PETROGRAPHICAL AND PETROCHEMICAL STUDIES OF THE GRANITIC ROCKS AROUND SAKTI, LADAKH DISTRICT, J & K STATE.

—— AJAY KUMAR SAPRU

THESIS SUBMITTED FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY OF JAMMU UNIVERSITY.

FACULTY OF SCIENCE
POST GRADUATE DEPARTMENT OF GEOLOGY
JAMMU UNIVERSITY
JAMMU-180 001.

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C E R T I F I C A T E

Certified that :

(i) the thesis embodies the work of Shri Ajay Kumar Sapru and is worthy of consideration for the award of Ph.D.degree ;

(ii) the candidate worked for the period required under rules ;

(iii) the candidate has put in the required attendance in the department during that period ;

(iv) the conduct of the scholar remained satisfactory during the period of research.

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"ANSWERS TO ROCKS ARE IN ROCKS THEMSELVES"

J.F.Schairer

(In Introduction to N.L.Bowen's
Evolution of Igneous Rocks,
Dover Publications, 1956).

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PREFACE

PREFACE

Ladakh region of North Western Himalayas, Jammu and Kashmir State, offers excellent opportunities for geological investigation especially of granite bodies as the (Ladakh) granite is a most important

igneous complex of this region. The present investigation aims at the petrographic and petrochemical studies of a part of this granite body to decifer its mode of origin.

The work has been carried out at the Post Graduate Department of Geology, Jammu University. In the earlier version of this thesis submitted for the award of Ph.D. degree in Geology, University of Jammu, certain improvements were suggested by the concerned reviewers of the thesis. Accordingly the necessary improvements are incorporated in this revised version of the thesis and resubmitted for evaluation.

Inhospitable and rugged terrain and other unavoidable factors hamper geological investigations in an area such as the present one.

I feel deeply indebted to Dr. B.L. Dhar, faculty member, Department of Geology, University of Jammu, Jammu, for his guidance and encouragement during the course of this investigation.

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Ajay Sapru

AJAY KUMAR SAPRU

A B S T R A C T

Transhimalayan granites cover a wide region in the western Himalaya. This thesis aims at a petrographic and petrochemical study of a part of this granite outcropping in the Ladakh region of Jammu & Kashmir State.

The study area is situated between Latitude 33° 48' and 34° 07' N and Longitude 77° 40' and 77° 52' E. It extends over an area of 450 sq. km and is a part of the Ladakh range of mountains which attain altitude of 3,337 m to 5,963 m above mean sea level. An interesting aspect of the area is

that it is a part of the Indus - Tsangpo Suture Zone tectonically considered to be the junction between the Indian and Chinese plates. The river Indus, the main drainage of the area, flows from southeast to northwest and is joined by a number of seasonal streams draining the high mountainous region. Topography, climate and vegetation, typical of high altitudes, prevail over the area. Structural and lithological variations in the area are clearly demarcated with the hard rocks exposed along the steep slopes, pointed peaks and cliffs, and soft rocks occupying the flat topped mountain peaks, ledges, gentle slopes and broad valleys. Close jointing in hard rocks and cleavage in soft rocks have greatly aided in the mechanical weathering of rocks.

Three broad structural units may be recognised in the area. To the north is the impressive Ladakh granite batholith and to its south is a volcano - sedimentary group of rocks, (Indus - Tsangpo Suture Zone unit) stratigraphically overlying the Ladakh granite basement complex. Further south is the Tethyan sediment unit.

Stratigraphically the rocks of the study area may be classified as follows:

River Alluvium	Fluvial	Recent to Sub Recent
Moraine Deposits	Fluvioglacial	Pleistocene
Tuchik Formation	Sandstone and Shale unit Basal conglomerate unit	Tertiary
	Unconformity	
Ladakh Granite	Monzogranite Granodiorite Tonalite	Cretaceous To Early Tertiary

The above stratigraphic units are very similar to those recognised classically in the Ladakh region.

Based on modal data the part of Ladakh granite under study, petrographically according to Streckeisen's (1976) nomenclature, are tonalites, granodiorites and monzo - granites. The contact among these varieties as seen in the field are gradational and therefore cannot be clearly demarcated on the geological map of the study area. On an average the tonalites are dark grey in colour, medium grained with specific gravity ranging from 2.68 to 2.82, flakes of hornblende and biotite are easily discernable. Granodiorites are medium to coarse grained and light grey in colour with an average specific gravity of 2.65 to 2.78. Monzo- Granites are light coloured with specific gravity 2.64 to 2.71. Tonalites are restricted to the periphery, manzo - granites to the centre and the granodiorites form an intermediate zone between the two varieties.

Petrographically the varieties of Ladakh granite contain quartz, plagioclase, potash feldspars, hornblende, biotite and other accessories muscovite, apatite, zircon and opaques. Quartz is hypidiomorphic

and shows crenulated borders and cracks. Plagioclases are sometimes zoned and range in anorthite content from An_8 to An_{45} with $n\beta$ values ranging between 1.535 to 1.555, the X-ray study of plagioclases indicate these to be of low structural state. Potash feldspars, isolated for X-ray studies and plotted on a graph after Wrieght (1968), indicate these to be of intermediate to maximum microcline and Triclinic in nature. Hornblende is dark green in colour, deeply pleochroic with $Z \wedge C$ ranging from 16° to 18°. Biotite is of two generations and shows bent and twisted lamallae with R.I. values (γ) ranging from 1.648 to 1.654 and weight percentage of $FeO + 2(Fe_2O_3 + TiO_2)$ from 25.50 to 29.50 (Heinrich, 1965).

The overlying sedimentaries (conglomerates, sandstone and shale) are considered as equalent to Indus molasse formation. The conglomerate contains boulders and pebbles of granite material. The st

sandstones are made up of quartz - feldspars and rock fragments and the shales occur as thin intercalations in sandstones.

Thirty representative rock samples of granite from different varieties were chemically analysed and the data treated in terms of two and three component diagrams. The results led to an invaluable conclusion that the part of Ladakh granite body under study is of magmatic origin. Supporting field, petrographic and minerological evidences are (1) presence of xenoliths in granites, (2) zonal nature of the granitic body, (3) decreasing An content of the plagioclases from periphery to the centre of the granitic body, (4) zoning of plagioclases, (5) low structural state of plagioclases and (6) Abundance of euhedral zircons.

Stratigraphic relationships of the granitic body in all probability indicate it to be of Cretaceous to early Tertiary age.

CHAPTER - I

INTRODUCTION

Granitic rocks of huge dimensions are found to occupy the central part of the Himalaya. These rocks have been studied for over a hundred years now, have been considered to form a central crystalline axis and commonly referred to, in earlier geological literature, as "Central Gneiss". Locally different names have been assigned to these granitic rocks

and 'Ladakh granite' is one given to such rocks in Ladakh Himalaya. With a view to study the petrographic and petrochemical aspects of a part of this granite around Sakti, the present investigation was undertaken at the Post Graduate Department of Geology, Jammu University, Jammu, under the title "Petrographical and Petrochemical Studies of the Granitic rocks around Sakti, Ladakh district, Jammu & Kashmir state". The objective of this study is to throw light on the mode of emplacement of this part of the granite body.

The granitic rocks form a part of the Indus-Tsangpo Suture belt which is supposed to be one of the crucial sectors in the evolution of the Himalaya.

AREA OF STUDY

The area of study lies southeast of Leh, district headquarters of Ladakh, Jammu & Kashmir state (Plate-1); and is confined within latitude 33°48' to 34° 07'N and longitude 77°40' to 77° 52' E. The study area is covered by parts of Survey of India topographic sheet nos. 52 F/12, 52 F/16, 52 G/9 and 52 G/13 (1:50000 Scale). The total extent of the area is 450 sq. kms.

Ladakh Himalaya constitutes parts of Karakoram,

North Kashmir, Zanskar, Great Himalaya and Ladakh ranges and has been occupying strategic position in the context of world politics as its borders touch Tibet, China, Pakistan, etc. (Plate-2). This area was closed to the tourists till recently.

Leh (34° 10' : 77° 37' ; elevation 3517 m), a small town with a wide market, has been known as an emplacement of Nomadas. It is connected with Srinagar by a 434 km long metalled road, remains open for about six months in a year and is closed to traffic for the rest of the period due to heavy snowfall. On way to Leh one has to cross some of the world's highest passes, namely Zoji-La-pass (3529 m), Namika-La-pass (3718 m) and Fotu-La-pass (4107 m).

Kharu (34° 40' : 77° 20' ;elevation 3140 m) is 35 km southeast of Leh on Leh - Manali road. It is essentially a camping ground on the mouth of Butbar Stream at the right bank of Indus.

Sakti (34° 05' : 77° 50' ;elevation 4116 m) is about 8 km NNE of Kharu. It is a large village situated at the junction of two streams. A path leads from here

to the famous Nubra Valley (Plate-5, Fig.1).

Chemere (33° 57' : 77° 51' ; elevation 3625 m) lies on the Kharu-Sakti road with fairly good population and a good monastery (Plate-5, Fig.2).

Hemis Gompa (35° 33' : 77° 45') is the largest and wealthiest monastery in Ladakh. It is on the left bank of the Indus, 30 km southeast of Leh. This monastery was built by King Seng-ge-rhain-rgyal, about 300 years ago. It has acquired world wide fame on account of its religious importance.

Stakna (34° 01' : 77° 44') lies southeast of Leh, on Leh-Manali road, and has been in lime light because of the Stakna Hydel Project which is supposed to generate enough electricity to meet the local demand.

Rainbirpura is a name of small habitation between Tikse and Stakna on the right bank of river Indus. It is named after Rainbir Singh, the second Dogra ruler of Kashmir (Plate-3, Fig.2).

Tikse (34° 05' : 77° 20' ; elevation 3354 m) is a

large village 20 km southeast of Leh. Here also a monastery is present (Plate-3, Fig. 2).

PHYSIOGRAPHY

Ladakh is commonly referred to as a cold desert falling in the higher Himalaya with a net work of ranges which are devoid of any noticeable vegetation. The valleys carved out mostly by seasonal streams are almost parallel to each other.

The study area constitutes a part of Ladakh range (4500-6000 m) which is distinguished by rough and barren topography with mature glacial relief, presenting a suitable example of the control of lithology over topographic features. The ranges comprising hard lithological units (granites) show sharp peaks, steep slopes and cliffs. The ranges which consist comparatively of softer lithological units have more wide valleys and almost rounded flat tops.

The altitude variation in the area of study is 3337 m (bank of river Indus towards northwest of study area) to 5963 m (Miru peak towards the south of

study area) . Some of the other important peaks are Pachuspha (5761 m), Kapni (5092 m), Shangdak (4706 m), Chaupura (4497 m), Shang (4195 m), Shisher (3908 m) etc. (Plate-4). These have constituted small valleys in between and are almost parallel with the general physiographic trend of the whole region.

DRAINAGE

Indus is the main drainage line of the study area flowing in a southeast-northwest direction. The source of this river lies to the northwest of the Holy lakes of Manasa-Rowara and Rowan Rudn, in the southwestern slopes of the Kailas mountain.

Flowing through deep steep sided valleys till almost south of Upshi, the Indus flows in a wide and smooth valley onwards till Nimmo, west of the study area; where it has again cut its valley in a deep gorge.

Various streams join the Indus in the study area, most of which are seasonal.

Chhabi Name Stream flows from southwest, meeting Indus at a place near Upshi (Plate-4). Similarly, Martislgag Takpo flows from southwest to join Indus slightly southeast of Kharu. Both these streams flow through softer formations and as such have cut wide and shallow valleys.

Stakma, Nang and Sakti streams flow almost parallel to each other from northeast to southeast to meet the Indus at various places between Stakna and Kharu. These streams flow in a hard formation like granite and have cut narrow and deep valleys with steep slopes.

AGRICULTURE

The rainfall here is very poor and climatic conditions unfavourable for agriculture. This has resulted in poor soil conditions and as such insignificant and inadequate vegetation is found.

FLORA

The area is barren with the exception of poplars and willows introduced recently. Scanty vegetation

observed is of the shruby nature restricted to two diverse habitats. Grass genera are represented by Agrophron, Agrostis, Avena etc. Some unusual class of grass like Catabresa arinus is found at very high altitudes.

FAUNA

A variety of fauna is noticeable in this area. These are kiang or wilk horses, Ibex, Marmot, Snow Leopard, the pashmina wool (soft wool) goat, Yak and the Purik. Yak is the beast of burden and Yaks are reared for transport purposes at high altitudes.

METHODS OF STUDY

The present investigation of a part of the Ladakh granite around Sakti is based on (a) field and (b) laboratory studies.

(a) The area has been geologically mapped on a scale 1:50,000.

A large number of representative samples of granites were collected for laboratory studies and

different varieties identified.

The stratigraphy of the surrounding rocks has been worked out. Different structural features, such as joints, foliation, etc. found in the granites, have been marked on the geological map.

Field photographs, indicating important physiographic and structural features of the area, have been incorporated in this work.

(b) In the laboratory, the field samples are described in hand-specimens.

For purpose of correct identification of plagioclases and alkali feldspars uncovered thin sections were stained for point counting. The volume percentages of the constituent minerals of a number of thin sections of the rocks was carried out on a Swift point counter.

Pure fractions (75 to 90 per cent purity) of plagioclases, alkali-feldspars, hornblende and biotite from the rocks were separated.

Plagioclases, alkali feldspars, hornblende and biotite were chemically analysed. The refractive indices of plagioclases, hornblende and biotite were also carried out in order to correctly identify the species of the minerals.

The plagioclases and alkali feldspars were subjected to X-ray diffraction studies.

Optic axial angle measurements have been carried out in some cases with a four - axis universal stage.

The morphological study of zircons from different varieties of granite has been carried out.

Chemical analyses of thirty samples from the granite body, representing the different varieties of granite, have been carried out both by rapid as well as by conventional methods. The different oxides SiO_2, Al_2O_3 and TiO_2 were determined with the help of Spectrophotometer. The remaining oxides such as CaO, MgO, FeO and Fe_2O_3 have been found by the wet classical method ; whereas Na_2O and k_2O were determined with the help of flame photometer.

The samples of the country rocks were collected in the field and studied in thin sections under petrological microscope.

Graphs and diagrams have been drawn to find out the variation trend of the granites. Fabric diagrams of joints and foliation have been drawn for elucidation of structural features. Drawings and sketches have been drawn to illustrate the text.

CHAPTER - II

HISTORICAL REVIEW

In this chapter an attempt has been made to present a brief review of the work carried out on the granites of Jammu & Kashmir state in a chronological order. Also contained herein is a resume of the work done in northwest Himalaya outside the present territorial limits of Jammu & Kashmir state for purposes of an integrated study of the

granites exposed here.

The geology of the area between Hazara and Bhutan was discussed by Stoliczka (1865, 1866). He called the granitic rocks as 'Central Gneiss' and considered them to be of Archaean age and of igneous origin. The granitic rocks of Ladakh were also included by him under the same term.

Lydekker (1883) thought the granitic rocks of Ladakh area to be of igneous origin. He was the first person to prepare a geological map of this part of the Himalaya.

McMohan (1900) believed the granitic rocks of Gilgit area to be of igneous origin. These are an extension of the Ladakh Granite.

Middlemiss (1911) has made a passing reference to the granites of Margund area in Sind Valley.

Hayden (1915) studied the granites and associated rocks of Gilgit area and considered them to be of metamorphic origin.

Wadia (1932) studied the granites of Nanga Parbat

and divided these rocks into two types : (a) gneissic granites; containing tourmaline and comparable to the Central Gneiss and (b) hornblende granites, of later phase. Later Wadia (1937) noticed the presence of basic lavas, gabbros and pyroxenites associated with marine sediments in Astor-Deosai region, and found granitic intrusives within these rocks.

De Terra (1935) marked the occurrence of hornblende granites at various places between Kashmir to Karakoram and also noted "an old biotite granite" near the Indus-Shyok confluence.

Norin (1946) studied the granites of Karakoram and classified these rocks as biotite-granites, biotite-hornblende-granites and biotite-muscovite-granites.

Misch (1949) studied the granitic rocks of Nanga Parbat area in detail. He recorded the presence of three major zones of metamorphism; from low grade to extreme granitization.

Berthelsen (1953) while investigating the Indus and Rupshu areas found a zone of exotic blocks. He

found the Indus Flysch and Ladakh granite in close association. The granites, according to him, are hornblende bearing.

Gansser (1964) gave a comprehensive account of the geology of Himalaya. He observed a normal transgression of clastic sediments on the Ladakh granites.

Tewari (1964) described the geology of Western Ladakh. According to him Ladakh Granite is intrusive into Palaeozoics, late Mesozoics and Tertiary fossiliferrous sediments. He preferred to call the Ladakh granite as "Ladakh Granite Fundament".

Ukai and Kimura (1965) studied the granitic rocks of Karakoram range. Detailed petrographic and petrochemical studies led them to conclude that these rocks are of metamorphic origin .

Munshi (1969) studied the granodiorites of Kangan. According to him these are medium grained, porphyritic and aplitic types. He assigned magmatic origin to the rocks.

Gupta et al. (1970) detailed the stratigraphy of Ladakh area and presented a complete succession of rocks from Pre-Cambrian to Cretaceous. A detailed reference to Ladakh granite is contained in this work.

Tewari et al.(1970) collected forminifera from Indus Flysch exposed near Gya and assigned Lower to Upper Cretaceous age to these rocks.

Dhar (1972) has described the granitic rocks north of Kishtwar consisting of plagioclase, Potash feldspar, quartz, biotite, etc. These rocks, according to him, show magmatic lineage.

Gupta and Kumar (1975) have given a comprehensive account of the geology of Ladakh region. They have assigned magmatic origin to Ladakh granites.

Shanker et al.(1976) carried out studies on some parts of Indus Suture Zone and consider Ladakh granite massif, to represent various episodes of acid igneous activity in Late Cretaceous and Tertiary times.

Shah et al. (1976) studied the geology of the

western part of the Indus Suture belt and have made a mention of two granites in Kargil area. These have been called as (1) Ladakh granite (north basement) of pre-Tertiary age and (2) the Tertiary granite (Intrusive in Indus Flysch) with Kargil thrust in between the two.

Gansser (1976) called the lower light coloured conglomerates as Hemis Conglomerates and sandstone-shale units as Indus Molasse (transgressing the Ladakh Granite) which were earlier treated as part of Indus Flysch.

Srikantia et al. (1976) referred to the granitic rocks of Ladakh region as intrusive and of magmatic origin.

Colchan and Le Fort (1977) described Ladakh granodiorites as of unique occurrence and one of the largest batholiths of the world.

Fuchs (1977) while traversing Zanskar area from Indus to Kashmir has considered Ladakh granites as a batholithic intrusion of pre-Upper Cretaceous age.

Frank et al. (1977) compared Ladakh granodiorites with the granitic rocks of Mount Kailash and considered

both to be of one age. They divided the Indus Molasse into an autochthonous belt and a southern para-autochthonous Zone (Hemis conglomerate) with lateral lithological facies changes.

Pal and Mathur (1977) find Indus Flysch formation overlain by continental Tertiary sediments known as Karroo formation which has been correlated by them with Ladakh Molasse of Tewari (1964). They have also divided the area between Bodh Kharbu and Upshi into three well defined formations with Ladakh granite (Tertiary age) to the north, Indus formation(Cretaceous age) and Bodh Kharbu formation (Trassic age) to the south of it.There are thrust contacts between these formations.

Uppal (1978) studied the Hant granites exposed towards Kazalwan side to the north of Wular Lake. He classified granites into (a) granodiorites, (b) qua-granodiorites and (c) granites; the granites have been considered by him to be of magmatic origin.

Srikantia and Bhargava (1978) prefer to call Indus Suture Zone as Indus Tectonic Zone and the Granites as Ladakh Granite Complex. The Indus formation of Indus

Suture Zone overlies the granites unconformably. The granites are leucocratic to melanocratic and fine grained to prophyritic and older than Albian in age.

Powar and Bhale (1978) investigating the granitic rocks of the Masi area in Lesser Kumaun Himalaya found that these granitic rocks are intimately associated with mesograde metasediments of the Almora crystalline Mass. According to them the field relationships, petrographical, mineralogical and chemical data suggests that the granitic rocks resulted from the permissive emplacement, during regional metamorphism, of anatectic magma into the metasediments.

Sharma and Kumar (1978) observe that the Ladakh batholith is exposed parallel to the Indus Suture Zone and on its southern side Indus Molasse (Miocene - Pliocene) rest unconformably over it. The granite varies from tonalite to granodiorite to granite.

Sharma et al.(1978) have given the pink porphyritic granite and leucogranite (representing

core portion of Ladakh batholith) 27.8 ± 0.6 M.a. age suggesting that the crystallization of the Ladakh batholith continued at least upto Upper Oligocene and possibly beyond into Lower Miocene.

Gansser (1979) in a reappraisal compared the Kailash region of Himalaya with ophiolitic suture zone of Ladakh and termed the granites as Transhimalayan Plutons.

Gupta (1980) made a study of Kazi Nag granites of Baramulla district. He classified these granitic rocks into (a) Syenogranites, (b) Monzogranites and (c) granodiorites. The detailed field and laboratory investigations led him to conclude that the granitic massif of Kazi Nag was of magmatic origin.

Sapru (1980) in a recent study of Ladakh granite around Leh, has found the younger southern soft rock formation (Tuchik Formation) to overlie the older northerly occuring Ladakh granite. The granitic rocks have been classified by him into (a) tonalites,

(b) granodiorites, (c) qua-granodiorites and (d) granites, The Tuchik Formation comprises a lower Basal Conglomerate followed upwards by a sandstone - shale unit. He has found the granitic rocks to be of magmatic lineage and has assigned a Cretaceous to early Tertiary age to these rocks.

Srikantia and Razdan (1980) divide the Indus Tectonic Zone into two groups (1) the Indus Group and (2) the Sangeluma Group. According to them the Ladakh Granitic Complex forms the basement for the Indus Group sediments and the contact between the two is unconformable. The Granitic Complex comprises a hetrogeneous association of granite, gabbro, basic injections, metavolcanics and metasediments with granitoids predominating over all other types. The upper age limit of Ladakh Granite Complex is fixed at upper Cretaceous.

Srikantia and Razdan (1981) further treat the Ladakh Granitoid zone as tectonically the lowest unit over which Indus Group transgresses forming an autochthon.

C H A P T E R - III

GEOLOGICAL SETTING, STRATIGRAPHY AND STRUCTURE OF THE AREA

The well defined volcano - sedimentary belt, extending in a linear position from the valley of Indus (west of Nanga Parbat) to the valley of Tsangpo(east of Kailash), is known as the Indus - Tsangpo Suture Zone. This belt has in recent years attained considerable importance with respect to global tectonics as it is

believed to represent the junction between the southerly Indian plate and the northerly Chinese plate(Biq Ching Chang, 1976; Colchen and Le Fort, 1977; Le Fort, 1975; Frank et al. 1977; Fuchs, 1977; Gansser,1974, 1976,1977, 1979; Hawkesworth et al., 1975; Klootwijk, 1976; Powell and Conaghan, 1973, 1975; Talalov, 1972). However, others (Sun Ai-Lin, 1972; Crawford, 1974, Kalia and Narain, 1976 and Srikantia and Bhargava, 1978) consider this zone only as a relic crustal fracture and believe the northern boundary of Indian plate to extent further north upto somewhere near the southern margin of Tienshan.

Litho-stratigraphically, Indus Tsangpo Suture Zone separates the Lithotectonic unit of the southerly Sub-Himalaya referred to as Tethys Himalayan Zone (containing among other things the Meso-Palaeozoics of Kashmir) from that of the northerly Ladakh granite referred to as Trans-Himalayan granites (Plate-6).

Rocks of the Indus Tsangpo Suture consist of a mixture of flyschoid-molasse formation associated with basic volcanics and ophiolitic-me'lange. There is a gradual change over from flysch to molasse as a result of strong facies variations. The rocks here generally show

an eastwest fold axis with low angle dips towards the south (Tewari, 1964). Shanker et al.(1976) divide these rocks into a lower part (Albian to Mastrichtian) and an upper part (Palaeocene to middle Eocene). Frank et al. (1977) divide this belt into four zones viz. Hemis Conglomerate, Indus flysch, Dras volcanics and ophiolitic-me'lange (Plate-6). Srikantia and Razdan(1980,1981) consider this zone to be consisting of two groups, namely the Indus Group(autochthon) and the Sangeluma Group(para-autochthonous) belt.

Hornblende bearing Ladakh granite is a huge batholith of unique occurrence and constitutes the major part of the Ladakh range. Petrographically, it ranges from tonalite to monzogranite. Similar granitic rocks bearing hornblende are absent in other parts of the Himalaya and consequently these rocks have been called Trans-Himalayan granites(Gansser, 1964). Different ages have been assigned to these granitic rocks, pre-Carboniferrous (Hayden 1904); Late Palaeozoic(Kazmi, 1951; Ivanea et al. 1955); Cretaceous(Stoliczka, 1969); Palaeocene(Desio et al.,1964); Tertiary(Misch, 1949); post Upper Cretaceous(Wadia, 1931). Frank et al. (1977) and Gansser (1979) have favoured late Cretaceous to Eocene age for

the granites. Srikantia and Razdan (1980) have fixed upper Cretaceous age for the granites.

Based on field relationships of different rock units, the general stratigraphic order, established for the study area, is given in Table-1.

The contact between the older Ladakh granite and the younger Tuchik Formation is roughly aligned parallel to the Indus valley. This contact is mostly concealed under vast spreads of scree and sand; it is, however, clear at a number of places, such as Kharu (front piece photograph). It is seen that the granitic rocks are unconformably overlain by the rocks of the Tuchik Formation. This junction is marked by a bed of badly sorted assemblages of pebbles of granite and various other rocks cemented together in a buff coloured clayey matrix.

Ladakh Granites

The granitic rocks exposed in the study area are a part of the larger Ladakh granite(Plate-Fig.1,2). The Ladakh granite is a huge batholith with a

Table - 1

River Alluvium	Fluvial	Recent to Sub Recent
Moraine Deposits	Fluvioglacial	Pleistocene
Tuchik Formation	Sandstone and Shale unit	Tertiary
	Basal conglomerate unit	
Unconformity		
Ladakh Granite	Monzogranite	Cretaceous To Early Tertiary
	Granodiorite	
	Tonalite	

lateral extension of over 25 km (Gansser,1979) and has been studied by Berthelsen (1953), De Terra(1932), Desio et al.(1964), Ivanea et al.(1955), Kazmi (1951), Misch (1949),Norin (1946), Tewari (1964), Sharma and Gupta (1978) and Sapru (1980).

The granites sometimes show a very crude NE - SW strike foliation while jointing is fairly common with NW - SE predominant strike direction (Plate-5, Fig.3). While as Shah et al.(1976) distinguish two granites (pre-Tertiary and Tertiary granite)Frank et al. (1977) and Srikantia and Razdan (1980) treat the whole intrusion as one major plutonic event of late Cretaceous to Eocene age and call it as Ladakh Intrusives.

From the field and laboratory observations, the part of the Ladakh granite presently studied is seen to be consisting of three varieties,(1) tonalite, (2) granodiorite and (3) monzogranite. The contacts between these varieties are not sharp and one type gradually passes on to other as is observed by an inspection of Plate-38. The three granites types are briefly described in the following pages.

1. Tonalite

It forms the southern peripheral part of the granite massif and is in contact with the softer rocks. The tonalites vary in colour from grey to dark grey, and are medium to coarse grained(Plate 8,Fig.1). These are composed of plagioclase, hornblende, alkali feldspar, quartz, biotite and other accessory minerals. Jointing is very common in these rocks (Plate-5, Fig.3). The average specific gravity varies from 2.68 to 2.82. A crude foliation is present at a few places. The extent of this type of granite is shown in Plate-38.

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2. Granodiorite

This type of granite is exposed in a wider belt (Plate-38). It is present in various shades of grey colour. These are medium to coarse grained (Plate 8, Fig.2,3). The rocks consist of plagioclase, quartz, alkali feldspar, hornblende and biotite with average grain size 3.2 mm. In this variety the jointing is also very common (Plate-5, Fig.4 & 5) and at a few places foliation is observed as noted on Plate-38. The average specific gravity varies from 2.65 to 2.78.

3. Monzogranite

The granites of the northern part of the study area consist of monzogranites (Streceiksen, 1976). These are mostly leucocratic and light grey in colour (Plate-8, Fig.4). The rocks are medium grained and are chiefly composed of quartz, alkali feldspars, plagioclases, hornblende, biotite and other accessory minerals. The specific gravity of this variety ranges from 2.64 to 2.71. Here less of jointing is recorded (Plate-5, Fig.6).

II Tuchik Formation

The sedimentary sequence exposed along the southern margin of Ladakh granite is in strike continuation of Tuchik formation of Sapru(1980); named after the village Tuchik (lying to the northwest of the study area) where the formation is well developed. This formation consists of sandstones and shales resting unconformably over the granites. (Frontispiece photograph)

Tuchik Formation is comparable to the Indus Molasse of Frank et al.(1977), Ladakh Molasse of Tewari(1964), Indus formation of Shanker et al.(1976),

Kargil formation of Shah et al. (1976) and Indus Group of Srikantia & Razdan (1980). Earlier this formation was treated as part of Indus Flysch but Colchen and Le Fort (1977) observed lateral variation of flysch into molasse.

