PETROLOGICAL AND PETROCHEMICAL STUDY OF PANJAL VOLCANICS AROUND BANIHAL AREA, KASHMIR HIMALAYA

THESIS SUBMITTED FOR THE AWARD OF DEGREE OF DOCTOR OF PHILOSOPHY,
FACULTY OF SCIENCE, UNIVERSITY OF JAMMU

(A VIEW OF BANIHAL VALLEY)

RAMAN KUMAR SHARMA

POST GRADUATE DEPTT. OF GEOLOGY
UNIVERSITY OF JAMMU,
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GEOLOGY- JAMMU AND KASHMIR

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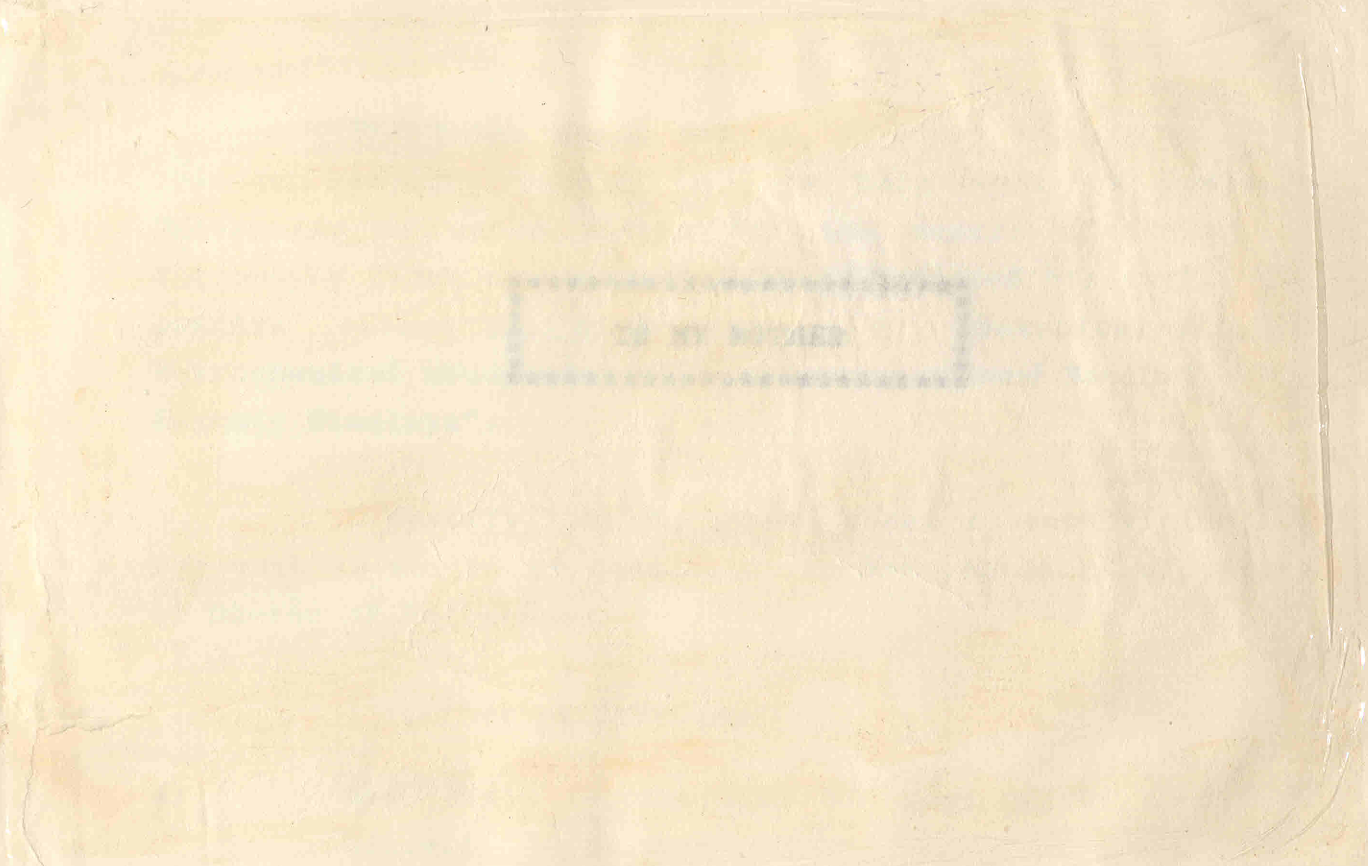

(A VIEW OF THE OLD TUNNEL)

RAMAN KUMAR SHARMA

POST GRADUATE DEPTT. OF GEOLOGY
UNIVERSITY OF JAMMU,
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1989

TO MY MOTHER

GEOLOGY - JAMMU AND KASHMIR

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C E R T I F I C A T E

Sh. Raman Kumar Sharma, 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 my supervision has completed his work. The precise title of his thesis is, **"Petrological and Petrochemical study of Panjal Volcanics around Banihal Area, Kashmir Himalaya".**

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

I further certify that :-

a) the thesis incorporates the work of the candidate himself;

b) the candidate worked under my supervision for the period required under statutes;

c) the candidate has put in the required attendance in this department during that period; and

d) the conduct of the candidate remained satisfactory during that period.

30-6-89

(C.L. Munshi)
Professor and Head
Supervisor

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INTRODUCTION

Kashmir Himalaya constitutes one of the most significant and fascinating sectors of the Himalaya both geographically as well as geologically as it forms the area of convergence of several major mountain chains of the world such as the Himalayan Range, the Karakoram Range, the Hindukush Range etc.(Fig.I). The Jammu and Kashmir State, which encompasses the Kashmir Himalaya is yet to be studied in detail from the geological point of view and geographically has been divided into three administrative parts, namely the Jammu region, the Kashmir region and the Ladakh region.

Named after the Pir Panjal Range, both the words "Pir" and "Panjal" signify a mountain peak or Range. The former being the Dogri and the latter the Kashmiri word. To speak, therefore, of the Pir Panjal Range is, therefore, three fold tautology.

Kashmir Himalaya is important from the geological view point as a complete geological succession right from Pre-Cambrian to Recent with only a few gaps can be traced in this part of the Himalaya. It has witnessed stupendous volcanic activity in the geological history of India. The volcanic activity commenced in the Carboniferous and is reported to have lasted upto the Triassic (Wadia 1934). The Panjal volcanic cycle, characterized by (i) Agglomeratic Slates and (ii) Lava flows has been designated as the Panjal Trap. The Agglomeratic Slates and the traps are found together over large parts of Kashmir and constitute a cardinal rock unit in the geology of Kashmir Himalaya.

AREA OF STUDY

The present investigation is confined to the study of Panjal volcanics outcropping between the Banihal town, on Jammu-Srinagar National Highway and to the South of the Old tunnel across the Pir Panjal Range (Plate 2, fig.1). The area under investigation falls in the Ramban Tehsil of the Doda district of Jammu and Kashmir State and constitutes a part of the Pir Panjal Range. The study area is confined to parts of Survey of India topographic sheet nos. 43 0/2 and 43 0/3 (1:50,000). Its boundaries are delimited by Lat. 33°25'10" to 33°35'20" N and Long. 75°07'20" to 75°15'10" E, encompasing an area of about 200 sq.kms.

The Banihal town is situated about 190 kms from Jammu on Jammu and Kashmir National Highway (Plate 2, fig.2). The valley of Kashmir which has become a centre of attraction for many geologists of the world is connected with this town through a low level tunnel named the Jawahar tunnel. The low level tunnel referred to above has been bored through the range to provide an all weather communication link between Kashmir Valley and the rest of the country. This tunnel is named after the first Prime Minister of India Pt. Jawahar Lal Nehru and is the longest tunnel in the country. It is about 2.5 kms in length and has been bored through the Pir Panjal Range by a team of German experts from 1956 to 1960. According to German geologists the life of this tunnel was about twenty years.

After sometime another tunnel has been bored through the Pir Panjal Range parallel to the Jawahar Tunnel. Both the tunnels are linked with each other at some points. The two tunnels are termed as the eastern tube and the western tube. After crossing this tunnel the valley of Kashmir is seen.

The other settlement stations like Tathar, Nugham, Charil, Lambar are also connected with the National Highway; whereas the interior parts are negotiable by trekking alone. The old road between the Old tunnel and the Jawahar tunnel has been completely damaged due to disuse and this area is now only accessible by trekking. A Panoramic view of this part is presented in plate 1 figs. 1 &2.

PHYSIOGRAPHY

The dominant physiographic feature of the Banihal region is the rugged snow covered Pir Panjal Range, cut into deep ridges and precipitious defiles (Fig.2). The area presents highly diversified relief with high mountains, and rugged topography, comprising high ranges, deep valleys, flat or gentle sloping meadows, deep slopes, escarpments and cliff faces and shows great variation in elevation from about 610m near Ramban and Dhamkund to about 4553m (Muni Mal) above the m.s.l. on the Pir Panjal Range. The general trend of the Range is NW-SE separating the regions of Jammu and Kashmir. To the south west of the Great Himalaya, the mountain range of great importance viz. the Pir Panjal Range separates Jammu region from the Valley of Kashmir. The study area lies on the southern flank of the Pir Panjal Range where the altitude varies from 2000 to 4000 meters above sea level. The terrain is highly mountainous and densely forested.

DRAINAGE

The main drainage of the area is the Bichlari river which drains through the area. The southerly flowing Bichlari river originates from the crest of the Pir Panjal Range in Banihal Sunder Top section, cuts through some subsidiary ranges in Ramsu-Didgdaul section on the Jammu-Srinagar National Highway. This river follows the course of the National Highway for a long distance till it meets the Mahu-Mangat nala at Nachleni (outside the study area) and then ultimately joins the river Chenab. There are some tributaries of the Bichlari river which are perennial and pour their discharge into it as is evident from an inspection of the physiographic map of this area. There are a number of other tributaries namely Lamber, Dauthar, Agar, Gagar, Zewag nala etc. which ultimately join the Bichlari river. The overall drainage pattern of the area is of dendritic type. The Pir Panjal Range is the main water divide of the area.

The Bichlari river is not a seasonal river its water is generally used for land irrigation.

CLIMATE

The area enjoys pleasant and bracing temperate climate, but there is a great variation in altitude from about 1000 m near Ramban to more than 4500m above m.s.l. at higher mountains and meadows there is also a great variation in climatic conditions. However, the average altitude of the area is 3000m; the upper reaches of the Pir Panjal Range remain snow bound throughout the year. The climate of the area is practically similar to that prevailing in other parts of Kashmir valley. The weather is excellent in spring and the summer is comparatively hot. In Autumn, the season is again fine. This season is very busy for farmers during which the crops are harvested. The lower reaches also experience snow during winter months. After this with the slight rise in temperature, the snow begins to melt and at times slides down from the mountains in the form of avalanches. The Shetani nala is well known for its avalanches and blizzards (Plate 2, fig.3).

The spring season starts from March to May, summer from June to August, Autumn from September to November and the winter from December to the end of February.

The spring and summer are the best months. The climate of the Banihal valley is temperate in spring, summer and Autumn; in the winter it represents almost arctic character. Total rainfall in this area is highly variable. At times the rains are less. The area experiences a fair amount of rainfall between June to August and the average annual rainfall ranges from 100 to 150 cm. In summer there is less of rainfall while in Autumn no rain falls. In winter rains are also quite common and during this period the precipitation is mostly in the form of snow. Snowfall usually starts in the last week of December and continues till March. Higher elevations remain snow bound for eight months (September to April); whereas the lower elevations remain snow bound for about four months (November to February). As already mentioned the whole area gets covered by snow and the temperature generally goes below zero degree centrigrade.

VEGETATION

The area is generally forested, mostly by the conifers upto the elevation of 2700m above mean sea level. The forests are mostly of lower oak to upper oak conifer types. Vegetation is influenced by climate, rainfall, soil and altitude. Since these factors vary as the altitude rises from the semi-arid fringe plain of the sub-mountainous region of Jammu province to the loftiest mountain ranges of the inner Himalayas, it is but natural that a wide distribution of flora should exist in the territories of Jammu and Kashmir.

A change of climate with a sudden rise in altitude and a marked difference in prevailing winds, varying pressures and rainfall is a note-worthy feature of the area.

The main types of tree being the varieties of Chir, Codar, Spruce, Kail, Fir, Birch, Oak Chestnut Rhododendran and Deodar etc. The low lying areas are covered by dense shrubs and grass. At higher elevation, the vegetation is scanty and only small meadows are found on the slopes.

Starting from the higher parts of the Pir Panjal Range between 8,000 feet and 10,500 feet, the vegetation cover is mainly composed of mixed conifers like those of Fir (Abies pindrow) and Spruce (Picea morinda) and a few broad leaved species notably (Fraxinus) species, high level oak (Quercus-semi carpiphore). In comparatively exposed localities, thick strands of temperate shrubs are met with. At the upper margins, fir forests, quercus-semicarpiphora and prunuspandus exist. Beyond this at 10,500 feet or above, there is a typical sub-Alpine type bushland mainly composed of low shrubs of Rhododendron, Junifers etc; and a large number of herbs.

Near about 11,5000 feet, the vegetation is characteristic of Alpine meadows or Tundra where extremely low shrubs, Rhododendrons etc., and a large number of herbs and grasses form multi-coloured carpets in the Autumn months. The important meadows found in the area are at Jwartha - Sharu, Zilant, Kaukut, Nandmarg, Godan-Banihal Pass, Sundertop and Muni Mal Sarkanth Mal.

In contrast to the southern aspect discussed above the vegetation in the northern slopes, facing Kashmir valley is more thick and lush.

The mixed conifer belt goes right upto the hills of lower elevation and we get a number of wild as well as cultivated plants. The important ones are composites, sunflower, lillies and others. The most important among cereals are Oryza sativa (Rice), Triticum aestivum (Wheat) and Zeamays (Maize) which are cultivated in this area and are harvested in Autumn. Among the vegetables, the most common are lathyrus species (Beans), Allium species (Onions) and Solenums (Potatoes).

Apple, walnut and almond are among the common temperate fruits that are cultivated in the area.

HABITATION

The small inner valleys enclosed between the northerly Pir Panjal Range and the southerly Kaplas

Jwartha-Sharu-Muni Mal Range are the Pugal-Paristhan Valley, Nil Valley, Banihal Valley, Mahu-Mangat Valley and some parts of the Pir Panjal Range with its rugged topography are not habitable. During the summer months, Gujars and Backerwals carry their belongings and cattle across the Pir Panjal Range. They usually live there on either side of the water divide and carry their flocks to great heights for grazing. In summer, Gujars and Backerwals live in small Dhoks. These Dhoks are deserted when they move their families and cattle to lower reaches during the winter months. The area is thinly populated and the main occupation of the people is agriculture.

COMMUNICATION

The State of Jammu and Kashmir is well connected with the rest of the country by rail, road, and air. Jammu Tawi Railway Station is the rail head for the area. There is a good network of feeder roads and all the district, tehsil and block head quarters are connected with Jammu by all weather metalled roads.

The only motorable road found in the area is Jammu-Srinagar National Highway which cuts through the area between Ramban and Jawahar Tunnel. In the rest of the area, the transportation is done either by mules or by headloads.

METHOD OF STUDY

This work consists of field study, collection of samples and the investigation of their petrological and petrochemical traits.

The field study is devoted to the preparation of a geological map of the study area on 1:50,000 scale; systematic sampling, location of volcanites exposed in the study area. The attitude of joints present in the area is marked on the geological map and the stratigraphy of the surrounding rocks has been worked out. For depicting the important features of the area, some field photographs are incorporated in the present work.

In the laboratory, the representative specimens of different rock types exposed in the study area have been adequately described megascopically. A large number of thin sections of the volcanics from this area have been prepared and their petrological characters studied in detail with the help of a petrological microscope. Modal analysis of each mineral in the samples has been carried out on a blood cell counter.

Pure fractions (85 to 95% purity) of Plagioclases, epidotes and chlorites were separated both by heavy liquid separation and Isodynamic separator. Chlorites and epidotes were separated using the density separation process. Heavy liquid of high purity like bromoform, tetrabromoethane and carbon tetrachloride were used according to the method of Emmons (1961) as later improved by Henley (1977) for the separation of these minerals. Further the Plagioclases were separated from the associated quartz grains under a high magnification binocular microscope. The separated fractions of Plagioclases, chlorites and epidotes were studied by optical and chemical methods.

Thirty representative rock samples of different varieties of Panjal Traps have been chemically analysed for their major and trace element study using the rapid method with the help of an atomic absorption spectrophotometer, after the sample preparation according to the method of Angino and Billings (1967). The analyses have been done on a Double Beam Atomic Absorption Spectrophotometer Model 902, Australian make. 0.1 gm of powdered dried sample was subjected to tri-acid (sulphuric acid, perchloric acid and hydrofluoric acid) digestion in a platinum dish on a sand bath in a fuming cupboard. After heating for half an hour till the fumes stopped coming out, the process was again repeated and the residue dissolved in 1:1 HCl (about 20 ml). The solution was made to 100 ml and stored in a polythene bottle. The standards were prepared from A.R. grade pure metals and salts (99.9% pure) as per the dissolution method indicated in the GBC Flame Method Manual for Atomic Absorption (1986). The sample weight and dilutions were carefully arranged to aim at possible final concentration range of the samples. To put various elements of the samples in range, required dilutions were made, wherever necessary. Fresh standard solutions were made for every element detection (both major and trace levels) and prescribed releasing agents/buffers used to check the chemical interference and suppressing ionization both in the case of standards and the samples. Integration time of 3 seconds was kept for each sample after optimization of standards for adjustment of burner in horizontal, rotational and vertical positions. The final optimization was performed by the Nebulizer with the lower standard and lastly by the fuel knob for maximum absorbance. Generally three standards were used for each element and a blank was run between them to ensure the base line (zero point). The instrument after feeding the standards was put in the concentration mode and direct display was read from the digital plate and its record printed automatically on the printer attached with the instrument.

For Aluminium 0.1 gm of dried sample was taken in a 50 cc Nickel crucible. The crucible was gently heated on a bunsen burner for five minutes. Then it was heated to redness for half an hour. The crucible was cooled in a dessicator and the solution made in distilled water. The contents were transferred to 1:1 HCl and HNO_3 in a beaker. The total volume made was 100 ml. The solution was aspirated through capillary to the A.A.S. for getting the concentration of Al direct on the digital plate and printer automatically. SiO_2 was calculated by difference at the end of analysing the samples. The data thus obtained have been treated in terms of various bivariate and trivariate plots. The results have been interpreted and incorporated in this work.

The samples of the Agglomeratic Slate have also been collected and their petrographic characters are also given at appropriate places in the text.

HISTORICAL REVIEW

The foundations of the present day knowledge of the geology of Kashmir Himalaya have been laid by Lydekker, Middlemiss, Bion and Wadia. The area under investigation has received the attention of some workers previously. In this chapter an attempt has been made to present the views of the earlier workers on the geology of the different sectors of Kashmir Himalaya, particularly on the Panjal volcanics listed in a chronological order in the succeeding lines.

Lydekker (1876 to 1883), a pioneering geologist of the nineteenth century, gave a detailed stratigraphical account of western Kashmir and the Pir Panjal Range. He divided Kashmir stratigraphy into five systems : (i) The Metamorphic System (ii) The Panjal System (iii) The Zanskar System (iv) The Tertiary System and (v) The Alluvial System.

Middlemiss (1909 to 1910) took traverses across the Pir Panjal Range and carried out systematic mapping of the south-eastern Kashmir. He revised the work of Lydekker and divided the Silurian-Trias sequence of Kashmir into two divisions A & B.

	A Division		**B Division**
6.	Fenestella series	11.	Upper Trias
5.	Passage beds	10.	Muschelkalk
4.	Syringothyris Limestone	9.	Lower Trias
3.	Muth Quartzite	8.	Zewan series
2.	Upper Silurian	7.	Gangmopteris beds, Panjal volcanic flows and Agglomeratic Slates.
1.	Lower Silurian		

The former constituting the succession below the Agglomeratic Slate and Panjal volcanic flows, while the latter covering the succession overlying the volcanic flows. According to Middlemiss, the Palaeozoic-Mesozoic succession of southeastern Kashmir is folded into Liddar anticline and its complementary Morgan syncline in the north and Marbal syncline in the south. He also recorded the occurrence of Gondwana plants from the Agglomeratic Slates of Apharwat in western Pir Panjal which proved to be of enormous importance for later workers. This classic work of Middlemiss still forms the base and is being followed with minor modifications here and there.

Middlemiss (1911) makes a mention of some important sections in the Pir Panjal Range and the Sind Valley. He described the section along Nilnag - Tatakuti, Gulmarg - Apharwat routes and also along the Gulab Garh pass which was examined by Middlemiss in the year 1909. After studying these sections, he found that the central high peaks which formed the watershed were composed of Agglomeratic Slates or Panjal Traps.

Bion (1928) followed Middlemiss and mapped the eastern part of Kashmir and described marine fauna from the Agglomeratic Slates which helped in fixing the lower age limit of the Panjal volcanics.

Wadia (1928) mapped the northwestern part of Kashmir Himalaya, covering the Ramban Poonch sector of the Jammu region and Muzaffrabad, Baramulla, Nanga Parbat area of the Kashmir region. According to him the region is covered by rock Formations ranging in age from Pre-Cambrian (Salkhalas) to Pleistocene boulder conglomerate. Wadia divided Lydekker's Panjal system into two major groups : (i) The Dogra Slates and (ii) The Agglomeratic Slates in association with Panjal Traps. He postulated a major Palaeozoic unconformity between the Dogra Slates and the Agglomeratic Slates and opined that during the Middle Carboniferous period, the Panjal area became part of the Kashmir geological province; a connection which endured upto the Trias, as indicated by the close similarity between the Carboniferous - Triassic sequence of the two areas.

Wadia (1931) structurally divided the rocks of Kashmir Himalaya into three sharply defined structural belts namely (i) The Foreland, (ii) The Autochthanous folded belt comprising rocks of Carboniferous and Eocene age and belonging to the Himalayan geosyncline area; thrust along the Muree thrust over the rocks of the Foreland; which represents a promontory of the Gondwana land covered under the Middle Tertiary sequence. Similarly the rocks of the Nappe zone comprising the oldest rocks of the Himalayan

Geosyncline thrust along the Panjal thrust over the rocks of the Autochthanous zone. He opined (1950) that the roots of the Kashmir Nappe lie in Zanskar region and it has come to its present position after a horizontal translation of more than 200 km from its homeland.

Wakhaloo and Mathur (1933) for the first time recorded quartz-felsite or rhyolite from Pantchuk and pitchstone showing superficial resemblance to basalt in the area around Kashmir Valley.

Wadia (1934) subsequently divided the metamorphics into two units, viz. the Salkhalas older in age and the Dogra Slates younger to the Salkhalas. He opined that the Cambrian and Ordovician rocks are rich in fossils in northwest Kashmir, and therefore, marked the Lower Palaeozoic sequence therein.

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

Ganju and Rajnath (1939) classified the traps into acid and andesitic rocks at some places in the Kashmir Valley.

Ganju (1943) in a subsequent paper recorded the occurrence of the acid rocks, viz. rhyolites, trachytes and dacites in the localities at Cheshmashahi and Avantipur.

Ganju (1957) in his paper entitled "Physiography and geology of the area around Gulmarg" reported the succession of rock Formations from Pre-Cambrian to Pleistocene, giving a detailed account of the Salkhalas, the Dogras, the Tanawals, the Agglomeratic Slates, the Triassics and the Karewas.

Pascoe (1959) followed the classic work of Middlemiss (op.cit.) and Wadia (op.cit.), gave an account of Panjal Traps. According to Pascoe (op.cit.) the lavas for the most part are basalts termed by him as "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 words of Pascoe "in the Lolab and Hundwara district 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, uralitization has been complete and universal.

Ahmed (1961) advocates a glacial origin for the Agglomeratic Slates of Kashmir.

Ganju and Srivastava (1961) reported the occurrence of Agglomeratic Slates near Bren in Kashmir Valley. The Agglomeratic Slates are of two types. The coarse grained variety consists of quartz, feldspar and some rock fragments which lie in an abundant glassy matrix. The other fine grained variety is predominantly glassy and contains numerous dark, lensoid patches of partially devitrified glass.

Hazra and Prasad (1963) worked out the geology of the Banihal region during the course of their survey for Jawahar tunnel.

Wakhaloo (1964) gave a detailed account of the petrography and petrology of Panjal volcanics including the Agglomeratic Slates. He suggests a marine origin for the Panjal Traps and the Agglomeratic Slates.

Pareek (1968) has reported streaks of coaly matter in the Panjal Trap area, east of Wular lake.

Sharma and Gupta (1972) described in detail the petrography and petrochemistry of the spilites and keratophyres and the Panjal Traps from Thanamandi area. They presumed that the Panjal Traps owe their origin to the combined role of submarine and subaerial volcanism.

Nakazawa and Kapoor (1973) studied the Panjal Traps of Guryul Ravine and exhibited pillow structure of the rocks and submarine origin for the traps about 12 kms. east of Srinagar.

Pareek (1973) makes a mention of the volcanics of Banihal area. He suggests the Agglomeratic Slates as the Pyroclastic nature of the volcanism in which the constituents were flown up into the atmosphere inflated by gas. Pareek (op.cit.) gave a detailed account of the textural and compositional variation of Panjal Traps basalts andesites and rhyolites etc. He further classifies the traps into two varieties viz., porphyritic and non-porphyritic traps on the basis of petrographical and geochemical tests.

Uppal (1973) while presenting an account of the geology of Banihal area has described the petrological characters of the volcanics from this area.

Acharya and Shah (1975) quoting Fox (1931), Gannser (1964), Fuchs and Gupta (1971) described the Agglomeratic Slates of Kashmir Valley intercalated with tilloids, tillites and Agglomerates and thus correlated them with the Blainis.

Fuchs (1975) while publishing his paper "Glaciogene Formation in the Himalayas" described "in detail that volcanic influence was much less as might be expected from the name of the Formation". He suggests glacial origin for the Agglomeratic Slates.

Gupta (1975) gave a formal classification for the Agglomeratic Slate sequence of Kashmir Valley and later on reviewed the stratigraphic position of a boulder bed in the Gulabgarh boulder Formation on the basis of palaeontological and stratigraphical aspects.

Srikantia (1975) gave an excellent account of the deposition of the Agglomeratic Slates of Kashmir Valley and is of the opinion that Permo-Carboniferous glaciation must have influenced the deposition.

Wakhaloo (1975) compares the Agglomeratic Slates with the Blainis and also described various building stones. Mostly the Igneous rocks used in Kashmir for building purposes are rhyolites which represent the acid lavas of the

Panjal volcanic series.

Sharma et al. (1976) worked on the stratigraphy and structure of Ramban-Banihal-Gul Gulab Garh-Budhil Sector of the Pir Panjal Range. He reviewed the stratigraphy succession of the area on lithological grounds.

Pareek (1977) published his paper "Agglomeratic Slates and Panjal Traps in the Lidder Valley, Jhelum, and Sind Valleys, Kashmir". Pareek (op.cit.) is of the opinion that the Agglomeratic Slate series as representing the Pyroclastic nature of the volcanism, in which the constituents were blown up into the atmosphere inflated by gas. The deposit was laid down under the influence of gravity and the resulting product compacted and solidified to form the Agglomerates, the glassy rocks and the welded tuffs. The Agglomerates show coarse banding, well rounded iron mineral grains with or without glass, or devitrified in many cases.

Wakhaloo (1977) described some intrusives of Kashmir and made a mention of trap rocks as spilites rather than andesites or basalts. He is of the opinion that the spilites have been derived from the normal crystallization of a hydrous magma.

Ahmed et al. (1978) suggests that the Agglomeratic

Slates were deposited in shallow marine water as well as continental set up and they are the products of glacial and volcanic activity.

Bhat and Zainuddin (1978) gave an account of the geochemistry of Panjal Traps of Mount Kayal, Lidderwat, Pahalgam, Kashmir and counted 32 flows of the Panjal Traps near Pahalgam from the base to the top of the flows. Besides the petrographic study of the above sequence of 32 flows, the genetic aspects of the Panjal Traps have been discussed in detail in the light of the behaviour of major and trace elements. They suggest that these rocks are dominantly basaltic-andesites and show a compositional and environmental affinity with accreting plate margin tholeiites.

Bhatia and Kakroo (1977) worked on the Sedimentological studies of Agglomeratic Slates, Anantnag district Kashmir and are of the opinion that the rocks of this series are mostly welded tuffs, which have been altered, devitrified and metamorphosed. According to them three types of tuffs have been categorised viz. vitric, crystal and lithic tuffs, but most of them belong to the intermediate types.

Chaudhary & Ashraf (1980) have given an account of volcanics of Poonch, Azad Kashmir. The rocks have been described as andesite-basalt associated with volcanic ash and tuffaceous material. He has assigned Upper Carboniferous age to these volcanics.

Raina (1982) worked on the Panjal Traps of Bandipore area. He ascribed these rocks to be of tholeiitic affinity which were deposited under marine conditions. He further suggests that the traps have not undergone too far in differentiation and therefore, refers them as middle stage basalts.

Sharma (1982) while working on the Panjal Traps of Banihal area suggests that the Panjal volcanics were deposited under marine conditions. These rocks according to the author are having tholeiitic affinity and the Agglomeratic Slates along with Panjal Traps have been extruded under marine environment.

Munshi & Sharma (1983) gave an account of Panjal Traps of Banihal area. The authors are of the opinion that these rocks are middle stage basalts and differentiation in the rocks has not proceeded beyond the andesite stage. The rocks bear a tholeiitic lineage.

Jamwal (1987) while working on the traps of Sudh Mahadev area, ascribed the rocks to be of andesitic nature and having undergone low grade metamorphism of albite - epidote - amphibolite facies. The author has further suggested marine origin for the rocks.

Dhar (1988) gave an account of the Panjal Traps of Hirpur, Shopyan area, Kashmir Himalaya. The author has concluded that the traps of the area are of andesitic character and bear a tholeiitic lineage. The rocks according to him have been extruded under marine conditions.

GEOLOGY OF THE AREA

In the Banihal area, a complete stratigraphic succession ranging in age from Devonian to Recent in order of superposition is well exposed on Jammu-Srinagar National Highway. Some refinements have been introduced to update it in the light of new findings, and some new names have been inducted to make it conform to the modern code of lithostratigraphic classification but at the same time sufficient care has been taken to see that continuity with the earlier classification and nomenclature is maintained (Fig.3).

Table 1 shows the geology of Banihal area starting from a little above Banihal township to the Old tunnel. A brief description of the stratigraphic sequence of the area is given in the lines that follow :

HALA QUARTZITE

This Formation is the oldest in the area under reference, and occupies stratigraphic position and possesses lithological characters similar to those of the Muth quartzite of Kashmir. In this Formation, the quartzite shows its typical development near Hala and Hustak in Nil and Pugal Valley respectively which lie outside the study area, east of Ramsu and as such have been designated as Hala Quartzite.

South of Banihal, near Injantrag, the Hala Quartzite has been repeated eight times due to folding into very tight and compressed synclines and anticlines, as a result of which it assumes great outcrop width. It again assumes tremendous outcrop width on the Injantrag ridge lying between Chamalwas and Duligam due to refolding.

Table 1 : Showing the stratigraphic sequence around Banihal area

FORMATION	LITHOLOGICAL CHARACTER	PROBABLE AGE
Alluvium & Terrace Deposits	Clay, shales and conglomerates	Recent to Sub-Recent
Gondwana Plant Bed (Vihi Plant Bed)	Siliceous & carbonaceous shale and sandy shale with plant fossils	Lower Permian
Panjal Volcanics	Thickly bedded greenish and greyish vesicular, amygdaloidal and massive andesitic basalt with flows of acidic and trachytic lava	
Gondwana Plant Bed (Nishat Bag Bed)	Carbonaceous shales and sandstones with thin lava flows	
Agglomeratic Slate	Sandstones, Greywackes, shales, conglomeratic grits and diamicrites with foreign rock and tuffaceous shales and slates	Upper Carboniferous
Fenestella Shale	Shales, slates, quartzites and quartzitic conglomerates	Middle Carboniferous
Syringothyris Limestone	Quartzites sandstones, limestones, shales, slates, phyllitic slates etc.	Lower Carboniferous
Chamalwas Slate	Splintry shales and siltstones	Pre-Carboniferous
Hala quartzite	Greyish white Massive quartzites	Devonian

Hala Quartzite in its type locality comprises of medium to coarse grained, thickly bedded, highly jointed, massive quartzite, with sedimentary structures such as ripple marks, current bedding etc. Locally it becomes coarse grained and gritty and even shows the presence of sporadic clasts here and there. It, however, shows great variation in its lithological characters from place to place due to sedimentary as well as metamorphic facies variations. The basis of its stratigraphic position and lithological characters this Formation has been assigned Devonian age.

CHAMALWAS SLATE

To the South of Banihal, between Banihal and Chamalwas, a thick zone of greenish, grey and pale brown shale-slate and siltstone sequence is well exposed on the National Highway and it has been designated as Chamalwas Slate after that village, where these rocks show their typical development. This Formation conformably overlies the Hala Quartzite and in turn is conformably overlain by the Syringothyris Limestone.

Chamalwas Formation in its type locality comprises of greenish grey and pale brown slate, with a thin band of micaceous shaly sandstone. At many places, they show great variation in their lithological characters from shale-slate to quartzitic slate and slaty quartzite. In Banihal area at many places these slate and slaty quartzites become sporadically pebbly and even contain lenticular bands of conglomerate and limestone.

The rocks of this Formation are folded into several tight anticlines and synclines as a result of which they have developed intricate bedding cleavage relationship in Banihal area. These rocks appear ideal for the preservation of fossils, but all efforts to find fossils in them failed probably because they generally splint along the cleavage planes instead of bedding planes.

Wadia (1934) mapped Ramban-Banihal area and recorded thick conglomerate bands below the Syringothyris limestone as seen south of Duligam Tragam area in Mahu Valley and about these he writes "the basal beds of the Syringothyris limestone are coarse boulder bed accompanied by massive quartzite. This quartzite conglomerate has been traced continuously at the base of the Syringothyris limestone." The author fully agrees with the above observation of Wadia but has grouped this under a new name referred to as Chamalwas Slate and are considered to represent a sort of transitional sequence between the Hala Quartzite and the Syringothyris limestone.

Chamalwas Slates undoubtedly show striking lithological resemblance with the rocks of the Shumbal Formation of Liddar Valley and on these consideration were mapped as Cambrian by Wadia. But these rocks conformably occur above the Hala Quartzite and considered as equivalent of Gugaldar Formation of Devonian age and underlies the Syringothyris limestone and hence has been assigned Pre-Carboniferous age.

SYRINGOTHYRIS LIMESTONE

A fairly thick band of Syringothyris limestone has been mapped in Banihal area, where it occurs in the core of the Banihal anticline and is well exposed between the Banihal toll post in the south and Charil in the north on the National Highway. Here it comprises impure argillaceous, grey, cream, purple and ocherous yellow limestone with inter stratified bands of medium to coarse grained massive and calcareous quartzite, which at places are gritty and pebbly. In the upper part, it comprises more of calcareous quartzite rather than limestone.

Southwest of Banihal, it extends into Mahu-Mangat Valley where it is folded into several anticlines and Synclines. In Mangat Bawe-Tragam area, the Syringothyris limestone is underlain by a thick band of hard compact boulder bed quartzitic conglomerate and conglomerate quartzite. This unit was identified by Wadia also in Banihal area and he considered these quartzites and conglomerates as part of the Syringothyris limestone. Southwest of Tragam, this Formation could not be traced, because of the early snowfall but is probably cut off by the intruding Sarkanth Granite.

The Syringothyris limestone includes grey to fawn coloured limestone with shale partings, slates, phyllites, sandstones, clays and quartzites. The shale is white to pink in colour sometime talcose giving a soapy touch. The talcose shale is brown to greyish brown in colour. The limestone is medium to coarse grained, brown in colour, loosely cemented, the matrix being argillaceous. Limestone dominates the basal portion grading to slate and quartzite at the upper part, which ultimately grades to overlying Fenestella Shales. The quartzite is white to grey in colour, fine grained, compact, sometimes micaceous. It is continuous throughout the area but its thickness varies from place to place.

Limestone is not reported to be richly fossiliferous but at places, it is seen to possess some brachiopod species. It is richly fossiliferous near Banihal area northeast of Duligam. The most frequently occurring brachiopod which characterises the series is Syringothyris cuspidata, which is a valuable Index fossil being also typical of the Lipak series of Spiti. The purple shale band which mostly contains the fossils near the military hospital at Banihal is full of Syringothyris cuspidata and other brachiopods. From the fossil assemblage, the Syringothyris limestone is proved to be of Lower Carboniferous age. The thickness of the limestones is estimated to vary from 2,000 to 3,000 feet in the Banihal area (Wadia 1961).

FENESTELLA SHALE

This Formation is one of the most important marker horizons of the area under reference. In the Banihal area, the Syringothyris limestone band overlies the Chamalwas Slates and grades upward into Fenestella Shales, which is very well exposed in Banihal - Mahu Mangat Valley, where they form the base of the Panjal volcanics, consisting of Agglomeratic Slates and Panjal Traps.

The Fenestella Shales are well developed in Tathar - Nowgam area on the Jammu-Srinagar National Highway, where this Formation is divisible into two parts. The lower part comprising of greyish white, hard, resistant massive quartzite showing beautiful current bedding and ripple marks and the upper consisting of Carbonaceous shale-slate with bands of limestone. These quartzites at a number of places are sporadically pebbly and even become conglomeratic as seen in the Tathar-Nowgam section on the National Highway.

The complete succession near Nowgam is as follows :-

Massive white quartzite
Slaty shale (Black) with Fenestella
Gritty quartzite
White shale
Pebbly quartzite
Gritty quartzite
Slate
Whitish shale (Fossiliferous)
Basic intrusive
Quartzite and shale

The lower members of this Formation are unfossiliferous and these form passage beds between the Syringothyris limestones and the Fenestella Shales. Towards the basal portion, the shale is of grey, whitish grey or greenish in colour and is flaky and splintary in nature. Towards the upper part, the shale is black in colour and practically slaty to be appropriately termed as slaty shale, which is well exposed on the roadside. Innumerable species of Fenestella have been reported from this series. The fossiliferous beds are, however, rare. From the fossil assemblages and the stratigraphic position it is concluded that this Formation is of Middle Carboniferous age.

AGGLOMERATIC SLATE

The Agglomeratic Slates overlie the Fenestella Shales, the latter gradually changes over to Agglomeratic Slates and at times it becomes difficult to draw the actual demarcation line between the two. Fenestella Shales are overlain by a heterogenous type of deposit, consisting of slate, shale, quartzite, sandstone, greywacke, grit, ash beds and conglomerates commonly known as Agglomeratic Slates. The Agglomeratic Slates are dotted with angular to sub-angular grains or fragments of different rocks and minerals like quartz, feldspar, quartzite with occasional slate and limestone.

The presence of fragments with resorption borders, vitroclastic texture and glass shards in this Formation are some of the strong evidences of its Pyroclastic nature. The blackish colour of the Agglomeratic Slates is primarily due to its high iron content. Layers, lenticular bands and pieces of sandstone, grit, quartzite and limestone occur within them. Thick Agglomeratic zones are characterised by the presence of large number of rounded pebbles or sharply angular fragments of quartzite, slate, limestone and chalcedony upto 15 cm in size.

In the Banihal range, the Agglomeratic Slate conformably overlies the Fenestella Shale and is thus of Upper Carboniferous age. These slates grade upwards into the overlying traps. According to Hazra and Prasad (1963) the Agglomeratic Slates and the Panjal Traps are 914 m and 1,423 m thick in this area.

GONDWANA PLANT BED OR (Nishat Bag Bed)

This horizon was reported first by Middlemiss in (1910), forming the limbs of syncline on the Pir Panjal Range. Detailed description of this outcrop has not been given because it falls outside the scope of this work. Traverses have, however, been taken across the Pir Panjal Range and outcrops have been plotted.

This Formation is very important from the geological point of view, for fixing of different age limits on the basis of fossil assemblages. It has been shown on the geological map to form the core of a syncline. Here this plant bed overlies the Agglomeratic Slates and is overlain by the Panjal Traps. Innumerable plant fossils have been reported from this horizon like Gangamopteris and Glassopteris in a thin band of Carbonaceous shale. On the basis of fossil assemblages this Formation is equivalent to the Nishat Bag Bed of Kashmir Valley. From the stratigraphic position and the fossil assemblages it is observed that this Formation is of Lower Permian age.

PANJAL VOLCANICS

The traps are named after the Pir Panjal Range where the rocks are typically developed. The traps are a manifestation of a volcanic activity that took place in two phases, the earlier one described above known as the Agglomeratic Slates and the younger one named as Panjal Trap representing the lava flows.

A thick and persistent band of Panjal Trap has been mapped from the Banihal Pass in the northwest to Kaukut Peak (4089m) area and in this section, it forms the crest of the Pir Panjal Range. To the northwest of Banihal, the main trap band continues and is disposed in the core of two major synclines namely the Tanakimal (3081m) syncline and Tragam syncline, which are complementary to the Mahu-Mangat anticline.

In Banihal area, the Panjal Trap forms a thick sequence of massive to bedded lava flows which show a fairly wide variation in colour, granularity and petrological characters. The traps are generally green to greenish grey in colour but some of the flows are pale yellow, purple and dark grey in colour. Different varieties of traps are present in the study area. These could be broadly classified as amygdaloidal and non-amygdaloidal traps. In the case of amygdaloidal variety, the amygdales consist of chlorite, calcite or quartz. Zeolites constituting the amygdales have also been reported by some workers (Hazra and Prasad, op.cit.) from this area but during the course of the present study, I did not come across any Zeolite constituting the infilling material in this variety. The non-amygdaloidal variety is generally a fine grained type of rock with various textural features, dense, compact and very hard. In addition to this hypabyssal equivalents of the volcanics have also been collected from this area. These show varying degrees of alteration. The Panjal Trap has undergone extensive epidotisation and chloritization which have imparted greenish colour to the rock. Quartz-epidote veins (Epidosites) are frequently met with in this area.

The Jawahar tunnel affords an opportunity to study the nature of the traps through the Banihal hill. The trap is generally hard and massive but at places it is schistose and foliated. Massive trap is mostly highly jointed.

GONDWANA PLANT BED OR (Vihi Plant Bed)

The traps are overlain by a younger Formation of Lower Permian age, consisting of siliceous and carbonaceous shales commonly known as the Vihi Plant Bed. It is very difficult to draw actual line between the two Gondwana Plant Beds, but the main difference between the two is based on their stratigraphic position. Here the Vihi plant bed overlies the Panjal Traps; but on the other hand, the earlier Gondwana plant bed or the Nishat Bag bed is conformably overlain by the Panjal Traps. The plant bed overlying the Agglomeratic Slates has been named as the Nishat Bag Bed by Kapoor (1977). Another plant bed overlying the traps has been referred to as the Vihi Plant Bed (Verma and Zutshi, 1988). This is the only difference between the two plant beds. Similarly some plant fossils have also been reported from this bed which are bigger in size than the fossils reported from the Nishat Bag bed. Hence, from the fossil assemblages and the stratigraphic position, it is concluded that this Formation is of Lower Permian age.

ALLUVIUM AND TERRACE DEPOSITS

These constitute the Pleistocene and Recent deposits and are composed of fine grained clay and sand with inter-bedded conglomerates.

PETROLOGY OF THE PANJAL VOLCANICS

The main object of this chapter is to present a comprehensive petrographic account of rocks exposed around Banihal area. In this chapter an attempt has been made to interpret the volcanic rocks of the area based on the field and petrographic aspects. As mentioned earlier, the Panjal volcanic rock series comprises of the basal Agglomeratic

Slate zone, of highly variable extent, thickness and distribution and the layered and massive Panjal Traps, showing frequent jointing. The petrographic study of the Panjal volcanics from the area under reference involves the identification of the rocks in the field, in hand specimens and in thin sections. For the purposes of petrographic classification of the volcanic rocks, the thin sections have been modally analysed on a blood cell counter and the model data thus obtained is given in table 3. Furthermore, the main mineral phases have been separated and thereafter subjected to optical and chemical studies.

PETROLOGY OF AGGLOMERATIC SLATES

Megascopically the Agglomeratic Slates vary in colour from dark grey to greyish-green, blackish, quite hard, with ferruginous permeations, along the joint and bedding planes. The blackish colour is due to the high iron content. Agglomerates of mineral and rock fragments are noticed in the rocks (Plate 2, fig.4). The Agglomeratic zones are characterised by the presence of large number of angular and subangular, rounded to ellipitical pebbles of quartz; quartzite and granite, varying from a millimetre to six mm in size along the longer axis. Sub-greywackes, arkosic sandstones, argillaceous slates and tuffaceous materials are seen in association with typical Agglomeratic

Slates.

Under the microscope, the typical Agglomeratic Slates, show fragmental inequigranular texture composed essentially of angular to sub-angular grains of quartz (Plate 3, figs. 1&2), rock and mineral fragments. Glass shards and iron oxides are noticed and are in an irresolvable matrix.

The Sub-greywackes (Plate 3, fig.3) associated with typical Agglomeratic Slates are seen to be essentially composed of Sub-rounded grains of quartz set in a fine grained clayey and sericitic matrix. The quartz grains show strain effects with attendant undulosity. Oxides of iron in the form of Pyrite and magnetite are present (Plate 3, fig.4).

The arkosic sandstones referred to above consist of quartz, feldspars and iron oxides in a fine grained matrix consisting of chlorite and sericite.

Argillaceous Slates generally found in this area are of highly fine grained nature consisting of minute sub-angular grains of quartz embedded in a cryptocrystalline matrix.

In the case of the Agglomeratic Slates of the area under study glass shards and volcanic tuffs are of common occurrence.

PETROLOGY OF THE PANJAL TRAPS

Megascopically the traps of the area vary in colour from green to greenish black but some of the flows are of pale yellow, purple and dark grey colour. Well developed jointing is noticed at many places in the rocks (Plate 2, figs. 5&6). It is noteworthy that the colour variation in the rock types is due to their compositional nature. The rocks owe their green colour to the presence of epidote and chlorite, greyish to blackish varieties have iron ore permeations. The Panjal Trap is essentially a fine grained greyish variety with abundant epidote, chlorite and calcareous matter.

The older traps exposed in the Jawahar tunnel area are mostly non-porphyritic though microphenocrystic, and fine grained; the younger traps exposed in the Banihal Range are mostly fine grained, epidotised, porphyritic and amygdaloidal. A green tuffaceous rock appears to be layered along with the flows and this may even mark the beginning of different flows.

Under the microscopic examination, the Panjal Traps in many instances show an aggregate of plagioclases, chlorites, epidotes and quartz with accessory minerals like magnetite and ilmenite. In general Panjal Trap is fine to medium grained and shows sub-ophitic to ophitic texture but the equigranular varieties show porphyritic texture. In the case of porphyritic varieties groundmass is generally fine to medium grained with sub-ophitic or ophitic texture consisting of coarse grained phenocrysts of plagioclase feldspars, and altered pyroxenes. In the highly altered varieties, the groundmass is mainly composed of sericite and chlorite with altered or epidotised phenocrysts of pyroxene. Some thin sections show complete saussuritisation and the resultant rock consists of epidote - quartz - sericite. In the vesicular varieties, vesicles are filled with quartz, epidote and chlorite.

Thin section study of Banihal traps clearly shows that these have undergone a low grade of metamorphism because of their involvement in the Himalayan Orogeny. Low grade metamorphism includes in it a lot of sub-facies as far as studies of various metamorphic belts in other parts of the world are concerned. In this case the aim of the author 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 homogenous.

Association like epidote + chlorite + actinolite is a stage in the low grade metamorphism, which is preceded by pumpellyte + 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 Sangam metamorphic belt (Hashimato et al. 1960 & 1976), Keweenawan basalts (Jolly and Smith, 1972), Western Southland in New Zealand (Landis and Ccombs, 1974) and the Tanzawa mountains (Seki et al. 1969a).

As mentioned earlier that the traps of the study area have been subjected to a metamorphism of low degree of Amphibolite facies. As a consequence of this the original minerals have suffered abundant alteration. The chief alteration is seen in original plagioclases and the main ferromagnesian mineral augite. The basicity of original plagioclases has decreased and the original pyroxenes have changed to amphiboles and chlorite. Zoisite and epidote have formed at the expense of the anorthite component of the plagioclases. The rocks irrespective of their textural variation consist in general of a mineralogical assemblage of plagioclases (An content varying from 52 to 70 percent), zoisite, epidote, hornblende, chlorite, sericite and opaque minerals like magnetite and ilmenite. It may be mentioned here that the An content of plagioclases as seen in the traps of this area is rather high as is also evidenced by a perusal of earlier literature in regard to the traps of Kashmir in general. Cases of plagioclases with high anorthite content co-existing with calcium 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, 1978). Grains of quartz are present in most of the sections and these are released as a result of alterations of plagioclases and pyroxenes.

In the present study, the traps of the area under investigation have been grouped as under :-

1. Amygdaloidal traps
2. Non-Amygdaloidal traps
3. Altered dyke equivalents of the volcanics
4. Quartz - epidote veins (epidosites) are of frequent occurrence in the study area.

1. Amygdaloidal Traps

In the case of this variety of trap, the original cavities and druses in the rocks have been filled in by chlorite, quartz, epidote and calcite.

Under the microscope, the rocks are seen to be composed of plagioclase microlites, epidote, chlorite, sericite, quartz or calcite. The groundmass is seen to be consisting of a cryptocrystalline aggregate of feldspar microlites, intimately interwoven with chlorite and sericite. In addition specks and grains of magnetite are present. The infilling minerals are quartz, chlorite, epidote (Plate 3, figs. 5&6; Plate 4, figs. 1,2 & 3; Plate 4, figs. 4,5 & 6; Plate 5, figs. 1,2,3 & 4; Plate 5, figs. 5 & 6).

2. Non-Amygdaloidal Traps

Non-Amygdaloidal traps consists of the most prevalent hard, compact and dense variety of traps. This variety is of wide-spread occurrence in the study area (Plate 6, fig.1).

Thin section study of this rock category shows the presence of hyalopilitic, pilotaxitic, and felty textures in them. The minerals entering into their composition are feldspar microlites, epidote grains, scales of chlorite and sericite, grains of quartz and oxides of iron (Plate 6, figs. 2 & 3).

The groundmass consists of a cryptocrystalline aggregate of the above constituents.

3. Altered Dyke equivalents of the Volcanics

The colour of these rocks varies from green to greenish-black in hand specimens and are found in the form of Dykes in the area under study.

The hypabyssal equivalents of Panjal Volcanics have been reported by various workers from different parts of Kashmir Himalaya. In this connection mention may be made of the work done by Wadia (1934), Wakhaloo (1943, 1972, 1977), Dhar (1973), Munshi (1974), Uppal (1978), Sharma (1982) and Raina (1982). Wiseman (1934) grouped similar rocks under the term of "epidiorites".

