

PETROLOGICAL STUDY OF ROCKS AROUND  
BANDIPURA, BARAMULLA DISTRICT,  
J & K STATE.

Thesis Submitted for the Degree of Doctor  
of Philosophy, Faculty of Science,  
University of Jammu

By

AUTAR KRISHEN RAINA

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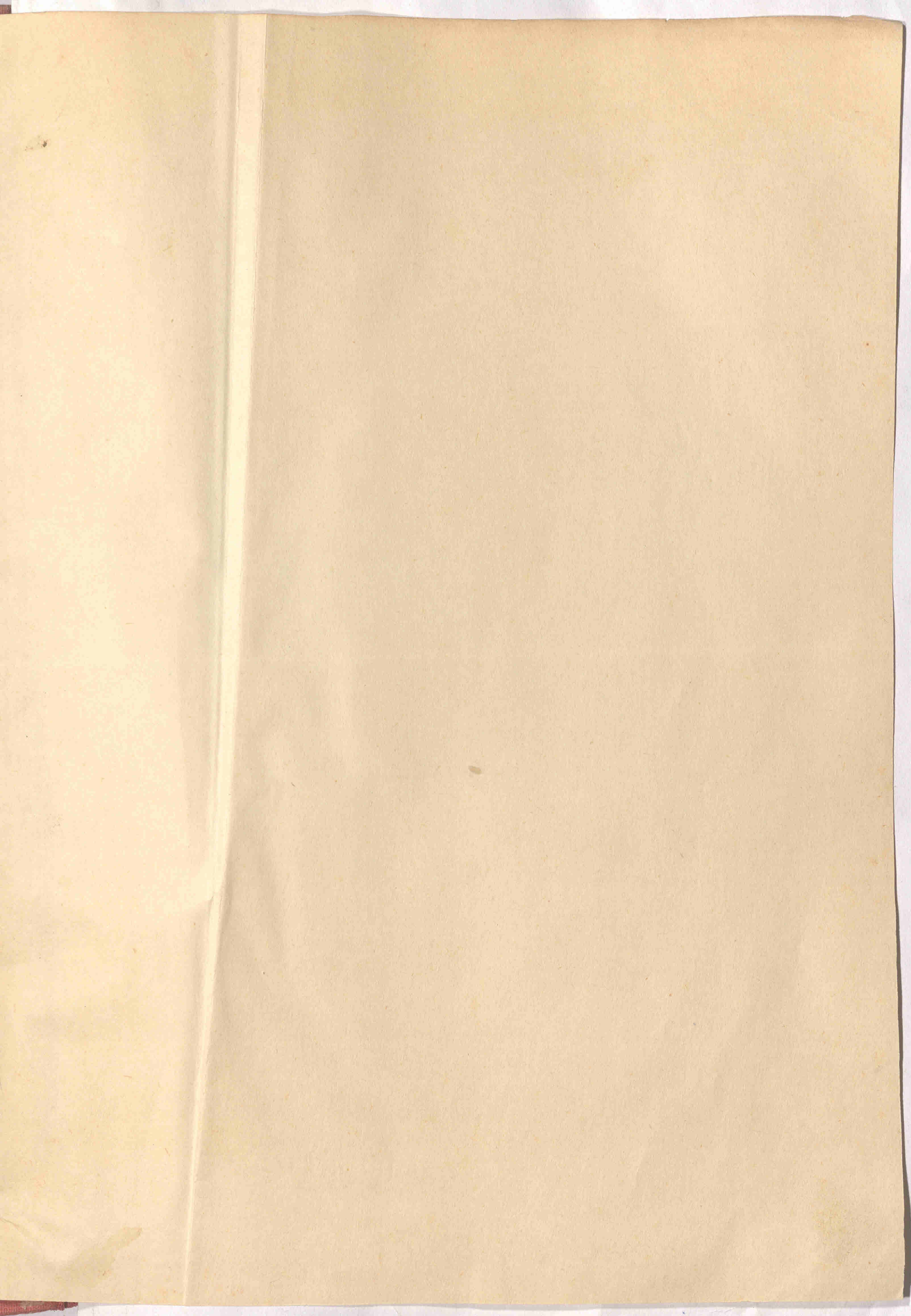
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POST GRADUATE DEPARTMENT OF GEOLOGY

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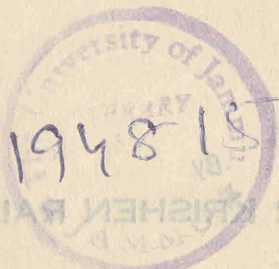
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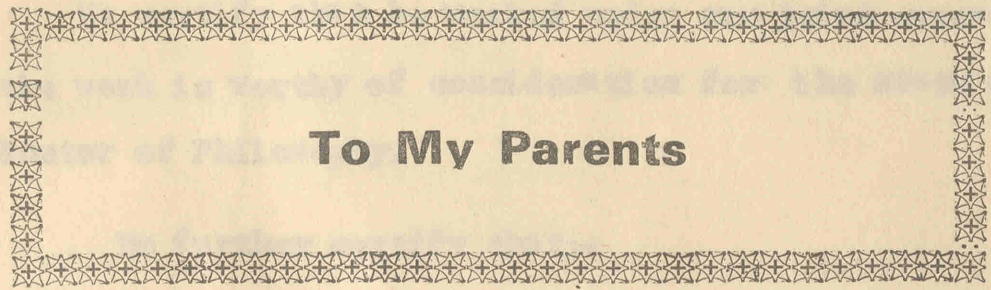
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DECLARATION

I hereby declare that the work presented in this thesis is my original work and has not been published elsewhere. I also declare that the work is not a plagiarized work and that I have not used any material from any source without the permission of the concerned authorities.



To My Parents

The work presented in this thesis is dedicated to my parents for their love, support and encouragement. I am grateful to them for their constant prayers and wishes for my success. I also thank them for their sacrifices and hard work for my education.

*[Signature]*  
Author

*[Signature]*  
Parent

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## C E R T I F I C A T E

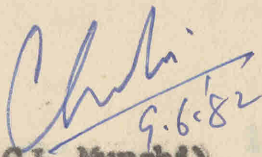
Mr. Autar Krishen Raina, who was registered as a regular Research scholar in the Department of Geology, University of Jammu, Jammu for the degree of Doctor of Philosophy under our supervision has completed his work. The precise title of his thesis is, " Petrological study of rocks around Bandipura, Baramulla district, J & K state."

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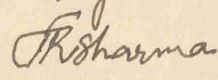
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- a)- the thesis incorporates the work of the candidate himself
- b)- the candidate worked under our supervision for the period required under statutes
- c)- the candidate has put in the required attendance in this department during that period
- d)- the conduct of the candidate remained satisfactory during that period

  
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## CHAPTER - I

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

Kashmir Himalaya has been attracting the attention of geologists from home and abroad since the early part of the nineteenth century because almost all the formations from Precambrian to Recent, with a few stratigraphical breaks are exposed here. To this date easily accessible areas have been investigated in some detail, especially during the course of the recent years, but many inaccessible portions remain to be studied and explored. After this is done, a clear picture of the geology of the entire region will emerge. The present study was taken up at the Post Graduate department of Geology, University of Jammu, Jammu, with this point in view. It is hoped this humble attempt primarily aimed at a field, petrological, mineralogical and petrochemical study of rocks

exposed around Bandipura will bridge an important gap in the geology of a hitherto less known area. The Cambrian-Triassic sequence of northwest Kashmir was investigated by Wadia (1934). He referred to the Panjal traps intercalated with Triassic limestones from this area. On the basis of this, Wadia obviously presumed that the Panjal trap activity lengthened up to the Triassic period. This aspect, though outside the scope of the present study, has been treated in Chapter-VII because of its importance.

#### AREA OF STUDY

The study area can be approached from Srinagar city after travelling a distance of about 50 km up to Bandipura - the tehsil headquarters of the region. The higher reaches of the area under investigation are connected by fair weather roads where only light vehicles can ply. The interior parts can be visited by various foot and bridal paths (fig.1). The pile of volcanites occur between Lat.  $34^{\circ} 23'$  to  $34^{\circ} 30'$  N and Long.  $74^{\circ} 35'$  to  $74^{\circ} 50'$  E. Limestone exposure lies between Lat.  $34^{\circ} 25'$  to  $34^{\circ} 30'$  N and Long.  $74^{\circ} 38'$  to  $74^{\circ} 47'$  E. The study area forms parts of Survey of India Toposheet nos. 43 J/11 and 43 J/15 (1" = 1 mile). Field work is possible from April to November in a year and for the remaining part it remains snow covered. A panoramic view of a portion of the

area under study is shown in plates 2 and 3 and in fig.4. In spite of these limitations, attempts have been made to prepare a geological map of the area as adequately as possible and collect perfectly fresh samples for laboratory studies.

#### PHYSIOGRAPHY

The Kashmir valley is a longitudinal depression in the Great northwestern Complex of the Himalayan ranges, and thus constitutes an important relief feature of geographic significance. It lies between the Great Himalayan Range to the north and the Pir Panjal Range to the south, the latter in turn, forming a divide between Jammu and Kashmir provinces (fig. 5).

The study area physiographically is confined to the Lesser Himalayas and presents topography typical of a mountain terrain (fig.6). To the north lies Tragal forest which is characterized by high peaks and latter extends upto Rajdhani Range (outside the study area) . Towards the northeastern part of the study area, Bajpathar and Lablachal (outside the study area) attain an average height of more than about 4890 m. As we move from north to south the lowest

4

place in height goes up to 4561 m with the central place of Bandipura which is 4664 m. In the entire area a number of high mountain ranges as well as ridges are seen. The area is rough and rugged intersected by criss-cross streams.

#### DRAINAGE

The drainage pattern of the study area is of dendritic type (fig.6). Two rivers namely Madhumati or Bod Kol and Erin rala with numerous other tributaries drain through it. The main features of these rivers are as follows:

(i) Madhumati River:

The Madhumati or Bod Kol drains through the northern slopes of the Harmukh precipice with its feeder streams over a vast area between Nagmarg in the west and Sarbal Nag in the east. The Madhumati after traversing through a course of nearly forty kms empties its water into the famous Wular lake near Bandipura. It is a full year stream and in winter its torrential waters affect the low lying lands to a great extent. The Madhumati like the Erin falls steeply, the average fall being 103 m.

Basin characters of the Madhumati river are shown in table-I (after Moonis Raza, 1978).

TABLE-1

Stream order	No. of streams	Bifurcation ratio	Length of segments in each order as (%) of the cumulative	Mean length of the segments.
			Length <sub>km</sub> Percent	
1	124		288.00 72.54	2.32
2	25	4.96	51.00 12.84	2.04
3	7	3.57	32.00 8.06	4.57
4	1	7.00	26.00 6.52	26.00
	total 157	average 5.17	Cumulative length 397.00	

(11) Erin River:

The Erin and the Madhumati belong to a larger group of tiny streams which feed the Wular lake. The Erin takes its source from the western flank of the Harmukh. After pursuing a course of about 25 kms, through a neatly cascaded valley, it falls into the famous Wular lake, south of Bandipura. The stream serves as an important means of transport for timber in the higher reaches. The basin characters of Erin nala are shown in table-2.

TABLE-2

Stream order	No. of streams.	Bifurcation ratio	Length of segments in each order as (%) of the cumulative.	Mean length of the segments	
1	71	4.23	134.00	63.80	1.75
2.	17	3.40	38.00	18.00	2.23
3	5	2.50	19.00	9.00	3.80
4	1	2.00	6.00	2.80	3.00
5	1		13.00	6.40	13.00
total		average	Cumulative length		
96		3.03	210.00		

A major asymmetrical anticlinal fold with an easterly plunging axis along the Madhumati stream is reported from this area (Wadia, 1934).

#### FAUNA AND FLORA

##### (i) Fauna:

The fauna of the area include bear, lion, monkey, snow leopard, Musk deer, snakes, etc. The Musk deer is a charming

animal having slender legs, beautiful eyes and ears. Horses and mules are reared for transport purposes. Among the game birds mention may be made of partridges.

(ii) Flora :

The area is densely forested in patches and bears an admixture of coniferous and broad leaved species. These include: Codrus doodara ( Deodar), Pinus wallichiana (Pail), Abies pindrow (fir), Parotia Jacquimontiana (Hatab), Aesculus Indica (Chestnut), Juglanes regia (Walnut), Betula utilis (Birch) etc. The birches are confined to the higher elevations only. Some herbal plants are not uncommon in this area.

CLIMATE

The climate in the upper reaches of the study area is of peculiar nature. The climate is mainly influenced by two rivers Madhumati or Bod Kol and Erin mala and the high mountain ranges which surround the area. The lowest average temperature in Bandipura in January is 16° F as against this in summer, i.e. in July, it is 92.9° F. Severe winter in B-andipura area extends over 70 days from the 24th December to 8th of March. The entire area looks like a refrigerator

with temperature often below zero. In spring the area experiences frequent showers. The high humidity in July and August is responsible for the discomfort felt during these months. Higher reaches of Bandipura sometimes experience an early snow fall in the month of October. During July and August fog is common over the surrounding hills of Bandipura. In winter months, mist and fog are common and the visibility is poor.

#### SPRINGS:

In the higher reaches of the study area, there are a number of natural springs. These springs are the source of drinking water for people living at higher altitudes.

#### METHOD OF STUDY

The present investigation consists of geological mapping, collection of representative specimens and their petrological and petrochemical studies. The study of Panjal traps and the limestones is made by (a) field and (b) laboratory methods.

(a)- The field work consists of geological mapping, systematic sampling, location of volcanites and the limestones and their jointing pattern. A geological map has been prepared on a scale of 1 : 50,000. The stratigraphy of the surrounding rocks

has been worked out. Fresh samples of Panjal traps and limestones have been collected for laboratory studies giving adequate representation to the different varieties identified in the field.

(b)- In the laboratory, the samples of Panjal traps have been adequately described in hand specimens and about three hundred thin sections prepared to carry out their detailed study under the petrological microscope. Two thin sections for each of the limestone samples were prepared, one uncovered thin section was stained for the estimation of calcite and dolomite and the other covered unstained section was qualitatively examined under the petrological microscope. Modal analyses of traps has been carried out.

Pure fractions (80 to 90 percent purity) of plagioclases, chlorites and epidotes were separated from the traps, chemically analysed and studied by optical and x-ray diffraction methods.

Twenty-nine samples of different varieties of Panjal traps have been chemically analysed for their major elements and the data obtained plotted on binary and ternary variation diagrams for purposes of gaining insight as to the petrochemical trend of the traps.

Twenty samples of limestones representing all the varieties were chemically analysed and calcite and dolomite percentages were plotted in an equitriangular diagram for purposes of petrographic classification of these rocks. More than half a dozen of the samples have been x-rayed.

The staining technique for carbonate rocks has been employed to distinguish between calcite and dolomite. The reagents used are Alizarin Red "S", Ferric chloride, Ammonium sulphide, copper nitrate, Harrisæmatoxylene etc. The Alizarin Red "S" and the Copper nitrate solution have been found most effective for distinguishing between calcite and dolomite.

## CHAPTER - II

### HISTORICAL REVIEW

During the course of his work on the Cambrian-Trias sequence of northwest Kashmir, Wadia (1934) referred to the Panjal Volcanics and the limestones of Triassic age from the area under study. The Panjal volcanic cycle, as is well known, is characterized by: (i) The Agglomeratic slates and (ii) Lava flows known as the Panjal traps. The Agglomeratic Slates and the traps are found together over large parts of Kashmir. In many cases, the two series are reported to be interbedded or

even intermingled to such an extent that their delineation is impossible on a geological map. The two groups are, therefore, considered to represent two phases of a single system.

In the light of the above reasons an attempt is, therefore, made in this chapter to present a review of the work done by earlier workers on the Panjal volcanics and the limestones of Triassic age in a chronological order for an integrated study of the problem under investigation. The Agglomeratic Slates are no doubt absent in this area, but are also dealt with for the sake of completeness.

Lydekker (1876-1883) gave a comprehensive account of the rock distribution and stratigraphy of Western Kashmir and the Pir Panjal Range. He broadly divided Kashmir stratigraphy into five systems: (i) Metamorphic system, (ii) Panjal system, (iii) Zaskar system, (iv) Tertiary system and (v) Alluvial system.

Middlemiss (1910) published his monumental work regarding the Silurian-Trias sequence in Kashmir. He gave a detailed account of the stratigraphy and structure of the various parts of Kashmir Himalaya and located important fossil horizons. He divided the Silurian-Trias into two main divisions which are

as follows:

<u>A-DIVISION</u>	<u>B-DIVISION</u>
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. Gangamopteris Beds, Panjal Volcanic flows and Agglomeratic slates.
1. Lower silurian	

Middlemiss (op.cit) dealt with the distribution of all these horizons on the basis of lithology, faunal assemblage, structural features, exact location of the fossiliferous zones and prepared a geological map showing the localities. He also recorded the occurrence of Gondwana plants from the Agglomeratic slates of Aharwat in Western Pir Panjal which proved to be of enormous importance for later workers.

Middlemiss (1911) made a detailed study of some sections in Pir Panjal Range and the Sindh valley. He described the

sections along Nilnag-Tatakuti, Gulmarg-Apharwat routes and also along the Gulab-Garh pass which was examined by him in the year 1909. After studying these sections, he found that the central high peaks which formed the watershed were composed of Panjal traps or Agglomeratic slates.

Bion and Middlemiss (1928) mapped the eastern part of Kashmir in continuation to the works of Middlemiss and described marine fauna from the Agglomeratic slates which helped in establishing the lower age limit of the Panjal volcanics. Some additional fauna from this formation was subsequently described by Reed (1932).

Wadia (1928) gave an excellent account of the stratigraphy and other geological aspects of Poonch and adjoining areas. Wadia divided Lydekker's Panjal system into two major groups: viz., (i) <sup>The</sup> Dogra slates and (ii) The Agglomeratic slates in association with Panjal traps.

Wakhaloo and Mathur (1933) for the first time referred to the differentiation in Panjal traps and described rhyolites from Pantchuk in Kashmir valley.

Wadia (1934) amended his views and divided the metamorphics

into an older galkhala series and a younger Dogra slate series. He also found fossiliferous Cambrian and Ordovician rocks in northwest Kashmir and thereby established the lower Palaeozoic sequence therein.

Coulson (1938) noted basic and acid rock types in Baramulla district, the former being epidotized and serpentinized with 43.3 percent silica and the latter as devitrified toscanites accompanied by acid tuffs.

Ganju (1943) and Ganju and Rajnath/are (1939) are of the opinion that the Panjal volcanic series is divisible into two phases, the earlier phase consisting of Agglomeratic slates and the latter phase of Panjal traps.

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 galkhalas, the Dogras, the Tarawals, the Agglomeratic slates, the Triassics and the Karewas.

Pascoe (1959) gave a detailed account of Panjal traps based on the works of Middlemiss (op. cit) and Wadia (op. cit). The lavas according to him for the most part are basalts

what he called "basic pyroxene andesites". He recognized a porphyritic variety of traps from the vicinity of Srinagar, epidotized and partly metamorphosed. He believed the coarse variety of traps as intrusive sills. According to him, there is a negative sign of appreciable magmatic differentiation in the traps, the flows having a high degree of liquidity of basic lavas, their composition showing a remarkable uniformity and markedly lenticular behaviour of individual flows. Further, in the words of Pascoe "in the Lolab and Hundwara districts of Kashmir and elsewhere a genetic connection is to be noted between the amygdaloidal lavas of the Panjal traps and numerous dykes of dolerite injected into the Silurian and older palaeozoic rocks of the region". In these hypabyssal roots of eruption, some of them are of considerable size, urelitzation has been complete and universal.

Ahmad (1961) suggests glacial origin for the Agglomeratic slates of Kashmir.

Ganju and Srivastava (1961) studied the Agglomeratic slates near Baramulla, Kashmir and found two types viz., coarse grained and fine grained. The coarse grained variety consists 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.

Hazra and Prasad (1963) studied the volcanics of Banihal area, during the course of their survey for Jawahar Tunnel.

Wakhaloo (1964) advocates a marine origin for the Agglomeratic slates and the Panjal traps.

Sharma and Gupta (1972) reported the presence of spilites and keratophyres and also Panjal traps from Thanamandi area. The traps have been inferred to owe their origin to the combined role of submarine and subaerial volcanism.

Nakazawa and Kapoor (1973) worked on the Panjal traps of Guryul Ravine and suggested submarine origin for the traps of the area and referred to the pillow structure of the rocks. Comparative account of the volcanites present in different parts of Kashmir is also given.

Pareek (1973) considers the Agglomeratic slates as representing the pyroclastic nature of the volcanism in which the constituents were blown up into the atmosphere inflated

by gas. Pareek (op.cit.) further gives a detailed textural and compositional variation of Panjal traps-basalts-andesites-rhyolites etc. He further classifies the traps into two categories; viz., porphyritic and non-porphyritic traps on the basis of petrographical and geochemical tests.

Acharya and Shah (1975) quoting Fox (1931), Gamser (1964), Fuchs and Gupta (1971) considered the Agglomeratic Slates of Kashmir valley intercalated with tilloids, tillites and Agglomerates and thus correlated them with the 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." He favoured glacial origin for the Agglomeratic Slates.

Gupta (1975) proposed a formal classification for the Agglomeratic slate sequence of Kashmir and reviewed the stratigraphic position of a boulder bed in its basal part - the Gulabgarh boulder formation - on palaeontological and stratigraphical grounds.

Srikantia (1975) is of the opinion that Permocarboneferous glaciation must have influenced the deposition of the

### Agglomeratic slates of Kashmir.

Wakhaloo (1975) correlates the Blainis with the Agglomeratic slate Series of Kashmir.

Pareek (1977) in his paper "Agglomeratic slates and Panjal traps in the Jhelum, Lidder and Sind valleys, Kashmir", considers the Agglomeratic slate series as representing the pyroclastic nature of the volcanism. The deposit was <sup>laid</sup> under the influence of gravity and the resulting product compacted and solidified to form the Agglomerates, the glassy rocks and the welded tuffs. According to him, the Agglomerates show coarse banding, well rounded iron mineral grains with or without glass, or devitrified in many cases.

Wakhaloo (1977) re-interprets the Panjal volcanics as spilites rather than andesites or basalts. He believes that the spilites have been derived from the normal crystallization of a hydrous magma.

Ahmad et al. (1978) state that the Agglomeratic slates represent the product of glacial and volcanic activity deposited in a shallow marine water as well as continental set up.

Bhat and Faruq (1978) gave a detailed account of the geochemistry of Panjal traps of Mount Kayol, Liddawat, Pahalgam, Kashmir. The authors have described twentyfour trap flows and studied the variation of various oxides from the base to the top of the flows. Genetic aspects of the volcanics have been discussed in the light of the behaviour of major and minor elements. Subaerial environment of eruption of the Panjal traps of Liddawat area has been put forth by the workers.

Bhatia and Kokroo (1978) on "Sedimentological studies of Agglomeratic slates, Anantnag district, Kashmir," discussed the petrography and the origin of these rocks. According to them, the rocks of this series are mostly welded tuffs, which have been altered, devitrified and metamorphosed. The three types of tuffs viz., vitric, crystaloid lithic tuffs have been found, but majority of them belong to the intermediate types.

Chaudhary and Ashraf (1980) have given an elaborate account of the geochemistry of Poonch volcanics from the so called "Azad Kashmir". The rocks have been described as andesites-basalts associated with volcanic ash and tuffaceous material. From the petrochemical data and the field studies,

the rocks have been suggested to be of Upper Carboniferous age.

Gupta et al. (1980) gave an account of the traps from different areas of Kashmir, Srinagar, Nishat Bagh, Lidder valley, Bandipura, Thanamandi, Kishtwar and Bejbehara. The volcanic activity is thought to have persisted for a longer duration in the western Kashmir continuing upto Late Trias as against the areas of eastern Kashmir, where it ended in the Permian period. They inferred the parental magma of the Panjal volcanics of the above places to be of tholeiitic lineage.

Bhat et al. (1981) are of the opinion that the Panjal lava eruption took place in a strongly extensional rift setting representing the first phase of the break-up of the Indian Plate from the Siberian plate.

Singh (1981) has given an account of the Permian-Trias sequence from the eastern parts of Kashmir with particular reference to their depositional environment. A perusal of literature reveals that it is the solitary work done to this date on the Triassic limestones of Kashmir.

## CHAPTER - III

GEOLOGICAL SETTING OF THE AREA  
AND STRATIGRAPHY

Part of the Himalaya falling between the Main Boundary Fault to the south and the Main Central Thrust to the north constitutes the Lesser Himalayan zone. In this portion of the Himalaya a pile of recumbently folded rock succession has moved to the south over a considerable distance as a series of low angled thrust sheets or nappes. These are the nappe zones of the Himalaya (Pilgrim and West, 1928).

Kashmir nappe is one such low angled thrust sheet having

moved from the north to the south over a long distance. In the Lesser Himalayas of Kashmir, a rock succession ranging in age from Cambrian to Trias is seen to overlie the Salkhalas (Early Precambrian) and the Dogras (Late Precambrian to Early Cambrian). (Wadia, 1931, 1976; Jhingran et al., 1976). //

The area under reference is a part of the Kashmir nappe. Fig.7 shows the regional geological setting of a portion of the Lesser Himalayas of Kashmir. The fractured portion on this figure shows the area under study. A major asymmetrical regional anticline (Wadia, 1934) has been observed here. This anticline has a WNW-ESE axis that runs almost along the Madhumati stream with a very steep plunge towards the east.

#### STRATIGRAPHY

In the area under investigation only Panjal traps and limestones of Triassic age with Recent and sub-Recent deposits are observed. The Salkhalas, the Dogras, the Cambrians and the Agglomeratic Slates are exposed in the adjoining areas to the north (fig.8). A complete stratigraphical succession of this region as worked out by Wadia (op.cit) is tabulated in table-3.

TABLE-3

## STRATIGRAPHIC SUCCESSION AROUND BANDI PURA

	<u>LITHOLOGY</u>	<u>POSSIBLE AGE</u>
Alluvium	Clays, pebbles, gravels and boulders	Recent and sub-Recent
Massive Limestone intermingled with shales, slates etc.	Microcrystalline rocks, dolomites and nodular limestones	Triassic
Hant Granite	Granite, quagranodiorite and granodiorite	Post Panjal trap
Panjali traps	Hard and massive traps, tuffs etc. predominantly basic lavas	Upper Carboniferous and Permian.
Agglomeratic slates	slates, greywackes, arkoses, argillaceous slates etc.	Upper Carboniferous
Cambrians	shales and phyllites	Cambrian
Dogra slates	Greywackes and slates	Late Precambrian to Early Cambrian
Sal khalas	Schists and phyllites	Early Precambrian

### SALKHALAS

This is the oldest formation (Early Precambrian) exposed in this region. It consists of schists, phyllites and carbonaceous slates. Gypsum, limestone and calcareous slates have also been reported from these rocks. The Salkhalas are devoid of fossils and display a high grade of metamorphism. This formation is exposed outside the area of present study.

### DOGRA SLATES

Dogra slates (Late Precambrian to Early Cambrian) consisting of slates and greywackes overlie the Salkhalas. The slates are light green to dark grey in colour and show incipient development of mica flakes. The greywackes are greyish-black in colour. Wadia (1928) in his monumental treatise on the geology of Poonch, states the name "Dogra Slates" - for a wide zone, entirely unfossiliferous, black and green cleavage slate or phyllites which is coextensive with the southwest border of Pir Panjal from Uri to Banihal. The degree of metamorphism of this formation is lower than that of the Salkhalas. This formation falls outside the study area.

### CAMBRIANS

The rocks generally show a gradational contact with the

underlying Dogra slates. The rocks of this formation consist of shales and phyllites. Shales are buff to light grey in colour and are characterized by the presence of well developed fauna. The phyllites show a poor silky sheen and possess a grey colour of various shades. Wadia (1934) discovered a number of Cambrian fossils from the rocks and naturally assigned these to Cambrian age.

#### AGGLOMERATIC SLATES

Middlemiss (1910) who introduced the term 'Agglomeratic slates' in Kashmir states that this <sup>u</sup>portion of Kashmir is an accumulation of clastic and sedimentary material formed around ruptured portions of the earth's crust, which eventually became the foci for the extrusion of basic lava flows. The Agglomeratic slate consists of a dark grey rock dotted with large patches of foreign angular pieces and sometimes rounded pebbles interbedded at places with sandstones, grits and conglomerates. These are not exposed in the area under study, but are present just outside it as is obvious by a <sup>ma</sup>perusal of fig.8.

#### PANJAL TRAPS

The Panjal traps constitute a cardinal rock unit in the

geology of Kashmir. This term is mostly restricted to a thick pile of lava flows of basaltic to andesitic character, which generally lie at the top of the Agglomeratic slates. Different sections of Kashmir Himalaya have been studied from time to time by many workers who have discussed petrographical characters and stratigraphic position of the traps.

Thick bedded flows of Panjal lavas cover a large part of Bandipura area and these in turn are overlain by limestones of Triassic age ( fig. 40 ). The general topography of the trap country is usually rugged and with steep cliffs which are difficult to negotiate. The present study is mainly based on these rocks. The traps are altered having been epidotized and chloritized.

Bandipura traps are hard, massive and compact, fine-grained with colours varying from greenish-grey to black. Purple coloured tuffs are present in this area. Amygdaloidal variety, wherein, the infilling materials are quartz, epidote, chlorite and sometimes calcite is present in the area. Glomeroporphyritic type traps are also seen and in these the plagioclases are arranged in a star-shaped pattern. The rocks vary in colour from blackish-green to green. Purple coloured tuffs present in the study area are totally unfossiliferous.

Good trap exposures in the study area are found in Tragbal, Saraibal, Kralpura, Erin, Shok-Baba and Chaki Arsalakhan. Traps with chlorite amygdales and epidotes are found in Saraibal, Kralpura and Chaki-Arsalakhan. The tuffs are present in the higher reaches of Erin valley. Glomeroporphyritic traps are present towards the east of Erin around Shok-Baba. The traps are followed by dyke rocks at some places. Presence of panjal traps in these localities has also been referred by Yadia (op. cit) and Bion and Middlemiss (op. cit).

#### HANT GRANITE

These granites are predominantly exposed in and around Hant (Uppal, 1977) outcropping through the Galkhalas, the Dogras and the Cambrians. The Hant granites consist of granodiorite, quartz granodiorite and granite. The minerals quartz, plagioclases, biotite and muscovite are present in the rocks. The granites are generally light grey in colour.

#### LIMESTONES

The traps are overlain in the present area by Triassic limestones. The limestones are noticed to contain crinoid stems.

Lithologically, the carbonate rocks comprise of thick, massive, light to grey coloured limestones, dull-white to

pinkish dolomite, siliceous limestones, grey shaly limestones etc. Different types of limestones have been noticed in the area. Microcrystalline type of limestones are also found here. The limestones are essentially composed of a cryptocrystalline aggregate of carbonate minerals, shale fragments and clay minerals. The accessories are quartz, biotite, magnetite etc. Crystals of calcite are identifiable in calcite veins which cut across calcilutite bands. At some places, the limestones are intermingled with shales. Crinoidal stems are seen in some of the limestone samples from Erin valley. Dolomites and biosparites are also present in the study area.

The best exposures of limestones in this area are found in Erin, Bandipura, Sonarwani, etc. Minor shale fragments associated with limestones are found at Naugam. The limestones are in contact with Panjal traps at Sonarwani and Semathan area. Wadia (op. cit.) regards the limestones to be of Triassic age.

#### ALLUVIUM

Alluvium is found close to the two main rivers which flow through the area of study, viz., Madhumati and Erin nala. The development of these deposits giving rise to agricultural outputs have to a large degree been responsible for habitation in these areas.

#### CHAPTER - IV

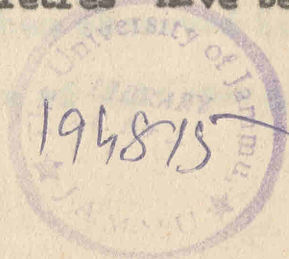
### P E T R O L O G Y   O F   P A N J A L   T R A P S

The present investigation as already stated is primarily aimed at a petrological account of the rocks exposed around Bandipura. The rock exposures as already stated consist of panjal traps and limestones with Recent and sub-Recent deposits at places. During the course of his work in this area, (Wadia, 1934), reported the occurrence of limestones interbedded with the Panjal traps of the area. This interesting aspect, though outside the scope of the present study, has also been treated at an appropriate place in the subsequent pages because of its importance.

In this chapter a petrographic account of the trap exposures is given. The volcanics have been studied in thin sections, the main mineral phases entering into their composition have been separated and their study undertaken by optical, chemical and x-ray methods.

Megascopically, the Panjal traps are of green to greenish black and purple colour. The rocks owe their green colour to the presence of epidote and chlorite. Fine grained, massive, hard and compact varieties as well as amygdaloidal types are present in the study area. The amygdales are bigger in dark green varieties. Some of the amygdales are elliptical or circular in outline. The purple coloured traps have numerous vesicles which are filled up with epidote, chlorite and quartz. The shape of the vesicles has been made by the passage made by active fluids through them. The traps in the eastern part of the study area are poor in vesicles. Sometimes the gas cavities are so numerous that the rocks display cellular structure (Augustithis, 1978). The average specific gravity of the traps ranges from 2.4 to 3. Flow structure is rarely seen in the rocks.

In the study area, the following trap varieties have been observed:



- 1- Glomeroporphyritic traps
- 2- Amygdaloidal traps with variegated shades of green, grey and purple colour. The amygdaloids consist of chlorite, epidote or quartz.
- 3-Dense, hard and compact green variety with chlorite, epidote and a little of quartz.
- 4-Purple coloured tuffs
- 5-Quartz-epidote veins (epidosites)
- 6-Dyke rocks.

Under the microscope, the panjal traps in many instances show an aggregate of plagioclases, chlorites, epidotes and quartz with accessory minerals like magnetite and ilmenite. In some cases, pyroxene has changed to tremolite and actinolite along the margins. The plagioclase phenocrysts are seen in some thin sections clustered in a radial pattern to produce glomeroporphyritic texture, whereas in some instances, pyroxene phenocrysts enclose plagioclase laths giving rise to ophitic and sub-ophitic textures.

Other textures present are intersertal, intergranular and hyalopilitic. The groundmass cannot optically be resolved in many instances because of its fineness and when observed is seen to consist of a cryptocrystalline aggregate of feldspars,

chlorite, epidotes etc.

Thin section study of Bandipura traps clearly reveals that these have undergone a low grade of metamorphism of the amphibolite facies because of their involvement in the Himalayan Orogeny. Low grade metamorphism includes in it a lot of subfacies as far as studies of various metamorphic belts in other parts of the world are concerned. The authors main idea is to assess the impact of metamorphism on the traps of the study area. The general rule of Miyashiro and Seki (1958a) suggesting that the compositional range of epidote enlarges with increasing temperature applies here also. Chlorite is generally homogeneous in the metabasites of this area.

Epidote + Chlorite + actinolite is a stage in the low grade metamorphism, which is preceded by <sup>m</sup>pumpellyite + epidote + chlorite + actinolite. Such associations are also present in various low grade metamorphic terrains of the world e.g. west side of Appalachian (Zen, 1974), Katsuyama area of the Sangun metamorphic belt (Hashimoto et al, 1976), Keweenaw basalts (Jolly and Smith, 1972), western southland in New Zealand (Landis and Coombs, 1974) and the Tanzawa Mountains (Seki et al. 1970).

Basic igneous rocks when subjected to a metamorphism of low grade, show alteration in their original plagioclases and the main ferromagnesian mineral augite. The basicity of original plagioclases is seen to decrease the original pyroxenes change into amphiboles and chlorite.

The traps of the present area irrespective of their textural variation consist in general of a mineralogical assemblage of plagioclases (An content varying from 54 percent to 74 percent), zoisite, epidote, hornblende, chlorite, and sericite. Opaque minerals like magnetite and ilmenite generally with an irresolvable matrix are also noticed. It may be mentioned here that the anorthite content of the plagioclases as witnessed in the traps of the present area and also from other parts of Kashmir investigated recently is rather high as is evidenced by a perusal of earlier literature in regard to the volcanics in general. Cases of plagioclases with high anorthite contents consisting with Ca-rich phases such as epidote or calcite have recently been investigated and are attributed to higher grades of metamorphism (Hyndman, 1972; Miyashiro, 1975; Mason, 1977; Nockolds, 1954). Grains of quartz seen in most of the sections are obviously released as a result of alteration of plagioclases and pyroxenes.

The rocks owe their present mineral assemblages to the

metamorphism to which these have been subjected to. As a result of this, sericitization, epidotization and clouding of plagioclases occurring in the basic rocks of the study area is common. Similarly, the main ferromagnesian mineral augite has changed to hornblende and chlorite. Clouding of plagioclases is a noteworthy feature.

According to McGregor (1931) clouding is due to the thermal metamorphism resulting in the ex-solution of sprinkled particles of iron initially present in the feldspar solid solutions.

After studying the clouding in feldspars, Anderson (1937) ascribed this to the formation of iron which at times is obtained by the transforming material. Experimental data shows the  $Fe^{+3}$  exsolves as haematite or magnetite (Rosenqvist, 1951; Faust, 1936).

According to Herz (1951) clouding can take place only due to high anorthite content.

Poldervaart and Gilkey (1954) suggested that slight clouding can take place because of ex-solution of iron dissolved in the plagioclase at the time of its formation.

Friedman (1955) and Garsten (1955) are of the opinion

that clouding may take place because of hydrothermal alteration as in coronites. It may also occur because of magmatic origin (Bentor, 1951; Carsten, 1955).

Pichamuthu (1959) suggested that clouding can take place due to palingenesis. Barth (1967) thought that clouding can be caused by thermal metamorphism.

Maibu (1960) clearly explains the clouding by the method of diffusion of ions during the evolution of rocks.

Stern (1964) (in Barth, 1967) thought that clouding may take place due to the persisters which permit easy diffusion of extraneous matter.

Reo (1964) suggested that clouding may occur due to metamorphic replacement of biotite or hornblende by plagioclases.

However, the suggestions given by Herz (1951), McGregor (1931), Anderson (1937), Poldervaart and Gilkey (1954) and Barth (1967) explain the clouding of plagioclases of Bandipura traps. The pyroxenes as already mentioned have been unaltered and chloritized.

The traps of Bandipura are mostly of basaltic to andesitic

character. Acidic varieties such as rhyolites and trachytes are absent. Petrographic account of different varieties of Bandipura traps is given below:

Glomeroporphyritic traps:

These rocks are of green colour with feldspars present in small clots and groups so as to give rise to glomeroporphyritic texture (Plate 10, figs. 1 & 2). The feldspars occurring in the form of clusters originated under conditions of high pressure and slow cooling which together with the enclosing mass were extruded to the surface. Under the microscope, the traps show <sup>the</sup> presence of plagioclases, epidote, and chlorite as the major constituents with magnetite and ilmenite as the accessory minerals. The anorthite content of the plagioclase of this rock category ranges from  $An_{54}$  to  $An_{61}$ .

2- Amygdaloidal traps:

Megascopically these rocks are of greenish grey colour except for a few specimens which are purple coloured. The amygdales consist of chlorite, epidotes and quartz. Microphotographs of these varieties are shown in plate 10, figs. 3 and 4. The infilling minerals have occupied the place of

vesicles originally present in the rock. The thin sections show the presence of epidote, chlorite, plagioclase (microclites) and cryptocrystalline groundmass of these minerals.

Palagonite has been observed in some thin sections of this variety (Plate 11, fig.3.). Anorthite content of the plagioclases of the rocks ranges from An<sub>55</sub> to An<sub>72</sub>.

### 3. Dense, hard and compact traps:

Megascopically, these rocks are hard, massive and compact with greenish grey colour. The rocks under the microscope show that the presence of epidote, chlorite, plagioclase & quartz as the major minerals with magnetite/ilmenite as the minor constituents. Microphotographs of this variety are shown in Plate 10, figs. 5 and 6. This variety of rocks is mostly found on the NW side of the study area. The anorthite content of the plagioclases is around An<sub>72</sub>.

### 4. Tuffs:

An important feature of the study area is the presence of purple coloured rocks having abundant greenish yellow spots. The thin section study of these rocks under the

microscope shows the abundance of glass particles which are isotropic under crossed nicols (Plate 11, figs 1 and 2). Quartz and magnetite/ ilmenite are also present in minor amounts. It is apparent by studying several thin sections of this variety that volcanic ash has mostly entered into the composition of the rocks which later on got indurated to give rise to the tuffs.

#### 5- Quartz-epidote veins (Epidosites)

These rocks are abundantly present in the study area and are of greenish yellow colour in hand specimens. The rocks are a product of metamorphic differentiation (Turner and Verhoogan, 1960; Huang, 1962 and Ramberg, 1952). Stillwater (1918) first proposed the term metamorphic differentiation which was later on elaborated by Eskola (1932). The term metamorphic differentiation was put forth by Turner (1948) "covers collectively the various processes by which different mineral assemblages develop from an initially uniform parent rock during metamorphism".

Thin sections of this variety show the presence of quartz, epidote and magnetite. Microphotographs of these rocks are shown in Plate 11, figs 4 and 5.

#### 6- Dyke rocks

A number of dyke rocks having dark green appearance are

present in this area. The presence of such rocks has been reported by earlier workers viz., Wadia (1934), Wakhaloo (1943), and Wakhaloo (1972) from this part of the Himalaya and are considered to be the dyke equivalents of Panjal traps. Wiseman (1934) grouped similar rocks under the term of "Epidiorites".

Some earlier workers like Johansen (1939, 1952), Moorehouse (1964) and Turner and Verhoogan (1960) <sup>classed</sup> the rocks as "Greenstones". It is, however, <sup>preferred</sup> to use the term "metadolerites" for such type of altered rocks; where the original textures are still preserved as has been done by Wilcox and Polder-vwart (1958) <sup>and</sup> Munshi (1969). When the original texture has been totally obliterated and original pyroxenes have been totally unaltered, so that the resultant rock is composed only of amphiboles and plagioclases with small amounts of chlorites, the term "amphibolite" is preferred.

Petrographically such type of rocks show the presence of plagioclases, amphiboles, chlorites and quartz with ilmenite and magnetite as accessory opaque minerals. Microphotograph of this variety is shown in Plate 11, fig. 6. The anorthite content of the plagioclases of this variety ranges from An<sub>69</sub> to An<sub>74</sub>.

## MODAL ANALYSIS

Modal proportions of minerals in igneous rocks are sought after for purposes of petrographic nomenclature and comparison of rock samples. Chemical composition of rocks derived from accurate modal analysis could be profitably used in many petrochemical studies (Holmes, 1927)

Chayes (1956) has examined carefully the problem of modal analysis of igneous rocks, the Delessee-Rosival area - volume relationship, grain size of rocks, index of coarseness and the so called Holmes's effect. One of the purposes of Chayes (op.cit.) is to demonstrate that in the modal analysis of medium to fine grained igneous rocks, the point count method as devised by him is superior to the classical Rosival-shand line integration approach. The point count method has a higher precision and reproducibility/<sup>factor</sup> as compared to line integration method. Initially Chayes (op.cit) invented a combination of a point count mechanical stage to give jumps of constant width over a horizontal traverse and an ordinary Clay - Adams (10 punch) Blood Cell Counter to record the modal tallies. Based on the mathematical soundness and simplicity of Chayes method of modal analysis, many automatic point counters are put on the market. After continuous experience with these automatic counters, it has been found that a machine initially working all right, later on,

TABLE 4

DATA SHEET FOR RECORDING MODAL COUNTS OF IGNEOUS ROCKS BY CHAYES POINT COUNT METHOD

Date of counting \_\_\_\_\_, Operator \_\_\_\_\_, Locality of the sample \_\_\_\_\_  
 Rock type \_\_\_\_\_, Area point counted \_\_\_\_\_, Grain size of rock \_\_\_\_\_  
 Counts per traverse \_\_\_\_\_, Total number of counts \_\_\_\_\_  
 Magnification constant \_\_\_\_\_, Horizontal traverse spacing \_\_\_\_\_  
 Jump width per traverse \_\_\_\_\_

Modal Minerals	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	T <sub>5</sub>	T <sub>6</sub>	T <sub>7</sub>	T <sub>8</sub>	T <sub>9</sub>	T <sub>N</sub>	Total counts per modal mineral.
Plagioclase, altered feldspar, sericite etc.	023	038	035	019	017	053	045	030	045	031	336
Pyroxene	003	005	001	000	000	005	001	005	005	000	025
Epidote	027	030	050	068	032	039	050	045	035	045	421
Chlorite	064	052	039	021	028	041	030	020	035	035	365
Quartz	043	033	013	027	060	010	005	035	010	021	257
Magnetite / ilmenite & other opaques.	003	019	029	011	013	002	000	010	020	003	110
Identifiable aggregates	001	001	000	000	000	002	010	005	000	005	024
Column Total	164	178	167	146	150	152	141	150	150	140	1538

TABLE-4a MODAL ANALYSES OF BANDIPURA TRAPS

Sample no.	Plagioclase feldspar etc.	Pyrox.	Epidote	Chlorite	Qz	Magnetite/ilmenite	un-identifiables.	Total
AR-20	15.21	-	22.74	44.04	1.00	14.90	2.11	100.0
A33	20.15	3.75	20.75	34.42	5.40	11.90	3.63	100.0
AK11	21.84	1.62	27.37	23.73	16.71	7.15	1.58	100.0
AR63	24.25	2.17	21.17	32.26	4.60	8.70	6.85	100.0
A68	24.72	3.70	36.87	21.54	3.59	8.10	1.48	100.0
A70	24.73	2.50	38.38	9.27	10.25	10.17	4.70	100.0
AK30	25.16	2.10	31.17	18.14	15.10	3.10	5.23	100.0
A20	26.49	0.60	42.82	13.87	11.56	4.00	0.66	100.0
A16	27.10	-	45.25	22.10	-	4.10	1.45	100.0
AR16	27.18	-	27.78	20.18	21.88	2.02	1.03	100.0
A19	28.81	-	45.37	15.02	4.62	6.00	0.18	100.0
AK11	29.27	-	33.18	19.26	10.70	2.40	5.19	100.0
A 45	30.21	1.70	18.17	22.14	14.22	7.10	6.46	100.0
AR 34	30.94	3.00	37.60	8.00	7.40	3.80	9.26	100.0
AK26	33.96	1.70	30.40	18.18	7.35	5.40	3.01	100.0
AR32	40.51	1.00	23.66	16.90	7.63	9.00	1.30	100.0
AK24	41.23	1.90	25.16	21.17	6.70	1.10	2.74	100.0
A48	41.24	0.50	19.67	19.32	10.21	6.70	2.36	100.0
AK20	45.29	2.30	22.50	14.64	10.00	2.22	3.05	100.0
AK21	54.45	-	15.02	8.84	11.97	7.60	2.12	100.0

starts either over or under counting the constituents without the knowledge of the operator thus casting a doubt on the obtained results. In the absence of an automatic point counter and /or Chayes point count mechanical stage, a device is adopted in this thesis which preserves all the essentials of point count theory as developed by Chayes (op.cit.) and yields very reliable results.