Karoo Formation of Pal & Mathur (1977) is taken to be a part of Tuchik formation and has, therefore, not been designated or shown separately.

Field studies reveal Tuchik Formation to be divisible into two litho units; (1) Basal Conglomerate unit at the base; and (2) Sandstone-shale unit at the top. The two units are treated in the succeeding lines.

1. Basal Conglomerate Unit

The lower part of Tuchik Formation is composed of a conglomerate bed and has been called Basal Conglomerate unit. The apparent thickness of this unit ranges from 5 m to 40 m. This unit predominantly contains pebbles and cobbles of granitic rocks, set in a loosely held granitic grit and reddish clayey

matrix (Plate-7,Fig.1). The distribution of this unit is shown in Plate-38.

2. Sandstone-Shale Unit

The basal conglomerates are overlain by the sandstone and shale unit. The sandstones are commonly grey and shales generally are green in colour. The sandstone-shale unit is of arenaceous nature. The rocks show frequent changes in the strike direction and are generally folded. The strike varies from N 40°W - S 40° E to N 65° W - S 65°E with an average dip of 30° to 45° towards southwestern to southern direction. This lithological unit is very well exposed near Kharu(Plate-7,Fig.2 and 3).

III. Moraine Deposits

These deposits consist of rounded to sub-rounded boulders and cobbles embedded in an angular to subangular loose material. These generally cover the foot of the mountains (Plate-7, Fig.4).

IV. River Alluvium

These constitute pebbly beds, conglomerate containing scree and sand material which owes its

origin to Recent to Sub-Recent sediments of the area (Plate-7, Fig.5). The deposits are composed of cobbles and pebbles of granite, sandstone, shale, etc.

STRUCTURE OF THE AREA

Three structural units are observed in Ladakh region, (Plate-6) from south to north.

1. Tethyan sediments
2. Indus - Tsangpo Suture Zone
3. Ladakh granite

The Tethyan sediments constitute the Palaeozoic sequence of the Kashmir-Zanskar area with older crystallines thrusting over the sedimentaries. The axis of these crystallines is almost parallel to the axis of the Tethyan - sequence. The Zanskar basin shows a well developed Permian - Trassic - Jurrasic sequence having a tectonic contact with the Indus - Tsangpo Zone as a result of which

Panjal Trap, Permian Limestone, Trassic shale and Trassic limestone are in contact with the rocks of the Indus - Tsangpo Suture Zone. The Tethys sequence shows NW trending folds with most of the faults showing NW - SE trends. Some oblique faults, cutting the regional faults, trend in NNE - SSW direction and are probably a younger Himalayan feature (Sharma and Kumar, 1978).

The Indus - Tsangpo Zone is a highly disturbed and complicated zone with high degree of folds and faults. This is a linear lithounit from Indus in the west to Tsangpo in the east lying unconformably over the Ladakh crystallines. Towards south of this unit Tethyan sediments are thrust over it. Rocks of this unit consist of pelagic and neritic sedimentries associated with volcanics and ophiolitic me'lange. The faults present in this unit are parallel to the main trend with east - west fold axis dipping at low angles towards south. Northern part of this zone is Albian to Maastuchtian - lower Indus Formation, and southern part - upper Indus Formation, Palaeocene to middle Eocene (Shanker et al. 1976). Frank et al.(1977)

divided this unit from north to south into four well defined zones, namely Indus Molasse; sub divided into northern autochthonous belt of post early Cretaceous age and a southern para autochthonous (Hemis Conglomerate) which is in part of Eocene age; Indus Flysch ; Dras volcanics and Ophiolitic me'lange(Plate-6). Sharma and Kumar (1978) report a tectonic contact between Indus Flysch (lower Mesozoic to Middle Tertiary) and Indus Molasse (Miocene - Pliocene).

The Ladakh granites with batholithic dimensions are exposed along the NW - SE trending Ladakh range running almost parallel with the Indus - Tsangpo Suture Zone (Plate-6). On its southern side Indus molasse rest unconformably above it. The granites range in composition from tonalite, granodiorite to granite with the development of general NE - SW trending crude foliation and predominant NW - SE trending wide spread jointing. A number of faults, with commonly east to west strike direction, are observed. Ladakh granite shows doming and the course of Indus river across these granites has exposed the core portions (Sharma and Gupta,1978).

I STRUCTURE IN GRANITIC ROCKS

The structural features noticed in the granitic rocks in the area of investigation are described as under:-

a) Jointing:

Well pronounced jointing is very predominant in the granitic rocks (Plate-5, Fig.2). The joint planes are smooth with inclination varying from 25° to 80°. These are mostly present in sets and often a number of sets occuring nearby cut each other as a result of which irregular blocks of the granitic rock break out. The prominant joint sets are given in Table-2. These have been arranged from strongest sets (Nos.1 and 2) to the weakest (Nos.5 and 6).

Table - 2

1)	N 10° - 40°W	S 10°- 40°E ;	Dip: 35°-65° N 50°-80°E
2)	N 45° -75°W	S 45°- 75°E ;	Dip: 20°-70° N 15°-45°E
3)	N 50° - 80°W	S 50°- 80°E ;	Dip: 25°-50° S 10°-40°W
4)	N	S ;	Dip: 35°-75° E - W
5)	N 15°- 45°E	S 15°- 45°W ;	Dip: 20°-60° N 45°-75°W
6)	N 15° - 50°E	S 15°- 50°W ;	Dip: 20°-50° S 40°-75°E

The research area has been divided into six sub areas (A to F, Plate-9) and the joint patterns of each area has been represented by contour diagrams (Plate-10). The poles of perpendiculars to the joints have been plotted in an equal area net and the contours have been drawn according to the method summarized by Ragan (1973).

Contour diagram of joints of sub area - A indicate that the joints are mostly vertical with general NW - SE strike direction. A few joints dip towards SE and a further smaller amount of these dip towards NW and NE.

Contour diagram of the joints of sub area - B show that joints are highly inclined with dip mostly towards NW and the general strike direction NE - SW. A few joints are dipping towards NE.

Study of the contour diagram of sub area - C show the joints with very high inclinations with the strike direction pointing primarly towards NW - SE. A few moderately inclined joints with dip directions towards SSE, NE and WSW are present.

Contour diagram of sub area - D show that the joints are on an average moderately inclined and here also the prominent strike direction is NW - SE.

An inspection of contour diagram of sub area - E shows that the majority of dips are almost vertical while as a few joints with very gentle inclinations dip towards NW.

Contour diagram of sub area - F indicate moderate to high inclination dips with a predominantly ENE -WSW strike direction. The moderately inclined joints are seen to dip towards N, SE and W directions.

In order to have clear understanding of joint pattern of the research area as a whole a contour diagram of all joints (from sub area A to F) has been drawn (Plate-11). It is observed that though joints show inclination in all directions majority of them dip either towards NE or towards SW with a predominating NW - SE strike direction. This is also supported by the attitude of major joint sets given in Table-2.

The origin of these joints which show dips from gentle inclinations (almost horizontal joints) to very steep inclinations (almost vertical joints) can be explained due to decrease in compression and expansion. The steep inclined joints can be regarded due to relaxation of compression (Hills, 1972; Turner and Weiss, 1963). The gently inclined joints can be regarded as a result of expansion of granitic rocks during emplacement (Ronald, 1973).

b) Foliation

Foliation is not as wide spread as the joints in the granitic rocks. It has been only observed at a few places. The foliation is very crude and is marked by the parallel alignment of biotite and hornblende with alternating streaks of quartz and feldspars. The foliation attitude varies from 20° to 50° generally towards north west with general strike direction NE - SW.

The attitude of recorded foliation data has been plotted on an equal area net (Plate-12) according

to the method illustrated by Badgley (1959). Study of this foliation contour diagram show that the majority of foliation dip towards north west with NE - SW strike direction. A few show dip direction towards NE and still smaller number towards SE and SW. The contour lie away from the centre of the net indicating the fact that the foliation dips are gentle. The foliations dip towards the gradual contact between different types of granites and can, therefore, be regarded as primary foliation (Hobbs, 1976).

II. STRUCTURES IN SEDIMENTARIES

Following sedimentary structures are noted in the soft rocks of the study area.

a) Laminations:

The soft rocks of the study area are generally structureless beds. But the thick sandstones show laminations towards the top and

sometimes the laminations are of bent and twisted type.

b) Graded Bedding:

In the upper most layer of the sandstones, which are generally light coloured and are fine grained, a crude form of graded bedding is noticed.

c) Ripple marks:

In some of the sandstones of the study area the ripple marks are noticed. The tops of some of the beds are characterised by the ripple marks. These ripples are regular in form.

C H A P T E R - IV

PETROGRAPHY OF THE SEDIMENTARY ROCKS

1. PETROGRAPHY

The sedimentary rocks of the area under study have been grouped under the term "Tuchik Formation" as is borne out by a study of Chapter III. The rocks comprise a basal conglomerate unit and an upper sandstone shale unit. A brief petrographic description of the rocks is given in the following lines.

a) Basal Conglomerate Unit

The conglomerate unit is found to overlie the Ladakh granite. These conglomerates are very poorly

sorted and consist of coarse, subangular to rounded pebbles embedded in a very light buff coloured fine to medium sized gritty to clayey matrix, (Plate-8, Fig.5). The density of the matrix varies from place to place. It has been noticed that the major portion of the pebbles is of granitic composition.

Thin section study of the conglomerates reveals the infilling material to be made up of sub-angular to subrounded quartz and feldspars embedded in a fine to medium grained material. The accessory minerals like zircon, rutile, hornblende, apatite and a very fine unidentifable clayey material are present.

b) Sandstone Unit

The sandstones are mostly greenish in colour but at a few places these are also purple coloured. The rocks are hard and compact, being composed of quartz, feldspars, rock fragments and accessory minerals.

The sandstones fall under two varieties: (1) Arkosic and (2) Feldspathic greywackes. This classification is based on the one given by Pettijohn(1975).

Under this scheme two separate triangles with quartz, feldspar and rock fragments are taken into consideration making the three apices of a triangle. Triangle (A) is considered when the matrix is less than 15 per cent and triangle (B) is taken into account for those specimens with matrix more than 15 per cent. Accordingly, from the modal analyses of the sandstones of the study area (Table-3) the proportions of quartz, feldspar and rock fragment are recalculated to hundred per cent and given in Table-3. These values when projected on the classification triangles (Plate-14) clearly indicate that the sandstones in the present case fall into the (1) Arkosic and (2) Feldspar greywacke groups.

The thin section study of sandstone is as follows:

(i) Quartz

It forms more than 40 per cent of the rock and is, therefore, one of its major constituents. It is angular to subrounded, This mineral shows occasional suture outline. An overgrowth of authigenic quartz grains with undifferentiated inclusions is noticed, (Plate-13, Fig. 1,2 and 3).

Table-3 : Volume percentages of Sandstone of Tuchik Formation.

Sample number	Qz*	Feld*	R.F.*	Matrix* & others	Recalculated to 100%		
					PQz	Feld	R.F.
1-AJS 3	49.11	36.88	9.17	4.84	51.60	38.75	9.65
2-AJS21	45.98	39.13	8.10	6.79	49.33	41.98	8.69
3-AJS28	55.10	34.13	5.11	5.66	58.40	36.18	5.42
4-AJS33	48.17	36.97	9.10	5.76	51.11	39.23	9.64
5-AJS51	47.00	40.16	7.12	5.72	49.85	42.60	7.55
6-AJS17	56.00	24.11	8.17	11.72	63.43	27.31	9.25
7-AJS34	19.13	53.16	11.13	16.58	22.93	63.72	13.35
8-AJS43	21.66	51.64	10.16	16.54	25.95	61.87	12.18
9-AJS43	18.19	55.14	9.16	17.51	22.05	66.85	11.10
10-AJS63	21.00	53.12	9.10	16.80	25.23	63.83	10.94

*Qz = Quartz.

*Feld = Feldspar

*R.F. = Rock Fragment.

Sample nos. 1,2,3,4,5, & 6 = Arkoses.

Sample nos.7,8,9 & 10 = Feldspathic Graywacke.

(ii) Feldspars

Feldspars form more than 50 per cent of the rock and is the dominating mineral. Under the microscope the feldspars are subangular to subrounded, mostly fresh and potash bearing (microcline). But in some thin sections plagioclases dominate, (Plate-13, Fig.4 and 6).

(iii) Rock Fragments

The rock fragments are present in a minor proportion as can be seen from Table-2.

(iv) Cement

The cement present in these rocks is generally calcareous and siliceous and at times clayey.

(v) Accessory minerals

The accessory minerals are tourmaline, zircon, hornblende and opaques.

c) Shale Unit

These occur as thin beds intercalcated with

sandstones. Megascopically the rock is fine grained having glossy sheen on the surface of spilliting and wavy texture. It is mostly light to dark green in colour while as steel grey varities are also observed at places. The bulk grainsare not recognised megascopically, still mineral lineation is discernible.

In thin sections shale shows well marked foliation and the development of scaly minerals viz., sericite and chlorite. The rock consist of feldspar, muscovite, chlorite, quartz, clay minerals and occasionally biotite. On very high magnification it is observed that most of the feldspars have been saussuritized and they are usually covered with iron ore dust making the identification very difficult. Quartz is the most abandent constituent mineral and occurs in clastic grains or as little lenticles or as streaks confirming with the general orientation. It also occurs as small recrystallised grains in the matrix. These rocks are poorly sorted (Plate-13, Fig.5).

Chlorite is also present in patches, may be due to mineral solibility. Very often little lenticles consisting of one or more flakes are also seen while as the lenticles themselves have regular fashion.

Muscovite occurs alongside chlorite, some times the flakes are curved. Iron ores form parallel bands with the foliation. These are present as streakes, blebs and small grains in the rocks.

CHAPTER-V

From the above discussion it can be safely inferred that the soft rock formation (Tuchik Formation) of the study area indicates the characters of marine sedimentation which has been rhythmic. It is quite evident from the monotonous assembledge of stratified sandstone and shale which is repeated almost in a cyclic order of deposition. It is also evident from the above discussion, that the material has not suffered much transportation and hence the source area could not be far away from the basin of deposition.

C H A P T E R - V

PETROGRAPHY OF THE GRANITES

Granite specimens from the part of Ladakh granite under reference have been studied in hand specimens and in thin sections. The constituent minerals from the rocks have been separated by the usual separation techniques and subjected to optical, chemical and X-ray diffraction studies.

Granitic rocks of the study area are mainly grey in colour. The intensity of colour, however, varies in different specimens. The grain size of

the rocks also increases from south to north.

In thin sections the granitic rocks are noted to contain quartz, plagioclases, alkali feldspars, hornblende, biotite and muscovite. The accessories include zircon, apatite, chlorite, tourmaline and opaques. The point counting of the rocks on thin sections has been done according to the method mentioned by Barratt and Parslon (1966). The main difficulty encountered while point counting the alkali feldspars, plagioclases, untwinned feldspars and quartz, on thin sections, is to distinguish between K-feldspars and plagioclases; and untwinned K-feldspars and quartz. To over come this difficulty the thin sections are stained for plagioclases and alkali feldspars. In this regard different methods have been proposed by Garbriel and Cox (1929), Keith (1939), Chayes (1952), Rosenblum (1956), Bailey and Stevens (1960), Dawson and Crawley (1963) and Hutchison (1974). In the present case the method given by Bailey & Stevens (1960) has been adopted and a brief description of the same is given below:-

The uncovered thin sections after having been cleaned with xylene were etched with HF and dipped in a solution of barium chloride to which a drop of HCl was added. The slide after this treatment was put in a saturated solution of Sodium cobaltinitrite. The section was removed and washed with water and put in a freshly prepared solution of potasium rhodizonate, and then washed and dried. The alkali feldspars were stained yellow and due to the barium rhodizonate the plagioclase assumed red colour.

The volume percentages, based on stained thin sections for plagioclases and alkali feldspars of 70 rock samples are given in Table-3. For purposes of petrographic classification according to Streckcisen(1976), the analyses were recalculated to hundred per cent for quartz, plagioclases and alkali feldspars and plotted on a trilinear diagram as given in Plate-15. From the study of this diagram the rocks of the study area plot as (1) Tonalites, (2) Granodiorites and (3) Monzogranites. When these plots are projected on the map of the study area,(Plate-38) it is noticed that the tonalites cover

Table-4 : Volume percentages of Ladakh Granites.
(Contd..)

S. No.	Sample Number	Qz	Pla	Alk	Horn	Bio	Mus	Others	Recalculated to 100% Qz	Pla	Alk
1.	AJ9*	20.55	57.00	7.05	10.05	2.36	1.78	1.21	24.29	67.38	8.33
2.	AJ19A*	22.15	58.28	6.15	9.15	2.23	1.04	1.00	25.58	67.32	7.10
3.	AJ83*	21.62	58.22	7.95	8.95	1.60	1.02	1.17	24.76	66.70	8.54
4.	AJ66	24.18	53.17	6.27	11.18	2.88	1.42	0.90	28.91	63.59	7.50
5.	AJ84*	23.04	58.17	6.48	7.76	2.60	1.00	0.95	26.27	66.33	7.40
6.	AJ58*	24.05	56.30	6.18	8.20	2.97	1.23	1.07	27.80	65.06	7.14
7.	AJ26	24.00	54.15	7.30	9.95	2.50	1.10	1.00	28.08	63.38	8.54
8.	AJ96	22.20	58.90	6.12	8.88	2.00	1.10	0.80	25.45	67.53	7.02
9.	AJ90	25.50	54.40	6.35	9.00	2.55	1.35	0.85	29.56	63.08	7.36
10.	AJ47	21.40	59.20	7.00	8.95	1.50	1.00	0.95	24.43	67.58	7.99

Qz = Quartz.
Pla = Plagioclases.
Alk = Alkali-feldspars.
Horn = Hornblende.
Bio = Biotite.
Mus = Muscovite.
Others include : Tourmaline, Zircon, Chlorite, Iron Ores, etc.

* Samples also chemically analysed.
Nos.1 to 10 = Tonalite.

Table-4 : Volume percentages of Ladakh Granites.
(Contd...)

S. No.	Sample Number	Qz	Pla	Alk	Horn	Bio	Mus	Others	Recalculated to 100%		
									Qz	Pla	Alk
11.	AJ70	23.75	58.20	5.40	10.00	1.00	0.95	0.76	27.19	66.63	6.18
12.	AJ20	23.00	58.85	5.35	8.54	1.75	1.20	1.30	26.37	67.49	6.14
13.	AJ116	21.15	59.28	7.15	8.15	2.13	1.10	1.04	24.15	67.68	8.17
14.	AJ97	20.81	58.40	5.85	10.15	2.31	1.08	1.40	23.29	65.35	17.36
15.	AJ105	24.36	55.15	5.60	9.00	3.10	1.79	1.00	27.52	62.32	10.16
16.	AJ108	21.00	60.80	7.13	7.45	1.85	1.00	0.80	23.61	68.36	8.03
17.	AJ72A	22.15	60.15	5.10	8.70	2.10	0.90	0.80	25.34	68.82	5.84
18.	AJ32A	20.85	61.95	7.20	7.20	1.00	1.00	0.80	23.16	68.83	8.01
19.	AJ61A	20.65	46,85	7.45	18.10	3.85	2.10	2.20	27.92	63.36	8.72
20.	AJ23	21.10	57.00	9.20	1.33	1.37	1.37	1.00	24.17	65.30	10.53

Qz = Quartz.
Pla = Plagioclases.
Alk = Alkali-feldspars.
Horn = Hornblende.
Bio = Biotite.
Mus = Muscovite.
Others include : Tourmaline, Zircon, Chlorite, Iron Ores, etc.

* Samples also chemically analysed.
Nos.11 to 20 = Tonalite.

Table-4 : Volume percentages of Ladakh Granites.
(Contd.....)

S. No.	Sample Number	Qz	Pla	Alk	Horn	Bio	Mus	Others	Recalculated to 100% Qz	Pla	Alk
21.	AJ121	23.17	58.04	5.48	7.56	2.70	1.90	1.00	26.55	67.18	6.27
22.	AJ93A	24.50	54.15	5.55	9.85	3.14	1.50	1.40	29.10	64.31	6.59
23.	AJ15A*	26.62	52.12	8.14	9.92	1.46	0.90	0.84	30.63	59.99	9.38
24.	AJ8*	27.28	53.32	6.88	8.10	1.46	1.36	1.00	31.38	60.96	7.86
25.	AJ78*	28.00	53.60	8.90	6.00	1.84	1.12	0.56	30.93	59.24	9.83
26.	AJ13*	24.60	50.20	9.10	10.00	3.10	2.00	1.00	29.32	59.83	10.85
27.	AJ62	26.00	52.10	9.00	9.20	1.45	1.25	1.00	29.85	59.82	10.33
28.	AJ59	27.60	54.70	5.10	8.50	1.50	1.10	1.50	31.57	62.58	5.85
29.	AJ6*	28.70	51.35	8.35	8.45	1.20	1.00	0.95	38.44	52.83	8.73
30.	AJ77*	35.20	48.40	8.00	5.00	1.35	1.25	0.80	38.42	52.84	8.74

Qz = Quartz.
Pla = Plagioclases.
Alk = Alkali-feldspars.
Horn = Hornblende.
Bio = Biotite.
Mus = Muscovite.
Others include : Tourmaline, Zircon, Chlorite, Iron Ores, etc.

* Samples also chemically analysed.

Nos.20 and 21 = Tonalite.
Nos.22 to 30 = Granodiorite.

Table-4 : Volume percentages of Ladakh Granites.
(Contd.....)

S. No.	Sample Number	Qz	Pla	Alk	Horn	Bio	Mus	Others	Recalculated to 100% Qz	Pla	Alk
31.	AJ37*	28.10	48.00	6.30	11.20	3.20	2.10	1.10	34.11	58.25	7.64
32.	AJ164	35.20	40.00	10.35	8.45	3.40	1.40	1.20	41.15	46.75	12.10
33.	AJ50*	25.50	53.25	9.80	7.15	1.30	1.00	1.00	28.79	60.13	11.08
34.	AJ17*	29.73	50.22	9.24	8.36	1.24	1.01	1.10	33.35	56.30	10.35
35.	AJ28*	36.00	40.16	11.44	7.26	2.44	1.60	1.10	41.10	45.85	13.05
36.	AJ17A	30.10	46.00	6.00	10.20	4.30	2.00	1.40	36.66	56.04	7.30
37.	AJ21A*	39.12	43.28	9.05	6.18	1.00	1.04	0.33	42.78	47.32	9.90
38.	AJ52*	22.00	42.18	17.94	11.52	3.71	1.13	1.52	26.79	51.36	21.85
39.	AJ137	34.00	43.15	10.43	6.36	2.94	2.00	1.12	38.83	49.27	11.90
40.	AJ5A*	30.45	50.81	9.05	6.84	1.05	0.80	1.00	33.72	56.26	10.02

Qz = Quartz.
Pla = Plagioclases.
Alk = Alkali-feldspars.
Horn = Hornblende.
Bio = Biotite.
Mus = Muscovite.
Others include : Tourmaline, Zircon, Chlorite, Iron Ores, etc.

* Samples also chemically analysed.

Nos.31 to 40 = Granodiorite.

Table-4 : Volume percentages of Ladakh Granites.
(Contd.....)

S. No.	Sample Number	Qz	Pla	Alk	Horn	Bio	Mus	Others	Recalculated to 100% Qz	Pla	Alk
41.	AJ36	36.00	41.20	10.40	7.40	2.40	1.50	1.10	41.10	47.03	11.87
42.	AJ14	25.64	48.91	8.85	10.00	4.48	1.00	1.02	30.74	58.65	10.61
43.	AJ5	25.80	51.20	11.20	7.60	1.00	1.00	1.00	29.25	58.04	12.71
44.	AJ45	40.20	44.40	9.00	4.00	1.00	0.90	0.50	42.95	47.43	9.62
45.	AJ99	28.80	51.25	8.40	8.15	1.15	1.14	1.11	32.56	57.94	9.50
46.	AJ111	30.55	50.74	10.12	5.80	0.78	1.08	1.02	33.42	55.50	11.08
47.	AJ166	29.19	52.41	9.31	5.54	1.56	1.18	0.90	32.10	57.65	10.25
48.	AJ64	26.80	48.85	7.85	10.00	4.00	1.00	1.50	32.09	58.50	9.41
49.	AJ85*	36.36	35.38	22.90	3.00	1.06	0.80	0.50	38.42	37.38	24.20
50.	AJ145	31.78	37.68	22.32	4.15	1.50	1.50	1.07	34.62	41.06	24.32

Qz = Quartz.
Pla = Plagioclases.
Alk = Alkali-feldspars.
Horn = Hornblende.
Bio = Biotite.
Mus = Muscovite.
Others include : Tourmaline, Zircon, Chlorite, Iron Ores, etc.

* Samples also chemically analysed.

Nos.41 to 48 and 50 = Granodiorite.
No.49 = Monzogranite.

Table-4 : Volume percentages of Ladakh Granites.
(Contd..)

S. No.	Sample Number	Qz	Pla	Alk	Horn	Bio	Mus	Others	Recalculated to 100% Qz	Pla	Alk
51.	AJ72	24.90	46.15	15.10	10.60	1.20	1.20	1.05	28.90	53.57	17.53
52.	AJ12	38.50	29.00	21.90	7.70	1.10	0.80	1.00	43.06	32.45	24.49
53.	AJ34	34.00	33.48	24.06	3.86	2.14	0.86	1.00	36.90	36.34	26.76
54.	AJ16	34.60	24.09	34.00	2.15	1.24	1.23	1.05	38.66	25.44	35.90
55.	AJ10	34.47	35.48	24.10	3.00	1.10	1.00	0.85	36.65	37.73	25.62
56.	AJ4*	32.68	36.32	23.78	4.45	1.20	1.00	0.55	35.22	39.14	25.64
57.	AJ88	29.64	39.00	21.60	7.40	1.25	0.74	0.55	32.84	43.22	23.94
58.	AJ30	30.10	38.64	25.14	3.72	1.28	0.66	0.56	32.06	41.16	26.78
59.	AJ18	35.47	34.50	23.00	2.90	1.85	1.28	1.00	38.15	37.10	24.10
60.	AJ81	32.64	31.46	23.00	8.56	2.44	1.10	0.80	37.47	36.12	26.41

Qz = Quartz.
Pla = Plagioclases.
Alk = Alkali-feldspars.
Horn = Hornblende.
Bio = Biotite.
Mus = Muscovite.
Others include : Tourmaline, Zircon, Chlorite, Iron Ores, etc.

* Samples also chemically analysed.

Nos.51 = Granodiorite.
Nos.52 to 60= Monzogranite.

Table-4 : Volume percentages of Ladakh Granites.
(Concluded)

S. No.	Sample Number	Qz	Pla	Alk	Horn	Bio	Mus	Others	Recalculated to 100% Qz	Pla	Alk
61.	AJ60	32.10	31.75	25.05	8.00	1.00	1.10	0.90	36.12	35.71	28.17
62.	AJ37*	32.70	34.20	24.00	6.35	1.10	1.10	0.55	35.98	37.62	26.30
63.	AJ57	35.00	31.60	23.30	6.00	1.90	1.20	1.00	38.93	35.15	25.92
64.	AJ76	33.00	32.85	25.10	7.05	0.90	1.00	1.10	36.28	36.12	27.00
65.	AJ15A*	29.20	42.40	19.30	6.55	1.00	0.65	1.00	32.12	46.65	21.23
66.	AJ77*	33.00	43.00	17.70	3.90	1.50	0.50	0.40	35.22	45.90	18.88
67.	AJ35A	32.84	46.00	12.02	5.07	2.12	0.91	1.04	36.14	50.64	13.22
68.	AJ94	34.48	44.32	14.02	3.11	3.07	0.66	0.34	37.15	47.75	15.10
69.	AJ68	31.32	37.48	16.11	8.02	4.00	1.35	1.72	36.88	44.14	18.98
70.	AJ27	35.12	36.48	14.31	6.82	3.93	2.21	1.13	40.88	42.46	16.66

Qz = Quartz.
Pla = Plagioclases.
Alk = Alkali-feldspars.
Horn = Hornblende.
Bio = Biotite.
Mus = Muscovite.
Others include : Tourmaline, Zircon, Chlorite, Iron Ores, etc.

* Samples also chemically analysed.

Nos. 61 to 70 = Monzogranite.

the southern side, monzogranites fall towards the north and granodiorites take up the intermediate position.

Petrography of the rocks of the study area is given below:-

Tonalites

The rocks towards the southern fringe of the granite body comprise of tonalites. Petrographically, these are generally coarse grained but at a few places medium grained rocks are also noticed. These are mesocratic, holocrystalline and hypidiomorphic. In thin sections the tonalites are chiefly composed of quartz, plagioclases, alkali feldspars, hornblende, biotite and accessories. The volume percentage of the different minerals of this type is given in Table-4. The specific gravity of this type of rocks varies from 2.68 to 2.82.

