the grains showing scattered sericite flakes and more commonly vacuoles a re also not uncommon.

Rock fragments: Muth quartzites, as a rule, do not contain any sand sized labile rock fragments of either sedimentary or metamorphic rocks, only chert grains as referred above are occasionally found dispersed among quartz grains. These too do not exceed 2 percent of the total framework constituents. Quartzose fragments are common and compose upto 10 percent of the rocks. Large quartzose fragments, micro and meso-crystalline quartz is rounded to well rounded in form and their internal grain contact may be straight or crenulated.

Matrix: These rocks are mature to superma-ture and do not contain any matrix of any type.

Cement and accessory constituents: Authigenic quartz is a most common cement of these rocks. This authegenic quartz is

responsible for producing condensed framework. Carbonate cement is not common.

II- ASSOCIATED SANDSTONES OF SYRINGOTHYRIS LIMESTONE:

Photomicrographs of representative samples of Associated sandstones of Syringothyris Limestone are shown in Plate-26 figs. 1-6.

Texture: As seen in the figures, these sandstones exhibit varied type of texture. In fig.3, there is a condensed type of framework produced due to interlocking arrangement of grains as seen in Muth quartzites. This rock also is equiangular as there are two distinct sized controlled fraction, but the difference in size is not so pronounced producing distinct bimodality, as seen in Muth quartzite. This condensed texture, is however, disrupted due to encroachment of Carbonate cement. In figs. 1 & 2 Plate-26 , this encroachment is slight, resulting in the separation of a few contacts, but the grains still have partial contacts with each other. In figs. 5 and 6, however, the effect of Carbonate cement is so much that original interlocking arrangment of the gr-ains no more exist, and the grains are seen floating in the carbonate cement. Most of the rocks are fine grained as the size of the grains does not exceed 0.2 mm. The grains in figs. 3 and 4, however, are a little coarser. More or less, these grains have good sorting; even where there is a bimodality, there exists a good sorting in the two size fractions. Each size fraction has a good sort-ing of its own

and the grains are less rounded as compared to that of Muth quartzites. This apparent angularity is due to replacement of their boundaries due to carbonate cement.

Composition: The modal analyses of representative samples of these sandstones are shown in Table-23 .

Quartz Resistates: Detrital quartz constitutes 38 to 76 percent of the rock and ranging in size from 0.05 to 0.5 mm. The average size ranges btween 0.125- 0.25 mm. The finer grains of quartz are largely angular to subrounded. Most of the quartz grains are either c lear or include randomly scattered vacuoles and rarely microlites. Some contain well developed inclusions of zircon and tourmaline. P-itting and frosting is common in some of the grains. In the right margin of photomicrograph No.3 (Plate-26), there is a rounded quartz grain showing smaller dots of clayey material. In other cases, the fro sting of quartz grains is due to carbonate c-ement. The chert occurs in most of the rocks, though it rarely exceeds 1.5 percent. It usually occurs in the modal grain size, and are evenly granular and sometimes partly recrystallized including impurities in the form of sericite and quartz.

Feldspar: Hardly a few grains of feldspars are noted in these rocks and the percentage never exceeds 3.50 percent. It occurs in the same size range as quartz, but is more common in fine fraction. It generally shows a similar rounding to that of quartz. As regards its type, intermediate plagioclase is more common than cross-hatched microcline or untwinned orthoclase feldspar.

TABLE- 23

MODAL COMPOSITION OF ASSOCIATED SANDSTONES OF SYRINGOTHYRIS LIMESTONE

Sr.No:	Sample No:	Quartz %	Feldspar %	R.Fragment %	Matrix/ Cement %	Mica %	Heavies %
1.	A-25	76.06	2.49	17.66	2.53	1.32	0.14
2.	A-81	62.38	2.21	9.66	25.49	-	0.26
3.	RA-6	61.54	0.50	9.44	28.44	-	0.12
4.	RA-25	58.60	1.50	7.34	30.36	1.00	0.20
5.	RK-1	46.53	1.97	16.32	34.42	0.32	0.40
6.	RK-22	38.60	3.50	10.61	45.00	2.23	0.23
7.	RK-47	49.18	1.49	20.12	29.58	0.49	0.14
8.	RK_2-7	74.33	1.45	11.93	9.10	2.86	0.33
9.	RK_2-32	61.44	3.13	12.46	21.07	-	0.40
10.	RK_2-37	53.53	1.34	23.24	21.68	-	0.21

Sr.No: 1 to 4: Aishmuqam
5 to 10: Kotsu.

Rock fragments: Unlike Muthquartzites, rock fragments are found in these rocks, but their percentage is very impressive in some samples and they constitute upto 23.24 percent. A bigger rock fragment of argillaceous sedimentary rock is seen near the right margin of the photomicrograph No: 4 (Plate-26). Some low rank metamorphic rock also appears among rock fragments, sometimes in these rocks.

Matrix: No matrix is found in these rocks, it has all been replaced to carbonate cement.

Cement: Calcium carbonate forms the principal cement in many of these rocks varying in amount from 5 to 45 percent. It is finely dessiminated in the rock and occupies large interstices corroding the boundaries of detrtital particles.

III- PASSAGE BEDS

Photomicrographs of representative samples of sandstones belonging to Passage zone are shown in Plate-27.

The chief peculiarities of these sandstones are as follows:

Texture: Texturally Passage beds show transitional characters between Muth quartzite and Associated sandstones of Syringothyris Limestone. A typical bimodal texture like that of Muth quartzite is seen in fig. 3 Plate-27, where a bigger grain of subangular quartz (0.4 mm size), is set in a mosaic of finer grained quartz, having a size range from 0.1 - 0.2 mm. This texture differs slightly from muth quartzites as there is little carbonate cement finely disseminated in the matrix. The samples represented by figs 1 and 2 exhibit the same closely

condensed texture of Muth quartzites, which is slightly disrupted by the penetration of carbona-te cement. Figures 5 and 6 (Plate-26) show more or less floating type of grains in carbonate cement, resulting due to more influx of carbonate solutions. It is, therefore, evident that Passage beds show mixed characters of textural features found both in Muth Quartzite and Associated sandstones of Syringothyris Limestone. The grains have a good sorting and are subangular to subrounded. Their apparent angularity is due to corroding of their boundaries by carbonate cement.

Composition: The modal analyses of representative samples of passage beds are shown in Table-24. The description of framework constituents is given below:-

Quartz Resistates: The detrital quartz occurs in about the same proportion as in the underlying Associated sandsto-ne-s, with less cement, and has same general textural characters. Quartz occurs both fine grained as well as coarse grained in different samples. Quartz grains in Fig 3 and 6 (Plate-27) are fine grained. The size ranges between 0.1 to 0.2 mm, while in figs. 1 and 2 of the same plate, the size ranges between 0.2 -0.5 mm. These quartz grains are mostly inclusionless, although in some grains inclusions of gas arranged linearly or in even accicular needles of zircon and tourmaline are present. Pitting and frosting due to carbonate cement is also very common. One of the characteristic peculiarity of these quartz grains is that small veinlets of carbonate cement have penetrated within them.

TABLE -24

MODAL COMPOSITION OF PASSAGE BEDS

S.No:	Sample No:	Quartz %	Feldspar %	R. Fragment %	Matrix/ Cement %	Mica %	Heavies %
1.	PQ-5	71.22	3.45	18.32	6.80	-	0.21
2.	PQ-7	73.04	1.57	17.26	8.00	-	0.13
3.	PQ-9	66.79	5.23	22.50	4.32	-	0.16
4.	PQ-11	69.90	2.37	25.00	2.60	1.93	0.00
5.	PQ-14	84.46	6.54	4.65	2.60	1.53	0.22
6.	PQ-15	76.65	2.73	16.62	2.31	1.56	0.13
7.	PQ-18	81.91	2.66	12.92	1.54	0.86	0.11
8.	PQ-19	67.27	4.98	15.16	12.57	-	0.02
9.	PQ-26	71.04	8.73	20.03	2.54	-	0.64
10.	PQ-28	57.40	3.62	35.67	1.33	0.98	1.00

Sr. No: 1 to 16 : Sindernar Gali Section, northeast of Aishmuqam.

This effect is well seen in fig.5 (Plate-27), where number of quartz grains are shattered into smaller fragments due to pressure exerted by this penetration. In the same fig. on the right margin, there is a rounded quartz grain which has been splitted up into number of smaller angular pieces due to the effect of Carbonate cement. In fig. 2 also, near the central portion of the left side of the photomicrograph, a quartz grain is splitted into two pieces by a thin carbonate veinlet. In fig.6 (Plate-27), a veinlet (stylolite), in which the limonitic material is seen, alongwith the crushing effect on the quartz grains. Besides, quartz, quartzose fragments mostly micro and meso-crystalline make up 5 to 10 percent of the rock and range in size from 0.1 to 0.3 mm. Chert is fairly widespread, though it rarely exceeds 3 percent and often occurs as rounded particles.

Feldspars: A very few feldspar grains have been noticed, their percentages are between 1.5 to 8.73 percent. All the feldspar grains found in these rocks are of lamellar twinned plagioclase variety. No grain of cross hatched microcline is noticed in these rocks. Plagioclase is mostly subrounded but locally may contain scattered flak-es of sericite.

Rock fragments: These rocks differ from Muth quartzites and Associated sandstones of Syringothyris Limestones in having medium to high percentage of rock fragments. Both low rank metamorphic and argillaceous sedimentary rocks occur in these sandstones.

Their percentage varies from 4 to 25 percent in various samples. Siltstone and phyllite, fragments are by far the most common ones. Argillite is also fairly widespread and igneous rock fragments are less common. In fig. 4 (Plate-27) in the central portion, a bigger rock fragment of argillaceous type, having irregular boundary is seen. Phyllite is occasionally present in these sandstones to the extent of about 2 percent, but being soft tends to flow between other grains. Often the sericite rich phyllite or siltstones are not differentiated from the matrix.

Matrix: It is unequally distributed in different samples and is generally less than 8 percent. Much of the matrix has been reconstituted to sericite which occurs in finely divided flakes. Some mica and chlorite flakes are also present.

Cement: In these rocks also calcium carbonate is the most important cement, which is finely disseminated in the matrix or occupies the large spaces by corroding and dissolving the detrital particles.

Accessory Constituents: The accessory minerals in these rocks are zircon, tourmaline and opaques. Large mica flakes are also seen. In Photomicrgraph No.1 (Plate-27), two large muscovite flakes are seen in the central portion, which are slightly bent under the pressure of the quartz grains in which these are enclosed.

PETROGRAPHIC CLASSIFICATION

Percentage composition in terms of quartz resistates, fledspar and rock fragments were recalculated to 100 percent and plotted in an equi-triangular diagram for some arenites only. The wacke diagram is not used, as these rocks are mostly mature to super-mature sandstones having little matrix, except some samples from Associated beds of Syringothyris limestone. In this work, the sandstone classification of Gilbert (1954), has been preferred. In this classification, the three end members of triangle are: (i) quartz, (ii) fledspar and (iii) rock fragments. The triangle is divided into five broad fields, representing various types of sandstones as seen in Plate-28. The advantage of adopting this classification is that it incorporates fundamental principles of the two main schools of classification i.e. Krynine and Pettijohn's schools. The sandstone classification evolving from Krynine, takes into consideration the factor of provenance and mineralogical maturity in addition to diastrophism; while Pettijohn & his associates include textural maturity (sorting Index) and fluidity factor (fluid viscosity and density in addition to mineralogical maturity. Gilbert classification fulfills both the aims.

In Plate-28, plots of sandstones of various units in terms of quartz resistates, feldspar and rock fragments are shown. It indicates that most of Muth Quartzites belong to pure quartz-arenite type, while the sandstones of Passage beds are lithic and sub-lithic arenites and, however, some of the samples of Associated beds are also of the same variety, as that of Passage beds but in some cases, the matrix exceeds 15 percent which has been recalculated to individual grain percentages.

RESULTS

Results of thin section studies are very significant i-n two respects:

(i) A positive petrographic difference was found amo^n^g sandstones of the three units of the Orthoquartzite Carbonate group which is reflected both from texture and composition. As a result of this study, it was found that Muth quartzi- tes are very immature to supermature sandstones, having very condensed type of texture which often shows bimodality. The sandstones of Associated beds have more often disrupted framework due to influx of carbonate cement. The sandstones of Passage beds have transitional type of texture as observed in Muth quartzites and Associated sandstone, which is neither condensed nor disrupted, but midway between the two.

With respect to composition also, there is a marked difference in these three units. It was observed that Muth Quartzites are mostly quartzarenite type, while as Associated sandstones of Syringothyris Limestone and that of Passage beds are sublitharenite and Lithi^-arenite types.

With these textural and compositional differences, it is, therefore, possible to mark and identify these units in the field to establish their stratigraphic positions.

(ii) Textural studies also prove helpful in understanding their mechanism of deposition. Das Gupta (1971), in his study of Muth quartzites of Spiti observed a distinct bimodal texture and on this basis he concluded that this texture is characteristic of desert pavements and that the bimodality is due to

mixing of two types of sands, highly sorted sands by wind action.

According to Folk (1968), many of the early Palaeozoic sandstones of North America, which are commonly supermature quartz arenites, show bimodal texture. There are two grain size modes, each mode well sorted, but there may be a diamter ratio of 6 : 1 or more between the two grain sizes. The large rounded grains in these sandstones are set randomely like plums in a pudding of fine quartz grains. Such rocks are supermature with regard to both mineral composition and rounding, and yet have overall poor sorting. This bimodality has been known from sands of the lower Ordovician Beekmantown group in Central Penninsylvania, particularly in Belleforte sandstones.

Many earlier workers also reported bimodal sandstones such as Baily (1924), who thought these to be of desert origin.

Mckee (1934), on Permian Coeonino sandstones Arizona, reported bimodal sandstones to be of desert origin.

Wilson (1962), described Cambrian Ihcikory sandstones Texas as bimodal and interpretted it as desert sandstone, as he found in these fresh feldspars, ventifacts and percussion marked coarse quartz sands.

Poole (1964), studied aeolean sands in the western United States and mentioned that coarse to medium sand sized floating grains are bimodal.

Regarding the mechanism of bimodality according to Folk (1968), the main tendency of the wind in modern deserts

is to remove that part of the poorly sorted source sediment, that is easiest to set in saltation, i.e. mostly the fine sand fraction around 0.1-0.3 mm and heap it into relatively well sorted sand dune, especially unimodal. Left behind on desert floor are (a) grains that are too coarse to saltate but that do roll into well sorted ripples, patches or lamillae and (b) the very fine sand and silt that forms a coherent, smooth cohesive surface that is difficult to move by wind action. Once it is disturbed, it may be blown in suspension for miles but eventually again settles out on the desert floor. In this way, the desert floor or reg sediments become a mixture of (a + b) and thus tend to be strongly bimodal.

The association of this bimodal type of sandstones with marine fossils found within the sand body suggest the presence of barrier island , within the ocean on the crest of which wind-blown sand dunes are formed. On its landward side, there may be complex of wash over fans and barrier flats formed of sand flushed over the barrier island during storms seaward. The beach deposits of the barrier island pass out into open marine environment. Marine transgression over such an area will produce marine deposits made up of grains, that retain their peculiar grain size distribution and bimodal good sorting.

SEDIMENTARY STRUCTURES

Table-25 and Plate-29 summarizes the association of sedimentary structures found in the quartzo sandstones of the various units of this group, and the interpreted flow processes that produced them. Most of the structures indicate the dominance of tidal current during their formation.

TABLE- 25

STRUCTURES	FLOW MODEL	UNIT IN WHICH PRESENT
Laminated beds Planar cross bedding Tangential cross bedding	Formed as a result of deposition on the point bars of small meandering channels or on the inclined surfaces of beaches and bars generated on point bars, less bioturbated or as a result of scour and channel fill feature, common in the intratidal zone.	Passage beds & Muth Quartzites.
Cross strata with flaser simple flaser bedding Tidal bedding	Alternation of tidal current bed load, transport with suspension during slack water periods.	Associated beds and Muth Quartzite.
Herringbone cross stratification, parallel laminae	Tidal current bed load, transport with bipolar reversal of flow direction.	Associated beds Muth quartzite.
Wave ripples often bifurcated crests, symmetrical, asymmetrical.	Action of waves on non-cohesive surface in coastal areas. Formed when the velocity of wave propagation falls between 9 cm/ sec to 90 cm/ sec. Larger ripples occur on coarser sand and smaller ripples in finer sands.	All the three units.
Tracks and trails.	Burrowing	Associated beds.

VERTICAL SEQUENCE

The vertical sequence represents a simple regressive composite of the various environments in the study area. The sequence generally fines upward reflecting a transition from the

relatively high energy, intratidal and subtidal environments to the low energy conditions of the upper intertidal and supratidal zones.

PALEOCURRENT STUDY

In this group, sedimentary structures are very abundant among which ripple marks and cross bedding structures have been used to find its paleocurrent pattern. Plate-30 figs.1-6 represents the semicircular rose diagrams of cross bedding, while as figs.7 to 10 represent ripple marks from the quartzo sandston-es of the Orthoquartzite Carbonate group. The data obtained from this study was further subjected to Tukey's chart to find out its preferred orientation direction. From all these diagrams it can be inferred that the source was in southeasterly direction.

TABLE - 26.

PALEOCURRENT DATA FROM CROSS BEDDING AND RIPPLE MARKS

Data No:	No: of readings	Pref. Orientation. Direction.	Chi Square.
1.	25	120.18	18.55
2.	25	120.60	15.70
3.	25	164.54	18.52
4.	25	135.18	28.60
5.	25	151.24	51.77
6.	25	105.18	25.56
7.	10	147.06	13.14
8.	10	111.06	12.26
9.	10	105.54	13.09
10.	10	142.18	13.94

Data 1 to 6 from cross bedding, 7 to 10 ripple marks.

FACIES WITHIN QUARTZO SANDSTONES

Within the quartzo sandstones of this group, three litho-facies can be delineated representing three distinct depositional environments. The broad features of these facies and their environmental interpretations are as follows:-

FACIES-A

This facies is characterized by sheet like sand body extending for miles, showing upward coarsening of the grain size. The sandstones are of orthoquartzitic type having quartz percentage exceeding 95 percent. Most of these sandstones have distinct bimodal grain size in which bigger grains are set in finer size like plums in pudding. Both the grain sizes show excellent sorting. The bedding is unequal but laterally continuous. No limestone beds have been found associated with this facies, although shale partings are occasionally found. At places within the quartzites and shales, marine invertebrate fauna consisting of brachiopods, crinoids etc. have been found. In this facies, both symmetrical and asymmetrical wave ripples are very common with straight but slightly undulating crests. The ripple index of both the types vary from 6 to 10. Besides this, flaser type of bedding is also common together with planar type of cross-bedding.

ENVIRONMENTAL INTERPRETATION

The geometry of the beds, lithology, sedimentary structures nature of the vertical sequence and biota is helpful in the

environmental reconstruction of this facies.

(i) The association of marine fossils of brachiopods, corals etc. suggest some type of marine basin in which these sediments were deposited.

(ii) The blanket or sheet like geometry of the beds indicate linear type of basin with depositional strike parallel to the shore line.

(iii) The standard deviation values of these sandstones are also suggestive of beach type of sands. The skewness values also give the same conclusion.

(iv) The presence of both symmetrical and asymmetrical ripples along with bimodality of the cross bedding is suggestive of shore line deposits.

(v) The bimodal grain size distribution, however, indicates some sort of aeolian action.

All these features are suggestive of barrier shore line environment having regressive type of marine cycle. In this cycle regression involves encroachment of the land on the sea, a result of arrested or very slow subsidence accompanied by active sedimentation. Here two models are possible, one is the inter-deltaic beach complex model, while the other one is shallow marine type. The first model is also known as barrier beach or barrier island which represents the shallow marine environment on one side from the lagoon and marsh behind the barrier. According to Potter (1967), the term barrier island complex include elongated sand bodies that formed from off-shore

bars from the beaches and dunes, which are parallel to strand lines and represents marine from non-marine environment. The crest of the barrier island is often formed of wind blown sand dunes, though these are sometimes stabilized by soil profile and vegetation. The crestal area passes seaward through a beach zone to the open sea. Potter (1967), has also given characteristic of both barrier island and marine shelf sand bodies. Texturally both these bodies show good to excellent sorting and high grain matrix ratio. Both of them have symmetrical and asymmetrical wave ripples with abundant cross bedding trails and burrows etc. These sand bodies are elongated, but widespread sheet of many miles is characteristic of marine shelf environment, with coarsening upward type of sequence. All these characteristic features have been recognized in facies A, however, rich and varied marine fauna is indicative of open sea environment, where as bimodality of grain size distribution etc., present in a few units is indicative of barrier island type. It is thus concluded that the sedimentation of facies A took place in both the environments depending upon the sea level.

FACIES-B

The sandstone of this facies consists of fine to medium grained , clean, wellsorted quart-arenite and lithic arenite with no interbedded siltstone or mudstone. In this facies, rocks are thin bedded to laminated, and are interbedded with limestones. Small scale cross bedding is common, while herring bone cross strata is observed occasionally and the ripple marks

are found on the bedding planes. Planar cross strata are rare. Foreset inclination of trough sets are bipolar and indicate SE direction. However, no bimodality is observed in the sandstones of this facies.

This facies is interpreted to represent traction current deposition in a relatively high energy areas of reversing current flow, with decreasing energy higher in the interval. This facies appears to have been formed behind the barrier in a lagoonal estaurine complex,as point bar deposits of meandering streams. Reversing current direction suggests that the streams were affected by coastal rise and fall of water and thus traversed intertidal flats.

FACIES-C

This facies consists of quartzwacke and lithic wacke with considerable matrix and some siltstones and mudstone beds. The sandstones on large scale are trough cross bedded, having ripples on bedding planes and also show flat bedding and lamination. Trails & burrows are quite common while as herring bone cross stratification and fossils have not been observed. No bimodality as well is found in these sandstones. The sandstones of this facies gradually grade into facies B.

Sandstones of this facies are interpreted to represent traction current deposition from relatively high energy currents of essentially unidirectional flow. The absence of marine fossils, evidence of high current velocity as seen in flat bedding and lamination, unimodal current direction and absence of herring bone cross strata indicate that current flow was not reversing but but was consistently to the northwest. These features suggest that these sandstones represent local distributary channels on the delta front which flowed southeastward down the palaeoslope.

B- PETROGRAPHY OF NON-CLASTIC ROCKS

Non-clastic rocks represented in the orthoquartzite-carbonate group is Syringothyris Limestone (Aishmuqam formation). This is the solitary formation in the non-clastic group in the area of study and lies below the Panjal volcanics. In this formation the limestone beds are found interbedded with sandstones and shales. The limestone is highly fossiliferous and contains a rich fauna of brachiopods, corals and crinoids. The Syringothyris being the most common genus after which the formation derives its name.

Except a brief paper by Bhatia and Kokroo (1978), on the petrography of Syringothyris Limestone, no earlier worker has described the petrography of these limestones. Their investigations revealed number of rock types including distinct dolomitization in the upper part of this formation.

More detailed petrographic work was warranted, to understand its depositional environment and mechanism of dolomitization which these rocks have undergone. The present study is, therefore, designed to work out its detailed chemical composition, petrographic types, textural and structural features to understand in detail exact domain of sedimentation and other physical and chemical parameters, tectonic control under the influence of which these limestones were deposited.

CHEMICAL COMPOSITION

The chemical analyses of both the lower and the upperparts of the Syringothyris limestone are given in Tables - 27 to 28. On the basis of this analysis data, percentages of Calcium - carbonate, magnesium carbonate and carbonates of calcium and magnesium were also calculated and are shown in Tables - 29 & 30.

The close study of these tables reveal the following facts:-

1- The limestones of lower part are rich in CaO and low in MgO, while in the upper part the reverse is true, i.e. the limestones of the upper part have higher percentages of MgO as compared to the lower part. In the lower part, majority of the samples have CaO percentage above 40 percent. Generally it ranges from 39.95 to 50.08 percent (only in one sample out of 15, it is less than 40 percent). This indicates that limestones of the lower part are comparatively of pure variety. In the upper part, majority of limestones have CaO percentage less than 40 percent (13 out of 15). CaO percentage in these limestones ranges between 30.68 to 49.05 percent. In two samples, however, the percentage is less than 30, while in one sample it is as low as 19 percent.

2- On the contrary, the MgO percentage in the lower part does not exceed 4.08 percent, while in the upper part the percentage is high and ranges between 7.52 to 21.25. Only in one sample out of fifteen, the MgO percentage is 1.20.

3- The insoluble residue percentages in both the parts is almost same. In case of the lower parts the percentage ranges between

TABLE 27 CHEMICAL ANALYSIS OF LOWER PART OF SYRINGOTHYRIS LIMESTONE.

S.No:	Sample No.	Acid Insolubles	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	Loss on Ignition.	Total
1.	A_2-17	3.23	1.46	1.98	46.58	1.80	0.10	0.60	43.83	99.58
2.	$14/A_2$	1.55	0.53	2.03	50.50	1.50	0.09	0.53	44.00	100.43
3.	$16/A_2$	2.02	0.54	0.86	47.88	2.81	0.18	0.32	44.26	98.87
4.	$19/A_2$	1.99	0.56	1.00	46.83	2.92	0.31	0.42	45.87	99.90
5.	5/A	0.70	0.38	0.88	49.31	1.66	0.06	0.53	46.98	100.50
6.	$14/A_1$	0.93	0.24	0.95	49.16	1.62	0.16	0.36	46.55	99.91
7.	$9/A_1$	1.10	1.06	2.62	48.46	2.05	0.80	0.12	43.84	99.75
8.	$12/A_1$	1.46	0.52	0.95	50.08	0.80	0.05	0.10	46.00	99.96
9.	15/A	12.37	0.62	1.39	41.86	4.08	0.20	0.30	39.01	99.83
10.	16/A	22.55	2.80	2.06	36.40	0.60	0.50	0.80	34.16	99.87
11.	5/A M	3.66	0.36	0.76	46.92	2.28	0.16	0.36	45.00	99.50
12.	10/A	10.75	3.32	5.05	39.95	1.32	0.52	0.02	37.88	99.41
13.	$11/A_1$	2.27	0.96	1.22	48.36	0.62	0.33	0.12	45.73	99.89
14.	$19/A_1$	12.36	2.53	2.58	40.62	1.50	0.30	0.40	39.28	99.47
15.	$21/A_1$	1.23	0.96	0.46	47.98	2.66	0.15	0.28	46.85	100.57

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TABLE - 28 CHEMICAL ANALYSIS OF UPPER PART OF SYRINGOTHYRIS LIMESTONE

S.No.	Sample No.	S.Gr.	Acid Insol.	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	Loss on Ign.	Total
1.	K/2		1.80	1.00	0.52	31.67	20.08	0.01	0.30	43.86	99.24
2.	K/1		5.55	0.26	0.34	36.98	8.02	0.18	0.23	47.96	99.52
3.	K/5		0.70	0.56	1.65	32.20	19.89	0.03	0.02	45.00	100.54
4.	K/7		2.53	0.38	0.42	38.82	11.93	0.08	0.32	45.00	99.48
5.	K/3		4.81	0.36	1.02	29.62	21.16	0.10	0.03	42.00	99.10
6.	K/12		5.90	0.38	0.42	49.05	1.20	0.12	0.31	42.96	100.34
7.	K_1/28		1.58	0.26	0.96	46.62	7.52	0.12	0.28	42.69	99.95
8.	K_1/32		0.93	0.40	1.20	30.08	21.25	0.50	0.23	44.550	99.09
9.	K_2/20		3.43	0.20	0.24	29.86	17.83	0.05	0.01	46.73	98.34
10.	K_2/33		9.34	0.66	1.32	39.43	21.02	0.03	0.18	27.57	99.55
11.	K_2/34		1.90	0.23	0.26	32.32	19.42	0.12	0.27	44.81	99.33
12.	K_2/36		1.40	2.00	0.92	32.02	20.10	0.42	0.08	42.38	99.32
13.	K_2/38		1.06	0.80	0.05	32.20	20.08	0.30	1.00	44.16	99.65
14.	K_2/40		7.46	1.23	1.86	31.37	9.23	0.08	0.12	47.98	99.33
15.	K_2/44		38.64	1.06	1.60	19.05	10.50	0.30	0.08	28.80	100.03

TABLE -29 CALCITE/DOLOMITE RATIO OF LOWER PART OF SYRINGOTHYRIS LIMESTONE

S.No.	Sample No.	Calcite(%)	Dolomite (%)	Insol. Residue (%)
1.	A_2-14	90.21	8.24	1.55
2.	A_2-16	85.49	12.49	2.02
3.	A_2-17	83.17	13.60	3.23
4.	A_2-19	83.62	17.39	1.99
5.	A_2-21	85.67	13.10	1.23
6.	A-5	88.05	11.25	0.70
7.	A-10	71.34	17.91	10.75
8.	A-15	74.74	12.89	12.37
9.	A-16	64.99	12.46	22.55
10.	A M-5	83.78	12.56	3.66
11.	A_1-9	86.53	12.37	1.10
12.	A_1-11	84.57	13.16	2.27
13.	A_1-12	89.42	9.12	1.46
14.	A_1-14	87.78	11.29	0.93
15.	A_1-19	76.01	11.63	12.36

Serial No. 1 to 15: Aisimukam/ Ichnar.

TABLE-30 CALCITE / DOLOMITE RATIO OF UPPER PART OF SYRINGOTHYRIS LIMESTONE.

S.No.	Sample No.	Calcite (%)	Dolomite (%)	Insol. Residue.(%)
1.	K-1	66.03	28.42	5.55
2.	K-2	56.55	41.65	1.80
3.	K-3	52.89	42.30	4.81
4.	K-5	56.96	42.34	0.70
5.	K-7	69.32	28.15	2.53
6.	K_1-28	83.24	15.18	1.58
7.	K_1-32	53.73	45.34	0.93
8.	K-12	87.58	6.52	5.90
9.	K_2-20	53.32	43.25	3.43
10.	K_2-33	70.41	20.25	9.34
11.	K_2-34	57.71	40.39	1.90
12.	K_2-36	57.17	41.43	1.40
13.	K_2-38	57.49	41.45	1.06
14.	K_2-40	56.01	36.53	7.46
15.	K_2-44	34.01	27.35	38.64

Serial No. 1 to 15: Kotsu (From three zones of the upper formation).

0.70 to 22.55 and in the upper part it is between 0.70 to 38.64. However, the higher percentages in the lower and upper parts are indicated by four samples & one sample respectively.

The calcite and dolomite percentages are plotted in an equitriangular diagram (Plate-31), which reveal the following varieties of limestones:- (i) Pure,(ii) impure limestone ,(iii) dolomitic limestone and (iv) impure dolomitic limestone.

DIFFERENTIAL THERMAL ANALYSIS

In order to confirm the results of the chemical analysis, number of representative samples were subjected to differential thermal analysis. This analysis takes into consideration the measurement of the heat reaction during constant heating or cooling of the mineral or of a mineral mixture in comparison with an inert substance (Smyketze,1974). All the processes in which heat is lost or gained, such as gaining or loosing of mechanically or of chemically bound water, crystallization changes in structure; oxidation and reduction are detected by D.T.A. and are recorded in curves. The exothermic reactions are recorded by deflection above the base line and endothermic reactions below the base line. In order to interpret the results the following points regarding the curves are to be noted such as initial temperature, amplified initial temperature, peak temperature, final temperature, temperature difference, reaction temperature (final minus initial) and base line and form (shape and character).

The D.T.A. curves of some of the representative samples of both lower and upper parts of Syringothyris limestone are shown in Plates -32 and 33 .

In case of Syringothyris limestone, there is only one major endothermic peak between 900- 920°C in all the samples. In this reaction, the initial temperature starts from 840°C near the thermodynamic equilbrium temperature, the amplified temperature near 800°C and the peak temperature at 920°C. The difference is almost proportional in all the samples, as the difference in temperature Δt is 100 to 120°C. Most of the curves are steep and in some cases the base line has shifted . This major endothermic peak clearly indicates the presence of calcite. In addition to this, major endothermic peak , there are other secondary endothermic peaks occurring at 200°C to 760°C. These minor endothermic peaks indicate the presence of non-carbonate material which may be shaly or quartzitic in nature.

In the upper part of the Syringothyris limestone, however, in addition to endothermic curves of (900-920°C) indicating the presence of calcite; there is another characteristic curve at 815° C indicating the presence of dolomite as well. The initial temperature for dolomite curve starts from 760 to 780°C and the peak temperature at 800 to 815°C showing thereby a very small temperature difference in the initial and final peak temerature. In just two samples, the bases line has shifted and the width of the curves is very less.

The D.T.A. results of this study, clearly confirms results of the chemical analysis in proving that, the lower Syringothyris limestone is non-dolomitic , while the upper ones are clearly dolomitic. In this, way it was found that the results of D.T.A. are in very close proximation to one obtained from chemical analysis.

STAINING

More than 100 thin sections were subjected to staining tests, for not only the estimation of calcite and dolomite, but also for the presence of any ferrous iron present in these rocks. For this purpose, the staining technique of Twenhofel (1941), and Evang (1969), were used. In this scheme a number of reagents were used (Table- 3).

Most of the samples of the Lower part of the Syringothyrise limestone acquired, red colour with Alizarin Red S. In most of the samples the colour change was complete, while in others only a few white patches remained indicating that dolomite content is either totally absent or present only in very small amounts. Some of the samples were having ferrous iron as indicated by the presence of maroon colour in a combined solution of potassium ferricynide and Alizarin Red S.

The upper Syringothyris limestone samples on the other hand mostly remained inert with Alizarin Red S treatment. In most of the samples either there was no colour at all or only a few patches became red, while others remained white. In these samples, the Fe/Mg ratios were less than 1 as indicated by light turquise blue colour. In no case dark turquise blue colour was obtained indicating Fe/Mg high. The staining results for both upper and lower parts of Syringothyris Limestone are identical to one obtained by chemical analysis and D.T.A.

INSOLUBLE RESIDUE STUDIES

For carbonate rocks, studies of insoluble residue are very useful for stratigraphic correlation and in recognizing different zones within a formation. Mcqueem (1931), Hills (1935), Miller (1955), Ireland (1947), McCracken (1955), Edward (1957), Schemidt (1964) developed various techniques and terminology for these studies and applied these methods in studying insoluble residue from different formations.

In the present work insoluble residue studies from of Syringothyris limestone have been made in detail. The results are as follows:-

Description of insoluble residue: Colour:- The colour of the insoluble residues is in different shades like grey, greyish black, white, greyish white and earthy brown. The upper member essentially represents grey to earthy brown, but majority is of earthy-brown colour. The lower part is essentially grey and greyish black (Tables-31&32).

(b) Types: The types of the insoluble residue which have been found in these limestones are: (i) Quartz (ii) arenaceous material, (iii) shale fragments (clay) ,(iv) pyrite etc.

(i) Quartz: Transparent to dull coloured quartz grains are present in both these members, like Euhedral to suhedral in outline. In both these members quartz is seen in abundance. However, there are euhedral and anhedral grains showing some fractured zones with some dusty material incorporated in them. Aggregates of

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TABLE 31

RELATIVE DISTRIBUTION AND CHARACTERISTICS OF THE INSOLUBLE RESIDUE FROM THE LOWER PART OF THE SYRINGOTHYRIS LIMESTONE.

S.No.	Sample No:	Residue %	Clay %	Silt %	QUARTZ: Drusy	QUARTZ: Rock crystals.	SAND: Loose	SAND: Aggregate.	CHERT: Chalky-	CHERT: Greysih Black	CHERT: Pyrite	Mica	Shale fragm.	COLOUR: Grey	COLOUR: Greyish-black	COLOUR: White	COLOUR: Earthy- brown	COLOUR: Black
1.	A_2-14	1.55	36.62	63.38	O	P	MC	Tr	-	P	-	Tr	P	-	-	X	-	-
2.	A_2-16	2.02	7.92	92.08	P	MC	P	-	P	-	P	-	Tr	X	-	-	-	-
3.	A_2-17	3.23	24.92	75.08	MC	O	P	O	P	-	Tr	-	Tr	X	-	-	-	-
4.	A_2-19	1.99	27.76	82.24	O	P	MC	-	-	-	O	P	-	-	-	-	-	X
5.	A_1-9	1.10	84.54	15.46	P	Pr	MC	-	P	-	-	P	O	-	X	-	X	-
6.	A_1-12	1.46	4.33	95.67	O	P	MC	R	P	-	P	-	-	-	X	-	-	-
7.	A_1-11	2.27	38.57	61.43	Tr	P	O	Tr	-	Tr	O	Tr	O	-	-	-	X	-
8.	A_1-19	12.36	64.43	35.37	MC	Tr	Tr	O	-	-	Tr	P	MC	X	-	-	-	-
9.	A_1-21	1.23	24.36	75.64	MC	O	P	-	P	-	P	Tr	Tr	X	-	-	-	-
10.	A-5	0.70	82.86	17.14	O	Tr	-	MC	P	-	P	P	O	X	-	-	-	-
11.	AM-5	3.66	22.14	77.86	MC	O	O	Tr	P	-	Tr	-	Tr	-	X	-	-	-
12.	A-10	10.75	63.44	36.56	Tr	O	P	-	O	-	-	-	-	-	X	-	-	-
13.	A-15	12.37	31.60	68.40	O	P	O	MC	P	-	O	Tr	O	-	X	-	-	-
14.	A_1-14	0.93	21.51	78.49	-	P	MC	P	-	Tr	Tr	O	MC	-	X	-	-	-
15.	A-16	22.55	62.17	37.83	O	-	MC	MC	P	P	P	-	Tr	X	-	-	-	-

Abbreviations used in the chart:
1.MC, stands for most common. 2. O, stands for abundant. 3. P, stands for present, 4. Tr ,stands for Traces.
X, indicates the colour of the residue.

TABLE- 32

RELATIVE DISTRIBUTION AND CHARACTERISTICS OF THE INSOLUBLE RESIDUES FROM THE UPPER PART OF SYRINGOTHYRIS LIMESTONE.

S.No:	Sample No.	Residue %	Clay %	Silt %	QUARTZ		SAND		CHERT					COLOUR				
					Drusy	Rock crystal.	Loose	Aggregate	White	Greyish-black	Py-rite.	Mica	Shale fragm.	Grey	Greyish black	White/ brow-nish	Earthy brown	Pin kish
1.	K-1	5.55	69.72	30.28	O	P	O	-	P	-	Tr	Tr	O	X	-	-	-	-
2.	K-2	1.80	88.33	11.67	O	P	-	O	-	Tr	Tr	Tr	P	-	-	-	X	-
3.	K-3	4-81	32.02	67.98	P	-	-	P	-	O	P	Tr	O	-	-	X	-	-
4.	K-5	0.70	77.14	22.86	MC	P	-	-	-	P	-	P	P	-	-	-	X	-
5.	K-7	2.53	64.12	35.88	P	MC	P	-	-	-	Tr	-	MC	-	-	-	X	-
6.	K-12	5.90	81.35	18.65	P	-	P	O	P	-	-	-	Tr	-	-	-	-	X
7.	K_1-28	1.58	39.25	60.75	O	P	Tr	-	-	-	Tr	-	Tr	-	-	X	-	-
8.	K_1-32	0.93	14.23	85.77	MC	MC	-	Mc	-	-	-	P	O	-	-	-	X	-
9.	K_2-20	3.43	74.63	25.37	MC	-	P	-	P	-	-	-	-	X	-	-	-	-
10.	K_2-33	9.34	91.12	8.88	P	-	P	P	-	-	Tr	Tr	-	-	-	-	X	-
11.	K_2-34	1.90	34.21	65.79	O	O	P	-	-	P	-	Tr	P	-	X	-	-	-
12.	K_2-36	1.40	45.40	54.60	MC	O	O	-	-	P	-	P	P	-	-	-	-	X
13.	K_2-38	1.06	25.48	74.52	MC	P	O	-	-	-	-	P	P	-	-	X	-	-
14.	K_2-40	7.46	37.94	62.06	P	MC	-	MC	-	-	P	Tr	MC	X	-	-	-	-
15.	K_2-44	38.64	74.16	25.84	P	P	-	MC	-	-	Tr	-	P	-	-	-	-	X

Abbreviations used in the chart:
1. O, stands for Abundant, 2. MC, stands for most common, 3. P, stands for Present, 4. Tr, stands for Traces.
X representing the colour of the residue.

consolidated residue consisting of frosted quartz exhibiting sort of overgrowths.

(ii) Arenaceous Material: The detrital loose sand is most common in the lower part and abundant in the upper part.In addition some chert fragments are also met within both the members which are identifiable by their lustre and transparency.

(iii) Shale fragments: Purple and buff coloured even brownish shale fragments are mostly present in the upper part of this formation. These fragments are irregular and porous in nature. The percentage of these fragments varies from 22.14 to 91.12 in both the members.(Tables-31-32).

(iv) Pyrite: Pyrite is mostly common in the lower part and is found in traces in the upper part. Grey to greyish black colour commonly observed in the lower part is due to the source of sulphide to nitrogenous content of organic matter under reducing conditions (Carrozi, 1960). The upper member,however, exhibits earthy brown and greyish white colour commonly, due to the presence of little oxides in them.

MAGNESIUM INSOLUBLE RESIDUE RELATIONSHIP

The results with reference to CaO/MgO and insoluble residue were plotted in scatter diagrams (Plate-34). These plots indicate the high MgO/CaO and low MgO/CaO and low insoluble residue contacts. Steidtman (1917),Decker & Merrit (1928), Lesley (1890), and Fairbridge (1957), observed good proportion of residue in limestones and increasing impurities with higher magnesium contents.

Similarly in Syringothyris limestone, the upper member exhibits high MgO and medium to low residue contents (Plate-34 fig. 4) have been observed which are probably due to the diagenetic changes. In the same plate, fig. 1 and 2 are interesting as the plotted ratios of clay and MgO , insoluble residue and MgO clearly distinguishes the upper and the lower members of this formation. Schemidt (1964), noticed higher dolomitic contents with increasing clay contents in the Gigas beds (Jurassic of Germany). Similar results have been noticed in the upper member of this formation, as in some of the dolomitic samples the clay percentage is very high. In the lower member, however, due to less percentage of MgO does not provide such clear relationship.

On the basis of insoluble residue percentages, a bar diagram (Plate-35) has been plotted, which indicates the approximate thickness of the beds and is represented in zones. Syringothyris limestone has been divided into six zones on the basis of insoluble residue percentage present in each zone. The most characteristic features noticed in these zones are that the base of this formation shows fairly good amount of insoluble residue, and the same is the case with the uppermost part. This phenomena is probably due to underlying sandstones and the overlying shales and slates, as they are conformably in contact with this formation.

THIN SECTION PETROGRAPHY

More than one hundred thin sections were made both from lower and the upper units of the Syringothyris limestone, to study in detail the microstructures, nature of the allochems and the petrographic types. In this study, it was found that most of the limestones of the upper part are moreor less replaced to dolostones, while the rocks of the lower unit are either not effected or show very little and incipient replacement.

THE NATURE OF THE ALLOCHEMS

Fossils: These are the most abundant allochems in the Syringo thyris limestone. They roughly make 3/4th of the total allochems present in these rocks. Fossils are mostly composed of calcite and aragonite, except where replaced by dolomite and silica. The fossils represented in these rocks are: bryozoans, corals, crinoids, mollusks and brachiopods.

Bryozoans: A few rocks are quite rich in bryozoan fossils, branching and fenestrate shapes are not uncommon. Besides the above, tabular, tangential sections are present, which reveal the cross sectional shapes of Zoocia.

Crinoids: These are well represented in Syringothyris limestone and appear in the form of stem plates which appear rounded in thin sections. These stem plates are centrally perforated by a hole (leun) which is also round. Some sections which are parallel to the stem exhibit rectangular cross section.

Brachiopods: These are most dominating in this formation and consist of two layers; a primary outer layer and a secondary inner layer. The outer layer appears finely granular in thin

section and the secondary layer consists of fibrous/ oblique to the shell surface.

Corals: These are generally recognized in thin sections by three types of micro- structural walls,which consist of fibrous rugosan and trabecular types. The fibrous walls have a parallel fibrous arranged obliquely to the wall surface. Rugosan wall microstructure is characterized by uniform dark fine grained layer.

Other Allochems:

Interclasts: Interclasts are seen in some of the samples, which consist of fragments of calcarenite, calcilutite and strained limestone. The size of these interclasts varies from 0.3 to 0.5 mm.

Pellets: These consists of microcrystalline calcite and are devoid of internal structures and are similar in appearance to small interclasts. In some of the samples, their average size being 0.2 mm. Their outer boundaries are hazy and grade into the surrounding matrix. Pellets are derived from several sources. Some are nearly small, well rounded and well sorted, while others may be lithified faecal pellets.

Oolites: Oolites are also represented in these limestones , mostly dolomitized and varying in size, from 0.1 mm to 0.3 mm. These oolites in most of the cases are rounded and deformed in a few cases. There are just one to two rings visible around the nucleus. Due to replacement of these bodies, the nature of the nucleus or the structure of the ring has become indeterminable.

MICROSTRUCTURES

The following microstructures have been observed in the Syringothyris Limestone:-

(i) Microstylolites: This microstructure has been observed in this formation, preferably common in the upper parts. It is recognized as irregular plains of discontinuity along which two rock units appear to be interlocked or mutually interpenetrating. These plains are characterized by the accumulation of insoluble residue along them which forms the stylolite seam. According to Park and Shehot (1968), stylolites may be classified geometrically into two ways, first by means of the two dimensional geometry of the stylolite seam itself and secondly by means of congruency of the stylolite in relation to bedding plane. According to this classification, rectangular type of stylolite both up peak and down peak type of are common. Some stylolites are even sutured type as well; with regard to the relation of stylolites with the bedding plane. Interconnected net work of stylolites with a number of branches having no relationship with the bedding plane are most common. Most of the stylolites cut across the grains, though in some cases they occur at grain boundaries, (Plate-36 fig. 3) . The lateral and vertical extents vary from 0.01 to 1.05 and 0.02 to 1.10 mm respectively; ferruginous and argillaceous material has been deposited at the point of junction.

(ii) Bird's Eye Structure: This microstructure is characteristic of the upper part of the Syringothyris Limestone, which has been obliterated by the dolomitization. It represents ancient vugs and cavities, which have been filled with sparry calcite. These vugs are formed during dessication and gas bubble migration (Shinn, 1968), in carbonate mud in supratidal environment. These vugs are horizontally elongated.

(iii) Calcite veinlets: In both dolomitized and non-dolomitized varieties, calcite veinlets are equally common. In general the grain size of a crystal in a veinlet is proportional to the width of the veinlet. Some veinlets contain crystal orientation perpendicular to veinlet wall forming comb structure. Calcite veinlets appear to have been formed at various intervals. Evidence of this is found in some veinlets which have sharp boundaries and appear to closely related to fracture, whereas others have been formed due to recrystallization of the original material in these rocks.