Some earlier workers like Johannsen (1939, 1952), Moorehouse (1964) and Turner and Verhoogan (1960) classed the rocks as "Greenstones". It is, however, preferred 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-Vaart (1958) and Munshi (1969).

The thin section study of rocks of this type shows the presence of plagioclase laths, altered pyroxenes, chlorite, sericite and quartz (Plate 6, figs. 4 & 5).

The plagioclases and amphiboles largely enter into the composition of some of the rocks and are as such termed as amphibolites.

4. Quartz-epidote Veins

These are yellowish green in colour in hand specimens and are found in this area. Ramberg (1952), Turner (1948), Hung (1962), Miyashiro (1975) consider such rocks as products of "metamorphic differentiation". Stillwell (1918) first proposed the term metamorphic differentiation which was later on elaborated by Eskola (1932). The term metamorphic differentiation as putforth by Turner (1948) "covers collectively the various processes by which different mineral assemblages develop from an initially uniform parent rock during metamorphism". Plate 6, fig. 6 shows a microphotograph of this variety essentially composed of quartz and epidote with minor chlorite and magnetite.

MODAL ANALYSIS

Modal analysis 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 broadly used in many aspects of petrochemical studies (Holmes, 1927).

Chayes (1956) has studied very carefully the problem of modal analysis of igneous rocks, the Delessee Rosiwal area volume relationship, grain size of rocks, index of coarseness and the so-called Holmes's effect. Chayes (op.cit.) demonstrated 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 Rosiwal-shand line integration approach. The point count method has a higher precision and reproducibility factor 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 in the market. In the absence of 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.

In the present work the method adopted, for modal analysis 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 caliberated. On the basis of this caliberation, 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 an 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 the ninth for cumulative count) Clay and Adams Blood cell counter. The readings on the counter on the completion of a traverse are recorded in a data-sheet as shown in table 2. 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 fine grained basic volcanic rocks were point counted according to the above indicated method and the results are tabulated in table 3.

STUDY OF MAIN MINERAL PHASES IN THE PANJAL TRAPS OF BANIHAL AREA

The Panjal Traps of Banihal area are generally composed of plagioclases, epidotes, chlorites and quartz as already stated. The opaque minerals like magnetite and ilmenite are also present as accessory minerals. The main mineral constituents of Panjal Traps viz. plagioclases, chlorites and epidotes have been studied by optical and chemical methods.

PLAGIOCLASES

Plagioclase is the most important mineral and the chief alteration is seen in original plagioclases. The plagioclases have been determined by two methods : (i)

Table 2. 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	Qz	Pla	Sericite	Chlorite	Epidote	Pyroxene	Opaque	Others	Total
T1	0	100	15	5	29	–	64	–	213
T2	0	101	10	4	40	–	67	–	222
T3	0	110	0	80	60	–	115	–	293
T4	0	119	10	12	50	–	72	–	263
T5	5	121	0	40	66	–	75	–	271
T6	5	103	4	7	66	–	65	–	250
T7	50	85	0	40	51	–	89	–	315
T8	40	85	0	40	50	–	80	–	295
T9	50	114	0	25	40	–	85	–	314
T10	50	55	10	9	50	–	55	–	229
T11	0	103	0	29	80	–	92	–	304
T12	0	118	0	2	96	–	102	–	318
T13	0	107	0	0	75	–	85	–	267
T14	10	108	0	25	85	–	123	–	351
T15	0	130	0	0	70	–	130	–	330
T16	0	130	0	50	52	–	130	–	317
T17	0	105	0	0	50	–	105	–	260
T18	0	105	0	4	60	–	105	–	274
T19	0	115	0	15	50	–	115	–	295
T20	0	115	0	15	50	–	115	–	295
Total	210	2129	49	249	1170	–	1869	–	5676

Table 3. Modal Analyses of Banihal Traps

Sample Number	Quartz	Plagio-clase	Pyroxene	Altered Pyroxene	Epidote	Clino-zosite	Chlorite	Sericite	Opaque	Others	Total
BT3	25.20	23.20	-	0.82	24.44	-	2.06	-	16.44	7.84	100.00
BT5	2.19	61.76	-	-	15.68	-	7.00	1.84	8.38	3.15	100.00
BT14	11.45	50.26	-	-	9.95	-	2.24	1.91	22.52	1.67	100.00
BT17	9.90	54.69	-	-	11.94	0.17	10.20	1.10	9.68	2.32	100.00
BT18	34.70	5.44	-	-	1.29	-	44.25	-	13.54	0.78	100.00
BT20	3.70	37.51	-	-	20.61	-	4.39	0.86	32.93	-	100.00
BT22	0.45	50.26	-	0.69	7.82	-	-	1.36	37.43	1.99	100.00
BT28	1.73	6.97	24.21	40.43	4.63	-	9.09	-	12.94	-	100.00
BT29	-	42.45	25.50	-	1.36	-	23.88	2.65	1.84	2.32	100.00
BT30	6.24	40.11	-	0.64	27.16	2.90	-	4.75	15.19	3.01	100.00
BT31	5.11	46.31	-	-	24.24	-	0.33	6.62	15.08	2.31	100.00
BT32	1.42	28.00	-	-	11.88	-	19.34	16.02	23.02	0.32	100.00
BT33	6.28	63.97	-	-	2.76	-	7.54	3.18	16.17	0.10	100.00
BT35	2.41	70.00	-	-	2.49	-	3.57	-	20.53	1.00	100.00
BT36	0.66	56.43	-	-	19.51	2.94	-	1.98	16.24	2.24	100.00
BT40	1.44	11.67	-	-	10.27	-	18.70	28.10	28.22	1.60	100.00
BT43	19.47	48.40	-	-	16.95	-	2.77	0.11	11.88	0.42	100.00
BT45	4.60	49.01	-	-	12.34	-	11.94	20.97	1.14	-	100.00
BT46	2.03	62.25	-	-	1.86	-	18.03	0.32	14.06	1.45	100.00
BT47	21.90	47.09	-	-	1.68	-	25.21	1.59	0.25	3.28	100.00

Sample Number	Quartz	Plagio-clase	Pyroxene	Altered Pyroxene	Epidote	Clino-zosite	Chlorite	Sericite	Opaque	Others	Total
BT51	2.40	37.92	-	-	12.31	-	15.74	27.21	4.42	-	100.00
BT59	9.63	37.32	-	-	8.68	-	7.23	1.45	35.69	-	100.00
BT60	4.11	41.08	-	-	20.87	-	0.64	4.13	29.17	-	100.00
BT63	3.02	55.29	-	0.18	19.52	2.95	-	-	18.65	0.39	100.00
BT66	5.34	19.59	-	-	9.17	-	8.65	39.75	17.50	-	100.00
BT69	3.67	24.89	-	-	7.24	-	13.92	24.52	25.76	-	100.00
BT71	4.45	17.00	-	55.54	2.53	-	6.78	-	12.89	0.81	100.00
BT72	4.87	40.64	-	-	17.17	-	7.17	3.40	26.50	0.25	100.00
BT82	1.44	26.60	-	-	33.56	-	4.04	3.40	27.33	3.63	100.00
BT83	9.47	35.99	-	-	45.99	-	-	-	7.70	0.85	100.00
BT88	12.53	16.43	-	40.09	19.07	-	-	-	11.88	-	100.00
BT89	15.81	39.06	-	-	3.50	-	21.80	4.16	14.06	1.61	100.00
BT94	3.64	56.03	-	-	7.44	-	15.98	0.49	15.25	1.17	100.00
BT95	2.66	68.84	-	-	1.02	-	8.94	-	18.25	0.29	100.00
BT101	21.80	23.73	-	-	2.87	-	27.91	1.23	17.78	4.68	100.00
BT102	6.84	44.70	-	-	7.50	-	-	4.32	36.64	-	100.00
BT108	17.00	11.19	-	-	58.28	-	0.44	2.19	8.77	2.13	100.00
BT109	5.95	63.00	-	-	10.86	-	-	0.59	17.88	1.72	100.00
BT114	16.91	17.82	-	-	53.48	-	-	-	11.79	-	100.00
BT121	22.95	49.87	-	-	5.45	-	8.60	-	13.13	-	100.00

optical and (ii) chemical.

i) Optical method

The main approach of this method is based on thin section study. The present study reveals that the plagioclases are present in almost all the sections. The mineral occurs as enhedral crystals, small laths and as microlites (Plate 6, figs. 1,2 & 3). The crystals are mostly twinned on the albite law and twin lamallae are mostly broad, few and sharp. The optical orientation of the plagioclases changes with the composition. The anorthite content of the plagioclases varies from 52% to 70%.

ii) Chemical method

This method is predominantly based on the chemical analysis of the pure plagioclases. Pure fraction of plagioclases were obtained according to the method of Emmons (1961) as modified by Henlay (1977). In this case the heavy liquids like tetrabromoethane and carbontetrachloride are used to a standard specific gravity for the separation of pure plagioclases from other mineral constituents. Before this heavy liquid separation the plagioclases were separated on an isodynamic separator. Pure concentrates of the plagioclases were later on obtained by resorting to separation with the help of heavy liquids and finally by hand picking. Great care has been taken to obtain pure mineral fractions and the results reveal that the separation process has been highly successful.

Pure concentrates of plagioclases thus obtained were **chemically analysed** by the rapid method for their major elements, and the structural formulae of analysed plagioclases, computed on the basis of 32(O) atoms are given in table 4. The chemical data show very small percentages of Mg and Fe^{+2} which may occur as impurities in the plagioclase structure (Deer et al. 1963). The normative plagioclases have been found to range in composition from An_{52} to An_{77}.

EPIDOTE

Epidote is also pursued along two methods i.e. optical and chemical method.

(i) Optical method

Epidote is the most important mineral and present in abundance in the traps of Banihal area. It is generally found in the shape of sporadic crystals as well as aggregates of small enhedral grains (Plate 5, figs. 5 & 6). This mineral shows interference colours varying from second to third order. Five samples of epidotes were separated by the usual separation method and subjected to chemical

Table 4. Chemical analyses of Plagioclases from Panjal Traps of Banihal area.

Sample	BT121	BT63	BT94	BT109	BT95
Number	1	2	3	4	5
Constituents					
SiO_2	48.88	49.65	52.24	54.53	55.66
Al_2O_3	32.54	31.95	29.95	28.60	28.04
TiO_2	0.02	0.05	0.04	–	0.05
Fe_2O_3	0.55	0.50	0.98	0.90	0.38
FeO	0.10	0.10	0.12	0.16	0.08
MgO	0.10	0.20	0.08	0.05	0.06
MnO	-	-	Tr	0.01	0.01
CaO	15.45	14.45	12.20	11.10	10.20
Na_2O	2.55	3.10	4.20	5.04	5.45
K_2O	0.12	0.10	0.30	0.15	0.40
H_2O^+	0.05	0.03	0.05	0.04	0.07
H_2O^-	0.03	-	-	0.01	0.02
Total	100.39	100.13	100.16	100.59	100.42

Table 4. Number of ions on the basis of 32(O)

Sample Number	BT121 1	BT63 2	BT94 3	BT109 4	BT95 5
Constituents					
Si	8.910	9.055	9.480	9.809	9.987
Al	6.992	6.869	6.408	6.065	5.932
Fe^{+3}	0.075	0.069	0.134	0.122	0.051
Ti	0.003	0.007	0.005	-	0.007
Mg	0.027	0.055	0.022	0.013	0.016
Fe^{+2}	0.015	0.015	0.018	0.024	0.012
Mn	-	-	-	0.001	0.001
Na	0.900	1.096	1.479	1.758	1.896
Ca	3.017	2.823	2.372	2.139	1.961
K	0.028	0.022	0.070	0.035	0.091
Or	0.57	0.57	1.71	1.13	2.24
Ab	21.75	26.60	36.39	43.16	46.61
An	77.68	72.83	61.90	55.71	51.15
$X(Ca+Na+K+Fe^{+2}+Mg)$	3.97	4.01	3.96	4.03	3.98
$Z(Si+Al+Fe^{+3}+Ti)$	15.98	16.00	16.03	16.00	15.98
Ab	21.87	26.76	37.03	43.66	47.68
An	78.13	73.24	62.97	56.34	52.32

studies.

(ii) Chemical method

Pure concentrates of epidotes isolated from the traps under study were chemically analysed by the rapid method for their major element study. The data thus obtained are tabulated in table 5. The structural formulae of the analysed samples calculated on the basis of 13 (O,OH) are also given in the same table. It has been observed from the analytical data that the epidotes under study correspond to epidote/zoisite variety.

CHLORITE

Chlorite is also determined by both optical and chemical method.

(i) Optical method

This mineral has been studied along the same pattern as the Plagioclases and epidotes. Chlorite is generally green in colour and sometimes shows pleochroism. It shows abnormal Berlin blue interference colours. Chlorite is an alteration product of original pyroxenes and mostly occurs as wisps and scales (Plate 4, figs. 4,5 & 6 and Plate 5, figs. 1,2,3 & 4).

(ii) Chemical method

Five chlorite samples have been chemically analysed

Table 5. Chemical analyses of Epidotes from Panjal Traps of Banihal area.

Sample Number	BT30 1	BT114 2	BT108 3	BT83 4	BT82 5
Constituents					
SiO_2	36.60	37.22	38.66	40.47	40.65
Al_2O_3	22.20	23.20	25.90	30.67	30.76
TiO_2	-	-	0.10	0.09	Tr
Fe_2O_3	16.20	13.80	8.90	0.70	0.52
FeO	0.50	0.60	0.90	1.63	1.27
MgO	0.10	0.20	0.15	0.60	0.74
MnO	-	0.24	0.04	-	-
CaO	22.90	23.40	23.80	23.10	22.96
Na_2O	0.02	0.03	0.01	0.02	0.01
K_2O	0.01	0.02	-	-	-
H_2O^+	1.40	1.30	1.50	2.57	2.75
H_2O^-	0.25	0.15	0.10	0.30	0.45
Total	100.18	100.16	100.06	100.15	100.11

Table 5. Number of ions on the basis of 13 (O, OH)

Sample Number	BT30 1		BT114 2		BT108 3		BT83 4		BT92 5	
Constituents										
Si	2.948	3.00	2.987	3.00	3.043	3.04	3.046	3.05	3.042	3.04
Al	0.052		0.013		-		-		-	
Al	2.057	3.04	2.182	3.02	2.403	2.94	2.722	2.77	2.713	2.74
Ti	-		-		0.006		0.005		-	
Fe^{+3}	0.982		0.833		0.527		0.039		0.029	
Fe^{+2}	0.033	2.03	0.040	2.10	0.059	2.09	0.103	2.04	0.080	2.01
Mg	0.012		0.024		0.018		0.067		0.082	
Ca	1.977		2.012		2.007		1.863		1.841	
Mn	-		0.016		0.003		-		-	
Na	0.003		0.005		0.002		0.003		0.002	
K	0.001		0.002		-		-		-	
OH	0.887		0.775		0.840		1.441		1.597	

for their major element by the rapid method. The data thus obtained are given in table 6. The structural formulae of the analysed chlorite samples computed on the basis of 28 oxygen equivalents ignoring water are also given in the same table.

The optical and chemical studies confirm that the chlorites under study are of Chamosite variety.

QUARTZ

It is generally seen in the form of small grains dispersed through the rock sections and occur as an important released mineral in basic rocks. Occasionally, it is found as an important infilling material in rock cavities (Plate 3, figs. 5 & 6 and Plate 4, figs. 1,2 & 3). It is present in various proportions in different rocks, but its percentage is more in epidosites. Large grains of quartz contain inclusions of ilmenite/magnetite. It shows undulatory extinction and first order grey interference colours.

ILMENITE/MAGNETITE AND OPAQUES

Ilmenite and magnetite usually occur as small grains and specks and the former generally altered to leucoxene.

Table 6. Chemical analyses of Chlorites from Panjal Traps of Banihal area.

Sample Number	BT18 1	BT193 2	BT89 3	BT101 4	BT47 5
Constituents					
SiO_2	31.82	31.40	30.60	27.60	26.34
Al_2O_3	15.50	17.80	18.20	19.00	18.23
TiO_2	0.18	0.12	0.08	Tr	Tr
Fe_2O_3	1.86	2.20	2.70	5.40	6.40
FeO	3.96	4.60	4.00	22.57	24.30
MgO	32.80	31.60	33.20	15.71	13.20
MnO	-	-	-	0.02	0.04
CaO	Tr	Tr	Tr	0.40	0.50
Na_2O	0.04	Tr	0.03	0.16	0.20
K_2O	0.02	0.03	0.12	0.06	0.12
H_2O^+	12.94	11.60	10.50	9.10	10.20
H_2O^-	0.95	0.70	0.60	0.35	0.70
Total	100.07	100.05	100.03	100.37	100.23

Table 6. Number of ions on the basis of 28(O) equivalents, ignoring water

Sample Number	BT18 1		BT193 2		BT189 3		BT101 4		BT47 5	
Constituents										
Si	6.117	8.00	5.945	8.00	5.732	8.00	5.608	8.00	5.546	8.00
Al	1.883		2.055		2.268		2.392		2.454	
Al	1.629	11.98	1.918	11.90	1.751	12.08	2.158	11.75	2.072	11.75
Ti	0.026		0.017		0.011		-		-	
Fe^{+3}	0.269		0.313		0.380		0.825		1.014	
Fe^{+2}	0.636		0.728		0.627		3.835		4.279	
Mg	9.397		8.916		9.268		4.757		4.142	
Mn	-		-		0.004		0.004		0.015	
Ca	-		-		-		0.087		0.113	
Na	0.014		-		0.011		0.064		0.081	
K	0.005		0.007		0.029		0.015		0.033	
OH	16.00		16.00		16.00		16.00		16.00	

MAJOR AND TRACE ELEMENT STUDY
OF PANJAL VOLCANICS

MAJOR ELEMENTS

The petrochemistry of rocks is an important and fundamental basis for assessing their chemical variation and behaviour. In order to discuss the petrochemical study of Panjal Traps of the Banihal area, thirty selected representative rock samples have been chemically analysed for their major and trace elements by rapid method of rock analysis. In this chapter, an effort has been made to investigate the various trends of major and trace elements of the volcanics under reference.

The analytical data thus obtained have been treated in terms of binary and ternary variation diagrams. From the chemical data it is revealed that the SiO_2 percentage of the rocks varies from 43.68 percent to 56.50 percent. The rocks are mostly rich in iron, low in alkalis and show overall basic character.

The major element data in respect of the rocks of the study area are listed in table 7. The C.I.P.W. norms and Niggli values calculated from the chemical analyses are presented in tables 8 and 9. Table 10 shows the values of cation per hundred oxygen anions of the trap rocks of the study area.

Initially the analytical data have been used in terms of binary variation diagrams which are drawn after Harker, Larsen, Thornton and Tuttle, Poldervaart and Parker and Kuno. Secondly the trap rocks of Banihal area have been plotted in terms of bivariate plots as recommended by some workers for assessing the nature of the primary basaltic magma. In the third instance the rocks of the study area

Table 7. Chemical analyses of Panjal Traps of Banihal area.

Sample number Constituents	BT86 1	BT109 2	BT189 3	BT101 4	BT73 5	BT71 6	BT58 7	BT5 8	BT115 9	BT28 10
SiO_2	43.68	43.85	43.96	44.90	45.56	46.84	46.92	47.52	47.80	48.28
Al_2O_3	18.32	19.38	17.90	14.88	18.40	14.46	16.72	15.80	14.14	19.00
TiO_2	1.75	1.98	1.40	2.18	1.54	1.82	1.54	1.96	0.84	1.75
Fe_2O_3	4.90	3.80	3.12	4.10	3.60	4.32	2.80	4.30	4.75	3.45
FeO	8.55	9.10	11.78	10.50	8.25	9.40	8.53	9.20	7.25	8.40
MgO	5.84	5.66	6.60	4.43	5.85	5.85	6.50	3.85	6.24	3.62
CaO	9.89	9.00	9.17	13.05	9.20	11.78	9.53	9.16	12.61	7.36
Na_2O	1.30	1.20	0.85	1.55	1.85	2.00	2.00	2.05	2.00	1.85
K_2O	0.60	0.70	0.40	0.20	0.50	0.70	0.50	0.88	0.70	1.05
MnO	0.16	0.18	0.11	0.16	0.17	0.17	0.15	0.19	0.18	0.17
H_2O^+	3.94	3.78	3.75	2.89	3.50	1.95	3.34	3.76	2.85	3.80
H_2O^-	1.05	1.42	0.98	1.20	1.54	0.70	1.56	1.35	0.62	1.33
Total	99.98	100.05	100.02	100.04	99.96	99.99	100.09	100.02	99.98	100.06

Location of the analysed samples.

1. 33° 27' 31" : 75° 15' 10"
2. 33° 28' 04" : 75° 15' 20"
3. 33° 28' 13" : 75° 15' 00"
4. 33° 28' 34" : 75° 15' 16"
5. 33° 28' 20" : 75° 14' 38"

Location of the analysed samples.

6. 33° 28' 41" : 75° 14' 16"
7. 33° 28' 49" : 75° 14' 36"
8. 33° 28' 52" : 75° 14' 36"
9. 33° 28' 52" : 75° 14' 10"
10. 33° 29' 43" : 755 14' 00"

Table 7. Chemical analyses of Panjal Traps of Banihal area.

Sample number Constituents	BT175 11	BT196 12	BT165 13	BT94 14	BT95 15	BT171 16	BT121 17	BT111 18	BT63 19	BT138 20
SiO_2	48.84	49.36	49.84	50.80	50.92	50.96	51.10	51.50	51.90	51.88
Al_2O_3	16.64	16.93	15.40	14.93	14.95	16.86	15.95	16.96	17.18	13.00
TiO_2	1.12	1.10	1.33	1.12	1.40	1.61	1.20	1.26	1.12	1.47
Fe_2O_3	2.22	2.38	1.32	2.50	4.07	3.70	1.45	2.25	2.22	4.51
FeO	9.18	8.32	9.48	7.10	7.18	7.32	6.83	8.70	8.10	7.04
MgO	5.20	5.60	5.84	6.81	4.83	4.72	5.84	4.63	4.63	5.24
CaO	8.93	8.16	8.70	9.36	7.85	6.90	8.80	6.86	6.57	11.50
Na_2O	2.20	2.18	2.26	2.32	2.44	2.40	2.48	2.30	3.00	1.90
K_2O	1.35	1.25	0.60	0.98	0.78	0.80	0.98	1.02	0.78	0.80
MnO	0.14	0.14	0.14	0.12	0.16	0.15	0.13	0.19	0.13	0.18
H_2O^+	2.90	3.08	3.84	2.95	3.88	3.46	3.75	2.98	2.86	1.10
H_2O^-	1.26	1.58	1.26	0.98	1.52	1.15	1.48	1.36	1.45	0.35
Total	99.98	100.08	100.01	99.97	99.98	100.03	99.99	100.01	99.94	99.97

Location of the analysed samples

11.	33° 28' 52"	: 75° 13' 34"
12.	33° 29' 48"	: 75° 12' 54"
13.	33° 30' 07"	: 75° 13' 34"
14.	33° 30' 22"	: 75° 12' 54"
15.	33° 30' 24"	: 75° 12' 40"

Location of the analysed samples

16.	33° 30' 19"	: 75° 12' 34"
17.	33° 30' 00"	: 75° 12' 16"
18.	33° 30' 41"	: 75° 12' 24"
19.	33° 30' 39"	: 75° 12' 16"
20.	33° 30' 41"	: 75° 12' 00"

Table 7. Chemical analyses of Panjal Traps of Banihal area.

Sample number Constituents	BT102 21	BT36 22	BT152 23	BT132 24	BT22 25	BT40 26	BT141 27	BT200 28	BT33 29	BT160 30
SiO_2	52.95	53.90	53.98	54.80	54.88	55.60	55.68	55.78	56.48	56.50
Al_2O_3	13.50	13.96	14.93	15.43	14.25	15.50	15.39	14.25	13.75	12.94
TiO_2	2.02	1.40	0.98	1.12	1.61	0.98	1.26	1.12	0.98	1.21
Fe_2O_3	3.20	2.85	2.48	1.53	2.17	2.15	1.70	2.25	3.07	5.20
FeO	11.05	6.25	7.04	7.47	6.60	6.70	8.15	7.35	7.70	8.02
MgO	5.04	4.80	6.24	4.22	3.02	4.63	5.03	5.00	5.45	3.85
CaO	6.32	9.48	7.50	8.24	9.80	6.80	7.60	8.60	7.01	6.78
Na_2O	2.70	2.40	3.00	2.45	3.00	2.80	1.78	3.05	2.86	3.08
K_2O	0.70	1.15	1.20	0.80	1.30	1.20	0.80	0.70	1.00	1.10
MnO	0.17	0.12	0.15	0.14	0.13	0.14	0.13	0.14	0.14	0.11
H_2O^+	1.60	2.95	1.50	2.80	2.38	2.80	2.14	1.45	1.34	0.90
H_2O^-	0.80	0.72	1.08	1.04	0.88	0.68	0.40	0.36	0.24	0.30
Total	100.05	99.98	100.08	100.04	100.02	99.98	100.06	100.05	100.02	99.99

Location of the analysed samples				Location of the analysed samples			
21.	33° 30' 58"	:	75° 12' 04"	26.	33° 31' 44"	:	75° 10' 44"
22.	33° 30' 43"	:	75° 11' 42"	27.	33° 31' 46"	:	75° 10' 12"
23.	33° 31' 01"	:	75° 11' 27"	28.	33° 31' 39"	:	75° 10' 00"
24.	33° 31' 36"	:	75° 11' 00"	29.	33° 31' 53"	:	75° 09' 56"
25.	33° 31' 25"	:	75° 10' 30"	30.	33° 31' 53"	:	75° 09' 20"

Table 8. C.I.P.W. norms of Banihal Traps.

Sample number Norm Minerals		BT86 1	BT109 2	BT189 3	BT101 4	BT73 5	BT71 6	BT58 7	BT5 8	BT115 9	BT28 10
Quartz	(Qz)	1.32	1.86	0.78	1.86	1.14	0.30	1.02	5.28	1.14	7.86
Orthoclase	(Or)	3.34	3.89	2.22	1.11	2.78	3.89	2.78	5.00	3.89	6.12
Albite	(Ab)	11.00	9.96	7.34	13.10	15.72	16.77	16.77	17.29	16.77	15.72
Anorthite	(An)	42.53	44.76	43.65	32.25	40.31	28.63	35.31	31.41	27.80	36.42
Corundum	(C)	-	0.31	-	-	-	-	-	-	-	1.43
Diopside	(Wo)	2.78	-	0.81	13.57	2.20	12.41	4.99	5.92	14.50	-
	(En)	1.60	-	0.40	6.30	1.30	6.80	2.80	2.80	8.90	-
	(Fs)	1.06	-	0.40	7.13	0.79	5.15	1.98	3.04	4.75	-
Hypersthene	(En)	13.00	14.20	16.10	4.80	13.30	7.80	14.50	6.80	6.70	9.10
	(Of)	7.92	10.56	16.24	5.41	9.11	5.81	8.98	7.39	3.56	9.90
Magnetite	(Mt)	7.19	5.57	4.64	6.03	5.34	6.26	4.18	6.26	6.96	5.10
Ilmenite	(Il)	3.34	3.80	2.74	4.10	2.89	3.50	2.89	3.80	1.67	3.34
Water	(H_2O)	4.99	5.20	4.73	4.09	5.04	2.65	4.90	5.11	3.47	5.13
Total		100.07	100.11	100.05	99.75	99.92	99.97	100.10	100.10	100.11	100.12

Table 8. C.I.P.W. norms of Banihal Traps.

Sample number Norm Minerals		BT175 11	BT196 12	BT165 13	BT94 14	BT95 15	BT171 16	BT121 17	BT111 18	BT63 19	BT138 20
Quartz	(Qz)	0.90	2.52	3.60	3.48	8.82	8.52	4.20	7.14	5.82	9.78
Orthoclase	(Or)	7.78	7.23	3.34	5.56	4.45	5.00	5.56	6.12	4.45	5.00
Albite	(Ab)	18.34	18.34	18.86	19.39	20.44	20.44	20.96	19.39	25.15	16.24
Anorthite	(An)	31.69	32.80	30.30	27.52	27.80	32.53	29.47	32.80	31.14	24.19
Corundum	(C)	-	-	-	-	-	-	-	-	-	-
Diopside	(Wo)	5.22	3.25	5.34	7.89	4.64	0.70	5.92	0.58	0.58	13.69
	(En)	2.50	1.70	2.60	4.80	2.70	0.40	3.40	0.30	0.30	8.30
	(Fs)	2.64	1.45	2.64	2.64	1.72	0.26	2.24	0.26	0.26	4.62
Hypersthene	(En)	10.50	12.30	12.00	12.20	9.40	11.40	11.20	11.30	11.30	4.80
	(Of)	10.82	10.30	11.75	6.73	6.07	7.79	7.39	12.14	11.22	2.64
Magnetite	(Mt)	3.25	3.48	1.86	3.71	5.80	5.34	2.09	3.25	3.25	6.50
Ilmenite	(Il)	2.13	2.13	2.58	2.13	2.74	3.04	2.28	2.43	2.13	2.74
Water	(H_2O)	4.16	4.66	5.10	3.93	5.40	4.61	5.23	4.34	4.31	1.45
Total		99.93	100.16	99.97	99.98	99.98	100.03	99.94	100.05	99.91	99.95

Table 8. C.I.P.W. norms of Banihal Traps.

Sample number Norm Minerals		BT102 21	BT36 22	BT152 23	BT132 24	BT22 25	BT40 26	BT141 27	BT200 28	BT33 29	BT160 30
Quartz	(Qz)	8.82	9.84	5.22	10.92	9.24	10.68	14.22	9.30	10.92	13.38
Orthoclase	(Or)	3.89	6.67	7.23	5.00	7.78	7.23	5.00	3.89	6.12	6.67
Albite	(Ab)	23.06	20.44	25.15	20.96	25.15	23.58	15.20	25.68	24.10	26.20
Anorthite	(An)	22.52	23.91	23.63	28.36	21.68	26.13	31.41	23.35	21.68	18.07
Corundum	(C)	-	-	-	-	-	-	-	-	-	-
Diopside	(Wo)	3.71	9.63	5.68	5.22	11.25	3.13	2.67	8.12	5.45	6.50
	(En)	1.70	5.80	3.40	2.50	5.40	1.70	1.40	4.40	3.00	3.30
	(Fs)	1.98	3.30	1.98	2.64	5.68	1.32	1.19	3.43	2.24	3.04
Hypersthene	(En)	10.90	6.20	12.20	8.10	2.20	9.90	11.20	8.10	10.60	6.30
	(Of)	12.54	3.70	7.52	8.18	2.24	7.92	10.43	6.60	8.05	5.54
Magnetite	(Mt)	4.64	4.18	3.71	2.32	3.25	3.02	2.55	3.25	4.41	7.76
Ilmenite	(Il)	3.80	2.74	1.82	2.13	3.04	1.82	2.43	2.13	1.82	2.28
Water	(H_2O)	2.40	3.67	2.58	3.84	3.26	3.48	2.54	1.81	1.58	1.20
Total		99.96	100.08	100.12	100.17	100.17	99.91	100.24	100.06	99.97	100.14

Table 9. Niggli values of Banihal Traps

Sample Number	Constituents							
	Si	qz	al	fm	c	alk	k	mg
BT86	102	-14	25	46	25	4	0.22	0.45
BT109	105	-11	27	46	23	4	0.27	0.45
BT189	101	- 7	24	51	23	2	0.22	0.45
BT101	105	-11	20	43	33	4	0.07	0.36
BT73	111	- 9	26	45	24	5	0.14	0.48
BT71	108	-12	20	46	29	5	0.18	0.44
BT58	114	- 6	24	46	25	5	0.14	0.51
BT5	124	- 4	24	43	26	7	0.21	0.35
BT115	111	-13	19	44	31	6	0.18	0.49
BT28	132	+ 4	31	41	21	7	0.27	0.36
BT175	124	- 4	25	44	24	7	0.29	0.45
BT196	127	- 1	26	44	23	7	0.27	0.49
BT165	129	+ 5	24	46	24	6	0.14	0.50
BT94	128	0	22	46	25	7	0.21	0.56
BT95	140	+ 8	24	45	23	8	0.17	0.45
BT171	141	+ 9	27	44	21	8	0.19	0.44
BT121	137	+ 5	25	42	25	8	0.20	0.56
BT111	143	+11	28	44	20	8	0.23	0.44
BT63	145	+ 9	28	43	20	9	0.14	0.45
BT138	134	+10	19	44	31	6	0.23	0.46
BT102	144	+12	22	52	18	8	0.14	0.39
BT36	150	+14	23	40	28	9	0.24	0.49
BT152	144	+ 4	23	46	21	10	0.21	0.55
BT132	158	+22	26	40	25	9	0.18	0.46
BT22	160	+16	24	34	31	11	0.23	0.39
BT40	164	+24	27	42	21	10	0.22	0.49
BT141	158	+34	26	45	23	6	0.24	0.48
BT200	154	+18	23	42	26	9	0.13	0.49
BT33	157	+21	23	47	21	9	0.19	0.48
BT160	162	+22	22	47	21	10	0.19	0.35

Table 10. Cations of chemically analysed samples of Banihal traps.

Sample No.	CONSTITUENTS										
	Si	Al	Ti	Fe^{+3}	Fe^{+2}	Mg	Ca	Na	K	Mn	H
BT86	20.42	9.70	1.05	3.43	6.65	3.52	7.07	0.96	0.50	0.12	0.55
BT109	20.50	10.26	1.19	2.66	7.07	3.41	6.43	0.89	0.58	0.14	0.58
BT189	20.55	9.47	0.84	2.18	9.16	3.98	6.55	0.63	0.33	0.08	0.53
BT101	20.99	7.88	1.31	2.87	8.16	2.67	9.33	1.15	0.17	0.12	0.45
BT73	21.30	9.74	0.92	2.52	6.41	3.53	6.57	1.37	0.41	0.13	0.56
BT71	21.90	7.65	1.09	3.02	7.31	3.53	8.42	1.48	0.58	0.13	0.29
BT58	21.93	8.85	0.92	1.96	6.63	3.92	6.81	1.48	0.41	0.12	0.54
BT5	22.21	8.36	1.17	3.01	7.15	2.32	6.55	1.52	0.73	0.15	0.57
BT115	22.34	7.48	0.50	3.32	5.64	3.76	9.01	1.48	0.58	0.14	0.38
BT28	22.57	10.06	1.05	2.41	6.53	2.18	5.26	1.37	0.87	0.13	0.57
BT175	22.83	8.81	0.67	1.55	7.14	3.14	6.38	1.63	1.12	0.11	0.46
BT196	23.07	8.96	0.66	1.66	6.47	3.38	5.83	1.62	1.04	0.11	0.52
BT165	23.30	8.15	0.80	0.92	7.37	3.52	6.22	1.68	0.50	0.11	0.57
BT94	23.75	7.90	0.67	1.75	5.52	4.11	6.69	1.72	0.81	0.09	0.44
BT95	23.80	7.91	0.84	2.85	5.48	2.91	5.61	1.81	0.65	0.12	0.60
BT171	23.82	8.92	0.96	2.59	5.69	2.85	4.93	1.78	0.66	0.12	0.51
BT121	23.89	8.44	0.71	1.01	5.31	3.52	6.29	1.84	0.81	0.10	0.58
BT111	24.07	8.98	0.75	1.57	6.76	2.79	4.90	1.71	0.85	0.15	0.48
BT63	24.26	9.09	0.67	1.55	6.30	2.79	4.69	2.23	0.65	0.10	0.48
BT138	24.72	6.88	0.88	3.15	5.47	3.16	8.22	1.41	0.66	0.14	0.16
BT102	24.75	7.14	1.21	2.24	8.59	3.04	4.52	2.00	0.58	0.13	0.27
BT26	25.20	7.39	0.84	1.99	4.86	2.89	6.77	1.78	0.95	0.09	0.41
BT152	25.23	7.90	0.59	1.73	5.47	3.76	5.36	2.23	1.00	0.12	0.29
BT132	25.62	8.17	0.67	1.07	5.81	2.54	5.89	1.82	0.66	0.11	0.43
BT22	25.62	7.54	0.96	1.52	5.13	1.82	7.00	2.23	1.08	0.10	0.36
BT40	25.99	8.20	0.59	1.50	5.21	2.79	4.86	2.08	1.00	0.11	0.39
BT141	26.03	8.14	0.75	1.19	6.33	3.03	5.43	1.32	0.66	0.10	0.28
BT200	26.07	7.54	0.67	1.57	5.71	3.01	6.15	2.26	0.58	0.11	0.20
BT33	26.40	7.28	0.59	2.15	5.99	3.29	5.01	2.12	0.83	0.11	0.17
BT160	26.41	6.85	0.72	3.64	6.23	2.32	4.85	2.28	0.91	0.08	0.13

have been investigated in terms of two component diagrams as suggested by different investigators for deciphering the differentiation trend of basaltic magmas. Fourthly the rocks of the area under reference have been studied according to the various methods advocated by some workers for comparing the typical rock suites and trend lines from many parts of the world. Lastly the chemical data of the rocks of the present area have been treated in terms of ternary variation diagrams and interpreted.

BINARY VARIATION DIAGRAMS

The following binary variation diagrams have been plotted :

HARKER VARIATION DIAGRAM

Harker (1909) advanced the oldest method of plotting of SiO_2 as abscissa and the remaining oxides as ordinate for studying the variation in the chemistry of igneous rocks. Text figure 4 is a Harker plot for the rocks of the study area.

An inspection of this figure shows a sympathetic relationship of K_2O, Na_2O and also total alkalis with silica. The oxides MgO, CaO, FeO, Fe_2O_3 and TiO_2 display a downward trend with the increase of SiO_2. The behaviour of Al_2O_3 is erratic and the various points are randomly distributed. An attempt has, however, been made to connect them with a curve. Al_2O_3 curve displays a scattering of points, and a general downward tendency with the rise of silica. The behaviour of Al_2O_3 in rocks is reported to be erratic. It may be possibly due to the fact that there is no exact method for determining Al_2O_3 in rocks and it is always calculated by difference.

This figure reveals a magmatic differentiation trend of the rocks under reference. The process of differentiation is in decreasing order of basicity, having proceeded from rocks of more basic to less basic character.

LARSEN VARIATION DIAGRAM

Larsen (1938) suggested a method for portraying the variation in the chemistry of igneous rocks whereby SiO_2, K_2O, CaO, MgO, FeO are compounded as 1/3 SiO_2 + K_2O - (MgO + CaO + FeO) termed as "Larsen Index". As per this method various oxide weight percentages are plotted as ordinate against the Larsen Indices as abscissa. Larsen scheme (op.cit.) is based on the principle that significant changes are observed in the behaviour of SiO_2, K_2O, CaO, MgO and FeO for rocks ranging in composition from basic to acidic types and that the oxides that form the components of Larsen Index are the important constituents needed to establish the consanguinity of igneous rocks. The oxides Al_2O_3 and Na_2O are excluded from the Index Components because they are thought to play a subsidary role by Larsen in magmatic differentiation; as the former generally shows a random behaviour and the latter varies insignificantly in its content with respect to Silica.

Text figure 5 shows the Larsen plot for the rocks of the study area. Larsen Indices computed from the present analytical data are given in table 11a. From this figure, it is seen that with the increase in the value of Larsen indices there is an increase of alkalis (Na_2O, K_2O) and also of the combined alkalis. The oxides CaO, MgO, Fe_2O_3, FeO, TiO_2 and Al_2O_3 register a downward trend with the fall in the value of Larsen Indices. The curve for SiO_2 displays some scattering of points but a general upward tendency is noticed, with rising value of Larsen Indices, which is later fractions appears to vary in a steady manner. It may be pointed out in the end that the behaviour of all the curves points to a definite differentiation trend of the rocks under discussion.

THORNTON AND TUTTLE VARIATION DIAGRAM

In the year (1937) Bowen concluded that the crystallization of silicate melts finally approaches the system SiO_2 - $NaAlSiO_4$ and $KAlSiO_4$ named as Petrogeny's

Table 11a. Larsen Indices of Banihal traps.

Sample No.	BT86 1	BT109 2	BT189 3	BT101 4	BT73 5	BT71 6	BT58 7	BT5 8	BT115 9	BT28 10
L.I.	-9.12	- 8.44	-12.50	-12.81	-7.61	-10.72	-8.42	-5.49	-9.47	-2.24

Table 11b. Differentiation Indices of Bänihal traps.

D.I.	15.66	15.71	10.34	16.07	19.64	20.96	20.57	27.57	21.80	29.70

Table 11c. Crystallization Indices of Banihal traps.

C.I.	55.09	55.02	55.79	49.20	52.43	48.77	50.81	42.22	51.70	44.23

Table 11d. Solidification Indices of Banihal traps.

S.I.	27.56	27.66	29.01	21.32	29.18	26.27	31.97	18.98	29.80	19.71

Table 11a. Larsen Indices of Banihal traps.

Sample No.	BT175 11	BT196 12	BT165 13	BT94 14	BT95 15	BT171 16	BT121 17	BT111 18	BT63 19	BT138 20
L.I.	-5.68	- 4.38	-6.81	-5.36	-2.11	-1.15	-3.46	-2.00	-1.22	-5.35

Table 11b. Differentiation Indices of Banihal traps.

D.I.	27.02	28.09	25.80	25.43	33.71	33.96	30.72	32.65	35.64	31.02

Table 11c. Crystallization Indices of Banihal traps.

C.I.	44.44	45.09	44.32	46.42	40.21	41.38	44.65	41.37	39.71	45.45

Table 11d. Solidification Indices of Banihal traps.

S.I.	25.81	28.38	29.95	34.55	25.03	24.92	33.22	24.50	24.72	26.89

Table 11a. Larsen Indices of Banihal traps.

Sample No.	BT102 21	BT36 22	BT152 23	BT132 24	BT22 25	BT40 26	BT141 27	BT200 28	BT33 29	BT160 30
L.I.	-4.06	-1.41	-1.59	-0.86	+0.17	+1.60	-1.42	-1.66	-0.33	+1.28

Table 11b. Differentiation Indices of Banihal traps.

D.I.	35.77	36.95	37.60	36.88	42.17	51.49	34.42	38.87	41.14	46.25

Table 11c. Crystallization Indices of Banihal traps.

C.I.	33.83	40.77	39.51	39.43	34.87	36.74	42.28	38.52	35.58	29.61

Table 11d. Solidification Indices of Banihal traps.

S.I.	22.21	27.51	31.26	25.62	18.77	26.49	28.81	27.25	27.14	18.12

"residual system". The study of the ternary systems $Mg_2Al_4Si_5O_{18}$ (Cordierite) - $KAlSi_2O_6$ (Leucite) - SiO_2 (Silica) and $Mg_2Al_4Si_5O_{18}$ (Cordierite) - $NaAlSi_3O_{18}$ (Albite) - SiO_2 (Silica) by Schairer (1954,1957) and of the system $KAlSi_3O_8$ - $CaAl_2Si_2O_8$ - H_2O by Yoder (1957) further support Bowen's (op.cit.) conclusion. This system obviously includes the composition of the following normative mineral molecules :- quartz, orthoclase, albite, nepheline, leucite and kalsilite.

Thornton and Tuttle (1960) introduced a new parameter known as the "Differentiation Index" based on the C.I.P.W. norms of igneous rocks for studying the petrochemical behaviour of igneous rock. The minerals of the residual system represent the salic constituents of the C.I.P.W. norm with the exception of anorthite which is considered as a basic constituent of igneous rocks together with zircon, corundum etc.

Differentiation Index has been defined as the sum of the weight percentages of normative quartz, orthoclase, albite, nepheline, leucite and kalsilite. Text figure 6 shows different oxides plotted as ordinate against the differentiation indices as abscissa for the Panjal Traps of Banihal area. The values of differentiation indices are calculated and listed in table 11b. A study of figure shows that the individual oxides K_2O & Na_2O display an upward trend in a linear manner with the increase in the value of differentiation indices. The total alkalis also behave similarly. Percontra, MgO, CaO, Fe_2O_3, FeO, TiO_2 and Al_2O_3 though showing some scattering of points display a downward trend with the increase in the value of differentiation indices.

An inspection of SiO_2 curve shows that there is scattering of points but an upward tendency with an increase in differentiation index is to be seen. The various curves in this diagram also point towards a magmatic differentiation trend.

POLDERVAART AND PARKER VARIATION DIAGRAM

Poldervaart and Parker (1964) putforth the use of "Crystallization Index" for deciphering the variation in the chemistry of igneous rocks. Here Crystallization Index (C.I.) is plotted along the X-axis and different oxide weight percentages along the y-axis. The felsic and mafic members of the reaction series are considered to play an important role in the fractionation of magma.

The basic idea behind this method is that in the case of the felsic series the fractionation is from Ca →(Na + K); while in the case of mafic series the trend is from Mg → $(Fe^{+2} + Fe^{+3})$. The simple ternary system

$CaAl_2Si_2O_8$ (anorthite), $CaMgSi_2O_6$ (diopside) and Mg_2SiO_4 (forsterite) refers to the earliest part of the reaction series and has as such been named as the "Petrogeny's primitive system". The Crystallization Index (C.I.) suggested by Poldervaart and Parker (op.cit.) as a measure of the level of differentiation attained by a magma is defined as under :

The crystallization index has been considered as the sum of An, Di, Fo' & Sp', where

An = Normative anorthite

Di = Magnesian diopside calculated from normative diopside

Fo' = Normative forsterite plus normative enstatite converted to forsterite

Sp' = Magnesian spinel ($MgAl_2O_4$) calculated from normative corundum in ultramafic rocks.

The value of Di and Fo' are calculated as follows :

$$\text{Di} = \frac{\text{Mol. wt. } CaMgSi_2O_6}{\text{Mol. wt. } MgSiO_3} \times \text{Endi (enstatite of normative diopside)}$$

$$= 2.15,7003 \text{ Endi (enstatite of normative diopside)}$$

$$\text{Fo}' = \text{Normative forsterite} + \frac{\text{Mol.wt. of } Mg_2SiO_4}{2 \times \text{Mol.wt. of } MgSiO_3} \times \text{EnHy}$$

Where En(Hy) is enstatite of normative hypersthene, or

Fo' = Fo + 0.700837 En(Hy) (enstatite of normative hypersthene).

In the case of ultramafic igneous rocks normative corundum is recalculated to normative spinel and included in C.I.

According to Poldervaart and Parker (op.cit.) C.I. lays stress on the early stages of the fractionation of magmas (Petrogeny's primitive system) and takes into account the felsic and mafic members of the reaction series as against the differentiation index of Thornton and Tuttle (op.cit.) which considers only the later stages of fractionation "Petrogeny's Residual System" and does not take into consideration the mafic components of the reaction series. Therefore, the inference deduced from Poldervaart and Parker (op.cit.) variation diagram is of greater significance than that of Thornton and Tuttle (op.cit.) method of representation.

In table 11c the crystallization indices for the analysed samples of the study area are included. Text figure 7 shows different oxide weight percentages plotted along the y-axis with C.I. against the x-axis. It is evident from the inspection of this figure that the curves for K_2O, Na_2O and the combined (Na_2O + K_2O) register a rise with the advanced crystallization of magma. This means that these oxides show an upward trend when we go from more basic to less basic members. The curves for CaO, MgO, Fe_2O_3, FeO, TiO_2 and Al_2O_3 show the reverse trend as compared to the alkalis. A study of this figure shows that as the C.I. values fall, the curves for these oxides display a downward trend. Points lying on the right hand side of the diagram correspond to more basic member from which those lying on the left hand side have been derived. The SiO_2 curve though showing an upward trend with the fall in C.I. values but a wide scattering of points is witnessed here. The behaviour of the various curves in this diagram also points to a magmatic differentiation trend.

KUNO'S VARIATION DIAGRAM

Kuno (1968) proposed the concept of a bivariate diagram on the basis of a new parameter known as the "Solidification Index" which is defined as:

$$\frac{MgO}{MgO + FeO + Fe_2O_3 + Na_2O + K_2O} \times 100$$

Kuno (op.cit.) assumed that "The S.I. value decreases proportionately with the amount of residual liquid". Table 11d shows the S.I. values calculated from the chemical analyses of the rocks under reference. Fig. 8 represents the plotting of S.I. values as abscissa and the remaining oxides as ordinate for the rocks of the study area. From this figure, it is evident that K_2O, Na_2O and the combined (Na_2O + K_2O) exhibit an increase with the decrease in the value of solidification indices. The oxides CaO, MgO, Fe_2O_3, FeO, TiO_2 and Al_2O_3 display a downward trend with falling S.I. values. As far as Al_2O_3 is concerned it shows some scattering of points, but presents a sympathetic relationship with the S.I. values. The curve for SiO_2 portrays a wide scattering of points though its general behaviour is antipathetic to S.I.

KUNO'S K_2O VERSUS Na_2O VARIATION DIAGRAM

Kuno (1959) recommended a binary plot of Soda versus potash. Plate 7 figure 1 shows a plot of K_2O versus Na_2O for the trap rocks of Banihal area. The values of K_2O & Na_2O are given in table 12a. In this diagram there are three fields.

1. Alkali basalt field
2. High alumina basalt field
3. Spilitic field

All the points of the present area are seen to occupy the high alumina basalt field, whereas one point lies

Table 12a. Na_2O and K_2O of Banihal traps.

Sample No.	BT86 1	BT109 1	BT189 3	BT101 4	BT73 5	BT71 6	BT58 7	BT5 8	BT115 9	BT28 10
Na_2O	1.30	1.20	0.85	1.55	1.85	2.00	2.00	2.05	2.00	1.85
K_2O	0.60	0.70	0.40	0.20	0.50	0.70	0.50	0.88	0.70	1.05

Table 12b. SiO_2 and (Na_2O + K_2O) of Banihal traps.

SiO_2	43.68	43.85	43.96	44.90	45.56	46.84	46.92	47.52	47.80	48.28
(Na_2O+K_2O)	1.90	1.90	1.25	1.75	2.35	2.70	2.50	2.93	2.70	2.90

Table 12c. Si and (al+fm)-(c+alk) values of Banihal traps.

Si	102	105	101	105	111	108	114	124	111	132
(al+fm)-(c+alk)	42	46	50	26	42	32	40	34	26	44

Table 12a. Na_2O and K_2O of Banihal traps.

Sample No.	BT175 11	BT196 12	BR165 13	BT94 14	BT95 15	BT171 16	BT121 17	BT111 18	BT63 19	BT138 20
Na_2O	2.20	2.18	2.26	2.32	2.44	2.40	2.48	2.30	3.00	1.90
K_2O	1.35	1.25	0.60	0.98	0.78	0.80	0.98	1.02	0.78	0.80

Table 12b. SiO_2 and $(Na_2O + K_2O)$ of Banihal traps.

SiO_2	48.84	49.36	49.84	50.80	50.92	50.96	51.10	51.50	51.90	52.88
(Na_2O+K_2O)	3.55	3.43	2.86	3.30	3.22	3.20	3.46	3.32	3.78	2.70

Table 12c. Si and (al+fm)-(c+alk) values of Banihal traps.