Granodiorites

This variety of the granite covers a large part

of the study area. These are usually medium grained to coarse grained, mesocratic to leucocratic, holocrystalline and hypidiomorphic. The rocks are composed of quartz, plagioclases, hornblende, alkali feldspars, biotite with muscovite, zircon, tourmaline, ilmenite, magnetite as accessories. The volume percentages of different minerals of this type is given in Table-4. The specific gravity of this type of rocks ranges from 2.65 to 2.78.

Monzogranites

The exposure of this rock type is shown in Plate-38. The rocks are light grey coloured and are medium grained, holocrystalline and hypidiomorphic. These rocks are composed of quartz, plagioclases, alkali feldspars, hornblende, biotite, muscovite with tourmaline, zircon and opaques as accessories. The volume percentages of various minerals of this type of granite is given in Table-4. The specific gravity of the rocks varies from 2.64 to 2.71.

Study of the minerals from the granitic rocks of the study area

The minerals constituting the rocks are quartz,

plagioclases, alkali feldspars, hornblende, biotite and muscovite with tourmaline, apatite, zircon and opaques as accessories. The important characteristics of these minerals are given below.

a) Quartz

Quartz is abundantly present as given on Table-4. Three sub types are recagonized, Quartz-I is medium to coarse grained, has low relief, fresh appearance and sometimes exhibits undulatory extinction (Plate-16 Fig.1). Wisps and scales of micas and feldspars are commonly found in quartz-I (Plate-16, Fig.2 & 3). In a few cases it shows crushed margins, due to the considerable strain, giving rise to what is commonly known as mortar texture and in other cases different grains of quartz show sutured contacts with each other (Plate-16, Fig.4). The interlocking arrangement of grains of quartz is very clear. These grains are length slow and give uniaxial figure. This mineral, evidently last to crystallize, fills the spaces between earlier crystallized minerals. In a few cases it shows absorption contact towards other minerals. This is particularly evident in the case of feldspar towards which it may show highly indented rims like those shown in (Plate-16, Fig.5).

The saw like texture mainly occur when the polysynthetic feldspar twins form a wide angle to the contact with the quartz. In some cases cracks present in this earlier crystallized (usual quartz) are filled by small fragments of quartz-II itself which is, therefore, of later generation. Another generation, quartz-III present on a minor scale is found in the form of inclusions in feldspars and micas and is indicative of this generation of quartz having been crystallized before other minerals have completely crystallized. This is quartz of much earlier generation.

b) Feldspars

Both plagioclases and alkali feldspars have been found in the rocks of the study area. The percentages of these is given in Table-4.

(i) Plagioclases

The plagioclases(Plate-16, Fig.6) are found in a large amount (Table-4). Plagioclases show wide spread twinning and in most of the cases these consist of fine polysynthetic lamallae which extent across

entire length of the crystal. The twinning is according to single albite twin law (Plate-17, Figs. 3 and 4). These are sometimes altered to sericite, muscovite and kaolin (Plate-17, Figs.1, 2,3 and 4) and show the development of cracks. The presence of relict oscillatory zoning in some sections has been noticed (Plate-17, Figs.5,6 and Plate-18, Fig.3), which may be due to the fact that this is an original igneous plagioclase (Karl, 1959). Plagioclases have been studied by three methods: (1) Optical, (2) Chemical and (3) X-ray diffractiometry method.

1. Optical Method

The study of plagioclases by optical methods include (1.a) determination of R.I.,(1.b) maximum symmetrical angle measurements in sections cut at right angle to (010) and (1.c) $2v_x$ determination.

(1.a) The refractive index measurements by immersion technique have been given by Bloss (1961),

Heinrich (1965), Hinnawi (1966), Zussman (1969), Phillips (1971), Wahlstrom (1971), Shalley (1975) and Battey (1976). For this purpose fifteen plagioclases from different specimens were separated (separation was done according to the method suggested by Hutchison, (1974). The refractive index ($n\beta$) determination carried out according to the method elucidated by Battey (1976) are plotted on a graph after Chayes (1952) (Plate-21). The refractive index ranges from 1.535 to 1.555, (From the observation of Plate-21), and it is evident that the plagioclases of the present study area range in composition from albite to andesine.

(1.b) The maximum symmetrical extinction angle measurements in sections cut at right angle to (010) also confirms that the plagioclase composition ranges from albite to andesine with An percentages from An_8 to An_{45}.

(1.c) The $2v_x$ of plagioclases has been carried out. The $2v_x$ determination has been carried out

according to Reinhard's method on a four axis universal stage as given by Naidu (1958). The 2v of plagioclases in the present case ranges from 77° to 83°. This corresponds to the An composition of An_{8} to An_{45}.

2. Chemical Method

Seven samples of plagioclases, two from monzogranite, three from granodiorite and two from tonalites, have been separated and subjected to chemical analyses as given in Table-5. These values indicate that plagioclases of granodiorites and tonalites are more calcic and less sodic. The analyses of plagioclases of the monzogranites also indicate that these range from albite to oligoclase. The values of granodiorite and tonalite plagioclases indicate that these range in composition from oligoclase to andesine.

An examination of Table-16, indicates that the normative plagioclases range in composition from $Ab_{67.22}$ $An_{34.78}$ to $Ab_{90.89}$ $An_{9.11}$. This confirms the result obtained above.

Table-5: Chemical analyses of plagioclases from Ladakh Granites.

Sample number	AJ42	AJ9	AJ22	AJ97	AJ55	AJ89	AJ77
Sr.No.	1	2	3	4	5	6	7
Constituents							
SiO_2	56.98	57.11	59.07	60.08	60.12	61.92	62.80
Al_2O_3	25.16	25.74	23.48	22.58	24.01	23.65	22.52
Fe_2O_3	1.14	0.91	2.30	1.80	0.91	1.00	1.35
FeO	0.06	0.05	0.04	0.04	0.06	0.10	0.05
TiO_2	0.05	0.02	0.03	0.02	0.03	Tr*	Tr*
MgO	0.62	0.68	1.03	0.36	0.58	0.30	0.30
CaO	10.78	8.78	8.02	7.96	6.00	4.18	3.28
Na_2O	4.06	4.16	5.22	6.03	7.02	8.05	8.57
K_2O	0.78	1.03	1.01	0.85	1.11	1.04	1.08
H_2O^+	0.05	0.06	0.13	0.07	0.08	0.15	0.10
H_2O^-	0.07	0.04	0.09	0.09	0.06	0.10	0.08
Total	99.75	99.58	100.42	99.88	100.16	100.49	100.06

Location of the analysed samples:

1. Tonalite (33° 58' 40" : 77° 46' 54")
2. Tonalite (34° 2' 43" : 77° 42' 35")
3. Granodiorite (34° 1' 21" : 77° 47' 6")
4. Granodiorite (33° 51' 3" : 77° 53' 11")
5. Granodiorite (33° 58' 37" : 77° 53' 17")
6. Monzogranite (33° 56' 42" : 77° 52' 58")
7. Monzogranite (33° 57' 56" : 77° 52' 55")

Tr* = in Traces.

3. X-ray Method

Three plagioclases from different varieties of granites were subjected to X-ray diffractometry according to the method of Vishwanathan (1971). These were X-rayed as powder mounts on Phillips, Holland, X-ray Diffractometer Model number 1050/25 with nickel filtered Cukα_1, radiation, electronically controlled chart recorder with $1/4^{\circ}$ 2 θ per min. goniometer rotation. The data obtained are given in Table-6. The anorthite content is given on Plate-22. From the data it is observed that the An content decreases from the periphery (border) to the centre of the granite body.

From the above methods for determining the composition of plagioclases, it can be seen that the anorthite content of these show a gradational decrease from the periphery towards the centre of the granite body.

Alteration of Plagioclase

Alteration of plagioclase has been noticed quite

Table: 6 Structural state of plagioclases from the Ladakh Granites determined by the X-ray method (after Vishwanatha, 1971). $KBrO_3$ peaks at 20.38 2 θ angles(intensity 100) is the internal standard.

Sample number	2 θ	Intensity	Face of diffraction	Anorthite contact	Structural state
AJ42	21.25	4.00	$\bar{2}01$	48	Low
	22.01	18.00	$\bar{2}01$		
	41.79	4.50	060		
	42.48	4.00	060		
	48.44	5.00	$\bar{4}03$		
	50.78	7.00	$\bar{2}04$		
	51.35	6.00	$\bar{2}04$		
AJ22	21.30	14.00	$\bar{2}01$	30	Low
	21.92	20.00	$\bar{2}01$		
	41.85	4.00	060		
	42.58	2.50	060		
	48.23	3.50	$\bar{4}03$		
	50.78	6.00	$\bar{2}04$		
AJ77	21.00	9.00	$\bar{2}01$	12	Low
	22.06	9.00	$\bar{2}01$		
	41.81	4.00	060		
	42.40	5.00	$\bar{4}03$		
	47.95	3.50	$\bar{2}04$		
	51.37	10.00	$\bar{2}04$		

Note: Values underlined have been used in the diagram.

often. In some cases plagioclases have been totally replaced by aggregates of sericite and kaolin(Plate-17, Figs.2 and 3). Bent and broken lamellae of plagioclases have been observed in a few instances.

Much literature exists on the alteration of plagioclases to sericite, paragonite, bohemite, zeolite and other clay minerals. Notable among such references are the works of Schwarz and Trageser(1933), Morey and Chen (1955), Morey and Cournier(1961) and Hamley et al. (1961).

The decomposition products of plagioclases, which are observed in the present case, are included in the list of products obtained experimentally by different workers. The following reactions have been suggested to denote the change:-

$$3\,(Na_2O.\,Al_2O_3.\,6SiO_2) + 2H_2O + 2CO_2$$
$$= Na_2O.\,3Al_2O_3.\,6SiO_2.\,2H_2O + 12SiO_2 + 2Na_2CO_3$$

(Paragonite)

$$Na_2O.\,Al_2O_3.\,Al_2O_3.\,6SiO_2 + 2H_2O + CO_2$$
$$= Al_2O_3.\,2SiO_2.2H_2O + 4SiO_2 + Na_2CO_3$$

(kaolin)

$$3(CaO.Al_2O_3.2SiO_2) + K_2O.Al_2O_3.6SiO_2 + 2CO_2 + 2H_2O$$
$$= K_2O.3Al_2O_3.6SiO_2.2H_2O + 2CaCO_3 + 4SiO_2$$

muscovite(sericite)

In the present case these changes (equations) seem to hold good as noticed by altered association of kaolinite and sericite with plagioclase(Plate-17, Figs.2 and 3).

ii. Alkali Feldspars

The study of alkali feldspars is persued along three lines (1) thin section study,(2) chemical analysis and (3) X-ray study.

1. Thin Section Study

The alkali feldspars show subhedral outline and cross-hatched twinning (Plate-18, Fig.1), as such the alkali feldspars show microcline characters (Plate-18, Fig.2). Alkali feldspars have been noticed to enclose blebs of albite in a few cases. In some instances laths of biotite are present in a bigger

crystal of alkali feldspar (Plate-18, Fig.4) and also alkali feldspar occurs in close contact with hornblende (Plate-18, Fig.5).

2. Chemical Analyses

Alkali feldspars separated from three granite varieties have been chemically analysed. The chemical analyses of alkali feldspars are given in Table-7. It is clear that the normative alkali feldspars range in composition from $Or_{30.68}$, $Ab_{55.90}$, $An_{13.42}$ to $Or_{40.63}$, $Ab_{50.74}$, $An_{8.63}$.

3. X-ray Study

Orville (1967) and Jones (1969) developed a X-ray method to determine the alkali feldspar bulk composition. The sample is heated with $KBrO_3$ to a temperature of 1050°C in a muffle furnace for 48 hours to homogenize the alkali feldspars with albitic inclusions and x-rayed with $KBrO_3$ as the internal standard.

The separation of $\bar{2}01$ peak or alkali feldspar

Table-7: Chemical analyses of alkali feldspars from Ladakh Granites.

Sample number	AJ9	AJ42	AJ22	AJ97	AJ55	AJ98	AJ77
Sr.No.	1	2	3	4	5	6	7
Constituents							
SiO_2	60.76	62.55	63.50	63.76	64.28	65.05	65.88
Al_2O_3	20.23	19.13	19.75	19.54	18.50	16.75	15.25
Fe_2O_3	1.18	1.17	1.15	1.11	1.05	1.33	2.56
FeO	0.88	0.75	0.55	0.50	0.45	0.40	0.85
TiO_2	0.13	Tr*	0.15	0.19	0.23	0.31	0.21
MgO	0 .66	0.80	0.55	0.58	0.64	0.76	0.56
CaO	1.21	0.91	0.88	0.71	1.33	0.98	1.04
Na_2O	3.12	2.70	1.51	1.61	1.37	1.51	1.23
K_2O	11.88	12.74	11.54	12.00	12.78	13.19	12.23
H_2O^+	0.13	0.12	0.15	0.11	0.09	0.08	0.12
H_2O^-	0.09	0.05	0.07	0.06	0.05	0.07	0.07
Total	100.27	100.92	100.20	100.17	100.77	100.43	100.00

Tr* = in Traces.

Location of the analysed samples:

1. Tonalite (34° 2' 43" : 77° 42' 35")
2. Tonalite (33° 58' 40" : 77° 46' 54")
3. Granodiorite (34° 1' 21" : 77° 47' 6")
4. Granodiorite (33° 51' 3" : 77° 53' 11")
5. Granodiorite (33° 58" 37" : 77° 53' 17")
6. Monzogranite (33° 56' 42" : 77° 52' 58")
7. Monzogranite (33° 57' 56" : 77° 52' 55")

Table-8: X-ray powder diffraction data ($KBrO_3$ internal standard) giving 2 θ values, their intensities (I/I_o) and the corresponding reflections for alkali-feldspars. The underlined values are used for structural state and triclinicity determination of alkali feldspars from Ladakh Granites.

(continued)

Sample number	2 θ	d values	I/I_o	Plane
AJ42	21.20	4.1872	6	$\bar{2}01$ K
	22.20	4.008	34	$\bar{2}01$ A
	23.20	3.8306	16	130 K
	23.86	3.7261	49	$\bar{1}30$ K
	24.48	3.6331	29	$\bar{1}\bar{3}1$ K
	26.90	3.3115	100	220 K
	27.52	3.2383	50	040 K
	28.22	3.1596	100	002 K
	29.50	3.0253	4	131 K
	30.08	2.9683	13	$\bar{1}\bar{3}1$ A
	35.48	2.5297	11	$\bar{2}41$ K
	36.20	2.4793	35	240 K
	41.68	2.1651	6	060 K
	48.50	1.8754	10	113 K
	49.46	1.8412	8	113 K
	50.69	1.7990	4	$\bar{2}04$ K
	51.80	1.7729	11	$\bar{2}04$ K

$\triangle$ = 0.7125

Table-8: X-ray powder diffraction data ($KBrO_3$ internal standard) giving 2 θ values, their intensities (I/I_o) and the corresponding reflections for alkali-feldspars. The underlined values are used for structural state and triclinicity determination of alkali feldspars from Ladakh Granites.

(continued)
concluded

Sample number	2 θ	d values	I/I_o	Plane
AJ22	<u>21.05</u>	<u>4.2128</u>	<u>4</u>	<u>$\bar{2}01$ K</u>
	22.00	4.0368	3	$\bar{2}01$ A
	24.20	3.6745	34	130 K
	26.62	3.3457	48	$\bar{1}\bar{1}2$ K
	27.52	3.2383	34	040 K
	27.59	3.2291	100	002 K
	<u>29.50</u>	<u>2.9265</u>	<u>5</u>	<u>$\bar{2}22$ K</u>
	30.08	2.9683	3	$\bar{1}36$ A
	35.22	2.5460	18	112 K
	35.70	2.5128	4	310 K
	36.58	2.4555	22	240 K
	37.04	2.4249	4	$\bar{1}50$ K
	37.60	2.3901	23	$\bar{3}31$ K
	38.60	2.3305	3	$\bar{1}\bar{1}3$ K
	<u>41.72</u>	<u>2.1631</u>	<u>5</u>	<u>060 K</u>
	49.38	1.8440	28	113 K
	50.20	1.8158	4	113 K
	<u>50.62</u>	<u>1.8017</u>	<u>4</u>	<u>$\bar{2}04$ K</u>
	51.38	1.7768	4	$\bar{2}04$ K

$\triangle$ = 0.4700

Table-8: X-ray powder diffraction data($KBrO_3$ internal standard) giving 2θ values, their intensities(I/I_o) and the corresponding reflections for alkali-feldspars. The underlined values are used for structural state and triclinicity determination of alkali feldspars from Ladakh Granites.

(continued)

Sample number	2 θ	d values	I/I_o	Plane
AJ77	<u>21.10</u>	<u>4.2069</u>	<u>4</u>	<u>$\bar{2}01$ K</u>
	22.00	4.0368	29	$\bar{2}01$ A
	23.62	3.7634	45	$\bar{1}30$ K
	24.32	3.6567	19	$\bar{1}31$ K
	26.68	3.3383	47	220 K
	27.54	3.2360	100	002 K
	27.98	3.1861	14	002 K
	<u>29.60</u>	<u>3.0153</u>	<u>4</u>	<u>131 K</u>
	<u>29.90</u>	<u>2.9857</u>	<u>13</u>	<u>$\bar{1}31$ K</u>
	30.46	2.9321	12	$\bar{1}31$ A
	38.96	2.3097	22	$\bar{1}13$ K
	<u>41.77</u>	<u>2.1591</u>	<u>5</u>	<u>060 K</u>
	48.50	1.8754	4	$\bar{4}03$ K
	49.26	1.8482	4	260 K
	50.26	1.8172	65	113 K
	<u>50.56</u>	<u>1.8030</u>	<u>14</u>	<u>$\bar{2}04$ K</u>
	51.36	1.7775	12	$\bar{2}04$ K

$\triangle$ = 0.3700

from 101 peak of $KBrO_3$ is taken as a measure of orthoclase content in alkali feldspar.

Wright (1968) proposed a calibration diagram wherein 2 θ angles for $\bar{2}01$, 060 and $\bar{2}04$ reflections are used to determine the structural state of alkali feldspars. In the present case three representative samples of each granite type from the study area were studied according to method of Wright and Stewart (1968) using X-ray Diffractometer Model No. 1050/25 with nickel filtered Cukα_1 radiation and scanning speed of $1/4^{\circ}$ per min. The results are given in Table-8 and plotted on the Wright's diagram(op.cit.) Plate-24. The study of this plate shows that the alkali feldspars under study classify as intermediate to maximum microcline and are triclinic.

Goldsmith and Laves (1954) proposed a measure of triclincity of alkali feldspars as :

$$\triangle = 12.5\ (d_{131} - d_{1\bar{3}1})$$

Where $\triangle$ is the measure of triclincity, d_{131}

and $d_{1\bar{3}1}$ is the 'd' spacings corresponding to 131 and $1\bar{3}1$ reflections. If $\Delta = 0$, the alkali feldspar is monoclinic (fully disordered) and $\Delta = 1$, most triclinic (fully ordered). Dietrich (1961) gives $0.25\,\Delta$ as the dividing value between orthoclase (or sanidine) and microcline. Values lower than 0.25 suggest monoclinic and values of 0.25 or above are indicative of triclinic alkali feldspars. Rhodes (1969) proposes $0.3\,\Delta$ as the discrimination value. In the granites of the study area, Δ values vary from 0.3700 to 0.7129 (Table-8). This would suggest that the alkali feldspars of the study area are triclinic in nature. Also the tonalites at the periphery cooled rapidly as compared to the other two types, which cooled rather slowly.

Alteration of Alkali Feldspars

Alkali feldspars have also undergone alteration like the plagioclases, but the alteration here is less (Plate-18, Fig.6).

The formation of kaolin and sericite from alkali feldspars under different conditions of

temperature, pressure and chemical environment have been witnessed by Stevens(1934), Norton(1941) and Grunner (1944). Later on Morey and Chen(1955) and Morey and Fournier(1961) subjected microcline to high temperature and pressure in the presence of water and produced muscovite and bohemite.Hamley(1959) obtained mica, kaolin and bohemite by exposing potash feldspars to very high temperature and pressure. Smith (1974) has discussed this in detail.

It can be said that sericite and kaolin resulted from the alteration of alkali feldspars (Plate- , Fig.6) according to the following equations:-

$$3(K_2O.Al_2O_3.6SiO_2) + 2H_2O + 2CO_2$$
$$= K_2O.\ 3Al_2O_3.6SiO_2 + 2H_2O + 12SiO_2 + 2K_2CO_3$$

(muscovite)

$$3(K_2O.Al_2O_3.6SiO_2) + 6H_2O + 3CO_2$$
$$= 3(Al_2O_3.2SiO_2.2H_2O) + 12SiO_2 + 3K_2CO_3$$

(kaolin)

c) Hornblende

Hornblende is one of the minerals which is abundantly found in all the three granite types of the study area(Table-4). The study of this mineral is undertaken by two methods: (1) optical and (2) chemical methods.

1. Optical Method

(1.a) In thin sections colour of this mineral is greenish grey to dark green. The green hornblende is characteristic of acid rocks. It is present in the form of laths riddled with cracks and inclusions(Plate-19, Fig.1). While in some cases it exhibits elongate shape. In some thin sections the inclusion of iron ore and quartz are present (Plate-19, Fig.2). The mineral is pleochroic in shades of dark green and light yellow. The pleochroic scheme of this mineral is as under:

X= Light yellow

Y= Green

Z= Dark green

$X > Y > Z$

(1.b) Four hornblende samples from the granites were separated (according to the method suggested by Hutchison, 1974) and subjected to R.I. measurement. The R.I.values obtained are given in Table-9a. These values have been plotted as indicated in Plate-25. Then R.I. of hornblende varies from 1.667 to 1.669.

(1.c) The $2V_x$ of the hornblende have been carried out on four axis universal stage according to the method suggested by Naidu(1958). The $2V_x$ of hornblende ranges from 71° to 76°.

2. Chemical Method

Seven samples of hornblende were subjected to the chemical analyses. The analyses of these are given in Table-9b.

From a close inspection of Table-9b and comparison of $100Mg/(Mg+Fe^{++}+Fe^{+++}+Mn)$, a close resemblance is noticed.

Table-9a: Optical and chemical data for hornblende from Ladakh Granites.

S.No.	Sample number	C	γ	100mg/ (mg+Fe^{++} + Fe^{+++} + Mn)*
1-	AJ9	16°	1.663	68
2-	AJ42	17°	1.670	60
3-	AJ55	17°	1.677	58
4-	AJ97	18°	1.679	55
5-	AJ22	18°	1.680	50

* Based on γ values (Deer, Howie and Zussman, 1966)

Sample nos.1 & 2 = Tonalite.

Sample Nos.3,4,& 5= Granodiorite.

Table-9b: Chemical analysis of hornblende from Ladakh granites.

Sample number	AJ9	AJ42	AJ58	AJ55	AJ97	AJ22	AJ10
S.No.	1	2	3	4	5	6	7
Constituents							
SiO_2	40.12	41.47	41.78	42.16	42.66	43.10	43.27
TiO_2	1.13	1.00	0.95	0.65	0.76	0.51	0.50
Al_2O_3	16.76	16.11	16.76	15.92	15.06	15.11	14.32
Fe_2O_3	4.90	4.12	3.80	3.40	2.90	2.76	2.30
FeO	15.78	14.20	14.12	13.66	13.46	12.98	13.11
MgO	8.16	8.96	9.02	10.22	10.76	11.12	11.19
CaO	12.13	13.17	10.98	1212	12.36	12.56	13.01
Na_2O	1.04	1.03	1.17	1.06	1.08	1.17	1.36
K_2O	0.88	0.76	0.98	0.66	0.76	0.56	0.63
$H_2O\pm$	0.60	0.41	0.76	0.56	0.90	0.43	0.40
Total	99.50	100.23	100.32	100.41	100.70	100.30	100.73

Location of the analysed samples:

1. Tonalite (34° 2' 43" : 77° 42' 35")
2. Tonalite (33° 58' 40" : 77° 46' 54")
3. Tonalite (33° 57' 59" : 77° 49' 2")
4. Granodiorite (33° 58' 37" : 77° 53' 17")
5. Granodiorite (33° 51' 3" : 77° 53' 11")
6. Granodiorite (34° 1' 21" : 77° 53' 11")
7. Granodiorite (34° 3' 43" : 77° 43' 15")

Alteration of Hornblende

It has been noticed in the present case that the hornblende is altered to biotite (Plate-19, Figs.3 and 4). It can be well explained by following reaction after Marmo(1967):

$$Ca_2(Mg,Fe)_3Al_4Si_6O_{22}(OH)_2 + \frac{1}{2}K_2O + SiO_2 + H_2O$$

(hornblende) (dissolved silicate)

$$= Fe(Mg,Fe)_3AlSi_3O_{10}(OH)_2 + Ca_2Al_3Si_3O_{12}(OH)$$

(biotite) (epidote)

d. Biotite

Biotite is another common mineral present in the granites of the study area. The biotites have also been subjected to two fold study by(1) optical and (2) chemical methods.

1. Optical Method

It includes the study of (1.a) thin sections and (1.b) R.I.measurements.

(1.a) Thin Section Study

In thin sections colour of this mineral varies from light brown to dark brown. While in a few cases it is brownish red to greenish brown. This mineral is highly pleochroic in the shades of dark brown to yellowish brown with maximum absorption occurring when its cleavages are parallel to the vibration direction of polarizer. The pleochroic scheme of the mineral is as under:

X = Yellowish brown.

X=Y = Dark brown

Z = Y > X.

The mineral has undergone strain defects which are evident from the bending of biotite lamellae noticed in a few cases(Plate-19,Fig.6 and Plate-20, Fig.1). Biotite laths have been observed in some sections to cut each other and this is a clear evidence of their being of two generations(Plate-20, Fig.2). In a few cases inclusions of leucoxene with kernels of ilmenite have been noticed(Plate-20,Fig.3). A number of minerals in small grains present in biotite

are iron ores, quartz, etc. (Plate-20, Fig.4).

(1.b) R.I.Measurements

Biotites obtained from seven samples of granites of the study area have been subjected to R.I. measurements and ' γ ' values determined. The ' γ ' values were plotted on Heinrich's (1965) curve which shows the relationship between ' γ ' Index and the proportion of FeO+ $2(Fe_2O_3+TiO_2)$ for biotites (Plate-26). From this figure it could be seen that the values of FeO $+2(Fe_2O_3+TiO_2)$ vary from 25.50 to 29.50 per cent. The R.I.range is from 1.648 to 1.655.

2. Chemical Method

Five biotite samples separated from different varieties of granite of the study area have been chemically analysed. The analyses are given in Table-10. From the inspection of this table, it is seen that the values show a close resemblance with the results obtained above.

Table-10: Chemical analysis of biotites from Ladakh Granites.

Sample number	AJ42	AJ9	AJ55	AJ97	AJ77
Sr.No.	1	2	3	4	5
Constituents					
SiO_2	35.64	36.22	37.12	38.18	38.52
Al_2O_3	15.12	15.72	17.27	16.21	16.12
Fe_2O_3	3.17	3.00	3.18	3.47	2.82
FeO	18.73	19.11	16.76	16.58	16.53
TiO_2	3.78	2.90	3.28	3.12	3.16
MgO	11.08	11.18	10.66	9.88	10.06
CaO	1.12	0.90	0.48	0.56	0.75
Na_2O	0.81	0.76	0.47	0.61	0.31
K_2O	9.11	8.63	9.25	9.88	9.90
$H_2O^*\pm$	2.00	2.11	2.08	1.92	1.80
Total	100.56	100.53	100.55	100.50	99.85

Location of the analysed samples:

1. Tonalite (33° 58' 40" : 77° 46' 54")
2. Tonalite (34° 2' 43" : 77° 42' 35")
3. Granodiorite (33° 58' 37" : 77° 53' 17")
4. Granodiorite (33° 51' 3" : 77° 53' 11")
5. Monzogranite (33° 57' 56" : 77° 52' 55")

Alteration of Biotites

It has been noticed that the mineral has undergone alteration like other minerals. In many cases the biotites show alteration to chlorite and Leucoxene. Schwartz(1958) and Wones and Eugster (1965) had worked on the alteration products of biotite. Chayes (1955) has given conversion of biotite to chlorite in the following way:

Biotite + Quartz $\longrightarrow$ Chlorite +Orthoclase

e. Muscovite

The mineral is present in small amounts in the granites of the study area. This mineral is characterised by a tabular habit(Plate-20,Fig.5). In some cases it has been noticed that it has a fan like appearance and is arranged in a criss-cross fashion. In few cases it occurs as an alteration product of feldspars and as such it may be termed as secondary muscovite (sericite) (Plate-20, Fig.6).

f. Tourmaline

The presence of this mineral is noticed only in a few thin sections. It exhibits dichroism and shows following dichroic scheme:

O= Brown

E= Pale yellow.

O > E

g. Chlorite

It is present in wisps and filaments mostly alongwith biotite. The mineral shows light green colour and exhibits following pleochroic scheme:

X = Pale green

Z = Light blue-green.