The method adopted in the present work is as follows: On a petrographic microscope, a right combination of an objective and an eye piece provided with a graduated scale is obtained to give a magnification constant so that the minerals under counting are clearly resolved for purposes of point counting. When such a condition is obtained, with the help of a stage micrometer, the graduated scale in the eye piece is calibrated. Based on this calibration, a number of points that could be obtained over a horizontal traverse on a thin section is found out. In the present work of point counting basic volcanic rock modal composition, a constant width of 0.05 mm was found suitable giving on the average 150 counts per traverse. If the counting is accomplished on ten equally spaced horizontal traverses covering the entire area of the slide, it would give statistically stable counts of

1500 per slide. For coarse grained plutonic rocks a separate procedure has to be adopted depending upon the situation of study. On an average, however, hundred counts per traverse spread over ten traverses thus yielding 1000 points per sample, are considered to yield satisfactory stable modal counts. The movement of the slide both horizontally and vertically is accomplished by an ordinary mechanical stage. On the horizontal traverse, each time the slide is moved a width of 0.05 mm and the mineral coming under cross wire is identified and correspondingly tallied on a nine punch ( eight for individual counts, and <sup>the</sup> ninth for cumulative count) (Clay and Adams Blood Cell counter. The readings on the counter on the completion of a traverse are recorded in <sup>a</sup> data-sheet as shown in table-4. The keys on the Blood Cell Counter are put back to zero before starting on the next traverse. On the completion of the total number of traverses on a slide tallies on the data sheet are finally added and reduced to modal proportions for purposes of comparison, petrographic nomenclature and for any other purpose, the data are needed.

Different varieties of 20 fine grained basic volcanic rocks were point counted according to the above indicated method and the results are tabulated in table-4a.

## STUDY OF MAIN MINERAL PHASES IN THE PANJAL TRAPS OF BANDIPURA

Irrespective of their petrographic identity, the Panjal traps of Bandipura area are mostly composed of plagioclases, chlorites, epidotes and quartz with magnetite/ilmenite as opaque accessory minerals. The main mineral constituents viz., plagioclases, chlorites and epidotes have been studied by optical, chemical and x-ray diffraction methods. Thin section study of quartz and ilmenite/magnetite is also given for the sake of completeness.

### Plagioclases:

The anorthite content of the plagioclases has been determined by three methods: (i) optical, (ii) chemical and (iii) x-ray diffractometry. The multiple approach was followed to evaluate whether corroborating results could be obtained from the three approaches.

#### (a) Optical method:

This method is mainly based on thin section study. Plagioclases are present in almost all the sections. The mineral occurs as euhedral crystals, small laths and as microlites. The crystals are mostly twinned on the albite law and twin lamellae are mostly broad, few and sharp. At some

(Contd. P. 49)

TABLE- 5 CHEMICAL ANALYSES OF PLAGIOCLASES  
FROM PANJAL TRAPS OF BANDIPURA (Contd.....)

sample no.	A11 1	A24 2	AK27 3	AK20 4	AK24 5	A70 6	A27 7
<u>Constituents</u>							
SiO <sub>2</sub>	48.82	49.80	51.08	53.78	54.60	55.18	56.15
Al <sub>2</sub> O <sub>3</sub>	32.20	31.74	30.30	29.00	28.90	28.01	27.60
Fe <sub>2</sub> O <sub>3</sub>	0.60	0.50	0.88	0.60	0.61	1.12	0.18
FeO	0.20	0.20	0.50	0.20	0.05	0.15	0.10
TiO <sub>2</sub>	0.00	0.02	0.06	0.05	0.03	0.05	-
CaO	15.30	15.10	13.80	12.10	10.45	10.60	9.75
MgO	0.20	0.05	0.15	0.10	0.10	-	0.06
Na <sub>2</sub> O	2.32	2.45	3.00	4.25	5.20	4.97	5.10
K <sub>2</sub> O	0.10	0.16	0.14	0.15	0.30	0.20	0.50
H <sub>2</sub> O (+)	0.40	0.10	0.20	0.20	0.10	0.15	0.50
H <sub>2</sub> O (-)	0.15	0.05	0.05	-	0.05	0.02	0.10
Total	100.29	100.17	100.16	100.43	100.39	100.45	100.04

Location of the Analysed samples:

Analyst: A.K. RAINA

1- 34° 28' 40"	74° 38' 03"
2- 34° 25' 13"	74° 37' 30"
3- 34° 20' 11"	74° 40' 35"
4- 34° 24' 25"	74° 43' 48"
5- 34° 24' 14"	74° 42' 40"
6- 34° 24' 07"	74° 44' 49"
7- 34° 27' 15"	74° 39' 32"

TABLE- 5 NUMBER OF IONS ON THE BASIS OF 32(O)

Sample no. Constituents	All 1	A24 2	AK27 3	AK20 4	AK24 5	A70 6	A27 7
Si	8.955	9.094	9.327	9.717	9.820	9.946	10.105
Al	6.964	6.834	6.521	6.177	6.138	5.894	5.860
Fe <sup>+3</sup>	0.083	0.068	0.121	0.082	0.076	0.130	0.023
Ti	-	0.003	0.009	0.006	0.004	0.008	-
Mg	0.055	0.013	0.041	0.027	0.030	-	0.019
Fe <sup>+2</sup>	0.030	0.030	0.077	0.030	0.007	0.026	0.016
Na	0.824	0.866	1.082	1.488	1.938	1.855	1.905
Ca	3.097	2.955	2.700	2.343	2.018	2.056	1.890
K	0.024	0.036	0.044	0.034	0.050	0.045	0.133
Or	0.58	1.15	0.60	1.15	1.69	1.15	2.93
Ab	20.23	21.24	26.73	37.47	45.08	43.75	45.53
An	79.19	77.21	72.62	61.38	53.23	55.10	51.54
Ab	20.35	21.89	26.89	37.91	45.90	44.25	46.90
An	79.65	78.11	73.11	62.09	54.10	55.75	53.10
X (Ca+Na+K+Fe <sup>+2</sup> +Mg)	4.04	3.90	3.94	3.92	3.97	3.98	3.94
Z (Si+Al+Fe <sup>+3</sup> +Ti)	16.01	16.00	15.99	15.99	16.03	15.98	16.00

places, the laths of plagioclases form a star-shaped radiation (Plate 10, figs. 1 and 2.). The anorthite content of the plagioclases ranges between  $An_{50}$  to  $An_{70}$ .

(b) Chemical method:

Pure concentrates of plagioclases for chemical analyses and x-ray studies were obtained according to the method of Emmons (1961) as modified by Henley (1977). This method is based on mixing of tetrabromoethane with carbon tetrachloride to a standard specific gravity of the liquid for the separation of plagioclases from other mineral constituents. The plagioclases were first treated on an isodynamic separator. Pure fractions were later on obtained by resorting to separation with the help of heavy liquids. Great care has been taken to obtain pure mineral concentrates and the results reveal that the separation process has been highly successful.

Plagioclases thus obtained were chemically analysed by the conventional wet method for their major elements and the structural formulae of analysed plagioclases, computed on the basis of 32(O) atoms are given in table-5. The chemical analyses of plagioclases show very small amounts of Mg and  $Fe^{+2}$  and these may occur as impurities in the plagioclase structure

(Contd. P.53)

TABLE- 6 STRUCTURAL STATE AND THE ANORTHITE CONTENT OF  
 FLAGIOCLASES FROM THE BANDIPURA TRAPS DETERMINED  
 BY X-RAY METHOD. (After Viswanathan, 1971) (Contd.....)

sample no.	2 $\theta$	d values	Intensity	Face of diffraction	Anorthite content	Structural state.			
AK 20	21.00	4.22	10	201	69	Medium			
	22.20	4.00	25	201					
	26.70	3.32	30	220					
	27.95	3.19	100	002					
	<u>29.24</u>	<u>3.05</u>	<u>15</u>	<u>131</u>					
	30.80	2.90	15	041					
	<u>31.30</u>	<u>2.85</u>	<u>10</u>	<u>131</u>					
	35.25	2.51	15	241					
	35.50	2.52	20	241					
	36.70	2.44	10	240					
	<u>41.94</u>	<u>2.16</u>	<u>10</u>	<u>060</u>					
	48.50	1.91	5	203					
	<u>51.31</u>	<u>1.78</u>	<u>10</u>	<u>204</u>					
	AK 27	21.00	4.22	30			201	74	High
		22.20	4.00	25			201		
26.70		3.32	50	220					
27.98		3.19	100	002					
<u>29.22</u>		<u>3.02</u>	<u>10</u>	<u>131</u>					
30.90		2.89	20	041					
<u>31.25</u>		<u>2.77</u>	<u>15</u>	<u>131</u>					
35.20		2.54	20	241					
35.30		2.55	15	241					
36.80		2.44	10	240					
<u>41.95</u>		<u>2.16</u>	<u>10</u>	<u>060</u>					
48.85		1.87	5	203					
<u>51.40</u>		<u>1.78</u>	<u>5</u>	<u>204</u>					

Note: The values underlined have been used in the diagram.

TABLE 6 STRUCTURAL STATE AND THE ANORTHITE CONTENT OF  
 FLAGIOCLASES FROM THE BANDI PURA TRAPS. DETERMINED  
 BY X-RAY METHOD (After Viswanathan, 1971) (Contd....)

Sample no.	$2\theta$	d values	Intensity	Face of diffraction	Anorthite content	Structural state.
A24	21.02	4.22	5	$\bar{2}01$		
	22.25	4.00	10	$\bar{2}01$		
	26.70	3.32	30	220		
	28.00	3.18	100	002		
	<u>29.25</u>	<u>3.05</u>	<u>20</u>	<u><math>\bar{1}31</math></u>		
	30.90	2.89	15	041		
	<u>31.30</u>	<u>2.85</u>	<u>15</u>	<u><math>\bar{1}31</math></u>	72	High
	35.55	2.50	15	$\bar{2}41$		
	35.70	2.51	15	$\bar{2}41$		
	36.80	2.44	20	240		
	<u>42.00</u>	<u>2.16</u>	<u>10</u>	<u>060</u>		
	48.40	1.87	10	$\bar{4}03$		
	<u>51.44</u>	<u>1.77</u>	<u>20</u>	<u><math>\bar{2}04</math></u>		
	A11	21.00	4.22	20	$\bar{2}01$	
22.20		4.00	15	$\bar{2}01$		
26.80		3.31	70	220		
27.60		3.22	100	002		
<u>29.15</u>		<u>3.06</u>	<u>10</u>	<u><math>\bar{1}31</math></u>		
31.00		2.88	40	041		
<u>31.25</u>		<u>2.86</u>	<u>10</u>	<u><math>\bar{1}31</math></u>	72	High
35.42		2.53	15	$\bar{2}41$		
35.60		2.51	25	$\bar{2}41$		
36.90		2.43	10	240		
<u>42.00</u>		<u>2.16</u>	<u>20</u>	<u>060</u>		
49.00		1.85	5	$\bar{4}03$		
<u>51.45</u>		<u>1.78</u>	<u>5</u>	<u><math>\bar{2}04</math></u>		

Note: The values underlined have been used in the diagrams.

TABLE- 6 STRUCTURAL STATE AND THE ANORTHITE CONTENT OF  
PLAGIOCLASES FROM THE BANDIPURA TRAPS DETERMINED  
BY X-RAY METHOD (After Viswanathan, 1971).

Sample no.	2 $\theta$	d values	Intensity	Face of diffraction	Anorthite content	Structural state.
A70	20.98	4.22	5	201	61	Medium
	22.10	4.01	15	201		
	26.80	3.31	30	220		
	27.70	3.21	100	002		
	29.20	3.05	10	131		
	30.90	2.89	15	041		
	31.30	2.85	15	131		
	35.40	2.53	20	221		
	35.50	2.52	15	241		
	36.80	2.44	10	240		
	41.70	2.16	15	060		
	48.50	1.87	10	403		
	51.25	1.77	10	204		
	AK24	21.00	4.22	25		
22.00		4.00	20	201		
26.80		3.31	45	220		
27.95		3.20	100	002		
29.20		3.05	10	131		
30.90		2.89	20	041		
31.28		2.85	15	131		
35.20		2.53	15	221		
35.35		2.54	30	241		
36.90		2.43	10	240		
41.85		2.15	25	060		
49.10		1.87	5	403		
51.20		1.82	10	204		
A27		21.00	4.22	20	201	55
	22.15	4.00	10	201		
	26.70	3.32	60	220		
	27.80	3.20	100	002		
	29.20	3.05	15	131		
	31.00	2.88	20	041		
	31.30	2.85	15	131		
	35.15	2.53	10	221		
	35.30	2.54	20	241		
	36.80	2.44	25	240		
	41.82	2.15	25	060		
	48.80	1.86	10	403		
	51.15	1.78	10	204		

Note: Values underlined have been used in the diagrams.

(Deer et al., 1963). The normative plagioclases have been found to range in composition from An<sub>53</sub> to An<sub>79</sub>.

(c) x-ray diffractometry:

The plagioclases from the trap rocks of Bandipura were determined by x-ray diffractometry according to the method of Viswanathan (1971). Seven samples of plagioclases from different rock types were x-rayed as powder mounts on Phillips, Holland, x-ray Diffractometer Model no. 1050/25 with Nickel filtered CuK $\alpha$ 1 radiation, with electronically controlled chart recorder with a scanning speed of 1/4<sup>o</sup> per /min goniometer rotation. The x-ray data is shown in table-6. The anorthite content has been read from Viswanathan's chart (fig.12). The x-ray data for plagioclases from Bandipura traps when plotted on figs. 13 and 14 has been found to show medium to high structural state (O/D).

The above studies i.e. optical, chemical and x-ray diffraction in regard to plagioclases of Bandipura traps reveals that their anorthite content varies from An<sub>54</sub> to An<sub>74</sub>.

The structural state of the mineral is found to be medium to high (O/D).

TABLE 7 CHEMICAL ANALYSES OF EPIDOTES  
FROM PANJAL TRAPS OF BANDIPURA

NUMBER OF IONS ON THE BASIS OF  
13(O,OH)

sample no.	AK21 1	AK72 2	A20 3	A27 4	sample no.	AK21 1	AK72 2	A20 3	A27 4
Constituents									
SiO <sub>2</sub>	36.88	37.32	38.84	40.80	Si	2.971	2.988	3.094	3.061
Al <sub>2</sub> O <sub>3</sub>	22.00	23.60	26.70	30.60	Al	0.029	0.012	0.009	0.002
Fe <sub>2</sub> O <sub>3</sub>	16.00	13.70	8.00	0.50	Al	2.0617	2.215	2.571	2.707
FeO	0.50	0.40	0.80	1.50	Fe <sup>+3</sup>	0.970	0.825	0.480	0.027
TiO <sub>2</sub>	Tr.	-	0.15	0.10	Ti	-	-	0.009	0.002
CaO	23.10	23.50	24.00	23.00	Mg <sup>+2</sup>	0.017	0.012	-	0.072
MgO	0.15	0.10	0.00	0.65	Fe <sup>+2</sup>	0.033	0.026	0.042	0.062
Na <sub>2</sub> O	0.03	0.01	0.02	0.01	Ca	1.994	2.015	2.031	1.849
K <sub>2</sub> O	0.01	0.02	0.01	Tr.	Na	0.004	0.002	0.002	0.207
H <sub>2</sub> O(+)	1.30	1.40	1.50	2.60	K	-	0.002	-	-
H <sub>2</sub> O(-)	0.25	0.05	0.10	0.40	OH	0.416	0.386	0.425	0.749
Total	100.22	100.10	100.12	100.16					

Analyst: A.K. RAJNA

Location of the Analysed samples:

1-	34° 24' 20"	74° 42' 30"	3.	34° 28' 03"	74° 39' 01"
2-	34° 29' 03"	74° 39' 01"	4.	34° 27' 15"	74° 39' 32"

Tr. = in traces.

## Epidote:

The study of epidote is pursued along three lines:- optical, chemical and x-ray methods.

### (a) Optical method:

Epidote is present in abundance in the traps of Bandipur. It occurs as sporadic crystals as well as aggregates of small anhedral grains. The interference colour of this mineral varies from second to third order. Four samples of epidotes were separated by the usual separation process and subjected to chemical and x-ray diffraction studies.

### (b) Chemical method:

Four epidote samples have been chemically analysed for their major elements by conventional wet method. The alkalis have, however, been determined by flame photometry. The analytical data is given in table-7. The structural formulae of the analysed samples calculated on the basis of  $13(O, OH)$  are given in the same table. From the chemical data, it has been seen that the epidotes under study correspond to epidote/zoisite variety.

TABLE 8

X-RAY POWDER DIFFRACTION DATA OF EPIDOTES FROM BANDIPURA TRAPS GIVING "d" SPACINGS, INTENSITY AND REFLECTION FACES. UNIT CELL DIMENSIONS AS COMPUTED FROM THIS DATA ARE GIVEN BELOW EACH SAMPLE.

Sample no.	d values	I/I <sub>0</sub>	Plane	sample no.	d values	I/I <sub>0</sub>	Plane
AK21	8.00	35	200	A20	8.10	35	200
	6.20	15	201		6.25	15	201
	5.02	20	002		5.00	35	002
	4.01	20	400		4.00	40	400
	3.76	15	401		3.76	10	401
	3.64	25	112, 311		3.64	15	112, 311
	3.31	20	410		3.30	20	410
	2.90	75	013		2.89	70	013
	2.80	30	020		2.78	30	020
	2.68	100	600, 511		2.68	100	600, 511
	2.54	15	313		2.54	20	313
	2.44	25	122		2.44	20	122
	2.33	20	222		2.35	15	222
a = 16.02, b = 5.60, c = 10.00				a = 16.14, b = 5.60, c = 9.92			
Sample no.	d values	I/I <sub>0</sub>	Plane	sample no.	d value	I/I <sub>0</sub>	Plane
A27	8.10	10	100	AK72	8.06	15	100
	4.60	15	002		4.58	20	002
	4.01	45	200		4.03	50	200
	3.47	20	211		3.40	40	102
	3.23	20	201		3.20	20	201
	2.90	100	113		2.89	100	113
	2.80	30	020		2.80	35	020
	2.68	60	021		2.67	100	300
	2.66	100	300		2.44	35	121
	2.44	30	121		2.37	25	022
	2.27	20	222				
a = 8.50, b = 5.60, c = 10.02 β = 115°				a = 8.60, b = 5.58, c = 10.20 β = 115°			

(c) x-ray studies:

Four samples of epidotes were x-rayed by powder method Phillips x-ray diffractometer model no. 1050/25 having Nickel filtered  $\text{CuK}\alpha_1$  radiation with a scanning speed of  $1/4^\circ$  per/min. and data are given in table. 8. The unit cell dimensions as calculated from the x-ray data are also contained in the same table.

It has been seen from the tabulated data that the epidotes are of zoisite and epidote variety confirming the earlier results.

From all the above modes of investigation, it is evident that the epidotes from Bandipura traps are of zoisite and epidote variety.

Chlorite:

The study of chlorites has been followed along the same lines as in the case of plagioclases and epidotes. Chlorite is mostly present as wisps and scales in the rocks under study and is an alteration product of original pyroxenes. This mineral is green in colour and sometimes shows pleochroism. At times it shows abnormal Berlin blue interference colours.

TABLE-9 CHEMICAL ANALYSES OF CHOKKIES FROM PANJAL TRAPS OF BANDI PURA

NUMBER OF IONS ON THE BASIS OF 28 OXYGEN EQUIVALENTS, IGNORING WATER

sample no.	AK75 1	AR41 2	AR20 3	A16 4	sample no.	AK75 1	AR41 2	AR20 3	A16 4
<u>Constituents</u>									
SiO <sub>2</sub>	31.42	30.74	26.54	26.24	Si	6.006	5.821	5.485	5.532
Al <sub>2</sub> O <sub>3</sub>	15.60	18.00	19.20	18.00	Al	1.994	2.179	2.515	2.468
Fe <sub>2</sub> O <sub>3</sub>	2.50	2.70	5.50	6.50	Al	1.520	1.834	2.161	2.006
FeO	4.00	4.80	22.80	24.00	Mn	-	0.021	-	11.81
TiO <sub>2</sub>	-	0.15	Tr.	-	Fe <sup>+3</sup>	0.360	0.384	0.854	1.031
CaO	Tr.	Tr.	0.50	0.60	Fe <sup>+2</sup>	0.639	0.760	3.940	4.231
MgO	33.40	32.70	15.00	13.50	Mg	9.515	8.945	4.619	4.341
Na <sub>2</sub> O	0.07	-	0.23	0.22	Ca	-	-	0.110	0.135
K <sub>2</sub> O	0.06	0.03	0.12	0.16	Na	0.024	-	0.090	0.088
H <sub>2</sub> O(+)	12.50	10.74	9.90	10.40	K	0.012	0.006	0.032	0.042
H <sub>2</sub> O(-)	0.60	0.40	1.00	0.60	(OH)	16.00	16.00	16.00	16.00
Total	100.15	100.26	100.79	100.22					
Analyst: A.K. RAINA									
Location of the									
Analysed samples:									
1-	34° 28' 38"	74° 43' 28"	74° 38' 33"	74° 42' 45"	3-	34° 25' 02"	74° 38' 33"	74° 38' 33"	74° 42' 45"
2-	34° 25' 02"	74° 43' 28"	74° 43' 28"	74° 43' 28"	4-	34° 28' 07"	74° 38' 33"	74° 38' 33"	74° 42' 45"

Tr. = in traces.

TABLE 10 X-RAY POWDER DIFFRACTION DATA OF CHLORITES FROM BANDI PURA TRAPS GIVING "d" SPACINGS, INTENSITY AND REFLECTION FACES. UNIT CELL DIMENSIONS AS COMPUTED FROM THIS DATA ARE GIVEN BELOW EACH SAMPLE.

Sample no.	d values	I/I <sub>0</sub>	Plane	Sample no.	d values	I/I <sub>0</sub>	Plane
AK75	7.06	100	001	A16	7.01	100	001
	4.63	25	020		4.66	25	020
	4.26	6	11 $\bar{1}$ M		4.30	5	11 $\bar{1}$ M
	3.53	100	002		3.52	100	002
	2.66	30	200		3.16	35	-
	2.53	70	201		2.67	35	200
	2.34	5	-		2.52	75	201
	2.15	50	202		2.37	5	-
	1.90	5	20 $\bar{2}$		2.16	50	202
	1.54	50	060		1.93	3	20 $\bar{2}$
					1.54	60	060

$$a = 5.30, b = 9.26, c = 7.04$$

$$\beta = 104.6^\circ$$

$$a = 5.49, b = 9.20, c = 7.04$$

$$\beta = 104.5^\circ$$

sample no	d values	I/I <sub>0</sub>	Plane	sample no.	d values	I/I <sub>0</sub>	Plane
AR 20	7.05	100	001	AR41	7.05	100	001
	4.62	10	020		4.67	20	020
	4.28	5	11 $\bar{1}$ M		4.25	5	11 $\bar{1}$ M
	3.52	100	002		3.54	100	002
	2.66	20	200		3.16	20	-
	2.50	70	201		2.67	40	200
	2.40	30	20 $\bar{2}$		2.52	80	201
	2.15	50	202		2.40	30	20 $\bar{2}$
	1.93	10	20 $\bar{2}$		2.14	50	202
	1.55	55	060		1.92	7	20 $\bar{2}$
					1.56	60	060

$$a = 5.48, b = 9.02, c = 7.00$$

$$\beta = 104.5^\circ$$

$$a = 5.36, b = 9.00, c = 7.16$$

$$\beta = 104.5^\circ$$

Four samples of chlorites isolated from the traps under study were chemically analysed for their major elements by the conventional wet method. The alkalis have, however, been determined by <sup>o</sup>Flame Photometer (E.H. Model). The results of the chemical analyses and structural formulae of chlorites determined on the bases of 28 oxygen equivalents ignoring water are given in table. 9.

Four separated samples of chlorites were x-rayed by powder method on Phillips x-ray diffractometer Model No. 1050/25 using Nickel filtered Cu K<sub>α1</sub> radiation having an electronically controlled chart recorder with a scanning speed of 1/4° per/min. The prominent reflections on the x-ray diffractograms were indexed and the results are given in table-10. From these results it can be seen that the chlorites of the traps under investigation are of Chamosite <sup>variety</sup> (iron-rich type). The unit cell dimensions as computed from the x-ray data are given in the same table. The unit cell dimensions also confirm that the chlorite under study are of Chamosite variety.

### Quartz

Quartz occurs as an important released mineral in the basic rocks of Bandipura area. It is usually seen in the form of small grains dispersed through the rock sections. Occasionally,

it is present as an important infilling material in rock cavities. It is seen in various proportions in different rocks, but its percentage is more in epidiosites. Large grains of quartz contain inclusions of ilmenite/magnetite. The mineral at places shows undulatory extinction and first order grey polarization colours.

Ilmenite/magnetite and opaques:

Ilmenite and magnetite occur as small grains and as specks and sometimes as big skeletal crystals. Ilmenite is generally altered to leucocene.

Average  $\text{SiO}_2$  value works out equal to 51.32 percent showing overall basic character of the rocks. The trap rocks are rich in iron and low in alkalis. The specific gravity of different types varies from 2.60 to 3.12.

The chemical analyses of the representative samples are shown in table 11, Niggli values and C.I.P.W. norms calculated from the chemical analyses are contained in tables 12 and 13. The values of cations per hundred oxygen anions of the traps are given in table 14.

It may be remarked that the analytical data has been treated initially in terms of conventional diagrams suggested by Harker, Larsen, Thornton and Tuttle, Poldervaart and Parker and Kuno. In the second instance, Bandipura traps have been studied as bivariate plots suggested by some investigators for assessing the nature of the primary basaltic magma. Thirdly the traps have been investigated in terms of two component diagrams put forth by some workers for deciphering the differentiation trend of basaltic magmas. Fourthly the traps of the area under discussion have been plotted according to the methods advanced by some workers for studying the trend lines of typical rock suites from different parts of the world. In some diagrams, however, two or even more aspects mentioned above are treated in one and the same diagram to

(Contd. P. 72.)

TABLE - 11 CHEMICAL ANALYSES OF PANJAL TRAPS OF BANDI PURA (.... Contd.)

Sample no.	AR 53 1	AR 39 2	A 16 3	AR 32 4	A 33 5	A36 6	AK62 7	A 38 8	AK 11 9	A 11 10
Constituents										
SiO <sub>2</sub>	44.66	45.44	46.54	47.72	48.40	48.40	48.41	48.50	49.14	49.15
Al <sub>2</sub> O <sub>3</sub>	19.66	18.19	16.12	19.97	20.52	16.20	15.33	15.83	15.32	17.00
Fe <sub>2</sub> O <sub>3</sub>	3.40	4.51	3.35	4.16	5.64	3.40	2.50	3.30	3.60	3.65
FeO	9.60	10.28	11.65	9.69	6.10	10.80	9.68	7.70	11.10	8.00
TiO <sub>2</sub>	1.60	1.18	1.66	0.76	0.80	0.55	1.95	2.15	1.15	1.82
CaO	9.85	8.50	9.40	7.85	9.68	8.41	9.53	10.95	9.00	9.00
MgO	5.24	5.40	4.02	3.24	3.56	4.05	6.86	6.55	3.08	6.15
Na <sub>2</sub> O	1.20	1.10	1.88	1.50	2.00	2.40	2.01	2.00	2.20	2.14
K <sub>2</sub> O	0.50	0.90	0.40	0.44	0.62	1.20	0.80	1.15	1.00	0.85
H <sub>2</sub> O(+)	3.00	3.00	3.00	3.06	2.00	3.60	3.14	1.10	3.80	1.20
H <sub>2</sub> O(-)	1.05	0.92	1.49	1.34	0.74	0.62	0.22	0.60	0.36	0.94
Total	99.76	99.42	99.51	99.73	100.06	99.63	100.43	99.83	99.75	99.90
Sped fic gravity	2.89	2.68	2.67	2.63	2.90	2.68	2.62	2.87	2.61	3.11
Location of the analysed samples:										
1-	34° 24' 55"	74° 44' 09"			6- 34° 27' 05"		74° 39' 04"			
2-	34° 25' 25"	74° 43' 05"			7- 34° 24' 55"		74° 44' 37"			
3-	34° 28' 07"	74° 38' 33"			8- 34° 28' 01"		74° 39' 52"			
4-	34° 25' 02"	74° 42' 45"			9- 34° 24' 49"		74° 44' 24"			
5-	34° 27' 25"	74° 39' 06"			10- 34° 28' 40"		74° 38' 03"			

Analyst: A.K. RAINA



TABLE-11 CHEMICAL ANALYSES OF PANJAL TRAPS OF BANDI PURA

Sample no.	NK 20 21	NK 72 22	A 45 23	AR 49 24	NK 21 25	A 20 26	A 19 27	AR 41 28	AR 63 29
Constituents									
SiO <sub>2</sub>	52.26	52.66	53.52	54.50	54.98	55.40	56.40	56.62	57.42
Al <sub>2</sub> O <sub>3</sub>	14.44	14.50	15.12	15.00	12.80	14.50	15.00	14.00	14.50
Fe <sub>2</sub> O <sub>3</sub>	3.30	3.60	3.40	4.00	3.70	2.00	3.00	3.00	2.02
FeO	8.20	7.15	9.50	8.00	9.30	8.09	8.09	8.20	8.10
TiO <sub>2</sub>	1.60	1.77	0.82	1.12	1.50	1.80	1.80	1.34	1.77
CaO	8.40	9.40	7.85	6.57	8.41	7.10	5.08	5.80	6.10
MgO	4.05	6.17	3.20	5.15	3.10	3.50	3.50	3.10	3.49
Na <sub>2</sub> O	1.70	2.95	2.25	1.15	2.20	2.40	2.50	2.60	2.52
K <sub>2</sub> O	0.30	0.50	1.52	0.35	1.20	1.01	0.91	0.95	0.90
H <sub>2</sub> O (+)	3.98	1.00	2.68	3.10	2.64	3.00	2.45	3.40	2.50
H <sub>2</sub> O (-)	1.00	0.68	0.78	0.90	0.50	0.90	1.00	0.92	1.00
Total:	99.23	100.38	100.64	99.84	100.33	99.70	99.73	99.93	100.32
Specific gravity:	2.60	2.80	2.68	3.12	2.61	2.70	2.80	3.07	2.90
Location of the Analysed samples:									
21- 34° 24' 25"		74° 43' 48"			26- 34° 28' 03"		74° 39' 01"		
22- 34° 29' 03"		74° 39' 01"			27- 34° 28' 25"		74° 38' 48"		
23- 34° 27' 36"		74° 40' 03"			28- 34° 25' 02"		74° 43' 28"		
24- 34° 24' 27"		74° 43' 43"			29- 34° 24' 35"		74° 44' 26"		
25- 34° 24' 20"		74° 42' 30"							

Analyst: A.K. RAJNA

TABLE - 12 NIGGLI VALUES OF BANDIPURA TRAPS

sample no.	C O N S T I T U E N T S							
	si	Qz	al	fm	c	alk	k	mg
AR53	106	-6	28	44	25	3	0.20	0.42
AR39	115	-1	27	51	18	4	0.35	0.40
A 16	117	-3	24	46	25	5	0.11	0.33
AR32	118	-2	29	40	26	5	0.17	0.31
A33	120	4	31	40	25	4	0.17	0.24
A36	123	-9	24	45	23	8	0.25	0.34
AR62	115	-9	21	49	24	6	0.21	0.50
A38	115	-9	22	44	28	6	0.27	0.52
AK 11	129	-3	24	43	25	8	0.30	0.28
A11	129	-4	24	46	24	6	0.20	0.49
AK76	128	0	23	43	27	7	0.28	0.37
AK 30	130	-2	22	44	26	8	0.30	0.46
A27	132	4	27	41	25	7	0.22	0.41
A68	117	-3	20	49	26	5	0.10	0.55
AK 24	136	8	22	48	23	7	0.25	0.41
A70	130	2	24	47	22	7	0.31	0.40
AR20	125	1	21	50	23	6	0.14	0.55
AR16	122	2	18	48	29	5	0.10	0.53
AK79	139	-1	21	48	21	10	0.26	0.36
AK75	142	10	24	42	26	8	0.20	0.39
AK20	150	30	25	44	26	5	0.10	0.39
AK72	131	-1	21	46	25	8	0.09	0.51
A45	150	18	25	43	24	8	0.30	0.31
AR49	134	22	22	58	17	3	0.17	0.33
AK21	159	27	22	44	26	8	0.27	0.30
A20	181	33	28	44	18	12	0.22	0.38
A19	179	39	28	45	17	10	0.20	0.36
AR41	180	40	26	44	20	10	0.19	0.33
AR63	181	45	27	43	21	9	0.19	0.38

TABLE - 13 C.I.P.W NOMS OF PANJAL TRAPS OF BANDI PURA (Contd.....)

Sample no.	AR53 1	AR39 2	A 16 3	AR 32 4	A 33 5	A36 6	AR62 7	A 38 8	AK 11 9	A 11 10
No. Minerals.										
Quartz (Qz)	7.92	7.32	3.54	5.58	6.48	1.50	0.96	2.64	3.78	2.52
Orthoclase (Or)	2.78	6.54	2.22	2.78	3.89	7.23	5.00	6.67	8.34	5.00
Albite (Ab)	9.95	9.43	15.72	12.57	16.76	20.44	16.76	16.76	18.34	18.34
Anorthite (An)	46.98	33.24	34.47	44.42	45.03	29.75	30.30	30.80	27.80	34.19
Corundum (C)	-	3.46	-	-	-	-	-	-	-	-
(Wo)	0.81	-	5.10	1.04	1.27	4.99	7.07	9.04	7.08	4.40
(En)	0.30	-	2.00	0.40	0.70	1.90	3.90	6.40	2.60	2.70
(Fs)	0.52	-	3.16	0.66	0.52	3.17	2.90	1.84	4.62	1.45
Hypersthene (En)	10.80	13.50	8.10	8.10	8.20	8.20	13.30	10.10	5.10	12.70
(Fs)	8.61	13.20	12.67	12.54	4.75	12.94	9.50	3.03	10.96	7.12
Magnetite (Mt)	4.87	6.49	4.87	6.03	8.12	4.87	3.71	6.74	5.10	5.33
Ilmenite (Il)	3.04	2.28	3.19	1.36	1.52	1.06	3.64	4.10	2.13	3.49
Water (H <sub>2</sub> O)	4.05	3.92	4.49	4.40	2.74	4.22	3.36	1.70	4.16	2.14
Total:	100.63	99.38	99.53	99.88	99.80	100.27	100.40	99.82	100.01	99.38

TABLE 13 C.I.P.V NOMS OF PAUJAL TRAPS OF BANDIPURA (Contd.....)

Sample no.	AK76 11	AK30 12	A 27 13	A 68 14	AK 24 15	A 70 16	AR20 17	AR 16 18	AK 79 19	AK 75 20
Quartz (Qz)	2.76	2.34	4.80	2.35	7.26	5.46	9.42	2.15	3.72	6.84
Orthoclase(Or)	7.78	9.45	5.56	2.22	6.11	8.34	3.89	2.23	9.45	6.11
Albite (Ab)	18.34	20.43	18.34	18.25	16.76	16.76	18.34	18.35	25.15	22.00
Anorthite (An)	28.07	23.63	34.75	28.25	25.85	30.30	15.84	28.36	17.79	25.85
Corundum(C)	-	-	-	-	-	-	-	-	-	-
(Wo)	8.12	9.62	3.71	9.10	5.80	3.82	12.06	9.75	7.65	7.07
(En)	3.30	5.10	1.60	6.00	2.70	1.80	7.80	6.21	3.30	3.40
(Fs)	4.85	4.22	2.11	2.47	3.03	1.98	3.50	2.90	4.35	3.56
(En)	6.80	7.90	9.20	13.31	9.80	10.70	11.20	12.51	7.60	6.60
(Fs)	9.76	6.46	12.01	6.20	10.82	10.95	7.54	6.08	9.63	7.26
Magnetite (Mt)	3.48	4.40	2.55	8.10	4.17	5.10	4.64	8.60	5.56	4.17
Ilmenite (Il)	2.43	1.97	2.12	2.03	2.58	2.43	3.80	2.13	1.21	2.43
Water(H <sub>2</sub> O)	3.90	4.08	3.14	1.50	4.58	2.52	1.50	1.10	4.12	4.14
Total	99.59	99.60	99.89	99.78	99.46	100.16	99.53	100.37	99.53	99.43

TABLE - 13 C.I.P.V. NOMS OF PANJAL TRAPS OF BANDI PURA.

Sample no.	AK 20 21	AK 72 22	A 45 23	AR 49 24	AK 21 25	A 20 26	A 19 27	AR 41 28	AR 63 29
Norm Minerals.									
Quartz (Qz)	11.10	7.03	9.18	20.10	14.16	16.68	18.00	17.88	17.22
Orthoclase(Or)	4.66	2.30	8.89	2.22	7.22	6.11	5.56	5.56	5.56
Albite(Al)	17.14	25.15	18.86	9.95	18.34	21.43	22.96	22.00	21.48
Anorthite(An)	30.13	24.25	26.68	32.52	23.40	26.29	25.29	23.63	25.29
Corundum (C)	-	-	-	0.71	-	0.10	0.61	-	-
	(Wo)	4.40	8.26	-	8.46	-	-	2.20	2.08
	(En)	2.20	6.01	-	3.50	-	-	1.00	1.00
	(Fs)	2.11	1.40	-	5.01	-	-	1.18	1.05
	(En)	7.90	9.05	7.10	12.90	5.30	8.70	6.80	7.70
	(Fs)	7.52	2.61	10.03	9.50	4.70	10.03	8.97	9.10
		4.87	9.45	4.87	5.80	3.20	3.01	4.40	3.01
		3.04	3.34	1.52	2.12	3.18	3.49	3.34	3.34
		4.98	1.68	3.46	4.00	3.14	3.90	3.45	3.50
Total	100.05	100.53	100.89	99.82	99.61	99.74	100.68	100.52	100.33

TABLE-14 CATIONS OF CHEMICALLY ANALYSED SAMPLES  
OF BANDIPURA TRAPS.

C O N S T I T U E N T S

sample no.	Si	Al	Fe <sup>+3</sup>	Fe <sup>+2</sup>	Mg	Ca	K	Na	Tl	H
AR53	20.85	10.40	2.37	7.45	3.15	7.04	0.41	0.89	0.95	0.45
AR39	21.22	9.62	3.15	7.98	2.71	6.07	0.74	0.81	0.70	0.43
A 16	21.73	8.52	2.34	9.05	2.42	6.72	0.33	1.39	0.99	0.50
AR32	22.28	10.56	2.90	7.52	1.95	5.61	0.36	1.11	0.45	0.49
A33	22.60	10.86	3.94	4.73	2.14	6.92	0.51	1.48	0.47	0.30
A36	22.60	8.56	2.37	8.39	2.44	6.01	0.99	1.78	0.32	0.47
AR62	22.60	8.10	2.51	8.62	4.13	6.81	0.66	1.49	0.68	0.37
A38	22.65	8.37	2.30	5.98	3.94	7.82	0.95	1.50	1.28	0.19
AK11	22.95	8.10	2.51	8.62	1.85	6.43	1.16	1.63	0.68	0.46
A11	22.95	8.99	2.55	3.88	3.70	6.43	0.70	1.58	1.09	0.23
AK76	23.07	8.06	1.71	7.92	2.44	6.86	1.07	1.63	0.76	0.49
AK 30	23.50	7.62	2.09	6.29	3.13	6.73	1.32	1.78	0.62	0.47
A 27	23.54	9.19	1.18	7.38	2.59	6.29	0.74	1.63	0.65	0.36
A68	23.60	7.64	2.09	6.60	4.73	7.57	0.29	1.59	0.65	0.16
AK24	23.66	7.35	1.95	7.84	3.01	5.72	0.83	1.48	0.82	0.51
A70	23.73	8.44	2.51	7.61	3.01	5.69	1.16	1.48	0.74	0.28
AR20	24.05	7.86	2.20	6.06	4.58	6.42	0.51	1.59	1.19	0.16
AR16	24.12	7.50	2.40	5.95	4.40	8.17	0.35	1.59	1.15	0.12
AK 79	24.12	6.98	2.72	7.69	2.62	5.21	1.32	2.22	0.38	0.53
AK75	24.13	7.88	1.95	6.48	2.41	6.15	0.83	1.92	0.74	0.53
AK 20	24.40	7.64	1.81	6.37	2.44	6.00	0.24	1.26	0.95	0.55
AK 72	24.50	7.67	2.51	7.60	3.72	6.61	0.41	2.18	0.95	0.18
A45	24.99	7.99	2.30	7.38	1.92	5.61	1.26	1.66	0.49	0.38
AR49	25.45	7.93	2.80	6.21	3.10	4.69	0.29	0.85	0.67	0.44
AK21	25.67	6.77	2.58	7.22	1.86	6.01	0.99	1.63	0.89	0.35
A20	25.87	7.67	1.39	6.29	2.11	5.07	0.83	1.78	1.07	0.43
A19	26.33	7.93	2.09	6.28	2.11	3.63	0.75	1.85	1.07	0.38
AR41	26.44	7.40	2.09	6.32	1.86	4.14	0.78	1.92	0.80	0.48
AR63	26.81	7.67	1.41	6.29	2.11	4.36	0.74	1.86	1.06	0.39

make the same broad based. Hence there is some unavoidable overlapping here and there. Finally the analytical data of the trap rocks of Bandipura have been studied in terms of ternary variation diagrams and the data interpreted.

#### BINARY VARIATION DIAGRAMS

The following binary variation diagrams have been drawn:-

#### HARKER VARIATION DIAGRAM

Fig.15 represents a plot of  $SiO_2$  versus all oxides.  $Al_2O_3$  curve displays a scattering of points, but a general downward tendency with the rise of silica is noticed. The scattering of points is possibly due to the fact that there is no accurate method for the determination of alumina in rocks, and it is computed by difference alone.  $TiO_2$  shows an almost linear trend in a downward direction with the increase in silica.  $Fe_2O_3$  and  $FeO$  show negative trends, that is in the more basic members there is a greater concentration of these oxides which get depleted in the later fractions. This is the usual characteristic of a differentiating magma.  $CaO$  also behaves likewise, that is there is higher concentration in the early basic members; and the same decreases as differentiation progresses.  $MgO$  shows a uniform decrease towards less basic members. Alkalis show a positive relation ( i.e. with the increase in

SiO<sub>2</sub> alkalis also increase) as is expected in a differentiation series.

#### LARSEN VARIATION DIAGRAM

Larsen (1938) suggested a method by virtue of which various oxides are plotted as ordinate against the sum of  $1/3 \text{ SiO}_2 + \text{K}_2\text{O} - (\text{FeO} + \text{MgO} + \text{CaO})$  as abscissa. The compounding of SiO<sub>2</sub>, K<sub>2</sub>O, MgO, CaO and FeO as  $1/3\text{SiO}_2 + \text{K}_2\text{O} - (\text{FeO} + \text{MgO} + \text{CaO})$  has been termed as "Larsen Index". The principle behind this method is that primarily significant changes are noticed in the behaviour of SiO<sub>2</sub>, K<sub>2</sub>O, FeO, MgO and CaO contents for rocks ranging in composition from basic to acid types. The oxides Al<sub>2</sub>O<sub>3</sub> and Na<sub>2</sub>O are thought by him to be playing a minor role, as the former is generally erratic in behaviour and the latter varies insignificantly in its content and both are not, therefore, included in the index components.