PETROGRAPHIC TYPES

In view of the large number of classifications in use, for the description of carbonate rocks, Black (1933), Pettijohn, (1957), Carrozi (1960), Dunhum (1962), Demirimen & Harbaugh (1965), Folk (1959), etc., a good deal of difficulty was experienced to give a suitable nomenclature to the limestones of the study area. As per Pettijohn (1957), and Carrozi (1960), classifications, these limestones are partly autochthonous and partly allochthonous, but the terms like calcarenite, calcrudite or calcilutite cannot

be applied in view of the great variations in size of the precipitated *in situ* matrix and detrital constituents . Hence the nomenclature of Folk (1959),and Dunhum (1962),was found more suitable. According to Folk (1959), classification, limestones are made up of three constituents viz., allochems, microcrystalline calcite, ooze matrix and coarser sparry calcite. In this classification four important allochems in limestones are interclasts, oolites, pellets and fossils; allochems provide the structural framework of limestones just as sand grains provide the structural framework of sandstones. Microcrystalline calcite and sparry calcite are analogous with the clay matrix and chemical cement of the sand stones. On the basis of relative proportion of allochems, calcite ooze matrix and sparry calcite cement, three major limestone families are defined:(i) consists of abundant allochems cemented by sparry calcite. These are clearly washed limestones,analogous with well sorted clay free sandstones and similarly formed in the loci of vigorous currents. (ii) consists of variable amounts of allochems embeded in a microcrystalline ooze matrix. These are poorly washed limestones analogues with clay, poorly sorted sandstones and form in a loci of ineffective currents.(iii) consists almost entirely of calcite ooze and are thus analogous with terriginous clay-stones. The first two limestone families are subdivided , taking into consideration the nature of the allochems; family one includes intrasparite ,oosparite, biosparite and pelsparite. Family second intramicrite, oomicrite, biomicrite and pelmicrite. Family third homogenous ooze (micrite) and disturbed ooze with irregular

openings filled with spar (dismicrite). For replacement limestones , however, the terms interclastic dolomite, oolitic dolomite and pelitic dolomite etc. have been used.

Dunhum(1962), classification is based on depositional texture and he broadly divided the limestones into two categories: (i) in this depositional textures are not recognizable and these are known as ' crystalline carbonates' ;(ii) in this depositional textures are recognizable and further subdivided into mud stone wackestone, packstone, grain stone and boundstone, depending upon the percentage of grains and mud present in these limestones.

In the present work, both these classifications have been combined. Firstly, the broad categories of Syringothyris limestone have been recognized as per Dunhum classification and within each one of these categories, petrographic types in terms of Folk classification have been used. The system of nomenclature have been little modified on the basis of nature of allochems and the calcic matrix present in these limestones to differentiate one type from another.

DESCRPTION OF THE ROCK TYPES

(A) GRAINSTONES AND PACKSTONES

In the present work, these two types have been grouped together. Those types which lack mud and are grain supported have been termed as ' grainstones' by Dunhum(1962). Some of the syringothyris limestone from Aishmuqam area belong to this category. However, both sparite and micrite types of limestones have been found within this group. The allochems are mostly

skeltal debris, oolites etc. The following subtypes have been found within this group:-

(1) Encrinite Biosparite: This type is mostly composed of crinoidal material which exceeds 70 percent or more. The other general class of organisms.are very less. A typical photomicro graphs are shown in Plate-36 figs.1 and 2 . Here mostly rim cemented crinoid stem plates are seen. Rim cement is optically continuous with stem plates. The rock is wholly composed of crinoidal plates and fragments of plates consisting of single crystal which displace well developed cleavage. Initially crinoid stem plates have fine perforate structure, but calcite that has filled the perforation is in optical continuity. The nucleus in the centre of each plate is also generally filled with calcite that too is optically continuous. The tendency for calcite to be precipitated in optical continuity reaches its maximum depending on the outer edges of crinoid plates, where calcite fills former voids (rim cementation) in the original sediment. In fig. 1, there seems to be a line of fracture in a straight course on the right margin. The size of the crinoid osscile ranges between 0.3 mm to 1.00 mm.

(ii) Biomicrite: The most dominant types in this group which are mostly composed of skeletal debris enclosed in a muddy or microcrystalline matrix. On the types of biota enclosed in the limestones, the following types have been recognized:-

(a) Bivalvebiomicrite: This particular type belongs to the lower member of the Syringothyris limestone from the Aishmuqam area.

Most of the allochems in this type belong to bivalve shells of lamellibranchs and brachiopods. The various parts of these shells have been in thin sections has shown in fig. 1 plate-37. The cement is mostly microcrystalline of greyish colour with dots of pyrite. The percentage of allochems is about 50 percent.

(b) Bryozoanbiomicrite: This type is similar in appearance to bivalvebiomicrite which have skeletal parts of fenestrate bryozoans in addition to bivalve shells and some crinoids. Actually alongwith bryozoan fossils, some ossciles of crinoids and algae of various sizes are presented and replaced by calcite. The perforation in the central portion to the crinoid stemplates is still present in a few cases inspite of its replacement by calcite.

(c) Spergenite-biomicrite: Pettijohn (1957), used the word spergenite for a detrital limestone containing all types of materials like skeletal debris, oolites and grains etc. from the type locality of Salem or Spergene limestone of Mississipean age of Indiana where it has been largely found. In Syringothyris limestone, there are types which resemble the above limestone containing almost all types of skeletal material like crinoids sand grains brachiopods lamellibranchs etc. (Plate-36 fig 6). This material is embedded in muddy matrix and some of the fossils are slightly approached by calcite. For these types of Syringothyris limestones , the term used is spergenite-biomicrite. The total percentage of allochems is about 60 to 70 percent. The average size of the sand grains range between 0.1 mm to 0.2 mm and the size of other allochems from 0.5 mm to 1.5 mm.

(B) WACKSTONES

Majority of the Syringothyris limestone samples more especially from the lower part, however, are wackstones as allochems exceed ten percent with muddy matrix in them. Some of the types are given below:-

(i) Wackbiomicrite: Compositionally this type is the same as that of biomicrites of grainstones and packstones except the percentage of allochems which has imparted a different texture to the rock. In this type, the percentage of allochems is less than 20 percent. In other words, this type can be named as dismicrite also. Typical photomicrographs are shown in Plate-37 figs. 3 and 4 and in Plate - 36 fig 4.5. In these figures, the allochems of lamellibrachs, ammonoids and crinoid cross section (PLATE 36 & 37). are present. The size of these allochems ranges between 0.7 mm to 1.75 mm.

(ii) Oomicrite: Some samples of Syringothyris limestone are exclusively composed of small oolite like bodies having one or two rings. But most of these rocks however, have been dolomitized and converted into dolo-oomicrite(Plate-38 fig 4).

(iii) Pelmicrite: This type is characterized by having small pellets as allochems alongwith a few skeletal debris. A typical photomicrograph is shown in Plate-37 fig.5. The grains are structureless without any rings and nucleus. Their size ranges between o.1 mm to 0.35 mm. These pellets are arranged in an irregular pattern, but are to some extent of uniform size.

(C) MUDSTONE

For mud supported rocks with less than 10 percent grains and the allochems, the general term mudstone has been used. The following are a few types :-

(i) Micrite: A number of samples belong to this type. It consists of lime mud of microcrystalline without having any allochems present in them. However, some quartz and pyrite grains are seen which are less than 0.02 mm and have intermixed with the muddy matrix. Photomicrograph of this type is shown in Plate-37 fig.6. In addition, lamination is characteristic feature of these rocks. The lamination structure has been interpretted to be due to algal mat.

(ii) Arenaceous micrite: Some micrites have higher percentage of quartz as terriginous material, thus these may be named as arenaceous micrite. In other textural and structural details, these are similar to micrites.

In addition to these types some other types from the dolomitized part of the Syringothyris limestone have been recognized which are described as under:-

(i) Dolo-biosparite: About ten percent of the Syringothyris limestone belongs to this category. These limestones in hand specimens are fine grained, hard, compact and grey-black in colour. Fossils are often not visible megascopically, but in thin sections various minute fossils packed closely together are readily seen. Typical photomicrographs of these limestones are shown in Plate-38 figs . 1 and 2. These fossils show an elliptical outline of various sizes, but majority of them are of 0.5 mm size. In a few cases, however, as shown in the right corner of the fig. 2, the size is about 1 mm and the minimum 0.25 mm. A few of the fossils have retained complete

Outline, but in some it is broken and replaced by dolomite. The small crystals of dolomite have not only completely replaced the inner calcite material of the shelf, but the encroachment of the replacement has extended beyond their outer boundary, develo ing a plate of dolomite in which the shells are floating. These plates are not composed of one crystal, but numerous subhedral, equigranular crystals of about 0.2 mm size interlocked together developing in a sacchroidal type of texture. Overall, no marked structure has been found in these rocks except some veins of smaller width.

(ii) Dolo-oosparite: These rocks are also represented in Syringothyris Limestone in the same proportion as that of dolo-biosparite and are fine grained, compact, grey to greyish black in colour. Under microscope, these oval bodies are oolites 0.1 to 0.3 mm size and have a distinct one or two rings with vague nucleus, while in others the original rings have been obliterated. These oval bodies have been considerably mutilated by recrystallization process. These oolites are cemented by subhedral grains of dolomite crystals of some what bigger sizes 0.2 mm to 0.4 mm. closely packed together. In a few samples, these oolites are visible, while in most of them, the crystallization is so much advanced that their shadows are seen, which have been named as ghosts- oolites, indicating thereby that originally the percentage of these must have been much more than what it is now left. Typical photomicrographs are shown in Plate-38 figs 2 & 3 in which the shadows are seen on the corners. In one of the slides from this type, a distinct

vein of 0.15 mm width was noticed.

(iii) Dolomicrite: Most of the rocks of Kotsu hill belong to this category. In hand specimens, the rock is very fine grained with typical greyish-black colour. In thin sections, it consists of the mosaic of very small equidimensional, hypidiomorphic grains of dolomite (0.05 - 0.1 mm) or even smaller in size shown in a typical photomicrograph fig. 5 Plate-38. On account of its very fine size, (as also seen in fig 6 Plate-37) it has been termed as micrite. No allochem is present, except a few scattered grains of quartz 0.1 mm size. These rocks are traversed by numorous small veins of very small width. In fig. 5 the vein is slightly curved and has developed into groomus type of structure. On staining it mostly acquired a red colour with Alizarin Red S indicating thereby that it is occupied mostly by calcite.

(iv) Dolosparite: It is almost in the same proportion as that of dolomicrite and are compositionally and texturally same as that of dolomicrite, with the only difference that the crystallinity is better developed. These rocks are also composed of exclusively subhedral, coarse grained crystals in which all the spaces of the original allochems have been obliterated. As a result of dolomitization, new microstructures like calcite veinlets stylolites etc. have been developed in these rocks. Fig.3 of Plate-38 represents this type, differing in one aspect from fig. 3 of Plate-36 in having dolomite percentage more, in comparison with the latter-(being chiefly composed of calcic material). In dolosparite variety, however, calcite

veinlets are of various widths having different types of fabric, of course not visible in the figure. Comby form of veins are ,however, common. Stylolites have no distinct orientation with the bedding planes, their size is upto 1.5 mm laterally and 0.01 mm to 0.02 mm vertically. Ferruginous material is most common insoluble residue deposited along the stylolitic junction and bird's eye structure probably representing the original fossil outlines.

(v) Porphyrodolomicrite: These are variety of dolomicrite in which dolomicritic base is quite evident alongwith some lime mud, composed of bigger , tabular crystals of dolomite and angular quartz crystals. These crystals have somewhat anamolous low order polarization colours but were identified by the rhombohedral cleavage and microchemical tests. A typical photomicrograph is shown in Plate - 38,fig. 6. These indicate that some of the crystals of dolomite have developed very rapidly,while others are in developing stage. In view of the sharp contrast in size between the bigger phenocrysts and groundmass, the texture may be termed as porphyrotopic. In this variety, however, some sub types have been suggested.

(a) Porphyromicrite: These rocks are ,though texturally similar, but just reverse of porphyrodolomicrite in the sense that instead of having dolomitic groundmass, these are still composed of limemud. A sharp contrast in composition, it becomes prominent, where the two polished samples are dipped in the

solution of Alizarin Red S. In this process samples of porphyrodolomicrite remains unaffected, while as the other samples turn totally red with some unaffected white patches. In this rock, the ground mass is composed of limemud with numerous small micro-dolomicrite crystals which are still in the developing stage. The other variety is termed as quartz dolo-sparite in which the quartz crystals are in abundance.

MECHANISM OF DOLOMITIZATION

Dolomitization of Syringothyris limestone of Kotsu is undoubtedly of secondary origin as is indicated by the presence of partially replaced rocks. Secondary dolomitization may occur during early stages of diagenesis ire. pencontemporaneous dolomitization, or it may occur later in the history of the rock.

Number of models have been suggested to account for secondary dolomitization. Common and necessary requirements of all the models for dolomitization are an almost unlimited source of Mg and a mechanism of circulation of reactive fluids through the pore spaces. Circulation is required to supply the mass of Mg necessary for the dolomitization reaction. In Sabkha model proposed by Illing et al (1965) ciruclation is obtained by evaporation. The intense evaporation brings about not only a concentration of salts in surface capillaries but also an upward movement of brine

from the permanent water table. The very high salinities attained , lead to the precipitation of Gypsum with a consequent rise in the Mg/Ca ratio that in turn encourages subsurface dolomitization.

The Sabkha model, however, is not applicable to Kotsu dolomitization owing to non extistant of gypsum which has not at all been found anywhere in these rocks.

In Bonair model (Deffeys et al, 1965) the circulation is by density gradient. The seepage reflux process is to be considered instrumental in bringing about dolomitization of underlying rocks by highly dense solution, derived from the landward lakes towards the sea. This model can explain very well the mechanics of Kotsu dolomitization. In recent years, Lucia (1968), has criticized this hypothesis, as his study from the lake Pekhemer has shown that no dolomite was found and the pore water was normal sea water, at a depth where a hypersaline brine would have been expected.

The possible mechanism of dolomitization, taking into consideration all the factors , therefore, seemed to be similar to one suggested by Shinn and Ginsburg (1964), involving very near surface precipitation of microcrystalline dolomite from evaporating Mg rich pore waters drawn upward to the surface of the tidal flat by capillary action. The size range of dolomite crystals of Kotsu are simil-ar to those of Shinn and Ginsburg study, showing thereby that the hypothesis is perfectly applicalbe to Kotsu limestones also.

FACIES AND ENVIRONMENTAL INTERPRETATION

The nonclastic rocks are chiefly composed of limestone beds alternating with shales and sandstones. The limestone contains abundant invertebrate fauna consisting of brachiopods, corals, crinoids and Pelcypods etc. The upper beds of limestone are dolomitized, which ranges from incipient alteration to complete dolomitization, while the lower beds are very little altered. In this three sub-facies can be identified, viz., tidal flat facies, shallow sub-tidal facies and deep sub-tidal facies. Each one of these sub-facies have its own characteristic features like lithology,primary sedimentary structures and palaeontology etc. The chief factors differentiating the facies suites are on-shore-off shore positions, their wave agitation, water circulation, relative rates of subsidence and terrigenous influx.

Tidal Flat facies: Recognition of tidal flat facies in an ancient rock was made possible only recently because of the various studies of modern carbonate tidal flats especially those in the South Florida, Bahamas, the Persian Gulf and Western Australia. These studies have outlined criteria for the recognition of supratidal/ intratidal deposits in the geological record and thus provide an important "Environmental Datum" to which other less well recognized carbonate facies may be environmentally related. This facies is characterized by limestones and dolomites that contain abundant suncracks, Bird's Eye structure,oolites (Laporta, 1971), regular to irregular lamina tions etc. All these lithological features have been described from present day supratidal and intra-tidal carbonate deposits and record intermittent subaerial exposure, dessication and wave score (Shinn, 1968). The accumulation of carbonate mud and sand in these environments depends upon local and often rapid changes in water agitation.

Palaeontologically, this facies contains relatively few fossils with many beds, often completely barren. When fossils do occur in a specific bed, they are usually abundant, but belong to very limited number of taxonomic group. Distribution and abundance of these marine texa are obviously restricted by high ecologic stress of supratidal and intratidal environments. In most cases, the fossils remain probably to reflect local current reworking or sorting or storm wave accumulation rather than aggregation of living population in place.

Shallow sub-tidal facies: This facies include medium to thick bedded limestone, calcarenites like biosparites or grainstone and calcilutites like biopelmicrite or wackstones, having considerable faunal diversity and traces of calcareous algae with brachiopods and bryozoans. This facies usually occur interbedded with tidal flat facies, indicating fluctuations in tidal flat depositional conditions from slightly above and below mean sea level. This facies is interpretted as being formed below mean low water and above mean wave base. Absence of features indicating intermittent subaerial exposure and relative abundance and diversity of shelly marine invertebrates indicate continued marine submergence.

Deep-subtidal facies: This facies is characterized of thick bedded to massive limestones which have muddy calcareous matrix, sometimes with abundant quartz- silt and argillaceous material. Palaeontologically, this facies have relatively high fossil diversity and abundance of brachiopods, corals and crinoids etc. The deep sub-tidal facies is interpretted forming off-shore,

below mean wave base. The carbonate fraction represents both in place carbonate production and deposition as well as the accumulation of finer grained carbonate transported seaward from the shallower more current agitated part of the adjacent shelf. The open marine situation of this facies accounts for its diverse and abundant fossil assemblage.

ENVIRONMENTAL INTERPRETATION

The three above mentioned facies resemble more or less with the three zones viz., X-zone(Open sea), Y-zone (barrier), and Z-zone (lagoon and Sabkha) of Irwan (1965) based on his study of upper Palaeozoic carbonates of the Williston Basin, North America or with the three facies described by Thompson (1970) viz., Spquatchie facies, intermediate facies and Juniata facies from the Ordovician rocks of Southern Appalachian valley. This facies relationship indicates that Syringothyris limestone represents shore-line sediments, where the amount of land derived sediment is so small that carbonate shore line facies develop. It creates imperceptibly into an open marine shelf. The three facies recognized in Syringothyris Limestone viz., Z, Y and X zones represent three stages from shore to open sea gradually.

DEPOSITIONAL ENVIRONMENTS OF ORTHOQUARTZITE - CARBONATE GROUP

The textural, structural and compositional features of rocks comprising orthoquartzite-Carbonate group indicate a fluctuation condition from sand barrier origin to open marine conditions, with periods of tidal flat developments.

The sedimentary features indicate that Muth Quartzite represents a shallow, subtidal sand barrier belt, composed of coalesced sand bodies, which locally were built into the intratidal zone followed by construction of subaerially exposed sand flats to aeolian reworking.

The array of environments existing during the deposition of Syringothyris limestone included an intermittently exposed barrier mud flat, fronting an open shallow marine shelf, dominated by brachiopods, bryozoans and crinoids etc. The dolomites were formed behind the barrier in a lagoon estaurine complex as tidal flat facies. The sand bodies, however, were deposited partly as sand bars and tidal channels, while carbonate rocks were formed in an open shelf. At times, the barrier flat had disappeared, making the distinction between lagoon and open shelf difficult.

The sandstones of Passage beds were ,however, deposited either as point bar deposits of meandering streams or as distributary channels on the delta front.

CHAPTER - VI

PETROGRAPHY OF VOLCANIC-CLASTIC GROUP

PETROGRAPHY OF VOLCANIC CLASTIC GROUP

Carozzi (1960) defined volcanic clastic rocks as a group of hybrid rocks in which the products of pyroclastic and sedimentary processes are intimately associated. In Kashmir, Palaeozoic sequence, rocks immediately below the Panjal lava flows have long been recognized as volcanic clastic rocks and termed as Panjal Agglomeratic slates(Middlemiss, 1910); although he expressed difficulty in defining the exact nature of the agency by which it was accumulated. He postulated that it was formed either by explosive volcanic action or by frost with ice transport. He was, however, more inclined to the explosive volcanic theory, but did not rule out the alternative hypothesis of glacial origin as in many respects it resembles with Blaini Conglomerate. No detailed petrographic work has been done by any earlier worker except a paper by Ganju and Srivastava (1961) describing therein Agglomeratic Slates of Bren Spur near Srinagar, which they considered as feldspathic quartz-sericite slates derived by the metamorphism, devitrification and alteration of originally rhyolitic crystal vitric welded tuff. Bhatia and Kokroo (1978), in a paper entitled, " Sedimentological Studies of Agglomeratic Slates of Anantnag District,Kashmir" recroded crystal and lithic tuff, in addition to vitric tuff. This was, however, only a preliminary paper dealing with a few localities. For this work, more detailed study was undertaken, in respect of texture and composition of these rocks. Although in many cases, these rocks have been severely subjected to weathering, devitrification, consolidation and

metamorphism, changing their original character,but still some original textural and compositional features were preserved rendering the identification easier.

Besides Agglomeratic slates , Fenestella shales also have been grouped and studied alongwith these rocks,as some of the black shales were found crowded with pyroclastic and glassy debris, crystals of feldspar, quartz, etc.

The rocks belonging to this group are admixture of varied types of material with a tendency to become coarser upwards. The rocks lying at the base in which Bryozoan fossil (Fenestella) abounds in a dark grey shale which on weathering have become earthy yellow. The rocks lying above this shaly material are also dark greyish to blackish grey, more consolidated,looking like fine grit or greywacke which enclose in them,angular grains of quartz and chert of various sizes. The upper horizons which have been exposed at a few places,are more conglomeratic,having angular to subrounded clasts of various sizes,set in a dark greyish matrix.

According to Wadia (1928), the series consists of a thick sequence of greywacke like rock,showing poor cleavage. Ganju and Srivastava (1961) recognized two types of Agglomeratic Slates viz., coarse grained and fine grained.The former is the massive variety, in which the constituents of the framework make up as much as 50 % of the rock; the other is fine grained,cleavable type with abundant micaceous and clay -like matrix,exceeding 65 percent.In this work also,two main types have been recognized,depending

upon their grain size. These are (i) rudaceous type consisting of coarser clasts embedded in a fine matrix,(ii) fine grained type consisting of sand and silt sized particles. Within the rudaceous rocks, two further sub-types are found. In one of the types, the rocks are greyish black in colour, resembling a basaltic rock, very hard and having more or less conchoidal fracture,with phenocrysts, giving the appearance of a breccia. Whereas the other type is more weathered having greenish brown colour with phenoclasts, more or less rounded, and of conglomeratic type. The fine grained varieties resemble very much with the fine grained material (matrix) of the rudaceous type and have varied types of colours like brownish, greyish white to black. The fine grained variety has also two types, viz., (i) non-cleavable, (ii) cleavable. These types correspond to that of Ganju and Srivastava (1961), coarse grained and fine grained. The latter has more matrix than the former. The Fenestella shales resemble more with the cleavable type. In other aspects they exhibit almost the same appearance and texture, except that along the cleavage planes, these are crowded with Bryozoan and other fossils.

METHODOLOGY

In this study, fine and coarse fractions have been studied separately. The fine fraction has been studied with respect to thin section petrography, grain size, sphericity and roundness, and mineral species; whileas the coarse fraction studied with respect to lithology, shape (form, sphericity and roundness) and fabric.

A-FINER FRACTION

All the types of Fenestella shales and the material composing the Agglomeratic Slates finer than 2 mm in size is designated as fine fraction. Fenestella shales are compact, fine grained mostly falling in silt size to clay sized grades and of various shades ranging from greyish white to greyish black, with brown and yellow patches often associated with Bryozoans and Brachiopod fossils. Agglomeratic slate on the other hand appears like greywacke type of rock, grey to greyish black in colour and hard. These occasionally contain bigger and angular grains of quartz, chert and other rock fragments which act as phenoclasts. The material of these rocks being hard, could not be disintegrated into separate grains and hence thin sections were made to study their textural and compositional features.

THIN S-ECTION PETROGRAPHY

Rocks constituting both Fenestella shales and Agglomeratic slates have broken framework (Plates - 39, 40 + 41). The framework constituents show very poor sorting, with a great variation in maximum and minimum sizes. The maximum grain size is more than 2 mm in some cases, while as the small particles of the framwork are hardly distinguishable from the material constituting the matrix. An arbitrary limit of 20 microns (William et al , 1955) is generally fixed for distinguishing between the two sizes. Grains smaller than 20 microns, are regarded as matrix, while the bigger grains form the framework.

Most of the grains are angular, while some of the bigger phenocrysts show some degree of roundness, in particular in photomicrograph (Fig.1 Plate-40), a perfectly rounded phenocryst of slate is seen.

Apart from these textural peculiarities, two very important microstructures characteristic of volcanic clastic rocks, have been noticed in these rocks. These microstructures are:-

1. Vitroclastic structure: This structure is found in all states of preservation, depending upon the amount of alterations which the rocks have undergone. The vitroclastic structure is recognized in having minute particles of glass shards, vesicular glass etc filled in between them by intersitial material of exclusively fine granular minute fragments of glass. It has been observed in rocks of more vitric type lying at the base commonly associated with the Fenestella shales and agglomerate slate (Plate-40, Fig.5)

2. Snow Flake structure: This structure has been described by Anderson (1969) in the Tertiary Ash flow tuffs in the Davis Mountain Texas, who explained its development in a transition from glassy welded tuff to crystallized welded tuff. The term snow flake texture was used first by Snyder (1962) for "patchy polarization" used earlier by Williams and others (1955). Fig. 4 of Plate-40 shows a typical snow flake texture. It has ill defined patches of birefringent material that resemble snow flakes in outline and texture. An individual patch is composed of optically continuous silica, enclosing a lath of

feldspar or quartz. The individual patches range in size from a fraction of a millimeter to about 0.3 mm in diameter. In other rocks faint birefringent patches were observed to which Anderson has given the name as " incipient" snowflake.

FRAMEWORK CONSTITUENTS

The modal composition of these rocks is shown in Table-33 to 34 . The quartz is by far the most dominant constituent of the framework. The size of most of the grains varying from 0.2 mm to 0.5 mm, a few larger grains also occur sporadically as seen in Plate-40, fig 3. Most of the grains are single, while in some cases polycrystalline quartz (Plate-40, fig 6) is also seen. Some of the quartz grains are in the form of broken enhedra, showing deeply — corroded margins. This type of quartz is characteristic of rhyolites.

Feldspar is also found in these rocks. Both potash and soda feldspars are found but the former type is more common; sanidine type of feldspar is mostly seen. A bigger phenoclast of feldspar (Plate 40, fig. 5) is that of sanidine. Its presence is confirmed by studying interference figures with very small 2V. The feldspar grains are mostly anhedral to subhedral types, generally fresh and show very little alteration.

A variety of rock fragments have been found in some of these rocks, such as fragments of quartzite, slate, gneiss and some volcanic rocks. Euhedral flakes of highly pleochroic biotite often with resorbed borders are also present.

TABLE- 53

MODAL COMPOSITION OF FENESTELLA SHALES

S.No:	Sample No:	Quartz %	Feldspar %	Rock % Fragm.	Matrix	Heavies/ Opaques %
1.	YF-3	21.12	1.36	13.62	71.93	2.87
2.	YF-5	32.22	4.12	2.20	70.46	0.80
3.	YF-7	20.32	1.32	12.92	64.31	1.13
4.	YF-9	27.16	19.13	8.47	50.01	1.23
5.	YF-10	35.93	2.61	4.12	56.54	0.80
6.	YF_2- 1	26.66	7.32	6.48	59.54	0.00
7.	YF_2-8	17.21	1.32	42.26	38.21	1.00
8.	YF_2-12	46.22	3.02	24.32	46.44	0.00
9.	YF_2-13	10.17	3.21	18.26	68.36	0.00
10.	YF_2-15	18.21	2.33	40.25	40.21	1.00

Sr.No: 1 to 5: Yenner/Ganeshpur
Sr.No: 6 to 10 Around Dhowat.

S

TABLE-34

MODAL COMPOSITION OF THE AGGLOMERATIC SLATES

S.No:	Sample No:	Quartz %	Feldspar %	Rock fragm. %	Matrix %	Heavies/ Opaques %
1.	BS-16	11.16	9.13	1.47	77.01	1.23
2.	BS-18	26.98	2.68	2.68	68.86	0.80
3.	BS-26	15.16	7.00	2.53	73.18	2.13
4.	TM-3	12.93	0.00	77.16	8.91	1.00
5.	TM-18	24.23	3.88	64.20	6.16	1.53
6.	TM-8	14.26	2.72	69.96	12.96	0.03
7.	BS-28	56.07	16.37	10.26	17.00	0.30
8.	BS-6	49.46	12.96	8.22	28.09	1.27
9.	DS-24	39.00	12.36	21.16	26.08	1.40
10.	DS-19	30.58	2.23	54.63	11.86	0.70

Sr.No: 1 to 3 and 7,8: Batkot.
Sr.No: 4,5,6. Tangwani/Naubug.
Sr. No: 9 and 10. Dohwat.

In some of the rocks partly devitrified glassy material in the form of dark lensoid patches are present. As also noticed by Ganju and Srivastava (1961), these dark patches are drawn out and their long axes are invariably parallel or sub-parallel to one another. Their outlines are not well defined and they generally merge imperceptibly with the devitrified matrix.

The framework constituents are embedded in a matrix consisting of fine grained mixture of quartz and sericite intermixed with abundant glassy base; which has been mostly devitrified. The sericite occurs in colourless fine folia or irregular shards like plates in the matrix. The sericite folia have penetrated the quartz grains from all sides producing teeth like projections around the grains. The percentage of matrix varies in different rocks and on this basis two types are distinguished. The cleavable variety has a high percentage of matrix exceeding 60 percent , while non-cleavable one has lower percentage of matrix.

TYPES

According to Pettijohn (1975), tuffs and other pyroclastic sediments should be classified both for their parentage (magmatic affinities) and their components. Three important components of tuffs are glass, rock fragments and crystals, depending upon their percentage in a tuff; three types of tuff viz., vitric tuff, lithic tuff and crystal tuff are possible. Further

subdivisions can be made depending on the percentage of glass and crystal. The same procedure of nomenclature may be followed for glass and rock fragments, rock fragments and crystal.

All the three types of tuffs have been found in the Agglomeratic slate. Fenestella shales are mostly vitric and crystal tuffs, while Agglomeratic slates are mostly crystal and lithic tuffs. Most of these tuffs are, however, subjected to devitrification and metamorphism. By the former process, the glass has been changed into feldspar and quartz. The effect of dynamic metamorphism is smashing and shearing, which destroys and obliterates the diagonostic characters of tuffs in proportion to the extent to which they have operated. The main effect of this process on tuffs is the production of sericite, converting the tuffs to sericite-schists or phyllites.

The characteristic features of various types of tuffs found in Fenestella shales and Agglomeratic slates are as follows:-

1. Vitric tuffs: According to Pettijohn (1975), these tuffs are characterized by abundance of glass material, shattered pumice forming shards, lunate or sickle shaped pieces of glass, whileas some pumice fragments into tube like forms. A typical example of this type is shown in Plate 40 fig 4+5 showing well developed snow flake texture. Some of the glass shards are undoubtedly isotropic but majority of them have been devitrified showing a fine aggregate polarization. Some of the vitric tuffs also have crystals of quartz and feldspar as shown in Plate-40 fig 5 .

Intersititial material consists of micro-granular substance of glass type. Vitroclastic structure though observed in some samples have been destroyed due to the metamorphic effect on these rocks. This structure has been observed both in the Fenestella shales and Agglomeratic slates.

2. Crystal Tuffs: Rocks of the Batkot area are rich in crystals and contain phenocrysts of quartz, feldspar, sanidine and subordinate biotite and tourmaline in a devitrified matrix consisting of sericite and quartz. Typical photomicrographs of these rocks are shown in Plate-41 figs 3,6 and (Plate-40, Fig 1+6) of Plate-41, In fig. 5, a sanidine crystal of 1 mm size is enclosed in a matrix consisting of quartz, feldspar and devitrified glass. Similarly, in fig. 3, (Plate-41) a crystal of rhyolitic quartz is seen in a similar matrix, quartz has almost altered into a material resembling the matrix. All the gradations between fine vitric tuff and fine crystal tuff, such as vitric crystal tuff and crystal vitric tuffs are seen in different samples. Much of the lower unit of the Agglomeratic slate belong to this type, and some of the samples of Fenestella shales also (Plate 39 fig. 3, 4+5).

3. Lithic tuff: A typical example of the lithic type is seen in plate-41 figs 1, 2 and 4. In fig. 4, subrounded large sized (1.5mm) quartzite phenocryst having resorption borders is embedded in a matrix of much the same material as that of crystal tuff. The resorb borders must have been developed due to infall of phenocryst in a very hot molten material. In fig. 1 of the same

plate a phenocryst of slate (1.25 mm) size rounded like a coin is seen showing similar resorbt borders and embeded in a glassy matrix which has been very much devitrified. Along with the slates, similar quartz crystals are also present. Other types of lithic fragments seen in these rocks are shales, gneisses and some igneous rocks. These lithic fragments represent the vent and other surrounding country rocks which were exploded along with the ash and have become rounded, possibly by grinding with the vent and ash cloud. Mostly upper part of the Agglomeratic slate belong to this type. Besides typical lithic tuff all gradations between lithic and crystal tuffs such as crystal lithic tuff and lithic crystal tuff, depending upon the relative percentage of crystal and lithic fragments present in these rocks. These three types of tuffs are restricted to lower, middle and upper units of the Volcanic Clastic Group, but majority of these rocks belong to intermediate character.

The modal composition of rocks of both Fenestella shales and Agglomeratic slates have been tabulated in Tables-33+34. The data obtained from the modal analysis has been graphically represented in an equi-triangular diagram, devised by Obrie (1963), in terms of vitric, crystals and lithic materials. This classification has been used in preference to that given by pettijohn (1975). In Pettijohn's classification, the triangle represents the main three types of tuffs, viz, vitric, crystal and lithic one, but in the present classification, instead of three ten fields have been used; which include the central

area containing appreciable amounts of all the components.

As seen in this diagram(Plate-42), majority of the Fenestella shales fall within the vitric to vitric crystal tuff,while as the Agglomeratic slates are intermixed ones falling in almost all the three categories; viz, crystal vitric tuff, crystal tuff, crystal lithic tuff, lithic crystal tuff and lithic tuff.

GRAIN SIZE ANALYSIS

Grain size studies of both Fenestella shales and Agglomeratic slates have been carried out in thin sections and their statistical parameters are shown in Tables-35 to 36 .

From this analysis data, the histograms and cumulative curves of both these formations were plotted and shown in Plates-43 to 47 . Some of the histograms such as No. 12 of Plate-43of Fenestella shale and Nos 7,8,9,10 and 11 of Plate-44, of Agglomeratic slate are bimodal and resembles nuees-aredentes type. But a few of these histograms are of normal character, Nos 3,10 and 11 of Plate-43 and No. 12 of Plate-44 . Majority of them show intermediate characters of both in having number of classes and poor sorting. The c-umulative curves (Plate-45to 47) also lead to the same conclusion as the curves of Fenestella shales (Plate-45) are comperatively better sorted as that of Agglomeratic slates. This fact is further corroborated with standard deviation values, which in the majority of the cases of Agglomeratic slates exceed 1.00 and in Fenestella shales also these values(of five samples out of twenty) exceed 1.00.

TABLE - 35 STATISTICAL PARAMETERS OF REPRESENTATIVE SAMPLES OF FENESTELLA SHALE

S.No.	Sample No.	Mean Size (MZ)	Standard deviation (S_1)	Skewness (SK_1)	Kurtosis (K_g)	Remarks
1.	YF-3	2.53	0.78	-0.017	1.07	Mesokurtic
2.	YF-4	3.32	0.94	-0.055	0.88	Mesokurtic
3.	YF-5	3.12	1.02	+0.087	0.88	Mesokurtic
4.	YF-6	3.25	0.85	-0.073	0.85	Mesokurtic
5.	YF-7	3.26	0.81	-0.154	1.10	Leptokurtic
6.	YF-8	3.16	0.80	-0.211	1.10	Leptolurtic
7.	YF-9	3.26	0.81	-0.154	1.12	Leptokurtic
8.	YF-10	3.16	1.02	+0.132	1.11	Leptokurtic
9.	YFK-1	3.23	0.94	-0.068	0.81	Mesokurtic
10.	YFK-4	2.60	1.12	+0.083	0.82	Mesokurtic
11.	YFK-7	3.35	0.86	-0.126	0.90	Mesokurtic
12.	YFK-8	3.52	1.20	-0.081	0.86	Platykurtic
13.	YF_2-1	2.96	0.81	+0.080	0.94	Mesokurtic
14.	YF_2-2	2.94	0.79	-0.117	1.08	Mesokurtic
15.	YF_2-6	3.33	1.06	+0.072	0.82	Platykurtic
16.	YF_2-8	3.00	0.89	-0.126	0.85	Platykurtic
17.	YF_2-9	3.00	0.92	+0.068	1.11	Leptokurtic
18.	YF_2-11	2.32	0.98	+0.092	0.88	Platykurtic
19.	YF_2-12	3.52	0.82	-0.152	0.97	Mesokurtic
20.	YF_2-13	3.22	0.78	-0.112	0.92	Mesokurtic.

Serial No. 1 to 8; Yenner ahead of Aishmukam.
Serial No. 9 to 12; Kullar NW of Aishmukam.
Serial No. 13 to 20; Around Dhowat.

TABLE -36 STATISTICAL PARAMETERS OF REPRESENTATIVE SAMPLES OF AGGLOMERATIC SLATES

S.No.	Sample No.	Mean Size (MZ)	Standard Deviation (S_1)	Skewness	Kurtosis	Remarks.
1.	BS-3	2.50	1.20	+ .130	1.11	Mesokurtic
2.	BS-5	2.20	0.95	+ .082	0.96	Mesokurtic
3.	BS-6	2.40	1.02	- .026	1.73	V.Leptokurtic
4.	BS-8	2.40	1.07	+ .105	1.20	Leptokurtic
5.	BS-11	2.60	1.06	- .082	1.21	Leptokurtic
6.	BS-12	2.50	1.24	+ .024	1.11	Mesokurtic
7.	BS-18	2.53	1.22	+ .113	0.74	Platykurtic
8.	BS-19	2.20	1.10	+ .026	1.12	Leptokurtic
9.	BS-26	2.20	0.86	- .016	1.05	Mesokurtic
10.	DS-8	2.50	1.21	+ .190	1.10	Mesokurtic
11.	DS-9	2.20	1.20	+ .017	0.98	Mesokurtic
12.	DS-11	2.50	0.89	- .180	0.96	Mesokurtic
13.	DS-16	2.30	0.93	+ .068	1.19	Leptokurtic
14.	TM-1	2.56	1.15	+ .145	1.02	Mesokurtic
15.	TM-3	2.40	1.14	- .217	1.11	Mesokurtic
16.	TM -5	2.66	1.01	- .130	0.68	Platykurtic
17.	TM-6	2.30	1.23	+ .018	1.20	Leptokurtic
18.	TM-12	2.87	0.89	- .086	1.11	Mesokurtic
19.	TM-13	2.56	1.10	+ .161	1.09	Mesokurtic
20.	TM -16	2.80	0.89	+ .028	1.11	Mesokurtic

Serial No. 1 to 9: In and around Batkot.
Serial No. 10 to 13: Dhowat/ Kullar.
Serial No.14 to 20: Naubug.

In both the cases, however, no sample shows standard deviation values less than 0.78. These higher values of standard deviation in marine deposits indicate a special nature of the deposits, which are formed by the reworking of either land derived pyroclastic material or by the infall of tuffaceous material into water. These values, therefore, indicate a mixing of normal sedimentary and pyroclastic material.

Most of these depositsfrom Fenestella shales show negative skewness, and only 7 samples out of 20 have positive skewness; while as most of the Agglomeratic slates are positively skewed. This reverse relationship indicate that the Fenestella shales as a whole may not be composed of volcanic clastic material. The majority of the samples of both Fenestella and Agglomeratic slates are mesokurtic, while platykurtic and leptokurtic types are also met with.

SPHERICITY AND ROUNDNESS

The mean sphericity and roundness values of the grains found in Fenestella shales and Agglomeratic slates have been summarized in Table Nos 37 to 38 . Each value represents 40 grains from each section.

The mean sphericity values in Fenestella shales are

TABLE-37 SPHERICITY AND ROUNDNESS VALUES OF FINESTELLA SHALES

S.No.	Sample No.	Sphericity		Roundness		Elongation
		Mean	Standard Deviation.	Mean	Standard Deviation.	Mean
1.	YF-3	0.53	0.110	0.19	0.039	2.50
2.	YF-4	0.52	0.062	0.22	0.054	2.10
3.	YF-5	0.58	0.126	0.22	0.057	1.21
4.	YF-6	0.61	0.021	0.25	0.064	1.55
5.	YF-7	0.55	0.074	0.27	0.072	1.71
6.	YF-8	0.68	0.113	0.19	0.043	1.72
7.	YF-9	0.56	0.078	0.17	0.083	1.50
8.	YF-10	0.57	0.132	0.30	0.096	1.50
9.	YFK-1	0.61	0.060	0.17	0.079	1.72
10.	YFK-4	0.63	0.069	0.15	0.084	1.55
11.	YFK-7	0.56	0.127	0.13	0.054	2.00
12.	YFK-8	0.54	0.054	0.27	0.069	1.53
13.	YF_2-1	0.52	0.076	0.18	0.076	1.75
14.	YF_2-2	0.52	0.079	0.17	0.068	1.61
15.	YF_2-6	0.53	0.102	0.26	0.067	1.55
16.	YF_2-8	0.77	0.164	0.22	0.042	1.58
17.	YF_2-9	0.61	0.110	0.25	0.074	1.55
18.	YF_2-11	0.55	0.623	0.21	0.022	1.71
19.	YF_2-12	0.55	0.106	0.25	0.074	1.55
20.	YF_2-13	0.58	0.098	0.22	0.044	1.61

Serial No. 1 to 8: Yenner.ahead of Aishmukam.
Serial No: 9 to 12:Kullar NW of Aishmukam.
Serial No. 13 to 20: Around Dhowat.

+ TABLE-38 SPHERICITY AND ROUNDNESS VALUES OF AGGLOMERATIC SLATES

S.No:	Sample No.	Sphericity		Roundness		Elongation
		Mean	Standard Deviation.	Mean	Standard deviation.	Mean
1.	BS-3	0.57	0.074	0.19	0.048	2.04
2.	BS-5	0.55	0.154	0.22	0.067	1.45
3.	BS-6	0.54	0.0747	0.17	0.049	1.82
4.	BS-12	0.56	0.187	0.19	0.067	1.77
5.	BS-16	0.65	0.100	0.20	0.045	1.66
6.	BS-18	0.56	0.137	0.19	0.064	1.56
7.	BS-26	0.64	0.121	0.27	0.067	1.41
8.	DS-8	0.68	0.126	0.20	0.091	1.94
9.	DS-11	0.55	0.144	0.22	0.111	1.61
10.	DS-19	0.61	0.111	0.23	0.078	1.55
11.	DS-24	0.52	0.110	0.18	0.046	2.10
12.	TM-3	0.56	0.158	0.16	0.063	1.56
13.	TM-5	0.56	0.172	0.17	0.092	1.76
14.	TM-6	0.54	0.111	0.18	0.037	1.28
15.	TM-8	0.61	0.153	0.23	0.063	1.82
16.	TM-9	0.54	0.110	0.19	0.043	1.48
17.	TM-11	0.60	0.157	0.17	0.067	1.45
18.	TM-12	0.62	0.122	0.25	0.066	1.72
19.	TM-13	0.61	0.121	0.24	0.068	1.92
20.	TM-16	0.53	0.152	0.22	0.063	1.53

SerialNos 1 to 7: Batkot
Serial No. 8 to 11 : Dohwat.
Serial No. 12 to 20: Tangwani/Naubug.

between 0.52 to 0.77, the roundness values 0.13 to 0.30 and the standard deviation values of the grains from 0.034 to 0.632. In case of Agglomeratic slates, the mean sphericity values range between 0.54 to 0.68 and the roundness values 0.16 to 0.27. Majority of the grains, however, have mean sphericity values as 0.56 and the mean roundness values between 0.16 to 0.30 in both these formations. The lower values of roundness and sphericity indicate little transportation of the grains. This fact is corroborated by the elongation ratios, which are between 1.11 to 2.01 in both the cases. Apparently, the source area was either near the basin or the material actually fell into the ocean basins where it accumulated. Although the mean roundness values are low, but in one of the sections the different grains have unequal roundness. Some are extremely rounded, while others are subangular. This fact points out some effect of glacial agency.

HEA-VY MINERALS

Samples of both the formations were subjected to heavy mineral separation. There is a reasonable percentage of heavies present in both the formations. Among the heavy mineral species, tourmaline is found in traces, while opaques such as magnetite, haematite etc. are dominating. The overall percentage of these heavies in both the formations range between 0.03 to 2.87. as shown in Table Nos 33 to 34 .

SEDIMENTARY STRUCTURES.

Volcanic clastic group of rocks as a rule do not constitute a good number of well developed sedimentary structures. The bedding in the Fenestella series is uneven, but continuous when laterally traced, and the individual beds are laminated. Agglomeratic slate series also show some uneven bedding in the lower part but the stratification is rude in the upper part. Neither any well developed graded bedding or current bedding has been observed in this formation, but in associated quartzites of Fenestella shales , the upper part is coarser and conglomeratic one, a type of graded bedding in which coarser material bearing finer, has been observed.

Regarding bedding plane features, well developed ripple marks are seen in associated quartzites of Fenestella shales. Both symmetric and asymmetric ripple marks are found. They are usually straight crested frequently showing bifurcation. (Plate-12 fig. 5). This feature is characteristic of wave ripple and never observed in the case of current formed small ripples and mega ripples (Renieck and Singh, 1973). The mean ripple index for symmetrical ripples ranges from 6 to 9 and for asymmetric ripples from 8 to 10.

In the Agglomeratic slate,itself some doubtful, grooved marks and flute cast structures have also been observed, due to which these could not be used to determine the paleocurrents or any other interpretations.

TABLE- 39

PALEOCURRENT DATA FROM GRAIN ORIENTATION
AND PEBBLES OF AGGLOMERATIC SLATES

Data No:	No: of readings	Preferred Orientation Direction	Chi Square
1.	100	146.00	106.38
2.	100	161.54	78.69
3.	100	127.54	82.49
4.	100	119.06	78.56
5.	100	153.12	129.32
6.	100	138.12	92.66

Data No: 1 to 2: from Oriented thin section-s
3 to 6: from mega clasts of the pebbles from Agglomeratic slates.
Localities: Naubug, Batkot, Virsrem.

PALEOCUURENT STUDY

In this study cross bedding has not been noticed in any of the samples found in Fenestella shales or Agglomeratic slates. Here the paleocurrent data was determined from preferred grain orientation of elongated grains from thin sections, pebble orientation studies of coarser clasts found in the upper horizons of Agglomeratic slates and ripple marks observed in Fenestella shales associated with quartzo-sandstones. The data has been presented in the form of rose diagrams. The data was also subjected to Tukey's Chi square test. The table-39 summarizes the direction of preferred orientation and Chi square obtained from different studies as shown in Table -39 . The paleocurrent direction obtained by grain orientation and pebble orientation fairly does not show much variation, but there is a difference of as much as 80 ^{o} with respect to paleocurrent direction obtained by ripple marks. It may be due to the fact that in this case ripple crest directions were measured.

Rose diagrams (Plate-48, Fig. 1 to 6) from the Azmuth of long axis of pebbles and grains are also bimodal and one of the mode is related to current direction determined statistically. Later modes may have been caused by the disturbance or some other local currents. The volcanic clastic group of rocks as indicated by these studies have two flow systems, one acting in the NW-SE direction and other flowing in the northeasterly direction.