X = Y > Z.

h. Apatite

It is an accessory mineral found in the

rocks of the study area.

i. Iron Ores

These occur as inclusions in biotite, hornblende, etc. and are invariably found in the rocks of the study area.

j. Zircon

The study of zircons is linked to the problem of granite origin (Poldervaart, 1968) and as such they have been studied in detail after being separated from the parent rock specimens. Five large selected rock samples from three different types of granite have been subjected to zircon separation by repeated crushing, hydrofluoric acid treatment, seiving and separation by heavy liquids. The method has been elucidated by Murthy (1968). The breakage of the crystals by laboratory methods has been minimum. The zircon concentrates so obtained have been mounted on one or more glass slides in canada balsam and care taken to distribute the grains evenly on the slide. Some of these have also been photographed(Plate-27).

Table-11: Morphological characters of Zircons from Ladakh Granites.

Sample number	AJ9	AJ42	AJ55	AJ97	AJ77
Sr.No.	1	2	3	4	5
Characters					
Euhedral	65	66	62	63	55
Rounded	15	16	14	11	20
Broken	20	18	24	21	25
Colourless	S	S	A	A	F
Pinkish	A	F	S	F	S
Brown	R	R	R	R	R
Zoning	S	S	A	F	R
Inclusions	F	S	F	S	S

Sample nos.1 & 2: Tonalite. A= Abundant.

Sample nos.3 & 4: Granodiorite. S=Significant.

Sample no. 5 : Monzogranite. R=Rare.

Morphologically, zircons of the granitic rocks of the study area are grouped into the following classes (Table-11).

1. Euhedral Zircons

Zircons with euhedral outlines come to about 62 per cent. These (Plate-27, Nos.1 to 6, 15 to 18 and 20) are mostly colourless to light pink and sometimes brown in colour. A few of these contain inclusions (Plate-27, Nos. 1 and 3 to 5). These crystals are often zoned.

2. Rounded Zircons

Rounded crystals come to about 15 per cent of the total zircon concentration (Plate-27, Nos 9 to 14 and 19). These zircons are mostly light brown in colour and are commonly referred to as Malacons. Zoning, inclusions and colour contrast between the peripheral and the central parts are common in such zircons.

Table-12: Dimensional data for Zircons in some Ladakh Granites.

Sample number	AJ9	AJ42	AJ55	AJ97	AJ77
S.No.	1	2	3	4	5
Parameters					
N	50	75	50	100	65
$\bar{X}$	0.0812	0.0965	0.1080	0.1117	0.0915
$\bar{Y}$	0.0254	0.0344	0.0357	0.0387	0.0290
S_x	0.0333	0.0440	0.0293	0.0235	0.0230
S_y	0.0113	0.0136	0.0660,	0.0085	0.0057
a	0.3246	0.3107	0.3513	0.3648	0.3240
θ	18° 16'	17° 22'	19° 25'	20° 15'	21° 05'
r	0.6963	0.7076	0.7275	0.6110	0.7210
Dd	28.48	31.33	32.00	19.00	28.50

Sample nos. 1 & 2 = Tonalite.

Sample nos.3 & 4 = Granodiorite.

Sample no. 5 = Monzogranite.

3. Broken Zircons

About 23 per cent of the total crystal concentrates are with broken terminations. Most often only one termination is broken (Plate-27, Nos.7,8, 21 and 23 to 25) but in some cases both the termination are broken (Plate-27, Nos. 8 and 22).

The methods given by Smithson (1939) and Spotts (1962) have been used for the preparation of size frequency curves of the zircons of the granitic rocks of the study area (Plate-28). These curves almost show monomodal trends and are characterised by sharp and prominent peaks. This is indicative of the fact that the granitic rocks containing these are of magmatic origin (Vishwanathan, 1968).

Reduced Major Axis (R.M.A.) studies of the zircons have been carried out, following the methods described by Larsen and Poldervaart (1957) and Murthy(1968). The data is given in Table-12 and has been plotted as shown in Plate-29. A study of the RMA's indicates the slope angle to be about 19°. Besides the comparable slope, the RMA's fall within a certain parallel

indicating the crystallization under similar conditions.

C H A P T E R - VI

PETROCHEMISTRY OF THE GRANITES

In order to study the variation in the petrochemistry of the granites of the study area and for a geochemical approach to the problem of origin of these rocks, thirty representative rock specimens from different types of granite of the study area have been chemically analysed for their major elements. Both conventional and rapid methods have been used for rock analysis. The conventional method of rock

analysis has been used for the estimation of CaO, MgO, FeO and Fe_2O_3 ; whereas SiO_2, Al_2O_3 and TiO_2 have been determined with the help of spectrophotometer (SP8-100 Ultraviolet Spectrophotometer, Pye-Unicam).

The rapid analytical method is given by Shapiro and Brannock (1962). The standards G_1 and W_1 were used for SiO_2 and Al_2O_3 determination. Both are international standards whose statistical variation and replicate analyses have been discussed by Fairbairn (1953) and Fleischer(1962). Synthetic standards made from Analar and pure chemicals whose blanks were predetermined were used for the determination of TiO_2. The alkalis were determined by Flamephotometer (EEL-England). Plus and minus water was determined by the modified method of Penfield.

Great care was taken towards the accuracy of the results and the margin of the error, it is hoped, cannot be more than $\pm$ 2 per cent. Different types of variation diagrams have been constructed from the

Table-13: Chemical analyses of Ladakh Granites

(contd...)

Sample number	AJ19A	AJ58	AJ84	AJ9	AJ8	AJ83	AJ78	AJ15A
Sr.No.	1	2	3	4	5	6	7	8
Constituents								
SiO_2	66.30	66.66	66.90	67.00	67.12	67.50	67.70	68.23
Al_2O_3	15.60	15.50	15.30	14.56	14.60	15.70	15.30	16.01
Fe_2O_3	1.75	1.60	1.45	1.55	1.73	1.40	1.50	1.55
FeO	3.35	3.30	3.25	3.30	3.45	3.25	3.35	3.00
TiO_2	0.55	0.40	0.40	0.54	0.59	0.58	0.50	0.33
MgO	1.95	1.80	1.90	1.70	1.84	1.75	1.60	1.40
CaO	2.65	2.55	2.40	2.35	2.40	2.30	2.20	2.10
Na_2O	2.75	2.80	3.00	2.95	3.00	2.95	3.50	3.05
K_2O	2.85	2.95	3.10	3.00	3.15	3.10	3.00	3.20
H_2O+	0.86	0.80	0.98	1.09	0.93	0.96	0.86	0.66
H_2O-	0.79	0.78	0.66	0.98	0.82	0.88	0.78	0.56
Total	99.40	99.15	99.42	99.02	99.63	100.37	100.29	100.09

Location of the analysed samples:

1. Tonalite (34° 1' 07" : 77° 44' 37")
2. Tonalite (33° 57' 59" : 77° 45' 58")
3. Tonalite (33° 53' 9" : 77° 49' 2")
4. Tonalite (34° 2' 43" : 77° 42' 35")
5. Monzogranite (34° 3' 37" : 77° 48' 15")
6. Tonalite (33° 54' 23" : 77° 47' 26")
7. Monzogranite (33° 57' 26" : 77° 53' 5")
8. Monzogranite (34° 4' 20" : 77° 49' 3")

Table-13: Chemical analyses of Ladakh Granites.
(contd..)

Sample number, Sr.No.,	AJ50 9	AJ28 10	AJ22 11	AJ5A 12	AJ52 13	AJ37 14	AJ41 15	AJ13 16
Constituents								
SiO_2	68.90	69.00	69.20	69.72	70.00	70.11	70.55	70.65
Al_2O_3	15.85	16.10	15.90	15.90	15.50	15.20	14.75	14.80
Fe_2O_3	1.05	1.35	1.30	1.30	1.15	1.20	1.25	1.25
FeO	2.65	2.55	2.68	2.50	2.40	2.10	2.20	1.95
TiO_2	0.40	0.55	0.35	0.50	0.35	0.35	0.30	0.45
MgO	0.85	1.25	0.90	1.20	1.05	1.15	0.90	0.85
CaO	2.00	1.90	2.00	1.80	1.65	2.10	1.60	1.95
Na_2O	3.10	3.30	3.25	3.50	3.60,	3.00	3.65	3.15
K_2O	3.25	3.10	3.20	3.20	3.00	3.25	3.35	3.50
H_2O+	0.85	0.62	0.60	0.82	0.80	0.60	0.75	0.98
H_2O-	0.72	0.58	0.42	0.20	0.61	0.42	0.22	0.65
Total	99.62	100.30	99.80	100.64	100.11	99.48	99.52	100.18

Location of the analysed samples:

9. Monzogranite (33° 58' 48" : 77° 52' 45")
10. Granodiorite (34° 2' 2" : 77° 47' 45")
11. Granodiorite (34° 1' 21" : 77° 47' 6")
12. Granodiorite (34° 0' 51" : 77° 48' 24")
13. Granodiorite (33° 57' 51" : 77° 49' 52")
14. Monzogranite (33° 59' 53" : 77° 57' 26")
15. Granodiorite (34° 1' 26" : 77°48' 34")
16. Monzogranite (34° 3' 16" : 77° 49' 52")

Table-13 : Chemical analysis of Ladakh Granites.
(Contd.....)

Sample Number Sr.No.	AJ17A 17	AJ6 18	AJ77 19	AJ34 20	AJ17 21	AJ21A 22	AJ16 23
Constituents							
SiO_2	71.52	71.80	72.50	73.18	73.20	73.50	73.68
Al_2O_3	14.00	14.40	13.00	13.40	13.65	12.70	13.81
Fe_2O_3	1.20	1.30	1.30	1.96	1.40	1.25	1.70
FeO	2.00	1.90	2.00	2.00	2.05	1.90	1.90
TiO_2	0.50	0.50	0.50	0.35	0.35	0.40	0.45
MgO	0.60	1.30	0.90	0.85	0.60	1.30	0.60
CaO	1.85	1.90	1.95	1.60	1.40	1.75	1.80
Na_2O	3.35	3.30	3.35	3.80	3.20	3.40	3.50
K_2O	3.25	3.40	3.45	3.00	3.60	3.65	3.20
H_2O+	0.80	0.66	0.72	0.46	0.45	0.60	0.20
H_2O-	0.68	0.27	0.11	0.15	0.20	0.30	0.10
Total	99.75	100.73	99.78	100.69	100.10	100.75	100.94

Location of the analysed samples:

17. Granodiorite (34° 3' 48" : 77° 47' 16")
18. Monzogranite (34° 4' 42" : 77° 48' 5")
19. Monzogranite (33° 58' 56" : 77° 52' 55")
20. Granodiorite (33° 58' 40" : 77° 49' 54")
21. Granodiorite (34° 3' 51" : 77°47' 56")
22. Granodiorite (33° 59' 53" : 77° 48' 24")
23. Granodiorite (34° 2' 27" : 77° 47' 8")

Table-13: Chemical analyses of Ladakh Granites. (Concluded).

Sample number Sr.No.	AJ10 24	AJ88 25	AJ85 26	AJ12 27	AJ18 28	AJ4 29	AJ30 30
Constituents							
SiO_2	74.10	74.50	74.75	75.10	75.30	75.55	76.00
Al_2O_3	11.80	12.00	13.00	12.92	12.85	12.00	12.25
Fe_2O_3	1.55	1.50	1.25	1.16	1.20	1.25	0.95
FeO	2.50	1.95	1.40	1.45	1.40	1.15	1.16
TiO_2	0.30	0.40	0.35	0.30	0.40	0.35	0.45
CaO	1.70	1.55	1.55	1.25	1.25	0.80	0.85
Na_2O	3.30	4.00	3.10	3.75	3.25	3.80	4.00
K_2O	3.80	3.40	3.70	3.55	3.85	4.00	4.15
H_2O+	0.46	0.28	0.45	0.20	0.30	0.60	0.35
H_2O-	0.10	0.16	0.15	0.16	0.17	0.20	0.26
Total	100.43	100.34	100.35	100.25	100.46	100.10	100.77

Location of the analysed samples :

24. Granodiorite (34° 3' 43" : 77° 43' 15")
25. Granodiorite (33°54' 32" : 77° 52' 59")
26. Granodiorite (33°53' 31" : 77° 50' 38")
27. Granodiorite (34° 2' 56" : 77° 48' 13")
28. Granodiorite (34° 3' 8" : 77° 48' 18")
29. Monzogranite (34° 3' 11" : 77° 49' 32")
30. Granodiorite (33°59' 52" : 77° 47' 33")

analytical data. The variation diagrams can be conveniently grouped as :

A. Binary variation diagrams ; and
B. Ternary variation diagrams.

A. Binary variation Diagrams

The following binary variation diagrams have been constructed after the following authorities:

1. Harker (1909),
2. Larsen (1938),
3. Niggli (1954),
4. Thornton and Tuttle (1960),
5. Poldervaart and Parker (1964) and
6. Kuno (1968).

1. Harker's Variation Diagram

In order to study the variation in the chemistry of rocks, the eminent petrologist, Harker (1909) suggested a variation diagram, using SiO_2 along

abscissa and remaining oxide weight percentages along the ordinate.

An inspection of Plate-30 shows the various exides plotted against SiO_2. It is evident from these curves, that there is a decrease in Fe_2O_3+FeO, MgO and CaO with the increase in SiO_2. With the increase of SiO_2 content, soda and potash show an increase. The total alkalis also display an upward trend with the increase of SiO_2 percentage. The behaviour of Al_2O_3 is somewhat erratic.

It has been shown by investigators like Wager and Deer(1939) and Walker and Poldervaart(1949) that the variation diagram suggested by Harker (op.cit.), suffers from the disadvantage of showing much more fractionation in the late stage than in the early to middle stages of magmatic differentiation.

2. Larsen Variation Diagram

Larsen (1938) gave a scheme of plotting various rock oxides as ordinate against the

Table-14: (a) Larsen Indices of Ladakh Granites.

Sample Number	AJ19A	AJ58	AJ84	AJ9	AJ8	AJ83	AJ78	AJ15A	AJ50	AJ28
S.No.	1	2	3	4	5	6	7	8	9	10
L.I.	17.00	17.52	17.65	17.98	17.83	18.30	18.51	19.44	20.71	20.40
					(b) Differentiation Indices of Ladakh Granites.					
D.I.	69.27	70.15	17.40	17.53	71.76	72.42	74.19	74.69	76.60	77.62
					(c) Crystallization Indices of Ladakh Granites.					
C.I.	12.23	12.57	11.95	11.67	11.95	11.12	10.84	10.28	10.00	9.45
					(d) Solidification Indices of Ladakh Granites.					
S.I.	16.45	15.38	16.03	14.71	15.18	14.64	13.55	12.28	8.29	11.79

Contd.....

Table-14 : (a) Larsen Indices of Ladakh Granites.

Sample number	AJ22	AJ5A	AJ52	AJ37	AJ41	AJ13	AJ17A	AJ6	AJ77	AJ34
S.No.	11	12	13	14	15	16	17	18	19	20
L.I.	20.68	20.94	20.23	21.27	22.16	22.30	22.64	22.23	22.76	22.94

(b) Differentiation Indices of Ladakh Granites.

D.I.	75.52	78.68	79.38	77.41	81.33	79.35	81.60	80.72	82.44	85.30

(c) Crystallization Indices of Ladakh Granites.

C.I.	10.00	8.90	8.06	10.29	7.78	9.73	9.17	9.45	9.73	7.78

(d) Solidification Indices of Ladakh Granites.

S.I.	8.41	11.32	10.04	10.74	8.37	7.49	5.85	11.71	5.63	7.33

Contd....

Table-14:(a) Larsen Indices of Ladakh Granites

Sample Number	AJ17	AJ21A	AJ16	AJ10	AJ88	AJ85	AJ12	AJ18	AJ4	AJ30
S.No.	21	22	23	24	25	26	27	28	29	30
L.I.	23.35	23.20	23.46	23.48	24.13	25.01	25.47	25.80	26.83	27.00
(b) Differentiation Indices of Ladakh Granites										
D.I.	84.26	85.00	83.64	86.43	88.70	85.98	88.19	88.07	91.25	92.49
(c) Crystallization Indices of Ladakh Granites.										
C.I.	6.95	8.62	8.90	4.72	6.11	7.50	6.11	6.12	3.89	3.36
(d) Solidification Indices of Ladakh Granites.										
S.I.	5.13	4.28	8.19	5.48	5.43	5.77	4.09	4.97	3.90	4.32

sum of $1/3SiO_2 + K_2O - (MgO + CaO + FeO)$ as abscissa. The quantity $1/3SiO_2 + K_2O - (MgO + CaO + FeO)$ has been termed as 'Larsen Index'. Larsen's method is based on the principle that significant changes are to be witnessed in the behaviour of SiO_2, K_2O, FeO, MgO and CaO for rocks varying in composition from basic to acidic types; whereas the remaining oxides Na_2O and Al_2O_3 play a subsidiary role in magmatic differentiation.

Larsen indices calculated from the chemical analyses of the study area are given in Table-14. In Plate-31 are shown major oxides plotted against Larsen Indices. The various curves obtained from the plottings show good evidences of differentiation undergone by the magma. The curves for Na_2O and K_2O show an upward trend with the increase in Larsen indices. The total alkalis also display an upward trend with the increase in the values of Larsen indices. The curves for CaO, MgO, FeO and Fe_2O_3 show a downward trend as the values of the Larsen indices increase. The curve for Al_2O_3 shows an upward tendency to begin with, later on, it displays downward trend, although

some scattering of points is noticed.

3. Niggli Variation Diagram

Niggli (1954) proposed a variation diagram calculated from the chemical analyses.

Niggli values (al, fm, c and alk) calculated from the chemical analyses are given in Table-15, Plate-32 shows al, fm, c and alk values plotted as ordinate against si values as abscissa. From an inspection of this diagram, it is seen that with the increase in si values, there is an increase in alk and a fall in fm and c values respectively. The curve for al shows an erratic behaviour.

4. Thornton and Tuttle's Variation Diagram

In 1960 Thornton and Tuttle proposed a new parameter for studying the variation in the chemistry of igneous rocks. This parameter has been known as "Differentiation Index" by the workers. The principle behind this method is that fractional

Table-15: Niggli values of Ladakh Granites.
(contd..)

Sample number	Constituents							
	Si	qz	al	fm	C	Alk	k	mg
AJ19A	291.55	104.45	40.37	28.49	11.60	19.52	0.40	0.46
AJ58	297.00	107.00	40.64	27.00	12.03	20.32	0.59	0.44
AJ84	297.33	126.67	40.00	26.93	11.46	21.6	0.59	0.47
AJ9	301.62	114.38	41.08	26.21	11.35	21.35	0.41	0.43
AJ8	292.93	131.07	40.05	27.48	11.25	21.20	0.41	0.44
AJ83	303.23	120.8	40.16	27.22	10.78	21.83	0.41	0.42
AJ78	303.22	148.78	40.32	25.53	10.48	23.65	0.36	0.42
AJ15A	314.08	117.92	43.37	23.48	10.22	22.92	0.40	0.41
AJ50	338.64	97.36	45.72	18.88	10.62	24.78	0.40	0.33
AJ28	326.70	117.30	44.88	21.02	9.66	24.43	0.38	0.32
AJ22	345.21	54.79	46.70	20.05	10.77	22.45	0.45	0.32
AJ5A	338-77	61.23	45.48	18.95	9.33	26.24	0.37	0.34
AJ52	346.00	114.00	45.10	19.58	8.60	26.70	0.35	0.39
AJ37	351.80	73.2	44.88	19.27	11.14	24.70	0.41	0.43
AJ41	360.73	115.27	44.16	18.40	8.58	28.83	0.37	0.36

Table-15 : Niggli values of Ladakh Granites.
(Concluded)

Sample number	Constituents							
	Si	qz	al	fm	C	alk	K	mg
AJ13	363.27	89.00	44.75	17.28	10.80	27.16	0.42	0.37
AJ17A	385.76	70.24	44.33	16.18	10.68	28.80	0.39	0.30
AJ6	363.52	92.48	42.85	19.75	10.33	27.05	0.40	0.49
AJ77	398.68	61.32	41.91	16.83	11.55	29.70	0.40	0.29
AJ34	393.22	82.78	41.29	19.35	9.03	30.32	0.34	0.33
AJ17	417.46	14.54	45.89	17.12	8.56	28.42	0.38	0.26
AJ21A	428.00	24.00	42.65	15.63	10.84	30.77	0.37	0.24
AJ16	388.60	71.4	42.72	18.67	10.12	28.48	0.37	0.38
AJ10	414.42	25.58	41.94	19.46	10.06	28.52	0.37	0.25
AJ88	426.44	73.56	39.66	17.29	9.15	38.89	0.36	0.29
AJ85	435.66	21.00	44.40	15.03	9.44	31.11	0.43	0.37
AJ12	443.97	44.03	44.68	13.12	7.80	34.39	0.38	0.27
AJ18	449.82	22.18	45.16	13.62	7.88	33.33	0.44	0.31
AJ4	468.02	43.78	43.86	12.63	5.20	38.28	0.40	0.29
AJ30	463.73	68.27	42.85	12.08	5.49	39.56	0.40	0.33

crystallization of all silicate melts ultimately reaches the system SiO_2 - $NaAlSiO_4$ - $KAlSiO_4$, which has been called as "Petrogeny's Risidual System" by Bowen(1937). This would mean that in any differentiating magma, according to the reaction principle, the earliest mineral to fractionate are anorthite, diopside, phyllite, and / or forsterite with concomitent enrichment of quartz, orthoclase, albite, nepheline, leucite and kalsilite molecules in the risidual magma.

The differentiation index as defined by Thornton and Tuttle (op.cit.) is the sum of the weight percentages of normative quartz + orthoclase + albite + nepheline + leucite + kalsilite. These six minerals minus anorthite are the salic components of C.I.P.W. norm. The above workers consider anorthite as the basic constituent of a rock together with zircon, corundum, etc.

The C.I.P.W. norms of the analysed rock samples are given in Table-16 and differentiation indices have been plotted as abscissa against various oxide percentages as ordinate (Plate-33). It

Table-16: C.I.P.W.norms of the Ladakh Granites.

(Contd...)

Sample Number		AJ19A	AJ58	AJ84	AJ9	AJ8	AJ83	AJ78	AJ15A	AJ50	AJ28
S.No.		1	2	3	4	5	6	7	8	9	10
Norm minerals											
Quartz	(Qu)	29.54	29.34	27.90	29.10	28.26	29.46	27.06	30.12	31.50	31.50
Orthoclase	(Or)	16.68	17.23	18.35	17.80	18.35	18.34	17.79	18.90	18.90	18.35
Albite	(Ab)	23.05	23.58	25.15	24.63	25.15	24.62	29.34	25.67	26.20	27.77
Anorthite	(An)	12.23	12.57	11.95	11.67	11.95	11.12	10.84	10.28	10.00	9.45
Corundum	(C)	3.57	3.16	2.65	2.24	1.91	3.46	2.35	3.77	3.57	3.86
Acmite	(Ac)	-	-	-	-	-	-	-	-	-	-
Diopside	(Wo)	-	-	-	-	-	-	-	-	-	-
	(En)	-	-	-	-	-	-	-	-	-	-
	(Fs)	-	-	-	-	-	-	-	-	-	-
Wollastonite	(Wo)	-	-	-	-	-	-	-	-	-	-
Hyperthene	(En)	5.00	4.50	4.70	4.20	4.60	4.30	4.00	3.50	2.10	2.10
	(Of)	4.75	4.09	4.09	4.09	3.96	4.09	4.09	3.69	3.43	2.64
Magnetite	(Mt)	2.55	2.32	2.08	2.08	2.55	1.85	.209	1.84	1.39	1.86
Hametite	(Ha)	-	-	-	-	-	-	-	-	-	-
Ilmanite	(Il)	1.06	0.76	0.76	0.91	1.06	0.91	0.91	0.61	0.76	1.06
Apatite	(Ap)	-	-	-	-	-	-	-	-	-	-
Water	(H_2O)	1.65	1.58	1.64	2.07	1.75	1.84	1.64	1.22	0.44	0.60

Table-16 : C.I.P.W.norms of the Ladakh Granites
(Contd..)

Sample Number		AJ22	AJ5A	AJ52	AJ37	AJ41	AJ13	AJ17A	AJ6	AJ77	AJ34
S.No.		11	12	13	14	15	16	17	18	19	20
Norm minerals											
Quartz	(Qu)	35.64	30.42	31.20	33.36	30.96	32.04	33.84	32.94	34.14	35.60
Orthoclase	(Or)	19.00	18.92	17.79	18.90	19.46	20.57	19.46	20.01	20.01	17.79
Albite	(Ab)	21.48	29.34	30.39	25.15	30.91	26.74	28.30	27.77	28.29	32.41
Anorthite	(An)	10.00	8.90	8.06	10.29	7.78	9.73	9.17	9.45	9.73	7.78
Corundum	(C)	4.59	3.46	3.36	3.10	2.26	2.24	1.53	1.83	0.20	0.91
Acmite	(Ac)	-	-	-	-	-	-	-	-	-	-
Diopside	(Wo)	-	-	-	-	-	-	-	-	-	-
	(En)	-	-	-	-	-	-	-	-	-	-
	(Fs)	-	-	-	-	-	-	-	-	-	-
Wollastonite	(Wo)	-	-	-	-	-	-	-	-	-	-
Hypersthene	(En)	2.20	3.00	2.60	2.80	2.20	2.10	1.50	3.20	1.50	0.20
	(Of)	3.30	2.90	2.90	2.38	2.38	1.85	1.72	1.72	1.84	1.58
Magnetite	(Mt)	1.86	1.85	1.62	1.62	1.87	1.86	1.62	1.62	1.86	2.78
Hametite	(Ha)	-	-	-	-	-	-	-	-	-	-
Ilmanite	(Il)	0.76	0.61	0.91	0.61	0.61	0.61	0.76	0.91	0.91	0.60
Apatite	(Ap)	-	-	-	-	-	-	-	-	-	-
Water	(H_2O)	1.02	1.02	1.41	1.02	0.97	1.63	1.48	0.93	0.83	0.61

Table-16 : C.I.P.W.norms of the Ladakh Granites.
(concluded)

Sample Number		AJ17A	AJ21A	AJ16	AJ10	AJ88	AJ85	AJ12	AJ18	AJ4	AJ30
S.No.		21	22	23	24	25	26	27	28	29	30
Norm minerals											
Quartz	(Qu)	36.42	34.50	34.50	36.42	35.16	38.10	36.18	38.04	35.94	34.50
Orthoclase	(or)	21.12	21.60	18.90	22.24	20.03	21.68	20.57	22.79	23.35	24.46
Albite	(Ab)	26.72	28.82	29.34	27.77	33.53	26.20	31.44	27.24	31.96	33.53
Anorthite	(An)	6.95	8.62	8.90	4.72	6.11	7.50	6.11	6.12	3.89	3.36
Corundum	(C)	2.64	0.91	1.33	1.53	0.51	1.12	0.71	1.12	0.10	-
Acmite	(Ac)	-	-	-	-	-	-	-	-	-	-
Diopside	(Wo)	-	-	-	-	-	-	-	-	-	0.34
	(En)	-	-	-	-	-	-	-	-	-	0.10
	(Fs)	-	-	-	-	-	-	-	-	-	0.26
Wollastonite	(Wo)	-	-	-	-	-	-	-	-	-	-
Hyperthene	(En)	1.30	1.10	2.30	1.50	1.50	1.60	1.00	1.20	1.00	1.00
	(Of)	1.98	1.72	1.45	2.77	1.71	0.08	1.71	0.92	0.53	0.39
Magnetite	(Mt)	2.09	1.86	2.32	2.00	2.00	1.86	1.62	1.62	1.86	1.39
Hametite	(Ha)	-	-	-	-	-	-	-	-	-	-
Ilmanite	(Il)	0.61	0.76	0.76	0.60	0.66	0.61	0.60	0.76	0.61	0.76
Apatite	(Ap)	-	-	-	-	-	-	-	-	-	-
Water	(H_2O)	0.65	0.90	0.30	0.56	0.44	0.60	0.36	0.47	0.80	0.51

is observed from Plate-33 that with the increase in differentiation indices, SiO_2 curve shows an upward trend. This clearly indicates that with the advance of crystallization of magmas, the concentration of SiO_2 in the remaining fractions increases so far as the behaviour of the remaining oxides is concerned, it is observed that with the increase in the values of differentiation indices, Al_2O_3, Fe_2O_3, FeO, CaO and MgO show a downward trend. The total alkalis, however, show an increase with the increase in differentiation indices. Likewise the curves for K_2O and Na_2O show an upward trend with the increase in differentiation indices.

5. Poldervaart and Parker's Variation Diagram

The two well known authorities made a further advance over the method of Thornton and Tuttle (op.cit.) and suggested a binary variation diagram to study the changes in the chemistry of igneous rocks using Crystallization Index(C.I) as a parameter and plotting weight percentages of different oxides against it. They suggested the concept of "Petrogeny's Primitive System". The Principle behind

this method is that the fractionation in the case of magmas is dominated by the felsic and the mafic members of the reaction series. In case of felsic series the fractionation is from Ca - (Na+K), whereas in the case of mafic series, the fractionation is from Mg -(Fe^{++} + Fe^{+++}). The concept of Poldervaart and Parker(1964) appears to be more valid than that of Thornton and Tuttle (op.cit.) as the onset of crystallization of magmas is dominated mainly by the system $CaAl_2Si_2O_8$ (anorthite)-$CaMgSi_2O_6$(diopside)-Mg_2SiO_4 (forsterite), and is a simplified affair of fractionation advances, the system SiO_2- $NaAlSiO_4$ - $KAlSiO_4$ may not entirely be representative of the residue of magmas. The crystallization index is defined as :

$$C.I. = \sum(An + Di' + Fo' + Sp')$$

where,

$\sum$ = Summation sign.