Si	124	127	129	128	140	141	137	143	145	134
(al+fm)-(c+alk)	38	40	40	36	38	42	34	44	42	26

Table 12a. Na_2O and K_2O of Banihal traps.

Sample No.	BT102 21	BT36 22	BT152 23	BT132 24	BT22 25	BT40 26	BT141 27	BT200 28	BT33 29	BT160 30
Na_2O	2.70	2.40	3.00	2.45	3.00	2.80	1.78	3.05	2.86	3.08
K_2O	0.70	1.15	1.20	0.80	1.30	1.20	0.80	0.70	1.00	1.10

Table 12b. SiO_2 and $(Na_2O + K_2O)$ of Banihal traps.

SiO_2	52.95	53.90	53.98	54.80	54.88	55.60	55.68	55.78	56.48	56.50
(Na_2O+K_2O)	3.40	3.55	4.20	3.25	4.30	4.00	2.58	3.75	3.86	4.18

Table 12c. Si and (al+fm)-(c+alk) values of Banihal traps.

Si	144	150	144	158	160	164	158	154	157	162
(al+fm)-(c+alk)	48	26	38	32	16	38	42	30	40	38

very close to the line of alkali basalt field. According to this diagram it is inferred that none of the points is seen to fall in either the alkali basalt field or in the spilitic field. Hence the presence of spilites and alkali basalts is ruled out from this area.

KUNO'S SiO_2 VERSUS $(Na_2O + K_2O)$ VARIATION DIAGRAM

Kuno (1963) advocated a plot of SiO_2 as abscissa against $(Na_2O + K_2O)$ as ordinate. He classified basaltic rocks into tholeiites, high alumina basalts and alkali olivine basalts. The values of SiO_2 and $(Na_2O + K_2O)$ are tabulated in table 12b. Plate 7 figure 2 represents a plot for the rocks of Banihal area. It is seen from this diagram that most of the points fall in the fields of tholeiites and high alumina basalts. It has been observed that the points which fall in the field of high alumina basalt are seen to contain Al_2O_3 greater than 16.5 percent. Since the points of the study area are seen to occupy the two fields on Kuno's diagram, the possibility of two phases of lava eruption is envisaged in this area.

SiO_2 VERSUS $(Na_2O + K_2O)$ VARIATION DIAGRAM

Macdonald and Katsura (1964) recommended a classification of basaltic rocks into tholeiites and alkali basalts. Plate 7 figure 3 shows a plot of SiO_2 as abscissa very close to the line of alkali basalt field. According to this diagram it is inferred that none of the points is seen to fall in either the alkali basalt field or in the spilitic field. Hence the presence of spilites and alkali basalts is ruled out from this area.

KUNO'S SiO_2 VERSUS ($Na_2O + K_2O$) VARIATION DIAGRAM

Kuno (1963) advocated a plot of SiO_2 as abscissa against ($Na_2O + K_2O$) as ordinate. He classified basaltic rocks into tholeiites, high alumina basalts and alkali olivine basalts. The values of SiO_2 and ($Na_2O + K_2O$) are tabulated in table 12b. Plate 7 figure 2 represents a plot for the rocks of Banihal area. It is seen from this diagram that most of the points fall in the fields of tholeiites and high alumina basalts. It has been observed that the points which fall in the field of high alumina basalt are seen to contain Al_2O_3 greater than 16.5 percent. Since the points of the study area are seen to occupy the two fields on Kuno's diagram, the possibility of two phases of lava eruption is envisaged in this area.

SiO_2 VERSUS ($Na_2O + K_2O$) VARIATION DIAGRAM

Macdonald and Katsura (1964) recommended a classification of basaltic rocks into tholeiites and alkali basalts. Plate 7 figure 3 shows a plot of SiO_2 as abscissa against the total alkalis (Na_2O + K_2O) as ordinate. Saggerson and Williams (1964) included one more field of strongly alkaline basalts to this diagram. Chayes (1966) also supported the plot of SiO_2 versus total alkalis for the rocks of same composition. The data in respect of the rocks under reference, when plotted on this diagram are seen to fall in the field of tholeiites with the exception of two points, which fall close to the demarcation line between the tholeiitic and alkali basalt fields. This plot suggests a strong tholeiitic lineage for the trap rocks of Banihal area.

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

Niggli suggested a plot of Si as abscissa against (al + fm) - (c + alk) as ordinate. Plate 8 figure 1 shows a plot of Si versus (al + fm) - (c + alk) for the trap rocks of the present area. The values of Si and (al + fm) - (c + alk) are tabulated in table 12c. In this diagram the majority of points are seen to occupy the volcanic field. On close examination of this diagram it is revealed that one point falls in calcareous field and a few among others occupy the position outside the volcanic field which may be ascribed to weathering and other deuteric changes.

NIGGLI c VERSUS mg VARIATION DIAGRAM

Plate 8 figure 2 represents a bivariate plot of c versus mg of Niggli. The Niggli values of Banihal traps are listed in table 9. In this diagram the maximum points of the present area are seen to fall in the igneous field and follow the trend of Karroo dolerites.

NIGGLI (al - alk) VERSUS c VARIATION DIAGRAM

Plate 8 figure 3 is a bivariate plot of (al - alk) as ordinate against c as abscissa. The Niggli values for the trap rocks of Banihal area are listed in table 13a. The majority of points in this plot are seen to cluster 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 in c versus mg variation diagram.

NIGGLI qz VERSUS C.I. VARIATION DIAGRAM

Poldervaart and Parker (1964) proposed this diagram for a plot of Niggli qz against C.I. Plate 8 figure 4 shows a plot of qz versus C.I. for the trap rocks of Banihal area. The values of Niggli qz and C.I. are given in table 13b. In this diagram most of the points are seen to fall in and around the basalt field. Some points are noticed to fall in the qz rich field indicative of later differentiates richer in silica.

Table 13a. c and (al-alk) values of Banihal traps.

Sample No.	BT86 1	BT109 2	BT189 3	BT101 4	BT73 5	BT71 6	BT58 7	BT5 8	BT115 9	BT28 10
c	25	23	23	33	24	29	25	26	31	21
(al-alk)	21	23	22	16	21	15	19	17	13	24

Table 13b. qz and C.I. values of Banihal traps.

qz	-14	-11	-7	-11	-9	-12	-6	-4	-13	+4
C.I.	55.09	55.02	55.79	49.20	52.43	48.77	50.81	42.22	51.70	44.23

Table 13c. Solidification Index values and SiO_2 (Wt.%) of Banihal traps.

S.I.	27.56	27.66	29.01	21.32	29.18	26.27	31.97	18.98	29.80	19.71
SiO_2	43.68	43.85	43.96	44.90	45.56	46.84	46.92	47.52	47.80	48.28

Table 13a. c and (al-alk) values of Banihal traps.

Sample No.	BT175 11	BT196 12	BT165 13	BT94 14	BT95 15	BT171 16	BT121 17	BT111 18	BT63 19	Bt138 20
c	24	23	24	25	23	21	25	20	20	31
(al-alk)	18	19	18	15	16	19	17	20	19	13

Table 13b. qz and C.I. values of Banihal traps.

qz	-4	-1	+5	0	+8	+9	+5	+11	+9	+10
C.I.	44.44	45.09	44.32	46.42	40.21	41.38	44.65	41.37	39.71	45.45

Table 13c. Solidification Index values and SiO_2 (Wt.%) of Banihal traps.

S.I.	25.81	28.38	29.95	34.55	25.03	24.92	33.22	24.50	24.72	26.89
SiO_2	48.84	49.36	49.84	50.80	50.92	50.96	51.10	51.50	51.90	52.88

Table 13a. c and (al-alk) values of Banihal traps.

Sample No.	BT102	BT36	BT152	BT132	BT22	BT40	BT141	BT200	BT33	BT160
	21	22	23	24	25	26	27	28	29	30
c	18	28	21	25	31	21	23	26	21	21
(al-alk)	14	14	13	17	13	17	20	14	14	12

Table 13b. qz and C.I. values of Banihal traps.

qz	+12	+14	+4	+22	+16	+24	+34	+18	+21	+22
C.I.	33.83	40.77	39.51	39.43	34.87	36.74	42.28	38.52	35.58	29.61

Table 13c. Solidification Index values and SiO_2 (Wt.%) of Banihal traps.

S.I.	22.21	27.51	31.26	25.62	18.77	26.49	28.81	27.25	27.14	18.12
SiO_2	52.95	53.90	53.98	54.80	54.88	55.60	55.68	55.78	56.48	56.50

SiO_2 VERSUS S.I. VARIATION DIAGRAM

Kuno (1968) advocated a plot of silica versus solidification index. Plate 9 figure 1 represents such a plot for the rocks of the study area. He differentiated hypersthenic and pigeonitic rock fields marked on this diagram. The values of solidification index and SiO_2 are listed in table 13c. In this plot the maximum points are seen to occupy the pigeonite field; whereas some points fall in the hypersthene rock series field. The clustering of points in both the pigeonite and hypersthene fields indicates the presence of pigeonite which may be present in the groundmass of the rocks of the study area.

(FeO + Fe_2O_3) VERSUS S.I. VARIATION DIAGRAM

Plate 9 figure 2 is a plot of (FeO + Fe_2O_3) versus S.I. The values of total iron and solidification indices are given in table 14a. The values when plotted on this diagram reveal that the majority of the points are seen to cluster in the pigeonite field; whereas a few points fall in the hypersthene rock series field thus corroborating the results obtained in SiO_2 versus S.I. variation diagram.

NORMATIVE PLAGIOCLASE COMPOSITION VERSUS Al_2O_3 VARIATION DIAGRAM

A plot of normative plagioclase composition as

Table 14a. Solidification Index values and total iron (Wt.%) of Banihal traps.

Sample No.	BT86 1	BT109 2	BT189 3	BT101 4	BT73 5	BT71 6	BT58 7	BT5 8	BT115 9	BT28 10
S.I.	27.56	27.66	29.01	21.32	29.18	26.27	31.97	18.98	29.80	19.71
$(FeO+Fe_2O_3)$	13.45	12.90	14.90	14.60	11.85	13.72	11.33	13.50	12.00	11.85

Table 14b. Normative Plagioclase composition and Al_2O_3 (Wt.%) of Banihal traps.

$\frac{(An\times100)}{(Ab+An)}$	79.45	81.80	85.61	71.11	71.94	63.06	67.80	64.50	62.37	69.85
Al_2O_3	18.32	19.38	17.90	14.88	18.40	14.46	16.71	15.80	14.14	19.00

Table 14c. FeO^{tot}/MgO versus FeO^{tot} ratio.

(FeO^{tot}/MgO)	1.84	1.91	2.00	2.79	1.69	1.94	1.51	2.89	1.50	2.75
FeO^{tot}	10.75	10.81	13.18	12.34	9.87	11.34	9.79	11.13	9.39	9.95

Table 14a. Solidification Index values and total iron (Wt.%) of Banihal traps.

Sample No.	BT175 11	BT196 12	BT165 13	BT94 14	BT95 15	BT171 16	BT121 17	BT111 18	BT63 19	BT138 20
S.I.	25.81	28.38	29.95	34.55	25.03	24.92	33.22	24.50	24.72	26.89
$(FeO+Fe_2O_3)$	11.40	10.70	10.80	9.60	11.25	11.02	8.28	10.95	10.32	11.55

Table 14b. Normative Plagioclase composition and Al_2O_3 (Wt.%) of Banihal traps.

$\frac{(An\times 100)}{(Ab+An)}$	63.34	64.14	61.64	58.67	57.63	61.41	58.44	62.85	55.32	59.83
Al_2O_3	16.64	16.93	15.40	14.93	14.95	16.86	15.95	16.96	17.18	13.00

Table 14c. FeO^{tot}/MgO versus FeO^{tot} ratio.

(FeO^{tot}/MgO)	1.96	1.68	1.72	1.21	1.86	1.90	1.28	2.10	1.96	1.73
FeO^{tot}	10.18	9.39	10.07	8.22	9.01	8.98	7.48	9.71	9.10	9.07

Table 14a. Solidification Index values and total iron (Wt.%) of Banihal traps.

Sample No.	BT102 21	BT36 22	BT152 23	BT132 24	BT22 25	BT40 26	BT141 27	BT200 28	BT33 29	BT160 30
S.I.	22.21	27.51	31.26	25.62	18.77	24.49	28.81	27.25	27.14	18.12
$(FeO+Fe_2O_3)$	14.25	9.10	9.52	9.00	8.77	8.85	9.85	9.60	10.77	13.22

Table 14b. Normative Plagioclase composition and Al_2O_3 (Wt.%) of Banihal traps.

$\frac{(An \times 100)}{(Ab+An)}$	49.41	53.91	48.44	57.50	46.30	52.56	67.39	47.62	47.36	40.82
Al_2O_3	13.50	13.96	14.93	15.43	14.25	15.50	15.39	14.25	13.75	12.94

Table 14c. FeO^{tot}/MgO versus FeO^{tot} ratio.

(FeO^{tot}/MgO)	2.48	1.57	1.31	1.93	2.51	1.66	1.77	1.67	1.67	2.69
FeO^{tot}	12.49	7.53	8.16	8.16	7.58	7.67	8.91	8.36	9.08	10.36

abscissa against Al_2O_3 as ordinate has been shown in plate 9 figure 3. The normative plagioclase composition is calculated as An x 100/(Ab + An). The values of the normative plagioclase composition and Al_2O_3 are given in table 14b. This diagram has a dividing line which separates two fields viz. (i) tholeiitic field (ii) Calc - alkaline field. The data in respect of the Banihal area when plotted on this diagram, are seen to fall predominantly in the tholeiitic field; whereas a few of the points fall in the calc - alkaline field close to the demarcation boundary. From a close inspection of this diagram, it is revealed that the traps of Banihal area bear a strong tholeiitic lineage.

SiO_2 VERSUS $(Na_2O + K_2O)$ VARIATION DIAGRAM

Segalistad (1979) suggested plotting of this diagram for the rocks of south-western region of Norway after Weigand (1975). Plate 10 figure 1 represents a plot of SiO_2 versus $(Na_2O + K_2O)$ for the rocks of the present area. The values of SiO_2 and total alkalis are tabulated in table 12b. This diagram has a number of dividing lines as is indicated by an inspection of figure 1. The Japan line by Kuno (1960) separates high alumina basalt (Ne = 0, hy < 10%) from tholeiites in Japan. The Hawaii line by Macdonald and Katsura (1964) divides the alkaline (Ne-normative) and sub-alkaline (hy-normative) rocks Hawaii. The alkali basalts have been further sub-divided by the Moheli trend 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 of East Africa.

The analysed samples of Panjal Traps from Banihal area when plotted on this diagram reveal that most of the points occupy the portion between basalt and alkali basalt fields and others occupy the field of tholeiites establishing the tholeiitic lineage for these rocks and reflects progressive differentiation from the rocks of higher basicity to those of lower basicity.

FeO^t/MgO VERSUS FeO^t VARIATION DIAGRAM

Gupta, et al. (1988) while working on the Delhi volcanics of Rajasthan area, suggested low potassic oceanic tholeiitic basalt origin for these rocks. In order to find out the nature of the source magma, they used this plot including some of other discriminating diagrams after Miyashiro (1975) and Glassley (1974). The same discriminating diagrams have been used for the trap rocks of Banihal area.

Plate 10 figure 2 (after Miyashiro, 1975) shows a plot of FeO^t/MgO versus FeO^t for the trap rocks of the study area. The values of FeO^t/MgO and FeO^t are listed in table 14c. The trap rocks of Banihal area when plotted on this diagram reveal that maximum points cluster in the tholeiitic field but a few points fall in the calc - alkaline field. From an inspection of this diagram it is seen that the Banihal traps follow almost the same trend line as the Delhi volcanics of Rajasthan area.

FeO^t/MgO VERSUS SiO_2 VARIATION DIAGRAM

Plate 10 figure 3 (after Miyashiro, 1975) represents a plot of FeO^t/MgO versus SiO_2. The calculated values of FeO^t/MgO and SiO_2 for the rocks under reference are given in table 15a. It is seen from plate 10 figure 3 that the maximum number of the analysed samples of Banihal traps when plotted on this diagram, are seen to occupy the tholeiitic field; but some of the points fall in the calc - alkaline field. From a close inspection of this diagram, it is further clear that the rocks of the present study area are of dominant tholeiitic character.

FeO^t/MgO VERSUS TiO_2 VARIATION DIAGRAM

Plate 11 figure 1 shows a plot of FeO^t/MgO against TiO_2 (after Glassley, 1974) for the trap rocks of Banihal area. The calculated values of FeO^t/MgO and TiO_2 are given

Table 15a. FeO^{tot}/MgO versus SiO_2 ratio.

Sample No.	BT86 1	BT109 2	BT189 3	BT101 4	BT73 5	BT71 6	BT58 7	BT5 8	BT115 9	BT28 10
FeO^{tot}/MgO	1.84	1.91	2.00	2.79	1.69	1.94	1.51	2.89	1.50	2.75
SiO_2	43.68	43.85	43.96	44.90	45.56	46.84	46.92	47.52	47.80	48.28

Table 15b. FeO^{tot}/MgO versus TiO_2 ratio.

FeO^{tot}/MgO	1.84	1.91	2.00	2.79	1.69	1.94	1.51	2.89	1.50	2.75
TiO_2	1.75	1.98	1.40	2.18	1.54	1.82	1.54	1.96	0.84	1.75

Table 15c. Mafic and Felsic Indices of Banihal traps.

Mafic Index	69.73	69.50	69.30	76.72	66.95	70.11	63.54	77.81	65.79	76.60
Felsic Index	16.12	17.43	12.00	11.82	20.35	18.65	20.78	24.23	17.64	28.27

Table 15a. FeO^{tot}/MgO versus SiO_2 ratio.

Sample No.	BT175 11	BT196 12	BT165 13	BT94 14	BT95 15	BT171 16	BT121 17	BT111 18	BT63 19	BT138 20
FeO^{tot}/MgO	1.96	1.68	1.72	1.21	1.86	1.90	1.28	2.10	1.96	1.73
SiO_2	48.84	49.36	49.84	50.80	50.92	50.96	51.10	51.50	51.90	52.88

Table 15b. FeO^{tot}/MgO versus TiO_2 ratio.

FeO^{tot}/MgO	1.96	1.68	1.72	1.21	1.86	1.90	1.28	2.10	1.96	1.73
TiO_2	1.12	1.10	1.33	1.12	1.40	1.61	1.20	1.26	1.12	1.47

Table 15c. Mafic and Felsic Indices of Banihal traps.

Mafic Index	68.67	65.64	64.90	58.50	69.96	70.01	58.64	70.28	69.03	68.79
Felsic Index	28.45	29.59	24.74	26.07	29.09	31.68	28.22	32.61	36.52	19.01

Table 15a. FeO^{tot}/MgO versus SiO_2 ratio.

Sample No.	BT102 21	BT36 22	BT152 23	BT132 24	BT22 25	BT40 26	BT141 27	BT200 28	BT33 29	BT160 30
FeO^{tot}/MgO	2.48	1.57	1.31	1.93	2.51	1.66	1.77	1.67	1.67	2.69
SiO_2	52.95	53.90	53.98	54.80	54.88	55.60	55.68	55.78	56.48	56.50

Table 15b. FeO^{tot}/MgO versus TiO_2 ratio.

FeO^{tot}/MgO	2.48	1.57	1.31	1.93	2.51	1.66	1.77	1.67	1.67	2.69
TiO_2	2.02	1.40	0.98	1.12	1.61	0.98	1.26	1.12	0.98	1.21

Table 15c. Mafic and Felsic Indices of Banihal traps.

Mafic Index	73.87	65.47	60.41	68.08	74.38	65.65	66.20	65.75	66.40	77.45
Felsic Index	34.98	27.24	35.90	28.29	30.50	37.04	25.34	30.36	35.51	38.14

in table 15b. In this diagram all the points for the trap rocks of the study area are seen to occupy the same trend line as the Delhi volcanics of Rajasthan. The behaviour of the plotted points indicates the basaltic character of the rocks with a tendency towards differentiation.

In plate 11 figure 2, the values of FeO^t/MgO versus TiO_2 are plotted on this diagram. It is seen that most of the points fall in the island arc tholeiitic basalt field and a few points lie in the ridge tholeiite basaltic field. Some points, however, lie in between the Island arc tholeiite field and Ridge tholeiite field. It is obvious from this diagram that the rocks were deposited under shallow water marine conditions and bear a tholeiitic lineage.

MAFIC INDEX VERSUS FELSIC INDEX VARIATION DIAGRAM

Simpson (1954) put forth an idea of plotting Mafic versus Felsic indices for studying the differentiation trend for basaltic magmas (Plate 11 figure 3). The mafic indices are plotted as abscissa against felsic indices as ordinate. The mafic index is calculated as

$$\text{Mafic Index} = \frac{FeO + Fe_2O_3}{(MgO + FeO + Fe_2O_3)} \times 100$$

and the felsic index is defined as

$$\text{Felsic Index} = \frac{Na_2O + K_2O}{(CaO + Na_2O + K_2O)} \times 100$$

The values of mafic and felsic indices are listed in table 15c.

This diagram is based on Green and Poldervaart (1958), wherein weight percentages are used (on a dry basis) instead of oxide weight percentages. The trends of Rajmahal basalts and Deccan traps are also superimposed in this diagram (Sukeshwala and Poldervaart,1958). Wager (1956), Wilcox and Poldervaart (1958) sub-divided 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. Wilcox et al. (1958) and Sukeshwala (1958), Mcdougall (1962), Deshmukh (1964), Hawkes (1966) have adopted Simpson's method of representation for deciphering the differentiation trend of basaltic rocks. The mafic and felsic indices when plotted for the trap rocks of Banihal area reveal that the maximum points fall in the middle to late stage basalts and only two points in the early stage basalts. The examination of this diagram shows that the Banihal traps follow the same trend as the Deccan basalts and these rocks are characterised by an early phase of iron enrichment succeeded by an enrichment of sodium and potassium. This shows that the differentiation of the magma has not proceeded beyond the late stage basalt field.

Al_2O_3/SiO_2 VERSUS MgO VARIATION DIAGRAM

Murata (1960) suggested a method of plotting of weight percentages of Al_2O_3/SiO_2 v/s MgO. The values of Al_2O_3/SiO_2 and MgO for the rocks under reference are given in table 16a.

Plate 11, figure 4 represents this diagram for the rocks of the present area. The majority of the points are seen to fall in the B(tholeiitic basalt field). Some points fall in the G (andesite) and C (quartz basalt) fields respectively. An inspection of this diagram shows that the rocks of Banihal area are of tholeiitic basalt-andesite and quartz-basalt character.

D.I. VERSUS (Na_2O + K_2O) VARIATION DIAGRAM

Tilley and Muir (1967) put forth a method of plotting of D.I. as abscissa against (Na_2O + K_2O) as ordinate. The values of D.I. and total alkalis for the rocks under study are given in table 16b. In order to study the degree of differentiation in the rocks, the data have been plotted in this diagram Plate 12, figure 1. The majority of the points are seen to cluster in the basalt field and rest of the points in the Hawaiite field. This shows that the differentiation in the present case has not proceeded beyond the Hawaiite stage thus confirming the

Table 16a. Al_2O_3/SiO_2 ratios and MgO (Wt.%) of Banihal traps.

Sample No.	BT86 1	BT109 2	BT189 3	BT101 4	BT73 5	BT71 6	BT58 7	BT5 8	BT115 9	BT28 10
Al_2O_3/SiO_2	0.42	0.44	0.41	0.33	0.40	0.31	0.36	0.33	0.30	0.39
MgO	5.84	5.66	6.60	4.43	5.85	5.85	6.50	5.85	6.24	3.62

Table 16b. Differentiation Index values and total Alkalis (Wt.%) of Banihal traps.

D.I.	15.66	15.71	10.34	16.07	19.64	20.96	20.57	27.57	21.80	29.70
$Na_2O + K_2O$	1.90	1.90	1.25	1.75	2.35	2.70	2.50	2.93	2.70	2.90

Table 16c. Normative Anx100/Ab+An and D.I. values of Banihal traps.

$\frac{(An\times100)}{(Ab+An)}$	79.45	81.80	85.61	71.11	71.94	63.06	67.80	64.50	62.37	69.85
D.I.	15.66	15.71	10.34	16.07	19.64	20.96	20.57	27.57	21.80	29.70

Table 16a. Al_2O_3/SiO_2 ratios and MgO (Wt.%) of Banihal traps.

Sample No.	BT175 11	BT196 12	BT165 13	BT94 14	BT95 15	BT171 16	BT121 17	BT111 18	BT63 19	BT138 20
Al_2O_3/SiO_2	0.34	0.34	0.31	0.29	0.29	0.33	0.31	0.33	0.33	0.25
MgO	5.20	5.60	5.84	6.81	4.83	4.72	5.84	4.63	4.63	5.24

Table 16b. Differentiation Index values and total Alkalis (Wt.%) of Banihal traps.

D.I.	27.02	28.09	25.80	28.43	33.71	33.96	30.72	32.65	35.42	31.02
$Na_2O + K_2O$	3.55	3.43	2.86	3.30	3.22	3.20	3.46	3.32	3.78	2.70

Table 16c. Normative Anx100/Ab+An and D.I. values of Banihal traps.

$\frac{(An \times 100)}{(Ab+An)}$	63.34	64.14	61.64	58.67	57.63	61.41	58.44	62.85	55.32	59.83
D.I.	27.02	28.09	25.80	28.43	33.71	33.96	30.72	32.65	35.42	31.02

Table 16a. Al_2O_3/SiO_2 ratios and MgO (Wt.%) of Banihal traps.

Sample No.	BT102 21	BT36 22	BT152 23	BT132 24	BT22 25	BT40 26	BT141 27	BT200 28	BT33 29	BT160 30
Al_2O_3/SIO_2	0.25	0.26	0.28	0.28	0.26	0.28	0.28	0.26	0.24	0.23
MgO	5.04	4.80	6.24	4.22	3.02	4.63	5.03	5.00	5.45	3.85

Table 16b. Differentiation Index values and total Alkalis (Wt.%) of Banihal traps.

D.I.	35.77	36.95	37.60	36.88	42.17	41.49	49.42	38.87	41.14	46.25
$Na_2O + K_2O$	3.40	3.55	4.20	3.25	4.30	4.00	2.58	3.75	3.86	4.18

Table 16c. Normative Anx100/Ab+An and D.I. values of Banihal traps.

$\frac{(Anx100)}{(Ab+An)}$	49.41	53.91	48.44	57.50	46.30	52.56	67.39	47.62	47.36	40.82
D.I.	35.77	36.95	37.60	36.88	42.17	41.49	34.42	38.87	41.14	46.25

earlier results.

MgO VERSUS CaO VARIATION DIAGRAM

Macdonald (1968) suggested a plot of MgO versus CaO for the rocks of basaltic composition. Floyed (1976) while working on the Greenstones of south-western England superimposed three trend lines viz., Oceanic Tholeiite (O.T.), Continental Tholeiite (C.T.) and Oceanic Alkaline Basalt (O.A.B.). The values of MgO and CaO are tabulated in table 7. The traps of the Banihal area when plotted on this diagram (plate 12 figure 2) are seen mostly to follow (O.T.) line i.e. Oceanic Tholeiite. Some of the points are seen to follow (O.A.B.) trend line i.e. Oceanic Alkaline Basalt; whereas a few points are close to the line of Continental Tholeiites and the remaining points away from the (O.T.) line. This diagram suggests an extrusion of traps of the area under marine conditions.

SiO_2 VERSUS (Na_2O + K_2O) VARIATION DIAGRAM

Irvine and Baragar (1971) gave a method of discriminating alkaline from sub-alkaline rocks by plotting SiO_2 as abscissa against total alkalis as ordinate. The values of SiO_2 and total alkalis for the rocks under reference are listed in table 12b.

In this diagram (Plate 12 figure 3) dividing lines of Irvine and Baragar and that of Macdonalds are also shown. From an inspection of this diagram, it is seen that all the points fall in the sub-alkaline field below the Irvine and Baragar line with the exception of two points which are noticed to fall on the dividing line. The plots in this diagram indicate the sub-alkaline nature of the traps of Banihal area.

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

Floyd (1976) advocated a plot of $\frac{\text{An} \times 100}{(\text{Ab} + \text{An})}$ versus D.I. for the greenstones of south-western England. He also suggested a superimposition of Tristan, Gough Island and Habridean trends on this diagram (Plate 13, figure 1). At the same time Floyd has marked fields of moderately potassic and sodic series on this diagram. Similarly, some other fields have also been demarcated on this diagram but only a few of them, however, are relevant to the present work. The values of $\frac{\text{An} \times 100}{(\text{Ab} + \text{An})}$ and D.I. are given in table 16c.

The analysed samples of Panjal traps from Banihal area when plotted in plate 13, figure 1 are seen to cluster between the potassic and the sodic series. In this diagram, the majority of points are seen to occupy the basalt field; whereas a few points fall in and close to the Hawaiite field. The trend of Banihal traps is seen to follow the

Gough trend (Hawaiite character).

The trend line for the rocks has been shown separately in plate 13, figure 2, which indicates the Gough trend of the rocks under study separately.

MCKIE VARIATION DIAGRAM

Mckie (1966) used a plot of Si versus cations per hundred oxygen anions. Plate 14, figures 1 to 9 show plots for the rocks of the present area. The calculated values of cations per hundred oxygen anions are tabulated in table 17. The values when plotted in these diagram reveal that Ca, Mg, Fe^{+2}, Fe^{+3} $(Fe^{+2} + Fe^{+3})$ and Al were abundant in the early stages and faced impoverishment with the increase of Si i.e. towards the field of decreasing order of basicity; whereas Na & K show an upward trend with the increase of Si values suggesting, thereby, that these two cations were enriched in the later stages of fractionation. These cations when plotted as oxides in Harker's diagram also indicate the same trend lines. In the case of Hydrogen (H) the curve is almost straight. There is no change with respect to Si suggesting thereby its passive role during the process of differentiation.

MgO VERSUS ALL OXIDES VARIATION DIAGRAM

Nisbet et al. (1977) recommended a plot of MgO

Table 17. Cations of chemically analysed samples in terms of hundred Oxygen Anions (after Mckie, 1966).

Sample No.	CONSTITUENTS									
	Si	Al	Fe^{+3}	Fe^{+2}	Mg	Ca	Na	K	Ti	H
BT86	23.54	11.64	1.96	3.82	4.74	5.73	1.35	0.41	0.67	17.73
BT109	23.63	12.31	1.52	4.07	4.59	5.22	1.25	0.48	0.75	17.01
BT189	23.69	11.37	1.25	5.26	5.35	5.32	0.88	0.27	0.53	16.88
BT101	24.20	9.45	1.64	4.69	3.59	7.56	1.61	0.14	0.83	13.01
BT73	24.55	11.69	1.44	3.69	4.74	5.33	1.93	0.34	0.59	15.75
BT71	25.24	9.19	1.73	4.20	4.74	6.83	2.08	0.48	0.69	8.78
BT58	25.28	10.62	1.12	3.81	5.27	5.52	2.08	0.34	0.59	15.03
BT5	25.61	10.04	1.72	4.11	3.12	5.31	2.13	0.60	0.75	16.92
BT115	25.76	8.98	1.90	3.24	5.06	7.31	2.08	0.48	0.32	12.83
BT28	26.02	12.07	1.38	3.75	2.94	4.27	1.93	0.71	0.67	17.10
BT175	26.32	10.57	0.89	4.10	4.22	5.18	2.29	0.92	0.43	13.15
BT196	26.60	10.75	0.95	3.72	4.54	4.73	2.27	0.85	0.42	13.86
BT165	26.86	9.78	0.53	4.24	4.74	5.04	2.35	0.41	0.51	17.28
BT94	27.38	9.48	1.00	3.17	5.52	5.43	2.42	0.67	0.43	13.28
BT95	27.44	9.50	1.63	3.21	3.92	4.55	2.54	0.53	0.53	17.46
BT171	27.46	10.71	1.48	3.27	3.83	4.00	2.50	0.54	0.61	15.57
BT121	27.54	10.13	0.58	3.05	4.74	5.10	2.58	0.67	0.46	16.88
BT111	27.75	10.77	0.90	3.89	3.75	3.98	2.39	0.69	0.48	13.41
BT63	27.97	10.91	0.89	3.62	3.75	3.81	3.12	0.53	0.43	12.87
BT138	28.50	8.26	1.80	3.14	4.25	6.67	1.98	0.54	0.56	4.95
BT102	28.53	8.58	1.28	4.94	4.09	3.66	2.81	0.48	0.77	7.20
BT36	29.05	8.87	1.14	2.79	3.89	5.50	2.50	0.78	0.53	13.28
BT152	29.09	9.48	0.99	3.14	5.06	4.35	3.12	0.82	0.37	6.75
BT132	29.53	9.80	0.61	3.34	3.42	4.78	2.55	0.54	0.43	12.60
BT22	29.57	9.05	0.87	2.95	2.45	5.68	3.12	0.88	0.61	10.72
BT40	29.96	9.85	0.86	2.99	3.75	3.94	2.91	0.82	0.37	12.60
BT141	30.01	9.78	0.68	3.64	4.08	4.41	1.85	0.54	0.48	9.63
BT200	30.06	9.05	0.90	3.28	4.06	4.98	3.17	0.48	0.43	6.53
BT33	30.44	8,73	1.23	3.44	4.42	4.06	2.98	0.68	0.37	6.03
BT160	30.45	8.22	2.08	3.58	3.12	3.93	3.21	0.75	0.46	4.05

versus all oxides for studying the differentiation trends in the lavas of Belingwe, Greenstone Belt of Rhodesia and differentiated Komatites from basalts. Differentiation trends obtained from such plots were used by him to arrive at their genetic history.

Plate 15, figures 1 to 5 represent plots along the same lines for the rocks of the Banihal area. Plate 15, figure 1 reveal a negative relation of MgO with respect to SiO_2 indicating thereby that with the increase of SiO_2 in the later differentiates MgO got depleted. Plate 15, figures 2 and 3 show a positive relation for FeO and CaO with respect to MgO. During the course of differentiation Ca & Mg get enriched in the early fractionates and thus it is consistent with the rules of differentiation. In case of alkalis negative relation is evident from the inspection of Plate 15, figures 4 and 5, indicating that with the increase of alkalis MgO got depleted in the later differentiates. In the last it may be remarked that in these plots the trend lines show a general tendency towards magmatic differentiation and therefore the trends shown are only generalized one.

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

Aniruddha De (1964) proposed for studying the iron enrichment in various basaltic suites including Deccan basalts viz. O.R. v/s SiO_2, O.R. v/s (Fe_2O_3 + FeO) and (Fe_2O_3 + FeO) v/s SiO_2 together with variation diagrams for basaltic suites of different places for comparison (i) Palisade, Eastern U.S.A., (ii) Dillsberg, U.S.A., (iii) Red Hill Tasmania. For the trap rocks of Banihal area the same graphs have been used for comparison (Plate 16, figures 1,2 and 3). The values of oxidation ratio, (Fe_2O_3 + FeO) and SiO_2 are given in tables 18a,b & c.

Plate 16, figure 1 shows a plot of O.R. versus SiO_2. On close examination of this diagram it reveals the same trend line for Banihal traps as shown by the Deccan traps. It is very important to mention here that the similarity in the two curves is restricted to a greater part of the Western limbs only as the higher values of SiO_2 for the rocks end at 56.50% in case of the samples of the study area; whereas in the Deccan traps higher acid members are also present.

In the plot of O.R. versus (Fe_2O_3 + FeO) (Plate 16, figure 2), the trend exhibited by Banihal traps is similar to that of the Deccan basalts with the only difference in the values of the oxidation ratios of the two different suites. In case of Banihal traps the values of O.R. do not exceed 36.93; whereas in the case of Deccan traps the

Table 18a. SiO_2 Wt.% and O.R. values of Banihal traps.

Sample No.	BT86 1	BT109 2	BT189 3	BT101 4	BT73 5	BT71 6	BT58 7	BT5 8	BT115 9	BT28 10
SiO_2	43.68	43.85	43.96	44.90	45.56	46.84	46.92	47.52	47.80	48.28
O.R.	34.08	27.17	19.21	25.89	28.12	29.35	22.88	29.67	36.87	26.87

Table 18b. Total Iron Wt.% and O.R. values of Banihal traps.

$FeO + Fe_2O_3$	13.45	12.90	14.90	14.60	11.85	13.72	11.33	13.50	12.00	11.85
O.R.	34.08	27.17	19.21	25.89	28.12	29.35	22.88	29.67	36.87	26.87

Table 18c. SiO_2 Wt.% and total Iron values of Banihal traps.

SiO_2	43.68	43.85	43.96	44.90	45.56	46.84	46.92	47.52	47.80	48.28
$FeO + Fe_2O_3$	13.45	12.90	14.90	14.60	11.85	13.72	11.33	13.50	12.00	11.85

Table 19. Log τ and Log σ values of Banihal traps.

Log τ	0.72	0.62	0.20	0.20	0.33	0.27	0.20	0.27	0.17	0.20
Log σ	0.98	0.96	1.08	0.78	1.03	0.83	0.98	0.84	1.15	0.99

Table 18a. SiO_2 Wt.% and O.R. values of Banihal traps.

Sample No.	BT175 11	BT196 12	BT165 13	BT94 14	BT95 15	BT171 16	BT121 17	BT111 18	BT63 19	BT138 20
SiO_2	48.84	49.36	49.84	50.80	50.92	50.96	51.10	51.50	51.90	52.88
O.R.	17.53	20.69	10.81	23.85	34.00	31.08	15.93	18.79	19.42	36.36

Table 18b. Total Iron Wt.% and O.R. values of Banihal traps.

$FeO + Fe_2O_3$	11.40	10.70	10.80	9.60	11.25	11.02	8.28	10.95	10.32	11.55
O.R.	17.53	20.69	10.81	23.85	34.00	31.08	15.93	18.79	19.42	36.36

Table 18c. SiO_2 Wt.% and total Iron values of Banihal traps.

SiO_2	48.84	49.36	49.84	50.80	50.92	50.96	51.10	51.50	51.90	52.88
$FeO + Fe_2O_3$	11.40	10.70	10.80	9.60	11.25	11.02	8.28	10.95	10.32	11.55

Table 19. Log τ and Log σ values of Banihal traps.

Log τ	0.33	0.26	0.07	0.14	0.11	0.10	0.16	0.11	0.20	- 0.13
Log σ	1.11	1.12	0.99	1.05	0.95	0.95	1.04	1.06	1.10	0.87

Table 18a. SiO_2 Wt.% and O.R. values of Banihal traps.

Sample No.	BT102 21	BT36 22	BT152 23	BT132 24	BT22 25	BT40 26	BT141 27	BT200 28	BT33 29	BT160 30
SiO_2	52.95	53.90	53.98	54.80	54.88	55.60	55.68	55.78	56.48	56.50
O.R.	20.73	29.27	24.03	15.45	22.69	22.50	15.67	21.54	26.21	36.93

Table 18b. Total Iron Wt.% and O.R. values of Banihal traps.

$FeO + Fe_2O_3$	14.25	9.10	9.52	9.00	8.77	8.85	9.85	9.60	10.77	13.22
O.R.	20.73	29.27	24.03	15.45	22.69	22.50	15.67	21.54	26.21	36.93

Table 18c. SiO_2 Wt.% and total Iron values of Banihal traps.

SiO_2	52.95	53.90	53.98	54.80	54.88	55.60	55.68	55.78	56.48	56.50
$FeO + Fe_2O_3$	14.25	9.10	9.52	9.00	8.77	8.85	9.85	9.60	10.77	13.22

Table 19. Log τ and Log σ values of Banihal traps.

Log τ	0.06	0.06	0.20	- 0.05	0.19	0.10	- 0.25	0.04	0.04	0.11
Log σ	0.72	0.91	1.08	1.06	0.84	1.11	1.00	1.00	1.04	0.91

maximum values of O.R. go upto 90. For this reason the similarity of the curves here also is restricted to lower limb only. However, the overall trend in both the rock suites are following similar patterns.

In the plot of (FeO + Fe_2O_3) versus SiO_2 (Plate 16, figure 3), the trend exhibited by the traps of Banihal area is almost similar to the Deccan trend. In this case also the similarity is restricted to a major part of the eastern limb only as the maximum concentration in the case of the traps of Banihal ends at 56.50% SiO_2.

It is clear from these diagrams, that the maximum iron enrichment in various basaltic suites takes place at different SiO_2 values. In the case of traps of Banihal area, the enrichment of iron has taken place at a low value of 43.96% SiO_2 indicating slow process of differentiation.

RITTMANN'S DIAGRAM

Rittmann,A. (1967-70) and Gottni, V. (1968-70) put forth a method of differentiating lavas of active volcanoes present in non-Orogenic regions, Orogenic belts and alkaline derivatives of both into three different fields such as 'A', 'B' and 'C'. In this diagram fields A&B are representative of Orogenic and non-Orogenic belts, whereas field C is defined as alkaline derivatives of both A and B among which sodic types are linked to A and the potassic ones to B.

Plate 17, figure 1 represents a plot of Log τ versus Log σ for the rocks of the present area. The values of Log τ and Log σ are calculated according to the method given by Rittmann (1967-70). This method is defined as

$$\tau = (Al_2O_3 - Na_2O)/TiO_2 \text{ (weight \%)}$$

$$\sigma = (K_2O + Na_2O)^2/SiO_2 - 43 \text{ (weight \%)}$$

In table 19 the values of Log τ and Log σ are listed for the rocks of the present area. The data of Banihal traps have been plotted in this diagram. It is seen that the rocks of the present area predominantly fall in the field of Orogenic belt; whereas some of the points are noticed to fall in the field of non-Orogenic region with the exception of a solitary point which falls in the field C. The broad picture which emerges from an inspection of this diagram is that the rocks of the present area have been extruded in an active Orogenic belt.

Al_2O_3 VERSUS TiO_2 VARIATION DIAGRAM

Tanaka et al. (1973) suggested a plot of Al_2O_3 versus TiO_2. This diagram has been demarcated into three different fields. A is the field of Cenozoic basalt of

Japan (circum oceanic), B is the field of Hawaiian tholeiites and oceanic ridge basalt (oceanic Island) and G is the field of late Palaeozoic green rocks of central Japan (Geosynclinal). The values of Al_2O_3 and TiO_2 for the rocks under study are tabulated in table 7. The analysed samples of the rocks of the present area are seen to fall in the field B, which suggests an extrusion of Panjal Traps of the area under marine conditions (Plate 17, figure 2).

TERNARY VARIATION DIAGRAMS

Ternary variation diagrams have been drawn for the rocks of the area under study in order to see their variation trends.

Q-A-P TRIANGULAR VARIATION DIAGRAM

Niggli (1931) proposed method of classification of igneous rocks which is based on a double triangle diagram. For the classification of volcanic rocks this diagram has been slightly modified by (Rittmann, 1933-1960) and finally elaborated by Streckeisen (1967, 1978). This diagram has been accepted by a large number of petrologists for uniform nomenclature of volcanic rocks.

Chayes (1981) has adopted Streckeisen's method of representation for the distribution of basalt, basanite, andesite and dacite in a normative equivalent of the double triangle diagram. In this diagram, modal coordinates have been replaced by linear combinations of conventional C.I.P.W. normative components, viz.

$Q = q/Sal$, $A = or/Sal$ $P = (an+ab)/Sal$.

$F = (ne+lc)/Sal$, Where $Sal = q+ne+lc+or+ab+an$.

The three components for the rocks under investigation with variables Q-A-P recalculated to hundred percent are shown in table 20a. Figure 9 shows the values of the plotted points. From a close inspection of this diagram it is seen that most of the points fall in the andesite, basalt and quartz latite- andesite fields. A few points are, however, noticed to fall in the fields of latite, dacite and quartz andesite. It is clear from their diagram that the rocks of the present area are predominantly of basaltic to andesitic character.

Na_2O-K_2O-CaO TERNARY VARIATION DIAGRAM

The values of the three components recalculated to 100 percent for the rocks of the present area are shown in table 20b. These values have been plotted in plate 18, figure 1. In this triangular diagram, the points are seen to cluster near the CaO corner showing thereby, that the rocks are rich in calcium and poor in alkalis.

Table 20. Combination of three components recalculated to hundred percent.

Sample Number	a			b			c		
	Q	A	P	Na_2O	K_2O	CaO	MgO	$(FeO+Fe_2O_3)$	(Na_2O+K_2O)
BT86	2.27	5.74	91.99	11.03	5.09	83.88	27.57	63.47	8.97
BT109	3.08	6.43	90.49	11.01	6.42	82.57	27.66	63.05	9.29
BT189	1.45	4.11	94.44	8.16	3.84	88.00	29.01	65.49	6.60
BT101	3.85	2.30	93.85	10.47	1.35	88.18	21.32	70.26	8.42
BT73	1.90	4.64	93.46	16.02	4.33	79.65	29.18	59.10	11.72
BT71	0.61	7.84	91.55	13.81	4.84	81.35	26.27	61.61	12.12
BT58	1.83	4.97	93.20	16.62	4.16	79.22	31.97	55.73	12.30
BT5	8.95	8.48	82.57	16.96	7.28	75.76	18.98	66.57	14.45
BT115	2.30	7.84	89.86	13.06	4.57	82.37	29.80	57.31	12.89
BT128	11.89	9.25	78.86	18.03	10.23	71.74	19.70	64.51	15.79
BT175	1.53	13.25	85.22	17.63	10.82	71.55	25.81	56.57	17.62
BT196	4.14	11.87	83.99	18.81	10.78	70.41	28.38	54.23	17.39
BT165	6.42	5.95	87.63	19.55	5.19	75.26	29.95	55.38	14.67
BT94	6.22	9.94	83.84	18.33	7.74	73.93	34.55	48.81	16.74
BT95	14.34	7.23	78.43	22.04	7.05	70.91	25.03	58.29	16.68
BT171	12.81	7.52	79.67	23.76	7.92	68.32	24.92	58.18	16.90
BT121	6.98	9.24	83.78	20.23	7.99	71.78	33.22	47.10	19.68
BT111	10.91	9.35	79.74	22.59	10.02	67.39	24.50	57.94	17.56
BT63	8.74	6.69	84.57	28.98	7.54	63.48	24.72	55.10	20.18
BT138	17.71	9.06	73.23	13.38	5.63	80.99	26.89	59.26	13.85
BT102	15.13	6.67	78.20	27.78	7.20	65.02	22.21	62.80	14.99
BT36	16.17	10.96	72.87	18.42	8.83	72.75	27.51	52.15	20.34
BT152	8.52	11.81	79.67	25.64	10.26	64.10	31.26	47.70	21.04
BT132	16.74	7.66	75.60	21.32	6.96	71.72	25.62	54.65	19.73
BT22	14.47	12.19	73.34	21.28	9.22	69.50	18.77	54.51	26.72
BT40	15.80	10.69	73.51	25.93	11.11	62.96	26.49	50.63	22.88
BT141	21.60	7.60	70.80	17.48	7.86	74.66	28.81	56.41	14.78
BT200	14.95	6.25	78.80	24.70	5.67	69.63	27.25	52.32	20.43
BT33	17.38	9.74	72.88	26.31	9.20	64.49	27.14	53.64	19.22
BT160	20.80	10.37	68.83	28.10	10.04	61.86	18.12	62.21	19.67

$(FeO + Fe_2O_3)$ - MgO - $(Na_2O + K_2O)$ TERNARY VARIATION DIAGRAM

The three components with variables $(FeO + Fe_2O_3)$, MgO and $(Na_2O + K_2O)$ recalculated to 100 percent for the analysed samples of Panjal Traps of Banihal area are shown in table 20c. Plate 18, figure 2 shows that the points cluster near $(FeO + Fe_2O_3)$ apex of the triangle. An inspection of this diagram indicates that the rocks are rich in iron and are of basaltic nature.

FeO - $(Na_2O + K_2O)$ - MgO TERNARY VARIATION DIAGRAM

Table 21a shows the three components recalculated to 100 percent for the analysed samples of Banihal traps. Plate 18, figure 3 shows the position of the plotted points. This diagram indicates that the rocks are iron and magnesium rich, thus showing their basaltic lineage.

$(Al_2O_3 - K_2O)$ - Na_2O - CaO TERNARY VARIATION DIAGRAM

The values of $(Al_2O_3 - K_2O)$, Na_2O and CaO recalculated to 100 percent for the analysed samples are shown in table 21b. Plate 19, figure 1 represents the data plotted on a triangular diagram. This diagram was proposed by Joly and Smith (1972) and three fields have been demarcated as :

Table 21. Combination of three components recalculated to hundred percent.

Sample Number	a			b			c			d		
	FeO	(Na_2O+K_2O)	MgO	CaO	$(Al_2O_3-K_2O)$	Na_2O	Or	Ab	An	A	C	F
BT86	52.49	11.66	35.85	34.21	61.29	4.50	5.87	19.34	74.79	46	22	32
BT109	54.62	11.41	33.97	31.16	64.68	4.16	6.64	16.99	76.37	47	20	33
BT189	60.01	6.37	33.62	33.32	63.59	3.09	4.17	13.80	82.03	42	19	39
BT101	62.95	10.49	26.56	44.57	50.14	5.29	2.39	28.20	69.41	38	29	33
BT73	50.15	14.29	35.56	31.78	61.83	6.39	4.73	26.73	68.54	46	21	33
BT71	52.37	15.04	32.59	42.78	49.96	7.26	7.89	34.02	58.09	37	27	36
BT58	48.66	14.26	37.08	34.34	58.45	7.21	5.07	30.57	64.36	41	23	36
BT5	57.57	18.34	24.09	35.06	57.10	7.84	9.31	32.20	58.49	43	23	34
BT115	44.78	16.68	38.54	44.96	47.91	7.13	8.03	34.60	57.37	38	30	32
BT28	56.30	19.44	24.26	27.10	66.09	6.81	10.51	26.98	62.51	50	19	31
BT175	51.20	19.80	29.00	33.80	57.87	8.33	13.46	31.72	54.82	39	23	38
BT196	47.95	19.77	32.28	31.36	60.26	8.38	12.39	31.42	56.19	42	21	37
BT165	52.15	15.73	32.12	36.10	54.52	9.38	6.36	35.92	57.72	36	23	41
BT94	41.26	19.17	39.57	36.52	54.43	9.05	10.60	36.95	52.45	38	25	37
BT95	47.14	21.14	31.72	32.09	57.93	9.98	8.45	38.79	52.76	44	22	34

Table 21. Combination of three components recalculated to hundred percent.