B – PETROGRAPHY OF THE COARSER FRACTION

The coarser material, constituting the rudaceous type of Agglomeratic slate does not exceed more than 20 percent of the total volume of the whole rock. This material is enclosed very hard in the rock and cannot be seprated without breaking the rock into smaller pieces. At least 100 pebbles per locality were separated in this way and these were studied with respect to lithology and shape. The results are as follows:-

LITHOLOGY

The pebbles so separated from the Agglomeratic material were thoroughly washed, cleaned and in some cases even broken to find out their true nature. An index collection of typical and diagonostic lithologies was compiled for separate counting. In selecting the pebbles for this purpose, the effect of granular variation was also considered as the effect of particle size, on lithology is well established fact (Plumaly, 1948, Potter, 1955, Krumbein, 1942, Dreimaris and Reavely 1953). It was, therefore, to restrict this study of pebble count in a particular grade; so that variation in lithology may be used for correlation purposes. For this study, pebbles ranging in size from 1.5 to 2.5 mm size were taken for counting as according to Potter (1955), this size grade contains the greatest variety of rock types.

The pebble count data of Agglomeratic slate of various localities is shown in Table -40 . It shows that the quartzite is the most dominating rock type found in these slates. Its percentage varies between 55 to 72 . Next to quartzites, are other

TABLE- 40

LITHOLOGICAL COMPOSITION OF THE AGGLOMERATES FROM RUDACEOUS TYPE

	Quartzites	Gneisses	Schists	Slates	Granites	Trap	sandstones	Limestones
1.	58	-	1	15	-	3	23	-
2.	55	3	1	3	-	12	26	-
3.	73	1	2	9	1	7	7	-
4.	66	-	-	11	4	4	11	-
5.	58	-	1	14	2	9	16	-
6.	62	-	-	13	2	5	18	-
7.	72	1	2	7	1ø	10	7	-
8.	67	1	-	12	-	7	13	-
9.	62	-	-	-	2	5	33	-
10.	62	-	-	4	-	8	26	-

Sample localities:
Sr.No: 1 to 3: Tangwani (Naubug)
4 to 6: Dohwat and Kullar
7 to 10: Batkot and Above.

metamorphic rocks like gneisses, chists and slates. Igneous rocks are also represented but their percentage does not exceed 10 percent in any case. Greywacke, like sandstone was found in a few cases; but no pebble of limestone has been found in them.

From the pebble count data it appears that most of these pebbles have been derived from Muth Qartzites and Passage beds. Rocks constituting Cambro-Silurian slates are also found in them, alongwith pebbles derived from igneous rocks intruded in the Cambro-Silurian slates at places. The nature of lithology represented in these pebbles suggest that the material did not come from very long distance, but the local rocks available at site intermignled with ash flows, to give rise to rudaceous type of Agglomeratic slates.

FORM AND SPHERICITY STUDIES

No earlier worker, has studied the form and shape of the coarser material and of Agglomeratic Slate. These studies are important in finding out the distance traversed by the pebbles from the source area; to site of deposition and for correlation purposes. In this work, therefore, form, sphericity and roundness of the pebbles earlier used for pebble; counts was also determined. The results are as follows:-

In this work form has been determined by Zingg (1935), method. The longest, intermediate and short diameter of the pebbles representing the a, b and c axes were measured and

plotted on a Krumbein (1941). Form , sphericity diagram shown in Plate - 49; to determine form and spericity. The data was further checked by tables devised by Catacosinos (1965). Use of these tables eliminates the manual plot of data in Sphericity chart of Krumbein and also increases the speed of determining the desired values.

FORM AND SHAPE

Plate-49 Fig,1 to 4, represents Zingg graph showing the plots of pebbles for four localities. This graph is divided into four fields representing four shape classes, viz., oblate, prolate, equiaxial and triaxial;on the basis of diameter ratios of clastic particles b/a and c/b where, a,b and c are the longest, intermediate and shortest diameters respectively. In spherical form both the ratios b/a and c/b are greater than 2/3; in bladed form both are less than 2/3. In oblate form, b/a is greater than 2/3, but c/b is less than that. In prolate form, the reverse is true, namely b/a is less than 2/3, but c/b is greater than that. The data representing 'form' is shown in Table-41 .

In Agglomeratic slates, most of the pebbles,are either discs or spheres, while bladed or rod shaped pebbles are less in number. There are, however, a few exceptions as in samples nos. 6 and 10, the number of rod shaped pebbles is 38 to 40 percent. In sample No. 1 and 2 likewise 30 percent

of the pebbles are rod shaped, but in majority of the cases their percentage ranges between 10 to 22 percent only. The bladed shaped pebbles in all the cases do not exceed ten percent.

SPHERICITY

In view of the higher percentages of equiaxial type of the pebbles in Agglomeratic slates, these have high values of sphericity. The mean sphericity values in all the cases range between 0.64 to 0.81, but in majority of the cases it is more than.70.percent. The results of these values are tabulated in Table No.-41 .

ROUNDNESS

Roundness studies,likewise have also not been done by any earlier worker for these rocks. Such studies are important, for finding out the amount of abrasion a pebble has undergone during transportation,and thus is useful in determining the distance traversed by the coarser material to reach its present depositional site. At places,roundness values have also been used for correlation purposes (Trambridge and Mortimore, 1925).

For this work, roundness values of only the quartizitic pebbles have been determined as they offer high resistence to the process of rounding and abrasion and thus can stand to a greater extent the degree of roundness once achieved in a particular environment. The mean roundness values range between 0.32 to 0.64, which indicates their subrounded to rounded nature & prolonged abrasion.

TABLE - 41 FORM AND ROUNDNESS OF ARGILLACEOUS TYPE OF AGGLOMERATIC SLATES.

S.No: Sample	FORM				SPHERICITY		ROUNDNESS	
	Disc	Sphere	Bladed	Rod	Mean	Standard Deviation	Mean	Standard Deviation
1.	26	34	10	30	0.75	0.1394	0.36	0.1211
2.	30	40	-	30	0.74	0.15	0.56	0.12
3.	36	42	10	10	0.76	0.10	0.44	0.24
4.	30	40	10	20	0.74	0.16	0.38	0.26
5.	25	47	10	18	0.16	0.19	0.54	0.10
6.	24	31	7	38	0.70	0.10	0.32	0.21
7.	30	36	4	30	0.73	0.11	0.64	0.10
8.	44	34	9	15	0.74	0.12	0.33	0.11
9.	28	42	8	22	0.72	0.10	0.43	0.11
10.	20	40	-	40	0.64	0.11	0.48	0.10

Sr. No: 1 to 3: Batkot.(Upper parts.)
Sr.No: 4 to 8 Tangwani(Naubug)
Sr.No: 9 and 10. Dohwat.

ORIGIN OF AGGLOMERATIC SLATE

According to Middlemiss (1910), it is not easy to define the exact nature of the agency by which the Agglomeratic slate was accumulated, as it is not a simple stratified deposit laid down under the action of water. According to him, there seem to be two main natural agents by which such a widespread and uniform deposits might have been accumulated. These are: (i) Explosive volcanic action, (ii) frost with ice transport. He, however, was more favourably inclined to explosive volcanic theory and considered the Agglomeratic slate, as the lower member of the volcanic series; accumulation of clastic and fragmentary material formed round ruptured portion of the earth's crust eventually became focii for the extrusion of basic lava flow. In support of this hypothesis, he also points out that the Agglomeratic slate even in the finest grained varieties contain no organic remain throughout the formation. But at the same time, he is also of the opinion, that " the alternative hypothesis should not be lost sight of, nor the possiblity that the formation was a joint project of both sets of activities combined with ordinary sub-aerial sedimentation."

Wadia (1928), regarded the fairly thick zone of Agglomeratic slate of central part of Pir Panjal, as of pure volcanic pyroclastic nature and further, says, that these rocks are compact volcanic tuff with a matrix which is

largely devitrified,but leaving some unaltered original glass. There is a very close connection between the Agglom-eratic slate and Panjal trap (Wadia, 1934), and that they are the products of contemporaneous volcanic eruption. This is,according to him, further corroborated by the fact that Agglomeratic slate passes both vertically and laterally into the lava flows.

Ganju and Srivastava (1961),made a petrographic study of the slates from several outcrops in the vicinity of Bren,near Srinagar and found in these rocks the abundance of devitrified glass matrix;alongwith unsortad angular debris consisting of quartz, feldspar, rock fragments and glass. These characters, according to them, are suggestive of their being originally rhyolitic- crystal-vitric welded tuffs; which have been subsequently metamorphosed,devitrified and altered to a feddspathic -quartz-sericite -slate.

Pareek (1977), considered the Agglomeratic slates representing the pyroclastic nature of the volcanism;in which the constituents were blown up into the atmosphere inflated by gas. The deposits were solidified to form Agglomerate, glassy rocks and welded tuffs under the influence of gravity.

Bhatia and Kokroo (1978), found additional evidences to support explosive volcanic theory, which are as under:-

(a) Vitroclastic and snowflake textures, characteristic of volcanic tuff were observed in some of the samples.

(b) Ganju and Srivastava (1961), mentioned only the presence of rhyolitic crystal-vitric welded tuff. However, in this study all the three types of tuff viz., vitric, crystal, lithic and welded tuffs and their sub-varieties were found.

(c) The presence of resorb borders of some lithic and other fragments embeded in the fine matrix, indicate that the tuffaceous debris was very hot and mobile at the time of its formation.

(d) In the whole of the Agglomeratic slate series, coarsening upward of the strata from base to top i.e. from finest vitric type at the base and lithic and conglomeratic at the top was noticed which is characteristic of tuffaceous material.

GENETIC MODELS OF THE AGGLOMERATIC SLATE

Lydekker (1878), was first to advocate glacial origin, and correlated this series with Talchirs.

Middlemiss (1910), considered, a great resemblance of Agglomeratic Slate with Blaini Conglomerate.

Wadia (1934), also considered, the Agglomeratic Slate series to be homotaxial, with the Talchir Damuda series.

Number of other workers, apart from Middlemiss and Wadia have also pointed out this resemblance.

Gupta (1975), proposed a formal classification of Agglomeratic slate sequence of Kashmir and reviewed the stratigraphic position of the boulder bed in its basal part- the Gulabgarh Boulder formation on palaeontological and stratigraphical grounds. He assigned the upper Carboniferous age to all the boulder beds including the Blainis.

Wakhaloo (1975), also correlates the Blainis with the Agglomeratic Slate series of Kashmir.

Acharya and Shah (1975), quoting (Fox 1931, Gansser, 1964, Fuchs and Gupta, 1971) considered Agglomeratic slate of Kashmir valley intercalated with tillites, tilloids and Agglomerates and thus correlated them with Blainis.

Fuchs (1975), in his paper 'Glaciogene formation in the Himalayas' mentioned that " in this formation volcanic influence was much less, as might be expected from the name of the formation. Particularly, the pebbly mudstone and sandstone seems to be glaciogene and not volcanic."

In view of the above, the following models may be considered for the origin of Agglomeratic slates:-

1. Glaciomarine sedimentation model.
2. Submarine slump and turbidite model
3. Mud flow model

1. GLACIOMARINE SEDIMENTATION MODEL

In recent years a sedimentation model has been proposed by Carey and Ahmed (1961), to explain the glaciomarine sedimentation. Number of workers have applied this

model, to explain the origin of Blainis (Cashyp,1969, Saxena and Padye ,1969,Gaur and Dev,1971, Bhargwa and Bhattacharya 1975, Bhatia and Parsad ,1975, Srikantia,1975). According to Srikantia, great Carboniferous-Permian glaciation in the Gondwana supercontinent after the Hercynian Orogeny may be an example of such a relationship between glaciation, tectonic movements and changes of relief. The Blainis were deposited under this influence. The great Carboniferous-Permian glaciation must have also brought changes in Kashmir region, affecting sedimentation, as it was also a part of that super Gondwana continent; indicated by the presence of Gondwana flora in Kashmir. The Agglomeratic Slate, therefore, must have had some influence of that glaciation in their deposition. There is no doubt that no striated , grooved or facetted boulders have been found in them; but poor sorting of the sediments, occurrence together of a wide range of grain size, extreme variation in the rounding of clasts, presence of angular and subangular clasts and a great diversity of rock types represented in the clasts do point out the work of some glacial agency.

Fuchs (1975), considered the glacial origin for Agglomeratic slates more plausible. According to him, "scattered in green, grey, brown matrix of Argillite, siltstones or sandstones, there are pebbles and boulders upto sizes of several decimetres. The components consist of

quartz, quartzite, sand or siltstone, carbonate rocks, mica schists, gneiss, granite and volcanics. The pebbles and boulders are unsorted and they occur in layers or are sporadic. Occasionally, it was observed that the layers of matrix are bent down under the load of a boulder or that boulders reach across the bedding planes. Such observations may only be explained by the assumption that the boulders dropped from floating ice into a sea in which flyschoid conditions of deposition prevailed."

Regarding the absence of striations or striated pavement in the Agglomeratic slate, it has been argued by Ahmad (1975), that " once the glacier enters the sea, even though it may be resting on sea floor, its weight is partly supported by the water andit does not exert its full pressure on the basement, so the chances of the development of striated pavements are reduced." Moreover, the unconsolidated sediments covering the sea floor will not be able to preserve fine striae for long.

Recently, Slatt (1971-72), described texture and composition of some tills and ice core deposits, from Alaskan valley glaciers, giving the details of their mean size, sorting, skewness and kurtosis. These values are ,more or less, comparable to the one obtained from the grain size studies of Agglomeratic slates. These are

medium to coarse sand sized,poorly sorted,fine to very fine skewed and nearly mesokurtic nature of the deposits. In fabric diagram also, there is some resemblance to till fabric and presence of dropstones and lenses of conglomerates and sandstones within the Agglomeratic slates.

The presence of marine fauna associated with the Agglomeratic slates, point out the marine basin in which the deposition took place. It shows the presence of piedmont glacier with the marine basin. The whole situation may be like the one as Srikantia (1975), visualized in the case of Blainis. According to him," due to abundant supply of ice from the neve, the valley glaciers emerged into the piedmont valley, where they fanned out. These expanded ends of valley glaciers coalescing with each other, formed a solid sheet of ice along the foot of the mountain; forming the Piedmont glaciers which ultimately reached the sea, where the deposits were laid down in the shelf zone.

SUBMARINE SLUMP AND TURBIDITE MODEL

Deposits like tillites, tilloids and other related rocks can also be formed by the turbidity currents (Crowell, 1957; Dott,1961; Schermerhorn and Stanton, 1963; Winterer,1964; Lindsey, 1966; MCbride , 1966; Aalto, 1972; Aalto and Dott, 1970). A similar process involving submarine slumping has also been advocated, to explain the origin of Blainis.(Rupke, 1968;Niyogi and Bhattachrya, 1978, Valdiya,1973. The

arguments in support of this hypotheisis include (i) the presence of angular and jagged megaelasts resembling disrupted and dislodged beds, which suggest that the material forming the clasts was not fully consolidated when it originated; (ii) presence of structures characteristic of turbidite formation; (iii) the occurrence of well rounded clasts of quartzite with extremely angular rock pieces of the same composition as the matrix.

According to Carry and Ahmad (1961), turbidites and turbidite, like deposits can develop under an ice sheet in two ways; under a wet base glacier, the rate of sedimentation, is high and if the gradient of the sea bed is also high turbidity currents may be generated, which deposit turbidites with other glacial and subglacial deposits. Secondly, when the glacier melts in the sea, the boulders at the base are pushed in the soft clay developing pressure shadows in front of them and alongwith these, clay balls and rolls develop.

Bouma (1962), considered certain internal sequence of structures known as Bouma sequence, as most essential feature for the identification of turbidite. The complete five-fold Bouma sequence consists of lower division (A), which may be graded or massive, overlain by laminated division(B) and cross lamination division (C) followed by the topmost divisions(D & E). This sequence alongwith cone shaped distribution of each turbidite layer is very diagonostic feature of

turbidites and flyschoid type of deposits.

In case of Agglomeratic slate, however, some doubtful flute cast like structures and pebbles having extremely variable roundness alongwith graded bedding have been found at a few places; although no Bouma sequence has been found anywhere. Fuchs (1975), also pointed out about the presence of flyschoid conditions, in which the boulders were dropped from floating ice into the sea, but he maintained," though graded bedding flaser and flume structure, load deformation and flute loads moulds indicate gliding in a flysch environment, the tilloids can not be explained by the assumption of Olistostromes. This view is inconsistent with the fact that the boulders are scattered in a layered matrix."

MUDFLOW MODEL

Pettijohn (1975), while discussing the origin and nature of volcanic clastic deposits explained, the mechanism of mud flows in the formation of such deposits. Mudflows are formed, when torrential rain falls on newly deposited ash and cinders, which move downslope giving rise to chaotic deposits having no assortment or stratification. More often, such flows enter the sea or formed by subaqueous slump. According to Pettijohn, these flows pass by degrees into turbidity currents, in which case they show all the usual features of turbidites. These deposits show on ly rude stratification and contain large , metre sized and smaller blocks embedded in a tuffaceous matrix. The other

characteristics of mud flow deposits are(i) absence of facetting, striations and polishing in the clasts and (ii) restricted nature of the deposits; as the mudflows are generally considered as local phenomena and would indicate transportation only for a short distance (Heezen and Hollister,1964).Acharyya (1973), suggested this hypothesis to explain the origin of Blainis. This mudflow model explains many features of the Agglomeratic slates.

1. The bulk of the material constituting these slates is pyroclastic, representing volcanic ash and cinders.
2. Many of the clasts have resorbe borders indicating very high temperature of the material in which these were embedded.
3. Absence of any facetting, striations etc. on these clasts.

This model, only however, cannot explain the wide aerial distribution of Agglomeratic slates, presence of fresh feldspars in these rocks and wide variation in the degree of roundness in these clasts.

In concluding remarks,it may be said that Agglomeratic slates were deposited in a variety of environments and one single model cannot explain all the features of Agglomeratic slates of different areas. These are undoubtedly reworked pyroclastic sediments which were deposited in marine basin under the influence of glacial climate. It appears that newly deposited tephra resting in many places on steep slope must have been reworked by different agencies. Some of the material might

have been picked up by the glaciers, which eventually took them near the sea in the form of Piedmont glaciers and the material might have been laid down by a dry based glacier in the outer part of the floating shelf zone, as suggested by Casshyap (1969), for boulder bed like Blaini. The other possibility that the glaciers might have actually floated in the ocean carrying the material on their surface generating turbidity currents, when the rate of sedimentation is high under a wet base glacier as explained by Ahmad (1975), and producing flyschoid type of deposits. Most of the material, however, must have moved like mud flow, which might have been ultimately carried to the sea either by itself or by alluvium of the streams, where they were either spread by submarine currents or eventually swept off the shelf and more seaward as a turbidity current. In all these processes, this reworked material have been much diluted by ordinary clastic debris.

CHAPTER -VII

DEPOSITIONAL MODEL

DEPOSITIONAL MODEL

The detailed stratigraphical cum petrographical studies of thick pile of rocks, ranging from Cambro-Silurian slates at the base to the Panjal Volcanic series at the top; was designed to understand the depositional pattern of these rocks and the nature of the basin, in which these rocks were deposited. This in other words implies the determining of the Palaeogeography of the area, which involves reconstruction of the basin, location of its margin, location of the area or region supplying the sedimentary fill, delineation of the shore line and relation between the structural and bathymatrix axes. This is mainly done by studying the nature of the sedimentary fill and determining the paleocurrent direction.

Due to lack of subsurface data on these rocks, it was not possible to/reconstruct lithofacies or isopack maps, which could have provided additional data regarding the configuration of the basin. The depositional model or sedimentary model, according to Potter and Pettijohn (1963), " in essence describes a recurring pattern of sedimentation." Furthermore, " the fundamental assumption of model concept is, that there is a close relationship between the arrangement of major sedimentation in a basin and direction structure in as much as both are a product of common dispersal pattern."

NATURE OF THE BASIN

From number of evidences, it is clear that Palaeozoic rocks of Anantnag district of Kashmir, were deposited in a marine basin, which was open towards sea and was more of a embayment type rather than a basin. This is confirmed by the elongated pattern of the outcrops, stretching from northwest of Handwara to the southeast of the Kashmir sedimentary basin, where it merges into the Spiti basin. In between these areas, there are other patches of Palaeozoic outcrops exposed in the Basmai anticline of Sind valley between Sonamarg and Kolhai and another synclinal basin extending from Wular Lake to Tithwal. All these basins are linearly arranged, marking the margin of the ancient continent. The isolation of the different basins within the linear patch is due to the presence of raised areas termed as arches, palaeohighs or positive areas alongwhich the palaeozoic sediments are absent.

Regarding the nature of this basin, Shah (1972), considered, Cambro-Silurian deposition of Anantnag area as extra- cratonic. He based this conclusion on the presence of trilobite fauna and flysch like nature of these sediments. Further according to him Devonian litho and bio-facies represents shelf fauna and during the Carboniferous, the sediments were deposited in a local isolated basins in the east, while the land area seems to have merged in west and northwest, with no upper Palaeozoic marine sedimentation.

From the available data, however, there is every likelihood

that the Anantnag basin was more of a epicratonic rather than intracratonic type, at least during the Lower Palaeozoic. The distinction between the two types is simple i.e. the intra-cratonic basins, lie within the continental crust, while the epicratonic basins lie on the edge of the continental crust and are partially open to the ocean basins. These two types often occur together, adjacent to one another with little fundamental difference in genesis or fill. Moreover, epicratonic basins, tend to be much less stable than intra-cratonic, due to their situation at continental margin. However, initial basin subsidence can be rapid resulting in an early phase of deep water sediments.

It is also clear that whole of the thick pile of palaeozoic sediments ranging from Cambro-Silurian slates to upper Palaeozoic were deposited in the same basin, in which sedimentation spanned; a range of environment ranging from deep water turbidite to linear shore line environment including tidal flat. The active history of the basin, was interrupted by a bout of Panjal volcanism, which resulted in the huge welling up of lava flow.

There are also indications that in the initial stages the basin axis and depocentre coincided, b-ut with the passage of time depocentre, shifted across the basin. It may be due to migration of the topographic axis of the basin or merely due to lateral progradation of the main locus of deposition across

an essentially stable basin floor.

The geometry of the basin and the depositional pattern of the sediments during the different phases of the history of the basin are as follows:-

1-SHALE -SLATE-GREYWACKE GROUP

Shae-slate-greywacke group of rocks were deposited during Cambro-Silurian times. The rocks are more or less of flyschoid nature, as indicated by their lithology, sedimentary structures and vertical sequence. The group is subdivided into Gauran Formation and Hapatnar Formation. The Gauran Formation, both in its lower and upper parts show turbidite features indicating deep oceanic conditions. The Hapatnar Formation also in its lower part is turbiditic in nature, indicating similar conditions, while the upper part does not show any turbidite features ;was also deposited in a fairly deep water to produce current dominating structures, although not as deep where turbidity currents could operate. The presence of graptolites in these rocks, also indicates deep water conditions.

BASIN GEOMETRY

During the deposition of shale slate greywacke group of rocks, the basin of deposition was an elongated one having NW-SE trend, which was more or less embayed, and open towards the ocean basins in the north. It was asymmetric in cross -

section and widening towards southeast. The basin was fairly narrow and deep, Estimates of the Paleobathymetry indicate from bathyal to abyssal depths. Apart from the presence of graptolites which are present in the upper part of Hapatnar formation there are other indirect evidences of deep water interpretation. These include the presence of abundant sedimentary structures and textures in common with other known deep water deposits and absence of shallow water structures or organisms.

PALEOCURRENT PATTERN

The paleocurrents display a consistent relationship to basin archtecture during the Palaeozoic. The principal direction of sediment transport as indicated by grain fabric in Gauran Formation was uniformly from NW-SE direction, which reflects a broad uniform paleoslope parallel or subparallel to basin axis. The Hapatnar paleoslope is poorly defined by diverse currents. They seem to indicate a linear trough, into which currents flowed longitudinally from northwestern side as well as transversely and obliquely to the trough axis, towards South-east.

SOURCE AREAS

Lithology of the shale slate greywacke group, is not an appropriate guide, regarding the source area; which supplied the material for filling up of the basin. The sandstones represented in, are unclean, muddy, greywacke type excepting a few outcrops, which are ortho-quartzitic type. The shales have undergone metamorphism and converted into slates and phyllites, rock

fragments are almost lacking. Heavy minerals are almost negligible, and the quartz grains are deformed. The only reliable guide is the paleocurrent pattern and direction, which points out that the main source area which supplied the sediments both for Gauran and Hapatnar Formations must be some tecton-ically active area along north-west margin of the basin. The nature of the inclusions in quartz, elongation ratio and predominance of undulatory extinction, however, point out that material was mostly derived from metamorphic, sedimentary rocks.

DEPOSITIONAL PATTERN

The flysch like nature of both, Gauran and Lower Hapatnar sediments suggest that this type of sedimentation took place in a deep trough; formed by major structural depression. Within this deep trough turbidity currents operated at continental margin building up of submarine fans of turbidites. The modern analogue of this model is north end of San Diego trough, California as described by Nand and Emery (1964). Another similar example of this type of model, is San Pedro and Santa Monica basins of Southern California (Gorsline and Emery, 1959). The submarine fans are formed at the foot of the submarine canyons, and they usually extend and die out in the deep sea floor. The fans are cone shaped wedges of sediment with their apisces at the foot of the submarine canyons. They thus, form

a small part of the basin apron". Fans are areas of near source deposition from turbidity currents, at the first major flattening of the slope. Fans often have channels and channels often have levees. They are straight or meandering with steep or shallow walls. Fan sediments, consist of alternating coarse and fine beds. Lower boundaries of sand layers are sharp . Several superimposed graded sand layers are sometimes present, known as sedimentary structures, which include, parallel lamination, ripple cross lamination, slumping and graded bedding.

The Gauran Formation is, therefore, believed to have been deposited from a series of laterally migrating fans, while the Hapatnar Formation has been formed on the slope above the submarine fans, (Plate - 50, Fig. 3).

TECTONIC SETTING

It is reasonable to assume some mild basin subsidence during deposition, due to which maximum bathymetry might have been reduced, but there are positive proofs, such as absence of marine unconformities indicating thereby that the basin was not tectonically uplifted during deposition.

2- ORTHOQUARTZITE CARBONATE GROUP

This group is composed of both clastic and non-clastic rocks, representing platform facies or stable shelf facies in recognition of the presumed structural stability of the site of deposition. The group is subdivided into three formations viz., Muth Quartzite (Gurderman Formation), Syringothyris limestone (Aishmuqam Formation) and Passage beds (Cindermar Gali Formation). Limestone is found only in Syringothyris limestone formation, while the other two formations are exclusively composed of quartzo sandstones. Except Passage beds shallow marine fauna indicating marine environments have been found both in Muth Quartzite and Syringothyris limestone. These features indicate following basin conditions:-

1. BASIN GEOMETRY

In view of the abrupt facies changes from deep water flyschoid type, of the Shale-Slate-Greywacke group, it is evident from the type of marine fauna, sedimentary structures and lithology that sedimentation of Orthoquartzite carbonate group took place in a marine basin of shallow water depths with approximate bathymetry not exceeding few hundred metres. Consequently, it cannot be the same basin in which earlier sediments of shale slate greywacke group were deposited. According to McIver (1970), flysch type of sediments and shallow marine deposits will not merge within a single basin and will be mutually exclusive. Seilacher (1967), have also recognized

that flysch suite is dignificantly different from other facies and that intermediate types are rare. It is, due to the fact that basic difference between a shallow marine basin and flysch basin is in the nature of basin tectonics. The depocentres of thick marine and deltaic sequence are localized by load tectonics i.e. subsidence in response to deposition of sediments. It is becasuee of this uneven balance between basin subsidence , marine and deltaic progradation that the complex intertonging of facies is resulted. Flysch basin on the other hand form with an early major structural depression and produce a deep trough.

The orientation of this new basin was, however, the same as that of the earlier one. It was still an elongated basin having NW-SE trend, which was also embayed and open towards north.

PALEOCURRENT PATTERN

The principal direction of sediment transport during orthoquartzite group as indicated by cross bedding and ripple marks, was uniformly from NW -SE. In addition to this, there was a second dispersal system which contributed some volume of the material to the basin. This system originated in stable southern cratonic source, which supplied the material to the basin located in its northern edge. It shows, therefore, that direction of infilling was both parallel and transverse

to the structural axis of the basin.

SOURCE AREA

Both lithology and paleocurrent pattern are sure guide to the source area, which supplied the material for filling up the basin, in which Orthoquartzite Carbonate group of rocks were deposited. The quarto-sandstones of all the formations are highly rich in quartz, which indicate a high degree of textural and mineralogical maturity. Such rocks represent the end product of protacted and profound weathering sorting and abrasion and indicate that source area must be tectonically stable. Similarly heavy mineral suite which consists mostly of Zircon, Rutile, and tourmaline, indicate that unstable minerals must have been removed by prolon-ged abrasion and repeated washing and winnowing of the material. However, the nature of elongation quotient of quartz grains indicate their derivation both from igneous and metamorphic source. The rounded nature of the grains and good sorting indicate a high degree of abrasion and low relief of the source area. The nature of zonning in zircon, indicate mostly igneous source; both prismatic and bipyramidal habits of zircon crystals also indicate igneous source. However, the rounded nature of these crystals suggest reworked source.

DEPOSITIONAL PATTERN

The epeiric sea model is considered to be the most plausable milieu, in which orthoquartzite carbonate group of

rocks might have been deposited. Epeiric sea (sea lying upon the continent) for the bodies of water that lie within the continent in the downwarps of continental masses. These areas in times past, have experienced great changes through variation of sea level, sometimes being more or less completely emptied of their water or filled with sediments and turned into land. Examples of present epeiric seas are Hudson Bay, the Gulf of St. Lawrence and the Baltic Sea.

According to Irwan (1965), in such eperic seas, three marine hydraulic energy zones prevail, which are (a) low energy zone prevailing in the open sea, beneath wave depths; where marine currents are the only form of hydraulic energy acting upon the bottom (b) an intermediate high energy belt, beginning where waves first impinge upon the sea floor and thus expand their kinetic energy upon the bottom extending landward to the limit of tidal action (c) an extremely shallow low energy zone occurring landwards. These are termed as X, Y Z zones respectively. This concept of three main shelf environments is applicable to clear water, which have received an influx of terriginous clastics and it explains very well the sedimentation of Syringothyris Limestone where most of the limestones were deposited in Y zone. The dolostones associated with these limestones were found in Z zone , while the Associated shales in X zone.

Within this eperic sea, there stand barrier island, which consist of number of distinctive physiographic units; that have open sea on one side, while on its landward side there may be a complex of wash over fans and barrier flats, formed of sand flushed over the barrier island during storms. Coastal geomorphologists used the term 'bar' to constructional features that are submerged at high tide and and the terms like barrier island, barrier beaches and spits for those, which are emergent. Most often, sand bodies of barrier island and open sea merge into one another. The most diagonostic feature of these sand bodies, is that they are linear shoe string type running parallel to the local shore line although there are other diagonostic features as well, such as upward coarsening grain size profile, their bioturbated nature in the lower part and massive or subhorizontally bedded towards the top. Moreover, the tops of these sandstones are abrupt overlain by marine or non-marine shelf. All these features indicate that, while muth quartzites were formed partly on the barrier island and partly in open marine sea. The sand bodies representing Passage beds were formed on the barrier flats towards the landward side of the barrier island. (Plate – 50, Figs 1 & 2).

TECTONIC SETTING

There appears to be mild to moderate basin subsidence during deposition and the basin was not tectonically uplifted during deposition.

3. VOLCANIC CLASTIC GROUP

This group includes both Fenestella shales and Agglomeratic slates, referred in this work as Yenner and Batkot formations. Both these formations are composed of welded tuffaceous material intercalated with tillite, tilloids and Agglomerates; which have been metamorphosed, devitrified and altered to feldspathic-

quartz-sericite slates. Shallow marine fauna consisting of bryozoan fossil, Fenestella, Pelcypod shells, Eurydesma and brachiopods etc. have been found in both these formations. The features indicate the following basin conditions:-

BASIN GEOMETRY

From all the available evidences, it is clear that the sedimentation of volcanic clastic group continued in the same basin, in which rocks of Orthoquartzite- Carbonate group were deposited. The subsidence kept pace with deposition and thus made an additional space to accomodate these sediments. It was still an linear trough trending NW-SE open towards ocean and asymmetric in cross section. The presence of marine fossils like Eurydesma , Fenestella ,Syringothyris and other sedimentary structures like ripple marks, indicated that the water depth did not exceed few metres.

PALEOCURRENT PATTERN

The direction of sediment transport, as interpreted from ripple marks and fabric has indicated that the paleoslope was inclined to the east and southeast.

SOURCE AREA

The mid Palaeozoic land mass of northwestern Kashmir, is considered to be the chief source area, which supplied the lithic fill; not only for this group, but also for Orthoquartzite Carbonate group. Evidence of this landmass is provided

not only by paleocurrent pattern, but also by wide spread regional unconformity from Hazara to northwestern Kashmir; as indicated by total blank geological record of these areas after Silurian system of rocks, which are succeeded by Panjal Volcanics deposits. It is on this landmass that material produced due to volcanic activity accumlated, which later-on flowed towards the basin. This material was further diluted by igneous metamorphic and other sedimentary rocks, present in the source area, as indicated by the nature of lithic fragments found in the lithic tuffs. The high percentage of feldspar indicated a fairly high relief of source area.

DEPOSITIONAL PATTERN

In the formation of these deposits, some sort of glacigene effect cannot be ruled out and the volcanic influence was less as might be expected from the name of the formation. Number of features, such as presence of pebbly and mudstones, their unsorted nature, varying degree of roundness, presence of fresh feldspars support this view.

For these deposits Fuchs (1975), visualized the model of floating ice into a sea, from which the boulders dropped in a basin in which flyschoid conditions of deposition prevailed. The greywacke light matric and other turbidite features can, however, be explained best by invoking glaciomarine model of Carry and Ahmed (1961) as further explained by Kashyap (1969).

The presence of high percentage of pyroclastic material, however, supported mud flow m-odel. Turbidite feature of the deposits can be explained by both. It is, therefore, presumed that the both the models might have operated during the deposition of these deposits.

TECTONIC SETTING

Only a mild basin subsidence due to load of the deposits appears to have taken place during the deposition of volcanic clastic group of rocks. There appears to be mild to moderate uplift of the distal source region, as indicated by varied and high percentage of rock fragments and feldspars.

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

This work embodies the sedimentological studies of the Palaeozoic rocks of Anantnag district of Kashmir, covering an area of about 700 sq.kms.

In the present work, a lithostratigraphic classification involving facies principle has been proposed. The Palaeozoic sequence has been divided into three main groups. These groups are further subdivided into number of formations. Each group represents a distinct consanguineous association, having similar type of basin geometry and depositional environments. The area of study forms a broad synclinorium, in which a famous Liddar valley anti cline and Margan syncline with number of longitudinal and trans verse faults are enclosed.

The shale-slate greywacke group, forms the basement rocks of the Palaeozoic sequence. As there are ample evidences of turbidites features, such as sole markings, graded bedding, truncated Bouma cycle alongwith greyawacke type of sandstones, therefore, these represent flyschoid type of rocks. On the basis of lithology and petrographic studies, two distinct units viz., Gauran and Hapatnar formations have been recognized within this group.

The Gauran formation is characterized by wackstones, intermixed with clay and phyllites. It is further subdivided into two facies, the lower and the upper. In both these facies greywacke type of sandstones are found and both have turbidite features present in them. The upper facies, however, have thicker bands of sandstones and the associated rocks show higher degree of metamorphism as

compared to the lower one. The sandstone beds in both the facies have sharp basis, but unlike the lower facies, the amalgamation of successive beds is very common in the upper one.

The Hapatnar facies is more argillaceous than Gauran facies, being composed of muddy siltstones, mudstones, slates, and phyllites; but the upper part have thick beds of sandstones. The Hapatnar sandstones are compositionally and texturally, more mature than Gauran sandstones in having less amount of matrix. The Hapatnar formation differs from Gauran formation, in having graptolites fauna present in them at places. This formation is also divisible into two facies, viz., lower and upper. The lower facies of this formation, also have some turbidity features indicating similar conditions to that of Gauran , while the upper facies do not show any turbidite features; although it is assumed to have been deposited in fairly deep water to produce current dominating structures, but not as deep where turbidity currents could operate.

All these evidences point out, that the Gauran formation was deposited from a series of migrating fans, while the Hapatnar formation is believed to have formed on the slope along the submarine fans.

Overlying the shale-slate greywacke group is orthoquartzite - carbonate group, which is composed of both clastic and nonclastic rocks.

In the clastic rocks, three types of quartzo-sandstones representing three rock units, viz., muth quartzite (Gunderman formation), Passage beds (Sinder nar Gali formation) and

Syringothyris limestone (Aishmuqam formation) have been studied in detail. There is much similarity in sandstones of all these formations, with respect to their grain size and heavy minerals.

In composition and texture, however, a difference was noted, as all these sandstones have somewhat lower values of standard deviation (mostly ranging between 0.4 to 0.8 ϕ with one or two exceptions), and majority of them have mesocurtic nature. But with respect to skewness, distinction can be made as there is a tendency of positive values of skewness in the associated sandstones of Syringothyris limestone and negative skewness in Muth Quartzites. Moreover, a distinct bimodality of grain size has been noticed in Muth quartzites in which bigger grains are set in finer grains like plums in pudding, ofcourse, both sizes have best sorting among themselves which is interpreted due to aeolian action. This bimodality is not noticed in any other sandstones of rest of the units. Among the sandstones, Muth quartzites are pure quartz-arenite type, while the passage beds and the Associated sandstones are mostly lithic and sub-lithic arenite types respectively. The heavy minerals, found in these sandstones have very less in amount (0.211 %) and consists of only a few stable species like zircon, tourmaline and rutile. From the nature of these mineral species a reworked source has been suggested.

These fatures point out that Orthoquartzitic sandstones of Muth quartzites were deposited in the Beach zone of barrier island environment within the ocean on the crest of which sand

dunes are formed. The sandstones of the other formations, however, represent open marine conditions.

The nonclastic rocks are found in Syringothyris Limestone, Aishmuqam formation) associated with sandstones and shales. These carbonates;also are very much dolomitized in the upper part. The lower part of the limestone is essentially of Allochthonous type,having number of petrographic types, consisting of both sparites and micrites, depending upon the type of allochems/cement present. The upper member has undergone distinct dolomitization ranging from incipient to complete alteration,obliterating the original structures with the development of new microstructures and petrographic types. The results have been confirmed by chemical analysis, D.T.A., insoluble residue studies , staining tests and thin section petrography. The dolomitization appears to have taken place in shallow water to supratidal environments, by some sort of reflux mechanism. On the basis of these textural, structural and compositional features, three broad facies of the carbonate rocks, viz, tidal flat facies, shallow subtidal facies, and deep subtidal facies representing onshore to open marine environment have been recognized.

The volcanic clastic group conformably overlies the orthoquartzite-carbonate group, and represents both Fenestella shales and Agglomeratic slates. This group has been subdivided into two formations, Yenner formation and Batkot formation. In this group a transitional relationship between the two formations

has been observed, as there is a gradual progression of tuffaceous material, from finest vitric type to lithic type. The Agglomeratic slates are mainly welded tuffs, which have been mostly altered; devitrified and metamorphosed. In this formation, three types viz., vitric, crystal and lithic type has been found, but the majority of them belong to intermediate type. The vitric type at the base and the lithic to conglomeratic at the top. In this work, it has also been observed that a part of Fenestella shales is composed of fine vitric type of tuff, except in the lower part which is mostly quartzitic in nature. The results of grain size and morphometric studies of the material, constituting these rocks are comparable to tuffaceous material of the other regions of the world.

Pyroclastic origin of these slates, is thus clearly established. But regarding the mode of sedimentation, various depositional models like Glaciomarine model, submarine slump and turbidity model and mud flow models have been considered. It was found that in the deposition of Agglomeratic slates, partly glaciomarine model and partly mud flow is applicable.

In the concluding part of the work, a synthesis of the relevant data of all the formations have been attempted to bring out the depositional model for the Palaeozoic deposition in Anantnag district, which include basin geometry, source area and depoisitional pattern etc.

From all the available evidences it appears that basin of deposition was elongated one, having NW-SE trend, which was more

or less of embayment type and open towards the ocean in the north. It was more of a epicratonic rather than intracratonic one; in which sedimentation spanned a range of environments, ranging from deep water turbidite to linear shore line environment including tidal flat. In the intial stages the basin axis and depo-centre coincided, but with the pessage of time the depo-centre shifted across the basin.

During the deposition of shale slate greywacke group, the basin was fairly narrow and deep one, having bathyal to abyssal depths formed by major structural depression in which submarine fans of turbidites were formed, depositing Gauran formation. The Hapatnar formation, however, was deposited on the slope above the submarine fans. The Palaeocurrent pattern, indicate some tectonically active source area along northwest margins of the basin.

During the Orthoquartzite- Carbonate group, which represents plateform stable shelf deposits. The sedimentation took place in eperic type of sea, in which due to fluctuations of sea level different types of deposits in on-shore to off-shore positions ranging from tidal flat facies to deep subtidal facies were deposited. To explain these fatures, barrier island and shelf sea models have been proposed. During this period, direction, of infilling was both parallel and transverse to the structural axis of the basin as a indicated by the Paleocurrent directions. The material was principally supplied from NW direction but

southern side also contributed some material towards north. The source area had low relief, than the rate of transportation which was extremely slow.

The volcanic clastic group which include both Fenestella shale and Agglomeratic slates represents pyroclastic deposits, which were carried out to the basin of deposition partly by mud flow and partly by glacio-marine mechanism.

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ILLUSTRATIONOF PLATES

(1 - 52)

P L A T E -1

Location and route map of the area.

LOCATION AND ROUTE MAP OF THE AREA

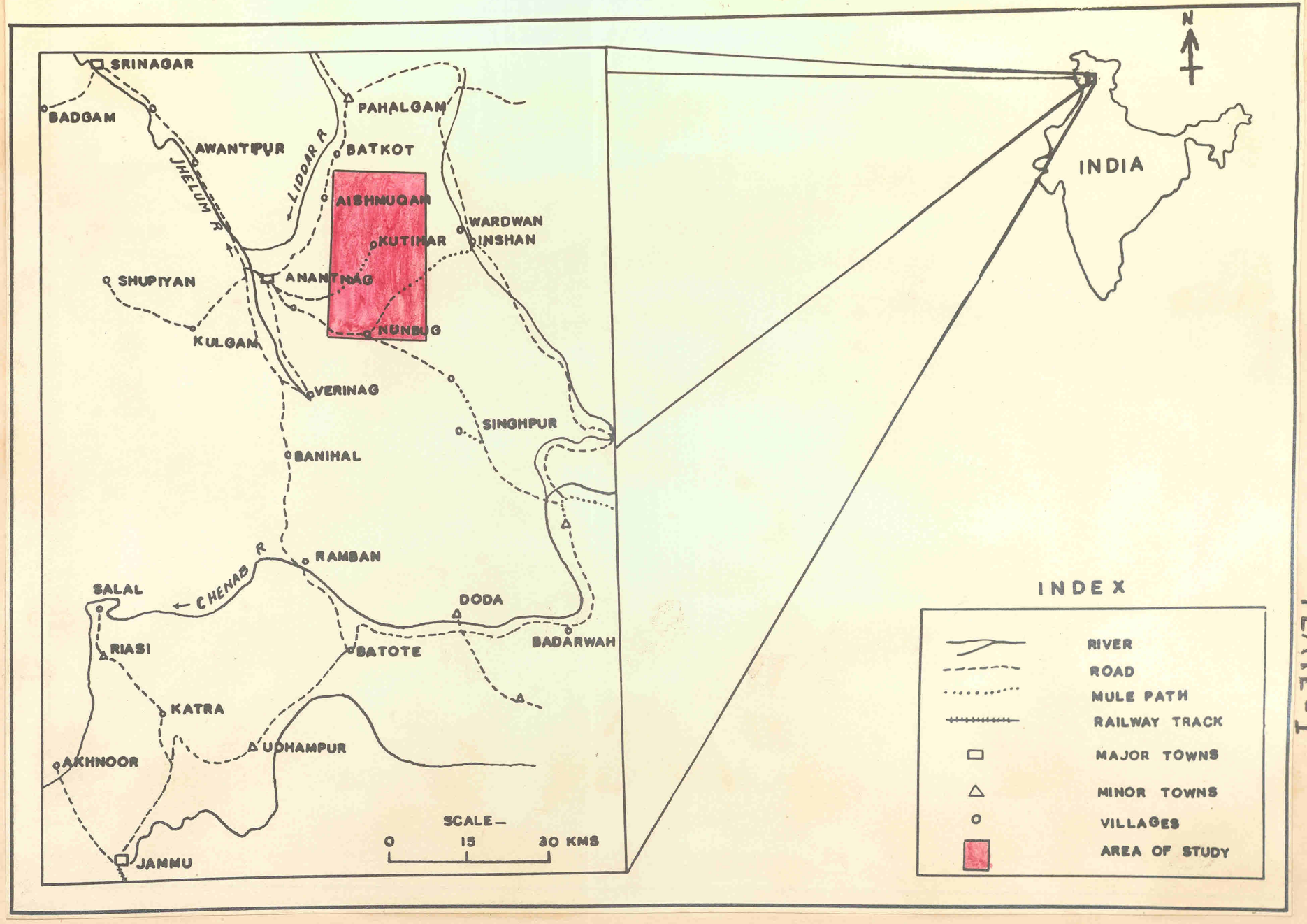
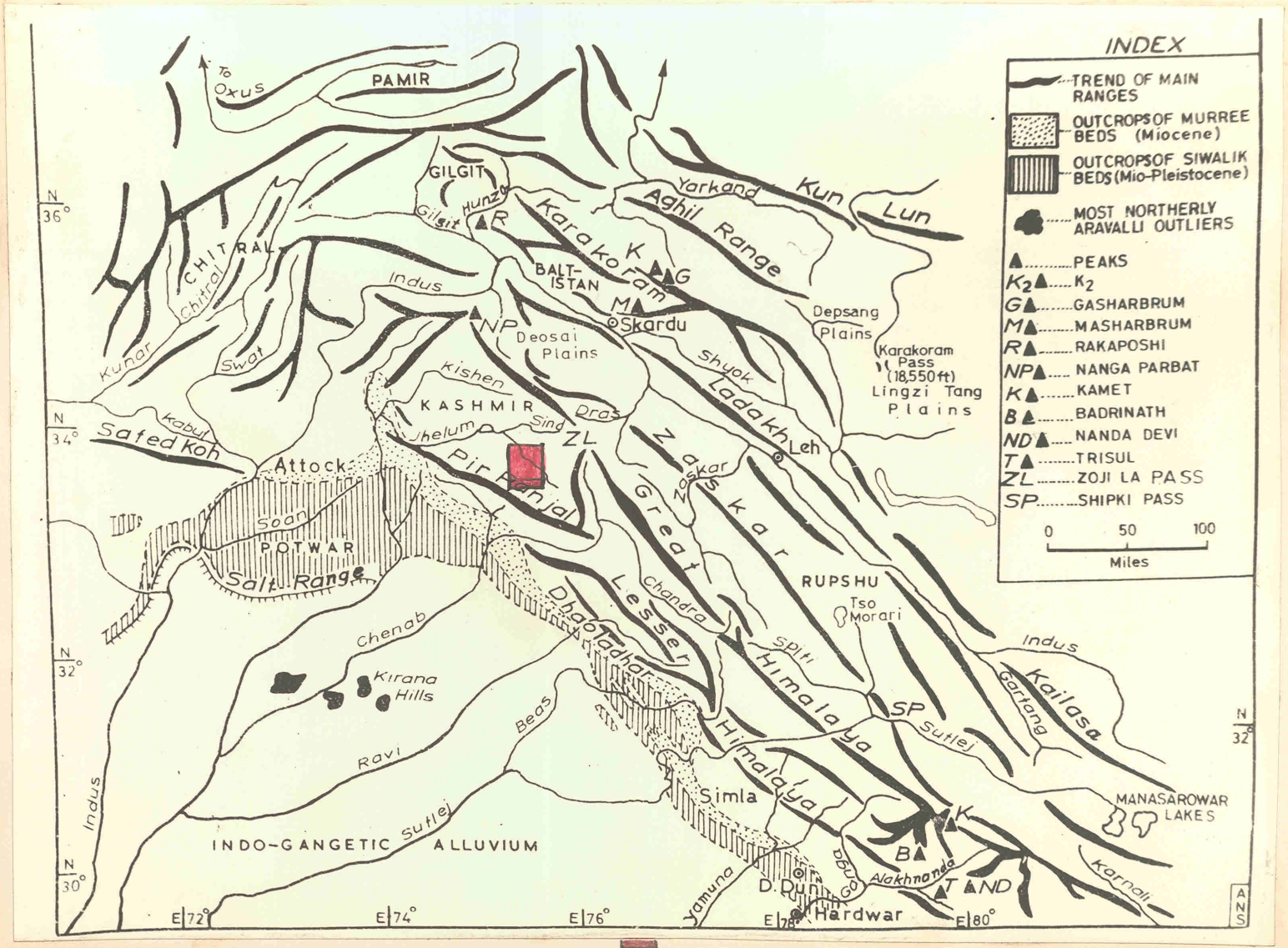


PLATE - 1

PLATE - 2

Trends of the principal mountain ranges
in the north-western Himalayan Complex.