An = normative anorthite.

Di' = Magnesian diopside(Ca Mg Si_2O_6) calculated from the normative diopside.

Fo' = Normative forsterite +normative enstatite converted to forsterite.

Sp' = Magnesian spinel (Mg Al_2O_4) calculated from normative corundum in ultramafic rocks.

the values of Di' and Fo' are calculated as:

$$Di' = \frac{\text{Mol.wt.of}CaMgSi_2O_6}{\text{Mol.wt. of } MgSiO_3} \times En_{di}(\text{Enstatite of normative diopside})$$

$$Di' = 2.15,\ 7003\ En_{di}(\text{Enstatite of normative dippside})$$

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

Where En_{hy} is enstatite of normative hypersthene.

$$Fo' = Fo + 0.700837\ En_{hy}(\text{enstatite of normative hypersthene})$$

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

The crystallization indices calculated from Table-16 are given in Table-14. Plate-34 shows different oxide weight percentages plotted against the crystallization indices. The curves for K_2O, Na_2O, $K_2O + Na_2O$, and SiO_2 show a general upward trend with the decrease in C.I. values. On the contrary MgO, CaO, FeO, Fe_2O_3 and Al_2O_3 curves display a downward trend with the fall in C.I. values.

6. Kuno Variation Diagram

Kuno (1968) suggested the construction of a binary variation diagram to study the chemistry of igneous rocks, using a new parameter which has been named by him as "Solidification Index" (S.I).
Kuno (op.cit.) defined solidification index as:

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

In Table-14 are given the solidification indices of analysed specimens of the granitic rocks of the study area calculated from Table-13. Plate-35 shows the S.I. values plotted as abscissa against the various oxides as the ordinate. The curves for Na_2O, K_2O, $Na_2O + K_2O$ and SiO_2 show a downward trend with the increase in the values of solidification indices. This clearly indicates a magmatic differentiation trend. The curves for MgO, CaO, FeO, Fe_2O_3 and Al_2O_3, however, display an upward trend with the rise in S.I.values.

The behaviour of the various binary variation diagrams shows that the rocks of the study area are of magmatic lineage.

B. Ternary Variation Diagrams

1. The System Quartz(SiO_2)- Potash-feldspar ($KAlSi_3O_8$)-Albite ($NaAlSi_3O_8$)

A number of ternary and a few quarternary diagrams, besides the above mentioned diagram, have been suggest-d from time to time for studying the chemistry of igneous rocks. The system SiO_2 (Quartz) - $KAlSi_3O_8$ (K-feldspar) - $NaAlSi_3O_8$ (Albite) investigated by Tuttle and Bowen (1938) is relevant to the case under consideration. This system is close to the composition of an "ideal granite". In this system the sides quartz-albite and quartz-K-feldspar, each have a binary eutectic E_2 and E_1 respectively (Plate-36, Fig.1). The two eutectic points E_1 and E_2 are connected up together by a cotectic line. The point of lowest temperature is close to the middle of the cotectic line and is marked

by the point 'M'. It is clear from the consideration of this diagram that from a magma of the composition of alkali granite, ultimately a liquid consisting approximately of equal amounts of SiO_2, $KAlSi_3O_8$ and $NaAlSi_3O_8$ will be obtained. This residual liquid will subsequently solidify to give a rock of the same composition. The two feldspars may form a single phase of mixed crystals if there is rapid cooling or a perthetic intergrowth showing partial unmixing of the solid solution or separate crystals if the cooling was very slow.

In support of above reasoning Bowen and Tuttle have shown that the composition of true granite falls near the low temperature minimum (near point 'M'). The results of this experiment support the crystallization - differentiation hypothesis for the formation of granites.

A serious flaw in Bowen's work is that calcium has not been taken into account and that the experiment is totally restricted to granites rich in alkalis and does not explain the origin of the

granite rich in anorthite component. This drawback has been overcome in the work of Von Platen (1965) who has demonstrated changes due to the addition of calcium in the above experiment of Bowen and Tuttle (op.cit.). We have thus a tetrahedral model consisting of SiO_2(quartz) - $NaAlSi_3O_8$ (albite) - $KAlSi_3O_8$ (potash-feldspar) - $CaAlSi_2O_8$(anorthite) arranged at its four corners. The different composition have been afterwards projected on to the plane of quartz, albite, potash-feldspar from the anorthite corner (Plate-36, Fig.2). The biggest advantage of this arrangement is that a system without anorthite can be easily compared with that containing it. An inspection of this system leads us to certain interesting observations which have a great significance. In the first instance, we can see that there are three sub-fields in this diagram meeting in a ternary eutectic, and each showing the initial crystallization of quartz or plagioclase or that of alkali feldspar. Furthermore, as the anorthite content increases, the position of ternary eutectic shifts towards increasing alkali feldspar and silica (E_3 shifts to E_4), which in effect means that there is an expansion of the plagioclase field (Plate-36, Fig.2).

Table-17: Percentages of normatives of Quartz(Qz) Orthoclase(Or)Albite(Ab),Orthoclase(Or) Albite(Ab)Anorthite(An)and Albite(Ab) Anorthite(An)from various samples recalculated to hundred per cent.

(Contd....)

Sample Number	Qz	Or	Ab	Or	Ab	An	Ab	An
AJ19A	42.65	24.08	33.27	32.10	44,36	23.54	65.33	34.67
AJ58	41.82	24.56	33.62	32.28	44.17	23.55	65.22	34.78
AJ85	39.07	25.70	35.23	33.10	45.35	21.55	67.78	32.22
AJ9	40.68	24.88	34.44	32.90	45.52	21.58	67.85	32.15
AJ8	39.38	25.57	35.05	33.10	33.35	21.55	67.79	32.21
AJ83	40.68	25.32	34.00	33.91	45.52	20.57	68.88	31.12
AJ78	36.47	23.98	39.55	30.69	50.61	18.70	73.02	26.98
AJ15A	40.32	25.30	34.38	34.46	46.80	18.74	71.40	28.60
AJ50	41.12	24.67	34.21	34.30	47.55	18.15	72.38	27.62
AJ28	40.58	23.64	35.78	33.03	49.97	17.00	74.61	25.39
AJ22	46.40	25.16	28.44	37.65	42.55	19.80	68.23	31.77
AJ5A	38.66	24.04	37.30	33.10	51.33	15.57	76.72	23.28
AJ52	39.30	22.41	38.29	31.63	54.04	14.33	79.03	20.97
AJ37	43.10	24.41	32.49	34.78	46.28	18.94	70.96	29.04
AJ41	38.07	23.93	38.00	33.46	53.15	13.39	79.90	20.10

Table-17: Percentages of normatives of Quartz(Qz) Orthoclase(Or) Albite (Ab), Orthoclase (Or) Albite (Ab) Anorthite (An) and Albite (Ab) Anorthite (An) from various samples recalculated to hundred per cent.

(concluded)

Sample Number	Qz	Or	Ab	Or	Ab	An	Ab	An
AJ13	40.37	25.93	33.70	36.06	46.88	17.06	73.32	26.68
AJ17A	41.47	23.85	34.68	34.18	49.71	16.11	75.52	24.48
AJ6	40.81	24.79	34.40	34.96	48.52	16.52	74.61	25.39
AJ77	41.41	24.27	34.32	34.48	48.75	16.77	74.40	25.60
AJ34	41.15	20.86	37.99	30.68	55.90	13.42	80.64	19.36
AJ17	43.22	25.06	31.72	38.55	48.77	12.68	79.31	17.29
AJ21A	40.63	25.53	33.94	36.67	48.75	14.58	76.97	23.03
AJ16	42.32	22.60	35.08	33.07	51.35	15.58	76.72	23.28
AJ10	42.14.	25.73	32.13	40.63	50.74	8.63	85.47	15.42
AJ88	39.63	22.58	37.79	33.54	56.21	10.25	84.58	15.42
AJ85	44.31	25.21	30.48	39.15	37.31	13.54	77.74	22.26
AJ12	41.02	23.32	35.66	35.39	54.10	10.51	83.73	16.27
AJ18	43.19	25.87	30.94	40.59	48.51	10.90	81.65	18.35
AJ4	39.39	25.59	35.02	39.44	53.98m	6.58m	89.15	10.85
AJ30	39.54	25.50	34.96	39.35	53.95	6.70	90.89	9.11

The normative quartz, albite and potash feldspar in the present case were recomputed to hundred per cent from the chemical analyses of the rocks and tabulated in Table-17. The data obtained is plotted on Plate-36, Fig.2. It is observed from the diagram that the plots do not fall near the central part of the diagram and show a scatter. This is because the granitic rocks of the area under mention are rich in calcium. Various points plotted on the figure suggest that the plagioclase field is enlarged, these are first to crystallise, and are in a wide range (An_8- An_{45}). This explains the well developed euhedral outlines in the granodiorite and monzogranite. A few points of some granites, with low anorthite content of plagioclase, plot close to Ab/An= ∞ line, thereby suggesting that these correspond in composition to the ideal granite of Bowen and Tuttle, (1938).

2. Trilinear Diagram According to Green and Poldervaart

Green and Poldervaart (1958) suggested ten ternary variation diagrams based on cation numbers.

The cations expressed as weight per cent have been grouped as indicated by the above workers. This investigation was found useful in fixing a definite variation trend for igneous rocks. The basic principle in the reasoning of Poldervaart and Green(1958) is that in the igneous rocks the major constituents are Si, Al, Fe(Total), Mg, Ca, Na and K. Si plays a passive role in magmatic differentiation in contrast to the one played by various cations occupying the interstitial position between various tetrahedra. So Si has accordingly been dropped. The two variable Na and K have been taken together as Na replaces K in rocks. The following five variables are Al, Fe(Total), Mg, Ca and (Na+K).

Ukai and Kimura (1965) worked on the above principle for granites of Karakoran and Hindukush and concluded that the majority of these rocks have originated through the process of granitization.

Similar study has been carried out on the rocks of the study area. The cation numbers calculated from the chemical analyses (Table-13) are given in Table-18. The ionic percentage calculated from the cation numbers is given in Table-19.

As already stated the five variables are Al, Fe(Total), Mg, Ca and (Na+K). These have been grouped in various combinations as shown in Table-19. Ten variation diagrams have been constructed as indicated in Plate-37.

(i) Group A

This group includes three variation diagrams in which the weight percentages of Fe (Total), Mg and Ca are plotted against the common weight percentages of Al and (Na+K) as shown in Plate-37, (Figs.1,3 and 4). An inspection of the points shows that these fall close to the middle of two corners represented by Al and (Na+K). This is characteristic of igneous rocks, although some of the points show scattering. These scattering of points is due to the lower and higher contents of Al and (Na+K) of some of the samples. The overall trend is, however, similar to those of igneous rocks.

(ii) Group B

Three diagrams in which Al, Ca

Table-18: Cations of the chemically analysed samples of Ladakh Granites.

(contd..)

Sample number	Constituents							
	Si	Al	Fe^{+3}	Fe^{+2}	Mg	Ca	Na	K
AJ19A	30.94	8.25	1.22	2.60	1.17	1.89	2.04	2.36
AJ58	31.10	8.20	1.12	2.56	1.08	1.82	2.07	2.45
AJ84	31.21	8.10	1.01	2.52	1.14	1.71	2.22	2.57
AJ9	31.26	8.23	1.18	2.56	1.02	1.68	2.18	2.61
AJ8	31.32	8.26	1.21	2.68	1.10	1.71	2.22	2.48
AJ83	31.49	8.31	0.74	2.52	1.05	1.64	2.18	2.61
AJ78	31.59	8.10	1.05	2.60	0.96	1.57	2.60	2.57
AJ15A	31.84	8.47	1.08	2.33	0.84	1.50	2.26	2.48
AJ50	32.15	8.39	0.73	2.06	0.51	1.42	2.29	2.65
AJ28	32.19	8.52	0.94	1.98	0.75	1.35	2.44	2.69
AJ22	32.29	8.41	0.91	2.08	0.54	1.42	1.89	2.57
AJ5A	32.53	8.41	0.91	1.94	0.54	1.28	2.60	2.65
AJ52	32.66	8.20	0.80	1.86	0.63	1.17	2.67	2.65
AJ37	32.71	8.04	0.84	1.63	0.69	1.49	2.22	2.69
AJ41	32.92	7.80	0.87	1.71	0.54	1.14	2.70	2.78

Table-18: Cations of the chemically analysed samples of Ladakh Granites.
(concluded)

Sample number	Constituents							
	Si	Al	Fe^{+3}	Fe^{+2}	Mg	Ca	Na	K
AJ13	32.96	7.83	0.87	1.51	0.51	1.39	2.33	2.90
AJ17A	33.37	7.41	0.84	1.55	0.36	1.32	2.48	2.69
AJ6	33.50	7.83	0.84	1.47	0.78	1.35	2.44	2.82
AJ77	33.83	6.24	0.91	1.55	0.36	1.39	2.48	2.86
AJ34	34.15	6.80	1.37	1.55	0.49	1.14	2.81	2.48
AJ17	34.15	7.22	0.98	1.59	0.31	1.00	0.37	2.98
AJ21A	34.30	7.25	0.87	1.47	0.27	1.25	2.52	3.02
AJ16	34.38	7.31	1.19	1.47	0.54	1.28	2.59	2.65
AJ10	34.57	6.77	1.08	1.94	0.36	1.21	2.44	3.15
AJ88	34.76	6.88	1.05	1.51	0.36	1.10	2.96	2.82
AJ85	34.88	6.88	1.08	0.87	0.39	1.10	2.30	3.07
AJ12	35.04	6.84	0.81	1.12	0.24	0.89	2.78	2.94
AJ18	35.13	6.80	0.84	1.08	0.30	0.89	2.41	3.19
AJ4	35.25	6.35	0.87	0.89	0.24	0.57	2.82	3.31
AJ30	35.46	6.48	0.66	0.90	0.27	0.60	2.89	3.44

and (Na+K) are plotted against common Fe and Mg (Plate-37,Figs.2,5 and 6). The points plotted in Fig.2 are similar to those of igneous rocks although a little scattering is noticed. The points plotted in Fig.5 show erratic behaviour but the general trend is similar to those of igneous rocks. The scattering of points appears to be due to the higher and lower contents of Ca and Mg. The system Mg - Fe (Total)-(Na+K) plotted in Fig.6 resembles those of igneous rocks.

Nockolds and Allen (1953) have suggested drawing of such diagrams and to them the curve shown here is representative of magmatic differentiation.

(iii) Group C

The last four diagrams plotted in Plate-37, Figs.7,8,9 and 10, where Ca occupies a corner in all with any of Mg, Al, (Na+K) or Fe(Total) occupying other two corners.

The variation systems Mg-Ca-Al

Table-19: Combination of three components expressed in ionic weight per cent.

(contd..)

Sample number	Fig.1			Fig.2		
	Ca	Al	Na+K	Mg	Total Fe	Al
AJ19A	13.00	56.74	30.26	8.83	28.85	62.32
AJ58	12.52	56.40	31.08	8.33	28.40	63.27
AJ84	11.72	55.48	32.80	8.93	27.64	63.43
AJ9	11.42	55.99	32.59	7.91	28.24	63.85
AJ8	11.65	56.30	32.05	8.30	29.36	62.34
AJ83	11.12	56.38	32.50	8.32	25.83	65.85
AJ78	10.58	54.58	34.84	7.56	28.71	64.73
AJ15A	10.20	57.58	32.22	6.62	26.80	66.58
AJ50	9.63	56.88	33.49	4.36	23.87	71.77
AJ28	9.00	56.80	34.20	6.15	23.95	69.90
AJ22	9.94	58.85	31.21	4.52	25.05	70.43
AJ5A	8.96	56.29	35.15	4.58	24.15	71.27
AJ52	7.96	55.82	36.22	5.48	23.15	71.37
AJ37	10.32	55.68	34.00	6.16	22.05	71.79
AJ41	7.90	54.10	38.00	4.66	23.62	71.44
AJ13	9.62	54.19	36.19	4.66	21.80	73.54
AJ17A	9.50	53.31	37.19	3.55	23.52	72.93
AJ6	9.35	54.22	36.43	7.15	21.15	71.70
AJ77	10.72	48.11	41.17	3.98	27.15	68.87
AJ34	8.62	51.40	39.98	4.80	28.60	66.60
AJ17	7.37	53.20	39.43	3.07	25.44	71.49
AJ21A	8.90	51.64	39.46	2.74	23.73	73.53
AJ16	9.25	52.86	37.89	5.14	25.31	69.55
AJ10	8.92	49.89	41.19	3.55	29.75	66.70
AJ88	8.00	50.00	42.00	3.68	26.12	70.20
AJ85	8.24	51.53	40.23	4.23	21.15	74.62
AJ12	6.62	50.85	42.53	2.67	21.42	75.91
AJ18	6.70	51.16	42.13	3.33	21.28	75.39
AJ4	4.37	58.65	46.98	2.89	21.07	76.04
AJ 30	4.47	48.33	47.20	3.25	18.77	77.98

Table-19: Combination of three components expressed in ionic weight per cent.

(contd..)

Sample number	Fig.3			Fig.4		
	Total Fe	Al	Na+K	Mg	Al	Na+K
AJ19A	23.20	50.10	26.70	8.47	59.69	31.84
AJ58	22.44	49.79	27.57	7.83	59.42	32.75
AJ84	21.50	49.33	29.17	8,13	57.73	34.14
AJ9	21.75	49.40	28.85	7.26	58.63	34.12
AJ8	23.09	49.02	27.89	7.82	58.74	33.44
AJ83	19.92	50.80	29.28	7.42	58.73	33.85
AJ78	21.57	47.87	30.56	6.74	56.92	36.34
AJ15A	20.52	50.96	28.52	5.98	60.28	33.74
AJ50	17.30	52.50	30.65	3.69	60.62	35.69
AJ28	19.88	58.00	34.92	5.21	59.16	35.63
AJ22	18.85	53.03	28.12	4.03	62.71	33.26
AJ5A	17.26	50.94	31.80	3.80	59.22	36.98
AJ52	16.44	50.68	32.88	4.45	57.95	37.60
AJ37	16.02	52.14	31.84	5.05	58.94	36.01
AJ41	16.26	49.18	34.56	3.90	56.44	39.66
AJ13	15.42	50.71	33.87	3.76	57.70	38.54
AJ17A	15.97	49.50	34.53	2.79	57.26	39.95
AJ6	15.00	50.84	34.16	5.62	56.45	37.93
AJ77	17.52	44.44	38.03	3.01	52.26	44.72
AJ34	19.45	45.30	35.25	3.89	54.05	42.06
AJ17	16.97	47.68	35.35	2.41	56.06	41.53
AJ21A	15.46	47.92	36.32	2.07	55.51	42.42
AJ16	17.49	48.06	34.45	4.12	55.84	40.04
AJ10	19.63	44.02	36.35	2.83	53.22	43.95
AJ88	16.82	45.20	37.98	2.76	52.84	44.40
AJ85	13.73	48.45	37.82	3.08	54.43	42.49
AJ12	13.32	47.20	39.48	1.88	53.43	44.69
AJ18	13.35	47.28	39.37	2.37	53.54	44.09
AJ4	12.36	44.60	43.04	1.89	49.92	48.19
AJ30	10.88	45.09	44.03	2.06	49.54	48.40

Table-19: Combination of three components expressed in ionic weight per cent.

(contd...)

Sample number	Fig.5			Fig.6		
	Mg	Ca	Total Fe	Mg	Total Fe	Na+K
AJ19A	17.00	27.48	55.52	12.46	40.68	46.86
AJ58	16.41	27.67	55.92	11.64	39.65	48.71
AJ84	17.87	26.80	55.33	12.05	37.31	50.64
AJ9	16.08	26.51	57.41	10.80	38.52	50.68
AJ8	16.42	25.52	58.06	11.35	40.14	48.51
AJ83	17.65	27.56	54.76	11.54	35.83	52.63
AJ78	15.53	25.41	59.06	9.82	37.32	52.86
AJ15A	14.61	26.09	59.30	9.34	37.93	52.73
AJ50	10.81	30.08	59.11	6.19	33.86	59.95
AJ28	14.94	26.90	58.16	8.52	33.18	58.30
AJ22	10.91	28.69	60.40	6.75	37.42	55.83
AJ5A	11.56	27.41	61.03	6.25	32.98	60.77
AJ52	14.12	26.23	59.65	7.31	30.89	61.60
AJ37	14.84	32.06	53.20	8.56	30.60	60.84
AJ41	12.68	26.76	60.56	6.28	30.00	63.72
AJ13	11.91	32.49	55.60	6.28	29.31	64.41
AJ17A	8.84	32.44	58.72	4.54	30.18	65.28
AJ6	17.56	30.42	52.02	9.34	27.66	63.00
AJ77	8.55	33.02	58.43	4,41	30.15	65.44
AJ34	10.77	25.05	64.18	5.64	33.56	60.80
AJ17	7.99	25.78	66.23	3.76	31.23	65.01
AJ21A	6.50	30.05	56.25	3.31	28.71	67.98
AJ16	12.05	28.57	59.38	6.40	31.51	62.09
AJ10	7.84	26.37	65.79	4.01	33.66	62.33
AJ88	8.65	23.98	55.70	4.13	29.42	66.45
AJ85	10.46	31.96	56.68	5.06	25.30	69.64
AJ12	12.75	29.08	63.07	3.05	24.46	72.49
AJ18	9.65	28.62	61.73	3.84	24.55	71.61
AJ4	9.34	22.18	68.48	2.95	21.65	75.40
AJ30	11.11	24.70	64.19	3.32	19.12	77.86

Table-19: Combination of three components expressed in ionic weight per cent.

(contd...)

Sample number	Fig.7			Fig.8		
	Mg	Ca	Al	Mg	Ca	Na+K
AJ19A	10.34	16.72	72.94	15.68	25.33	58.99
AJ58	9.73	16.40	73.87	14.55	24.52	60.93
AJ84	10.41	15.61	73.98	14.92	22.38	62.70
AJ9	9.33	15.37	75.30	13.62	22.43	63.95
AJ8	9.94	15.44	74.62	14.64	22.76	63.00
AJ83	9.56	14.90	75.54	14.03	21.92	64.05
AJ78	9.04	14.76	76.20	12.47	20.38	67.15
AJ15A	7.78	13.87	78.35	11.64	21.19	66.97
AJ50	4.95	13.75	81.30	7.42	20.67	71.91
AJ28	7.06	12.72	80.22	10.37	18.67	70.96
AJ22	5.20	13.70	81.10	8.41	22.11	69.48
AJ5A	5.28	12.52	82.20	7.63	18.11	74.26
AJ52	6.30	11.70	82.00	8.85	16.43	74.72
AJ37	6.75	14.58	78.67	9.73	21.01	69.26
AJ41	5.70	12.02	82.28	7.54	15.92	76.54
AJ13	5.24	14.30	80.16	7.15	19.50	73.35
AJ17A	3.96	14.52	81.52	5.26	19.27	75.47
AJ6	7.84	13.55	78.62	10.55	18.27	71.18
AJ77	4.50	17.40	78.10	5.08	19.60	75.32
AJ34	5.81	13.53	80.66	7.08	16.47	76.45
AJ17	3.63	11.73	84.64	4.65	15.01	80.34
AJ21A	3.08	14.25	82.67	3.82	17.70	78.48
AJ16	5.92	13.72	80.06	7.64	18.13	74.23
AJ10	6.47	15.35	81.18	5.03	16.90	78.07
AJ88	4.32	13.19	82.49	4.97	15.20	79.83
AJ85	4.66	13.14	82.20	5.68	16.04	78.28
AJ12	3.02	11.16	85.82	3.50	13.00	83.50
AJ18	3.75	11.13	85.12	4.42	13.10	82.48
AJ4	3.35	7.97	88.68	3.46	8.21	88.33
AJ30	3.67	8.17	88.16	3.75	8.33	87.92

Table-19 : Combination of three components expressed in ionic weight per cent.

(Concluded)

Sample number	Fig.9			Fig.10		
	Ca	Total Fe	Al	Ca	Total Fe	Na+K
AJ19A	13.54	27.36	59.10	18.69	37.79	43.52
AJ58	13.29	26.86	59.85	18.16	36.72	45.12
AJ84	12.82	26.46	60.72	17.05	35.19	47.56
AJ9	12.40	26.86	60.74	16.62	36.00	47.38
AJ8	12.34	28.06	59.60	16.60	37.77	43.63
AJ83	12.42	24.68	62.90	16.92	33.64	49.44
AJ78	11.79	27.40	60.81	15.11	35.13	49.76
AJ15A	11.21	25.49	63.30	15.44	35.34	49.22
AJ50	11.27	22.14	66.59	15.52	30.50	53.98
AJ28	10.56	22.83	66.61	14.36	31.06	54.58
AJ22	11.08	23.32	65.60	16.00	33.70	50.30
AJ5A	10.20	22.73	67.07	13.65	30.38	55.97
AJ52	9.73	22.11	68.16	12.78	29.07	58.15
AJ37	12.42	20.58	67.00	16.80	27.84	55.36
AJ41	9.89	22.40	67.71	12.40	28.05	59.55
AJ13	11.98	20.52	67.50	15.45	26.44	58.11
AJ17A	11.86	21.50	66.64	14.87	26.91	58.22
AJ6	11.75	20.10	68.15	15.31	25.90	58.79
AJ77	13.78	24.38	61.84	15.12	26.77	58.11
AJ34	10.50	26.89	62.61	12.20	31.23	56.57
AJ17	9.27	23.82	66.91	11.21	28.81	59.98
AJ21A	11.53	21.59	66.88	13.70	25.63	60.67
AJ16	11.38	23.64	64.98	13.94	28.97	57.09
AJ10	11.00	27.45	61.55	12.32	30.75	56.93
AJ88	10.43	24.29	65.28	11.68	27.11	61.23
AJ85	11.08	19.64	69.28	13.06	23.16	63.78
AJ12	9.22	19.98	70.80	10.42	22.60	66.78
AJ18	9.26	19.98	70.76	10.58	22.83	66.59
AJ4	6.57	20.27	73.16	6.74	20.80	72.46
AJ30	6.94	18.06	75.00	7.61	19.77	80.42

and Mg-Ca-(Na+K) plotted in Fig.7 and 8 respectively, show a trend which is similar to those of igneous rocks. In case of Figs. 9 and 10 the points plotted closely follow the variation course of igneous rocks.

It is evident from the above discussion of ten variation diagrams that the rocks of the area show a magmatic differentiation trend.

A close study of the various binary and ternary systems clearly shows that the rocks of the study area are of magmatic lineage.

C H A P T E R - VII

EMPLACEMENT AND AGE OF THE GRANITES

A - Emplacement of Granites

The following field, mineralogical, petrographic and petrochemical evidences suggest a magmatic origin for the granitic rocks of the part of Ladakh granite exposed around Sakti.

(1) The uncomformable contact of the granitic rocks with the overlying sedimentaries of the area (Tuchik Formation) (See frontise piece).

(2) Small xenoliths with zig-zag outline composed predominently of biotite, quartz, feldspar and some accessory minerals, are seen at a few places enclosed in the body of the granitic rocks (Plate-7, Fig.6). Feldspars are intensively sericitized.

(3) There is a zonal arrangement of the granitic rocks from central part of the granitic body to the periphery. Monzogranite occupies the central part of the granite body (northern part in the study area) and it is followed to the periphery by granodiorites and tonalites (Plate-38).

(4) The anorthite content in the feldspars of the peripheral tonalites is to a higher extent as compared to the feldspars of transtional granodiorites and central monzogranites.

(5) The plagioclases of the granitic rocks are of a low structural state. According to Vogel (1964) plagioclases of low structural state generally characterise granitic rocks of magmatic lineage.

(6) Many plagioclases in the granitic rocks under study show relict oscillatory zoning when seen under the microscope (Plate-17, Figs.5,6 and Plate-18, Fig.3). Relict oscillatory zoning, according to Karl (1959), is characteristic of plagioclases in granitic rocks of magmatic origin.

(7) The zircons in the granitic rocks under study are mostly euhedral and show a very peaked unimodal size distribution. They also show a significant linear Reduced Major Axis trend. These characteristics of zircons in granitic rocks, according to many authorities (e.g. Poldervaart, 1968), is suggestive of granitic rocks of magmatic origin.

(8) Petrochemical studies (in terms

of Binary and Ternary diagrams; (see Chapter VI) also suggest that the granitic rocks under study are of magmatic lineage.

(9) Mineralogical and to some extent chemical characters of the rocks of the study area are indicative of a single but prolonged magmatic phase for these rocks.