Sample Number	a			b			c			d		
	FeO	(Na_2O+K_2O)	MgO	CaO	$(Al_2O_3-K_2O)$	Na_2O	Or	Ab	An	A	C	F
BT171	48.03	21.00	30.97	27.21	63.33	9.46	8.63	35.36	56.11	48	19	33
BT121	42.34	21.45	36.21	33.52	47.04	9.45	9.93	37.44	52.63	39	25	36
BT111	52.25	19.94	27.81	27.33	63.51	9.16	10.50	33.25	56.25	44	19	37
BT63	49.06	22.90	28.04	25.30	63.15	11.55	7.33	41.40	51.27	44	19	37
BT138	47.00	18.02	34.98	44.92	47.66	7.42	11.00	35.75	53.25	38	30	32
BT102	56.70	17.44	25.86	28.97	58.66	12.37	7.86	46.62	45.52	37	18	45
BT36	42.81	24.31	32.88	38.40	51.88	9.72	13.07	40.06	46.87	39	28	33
BT152	40.27	24.03	35.70	30.95	56.67	12.38	12.91	44.90	42.19	39	22	39
BT132	50.00	21.75	28.25	32.54	57.78	9.68	9.20	38.59	52.21	41	24	35
BT22	47.41	30.89	21.70	38.06	50.29	11.65	14.25	46.05	39.70	38	31	31
BT40	43.71	26.09	30.20	28.45	59.83	11.72	12.70	41.41	45.89	43	21	36
BT141	51.71	16.37	31.92	31.71	60.87	7.42	9.69	29.45	60.86	41	21	38
BT200	45.65	23.29	31.06	34.13	53.77	12.10	7.35	48.53	44.12	38	25	37
BT33	45.27	22.69	32.04	30.99	56.37	12.64	11.79	46.44	41.77	39	21	40
BT160	49.97	26.04	23.99	31.25	54.56	14.19	13.10	51.43	35.47	43	20	37

(i) Unaltered basalts

(ii) Basalts containing albitized feldspar

(iii) Basalts with chlorite and epidote

The traps of Banihal area when plotted on a triangular diagram with the above three apices show that the majority of the points fall in field III; whereas a few points fall in field II of this diagram. This suggests that the rocks are containing alumina in high content and the maximum points fall in the field of basalt with chlorite and epidote. The thin section study of the rocks corroborates this observation.

Or-Ab-An TRIANGULAR VARIATION DIAGRAM

According to the method of Irvine and Baragar (1971) the normative feldspars are reduced to 100 percent and the values have been plotted on a triangular variation diagram. In this diagram different fields have been demarcated such as the field of average igneous rocks, K-poor basalts, K-rich andesites, rhyodacites and potassic rhyolites. Here An occupies the top apex of the triangle, while the remaining two apices are contained by Ab and Or. The values of Or, Ab and An recalculated to 100 percent are listed in table 21c. These values for the rocks of Banihal area have been plotted in the diagram shown in plate 19, figure 2.

The analysed samples of the Panjal Traps of Banihal area when plotted on this diagram are seen to fall in the field of K-poor basalts; whereas a few points fall in the K-rich andesites field. Some of the points are, however, noticed to fall in the field of average igneous rocks but the overall data of the plotted points shows the maximum concentration towards the K-poor basalts. From a close inspection of this diagram, it is observed that the majority of the points follow a trend from K-poor basalt towards the sodic pole of the triangle which suggests that there has been a slight enrichment of soda in the later fractions of the magma as compared to potash.

A-C-F TRIANGULAR VARIATION DIAGRAM

Miyashiro (1974) proposed this diagram for the volcanic rocks of Japan. The three components with variables $A = (Al_2O_3 + Fe_2O_3) - (Na_2O + K_2O)$, $C = CaO$ and $F = FeO + MgO + MnO$ recalculated to 100 percent for the rocks of the present area are shown in table 21d. Figure 10 shows the position of the plotted points in this diagram, used for the traps of Banihal area which provides two distinct fields viz. (i) Shale and Greywacke and (ii) Basalt andesite.

The traps of the Banihal area when plotted on this diagram, are seen to fall in the basalt andesite field thus characterising their basaltic nature.

The major element study of the rocks under discussion finally leads us to the following conclusions :-

1. The petrochemical trend for the trap rocks of the Banihal area reveals that these rocks are predominantly of tholeiitic lineage.
2. It also appears that the trap rocks of the study area have been extruded under shallow water marine conditions.
3. The rocks have undergone differentiation in decreasing order of basicity viz., from more basic to less basic members. The differentiation has not proceeded too far as the rocks belong to early and middle stage basalts of Simpson or Basalt and Hawaiite stage of Tilley and Muir.
4. The spilitic type of rocks are absent from this area.
5. The diagrams based on Niggli values suggest that these traps have a similarity with Karroo basalts of South Africa and Deccan basalts of India. From the tectonic setting point of view, the traps of Banihal area are akin to Island arc tholeiites and Mid-oceanic ridge basalts.
6. Oxidation ratio diagrams show that iron enrichment of the rocks has taken place at a lower value of SiO_2 and hence the rate of differentiation has been shown slow in these rocks.

TRACE ELEMENTS

The distribution of major elements has already been given in the preceding pages. It is now intended to discuss the distribution and behaviour of trace elements occurring in the volcanics of Banihal area and to find a link of these with the major elements. Studies relating to the behaviour of trace elements during crystallization are of great importance in delineating the various processes involved in the formation of these rocks. Such studies have revealed at times different patterns both related to crystallization sequence as well as its nature and magnitude.

In the present work thirty representative rock samples of Banihal area have been analysed for the following trace elements : Ba, Cd, Co, Cr, Cs, Cu, Ga, Li, Mo, Ni, Pb, Rb, Sr, V, Y, Zn and Zr. The trace element data have been presented in table 22. Various diagrams are drawn with the trace elements to find out the genesis of the rocks and the tectonic environment in which these have been deposited. Each trace element has been described below :

BARIUM (Ba^{+2}) 1.43 A°

Geochemistry of Ba shows that in the magmatic environments it is captured by K-bearing minerals. It has been generally observed that except for the plagioclases which may contain K in solid solutions there is no other mineral appreciably rich in K and hence low values of Barium are observed in the traps of Banihal area. There also goes a suggestion that the traps of Banihal area have not undergone complete fractionation and hence the overall Ba content is low in the rocks. In volcanics, Ba lies in the

Table 22. Trace element data of the Panjal Traps of Banihal area. Values given in ppm

Sample Number	Ba	Cd	Co	Cr	Cs	Cu	Ga	Li	Mo	Ni	Pb	Rb	Sr	V	Y	Zn	Zr
BT86	70	.020	72	297	12	205	27	9	8	350	22	21	244	80	18	223	41
BT109	92	.014	58	244	14	172	24	12	6	195	29	15	193	72	20	211	68
BT189	81	.019	79	211	11	144	34	7	7	321	26	19	220	76	17	176	59
BT101	64	.016	62	220	12	155	35	10	4	230	21	32	151	56	15	154	47
BT73	84	.008	49	253	9	140	21	14	5	190	25	21	180	54	18	133	68
BT71	79	.012	54	228	11	180	30	13	2	210	21	38	160	60	22	148	86
BT58	99	.008	62	180	9	100	38	10	7	189	26	50	134	39	25	120	74
BT5	118	.010	60	200	12	173	24	16	5	241	30	41	126	49	21	182	67
BT115	101	.010	48	185	10	104	26	14	3	172	21	51	137	70	18	116	70
BT28	68	.012	51	231	6	119	32	19	5	207	9	60	179	50	19	125	52
BT175	110	.008	46	195	8	64	32	8	2	188	17	44	102	59	25	103	84
BT196	82	.010	40	170	7	115	40	15	5	161	19	94	86	60	24	140	82
BT165	98	.012	54	202	10	159	24	20	4	178	27	55	173	40	20	94	60
BT94	121	.013	48	174	12	88	15	15	7	220	14	17	119	43	26	120	92
BT95	60	.009	45	150	8	126	36	16	3	190	27	47	86	49	20	85	70

Sample Nunber	Ba	Cd	Co	Cr	Cs	Cu	Ga	Li	Mo	Ni	Pb	Rb	Sr	V	Y	Zn	Zr
BT171	77	.10	48	188	6	146	22	14	5	200	39	62	150	39	15	103	51
BT121	93	.015	40	177	9	153	24	22	5	126	23	29	48	66	23	145	90
BT111	111	.014	45	181	7	58	22	20	2	149	16	77	75	34	29	82	95
BT63	85	.009	41	195	7	110	29	12	4	155	18	48	107	39	24	131	82
BT138	115	.010	45	155	6	120	31	20	2	120	17	72	59	46	21	98	76
BT102	88	.007	36	112	3	73	34	18	5	161	32	92	96	52	26	108	99
BT36	132	.013	43	181	4	102	32	14	2	172	24	45	75	44	20	81	60
BT152	165	.011	40	156	7	115	35	20	3	143	32	104	51	30	31	103	106
BT132	87	.010	34	110	3	66	28	22	1	143	23	57	111	39	28	82	100
BT22	131	.008	42	185	5	100	32	14	4	149	28	77	42	34	24	120	90
BT40	126	.012	37	172	6	119	34	17	5	161	17	112	94	42	31	44	115
BT141	202	.010	50	130	2	64	30	19	3	155	10	74	51	39	33	61	120
BT200	167	.006	42	143	3	49	29	15	1	160	15	98	59	34	25	97	95
BT33	229	.008	43	120	2	62	26	24	2	200	20	88	76	27	32	62	119
BT160	255	.006	38	95	3	35	34	21	1	140	14	141	44	30	36	51	137
Average	113	.011	48	181	7	114	29	16	4	186	22	59	114	48	24	117	82

range of 81-255 ppm with an average value of 113 ppm.

Barium distribution in K-feldspars has been investigated by many authors. As a general pattern, it was found that in magmatic sequences, the early crystallized K-feldspars show the highest Ba concentrations; whereas microclines from pegmatites contain low concentrations (Schimer, 1943; Bray, 1942, in Wedepohl, 1978). The distribution of Ba in granites of Black-Forest Germany was discussed by Emmermann (1968). He reported highest Ba concentrations in the granites referred to above due to metasomatic alteration which caused K-feldspars to crystallize abundantly in the rocks. Investigations by other workers have proved that micas are the most important Ba carriers in igneous rocks. Petrov et al. (1965) found that the relative concentrations of Barium in biotites increase with metamorphic grade.

From the discussion of the Geochemistry of Ba, it is now clear that there are no micas in the traps of Banihal area, therefore, Ba appears to have chosen K-feldspar sites.

So far as the Ba concentration is concerned, basalts can be divided into four groups :-

(i) Oceanic Tholeitic basalts with average Ba 14.5 ppm

(ii) Tholeiitic basalts of continents and oceanic Islands 140 ppm

(iii) Alkali Basalts 613 ppm

(iv) Mid Oceanic Ridge basalts with average Ba 220 ppm.

Traps of Banihal area are more closer to no. (iv), showing that these rocks are more akin to Mid-oceanic ridge basalts. Figure 11 represents a graph of SiO_2 v/s Ba. In this graph Ba follows a linear trend upto a value of 52% SiO_2, but onwards it demonstrates an upward trend. The maximum value of Barium is attained at 56.5% SiO_2.

Plate 20, figure 1 represents a plot of Ba v/s Ca. The values of Ba and Ca are given in table 24a. Barium shows decrease with the increase of Ca. This diagram indicates antipathic relation of Ba with Ca.

K/Ba ratios in the traps of Banihal area lie in the range of 29 to 104, with an A.M. of 66.5 ppm (table 23). On comparing this ratio with K/Rb and K/Cs, it is revealed that maximum K in the rocks has been replaced by Ba, to lesser extent by Rb and least by Cs. Sr/Ba and Ca/Ba ratios (table 23) indicate maximum Barium concentration in the later differentiates. Ba/Rb ratio (table 23) indicates that Ba has been taken up by acid members in a less quantity than

Table 23. Trace element ratios for the Banihal traps.

Sample No.	K/Rb	K/Ba	K/Sr	Ba/Rb	Sr/Ba	Ni/Mo	Ca/Ba
BT86	195	59	17	3.33	3.49	44	819
BT109	320	52	25	6.13	2.10	32	567
BT189	142	33	12	4.26	2.72	46	657
BT101	44	22	9	2.00	2.36	57	1181
BT73	162	40	19	4.00	2.14	38	634
BT71	126	61	30	2.08	2.02	105	865
BT58	68	34	25	1.98	1.35	27	558
BT5	146	51	48	2.88	1.07	48	450
BT115	94	47	35	1.98	1.36	57	724
BT28	118	104	40	1.13	2.63	41	628
BT175	209	84	90	2.50	0.93	94	471
BT196	90	104	99	0.87	1.05	32	577
BT165	75	42	24	1.78	1.76	44	514
BT94	394	55	56	7.12	0.98	31	449
BT95	113	88	62	1.28	1.43	63	758
BT171	87	70	36	1.24	1.95	40	519
BT121	231	72	140	3.21	0.52	25	548
BT111	90	62	92	1.44	0.68	74	359
BT63	110	62	49	1.77	1.26	39	448
BT138	75	47	91	1.60	0.51	60	580
BT102	52	54	50	0.96	1.09	32	416
BT36	173	59	104	2.93	0.57	86	417
BT152	79	50	161	1.59	0.31	48	264
BT132	95	62	49	1.53	1.28	143	549
BT22	114	67	209	1.70	0.32	37	434
BT40	73	65	87	1.12	0.75	32	313
BT141	73	27	106	2.73	0.25	52	218
BT200	49	29	81	1.70	0.35	160	298
BT33	77	30	89	2.60	0.33	100	177
BT160	53	29	170	1.81	0.17	140	154

Table 23. Trace element ratios for the Banihal traps.

Sample No.	K/Cs	Mg/Ni	Ni/Cr	Zr/Y	(Na+K)/Y	Al/Ga x 10^3
BT86	342	135	1.18	2.28	978	4.31
BT109	343	235	0.80	3.40	865	5.13
BT189	245	167	1.52	3.47	676	3.34
BT101	117	156	1.04	3.13	1167	2.70
BT73	378	249	0.75	3.78	1261	5.57
BT71	436	226	0.92	3.91	1164	3.06
BT58	378	279	1.05	2.96	968	2.79
BT5	500	129	1.20	3.19	1300	4.18
BT115	480	294	0.93	3.89	1422	3.45
BT28	1183	142	0.90	2.74	1389	3.77
BT175	1150	224	0.96	3.36	1284	3.30
BT196	1214	282	0.95	3.42	1300	2.69
BT165	410	266	0.88	3.00	1380	4.07
BT94	558	251	1.26	3.54	1188	6.32
BT95	662	206	1.27	3.50	1535	2.64
BT171	900	191	1.06	3.40	2027	4.87
BT121	744	376	0.71	3.91	1413	4.22
BT111	986	252	0.82	3.27	1062	4.89
BT63	757	242	0.79	3.42	1521	3.76
BT138	900	354	0.77	3.62	1200	2.66
BT102	1600	254	1.44	3.81	1265	2.52
BT36	1950	226	0.95	3.00	1640	2.77
BT152	1171	354	0.92	3.42	1271	2.71
BT132	1800	239	1.30	3.57	1103	3.50
BT22	1760	164	0.80	3.75	1667	2.83
BT40	1367	233	0.94	3.71	1203	2.90
BT141	2700	263	1.19	3.64	724	3.26
BT200	1600	254	1.12	3.80	1460	3.12
BT33	3400	221	1.67	3.72	1144	3.36
BT160	2500	223	1.47	3.80	1100	2.42

Table 24a. Ca versus Ba values of Banihal traps.

Sample Number	BT86 1	BT109 2	BT189 3	BT101 4	BT73 5	BT71 6	BT58 7	BT5 8	BT115 9	BT28 10	BT175 11	BT196 12	BT165 13	BT94 14	BT95 15
Ca	5.73	5.22	5.32	7.56	5.33	6.83	5.52	5.31	7.31	4.27	5.18	4.73	5.04	5.43	4.55
Ba	70	92	81	64	84	79	99	118	101	68	110	82	98	121	60

Table 24b. Cr versus SiO_2 values of Banihal traps.

Cr	297	244	211	220	253	228	180	200	185	231	195	170	202	174	150
SiO_2	43.68	43.85	43.96	44.90	45.56	46.84	46.92	47.52	47.80	48.28	48.84	49.36	49.84	50.80	50.92

Table 24c. Cr versus V values of Banihal traps.

Cr	297	244	211	220	253	228	180	200	185	231	195	170	202	174	150
V	80	72	76	56	54	60	39	49	70	50	59	60	40	43	49

Table 24d. Fe_2O_3+FeO/MgO versus V values of Banihal traps.

T.Iron/MgO	1.84	1.91	2.00	2.79	1.69	1.94	1.51	2.89	1.50	2.75	1.96	1.68	1.72	1.21	1.86
V	80	72	76	56	54	60	39	49	70	50	59	60	40	43	49

Table 24a. Ca versus Ba values of Banihal traps.

Sample Number	BT171 16	BT121 17	BT111 18	BT63 19	BT138 20	BT102 21	BT36 22	BT152 23	BT132 24	BT22 25	BT40 26	BT141 27	BT200 28	BT33 29	BT160 30
Ca	4.00	5.10	3.98	3.81	6.67	3.66	5.50	4.35	4.78	5.68	3.94	4.41	4.98	4.06	3.93
Ba	77	93	111	85	115	88	132	165	87	131	126	202	167	229	255

Table 24b. Cr versus SiO_2 values of Banihal traps.

Cr	188	177	181	195	155	112	181	156	110	185	172	130	143	120	95
SiO_2	50.96	51.10	51.50	51.90	52.88	52.95	53.90	53.98	54.80	54.88	55.60	55.68	55.78	56.48	56.50

Table 24c. Cr versus V values of Banihal traps.

Cr	188	177	181	195	155	112	181	156	110	185	172	130	143	120	95
V	39	66	34	39	46	52	44	30	39	34	42	39	34	27	30

Table 24d. Fe_2O_3+FeO/MgO versus V values of Banihal traps.

T.Iron/MgO	1.90	1.28	2.10	1.96	1.73	2.48	1.57	1.31	1.93	2.51	1.66	1.77	1.67	1.67	2.69
V	39	66	34	39	46	51	44	30	39	34	42	39	34	27	30

Rb. An increase of Ba is less in basic members and decrease in Ca in them makes the ratio to fall from 1181 to 154 and the ratio shows a downward trend in case of Sr/Ba also. This overall indicates an active role of Ba in the volcanics.

CADMIUM (Cd^{+2}) 1.03 A°

Crystalochemical relations between Cadmium and other elements are governed by the size relationship of their radii. The ionic radius of Cadmium in octahedral coordination is 1.02 A°, quite close to those of sodium 0.98 and calcium 1.06 A°. We may, therefore, expect that some of the Cadmium will enter into minerals of calcium and sodium such as the plagioclases, just as Zinc enters ferrous or ferromagnesian minerals. Experiments and various studies have shown that Cadmium enters the mineral structures of early crystallizates of gabbroid magmas. Mn^{+2} also contains some amount of Cd^{+2} as Ionic radius of Mn is also close to that of Cadmium (Mn^{+2} 0.91 and Cd^{+2} 1.03). One more geochemical behaviour of Cadmium is that it has stronger affinity for sulphide ores.

Goldschmidt (1954) reported that Cadmium gets enriched in early and intermediate basic rocks and it is found in lesser amounts in granites and nepheline syenites.

Though much work has been done on the behaviour of Cadmium in igneous rocks yet because of its low concentrations in them, it cannot give us any idea about the source magma, but whatever published literature exists about Cadmium in different types of rocks, its geochemistry is discussed in the light of that.

Wahler (1968) found Cadmium concentration of 0.017 ppm in andesites of lake County, Oregon, U.S.A. Brooks and Ahrens (1961) found 0.03 ppm concentration of Cadmium in the basalts of S.W. Africa. Wahler (1968) found even lesser quantities of Cadmium in Deccan basalts (India). He found the values of Cadmium in such rocks as 0.006 ppm.

Brooks et al. (1960) reported more Cadmium in gabbros than basalts in Skaargarh intrusion.

The findings of various workers given above reveal that Cd^{+2} gets more concentrated in the intermediate rocks provided there are abundances of Ca^{+2}, Mn^{+2}, Zn^{+2} and sulphide ions present in appreciable quantity in the magma. Above all, the geochemistry of Cadmium is mainly controlled by sulphide phase in the differentiation course (Rankama and Sahama, 1950). The ascent of magma, whether rapid or slow also is a controlling factor for the enrichment of this element. If the ascent of magma is slow, olivine and so many other minerals having affinity with sulphide ions will remain longer in the residual liquors without coming up, resulting in the impoverishment of Cadmium in the crustal reservoirs, hence in the later fractions the concentration of Cadmium considerably falls. This model exactly fits in as far as the traps of Banihal area are concerned.

The concentration of Cadmium in the Banihal traps ranges between 0.01 to 0.02 ppm, with an average value of 0.01 ppm. The overall concentration is low in all the analysed samples, but it shows a slight decrease in the less basic members, such a low Cadmium concentration in the traps of Banihal area demonstrates that Cadmium may have got separated in the sulphide phase before the early phase of eruption of lava. The geochemistry of Cd^{+2} is controlled by minerals like plagioclases, epidotes and to a greater extent sulphide phase associated with other chalcophile elements.

Figure 11 represents a graph showing the plot of Cd v/s SiO_2. Cadmium is showing a decline from more basic to less basic members, which is steady initially but more marked in later members.

COBALT (Co) 0.82 A°

The ionic radius of Cobalt is close to that of Fe^{+2}. It, therefore, follows iron very closely, but unlike many other minerals having affinity with sulphide ions will remain longer in the residual liquors without coming up, resulting in the impoverishment of Cadmium in the crustal reservoirs, hence in the later fractions the concentration of Cadmium considerably falls. This model exactly fits in as far as the traps of Banihal area are concerned.

The concentration of Cadmium in the Banihal traps ranges between 0.01 to 0.02 ppm, with an average value of 0.01 ppm. The overall concentration is low in all the analysed samples, but it shows a slight decrease in the less basic members, such a low Cadmium concentration in the traps of Banihal area demonstrates that Cadmium may have got separated in the sulphide phase before the early phase of eruption of lava. The geochemistry of Cd^{+2} is controlled by minerals like plagioclases, epidotes and to a greater extent sulphide phase associated with other chalcophile elements.

Figure 11 represents a graph showing the plot of Cd v/s SiO_2. Cadmium is showing a decline from more basic to less basic members, which is steady initially but more marked in later members.

COBALT (Co) 0.82 A°

The ionic radius of Cobalt is close to that of Fe^{+2}. It, therefore, follows iron very closely, but unlike iron, it has an odd atomic number and hence is less abundant in nature. Cobalt also follows Mg closely and it separates from the magma as rapidly as Mg. Regarding the behaviour of Cobalt during mineralization, it may be observed that Co behaves like Ga and Y, however, the coherence of Mg-Fe with Cobalt is restricted to such systems which are held at high temperatures. It can be concluded from this that in the later differentiates, this element cannot capture Mg-Fe sites, especially when the temperature is low.

In the Banihal traps, the average Cobalt concentration is 48 ppm and its range lies between 34 ppm to 79 ppm. Removal of Mg in the early differentiates is the reason for its low concentration in the later differentiates. McDougall and Lovering (1963), Carslens (1959), Turekian and Carr (1960) found that Cobalt follows very closely Mg-Fe sites. Cobalt also enters the same minerals as Ni, but in lesser amounts. Further McDougall and Lovering (op.cit.) found that pigeonite contains more Co than co-existing Augite. There has been much discussion of the coherence of Co-Fe as compared to Co-Mg^{+2}, but Turekian and Carr (1960) found that the Co content of Pyroxenes is a function of total Fe-Mg sites and is not dependent upon Fe/Mg ratio. Clinopyroxenes and to a greater extent orthopyroxenes capture Co in their sites (Turekian & Carr, 1960). In Banihal area Co concentration is due to the presence of magnetite, and altered pyroxenes in which the trap rocks are substantially rich.

Figure 11 represents a graph of SiO_2 v/s Co. A clear downward trend is revealed from the graph, which indicates that Co got separated during the course of differentiation process earlier.

CHROMIUM (Cr) 0.69 A°

In magmatic rocks the distribution of Chromium is correlated with the sequence of crystallization (Goldschmidt, 1954) in such a way that the element appears in the early crystallizates rich in silicates of magnesium such as olivine bearing rocks and to a somewhat lesser extent in pyroxenites. In these rocks chromium content may range from 1000 to 4000 ppm. In gabbros and basalts, the amount of Cr is about one tenth than in the rocks mentioned earlier viz. 100-400 ppm. In diorites and andesites the amount is still less viz. about 25-80 ppm.

Major element chemistry indicates that olivine got separated in the Banihal traps in the early phases of eruption as in the later differentiates there is impoverishment of Mg. On comparing the values of Cr of the Banihal traps with volcanic rocks of different places, it is revealed that Cr is a bit on the higher side of the normal. One of the plausible explanations for this is that the primary magma may have been rich in Chromium. Second reason for the high values is that Chromium has great affinity for Nickel and in the present case Ni concentration is also high in the trap rocks. Chromium also follows Iron closely and the high values of Cr in traps of Banihal area may have chosen preferably the Fe-sites.

The geochemistry of Cr is controlled by iron, Mg and to some extent by alumina. The alumina concentration in the traps of Banihal area is higher than that found in normal basalts. This also accounts for the higher concentration of Cr in these rocks.

There goes one suggestion regarding the concentration of Cr in the traps of Banihal area that there must have been extensive pyroxene content at the source magma stage, which had not been removed before eruption. Cr may have then chosen the sites of pyroxenes and with the later stages of differentiation, uniform but higher values got distributed in the later differentiates. The average concentration of Cr in these rocks is 181 ppm and range is from95-297 ppm.

Figure 11 represents a graph of Cr v/s SiO_2. On close examination of this graph a sharp decline of Cr with the increase of SiO_2 is noticed. Plate 20, figure 2 represents a graph of SiO_2 v/s Cr. The values of Cr and SiO_2 are tabulated in table 24b. This diagram indicates two fields viz. tholeiite and calc-alkaline. The traps of Banihal area are akin predominantly to tholeiite situation; whereas some points are seen to occupy a field above the demarcation line indicating thereby its association with calc-alkaline magma also.

Miyashiro and Shido (1975) used V v/s Cr and V v/s Fe_2O_3 + FeO/MgO variation diagrams to discriminate between various types of basalts.

Plate 20, figures 3 and 4 represent these diagrams in which A,B and C fields stand for calc-alkaline basalts, mixed basalts and tholeiitic basalts respectively in both the diagrams. Encircled fields in both the diagrams indicate Abyssal tholeiitic basalts. The values of V, Cr and Fe_2O_3 + FeO/MgO are presented in tables 24c & d. Plots of Banihal Traps occupy tholeiitic field in both the diagrams thus confirming the earlier results in bivariate diagrams that have been drawn for the major elements.

Cr has been used in various tectonic discriminant diagrams by many workers such as Leake (1963), Miyashiro (1975), Miyashiro and Shido (1975), Pearce et al. (1982).

Plate 20, figure 5 shows a bivariate discriminant diagram in which analyses of Banihal traps has been plotted. In this diagram Cr has been plotted against Yttrium. The values of Cr and Y are tabulated in table 25a. This plot shows that Banihal traps are akin to both IAT and MORB situations.

Chromium has also been plotted against Niggli mg in plate 20,figure 6. The values of Cr and Niggli mg are tabulated in table 25b. It demonstrates an igneous trend showing sympathetic relation with Mg in the rocks.

Ni and Cr get enriched more in basic rocks and this ratio, therefore, is very important in deciphering the magmatic character of the rocks. The Ni/Cr ratio for the rocks of Banihal area lies between 0.77 to 1.67 with A.M. of 1.22 (table 23). This ratio shows a linear increase from more basic to less basic members of the suite. About half of the samples of the area have ratio greater than 1 and in others it is less than 1. Overall the ratio represents a basic igneous trend in which the concentration of Cr in the later fractions comes down to result in the maximum ratio of 1.67 in the less basic members of the suite. Ni and Cr have paced well in the differentiation course of the rocks. Small range of ratios suggests the less basic character of the rocks.

CAESIUM (Cs) 1.65 A°

The large ionic radius of Caesium in igneous rocks

Table 25a. Y versus Cr values of Banihal traps.

Sample Number	BT86 1	BT109 2	BT189 3	BT101 4	BT73 5	BT71 6	BT58 7	BT5 8	BT115 9	BT28 10	BT175 11	BT196 12	BT165 13	BT84 14	BT95 15
Y	18	20	17	15	18	22	25	21	18	19	25	24	20	26	20
Cr	297	244	211	220	253	228	180	200	185	231	195	170	202	174	150

Table 25b. mg versus Cr values of Banihal traps.

mg	0.45	0.45	0.45	0.36	0.48	0.44	0.51	0.35	0.49	0.36	0.45	0.49	0.59	0.56	0.45
Cr	297	244	211	220	253	228	180	200	185	231	195	170	202	174	150

Table 25c. Mo versus Ni values of Banihal traps.

Mo	8	6	7	4	5	2	7	5	3	5	2	5	4	7	3
Ni	350	195	321	230	190	210	189	241	172	207	188	161	178	220	190

Table 25a. Y versus Cr values of Banihal traps.

Sample Number	BT171 16	BT121 17	BT111 18	BT63 19	BT138 20	BT102 21	BT36 22	BT152 23	BT132 24	BT22 25	BT40 26	BT141 27	BT200 28	BT33 29	BT160 30
Y	15	23	29	24	21	26	20	31	28	24	31	33	25	32	36
Cr	188	177	181	195	155	112	181	156	110	185	172	130	143	120	95

Table 25b. mg versus Cr values of Banihal traps.

mg	0.44	0.56	0.44	0.45	0.46	0.39	0.49	0.55	0.46	0.39	0.49	0.48	0.49	0.48	0.35
Cr	188	177	181	195	155	112	181	156	110	185	172	130	143	120	95

Table 25c. Mo versus Ni values of Banihal traps.

Mo	5	5	2	4	2	5	2	3	1	4	5	3	1	2	1
Ni	200	126	149	155	120	161	172	143	143	149	161	155	160	200	140

makes this element to be enriched in late crystallizates. The heavy alkali metals Rb and Cs occur together in nature. As a general rule, they follow potassium as far as their manner of occurrence is concerned. Unlike lithium Caesium becomes incorporated in salic minerals during crystallization. They resemble potassium chemically but their ionic dimensions are even greater than that of potassium. Caesium is a typical representative of dispersed elements of Vernadsky (1924). According to him such elements very seldom, if ever form independent minerals. In the last stages of differentiation, if Cs is large enough, it replaces Rb.

Horstman (1957) indicated less than 1 ppm Cs in ultramafic rocks. Heir & Adams (1964) suggested that the Cs content in ultramafic rocks could be less than 0.01 ppm. Gurney et al. (1966) found an average of 5.9 ppm Cs (K/Cs = 1.817) in eclogites, from the Roberts Victor mine, South Africa; and 6 ppm as the average for basalts has been worked out by a number of workers. Gast (1960a) found Cs content of 0.10 ppm for olivine basalts.

Hart and Nalwalk (1970) found an average Cs content of 0.1191 (range 0.038 to 0.2714 ppm and K/Cs ratio of 31.936) in ten puerto Rican trench basalts.

As far as Cs concentration in the traps of Banihal area is concerned, it is higher than any of the values given above viz. (2 ppm - 14 ppm av = 7 ppm). The maximum concentration is at 43.85% SiO_2. It, therefore, seems plausible to assume that Cs was already enriched in the source magma so as to affect the high concentration in the traps of Banihal area. Rb captures K-minerals more quickly than Cs does, but in the present case Rb and Cs have both paced well during the course of differentiation. Cs being more volatile may have selected the K-sites of the plagioclases immediately after the eruption of lavas. Secondly Cs was present in good amounts at the source magma level that concentrated Rb could not check this element in getting concentrated more in the less basic members.

Figure 11 represents a plot of Cs v/s SiO_2. The trend in this case is showing a sharp decline with the increase of SiO_2 values. K/Cs ratios in the case of Banihal traps range between 117 to 3400 with A.M. of 1758 (table 23). Such high values for K/Cs and its comparison with K/Rb ratio makes it vividly clear that Rb has strongly replaced K as compared to Cs. Overall examination of this ratio reveals that it is very close to Karroo basalts. Major element chemistry also has revealed this similarity.

COPPER (Cu^{+2}) 0.83 A°

The geochemistry of Copper is not quite well known and the element is characterized by strong chalcophile character. The crystal chemistry data of this element is very uncertain and not so quantitative and accurate as that of other elements chiefly because it does not form simple ionic compounds either synthetically or in nature. However, from whatever, source the data are available, the geochemistry of this element in the traps of Banihal area has been discussed.

Wager and Mitchell (1951) found that the amount of Copper that enters olivine, pyroxene, plagioclase and iron ores is less than in the liquid. It, therefore, accumulates in the residual magma till the sulphide phase develops (Ringwood, 1955a). At this stage Copper gets strongly fractionated and the concentration starts to decline. Plagioclases and iron ores of late fractionation stages contain highest amounts of Copper possibly due to earlier separation of sulphide phase in the middle stage (Prinz, 1967).

In the traps of Banihal area Copper content ranges from 35 to 205 ppm with an average value of 114 ppm. Such high values indicate rapidly evolved nature of the magma in the initial stages of eruption. The often observed pyrite cubes in the traps of the magma had reached the early stages of separation of sulphide phase at the time of eruption.

Copper replaces sodium and divalent iron in silicate and oxide minerals (Wager & Mitchell, 1951, Synder, 1969). In the Mount Willington dolerite of Tasmania, Tiller (1959) has shown that the Copper is present in the pyroxene, plagioclase and iron ore fractions and McDonald & Lovering (1963) have demonstrated the same distribution of Copper in the Red Hill Tasmania granophyre.

Figure 11 represents a graph in which Cu has been plotted against SiO_2. In so far as the distribution of Copper in the volcanics of the Banihal area is concerned, it shows maximum enrichment in the more basic members and it decreases with higher values of SiO_2.

Some of the averages of tholeiitic basalts are given below for comparison with the trap rocks of Banihal area :

		Av. Cu (ppm)
1.	Basalt (quartz normative tholeiites)	81.2
2.	Basalt (Tholeiitic, Norseman area, West Australia)	1.42
3.	Basalt (Siberia U.S.S.R.)	43.0
4.	Basalt tholeiite (Andesite Parana Basin Brazil)	110.1

Traps of Banihal area are closer to No.4. The overall high values of Copper in the traps of Banihal area can be ascribed to middle stage of sulphide phase development in these rocks. It seems probable that these volcanics contain a distribution of Copper between the silicates, oxides and sulphide minerals.

GALLIUM (Ga^{+3}) 0.62 A°

The size of the trivalent cations of Gallium 0.62 A° and aluminium 0.57 A° are so nearly alike that most of Ga in the lithosphere is hidden away or camoflauged in aluminium minerals. Subordinate amount of Ga is not associated with aluminium, but enters into certain sulphide minerals, indicating that the metal to some extent is chalcophile. The difference between the radii of Gallium and aluminium indicates that Ga is less strongly bonded than aluminium at least in oxygen compounds and we may then expect to find it concentrated relative to aluminium towards the end of magmatic crystallization and continue to accumulate in the residual pegmatite and hydrothermal solutions.

Geochemistry of Ga is very important for the study of basic as well as acid rocks among the common rock forming minerals. Gallium is generally concentrated above its crustal abundance only in some feldspars, amphiboles, micas and magnetites.

Its concentration is usually low in pyroxenes and is particularly low in olivine and quartz. The variation of Ga content has been measured over a very wide range by many workers viz., Sen et al. (1960), Wilkinson (1959), Wager and Mitchell (1951) found marked enrichment in the plagioclases which crystallize towards the last crystallizates. Hall (1967), (in Wedepohl, 1978) found Gallium concentration in feldspars of granite complexes to be highest in the rocks of higher silicon content.

Figure 12 represents a graph in which analysed samples have been plotted for Ga against SiO_2. In the diagram Ga is showing a steady decline with the rise of SiO_2 in the rocks.

As far as Ga in traps of Banihal is concerned, its concentration is in the range of 15 to 40 ppm with an average of 29 ppm. There is abundance of plagioclases, iron and aluminium bearing minerals in the trap rocks of Banihal area which seem to have captured Ga in their structures. The overall concentration of Ga appears to be increasing in the less basic members indicating its active role during the process of differentiations. $Al/Ga \times 10^3$ ratio deciphers a steady trend from more basic to less basic rocks, in the case of traps of Banihal area. $Al/Ga \times 10^3$ ratios in the Banihal traps range between 2.42 to 6.32 (table 23). The smaller range of these values indicates less fractionated character of the rocks.

LITHIUM (Li) 0.78 A°

The ionic radii of Lithium and magnesium are same and so Lithium replaces Mg^{+2} in rocks during the course of differentiation (Strock, 1936). The important carriers of Li in rocks are chiefly pyroxenes, micas, and other Mg bearing minerals. Strock (op.cit.) explained that the increase in the Lithium content during the progressive differentiation is a result of Fe^{+3}/Fe^{+2} ratio. However, Wickman (1948) pointed out that Fe^{+3} content does not materially change during the course of differentiation because Fe^{+3} ion is so immobile that it will become incorporated in a suitable minerals structure under any condition. On the other hand the Fe^{+2} content decreases during the differentiation partly owing to the oxidation of Fe^{+2} to Fe^{+3} and this process is mainly responsible for the change in the Fe^{+3}/Fe^{+2} ratio.

The traps of Banihal area have the concentration range of Li between 8 to 24 ppm with an average value of 16 ppm. Li shows an increase towards the less basic differentiates which is quite normal. The rocks of Banihal area have almost uniform distribution of MgO in all the thirty analysed samples and so Li has kept a slow pace in the replacement process of Mg during the differentiation course.

Figure 12 represents a plot of Li v/s SiO_2. On close examination of this diagram it is revealed that there is a steady increase of Li with the increase of SiO_2. It appears that Li has besides magnesium chosen the Fe-sites during the differentiation course.

The Li content found in the basalts of different provinces of the world for comparison with the traps of the Banihal area are given below :

		ppm (Li)	
1.	Oceanic tholeiites	15	Engel et al. (1965)
2.	Alkali Basalts from Seamounts and Islands	6	-do-
3.	Basalts (Hawaii)	5.5	Gladkikh and Chernysheva (1968)
4.	Basic Andesites	10	Taylor & White (1966)
5.	124 Samples of Andesites (Japan)	6	-do-
6.	Andesites New Zealand	32	Ewart et al. (1968)

The traps of Banihal area are closer to Nos. 1 and 2 as far as Li concentration in them is concerned. This clearly indicates marine environment for the traps of Banihal area.

MOLYBDENUM (Mo) 1.40 A°

Molybdenum is one of the main chalcophile elements and the geochemical distributions in igneous rocks is characterized by a preference for late products of magmatic fractionation.

Molybdenum prefers an acid type of environment and it is found in good amounts in pneumatolytic products of magmas and smaller amounts are usually found in gabbroid magmas and norites.

The geochemical distribution of Mo in igneous rocks is characterized by a preference for the late products of magmatic fractionation and as such maximum concentration of Mo has been reported from granites by a number of workers. (Goldschmidt, 1954; Noddack and Noddack, 1934; Sandell, 1946), Magmatic sulphides contain on an average 20 ppm Mo. According to Goldschmidt (1954) titaniferous iron ores contain less than 50 ppm of Mo in them. The high affinity of Mo for sulphur is illustrated by the fact that it readily collects all sulphur available to form molybdenite. In the presence of considerable content of Molybdenum during the crystallization, sulphides of other metals may be formed only if there is still sulphur available after the formation of molybdenite. Tungsten also forms the sulphide tungstenite, but it is rare and without any geochemical importance (Goldschmidt, 1954).

In the traps of Banihal area, there is extensive Formation of pyrite. According to Goldschmidt's view pyrite Formation in these rocks might have taken place after Molybdenum got concentrated by selecting the sites of early magmatic nickliferous sulphide rocks of the area. This agrees well in the present case, sufficient Mo had fractionated in the early crystallizates and then only extensive pyrite Formation resulted. Vingradov et al. (1962) gave the figure of 2.8 ppm for the basalts of U.S.S.R. and 10 ppm for the andesites of U.S.S.R. Molybdenum concentration is more in the more basic members of the suite in the traps of Banihal area though overall concentration in all the samples is less than 10 ppm. This indicates that the sulphide phase had started earlier during the eruption of the Banihal traps. In the later differentiates the Mo concentration is reduced to an extent of 1 ppm. Overall Mo distribution is normal in the rocks in question and it has paced well with Ni.

Figure 12 represents a plot of Mo v/s SiO_2. It is clear from this figure that Mo shows an overall decrease in the later differentiates. The trend is declining from more basic to less basic members. Molybdenum gets concentrated in the sulphide phase, which in the present case appears to have got separated in the early phase of eruption.

In other words it can be inferred that the rocks did not proceed far in the differentiation course and hence that explains the Mo depleted character of the rocks. The average value of Mo in the rocks of Banihal area comes to 4 ppm and the range lies between 1 ppm to 8 ppm.

Plate 21, figure 1 shows a bivariate diagram of Mo v/s Ni. The values of Mo & Ni are given in table 25c. The trend line in this case is very clear and both Mo and Ni have played a positive role during the differentiation course of the rocks with the increase in nickel, Mo has also increased.

Ni/Mo ratio shows an increase towards the later crystallizates (table 23). Molybdenum is related to the sulphide phase and in the trap rocks of Banihal area it started earlier as concluded from the discussion on the geochemistry of Mo. Molybdenum in the later fractions gets much reduced as compared to nickel and as such the ratio increases in the later fractions.

NICKEL (Ni^{+2}) 0.78 A°

Like magmatic sulphides Nickel bearing igneous also constitute the main stage of magmatic crystallization. Nickel and cobalt are incorporated in the early silicate minerals of the early differentiation course and both these elements decrease in concentration in the later crystallizates.

Nickel is on the one hand chalcophile and on the other hand it selects Mg-Fe sites. Nickel in the case of traps of Banihal area has concentrated in pyroxenes and magnetites to which it is crystal chemically related.

Recent literature about the concentration of Nickel in basalts has been discussed by many workers. Turekian (1963), Nockolds & Allen (1953), Hart et al. (1972) and Taylor et al. (1969). The following table will clearly show the concentration of Nickel in various types of basalts :-

	Rock type/place	Av. Nickel (ppm)
1.	Basalt mostly Tholeiitic (world-with average)	134
2.	Basalts Hawaii	191
3.	Tholeiitic Basalts	530
4.	Basalts Karroo (S. Africa)	164
5.	Tholeiites Columbia River	48
6.	Mid Oceanic Ridge basalts	160
7.	High alumina basalts	25
8.	Low potassium andesites world wide.	15

In the present case Ni lies in the range of 120-350 ppm with an average of 187 ppm, so it is very close to the basalts of Karroo (S. Africa) and basalts of Hawaii. As far as Nickel is concerned the traps of Banihal area are akin to MORB.

Figure 12 represents a graph in which Ni has been plotted against SiO_2. The examination of the plot, shows that Ni has a sharp fall upto SiO_2 value of 49% and then onwards there is a steady decrease in its content. This signifies that Ni in the early stages got fractionated rapidly and was later on deposited almost uniformly in the later differentiates.

Ni being immobile has been preferred to be used in tectonic discriminant diagrams frequently. Plate 21, figure 1 represents a plot of Ni v/s Mo, which indicates that both have acted sympathetically in the differentiation process. In Plate 21, figure 2 Ni has been plotted against Niggli mg which demonstrates an igneous trend for the trap rocks of Banihal area. The values of Ni v/s mg are given in table 26a.

Ni gets impoverished along with Mg in the later differentiates. Mg/Ni lie between 135 to 294. The low value of Mg/Ni ratio (table 23) indicates that the concentration of Ni in the Banihal traps is more than the average of other basaltic suites; lower values are well within the oceanic tholeiitic basalts. Further such values

Table 26a. mg versus Ni values of Banihal traps.

Sample Number	BT86 1	BT109 2	BT189 3	BT101 4	BT73 5	BT71 6	BT58 7	BT5 8	BT115 9	BT28 10	BT75 11	BT196 12	BT165 13	BT94 14	BT95 15
mg	0.45	0.45	0.45	0.36	0.48	0.44	0.51	0.35	0.49	0.36	0.45	0.49	0.50	0.56	0.45
Ni	350	195	321	230	190	210	189	241	172	207	188	161	178	220	190

Table 26b. Ca versus Sr values of Banihal traps.

Ca	5.73	5.22	5.32	7.56	5.33	6.83	5.52	5.31	7.31	4.27	5.18	4.73	5.04	5.43	4.55
Sr	244	193	220	151	180	160	134	126	137	179	102	86	173	119	86

Table 26c. Sr versus Pb values of Banihal traps.

Sr	244	193	220	151	180	160	134	126	137	179	102	86	173	119	86
Pb	22	29	26	21	25	21	26	30	21	9	17	19	27	14	27

Table 26a. mg versus Ni values of Banihal traps.

Sample Number	BT171 16	BT121 17	BT111 18	BT63 19	BT138 20	BT102 21	BT36 22	BT152 23	BT132 24	BT22 25	BT40 26	BT141 27	BT200 28	BT33 29	BT160 30
mg	0.44	0.56	0.44	0.45	0.46	0.39	0.49	0.55	0.46	0.39	0.49	0.48	0.49	0.48	0.35
Ni	200	126	149	155	120	161	172	143	143	149	161	155	160	200	140

Table 26b. Ca versus Sr values of Banihal traps.

Ca	4.00	5.10	3.98	3.81	6.67	3.66	5.50	4.35	4.78	5.68	3.94	4.41	4.98	4.06	3.93
Sr	150	48	75	107	59	96	75	51	111	42	94	51	59	76	44

Table 26c. Sr versus Pb values of Banihal traps.

Sr	150	48	75	107	59	96	75	51	111	42	94	51	59	76	44
Pb	39	23	16	18	17	32	24	32	23	28	17	10	15	20	14

are indicative of the less basic character of the rocks.

Ni and Cr is enriched more in basic rocks, and this ratio, therefore, is very important in deciphering the magmatic character of the rocks. The ratio Ni/Cr for the rocks of Banihal area lies between 0.77 to 1.67 with an arithematic mean of 1.22 (table 23). The ratio shows a linear increase from more basic to less basic members of the suite. About half of the samples of the area have a ratio greater than 1 and in others it is less than 1. On the whole, the ratio represents a basic igneous trend, in which the concentration of Cr in the later fractions came down to result in the maximum ratio of 1.67 in the less basic members of the suite. Ni and Cr have paced well in the differentiation course of the rocks. Small range of ratios suggests the less basic character of the rocks.

LEAD (Pb) 1.32 A°

Lead as a divalent ion is closely associated with strontium which has a very similar ionic radius. It is captured in potassic minerals and small amounts are found in magmatic rocks (often 3-10 ppm of Pb). Magmatic apatite has a great capacity for more ions even if their radii differ notably from that of calcium, and, therefore, it is a common host mineral for lead. Potash feldspars may contain 5-100 ppm, the highest amounts usually occurring in early crystallizates of feldspars. The geochemical data leave no doubt that the distribution of lead in magmatic rocks is generally controlled by the laws of crystal chemistry, lead ions being concentrated in the potassium minerals, especially the early crystallizates.

The Pb concentration in the rocks of Banihal area ranges from 9 to 39 ppm with an average value of 22 ppm. Close examination of the table 22 reveals that Pb gets concentrated more in the later differentiates. The traps of Banihal area are low in K_2O and as such Pb in the present case appears to have followed strontium. Some of the lead appears to have followed pyroxene sites. Lead in the present case has maximum enrichment at 50.96 percent SiO_2 which suggests that Pb got enriched during the initial phases of magmatic activity.

Lead concentrations from different provinces as compiled by Wedepohl (1978) is given as under for comparison :-

High alumina basalt	Cascade Mts California U.S.A.	2.88 ppm
Tholeiitic basalt	Washington	4.8 ppm
Andesites	Calimanian Mts (Roumania)	27.9 ppm
Andesites	Aegina, Methana (Greece)	10.6 ppm

Andesites	Oki Island (Japan)	8.2ppm
Andesites	Central (Khazakistan U.S.S.R.)	14.2ppm

From the table it appears that the traps of Banihal area are more closer to the andesites of Roumania, as far as Pb concentration in these is concerned.

Figure 12 shows a plot of Pb v/s SiO_2. It is very much clear from this figure that Pb shows an overall decrease in the later differentiates. The trend is declining from the basic to less basic members. Maximum enrichment of lead is at 50.96 percent SiO_2. The range of lead in the rocks is between 9 ppm to 39 ppm with an average value of 22 ppm. Lead prefers an acid environment and as such it shows concomitant increase in slightly less basic members of the suite. Its behaviour, therefore, is normal with the differentiation course of the rocks.

RUBIDIUM (Rb) 1.49 A°

As a general rule Rb follows potassium so far as its manner of occurrence is concerned (Leibenberg, 1960; Gast, 1968; Nockolds & Allen, 1953). The radius of Rb(1.49 A°) is quite similar to that of K^+ (1.33 A°) and, therefore, Rb is present in the minerals of much more abundant potassium.

Generally, Rb appears to be present in detectable amounts only in feldspars and feldspathoids. Wager & Mitchel (1951) detected some Rb in the latest pyroxenes in the Skaargarh intrusion. Wilkinson (1959) found Rb concentration in analcite bearing rocks and micaceous granites. Rb prefers K-feldspars to plagioclases (Heir, 1962) with an increase in the anorthite content of plagioclases Rb gets depleted to a great extent.

Rb content in the volcanics of Banihal area lies in the range of 19 to 141 ppm; with an average value of 59 ppm. Rb in these rocks appears to have got concentrated to some extent in pyroxenes and largely in feldspars. The slightly high values of Rb in the rocks of Banihal area may be due to the presence of K-feldspars in solution. Geochemical behaviour of Rb is that it gets increased towards the late stages of differentiation (Nockolds & Allen, 1953). The present study reveals that Rb does increase towards the acid fractions primarily due to high concentration of this element in the primary magma.

Some examples of tholeiitic basalts of various localities are given below for comparison with the traps of Banihal area as far as Rb concentration is concerned.

	Rock type/place	Av. (ppm)
1.	Basalt Indian Ocean	17
2.	Andesites Indian Ocean	50

	Rock type/place	Av.(ppm)
3.	Tholeiitic Basalt Hawaii	8
4.	Andesites (Hawaii)	23
5.	Andesites (Japan)	20
6.	Andesites (New Zealand)	45
7.	Andesites (Puerto Rico)	30
8.	Andesites (Karroo)	56
9.	Submarine (Dredge have Tholeiites)	2
10.	Island Arc Tholeiites	5
11.	Alkali Basalts	46

From the perusal of the averages given above it is evident that the traps of Banihal area are closer to andesites of Karroo basalts.

Figure 12 represents a plot of Rb v/s SiO_2. On close examination of the diagram it is revealed that Rb shows a slow increase upto a value of 54% SiO_2 and onwards it depicts a rapid increase. The late stage Rb addition is ascribed to the abundant crystallization of plagioclases in which K may have been present in solution. The study of Ba/Rb ratio for the trap rocks of Banihal area reveals the active role of Rb than Ba during the course of differentiation as Ba/Rb ratio declines in the less basic members in the present case (table 23).