The values of Larsen Indices of Bandipura traps are given in table 15a.

It is evidently clear from fig.16 that SiO<sub>2</sub> curve displays an increasing trend with the increase in the value of Larsen Indices though some scattering of points is noticed. There is a decrease in the case of TiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, FeO, CaO and

(Contd. P.77)

TABLE 15 (a) LARSEN INDICES OF BANDI PURA TRAPS (Contd.....)

Sample no.	AR53 1	AR39 2	A16 3	AR32 4	A33 5	A36 6	AR62 7	A38 8	AK11 9	AI1 10
L.I	-9.53	-8.74	-9.16	-3.71	-3.50	-5.93	-9.14	-8.17	-5.40	-6.49

(b) DIFFERENTIATION INDICES OF BANDI PURA TRAPS

D.I.	20.67	23.29	21.48	20.93	31.39	29.17	22.72	26.05	30.46	25.86
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(c) CRYSTALLIZATION INDICES OF BANDI PURA TRAPS

C.I.	47.46	42.84	44.45	41.97	47.55	39.58	48.03	53.11	36.97	53.65
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(d) SOLIDIFICATION INDICES OF BANDI PURA TRAPS

S.I.	25.26	24.33	18.87	17.02	12.15	18.53	31.39	35.15	14.40	29.58
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TABLE - 15 (a) LARSEN INDICES OF BANDI PURA TRAPS (Contd.....)

sample no.	AK 76 11	AK 30 12	A27 13	A68 14	AK24 15	A70 16	AR20 17	AR16 18	AK79 19	AK75 20
L.I	-6.08	-4.34	-4.90	-9.10	-5.21	-4.42	-6.10	-9.25	-2.73	-2.75

(b) DIFFERENTIATION INDICES OF BANDI PURA TRAPS

D.I.	28.88	32.22	28.70	22.82	30.13	30.56	28.80	23.00	38.32	34.95
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(c) CRYSTALLIZATION INDICES OF BANDI PURA TRAPS

C.I.	39.94	40.16	44.64	50.60	38.53	41.67	47.90	50.00	30.22	37.80
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(d) SOLIDIFICATION INDICES FOR BANDI PURA TRAPS

S.I.	20.04	25.61	23.11	35.40	23.92	22.93	34.40	32.20	19.12	21.37
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15

TABL R- (a) LARSEN I N D I C E S O F B A N D I P U R A T R A P S .

Sample No.	AK20 21	AK72 22	AK5 23	AK9 24	AK21 25	A20 26	A19 27	AK1 28	AK63 29
L.I.	-3.13	-5.15	-1.16	-1.44	-1.29	0.11	2.43	2.09	1.75
(b) DIFFERENTIATION INDICES OF BANDI PURA TRAPS									
D.I.	26.90	34.36	36.93	32.27	39.72	44.22	46.52	45.44	44.26
(c) CRYSTALLIZATION INDICES OF BANDI PURA TRAPS									
C.I.	38.53	43.35	35.74	26.82	31.95	20.10	20.25	20.30	21.43
(d) SOLIDIFICATION INDICES OF BANDI PURA TRAPS									
S.I.	23.07	30.30	16.10	27.61	15.89	20.58	19.44	17.36	20.49

MgO curves towards higher values of Larsen Indices. The curve for  $Al_2O_3$  shows a downward trend with the increase in Larsen indices though some scattering of points, as in Harker's diagram is evident. On the contrary alkalis show an increase with the rise in the value of Larsen indices from rocks of higher basicity to those of lesser basicity corroborating "Larsen's Petrogenetic Principle". The individual oxides  $K_2O$  and  $Na_2O$  show a rise in a linear manner with the increase in the values of Larsen indices.

#### THORNTON AND TUTTLE VARIATION DIAGRAM

Bowen (1937) demonstrated that the fractional crystallization of silicate magmas ultimately reaches the system  $SiO_2$ - $NaAlSi_3O_8$ - $KAlSi_3O_8$ , which has been named as "Petrogeny's Residual System". The experimental studies by Schairer (1954, 1957) on the ternary systems  $Mg_2Al_4Si_5O_{18}$  (cordierite)- $KAlSi_2O_6$  (Leucite)- $SiO_2$  (Silica) and  $Mg_2Al_4Si_5O_{18}$  (Cordierite)- $NaAlSi_3O_8$  (Albite)- $SiO_2$  (Silica) confirmed Bowen's findings. Yoder (1957) studied the trivariate system  $KAlSi_3O_8$ - $Al_2Si_2O_8$ - $H_2O$  and supported the above conclusion arrived at by Bowen (op. cit.). The 'Petrogeny's residual system', evidently includes <sup>the</sup> composition of the following normative mineral molecules: quartz, orthoclase, albite, nepheline, leucite and

kalsilite.

Thornton and Tuttle (1960) have made use of the above mentioned concept by proposing a new parameter the "Differentiation Index" (D.I.) against which various oxides are plotted and the variation in the chemistry of rocks studied.

The differentiation index has been defined as the sum of weight percentages of normative quartz, orthoclase, albite, nepheline, leucite and kalsilite. These evidently are the silic constituents of the C.I.P.W norm with the important exception of anorthite, which is considered as a basic constituent of rocks together with zircon, corundum etc.

Fig.17 shows various oxides plotted against the differentiation indices for Bandipura traps. The values of D.I. for the rocks are tabulated in table 15b. An inspection of curves shows that  $\text{SiO}_2$  attains an upward trend with the increase in the values of D.I., though some scattering of points is noticed. This means that  $\text{SiO}_2$  molecule was added upto the later fractions when the magma changed from rocks of higher basic contents to those of lesser basic members during the course of differentiation.  $\text{Al}_2\text{O}_3$  in this diagram shows a scatter of points, but a general downward trend is evidenced.  $\text{TiO}_2$  curve displays a

downward trend in a linear fashion.  $\text{Fe}_2\text{O}_3$  and  $\text{FeO}$  curves show a decline towards later differentiates. This means that with the progress of differentiation, these two oxides got impoverished in the residual liquids and hence the later fractions were depleted in the concentration of both. The curves for  $\text{CaO}$  and  $\text{MgO}$  show a decrease with the increase in D.I. values. This is fully in accordance with the observation that these two constituents are being removed continuously from the magma with the result that their concentration is very small in its end fractions. The individual and combined curves for  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$  show an increase with the increase in D.I. as a result of advanced differentiation.

#### POLDERVAART AND PARKER VARIATION DIAGRAM

Poldervaart and Parker (1964) suggested the use of "Crystallization Index" for deciphering the variation in the chemistry of igneous rocks. In this C.I. is taken as abscissa and various oxide weight percentages as ordinate.

The basic principle behind this method is that in the crystallization of magmas, dominant part is played by the felsic and the mafic constituents of the reaction series; in the former the fractionation is from  $\text{Ca} \rightarrow (\text{Na}+\text{K})$ , while in the latter it is from  $\text{Mg} \rightarrow (\text{Fe}^{+2} + \text{Fe}^{+3})$ . The earliest part

of the reaction series consists primarily of the simple system  $\text{CaAl}_2\text{Si}_2\text{O}_8$  (anorthite),  $\text{CaMgSi}_2\text{O}_6$  (diopside) and  $\text{Mg}_2\text{SiO}_4$  (Forsterite) referred to as the "Petrogeny's Primitive System".

The Crystallization Index has been considered as the sum of An, Di, FO' and Sp', where

- An = normative anorthite
- Di = magnesian diopside calculated from normative diopside, and
- FO' = normative forsterite + normative enstatite converted to forsterite
- Sp' = magnesian spinel ( $\text{MgAl}_2\text{O}_4$ ) calculated from normative corundum in ultramafic rocks.

The values of Di' and FO' are calculated as follows:

$$Di' = \frac{\text{molecular weight of } \text{CaMgSi}_2\text{O}_6}{\text{molecular weight of } \text{MgSiO}_3} \times \text{En Di (enstatite of normative diopside)}$$

or

$$Fo' = \text{normative forsterite} + \frac{2.157003 \times \text{En Di (enstatite of normative diopside)}}{2 \times \text{molecular weight of } \text{Mg}_2\text{SiO}_4} \times \text{En Hy}$$

where En(Hy) is enstatite of normative hypersthene

$$\text{or } = Fo' + 0.700837 \times \text{EnHy (enstatite of normative hypersthene)}.$$

Fig.18 shows oxide weight percentages plotted as ordinate against the crystallization indices as abscissa. The values of crystallization indices have been tabulated in table 15c. It is evident from this figure that  $SiO_2$  curve shows an upward trend with the lower values of C.I., though some scattering of points is noticed. As far as  $Al_2O_3$  is concerned, it displays a wide scatter of points, but a downward trend is seen with falling C.I. values. Curves for  $TiO_2$ ,  $Fe_2O_3$ ,  $FeO$ ,  $CaO$  and  $MgO$  show a gradual decline with the advanced crystallization of the magma. As far as individual and total alkalis are concerned, these show a gradual increase with the fall of C.I. values.

#### KUNO'S VARIATION DIAGRAM

Kuno (1968) introduced the concept of "Solidification Index" calculated as:-

$$S.I. = \frac{MgO}{MgO + FeO + Fe_2O_3 + Na_2O + K_2O} \times 100$$

Kuno assumes that "S.I. values decrease proportionately with the amount of residual liquid". Table 15d shows the S.I. values for the trap rocks of B-andipur. These values have been plotted as abscissa against different oxides as ordinate (fig.19).

As a general rule, with the progress of solidification, ferromagnesian minerals and also  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  undergo a radical change. This gives an idea about the differentiation process in magmas. In this context, the trends of different oxides obtained are critically examined.

In the case of  $\text{SiO}_2$  curve, there is wide scatter of points, but an upward tendency is evident with the fall in S.I. values.  $\text{Al}_2\text{O}_3$  plots show a downward trend with the fall in S.I. content.  $\text{TiO}_2$  Curve shows a downward trend in a linear manner with falling S.I. values. The curves for  $\text{Fe}_2\text{O}_3$ ,  $\text{FeO}$ ,  $\text{CaO}$ , and  $\text{MgO}$  register a fall with the decrease in S.I. values. The alkalis and their total content on the contrary, show an upward trend with the fall in S.I. values. This is in conformity with a differentiating magma.

#### $(\text{Na}_2\text{O} + \text{K}_2\text{O})$ VERSUS $\text{SiO}_2$ VARIATION DIAGRAM

Macdonald and Katsura (1964) suggested a classification of basaltic rocks into tholeiites and alkali basalts. Here  $\text{SiO}_2$  wt. percentage is plotted as abscissa and  $(\text{Na}_2\text{O} + \text{K}_2\text{O})$  as ordinate. Saggerson and Williams (1964) added one more field of strongly alkaline basalts to this diagram. Chayes (1966) also recommended the plot of total alkalis versus  $\text{SiO}_2$  for rocks of basaltic composition. Bandipura traps

when plotted on this diagram are seen to fall in the field of tholeiites with the exception of a solitary point (plate 20, fig.1). This would suggest a tholeiitic parentage of the traps of the study area.

Kuno (1963) put forth the concept of classifying basalts into tholeiites and alkali -olivine basalts using the above mentioned variables. A transitional variety between the two basalts has been recognized by Kuno (op.cit.). It has been given the name of high alumina basalt. In the case of fine grained rocks, the high alumina basalt as distinguished by Kuno (op.cit) is considered by him to contain  $Al_2O_3$  content greater than 16.5 percent and total alkalis between the other two basalt types for a given silica content. When plotted on Kuno's diagram, Bandipura traps are seen to fall in the field of tholeiites and high alumina basalts. The majority of points, however, fall in the field of tholeiites. It has been observed that the plots for rocks that fall in the field of High Alumina Basalt are seen to contain  $Al_2O_3$  greater than 16.5 percent. Since Bandipura traps are seen to occupy the two fields on Kuno's diagram (plate 20, fig.2), the possibility of two phases of lava eruption is envisaged in this area.

#### KUNO'S POTASH-SODA VARIATION DIAGRAM

Plate 20, fig.3 represents a plot of  $K_2O$  versus  $Na_2O$  for the rocks of panjal traps of Bandipura (Kuno, 1968). In this diagram, there exist three fields, viz., alkali basalt field, high alumina basalt field and spilite field. Majority of points are seen to occupy the field of High Alumina Basalt, whereas two points fall on the discriminating boundary between high alumina basalt and alkali basalt. One point lies on the line of spilites and high alumina basalt field. A point of great interest from this diagram lies in the fact that none of the points falls in the spilite field. Hence the presence of spilites in the study area is ruled out.

#### NIGGLI c VERSUS Mg VARIATION DIAGRAM

Niggli values of Bandipura traps are tabulated in table 12. In plate 21, fig.1, the traps of the study area are seen to fall mainly in the igneous field and follow the trend of Karoo dolerites.

#### NIGGLI (al-alk) VERSUS c VARIATION DIAGRAM

Niggli suggested plotting of a bivariate diagram with

(al-alk) as ordinate and c as the abscissa. Plate 21, fig. 2 shows this type of plot for the rocks of the present area. The plotted points in this diagram are seen to cluster mainly in the field of Karroo dolerites with some points occupying the overall field of igneous rocks and falling outside the Karroo field thus confirming the earlier results obtained by the study of c versus mg variation diagram.

#### NIGGLI si VERSUS (al + fm) - (c + alk) VARIATION DIAGRAM

A plot of Niggli si versus (al + fm) - (c + alk) has been shown in plate 21, fig. 3. In this diagram, most of the points are seen to occupy the volcanic field. The values of si and (al + fm) - (c + alk) are given in table 20d. A few points are, however, noticed to fall outside this field which may be due to the erratic behaviour of al, one of the variables partly involved along the ordinate.

#### NORMATIVE QUARTZ VERSUS C.I. VARIATION DIAGRAM

Poldervaart and Parker proposed this diagram in 1964. Plate 22, fig. 1 shows plots of normative quartz against C.I. for the trap rocks of Bandipur. Most of the points are seen to occupy the basalt field; whereas a few points fall

in the field of ultra-alkaline rocks close to the basalt field. Some points fall in the ultraalkaline field away from the basalt field. The behaviour of the plotted points indicates the basaltic character of <sup>the</sup> rocks with a tendency towards differentiation.

$\text{SiO}_2$  VERSUS S.I. AND  $(\text{FeO} + \text{Fe}_2\text{O}_3)$  VERSUS S.I.  
VARIATION DIAGRAMS

Kuno (1968) advocated the use of solidification index as abscissa and  $\text{SiO}_2$  as ordinate (plate 22, fig.2). The values are given in table 18c. He differentiated hypersthenic and pigeonitic rock fields on this diagram. The plot of the rocks of the present area in this manner suggests a clustering of points in the pigeonite field, though a few points fall in the hypersthenic rock series field. Total oxides of iron when plotted in plate 22, fig.3 also show clustering of points of the rocks of <sup>the</sup> study area in the pigeonitic field corroborating the results obtained in plate 22, fig.2. Total iron and S.I. values are tabulated in 18 d. The clustering of points in both the diagrams in the pigeonitic field would indicate the presence of pigeonite in thin sections of the rocks under study. It has not, however, been observed in

thin sections and may be present in the groundmass.

LINKAGE FACTOR VERSUS  $Mg \times 100 / Mg + Fe$  (total)  
VARIATION DIAGRAM

Poldervaart and Elston (1954) attempted to distinguish the fractionation trends of tholeiitic series from that of calc-alkaline series with the help of a diagram, in which  $Mg \times 100 / Mg + Fe$  (total) was plotted against L.F. The values of linkage factor for the analysed rocks are tabulated in table 16 b and also this table contains the values of  $Mg \times 100 / (Mg + Fe)_{Total}$ . Linkage Factor is calculated from the chemical analyses as follows:-

$$\text{Linkage Factor (L.F.)} = \frac{\text{Total oxygen not combined in (OH)}}{Si^4 - (Al^3 \text{ in 4 coordination})}$$

In plate 23 fig.1, the fractionation trends of Stillwater Complex, Elephant's Head dyke and New Amalfi have been taken as examples of typical tholeiitic series and those of Daly's average basalt-andesite-dacite-rhyolite as examples of calc-alkaline series. The trends of pigeonite rock series of Japan, Palale and Kilauea series of Hawaii have also been superimposed on this diagram for comparison. It is obvious from these curves that there is a marked

(Contd. P. 91)

TABLE 16 (a) NOMINATIVE AN x 100/Ab+An AND D.I. VALUES OF BANDI PURA TRAPS (Contd.....)

Sample No.	AR53 1	AR39 2	A16 3	AR32 4	A33 5	A36 6	AR62 7	A38 8	AK11 9	AK11 10
An x100/Ab+An	82.52	77.90	85.76	77.94	72.87	59.27	64.38	64.76	60.25	65.08
D.I.	20.67	23.29	21.48	20.93	31.39	29.17	22.77	26.05	30.46	25.86

(b) LINKAGE FACTOR AND MG x 100/MG+ Fe (Total) OF BANDI PURA TRAPS.

L.F.	30.02	29.59	24.89	27.53	28.90	23.53	23.16	28.65	22.36	27.10
Mg x 100/Mg+Fe (Total)	24.28	19.58	17.52	15.76	19.81	18.48	30.84	41.10	29.84	30.10

(c) MgO (wt%) AND CaO/AL<sub>2</sub>O<sub>3</sub> RATIOS OF BANDI PURA TRAPS.

MgO	5.24	5.40	4.02	3.24	3.56	4.05	6.86	6.55	6.86	6.15
CaO/AL <sub>2</sub> O <sub>3</sub>	0.50	0.46	0.58	0.41	0.47	0.51	0.62	0.69	0.62	0.52

TABLE 16 (a) NORMATIVE AN x 100/Ab+An AND D.I. VALUES OF BANDIPURA TRAPS (Contd.....)

Sample no.	AK 76 11	AK 30 12	A27 13	A68 14	AK 24 15	A70 16	AK 20 17	AK 16 18	AK 79 19	AK 75 20
An x 100/Ab+An	60.48	53.63	65.45	60.75	60.66	64.38	46.34	60.71	41.42	54.02
D.I.	28.88	32.22	28.70	22.82	30.13	30.56	28.80	23.00	38.32	34.95

(b) LINKAGE FACTOR AND Mg x 100/Mg + Fe (Total) OF BANDIPURA TRAPS.

L.F.	21.80	20.87	22.92	21.40	20.11	22.35	20.55	20.21	19.42	20.33
Mg x 100/Mg+Fe (total)	20.21	32.91	23.22	23.51	23.51	22.92	35.66	40.50	20.10	22.23

(c) MgO (wt %) AND CaO/Al<sub>2</sub>O<sub>3</sub> RATIOS OF BANDIPURA TRAPS.

MgO	4.05	5.20	4.30	7.85	5.00	5.00	7.60	7.20	4.35	4.01
CaO/Al <sub>2</sub> O <sub>3</sub>	0.62	0.65	0.50	0.73	0.57	0.49	0.60	0.84	0.55	0.57

TABLE- 16 (a) NOMINATIVE AN x 100/Ab+An AND D.I. VALUES OF BANDIPURA TRAPS.

Sample No.	AK20 21	AK72 22	A45 23	AK49 24	AK21 25	A20 26	A19 27	AK41 28	AK53 29
Amx100/Ab+An	63.74	49.08	58.58	76.57	56.06	55.09	52.41	51.78	54.07
D.I.	26.90	34.36	36.93	32.27	39.72	44.22	46.52	45.44	44.26

(b) LINKAGE FACTOR AND Mg<sub>x</sub>100/Mg+Fe(Total) OF BANDIPURA TRAPS.

L.F	19-17	20.15	19.87	19.05	17.50	22.60	22.63	22.65	21.55
Mg <sub>x</sub> 100/Mg+Fe (Total)	22.97	19.93	16.45	19.00	15.95	24.10	21.57	25.72	21.50

(c) MgO (Wt%) AND CaO/Al<sub>2</sub>O<sub>3</sub> RATIOS OF BANDIPURA TRAPS.

MgO	4.05	6.17	3.20	5.15	3.10	3.50	3.50	3.10	3.49
CaO/Al <sub>2</sub> O <sub>3</sub>	0.58	0.64	0.51	0.43	0.65	0.48	0.33	0.41	0.42

diversity in the fractionation trends of typical tholeiitic series. On comparison of the trend exhibited by Bandipura traps in this diagram, it is obvious from an inspection of curve AG that the portions BC, DE, and FG compare well with the trends exhibited by tholeiitic series in so far as there is a linear decrease in  $Mg \times 100 / Mg + Fe$  (total) with the increase in the linkage factor which is characteristic of tholeiitic series. The portions AB, CD and EF, however, display a somewhat different trend due to reasons possibly inherent in this type of representation.

In plate 23 , fig.2, the trend of Bandipura traps has been plotted separately with linkage factor along abscissa and  $Mg \times 100 / Mg + Fe$  (total) as ordinate. It is revealed by the inspection of the curve that the andesitic field as demarcated by Sinha and Tewari (1964) for the rocks of Pavagarh area closely corresponds to those of the rocks under discussion. The extreme right hand side of the curve shows the more basic members from which rocks falling on the left hand side of the diagram have been derived.

#### TOTAL ALKALIS VERSUS $SiO_2$ VARIATION DIAGRAM

Segalstad (1979) plotted  $(Na_2O + K_2O)$  versus  $SiO_2$

(after Weigand, 1975) for studying the Skien basaltic rocks, southwestern Oslo region, Norway. This diagram has a number of dividing lines. The Hawaiian line by Macdonald and Katsura (1964), separates the alkaline (Ne-normative) and subalkaline (Hy-normative) rocks in Hawaii. The Japan line by Kuno (1960) represents his high alumina basalt ( $Hy < 10\%$ ) from tholeiites in Japan. The alkali basalts have been further subdivided by the Moheli line of Strong (1972) separating basanite rocks ( $Ne > 5\%$ ) and alkali basalts ( $Ne < 5\%$ ) in the Western Indian ocean. Kenya line of Saggerson and Williams (1964) separates Nepheline and basanite rocks in east Africa.

In fig. 24, with the dividing lines indicated, most of the points of Bandipura traps are seen to occupy the portion between tholeiite and alkali basalt fields. Some points are seen to occupy the fields between basalts and alkali basalts. The remaining points fall in the tholeiitic field. This diagram again shows the predominant tholeiite basalt lineage of the rocks under study and reflects progressive differentiation from the rocks of higher basicity to those of lower basic nature.

NORMATIVE PLAGIOCLASE COMPOSITION VERSUS  
 $Al_2O_3$  VARIATION DIAGRAM

Plate 25 fig.1 is a plot of  $Al_2O_3$  as ordinate against the normative plagioclase composition as abscissa. The normative plagioclase composition is calculated as  $An \times 100 / (Ab + An)$ . The normative plagioclase composition for the analysed samples is tabulated in table 17. This diagram constitutes two fields viz., (i) tholeiitic field, (ii) calc-alkaline field. Trap rocks of Bandipura plot predominantly in the tholeiitic field thereby indicating that the traps of the area bear a tholeiitic lineage. Some points, however, fall close to the discriminating boundary between the tholeiitic field and the calc-alkaline field.

Plate 25 fig.2 shows a plot of normative colour index versus normative plagioclase composition. Normative colour index is obtained by the addition of normative hypersthene, diopside, wollastonite, magnetite and ilmenite and the values are tabulated in table 17. In this diagram, maximum points cluster in the field of basalts and some points lie in the andesitic field. This clearly shows that the rocks under study have undergone differentiation from basalt to andesite. The differentiation has not obviously

(Contd. P.97)

TABLE 17 (a) NOMINATIVE FLAGIOCLASE COMPOSITION AND NOMINATIVE COLOUR INDEX OF BANDI PURA TRAPS (Contd.....)

sample no.	AP53 1	AP39 2	AP16 3	AP32 4	AP33 5	AP36 6	AP62 7	AP38 8	AK11 9	AL1 10
Normative plagioclase composition	82.52	77.90	85.76	77.94	72.87	59.27	64.38	64.76	60.25	65.08
Normative colour index.	27.32	35.47	28.83	28.03	22.59	27.07	30.15	34.05	23.29	36.10

(b) LOG  $\omega$  AND LOG  $\gamma$  VALUES OF BANDI PURA TRAPS

Log $\omega$	0.46	0.60	0.26	0.43	0.30	0.18	0.25	0.55	0.15	0.40
Log $\gamma$	0.98	0.74	1.15	0.94	0.75	1.10	0.90	0.90	0.88	0.75

(c)  $Al_2O_3/SiO_2$  RATIOS AND MgO (wt %) OF BANDI PURA TRAPS

$Al_2O_3/SiO_2$	0.44	0.40	0.34	0.39	0.42	0.33	0.31	0.32	0.31	0.34
MgO	5.24	5.40	4.02	3.24	3.56	4.05	6.86	6.55	3.08	6.15

TABLE 17 (a) NORMATIVE PLAGIOCLASE COMPOSITION AND  
NORMATIVE COLOUR INDEX OF BANDI PURA TRAPS (Contd.....)

Sample no.	AK76 11	AK30 12	A27 13	A68 14	AK24 15	A70 16	AK20 17	AK16 18	AK79 19	AK75 20
Normative Plagioclase Composition	60.48	53.63	65.45	60.75	60.66	64.38	46.34	60.71	41.42	54.02
Normative Colour Index	22.47	20.73	25.88	39.00	27.37	29.18	22.00	39.05	24.00	18.46

(b) LOG  $\alpha$  AND LOG  $\gamma$  VALUES OF BANDI PURA TRAPS

Log $\alpha$	0.27	0.45	0.21	0.45	0.23	0.24	0.18	0.25	0.38	0.17
Log $\gamma$	0.92	0.95	1.19	1.00	1.20	1.25	0.85	0.83	1.21	0.97

(c)  $Al_2O_3/SiO_2$  RATIOS AND MgO (wt %) OF  
BANDI PURA TRAPS.

$Al_2O_3/SiO_2$	0.30	0.28	0.34	0.28	0.27	0.31	0.28	0.26	0.25	0.28
MgO	4.05	5.20	4.30	7.85	5.00	5.00	7.60	7.20	4.35	4.01

TABLE 17 (a) NORMATIVE PLAGIOCLASE COMPOSITION AND  
NORMATIVE COLOUR INDEX OF BANDI PURA TRAPS.

Sample no.	AK20 21	AK72 22	AK45 23	AK49 24	AK21 25	A20 26	AK19 27	AK41 28	AK63 29
Normative Plagioclase Composition	63.74	49.08	58.58	76.57	56.06	55.09	52.41	51.78	54.07
Normative Colour Index	21.21	22.05	23.52	25.10	18.97	15.00	24.10	25.00	29.00

(b) LOG  $\omega$  AND LOG  $\gamma$  VALUES OF  
BANDI PURA TRAPS

Log $\omega$	-0.05	0.30	0.43	0.35	-0.01	0.44	-0.07	-0.09	0.25
Log $\gamma$	0.91	0.60	1.24	1.30	0.88	0.87	1.21	1.10	0.93

(c)  $Al_2O_3/SiO_2$  RATIOS AND MgO (Wt %) OF  
BANDI PURA TRAPS.

$Al_2O_3/SiO_2$	0.27	0.27	0.28	0.27	0.23	0.26	0.26	0.24	0.25
MgO	4.05	6.17	3.20	5.15	3.10	3.50	3.50	3.10	3.49

proceeded beyond the andesitic stage. This is consistent with the results got from thin section petrography also. This diagram further shows that the extreme acidic members are absent in the rocks.

#### TOTAL ALKALIS VERSUS $\text{SiO}_2$ VARIATION DIAGRAM

Irvine and Baragar (1971) put forth a method of differentiating alkaline rocks from subalkaline rocks by plotting alkalis versus  $\text{SiO}_2$ . The values of alkalis and silica are given in table 18b. This figure marks the dividing line of Irvine and Baragar and Macdonald. Plate 26, fig.1 shows a plot of total alkalis versus  $\text{SiO}_2$  for the trap rocks of Bandipura and an inspection of this diagram shows that if Irvine and Baragar dividing line is followed, all the points fall in the subalkaline field.

Some of the broad based diagrams referred to earlier in this chapter have now been taken up for discussion. The first of these is the one proposed by Tilley and Muir (1967).

#### ( $\text{Na}_2\text{O} + \text{K}_2\text{O}$ ) VERSUS D.I. VARIATION DIAGRAM

In order to study the degree of differentiation in the rocks of Bandipura, the samples have been plotted in plate 26, fig.2. (after Tilley and Muir, 1967). The values of total

alkalis and D.I. are given in table 20 c.

From this diagram, it is seen that the rocks of the Bandipura area occupy two fields. The points are seen mostly to cluster in the basalt field and some, however, fall in the Hawaiite field. The differentiation does not appear to have gone too far because the plots end up in the Hawaiite field.

#### MgO VERSUS $Al_2O_3/SiO_2$ VARIATION DIAGRAM

Murata (1960) gave a method of plotting MgO versus  $Al_2O_3/SiO_2$  to distinguish between the alkali basalt series and tholeiitic basalt series (plate 26, fig.3). The traps of the present area are plotted in this diagram. The values of  $Al_2O_3/SiO_2$  and MgO are contained in table 17 c. It is seen that the points in this diagram cluster between B and G fields (tholeiitic and Hawaiite fields), revealing the heterogeneity of the rocks. This shows that the differentiation of the original magma has proceeded from tholeiitic basalt to Hawaiite.

#### FELSIC INDEX VERSUS MAFIC INDEX VARIATION DIAGRAM

According to Simpson (1954), the magmatic differentiation can be studied by plotting the mafic index  $100(FeO + Fe_2O_3)/(MgO + FeO + Fe_2O_3)$  as abscissa and felsic index  $100(Na_2O + K_2O)/$

(Contd. P. 102)

TABLE 18

(a) MAJIC AND FELSIC INDICES OF BANDIPURA TRAPS (Contd....)

Sample no.	AR39	AR32	A33	A36	AR62	A38	AK11	All
	2	4	5	6	7	8	9	10
M.I.	76.67	81.04	76.73	77.80	63.97	79.00	82.67	65.44
F.I.	19.04	19.89	21.30	29.97	22.77	24.80	26.22	24.93

(b) SiO<sub>2</sub> AND (Na<sub>2</sub>O + K<sub>2</sub>O) OF BANDIPURA TRAPS

SiO <sub>2</sub>	44.66	45.04	46.54	47.22	48.40	48.41	48.50	49.14	49.15
(Na <sub>2</sub> O + K <sub>2</sub> O)	1.70	2.00	2.28	1.95	2.62	2.81	3.15	3.20	2.99

(c) SOLIDIFICATION INDEX VALUES AND SiO<sub>2</sub> (wt %) OF BANDIPURA TRAPS

S.I.	25.26	24.33	18.87	17.02	12.15	18.53	31.39	35.15	14.40	29.58
SiO <sub>2</sub>	44.66	45.04	46.54	47.72	48.40	48.40	48.41	48.50	49.14	49.15

(d) SOLIDIFICATION INDEX VALUES AND TOTAL ION (wt %) OF BANDIPURA TRAPS

S.I.	25.26	24.33	18.87	17.02	12.15	18.53	31.39	35.15	14.40	29.58
(FeO + Fe <sub>2</sub> O <sub>3</sub> )	13.00	14.79	15.00	13.85	11.74	14.20	12.18	11.00	14.70	8.65

TABLE- 18 (a) MAFIC AND FELSIC INDICES OF BANDIPURA TRAPS (Contd.....)

Sample no.	AK76 11	AK30 12	A27 13	A68 14	AK24 15	A70 16	AK20 17	AR16 18	AK79 19	AK75 20
M.I.	75.74	68.09	72.25	59.43	72.06	72.82	55.03	59.02	76.03	73.54
F.I.	25.54	29.80	26.05	19.08	37.50	29.92	23.55	17.63	38.65	29.48

(b) SiO<sub>2</sub> AND (Na<sub>2</sub>O + K<sub>2</sub>O) OF BANDIPURA TRAPS

SiO <sub>2</sub>	49.42	50.34	50.42	50.55	50.68	50.83	51.52	51.65	51.66	51.68
(Na <sub>2</sub> O+K <sub>2</sub> O)	3.50	4.00	3.10	2.50	3.00	3.40	2.77	2.45	4.60	3.60

(c) SOLIDIFICATION INDEX VALUES AND SiO<sub>2</sub> (Wt %) OF BANDIPURA TRAPS.

S.I.	20.04	25.61	23.11	35.40	23.92	22.93	34.40	32.20	19.12	21.37
SiO <sub>2</sub>	49.42	50.34	50.42	50.55	50.68	50.83	51.52	51.65	51.66	51.68

(d) SOLIDIFICATION INDEX VALUES AND TOTAL IRON (Wt %) OF BANDIPURA TRAPS.

S.I.	20.04	25.61	23.11	35.40	23.92	22.93	34.40	32.20	19.12	21.37
(FeO + Fe <sub>2</sub> O <sub>3</sub> )	12.65	11.10	11.20	11.50	12.90	13.40	10.95	11.57	13.80	11.15

TABLE- 18

(a) MAJIC AND FLSIC INDICES OF BANDI PURA TRAPS

Sample no.	MK20 21	MK72 22	A45 23	AM49 24	MK21 25	A20 26	A19 27	AM1 28	AM63 29
M.I.	72.72	50.05	80.12	78.00	80.74	76.40	76.30	74.00	74.35
F.I.	19.20	26.84	32.44	18.58	28.78	32.44	40.16	37.96	35.92

(b) SiO<sub>2</sub> AND (Na<sub>2</sub>O + K<sub>2</sub>O) OF BANDI PURA TRAPS

SiO <sub>2</sub>	52.26	52.55	53.52	54.50	54.98	55.40	56.40	56.62	57.42
(Na <sub>2</sub> O + K <sub>2</sub> O)	2.00	3.45	3.77	1.50	3.40	3.41	3.41	3.55	3.42

(c) SOLIDIFICATION INDEX VALUES AND SiO<sub>2</sub> (Wt %) OF BANDI PURA TRAPS.

S.I.	23.07	30.30	16.10	27.61	15.89	20.58	19.44	17.36	20.49
SiO <sub>2</sub>	52.26	52.55	53.52	54.50	54.98	55.40	56.40	56.62	57.42

(d) SOLIDIFICATION INDEX VALUES AND TOTAL IRON (Wt %) OF BANDI PURA TRAPS.

S.I.	23.07	30.30	16.10	27.61	15.89	20.58	19.44	17.36	20.49
(FeO + Fe <sub>2</sub> O <sub>3</sub> )	10.80	10.75	12.90	18.05	13.00	11.09	10.09	11.20	10.12

( $\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O}$ ) as ordinate. The values of felsic and mafic indices are tabulated in table 18a. Plate 26, fig .4 based on Green and Poldervaart (1958), weight percentages are used (on a dry basis) instead of oxide wt. percentages. The trends of Rajmahal basalts and Deccan traps are also included in this diagram (Sukeshwala and Poldervaart, 1958). Wager (1956) and Wilcox and Poldervaart (1958) subdivided the crystallization history of basaltic rocks into different stages, viz., early stage basalt, middle stage basalt and late stage basalt, intermediate differentiates and felsic differentiates. It is seen in this diagram that the majority of the traps of Bandipura area fall in the middle to the late stage basalts, with most of the points falling in the field of late stage basalts. A few points occupy the field of intermediate differentiates. Further study of this diagram, shows that the acidic rocks in this suite are absent, which is also revealed by thin section petrography. An inspection of this diagram shows that the Bandipura traps, follow the same trend as the Deccan basalts and these rocks are characterized by an early phase of iron enrichment succeeded by an enrichment of sodium and potassium.

**NORMATIVE An x 100/ (Ab + An) VERSUS D.I. VARIATION DIAGRAM**

Floyd (1976) suggested a bivariate plot of  $\frac{\text{An} \times 100}{(\text{Ab} + \text{An})}$

versus D.I. for the Greenstones of S.W England. He also attempted a superimposition of Tristan, Gough Island and Hebridean trends on this diagram (plate 27, fig.A). Floyd (op. cit) has at the same time demarcated moderately potassic series and sodic series on this diagram. In this painstaking study, Floyd has demarcated a number of other fields on this diagram. For the present study only a few are, however, relevant.

The values of  $An \times 100 / (Ab + An)$  and D.I. for Bandipura traps are tabulated in table 16 a. The rocks of the present area when similarly plotted in plate 27, fig. B. reveal a differentiation trend in decreasing order of basicity. Fig A of the same plate shows that the rocks of the Bandipura area cluster between the potassic and the sodic series with an increasing tendency initially towards the sodic end (Hebridean trend) which later on follows the potassic series (Tristan trend). From a close inspection of this diagram, it is also clear that most of the points fall in the basalt field and a few fall in and close to the Hawaiite field. This is also revealed by an inspection of plate 26, fig.2 (after Tilley and Muir, 1967).

#### MCKIE VARIATION DIAGRAM

Mckie (1966) suggested a plot of cations per hundred

TABLE - 19 CATIONS OF CHEMICALLY ANALYSED SAMPLES  
 IN TERMS OF HUNDRED OXYGEN ANIONS (After McKie, 1966)

Sample no.	C O N S T I T U E N T S									
	Si	Al	Fe <sup>+3</sup>	Fe <sup>+2</sup>	Mg	Ca	K	Na	Ti	H
AR53	24.07	12.49	1.36	4.29	4.25	5.71	0.34	1.25	0.61	13.00
AR39	24.28	11.56	1.80	4.59	3.66	4.93	0.61	1.14	0.45	12.58
A16	25.08	10.24	1.34	5.21	3.26	5.45	0.27	1.96	0.63	14.41
AR32	25.72	12.69	1.66	4.33	2.63	4.55	0.30	1.56	0.29	14.12
A33	26.09	13.04	2.25	2.72	2.89	5.61	0.42	2.08	0.30	8.79
A36	26.09	10.29	1.36	4.83	3.27	4.87	0.82	2.50	0.21	13.54
AR62	26.10	9.74	1.00	4.32	5.57	5.52	0.55	2.08	0.75	10.78
A38	26.14	10.06	1.32	3.44	5.32	6.35	0.79	2.08	0.82	5.45
AK11	26.49	9.73	1.44	4.96	2.50	5.22	0.68	2.29	0.44	13.35
A11	26.50	10.80	1.46	2.23	4.99	5.22	0.58	2.23	0.70	6.86
AK76	26.64	9.69	0.98	4.56	3.29	5.56	0.89	2.29	0.94	12.51
AK30	27.13	9.16	1.20	3.62	4.22	5.46	1.10	2.50	0.40	13.09
A27	27.18	11.05	0.68	4.24	3.49	5.10	0.61	2.29	0.43	10.07
A68	27.25	9.18	1.20	3.80	6.37	6.15	0.68	2.25	0.43	4.81
AK24	27.32	8.83	1.12	4.51	4.06	4.64	0.96	2.08	0.53	14.70
A70	27.40	10.14	1.44	4.38	4.06	4.61	0.99	2.08	0.48	8.08
AR20	27.77	9.45	1.26	3.48	6.17	5.21	0.42	2.25	0.76	4.81
AR16	27.84	8.61	1.64	3.33	5.85	3.86	0.24	2.20	0.70	3.53
AK79	27.85	8.38	1.56	4.42	3.53	4.23	1.10	3.13	0.25	13.22
AK75	27.86	9.47	1.12	3.73	3.25	4.99	0.96	2.71	0.48	13.28
AK20	28.17	9.17	1.04	3.66	3.29	4.87	0.20	1.77	0.61	15.98
AK72	28.32	9.21	1.44	3.19	5.01	5.45	0.34	3.08	0.68	5.39
A45	28.85	9.61	1.36	4.24	2.60	4.55	1.04	2.35	0.31	9.18
AR49	28.38	9.53	0.80	3.57	4.18	3.81	0.24	1.20	0.43	9.63
AK21	29.63	8.13	1.48	4.15	2.51	4.87	0.82	2.29	0.55	10.07
A20	29.86	9.21	0.80	4.06	2.84	4.11	0.69	2.50	0.69	10.91
A19	30.40	9.53	0.80	3.61	2.84	2.94	0.62	2.61	0.69	11.07
AR41	30.52	8.89	0.80	3.61	2.51	3.36	0.65	2.71	0.51	7.44
AR63	30.95	9.21	0.80	3.62	2.76	3.53	0.61	2.63	0.68	11.23

oxygen anions against si. This method has been followed for the rocks of the present area and the calculated values of cations per hundred oxygen anions are given in table 19. Plate 28, figs 1 to 9, show such plots for the traps of the mapped area. It is seen that Ca, Mg, Fe<sup>+2</sup>, Fe<sup>+3</sup>, (Fe<sup>+2</sup> + Fe<sup>+3</sup>) and Al were comparatively abundant in the early stages and suffered impoverishment with the increase in Si i.e. towards the field of decreasing order of basicity. Na and K on the contrary show an upward trend with the increase in Si, revealing thereby that the two cations were enriched in the later fractions of the magma as a result of differentiation. The above mentioned cations when plotted as oxides in Harker's diagram also behave in the same manner. Hydrogen (H) plate 28, fig.9 shows no change with respect to Si throughout, indicating thereby, its insensitive character during the process of differentiation, since the curve is straight.

#### MgO VERSUS ALL OXIDES VARIATION DIAGRAM

Mg plays a major role in the differentiation process. Nisbet et al.(1977) used MgO versus all oxides for studying the differentiation trends in the lavas of Belingwe, Greenstone Belt of Rhodesia and differentiated basalts from komatites and various differentiation trends obtained in such

graphs were utilized by him to arrive at their genetic history. The traps of Bandipur<sup>a</sup> have been similarly treated. The plots are shown in plate 29, figs 1 to 5. It may be pointed out at the outset that in this method of representation, some trends are noticed in all the cases, but scattering of points is manifest throughout. CaO clearly shows a positive trend with respect to MgO, showing thereby concentration of both and their impoverishment in the later magmatic fractions. In fig. 2 of the same plate, FeO shows a sympathetic relation with respect to MgO showing its concentration in the early magma and decline in the later portions. Fig. 3 shows a negative trend pointing to the fact that SiO<sub>2</sub> was less in the early fractions and was enriched in the later differentiates. Plate 29, figs 4 and 5 show a plot of MgO versus K<sub>2</sub>O and Na<sub>2</sub>O. In these diagrams, the trend displayed is consistent with a differentiating magma, since with the fall of MgO, there is an upward tendency in K<sub>2</sub>O and Na<sub>2</sub>O contents. It may be remarked in the end, that in these plots the trend lines show a general tendency towards magmatic differentiation and without exception there is a scattering of points and hence the trends shown are only generalized ones.

PLOT OF OXIDATION RATIO VERSUS  $SiO_2$ ,  
 O. R VERSUS  $(FeO + Fe_2O_3)$  AND  $(FeO + Fe_2O_3)$  VERSUS  $SiO_2$

It is seen from plate 30, fig. a that the Bandipura traps exhibit the same trend as the Deccan basalts. In this diagram, it needs to be mentioned that the similarity in the two curves in each case is restricted to the western limbs only. This is expected in as much as the traps of the study area do not contain acid differentiates marked by the eastern limb of the Deccan trap curves. Similarly in the plot of Oxidation ratio versus  $(FeO + Fe_2O_3)$  (plate 30 fig. b), Bandipura trend is similar to the Deccan trap <sup>trend</sup> as far as the lower portion of the curve is concerned. This is again due to the absence of acid differentiates in the traps of the study area. The values of oxidation ratio, Silica and total iron are tabulated in table 20a and b.

Plate 30 fig. c shows  $(FeO + Fe_2O_3)$  as ordinate versus  $SiO_2$  as abscissa for rock suites indicated as under:-

- (i) Palisade, eastern U.S.A.
- (ii) Deccan trap, India,
- (iii) Dillsberg, U.S.A.,
- (iv) Red Hill, Tasmania.

(Contd., P. III)

TABLE 20 (a)  $SiO_2$  wt % AND OXIDATION RATIO VALUES OF BANDI PURA TRAPS (Contd...)

Sample no.	AR53 1	AR39 2	A16 3	AR32 4	A33 5	A36 6	AR62 7	A38 8	AK11 9	All 10
$SiO_2$	44.66	45.04	46.54	47.72	48.40	48.40	48.41	48.50	49.14	49.15
O.R.	19.10	34.90	16.86	22.30	40.00	17.34	14.68	20.25	17.77	35.15

(b) TOTAL IRON wt % AND OXIDATION RATIO VALUES OF BANDI PURA TRAPS

(FeO + $Fe_2O_3$ )	13.00	14.79	15.00	13.85	11.74	14.20	12.18	11.00	14.70	8.65
O.R.	19.10	34.90	16.86	22.30	40.00	17.34	14.68	20.25	17.77	35.15

(c) DIFFERENTIATION INDEX VALUES AND ( $Na_2O + K_2O$  wt %)  
OF BANDI PURA TRAPS.