While Shah et al. (1976) believe Ladakh granite to be of two separate episodes of igneous activity, others (Frank et al. 1977; Colchen and Le Fort, 1977; Gansser, 1979; Sapru, 1980; and Srikantia and Razdan, 1980) believe that the whole intrusive is of a single major plutonic event. The present study support the opinion of Frank et al.(1977), Sapru (1980) and others than of Shah et al.(op.cit.). The low structural state of plagioclases (as determined by X-ray diffraction method) indicates that the granite magma cooled at a slow rate. Besides, X-ray study of the alkali feldspars in the tonalites suggests that they are of lower triclinicity as compared to the alkali feldspars

of centrally disposed monzogranites which would suggest that the cooling rate of magma towards the northern side of the granitic body was at a slower rate than at the peripheral part (tonalites).

From the data at hand and considering the work of other authors on other parts of this batholith, an attempt may be made to trace the plutonic history of Ladakh granite. Ladakh granite essentially constitutes the basement of the region, the batholith having been formed as a single magmatic episode. The prolonged magmatic history of the granite body is proved by the evidences indicating slow cooling as suggested above. It is possible that in certain parts of the batholith occasional remoblization at a later date could have taken place but no such evidence is available in the present area of study. The Ladakh granite batholith must have been emplaced as a single but a prolonged episode during Pre-Tertiary times.

B - Age of Ladakh Granite

Ladakh granite extends over a distance of nearly 1600 kms from Nanga Parbat in the northwest to Kailash mountains in the southeast. Consequently several age interpretations, based on some local stratigraphic evidence as to these rocks are given in the literature. Precise radio - metric age determinations of the rocks are conspicuous by their absence. What exists is only fragmentary and again highly controversial. An attempt is made in this section to review briefly several age interpretations given to the Ladakh granites and the probable age the author likes to assign to these granites purely based on stratigraphic evidence.

Strachey (1851) thought the granitic rocks of Ladakh region as of pre-Cambrian age as he noticed at several localities the granite body intrusive into pre-Cambrian schists. Stoliczka (1866) assigned a Cretaceous age to the rocks and Hayden (1904) a pre-Carboniferous

age as he noticed fragments of the granitic rocks included in Kuling shales of upper Permian age and also in the Agglomeratic slates of Kashmir of Upper Carboniferrous age. Wadia (1931 - 32) assigned a post Cretaceous age to the granitic rocks as they cut across orbitolina limestone decidedly of Upper Cretaceous age. De Terra (1932) gave a Hercynian age, Norin (1946) a post Palaeozoic and Misch (1949) a Tertiary age to the granitic rocks of Ladakh region.

Kazmi (1951) considered the hornblende granites of Gilgit area as extension of Ladakh granites and assigned a Palaeozoic age to these rocks. Berthelsen (1953) mapped the contact of Rupshu granite and Tso - Morari gneiss of Ladakh with upper Palaeozoic rocks as tectonic. Ivanae et al. (1955) also observed that the hornblende granitic rocks of Gilgit area as intrusive into upper Palaeozoics and therefore assigned a post upper - Palaeozoic age to the proper Ladakh granite.

Desio et al. (1964) observed Karakoram and Ladakh granites to be in thrust contact with upper Cretaceous rocks and assigned post Miocene age to Karakoram granites. Tewari (1964) has observed that Ladakh granite is intrusive into Palaeozoic, Late Mesozoic and even Tertiary fossiliferrous sediments. Gansser (1964) assigned a pre - upper Cretaceous age to these rocks. Sapru (1980) considers that Ladakh granite emplaced during Cretaceous to early Tertiary times.

Extensive radiometric data as to age are not yet available on Ladakh granite; what exists is only fragmentary. These sporadic determinations give an age between 49 - 45 million years to these rocks. An age of 45 million years by Rb - Sr method has been suggested by Desio and Zanettin (1970). Saxena and Miller (1972) calculated the age of these granitic rocks by K - Ar method on biotites and found them to be 48.4 ± 1.7 m.y Lal and Nagpaul (1975) based on fusion track studies on apatites, dated the rocks of

Ladakh granite to be 46 ± 5 m.y. of age. Geological Survey of India (1976) give the range between 48 to 45 m.y.

Shah et al. (1976) consider that the granites consists of two phases; a metamorphic phase of pre - Tertiary age and non - metamphic phase of Tertiary age. Frank et al. (1977) assign a late Cretaceous to early Tertiary age to these Ladakh intrusives. Srikantia and Razdan (1980) conclude upper Cretaceous as the upper age limit of the Ladakh granite body.

It is to be noted however that the sedimentaries of the region named differently by different workers (Indus Molasse - Gansser, 1976 ; 1979, Frank et al., 1977; Tuchik Formation - Sapru 1980; Indus group Srikantia and Razdan , 1980) transgress over Ladakh granites. The sedimentaries are shown to be decidedly of Tertiary age. Therefore, the granitic rocks must be atleast of pre - Tertiary age. The basal part of Tuchik Formation shows granitic boulders of Ladakh granite affinity. This further substantiates

pre - Tertiary age for the Ladakh granites.

From the above line of argument it could be safely concluded that the Ladakh granitic rocks at least in the study area are of pre - Tertiary age.

The granitic activity was followed by the emergence of the area at a very rapid rate. The time gap between the emplacement and emergence cannot be precisely determined because nothing definite is known about the last stage of episode or the upper age limit of the batholith. But the succeeding sedimentaries (Tuchik Formation) contain a basal conglomerate unit bearing a large proportion of the granite pebbles and boulders derived from the batholith and the conglomerate itself is believed to be of middle Tertiary age. This suggests that by that time granite batholith had already emerged and was a region of positive relief. No where in the area of study is the granite showing intrusive relationship with any of the sedimentary units and, therefore, it may be regarded that the emplacement of the granite body had concluded long before the deposition of the overlying sedimentary sequence.

Ladakh batholith is reported to bear a variety of other differentiates within the complex. But a batholith of this dimension can be expected to have various trends of differentiation in a linear fashion. The present area of study only represents a limited part of the whole granite mass and, therefore, it may not be possible to work out a complete history of magmatic differentiation based on a local study of this type. But suffice it to say that the present study supports the idea of magmatic origin of the granitic rocks entirely within a batholithic frame work.

C H A P T E R - VIII

SUMMARY AND CONCLUSIONS

A field, mineralogic, petrographic and petrochemical study of a part of Ladakh granite around Sakti, Ladakh district of Jammu and Kashmir State, has revealed the following important characters:-

(1) Regionally three broad structural units are recognised in the area : (a) the impressive Ladakh granite batholith to the north;

(b) the volcanogenic - sedimentary rocks known as Indus - Tsangpo Suture Zone sequence to the south stratigraphically (with an unconformity) overlying the northern granites; and (c) the southern most Tethyan sediments.

The Indus Tsangpo Suture Zone separates the lithotectonic sub - Himalayan unit from those of Transhimalaya which form altogether a different geological province.

(2) Two litho stratigraphic units are recognised in the study area. The earlier, the Ladakh granite massif itself and the later unconformably overlying it, Tuchik Formation. There is a veener over these formations of Pleistocene to Subrecent, fluvioglacial to fluvial deposits.

(3) Three sets of joints characterise Ladakh granite. There are two sets of vertical

and horizontal joints and the third is at an angle of 25° to 80° to the vertical. These three sets of joints are responsible for weathering of the granite body giving rise to angular blocks which are seen scattered all around the granite body especially at the lower reaches. Mild foliation trending northwest characterise the rocks.

(4) The Tuchik Formation consists of two sub-units. A lower conglomerate unit and an upper sandstone - shale unit. The sandstone of the upper unit is made up of quartz, feldspar and rock fragments. The shale occurs as thin intercalations in the sandstone.

(5) The basal conglomerate unit of Tuchik Formation is predominently made up of boulders and pebbles of granite composition. The rocks of the overlying sandstone unit petrographically may be referred to as subaskoses and feldspathic graywackes. The frame work grains are quartz, feldspar, granitic

rock fragments cemented or held together by a matrix of clayey material.

(6) Intercalated shales with sandstone are light to dark green in colour, well foliated, with a glassy sheen along the planes of foliation. Petrographically they are made up of flakes of chlorite and muscovite, feldspars, quartz and occasional biotite.

(7) Sandstone unit of Tuchik Formation shows crude lamination, some ripple marks and graded bedding.

The sandstone units of Tuchik Formation show a strike of N 40° W - S 40° E to N 65° W - S 65° E with a dip 30° to 45°NW.

(8) Based on modal counts of 70 representative thin sections, granitic rocks of the area are petrographically classifiable as tonalites, granodiorites and monzogranites (Petrographic nomenclature after Streikeisen, 1976).

(9) Tonalites, granodiorites and monzogranites in the field show gradational contacts, monzogranites at the core of the granite body giving place to tonalites at the margin with the granodiorites as the transitional zone in between.

(10) Tonalites in handspacemens are dark grey in colour, vary in specific gravity from 2.68 to 2.82. Hornblende and biotite can be seen megascopically in these rocks. Granodiorites are medium to coarse grained in texture (with overall grain size 3.2mm), light grey in colour, with specific gravity varying from 2.65 - 2.78. Monzogranites are light coloured and vary in specific gravity from 2.64 - 2.71.

(11) Mineralogically the granitic rocks are composed of quartz, plagioclases, potash feldspars, hornblende, biotite, muscovite and accessories like apatite, zircon and opaques. Plagioclases range in An content from An_8 to An_{45} with $n\beta$ values varying from 1.535 to 1.555 as estimated by

chemical and optical data. The X-ray study of plagioclases indicate these to be of low structural state. The $2V_x$ range is from 77° to 83°.

The X-ray study of plagioclases indicate these to be of low structural state. Similar study of orthoclases suggest that they are of intermediate to maximum microcline and triclinic in crystal structure. The chemical data of orthoclases show that these range in composition from $^{Or}30.68$, $^{Ab}55.90$, $^{An}13.42$ to $Or_{40.63}$, $Ab_{50.74}$, $An_{8.63}$.

The plagioclases as seen in thin sections show alteration to sericite and kaoline, and potash feldspars to muscovite and kaoline. The degree of alteration appears to be less in potash feldspars as compared to the degree of alteration in plagioclases.

Hornblende is dark green in colour, mostly prismatic in shape, highly pleochroic with extention angle ($Z \wedge C$) from 16° to 18° and $2V_x$

ranging from 71° - 76°. Biotite occurs as twisted and bent flakes with R.I. (γ values) varying from 1.648 to 1.654 indicating a weight percentage of Feo + 2 (Fe_2O_3 + TiO_2) from 25.50 to 29.50. It appears to be of two generations as it is observed either as independent flakes or included in other minerals suggestive of an early generation.

(12) The following evidences suggest as to the magmatic origin of Ladakh granite as studied around Sakti.

(a) presence of xenoliths in the granite body;

(b) zonal arrangement of the granitic rocks, monzogranites towards the north (central part of the granite body) followed by granodiorites and tonalites towards the periphery;

(c) plagioclases having more An content are found in the southern part (An_{45}) as compared to those found in the northern part (An_8) of the

granite body.

(d) relict oscillatory zoning in the plagioclases.

(e) low structural state of the plagioclases.

(f) euhedral nature of the zircons and their significant linear RMA trend, indicate a magmatic lineage for the granitic rocks of the study area.

(13) Petrochemical study of the rocks (in terms of binary and ternary systems of major elements) also suggest a magmatic origin of the granitic rocks.

(14) As to the age of the Ladakh granite body under study around Sakti, although no conclusive age data are available, the author on the basis of field and preliminary radiometric data by others feels that it represents more or less a Cretaceous to early Tertiary magmatic event.

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ILLUSTRATIONS

Explanation of Plate - 1

Location and route map of the study area.

LOCATION AND ROUTE MAP

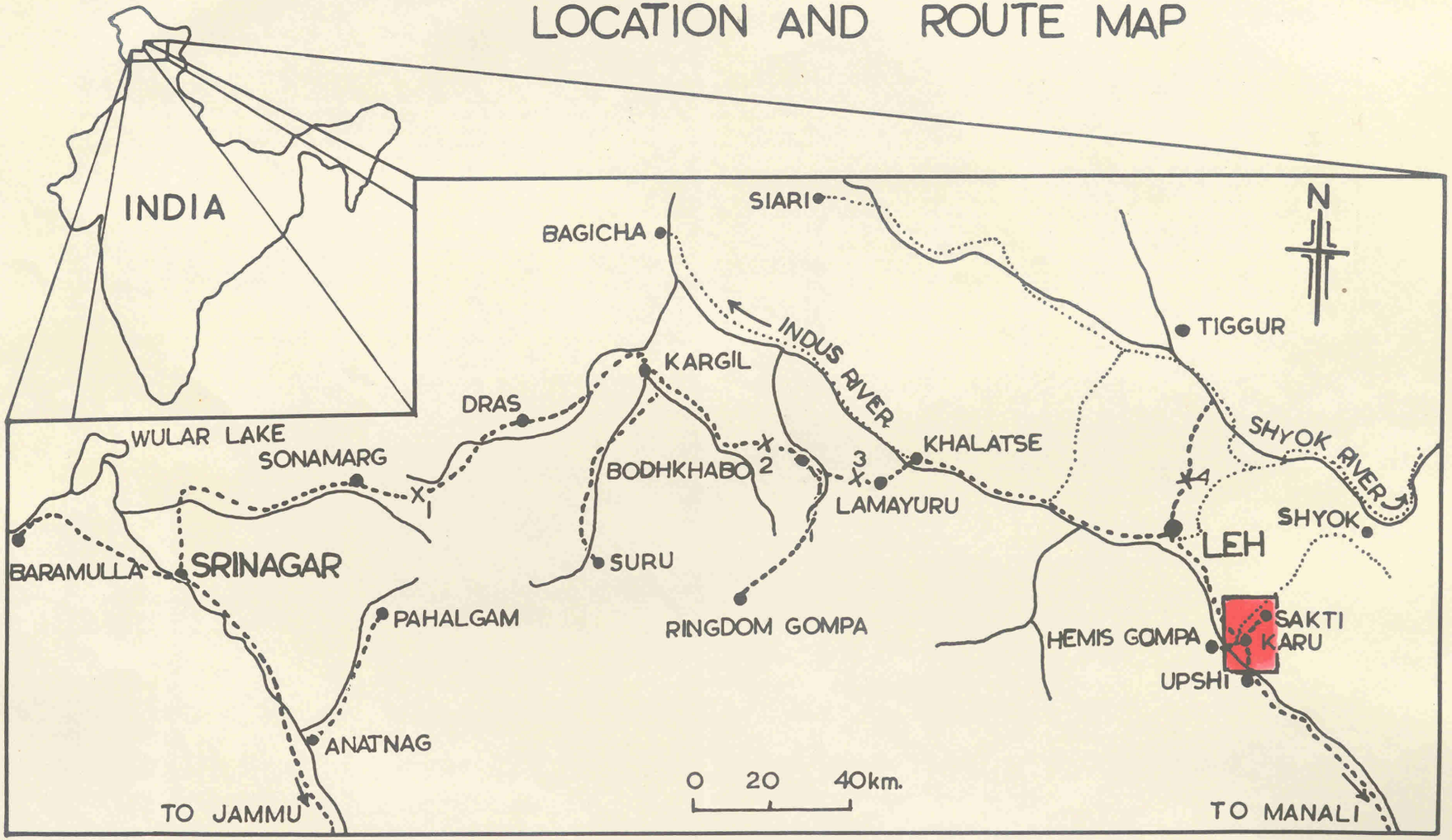
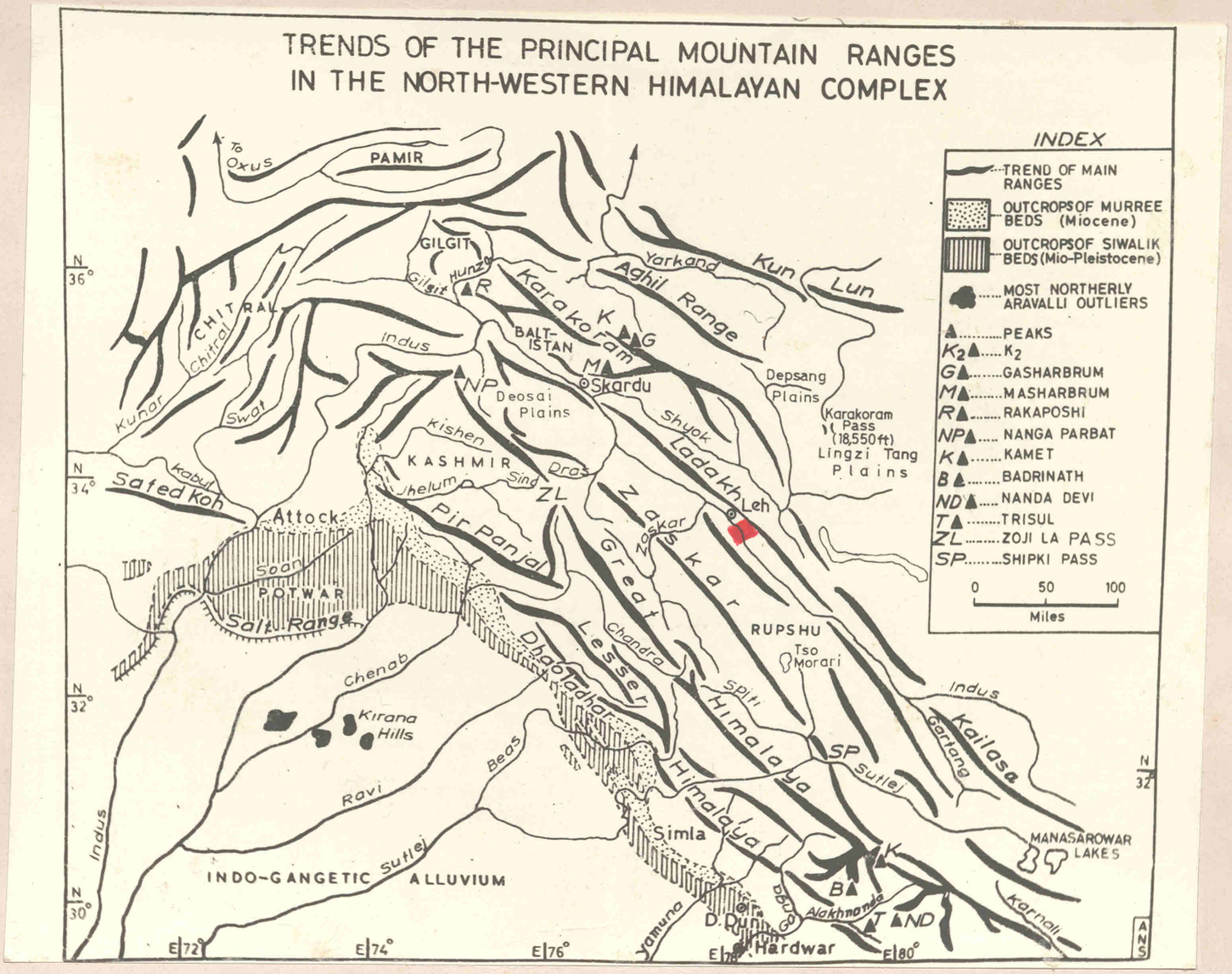


PLATE-1

Explanation of Plate - 2

Physiographic map of Jammu and Kashmir State.


TRENDS OF THE PRINCIPAL MOUNTAIN RANGES
IN THE NORTH-WESTERN HIMALAYAN COMPLEX
INDEX
TREND OF MAIN RANGES
OUTCROPS OF MURREE BEDS (Miocene)
OUTCROPS OF SIWALIK BEDS (Mio-Pleistocene)
MOST NORTHERLY ARAVALLI OUTLIERS
PEAKS
K2 ..... K2
G ..... GASHARBRUM
M ..... MASHARBRUM
R ..... RAKAPOSHI
NP ..... NANGA PARBAT
K ..... KAMET
B ..... BADRINATH
ND ..... NANDA DEVI
T ..... TRISUL
ZL ..... ZOJI LA PASS
SP ..... SHIPKI PASS
0 50 100
Miles
PAMIR
To Oxus
GILGIT
Hunza R
Gilgit
Yarkand
Kun Lun
Aghil Range
Karakoram
K
G
BALTISTAN
M
Skardu
NP
Deosai Plains
Depsang Plains
Karakoram Pass (18,550 ft)
Lingzi Tang Plains
Shyok
Ladakh
Leh
CHITRAL
Chitral
Indus
Kunar
Swat
Kishen Ganga
KASHMIR
Jhelum
Sind
Dras
ZL
Zaskar
Kabul
Safed Koh
Attock
Pir Panjal
Great Zaskar
Soan
POTWAR
Salt Range
Indus
Chenab
Dhaola Dhar
Lesser Himalaya
Chandra
Spiti
RUPSHU
Tso Morari
Kirana Hills
Beas
Ravi
Sutlej
Himalaya
SP
Indus
Gartang
Kailasa
MANASAROWAR LAKES
Simla
INDO-GANGETIC ALLUVIUM
Yamuna
Dehra Dun
Hardwar
Alakhnanda
Bhagirathi
Karnali
N 36°
N 34°
N 32°
N 30°
E 72°
E 74°
E 76°
E 78°
E 80°

PLATE—2

Explanation of Plate - 3

Fig.1 Panormic view of a part of Ladakh range comprising of Ladakh granite, near Sakti.Camera facing northwest.

Fig.2 Panormic view of Ladakh granite, near Tikse. Camera facing north.

PLATE—3

Fig 1

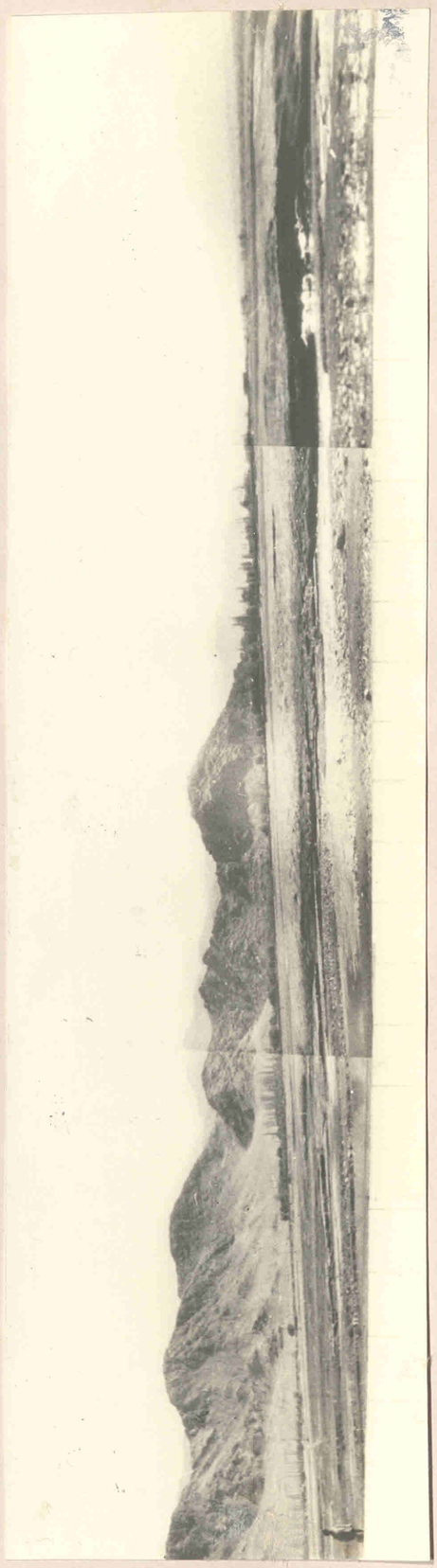


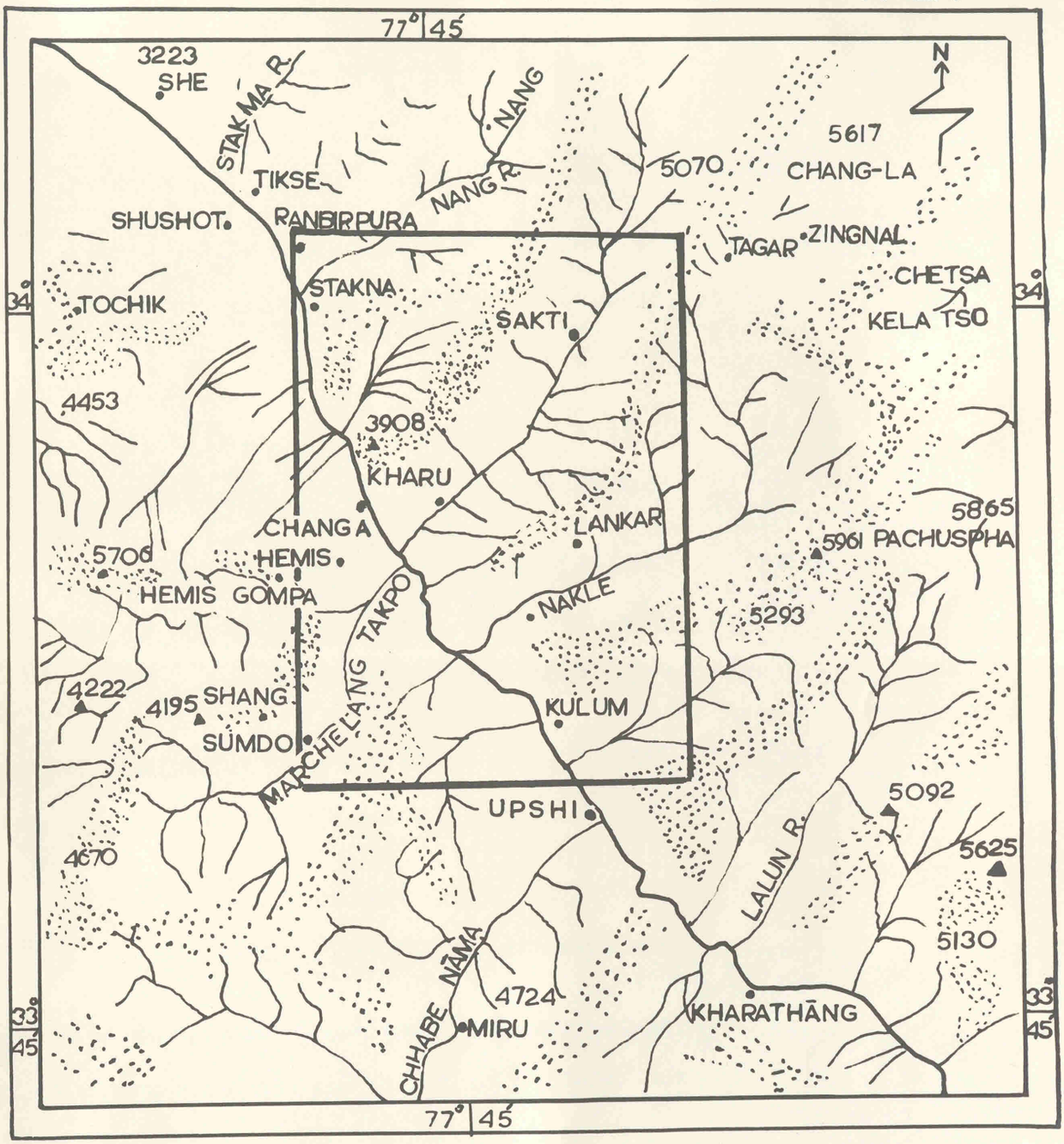
Fig 2

Explanation of Plate - 4

Physiographic map of Sakti and adjoining areas.

PLATE–4

PHYSIOGRAPHIC MAP OF THE STUDY AREA



● PLACES, ▲ PEAKES, MOUNTAIN RANGES,

RIVER, STREAMS, HEIGHT IN METRES,

AREA OF STUDY

Explanation of Plate - 5

Field Photographs

Fig.1 A view of Sakti village, with Ladakh granites in the background. Camera facing north.

Fig.2 A view of Chemere village, situated on the Ladakh granites. Camera facing northwest.

Fig.3 Typical jointing in two directions in tonalite resulting in breakage of this rock into geometrical shapes.

Fig.4 Photographs showing development of jointing in granodiorites near Stakna.

Fig.5 Photograph of granodiorite showing development of jointing near Tikse.

Fig.6 Photograph showing well developed jointing in Ladakh granites. Camera facing northwest.