K/Cs and K/Rb ratios reveal that Rb concentration has increased during the fractionation course much more rapidly than Cs, though both Cs and Rb must have chosen K-feldspar sites during magmatic differentiation course.

Lessing et al. (1964) pointed out that the volcanic rocks in Hawaii were characterized by high K/Rb ratios and subsequent research has demonstrated that high K/Rb ratios are observed in basalts dredged from the deep ocean floors and these are also low in K. The low K/Rb ratios of continental basalts may reflect conditions in the upper mantle and a selective combination process affecting the concentration as it ascends through the Rb rich environment in the continental crust.

Data compiled by Wedepohl (1978) for different types of basalts and andesite associations reveals the basalts of Atlantic Island with K/Rb ratio of 428 : basalts from Pacific Islands give a ratio equal to 418 . Basalts of Indian ocean 417; andesite of Indian ocean as 332; tholeiitic basalts Hawaii as 543 and Karroo basalt as 157. Traps of Banihal resemble basalts of Indian ocean closely thus pointing to their marine origin. Slightly overall low values of K/Rb (table 23) may be due to the more concentration of Rb in these rocks. Recent work has demonstrated that K and Rb are significantly fractionated by processes normally associated with regional metamorphism. The imprint of metamorphism of a low degree has been witnessed in the trap rocks of Banihal area and so this may be the probable cause for the depletion of Rb & K in the rocks, after getting fractionated these two elements may have simultaneously been leached from the rocks.

STRONTIUM (Sr) 1.27 A°

The geochemistry of Strontium in igneous rocks is controlled chiefly by its corresponding major elements Ca^{+2} and K. It is camouflaged in some of the Ca bearing minerals chiefly the plagioclase feldspars. Experiments and analytical data have shown that Ca bearing pyroxenites are not suitable for the replacement of Ca by Sr. As far as traps of Banihal area are concerned, K is low in all the samples and this may be one of the main reasons for Sr depleted character of the rocks. Plagioclases which have been altered substantially could easily camouflage Sr, but still the overall concentration of Sr is less in the traps of Banihal area (Av. value = 114 ppm and range = 42-244 ppm). This indicates that Sr may have been less in the primary magma.

Ringwood (1955a) suggested that basalts fractionate along two trends (i) Strontium fractionation trend (ii) Strontium depletion fractionation trend characteristics of Jurassic tholeiites from Antarctica and Tasmania and Pre-Cambrian tholeiites from Wyoming. Ringwood (op.cit.)

accounted for the Strontium depleted character of Tasmanian and Antarctic tholeiites by shallow wall rock reaction of the magma. Condie et al. (1969) refuted this model and instead pointed out that extensive plagioclase crystallization lends support to explain Sr depletion in such rocks. This view applies to traps of Banihal area. Plagioclase crystallizations in the first phase of eruptions may have separated out Sr in a great quantity that it was very low in the later differentiates. Figure 13 represents a graph in which Sr values of the rocks under discussion have been plotted against SiO_2. Strontium shows a gradual fall in the later differentiates of the volcanic suite. Its maximum enrichment is at 43.68% of SiO_2.

Condie et al. (1969) compiled data of Sr concentrations in various tholeiitic basalt provinces as : (i) 428 ppm for continental tholeiites, (ii) 397 ppm for Island arc tholeiites, (iii) 353 ppm for Island tholeiites (iv) submarine Dredge haul basalts have 123 ppm of Sr as an average.

From the perusal of this data, it is revealed that the traps of Banihal area are closer to submarine Dredge haul basalts thus confirming their extrusion in marine environment.

Sr has paced well with Ca and Pb ions during the differentiation process. This is well demonstrated by plate 21, figures 3 and 4. The values of Sr v/s Ca and Sr v/s Pb are listed in tables 26b & c.

K/Sr ratio for the trap rocks of Banihal area is in the range of 9 to 209 (table 23). No sharp trend is depicted by these ratios. Overall Sr appears to have been depleted in less basic members.

Sr/Ba ratio in the case of traps of Banihal area lies between 0.17 to 3.49 (table 23). This ratio reveals downward trend indicating increase of Ba in the less basic members.

VANADIUM (V^{+5})

Vanadium in magmatic rocks has an affinity for Fe^{+3} which it follows during the differentiation of basic magma. Because of the closeness of ionic size in the trivalent state it gets concentrated in early and intermediate stages of magmatic evolution. Goldschmidt (1954), Prinz (1967), Wager & Mitchell (1951) reported that in the rocks of east Greenland, the chief mineral structures which contain Vanadium are in order of preference magnetites, pyroxenes and the olivines. Since olivine is not present in the trap rocks of Banihal area, therefore, it can be inferred that Vanadium in these trap rocks is concentrated in the lattices of magnetites and pyroxenes. Pyroxenes in these traps have altered to amphiboles and chlorites and much of the Vanadium thus appears to have been occupied in the lattices of magnetites and lesser quantity in the pyroxenes and their altered products. Maximum of Vanadium concentrations in traps of Banihal area has actively followed ferric iron which is more in the basic members (BT-86 sample with Fe_2O_3 = 4.90%) and in the later differentiates Vanadium shows decline. According to Goldschmidt (1954), apatites also contain a good amount of Vanadium in them, since apatite is not found in the trap rocks of Banihal area, this may be the reason for overall low concentration of Vanadium in later differentiates.

Goldschmidt (1954) gave a range of Vanadium for andesites as 100-250 ppm, but in the present case the range is 27-80 ppm, with an average value of 48 ppm. The Vanadium depleted character of these rocks may be due to overall less content of Fe_2O_3 in them.

Figure 13 shows a graph in which Vanadium has been plotted against SiO_2. The graph indicates a sharp decline in the later differentiates. Maximum concentration of Vanadium in the traps of Banihal area is at 43.68% SiO_2.

YTTRIUM (Y^{+3}) 1.06 A°

Yttrium is a very common constituent of minerals and rocks even though it occurs in low concentrations. It is found with the Lanthanide group of elements. Owing to its large ionic radius it cannot replace magnesium and ferrous iron in mineral structures. However, Yttrium is greatly affected by Fe_2O_3/FeO ratio. With the increase in this ratio, Y also shows a marked increase. Yttrium has great affinity for phosphorus but Banihal traps have not been analysed for phosphorus and so relation of Y with phosphorus cannot be assessed in the present case. Other important carriers of Yttrium are zircon, garnet epidotes, and clinozoisite group of minerals. Zircons and garnets are both absent in the traps of Banihal area and so Y has chosen iron and epidote sites.

Trace element study with respect to Yttrium and Lanthanide distribution has been made by a number of workers.

Frey et al. (1964 & 1968) gave the data for Yttrium for Mid-Atlantic Ridge basalts as 34 ppm; and 22.35 ppm for East Pacific Rise tholeiitic basalts. Schmitt et al. (1963) reported 24 ppm Y as an average for Hawaiian tholeiitic basalts. Frey in Haskin (op.cit.) working on Deccan plateau basalts found concentration of Yttrium as 52 ppm. Balashov et al. (1966) gave a figure of 23 ppm for the tholeiitic basalts of Siberian platform.

Herrmann (1968) gave a figure of 19 ppm of Yttrium for tertiary volcanic rocks of N.W. Germany.

The traps of Banihal area have a range of Yttrium between 15-36 ppm with an average value of 24 ppm. This figure is close to Atlantic Ridge basalts, Hawaiian tholeiitic basalts and Siberian basalts. The values are, however, lower than Deccan plateau basalts, which may be due to the difference in their respective mineral compositions.

Figure 13 shows a plot of Y v/s SiO_2. The trend of Yttrium is higher in the samples having higher values of SiO_2. Plate 21, figures 4 & 5 represent bivariate diagrams in which Y has been plotted against Mg & Ca respectively. In both the diagrams, Yttrium demonstrates an overall decline with the higher values of Mg and Ca. Y v/s Mg and Y v/s Ca values are indicated in tables 27a & b.

Winchester & Max (1982) used Y v/s FeO/MgO diagram for discriminating tholeiitic basalts from Calc-alkaline series. The values of FeO/MgO and Y are given in table 27c. Plate 22, figure 1 represents a plot of traps of Banihal area. This diagram demonstrates tholeiitic lineage for these rocks.

The geochemistry of Yttrium is highly influenced by the alkali enrichment in the basaltic suites and as such this ratio is important in deciphering the magmatic character of the rocks. The values of (Na + K)/Y for the

Table 27a. Mg versus Y values of Banihal traps.

Sample Number	BT86 1	BT109 2	BT189 3	BT101 4	BT73 5	BT71 6	BT58 7	BT5 8	BT115 9	BT28 10	BT175 11	BT196 12	BT165 13	BT94 14	BT95 15
Mg	4.74	4.59	5.35	3.59	4.74	4.74	5.27	3.12	5.06	2.94	4.22	4.54	4.74	5.52	3.92
Y	18	20	17	15	18	22	25	21	18	19	25	24	20	26	20

Table 27b. Ca versus Y values of Banihal traps.

Ca	5.73	5.22	5.32	7.56	5.33	6.83	5.52	5.31	7.31	4.27	5.18	4.73	5.04	5.43	4.55
Y	18	20	17	15	18	22	25	21	18	19	25	24	20	26	20

Table 27c. FeO/MgO versus Y values of Banihal traps.

FeO/MgO	1.46	1.61	1.78	2.37	1.41	1.61	1.31	2.39	1.16	2.32	1.77	1.49	1.62	1.04	1.49
Y	18	20	17	15	18	22	25	21	18	19	25	24	20	26	20

Table 27d. Zr versus Zr/Y values of Banihal traps.

Zr	41	68	59	47	68	86	74	67	70	52	84	82	60	92	70
Zr/Y	2.28	3.40	3.47	3.13	3.78	3.91	2.96	3.19	3.89	2.74	3.36	3.42	3.00	3.54	3.50

Table 27a. Mg versus Y values of Banihal traps.

Sample Number	BT171 16	BT121 17	BT111 18	BT63 19	BT138 20	BT102 21	BT36 22	BT152 23	BT132 24	BT22 25	BT40 26	BT141 27	BT200 28	BT33 29	BT160 30
Mg	3.83	4.74	3.75	3.75	4.25	4.09	3.89	5.06	3.42	2.45	3.75	4.08	4.06	4.42	3.12
Y	15	23	29	24	21	26	20	31	28	24	31	33	25	32	36

Table 27b. Ca versus Y values of Banihal traps.

Ca	4.00	5.10	3.98	3.81	6.67	3.66	5.50	4.35	4.78	5.68	3.94	4.41	4.98	4.06	3.93
Y	15	23	29	24	21	26	20	31	28	24	31	33	25	32	36

Table 27c. FeO/MgO versus Y values of Banihal traps.

FeO/MgO	1.55	1.17	1.88	1.75	1.34	2.19	1.30	1.13	1.77	2.19	1.45	1.62	1.47	1.41	2.08
Y	15	23	29	24	21	26	20	31	28	24	31	33	25	32	36

Table 27d. Zr versus Zr/Y values of Banihal traps.

Zr	51	90	95	82	76	99	60	106	100	90	115	120	95	119	137
Zr/Y	3.40	3.91	3.27	3.42	3.62	3.81	3.00	3.42	3.57	3.75	3.71	3.64	3.80	3.72	3.80

traps of Banihal area lie in the range of 978-1640 with A.M. of 1309. Though alkalis are found in low concentrations in the rocks under study, yet the ratios are well within the Island arc tholeiites (IAT) and Mid-Oceanic Ridge Basalts (MORB). The ratios, however, deviate from such basaltic suites in which alkali metasomatism has taken place. The alkali metasomatism in the rocks of the present area is ruled out on the basis of low values of Na and K. Comparison of (Na + K)/Y and Zr/Y ratios (table 23) indicate that Yttrium has selected zircon sites in preference to alkali elements.

ZINC (Zn^{+2}) 0.83 A°

In the early magmatic sulphides the amount of Zinc is relatively low. Zinc follows iron and magnesium during the course of differentiation. Since ferromagnesian minerals are more in the early stages of differentiation, Zinc will get a sharp decline in the later differentiates and consequently it will select the Fe-Mg sites of early formed differentiates. Sphalerite contains large proportions of Zinc, but since this mineral is rare in igneous rocks, other Zinc carriers should be taken into consideration while studying the geochemistry of this element. Sandell and Goldich (1943) have shown that the silicate rocks formed during the main stages of differentiation contain proportionately more Zinc.

The manner of occurrence of Zinc is determined by its property of diadochically replacing ferrous iron and magnesium in mineral structures. The closeness of ionic radii of Zinc, Fe, and Mg (0.83 A°,0.83 A° and 0.78 A° respectively) causes the presence of Zinc in magnetite and ilmenite and explains the fact that early magmatic oxide ores are weakly zinciferous. During the magmatic differentiation Zinc and cadmium together with many other elements remain largely in the residual melts and solutions throughout the main stages of crystallization. Many workers have found the highest Zinc contents in more acidic products of differentiation and in such later differentiates as have the highest content of biotite.

The traps of Banihal area contain Zinc between the range of 44-223 ppm with an average value of 117 ppm. Zinc in the rocks under discussion is concentrated in the more basic members. The possible minerals as Zinc carriers in the traps of Banihal area that appear to have camouflaged Zinc are : magnesium, magnetite and ilmenite. These traps contain abundant proportion of these minerals. No other mineral except these is expected to carry Zinc in these rocks. Olivines and biotites are not found in the traps of Banihal area. Zinc concentration sharply falls in the later differentiates, though the Fe_2O_3 and MgO are almost uniformly distributed in the rocks of the present area. This clearly indicates that alongwith pyroxenes and olivines Zinc must also have separated in the early eruptive phase.

Many workers have worked on the Zinc abundances in intermediate as well as basic igneous rocks in different provinces of the world. Morita (1955) : in Wedepohl (1978) from 26 analyses of andesites of Japan found average Zinc value as 87 ppm; whereas Savel et al. (1956a) : in Wedepohl (1978) gave the figure of 63 ppm for the andesites of Roumania. Sandell and Goldich (1943) while working on the andesites of California gave an average value of Zn for 12 analysis as 63 ppm. Smith (1964) gave the figure of 94 ppm for the metabasalts. The data given above shows the Zinc concentration to be more in metabasalts than the unmetamorphosed igneous rocks. In the present case Zinc concentration is slightly higher than the given averages above and it may be due to low grade of metamorphism suffered by traps of Banihal area.

Figure 13 represents a plot of Zn v/s SiO_2. On close examination of this graph, it is revealed that Zinc considerably declines with the higher values of SiO_2. The maximum zinc concentration in these volcanics is at 43.86 percent SiO_2.

ZIRCONIUM (Zr^{+4}) 0.80 A°

Zirconium geochemistry is dominated by its lithophile nature. Mumpton and Roy (1961) and Caruba et al. (1975) have shown that the crystallization of Zircon requires an acidic environment. Chao and Fleicher (1960) : in Wedepohl (1978) noted that the large range in the concentration encountered in mafic rocks was related to geographic variations and the concentrations were mostly dependent on tactonic framework.

Zirconium abundances in intermediate rocks should be compared to the averages given by Degunhardt (1957) : in Wedepohl (1978) for andesites (120 ppm Zr) and trachytes (500 ppm Zr). Chao & Fleicher (1960) data showed that andesites (25-110 ppm) contain less Zirconium than the other oceanic lavas of equivalent compositions such as mugearites (250-520 ppm). Data for oceanic rocks given by a number of workers indicate that all intermediate rocks are enriched in Zirconium as compared to possible parental mafic varieties. However, the rate of increase is such that the alkali basalt suite differentiates (Trachy-andesites, mugearites through to trachytes) are relatively more enriched in Zirconium (commonly 400-1000 ppm and upto 1800 ppm in Gough Island Trachytes) than tholeiitic differentiates (about 500 ppm in Icelandites) and Island arc andesites (30-120 ppm).

In oceanic basalts Zirconium increases in the sequence calc-alkali basalt or low K-tholeiite (10-100 ppm), oceanic tholeiite about (70-200 ppm), alkali basalts (200-300 ppm). The later differentiates (Hawaiites and trachybasalts) contain even higher.

The average of the trap rocks of Banihal area falls in the oceanic tholeiites (82 av.) thereby confirming their tholeiitic character and marine environment of deposition. Figure 13 represents a plot of Zr v/s SiO_2 and this graph demonstrates higher values towards the increasing values of SiO_2.

TECTONIC DISCRIMINANT DIAGRAMS

In order to study the tectonic environment of deposition in respect of Banihal volcanics, some tectonic discriminant diagrams have been drawn with immobile elements such as Ti, Zr and Y. These immobile elements have recently been used by Qasim Jan (1988) while working on the amphibolites from the southern part of the Kohistan arc, N. Pakistan. Some of the tectonic diagrams on these lines are discussed below :

Zr/Y VERSUS Zr BIVARIATE DIAGRAM

Pearce and Cann (1973) suggested this diagram in which three basalt fields are discriminated viz. (i) within plate basalts (WPB), (ii) mid-oceanic ridge basalts (MORB) and (iii) Island arc tholeiite basalts (IAT). The values of Zr/Y and Zr are listed in table 27d. Plot of data in respect of the traps under study in this diagram (plate 22, figure 2) reveals that these volcanics are akin to Island arc tholeiites and mid-oceanic ridge basalts.

The plot of traps of Banihal area occupies mainly MORB. However, 4 points lie very close to MORB boundary in the arc lavas and a few other points occupy a place between WPB and arc lava fields but these two are very near the demarcation boundary of MORB field.

Ti/100-Zr-Y x 3 TRIANGULAR VARIATION DIAGRAM

Pearce and Cann (1973) used this diagram for discriminating ocean floor basalts, Island arc tholeiites, mid-oceanic ridge basalts, calc-alkaline basalts and within plate basalts. The values of Ti, Zr and Y calculated to hundred percent are presented in table 28a. Plate 22, figure 3 represents such a diagram for the trap rocks of Banihal area. It is clearly seen from this diagram that the majority of the points occupy fields A and B with a few points in field D.

It shows close similarity of the traps of Banihal area with Mid-oceanic ridge basalts and Island arc tholeiitic basalts.

Table 28a. Ti/100-Zr-Yx3 values of Banihal traps.

Sample Number	BT86 1	BT109 2	BT189 3	BT101 4	BT73 5	BT71 6	BT58 7	BT5 8	BT115 9	BT28 10	BT175 11	BT196 12	BT165 13	BT94 14	BT95 15
Ti/100	53	46	43	59	43	42	38	47	29	49	30	30	40	28	39
Zr	20	29	31	21	32	33	31	27	40	24	37	37	30	39	33
Y x 3	27	25	26	20	25	25	31	26	31	27	33	33	30	33	28

Table 28b. Cr versus Ti values of Banihal traps.

Cr	297	244	211	220	253	228	180	200	185	231	195	170	202	174	150
Ti	10492	11870	8393	13069	9233	10911	9233	11750	5036	10492	6715	6595	7974	6715	8393

Table 28c. Zr versus Ti values of Banihal traps.

Zr	41	68	59	47	68	86	74	67	70	52	84	82	60	92	70
Ti	10492	11870	8393	13069	9233	10911	9233	11750	5036	10492	6715	6595	7974	6715	8393

Table 28a. Ti/100-Zr-Yx3 values of Banihal traps.

Sample Number	BT171 16	BT121 17	BT111 18	BT63 19	BT138 20	BT102 21	BT36 22	BT152 23	BT131 24	BT22 25	BT40 26	BT141 27	BT200 28	BT33 29	BT160 30
Ti/100	50	31	29	30	39	41	40	23	27	37	22	26	28	22	23
Zr	27	39	37	37	33	33	30	41	40	35	43	41	40	43	43
Y x 3	23	30	34	33	28	26	30	36	33	28	35	33	32	35	34

Table 28b. Cr versus Ti values of Banihal traps.

Cr	188	177	181	195	155	112	181	156	110	185	172	130	143	120	95
Ti	9652	7194	7554	6715	8813	12110	8393	5875	6715	9652	5875	7554	6715	5875	7254

Table 28c. Zr versus Ti values of Banihal traps.

Zr	51	90	95	82	76	99	60	106	100	90	115	120	95	119	137
Ti	9652	7194	7554	6715	8813	12110	8393	5875	6715	9652	5875	7554	6715	5875	7252

Ti v/s Cr BIVARIATE DIAGRAM

Pearce (1988) gave one more diagram of differentiating Ocean floor basalts and Island arc tholeiites. The values of Ti and Cr are given in table 28b. Plate 22, figure 4 in the case of traps of Banihal area shows that majority of points occupy the tholeiitic field with a few of the points above the line of demarcation in the OFB field. This also suggests tholeiitic character and marine origin for the traps of Banihal area.

Ti v/s Zr BIVARIATE DIAGRAM

Pearce et al. (1981) used a bivariate plot of Ti versus Zr for discriminating arc lavas, Mid-oceanic ridge basalts and within plate basalts. The values of Ti v/s Zr are listed in table 28c. The plots of the Banihal traps (plate 24, figure 5) are seen falling in MORB and arc lava fields. Four points are very near to the demarcation boundaries of MORB and arc lava fields and two points are very near to the MORB boundary. The plots as a whole reveal these rocks to be akin to MORB & IAT situations.

Observations, in general, about trace element studies have been summarized below :

1. Ti-Zr variation diagram V v/s $(Fe_2O_3 + FeO)/MgO$, V v/s Cr (after Miyashiro diagrams) all show marine environment for the trap rocks of Banihal area.

2. The Cr-Mg, Ni-Mg both show a positive correlation between Cr and Ni characteristic feature of igneous rocks.

3. SiO_2 increase depicts depletion of Cr in the rocks as an indication of igneous source. Further this plot suggests tholeiitic character of the rocks and also plot of Y v/s FeO/MgO shows tholeiitic lineage for the rocks.

4. Cr, Ni, Ti are rich in traps of Banihal area. This together with low Niggli k values can be derived only from igneous predecessors (Leake, 1963).

5. Miyashiro diagrams together with Zr/Y v/s Zr; Ti v/s Cr diagrams all point towards the marine origin for the rocks of Banihal area. The rocks in general are akin to MORB and IAT suggesting tholeiitic affinity and marine environment of deposition. Ti & Cr show a positive correlation characteristic of igneous source.

6. The concentration of Pb, Cu, Mo in the Banihal rocks depleting in the later differentiates suggests slow rate of eruption because of sulphide enrichment

having taken place earlier in the course of differentiation.

7. The geochemical affinity of Co with Mg, Pb with Sr and V with Fe^{+3} is normal in these rocks suggesting overall less basic character of the rocks in question.

8. The overall low values of Sr and Ba in the trap rocks of Banihal area show again their less basic character. Comparison of the average values of these two elements suggests that these rocks are akin to tholeiitic basalts of continents and oceanic islands.

9. The olivine free, nature, and extensive plagioclase concentration in these rocks is the probable cause of Sr depletion in the traps of Banihal area as suggested by Condie et al. (1967).

10. Low grade metamorphism in the traps of Banihal area has depleted Pb, K and Ba in these rocks and to a lesser extent Na, Pb & Sr as suggested by workers for other such metamorphic terrains of the world (Sighinolfi & Gorgoni, 1978 and Rollinson and Windley, 1980).

11. The study of trace element data like the major element rules out the spilitic character for the

traps of Banihal area.

12. The study of different ratios such as K/Rb, Zr/Y have revealed that the rocks of Banihal area are akin to MORB and IAT basalts.

13. Ni/Cr, Mg/Ni and Al/Gaxio^{3} have indicated less basic character of the traps of Banihal area.

14. Zr/Y ratio indicates that Yttrium has selected Zirconium-sites in preference to alkalis.

15. K/Rb & K/Cs ratio indicate that Rb has strongly replaced K as compared to Cs and K/Ba ratio as compared to K/Rb & K/Cs indicates that maximum K in the rocks has been replaced by Ba, a lesser extent by Rb and least by Cs.

ORIGIN AND SOURCE OF THE PANJAL VOLCANICS

This chapter deals with the origin and source of the Panjal volcanics based on a detailed study of these rocks in the light of observational and experimental studies of the basaltic provinces of the world and synthetic phase systems under different pressure temperature conditions.

Whenever there is reduction in pressure in the earth's crust in any part of the globe, the melting point of rocks is reduced resulting in their fusion. A part of the crust may also be buried to such a depth as to cause melting of rocks. The earth cannot be separated into different segments from the tectonic point of view. This is due to the fact that tectonic forces in any part of the globe have their effects in other far flung areas. The earth movements of Hercynian age which were of compressive nature in Europe (Orogenic) were manifest in the Indian subcontinent in the shape of tensional movements primarily to compensate for the crustal shortening taking place in Europe. In the peninsular India trough faulting was caused by these tensional movements and fluviatile Gondwana deposits were laid down.

The Panjal volcanic activity is also a side effect of Hercynian Orogeny which was more conspicuous in Europe. The Tethyan sea had fully encroached upon the various parts of the Himalayan belt during this period. In Kashmir Valley products of true volcanic nature were being outpoured. It is plausible to think that development of long fissures took place on the site of the present valley of Kashmir and adjacent parts through which products of Panjal volcanic activity were outpoured. So far as the origin of the Panjal volcanics is concerned the origin of its lower member e.g. the Agglomeratic Slate has been a matter of much debate. It is possible that such a wide-spread and uniform deposit might have accumulated by :

(i) Explosive volcanic action
(ii) Frost with ice transportation
(iii) Joint products of both the activities combined with ordinary sub-aerial sedimentation.

Middlemiss (1910) suggested pyroclastic origin and considered them as predecessors to the main lava outpouring that followed in the form of what are now called the Panjal Traps.

Bion and Middlemiss (1928) regarded the Agglomeratic Slates as products of extensive volcanic action combined with ordinary sub-aerial deposition. Wadia (1928) while working in the Pir Panjal Range thought that the Slates were of pyroclastic nature.

One more contrasting view with regard to the origin of Agglomeratic Slates is that these are produced due to frost action under glacial conditions (Permo-Carboniferous Glaciation).

There are some evidences supporting the belief that the Agglomeratic Slates have been deposited under glacial conditions. These are :

1. The Agglomeratic Slates cover a large part in Kashmir, only a wide spread glaciation can account for such a large scale Formation, which is over 500m thick at places.

2. Gangamopteris beds overlie the volcanics. From this it is inferred that Agglomeratic Slates are a glacial deposit corresponding to the Talchir boulder bed Wadia (1934). Unsorted grains of all sizes and shapes are present in an argillaceous matrix of cryptocrystalline nature. Similarly Twenhofel (1950) suggests this as a typical glacial evidence. This reasoning would lead one to conclude that the Agglomeratic Slates were deposited under glacial environments.

Permo-Carboniferous glaciation was of wide spread occurrence throughout the world and was prevalent in India.

Ahmed (1961) suggested glacial origin for the Agglomeratic Slates of Kashmir.

Wakhaloo and Dhar (1971) regard the Agglomeratic Slates to be of glacial origin.

Similarly Fuchs (1975), Srikantia (1973), also favour a glacial origin for the Agglomeratic Slates. Ahmed et al. (1978) consider that the Agglomeratic Slates represent the products of glacial and volcanic activity deposited in a shallow water marine as well as continental set up. It may be pointed out that the Agglomeratic Slate series as a whole appears to be a product of the two sets of activities listed as (i) and (ii) in the beginning.

NATURE OF ERUPTION

The Panjal Traps for the major part are of basic character. The traps are reported to represent undifferentiated products of a basaltic magma over considerable distances. At some places in Kashmir acidic differentiates like rhyolites have been described by Mathur and Wakhaloo (1933).

These rocks show evidences of a fissure type of eruption. This is substantiated by the following points :

1. Flow like behaviour of lavas
2. Immense thickness of the deposits
3. Continuous and linear outcrops of the traps
4. Absence of conical shaped hills of the central type of eruption.

The traps in general are reported to be of basaltic to andesitic character with tholeiitic lineage having been deposited under sub-aerial as well as marine conditions. An attempt has, therefore, been made to discuss the source of the magma in general and that of the Panjal volcanics in particular. Basaltic magma is regarded as a primary magma by leading petrologists. There is some difference of opinion, however, whether tholeiitic, high alumina basalt and alkali olivine basalt 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) thought that the basaltic magma was produced as a result of the fusion of the amphibolite at great depth.

Kennedy (1938) thought in terms of two primary basaltic magmas (i) olivine basalt (ii) tholeiite. Both derived as a result of fusion of the upper and lower layers of the earth's crust. Daly (1946) put forth the idea that basaltic magma was derived from a sub-crustal layer composed of vitreous basaltic material.

Hatch (1949), Ross et al. (1954), and Bederke (1957) believed that basaltic magma was derived as a result of fusion of the peridotite shell of the globe. Burmick and Noble (1959), Taylor and Noble (1960), Turner Verhoogan (1962), and Yoder and Tilley (1962), considered that the peridotite layer constituting the upper mantle contributes to the production of basaltic magma.

Ringwood (1962a), Green and Ringwood (1963, 1967) thought the upper mantle to be composed of garnet pyrolite, spinel pyrolite and plagioclase pyrolite. According to them these on melting produced basaltic magma.

O'Hara (1965, 1967a and 1967b, 1968), O'Hara and Yoder (1967) consider that the upper mantle was composed of garnet lherzolite due to the partial fusion of which basaltic magma was generated.

Kuno (1963) suggests that the generation of different types of basaltic magma in the upper mantle was a function of depth. He postulated that tholeiitic magma was generated at shallow depths in the mantle, alkali olivine basalt at intermediate depths and nepheline basalt at still greater depths.

Gast (1965), Griffin and Murthy (1969) agreed that tholeiitic magmas are produced by extensive partial melting.

Strong (1972) has suggested that large high density peridotite inclusions in the La Grilla lavas, Grande Comore reflect faster rate of magma ascent. The separation of olivine from the Panjal magma during its ascent from mantle to crustal reservoirs may have caused to depletion of mafic constituents in the magma. The rate of ascent, as already stated must be slow resulting in the complete separation of olivine.

From what has been given in earlier chapters, it is inferred that the volcanics under reference are of basaltic to andesitic character having been extruded under marine environment. The rocks bear a tholeiitic affinity under the tectonic setting of MORB and IAT basalts. The study of the lower member of the series e.g. the Agglomeratic Slate leads us to conclude that they are essentially the products of explosive volcanic activity in the present area. Glacial environment also appears to have helped in their deposition elsewhere in Kashmir. The Panjal volcanics as a whole are a manifestation of Hercynian volcanic activity which caused outpouring of extensive lava flows. These must have travelled over considerable distance due to their high mobility. The traps have their hypabyssal representatives in this part of the Himalaya (Wadia, 1934).

SUMMARY AND CONCLUSIONS

The present work entitled "Petrological and petrochemical study of Panjal volcanics around Banihal area, Kashmir Himalaya" is based on the geological investigation of an area between Banihal town, on Jammu-Srinagar National Highway, and to the south of the Old tunnel across the Pir

Panjal Range. The area covers parts of Survey of India topographic sheet nos. 43 0/2 and 43 0/3 (1:50,000). Its boundaries are delimited by Lat. 33°25'10" to 30°35'20"N and Long. 75°07'22" to 75°15'10"E encompasing an area of about 200 sq.kms. The Banihal town is situated about 190 kms from Jammu on Jammu-Srinagar National Highway and after crossing the Jawahar tunnel the Valley of Kashmir is seen. The main drainage of the area is Bichlari nala which drains through the area. The overall drainage pattern of the area is of dendritic type.

In this area, Hala quartzite, Chamalwas Slates, Syringothyris limestones, Fenestella Shales Agglomeratic Slates and the Panjal Traps are well exposed as has been revealed by the geological mapping of this region. The area is covered by rock Formations ranging in age from Devonian to Recent. The Formations overlying the Hala quartzite are richly fossiliferous.

The rock Formations in general, trend in NW-SE direction and dip to the northeast. The various rock Formations are repeated several times due to folding. The most important of which are the Banihal and Mahu anticlines and their complementary synclines.

The Agglomeratic Slates are seen to consist of angular to sub-angular grains of quartz, rock and mineral fragments. Under the petrological microscope, glass shards and iron oxides in the form of minute grains of magnetite are present in an irresolvable matrix. Sub greywacks, arkosic sandstones and argillaceous slates are associated with typical Agglomeratic Slates. The Slates of this area are considered to be essentially of tuffaceous nature.

The Agglomeratic Slates of this area are seen to be overlain by the Panjal Traps of Upper Carboniferous to Lower Permian age. The Panjal volcanic rock series comprises the basal Agglomeratic Slate zone, of highly variable extent, thickness and distribution, and the layered and massive Panjal Traps, showing frequent jointing. The Panjal Traps are generally green to greenish grey in colour but some of the flows are of pale yellow, purple and dark grey colour. The rocks owe their green colour to the presence of epidote and chlorite. In this area the following varieties of traps have been observed :

i) Amygdaloidal traps
ii) Non/amygdaloidal traps
iii) Altered dyke equivalents of volcanics
iv) Lastly quartz-epidote veins (epidosites)
are of frequent occurrence in the study area.

About forty thin sections of different varieties of fine grained volcanic rocks have been point counted according to the method suggested by Chayes using Clay-Adams blood cell counter. The different percentages of minerals present in the traps have thus been calculated.

Microscopic examination of the traps in many instances shows the presence of a mineralogical assemblage of plagioclases, chlorites, epidotes and quartz with magnetite and ilmenite as the opaque accessory minerals. Thin section study reveals that these have been subjected to a metamorphism of low degree of the amphibolite facies. As a consequence of this the original minerals have suffered abundant alteration. The chief alteration is seen in the original plagioclases and the main ferromagnesian mineral augite. The basicity of original plagioclases has decreased and the original pyroxenes have changed to amphiboles and chlorite. Plagioclases, chlorites and epidotes have been separated from the volcanics. Pure fractions (85% to 95% purity) of these minerals have been optically studied and chemically analysed.

Thirty representative samples of Panjal Traps of the study area have been analysed for their major and trace element using the rapid method of rock analysis. The C.I.P.W. norms of the rocks have been calculated and percentages of quartz, plagioclases and alkali feldspars recalculated to hundred percent have been plotted on

Streckeisen's triangular variation diagram. The rocks are seen predominantly to fall in the basalt, andesite fields. Some points are, however, falling in the quartz-latite-andesite field, close to the demarcation line between the andesite and quartz-latite-andesite fields.

The analytical data obtained have been treated in terms of various bivariate and trivariate plots. The results indicate that the Panjal Traps of Banihal area have undergone differentiation in decreasing order of basicity i.e. from rocks of more basic composition to those of less basic composition. The differentiation has not, however, proceeded too far as the rocks fall in the early and middle stage basalt fields.

The concentration of trace elements in rocks of higher basicity and those of lower basicity show a definite trend. The elements Cd, Co, Cr, Cs, Cu, Ga, Mo, Ni, Pb, Sr, V & Zn show greater concentration in more basic members; whereas the elements Ba, Li, Rb, Y and Zr show higher concentration in later differentiates i.e. rocks of lesser basicity.

Trace element data have also given consistent results regarding the origin of Banihal traps like major element geochemistry; the diagrams based on trace elements like Ti-Zr, V v/s Fe_2O_3+FeO/MgO, V v/s Cr (after Miyashiro,

1975) all show marine environment of deposition for Banihal traps. Tholeiitic character of these rocks has been confirmed by drawing plots of Y v/s FeO/MgO, Cr v/s SiO_2. This has also been confirmed by the closeness of concentration of index trace elements like Ba, Rb, Cr, Ni, Sr, Zr, and Cu when compared to different basaltic provinces of the world. The rocks are akin to MORB & IAT basalts as revealed by different ratios e.g. K/RB, Zr/Y. Ratios like Ni/Cr, Mg/Ni & Al/Ga x 10^3 show unmistakably the less basic character of these rocks. Ti-Cr, Ni-Mg, Cr-Mg variation diagrams better reveal a positive relationship of major elements like Ti and Mg with Cr and Ni which is most characteristic of igneous rocks. Furthermore, the olivine free-nature & extensive plagioclase concentration in these rocks is the probable cause of strontium depletion as suggested by Condie et al. (1967). Low grade metamorphism has depleted Rb to some extent and K and Ba to a large extent in these rocks. The less concentration of K in particular again confirms the tholeiitic affinity of these rocks under discussion.

The behaviour of trace elements together with petrochemical diagrams based on these reveal that the volcanics of Banihal area are of tholeiitic affinity, with minimum differentiation and are extruded in a marine environment. The trace element data confirm the results obtained from the major element study of the rocks.

From the available evidences, it seems that the traps of Banihal area are of tholeiitic lineage and have possibly been generated due to the partial fusion of upper mantle at a shallow depth. The rocks also appear to have been extruded under marine conditions. The Panjal volcanics as a whole are a manifestation of Hercynian volcanic activity which caused outpouring of extensive lava flows. Lastly it may be mentioned that the rocks of spilitic nature are absent from this area.

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ILLUSTRATIONS

Fig.1. Physiographic map of the north-western Himalayan Complex showing trend of Principal mountain ranges.

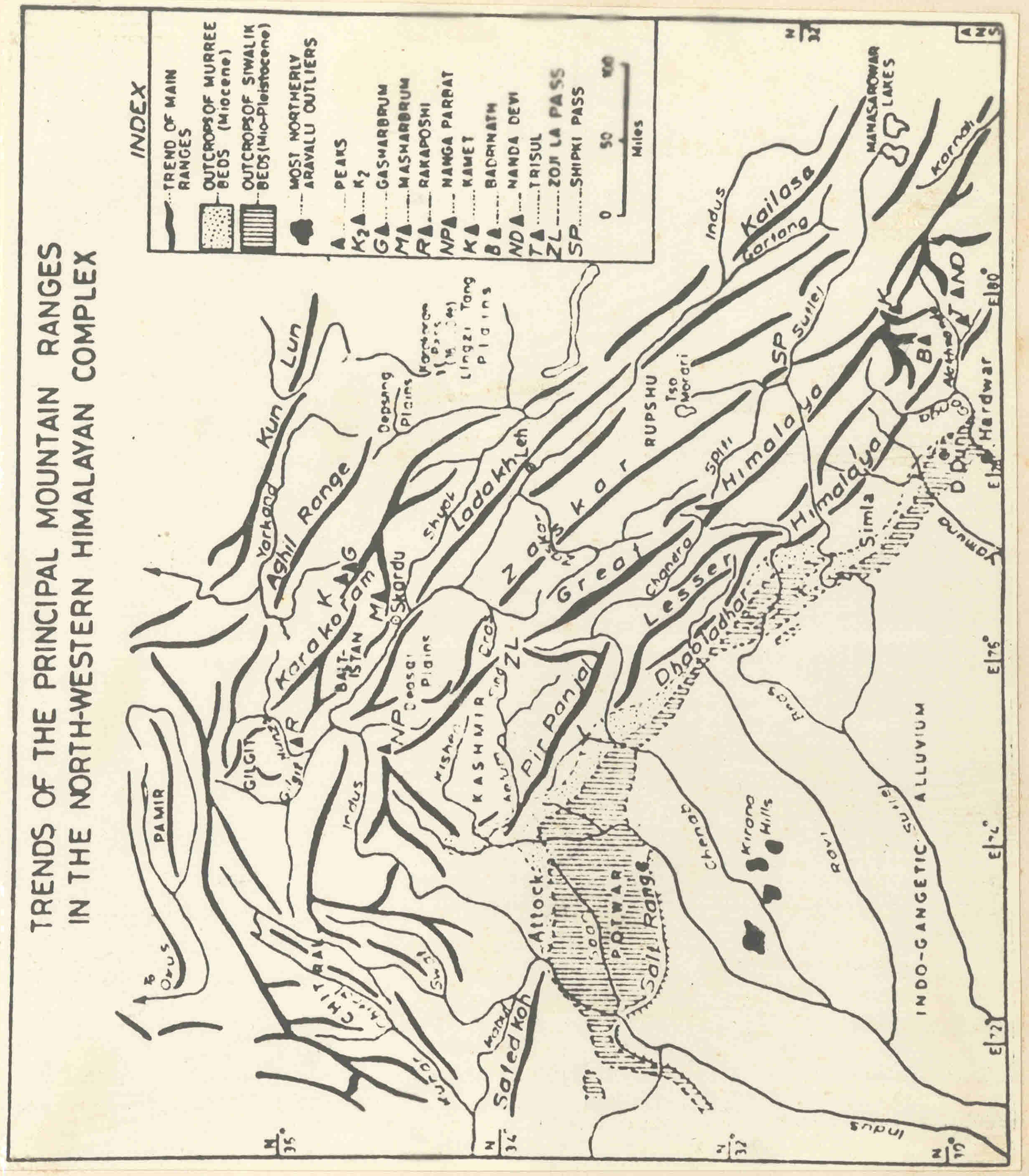


Plate 1

Fig.1. A Panoramic view of Panjal Traps exposed near Naugam valley camera facing south.

Fig.2. A Panoramic view of Panjal Traps of Banihal area near Old tunnel camera facing northeast.

Plate -1

Fig.1

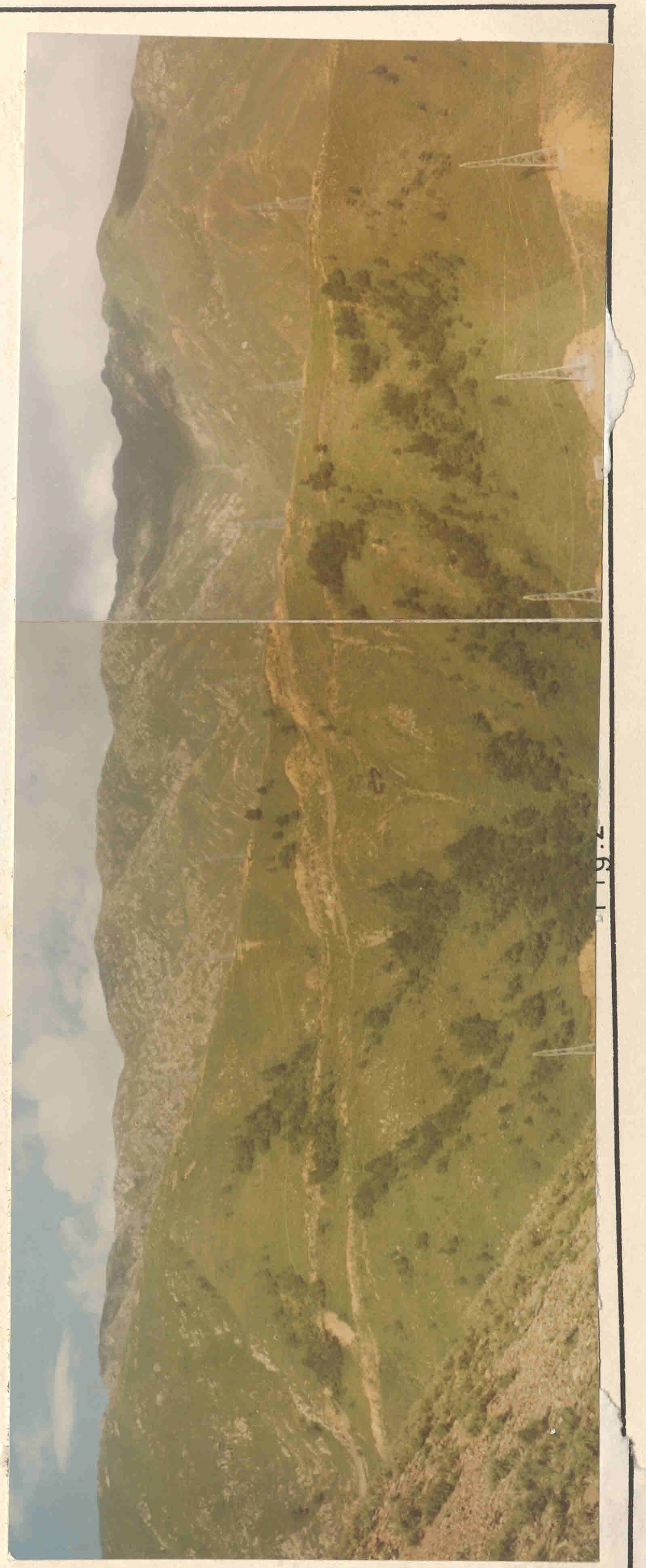


Fig.2

Fig.2. Physiographic map of the area in and around Banihal Town.

PHYSIOGRAPHIC MAP OF THE AREA IN AND AROUND BANIHAL TOWN J & K STATE

Fig. 2

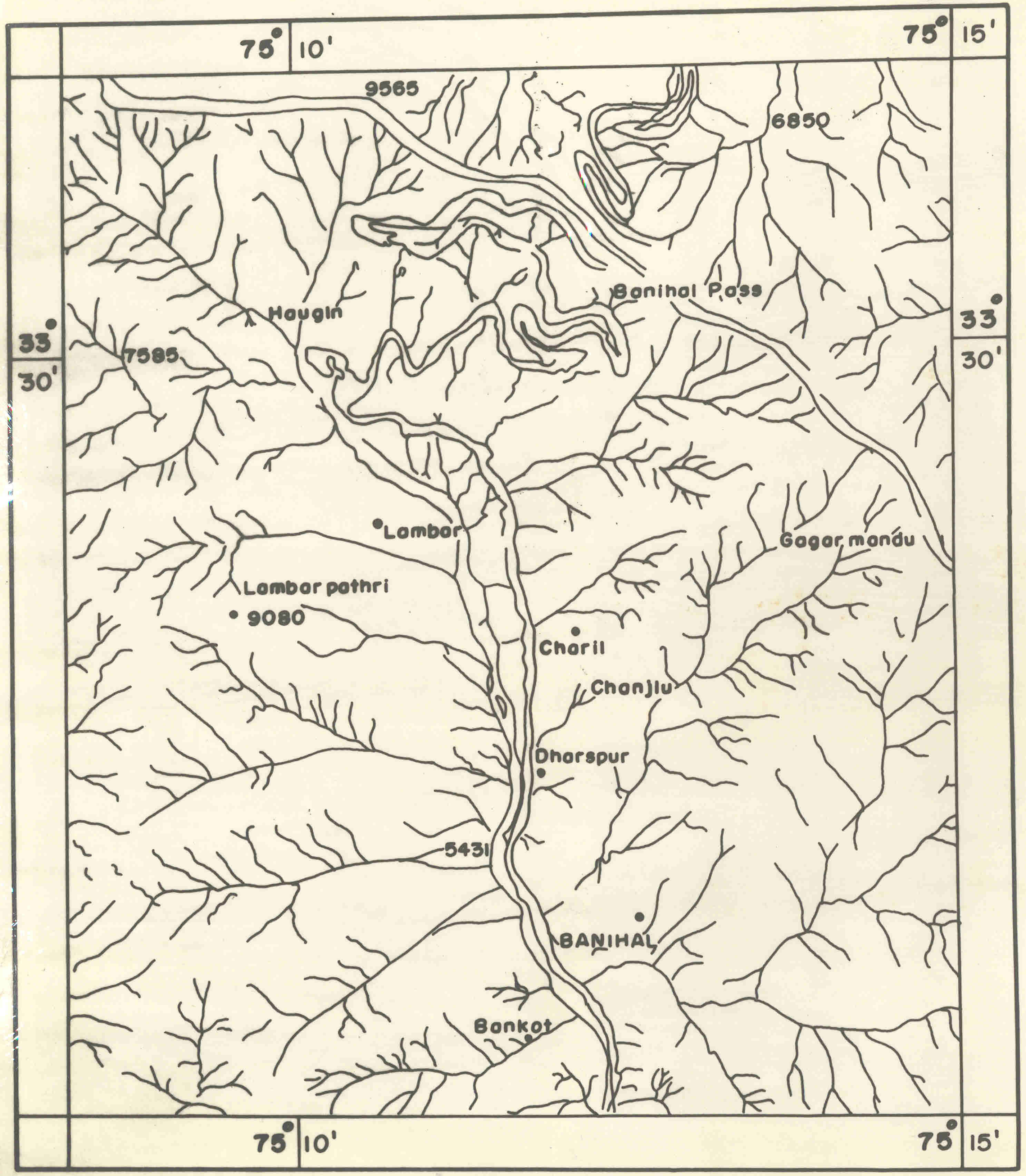


Plate 2

Fig.1. A view of the Old tunnel camera facing north.

Fig.2. A view of the Banihal Valley camera facing south.

Fig.3. A view of the Shetani nala on the National Highway camera facing north.

Fig.4. Agglomeratic slates showing angular to subangular grains of quartz as exposed near Jawahar tunnel.

Figs.5&6. Field photograph showing jointing in Panjal Traps near Old tunnel.

PLATE - 2

Fig-1

Fig-2

Fig-3

Fig-4

Fig-5

Fig-6

Fig.3. Geological map showing the means of communication and the location of the study area, Doda District, Jammu.

Figure-3

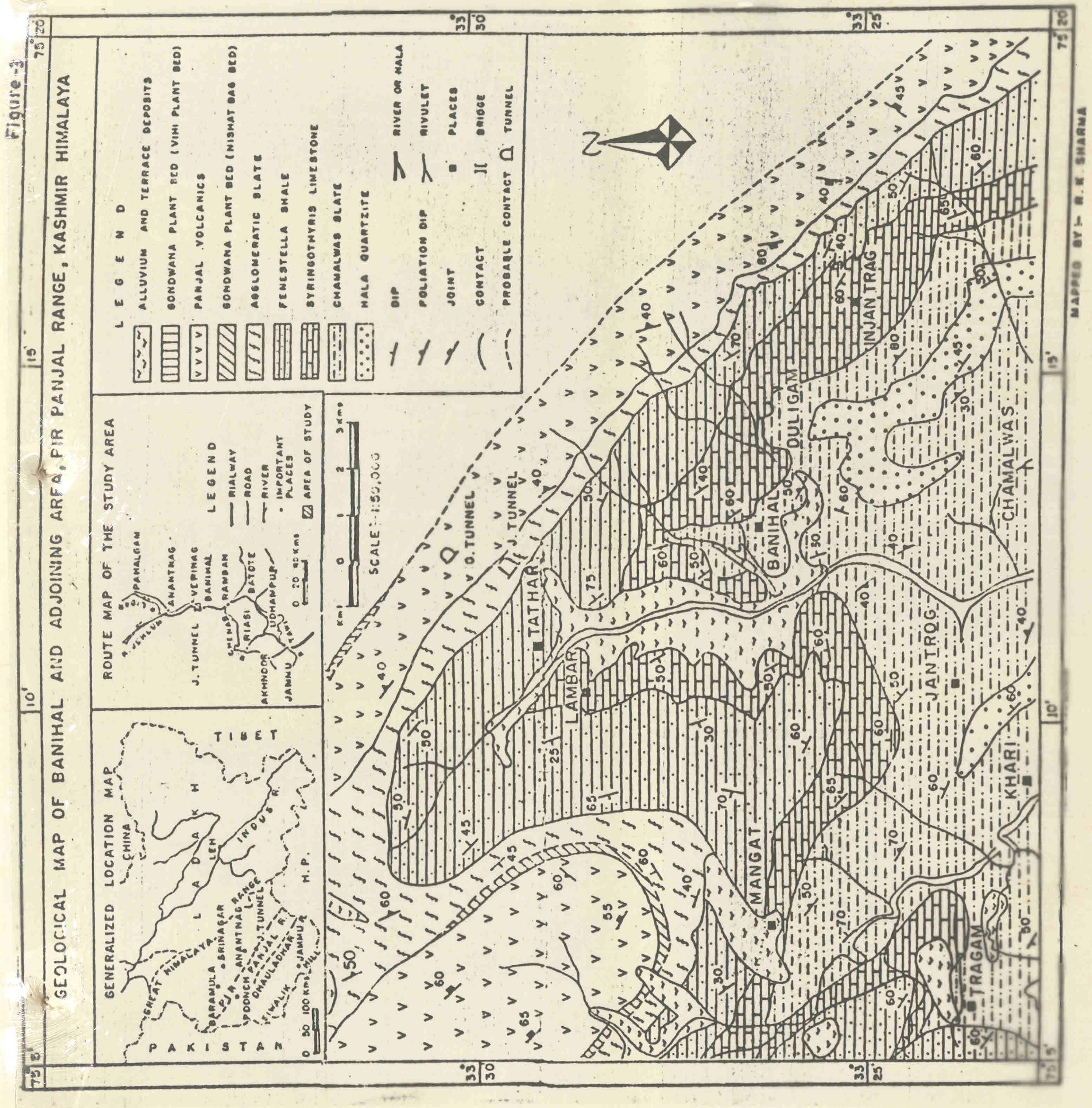


Plate 3

Figs.1&2. Photomicrographs of an Agglomeratic Slates showing angular to subangular grains of quartz, scales of sericite, glass shards and iron oxide set in an irresolvable matrix.(Crossed Nicols x 45).