D.I.	20.67	23.29	21.48	20.93	31.39	29.17	22.72	26.05	30.46	25.86
( $Na_2O + K_2O$ )	1.70	2.00	2.28	1.95	2.62	3.60	2.88	3.15	3.20	2.99

(d) sl AND (al+fm)-(c+alk) VALUES OF BANDI PURA TRAPS.

sl	106	115	117	118	120	123	115	115	129	120
(al + fm) - (c+alk)	44	56	40	38	42	38	40	32	34	40

TABLE 20 (a) SiO<sub>2</sub> wt % AND OXIDATION RATIO VALUES OF BANDIPURA TRAPS (Contd.....)

Sample no.	AK76 11	AK30 12	A27 13	A68 14	AK24 15	A70 16	AR20 17	AR16 18	AK79 19	AK75 20
SiO <sub>2</sub>	49.42	50.34	50.42	50.55	50.68	50.83	51.52	51.65	51.66	51.68
O.R.	13.80	19.80	10.70	20.10	15.60	19.68	20.10	26.15	20.81	17.72

(b) TOTAL IRON wt % AND OXIDATION RATIO VALUES OF BANDIPURA TRAPS

(FeO + Fe <sub>2</sub> O <sub>3</sub> )	12.65	11.10	11.20	11.50	12.90	13.40	10.95	11.57	13.80	11.15
O.R.	13.80	19.80	10.70	20.10	15.60	19.68	20.10	26.15	20.81	17.72

(c) DIFFERENTIATION INDEX VALUES AND (Na<sub>2</sub>O + K<sub>2</sub>O wt %)

D.I.	28.88	32.22	28.70	22.82	30.13	30.56	28.80	23.00	38.32	34.95
(Na <sub>2</sub> O + K <sub>2</sub> O)	3.50	4.00	3.10	2.50	3.00	3.40	2.77	2.45	4.60	3.60

(d) Si AND (al+fm)-(catalk) VALUES OF BANDIPURA TRAPS

S.I	128	130	132	117	136	130	125	122	139	142
(al+fm)-(catalk)	32	32	36	38	40	42	42	32	38	32

TABLE 20 (a) SiO<sub>2</sub> wt % AND OXIDATION RATIO VALUES OF BANDI PURA TRAPS.

Sample no.	AK20 21	AK72 22	A45 23	AR49 24	AK21 25	A20 26	A19 27	AR41 28	AR63 29
SiO <sub>2</sub>	52.26	52.55	53.52	54.50	54.98	55.40	56.40	56.62	57.42
O.R.	17.50	26.15	19.26	21.10	20.96	15.00	15.50	20.10	16.10

(b) TOTAL IRON wt % AND OXIDATION RATIO VALUES OF BANDI PURA TRAPS.

(FeO + Fe <sub>2</sub> O <sub>3</sub> )	10.80	10.75	12.90	18.05	13.00	11.09	10.09	11.20	10.12
O.R.	17.50	26.15	19.26	21.10	20.96	15.00	15.50	20.10	16.10

(c) DIFFERENTIATION INDEX VALUES AND (Na<sub>2</sub>O + K<sub>2</sub>O wt %)  
OF BANDI PURA TRAPS.

D.I.	26.90	34.36	36.93	32.27	39.72	44.22	46.52	45.44	44.26
(Na <sub>2</sub> O + K <sub>2</sub> O)	2.00	3.45	3.77	1.50	3.40	3.41	3.41	3.55	3.42

(d) si AND (a1+fm)-(c+alk) VALUES OF BANDI PURA TRAPS

si	150	131	150	134	159	188	179	180	181
(a1+fm)-(c+alk)	38	34	36	52	32	42	46	40	40

The trend of analysed traps from Bandipura area is also shown for comparison. It is clearly seen from these diagrams that maximum iron enrichment has taken place at different stages of differentiation in these rock suites. The trend of Bandipura traps is similar to the Deccan trend as far as the western limb of the curve is concerned. It may be mentioned here, that maximum iron enrichment has taken place at 50 percent  $\text{SiO}_2$  which is similar to the one for the Bandipura traps. In Red Hill maximum concentration of  $(\text{FeO} + \text{Fe}_2\text{O}_3)$  takes place around 55 percent  $\text{SiO}_2$ .

#### RITTMANN'S DIAGRAM

Rittmann (1961) devised a method of differentiating lavas of volcanoes situated in non-orogenic regions, orogenic belts and alkaline derivatives of both into three different fields as 'A', 'B' and 'C' (fig.31). The values of  $\text{Log } \sigma$  and  $\text{Log } \tau$  for the rocks under study have been tabulated in table 17b and plotted in this diagram which clearly shows that Bandipura traps predominantly fall in the field of orogenic region. Some points, however, fall in the non-orogenic field, but lie close to the discriminating boundary. From the position of the plotted points, it is seen that the rocks under study have been extruded in an active orogenic belt.

### TERNARY VARIATION DIAGRAMS

Ternary variation diagrams have been drawn in order to understand the petrochemical behaviour of the rocks from the study area.

#### $\text{Na}_2\text{O} - \text{K}_2\text{O} - \text{CaO}$ TERNARY VARIATION DIAGRAM

The values of  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$  and  $\text{CaO}$  recalculated to hundred percent for the traps of Bandipura have been tabulated in table 21 B. The plotted values in this triangular diagram show (plate 32, fig.1) that the points mostly cluster close to the  $\text{CaO}$  corner of the diagram, showing thereby that the rocks are rich in calcium and poor in alkalis.

#### A-N-C TERNARY VARIATION DIAGRAM

The values of A ( $\text{Al}_2\text{O}_3 - \text{K}_2\text{O}$ ), N ( $\text{Na}_2\text{O}$ ) and C ( $\text{CaO}$ ) recalculated to hundred percent for the analysed samples are tabulated in table 21 C. These values for the traps of the study area have been plotted on this diagram. (Jolly and Smith, 1972; plate 32, fig.2). The three regions in this diagram represent (i) unaltered basalts, (ii) basalts containing albitized feldspar and (iii) basalts with chlorite and epidote. All the varieties exist in the Keweenaw lavas.

(Contd. P.116)

TABLE-21 COMBINATION OF THREE COMPONENTS RECALCULATED  
TO HUNDRED PERCENT (Contd.....)

sample no.	A			B			C		
	Qr.	Ab	An	A	G	F	A	C	N
AR53	5	17	78	40	28	32	63	33	4
AR39	13	19	68	43	26	31	64	32	4
A16	4	30	66	39	26	35	58	35	7
AR32	9	40	51	47	25	28	68	27	5
A33	6	25	69	54	23	23	63	31	6
A36	13	36	51	39	26	35	58	37	9
AR62	10	32	58	35	26	39	56	37	7
A38	12	31	57	39	26	35	53	40	7
AK11	15	34	51	37	29	34	55	36	9
A11	8	32	60	51	22	27	59	33	8
AK76	14	34	52	35	29	36	54	37	9
AK30	18	38	44	35	31	34	52	38	10
A 27	9	31	60	41	25	34	60	32	8
A68	5	36	59	35	25	40	53	39	8
AK24	13	34	53	35	26	39	36	35	9
A70	15	30	55	37	29	34	59	32	9
AR 20	6	49	45	37	27	36	56	35	9
AR16	5	49	46	37	27	36	48	44	8
AK79	18	48	34	33	28	39	53	33	14
AK75	11	41	48	38	29	33	55	34	11
AK 20	4	31	65	39	29	32	58	35	7
AK 72	18	11	71	37	26	37	53	36	11
A45	16	35	49	40	28	32	57	33	10
AK49	5	22	73	43	24	33	65	29	6
AK21	15	39	46	35	32	33	52	38	10
A20	11	40	49	43	19	38	56	30	14
A19	10	43	47	40	20	40	65	23	12
AR41	11	43	46	50	19	31	60	27	13
AR53	11	41	48	39	20	41	61	27	12

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TABLE E - COMBINATION OF THREE COMPONENTS  
 RECALCULATED TO HUNDRED PERCENT (Contd.....)

Sample no.	D			E		
	F	M	A	2alk	(100-2a1) <sup>2</sup>	(a1-a1k)
AR53	65	26	9	16	50	34
AR39	67	24	9	18	50	32
A16	70	19	11	10	52	38
AR32	73	17	10	14	42	44
A33	60	20	14	12	56	32
A36	65	19	16	16	52	32
AR62	56	31	13	12	58	30
A38	53	32	15	12	56	32
AK11	69	14	17	16	52	32
A11	56	29	15	14	42	44
AK76	63	20	17	14	54	32
AK30	55	26	19	16	56	28
A27	60	23	17	14	46	40
A68	52	36	12	10	60	30
AK24	62	24	14	14	56	30
A70	61	23	16	14	52	34
AR20	51	36	13	12	58	30
AR16	54	34	12	10	64	26
AK79	61	19	20	20	58	22
AK75	59	21	20	16	52	32
AK20	65	23	12	14	52	32
AK72	53	30	17	16	58	26
A45	65	16	19	16	50	34
AR49	64	28	8	12	88	50
AK21	67	16	17	16	56	28
A20	59	21	20	12	20	68
A19	61	19	20	13	19	68
AR41	62	17	21	14	20	66
AR63	59	21	20	20	32	48

TABLE 21 COMBINATION OF THREE COMPONENTS RECALCULATED TO HUNDRED PERCENT.

Sample no.	F			G		
	FeO	(Na <sub>2</sub> O + K <sub>2</sub> O)	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	CaO
AR53	58	10	32	10	4	86
AR39	58	11	31	10	9	81
A16	65	13	22	16	3	81
AR32	57	24	19	15	4	81
A33	50	21	29	16	5	79
A36	59	20	21	20	10	70
AR62	51	15	34	16	6	78
A38	44	18	38	14	8	78
AK11	62	20	18	17	11	72
A11	47	17	36	18	7	75
AK76	57	20	23	17	10	73
AK30	47	23	30	18	12	70
A27	56	18	26	18	8	74
A68	45	13	42	16	3	81
AK24	56	17	27	18	9	73
A70	54	19	27	18	12	70
AR20	43	15	42	19	5	76
AR16	44	14	42	15	3	82
AK79	53	24	23	25	13	62
AK75	52	23	25	21	8	71
AK20	58	14	28	16	3	81
AK72	43	21	36	23	4	73
A45	58	23	19	19	13	78
AR49	55	10	35	14	4	82
AK21	59	22	19	19	10	71
A20	54	23	23	23	10	67
A19	54	23	23	29	11	60
AR41	55	24	21	28	10	62
AR63	54	22	24	26	9	65

The traps of the mapped area fall in the field (III) of this diagram, suggesting thereby that the rocks should contain chlorite and epidote. This is corroborated by thin section study. This diagram also points to high alumina character of the rocks.

#### NORMATIVE FELDSPAR TRIANGULAR VARIATION DIAGRAM

For the normative feldspar variation diagram, the values of Or, Ab and An recalculated to hundred percent are given in table 21a. Plate 32, fig.3 shows the normative feldspar, Orthoclase (Or), anorthite (An) and albite (Ab) plotted on a triangular variation diagram which clearly points towards the calcic nature of the feldspars and the field indicates the region of basaltic rocks (Le Maitre, 1976).

#### $2\text{alk} - 2(\text{al} - \text{alk}) - (100 - 2\text{al})$ TRIANGULAR VARIATION DIAGRAM

$2\text{alk} - 2(\text{al} - \text{alk}) - (100 - 2\text{al})$  triangular variation diagram of Niggli is another important method to study the petrochemical nature of igneous rocks. These values recalculated to hundred percent for Bandipura traps are contained in table 21 e. Plate 32, fig.5 shows that the rocks are poor in alkalis.

### F-M-A TRIANGULAR VARIATION DIAGRAM

In table 21b, the values of M, F and A recalculated to hundred percent are tabulated. Here  $F = (\text{FeO} + \text{Fe}_2\text{O}_3)$ ,  $M = \text{MgO}$  and  $A = (\text{Na}_2\text{O} + \text{K}_2\text{O})$ . The plots of plate 32 fig 6 are near to the "F" corner of the triangle. The rocks are, therefore, rich in iron showing their basaltic character.

In plate 32, fig 4, a trivariate plot with variables FeO,  $(\text{Na}_2\text{O} + \text{K}_2\text{O})$  and MgO, recalculated to hundred percent for the rocks of the study area are shown in table 21 f. The position of the plotted points indicates that these are rich in FeO and MgO, thus pointing towards their basaltic character.

A trilinear diagram with variables  $A = (\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3) - (\text{Na}_2\text{O} + \text{K}_2\text{O})$ ,  $C = \text{CaO}$  and  $F = (\text{FeO} + \text{MgO} + \text{MnO})$  recalculated to hundred percent for Bandipura traps are tabulated in table 21b and plotted in plate 33 fig.1. This diagram (after Miyashiro, 1974), shows two fields, viz., (i) shales and greywackes and (ii) Basalts and andesites. The rocks of the study area are seen to fall in the basalt-andesite field, confirming earlier results.

### AN-AB-OR TRIANGULAR VARIATION DIAGRAM

Irvine and Baragar (1971) put forth the idea of plotting a triangular variation diagram with An, Ab, Or variables. In this diagram, different fields have been demarcated such as the field of average igneous rocks. Furthermore, in this diagram, separate fields such as K-poor basalts, K-rich andesites, rhyodacites and potassic rhyolites are given. Plot of traps from Bandipura area in this diagram (plate 33, fig. 2) reveals that a few points fall in the field of potassium poor basalts, and potassium rich andesites and majority of them occupy the field of average igneous rocks. This strongly suggests igneous parentage of the rocks under study.

### PETROGENESIS OF THE BANDIPURA TRAPS

In these lines an attempt has been made to discuss the petrogenesis of Panjal traps of Bandipura area. A bivariate plot of the rocks with silica as abscissa and the total alkalis as ordinate when plotted on a diagram by Macdonald and Katsura (1964) and Saggerson and Williams (1964) unmistakably points towards the tholeiitic lineage of the traps under discussion. The rocks of the area when plotted on Kuno's (1968) diagram with silica and total alkalis as the two variables as in the

above case shows that the traps of the present area fall in the fields of tholeiite and high alumina basalt. The majority of the points are, however, seen to occupy the tholeiitic field of Kuno; some of the points go off balance to the field of High Alumina Basalt. The rocks with the percentage of  $Al_2O_3$  exceeding 16.5 percent and with total alkalis lying between tholeiite and alkali basalt series for a given silica content fall in the High Alumina Basalt field. Since the rocks of the present area are seen to occupy, two fields on Kuno's diagram, the possibility of two phases of lava eruption in this area cannot be ruled out. It may, however, be emphasized that the majority of the points are seen to fall in the tholeiite field of Kuno as in the earlier diagram (plate 20, fig. 2). Segalstad (1979) also suggested a binary plot of  $(Na_2O + K_2O)$  as ordinate and  $SiO_2$  as abscissa for the rocks of the southwest Oslo region, Norway. This diagram also strongly suggests a predominant tholeiitic parentage of the rocks in question. Normative plagioclases when plotted as abscissa against  $Al_2O_3$  as ordinate for Bandipura traps according to <sup>the</sup> method of Irvine and Baragar (1971) conclusively points to the tholeiitic lineage for the rocks under question.

From an inspection of table 11 it is seen that the

TABLE B-22 AVERAGE K<sub>2</sub>O AND MgO IN THOLEIITES FROM VARIOUS PROVINCES (After Jamieson et al 1969)  
AND ITS COMPARISON WITH TRAP ROCKS OF BANDIPURA.

Serial no.	Province	No: of Analyses	K <sub>2</sub> O (wt%)	MgO (wt %)
1.	Yakima Basalts Columbia River	12	1.40	4.30
2.	palisades Dolerites	4	0.80	7.30
3.	Japanese Parental Tholeiites	3	0.29	7.79
4.	Deccan Traps Bombay	10	0.89	5.40
5.	Greenstone Flow Lake Superior	17	0.49	6.88
6.	Non-porphyrific General Magna type (U.K.)	11	1.11	5.30
7.	Plataeu Basalts of Scotland	9	0.60	8.40
8.	Western Australian Tertiary Tholeiites	3	0.58	6.14
9.	Medine L-ake Highlands California	7	0.30	8.00
10.	Toas, New Mexico	17	0.80	7.10
11.	Traps of B-andipura	29	0.85	5.72

maximum value of total alkalis for Bandipura traps goes upto 4.60 percent. It is within the recommended value set by Chayes (1966) and Irvine and Baragar (1971) for tholeiites. Table 22 gives  $K_2O$  and  $MgO$  weight percentages on the average basis for the various tholeiitic provinces of the world (after Jamieson et al. 1969). A close comparison of these values with the  $MgO$  and  $K_2O$  weight percentages reveals that the traps of the study area are more akin to Deccan basalts. It is interesting to note that the diagrams based on the chemical data of the present area of study described earlier also reveal that the traps of the Bandipura are compositionally comparable to the Deccan traps.

The Bandipura traps have more resemblance to Hawaiian tholeiites where the primary magma contains  $MgO$  upto a maximum of 9 percent after extrusion as is indicated by Maloe and Peterson, (1979), while comparing the trends of Pacific ocean and Hawaiian tholeiites.

The above discussion undoubtedly points to the fact that the source magma for the Bandipura traps is of tholeiitic character. Absence of olivine in the mode as well as in the norm strongly supports this view. Furthermore, the rocks are seen to contain normative quartz and hypersthene like

other tholeiites of the world. The rocks of spilitic character are absent from the area under study. Evidences of submarine mode of eruption of the traps are entirely absent and their extrusion has not taken place under these conditions.

The trap rocks of Bandipur area have not undergone complete fractionation as all the points fall in the fields of middle to late stage basalts with a few points falling in the field of intermediate differentiates (Simpson op. cit.). The traps under study are characterized by <sup>an</sup> early phase of iron enrichment followed by alkali enrichment like Deccan basalts. The rocks have in short undergone differentiation in a decreasing order of basicity from more basic to less basic members.

The systematic fractionation appears to have started from basalt rich magma to Hawaiite stage of Tilley and Muir (1967). The extreme acid members are entirely absent from the area under investigation. This is in conformity with petrographic evidences.

There are no breaks in the curves of various binary

variation diagrams. From this it is inferred that the differentiation process seems to be continuous unlike those of Deccan basalts where there are indications of fractionation having proceeded at different stages. There is, of course, no doubt that the fractionation processes has slowed down only after reaching the field of intermediate differentiates (Simpson, op.cit.).

Oxidation ratio of Bandipura traps is maximum at 49.15 percent silica (Anirudda De, 1964). A trend in the variation of oxidation ratio gives an idea to the prevailing nature of fugacity of oxygen. The trend is well comparable to the Deccan trend ~~compares~~ with the difference that only a part of the Deccan trap curves is similar to the rocks under study. This is but natural, since Bandipura traps are essentially basic in character and possess no members of late acid differentiates as is very well seen from the inspection of various diagrams pertaining to this aspect.

The study of petrochemical data ultimately leads us to the conclusion that the traps of the Bandipura area are of tholeiitic character and appear to have been outpoured under sub-aerial conditions. The source of the tholeiitic magma, however, needs discussion. An attempt is, therefore, made to

discuss the ultimate source of the tholeiitic magma in general and that of Panjal volcanics in particular. Leading petrologists are of the view that the basaltic magma is a primary magma. Some differences of opinion, however, exist whether tholeiite, High Alumina Basalt and alkali-olivine basalts are derived from one primary basaltic magma or each in itself constitutes an independent magma type

Wagner (1928), Gisolf (1929), Waters (1955) and Hunt (1958) think that the magma of basaltic composition is derived as a result of fusion of amphibolite at great depths.

Kennedy (1938) thinks in terms of two primary basaltic magmas, olivine basalt and tholeiite. He considered both as the products of fusion of the upper and lower layers of the earth's crust.

Daly (1946) considered that the basaltic magma was derived as a result of fusion of a sub-crustal layer composed of vitreous basaltic material.

Hatch et al. (1949), Ross (1954) and Bederke (1957) considered basaltic magma as the product of fusion of the peridotite shell of the globe.

B-urmick and Noble (1959), Taylor and Noble (1960), Turner and Verhoogan (1962) and Yoder and Tilley (1962), believed that the generation of basaltic magma took place in the peridotite layer constituting the upper mantle.

The upper mantle has been considered by Ringwood (1962) and Green and Ringwood (1963 and 1967) to be composed of Garnet pyroxene, spinel pyroxene and plagioclase pyroxene. These on melting has been thought by these workers to contribute to the production of basaltic magma.

O' Hara (1965, 1967a, and 1967b, 1968), O' Hara and Yoder (1967) regarded the upper mantle to be composed of garnet lherzolite which on partial fusion produced basaltic magma.

Kuno (1963) considered that the generation of different types of basaltic magmas in the upper mantle was a function of depth. He regards that the tholeiitic magma is generated at a shallower depth in the mantle, alkali olivine basalt at intermediate depths and nepheline basalts at still greater depths.

In view of the above reasons, it is reasonable to

conclude that the Panjal trap magma of the area under study showing predominant tholeiitic character, was possibly generated due to the partial fusion of upper mantle at a shallower depth. The magma also appears to have been extruded under subaerial conditions. The volcanics are regarded as a manifestation of world-wide Hercynian volcanic activity which caused the outpouring of extensive lava flows. The lavas must have travelled over long distances because of their high mobility. The volcanics reportedly have their hypabyssal and plutonic representatives in this part of the Himalayas (Wadia, 1934).

## CHAPTER - VI

PETROGRAPHY OF LIMESTONES

The limestones of the present area<sup>s</sup> aerially appear enclosed by the Panjal traps and are seen to outcrop almost in the central part of the study area<sup>s</sup>. The limestones are usually intermingled with shales. No fossils except for crinoidal stems have been noticed in the rocks during the course of <sup>the</sup> present investigation.

In the present study, the author has worked out detailed chemical composition, stained thin sections for optical study.

TABLE 34 CHEMICAL ANALYSES OF LIMESTONES OF BANDIPURA

Sample no.	Acid insolu- ble	C O N S T I T U E N T S			L.O.I.	Total
		$\text{CaO}$	$\text{MgO}$	$\text{SiO}_2$		
AR1	3.50	1.90	49.50	3.30	42.10	100.30
AR71	0.95	1.60	30.05	21.28	45.28	99.16
A6	2.53	1.20	38.80	11.95	45.00	99.48
AR4	5.48	2.10	47.10	4.20	41.00	99.88
AR7	6.80	1.10	49.10	2.20	40.90	100.10
A51	3.45	1.48	29.85	17.85	46.72	99.35
AR10	4.55	2.00	46.25	3.80	43.30	99.90
AR5	4.48	2.46	48.08	3.04	42.20	100.26
AK 2	1.40	2.92	32.00	20.12	42.88	99.32
AR 98	2.88	1.09	46.68	3.15	46.00	99.80
AK 62	6.26	1.34	45.00	5.30	42.64	100.54
A60	5.50	1.01	37.03	8.00	47.99	99.53
AR3	1.79	1.83	31.66	20.10	43.96	99.34
AK 45	2.40	1.90	40.80	6.70	47.87	99.67
AR3	4.60	0.90	43.40	4.95	46.03	99.88
A58	16.76	2.34	42.65	5.50	33.20	100.45
AK7	0.70	2.12	32.22	19.87	45.00	99.91
A63	14.98	2.32	41.30	2.40	38.20	99.20
AK 55	4.80	2.51	29.60	21.18	42.00	100.09
AK65	4.50	1.25	46.50	4.80	43.15	100.20

conducted x-ray analysis, described textural and structural features of the carbonate rocks and described various petrographic types in order to follow the exact domain of sedimentation and other physical and chemical parameters, tectonic control under the conditions of which the limestones of the study area were deposited.

#### CHEMICAL COMPOSITION

The chemical analyses of the limestones of the present area are tabulated in table-34. On the basis of chemical data the ratios of calcite/dolomite were calculated and these are given in table-35. The analytical data reveals the following facts:

- 1) The limestones of the present area are rich in CaO and poor in MgO. Mostly the samples have CaO percentage in the range of 29.60 percent to 49.10 percent. This clearly indicates that the limestones are comparatively of a poor variety.
- 2) The MgO percentage as compared to that of CaO is low. The MgO percentage does not exceed 21.28 percent. Generally the percentage ranges from 2.20 to 21.28 percent.
- 3) The insoluble residue percentage ranges from 0.70 to 16.76 percent.

**TABLE-35 CALCITE/DOLomite RATIOS OF LIMESTONES OF  
BANDIPURA**

S. No.	Sample Number	Calcite (%)	Dolomite (%)	Insoluble Residue (%)
1.	AR1	88.39	8.11	3.50
2.	AR71	53.70	45.35	0.95
3.	A6	69.33	28.14	2.53
4.	AR4	84.10	10.42	5.48
5.	ARB7	87.67	5.53	6.80
6.	A51	53.35	43.20	3.45
7.	AR10	82.88	12.87	4.55
8.	AR 5	85.85	9.67	4.48
9.	AK2	57.15	41.45	1.40
10.	AR 98	83.35	13.77	2.88
11.	AK62	80.35	13.39	6.26
12.	A60	66.07	28.43	5.50
13.	ARB3	56.50	41.71	1.79
14.	AK45	72.85	24.75	2.40
15.	AR 93	77.50	17.90	4.60
16.	A58	76.16	7.08	16.76
17.	AK7	56.95	42.35	0.70
18.	A 63	73.75	11.27	14.98
19.	AK 55	52.90	42.30	4.80
20.	AK65	83.03	12.47	4.50

The calcite and dolomite percentages are plotted in an equitriangular diagram (fig.34), which reveals the following types of limestones:

1- Pure, (ii) impure limestones, (iii) dolomitic limestones and (iv) impure dolomitic limestones.

#### STAINING

More than fifty thin sections of these limestones were stained not only for the estimation of calcite and dolomite, but also for the presence of ferrous iron in the rocks. For this purpose, the staining technique of Tvenhofel (1941) was used. In this scheme number of reagents were used.

The uncovered limestone sections acquired red colour with Alizarin Red "S" showing the presence of calcite and those which remained unchanged showed the presence of dolomite. Ferrous iron is present in some samples was indicated by maroon colour in a combined solution of potassium ferricyanide and Alizarin Red "S".

#### X-RAY STUDIES

The x-ray diffraction studies of about more than half a dozen samples were done at the Post Graduate department of Geology,

TABLE- 36 X-RAY POWDER DIFFRACTION DATA OF THE LIMESTONES OF BANDI PURA GIVING "d" SPACINGS, INTENSITY AND REFLECTION FACES (Contd.....)

-----  
sample no. AR5

<u>d values</u>	<u>I/I<sub>o</sub></u>	<u>Planes</u>
4.22	3	110
3.83	10	102
3.30	25	021
3.01	100	104
2.47	15	110
2.28	20	113
2.08	18	202
1.90	17	108
1.86	20	024

CALCI TE

Sample no. AR 83

<u>d values</u>	<u>I/I<sub>o</sub></u>	<u>Planes</u>
4.00	3	101
3.67	5	012
3.29	5	021
3.04	10	104
2.88	100	104
2.66	10	006
2.54	10	015
2.40	15	110
2.18	30	113
2.05	5	021
2.01	15	202
1.84	5	024
1.79	25	46
1.78	25	009

DOLOMI TE

sample no. AK7

<u>d values</u>	<u>I/I<sub>o</sub></u>	<u>Planes</u>
3.17	10	021
2.95	5	002
2.89	100	104
2.49	10	110
2.18	15	113
2.02	20	112
1.88	11	024

DOLOMI TE

sample no. AK 59

<u>d values</u>	<u>I/I<sub>o</sub></u>	<u>Planes</u>
3.98	5	101
3.64	7	012
3.00	25	104
2.86	100	104
2.64	10	006
2.51	8	015
2.47	10	110
2.38	12	110
2.17	30	113
1.97	15	202
1.86	5	024
1.76	15	46
1.75	20	009

DOLOMI TE

-----

TABLE-36 X-RAY POWDER DIFFRACTION DATA OF THE LIMESTONES OF BANDIPURA GIVING "d" SPACINGS, INTENSITY AND REFLECTION FACES

sample no. AK47

sample no. AR/1

sample no. A51

d values	I/I <sub>0</sub>	Planes	d values	I/I <sub>0</sub>	Planes	d values	I/I <sub>0</sub>	Planes
3.79	12	102	3.67	5	012	4.20	3	110
3.30	5	021	3.31	12	021	4.03	5	101
3.00	100	104	3.00	10	104	3.89	10	102
2.91	10	006	2.87	100	104	3.45	15	111
2.50	14	110	2.65	9	006	3.20	20	021
2.29	18	113	2.52	6	015	3.06	100	104
2.10	18	202	2.39	10	110	2.50	15	110
1.91	20	108	2.33	15	110	2.30	20	113
1.87	17	116	2.17	30	113	2.10	18	202
			2.02	50	202	1.92	10	204
			2.00	15	202	1.87	17	116
			1.79	X				
			1.77	X	30 009 <sup>66</sup>			

CALCI TE

CALCI TE

DOLOMI TE

University of Delhi, Delhi. The x-ray diffractograms were taken with the help of Phillips Holland, X-ray Diffractometer model no. 1050/25 with nickel filters  $\text{CuK}\alpha 1$  radiation electronically controlled chart recorder. Samples were run from  $15^\circ$  to  $52^\circ$  at a scanning speed of one degree per minute. The "d" values were calculated and compared with the A.S.T.M. cards and the mineral species present in the rocks were identified. The results of x-ray diffraction data are given in table-36.

The x-ray studies show that some limestones are purely calcitic while some are dolomitized, thus confirming the earlier results as inferred from staining technique.

#### INSOLUBLE RESIDUE STUDIES

The studies of insoluble residues in the case of carbonate rocks is very useful for stratigraphical correlation and in recognizing various zones in the formation. Various workers viz., McQueen (1931), Hills (1935), Ireland (1947), Maccracken (1955), Edward (1957) and Schmidt (1964) have developed different techniques and terminologies for these studies and applied these methods in studying the insoluble residues from different formations.

The insoluble residues (table-37) in the case of the present work have been studied in detail and the results are given below:

Colour: The colour of the insoluble residues shows different shades of grey, light greyish black and greyish white. Majority of the residues show grey and greyish black colouration.

Types: The different types of insoluble residues present in these limestones are: (i) quartz, (ii) ferruginous matter, (iii) clay minerals and (iv) others including shaly fragments, pyrite etc.

Quartz: Transparent to dull coloured quartz grains are abundantly present in the limestones. These grains exhibit anhedral to euhedral outlines. Some are fractured, the fractures being filled by dusty material consisting of frosted quartz grains showing sort of overgrowths. The percentage of these fragments ranges from 10 to 65.

Ferruginous matter: Ferruginous material is present in small quantities as compared to quartz. These fragments are easily recognizable, because of their lustre and transparency. The percentage of these ranges from 5 to 30.

Clay minerals: These minerals show purple and buff colouration. These fragments are irregular and porous in nature.

TABLE- 37 SHOWING VARIOUS INSOLUBLE RESIDUES IN THE  
LIMESTONES OF BANDI PURA

Sample no.	Quartz	Ferruginous matter	Clay mineral	Others	Total
AR1	35%	20%	20%	25%	100
AR71	10%	30%	45%	15%	100
A6	35%	15%	20%	30%	100
AR4	20%	5%	50%	25%	100
AR87	25%	15%	35%	25%	100
A51	55%	30%	5%	10%	100
AR10	30%	24%	22%	24%	100
AR5	32%	10%	15%	43%	100
AK2	52%	25%	13%	10%	100
AR98	15%	20%	25%	40%	100
AK62	35%	30%	25%	10%	100
A60	65%	10%	17%	8%	100
AR83	30%	5%	50%	25%	100
AK45	23%	15%	45%	17%	100
AR93	30%	25%	35%	10%	100
A58	58%	7%	26%	9%	100
AK7	50%	30%	16%	4%	100
A63	51%	20%	10%	19%	100
AK55	35%	24%	21%	20%	100
AK65	30%	5%	55%	10%	100

The percentage of these ranges from 5 to 55 (plate-35, figs 1 to 3).

Others: Others include shale fragments and in some cases traces of pyrite and unidentifiable fragments. In some cases these show buff colouration. Traces of pyrite show greyish black and greyish white colouration. The percentage of these ranges from 4 to 40.

#### THIN SECTION PETROGRAPHY

More than one hundred thin sections of carbonate rocks were studied in detail for thin section petrography including the study of allochems, microstructures and petrographic types.

The allochems are interclasts which are found in some of the samples mainly consisting fragments of calcarenite and calcilutite. The other allochems are pellets which consists of microcrystalline calcite similar in appearance to small interclasts. Their external boundaries are hazy and grade into the surrounding matrix.

The following microstructures have been observed in B-andipura limestone:

Microstylolites : This microstructure has been observed in micritic limestones (plate-36 figs 3 and 5) and are recognized

as irregular planes of discontinuity along which two rock units appear to be interlocked. These planes are characterized by the accumulation of insoluble residues along them which the stylolite seams are formed. 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 planes.

Calcite veinlets: Calcite veinlets are common in the dolomitized and the non-dolomitized varieties. The grain size of crystals in general in a veinlet is proportional to the width of the veinlet. The veinlets appear to have been formed at various intervals. This evidence is found in some limestones which have sharp boundaries and appear closely related to fractures; whereas others have been formed due to recrystallization of the original material in the rocks.

#### PETROGRAPHIC TYPES

At the outset, here it may be mentioned that the different workers have given several classifications for those of Black (1933), Pettijohn (1957), Carrozi (1960), Dunham (1962), Demerian and Harbaugh (1965), Folk (1959) etc. of which only two classifications have been found suitable for the present work.

Broadly there exist two types of these rocks, viz., limestones

and dolomites. The limestones are partly autochthonous and partly allochthonous according to Pettijohn (1957) and Garrozi (1960). The nomenclature of Folk (1959) and Dunham (1962) was found more suitable for the rocks of the study area.

As per Folk classification, limestones are mainly made up of three constituents, namely allochems, microcrystalline calcite, ooze matrix and coarser sparry calcite. According to this classification important allochems in limestones are interclasts, oolites, pellets and fossils. Allochems provide the structural framework of limestones just as sand grains for sandstones. Microcrystalline calcite and sparry calcite are adjacent with the clay matrix and chemical cement of the sandstones. On the basis of relative proportion of allochems calcite ooze matrix and sparry calcite cement, three major families of limestones are distinguished: (a) limestones containing abundance of allochems, cemented by sparry calcite. These are clearly washed limestones, resembles with well sorted clay free sandstones and similarly formed of vigorous currents.

(b)- The limestones containing various amounts of allochems embedded in a microcrystalline ooze matrix. These are poorly washed limestones analogous with clay, poorly sorted sandstones

and formed in a loci of ineffective currents.

(c)- The third type of limestones is that contains totally of calcite ooze and thus resembles with terrigenous claystone. The first two limestone families are subdivided taking into consideration the nature of the allochans, first family includes intrasparite, cosparite, biosparite and pelisparite, second includes intramicrite, oomicrite, biomicrite and pelmicrite; third family includes homogenous ooze (micrite) and disturbed ooze with irregular openings filled with spar (dismicrite). For replacement limestones, however, the terms intraclastic dolomite, colitic dolomite and pelitic dolomites have been used.

Dunham ( 1962) broadly divided the limestones into two categories on the basis of depositional texture (i) in the first category the depositional textures are not recognizable and these are known as crystalline, (ii) in the second category, the depositional texture are recognizable and further subdivided into mudstones, wackstones, packstones, grainstones and boundstones, depending upon the percentage of grains and mud present in these limestones.

After applicability of the above two said classifications in the present work, it was thought better to follow the combined classifications of the two authors referred to above

(viz Folk, 1957 and Dunham, 1962). Firstly the broad group of limestones has been recognized by Dunham classification and within each one of these categories petrographic types in terms of Folk's classifications have been used.

#### DESCRIPTION OF ROCK TYPES

It is seen from the inspection of analytical data, staining technique, x-ray studies that the limestones are broadly divisible into two groups: viz., limestones and dolomites. Their detailed petrographic description is as follows:-

##### Limestones:

The limestones of Bandipura area vary from wackstone to packstone types depending upon the percentage of allochems. Most of them are micritic type although a few biosparites are also met with in the area under investigation. Broadly the following types have been found:-

##### Crinoidal limestones:

The biosparites of the Bandipura area are made up of crinoidal material consisting of large crinoid ossicles and stem plates. The size of these plates varies from 0.5 mm to

0.1 mm in diameter. Mostly the plates are circular in outline. Large fragmented grains are set in a matrix of crystalline calcite. Individual plate of a crinoid acts optically as a single crystal of calcite which acts as a nucleation site for calcite cement. Mostly the plates have fine perforation with radial arrangement but in some plates perforations have either disappeared or become indistinct because of calcite filling. Their typical photomicrographs are shown in plate 37 figs 1 to 6. The holes in the centre of this plate have also been filled up with calcite that is optically continuous.

#### Calcarenites:

Some of the beds of the calcarenite and calcilutite are intermixed with limestone beds in Bandipur area. These rocks contain a few subangular grains of quartz intermixed with lime mud. The grains show good sorting and without any contact with each other. Typical photomicrographs are shown in plate 38 figs 1 to 6.

#### Microcrystalline Rocks:

All these rocks having less than ten percent of allochems and largely consisting of microcrystalline calcite have been termed by Folk (1959) as microcrystalline rocks. Mostly these

rocks are structureless but some of them have developed microstylolites and calcite veins. Mostly these are simple microlithic types. Some of them are micrites containing large amount of terrigenous quartz. Some varieties contain irregular grains of sparry calcite and have passed into dismicrite variety.

Evidences regarding recrystallization present in some of the micrites involves enlargement of grain size resulting from the development of equant mosaic crystals of sparry calcite. These rocks indicate deposition in calm water condition both shallow and deep. The micritic types can be formed in a number of ways such as burrowing of animals, slumping, mud crack openings in semicoherent mud caused by the passage of gas bubbles and recrystallization processes.

#### Dolomites:

Dolomitic rocks of appreciable thickness are also present in the carbonate rocks of the study area. These rocks look similar to limestones in hand specimens and are of greyish white in colour and partly crystallized. A number of thin sections were studied to work out their detailed petrographic character.

### Hypidiotopic dolostone:

Rocks of this type are present in Bandipura area. These usually consist of subhedral to euhedral pentagonal grains forming a uniform mosaic type. The rocks are equigranular although the size of the grains varies in different sections. Some of these are fairly crystalline whereas a few are moderately crystalline. Hypidiotopic dolostones are generally free from any microstructure. Microphotographs showing hypidiotopic textures are shown in Plate 39 figs 1 and 2.

### Porphyrodolomicrite:

These are dolomicritic varieties in which bigger coarse crystals of dolomite are embedded in fine crystalline hypidiotopic grains. The bigger crystals represent vugs and cavities in the fine grained dolomites in which bigger and more crystalline grains of dolomites were developed producing porphyrotopic texture.

### MECHANISM OF DOLOMITIZATION

There is no direct evidence of the presence of any secondary dolomite in the rocks of the study area as no dolomite sample has been found to contain relict (dolomitized)

fossil. This clearly shows that the dolomites present in the study area are of evaporitic (primary) in nature. These are generally buff grey in colour, very hard and brittle and exhibit a subconchoidal fracture because of the absence of shaly partings.

The problem about the primary chemical precipitation arises among the geologists for a long time. Mostly the dolomites in the geological record resulted from a replacement process on the basis of stratigraphic and petrographic evidences in which half of the  $\text{Ca}$  in  $\text{CaCO}_3$  molecule is substituted by  $\text{Mg}$ , forming  $\text{CaMg}(\text{CO}_3)_2$ . The kinetics of the process are slow offering one explanation for the lack of dolomites on the sea floor and its rarity in sediments as compared with its abundance in the geological record.

Twenhofel (1932) found the common occurrence of dolomite in deposits of desiccating basins and suggested the possibility of direct chemical precipitation of dolomites from sea water through the process of evaporation. He admits that the process of primary dolomites in the sea floor at present is completely unknown. It is concluded that the dolomite beds in Bandipur area have also been formed because of some early diagenetic changes induced before the cementation of calcitic matrix during their emergence from the sea.

Wilson (1975) gave four pre-requisites for the early diagenetic dolomites. These are (a) sufficiently coarse and permeable calcareous sediments to act as the host for the replacement of Mg, (b) a fluid of the correct chemical composition to react and capable of dissolving  $\text{CaCO}_3$  and releasing Mg, (c) a long enduring supply of Mg, (d) a hydrodynamic head to force great volume of water.

Number of earlier workers like Adams and Rhodes (1960) Deffeyes et al. (1965) and Illing et al. (1965) suggested dolomitization theory based on the development of Mg-rich brines through evaporation on the basis of the above mentioned conditions. The first two groups of authors proposed that dense saline brines whose Mg/Ca ratio has been raised by loss of  $\text{Ca}$  through evaporative precipitation of gypsum and anhydrite in tidal flats ponds and supratidal reefs (sabkhas) migrated regularly down through lime sediments and dolomitized it (evaporative reflux). The enrichment of brines might also occur as suggested by Bathurst (1971) when inflowing sea water repeatedly dissolves calcite in earlier formed carbonate sediments and mixes with earlier and trapped brines and salts saturating the sediments. Under these conditions, there will be continuous addition of more soluble Mg salts to the brines and continual loss of  $\text{Ca}$ . organic or chemical precipitation of  $\text{CaCO}_3$  steadily increasing Mg/ $\text{Ca}$

ratio. The eventual seepage of such brines through sediments underlying the supratidal areas are below the bottom of shallow ephemeral lakes and ponds would induce dolomitization.

Badiuzzamani (1973) suggested that fresh perched water with small amounts of Mg when combined with marine water forms a fluid which may be undersaturated with respect to calcite. Shinn and Ginsburg (1964) suggested a process which resembles the dolomites of Bandipura area by involving very near surface precipitation of microcrystalline dolomite from evaporating Mg-rich water drawn upwards to the surface of tidal flats by capillary hypothesis.

#### DEPOSITIONAL ENVIRONMENT

The detailed sedimentological studies carried out on Bandipura limestone reveals the presence of three main facies types; the lower member consists of greyish brown limestone mostly of the lithoclastic-bioclastic crinoidal wackstone type which rests on dark shales.

The middle member consists of a facies of lime mudstone lacking any mega fauna but containing restricted marine or brackish microfauna of ostracods and interbedded with laminated beds of homogenous lime mudstones. The top beds are composed of greyish grey, very fine grained dolomite

displaying intratidal and supratidal sedimentary structures.

The grainstone or packstone type limestones are very uncommon and are only found in thin channel/natural levee deposits. Micritic texture is the most common one throughout from bottom to top. Nowhere oolitic and grainstone type limestones are met with in this area. This sequence, therefore, indicates definitely open marine but partly restricted sediment while the upper part is a tidal flat sequence indicated by dolomitization. This type of sequence generally occurs in shallow and adjoining shelves of many countries. The best known examples are that of marine shelf and platform strata of the Clear Fork and San Anders Formations of West Texas & New Mexico. These beds represent one of the major marine transgressions through southwestern north America, extending from central Texas from west to the Great Canyon and south of Central New Mexico into Chihuahua (Couch's Limestone). Lucia (1972) has described this type of sequence of the Clear Fork cycles on the central basin platform.

From the above considerations, it is, therefore, concluded that Bandipur limestone represents a type of shore-line carbonate sedimentation in a isolated shallow basin which was periodically and apparently flooded with marine

Permitting certain benthonic organisms to flourish. Gradual shallowing as sedimentation filled in the basin resulted in extensive tidal flats and evaporated sabkhas. The absence of oolitic and grainstone rock further correlate that the basin of deposition of Bandipura limestone was an isolated one, a little away from the open side of the shelf with essentially low energy carbonate deposition without any turbulence.

## CHAPTER - VI

### DEPOSITIONAL HISTORY

Subsequent to the deposition of Fenestella shales Kashmir area was converted into a scene of great volcanic activity whereby stupendous masses of lava were outpoured. These lava flows have been given the name of "Panjal Volcanics" which buried large parts of Kashmir under it. The volcanic-s are divisible into two parts, a lower part, in general, termed as the "Agglomeratic slates" and the upper part the "Panjal traps". The Panjal traps attain a thickness of as much as 5040 m to 6720 m in Kashmir valley. The total thickness of

traps is estimated at 4200 - 5080 m in the sections between Bandipura ( $34^{\circ} 25'$  ;  $74^{\circ} 39'$ ) and Tragbal ( $34^{\circ} 29'$  ;  $74^{\circ} 38'$ ).

The volcanic activity is reported by different investigators to be submarine or subaerial and as already mentioned is characterized by ashes and tuffs known as the Agglomeratic slates followed by a thick succession of lava flows of basaltic to andesitic character named as Panjal traps of predominantly tholeiitic affinity.

The present investigation is aimed at a petrological account of rock units exposed around Bandipura. The rock exposures consist of Panjal volcanics and limestones covered by deposits of Recent and sub-Recent at places.

Wadia (1934) in his well known work on the Cambrian-Trias sequence of northwest Kashmir reported for the first time that the traps of the area under study are interbedded with the limestones of Triassic age. The limestones obviously forming what could be properly referred to as "Intertroppean beds". On the basis of this observation, Wadia (op. cit.) concluded that the Panjal trap activity in northwest Kashmir was of a lengthened nature and continued up to Trias.