AREA OF STUDY ⟶

PLATE - 2

PLATE - 3

Physiographic map of the area.

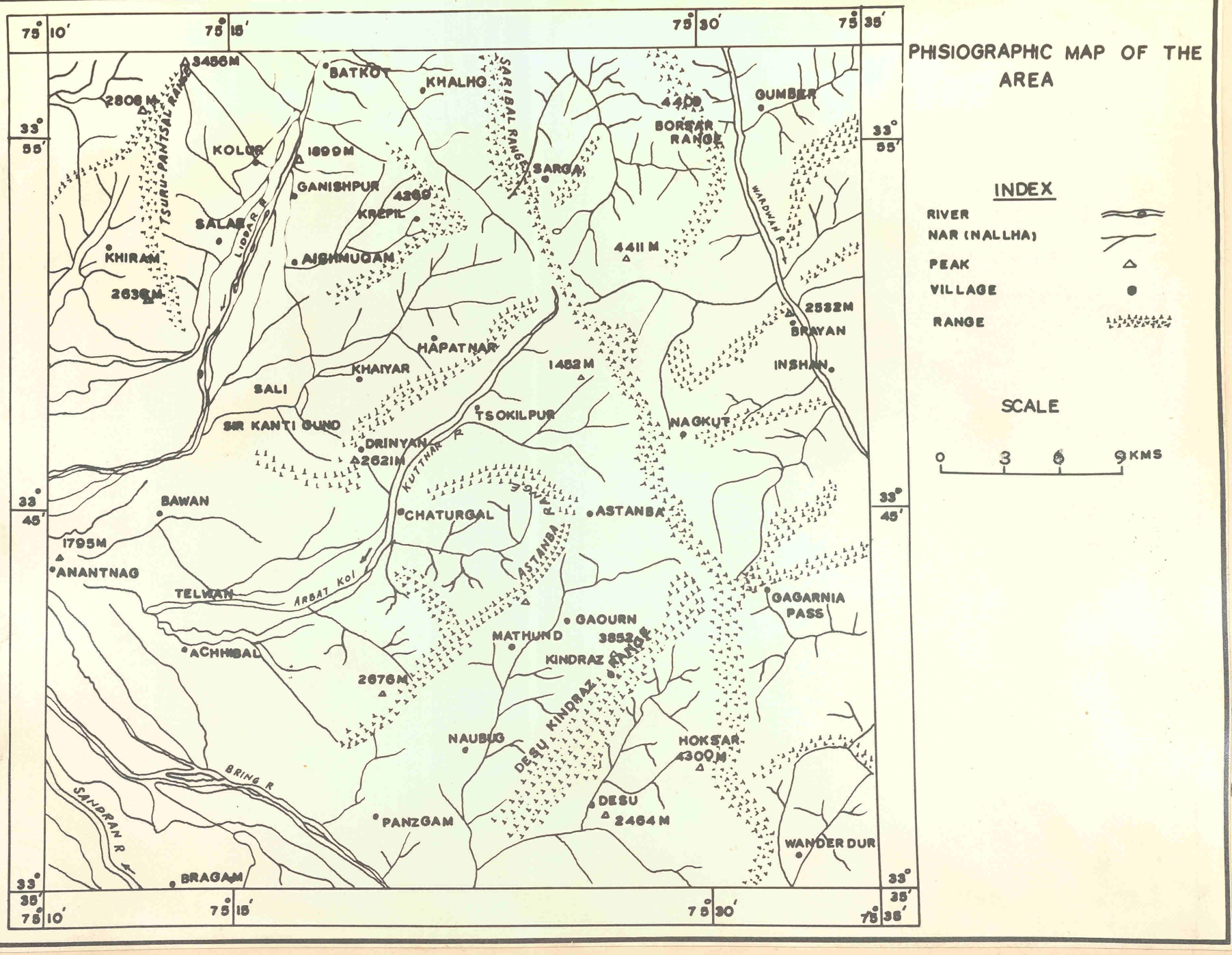

PHISIOGRAPHIC MAP OF THE AREA
INDEX
RIVER
NAR (NALLHA)
PEAK
VILLAGE
RANGE
SCALE
0 3 6 9 KMS
75° 10'
75° 15'
75° 30'
75° 35'
33° 55'
33° 45'
33° 35'
3456M
BATKOT
KHALHG
2808 M
TSURU-PANTSAL RANGE
SARIBAL RANGE
4400
BORTAR RANGE
GUMBER
KOLOR
1899M
GANISHPUR
SARGA
4200
KREPIL
SALAR
LIDDAR R
WARDWAN R
KHIRAM
2639M
AISHMUGAM
4411M
2532M
BRAYAN
HAPATNAR
1482M
INSHAN
KHAIYAR
SALI
SIR KANTI GUND
TSOKILPUR
NAGKUT
DRINYAN
2621M
KUTTNAR R
BAWAN
CHATURGAL
ASTANBA
1795M
ANANTNAG
ASTANBA
TELWAN
ARBAT KOL
GAGARNIA PASS
GAOURN
MATHUND
3852
KINDRAZ RANGE
ACHHBAL
2676M
KINDRAZ
NAUBUG
DESU
HOKSAR 4300M
BRING R
SANDRAN R
PANZGAM
DESU
2464 M
WANDERDUR
BRAGAM

PLATE - 3

P L A T E - 4

No:

1. Photograph showing isolated Kotsu hill composed chiefly of Syringothyris Limestone. (Camera facing north)

2. Panoramic view of a part of Naubug valley.
   G- Gauran formation
   GD-Part of Gurderman formation,
   R -Margan Pass.
   (Camera facing North)

PLATE - 4

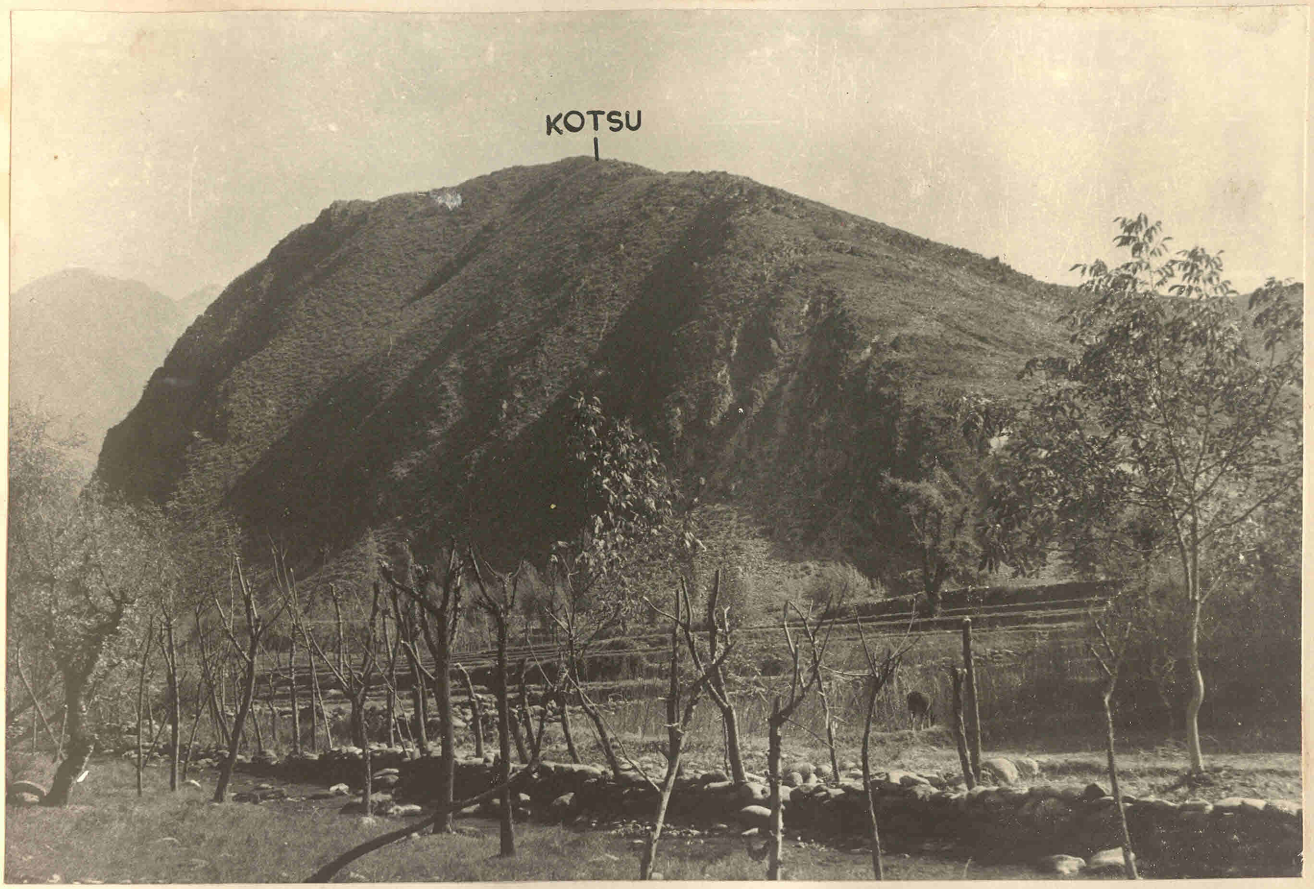


FIG-1

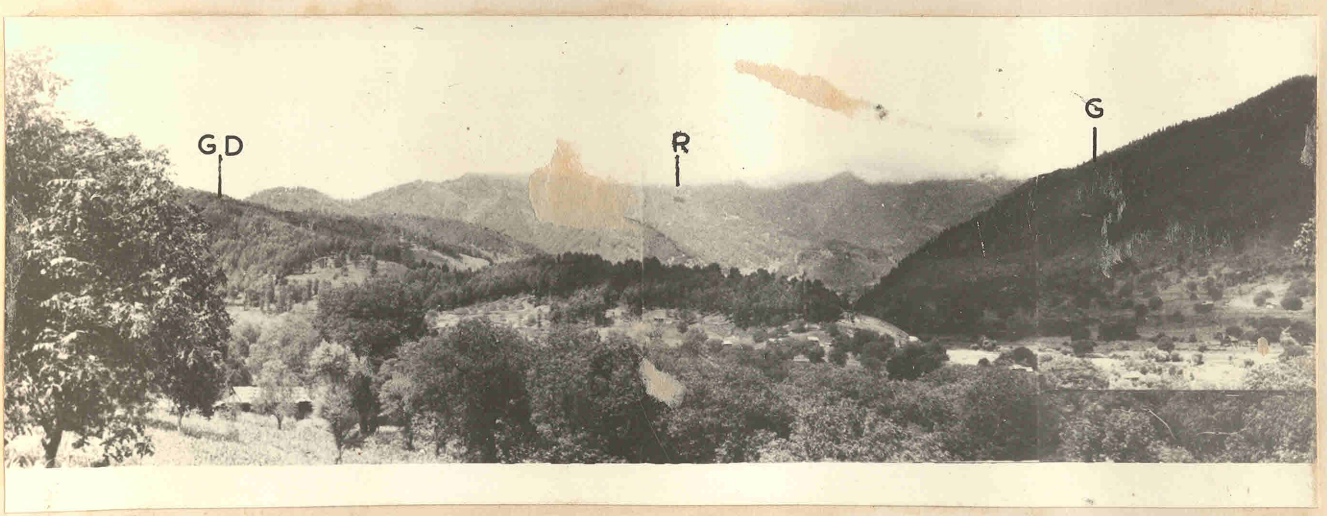


FIG-2

PLATE - 5

No:

1. Panoramic view of the Aishmuqam area showing Aishmuqam formation(Syringothyris Limestone and associated quartzites.
(Camera facing north)
2. Panoramic view of Gurderman area (Naubug valley) The formation is Muth Quartzite.
(Camera facing North).

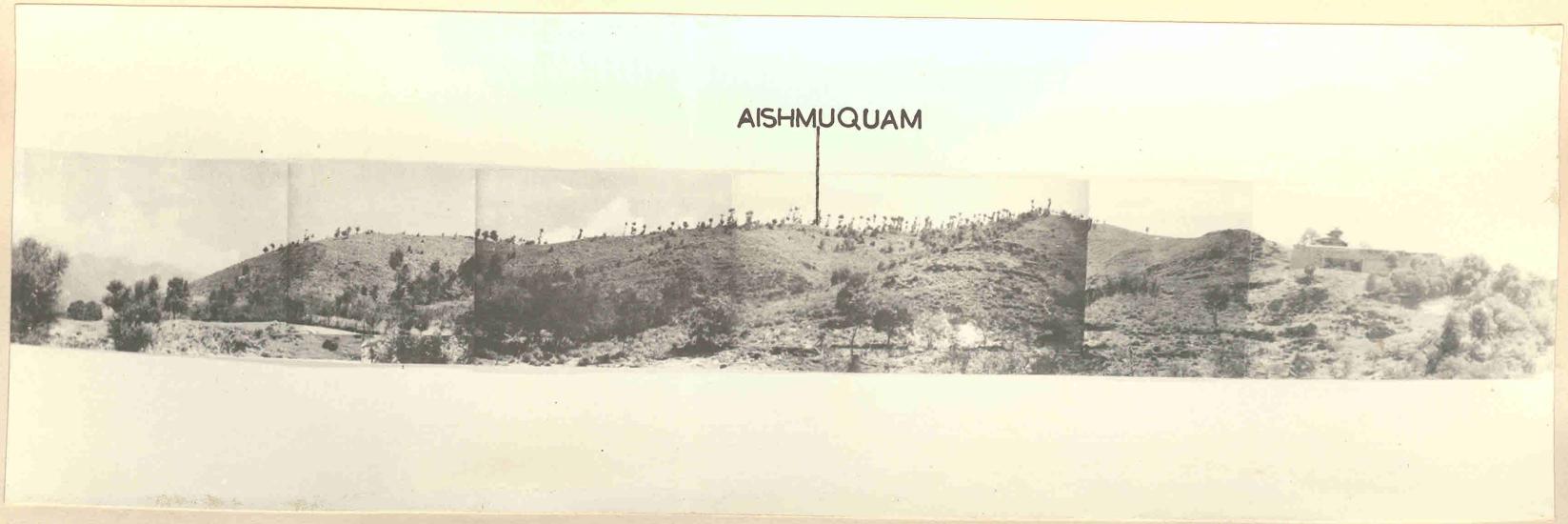


FIG-1

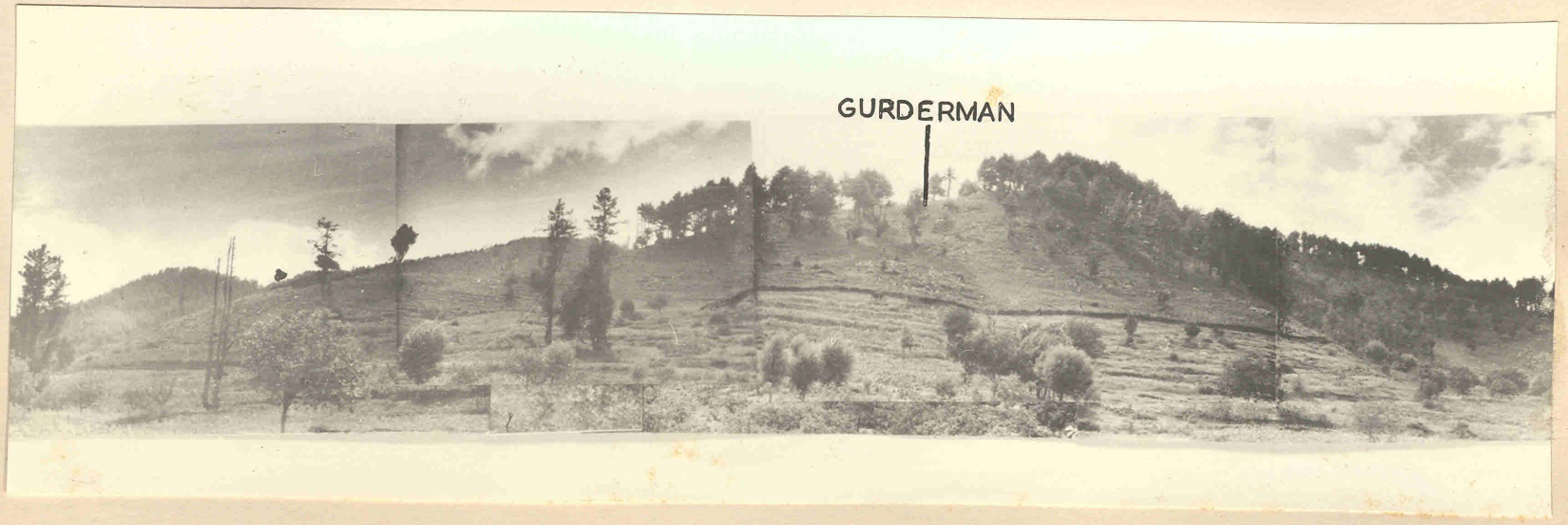


FIG-2

PLATE - 5

PLATE - 6

No:

1. A view of Gurderman area(Muth quartzite) showing the contact with the phyllites towards right of the photograph.
(Camera facing northwest.)

2. A panoramic view from the left bank of river Bring, showing valley in the centre at Ren with dense vegetation.
(Camera facing northeast.)

FIG-1

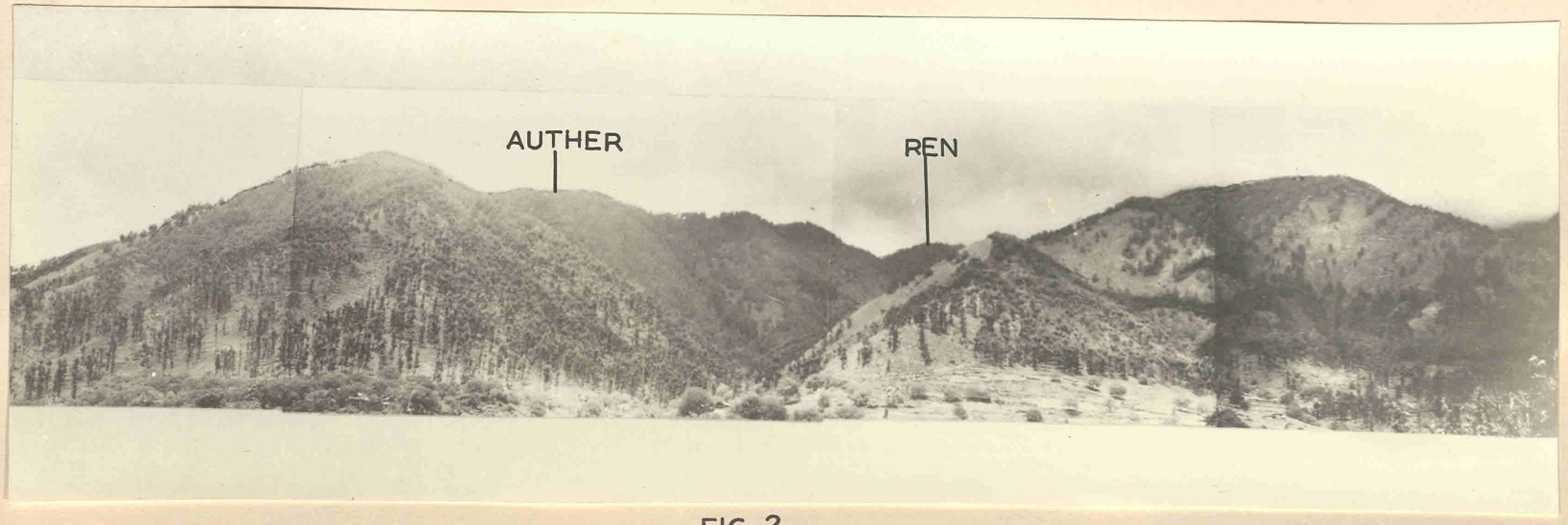


FIG-2

PLATE - 6

PLATE-7

Fig.1 showing isoclinal folding in the Syringothyris limestone near Ichnar.

Fig.2. Showing well developed cross bedding in Muth quartzites at Tangwani (Naubug).

Fig.3 Steeply inclined beds of Associated quartzites with Syringothyris Limestone showing columnar jointing at Kotsu.

Fig.4. Well developed cross jointing in quartzite sheet at Kotsu.

Fig.5.showing laminations at the bottom and inclined jointing in Fenestella shales near Yenner.

Fig.6. A typical photograph of asymmetrical ripple marks in Muth Quartzite at Gurderman.

PLATE - 7

FIG : 1

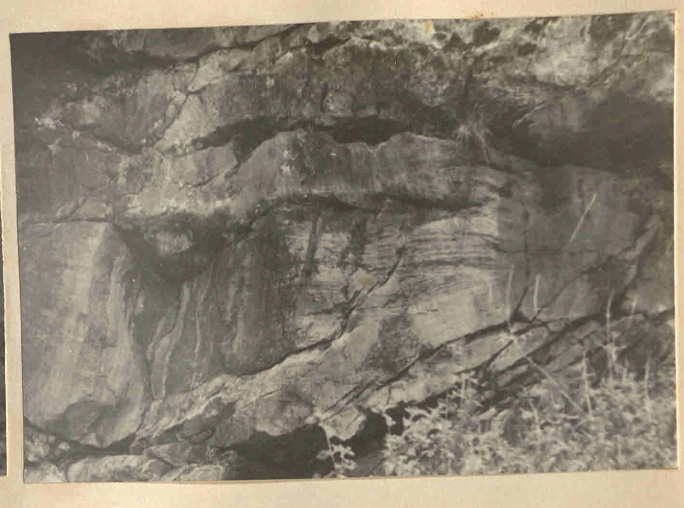


FIG : 2

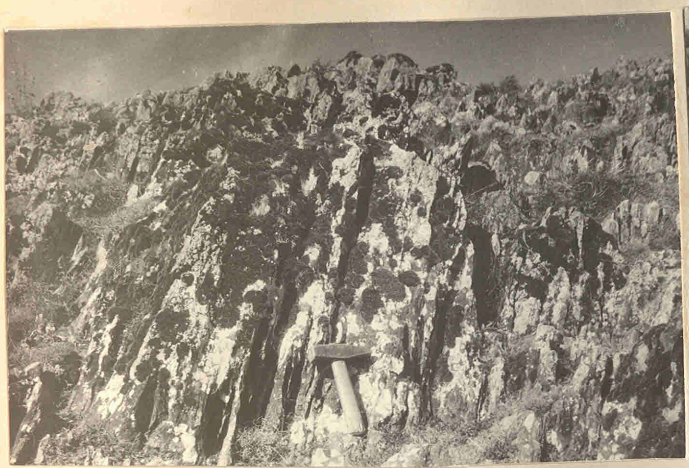


FIG : 3

FIG : 4

FIG : 5

FIG : 6

P L A T E-8

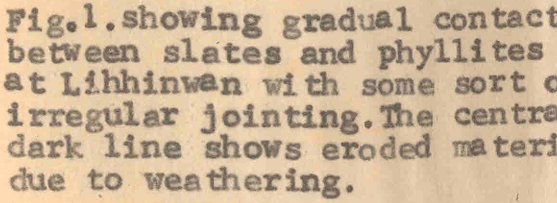


Fig.1. showing gradual contact between slates and phyllites at Lihhinwan with some sort of irregular jointing. The central dark line shows eroded material due to weathering.

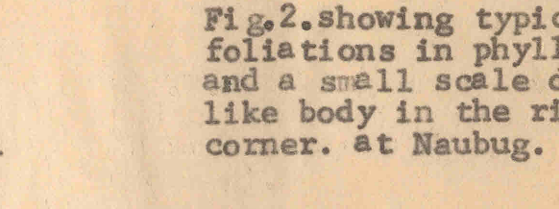


Fig.2. showing typical foliations in phyllites and a small scale dyke-like body in the right corner. at Naubug.

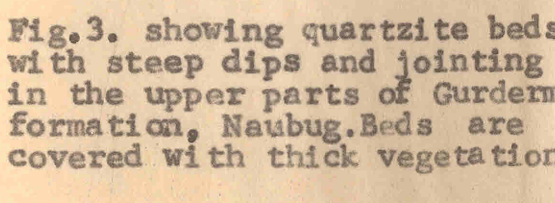


Fig.3. showing quartzite beds with steep dips and jointing in the upper parts of Gurderman formation, Naubug. Beds are covered with thick vegetation.

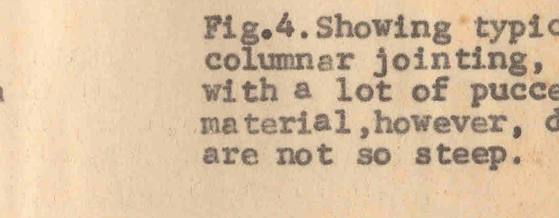


Fig.4. Showing typical columnar jointing, with a lot of puccered material, however, dips are not so steep.

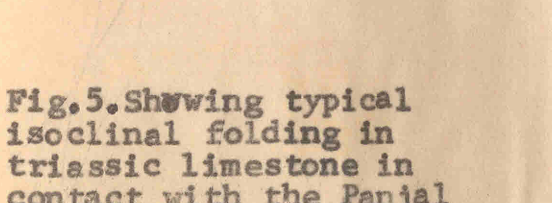


Fig.5. Showing typical isoclinal folding in triassic limestone in contact with the Panjal Traps. at Shatru (Naubug).

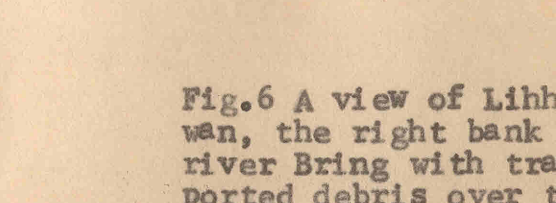


Fig.6 A view of Lihhinwan, the right bank of river Bring with transported debris over the banks. Meandering of the river Bring is clearly visible.

PLATE - 8

FIG : 1

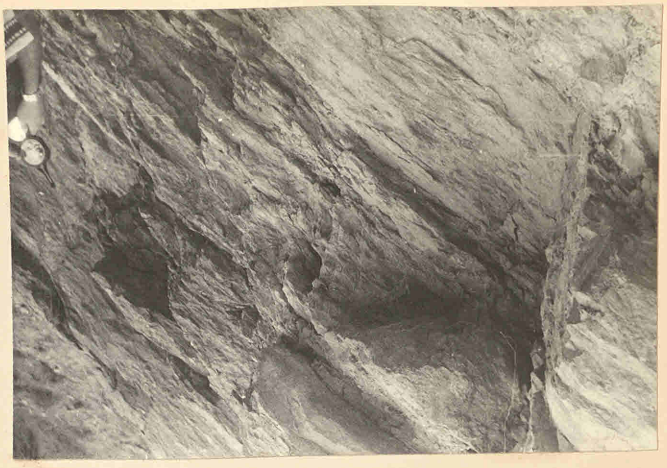


FIG : 2

FIG : 3

FIG : 4

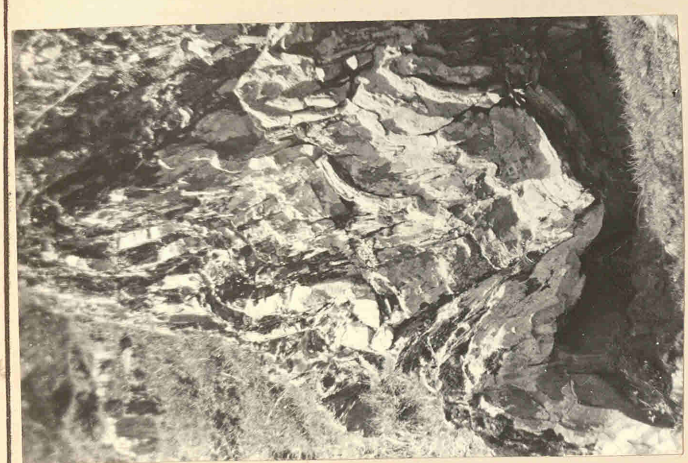


FIG : 5

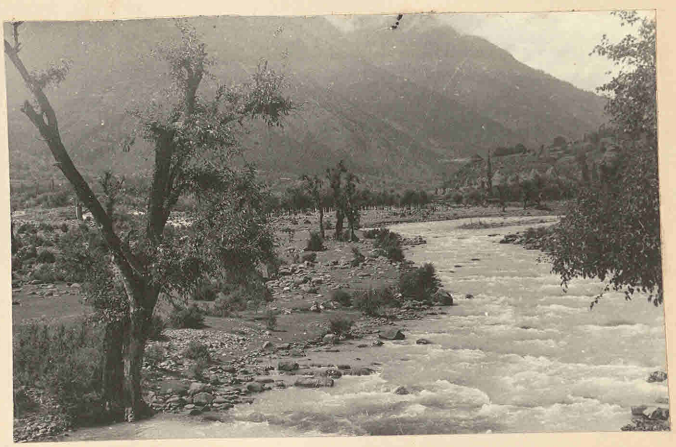


FIG : 6

PLATE - 9

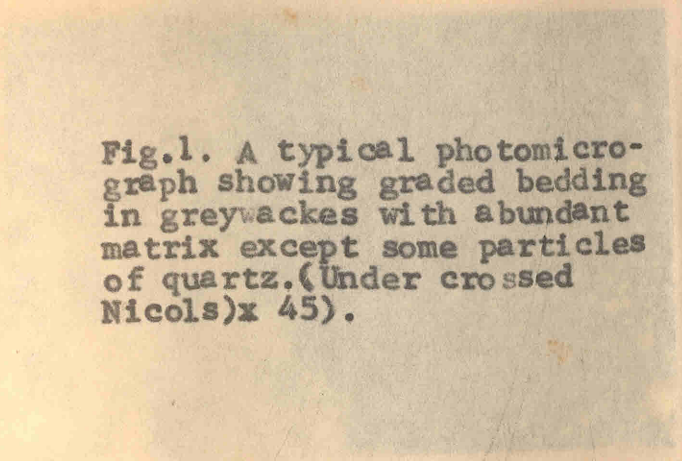


Fig.1. A typical photomicrograph showing graded bedding in greywackes with abundant matrix except some particles of quartz.(Under crossed Nicols)x 45).

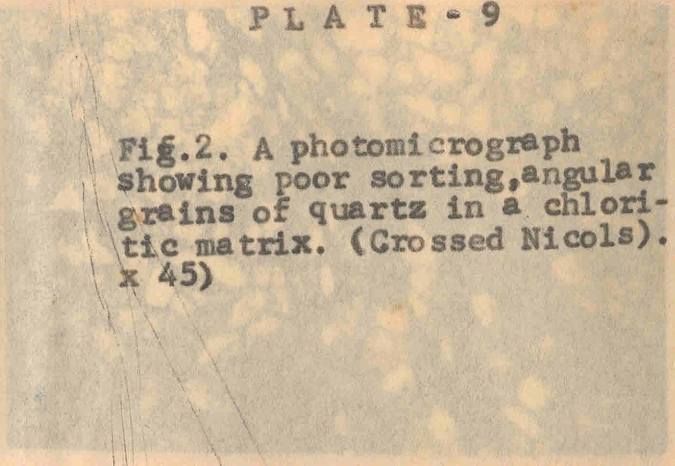


Fig.2. A photomicrograph showing poor sorting,angular grains of quartz in a chloritic matrix. (Crossed Nicols). x 45)

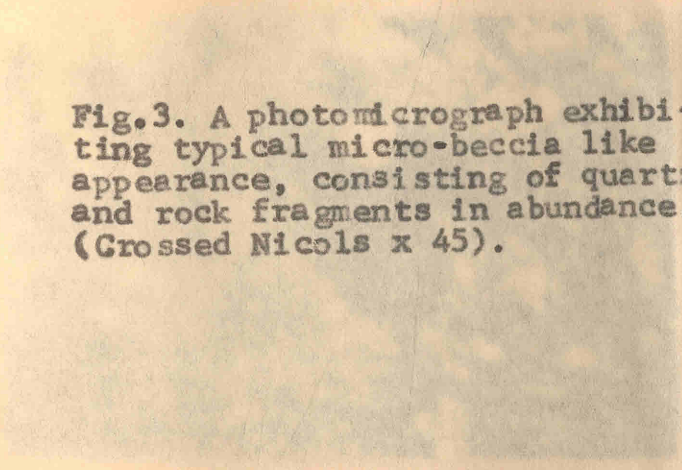


Fig.3. A photomicrograph exhibiting typical micro-beccia like appearance, consisting of quartz, and rock fragments in abundance. (Crossed Nicols x 45).

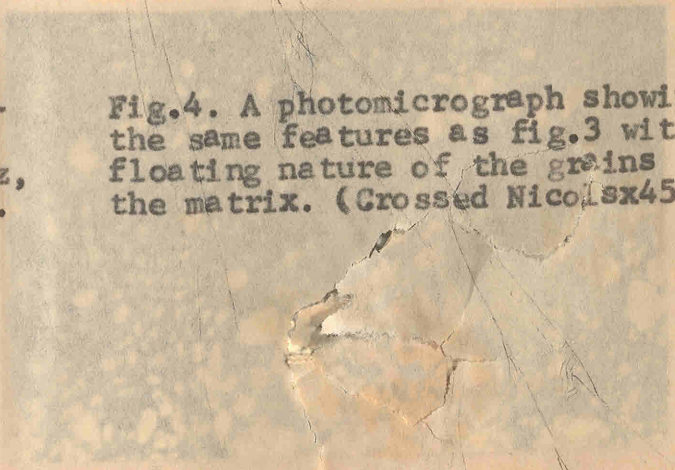


Fig.4. A photomicrograph showing the same features as fig.3 with floating nature of the grains in the matrix. (Crossed Nicolsx45).

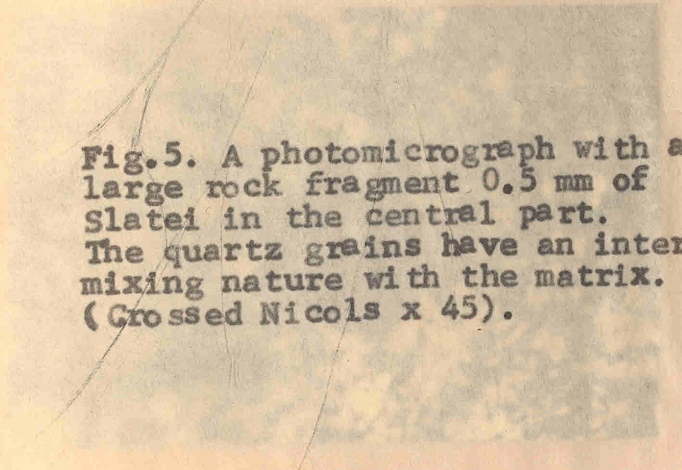


Fig.5. A photomicrograph with a large rock fragment 0.5 mm of Slatei in the central part. The quartz grains have an intermixing nature with the matrix. (Crossed Nicols x 45).

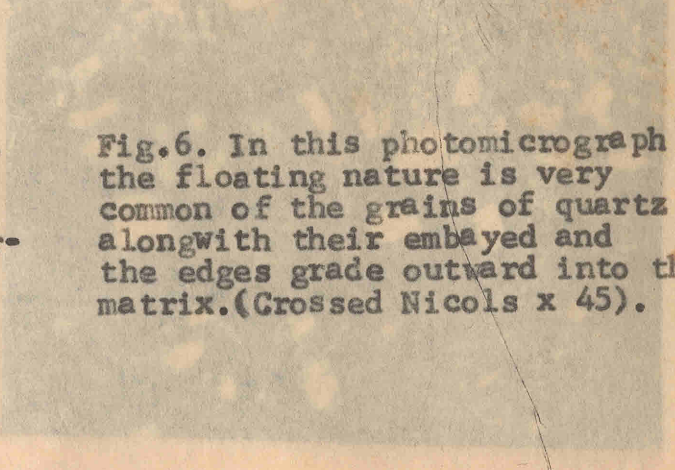


Fig.6. In this photomicrograph the floating nature is very common of the grains of quartz alongwith their embayed and the edges grade outward into the matrix.(Crossed Nicols x 45).

PLATE - 9

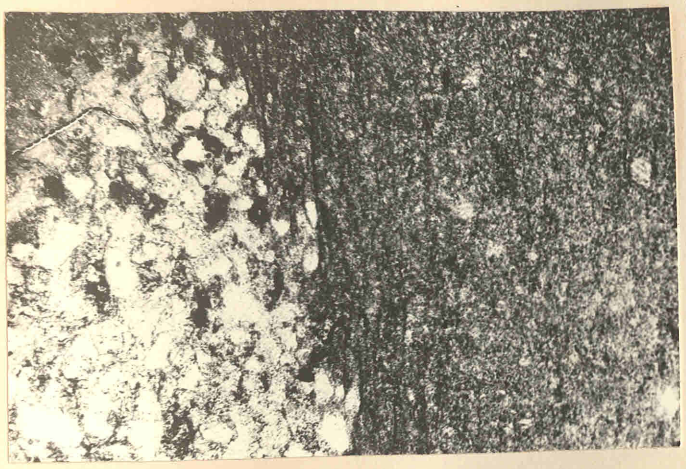


FIG : 1

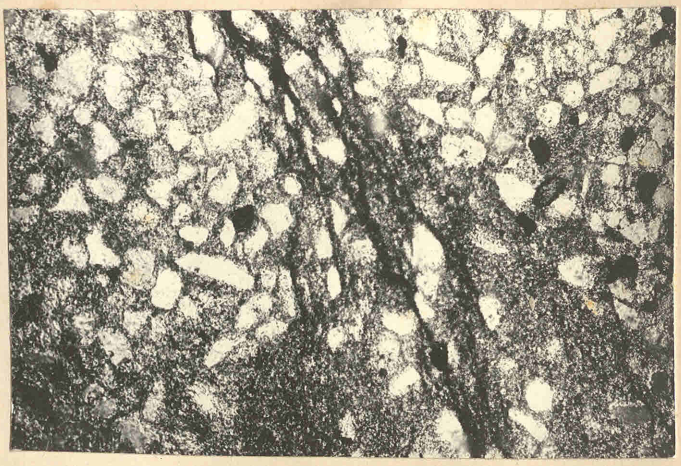


FIG : 2

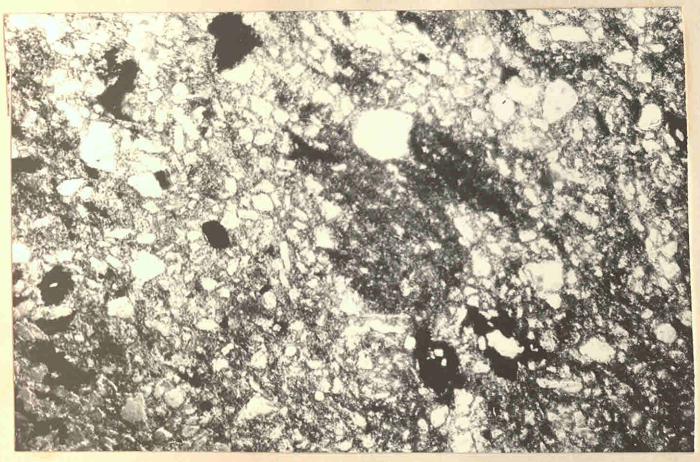


FIG : 3

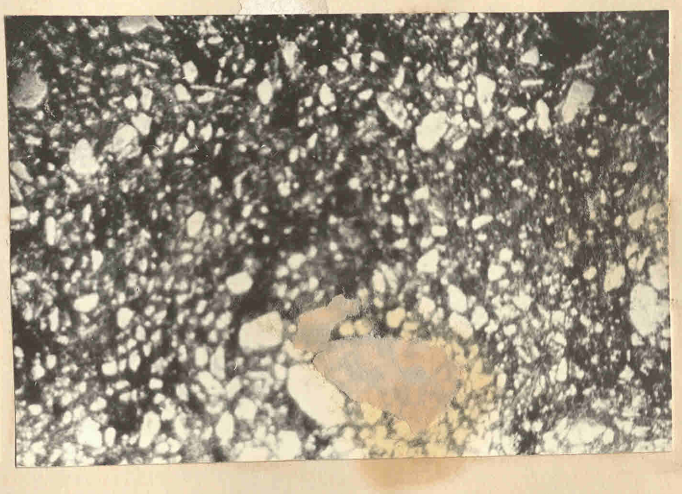


FIG : 4

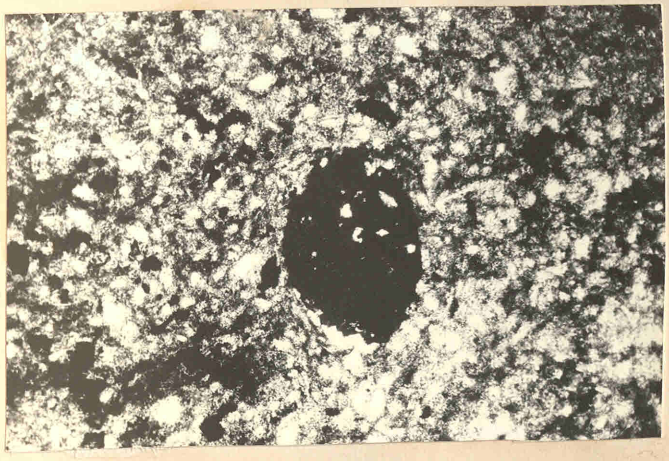


FIG : 5

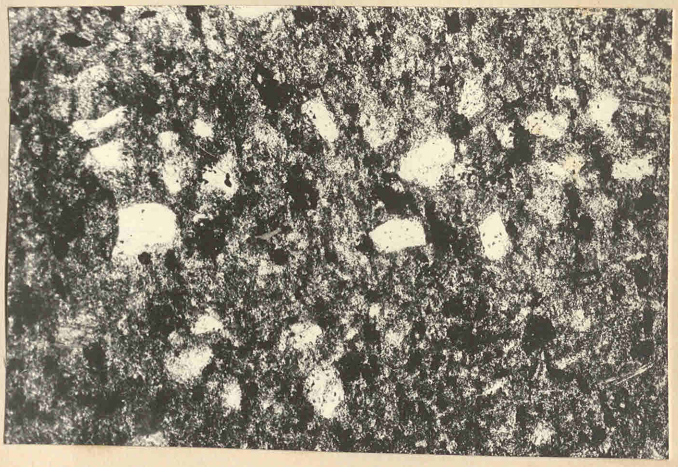


FIG : 6

PLATE-10

An equitriangular diagram showing the plots of quartz, feldspar, rock fragments and matrix of greywackes and sandstones of the Kapatnar formation.

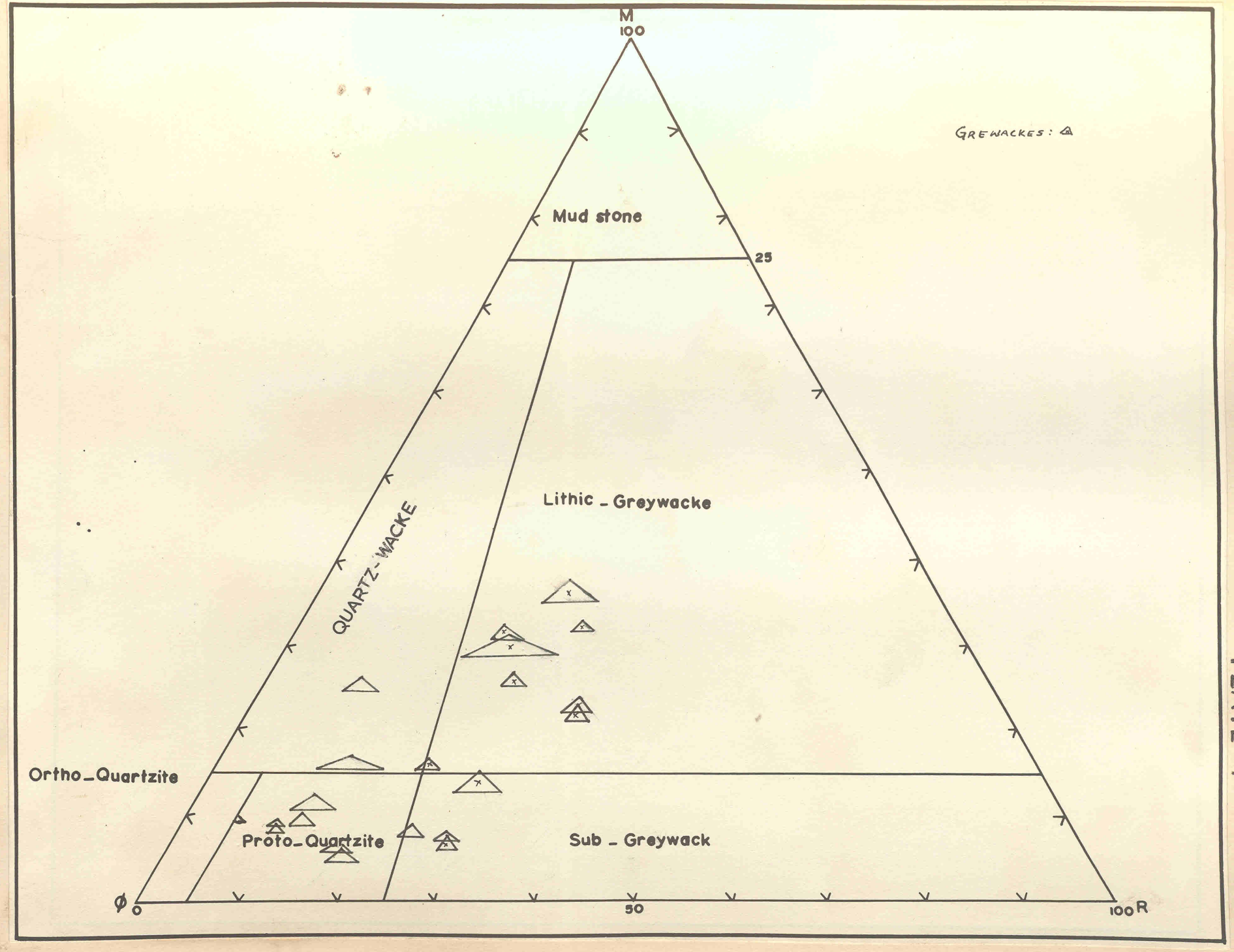

M
100
GREWACKES : ▲
Mud stone
25
QUARTZ-WACKE
Lithic _ Greywacke
Ortho_Quartzite
Proto_Quartzite
Sub _ Greywack
Ø
0
50
100 R

PLATE - 10

PLATE - 11

Cumulative curves showing mechnical composition
of the representative samples of the greywackes(Gauran)
and the sandstones(Hapatnar) formations respectively.