Fig.3. Photomicrograph of a sub-greywacke with rounded and sub-rounded grains of quartz set in a fine grained clayey and sericitic material.(Crossed Nicols x 45).

Fig.4. Photomicrograph showing Pyrite with inclusions of quartz.(Ordinary light).

Fig.5. Photomicrograph showing amygdaloidal variety of trap. Here grains of quartz are arranged in the form of an ellipse. Epidote grains and sericite scales are bordering the elliptical body.(Crossed Nicols x 45).

Fig.6. Photomicrograph of an amygdaloidal variety of trap showing grains of quartz displaying undulatory extinction with an almost circular outline.(Crossed Nicols x 45).

PLATE - 3

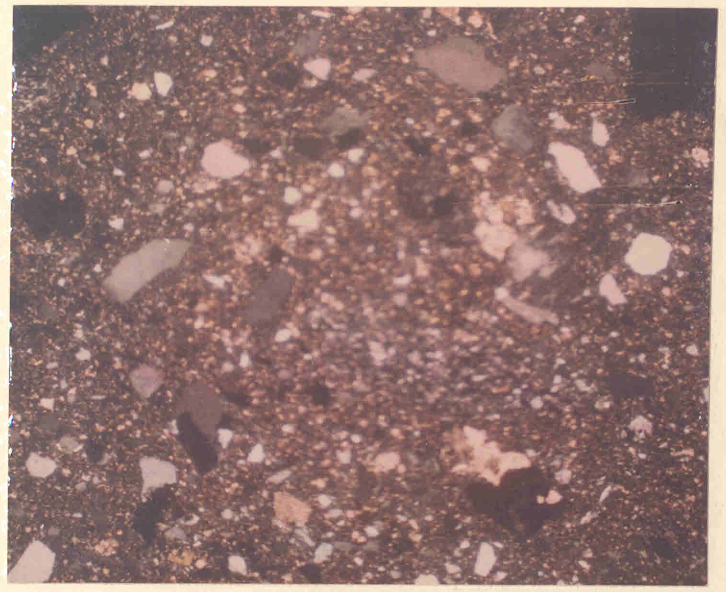


Fig-1

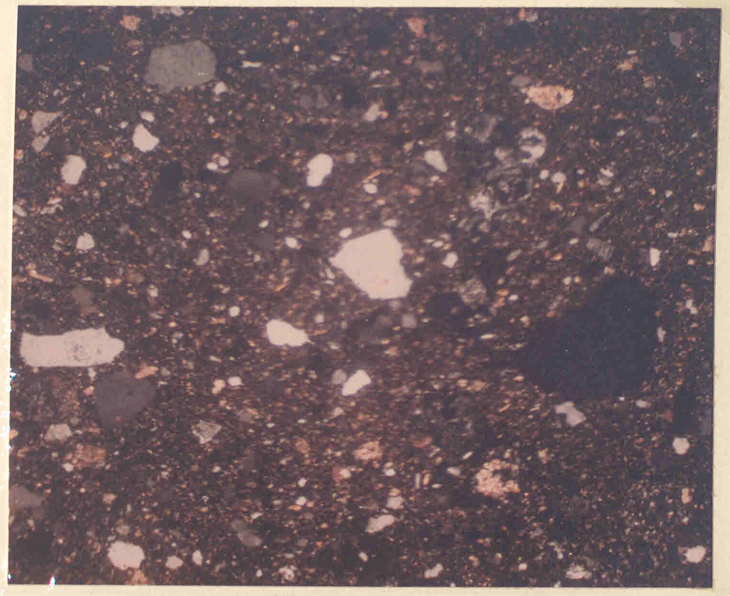


Fig-2

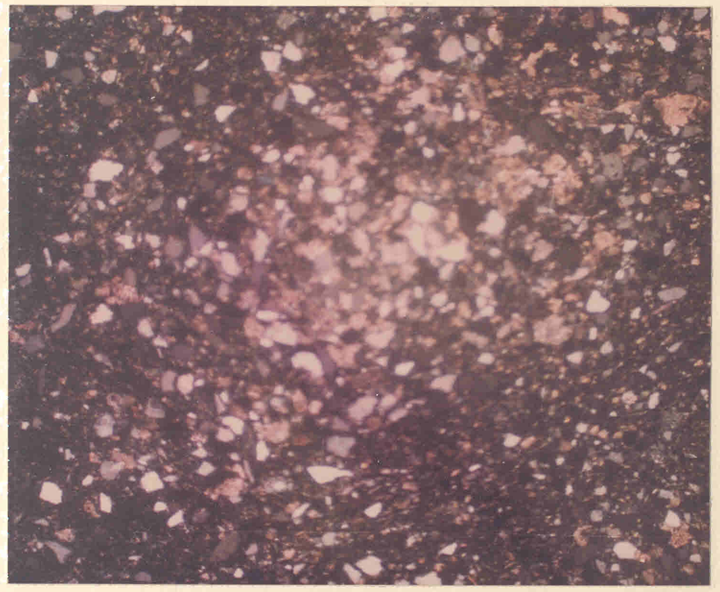


Fig-3


Fig-4

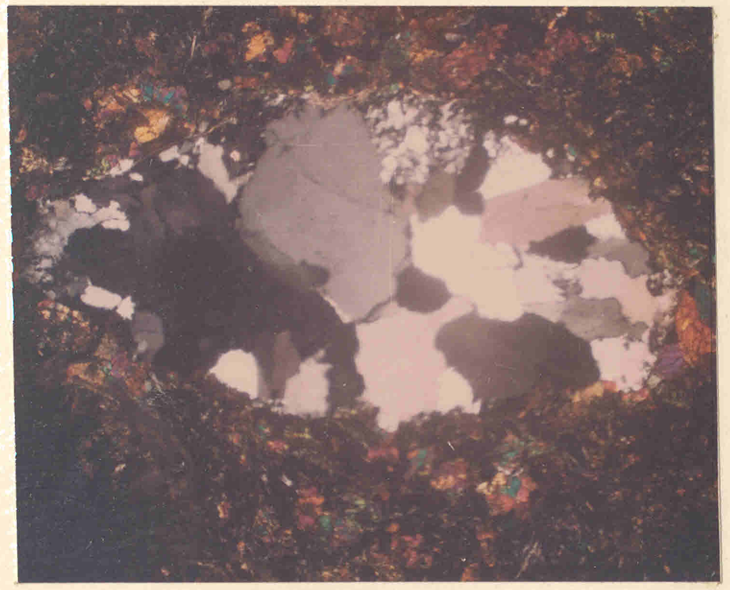


Fig-5


Fig-6

Plate 4

Fig.1. Photomicrograph of an amygdaloidal variety of trap showing grains of quartz arranged in an almost circular manner and surrounded by a fine grained matrix. (Crossed Nicols x 45).

Fig.2. Photomicrograph of an amygdaloidal variety of trap showing grains of quartz arranged in an almond shaped fashion. The marginal portion is showing final grains than the central. The amygdale is set in a fine grained matrix. (Crossed Nicols x 45).

Fig.3. Photomicrograph of an amygdaloidal variety of trap showingsmall grains of quartz arranged in the form of a circlehe border is of epidote grains. The rock maix consists of epidote, quartz and sericite.(Crossed Nicols x 45).

Fig.4. Photomicrograph of an amygdaloidal variety of trap showing fan shaped aggregate of chlorite with Berlin blue interference colours arranged in the circular mannr. The chlorite is bordered by minute grains of quartz. The amygdale is embedded in an irresolvable matrix. (Crossed Nicols x 45).

Fig.5. Photomicrograph showing grains of epidote from an amygdaloidal variof trap arranged in the form of a distorted ellipse. The central portion is consisting of minute scales of chlorite. The remaining portion of the microphotograph consists of epidote, quartz and sericite.

Fig.6. Photomicrograph of an amygdaloidal variety of trap showing chloritith scales of sericite arranged in the form an ellipse bordered by fine grained quartz im.

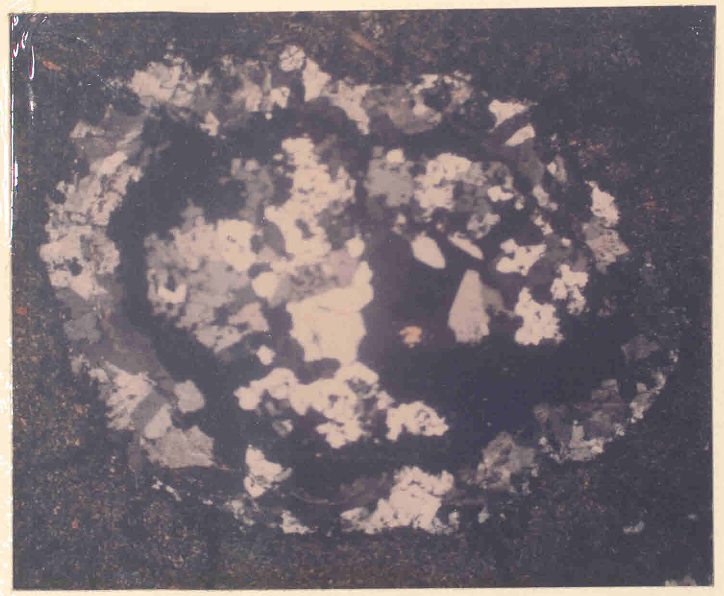


Fig-1

Fig-2

Fig-3

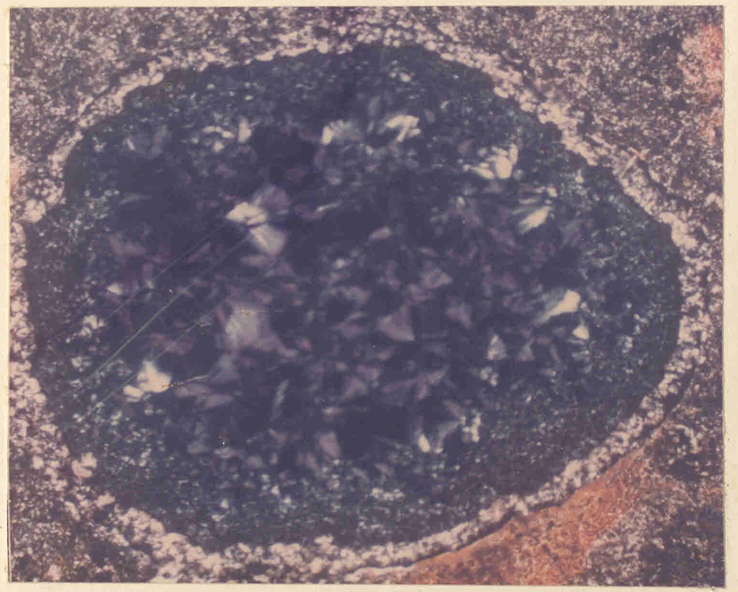


Fig-4

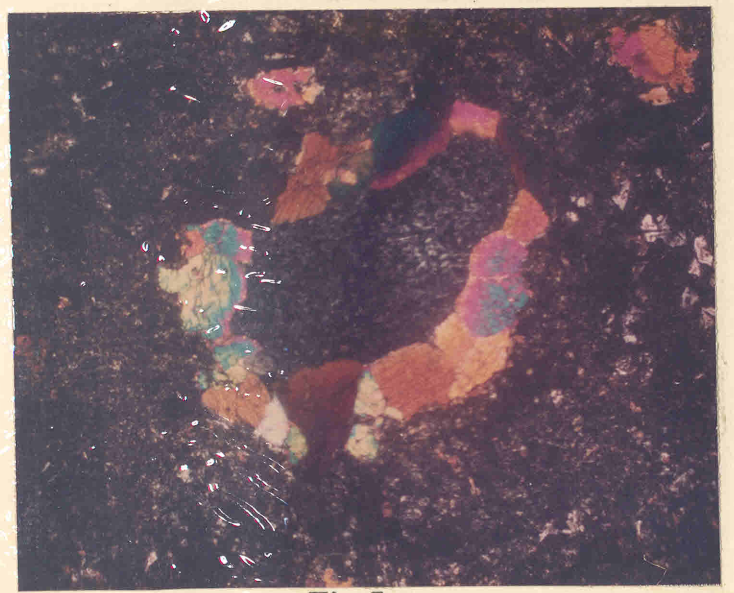


Fig-5

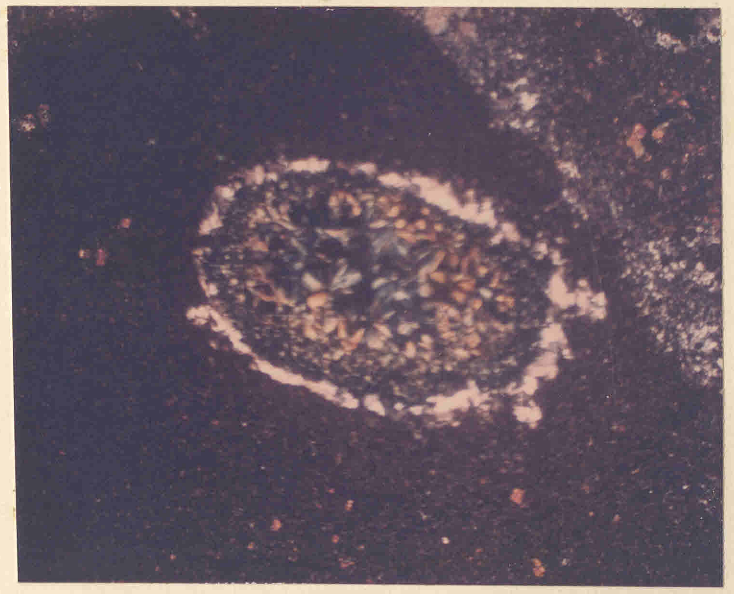


Fig-6

Plate 5

Fig.1. Photomicrograph of an amygdaloidal variety of trap showing minute flakes of chlorite arranged in the form of an almond shaped kernel. The remaining portion of the photograph consists of a cryptocrystalline material. (Crossed Nicols x 45).

Fig.2. Photomicrograph of an amygdaloidal variety of trap showing one circular chlorite displaying concentric layering. Plagioclase microlites and minute grains of quartz and sericite scales are also noticed. (Crossed Nicols x 45).

Fig.3. Photomicrograph of an amygdaloidal variety of trap showing chlorite in the centre surrounded by plagioclase microlites and minute grains of quartz and epidote. (Crossed Nicols x 45).

Fig.4. Photomicrograph of an amygdaloidal variety of trap showing grains of quartz arranged in a circular manner. The central portion consists of chlorite and the remaining portion is composed of minute grains of quartz, epidote, sericite and chlorite. (Crossed Nicols x 45).

Fig.5. Photomicrograph of an amygdaloidal variety of trap showing grains of epidote arranged in an almost distorted circular form bordered by minute grains of quartz and scale of sericite. (Crossed Nicols x 450.

Fig.6. Photomicrograph of an amygdaloidal variety of trap showing epidote and quartz displaying a roughly circular outline, one on the right hand side of the microphotograph; whereas the other towards the left hand side, quartz and epidote are intermixed together with no regular form. (Crossed Nicols x 45).

PLATE-5


Fig-1

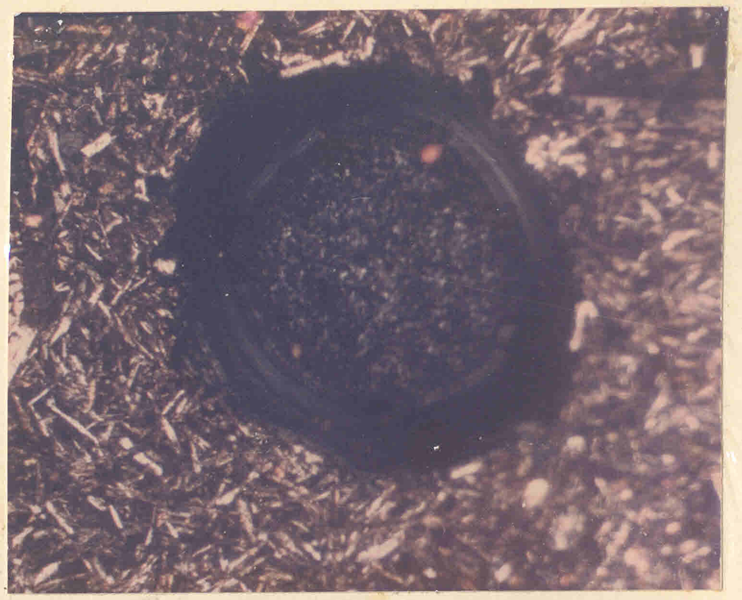


Fig-2

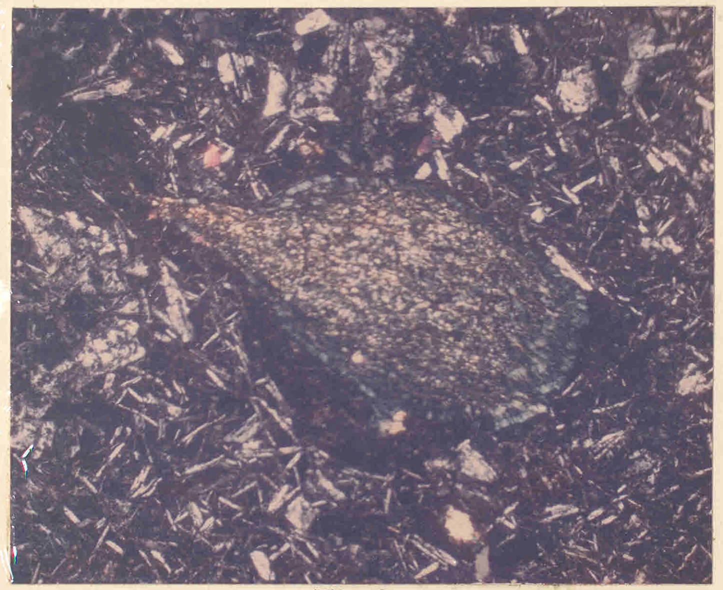


Fig-3

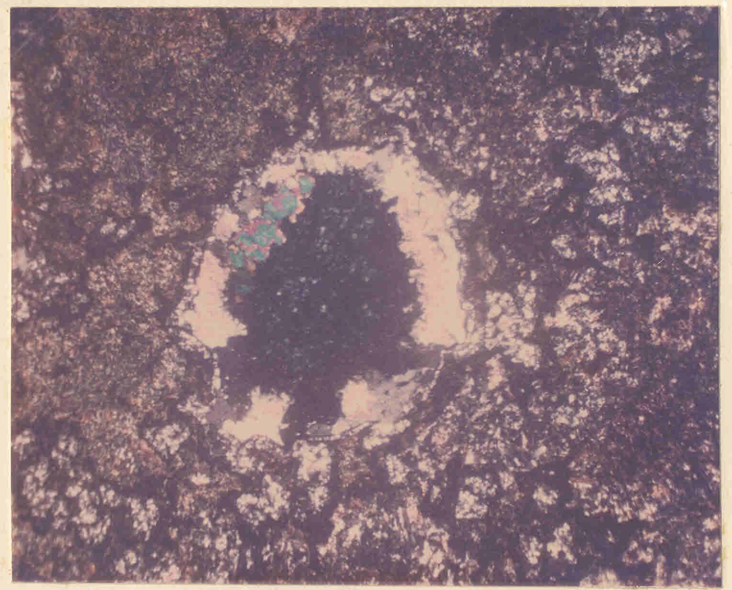


Fig-4

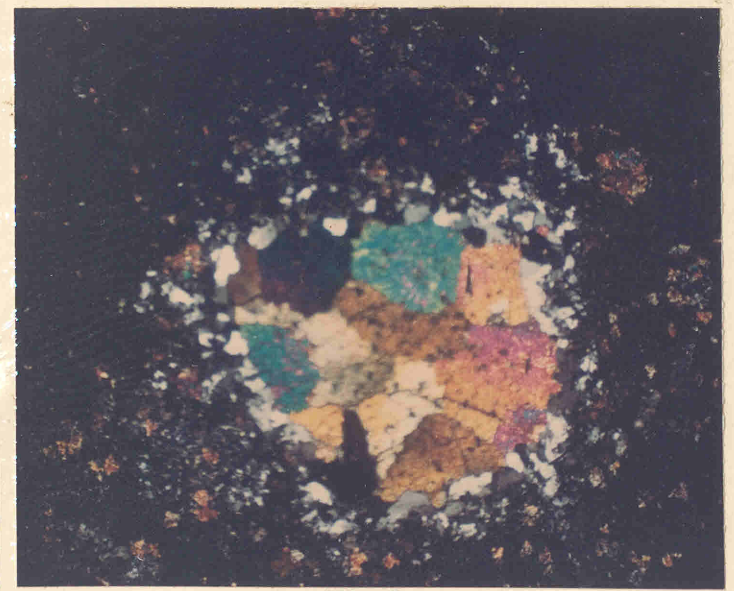


Fig-5


Fig-6

Plate 6

Fig.1. Photomicrograph showing hard and compact variety of trap with plagioclase microlite, scales of sericite, chlorite and grains of quartz set in a fine grained groundmass. (Crossed Nicols x 45).

Fig.2. Photomicrograph of a non-amygdaloidal varierty of trap showing hyalopilitic texture (Crossed Nicols x 45).

Fig.3. Photomicrograph of a non-amygdaloidal variety of trap showing pilotaxitic texture. (Crossed Nicols x 45).

Fig.4. Photomicrograph of a dyke rock showing ophitic texture with pyroxene containing small laths of Plagioclase. (Crossed Nicols x 45).

Fig.5. Photomicrograph showing a dyke rock with lath shaped pyroxene crystal set in a fine grained matrix of sericite, chlorite, epidote and quartz. (Crossed Nicols x 45).

Fig.6. Photomicrograph of quartz epidote vein essentially composed of quartz, epidote, minor chlorite and magnetite. (Crossed Nicols x 45).

PLATE - 6

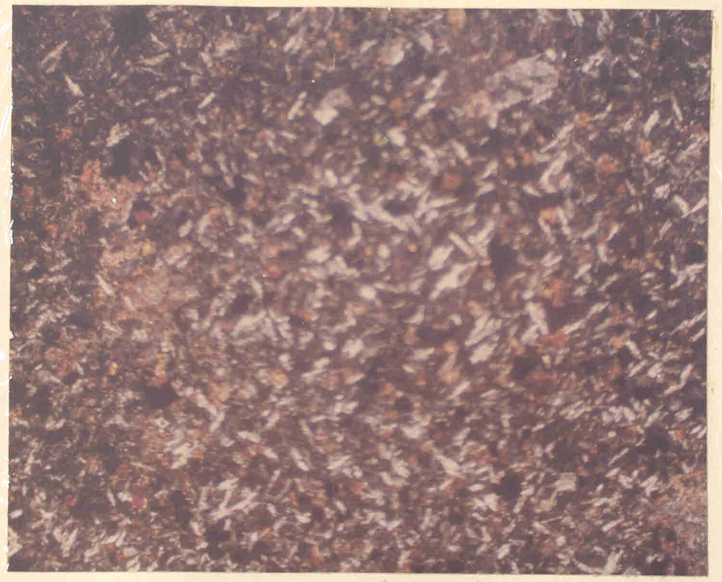


Fig-1


Fig-2


Fig-3


Fig-4


Fig-5

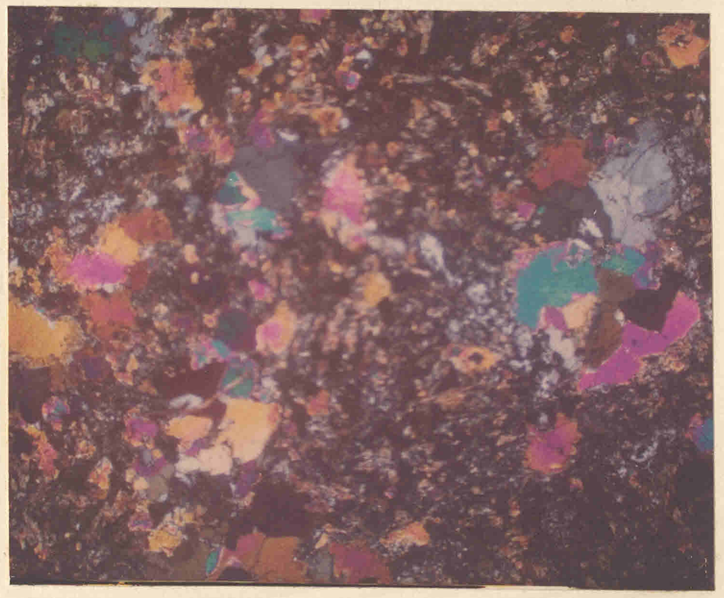
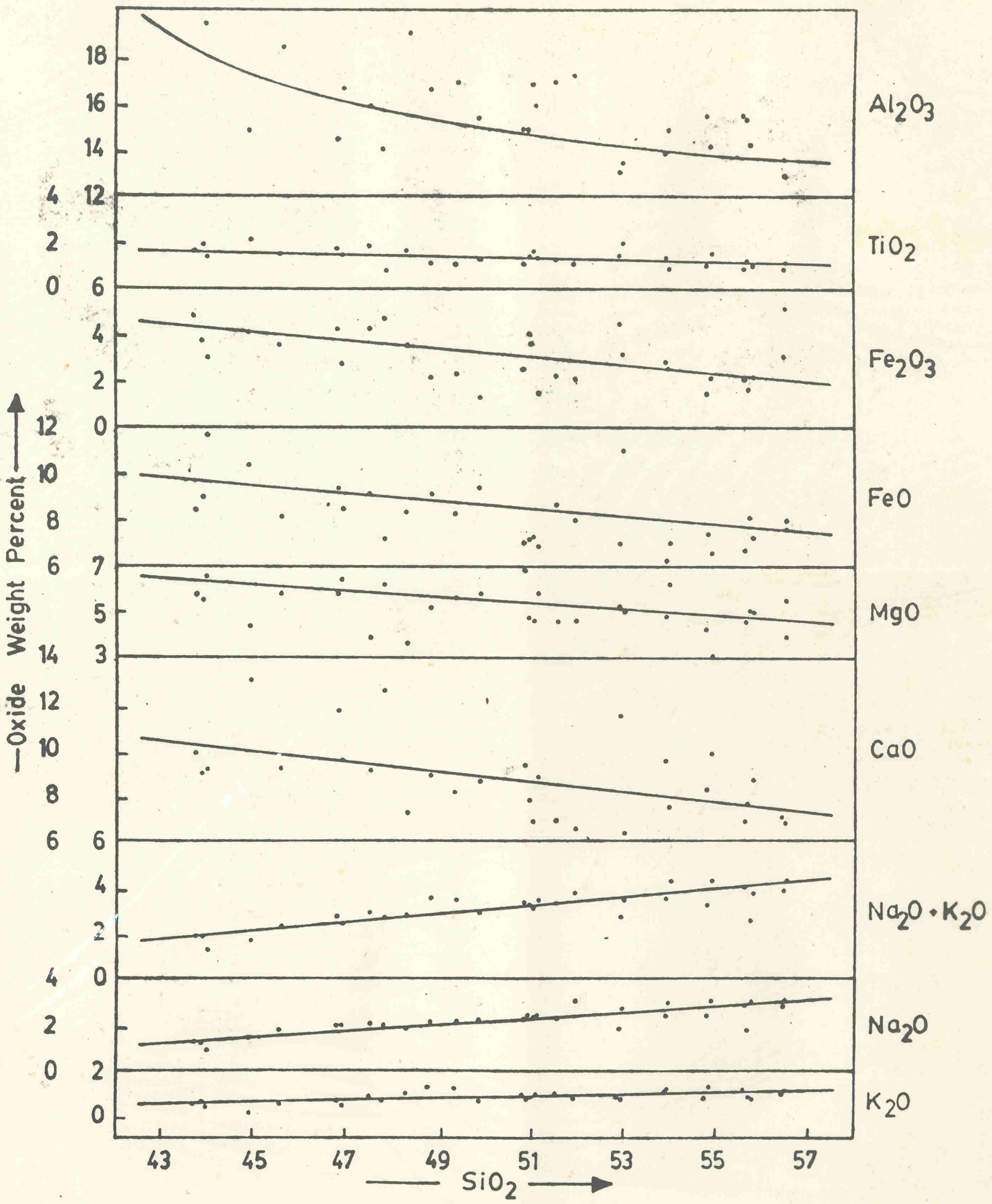


Fig-6

Fig.4. Harker (1909) variation diagram showing several oxides plotted with respect to Silica. Dots represent individual trap Samples around Banihal area.

Figure-4



Harker Variation Diagram

Fig.5. Larsen (1938) variation diagram showing the relationship of several oxides with respect to "Larsen Index". Dots represent individual trap samples around Banihal area.

Figure-5

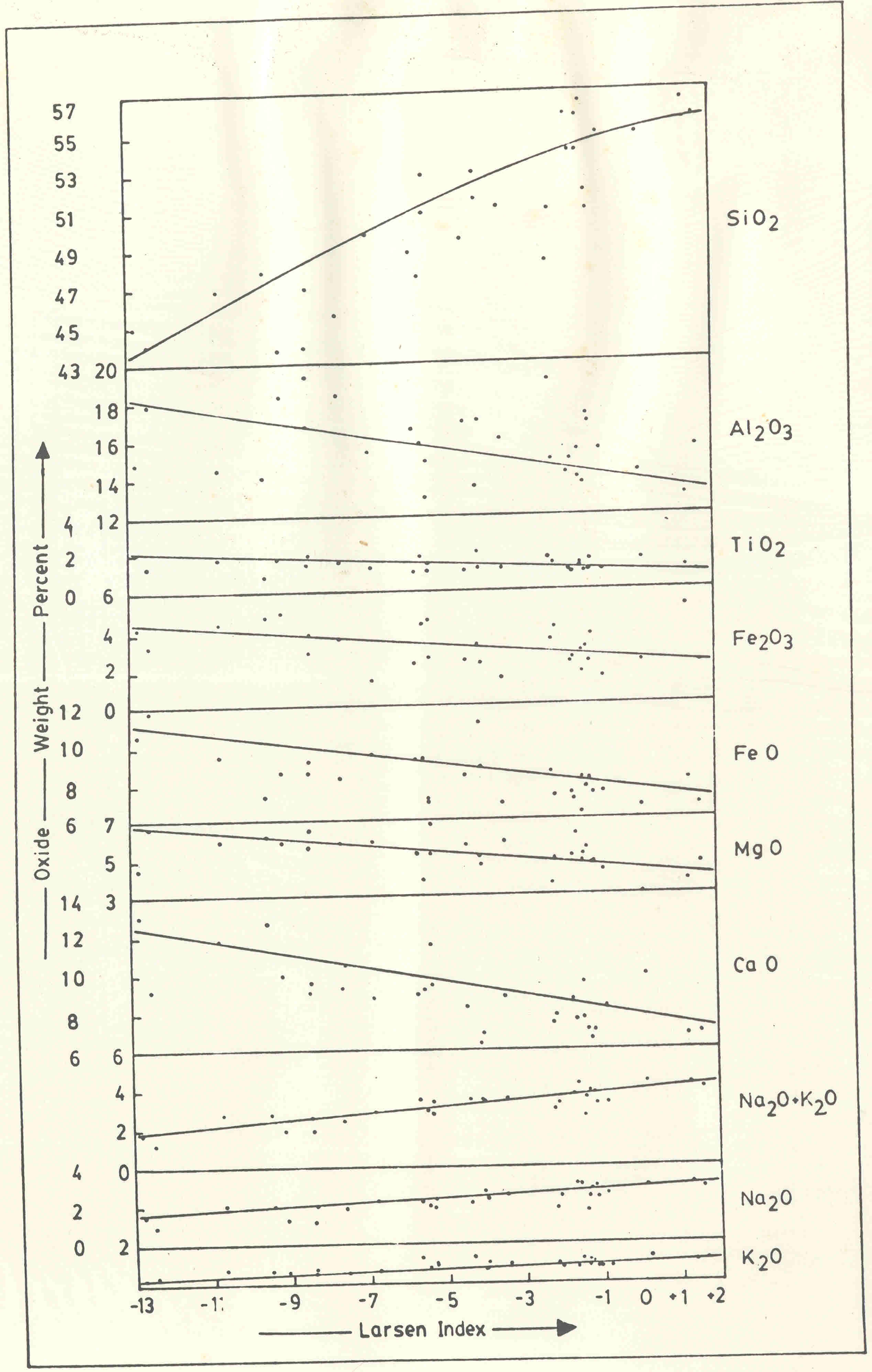


Fig.6. Thornton and Tuttle variation diagram showing the relationship of several oxides with respect to "Differentiation Index". Dots represent individual trap samples around Banihal area.

Figure-6

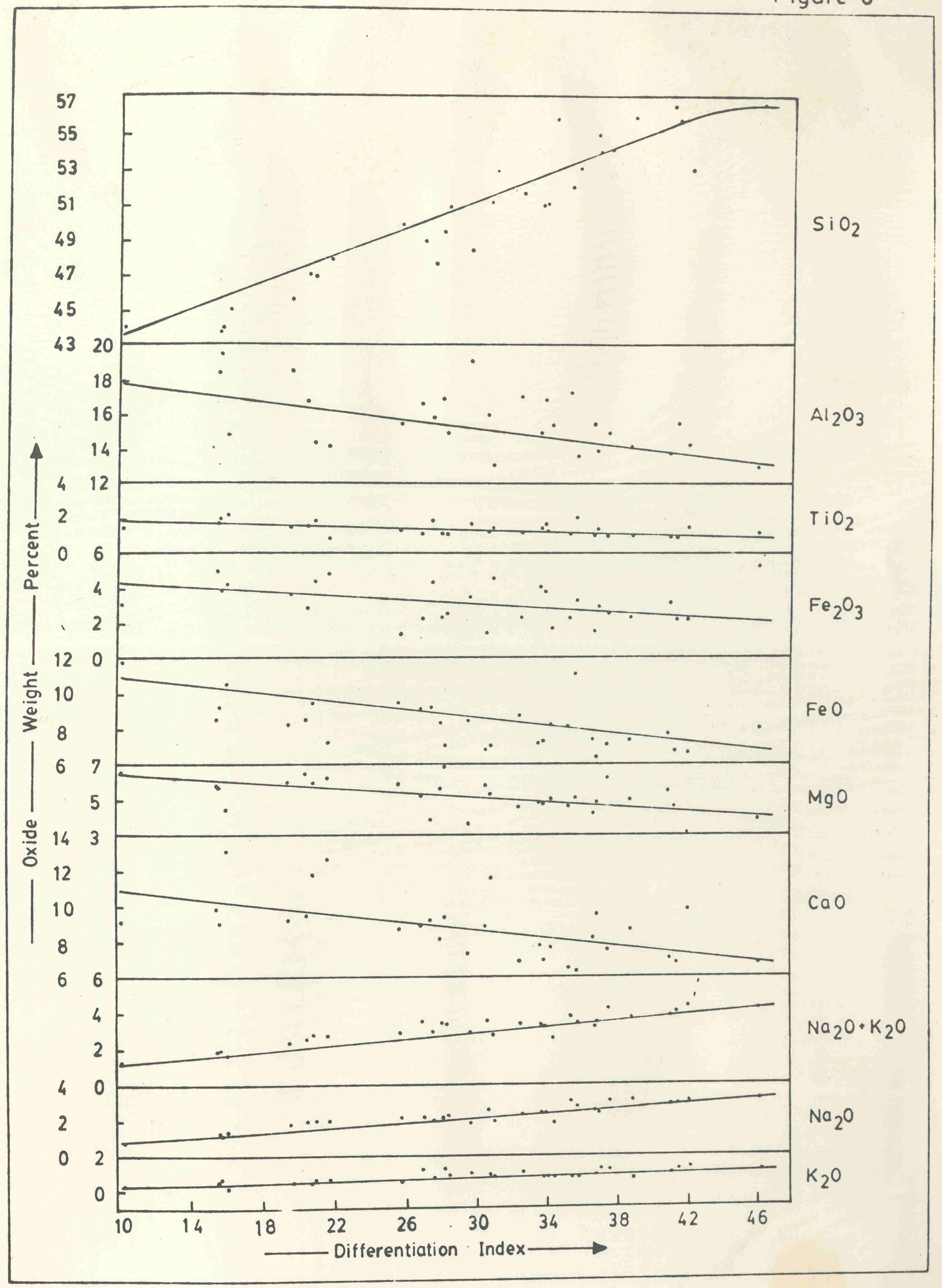


Fig.7. Poldervaart and Parker (1964) variation diagram of several oxides with respect to "Crystallization Index". Dots represent individual trap samples around Banihal area.

Figure-7

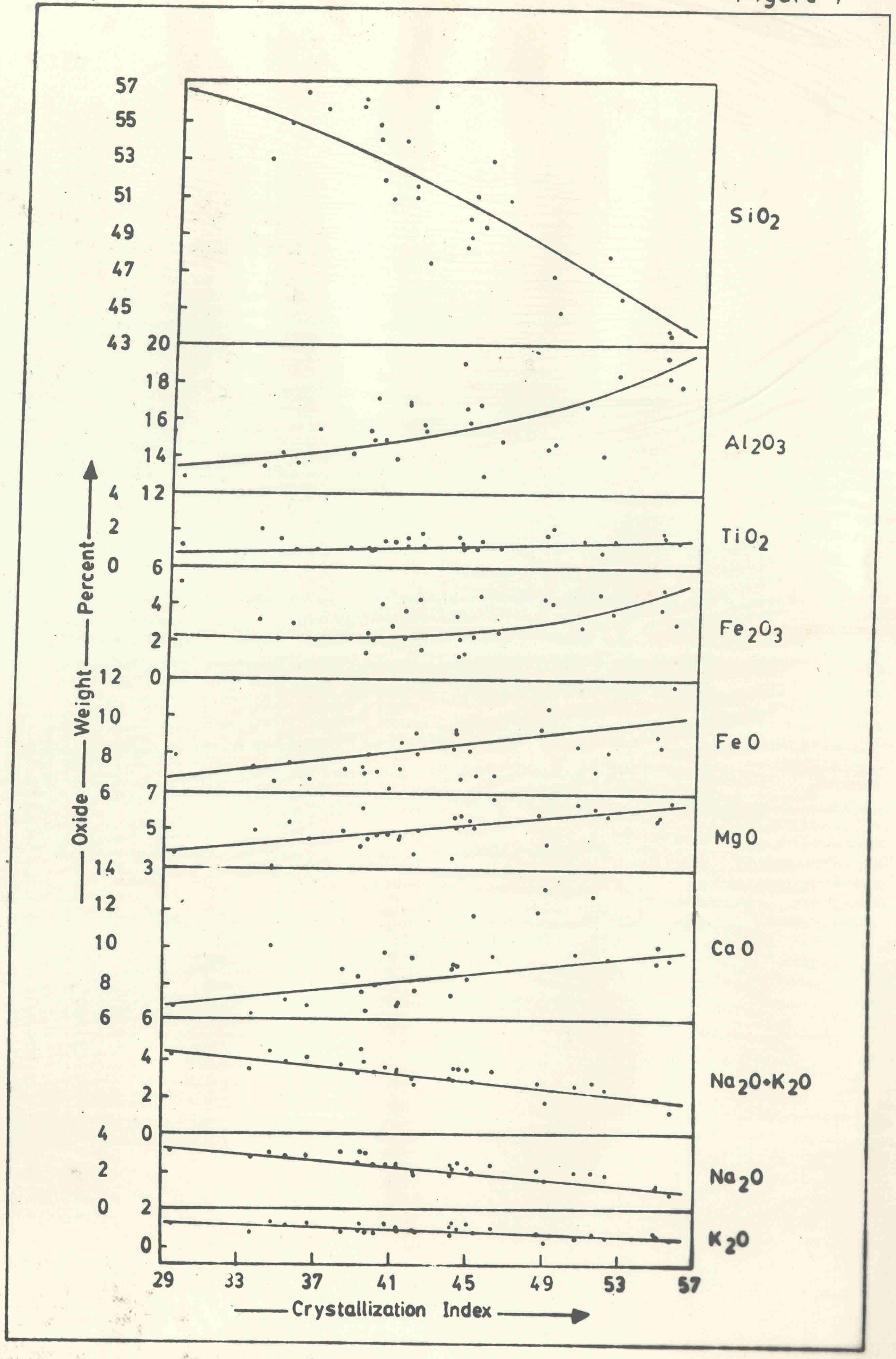


Fig.8. Kuno (1968) variation diagram of several oxides with respect to "Solidification Index". Dots represent individual trap samples around Banihal area.

Figure-8

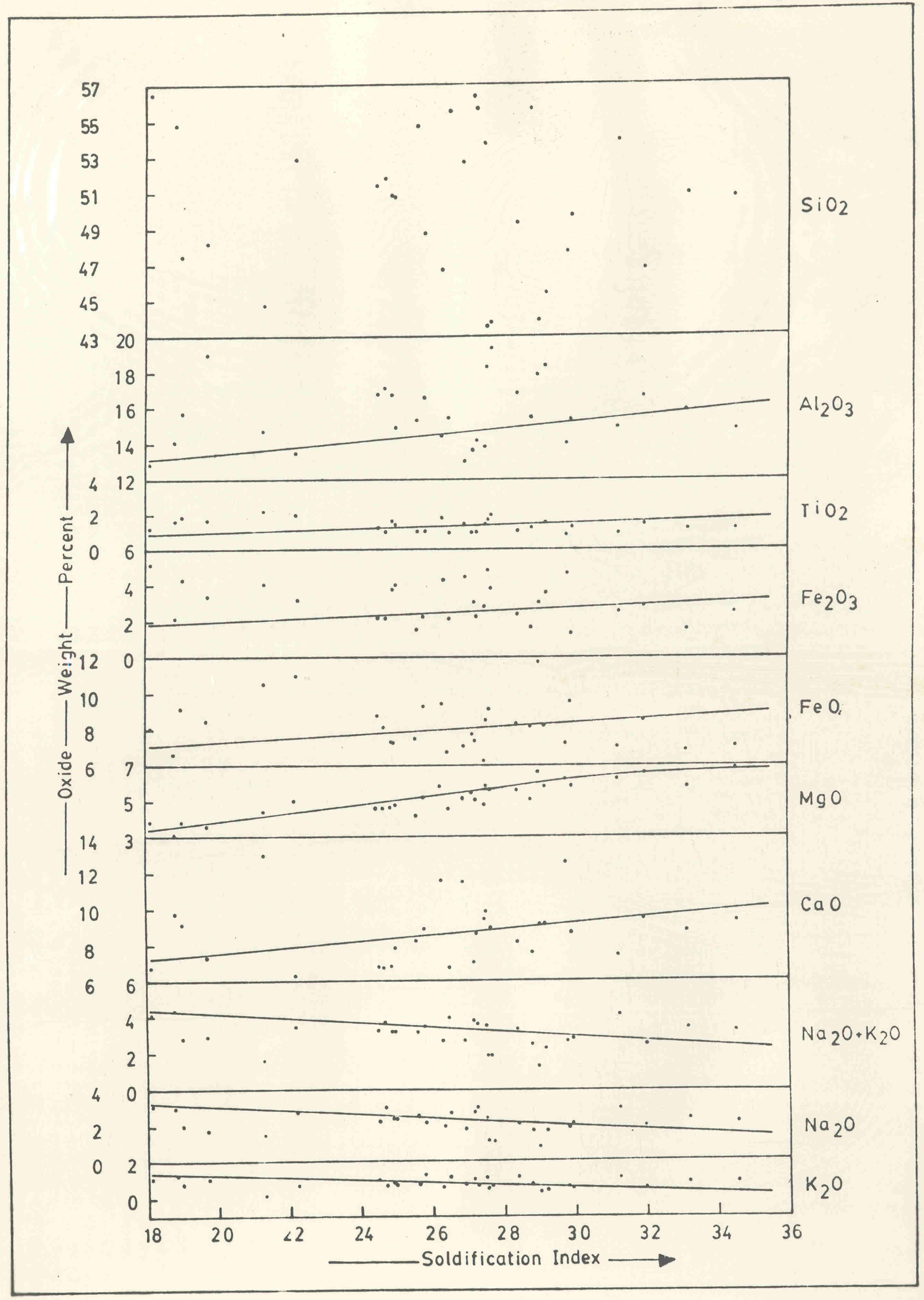


Plate 7

Fig.1. Bivariate diagram showing the relationship between Na_2O & K_2O (after Kuno, 1959). Dots represent individual trap samples from the study area.

Fig.2. Bivariate diagram showing the relationship between Silica and total alkalis (after Kuno op.cit.). Dots represent individual trap samples from the study area.

Fig.3. Bivariate diagram showing the relationship between Silica and total alkalis (after Macdonald and Katsura, 1964 and Saggerson and Williams, 1964). Dots represent individual Banihal samples.

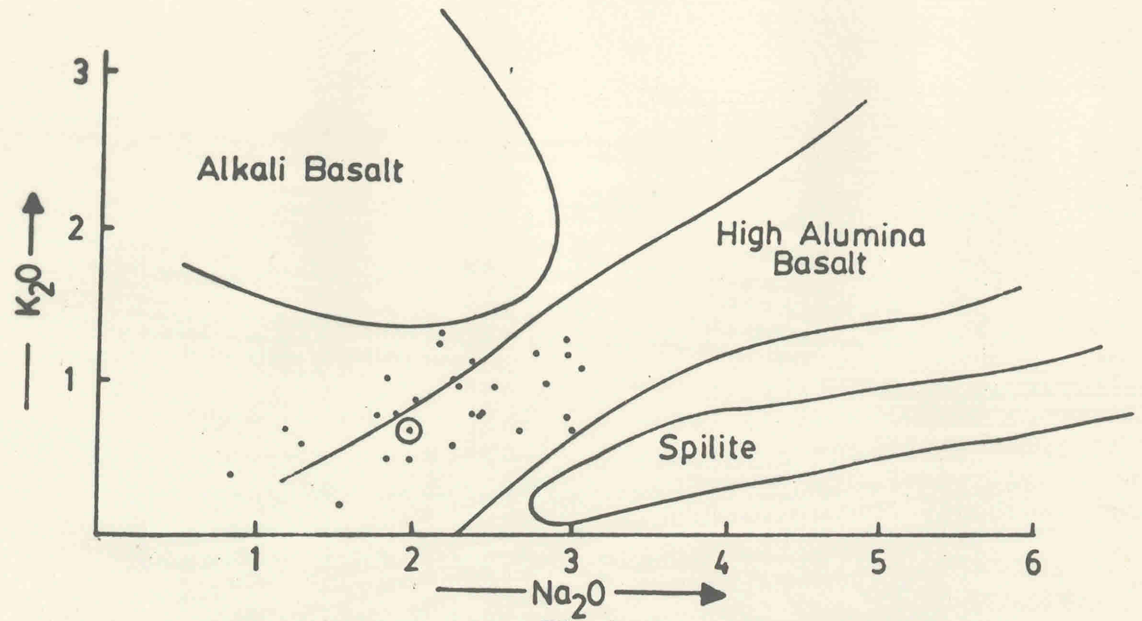


Fig.1

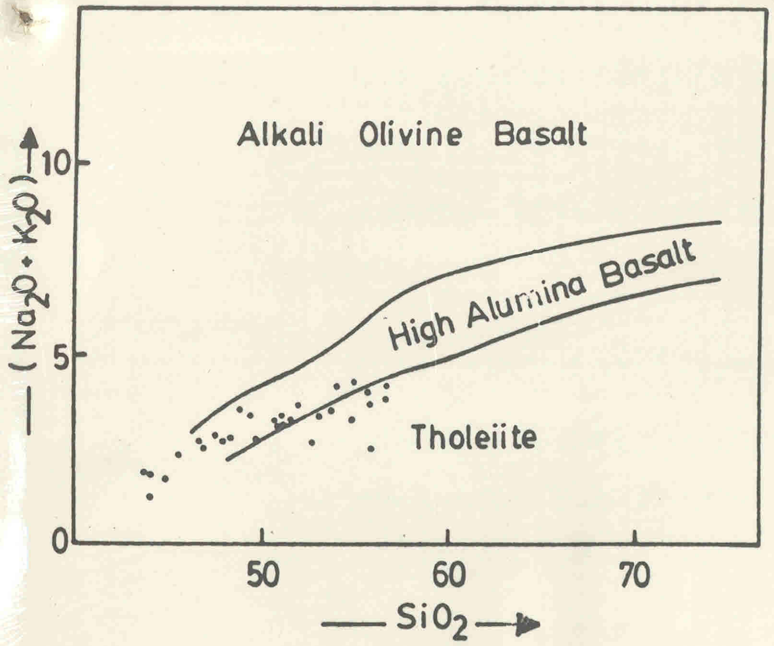


Fig.2

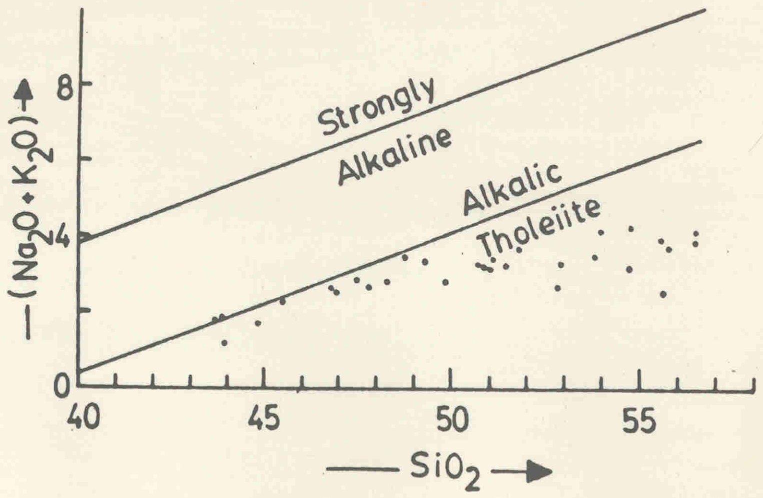


Fig.3

Plate 8

Fig.1. Niggli (1954) variation diagram showing the relationship between Si and (al+fm)-(c+alk). Dots represent individual Banihal Panjal Trap samples.