Wadia's (op. cit.) contention that the Panjal trap activity

continued right upto Trias does not appear to be substantiated by different evidences and needs further investigation. That the volcanic cycle did not extend upto the Trias and the limestones do not form "Inter Trappean Beds" is substantiated by the following facts:-

1- The petrology of the traps under study is in no way different from those of the known Permian occurrences in this part of the Himalaya. There are no new features in the traps of the present area which could distinguish them from the traps of Kashmir Himalaya in general. The present study has revealed different petrological types. A comparison of these with other known upper Carboniferous to Permian trap occurrences from this part of the Himalaya ( Gupta, 1973; Bains, 1981) suggests that the traps of the present area are in no way different from the trap occurrences of other places. Petrochemical studies have similarly indicated the tholeiitic parentage of the rocks.

2- No pillow lavas are found in the study area. Traps of spilitic nature are not to be seen anywhere here. Evidences of submarine mode of eruption of the rocks are absent.

3- In the case of lavas erupted under subaqueous conditions, the separation of dissolved gases is hindered below a certain depth due to the pressure of overlying water as has been shown

by the studies of Rittmann (1936), Macdonald (1954a), McBirney (1963). During the course of dredging on the submerged portions of the east Rift zone of Kilauea volcano in Hawaii, Rittmann's (op.cit) contention of 2000 m as a critical depth has very recently been confirmed. Vesicles with an average diameter of less than 0.1 mm are rare at a depth of 4,000 m. Moore (1965) observed that lavas erupted at 800 m have only ten percent of the vesicles with an average diameter greater than 0.5 mm. Vesicles are seen to be smaller and lesser in number below this depth.

In the case of the rocks of the study area, abundance of vesicular type of traps conclusively points towards their continental environment of deposition. This is further corroborated by the absence of pillow lavas from Bandipura area.

4- The volcanic tuffs of the area do not contain fossils. The Agglomeratic slates of tuffaceous character found in the adjoining areas are reportedly unfossiliferous. Hence the submarine origin of the traps under study is ruled out.

5- An important negative evidence about the "inter trappean" nature of the limestones is provided by the facts that no contact metamorphic effects are noticed at the junction of limestones

and traps. L-ime silicate minerals which should have normally formed at the limestone-trap contact, had the limestones been of "Inter trappean" character are entirely absent. This again shows that the limestones do not form "Inter trappean Beds" as was envisaged by Wadia.

6- The type of limestone sequence present in Bandipura area indicates a specific transgression phase followed by marine regression. The lower part of the sequence consisting of crinoidal limestone indicates extension of an epicontinental sea in this area, which permitted biomicritic type of limestone to be deposited. The dolomites at the top indicate the final regression of the sea. This points to a temporary transgression of the Triassic sea on the Panjal trap country and its subsequent regression.

7- The absence of oolitic and grainstone rocks further corroborate that the basin of deposition of Bandipura rocks was an isolated one, a little away from the open side of the shelf with essentially low energy carbonate deposition without any turbulence.

From what has been stated above, it is clear that subsequent to the deposition of the traps of the study area, there was a type of shore line carbonate sedimentation in an isolated shelf basin which was periodically and apparently rapidly flooded with marine water permitting certain Benthonic organisms to flourish. Gradual shallowing as sedimentation filled in the basin resulted in extensive tidal flats. The Panjel trap activity in this area also appears to have died down in the Permian period as in other parts of Kashmir. There was thus a temporary incursion of a part of the Triassic sea in the area under study, and the limestones of that age were deposited on the traps in the form of an isolated outcrop. As was pointed out in the beginning of this chapter, Wadia's (Op.cit.) contention that the limestone formed "Inter trappan" beds does not appear to be substantiated by facts. The author very respectfully differs with Wadia's affirmation and would suggest further investigation in this direction.

**CHAPTER - VII****S U M M A R Y   A N D   C O N C L U S I O N S**

This work embodies the petrological study of rocks exposed around Bandipura, Baramulla district, J & K state. The study area forms parts of Survey of India Topographic sheet nos. 43 J/11 and 43 J/15 (1 : 50,000), and can be approached from Srinagar city by a 55 km metalled road up to Bandipura. The interior parts can be visited by trekking. The area shows dendritic type of drainage. Two important rivers Madhumati and Erin nala with other tributaries drain through the area.

In this study an area of about 175 sq.kms has been covered.

Panjal traps and limestones are the only formations exposed in the present area with Recent and sub-Recent deposits.

The volcanics have been classified as (i) glomeroporphyritic traps, (ii) amygdaloidal traps, (iii) hard and compact traps, (iv) purple coloured tuffs, (v) epidotes and (vi) dyke rocks. Thin section study of the traps in many instances shows the presence of plagioclases, chlorites, epidotes and quartz with magnetite and ilmenite as the opaque accessory minerals. Presence of hornblende is witnessed in altered dyke rocks. The groundmass of the traps cannot be generally optically resolved because of its fineness and when observed, it is seen to consist of a cryptocrystalline aggregate of feldspars, chlorites, epidotes etc. The rocks have obviously undergone a low grade of metamorphism of the amphibolite facies, because of their involvement in the Himalayan orogeny and their present mineral assemblage is due to it.

Plagioclases, chlorites and epidotes have been separated from the volcanics. The separated minerals have been optically studied, chemically analysed and x-rayed. The anorthite content of the plagioclases ranges from  $An_{54}$  to  $An_{74}$  with

intermediate (O/D) to high structural state. It means that the plagioclases have changed from their original disordered structural state to medium condition. Zoisite and epidote have been identified from the epidote group of minerals. Chlorite is the iron-rich Chamosite variety.

Twenty-nine samples of Panjal traps of the study area have been analysed for their major elements using the conventional method of rock analysis. The alkalis have, however, been estimated by flame photometry. The study of the petrochemical data leads us to the conclusion that the traps of Bandipura area are of tholeiitic character and appear to have been outpoured under sub-aerial conditions. The rocks are generally of basaltic to andesitic character and portray a magmatic differentiation trend.

The limestones of the study area are usually intermingled with shales. Except for crinoid stems, no other fossil has been found in the rocks. Detailed chemical composition of the carbonate group of rocks has been worked out, various petrographic types described, their textural and structural features studied and x-ray studies made so as to follow the exact domain of sedimentation and other physical and chemical

parameters and tectonic control of limestone deposition of the study area. The x-ray study and staining techniques show that the limestones are of calcitic and dolomitic character.

The analytical data of the limestone shows that the rocks are rich in calcium and poor in magnesium. The ratios of calcite/dolomite when plotted on a trivariate diagram reveals the presence of pure, impure limestones, dolomitic limestones and impure dolomitic limestones. The limestones of the present area vary from wackstone to packstone types depending upon the percentages of allochems. The carbonate rocks are dolomitized in the upper part. The lower part essentially consists of micrites and a few biosparites. The presence of dolomite has been confirmed by chemical analysis, x-ray 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.

From all the available evidences, it appears that Bandipura limestones represent a type of shore line carbonate sedimentation in an isolated shallow basin which was periodically and apparently rapidly flooded with marine water permitting certain benthonic organisms to flourish. This is further corroborated by the absence of oolitic and grainstone rocks.

The depositional basin of Bandipura limestone was an isolated one, a little away from the open side of the shelf with essentially low energy carbonate deposition without any turbulence. The Panjal traps provided the basement on which the carbonate group of rocks was deposited. Wadia's (op. cit.) contention that the limestones of the area represent "intertropical" beds is not supported by different evidences and needs further investigation.

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ILLUSTRATIONS

FIGURE-1

Map showing the means of communication and the location of the study area, Baramulla district, Kashmir.

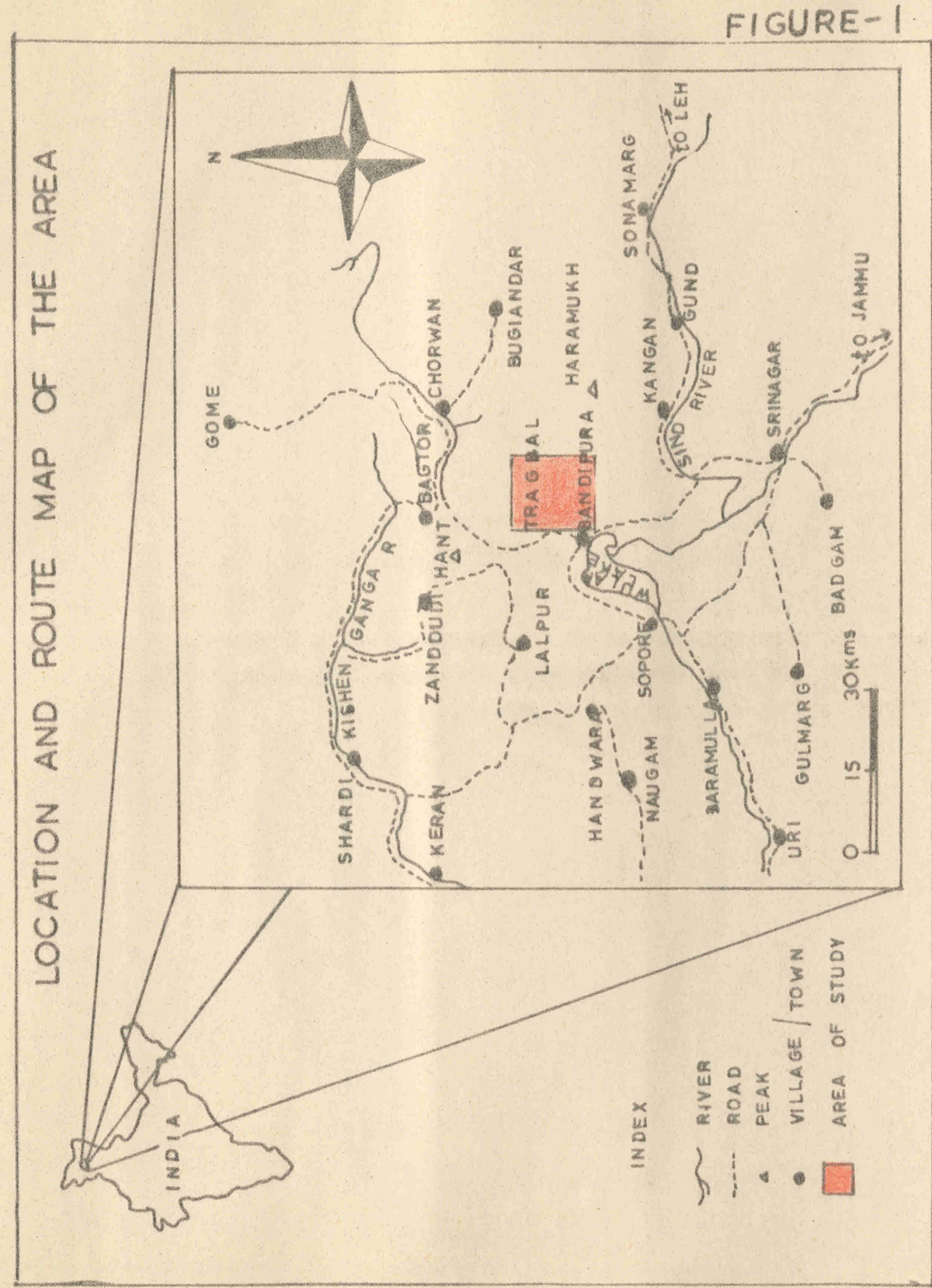


PLATE 2

Fig.1 - A panoramic view of Triassic limestone of Erin Valley. Camera facing northwest.

Fig.2- A panoramic view of Triassic limestone exposed in Chitarras as seen from Sorbarani. Camera facing southeast.

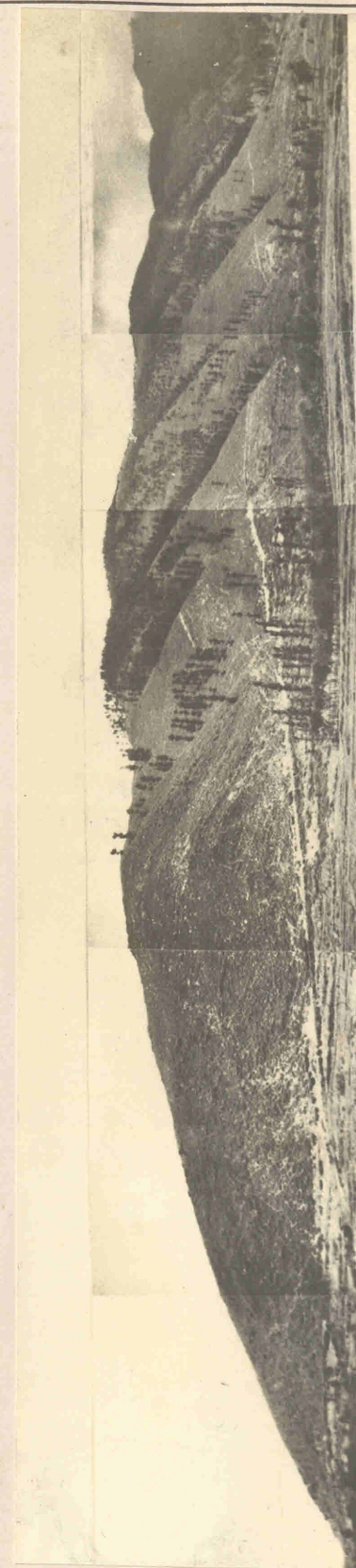


Fig:1

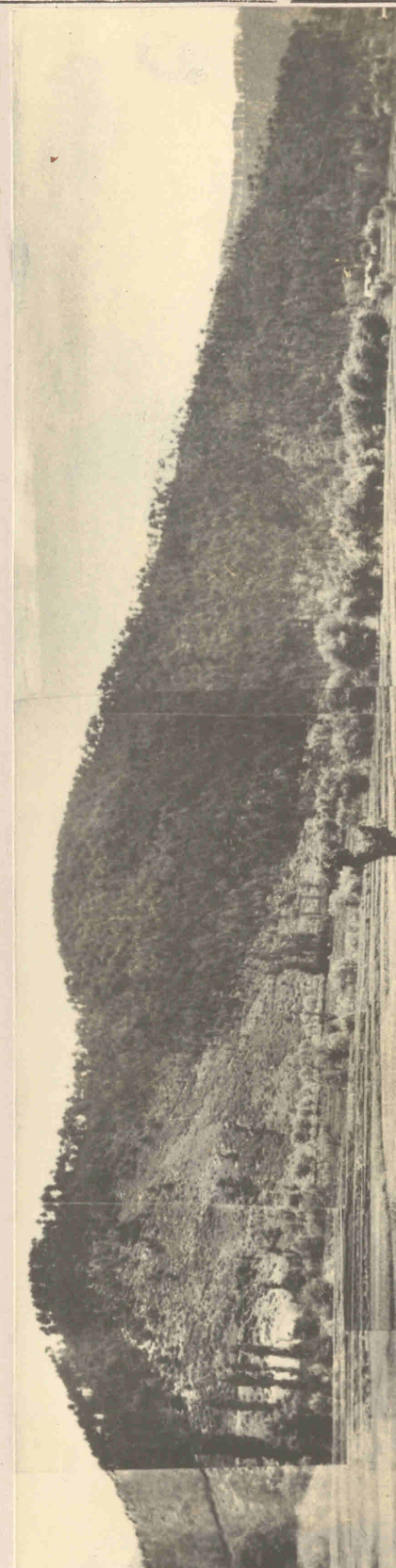


Fig:2

PLATE - 3

- Fig.1-** A panoramic view of Panjal traps of Erin valley. Camera facing east.
- Fig.2-** A panoramic view of trap country between Tragbal and Saribal. Photograph taken from Sonarwani. Camera facing northeast.

PLATE - 3

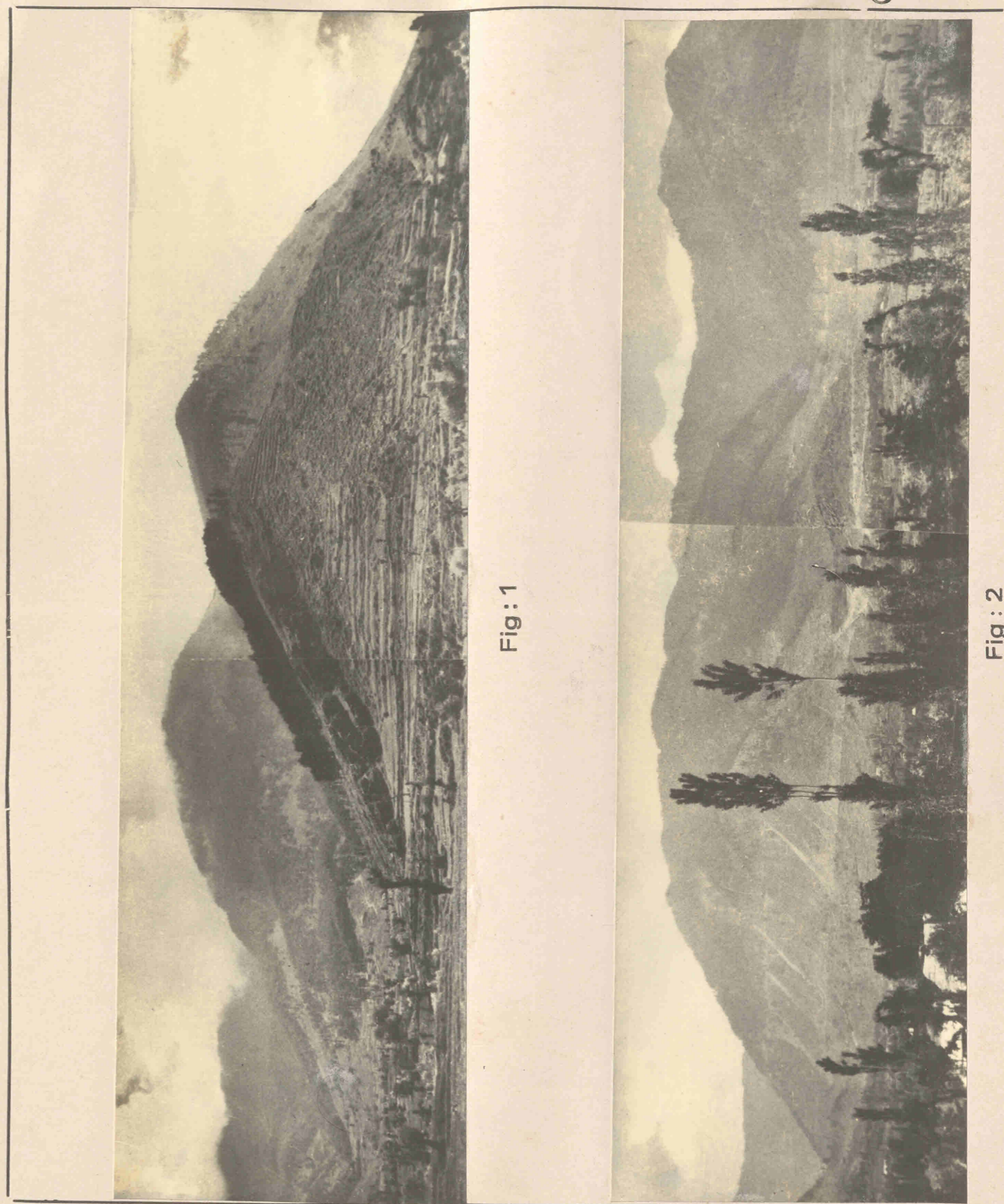


Fig: 1

Fig: 2

FIGURE - 4

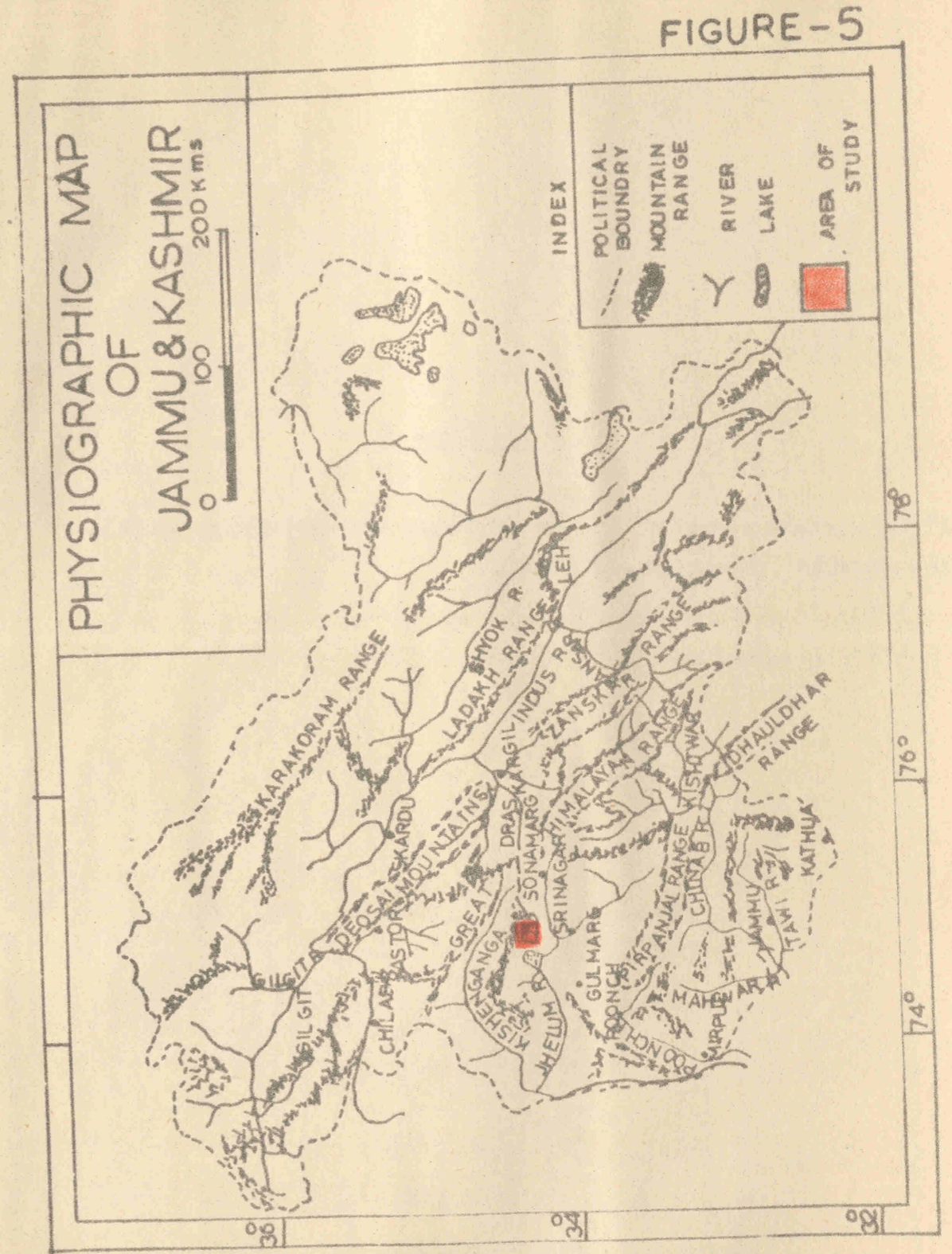


FIGURE - 4

A panoramic view of Tragbal as seen from  
Kralpara. Camera facing northwest.

**FIGURE - 5**

A Physiographic map of Jammu and Kashmir state, showing prominent mountain ranges and rivers.



**FIGURE - 6**

Physiographic map of the study area and adjoining parts,  
Baramulla district, Kashmir.

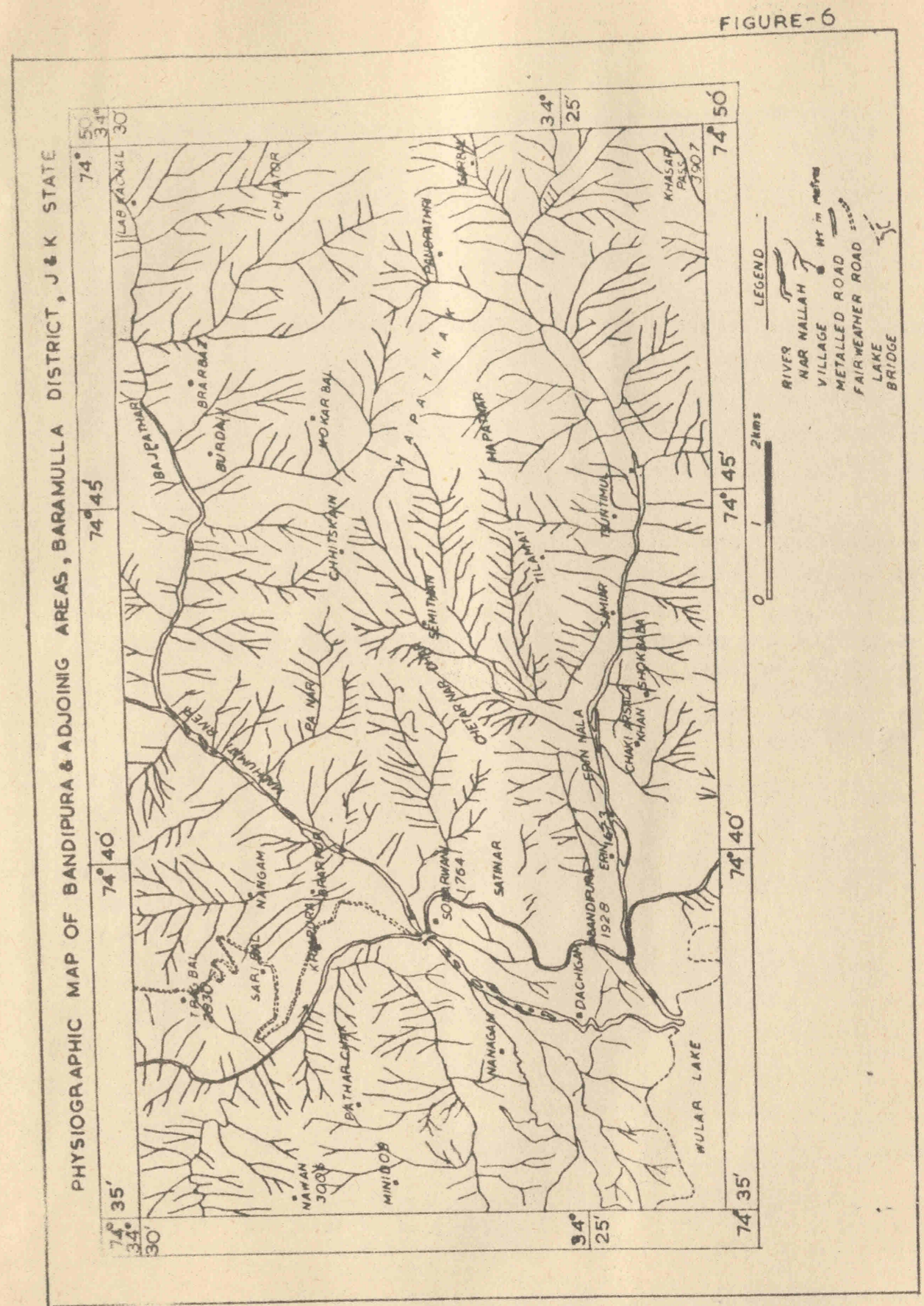


FIGURE - 7

R-regional geological map of a part of Kashmir Himalaya (After Gansser, 1964) showing the disposition of the rock units and the tectonics of the area. The study area is indicated on the map by an enclosing rectangle.

- 10- Alluvium
- 9- Karewas
- 8- Murrees
- 7- Eocene
- 6- Triassic
- 5- Panjal volcanics (including Agglomeratic slates)
- 4- Dogra slates
- 3- Saikhalas
- 2- Central gneiss
- 1-Granites.

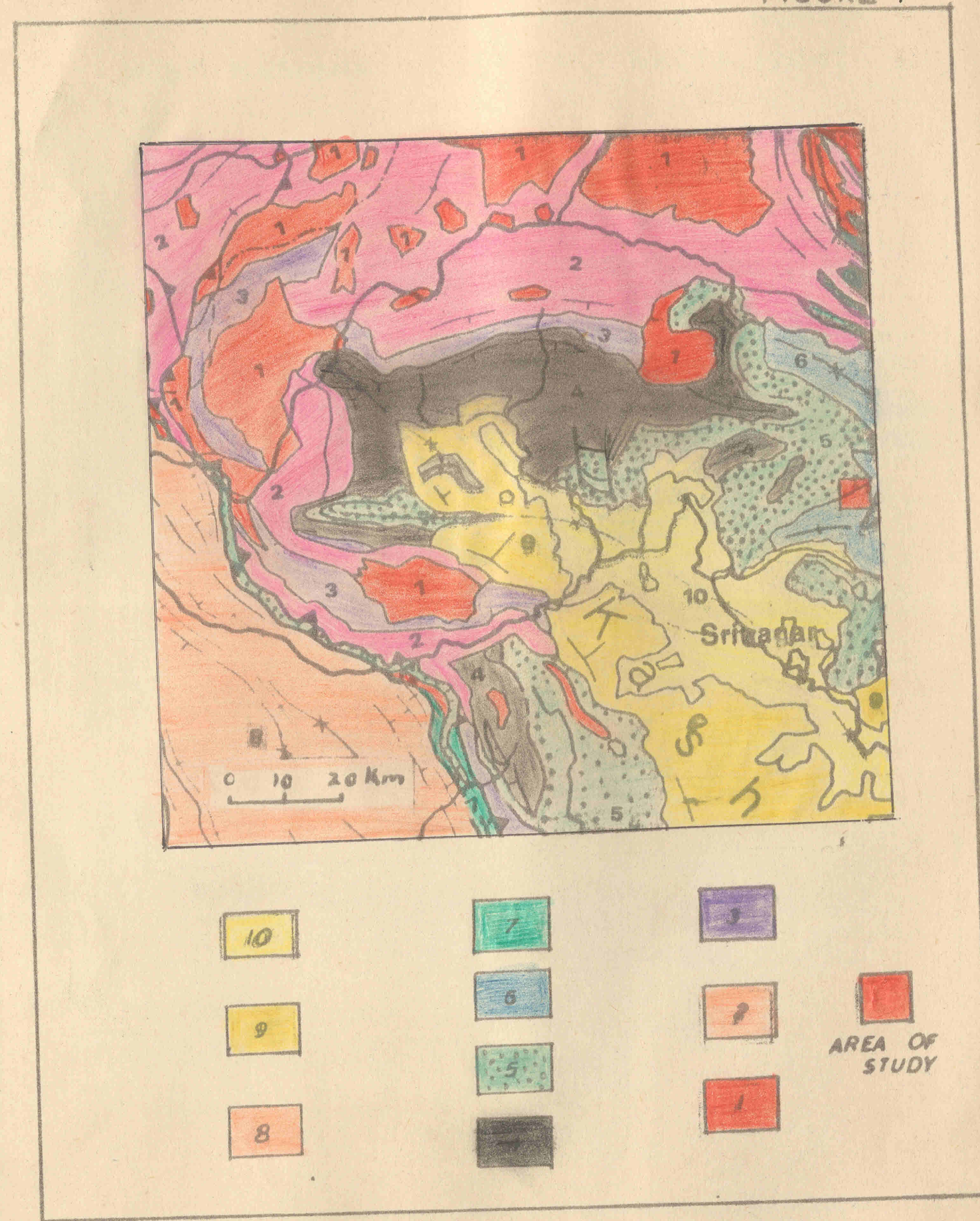


FIGURE-8

GEOLOGICAL MAP OF A PART OF NORTH-  
WEST KASHMIR (AFTER WADIA, 1934)



0 4 MILES

INDEX

- ALLUVIUM
- TRIASSIC LIMESTONE
- PANJAL
- TRAP
- AGGLOMERATIC SLATE
- CAMBRIAN
- DOGRA SLATE
- SALKHALAS
- HANT GRANITES

FIGURE - 8

Geological map of a part of northwest Kashmir  
(After Wadia, 1934)

PLATE - 9

Field photographs

- Fig.1- A small hillock of traps as seen at Kralpura. Camera facing southeast.
- Fig.2- Plagioclase laths in the traps near Mudor village. Camera facing northwest.
- Fig.3- A view of Wular lake (in the back ground) as seen from B-andipura. Camera facing west.
- Fig.4- Traps showing glomeroporphyritic texture near Shok-Baba. Camera facing west.
- Fig.5- Bedding in limestones near water reservoir, Bandipura. Camera facing northeast.
- Fig.6- Jointing seen in Panjal traps on the right bank of E-rin nala near Daradpura. Camera facing east.



Fig : 1



Fig : 2



Fig : 3



Fig : 4



Fig : 5



Fig : 6

PLATE -10

Figs.1 and 2. Microphotograph showing glomeroporphyritic trap variety. Crossed Nicols x 45.

Figs 3 and 4. Microphotograph of amygdaloidal traps. Here the amydales of chlorite and epidote are seen. Ordinary light x 45.

Figs 5 and 6. Microphotographs of hard and compact variety of traps with plagioclase microlites. The rocks show hyalopilitic texture. Crossed Nicols x 45.



Fig : 1



Fig : 2

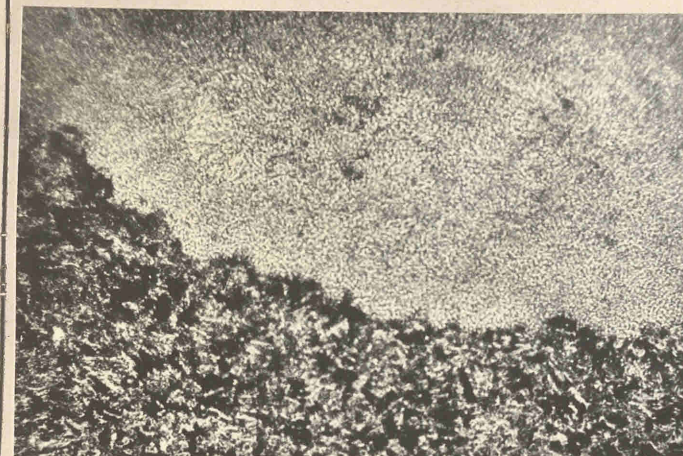


Fig : 3

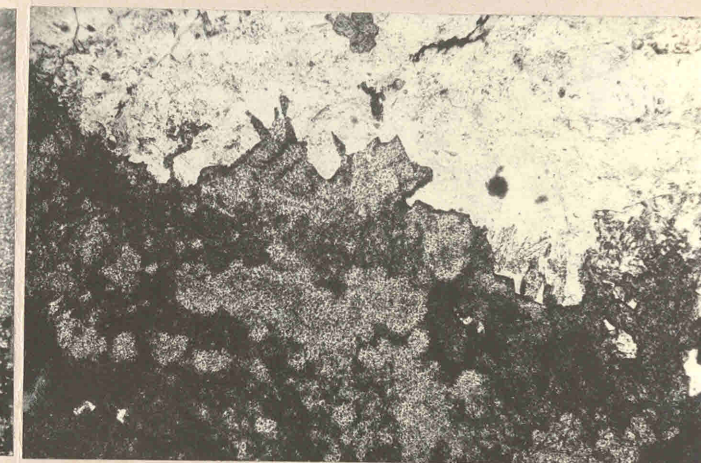


Fig : 4



Fig : 5

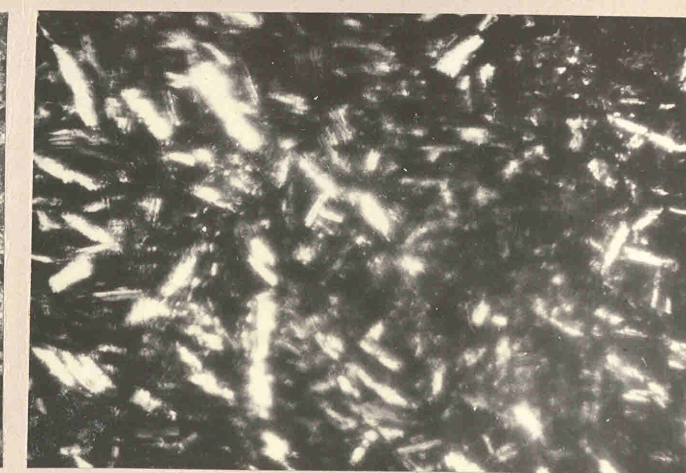


Fig : 6

PLATE -11

Figs 1 and 2- Microphotographs of tuffs of the study area showing a fine grained glassy matrix with a few grains of quartz and magnetite. Ordinary light x 45.

Fig.3. Microphotograph of plagioclase as seen in the traps of the study area. Crossed Nicols x 45.

Figs 4 and 5.- Microphotographs of epidotes showing grains of epidote and quartz together with magnetite. Crossed Nicols x 45.

Fig.6. Microphotograph showing laths of plagioclases, amphiboles and chlorites from an altered dyke rock . crossed Nicols x 45.

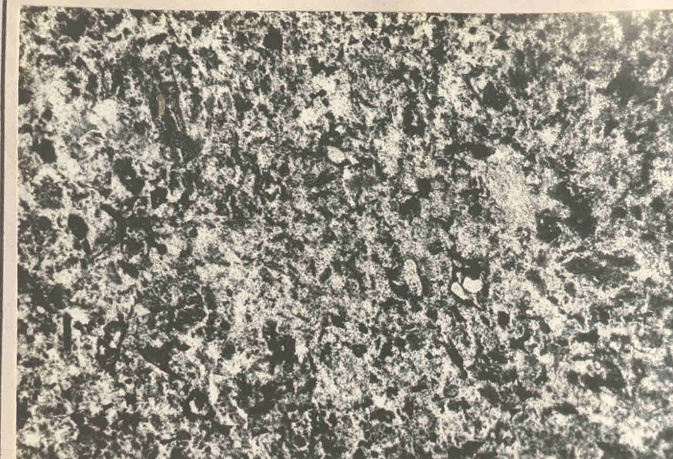


Fig : 1



Fig : 2

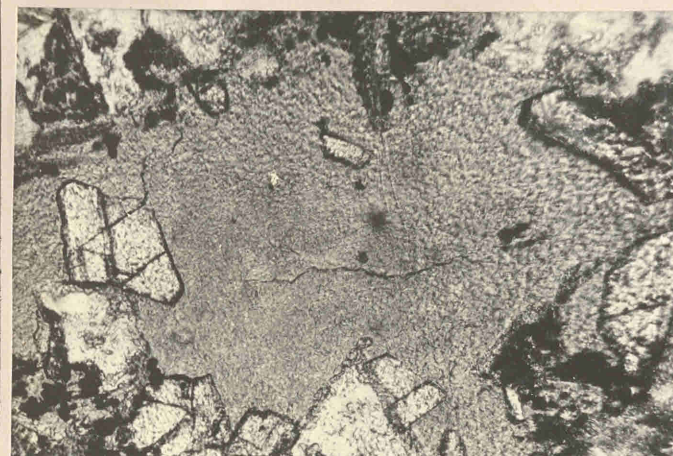


Fig : 3

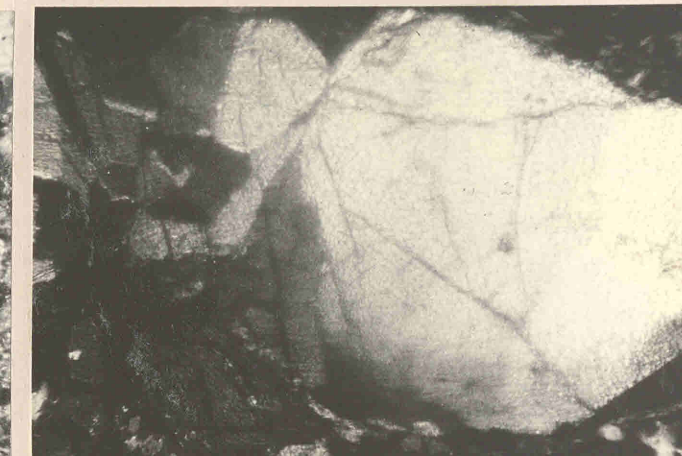


Fig : 4

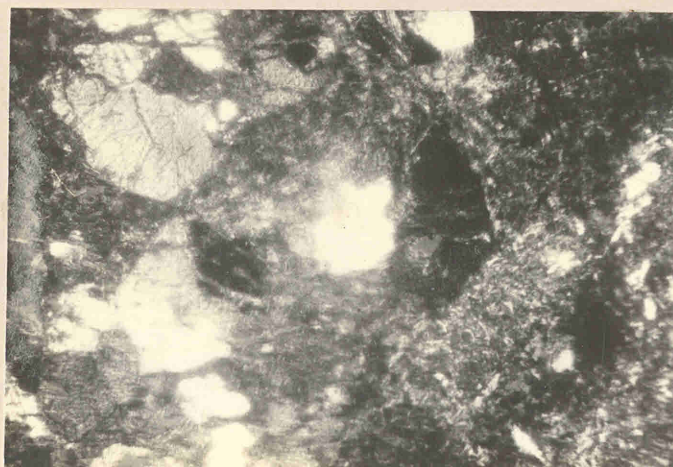


Fig : 5

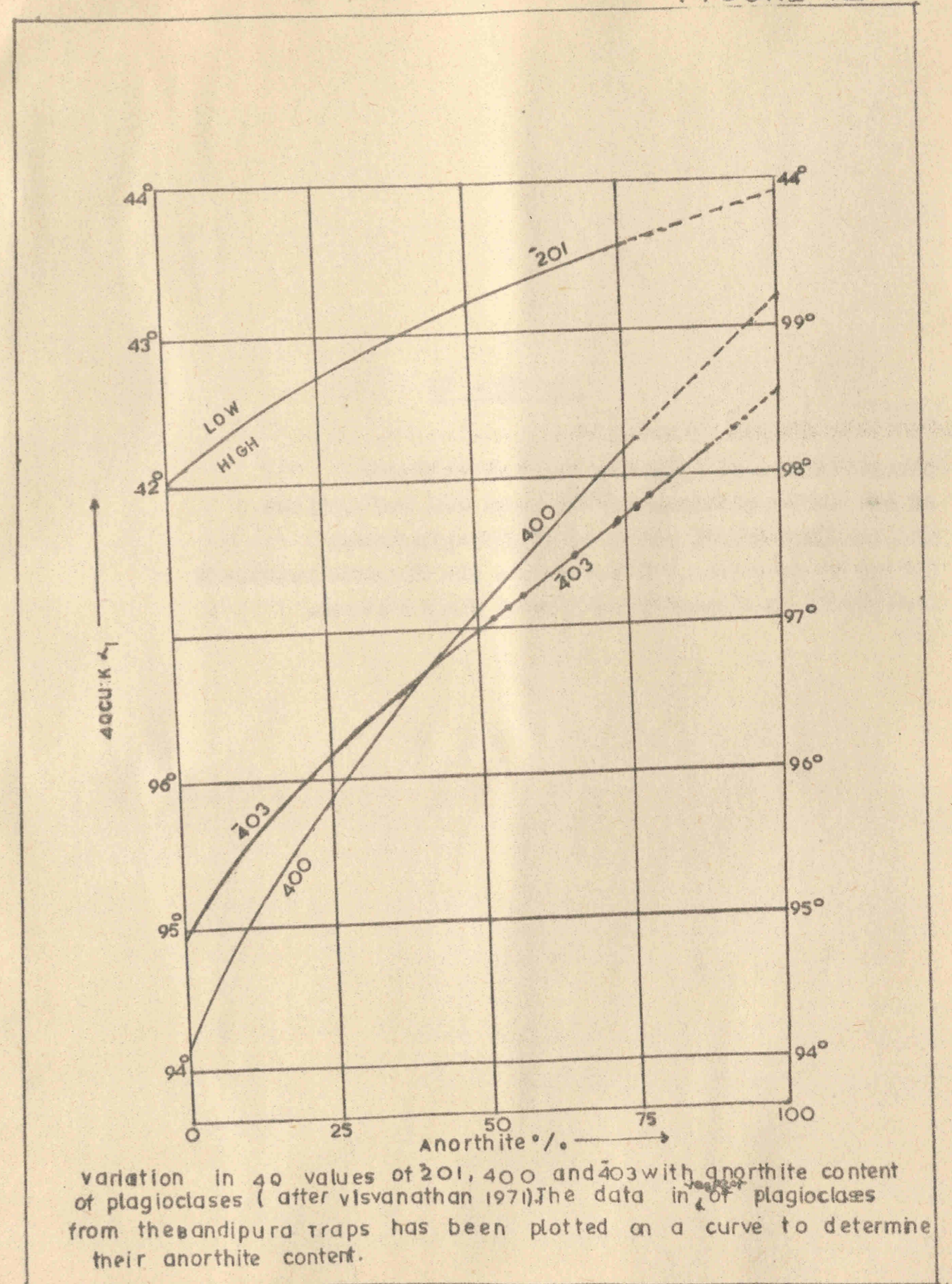


Fig : 6

FIGURE -12

Bivariate diagram showing the relationship of  $4\theta$  peak positions of  $\bar{2}01$ ,  $400$  and  $\bar{4}03$  reflections and the anorthite content of plagioclases (after viswanathan, 1971.). Plagioclases of Bandipura traps plot on one of the curves (dots in the diagram) from which anorthite content of the plagioclases could be easily estimated.