PLATE—5

FIG : 1

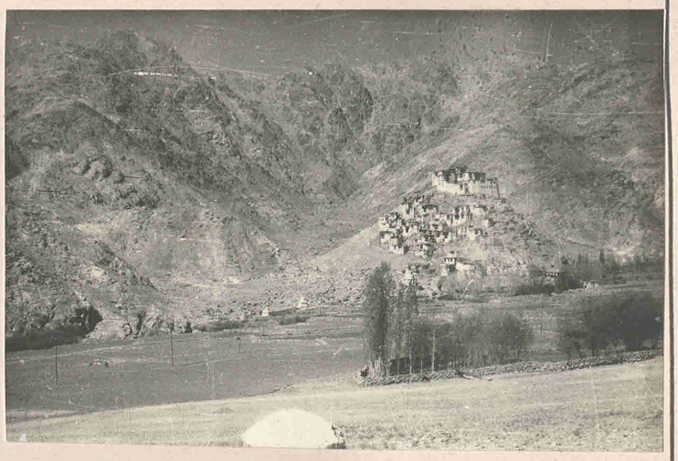


FIG : 2

FIG : 3

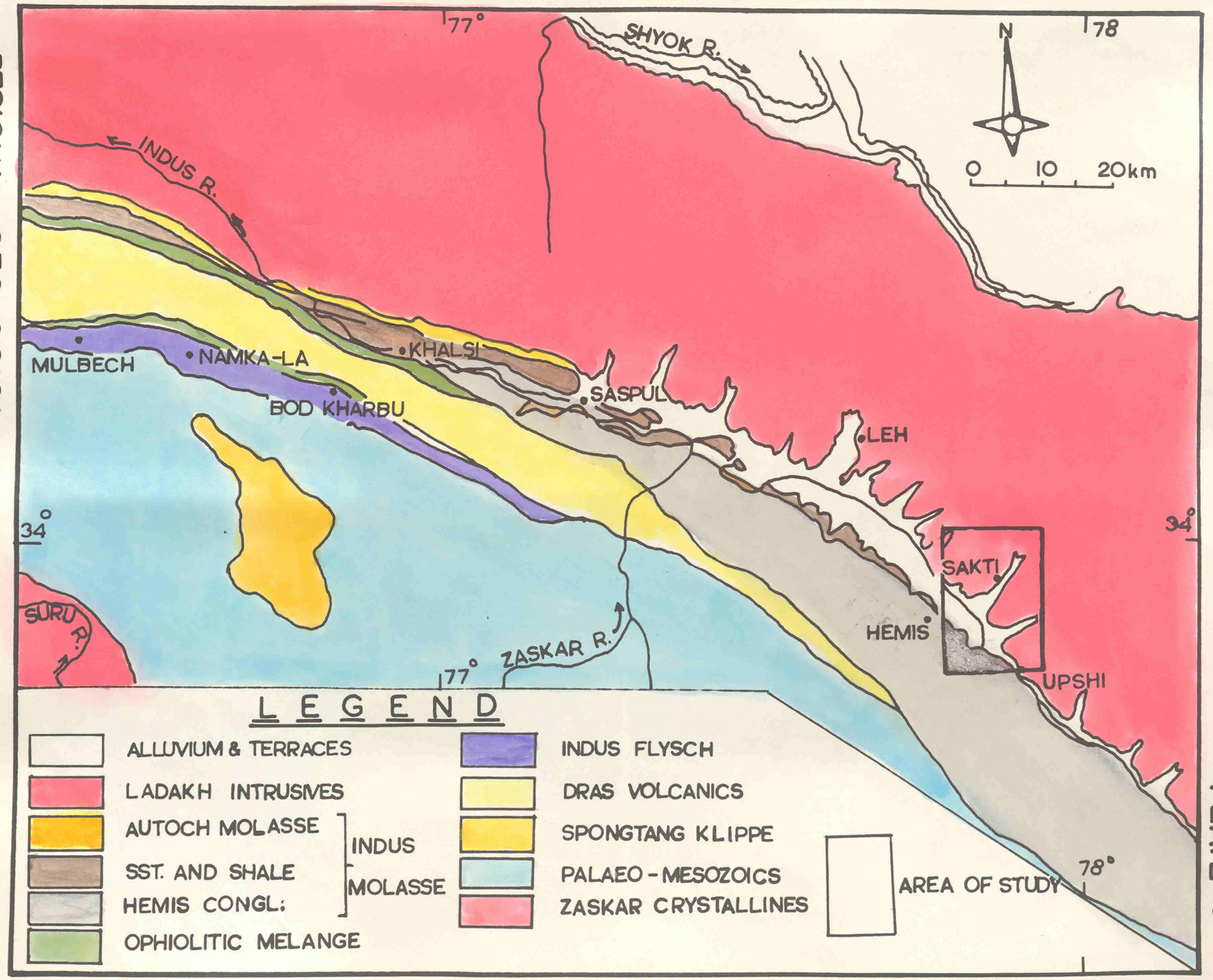
FIG : 4

FIG : 5

FIG : 6

Explanation of Plate - 6

Regional Geological map. After Frank *et al.*,(1977).



REGIONAL GEOLOGICAL MAP (After Frank et al 1977)

PLATE-6

Explanation of Plate - 7

Field Photographs

Fig.1 A view of Tuchik Formation comprising of Basal Conglomerate at the base and Sandstone - Shale unit at the top, at a place near Hemis.

Fig.2 A part of Shale,(Part of Sandstone - Shale unit, of Tuchik Formation, Camera facing southeast.

Fig.3 A part of Sandstone, part of Sandstone - Shale unit, of Tuchik formation.

Fig.4 Photograph of the sub-Recent deposits comprising of the pebbles, scree and sand material.

Fig.5 Photograph of Recent deposits comprising of the gravels, pebbles and boulders.

Fig.6 Photograph showing development of Xenoliths in granodiorites.

PLATE—7

FIG : 1

FIG : 2

FIG : 3

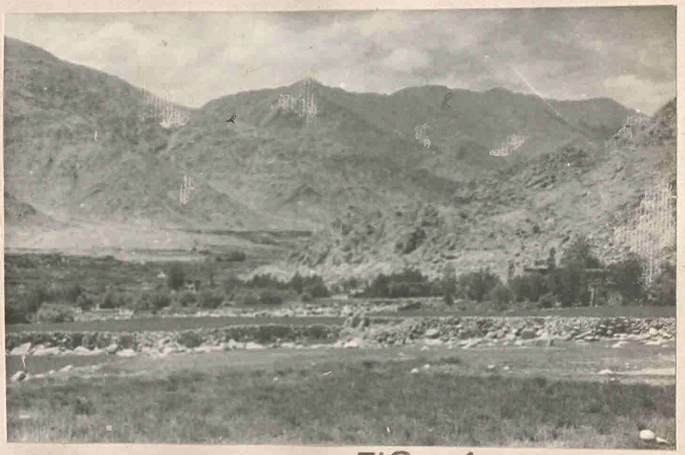


FIG : 4

FIG : 5

FIG : 6

Explanation of Plate - 8

Fig.1 Tonalite in handspecimen.

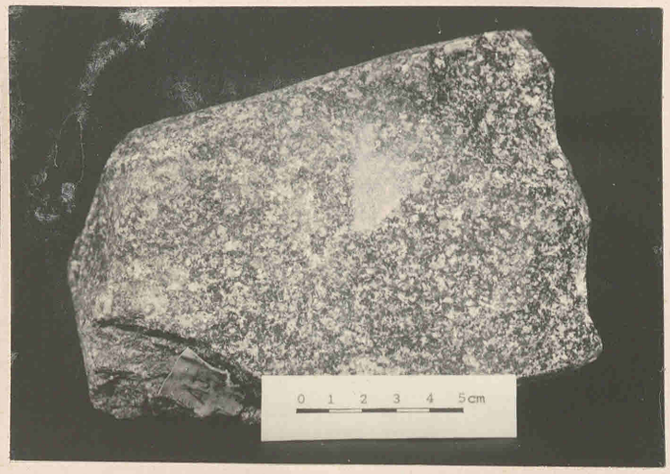
Fig.2 Granodiorite in handspecimen.

Fig.3 Granodiorite in handspecimen.

Fig.4 Monzogranite in handspecimen.

Fig.5 Basal conglomerate in handspecimen.

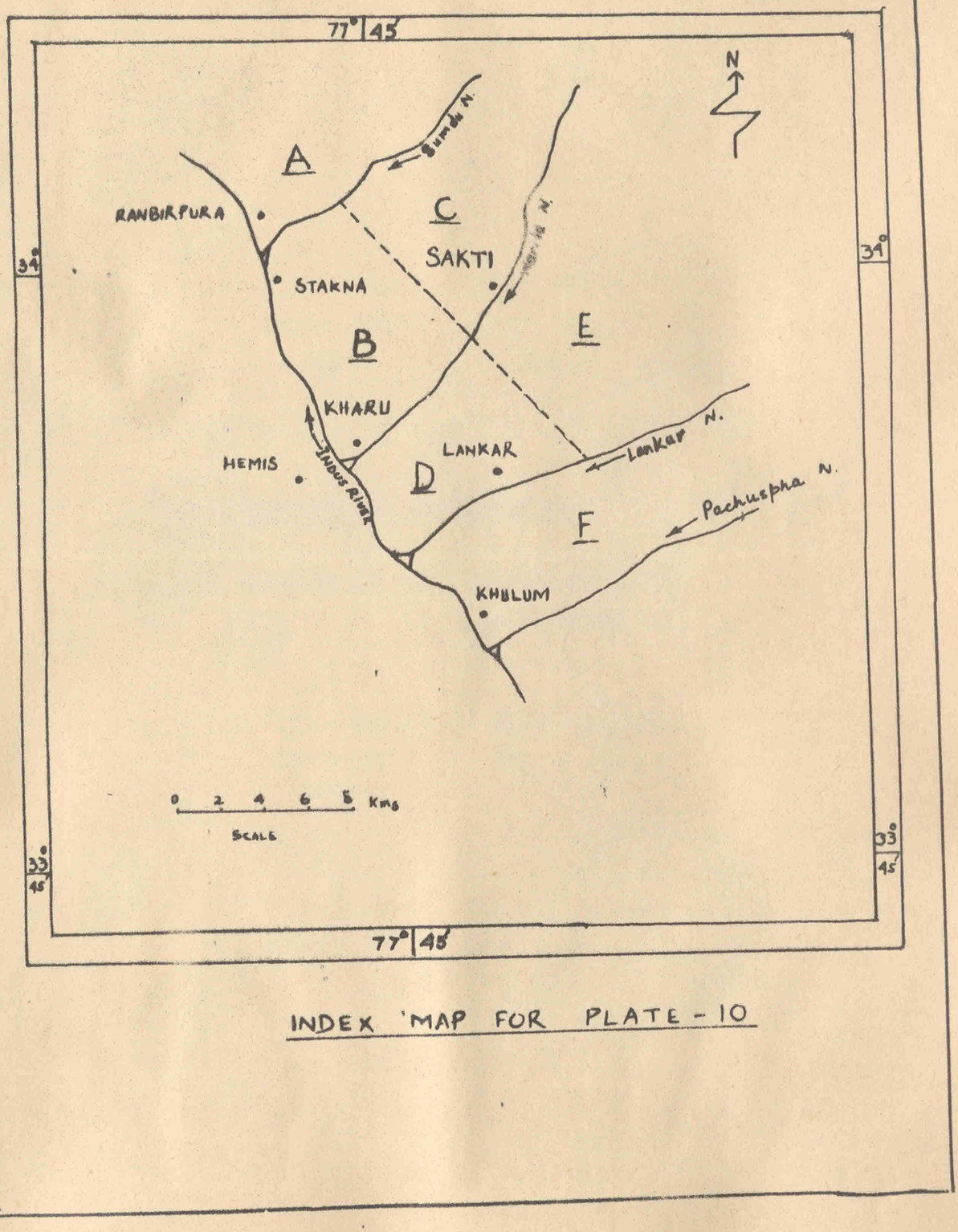
PLATE—8



Explanation of Plate-9

Index map for the contour diagrams of different parts of the research area.

PLATE – 9

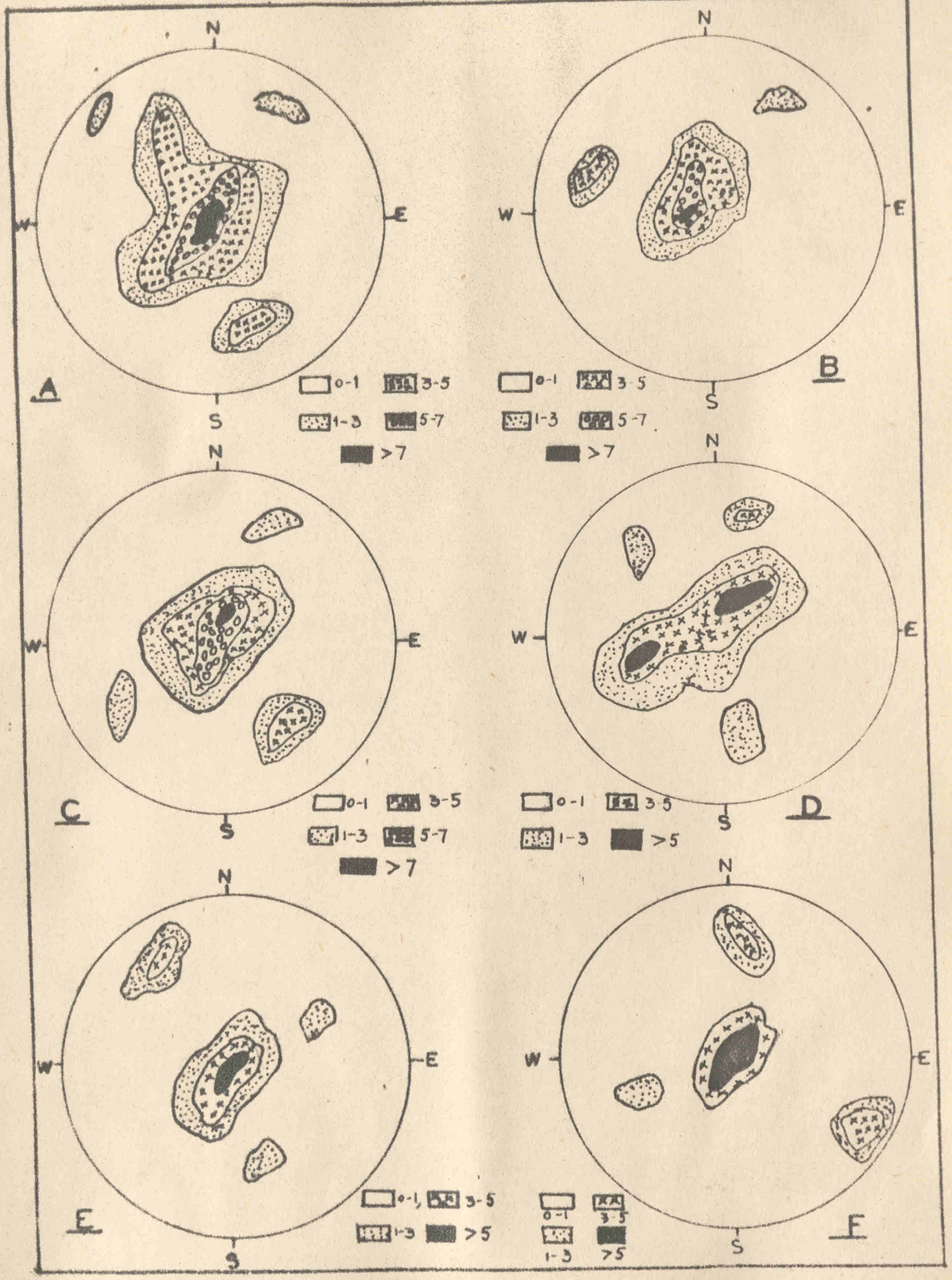


INDEX 'MAP FOR PLATE – 10

Explanation of Plate-10

Joint diagrams of different areas of the study area.

PLATE-10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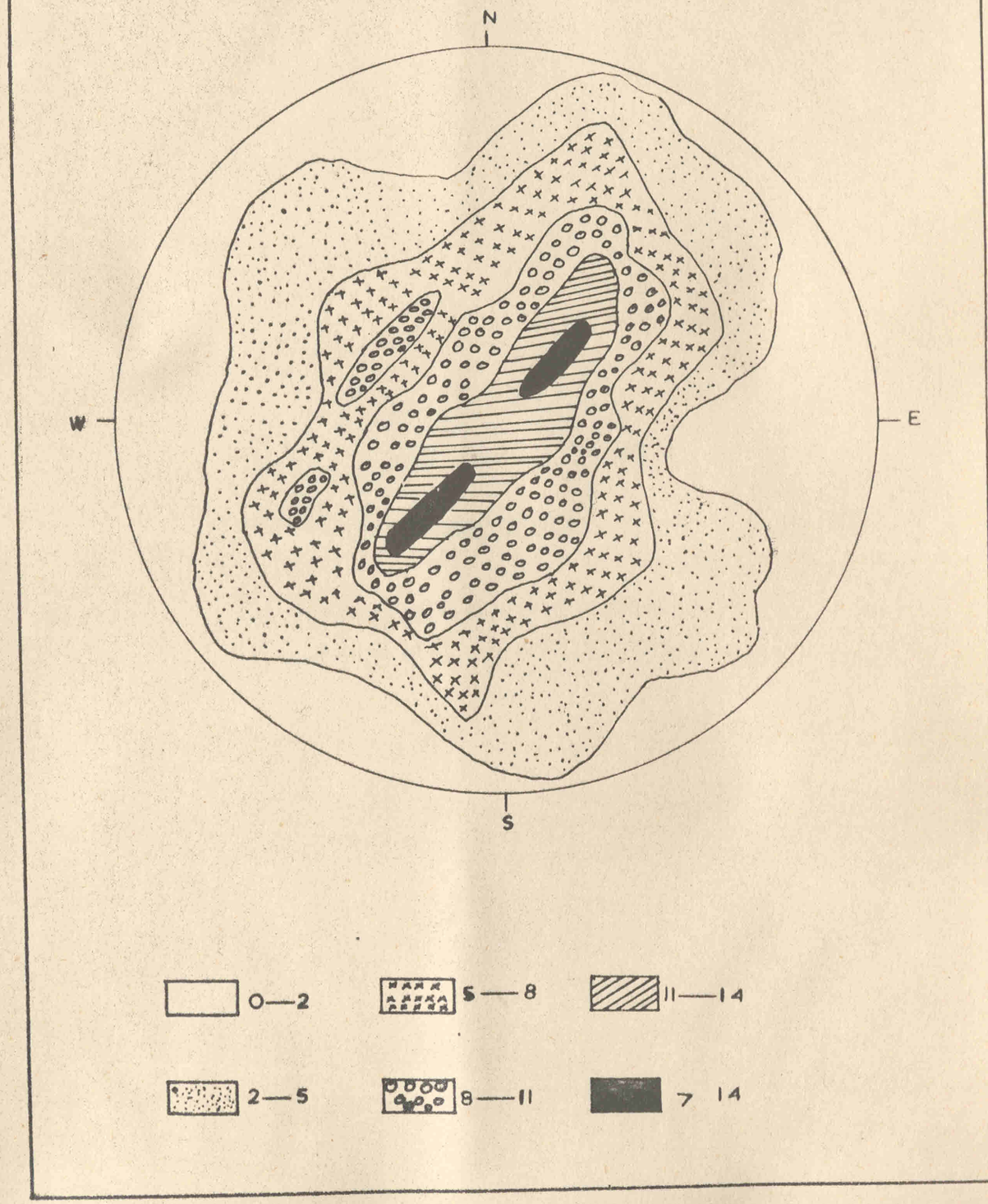
Explanation of Plate-11

Contour diagram of all joints of granitic rocks of the study area.

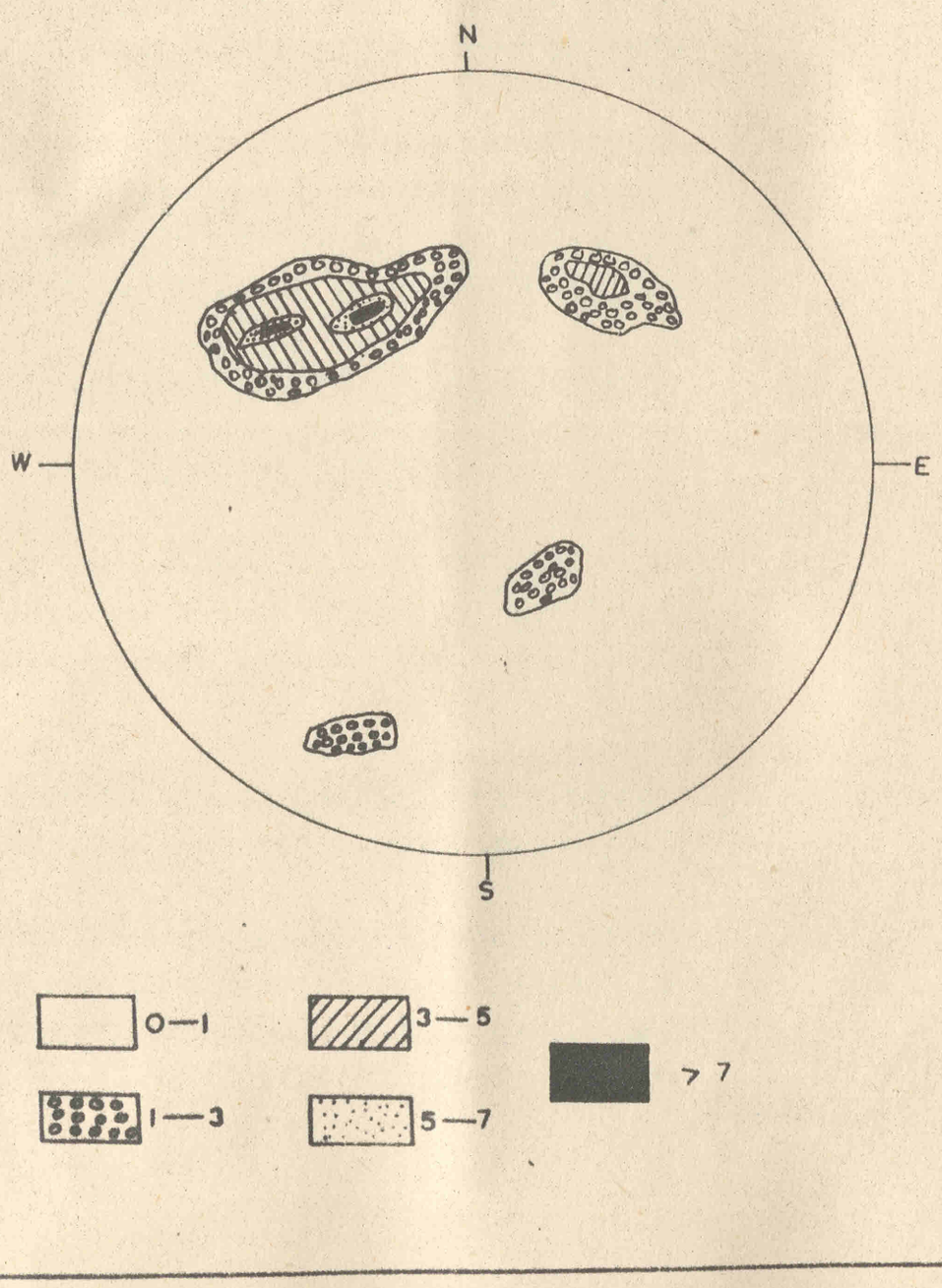
PLATE–11



Exolanation of Plate-12

Contour diagram of foliation of granitic rocks of the study area.

PLATE-12



Explanation of Plate - 13

Photomicrographs

Fig.1 Angular poorly sorted grains with inclusions in silicious cement from feldspathic grey - wackes. Crossed Nicols (x 60).

Fig.2 Arkosic sandstone of Tuchik formation showing angular to sub-angular poorly sorted grains of quartz and feldspars embedded in silicious but clayey cement. Crossed Nicols (x 60).

Fig.3 Equigranular and granular grains of quartz and feldspars in the sandstone of Tuchik formation. Crossed Nicols (x 60).

Fig.4 Arkosic sandstone of Tuchik Formation show angular to sub-angular poorly sorted grains of feldspar and quartz. Crossed Nicols(x 60).

Fig.5 Poorly sorted angular grains of quartz embedded in a clayey matrix in shale of Tuchik Formation. Crossed Nicols (x 75).

Fig.6 Photomicrograph showing arkosic sandstone of Tuchik Formation with equigranular and sub-angular grains of feldspar. Crossed nicols (x 60).

PLATE—13

FIG : 1

FIG : 2

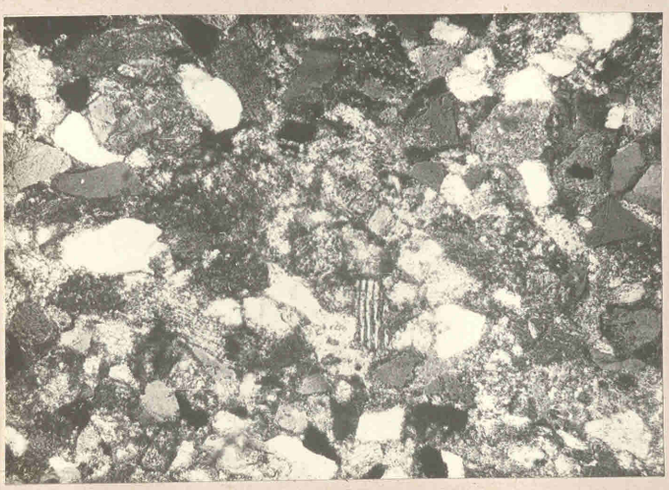


FIG : 3

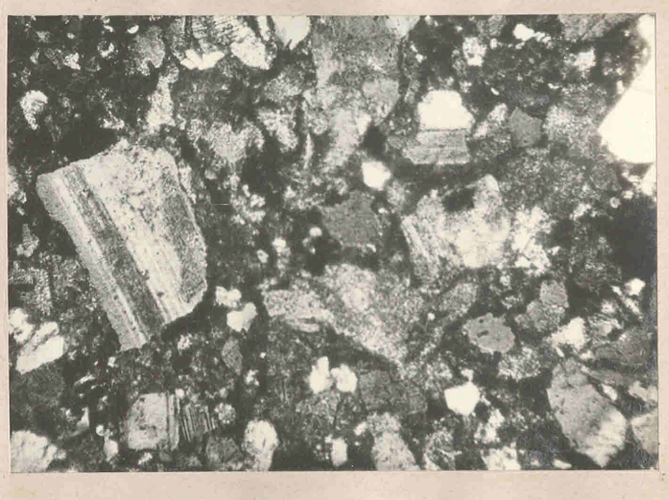


FIG : 4

FIG : 5

FIG : 6

Explanation of Plate - 14

Classification of sandstones. (After Pettijohn, 1975).

Fig.A Represented for samples containing matrix less than 15 per cent.

Fig.B Represented for samples containing matrix more than 15 per cent.