PLATE - 11

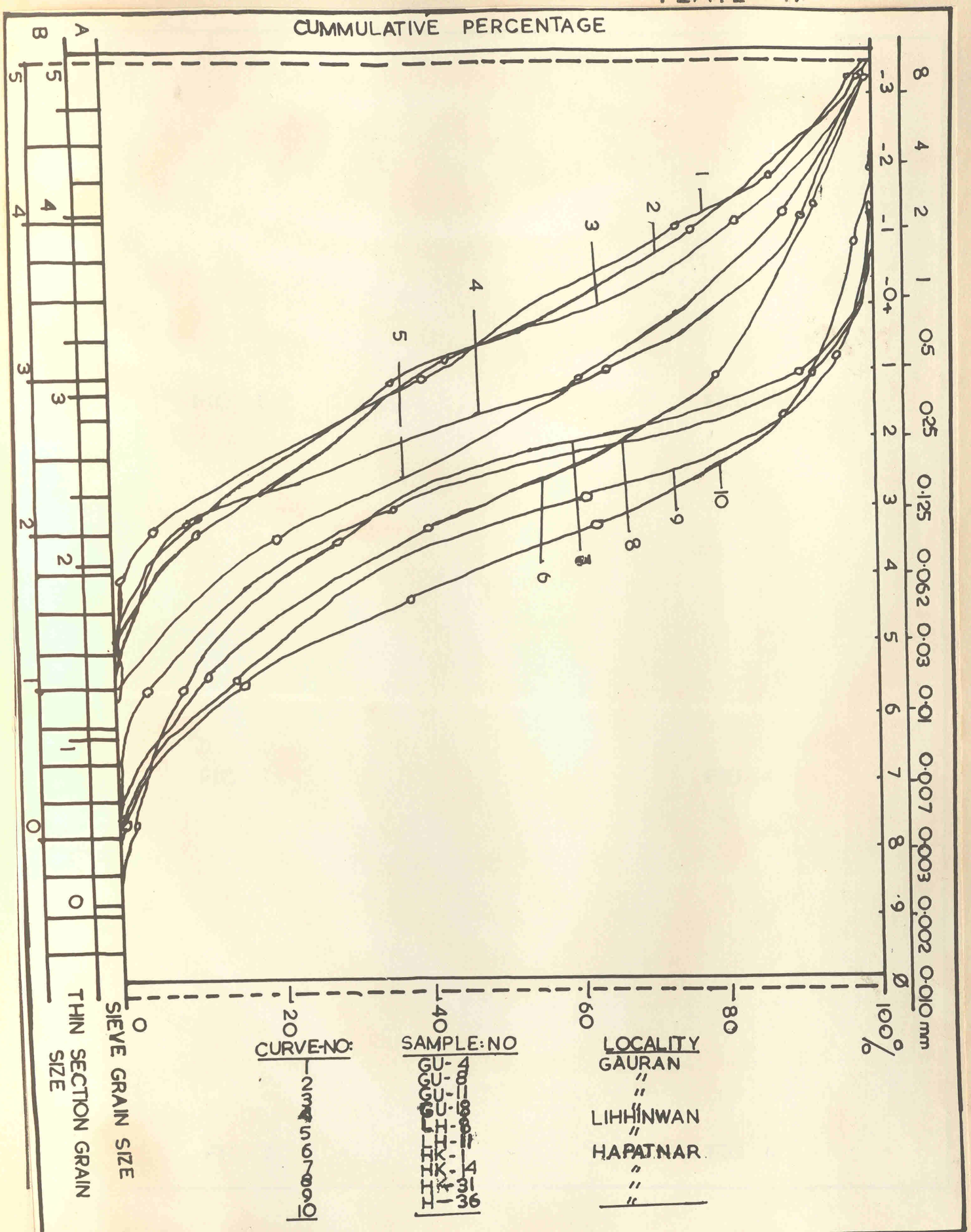

CUMMULATIVE PERCENTAGE
A
B
15
4
3
2
1
0
5
4
3
2
1
0
8 4 2 1 0·5 0·25 0·125 0·062 0·03 0·01 0·007 0·003 0·002 0·010 mm
-3 -2 -1 -0+ 1 2 3 4 5 6 7 8 9 Ø
0 20 40 60 80 100%
SIEVE GRAIN SIZE
THIN SECTION GRAIN SIZE
CURVE-NO:
SAMPLE:NO
LOCALITY
GAURAN
LIHHINWAN
HAPATNAR

PLATE - 12

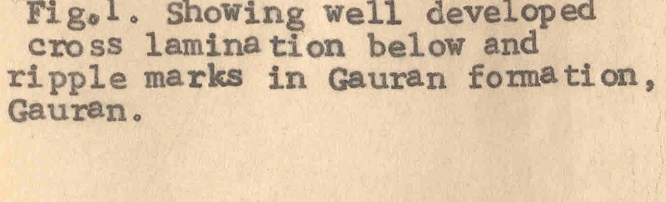


Fig.1. Showing well developed cross lamination below and ripple marks in Gauran formation, Gauran.

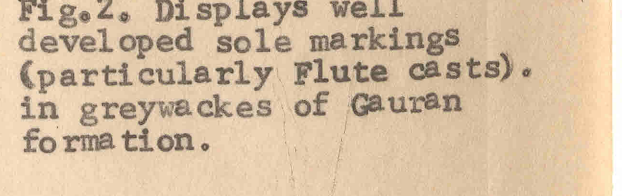


Fig.2. Displays well developed sole markings (particularly Flute casts). in greywackes of Gauran formation.

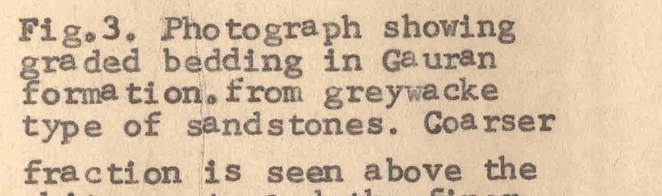


Fig.3. Photograph showing graded bedding in Gauran formation. from greywacke type of sandstones. Coarser fraction is seen above the white spots and the finer fraction below it.

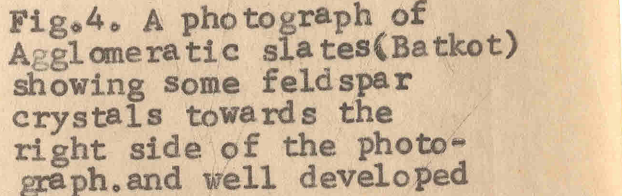


Fig.4. A photograph of Agglomeratic slates(Batkot) showing some feldspar crystals towards the right side of the photo-graph. and well developed slaty cleavage.

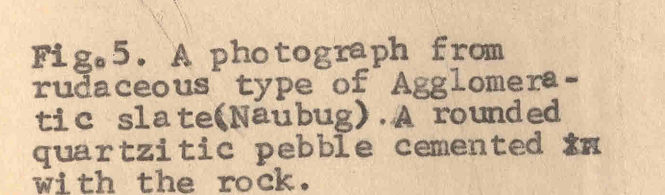


Fig.5. A photograph from rudaceous type of Agglomera-tic slate(Naubug). A rounded quartzitic pebble cemented in with the rock.

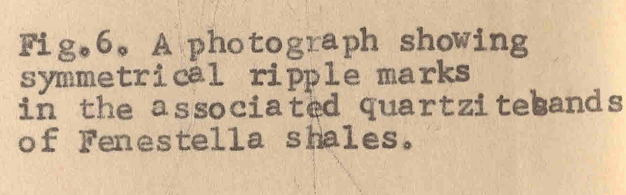


Fig.6. A photograph showing symmetrical ripple marks in the associated quartzite bands of Fenestella shales.

PLATE - 12

FIG : 1

FIG : 2

FIG : 3

FIG : 4

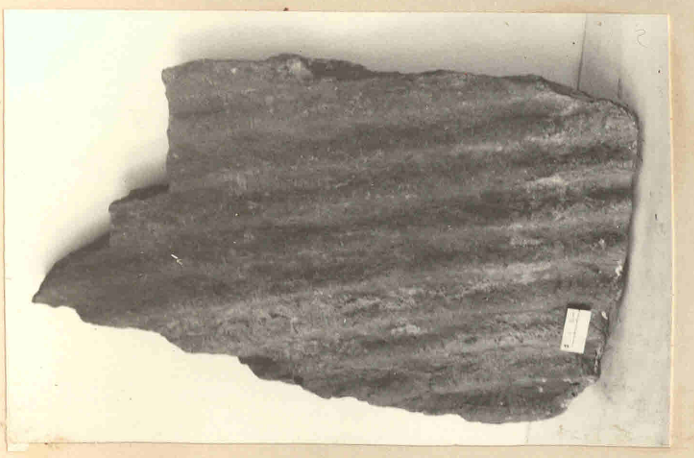


FIG : 5

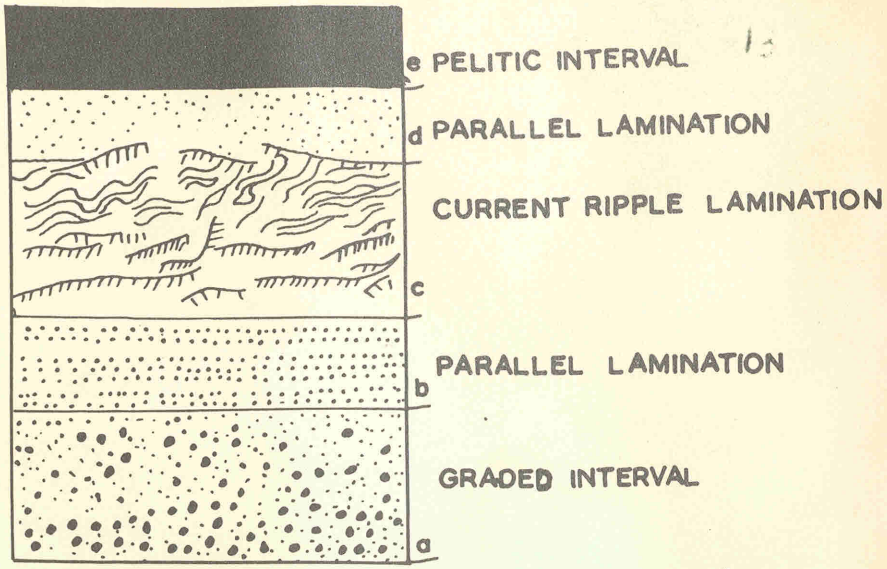
FIG : 6

PALATE 13

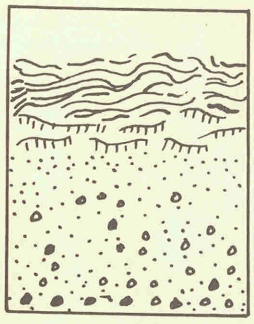
Fig.1 showing
Bouma's sedimentary cycle

Fig. A,B,C and D showing sedimentary cycles found in Gauran formation.

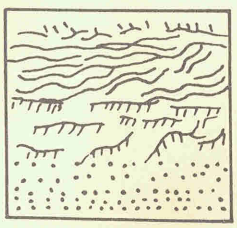
PLATE-13



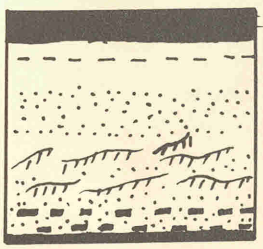
BOUMAS (1962) IDEAL CYCLE



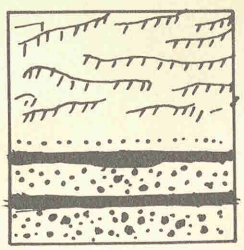
A



B



C



D

CYCLES FOUND IN THE GAURAN AND LIHHIWAN AREA (NAUBAD)
NOT TO THE SCALE

Fig.1.A photomicrograph of slate exhibiting very fine nature,characteristically composed of chloritic matrix, In the central part a micro-sandstone dyke like body is intersecting horizontally. (Crossed Nicols x 45)

Fig.2. A photomicrograph of slate similar to that of Fig.1 except that the quartz has crystallized with parallel fibrous arrangement. (Crossed Nicols x 45).

Fig.3.A photomicrograph of slate, just coarser that the above.A large rock fragment 1 mm size essentially quartzitic in nature clouded with miner inclusions. (Crossed Nicols x 45).

Fig.4.A photomicrograph of siltstone in contact with the slates of Hapatnar formation showing very fine nature of the grains particularly quartz. having size range less than 0.1 mm. (Crossed Nicols x 45).

Fig.5. A photomicrograph of sandstones of Upper Hapatnar formation exhibiting subangular to subrounded grains in a calcic matrix. The grains also exhibit overgrowths and intact framework. Crossed Nicols x 45).

Fig.6. A photomicrograph similar to that of fig.5 with overgrowths and tangential contacts between the grains.(Crossed Nicols x45)

PLATE - 14

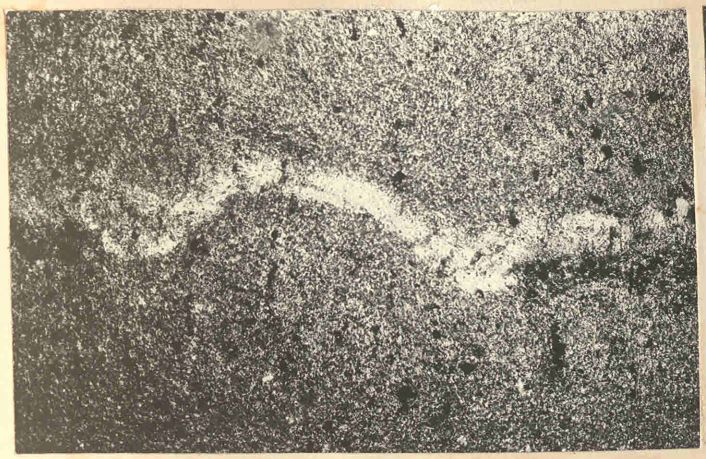


FIG : 1

FIG : 2

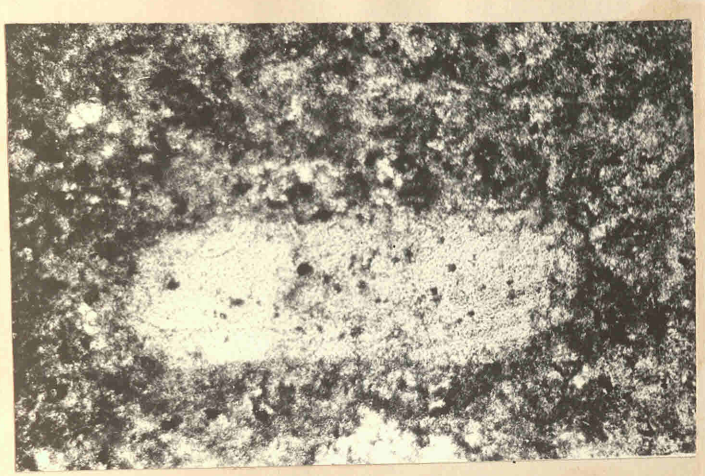


FIG : 3

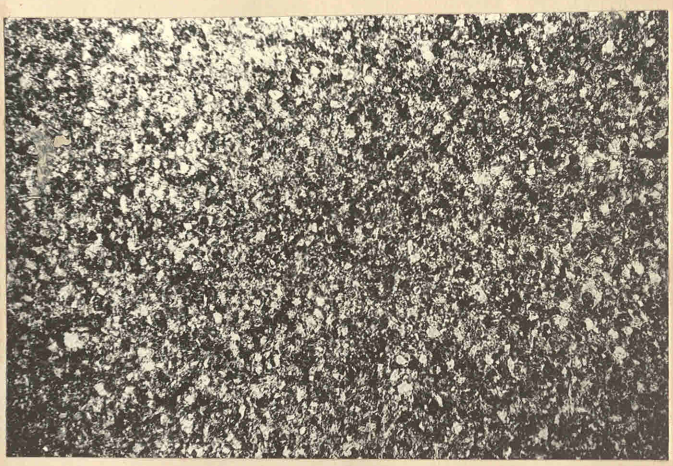


FIG : 4

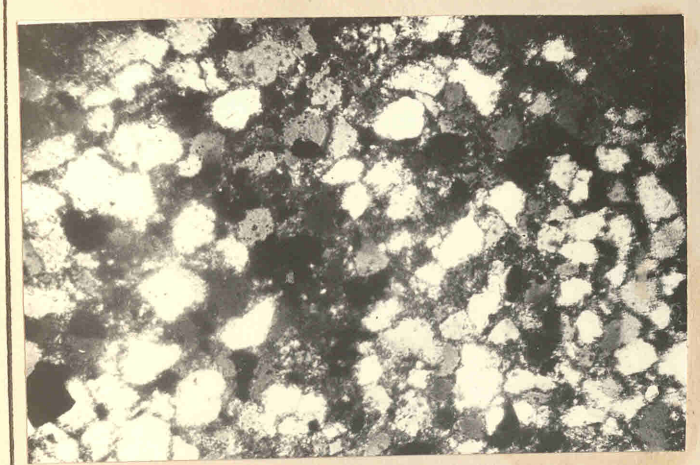


FIG : 5

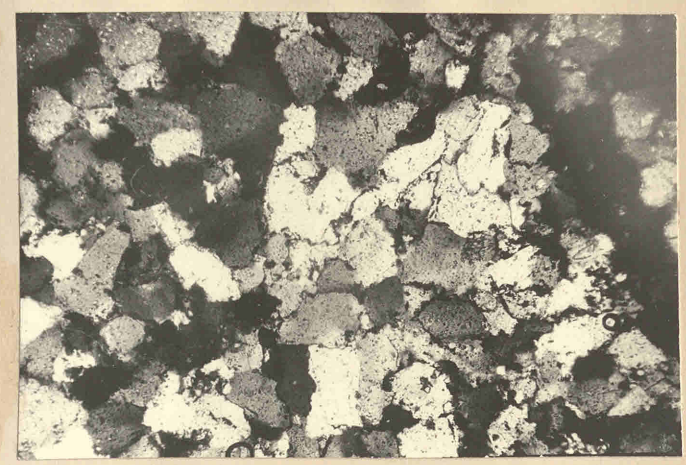
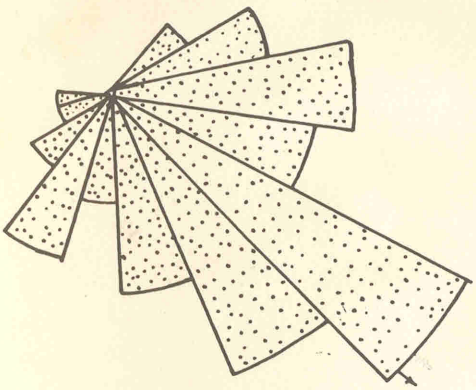


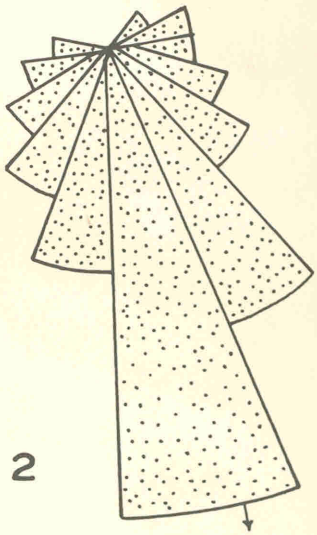
FIG : 6

PLATE-15

Semicircular rose diagrams of oriented thin sections to the long axis of greywackes.



1



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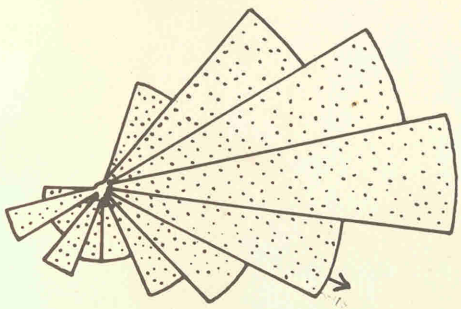

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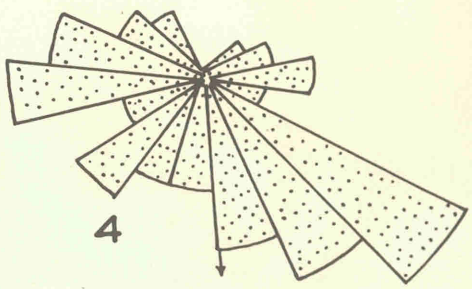

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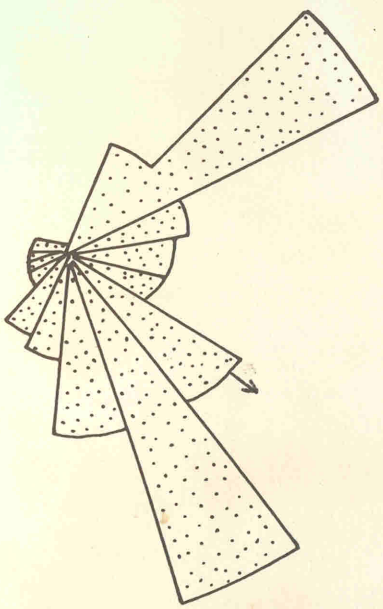

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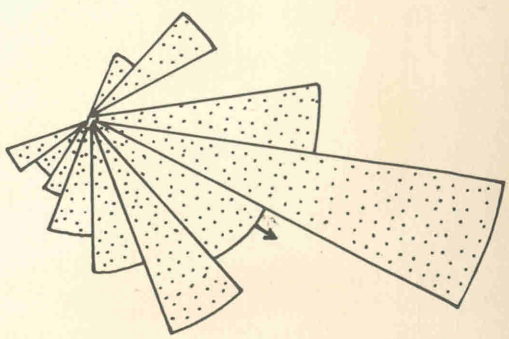


6

PLATE - 16

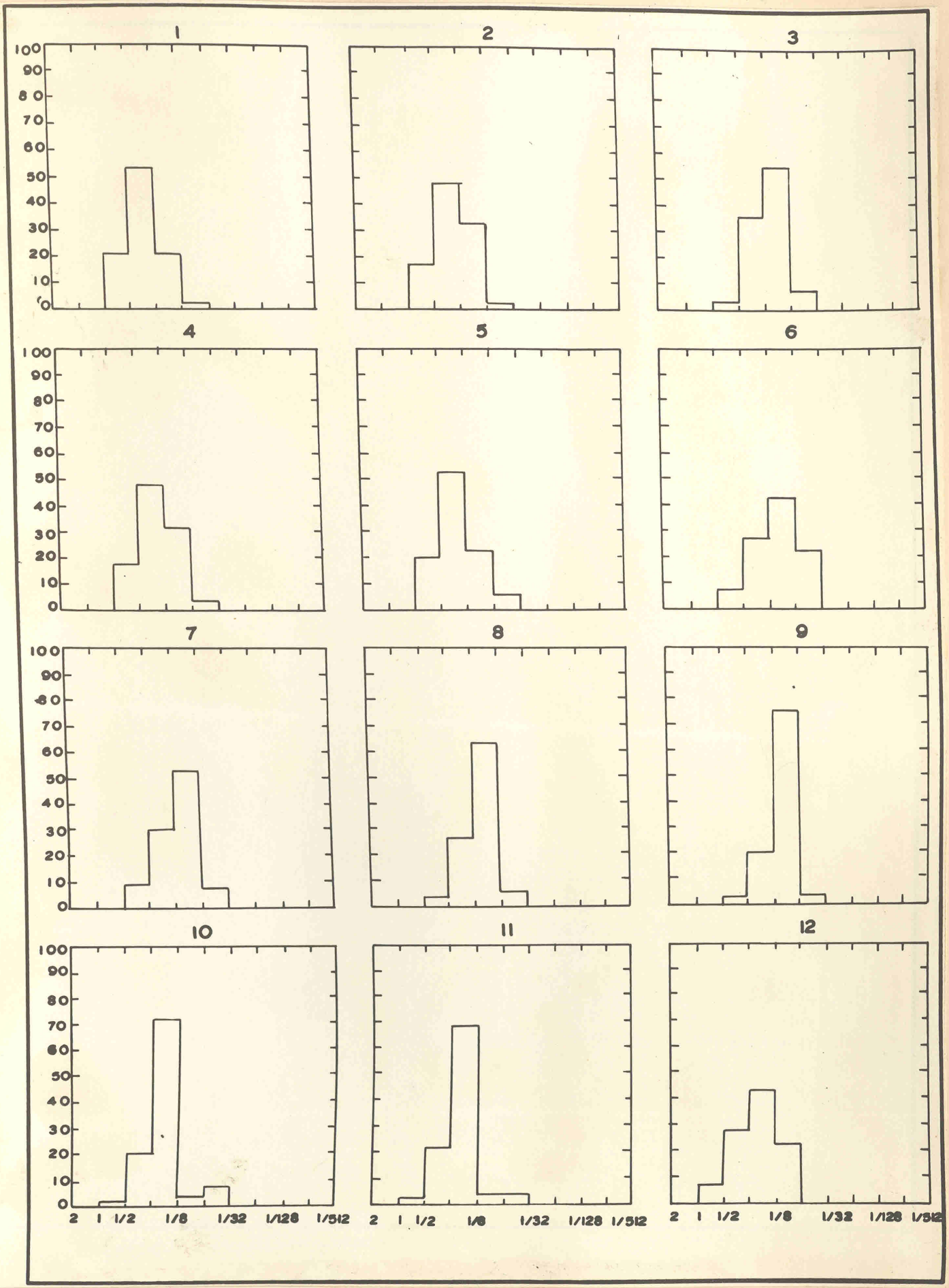

1
2
3
4
5
6
7
8
9
10
11
12
100
90
80
70
60
50
40
30
20
10
0
2
1
1/2
1/8
1/32
1/128
1/512

PLATE - 16

Histograms of some representative samples from Muth Quartzites.

PLATE - 17

Histograms of some selected samples from Passage beds and the Associated quartzites of Syringothyris Limestone.

PLATE - 17

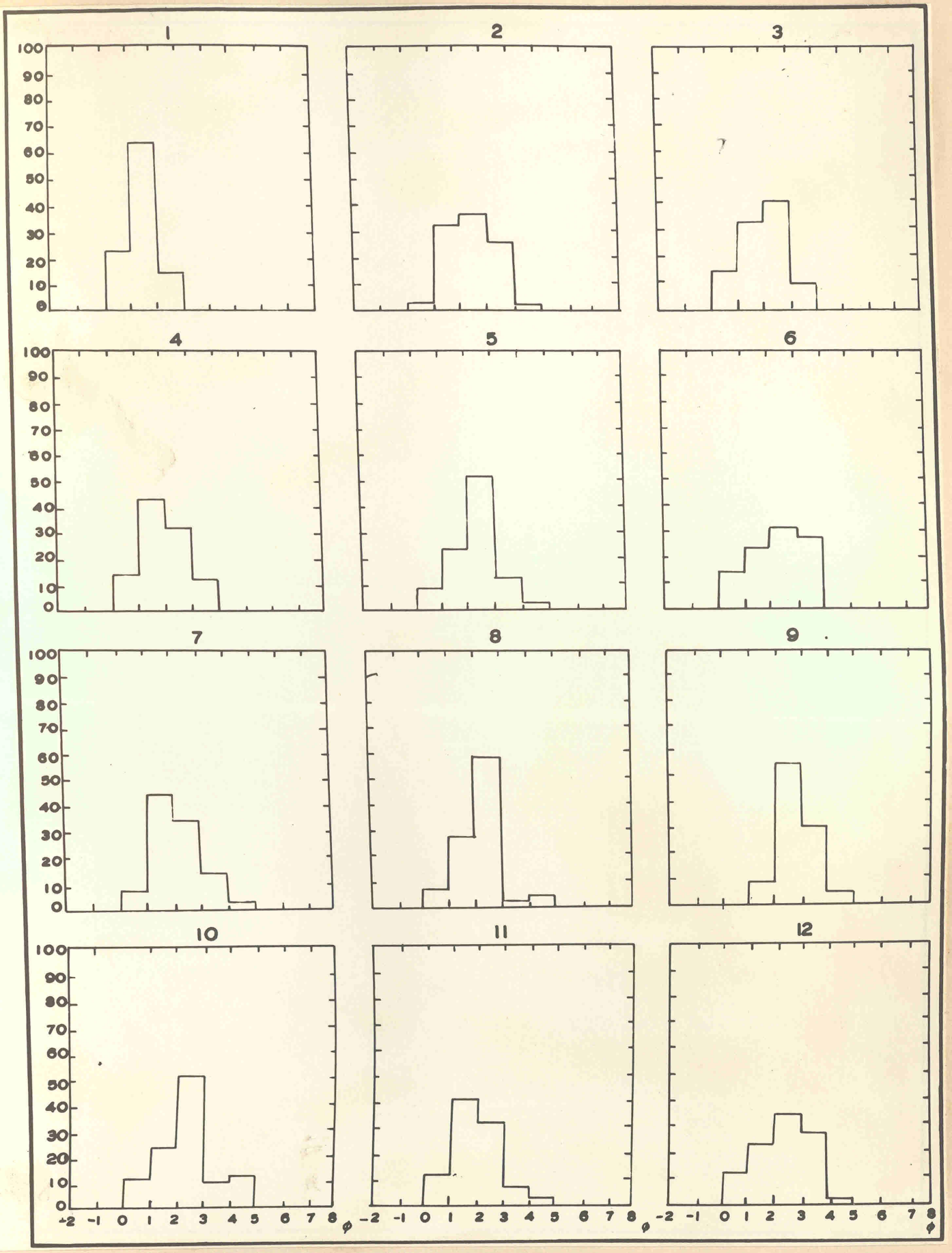
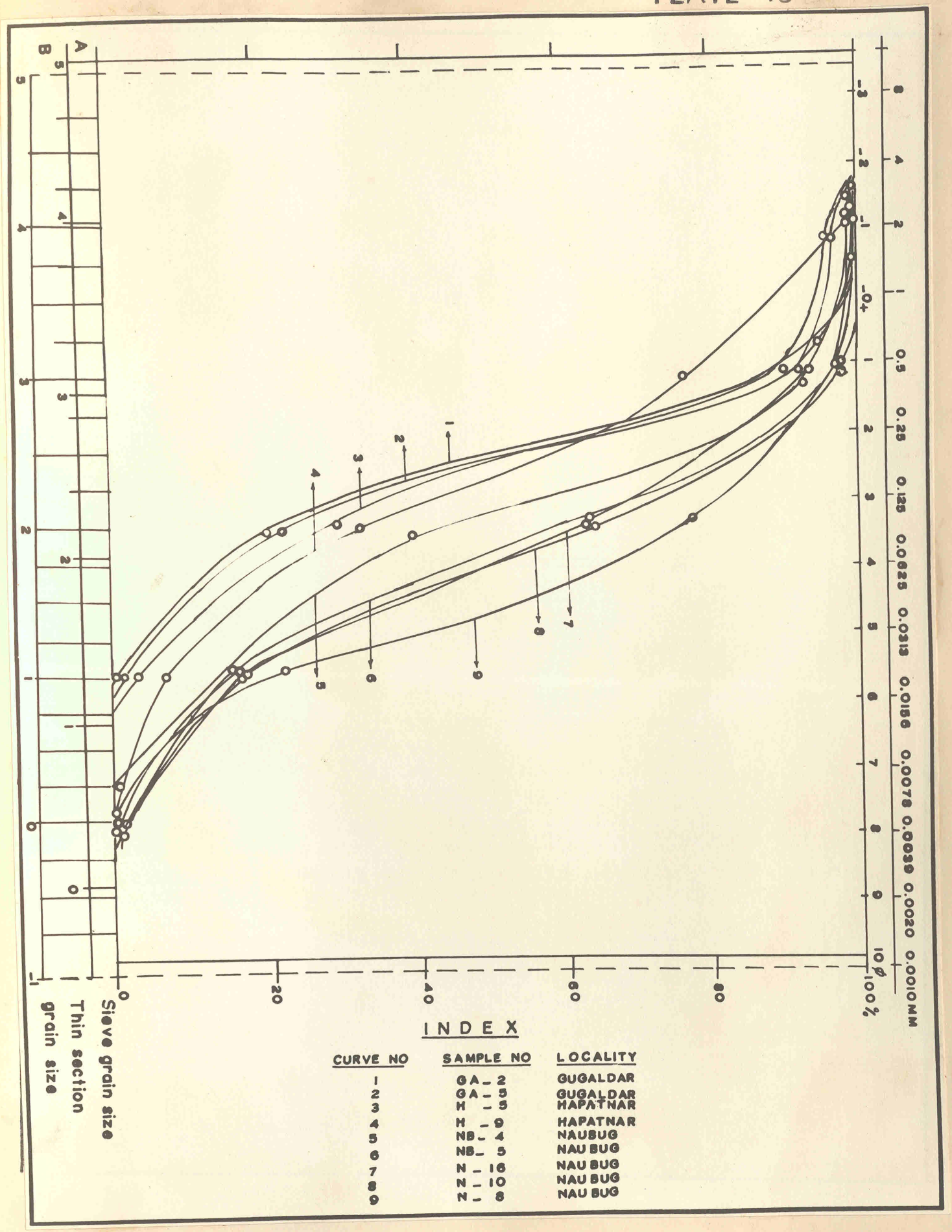


PLATE - 18

Cumulative curves of some selected samples
showing mechanical composition of Muth quartzites.

PLATE - 18



INDEX

CURVE NO	SAMPLE NO	LOCALITY
1	GA_2	GUGALDAR
2	GA_5	GUGALDAR
3	H _5	HAPATNAR
4	H _9	HAPATNAR
5	NB_4	NAUBUG
6	NB_5	NAU BUG
7	N _16	NAU BUG
8	N _10	NAU BUG
9	N _8	NAU BUG

PLATE - 19

Cumulative curves of Passage beds and the Associated quartzites of Syringothyris limestone.

PLATE - 19

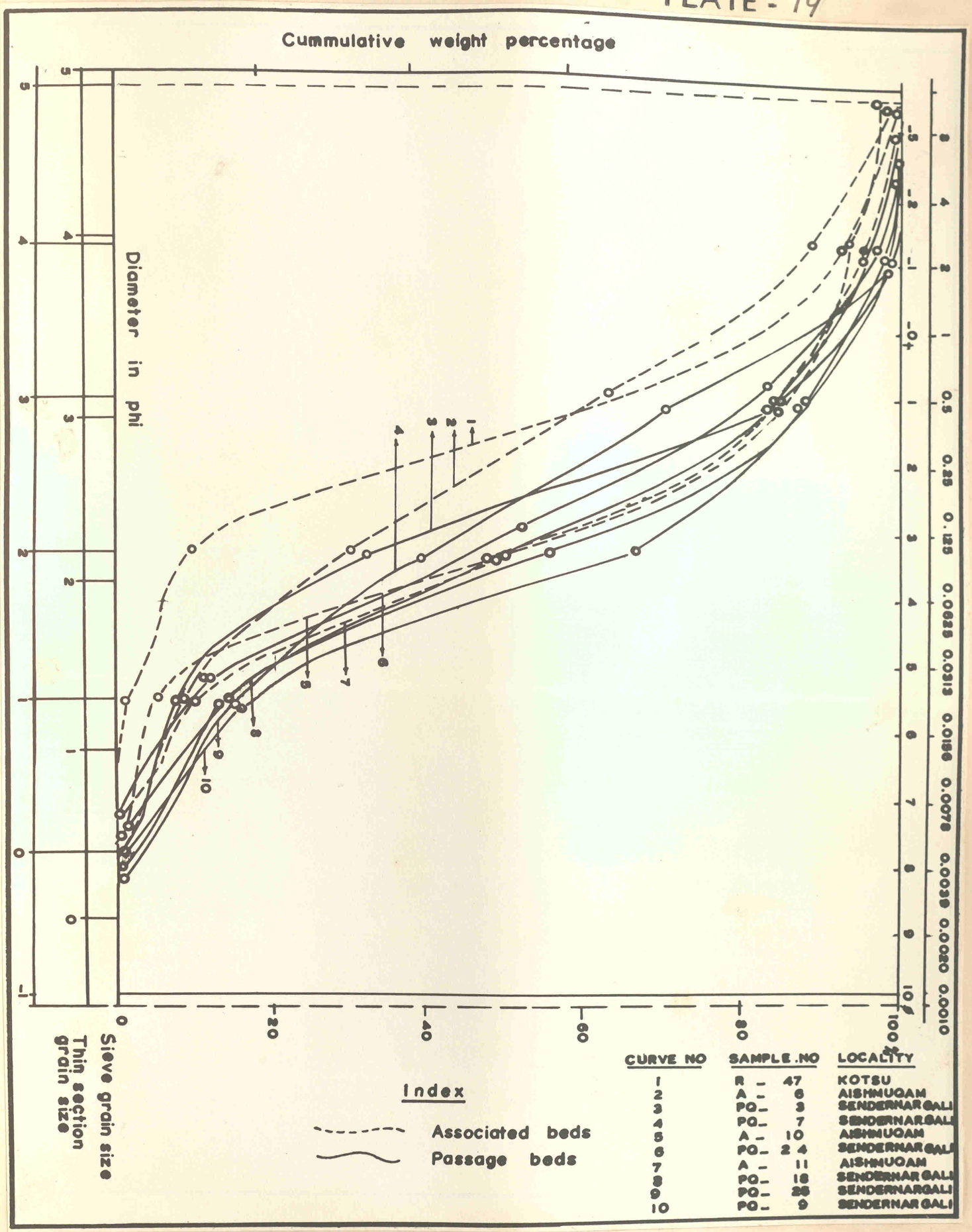

Cummulative weight percentage
Diameter in phi
Sieve grain size
Thin section grain size
0
20
40
60
80
100
Index
Associated beds
Passage beds
CURVE NO
SAMPLE NO
LOCALITY
1 R - 47 KOTSU
2 A - 6 AISHMUQAM
3 PQ- 3 SENDERNARGALI
4 PQ- 7 SENDERNARGALI
5 A - 10 AISHMUQAM
6 PQ- 24 SENDERNARGALI
7 A - 11 AISHMUQAM
8 PQ- 18 SENDERNARGALI
9 PQ- 25 SENDERNARGALI
10 PQ- 9 SENDERNARGALI

PLATE -20

Fig.1 showing mean diameter versus standard deviation, Moiola and Weiser(1968).

Fig.2. Showing skewness versus kurtosis (After Moiola, 1968)

Fig.3 Skewness versus Mean diameter

Fig.4. Skewness versus standard deviation (After Friedman,1961)

Fig.5 Skewness versus kurtosis in quarter Phi units.(Moiola and Weiser,1968).

(Fig 1 to 5 showing plots of some textural parameters of grain size analysis)

Fig _ 1

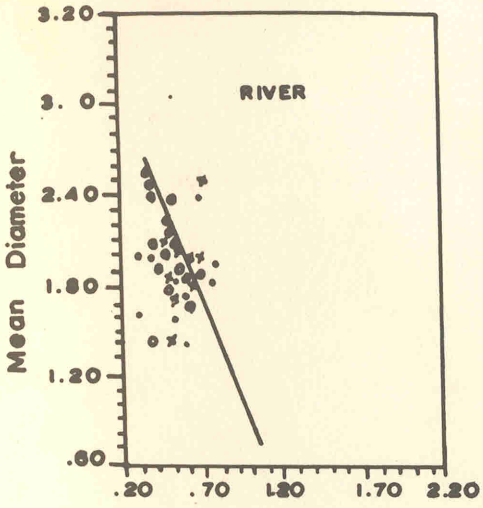


Fig _ 2

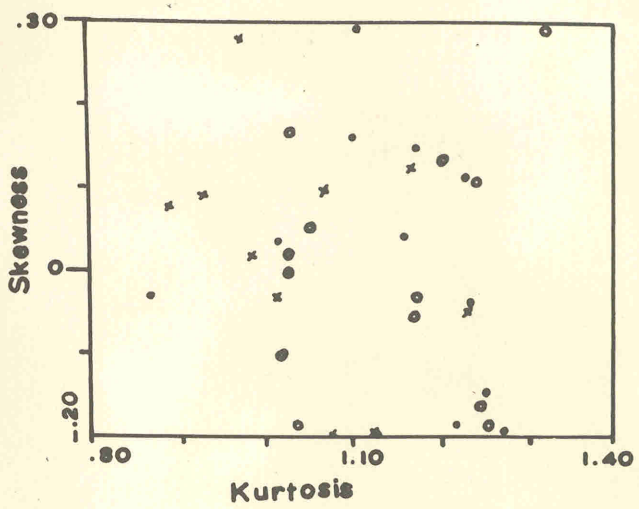


Fig_ 4

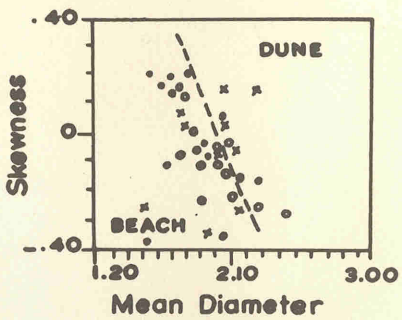


Fig_ 3

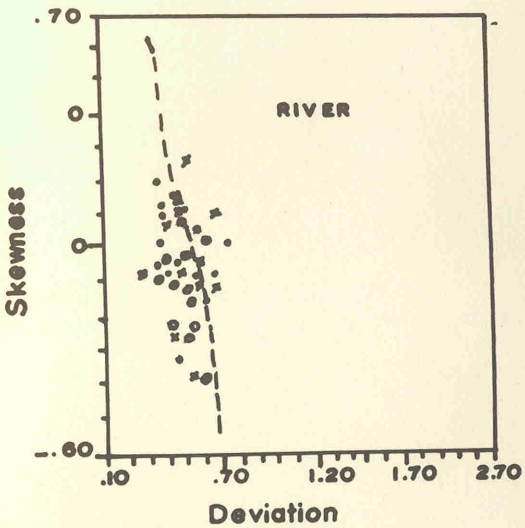
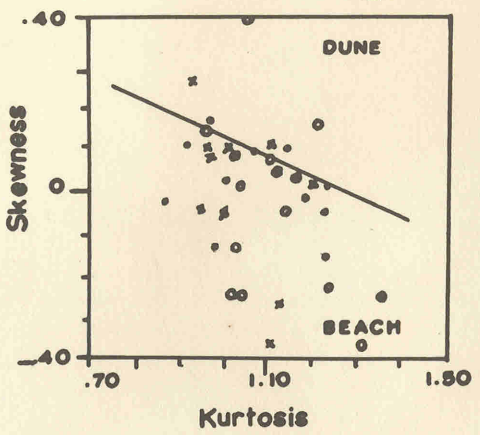


Fig_5



REFERENCES

- ○ MUTH QUARTZITE
- • PASSAGE BEDS
- × ASSOCIATED QUARTZITE (SYRINGOTHYRIS LIMESTONE)

Fig: 1, 2, 3, 4 Whole phi units and Fig: 5 in quarter phi units

PLATE - 21

Fig.1. A scatter diagram showing relationship between sphericity and the roundness values from Muth Quartzites, Passage beds and the Associated beds of Syringothyris Limestone.

Fig.2 Bar diagrams representing percentages of Zircon, Tourmaline Rutile, apatite etc. from the above mentioned formations.

Fig.3. showing morphological characters of Zircon present in all the three formations and their percentages.