FIGURE-12



**FIGURE - 13**

Bivariate diagram showing the relationship of 4θ peak positions of 204 and 060 reflections and the structural state of the plagioclases (after Viswanathan, 1971). Dots on the diagram represent individual Bandipura Panjal trap plagioclases.

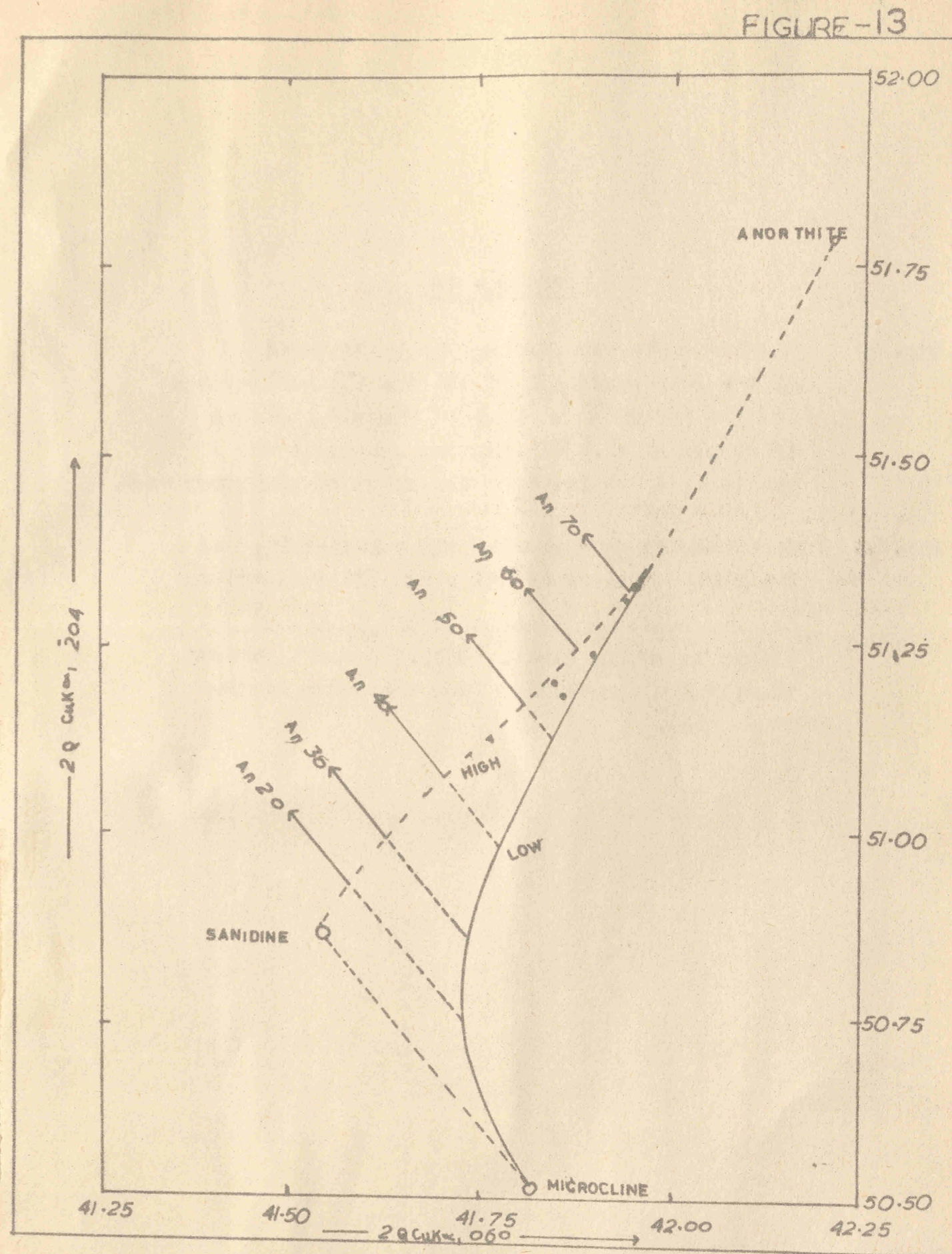


PLATE - 14

Fig.1- Bivariate diagram showing the relationship of 2  $\theta$  peak positions of 131 and 131 reflections and the anorthite content of the plagioclases (Bambauer et al.1967). Crosses represent the plagioclase samples from the traps of the study area.

Fig.2.- Bivariate diagram showing the relationship of 2  $\theta$  peak positions of 241 and 241 reflections and the anorthite content of plagioclases (after Bambauer, et al. 1967). Crosses represent the plagioclase samples from the traps of the study area.

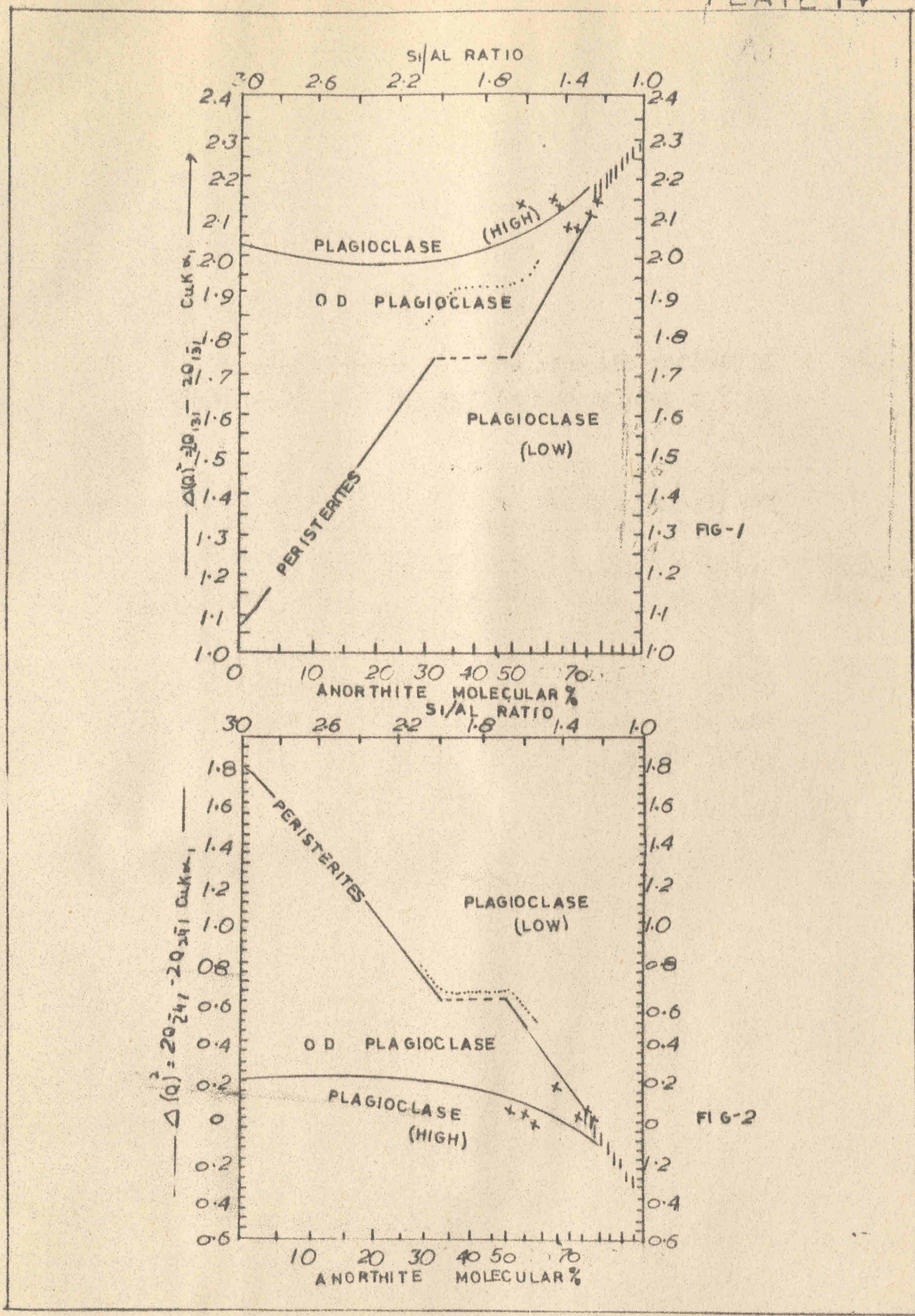


FIGURE-15

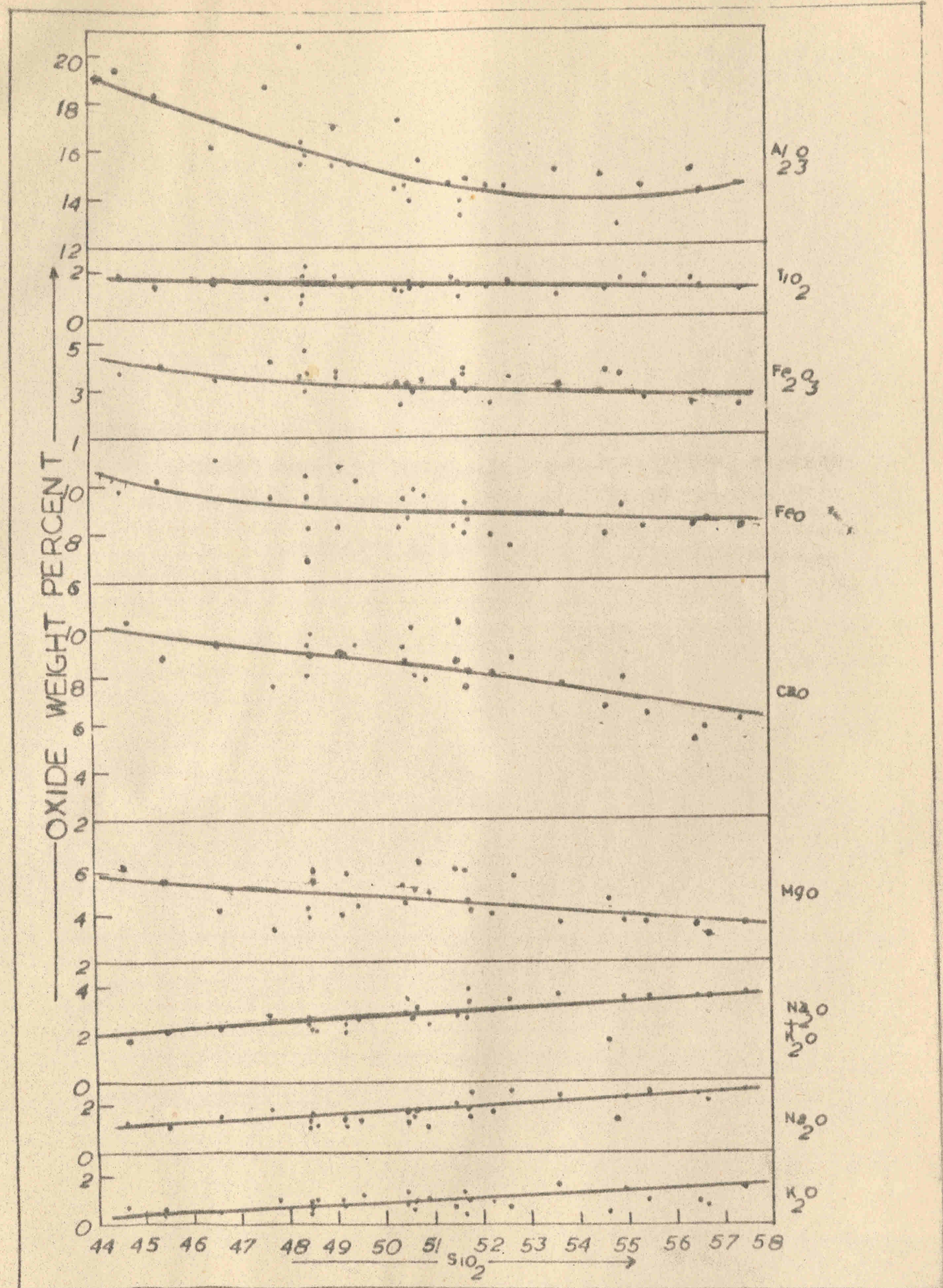


FIGURE - 15

Harkers (1909) variation diagram of several oxides with respect to silica. Dots represent individual Bandipura trap samples and dots within circles where two or more samples coincide.

FIGURE-16

FIGURE- 16  
 Larsen (1938) variation diagram showing the relationship of several oxides with respect to "Larsen Index". Dots represent individual Bandipura traps and dots within circle where two or more samples coincide.

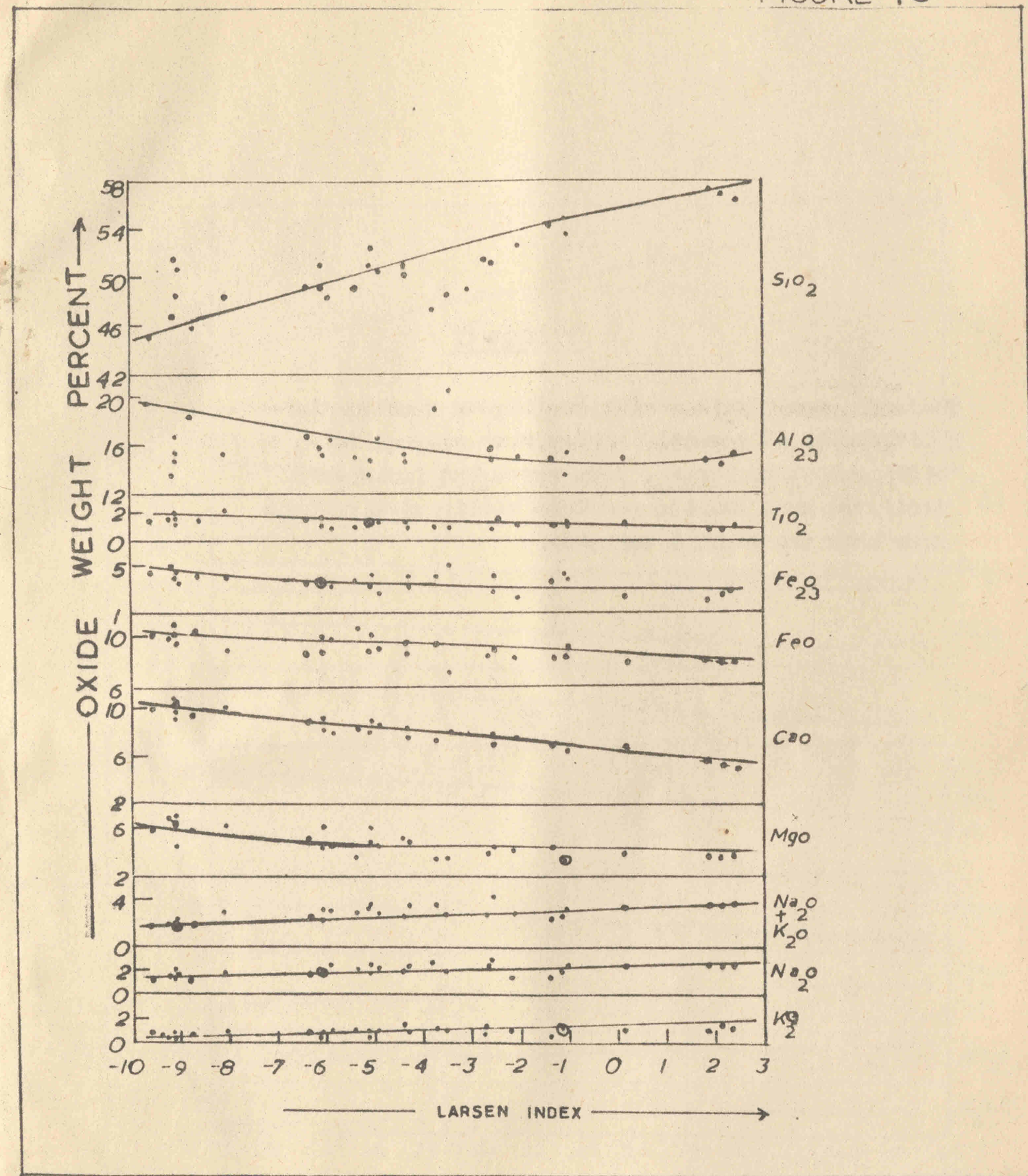


FIGURE-17

FIGURE-17

Thornton and Tuttle variation diagram showing the relationship of several oxides with respect to "Differentiation Index". Dots represent individual Bandipur trap samples and dots within a circle where more than two samples coincide.

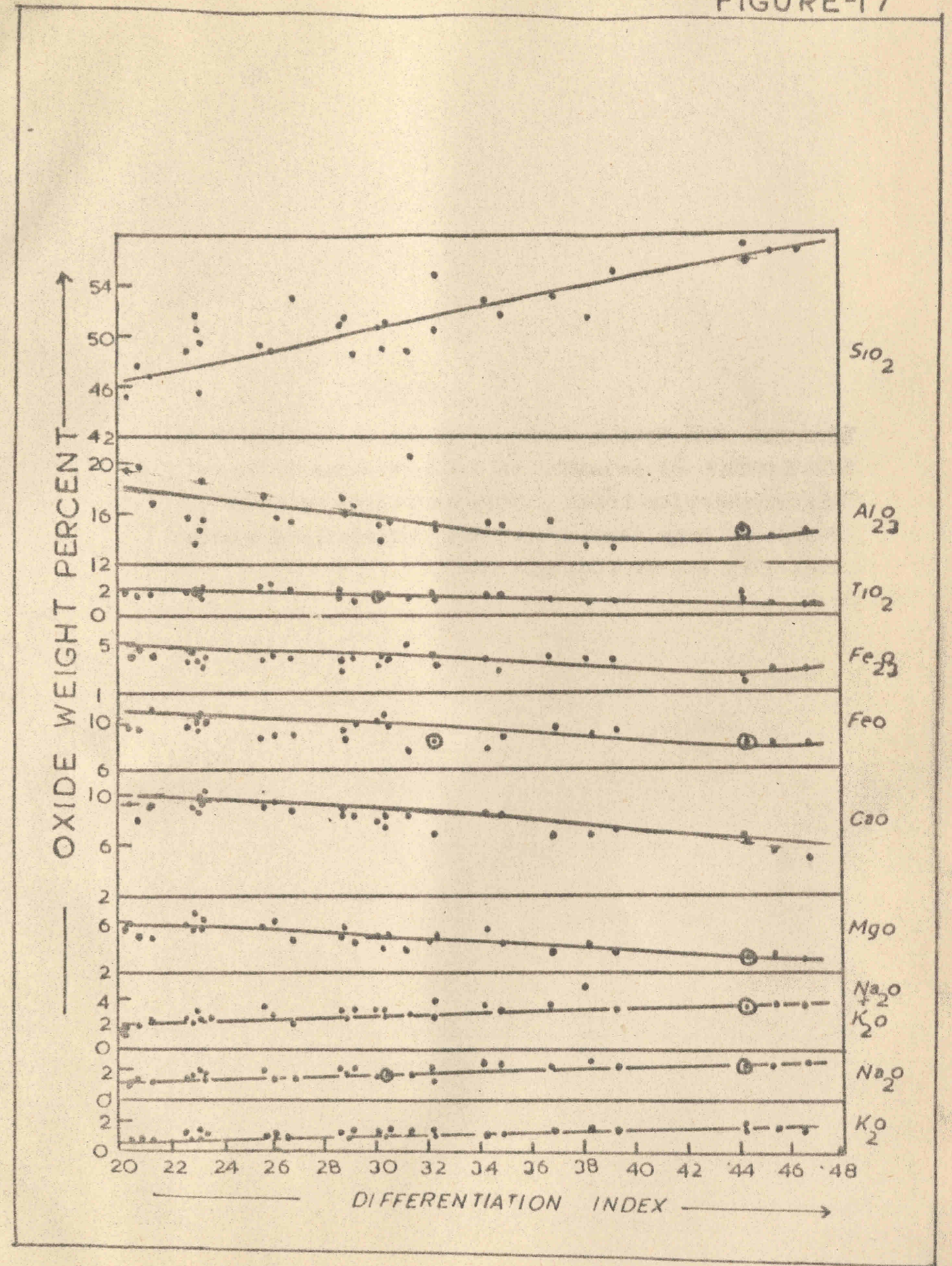


FIGURE-18

variation diagram of several oxides with respect to "Crystallization Index" of Poldervaart and Parker (1964). Dots indicate individual Bandipur trap samples and dots within circles where two or more samples coincide.

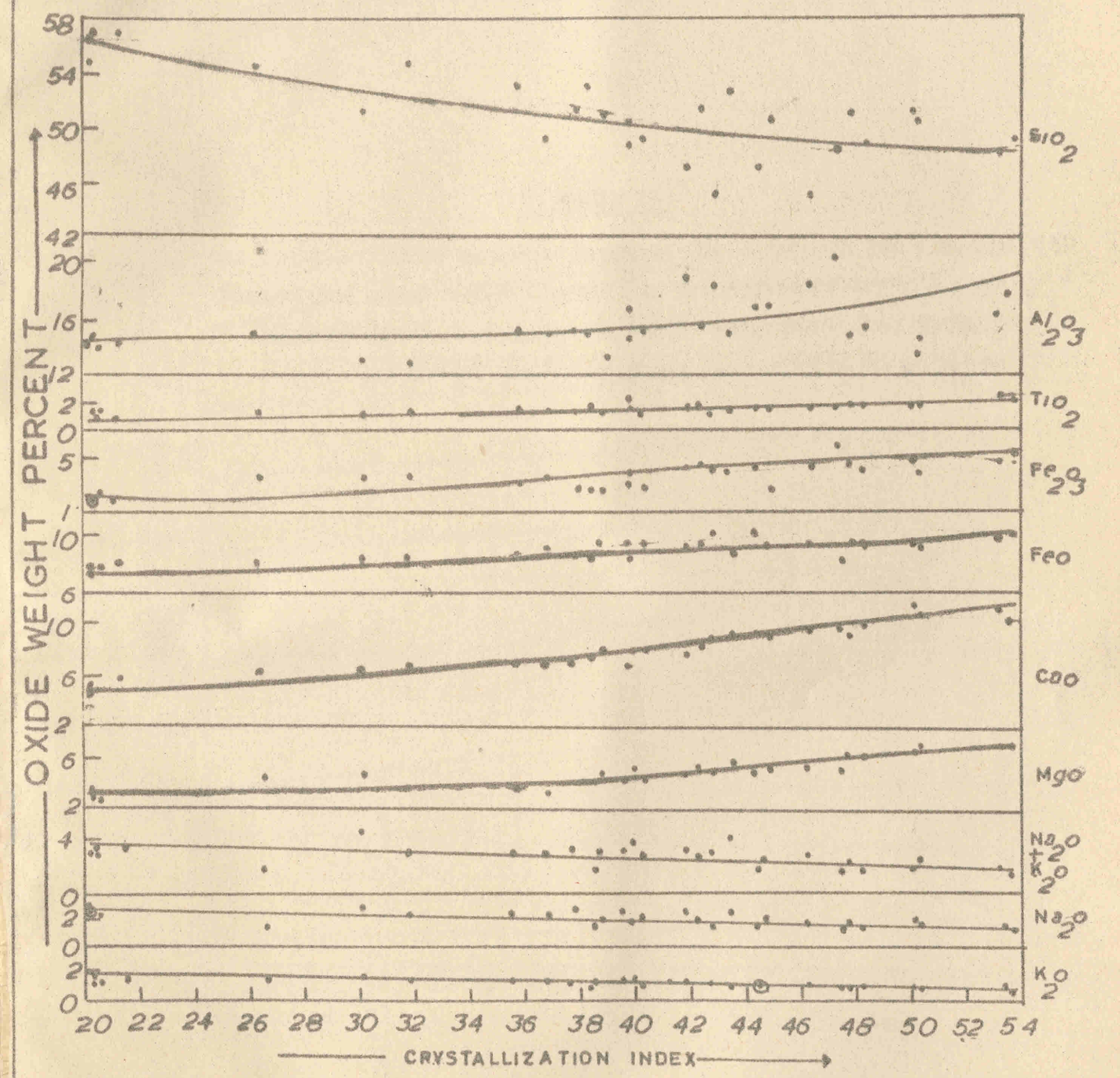


FIGURE-19

FIGURE-19

variation diagram of several oxides with respect to "solidification Index" of Kuno(1968). Dots represent individual Bandipura trap samples and dots within circles where two or more samples coincide.

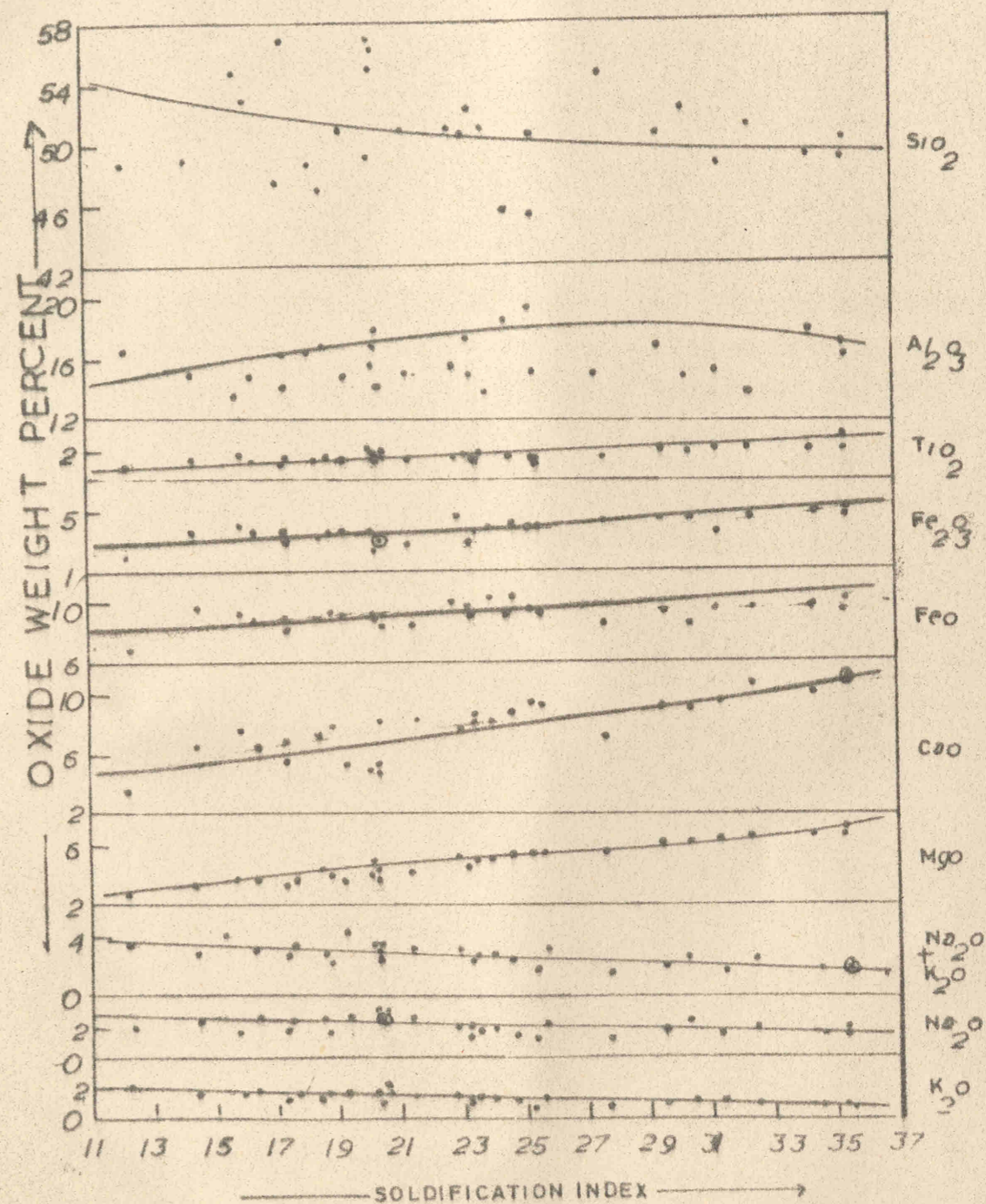


PLATE -20

- Fig.1. Bivariate diagram showing the relationship between alkalis and silica (after Macdonald and Katsura, 1964 and Saggerson and Williams, 1964). Dots represent individual Bandipura Panjal trap samples.
- Fig.2. Bivariate diagram showing the relationship between alkalis and silica (after Kuno, 1968). Dots represent individual Bandipura Panjal trap samples.
- Fig.3. Bivariate diagram showing the relationship between potash and soda (after Kuno (op. cit.)). Dots represent individual Bandipura Panjal trap samples.

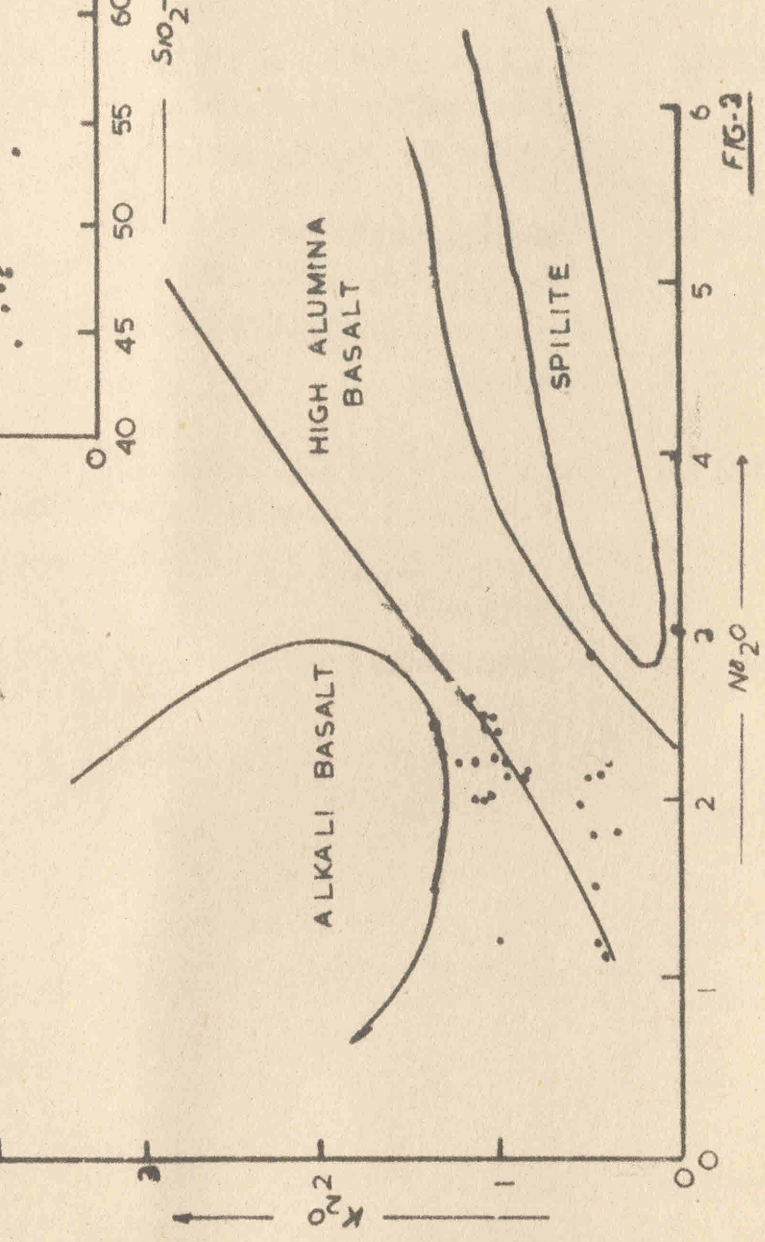
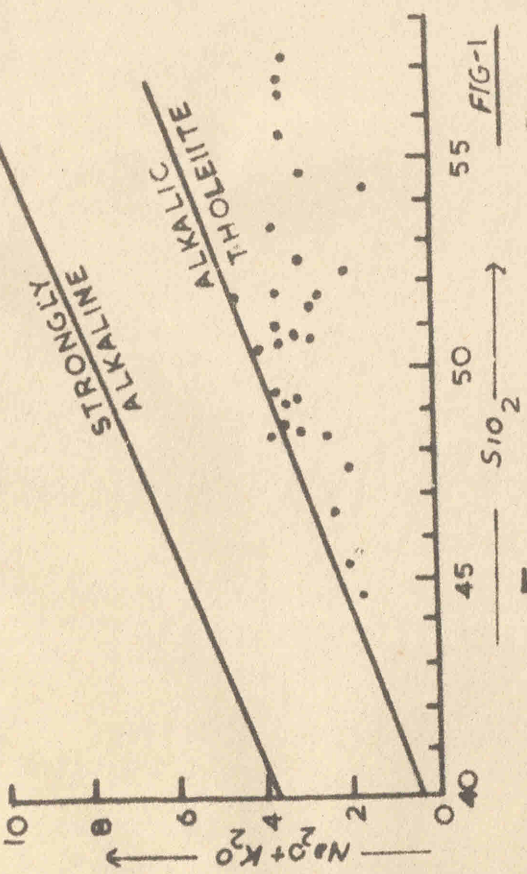
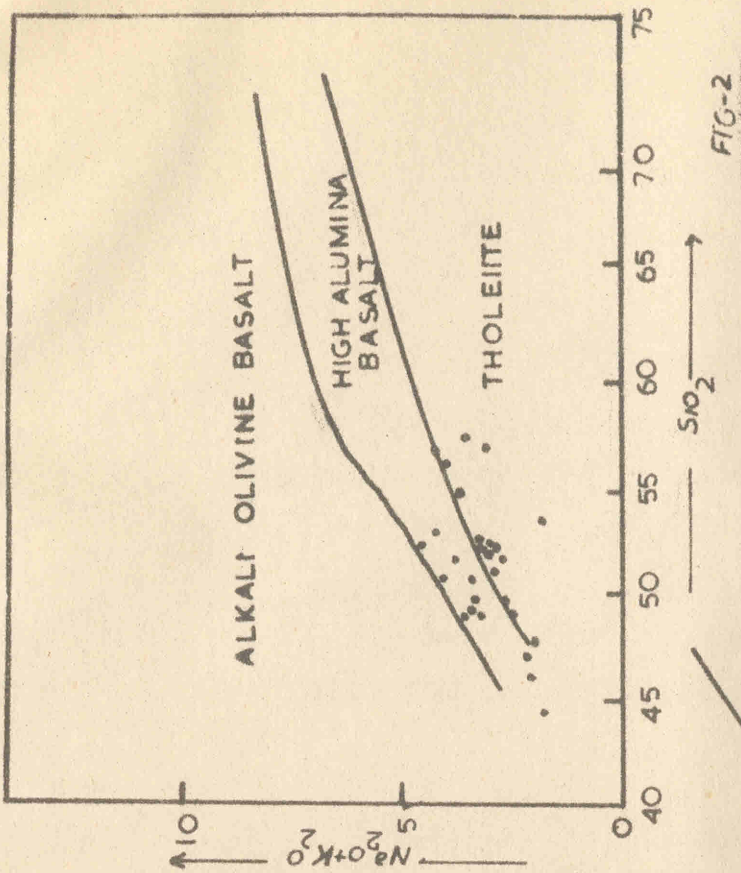


PLATE -21

- Fig.1. Niggli ( 1954) bivariate diagram showing relationship between c and mg. Dots represent individual Bandipura panjal trap samples.
- Fig.2. Niggli (op. cit.) variation diagram showing relationship between al-alk and c. Dots represent individual Bandipura panjal trap samples.
- Fig.3. Niggli (op. cit.) variation diagram showing the relationship between  $(al + fm) - (c + alk)$  and si. Dots represent individual Bandipura Panjal trap samples.

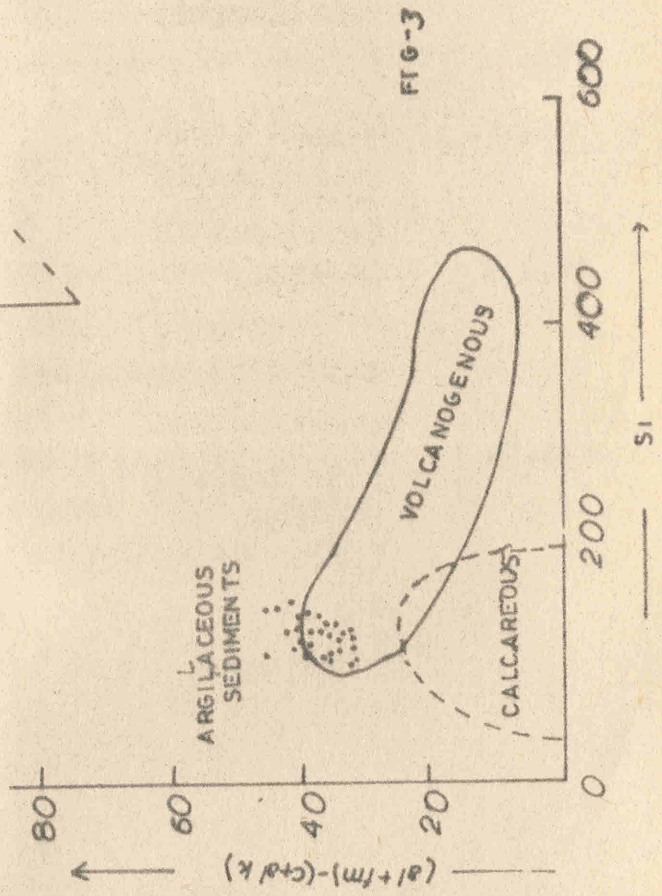
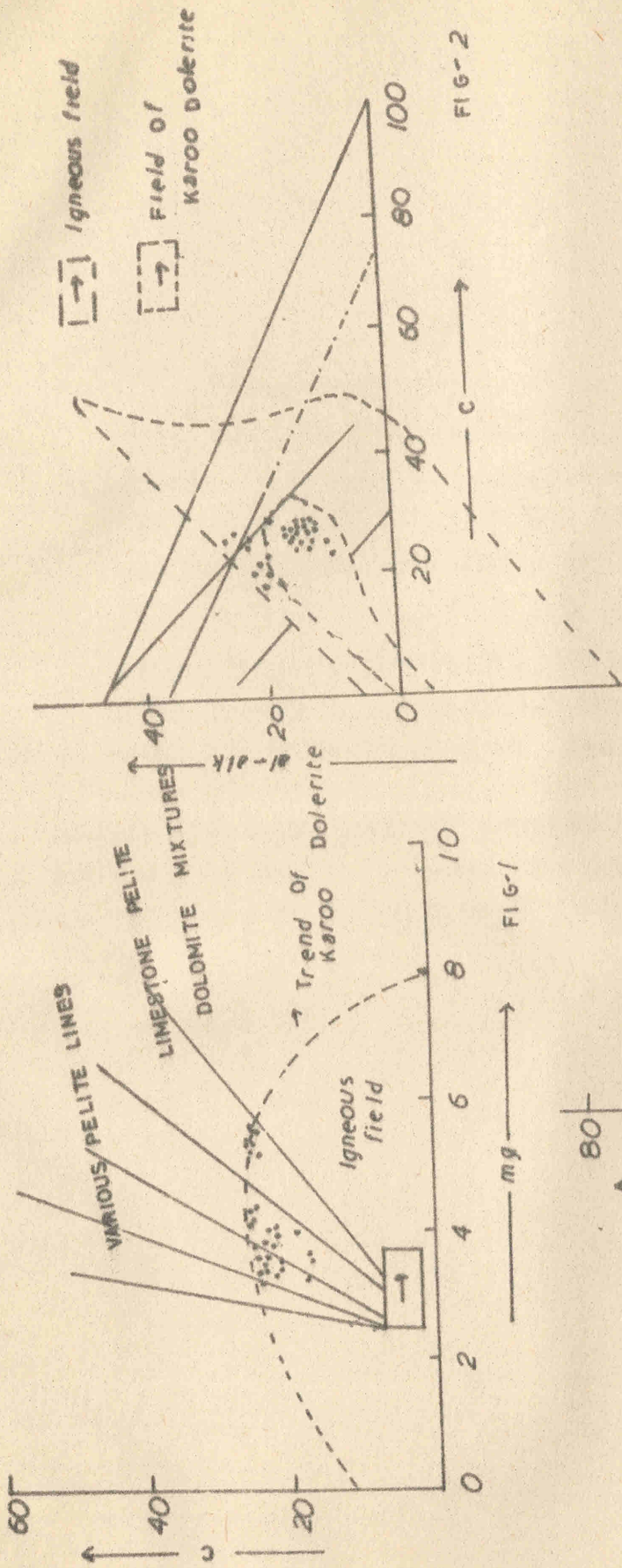


PLATE - 22

- Fig.1.** Binary variation diagram showing the relationship between Miggli qz and Crystallization Index. Dots represent individual trap samples of the study area.
- Fig.2.** Binary variation diagram showing relationship between silica and solidification index. Dots represent individual trap samples of the study area.
- Fig.3.** Binary variation diagram showing the relationship between total iron and solidification index. Dots represent individual trap samples of the study area.

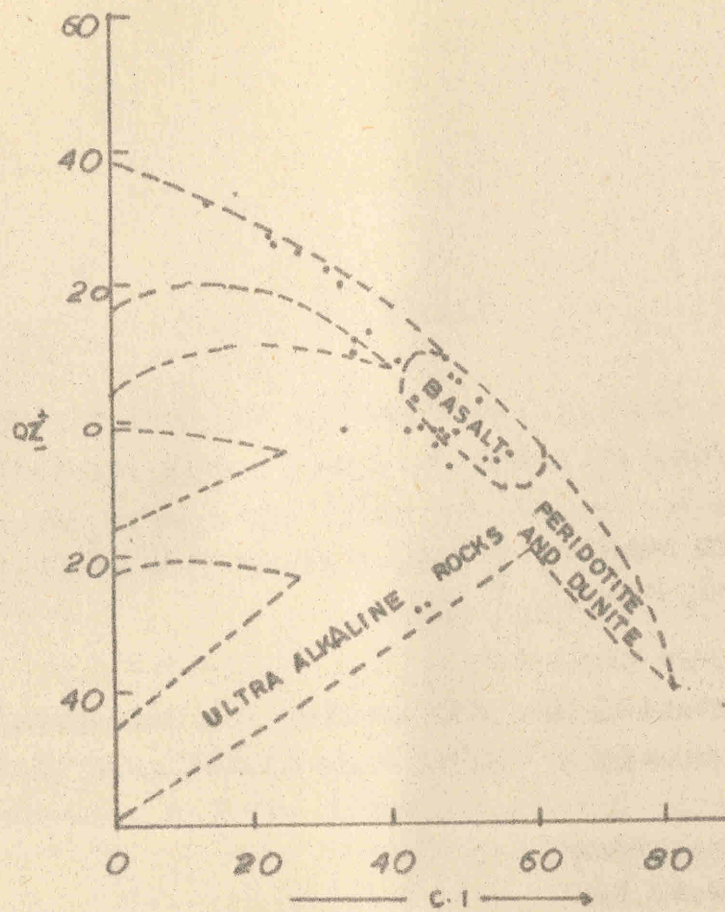


FIG-1

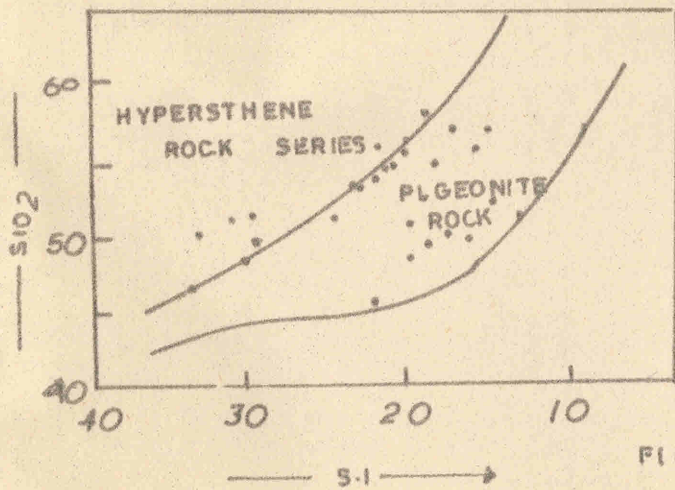


FIG-2

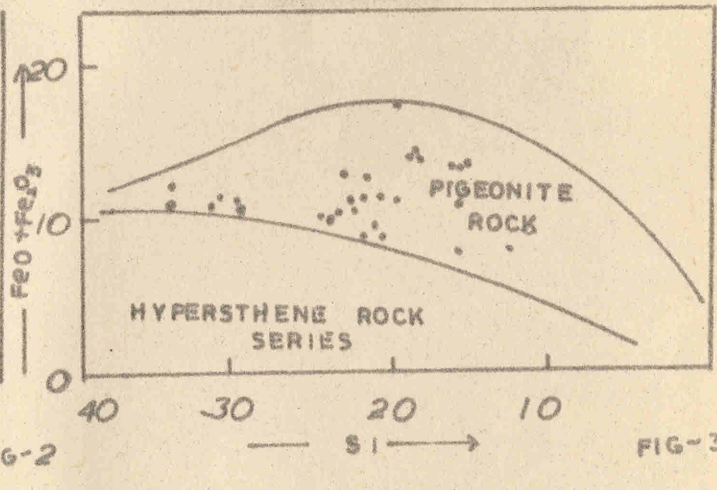


FIG-3

PLATE 23

**Fig.1** Bivariate diagram showing the relationship between  $Mg \times 100 / Mg + Fe$  (total) and L-linkage factor. Crosses in small circles represent traps of Bandipura. Different trend lines are also present in this figure.