Fig.2. Niggli (1954) variation diagram showing the relationship between c and mg. Dots represent individual trap samples around Banihal area.

Fig.3. Niggli (op.cit.) variation diagram showing the relationship between c and (al-alk). Dots represent individualrap samples around Banihal area.

Fig.4. Binary variation diagram showing the relationship between C.I. and Niggli $qz^{\pm}$. Dots represent individual trap samples of the study area.

Plate -8

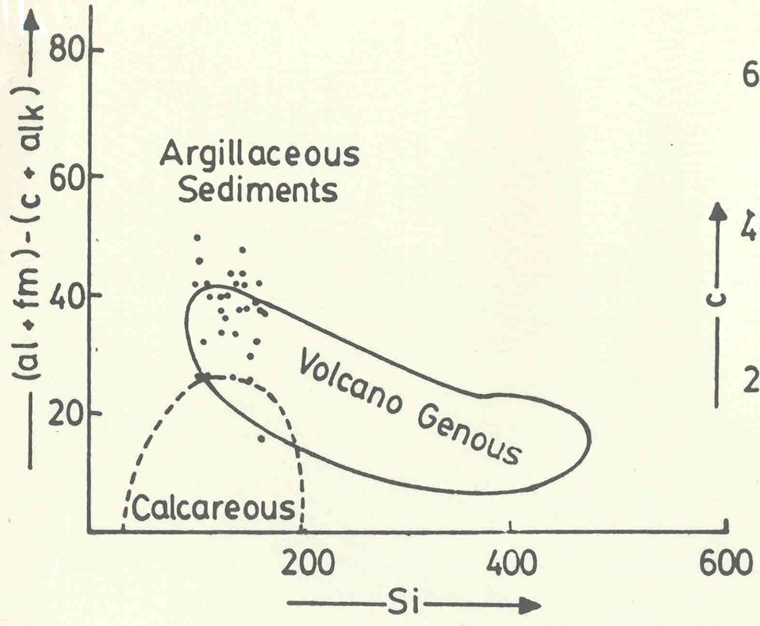


Fig.1

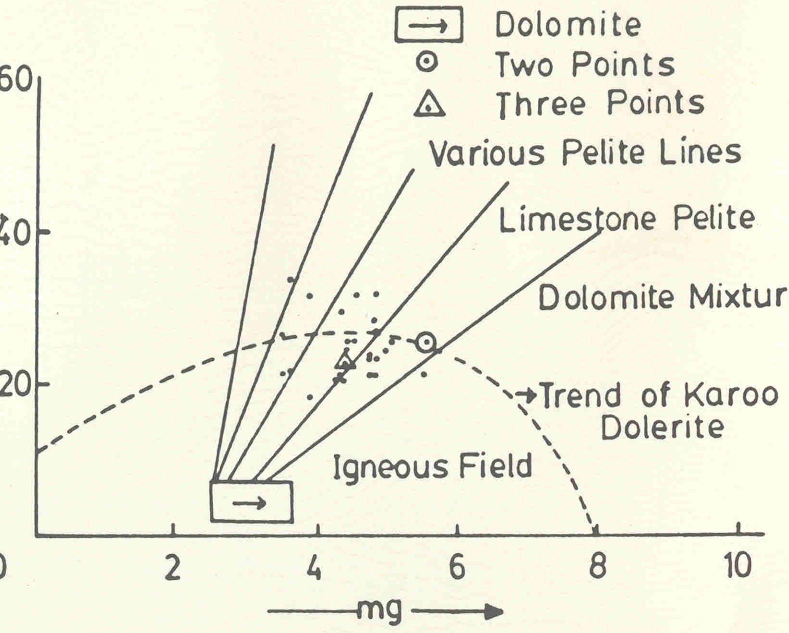


Fig.2

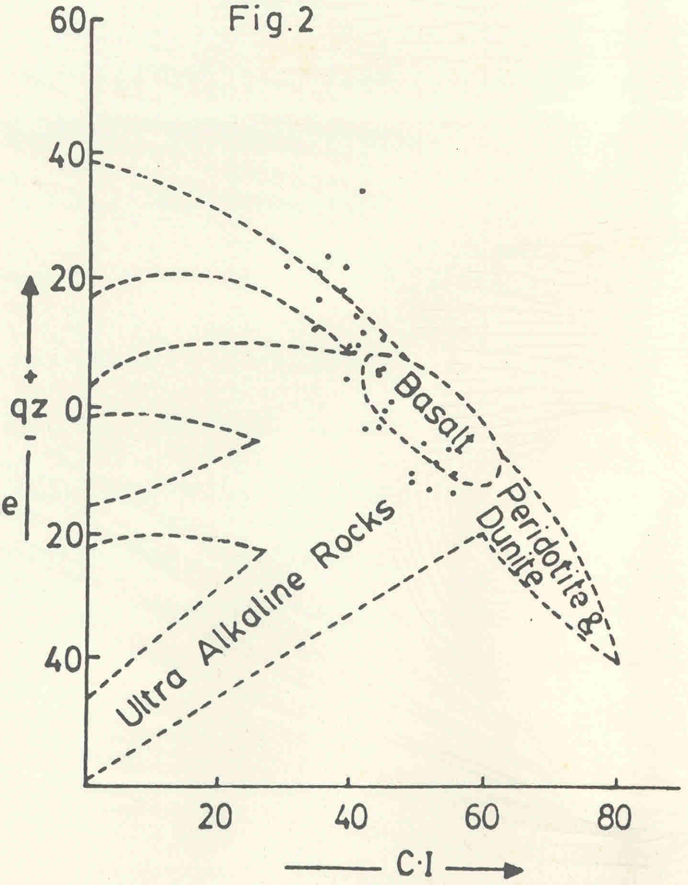


Fig.4

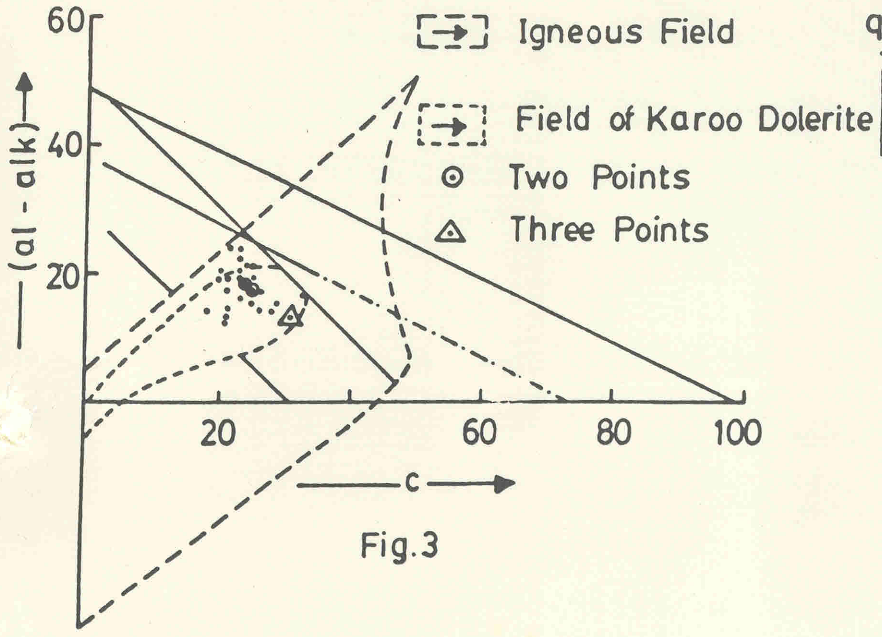


Fig.3

Plate 9

Fig.1. Binary variation diagram showing the relationship between S.I. and SiO_2. Dots represent individual trap samples of the study area.

Fig.2. Binary variation diagram showing the relationship between S.I. and total iron. Dots represent individual trap samples of the study area.

Fig.3. Bivariate diagram indicating two fields showing relationship between Normative plagioclase composition and Al_2O_3 weight percent. Dots represent individual trap samples from the study area (After Irvine and Baragar, 1971).

Plate-9

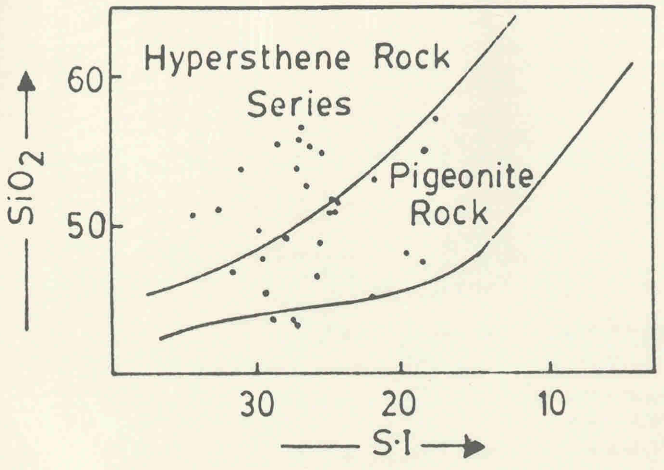


Fig. 1

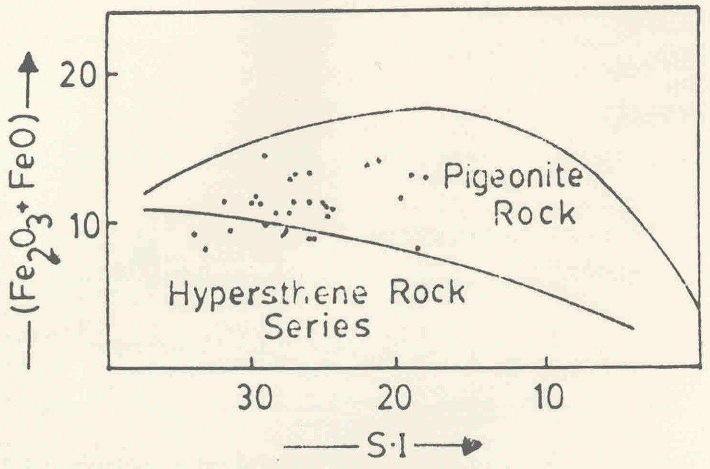


Fig. 2

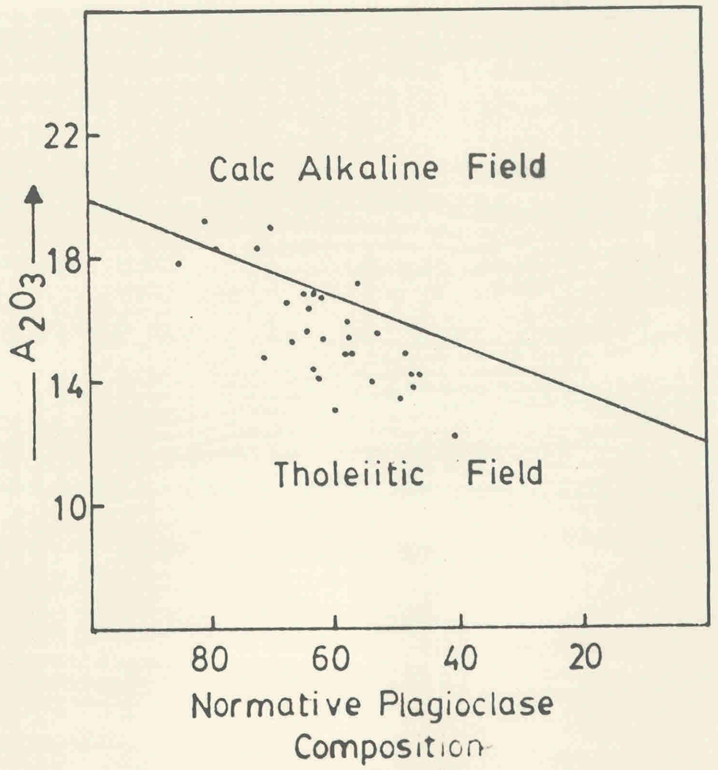


Fig. 3

Plate 10

Fig.1. Bivariate diagram showing the relationship between Silica versus total alkalis with the plots from the Skien Basaltic rocks for comparison with traps of Banihal area. Dots represent individual trap samples of the study area.

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

Fig.2. Bivariate diagram showing the relationship between FeO^{tot}/Mgo and FeO^{tot}. Dots represent individual trap samples of the study area (After Miyashiro, 1975).

Fig.3. Bivariate diagram showing the relationship between FeO^{tot}/MgO and Silica. Dots represent individual trap samples of the study area (After Miyashiro, op.cit.).

Plate-10

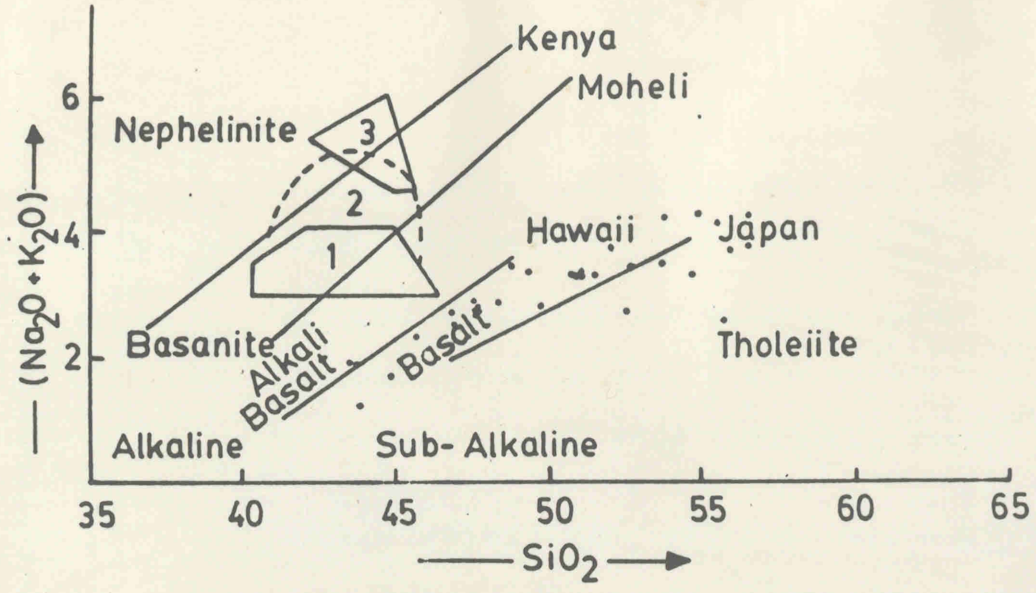


Fig.1

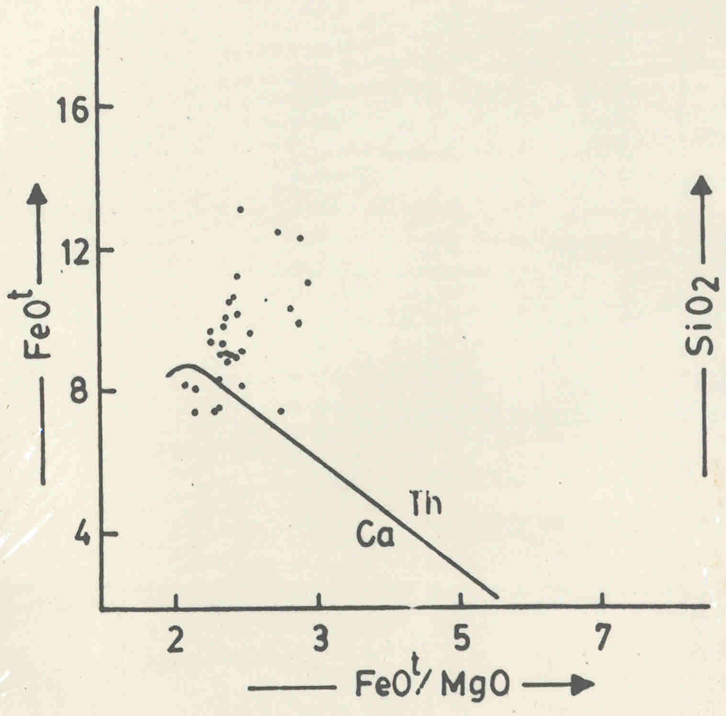


Fig. 2

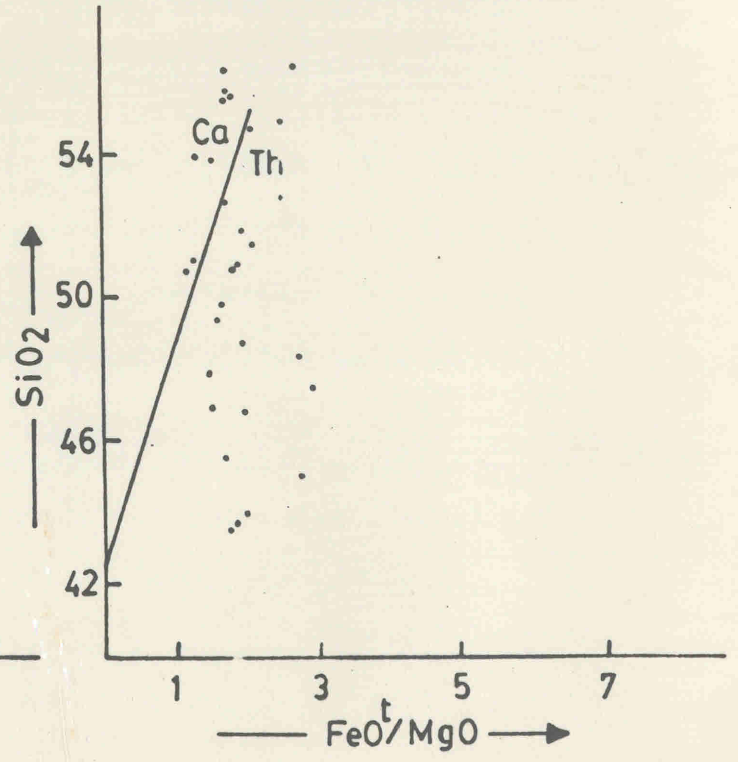


Fig. 3

Plate 11

Fig.1. Bivariate diagram showing the relationship between FeO^{tot}/MgO and TiO_2. Dots represent individual trap samples of the study area & dots within circle where two or more samples coincide (After Glassley, 1974).

Fig.2. Bivariate diagram showing the relationship between TiO_2 and FeO^{tot}/MgO. Dots represent individual trap samples of the study area and dots within circle where two or more samples coincide (After Glassley, 1974).

Fig.3. Bivariate diagram showing the relationship between Mafic and Felsic Indices. Dots represent individual trap samples from the study area (After Simpson, 1954).

Fig.4. Bivariate diagram showing the relationship between MgO and Al_2O_3/SiO_2 ratio. Dots represent individual trap samples from the study area and dots within circles where two or more samples coincide.

Plate-11

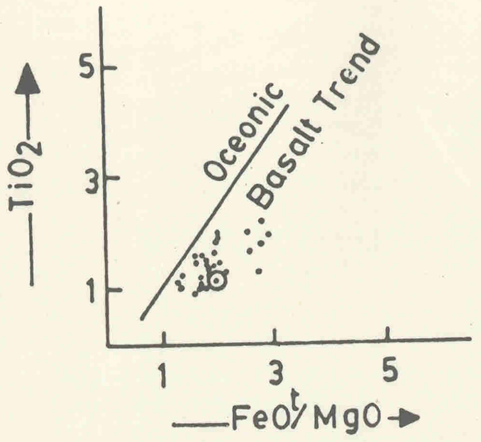


Fig.1

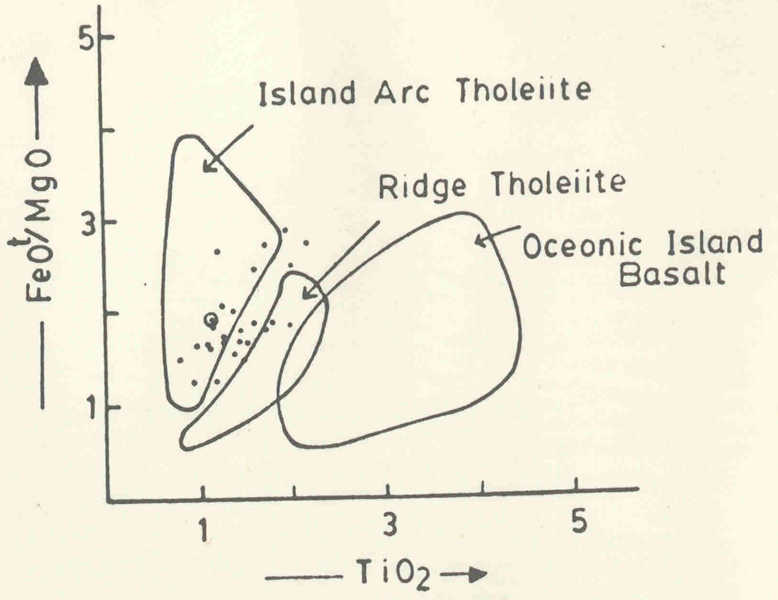


Fig.2

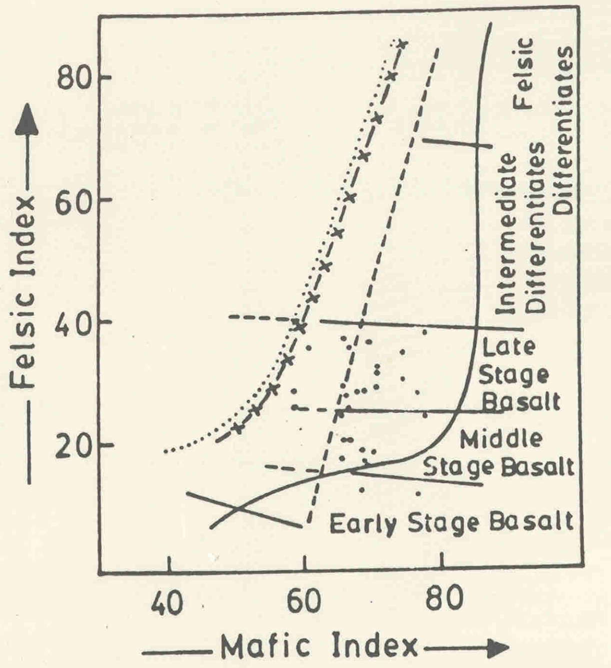


Fig.3

- - - Rajmehal Trend
—— Deccan Trend
------ Trend of Igneous Rocks (Average)
.... Trend of Traps of Banihal

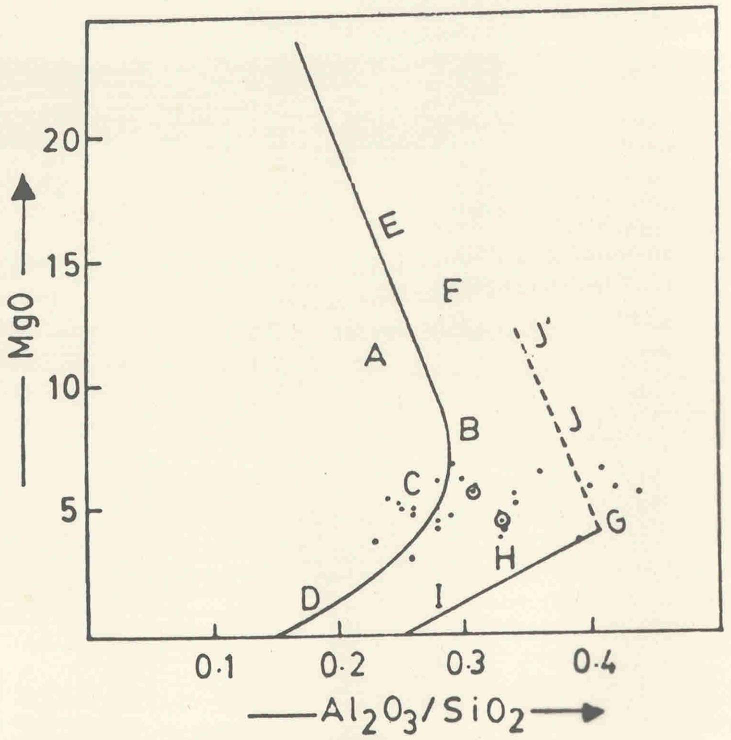


Fig.4

Plate 12

Fig.1. Bivariate diagram showing the relationship between D.I. and total alkalis. Dots represent individual trap samphe study area (After Tilley & Muir, 1967).

Fig.2. Bivariate diagram showing the relationship between MgO and CaO. Dots represent individual trap samples from the study area (After Macdonald, 1968).

Fig.3. Bivariate diagram showingthe relationship between Silica and total alkalis. Dots represent individual trap samples from the study area (After Irvine & Baragar, 1971).

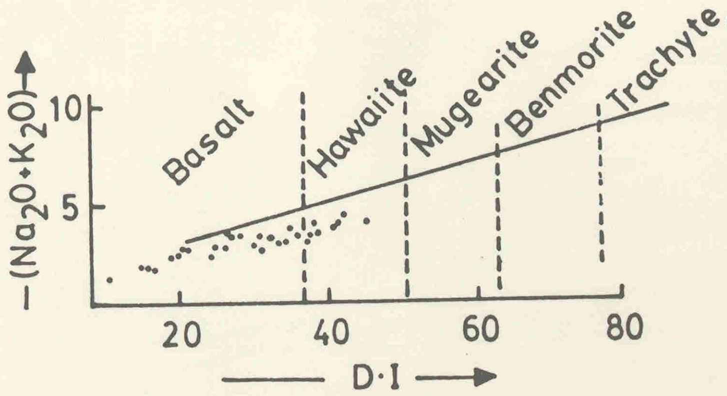


Fig.1

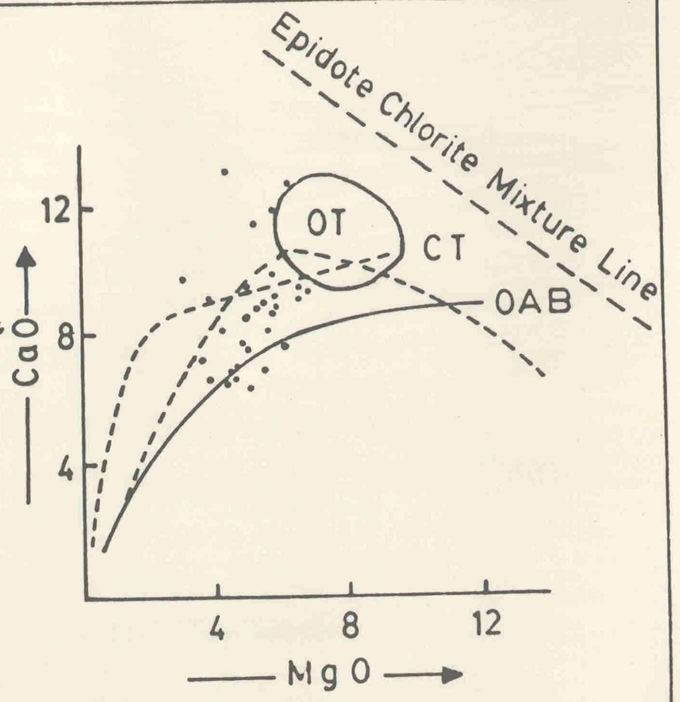


Fig.2

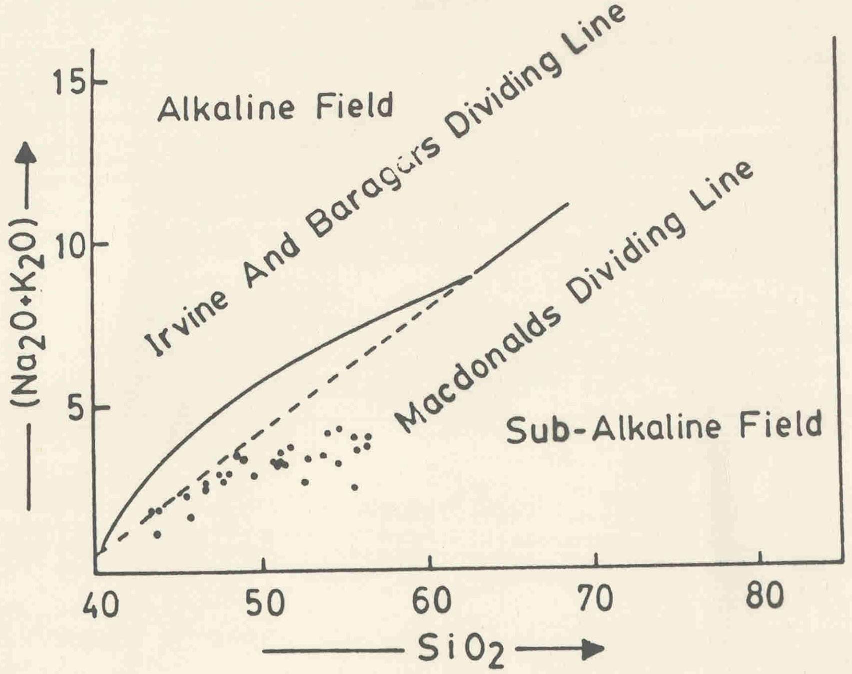


Fig.3

Plate 13

Fig.1. Bivariate diagram showing the relationship between normative Anx100/(Ab+An) and D.i. Dots represent individual trap samples of the study area (After Flyod, 1976).

Fig.2. Bivariate diagram showing the relationship between normative Anx100/(Ab+An) and D.I. Trend line for the traps of the study area is indicated in this plot (After Flyod, 1976).

Plate -13

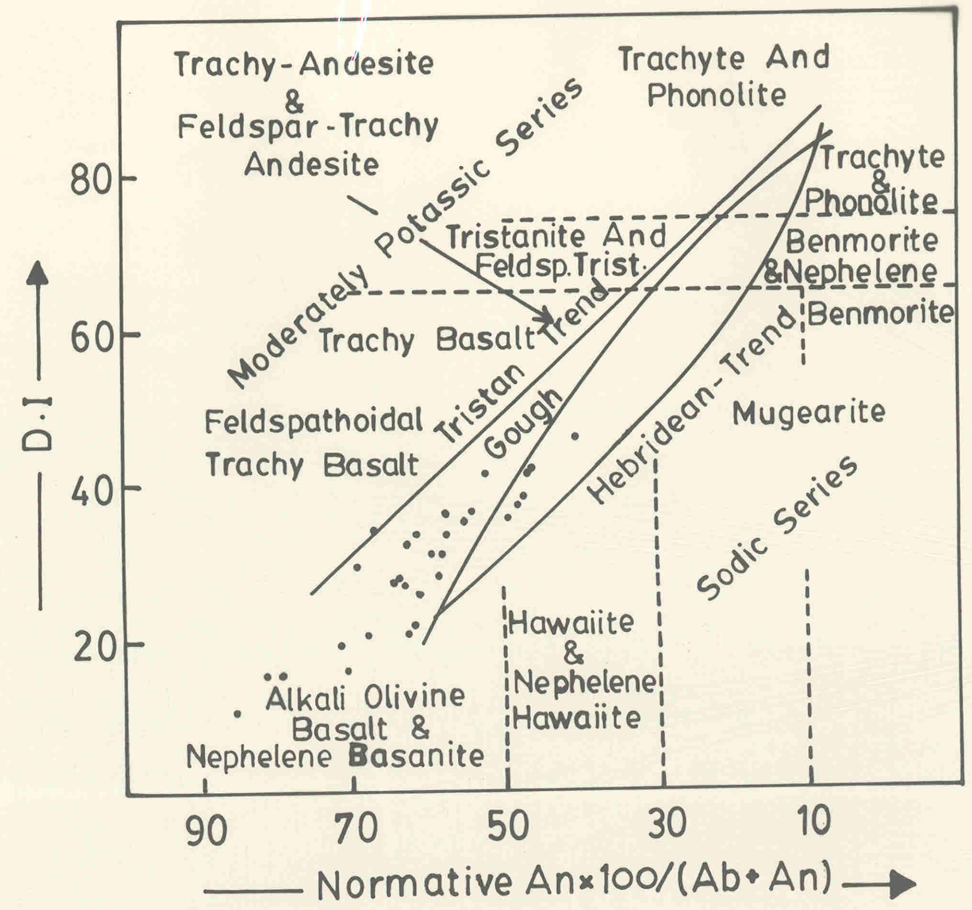


Fig. 1

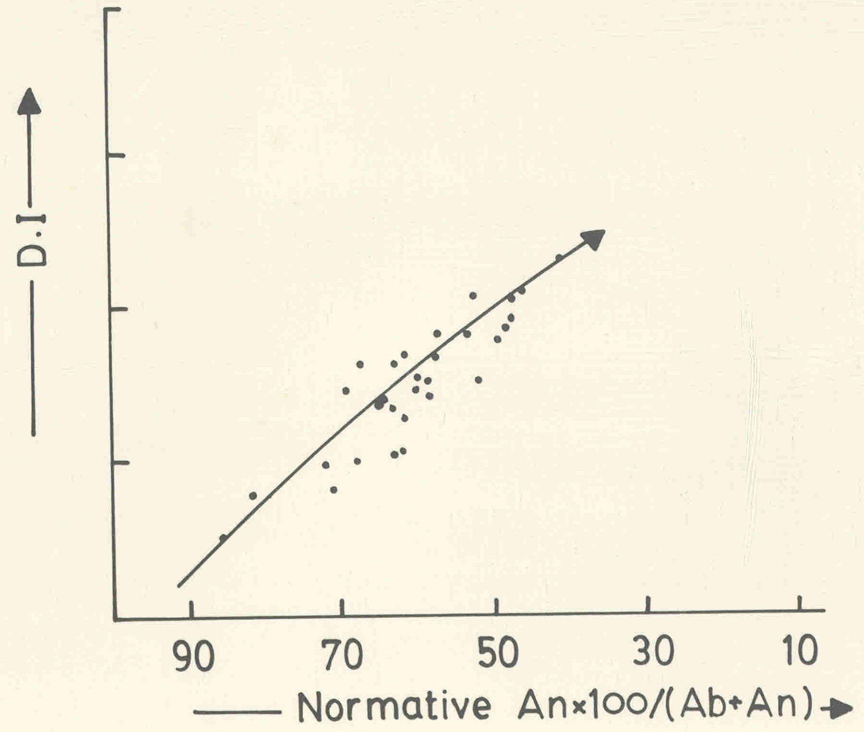


Fig.2

Plate 14

Figs. 1 - 9. Mckie (1966) variation diagrams showing the relationship of Si with respect to several cations. Dots represent individual trap samples of the study area.

Plate-14

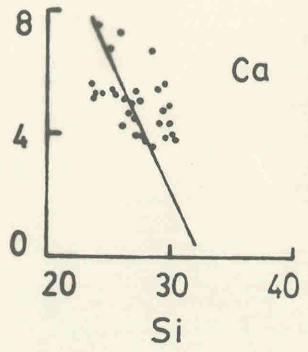


Fig.1

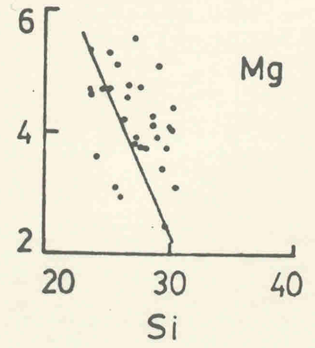


Fig.2

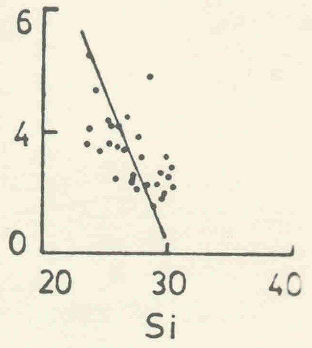


Fig.3

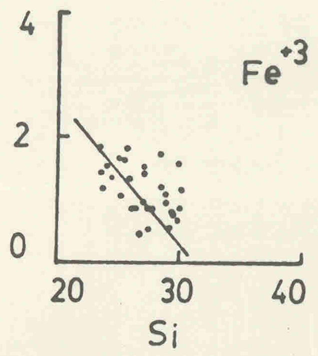


Fig.4

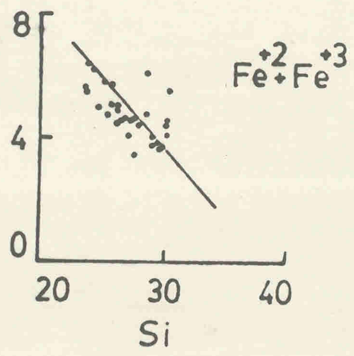


Fig.5

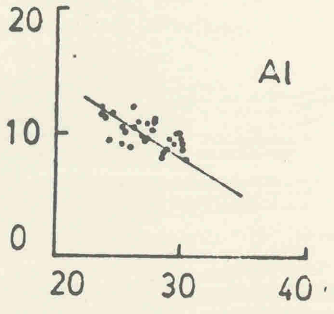


Fig.6

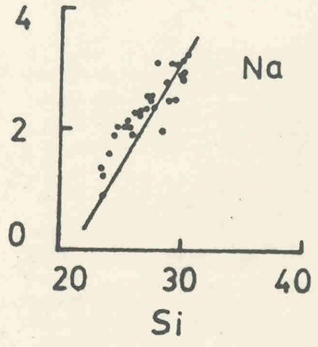


Fig.7

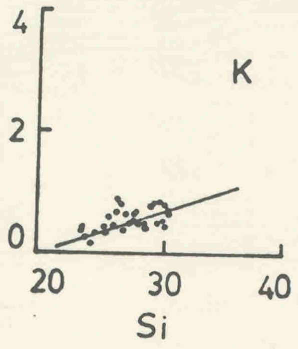


Fig.8

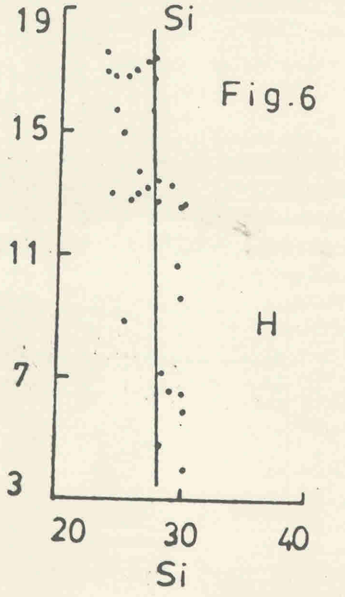


Fig.9

Plate 15

Figs. 1 - 5. Binary variation diagrams showing the relationship of MgO with several oxides. Dots represent individual trap samples of the study area. (After Nisbet et al., 1977).

Plate-15

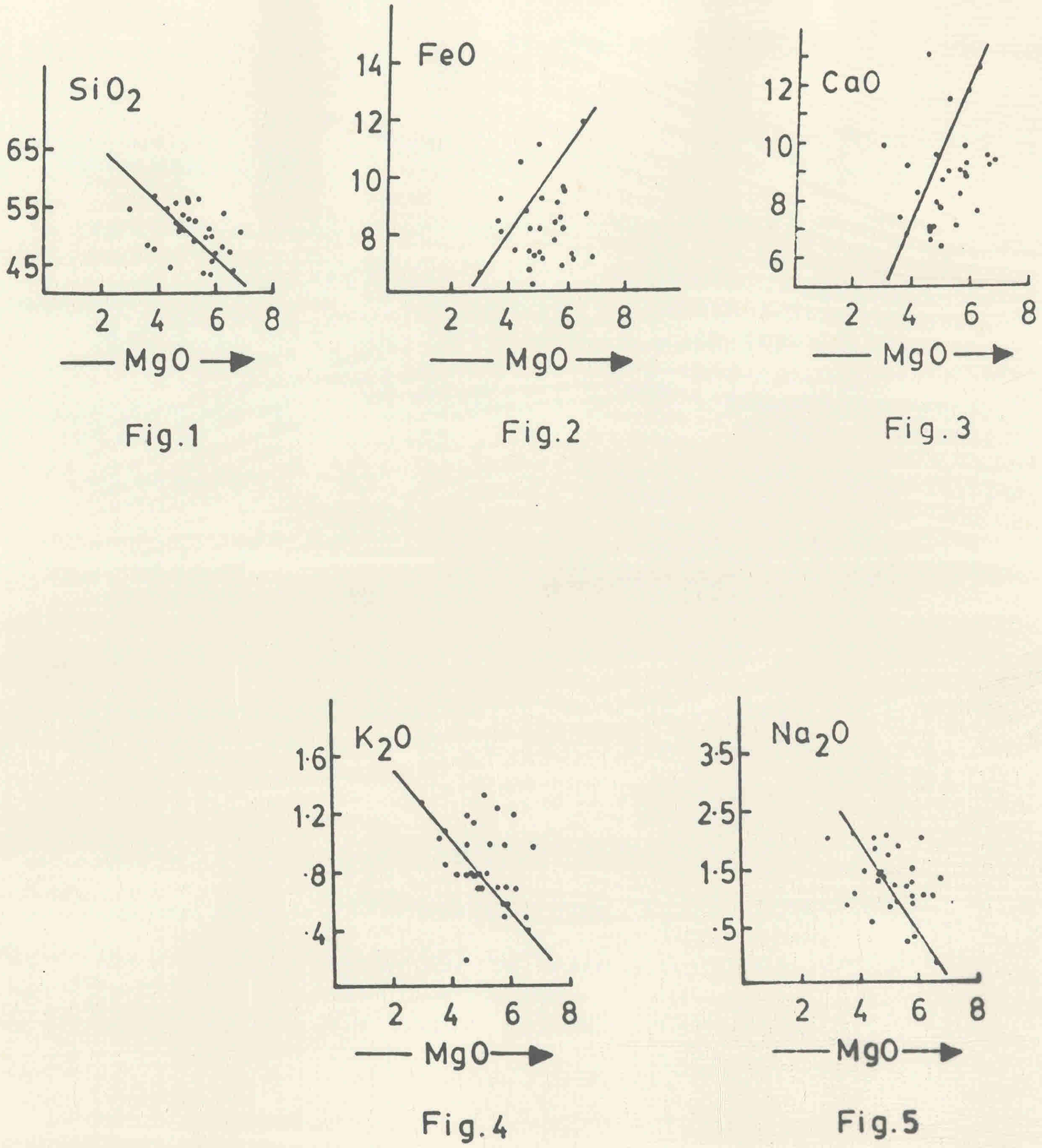


Fig.1 Fig.2 Fig.3

Fig.4 Fig.5

Plate 16

Fig.1. Bivariate diagram showing the relationship between Silica and Oxidation ratio. In all the diagrams different trend lines are seen. Dots represent individual trap samples from the study area. (After Aniruddha De, 1964).

Fig.2. Bivariate diagram showing the relationship between total iron and oxidation ratio. Different trend lines are seen in different plots. Dots represent individual trap samples from the study area. (After Aniruddha De, 1964).

Fig.3. Bivariate diagram showing the relationship between Silica and total iron. Different trend lines are seen in different plots. Dots represent indv. samples from the study area. (After Aniruddha De, 1964).

Plate-16

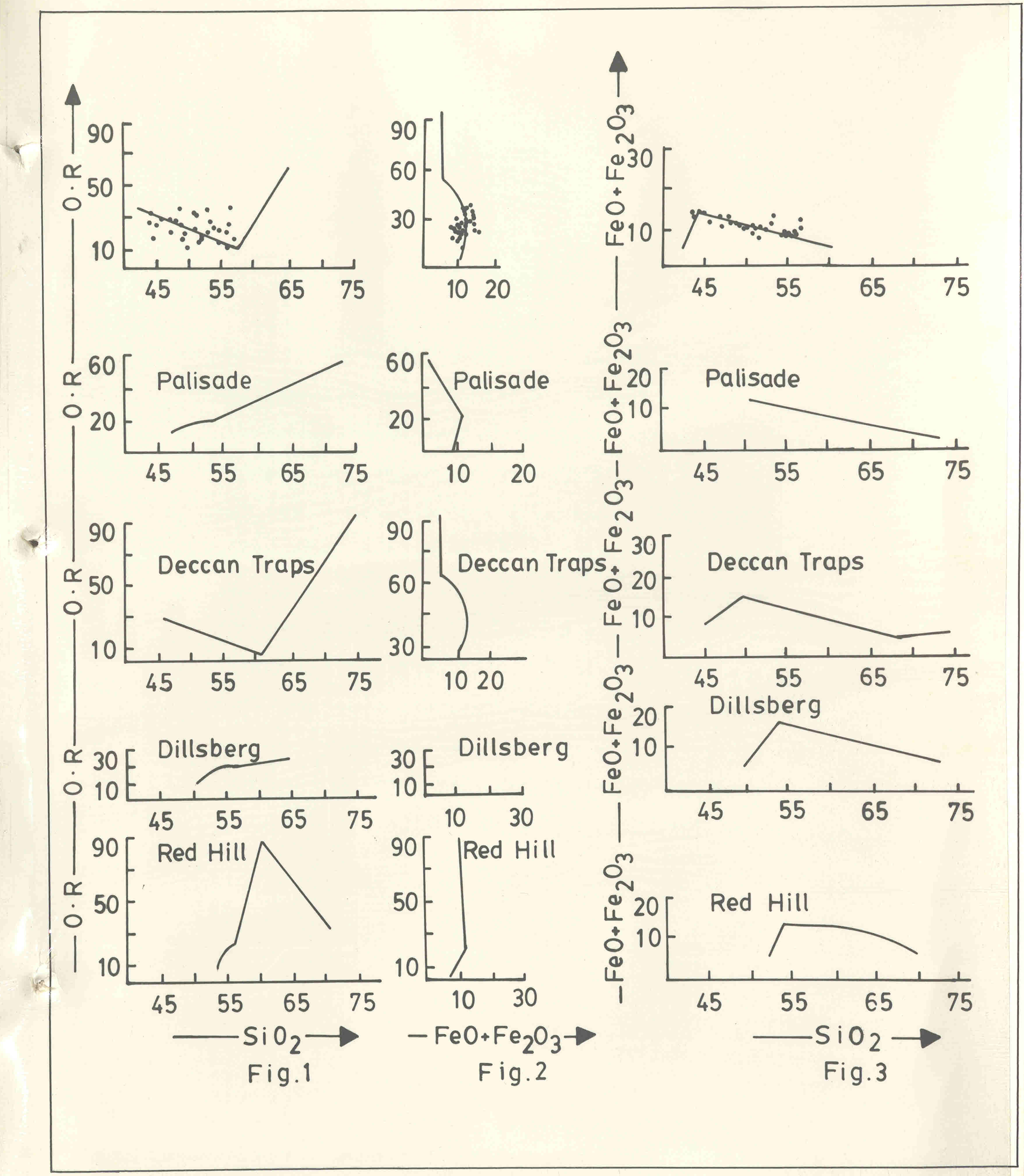


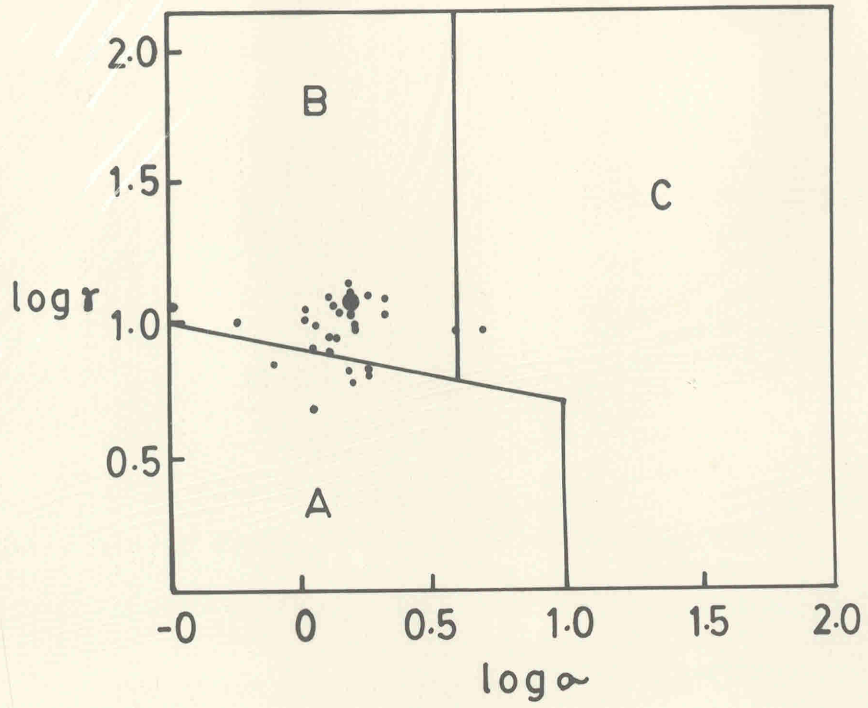
Fig.1 Fig.2 Fig.3

Plate 17

Fig.1. Gottini-rittmann diagram showing three different fields. In field A are falling lavas of volcanoes situated in non-orogenic regions; in field B, those of volcanoes in orogenic belts and Island arcs and in field C are the alkaline derivatives of both, i.e. trachytes, phonolites, tepherites etc., among which the sodic types are generally linked to A, and the potassic ones to B. Dots represent individual trap samples around Banihal area and dots within circle where two or more samples coincide (After Rittmann,1967,70 and Gottini, 1968-70).

Fig.2. Bivariate diagram showing the relationship between TiO_2 and Al_2O_3. Dots represent individual trap samples around Banihal area (After Tanaka et al. 1973).

Plate-17



Gottini Rittman Diagram

Fig.1

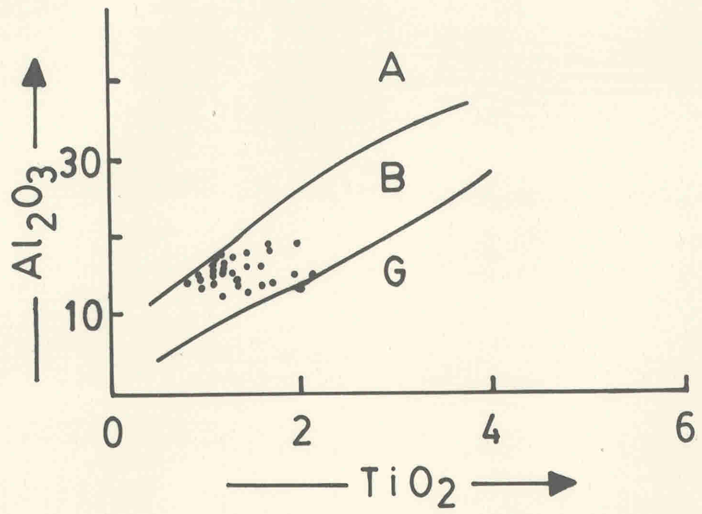


Fig.2

Fig.9. Classification of volcanic rocks (After Streckeisen, 1978).