PLATE - 21

Fig - 1

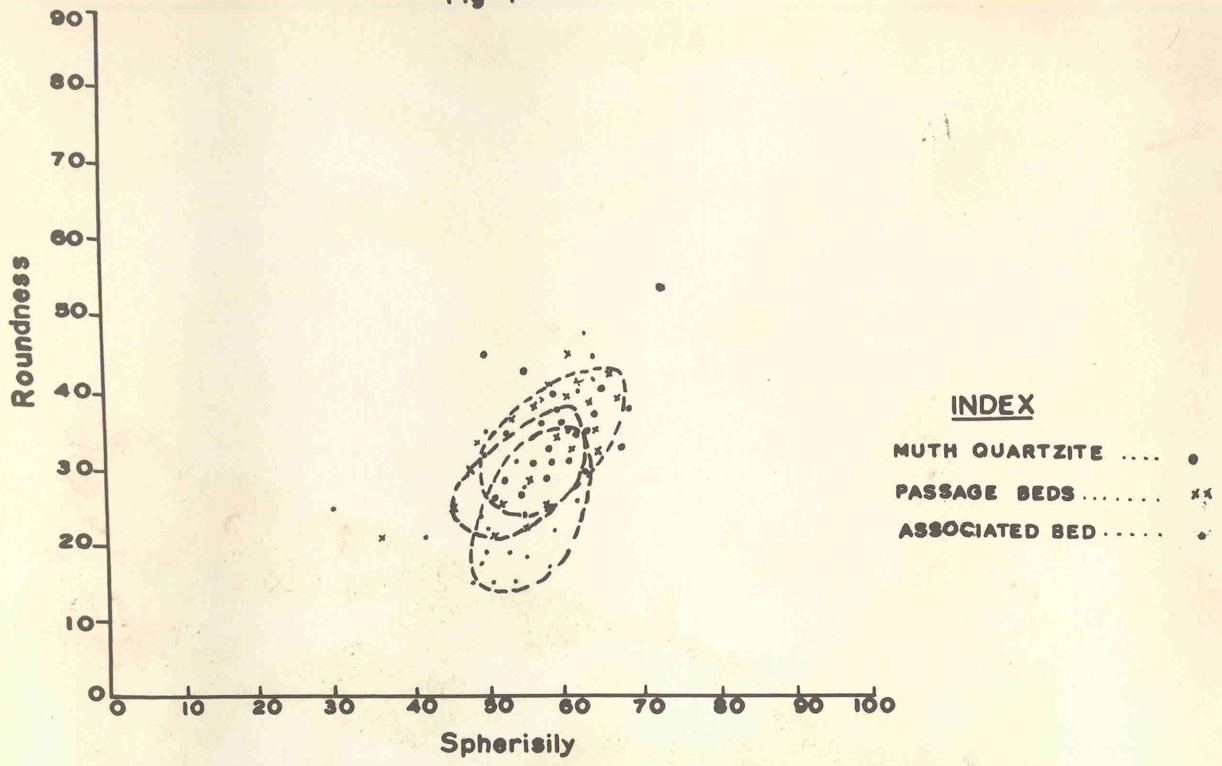


Fig - 2

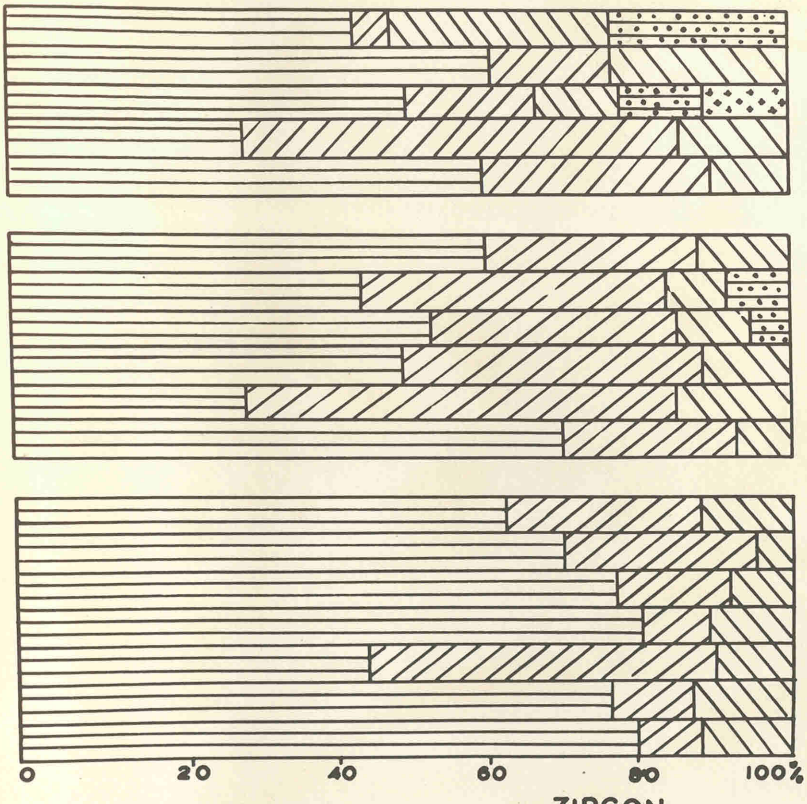
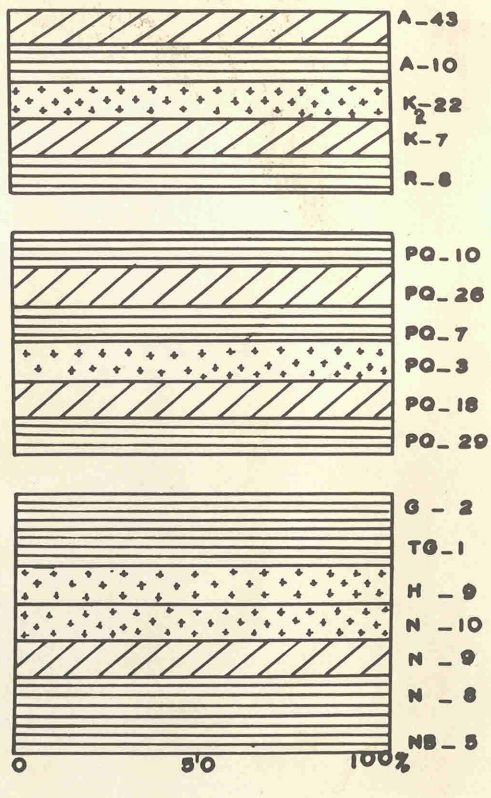


Fig - 3



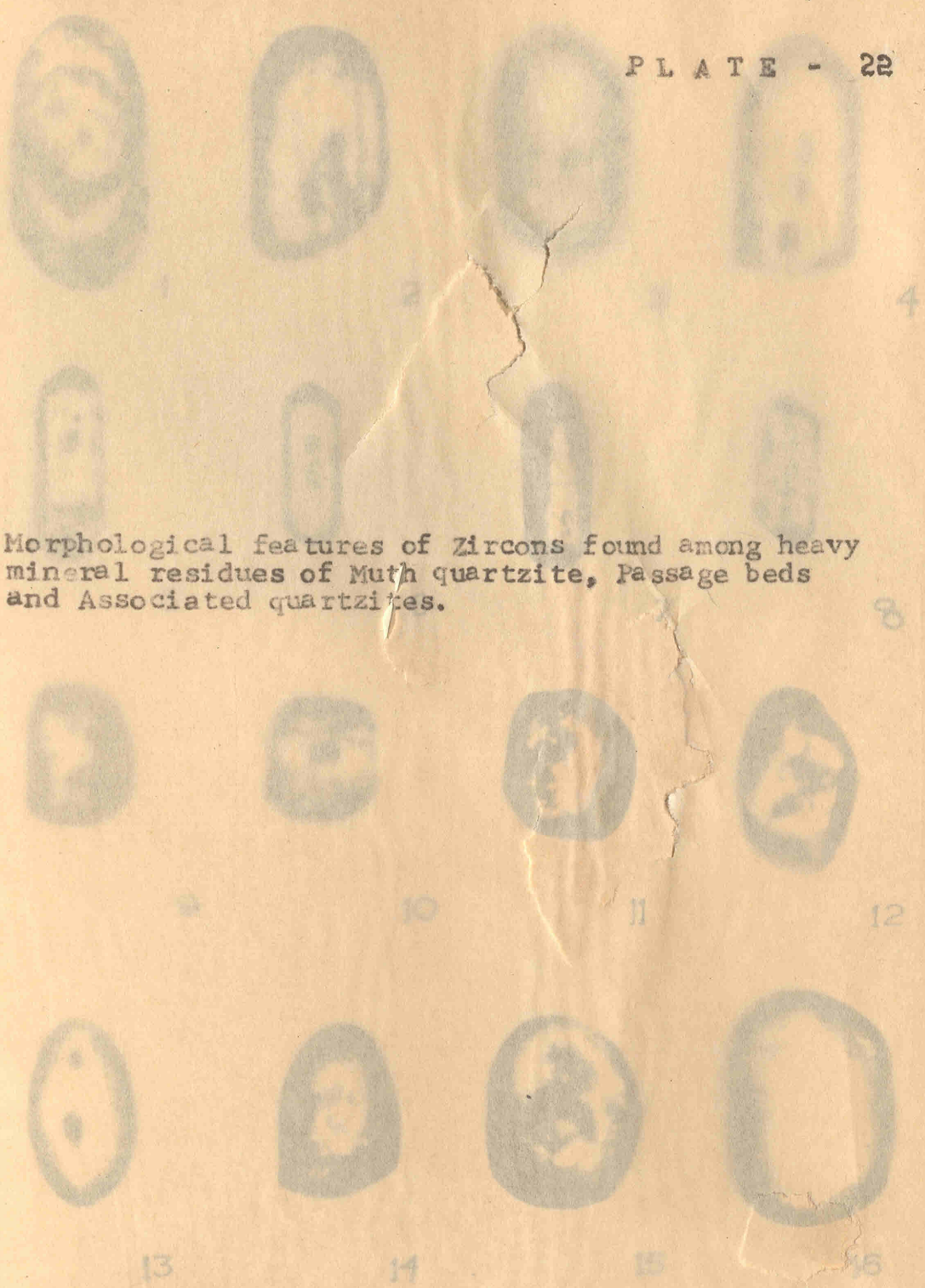
PERCENTAGE

Z: ZIRCON
T: TOURMALIN
R: RUTILE
A: APPATITE
AL ALTEREAL SPLCIES

MORPHOLOGY

SUB HEDRAL < 50%
SUB HEDRAL > 50%
ANHEDRAL 50%
EUHEDRAL 50%

PLATE - 22



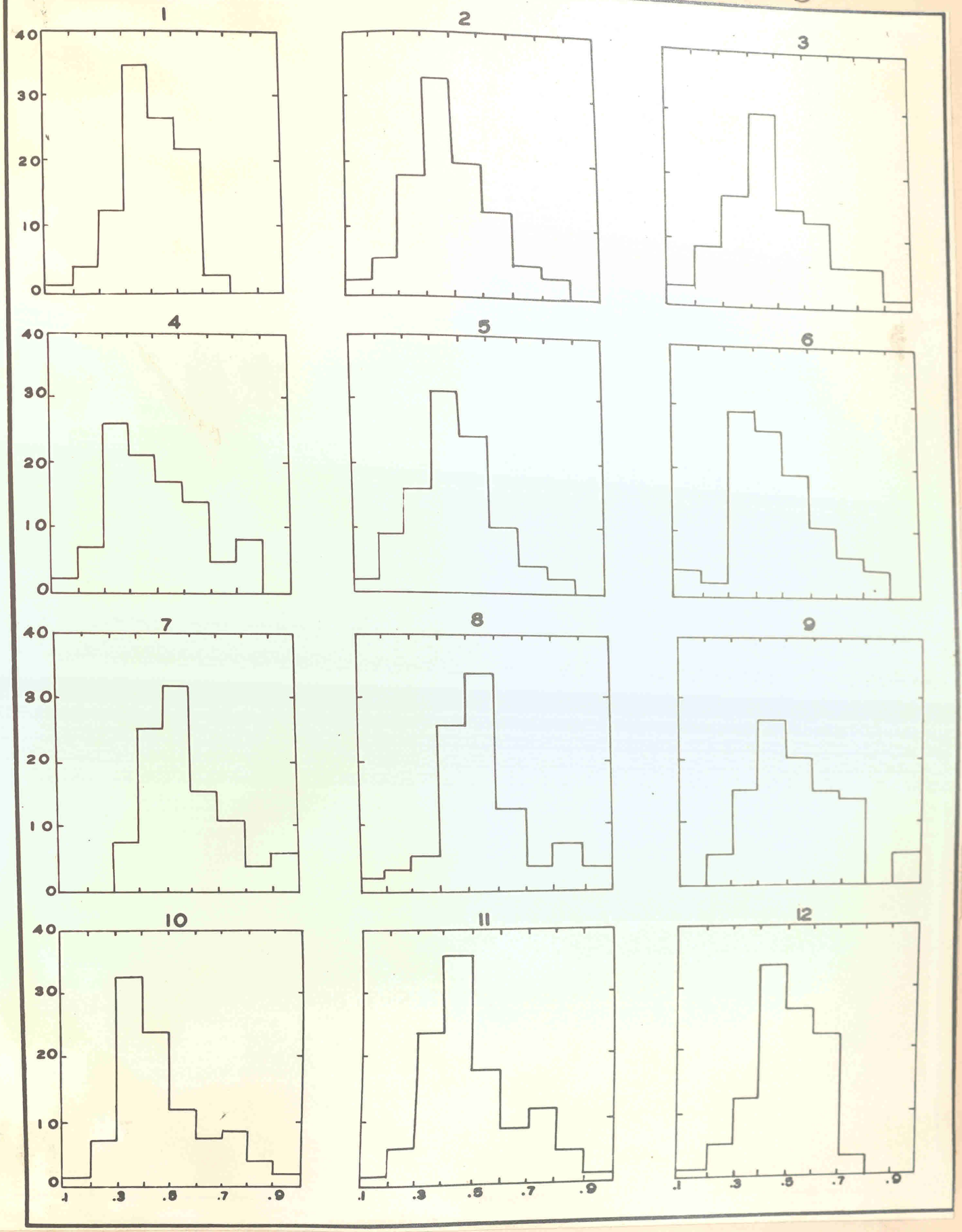
Morphological features of Zircons found among heavy mineral residues of Muth quartzite, Passage beds and Associated quartzites.

PLATE - 23

Figs. 1 to 12 representing frequency elongation Histograms of Zircons in Muth Quartzites and Passage beds.

In these histograms; number of zircons = 100 and standard deviation/Mean given in the text.

PLATE - 23



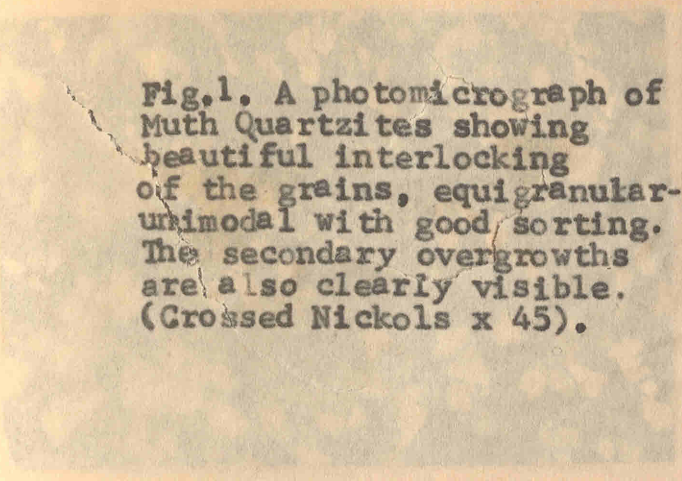


Fig.1. A photomicrograph of Muth Quartzites showing beautiful interlocking of the grains, equigranular-unimodal with good sorting. The secondary overgrowths are also clearly visible. (Crossed Nickols x 45).

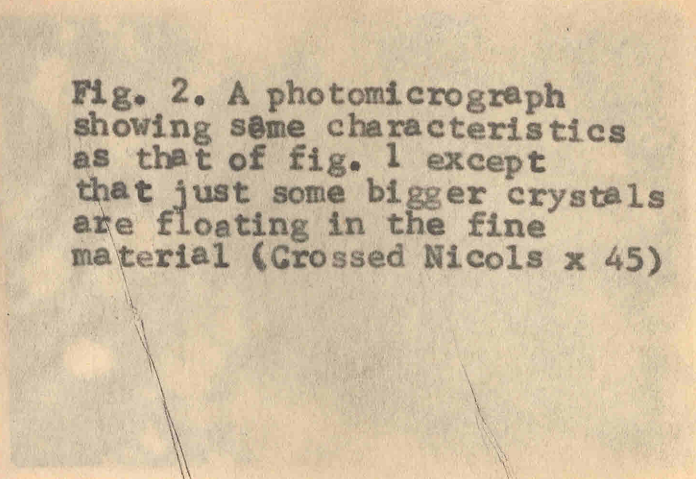


Fig. 2. A photomicrograph showing same characteristics as that of fig. 1 except that just some bigger crystals are floating in the fine material (Crossed Nicols x 45)

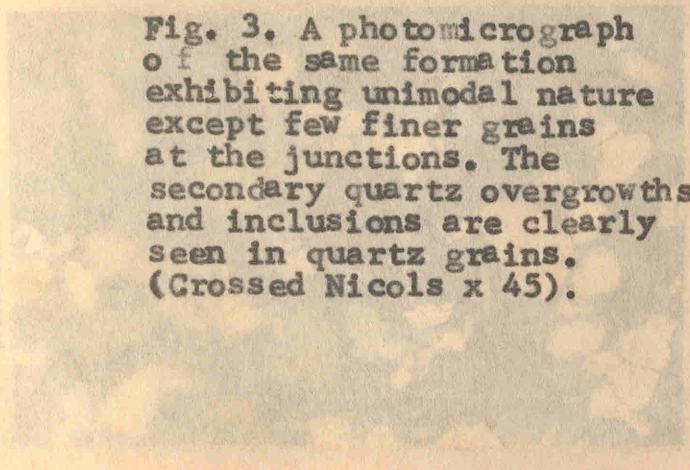


Fig. 3. A photomicrograph of the same formation exhibiting unimodal nature except few finer grains at the junctions. The secondary quartz overgrowths and inclusions are clearly seen in quartz grains. (Crossed Nicols x 45).

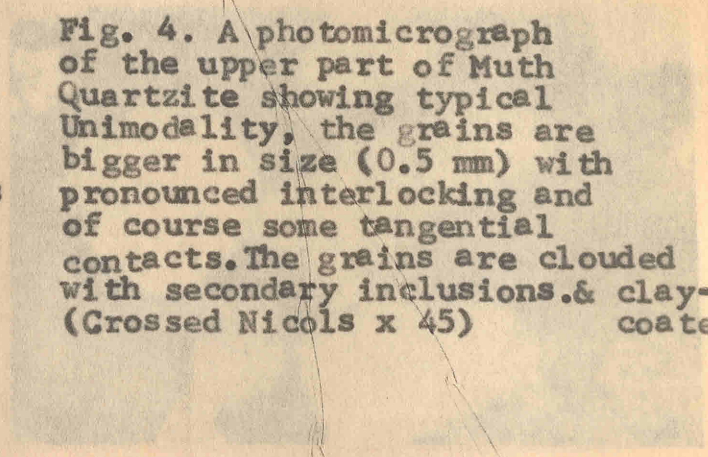


Fig. 4. A photomicrograph of the upper part of Muth Quartzite showing typical Unimodality, the grains are bigger in size (0.5 mm) with pronounced interlocking and of course some tangential contacts. The grains are clouded with secondary inclusions.& clay-coated. (Crossed Nicols x 45)

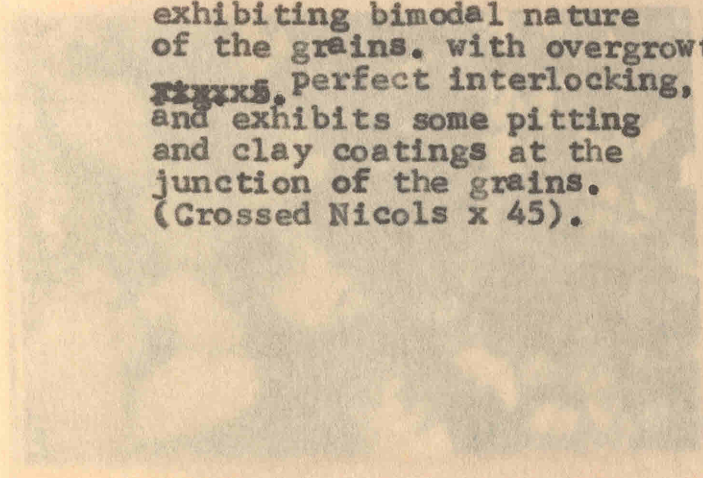


Fig.5. A photomicrograph of the same formation exhibiting bimodal nature of the grains. with overgrowths, perfect interlocking, and exhibits some pitting and clay coatings at the junction of the grains. (Crossed Nicols x 45).

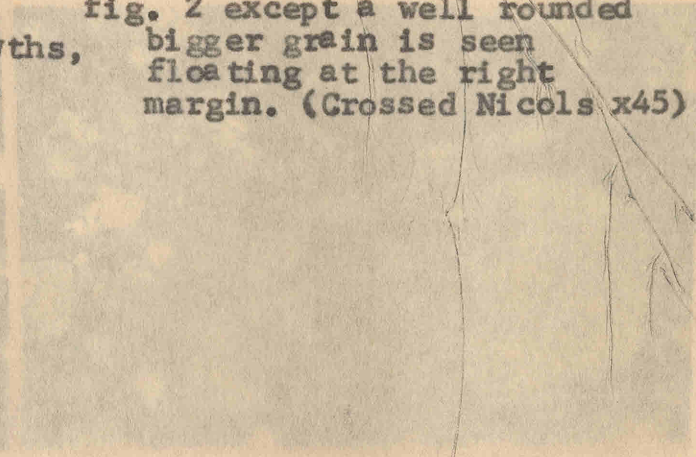


Fig. 6. Exhibiting same characteristics as that of fig. 2 except a well rounded bigger grain is seen floating at the right margin. (Crossed Nicols x45)

PLATE - 25

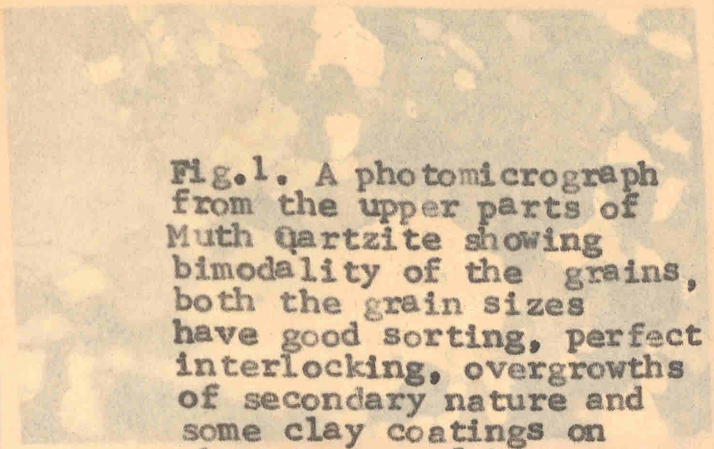


Fig.1. A photomicrograph from the upper parts of Muth Qartzite showing bimodality of the grains, both the grain sizes have good sorting, perfect interlocking, overgrowths of secondary nature and some clay coatings on the margins of bigger grains.(Crossed Nicols x 45).

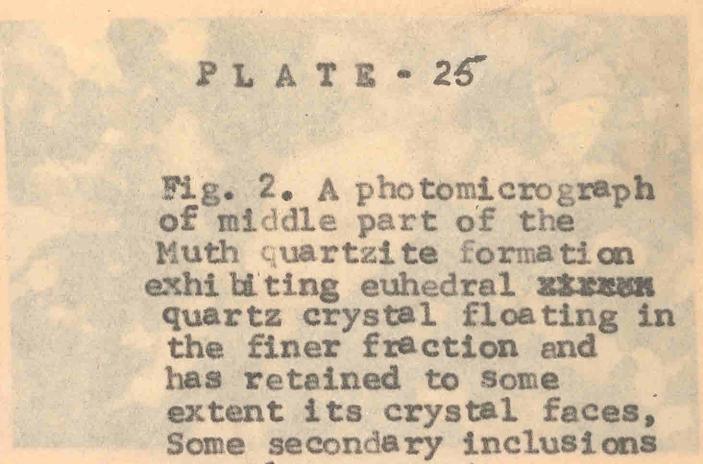


Fig. 2. A photomicrograph of middle part of the Muth quartzite formation exhibiting euhedral ~~zirzon~~ quartz crystal floating in the finer fraction and has retained to some extent its crystal faces, Some secondary inclusions are also present. (Crossed Nicols x 45).

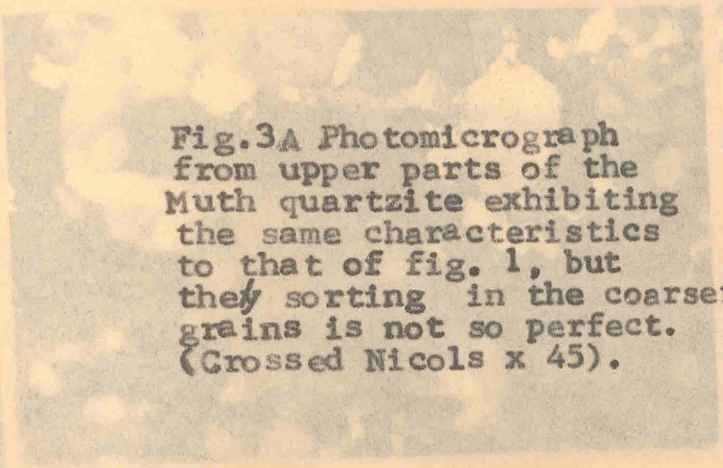


Fig.3A Photomicrograph from upper parts of the Muth quartzite exhibiting the same characteristics to that of fig. 1, but the~~y~~ sorting in the coarser grains is not so perfect. (Crossed Nicols x 45).

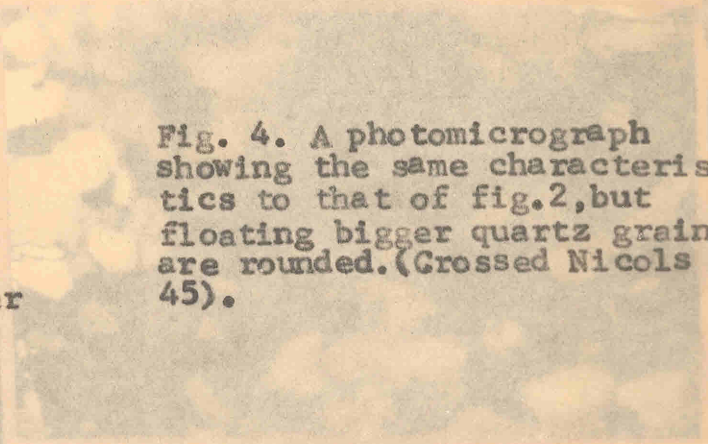


Fig. 4. A photomicrograph showing the same characteristics to that of fig.2,but floating bigger quartz grains are rounded.(Crossed Nicols x 45).

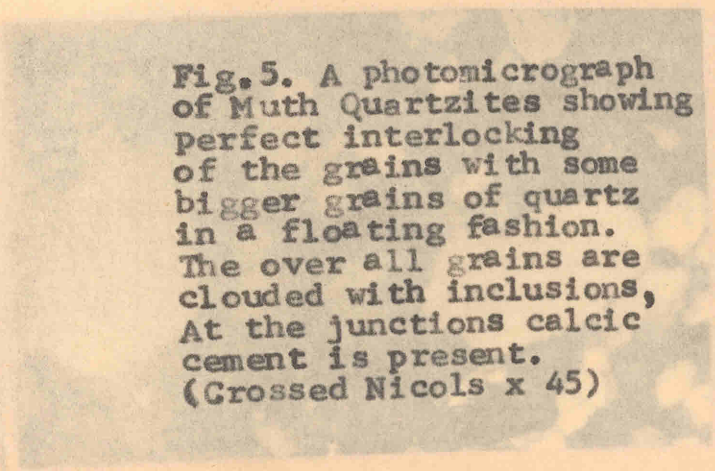


Fig.5. A photomicrograph of Muth Quartzites showing perfect interlocking of the grains with some bigger grains of quartz in a floating fashion. The over all grains are clouded with inclusions, At the junctions calcic cement is present. (Crossed Nicols x 45)

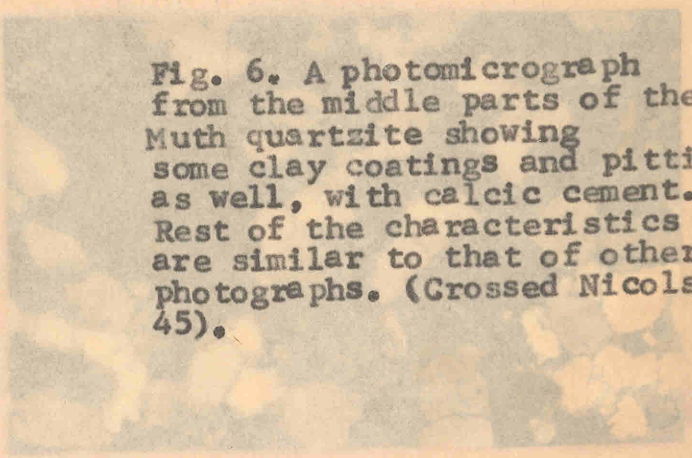


Fig. 6. A photomicrograph from the middle parts of the Muth quartzite showing some clay coatings and pitting as well, with calcic cement. Rest of the characteristics are similar to that of other photographs. (Crossed Nicolsx 45).

PLATE - 26

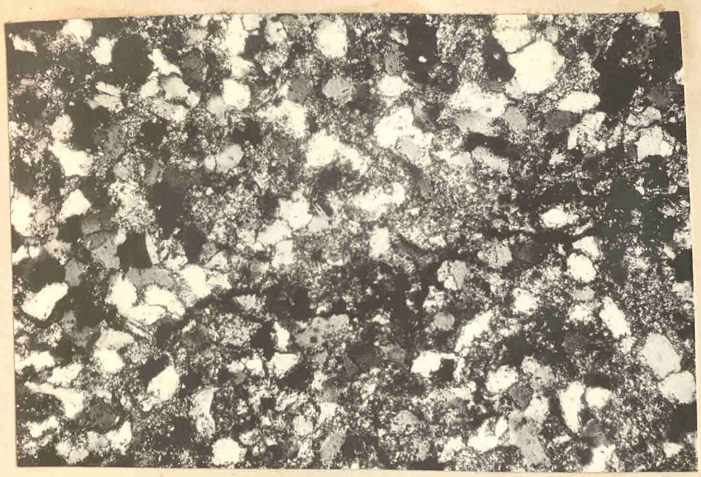


FIG : 1

FIG : 2

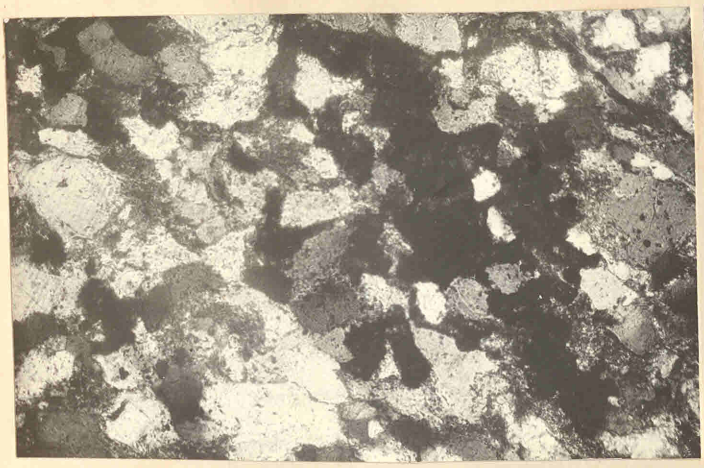


FIG : 3

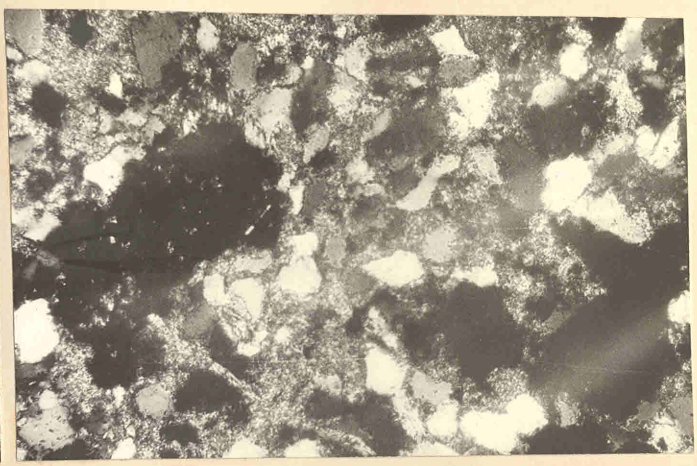


FIG : 4

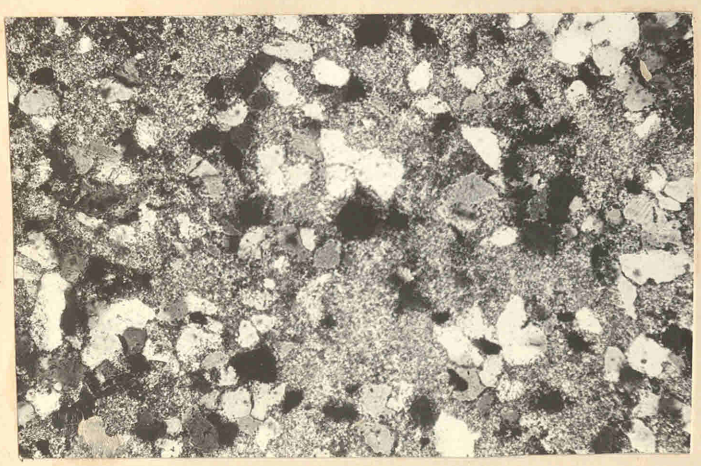


FIG : 5

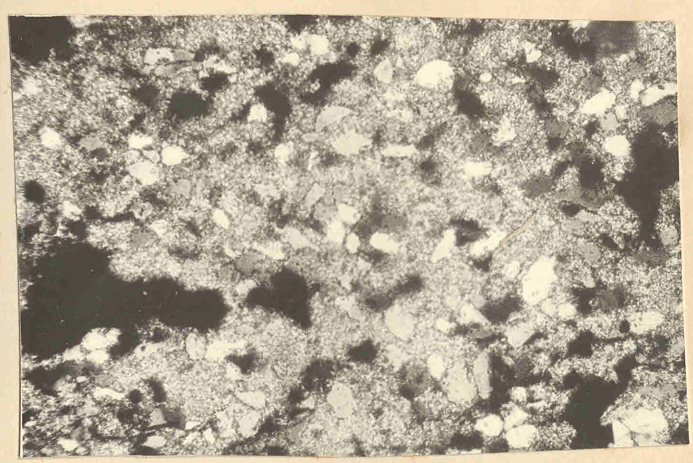


FIG : 6

P L A T E -26

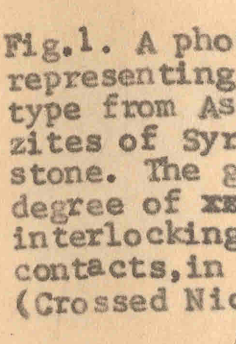


Fig.1. A photomicrograph representing sublithic arenite type from Associated quartzites of Syringothyris Limestone. The grains show some degree of xxxxxxxx interlocking and tangential contacts,in a calcic cement. (Crossed Nicols x 45.)

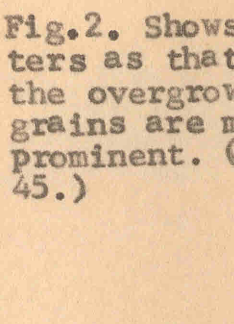


Fig.2. Shows the same characters as that of fig.1.,but the overgrowth on the quartz grains are more or less prominent. (Crossed Nicols x 45.)

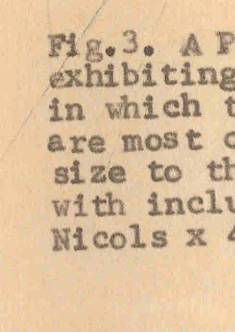


Fig.3. A Photomicrograph exhibiting lithic arenite variety in which the rock fragments are most common with a bigger size to that of quartz, clouded with inclusions.(Under crossed Nicols x 45.)

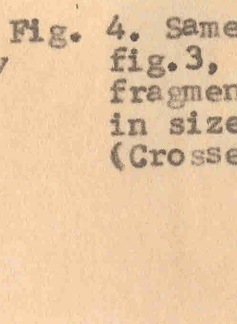


Fig. 4. Same as that of fig.3, but the rock fragments are larger in size. (Crossed Nicols x 45.)

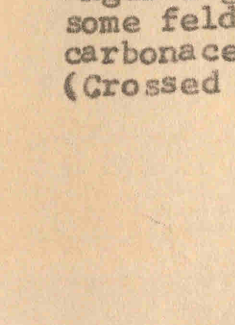


Fig.5 A photomicrograph showing angular grains of quartz and some feldspars floating in a carbonaceous matrix. (Crossed Nicols x 45.)

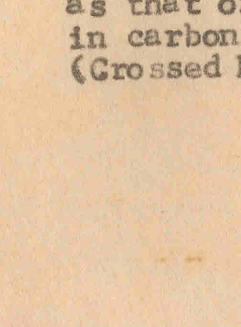


Fig.6. Showing the same characteristic features as that of Fig.5 and set in carbonaceous matrix. (Crossed Nicols x 45).

PLATE - 27

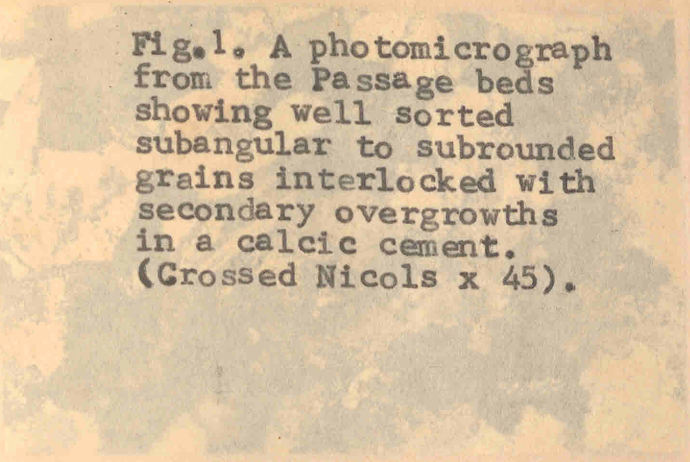


Fig.1. A photomicrograph from the Passage beds showing well sorted subangular to subrounded grains interlocked with secondary overgrowths in a calcic cement. (Crossed Nicols x 45).

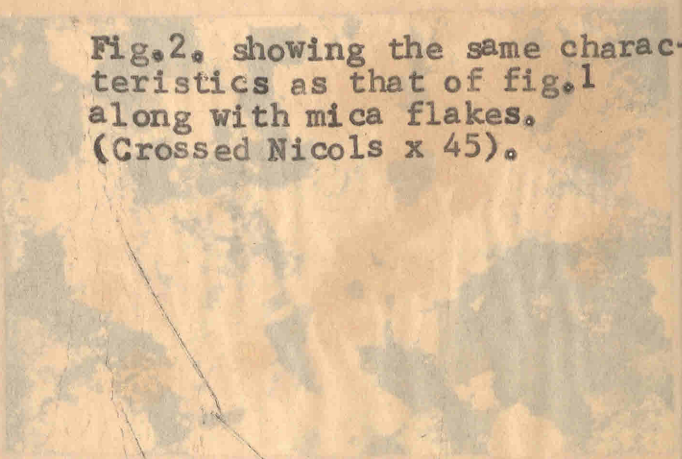


Fig.2. showing the same characteristics as that of fig.1 along with mica flakes. (Crossed Nicols x 45).

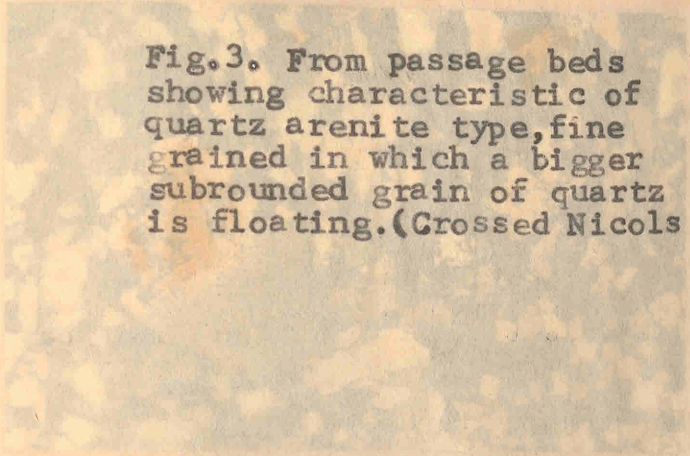


Fig.3. From passage beds showing characteristic of quartz arenite type, fine grained in which a bigger subrounded grain of quartz is floating. (Crossed Nicols x 45).

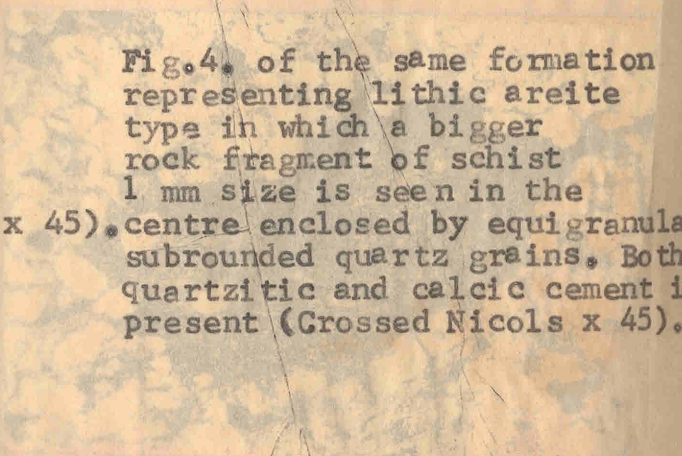


Fig.4. of the same formation representing lithic areite type in which a bigger rock fragment of schist 1 mm size is seen in the centre enclosed by equigranular subrounded quartz grains. Both quartzitic and calcic cement is present (Crossed Nicols x 45).

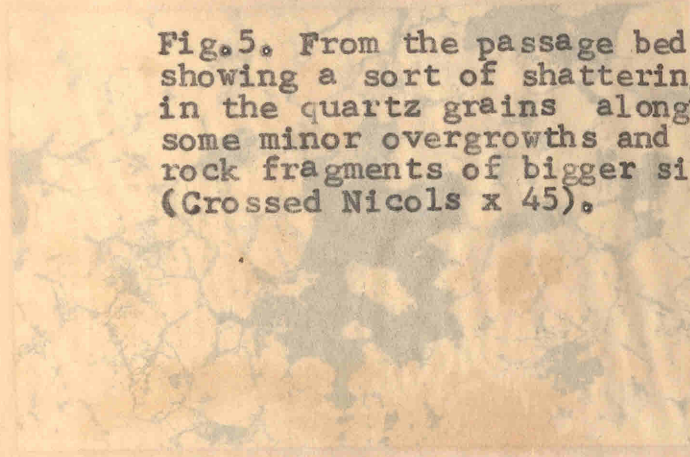


Fig.5. From the passage beds showing a sort of shattering in the quartz grains alongwith some minor overgrowths and some rock fragments of bigger sizes. (Crossed Nicols x 45).

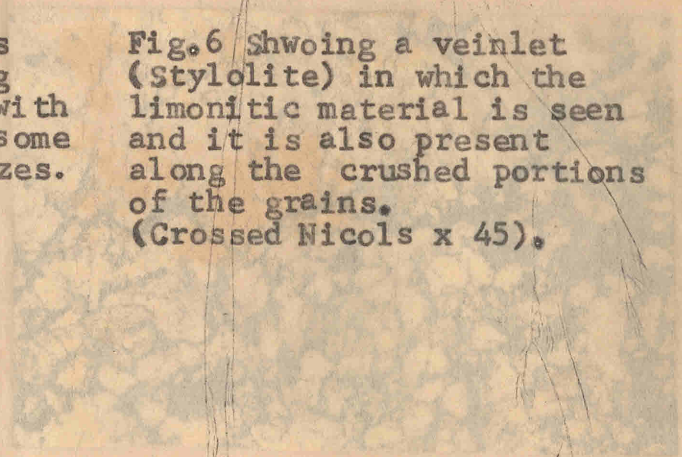


Fig.6 Shwoing a veinlet (Stylolite) in which the limonitic material is seen and it is also present along the crushed portions of the grains. (Crossed Nicols x 45).

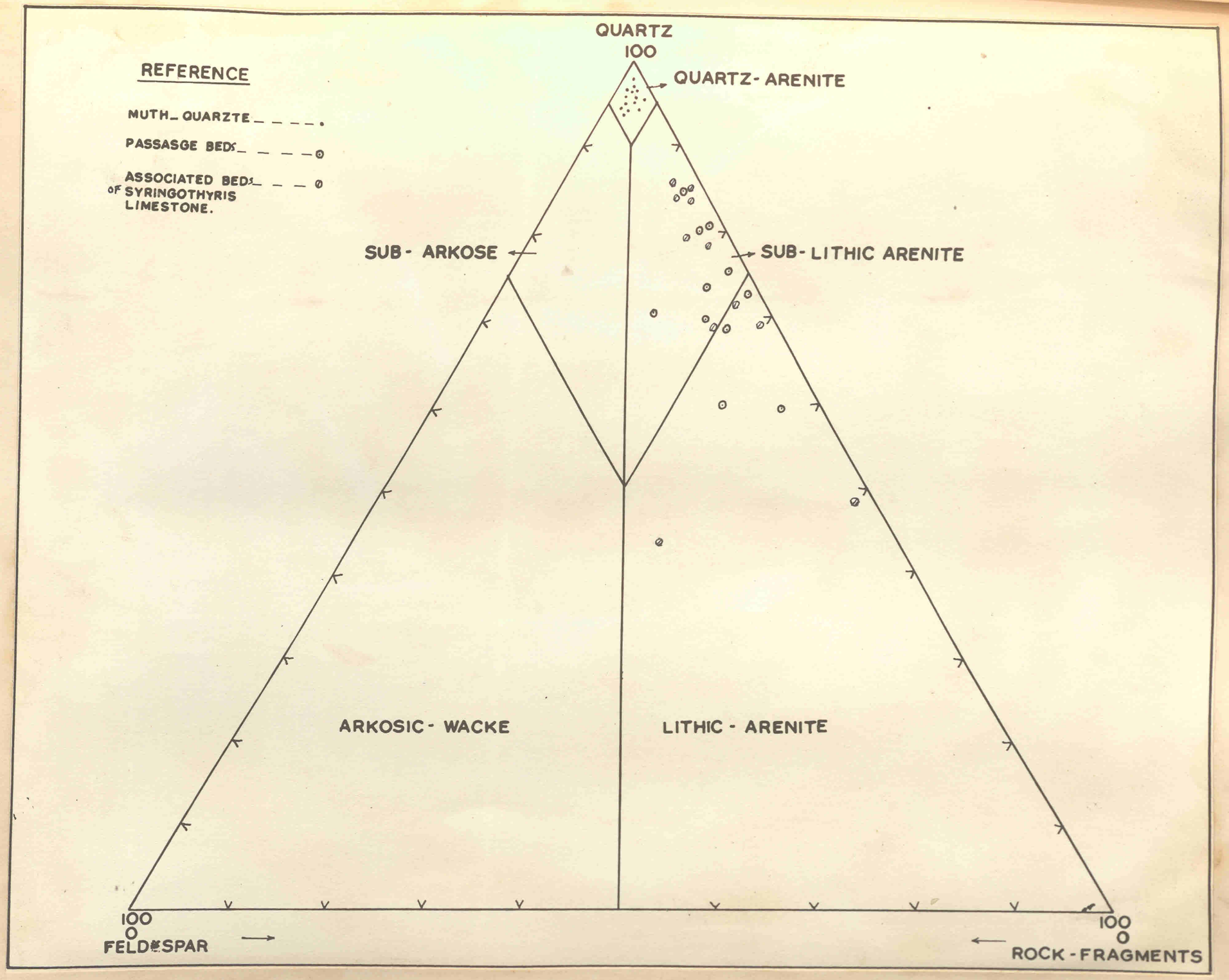

QUARTZ
100
REFERENCE
MUTH_ QUARZTE _ _ _ _ •
PASSASGE BEDS _ _ _ _ ⊙
ASSOCIATED BEDS OF SYRINGOTHYRIS LIMESTONE. _ _ _ ∅
QUARTZ- ARENITE
SUB- ARKOSE
SUB- LITHIC ARENITE
ARKOSIC- WACKE
LITHIC - ARENITE
100
0
FELDSPAR
100
0
ROCK - FRAGMENTS

PLATE-28

PLATE -29

Fig.1. A photograph exhibiting cross hering bone structure as well as laminations in Associated Quartzites. of Syringothyris Limestone.

Fig. 2 A photograph exhibiting typical current lamination structure in Muth Quartzite.

Fig.3. A photograph showing asymmetrical ripple marks in Muth Quartzites, with some limonitic spots.

Fig.4. A photograph exhibiting symmetrical wave ripples in Muth Quartzite.

Fig.5. A photograph showing tracks of some trace fossils in the Associated quartzites of Syringothyris Limestone.

Fig.6. A photograph showing trace fossils probably of Planolites in the Associated beds.

PLATE - 29

FIG : 1

FIG : 2

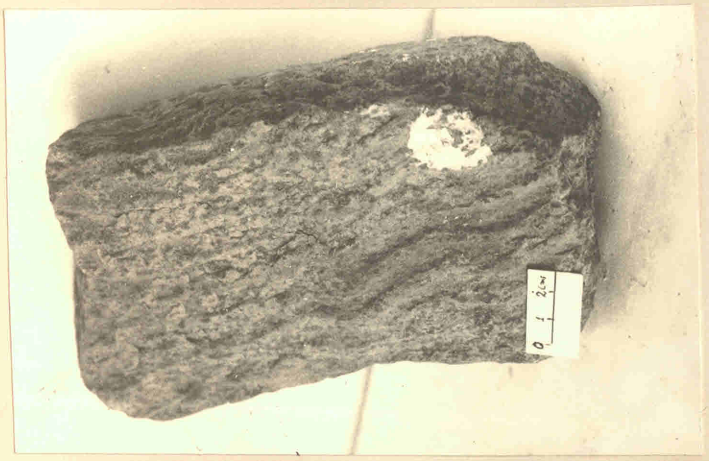
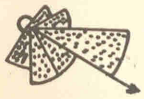


FIG : 3

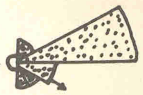
FIG : 4

FIG : 5

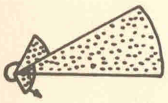
FIG : 6



1

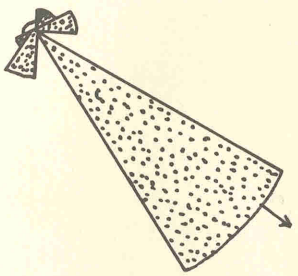


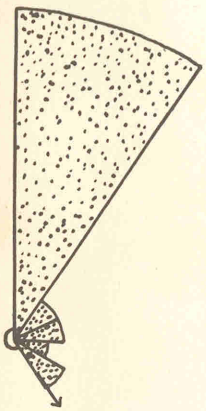
2



3

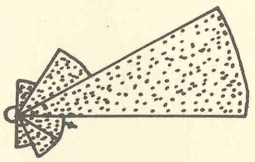
4





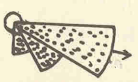
5

6



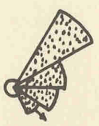
7

8



9

10



Semicircular Rose diagrams with their preferred orientation directions.