**Fig.2.** Bivariate diagram showing the relationship between  $Mg \times 100 / Mg + Fe$  (total) and Linkage factor. Crosses in small circles represent traps of Bandipura.

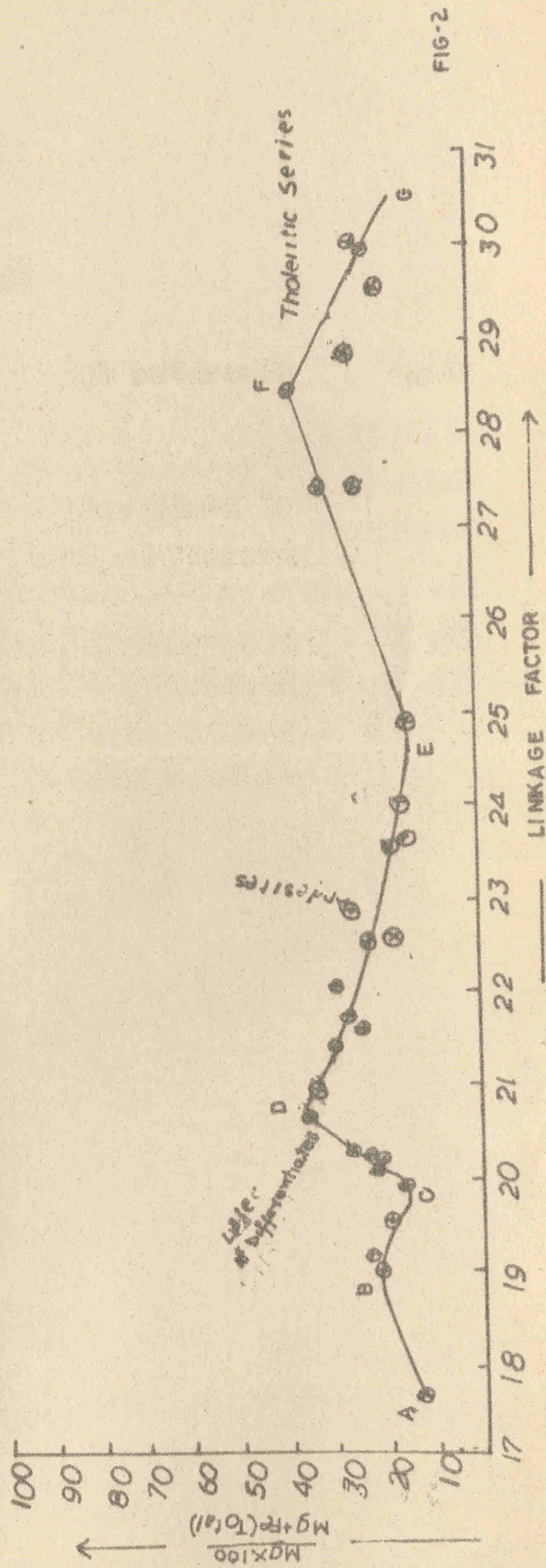
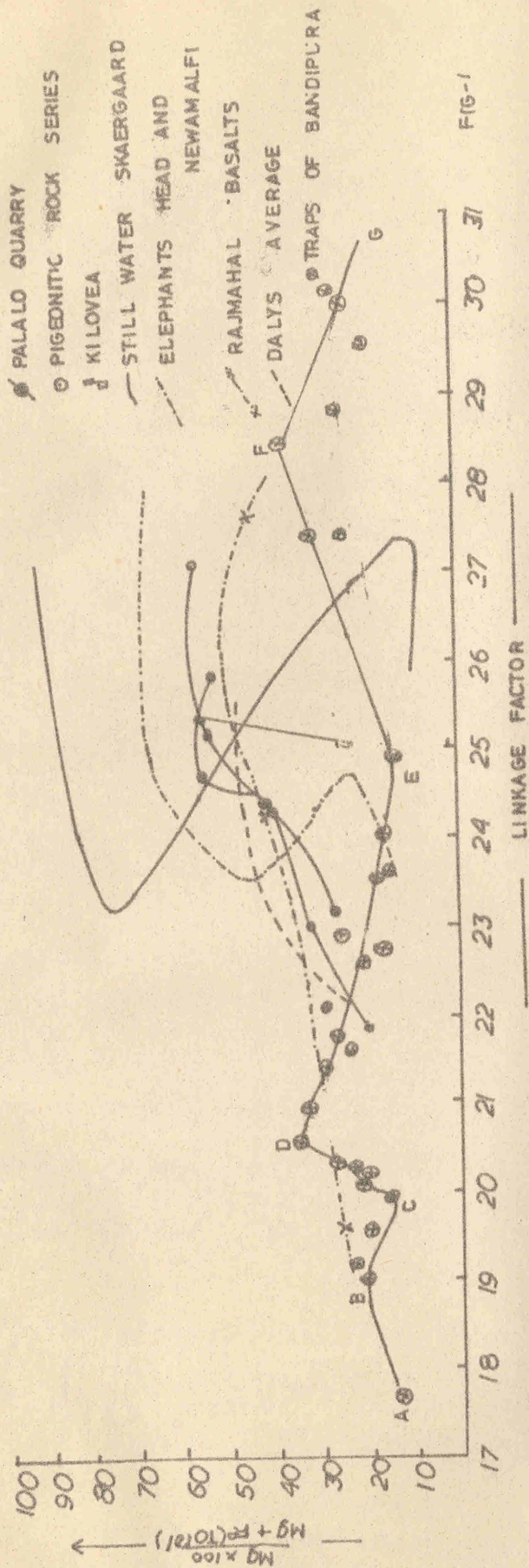
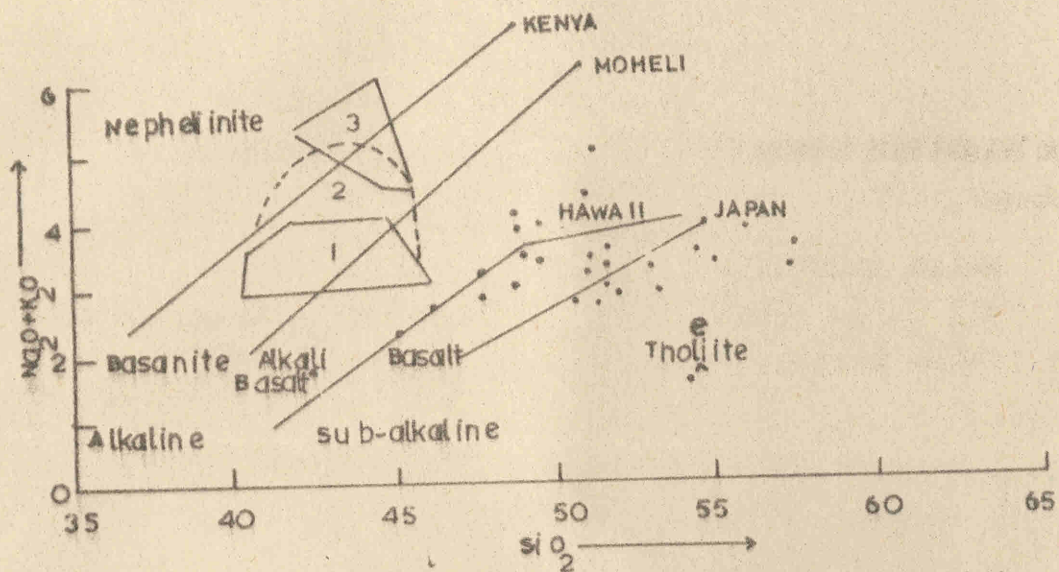


FIGURE- 24

Alkalis versus silica variation diagram with plots from the Skien Basaltic rocks for comparison with the traps of Bandipura.

- 1)- Skien Ankromite field
- 2)- All Skien Ankromite field including altered samples
- 3)- Skien Basanite field (After Weigand, 1975).

FIGURE - 24



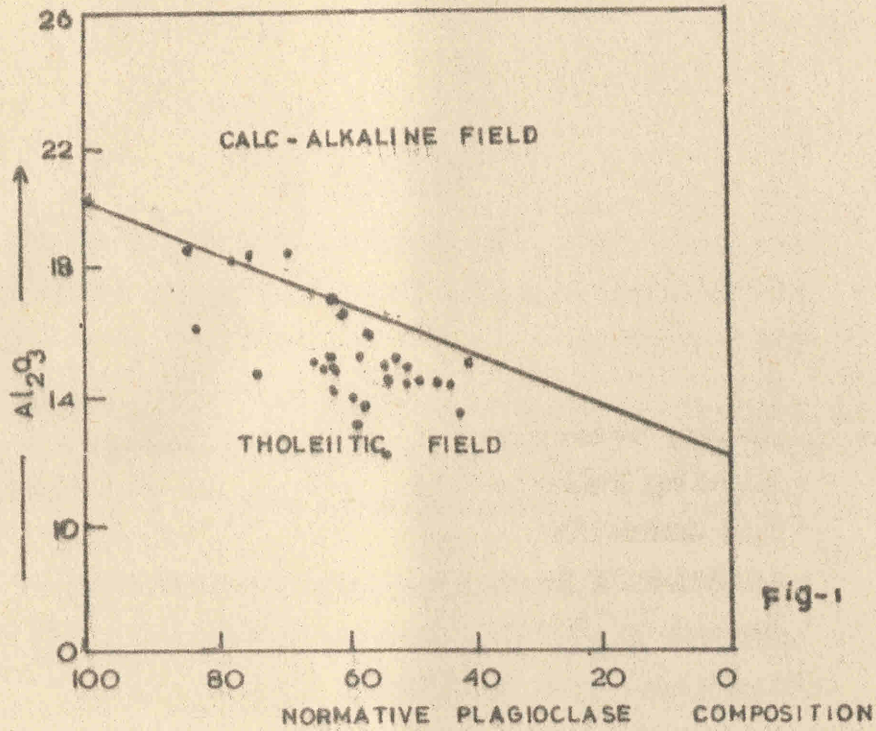
$SiO_2$  -  $Na_2O + K_2O$  variation diagram with plots from the skien basaltic rocks for comparison with the trap rocks of Bandipura

- 1 - skien ankaramite field
- 2 - All skien ankaramite field including altered samples
- 3 - skien basanite field (After Weigand, 1975)

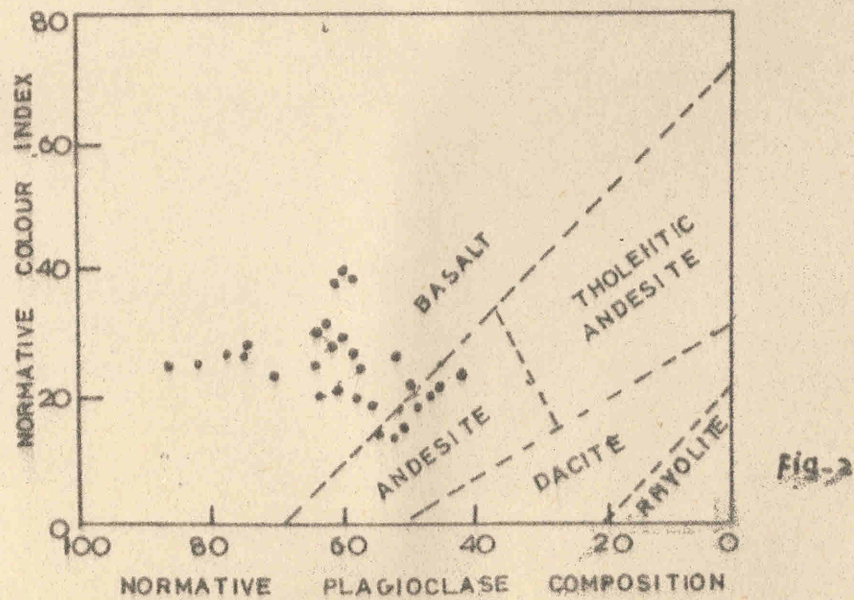
PLATE - 25

**Fig.1.** Binary variation diagram indicating two fields showing relationship between  $Al_2O_3$  weight percent and normative plagioclase composition. Dots indicate individual Bandipura trap samples (after Irvine and Baragar, 1971).

**Fig.2.** Binary variation diagram indicating different fields showing relationship between normative colour index and normative plagioclase composition. Dots indicate individual Bandipura trap samples (after Irvine and Baragar, 1971).



Plot of  $w\%Al_2O_3$  vs normative plagioclase composition for Trap Rocks of Bandipura (After Irvine and Baragar, 1971)



Plot of normative colour index vs normative plagioclase composition for Trap Rocks of Bandipura (After Irvine and Baragar, 1971)

PLATE - 26

- Fig.1. Bivariate diagram showing the relationship between alkalis and silica. Dots represent individual Bandipura trap samples.
- Fig.2. Bivariate diagram showing the relationship between alkalis and differentiation index. Dots represent individual Bandipura trap samples.
- Fig.3. Bivariate diagram showing the relationship between MgO and  $Al_2O_3/SiO_2$  ratio. Dots represent individual Bandipura trap samples.
- Fig.4. Bivariate diagram showing the relationship between felsic and mafic indices. Dots represent individual Bandipura trap samples.

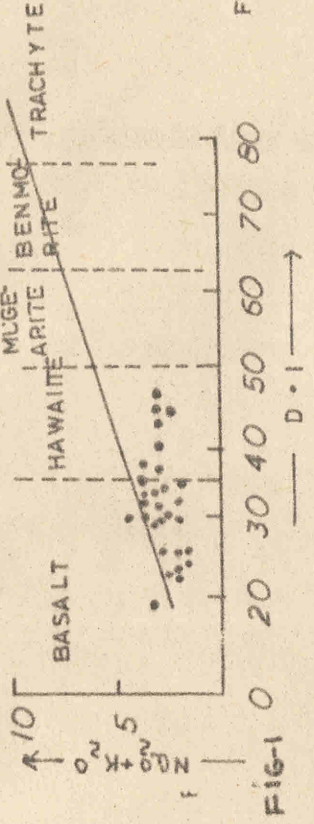
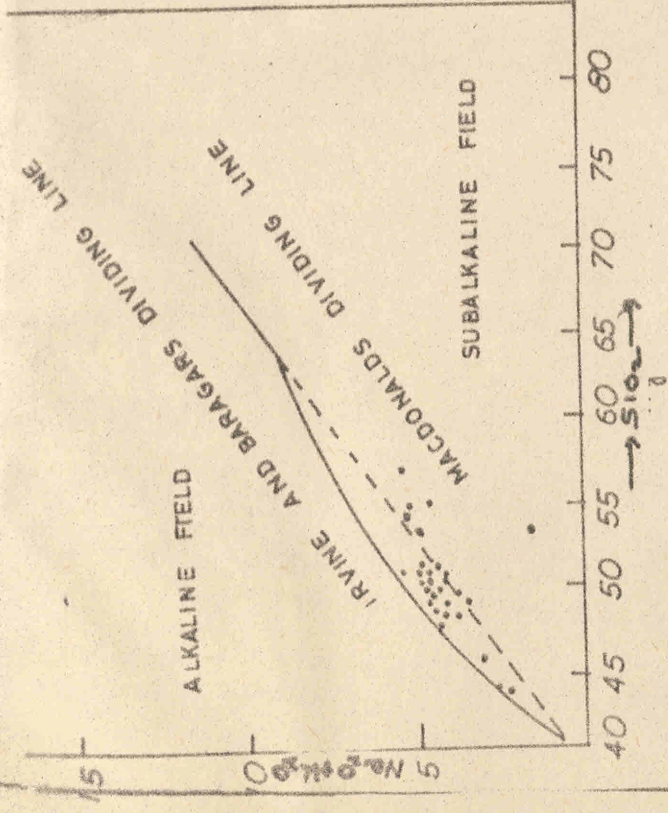


FIG-2

FIG-1

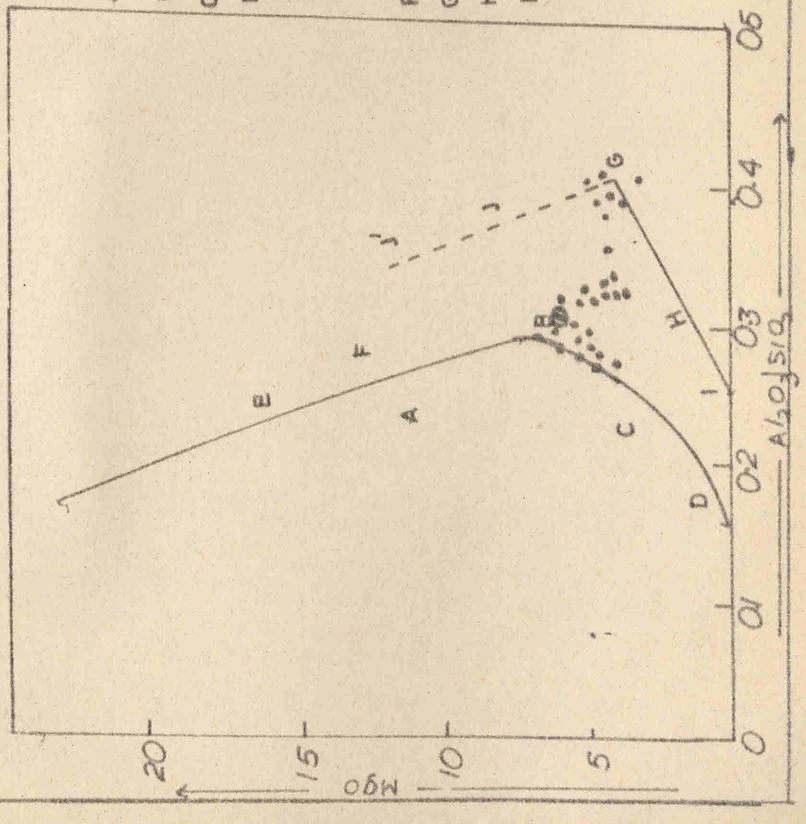
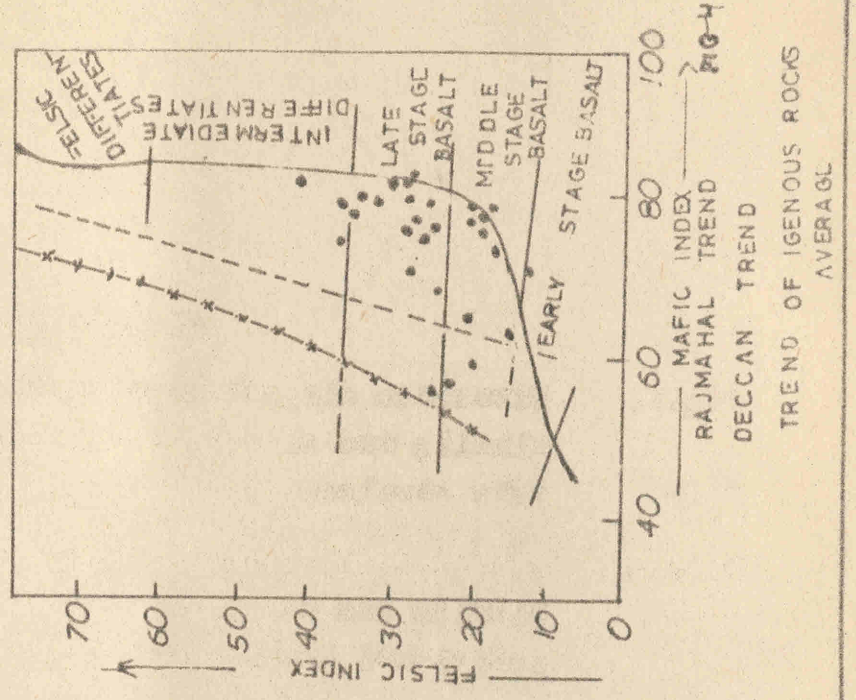


FIG-3



- THOLEIITIC BASALT SERIES
- A - THOLEIITIC OLIVINE BASALT
- B - THOLEIITE BASALT
- C - QUARTZ BASALT
- D - GRANOPHYRE
- E - PICRITE OCEANITE
- ALKALI BASALT SERIES
- F - ANKRANITE
- G - HAWAIIITE
- H - MUGEARITE
- I - TRACHYTE

MAFIC INDEX TREND  
 RAJMAHAL TREND  
 DECCAN TREND  
 TREND OF IGENOUS ROCKS AVERAGE

PLATE - 27

**Fig.A** Bivariate diagram showing the relationship between D.I. and normative  $A_n \times 100 / (A_b + A_n)$ . Different fields and trend lines are indicated in this figure. Dots represent individual trap samples of the study area.

**Fig.B.** Bivariate diagram showing the relationship between D.I. and the normative  $A_n \times 100 / (A_b + A_n)$ . Trend line for the traps of the study area is indicated in this figure.

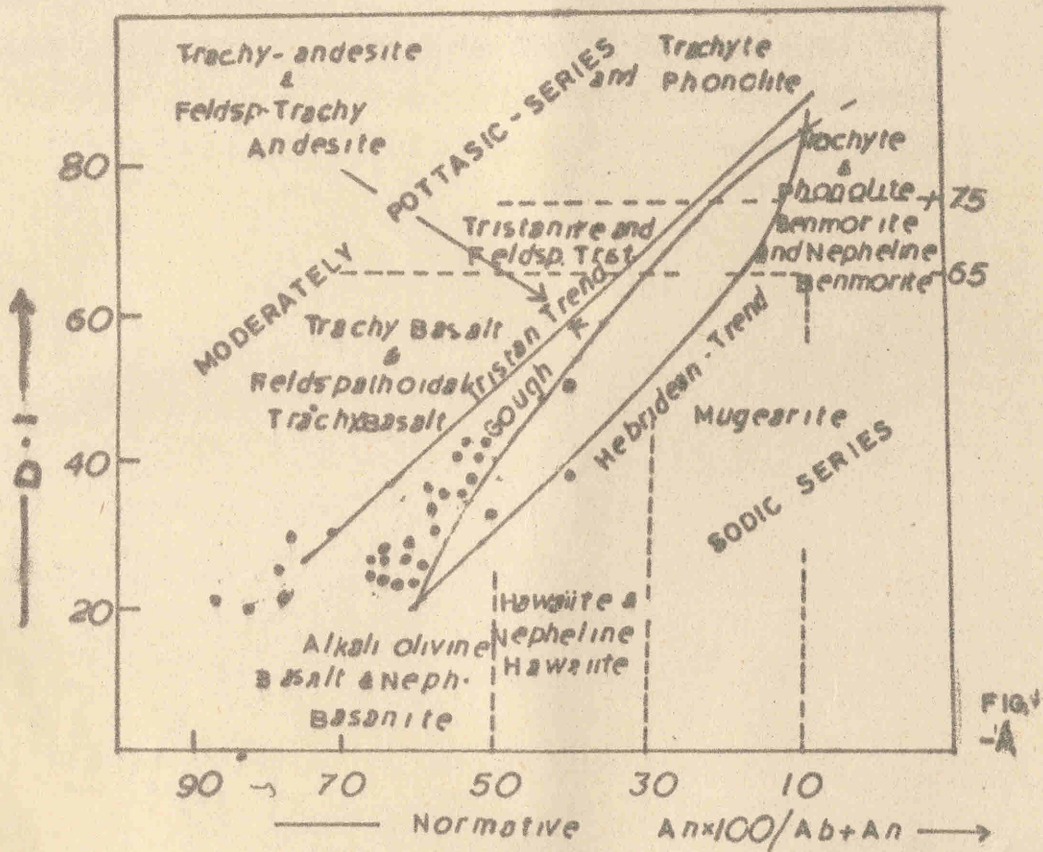
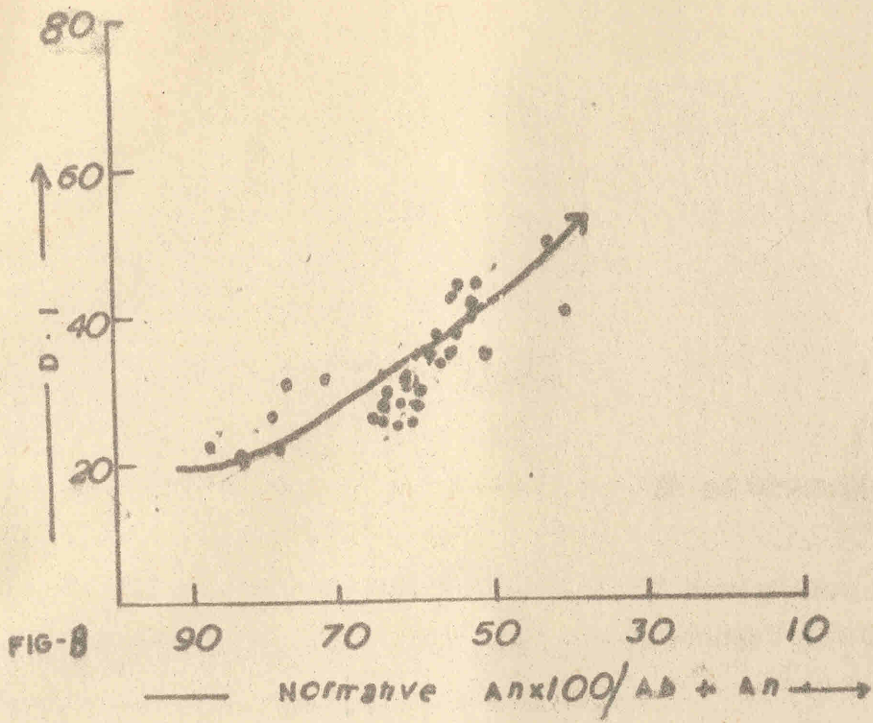


PLATE - 28

Figs 1 to 9.

Mekie (1966) variation diagrams showing the relationship of several molecules with respect to si molecule. Dots represent individual trap samples of the study area.

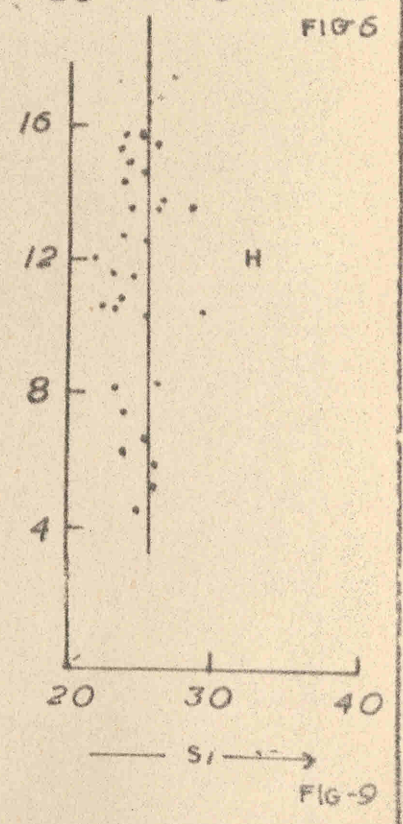
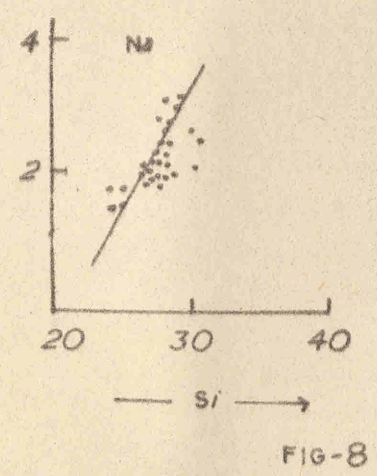
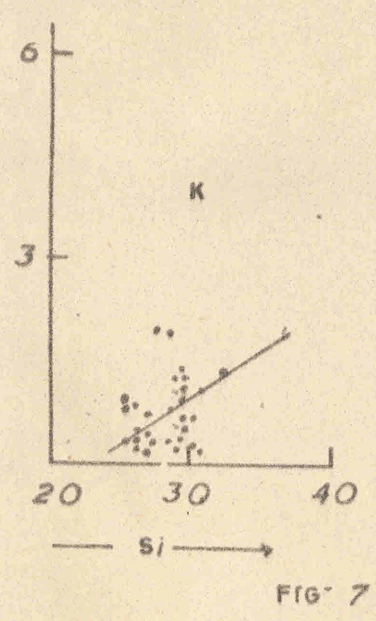
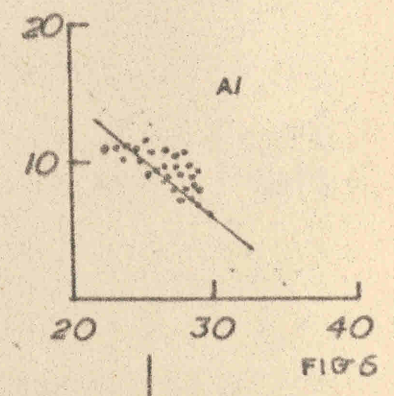
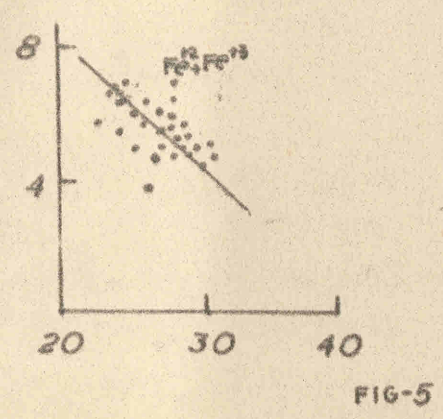
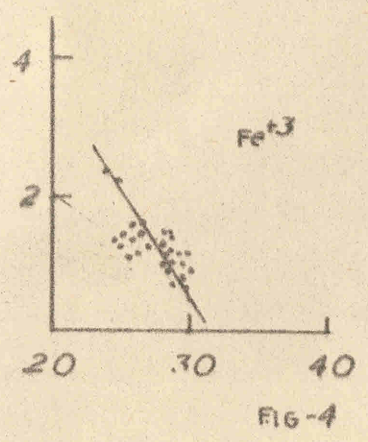
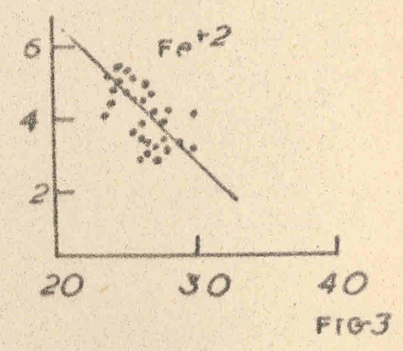
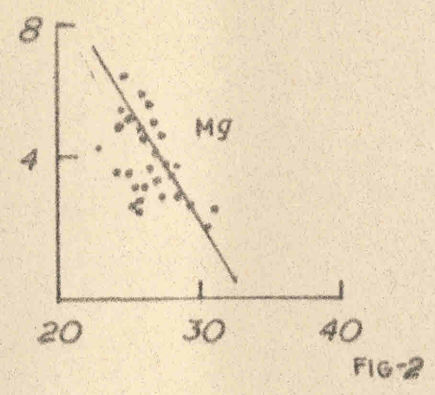
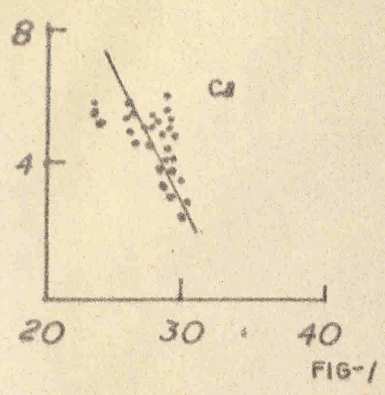


PLATE • 29

**Figs 1 to 5.**

Binary variation diagrams showing the relationship of several oxides with respect to MgO. Dots indicate the trap samples of Bandipura area.

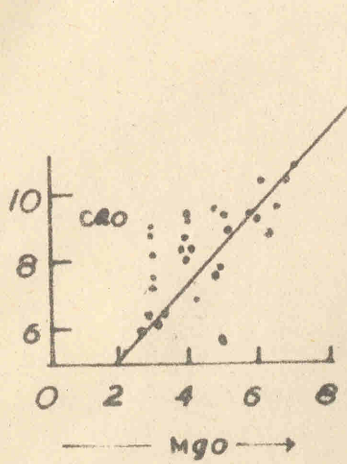


FIG-1

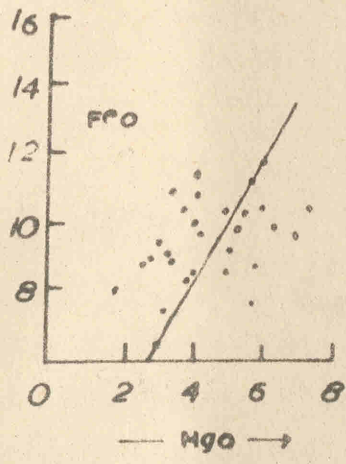


FIG-2

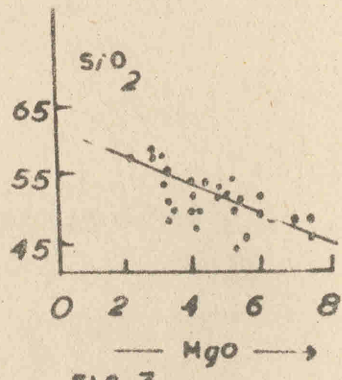


FIG-3

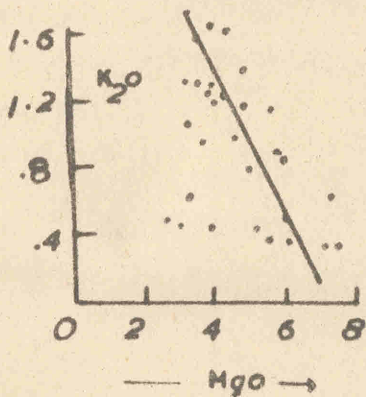


FIG-4

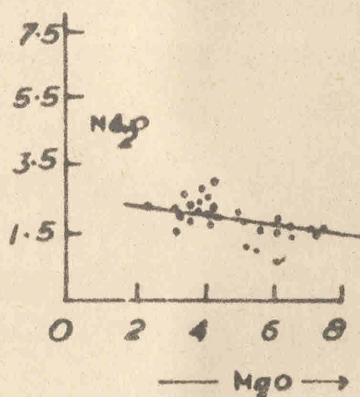
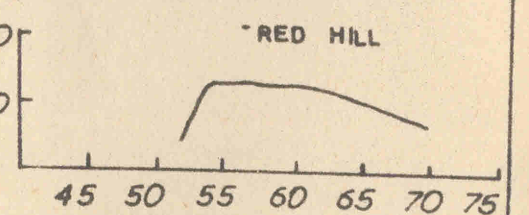
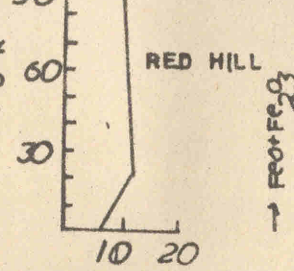
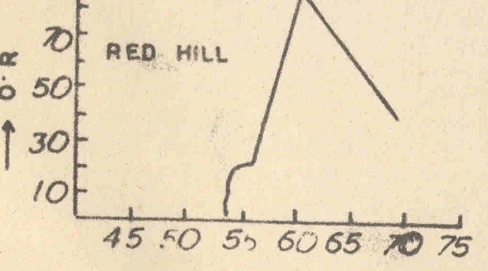
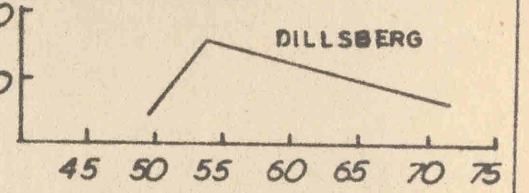
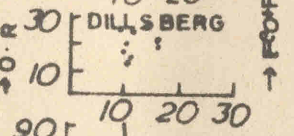
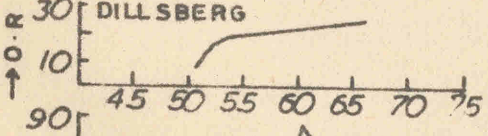
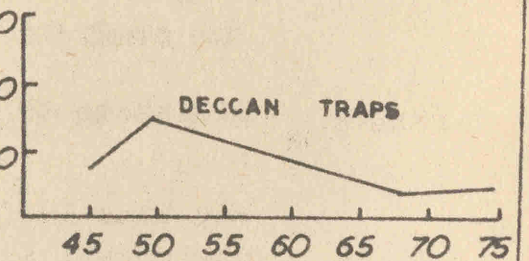
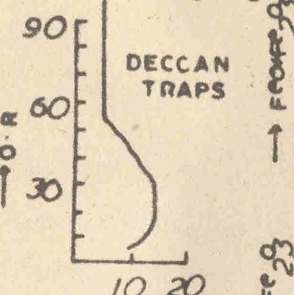
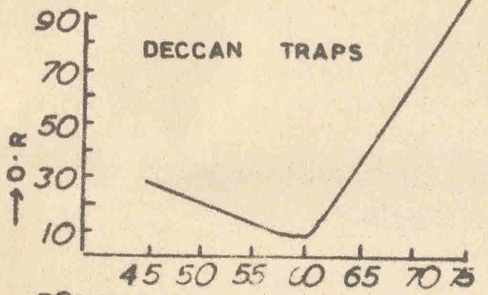
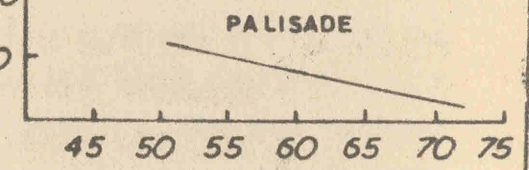
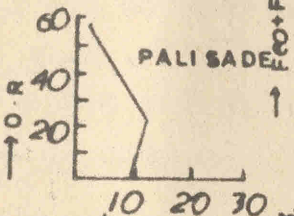
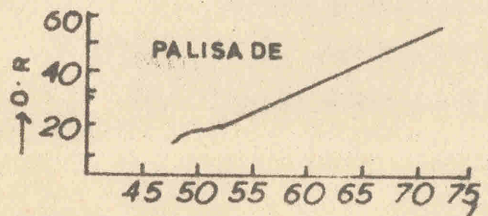
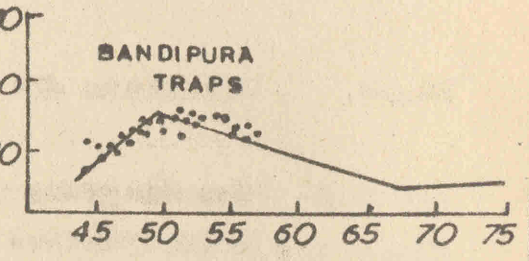
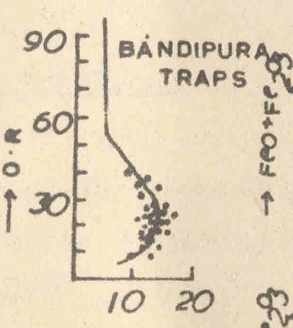
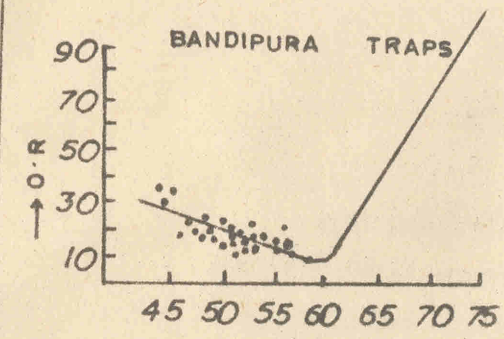


FIG-5

PLATE 30

- Fig. a.** Bivariate diagrams showing the relationship between oxidation ratio and silica. In all the diagrams different trend lines are seen. Dots indicate individual samples of the study area.
- Fig. b.** Bivariate diagrams showing the relationship between oxidation ratio and total iron. Different trend lines are seen in different diagrams. Dots indicate individual samples of the study area.
- Fig. c.** Bivariate diagram showing the relationship between total iron and silica. Different trends are seen in different diagrams. Dots represent individual samples of the study area.



SiO<sub>2</sub> →  
FIG-a

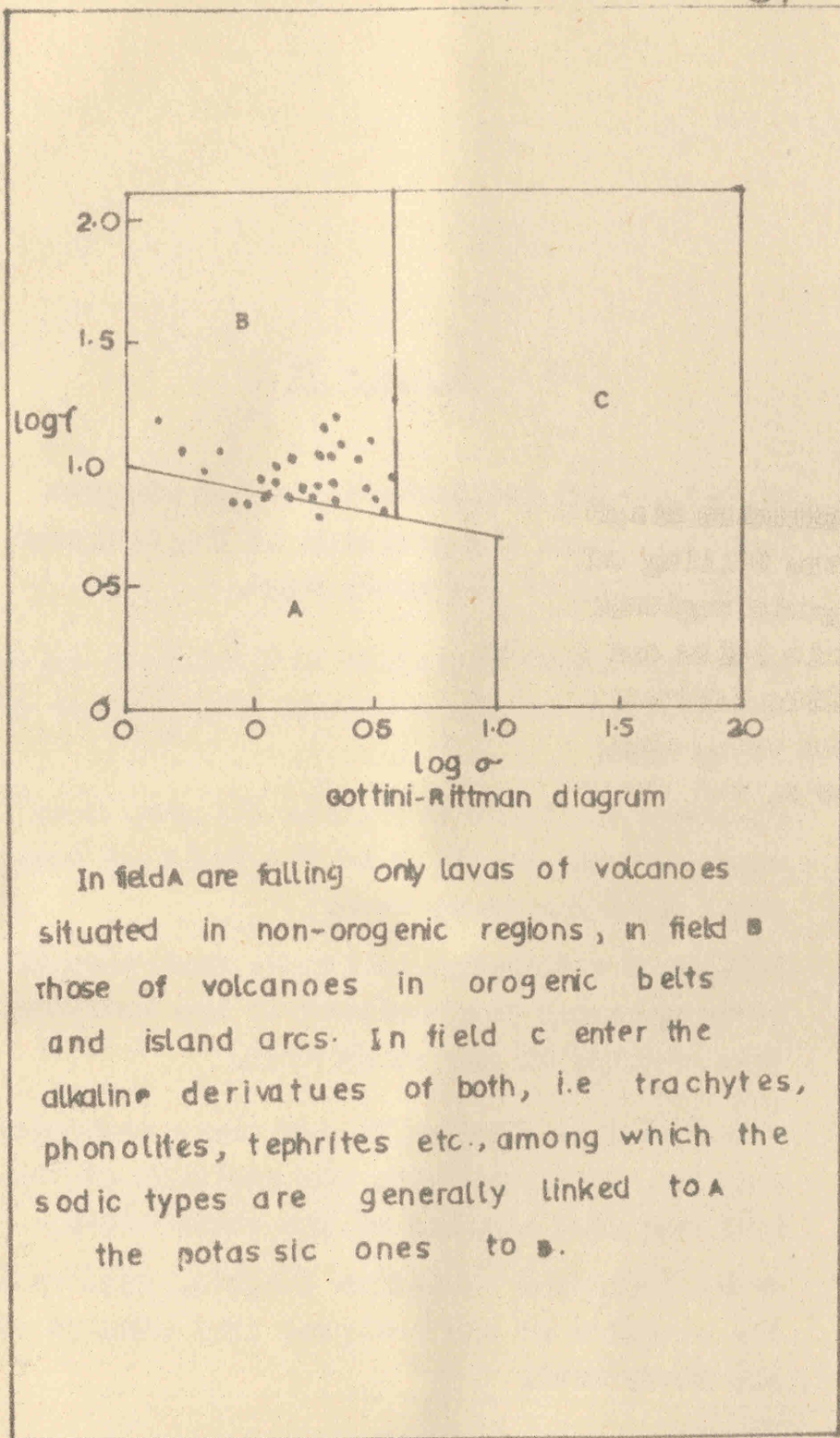
FeO + Fe<sub>2</sub>O<sub>3</sub> →  
FIG-b

SiO<sub>2</sub> →  
FIG-c

FIGURE - 31.

Gottini-Rittmann diagram showing three fields. In Field A are falling only lavas of volcanoes situated in non-orogenic regions; in field B, those of volcanoes in orogenic belts and island arcs and in field C enter the alkaline derivatives of both, i.e. trachytes, phonolites, tephrites etc., among which the sodic types are generally linked to A, and the potassic ones to B.

FIGURE -3|



In field A are falling only lavas of volcanoes situated in non-orogenic regions, in field B those of volcanoes in orogenic belts and island arcs. In field C enter the alkaline derivatives of both, i.e. trachytes, phonolites, tephrites etc., among which the sodic types are generally linked to A the potassic ones to B.