Figure-9

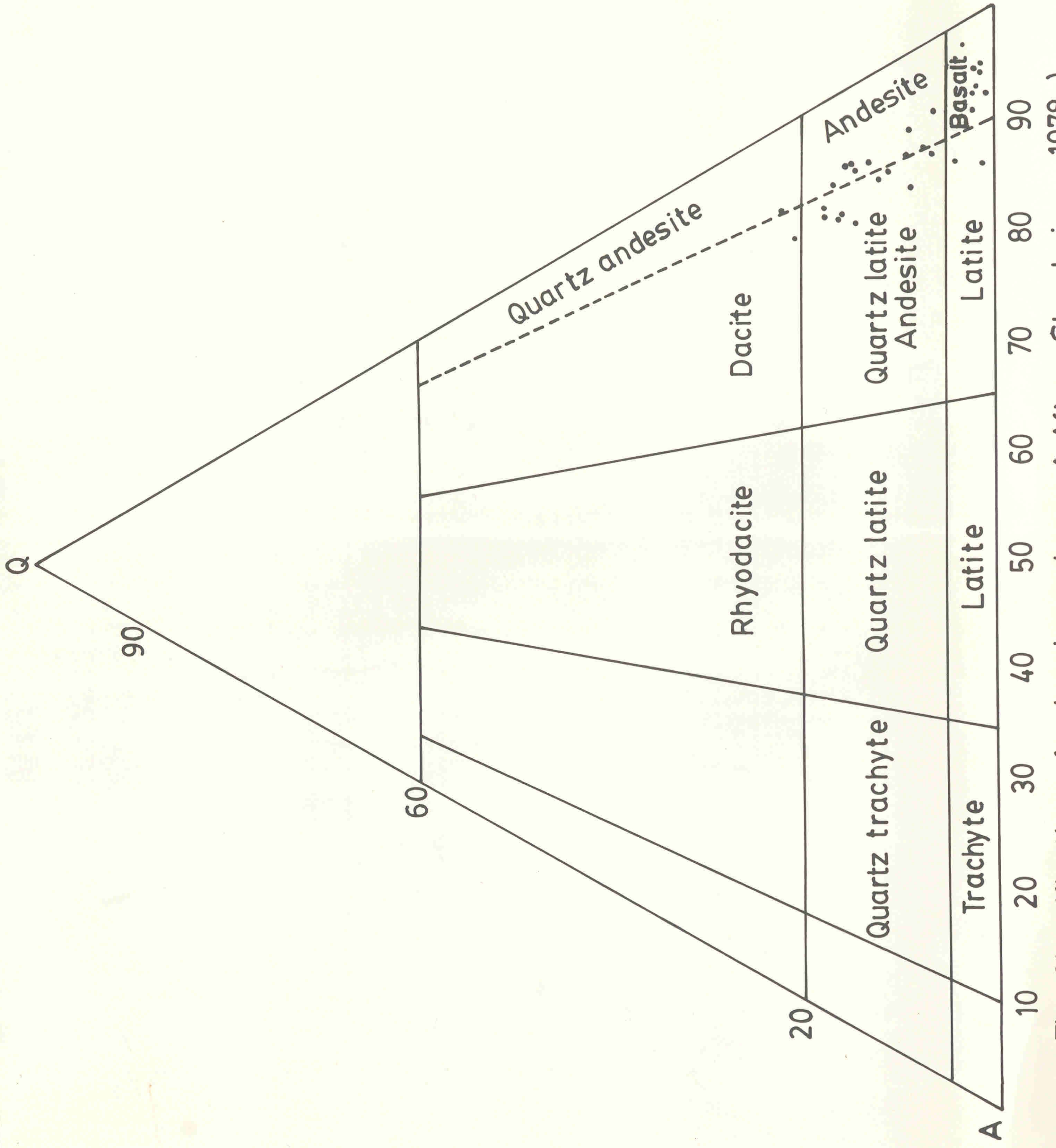


Fig. Classification of volcanic rocks (After Streckeisen, 1978)

Plate 18

Fig.1. Na_2O-K_2O-CaO trilinear variation diagram. Dots represent the position of the analysed trap samples of the study area. Field of volcanics has been indicated in the diagram.

Fig.2. MgO-(FeO+Fe_2O_3)-(Na_2O+K_2O) trilinear variation diagram. Dots represent the position of the analysed trap samples of the study area. Field of volcanics has been indicated in the diagram.

Fig.3. FeO-(Na_2O+K_2O)-MgO trilinear variation diagram. Dots represent the position of the analysed trap samples of the study area. Field of volcanics has been indicated in the diagram.

Plate-18

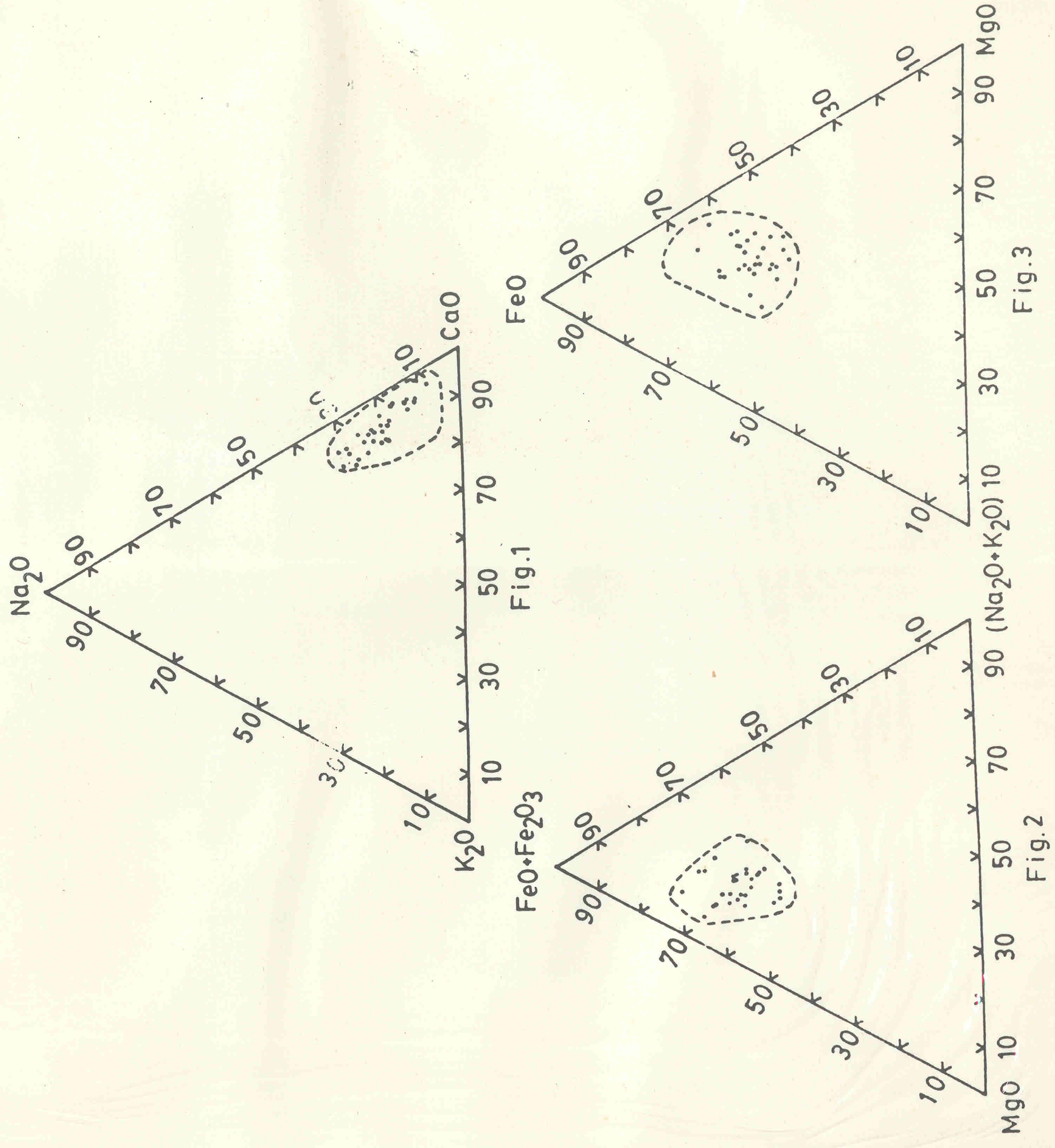


Plate 19

Fig.1. CaO-(Al_2O_3-K_2O)-Na_2O trilinear variation diagram. Dots represent the position of the analysed trap samples of the study area (After Joly & Smith, 1972).

Fig.2. An-Ab-Or trilinear variation diagram indicating different fields. Dots represent the position of the analysed trap samples of the study area (After Irvine & Baragar, 1971).

Plate-19

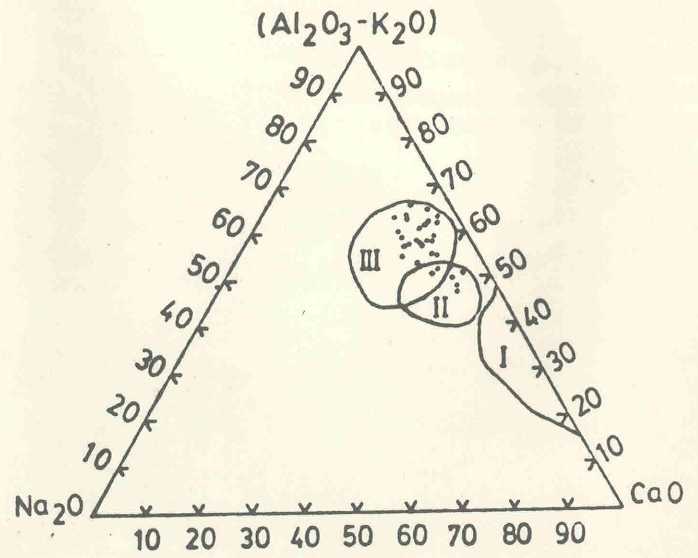


Fig.1

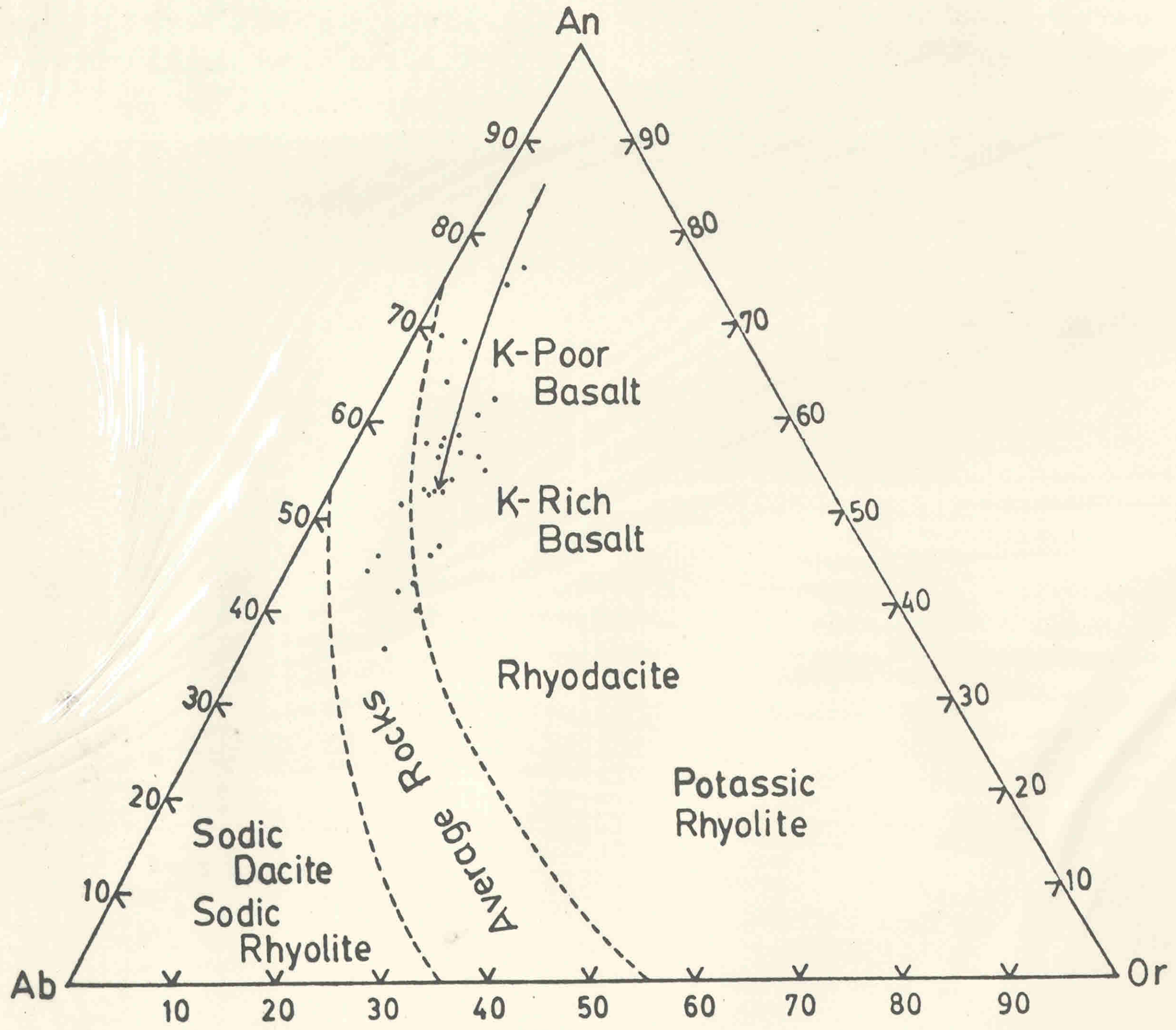


Fig.2

Fig.10. A-C-F trilinear variation diagram. Dots showing the position of the analysed Panjal Trap samples of Banihal area. (After Miyashiro, 1974).

Figure-10

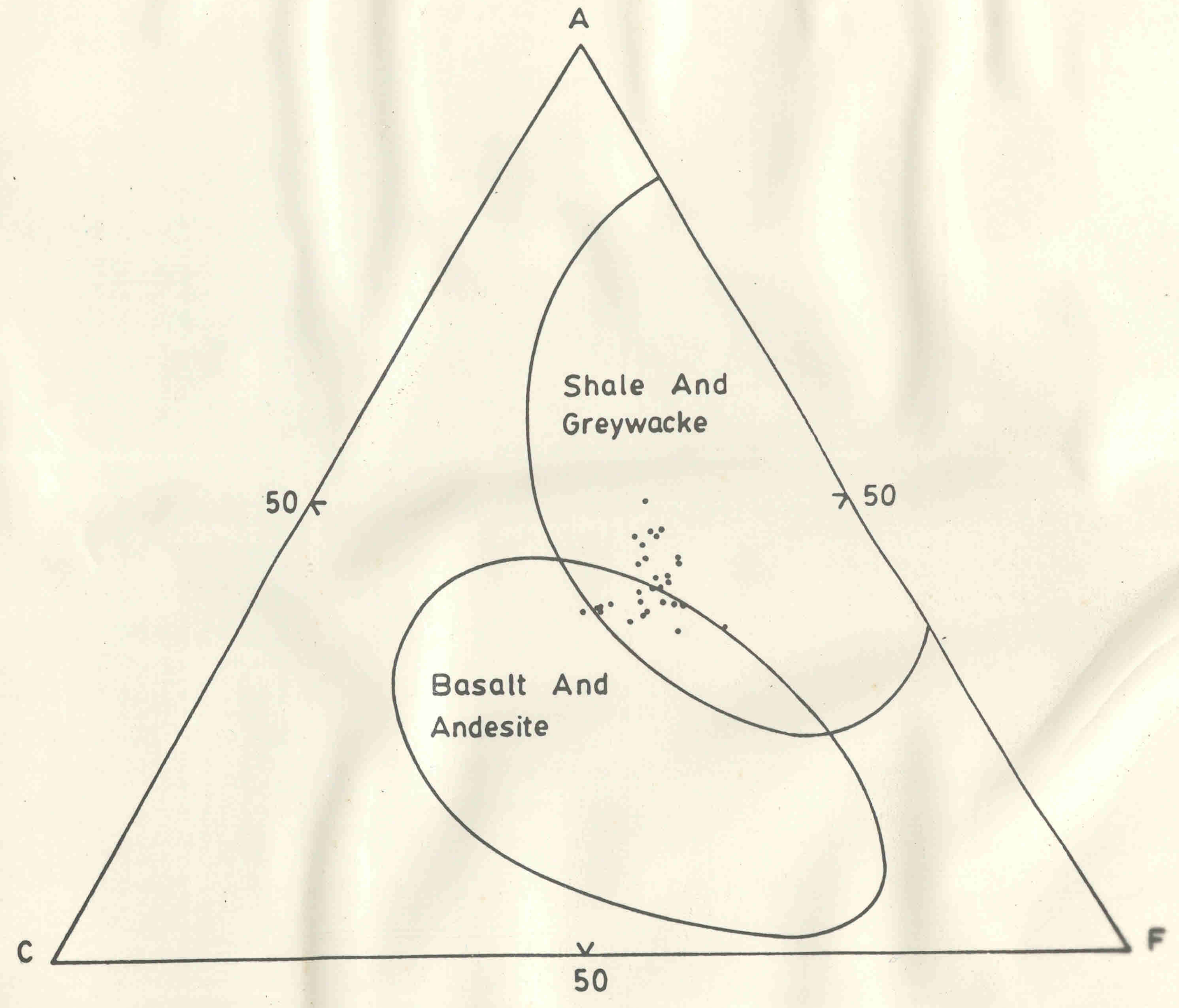


Fig.11. Graph showing a plot of Ba, Cd, Co, Cr, Cs and Cu with respect to SiO_2. Dots represent individual trap samples around Banihal area.

Figure-11

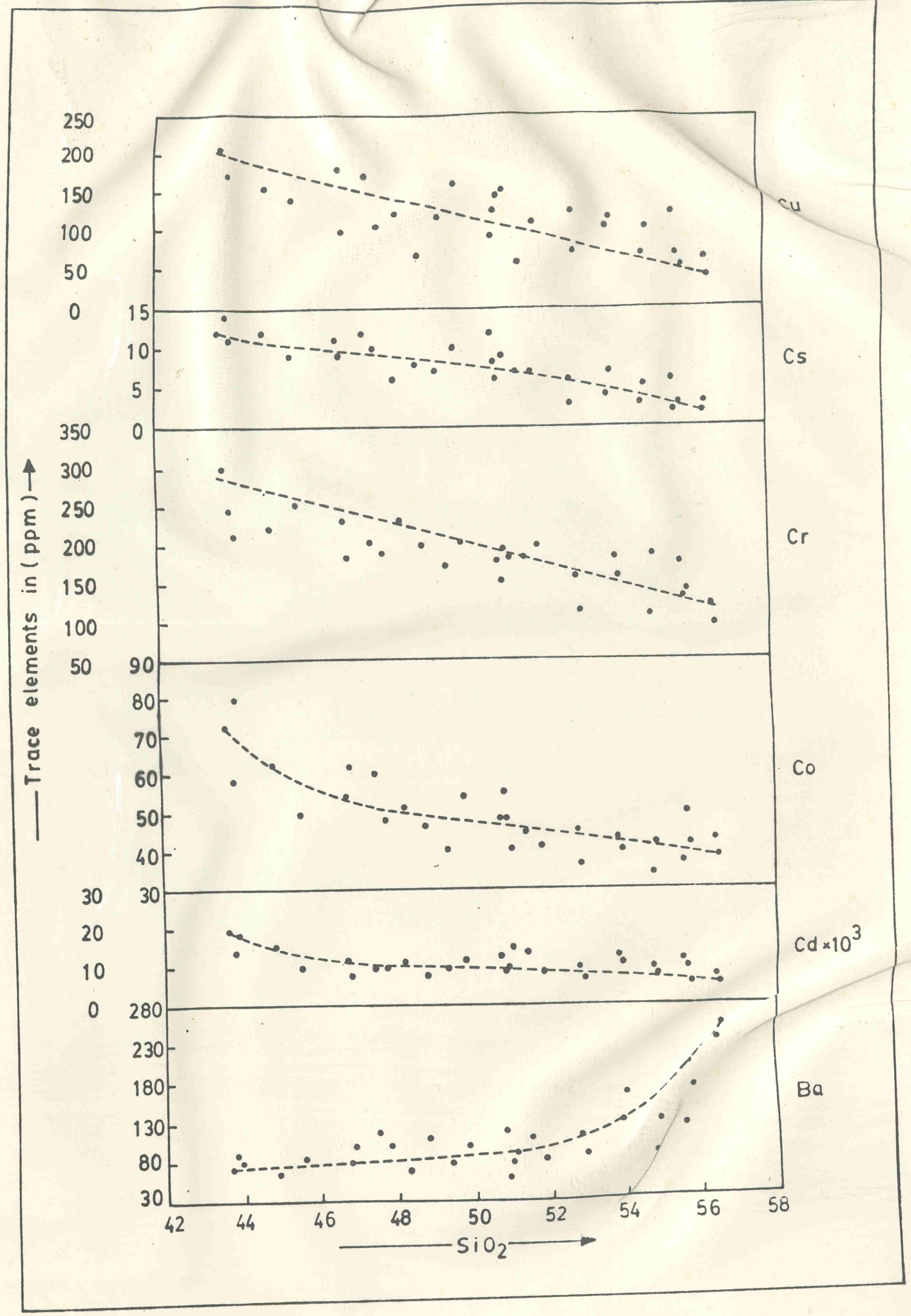


Plate 20

Fig.1. Graph showing a plot of Ba v/s Ca. Dots represent individual trap samples around Banihal area.

Fig.2. Graph showing a plot of Cr v/s SiO_2. Dots represent individual trap samples around Banihal area (After Miyashiro & Shido, 1975).

Fig.3. Graph showing a plot of Cr v/s V. Dots represent individual trap samples around Banihal area. In this diagram the boundary lines separate the three regions : A- calc-alkaline basalts, B- mixed basalts and C- tholeiitic basalts (After Miyashiro & Shido, 1975).

Fig.4. Graph showing a plot of V v/s Fe_2O_3+FeO/MgO. Dots represent individual trap samples around Banihal area. In this diagram the boundary lines separate the three regions : A- calc-alkaline basalt, B- mixed basalts and C- tholeiitic basalts (After Miyashiro & Shido, 1975).

Fig.5. Graph showing a plot of Cr v/s Y. Dots represent individual trap samples around Banihal area. In this diagram three fields MORB, IAT and Bay of Island are demarcated (After Pearce, 1982).

Fig.6. Graph showing a plot of Cr v/s Niggli mg. Dots represent individual samples around Banihal area. The plot demonstrates an Igneous trend.

Plate-20

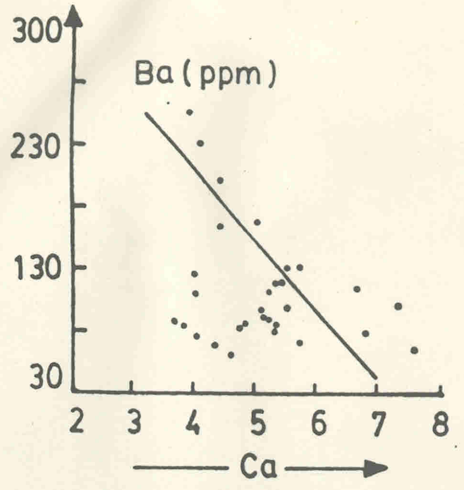


Fig.1

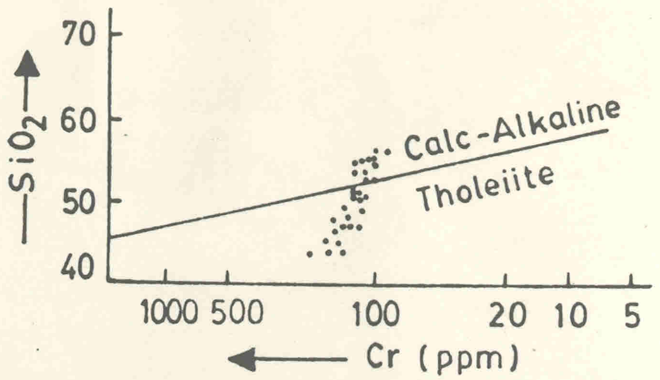


Fig.2

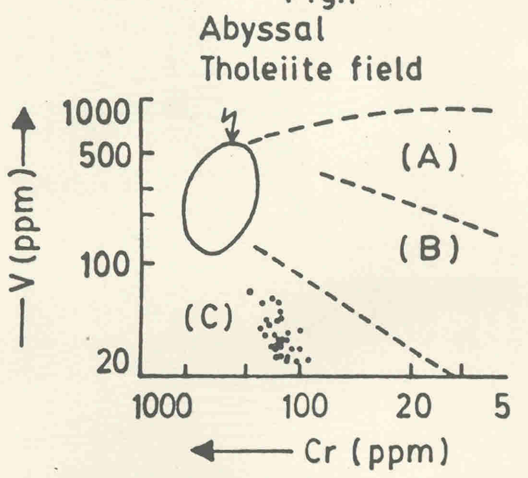


Fig.3

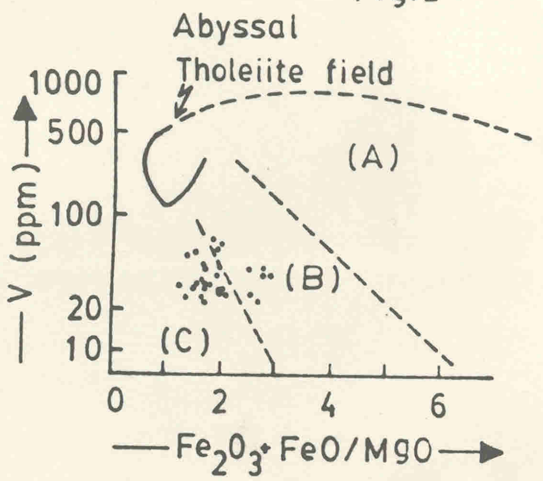


Fig.4

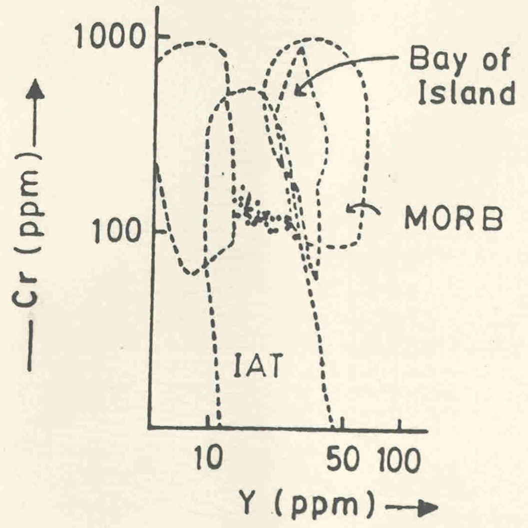


Fig.5

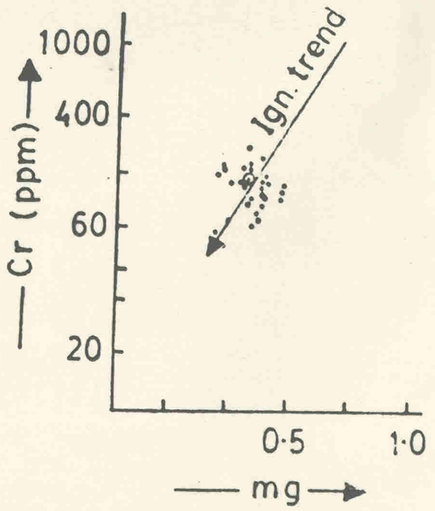


Fig.6

Fig.12. Graph showing a plot of Ga, Li, Mo, Ni, Pb and Rb with respect to SiO_2. Dots represent individual trap samples around Banihal area.

Figure -12

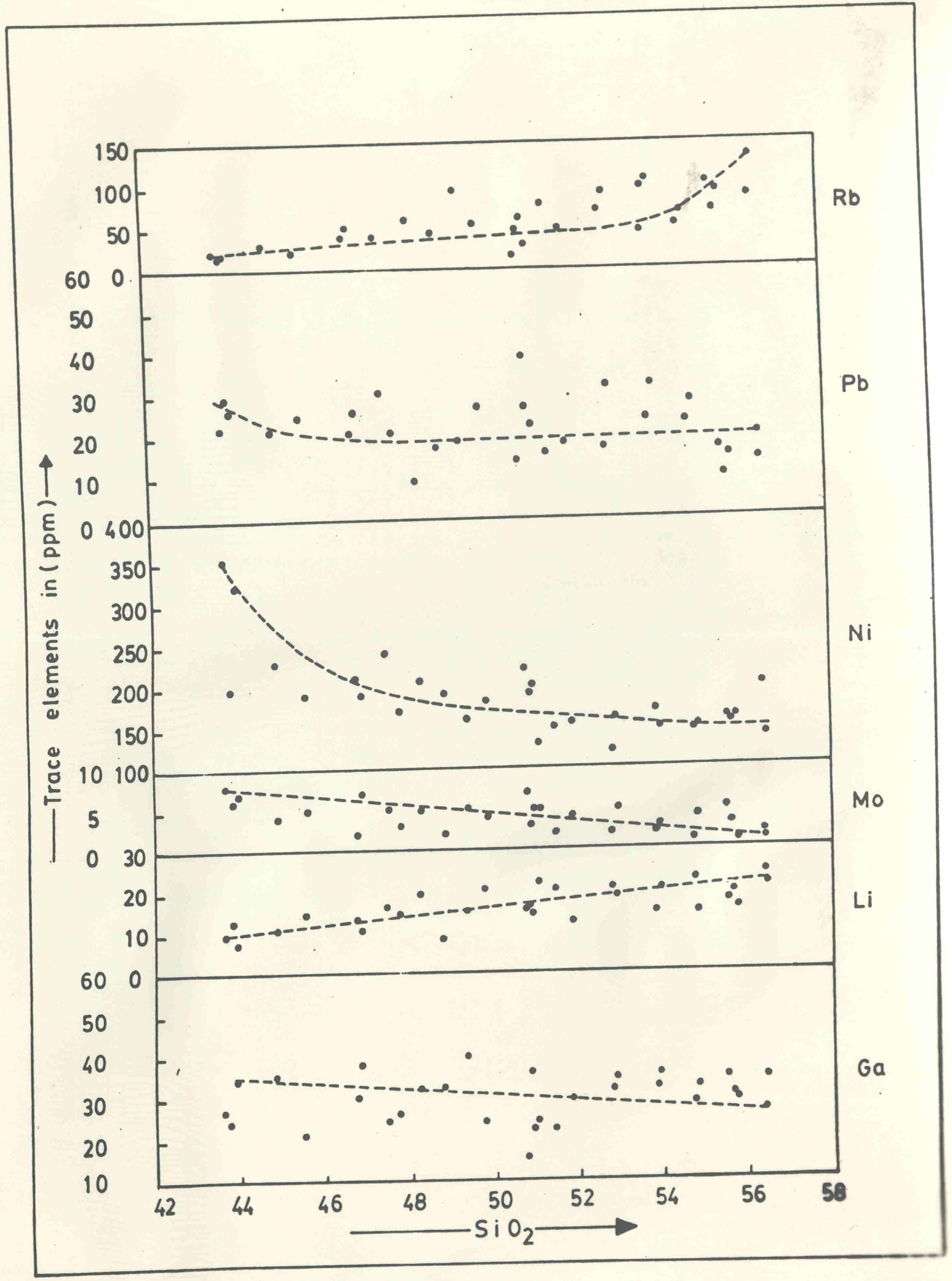


Fig.12. Graph showing a plot of Ga, Li, Mo, Ni, Pb and Rb with respect to SiO_2. Dots represent individual trap samples around Banihal area.

Figure -12

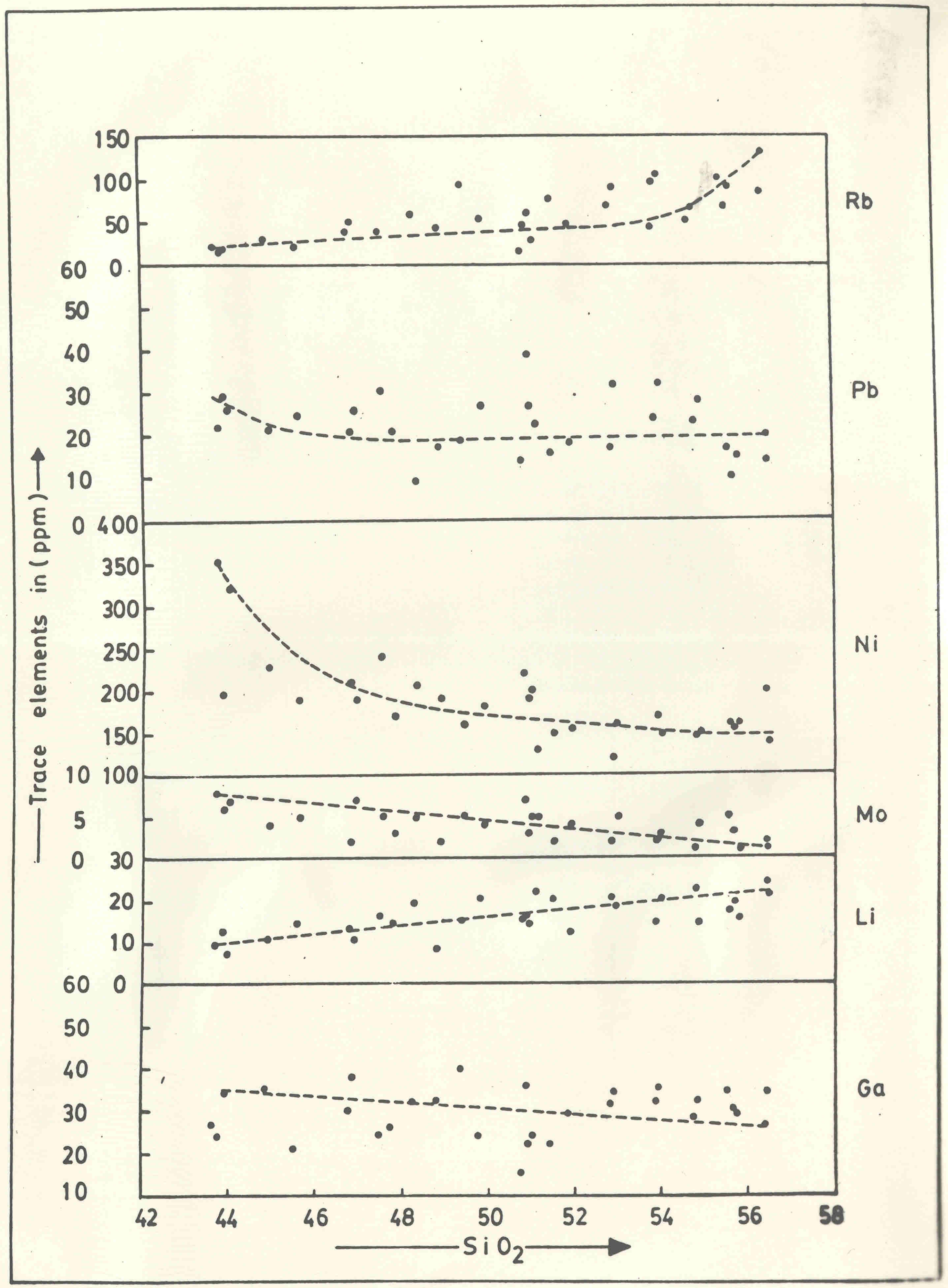


Plate 21

Fig.1. Graph showing a plot of Mo v/s Ni. Dots represent individual trap samples around Banihal area and the dots within triangles where three samples coincide.

Fig.2. Graph showing a plot of Ni v/s Niggli mg. Dots represent individual trap samples around Banihal area. The plot demonstrates an Igneous trend (After Leake, 1964).

Fig.3. Graph showing a plot of Sr v/s Ca. The dots represent individual trap samples around Banihal area.

Fig.4. Graph showing a plot of Pb v/s Sr. Dots represent individual trap samples around Banihal area.

Fig.5. Graph showing a plot of Y v/s mg. Dots represent individual trap samples around Banihal area.

Fig.6. Graph showing a plot of Y v/s Ca. Dots represent individual trap samples around Banihal area.

Plate-21

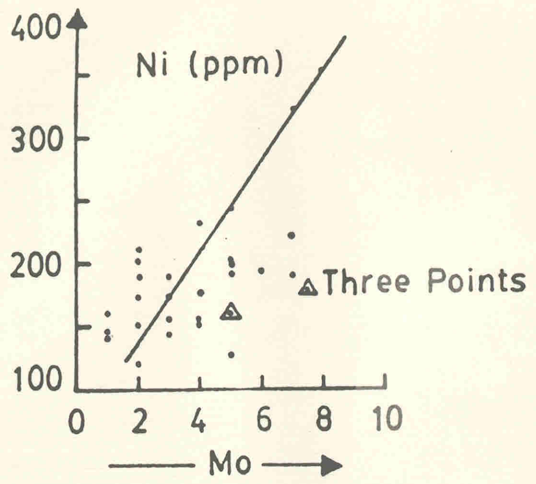


Fig.1

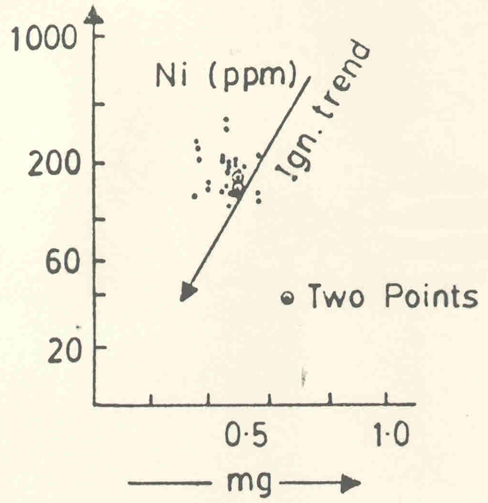


Fig. 2

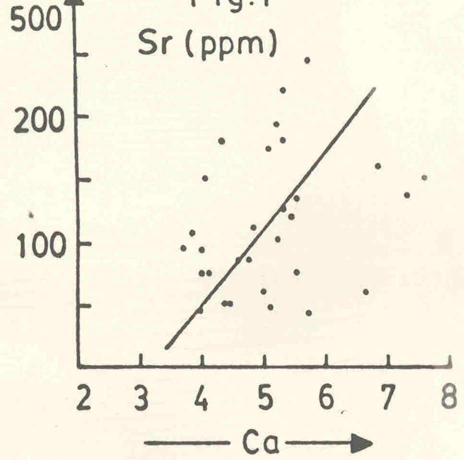


Fig.3

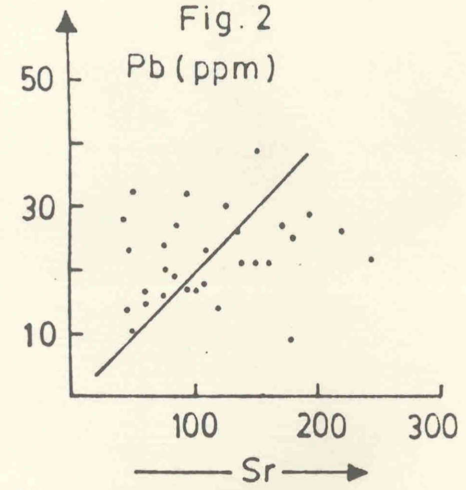


Fig.4

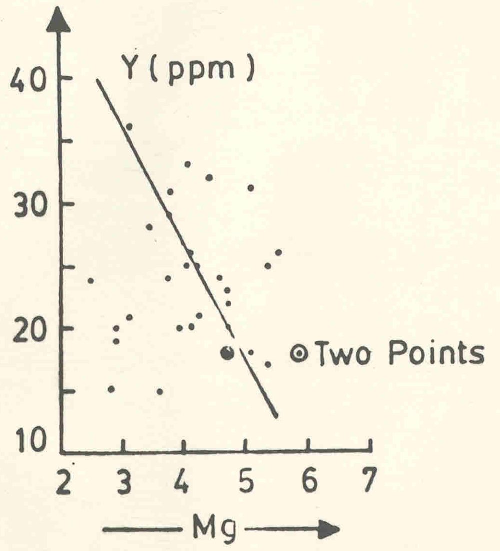


Fig 5

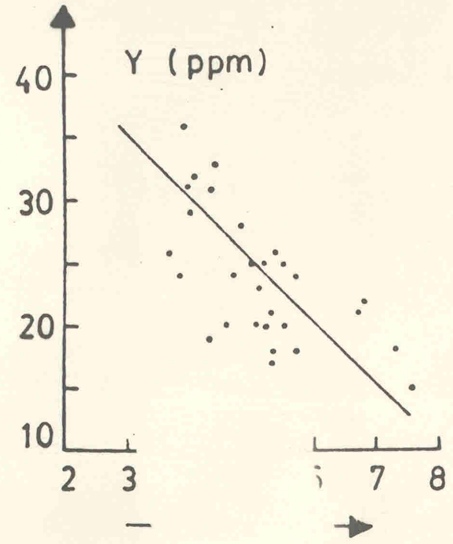


Fig. 6

Fig.13. Graph showing a plot of Sr, V, Y, Zn, and Zr with respect to SiO_2. Dots represent individual trap samples around Banihal area.

Figure -13

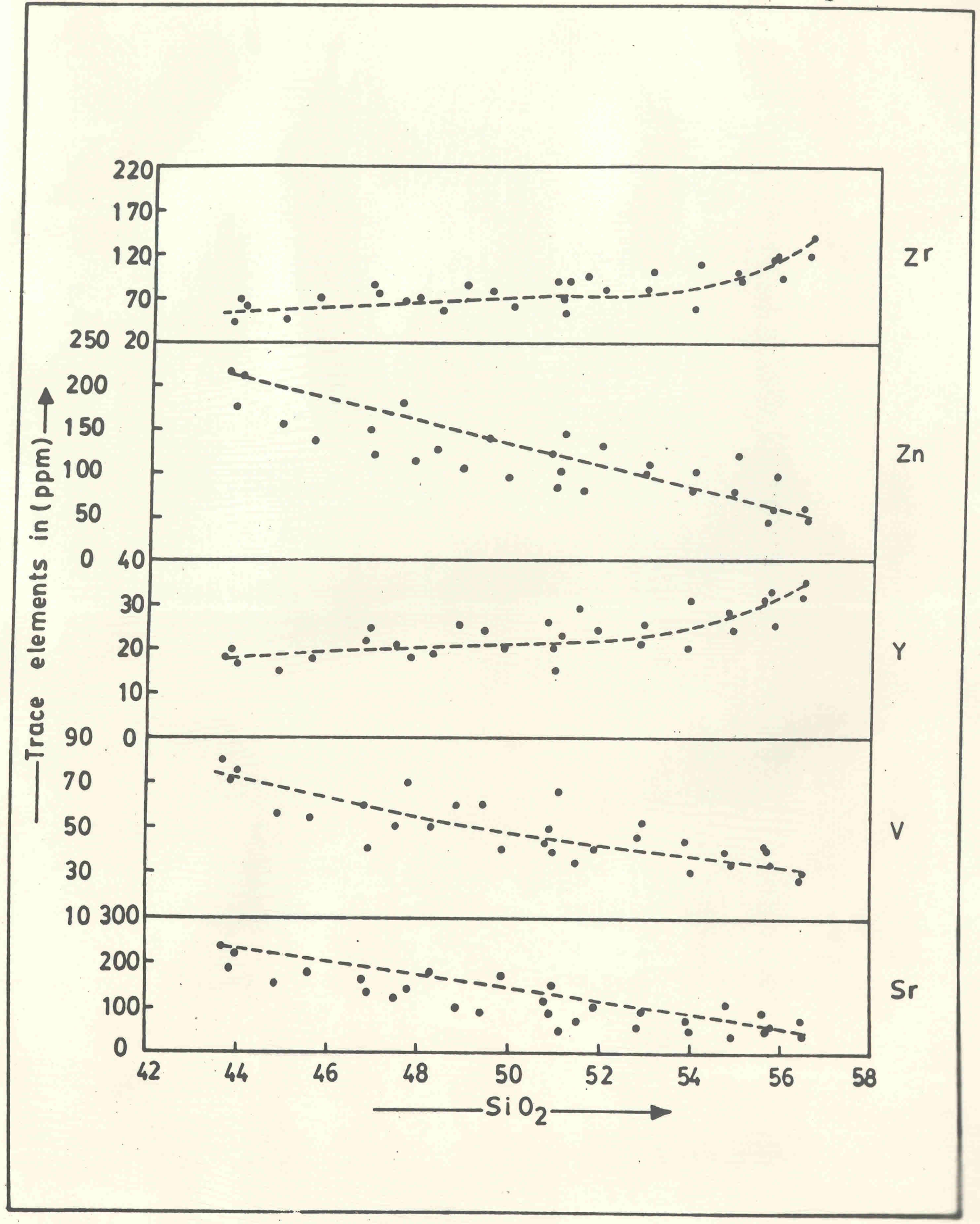


Plate 22

Fig.1. Graph showing a plot of Y v/s FeO/mgO. Dots represent individual trap samples around Banihal area. Dotted line demarcates two fields : tholeiitic basalt field and calc-alkaline basalt field (After Winchester & Max, 1982).

Fig.2. Graph showing a plot of Zr/Y v/s Zr. Dots represent individual trap samples around Banihal area and dots within the circle where two or more samples coincide. The diagram indicates three fields :

WPB - Within Plate Basalt field
MORB - Mid Oceanic Ridge Basalt field
IAT - Island Arc Tholeiitic basalts
(After Pearce & Cann, 1973).

Fig.3. Ti/100-Zr-Yx3 trilinear variation diagram. Dots represent individual trap samples around Banihal area and dots within circle where more than two samples coincide. Four fields are indicated in this diagram as :

A - IAT (Island Arc Tholeiitic basalts)
B - MORB (Mid Oceanic Ridge Basalts)
C - CAB (Calc-alkaline Basalts)
D - WPB (Within Plate Basalts)
(After Pearce & Cann, 1973).

Fig.4. Graph showing the plot of Ti v/s Cr. Dots represent individual trap samples around Banihal area and dots within circle where two or more samples coincide (After Pearce, 1980).

Fig.5. Graph showing a plot of Ti v/s Zr. Dots represent individual trap samples around Banihal area. Three fields are indicated in this diagram:

WPB - Within Plate Basalt field
MORB - Mid Oceanic Ridge Basalt field
Arc Lavas (After Pearce, 1981).

Plate-22

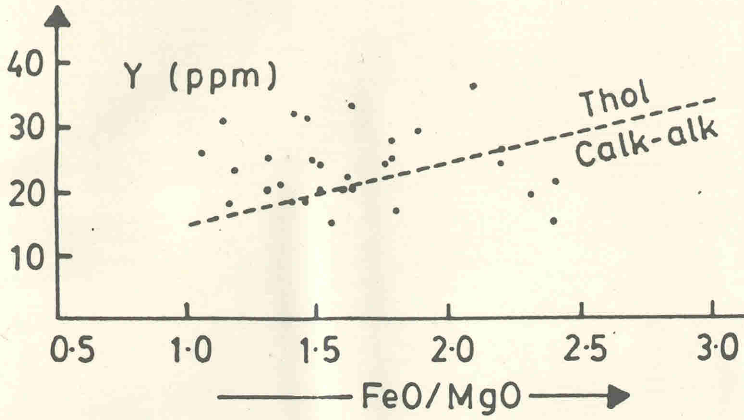


Fig.1

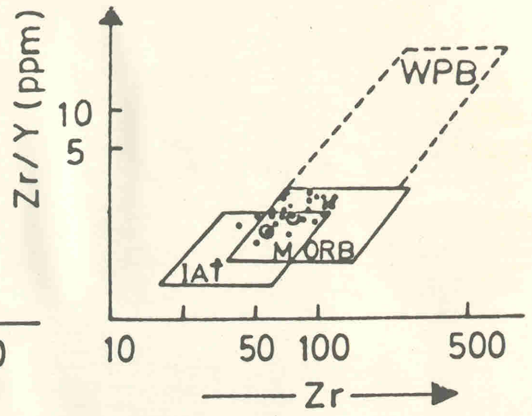


Fig.2

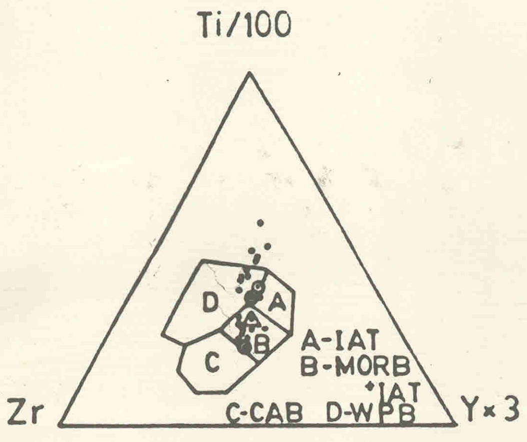


Fig.3

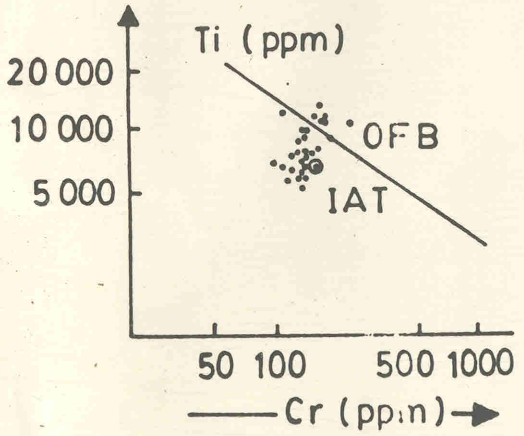


Fig.4

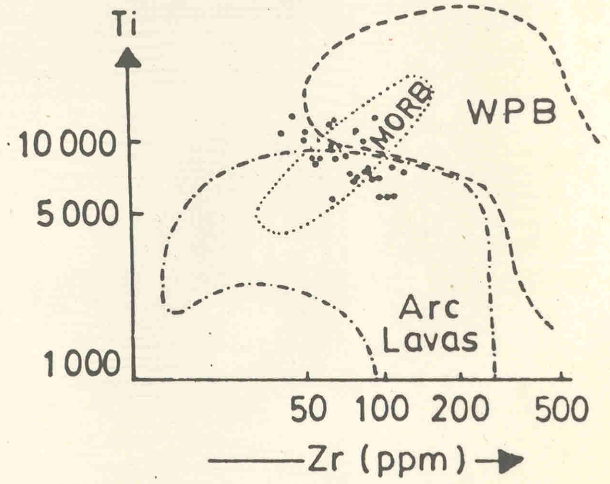


Fig.5

FIG. 3 (ENLARGED)