Fig 1 to 6 Rose diagrams from cross bedding in Muth Quartzites and Associated quartzites.

Fig 7 to 10. Rose diagrams from ripple marks of the same formation.

PLATE-31

An Equitriangular diagram showing the plot of percentages of calcite, dolomite and Acid insolubles.

PLATE - 32

D.T.A. Curves of some selected samples from the lower part of the Syringothyris Limestone.

PLATE - 32

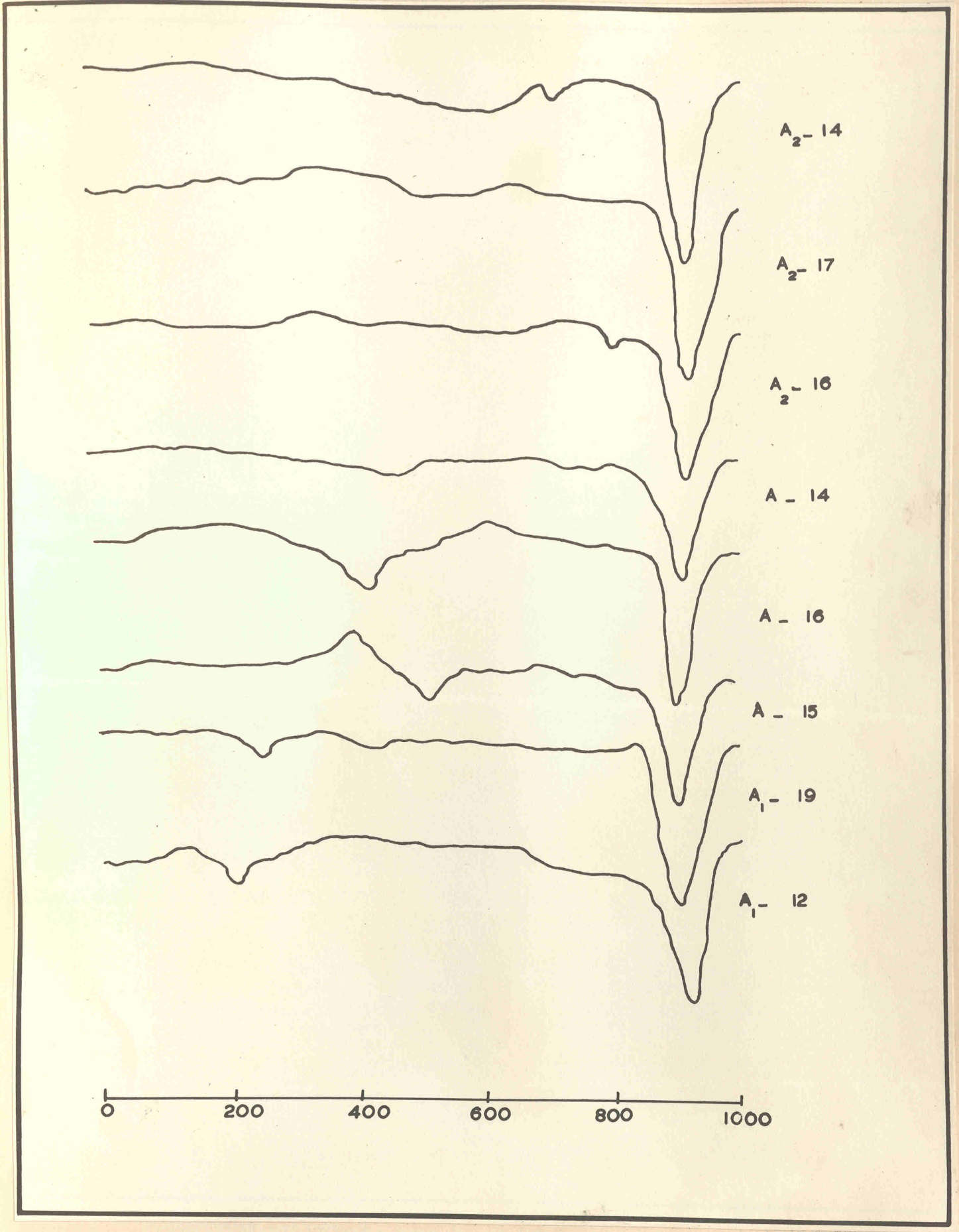


PLATE-33

D.T.A. curves of some selected samples from the upper part of the Syringothyris Limestone.

PLATE - 33

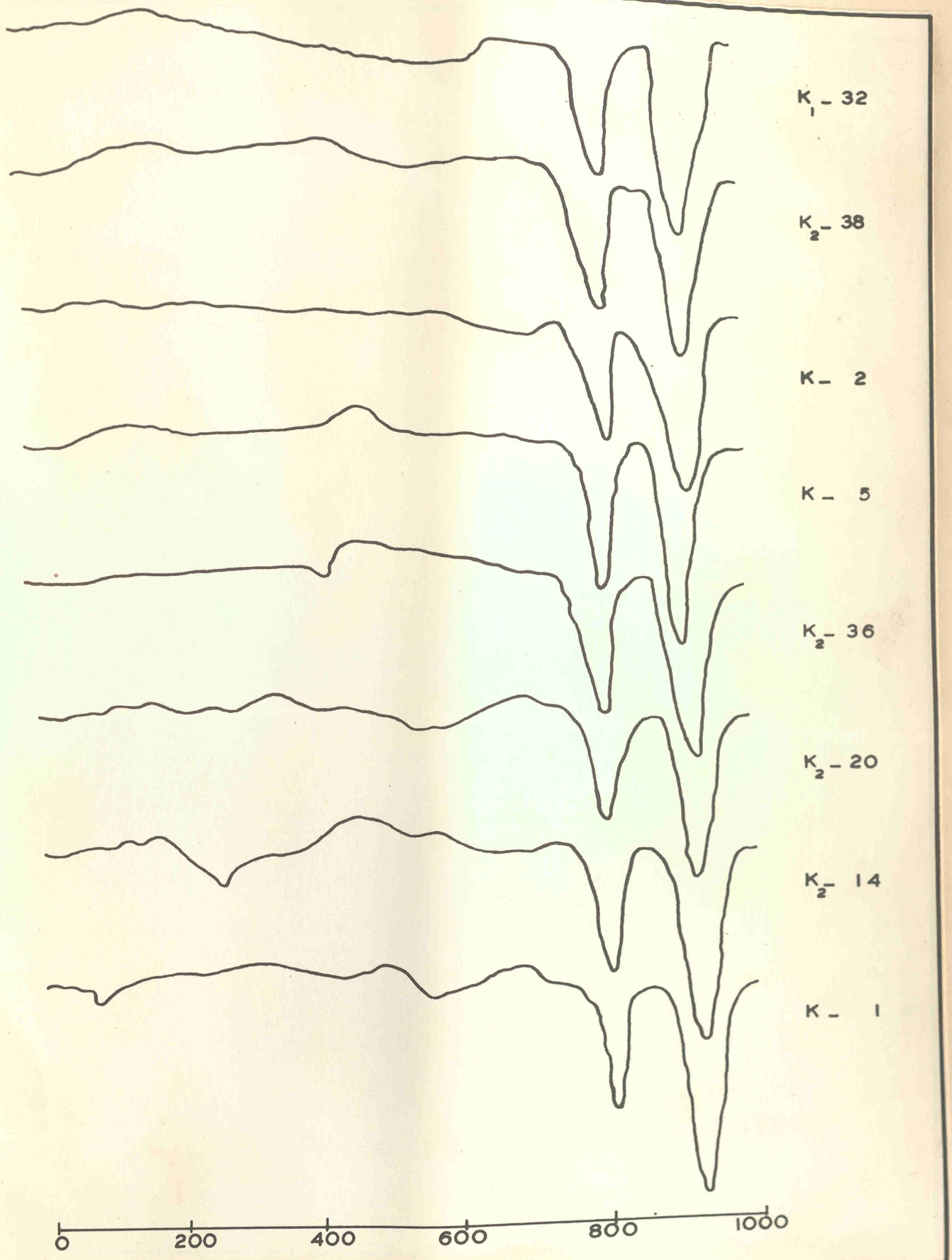


PLATE - 34

Fig.1. Plots of clay percentage versus MgO percentage.

Fig.2. Clay percentage versus insoluble residue percentage.plots.

Fig.4.Silt percentage versus insoluble residue percentage. plots.

Fig.3.showing plots of insoluble residue versus MgO percentage.

MAGNESIUM-INSOLUBLE RESIDUE RELATIONSHIP OF SYRINGOTHYRIS LIMESTONE.

plots.

PLATE - 34

Fig- 1

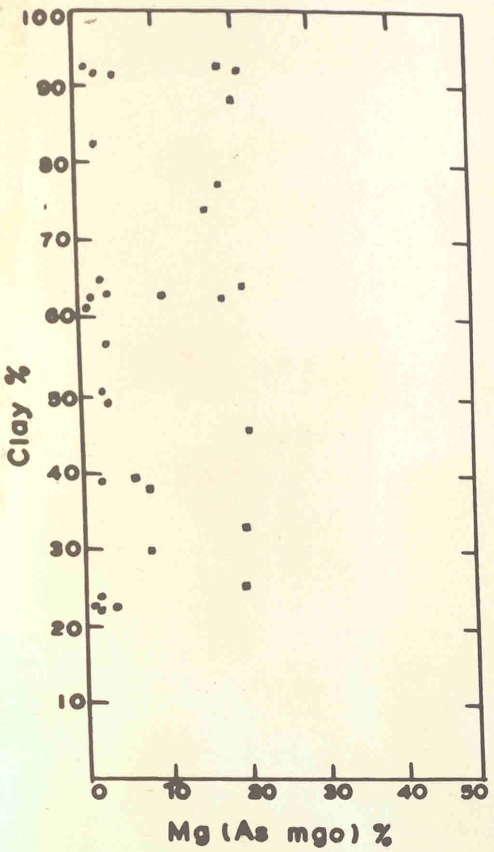


Fig- 2

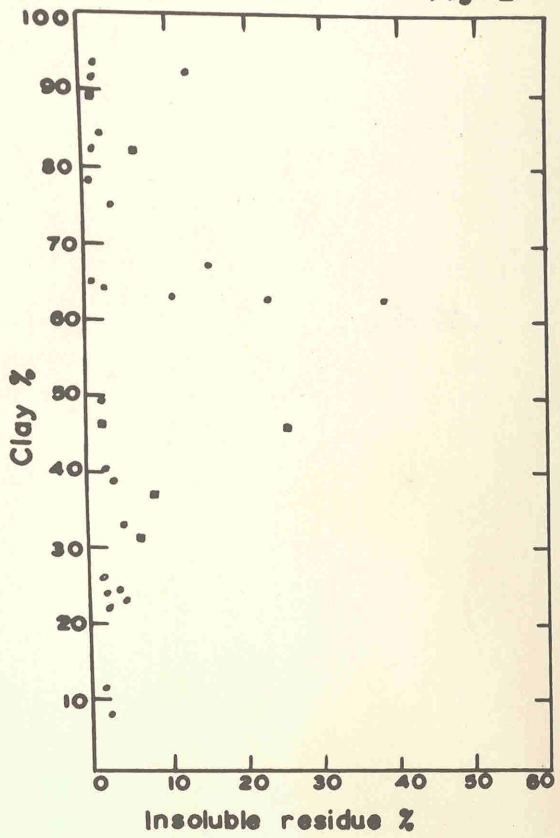


Fig- 4

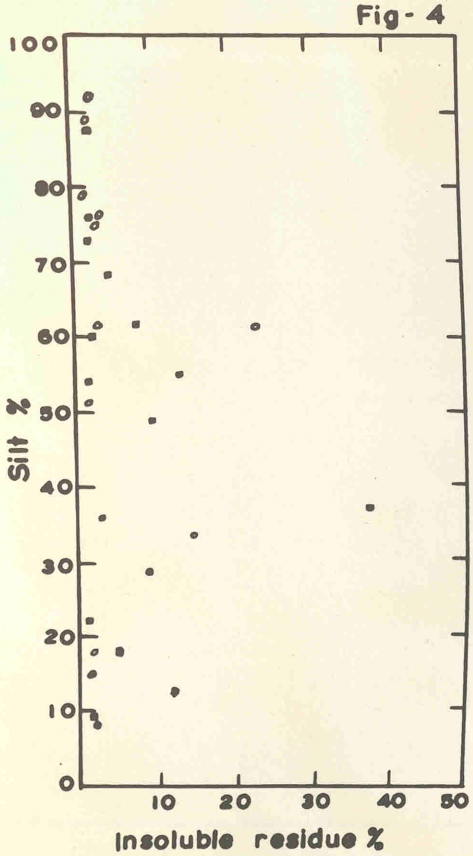
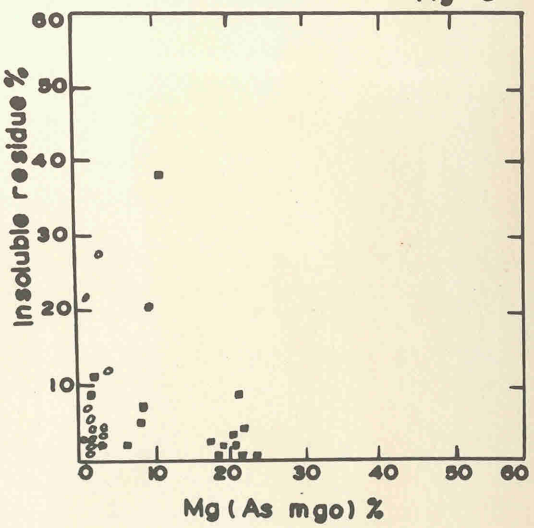


Fig- 3



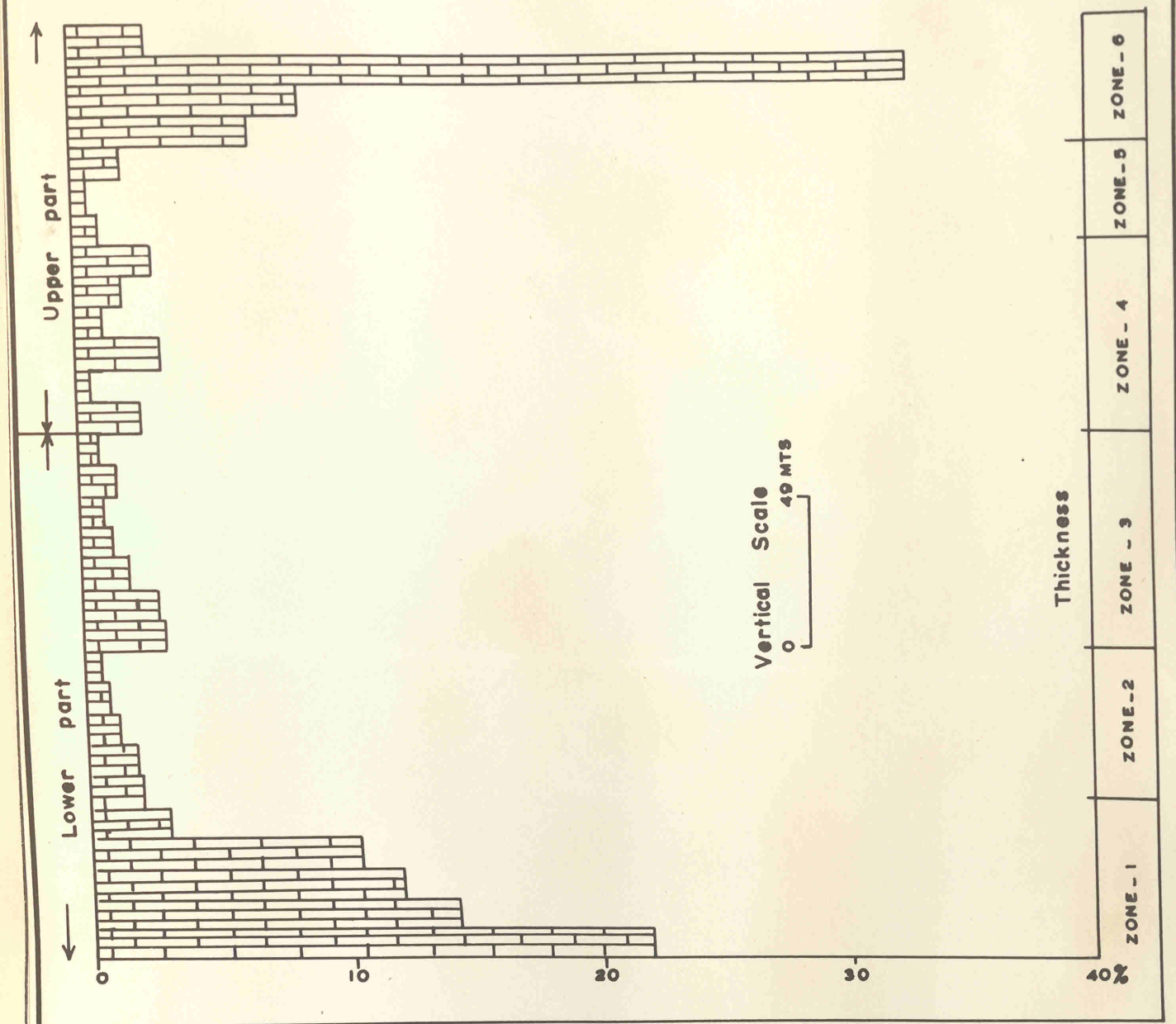
INDEX

UPPER	
LOWER	

PLATE - 35

A Bar diagram showing the bedding interval and approximate thickness of the individual beds in the Syringothyris Limestone, and their different zones plotted on the basis of the insoluble residue percentage.

PLATE - 35



Bar diagram showing the bedding interval/ thickness of the indidual beds in the syringothtris limestone on the basis of precntage insoluble residue.

Scale 1" to 49 mts

PLATE-36

Fig.1 A typical photomicrograph representing encrinoid biosparite variety. showing well developed crinoid stemplate with sparry-calcite. Aláso a well deveoped crack is seen in which calcite lies inserted. (Crossed Nicols x 45).

Fig.2. showing the same characteristic features as that of Fig.1 from the Syringothyris Limestone. except that it is of smaller size. (Crossed Nicols x 45).

Fig.3. showing well preserved calcite slabs (sparry) with well developed cleavages. It also exhibits some stylolites at the junction of these slabs. The photograph represents sparite variety of lower parts of Syringothyris Limestone. (Crossed Nicols x 45).

Fig.4. A stained thin section from the lower part of Syringothyris limestone showing incipient effect of dolomitization along the margins of some brachiopod shells, (white portions) and the dark part is calcic in nature which on staining acquired red colour. (Crossed Nicols x 45).

Fig.5. A photomicrograph of the lower part of Syringothyris limestone showing well preserved crinoidal stem towards left with other allochems in a micritic mass. (Crossed Nicols x 45).

Fig.6. A photomicrograph of lower part of Syringothyris Limestone representing supergenite variety in which the shells of crinoids, skeletal parts of lamellibranchs, brachiopods are present in a sparry calcite mass).(Crossed Nicols x 45)

PLATE - 36

FIG : 1

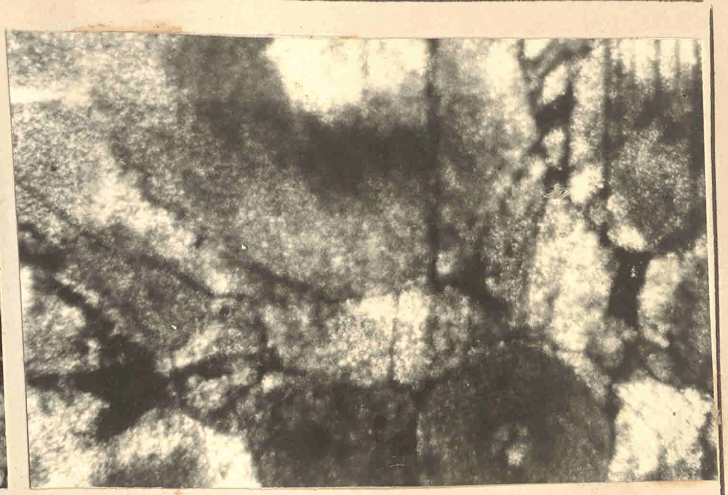


FIG : 2

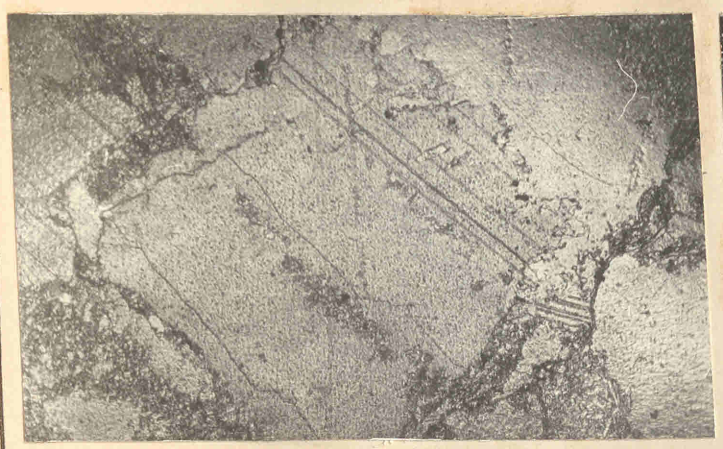


FIG : 3

FIG : 4

FIG : 5

FIG : 6

PLATE - 37

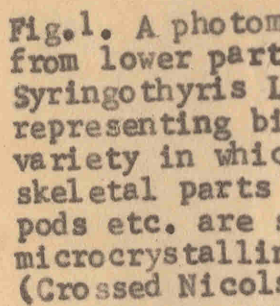


Fig.1. A photomicrograph from lower part of Syringothyris Limestone representing biomicritic variety in which the skeletal parts of brachiopods etc. are set in a microcrystalline cement. (Crossed Nicols x 45)

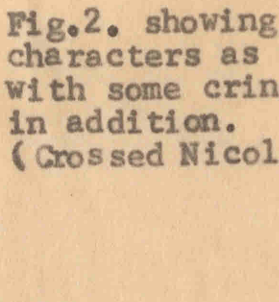


Fig.2. showing the same characters as that of fig.1 with some crinoidal plates in addition. (Crossed Nicols x 45).

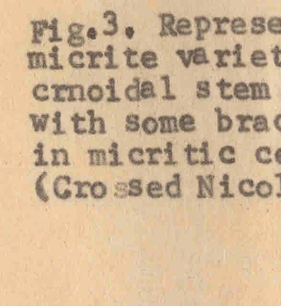


Fig.3. Representing a dismicrite variety in which crnoidal stem is seen along with some brachiopods shells in micritic cement. (Crossed Nicols x 45).

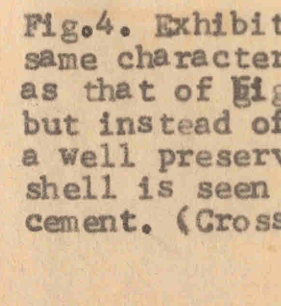


Fig.4. Exhibiting the same characteristics as that of Figure.3. but instead of crinoids a well preserved Ammonoid shell is seen in micritic cement. (Crossed Nicols x 45).

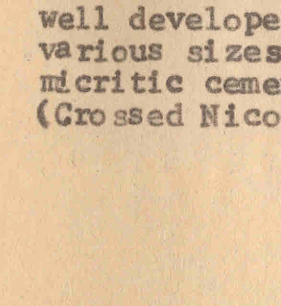


Fig.5 A photomicrograph of the same formation showing well developed pellets of various sizes set in a micritic cement. (Crossed Nicols x 45).

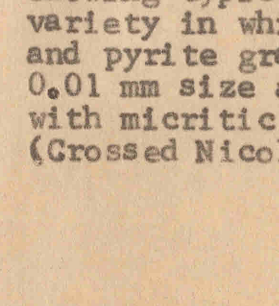


Fig.6. A photomicrograph showing typical micritic variety in which some quartz and pyrite grains less than 0.01 mm size are intermixed with micritic cement. (Crossed Nicols x 45).

PLATE - 37

FIG : 1

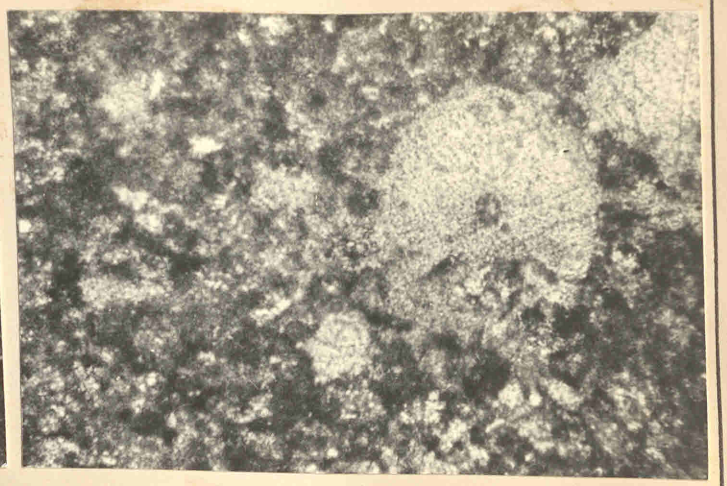


FIG : 2

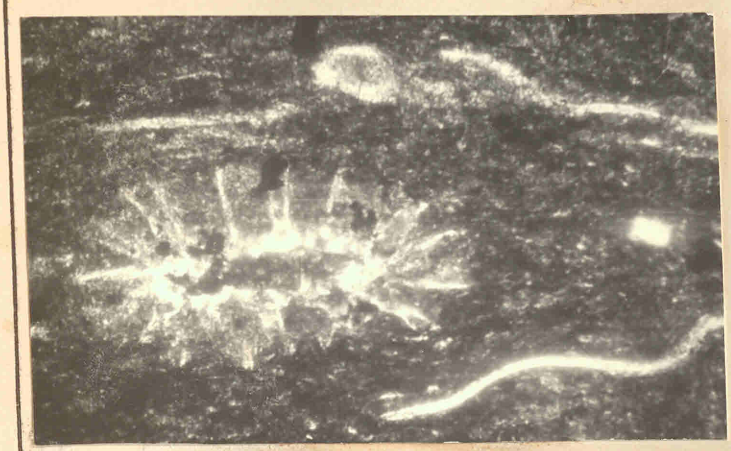


FIG : 3

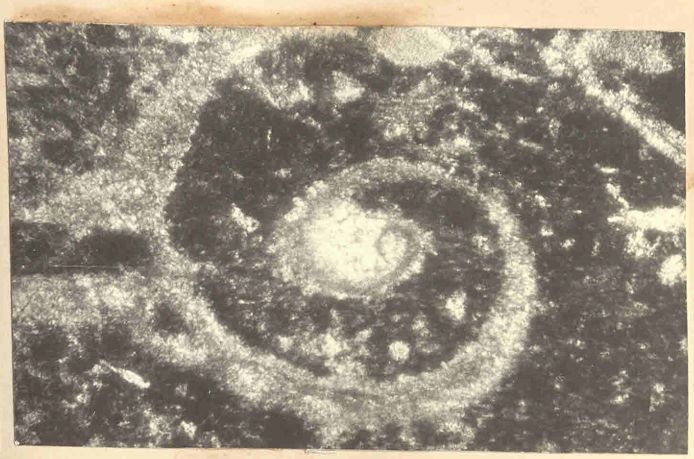


FIG : 4

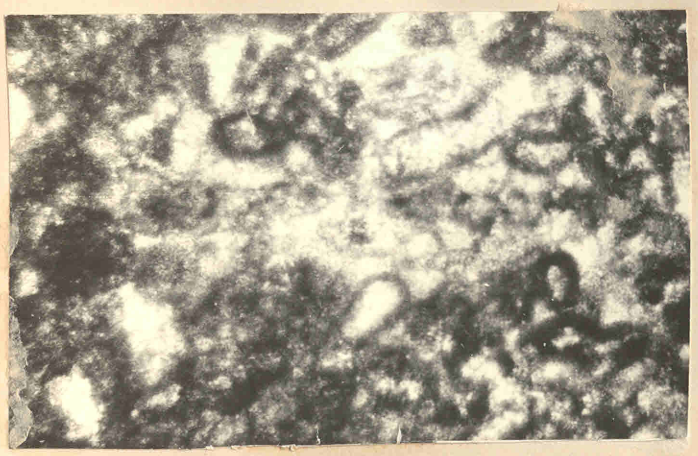


FIG : 5

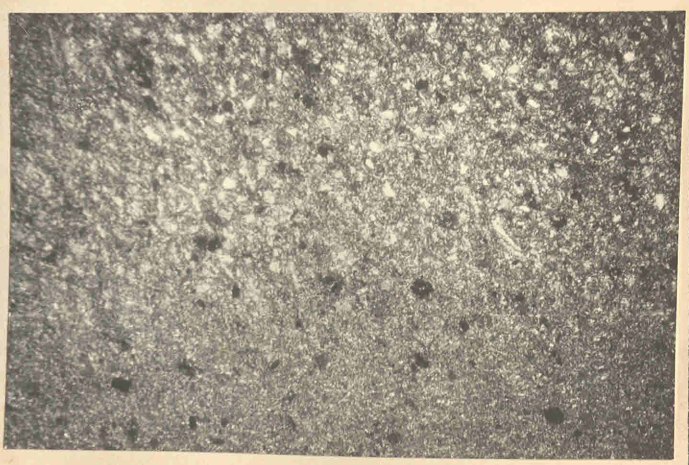


FIG : 6

PLATE - 38

Fig.1. A photomicrograph from the upper part of the Syringothyris Limestone represents dolomiosparitic variety in which the fossil outlines are clearly visible within the dolomitic base. (Crossed Nicols x 45).

Fig.2. showing the same characteristic features as that of Fig.1. (Crossed Nicols x 45).

Fig.3. Showing well developed dolomite rhombs in which the shadows of oolites are seen representing dolo-oosparite and dolosparite varieties from the upper part of this formation. (Crossed Nicols x 45).

Fig.4. A photomicrograph from the upper part of the Syringo thyris Limestone exhibiting same features as that of fig 3, but some well developed oolites in the centre and on the margins in the photograph are seen. (Ghosts oolites) Crossed Nicols x 45).

Fig.5. A photomicrograph showing equidimensional hypediomorphic grains of dolomite 0.05-0.1 mm size with a straight veinlet and forming a mosaic of the grains. It represents dolomicrite variety. (Crossed Nicols x 45).

Fig.6. Representing porphyrodolomicritic variety in which dolomicritic base is quite evident alongwith some lime-mud composed of bigger crystals of quartz and dolomite. (Crossed Nicols x 45).

PLATE - 38

FIG : 1

FIG : 2

FIG : 3

FIG : 4

FIG : 5

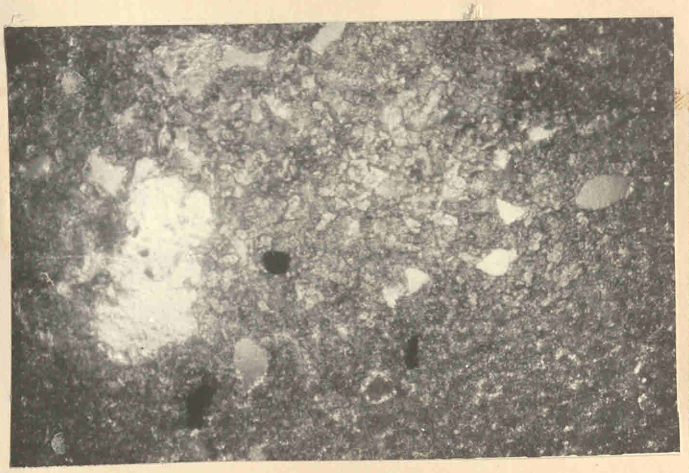


FIG : 6

PLATE-39

Fig.1 A photomicrograph of Fenestella shales representing vitric type of tuff in which the angular grains of quartz less than 0.2 mm size are set in a divitrified glassy matrix. (Crossed Nicols x 45).

Fig. 2. showing the same characteristics features as that of fig. 1 and in it 0.4 mm sized angular quartz grain is embedded in the same matrix.(Crossed Nicols x 45).

Fig.3. representing crystal vitric type of tuff in which a oval shaped portion is seen (preferably skeletal part of a brachiopod fossil) which is encroached by sericitization. (Crossed Nicols x 45).

Fig.4. representing crystal lithic variety in which a large crystal of 0.5 mm size of feldspar is seen with embayed edges towards the glassy matrix. (Crossed Nicols x 45.)

Fig.5. Showing vitric crystal variety in which feldspar grains predominates. (Crossed Nicols x 45).

Fig.6. Of the same formation from the middle part exhibiting angular grains of quartz and a rock fragment with irregular boundaries in the central part. Embedded in a sort of quartzitic cement. (Crossed Nicols x 45.).

PLATE - 39

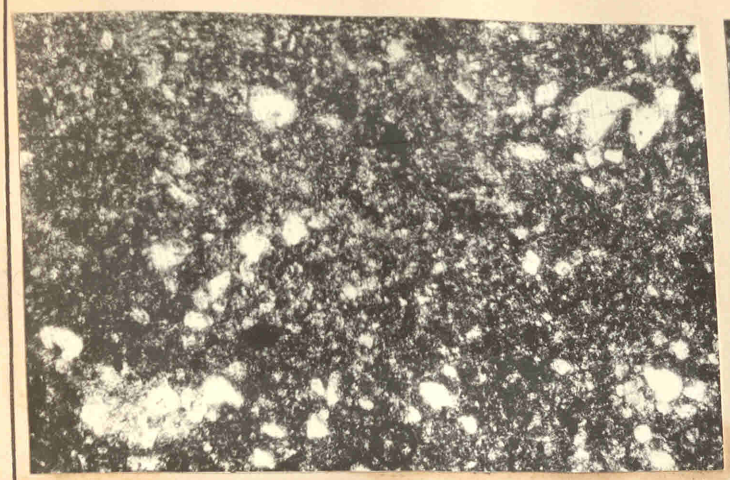


FIG : 1

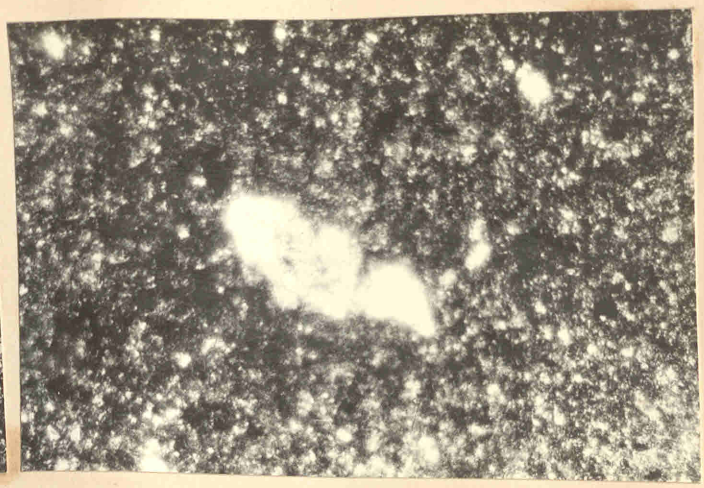


FIG : 2

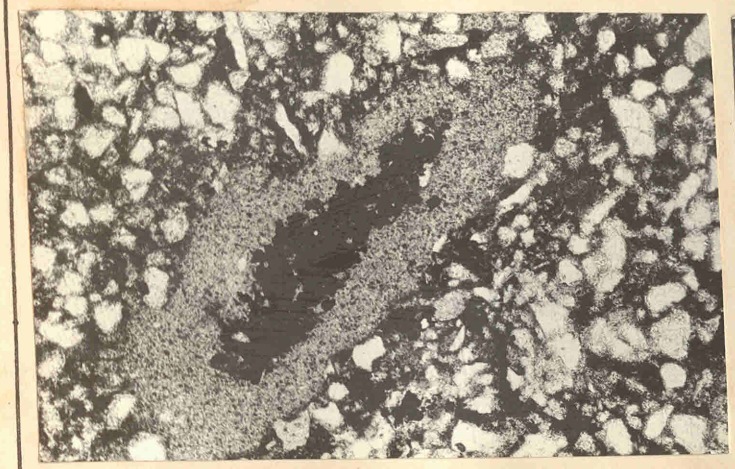


FIG : 3

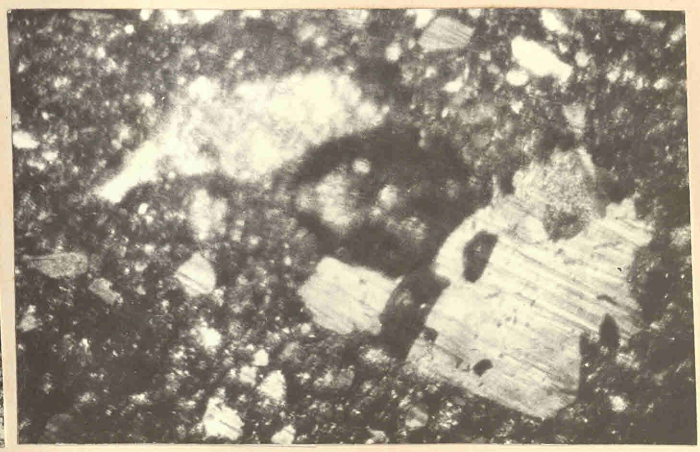


FIG : 4

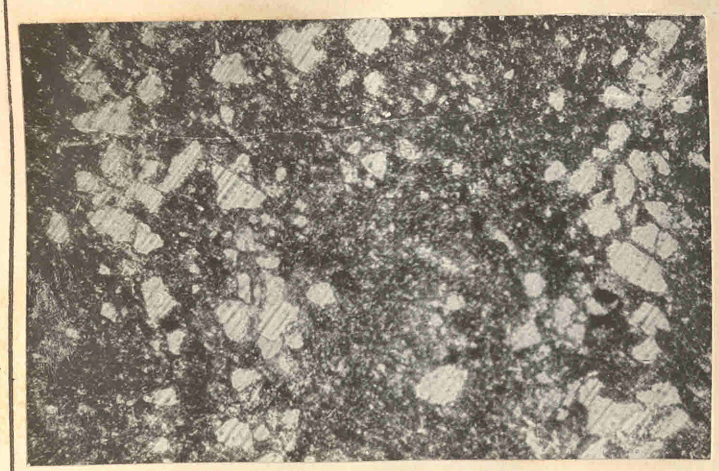


FIG : 5

FIG : 6

PLATE-40

Fig.1. A photomicrograph of Agglomeratic slate exhibiting crystal tuff variety, in which the crystals of quartz and rock fragments are floating in divitrified matrix. (Crossed Nicols x 45).

Fig. 2. showing well developed pattern of lava flow in which the crystals, fine and coarse are set in grades.from Agglomeratic slates. of Batkot. (Ordinary light x 45).

Fig.3. A photomicrograph of basal parts of Agglomeratic slate exhibiting vitric type in which the angular grains are set in a devitrified matrix. (Crossed Nicols x 45).

Fig.4. A photomicrograph of Agglomeratic slates (Lower) showing well developed snow flake texture. (Crossed Nicols x 45).

Fig.5. Showing well developed vitroclastic structure, in which glass shards alongwith some pumice type of material is set in a glassy matrix. (Crossed Nicols x 45).

Fig. 6. Exhibiting same characters as that of fig.1 with angular to subrounded grains of quartz and feldspar in glassy matrix. (Ordinary light x 45).

PLATE - 40

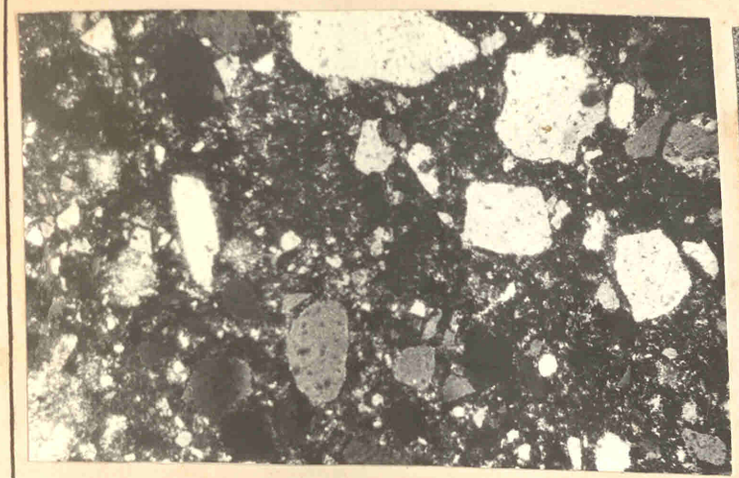


FIG : 1

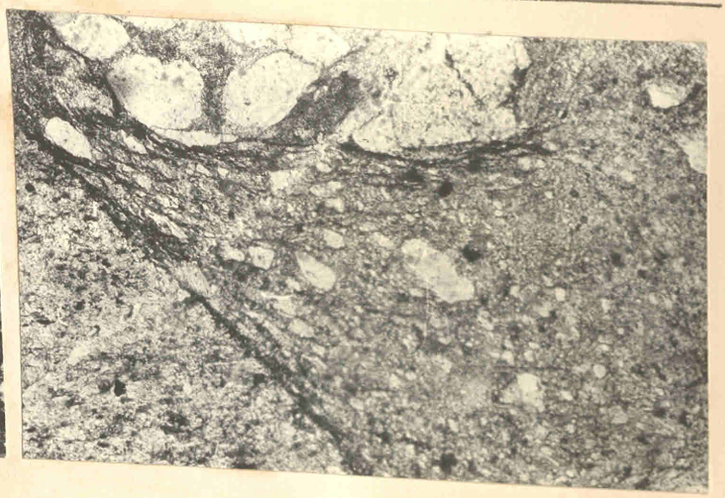


FIG : 2

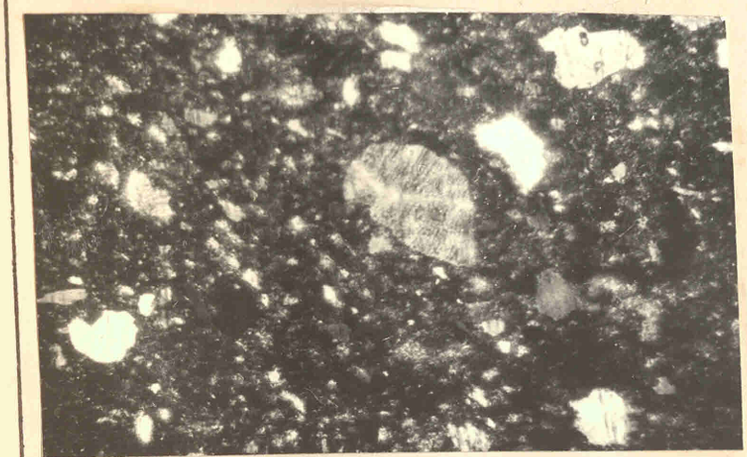


FIG : 3

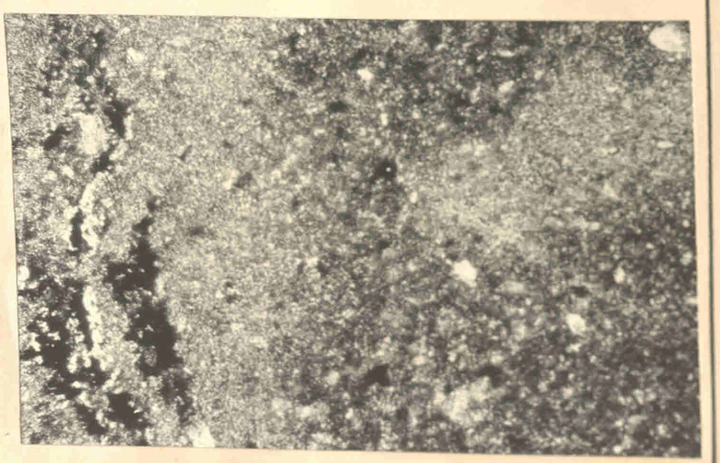


FIG : 4

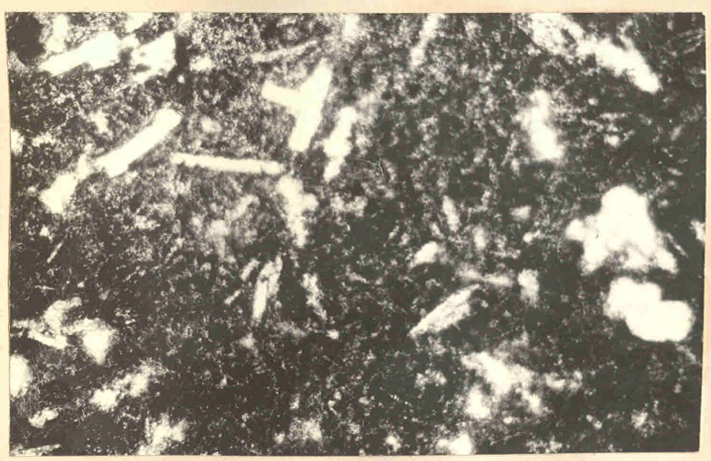


FIG : 5

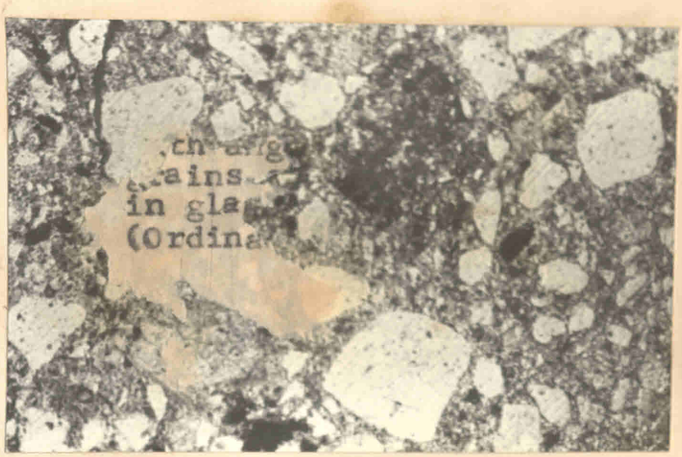


FIG : 6

Fig.1. A photomicrograph from the upper part of Agglomeratic slate exhibiting lithic variety, in which a rounded phenocryst of a coin shape with resorb-borders embedded in a glassy matrix. (Crossed Nicols x 45).

Fig. 2. showing same characters as that of Fig.1, but a lithic fragment of quartzite is seen with a dark coloured seam at the right side with some secondary material surrounded by grains of unequal dimensions. (Ordinary light x 45).

Fig.3. exhibits a rhyolitic phenocryst of quartz which is more or less sericitized, embedded in a glassy matrix. (Crossed Nicols x 45).