PLATE - 32

- Fig.1.  $\text{Na}_2\text{O}-\text{K}_2\text{O}-\text{CaO}$  trilinear variation diagram. Dots represent the position of the analysed trap samples of the study area.
- Fig.2. A-N-C trilinear variation diagram. Dots represent the position of the analysed trap samples of the study area.
- Fig.3. Or-Ab-An trilinear variation diagram. Dots represent the position of the analysed trap samples of the study area.
- Fig.4.  $\text{FeO}-(\text{Na}_2\text{O} + \text{K}_2\text{O})-\text{MgO}$  trilinear variation diagram. Dots represent the position of the analysed trap samples of the study area.
- Fig.5.  $\text{alk}-(100-\text{al})-2(\text{al}-\text{alk})$  trilinear variation diagram. Dots represent the position of the analysed trap samples of the study area.
- Fig.6. F-M-A trilinear variation diagram. Dots represent the position of the analysed trap samples of the study area.

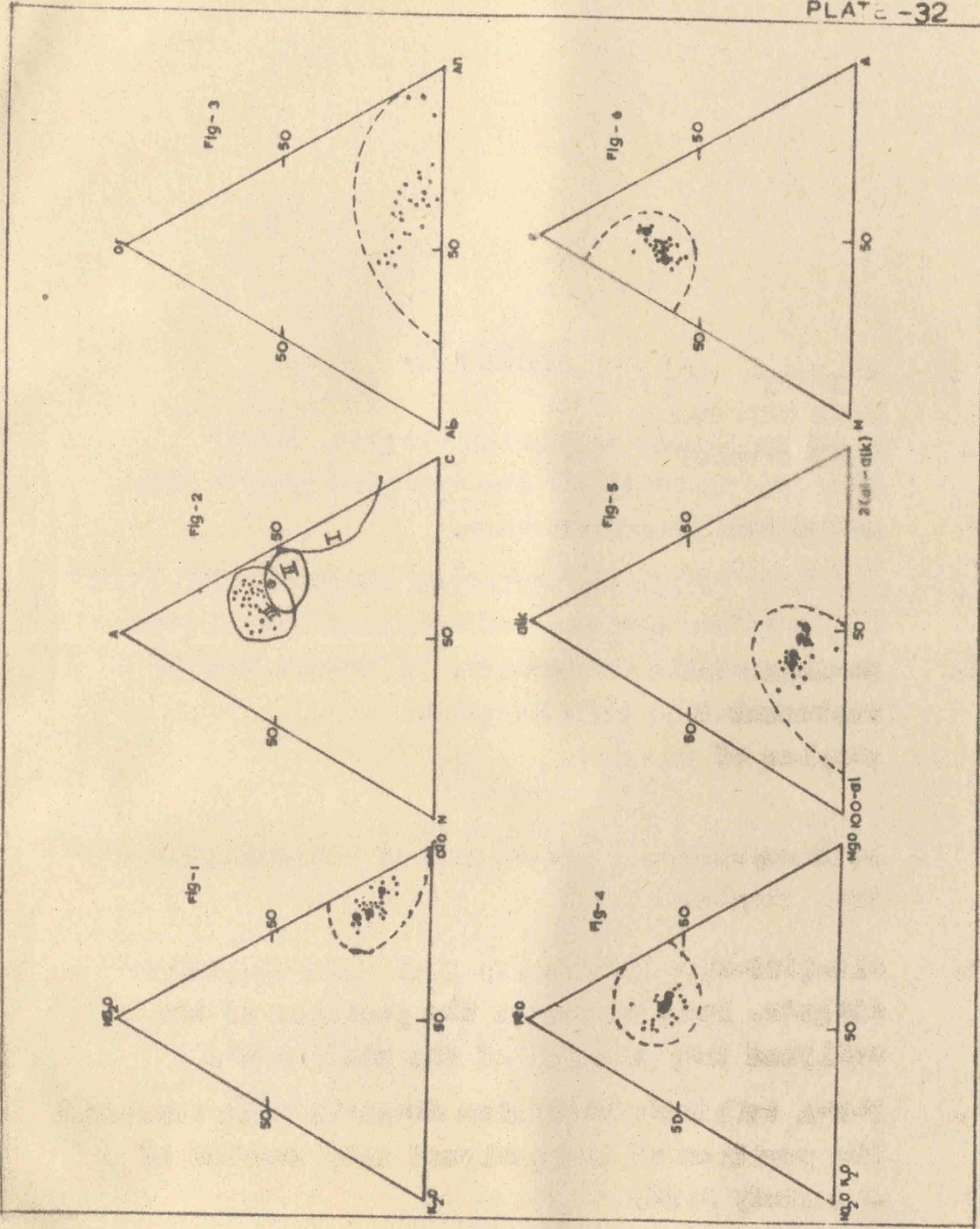


PLATE -33.

**Fig.1.** A-C-F trilinear variation diagram. Dots show the position of the analysed panjal trap samples of Bandipura area.

**Fig.2.** An-Ab-Or trilinear variation diagram. Dots indicate the position of analysed Panjal trap samples of the study area. Different fields are present in this diagram.

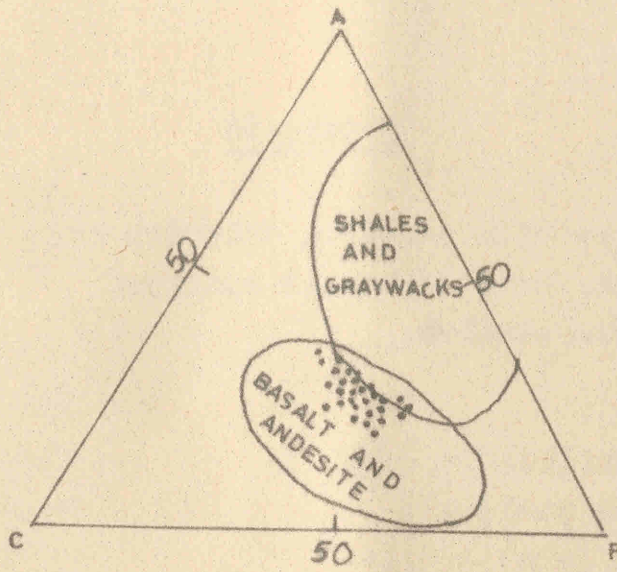


FIG-1

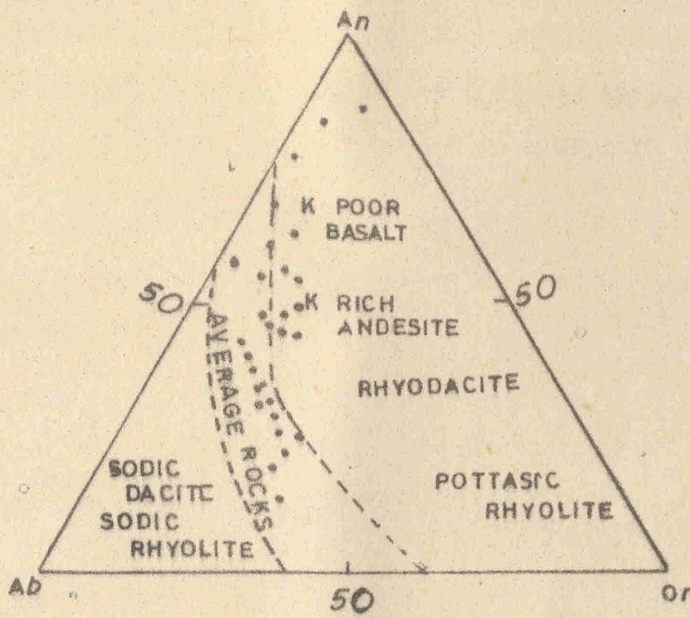


FIG-2

FIGURE-34

A trilinear diagram with calcite, dolomite and Insoluble residues. Dots represent analysed Bandipura limestone samples.

FIGURE -34

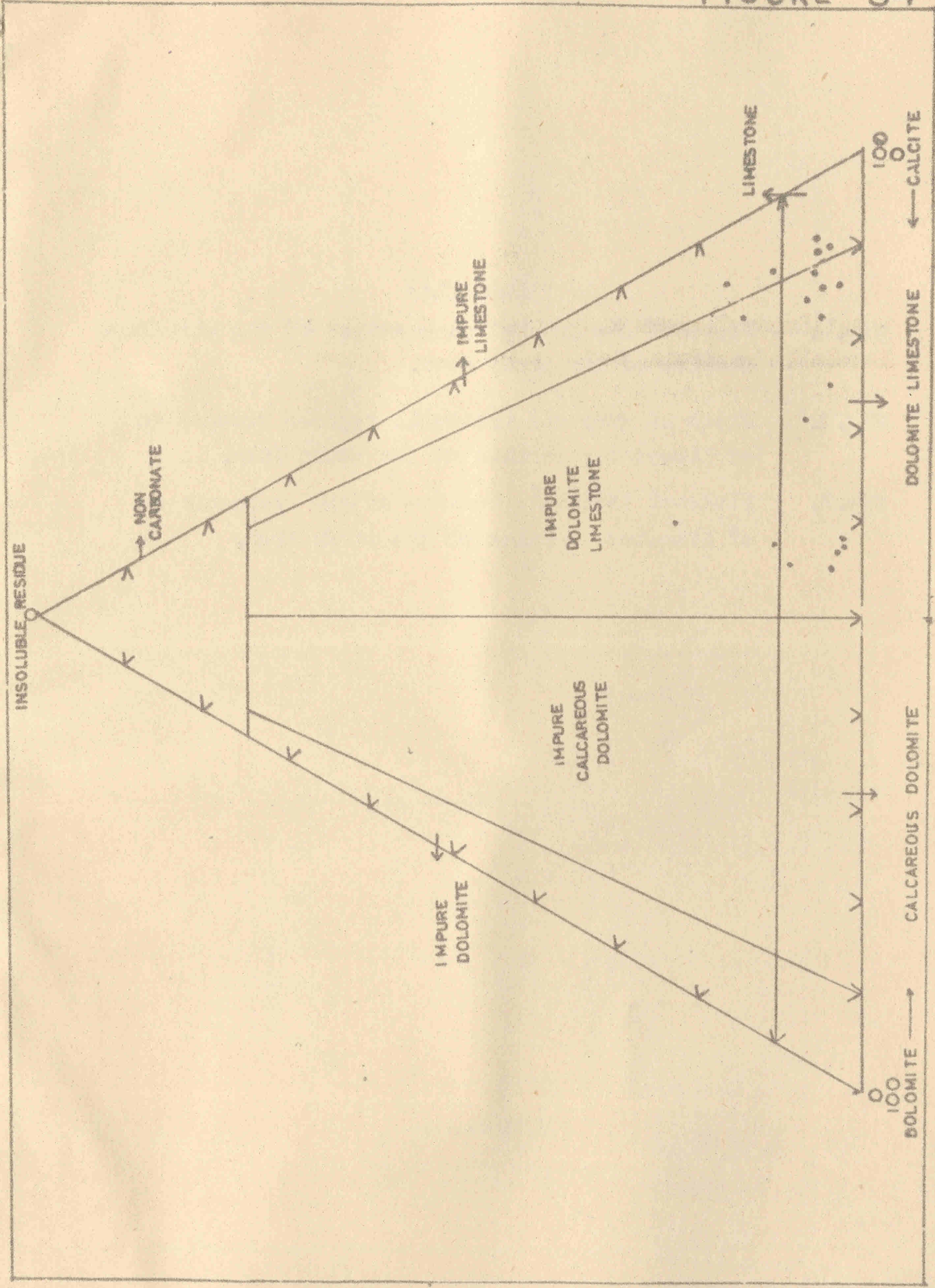


PLATE -35

- Fig.1. Plots of clay and MgO percentages of the limestone samples of the study area<sup>a</sup>.
- Fig.2. Plots of clay and insoluble residue percentage of limestones samples of the study area<sup>a</sup>.
- Fig.3. Plots of insoluble residue<sup>a</sup> and MgO percentages of limestone samples of the study area<sup>a</sup>.

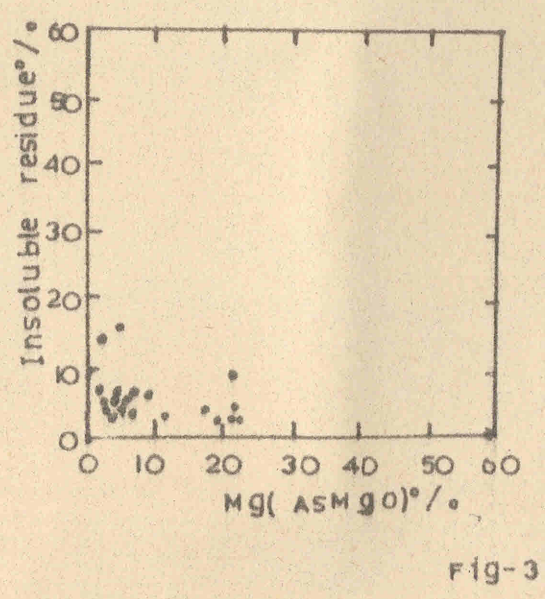
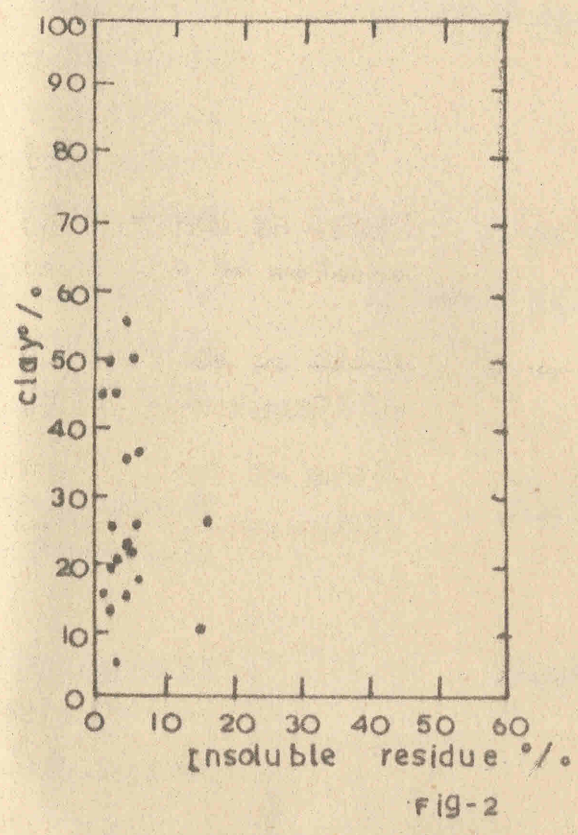
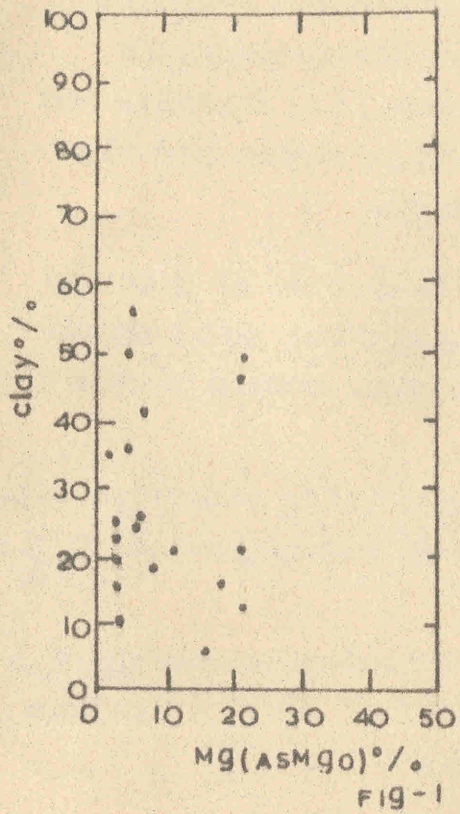


PLATE -36

Figs 1 and 2.

Microphotographs of laminated dolomite lime-mudstone without bioclasts. Light layers are cryptocrystalline dolomite and white specks of dolomite rhombs are also seen. Cross<sup>ed</sup> nicols x 45.

Figs 3 and 5.

Microphotographs of wackstone of filamentous bivalve micrite showing small undulatory veins and stylolites. crossed nicols x 45.

Fig.4.

Microphotograph of encrinite packstone, biosparite showing crinoidal stems. Crossed nicols x 45.

Fig.6.

Microphotograph of dolomicrite showing a straight line composed of small dolomitic rhombs. crossed nicols x 45.

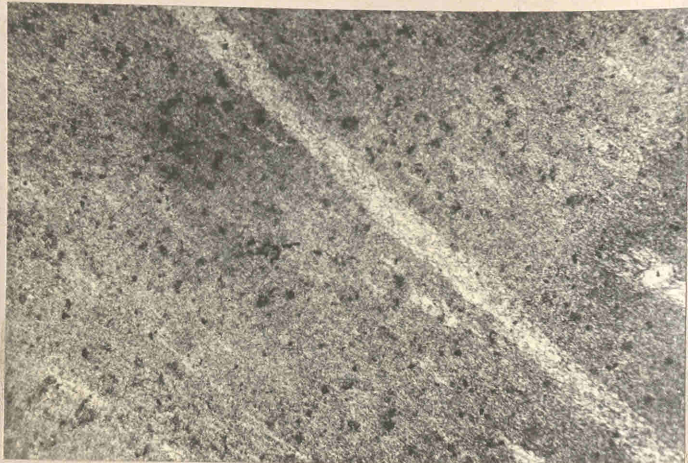


Fig : 1

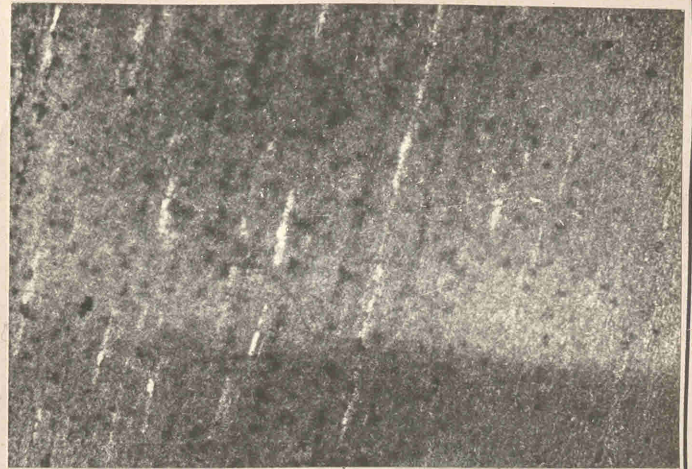


Fig : 2

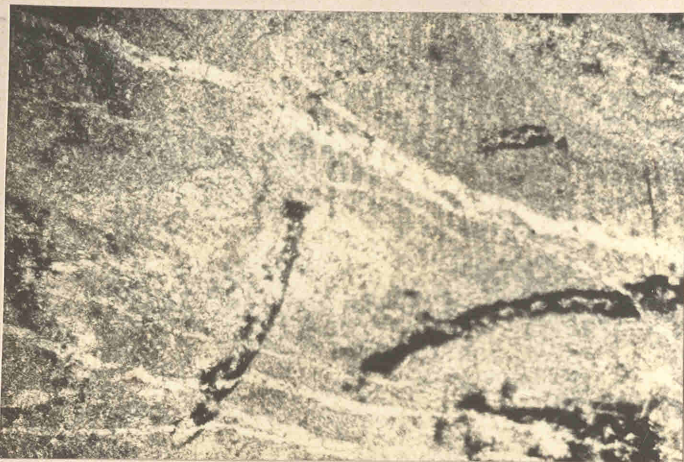


Fig : 3



Fig : 4



Fig : 5

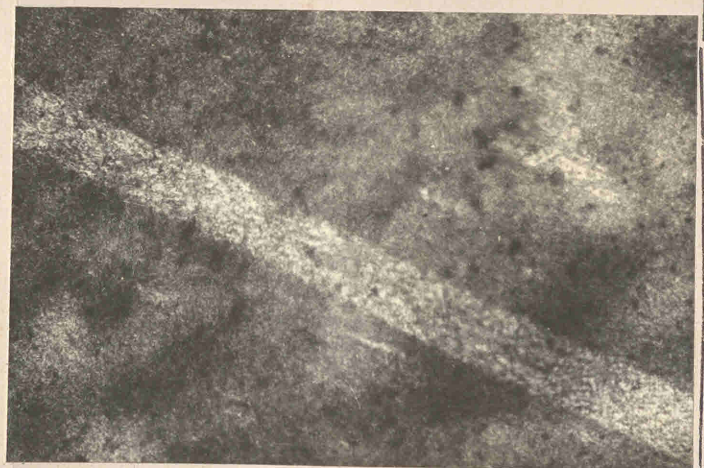


Fig : 6

PLATE 37

Figs 1 and 2.

Microphotographs of biosparite with crinoid stems showing the central part filled with sparry calcite. Crossed nicols x45.

Fig. 3.

Microphotograph of biosparite with large sections of a plate of crinoid showing large hole filled with calcite in the centre. The material is bedded in sparry calcite. crossed nicols x 45.

Figs. 4 and 6.

Microphotograph of encrinite crinoidal wackstone having sparry calcite cement with coated grains. crossed nicols x 45.

Fig. 5.

Microphotograph of biosparite limestone showing perforated crinoidal stems along with interclast material. crossed nicols x45.

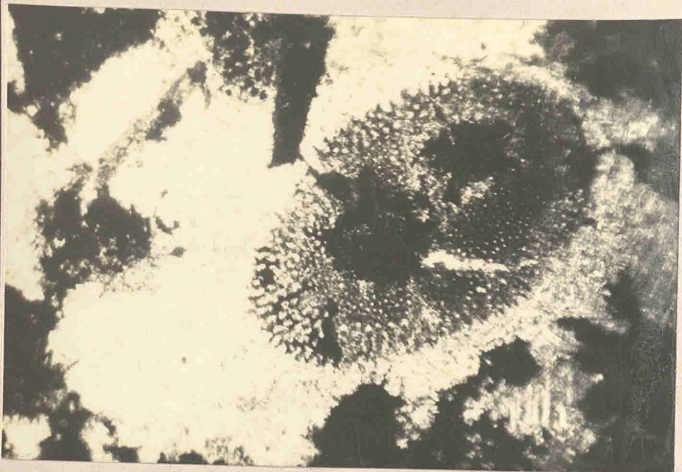


Fig : 1

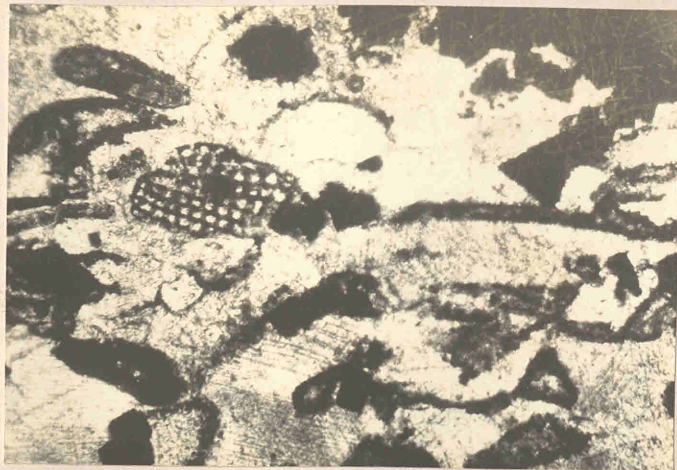


Fig : 2

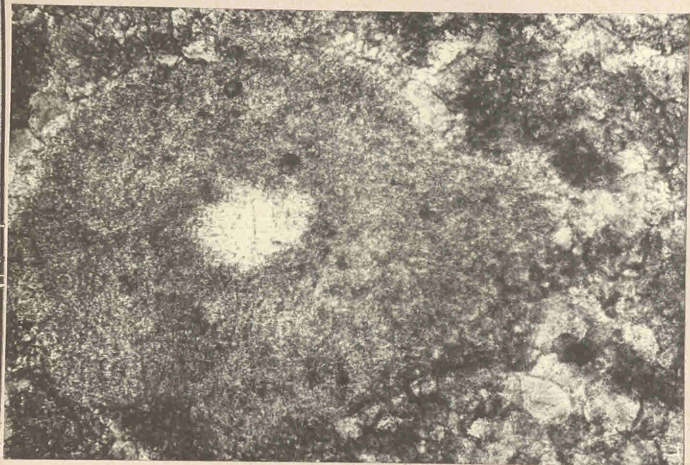


Fig : 3

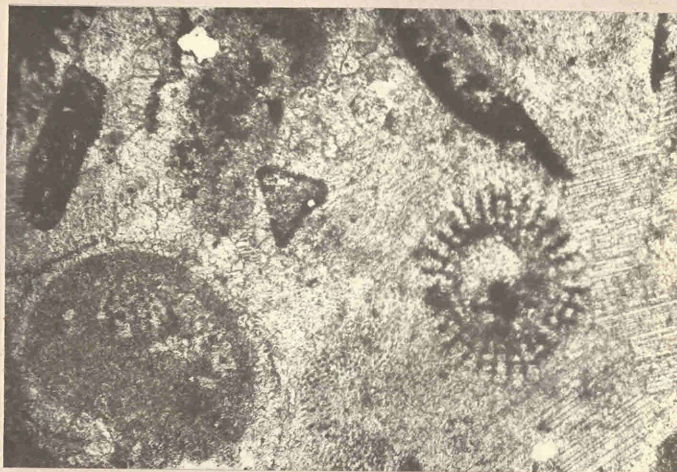


Fig : 4

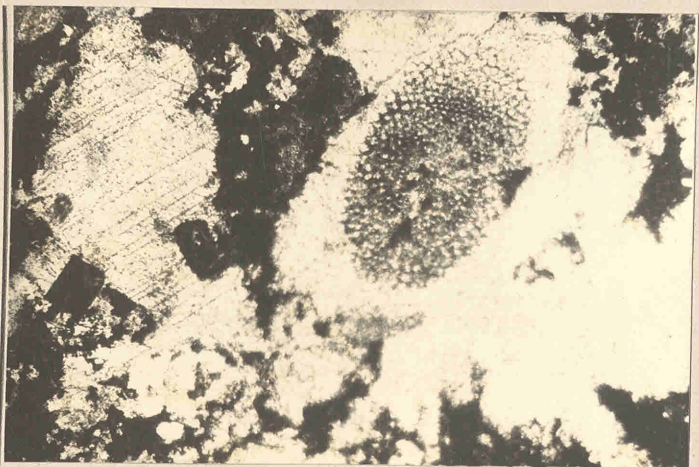


Fig : 5

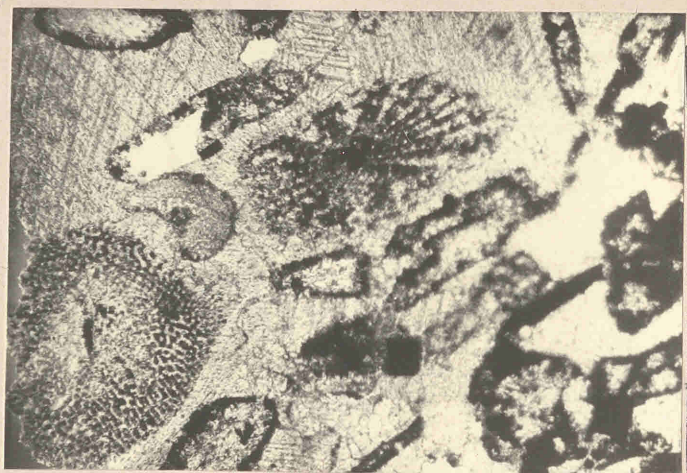


Fig : 6

PLATE -38

Figs 1 to 6.

Microphotographs of typical calcarenites  
having lot of silty material intermixed  
with fossil debris. Crossed nicols x 45.

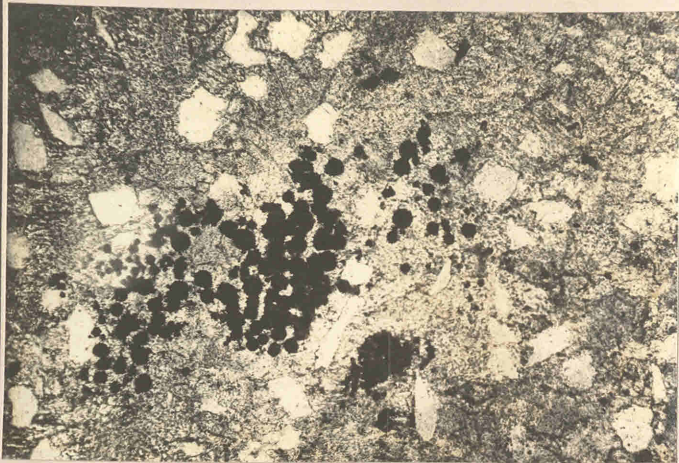


Fig: 1

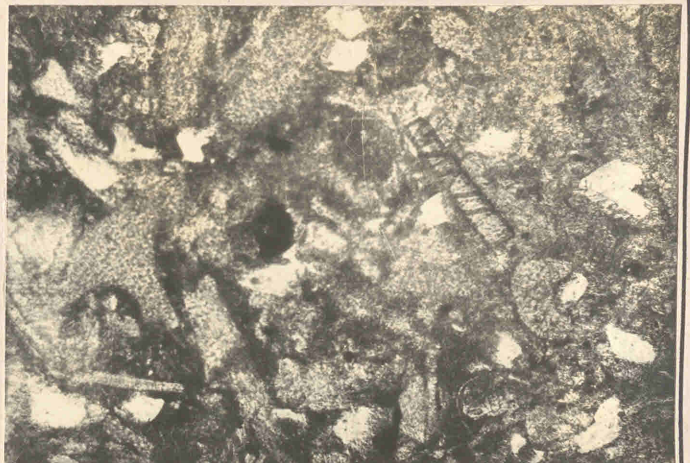


Fig: 2

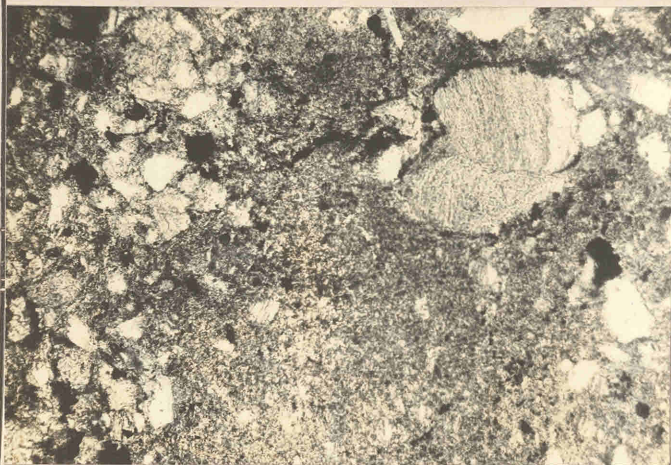


Fig: 3

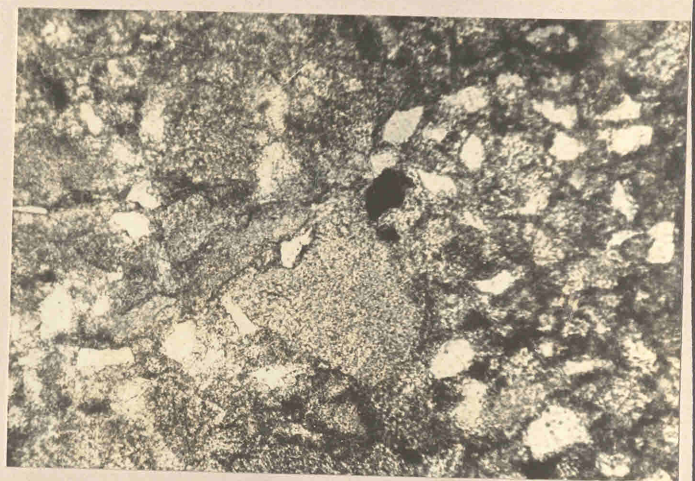


Fig: 4



Fig: 5



Fig: 6

PLATE -39

- Figs 1 and 2.** Microphotographs of dolosparite showing the hypidiotopic texture. crossed nicols x 45.
- Figs 3 and 4.** Microphotograph showing dolostone with undolomitized micritic material in the centre. Crossed nicols x 45.
- Figs 5 and 6.** Microphotographs of bi dolomicrite , probably the longitudinal crinoidal stems are seen in the centre. Crossed nicols x 45.

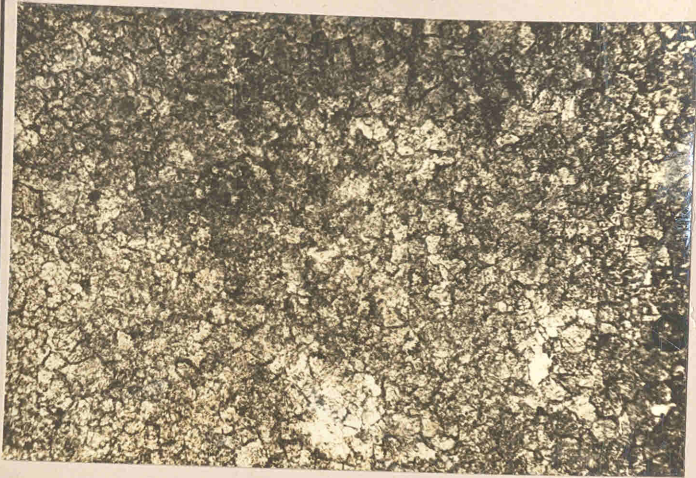


Fig : 1

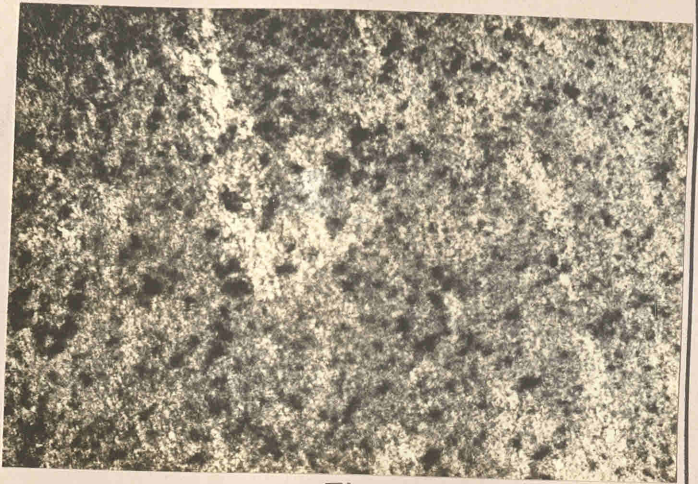


Fig : 2

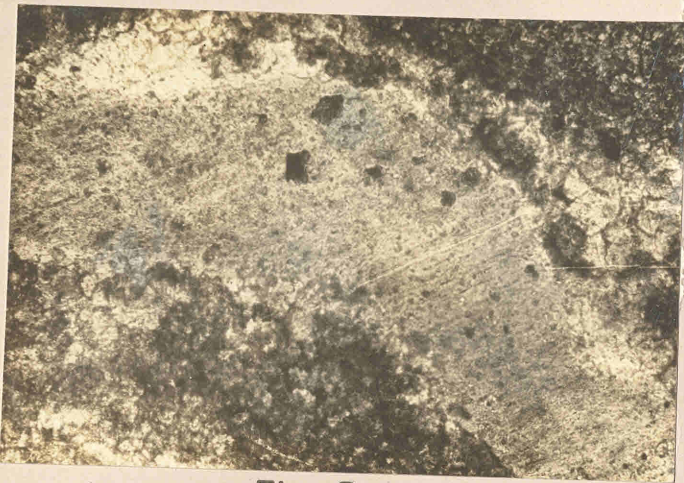


Fig : 3

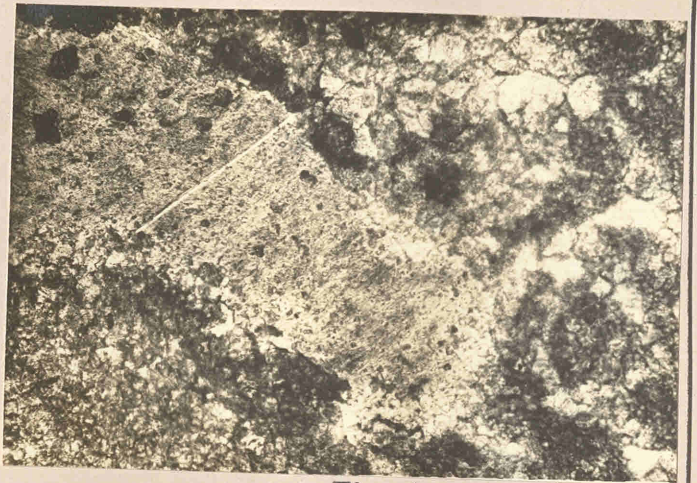


Fig : 4

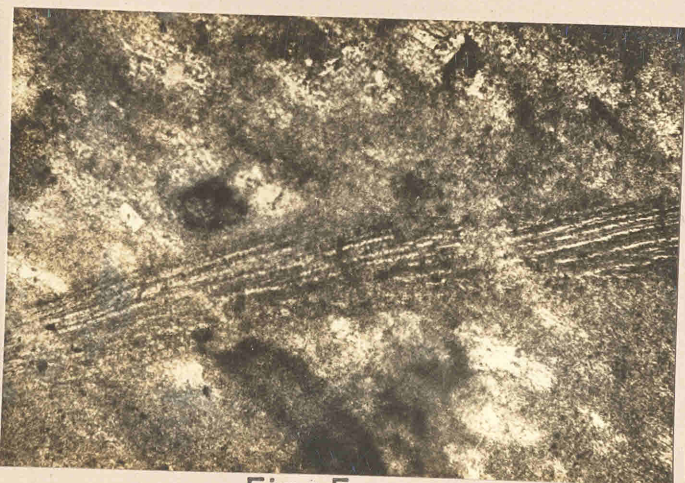
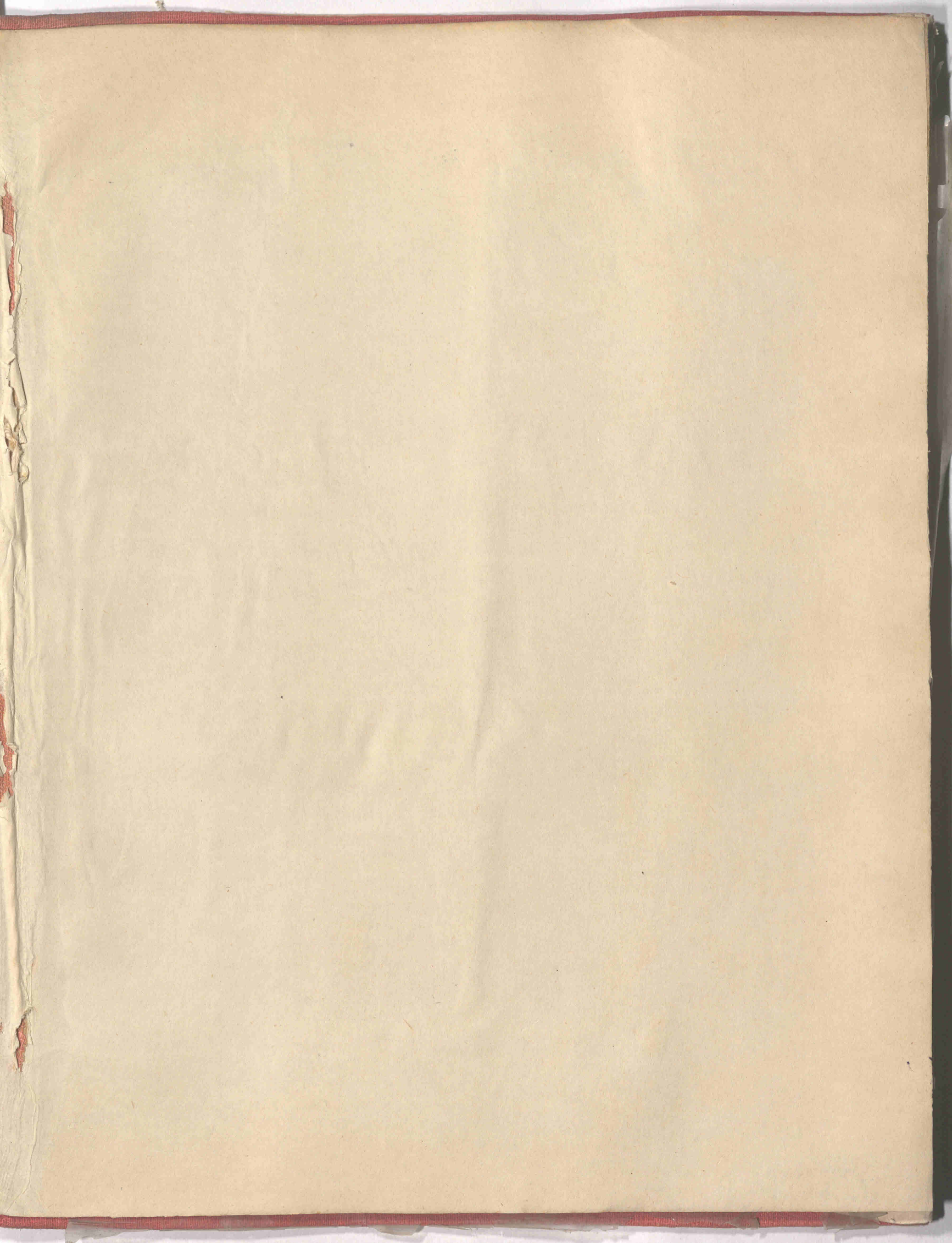


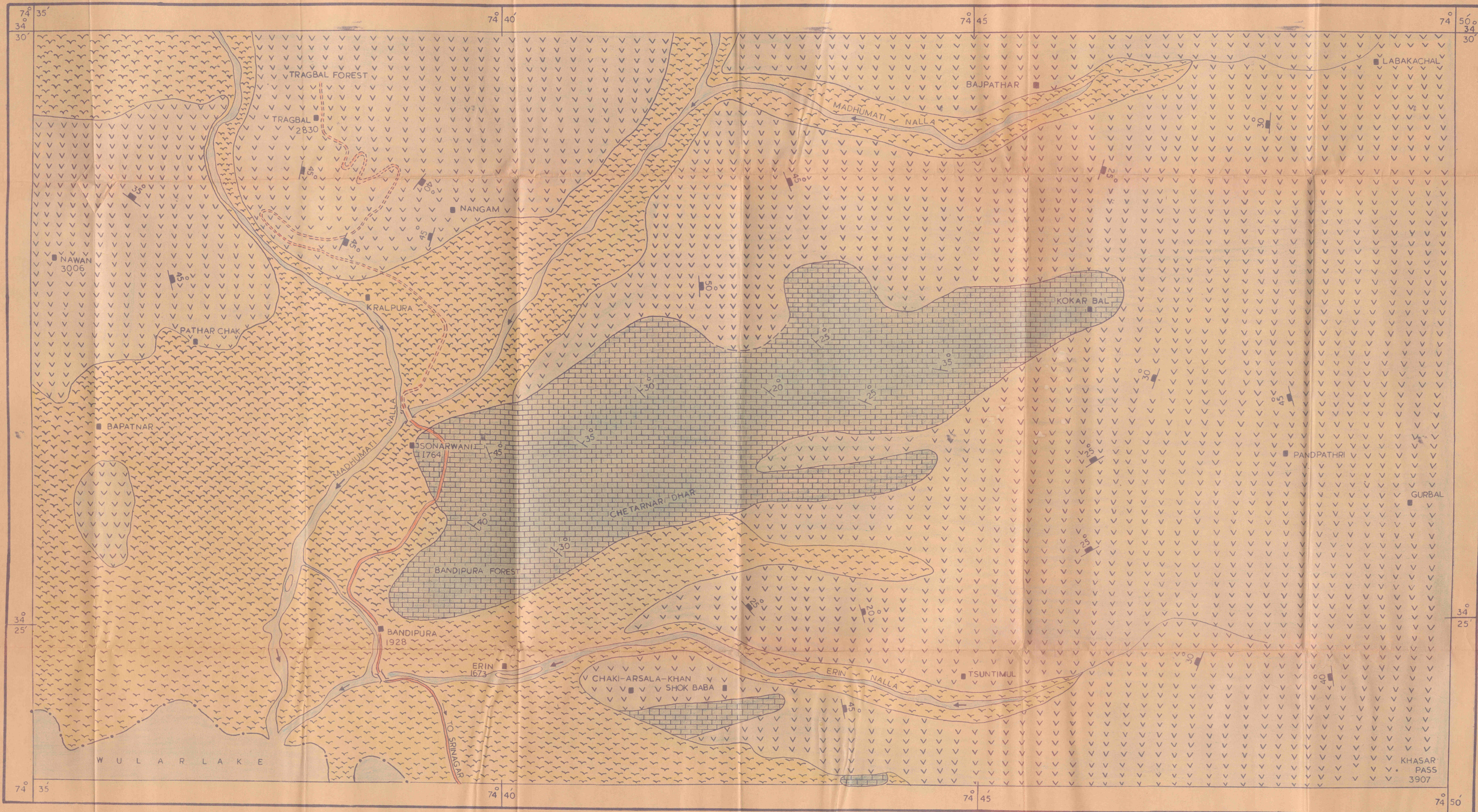
Fig : 5



Fig : 6



# GEOLOGICAL MAP OF BANDIPURA & ADJOINING AREAS, BARAMULLA DISTRICT, JAMMU & KASHMIR STATE



LEGEND		
	RECENT & SUBRECENT	
	TRIASSIC LIMESTONE	
	PANJAL TRAPS	

MAPPED BY  
A. K. RAINA

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FIGURE - 40

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