Fig. 4. A photograph from the upper parts of the Agglomeratic slates showing a large sized quartzitic fragment with its resorbed borders towards the right side embedded in a devitrified matrix.(Sericitic). (Ordinary light x 45).

Fig.5. of the same formation showing a large sized fragment of sanidine which is encroached by sericite in the central part and embedded in a devitrified glassy matrix.(Crossed Nicols x 45).

Fig.6. Exhibiting same characters as that of fig.2 but a big subangular quartz crystal is seen with cracks and secondary overgrowths in a devitrified, sericitized glassy matrix.(Crossed Nicolsx 45).

PLATE - 41

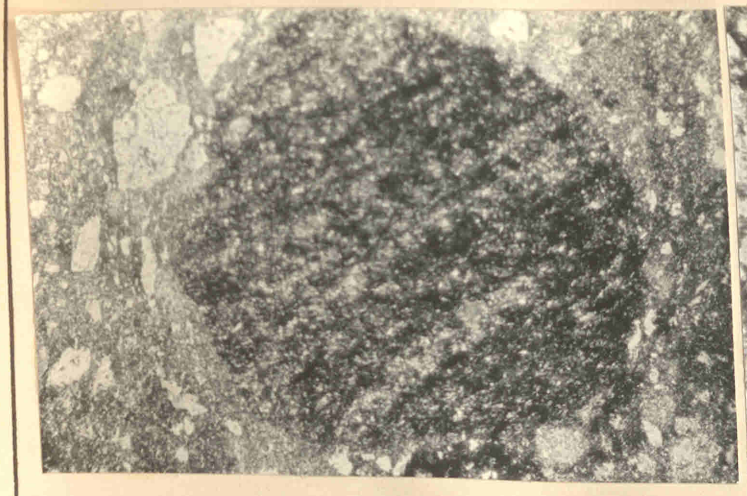


FIG : 1

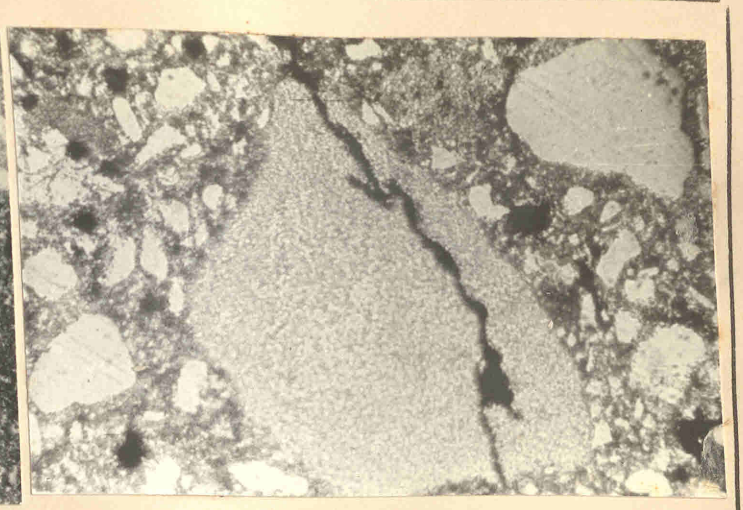


FIG : 2

FIG : 3

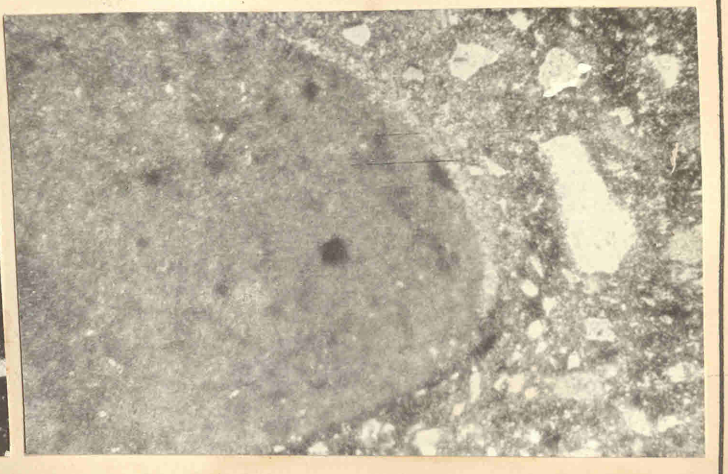


FIG : 4

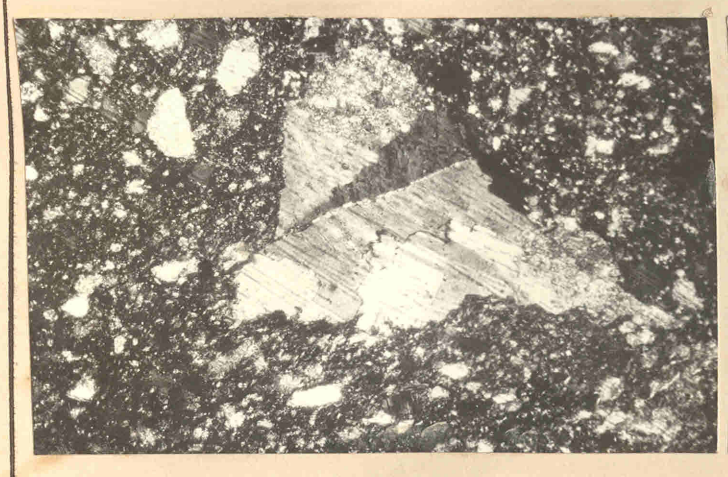


FIG : 5

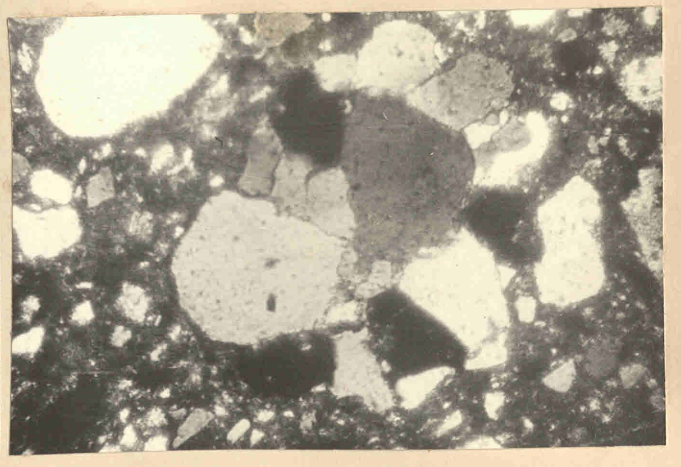
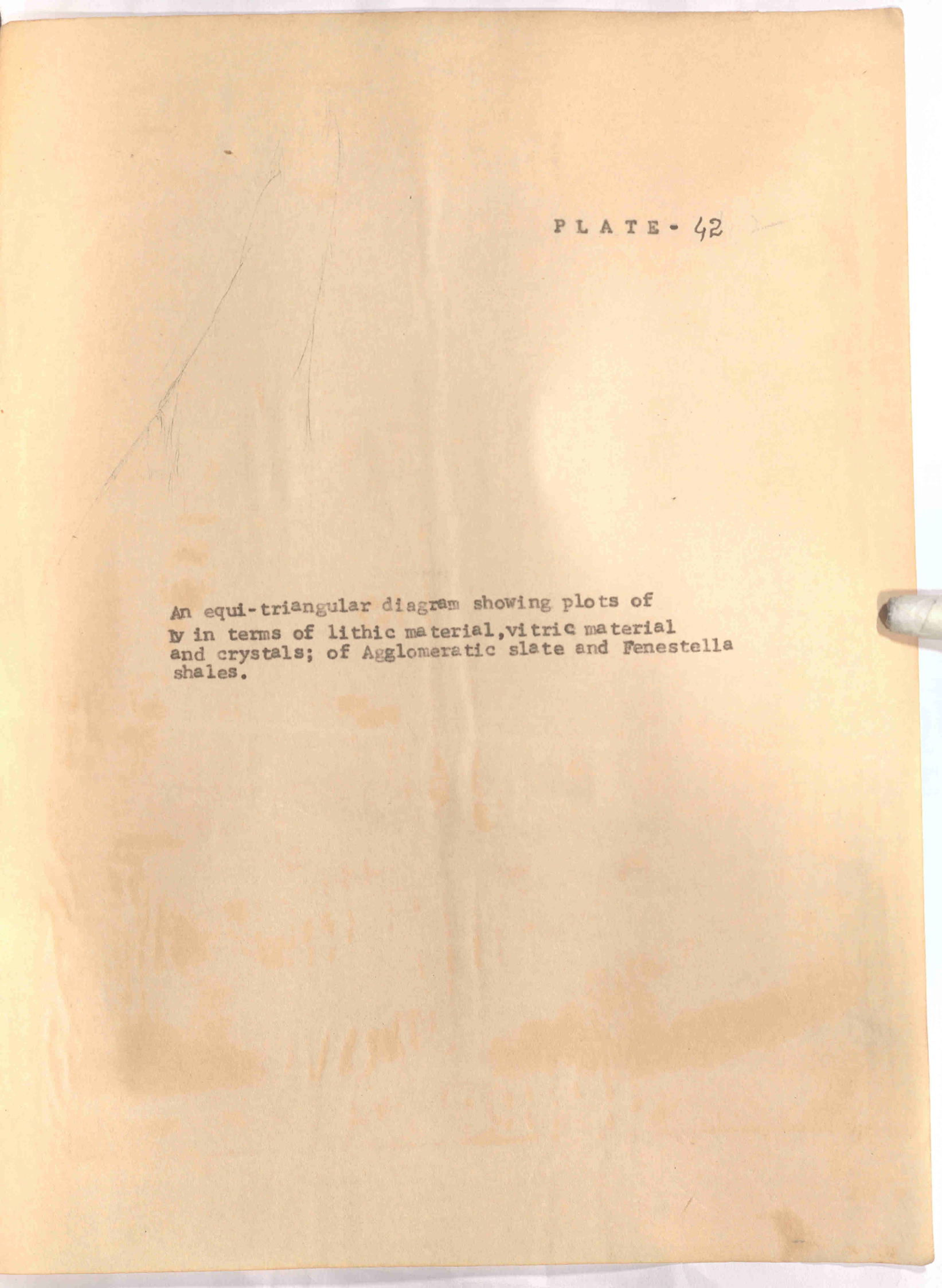


FIG : 6

PLATE - 42



An equi-triangular diagram showing plots of Ny in terms of lithic material, vitric material and crystals; of Agglomeratic slate and Fenestella shales.

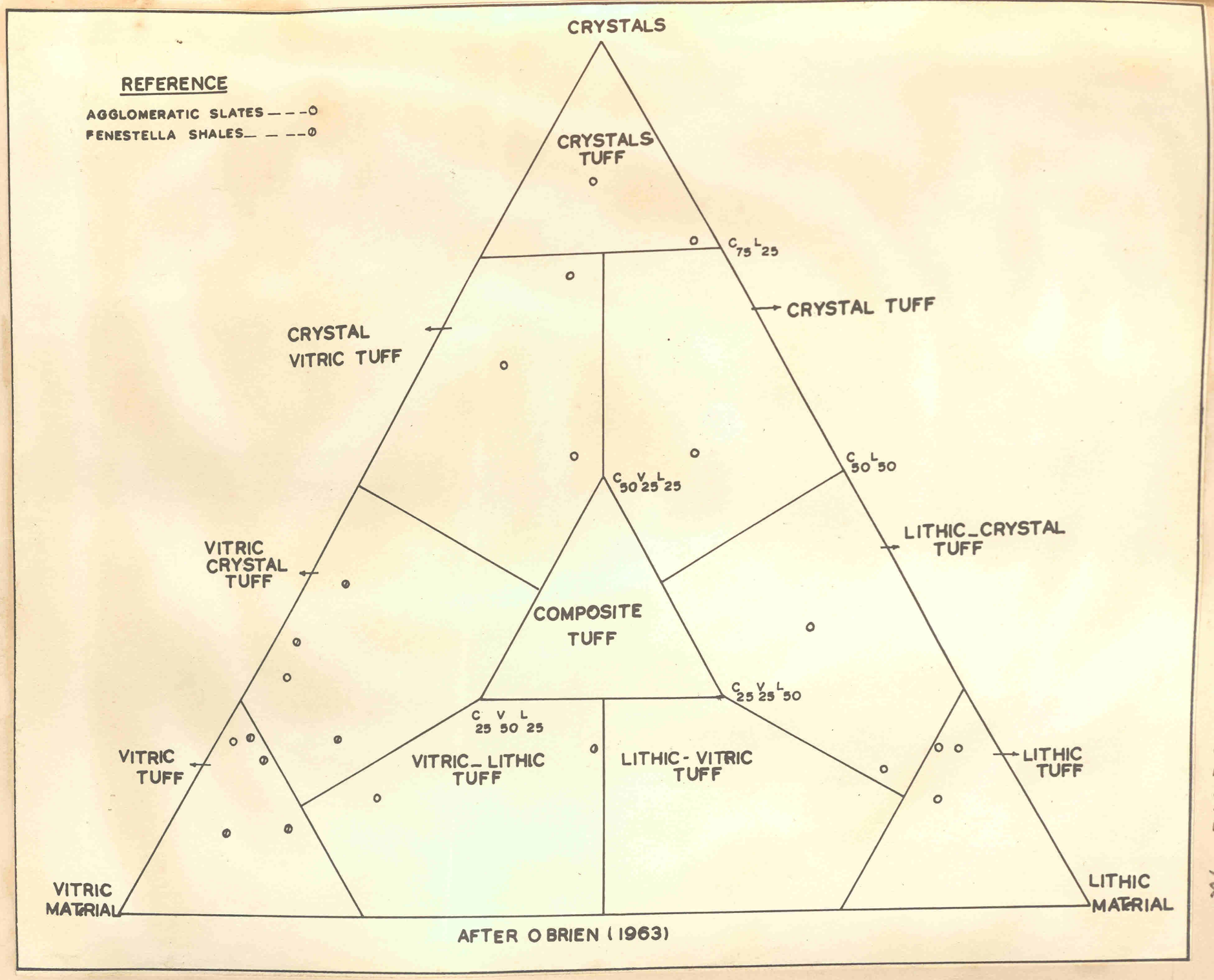

CRYSTALS
REFERENCE
AGGLOMERATIC SLATES
FENESTELLA SHALES
CRYSTALS TUFF
$C_{75}L_{25}$
CRYSTAL TUFF
CRYSTAL VITRIC TUFF
$C_{50}L_{50}$
$C_{50}V_{25}L_{25}$
LITHIC_CRYSTAL TUFF
VITRIC CRYSTAL TUFF
COMPOSITE TUFF
$C_{25}V_{25}L_{50}$
$C_{25}V_{50}L_{25}$
VITRIC TUFF
VITRIC_LITHIC TUFF
LITHIC-VITRIC TUFF
LITHIC TUFF
VITRIC MATERIAL
LITHIC MATERIAL
AFTER O BRIEN (1963)

PLATE-42

PLATE - 43

Histograms of some representative samples
of Fenestella shales.

PLATE - 43

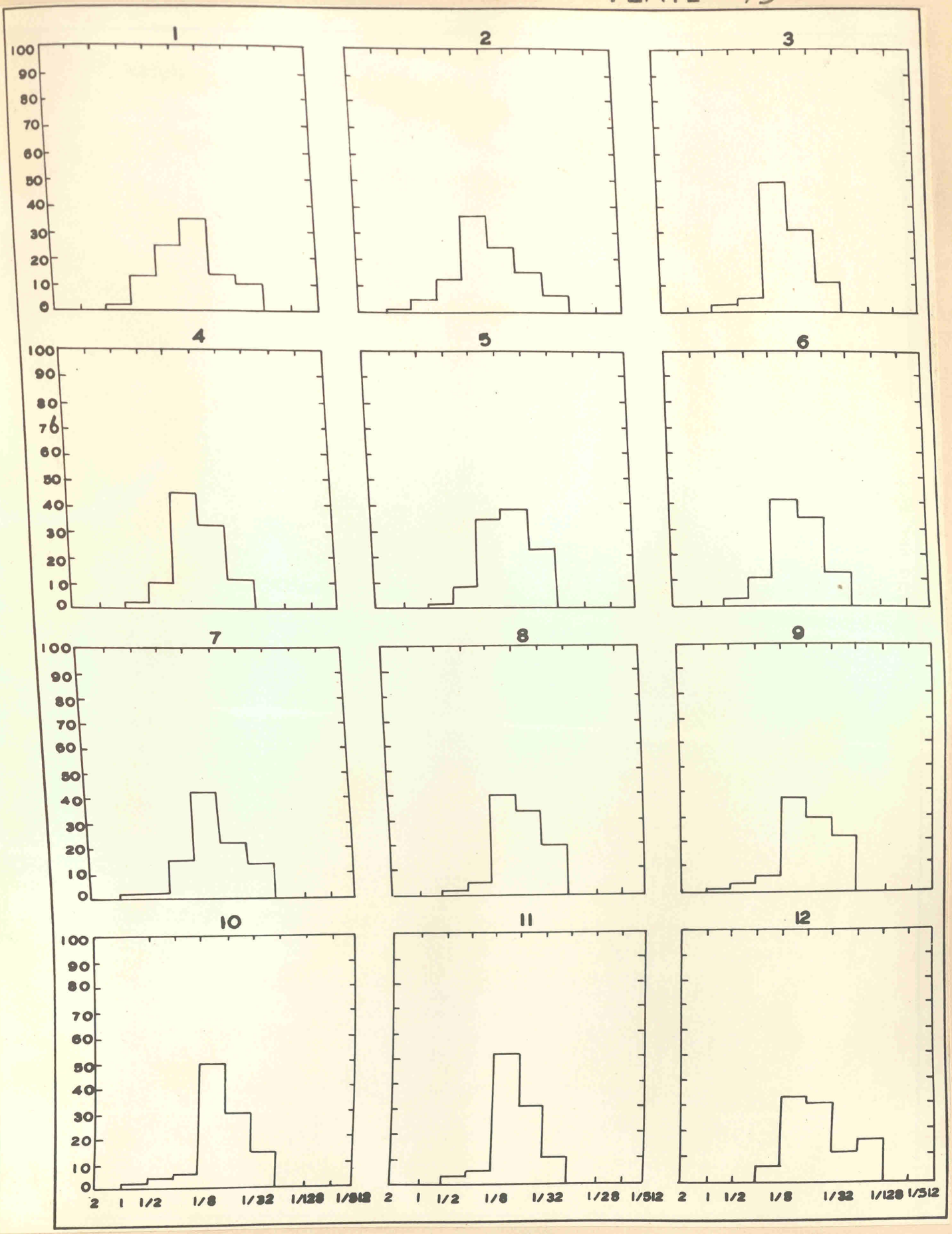

1
2
3
4
5
6
7
8
9
10
11
12
100
90
80
70
60
50
40
30
20
10
0
2 1 1/2 1/8 1/32 1/128 1/512

PLATE - 44

Histograms of some selected samples from the Agglomeratic Slates.

PLATE - 44

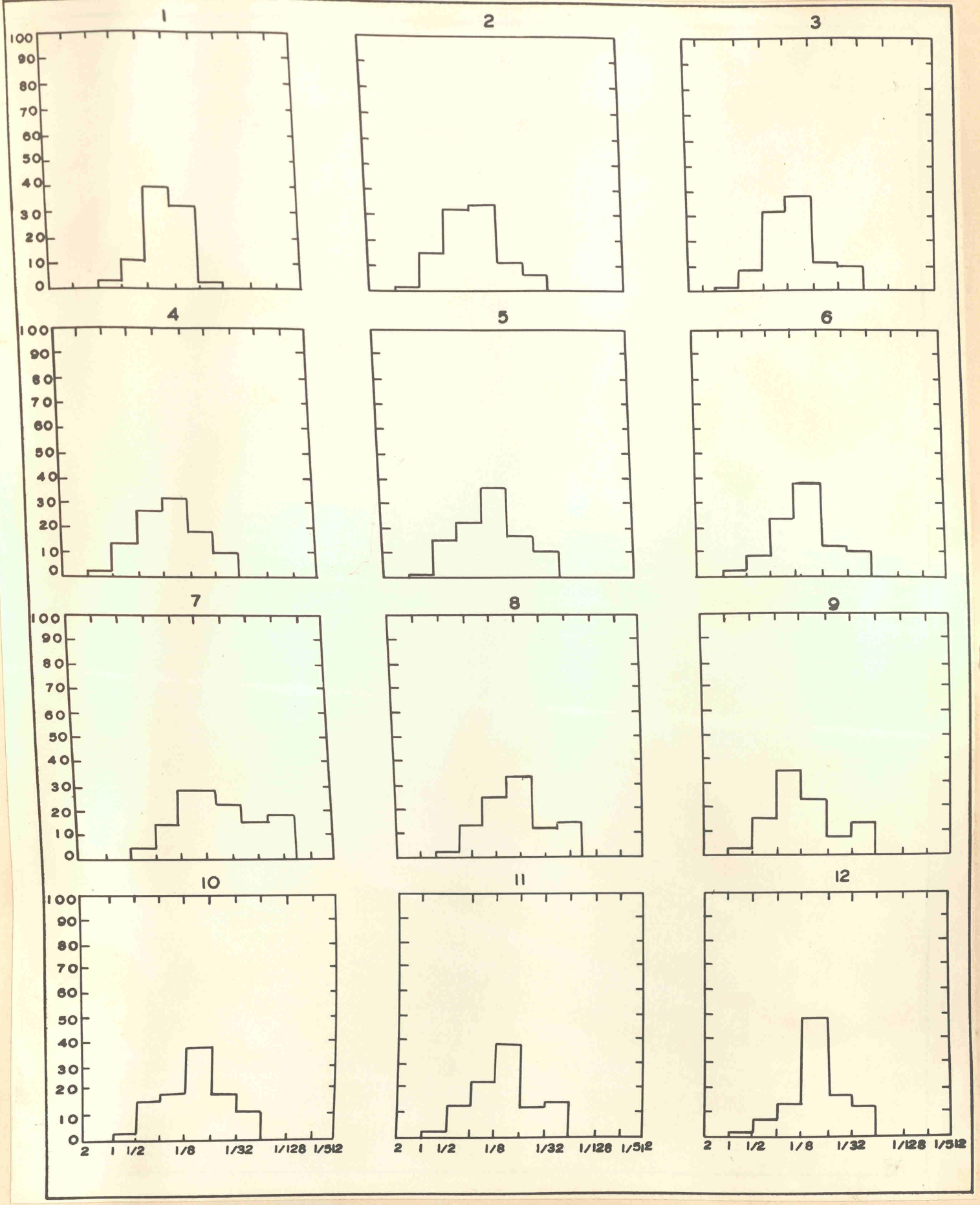
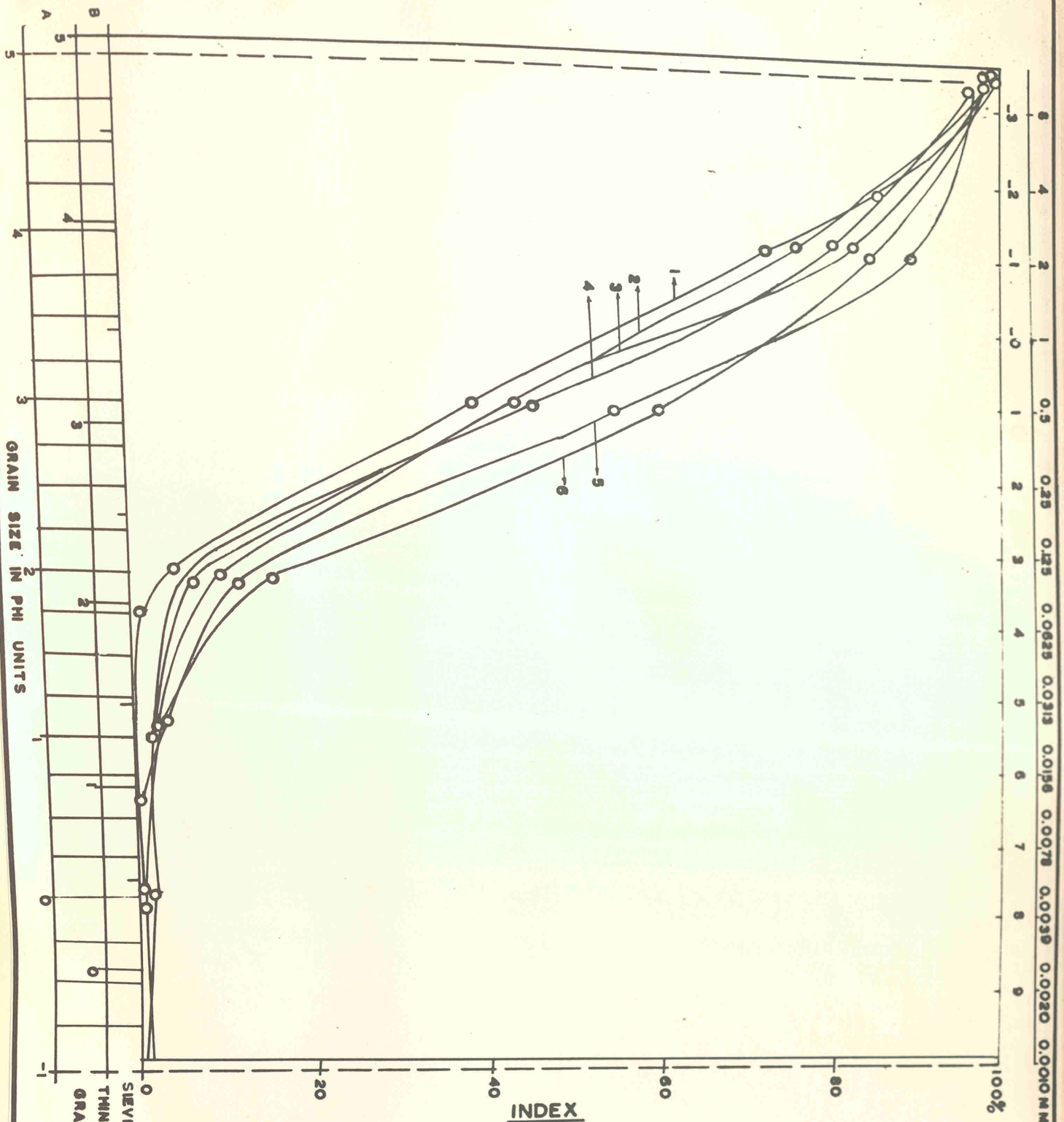

1
2
3
4
5
6
7
8
9
10
11
12
100
90
80
70
60
50
40
30
20
10
0
2
1
1/2
1/8
1/32
1/128
1/512

PLATE • 45.

Cummulative curves showing mechanical composition
of the representative samples of the Fenestella shales.

PLATE - 45



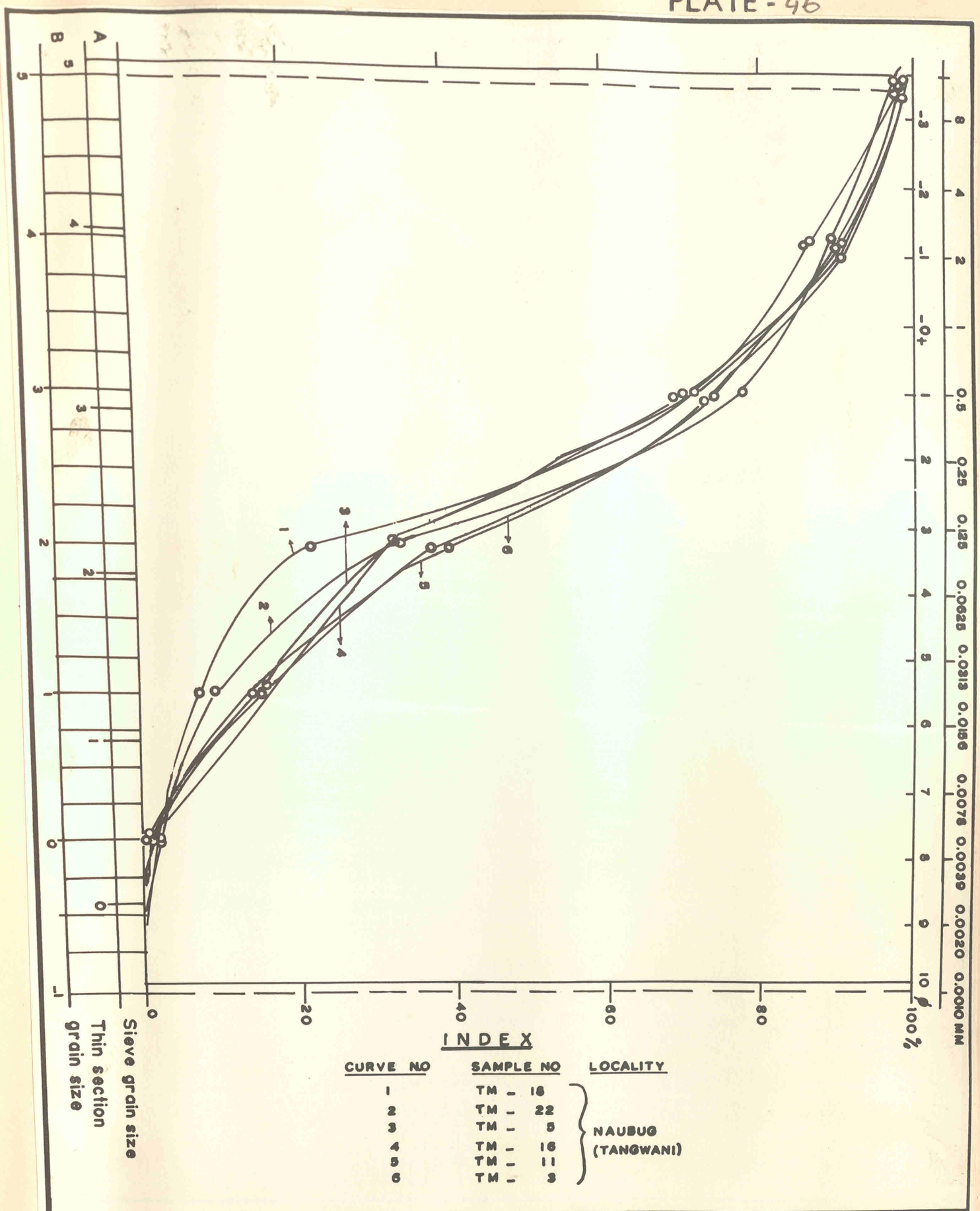
INDEX

CURVE NO	SAMPLE NO	LOCALITY
1	F - 4	YENNER
2	F - 6	YENNER
3	F - 10	YENNER
4	F - 9	YENNER
5	F_2 - 3	DHOWAT
6	F_2 - 5	DHOWAT

PLATE-46

Cummulative curves showing mechniacal composition of representative samples from Naubug of Agglomeratic slates.

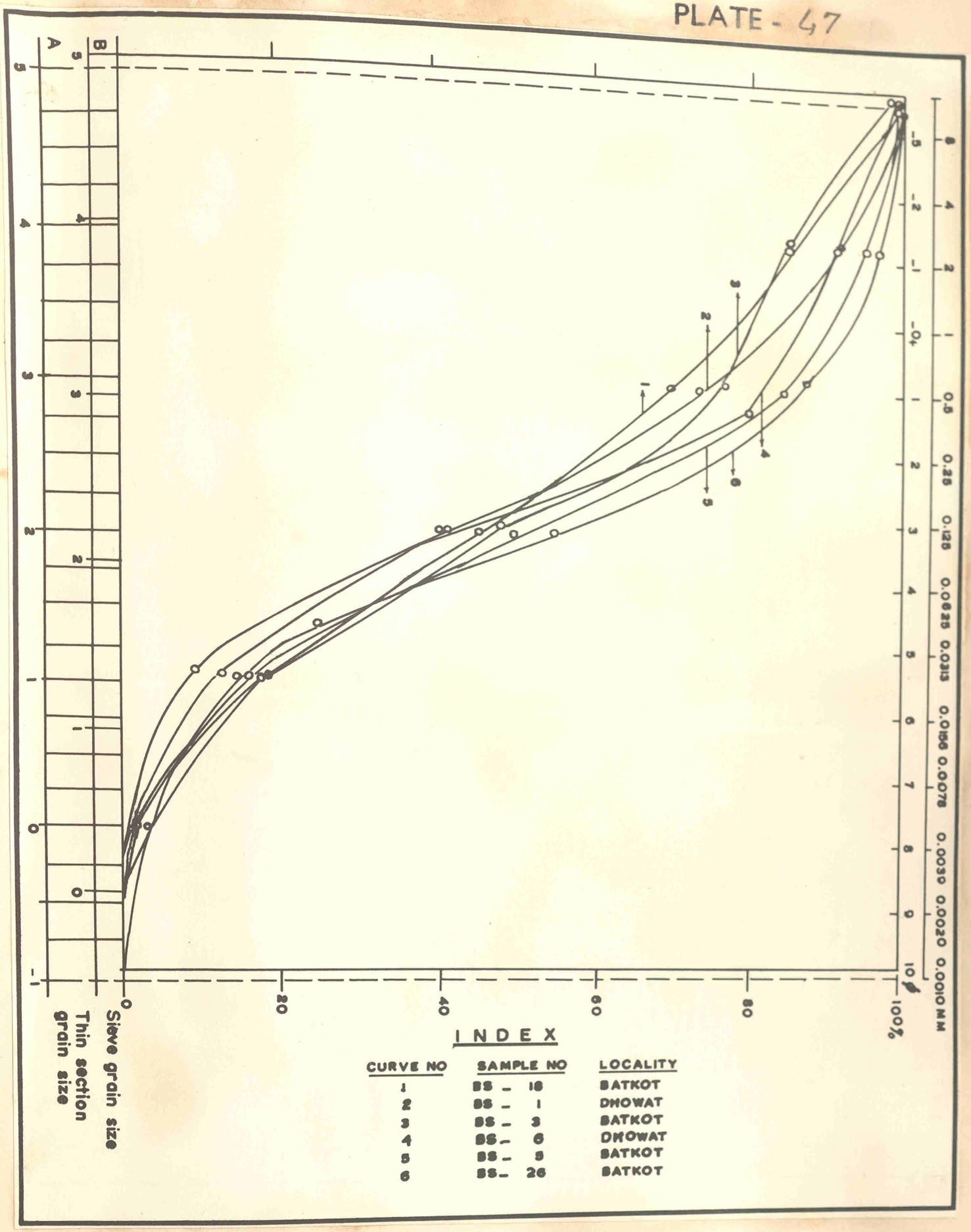
PLATE - 46



INDEX

CURVE NO	SAMPLE NO	LOCALITY
1	TM - 18	NAUBUG (TANGWANI)
2	TM - 22	
3	TM - 5	
4	TM - 16	
5	TM - 11	
6	TM - 3	

PLATE - 47



INDEX

CURVE NO	SAMPLE NO	LOCALITY
1	BS - 18	BATKOT
2	BS - 1	DHOWAT
3	BS - 3	BATKOT
4	BS - 6	DHOWAT
5	BS - 5	BATKOT
6	BS - 26	BATKOT

PLATE - 47

Cummulative curves of the representative smaples from Batkot area. of Agglomeratic Slates.

PLATE - 48

N

FIG-1

FIG-2

FIG-3

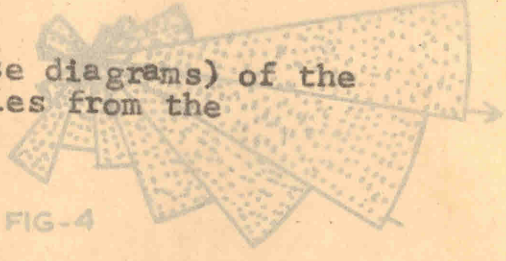


FIG-4

Semicircular histograms (Rose diagrams) of the grain orientations and pebbles from the Agglomeratic slates.

FIG-5

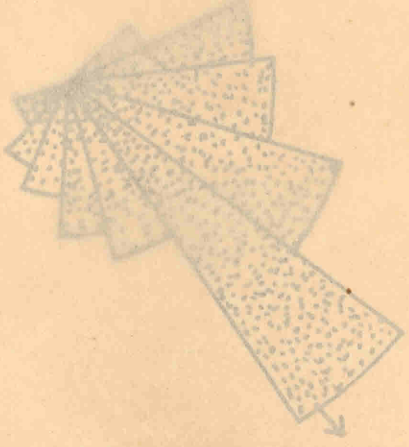
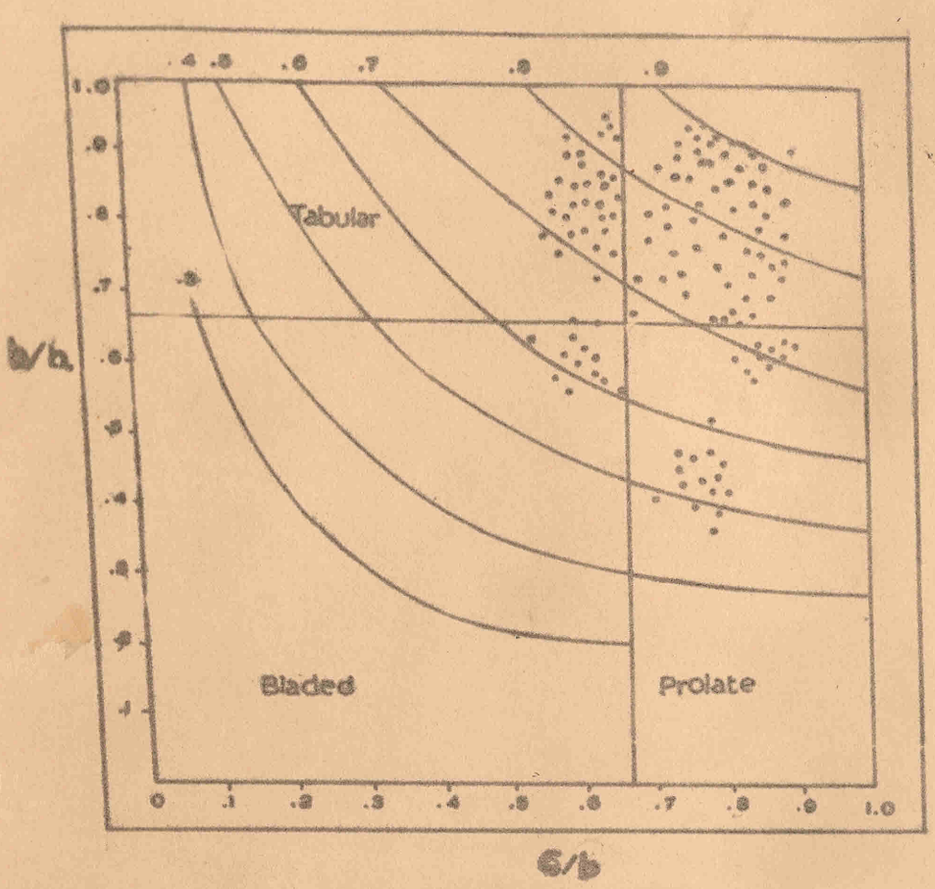


FIG-6

PLATE - 49

Zingg diagram showing the plots of mega clasts of the pebbles of quartzites and slates from the Agglomeratic series.

PLATE - 49



$$b/a = \frac{\text{intermediate axis}}{\text{Long axis}}$$

$$c/b = \frac{\text{Short axis}}{\text{intermediate axis}}$$

Localities :

Tangwani - Naubug
Batkot — virsren
Dhowat

ZINGG DIAGRAM FOR THE MEGACLASTS OF THE PEBBLES OF QUARTZITES, SLATS etc. FROM AGGLOMERATIC SLATES.

PLATE- 50

Sedimentary models for the Palaeozoic rocks of Anantnag, Kashmir.

SEDIMENTARY MODEL'S FOR THE PALAEOZOIC'S OF ANANTNAG.

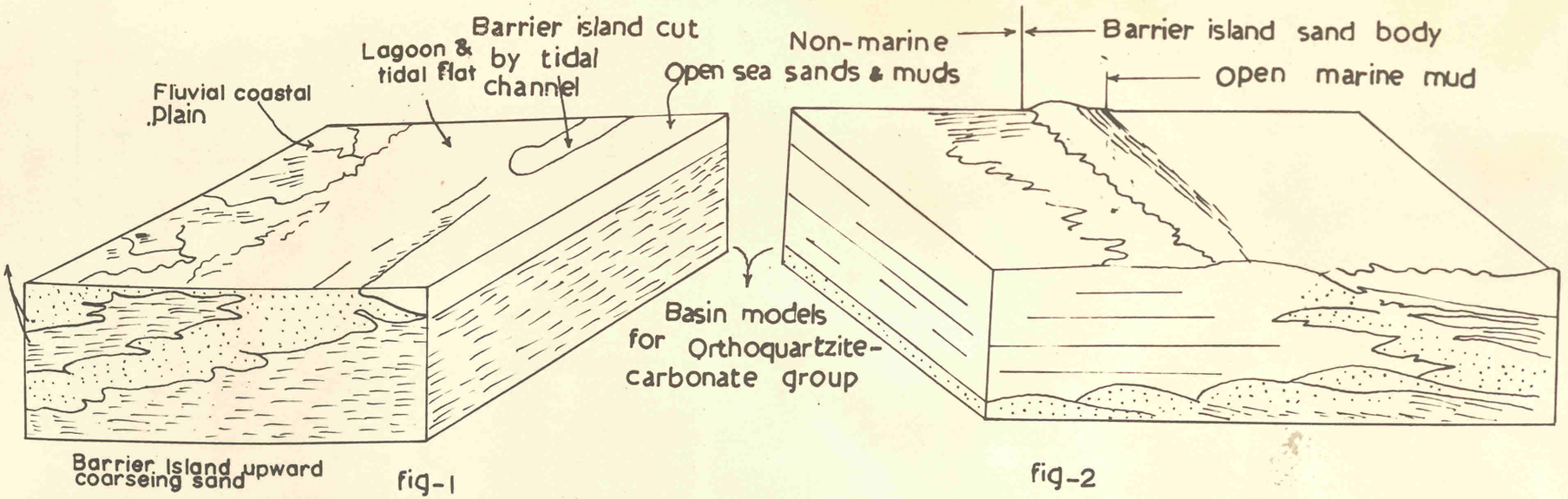


fig-1

fig-2

Basin models for Orthoquartzite-carbonate group

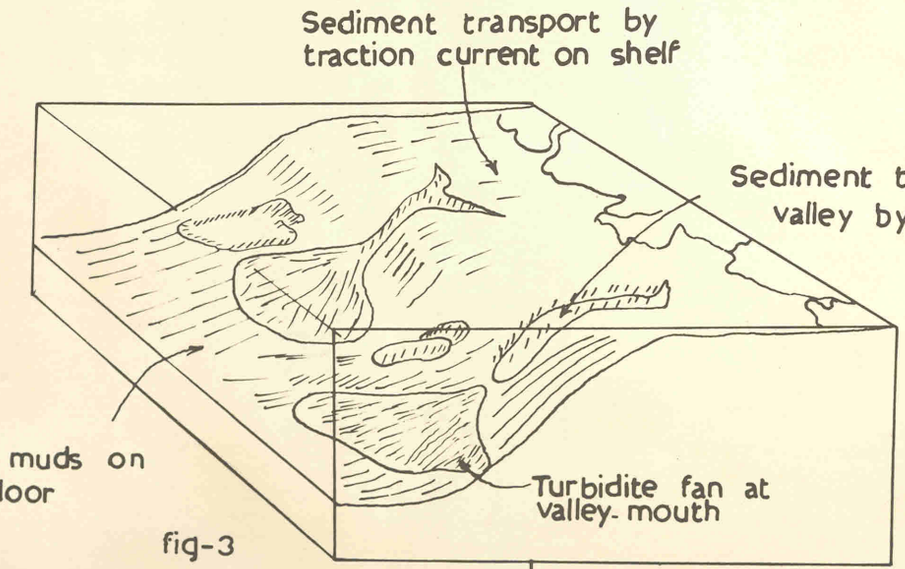


fig-3

(After, Selley 1976)

SEDIMENTARY MODEL FOR SHALE-SLATE-GREYWACKE GROUP

PLATE - 50

PLATE-52

0 2 4 kms

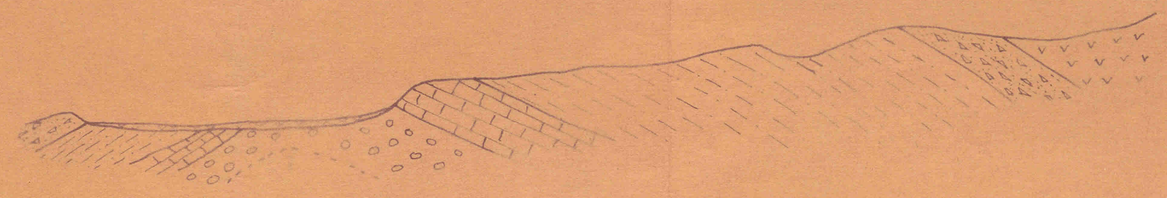
S 54° W

A

N 54° E

A'

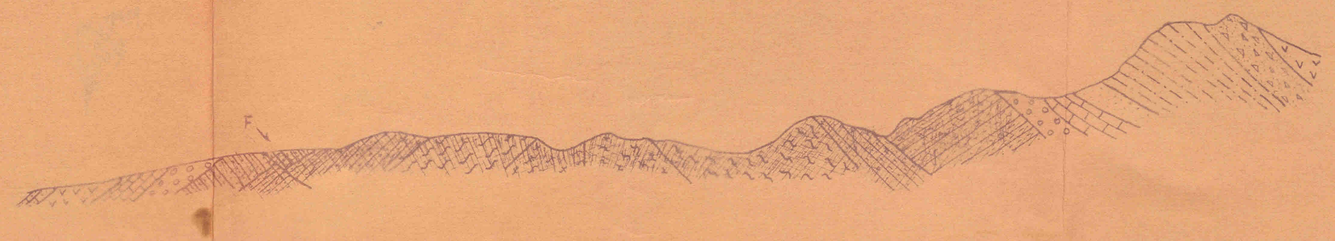
3000m
2000m
1000m



B

B'

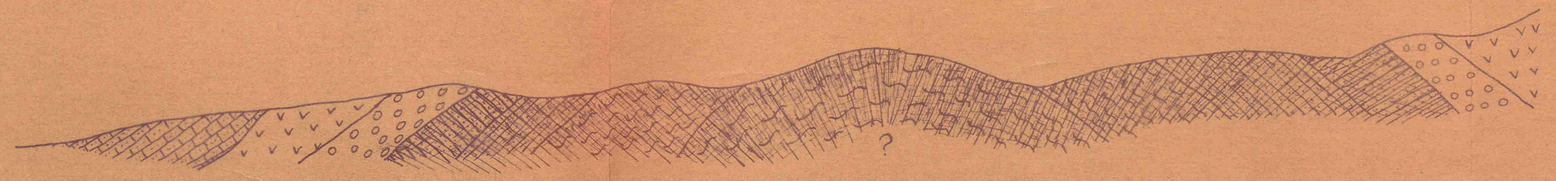
4000 m
3000 m
2000 m
1000 m



C

C'

3000 m
2000 m
1000 m



ALLUVIUM

TRIASSIC LIMESTONE

PANJAL TRAP

BATKOT FORMATION

YENNER FORMATION

CINDERNAR GALI FORMATION

AISHMUQAM FORMATION

GURDERMAN FORMATION

UPPER
LOWER
HAPTNAR FORMATION

UPPER
LOWER
GAURAN FORMATION

PLATE - 28

An Equi-triangular diagram showing the plot of the Percentages of Quartz, feldspar and rock fragments of Muth quartzites, Passage beds and Associated quartzites.