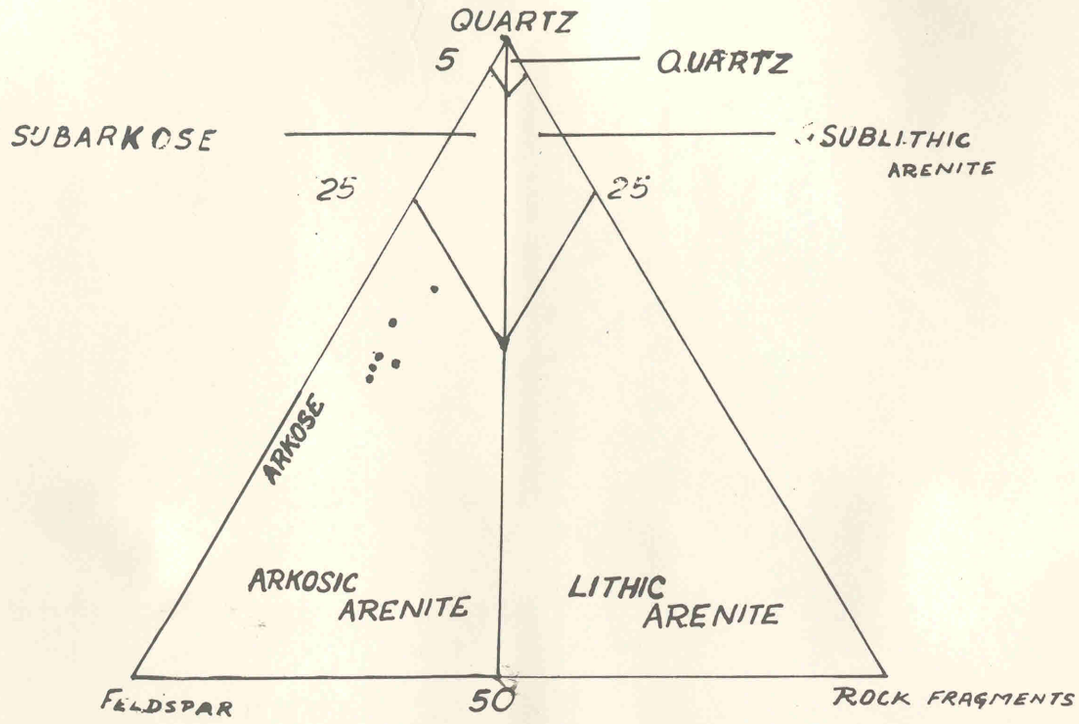

QUARTZ
5
QUARTZ
SUBARKOSE
SUBLITHIC
ARENITE
25
25
ARKOSE
ARKOSIC
ARENITE
LITHIC
ARENITE
FELDSPAR
50
ROCK FRAGMENTS

Fig A

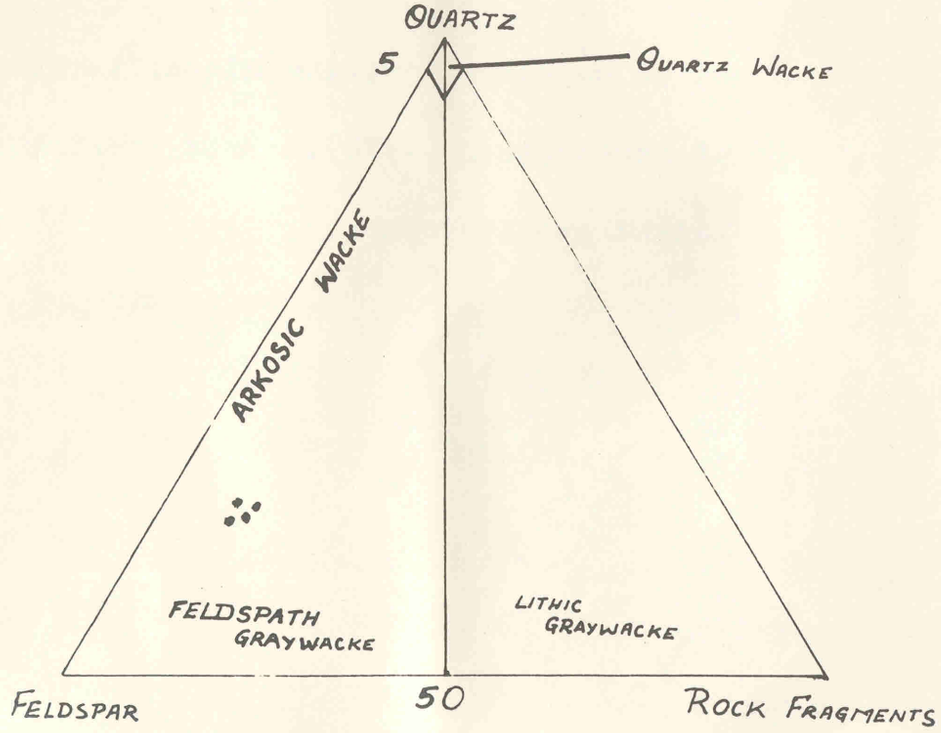
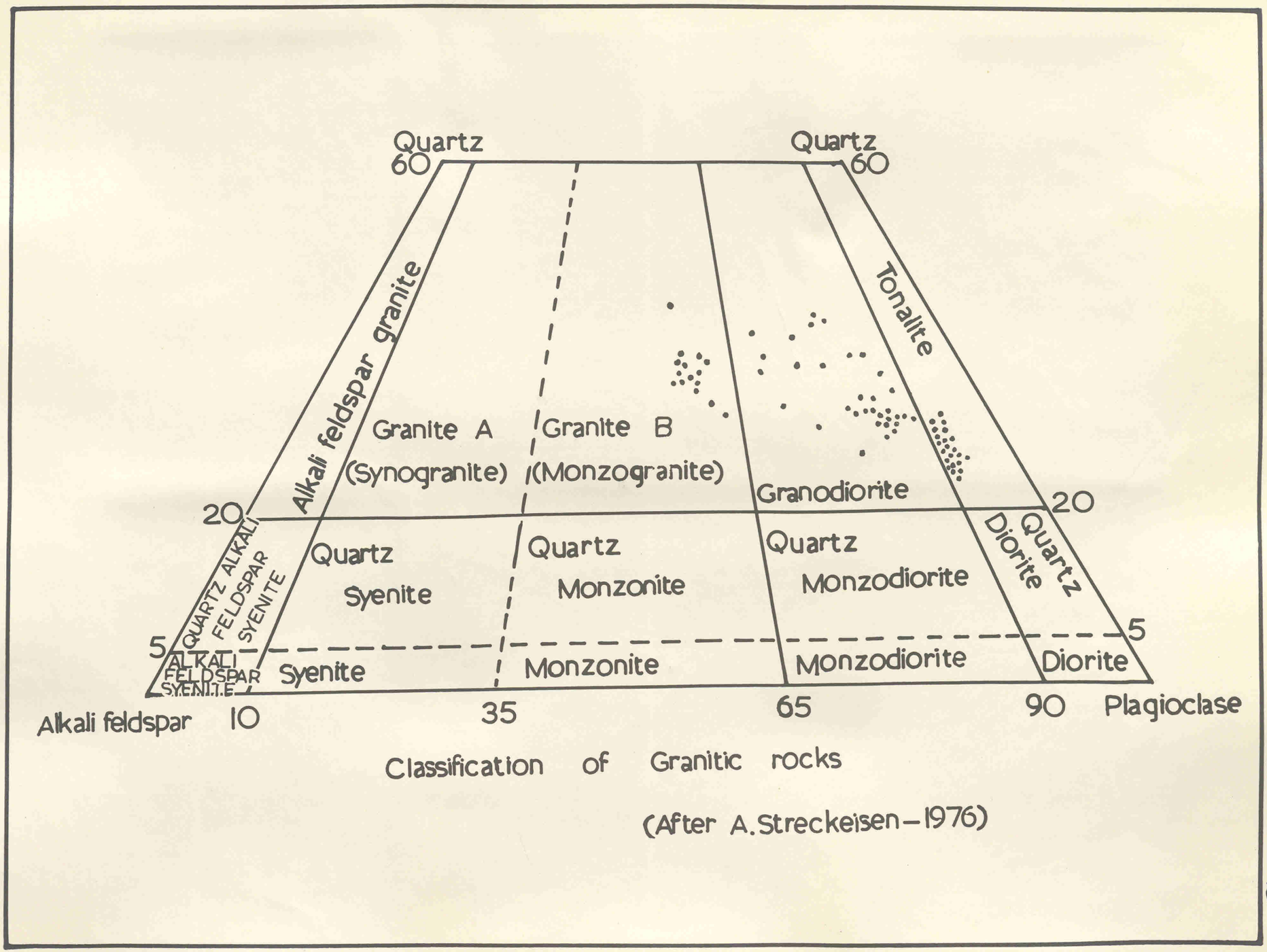

QUARTZ
5
QUARTZ WACKE
ARKOSIC WACKE
FELDSPATH
GRAYWACKE
LITHIC
GRAYWACKE
FELDSPAR
50
ROCK FRAGMENTS

Fig B

Explanation of Plate - 15

Three component granite classification diagram of Streckeisen (1976). Dots represent individual Ladakh granite samples.



Classification of Granitic rocks

(After A. Streckeisen – 1976)

PLATE-15

Explanation of Plate - 16

Photomicrograph

Fig.1 Tonalite exhibiting undulatory extinction and interlocking arrangement of quartz grain. Crossed Nicols (x 90).

Fig.2 Quartz from granodiorite showing inclusions of feldspars in it. Crossed Nicols (x 75).

Fig.3 Quartz from tonalite showing inclusions of micas in it. Crossed Nicols (x 75).

Fig.4 Granodiorite showing sutured contact of quartz grain. Crossed Nicols (x 60).

Fig.5 Tonalite showing quartz grain with highly indented rims and absorption contact towards feldspars. Crossed Nicols (x 75).

Fig.6 Plagioclase from tonalite exhibiting albite twin lamallae. Crossed Nicols(x 75).

PLATE—16

FIG : 1

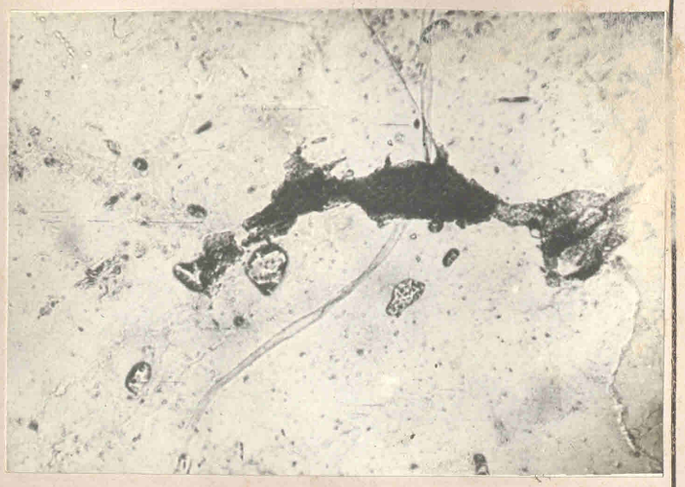


FIG : 2

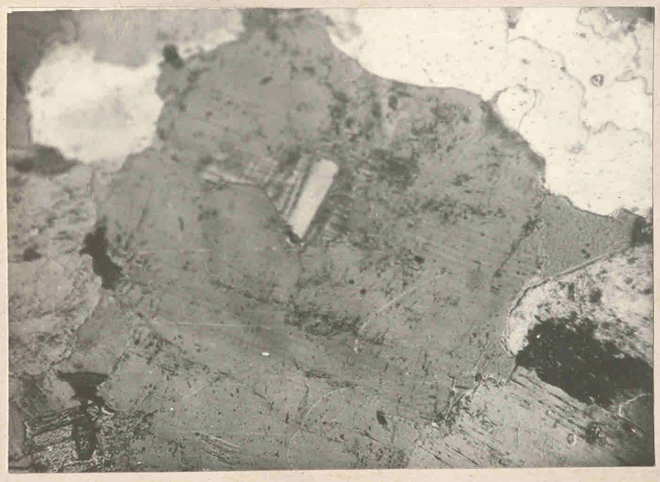


FIG : 3

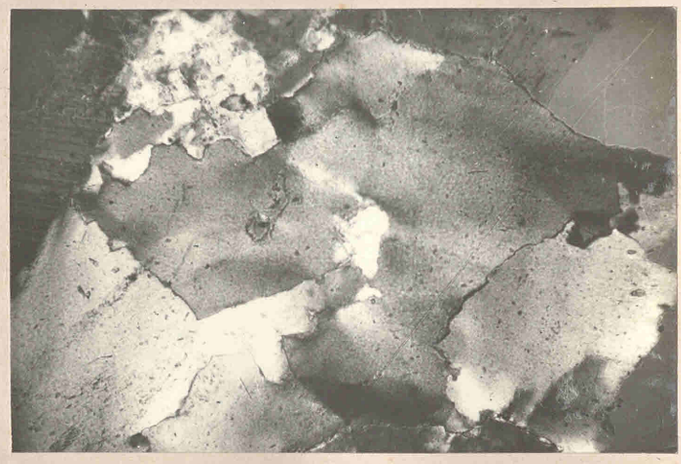


FIG : 4

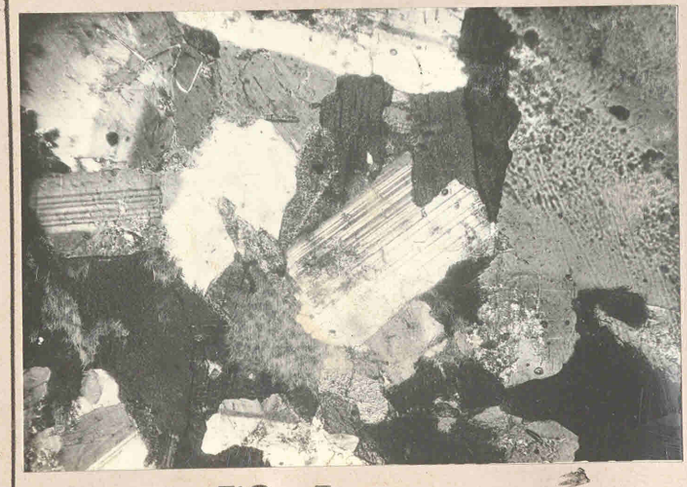


FIG : 5

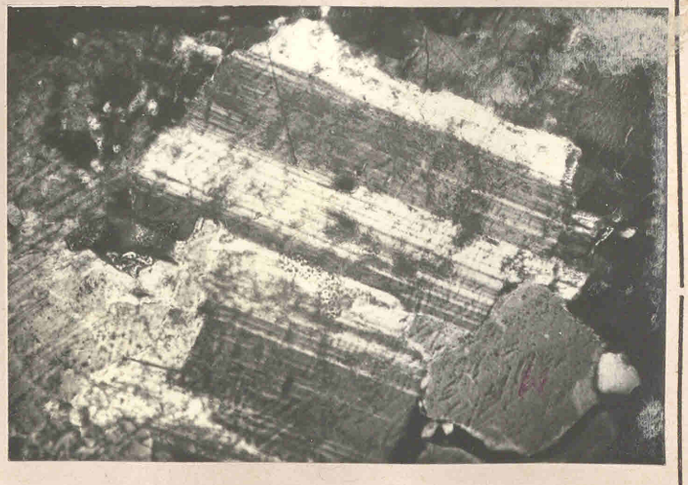


FIG : 6

Explanation of Plate - 17

Photomicrograph

Fig.1 Plagioclase in tonalite showing alteration to muscovite. Crossed Nicols (x 75).

Fig.2 Plagioclase from granodiorite showing alteration to kaolinite. Crossed Nicols (x 75).

Fig.3 Plagioclase from tonalite showing alteration to sericite. Crossed Nicols (x 75).

Fig.4 Plagioclase showing alteration to sericite. Crossed Nicols (x 75).

Fig.5 Plagioclase showing oscillatory zoning in granodiorite. Crossed Nicols (x 60).

Fig.6 Oscillatory zoning in plagioclases from tonalite. Crossed Nicols (x 60).

PLATE—17

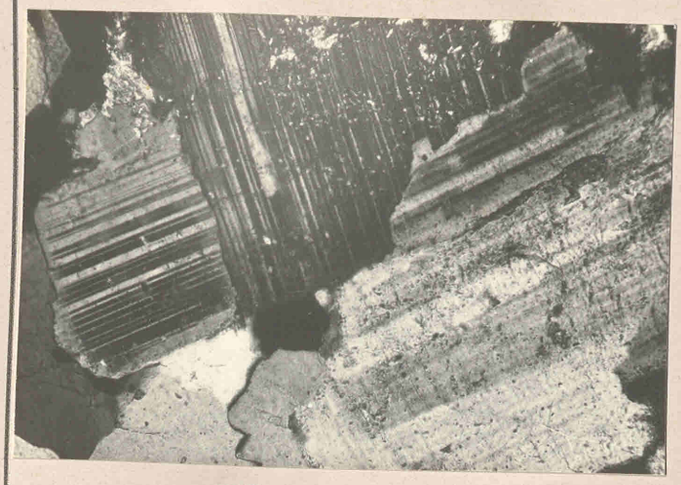


FIG : 1

FIG : 2

FIG : 3

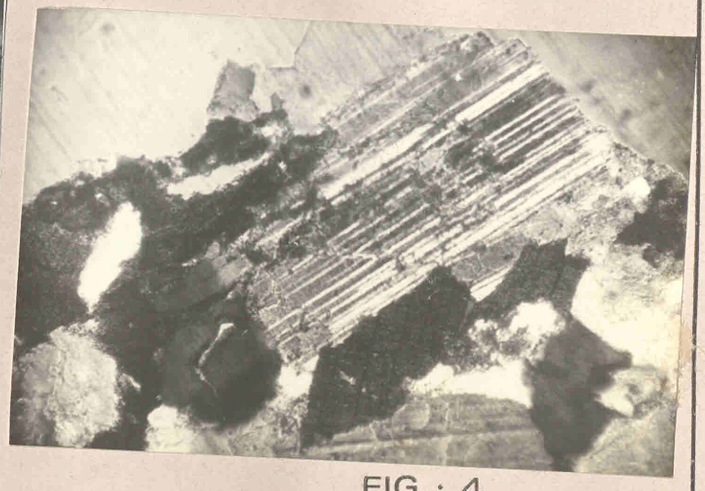


FIG : 4

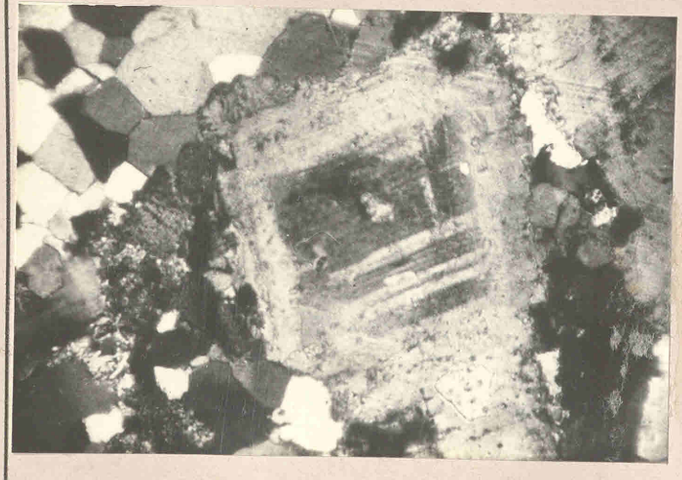


FIG : 5

FIG : 6

Explanation of Plate - 18

Photomicrograph

Fig.1 Microcline from monzogranite showing well developed cross hetched twinning. Crossed Nicols (x 75).

Fig.2 Photomicrograph of Microcline from monzogranite. Crossed Nicols (x 90).

Fig.3 Plagioclase from tonalite showing oscillatory zoning. Crossed Nicols(x 60).

Fig.4 Alkali feldspars in monzogranite containing small lath of biotite.

Fig.5 Alkali feldspar in monzogranite showing close contact with hornblende.Crossed Nicols (x 60).

Fig.6 Alkali feldspar from monzogranite showing its alteration to kaolin. Crossed Nicols (x 60).

PLATE—18

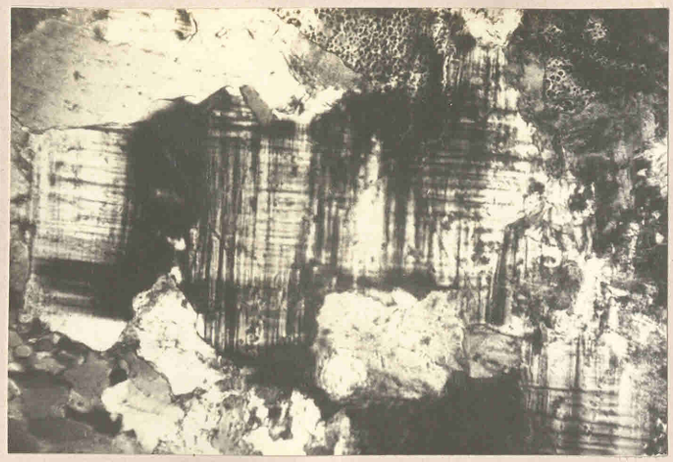


FIG : 1

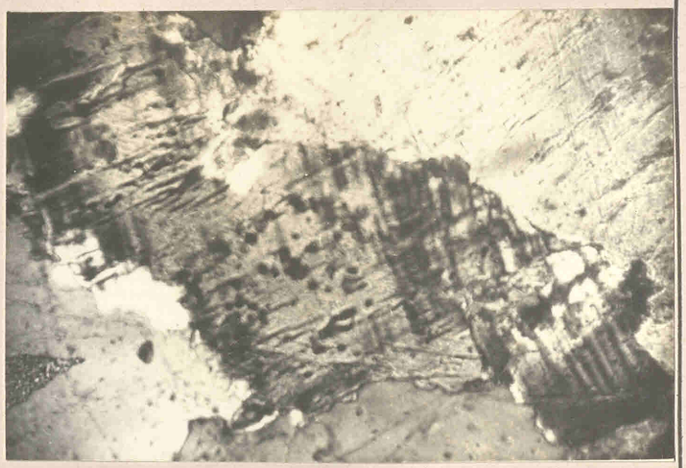


FIG : 2

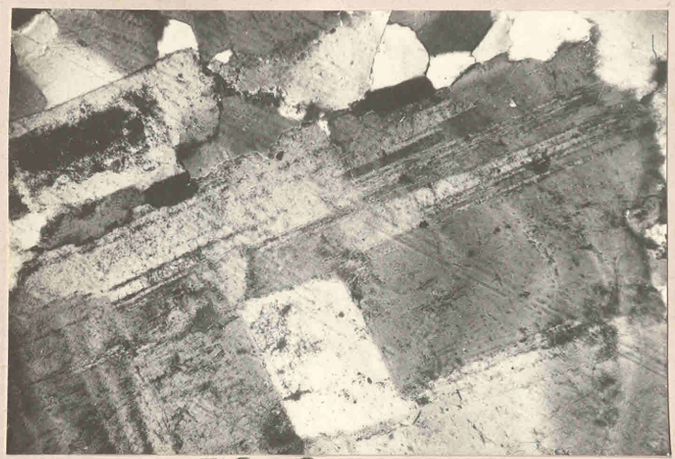


FIG : 3

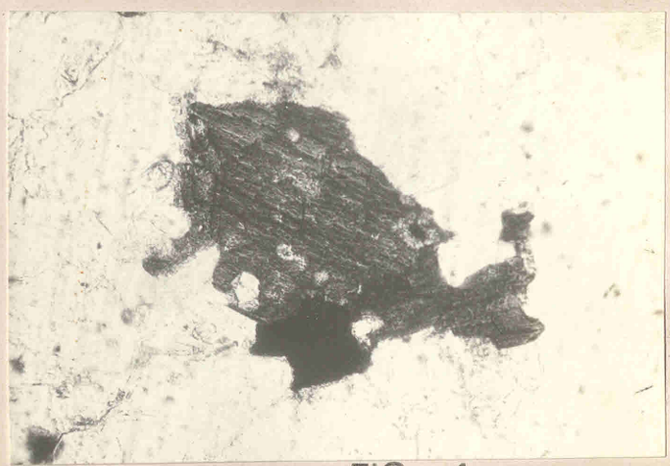


FIG : 4

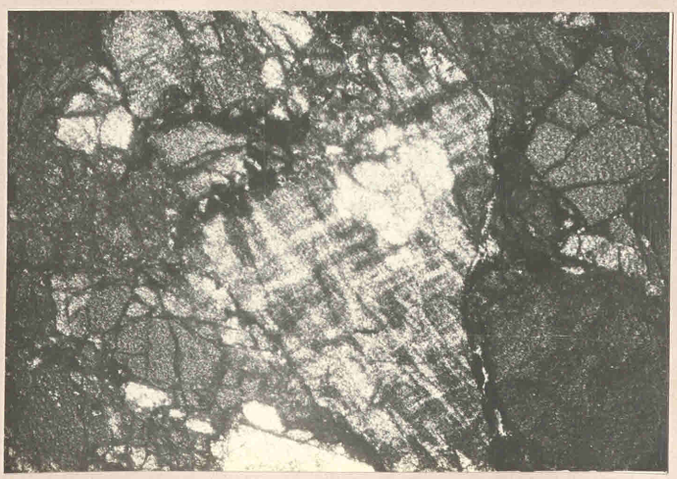


FIG : 5

FIG : 6

Explanation of Plate - 19

Photomicrograph

Fig.1 Hornblende lath riddled with cracks and inclusions from tonalite. Crossed Nicols (x 60).

Fig.2 A lath of hornblende with inclusions of iron ores. Ordinary light.

Fig.3 Hornblende showing alteration to biotite from tonalite. Ordinary light.

Fig.4 Hornblende from granodiorite showing alteration to biotite. Ordinary light.

Fig.5 Laemllar biotite showing the development of bending. Ordinary light.

Fig.6 Biotite from granodiorite showing bending in biotites. Ordinary light.

PLATE—19

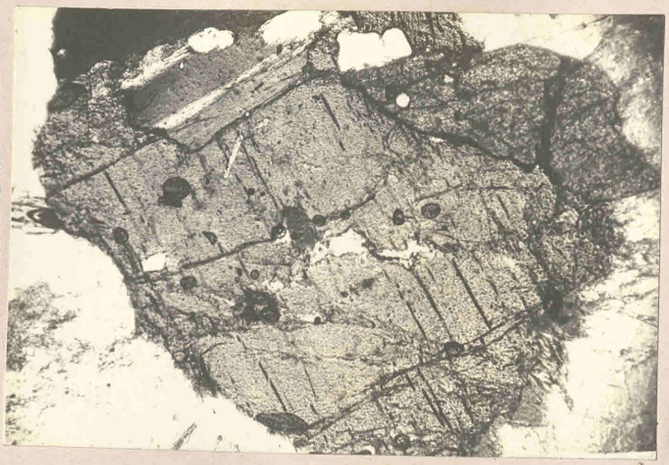


FIG : 1

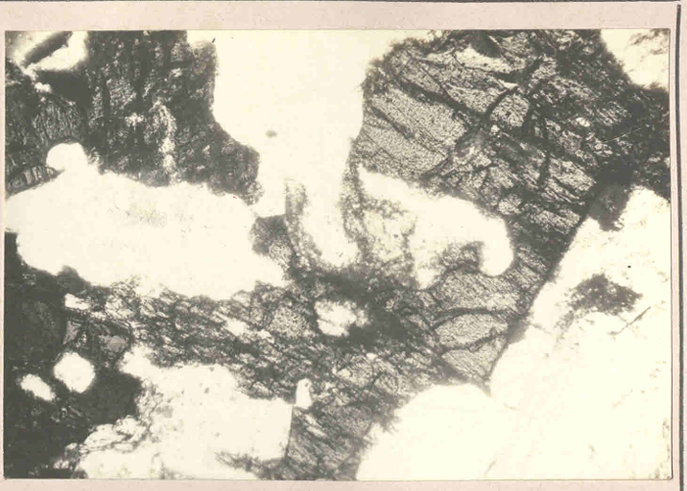


FIG : 2

FIG : 3

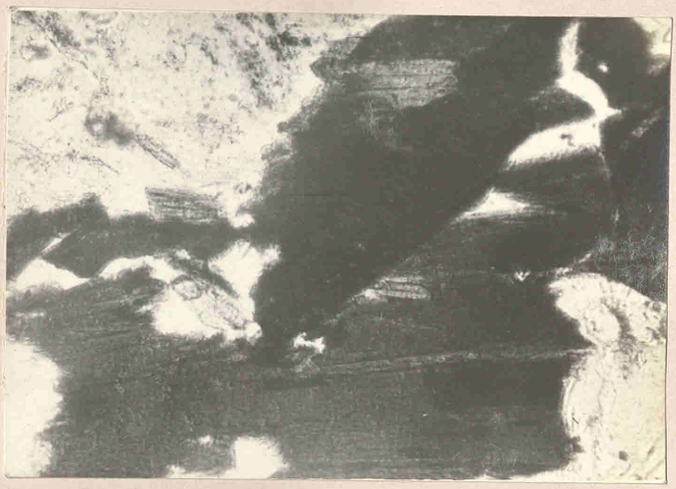


FIG : 4

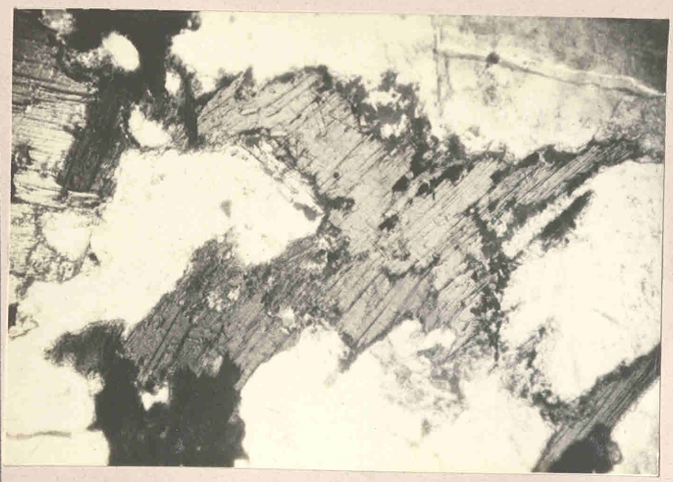


FIG : 5

FIG : 6

Explanation of Plate - 20

Photomicrograph

Fig.1 Biotite from tonalite showing development of bending. Ordinary light.

Fig.2 Tonalite showing different lath of biotite cutting each other.Crossed Nicols (x 60).

Fig.3 Granodiorite showing an ilmenite kernal surrounded by leucoxane. Ordinary light.

Fig.4 Biotite having inclusions of iron ores, etc. from granite. Ordinary light.

Fig.5 Muscovite from granodiorite showing the development of tabular habit. Crossed Nicols (x 60).

Fig.6 Photomicrograph of muscovite showing muscovite as an alteration product of feldspar. Crossed Nicols (x 75).

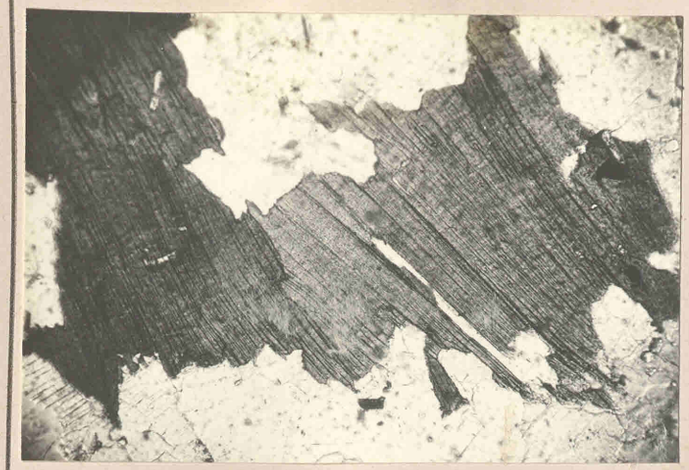


FIG : 1

FIG : 2

FIG : 3

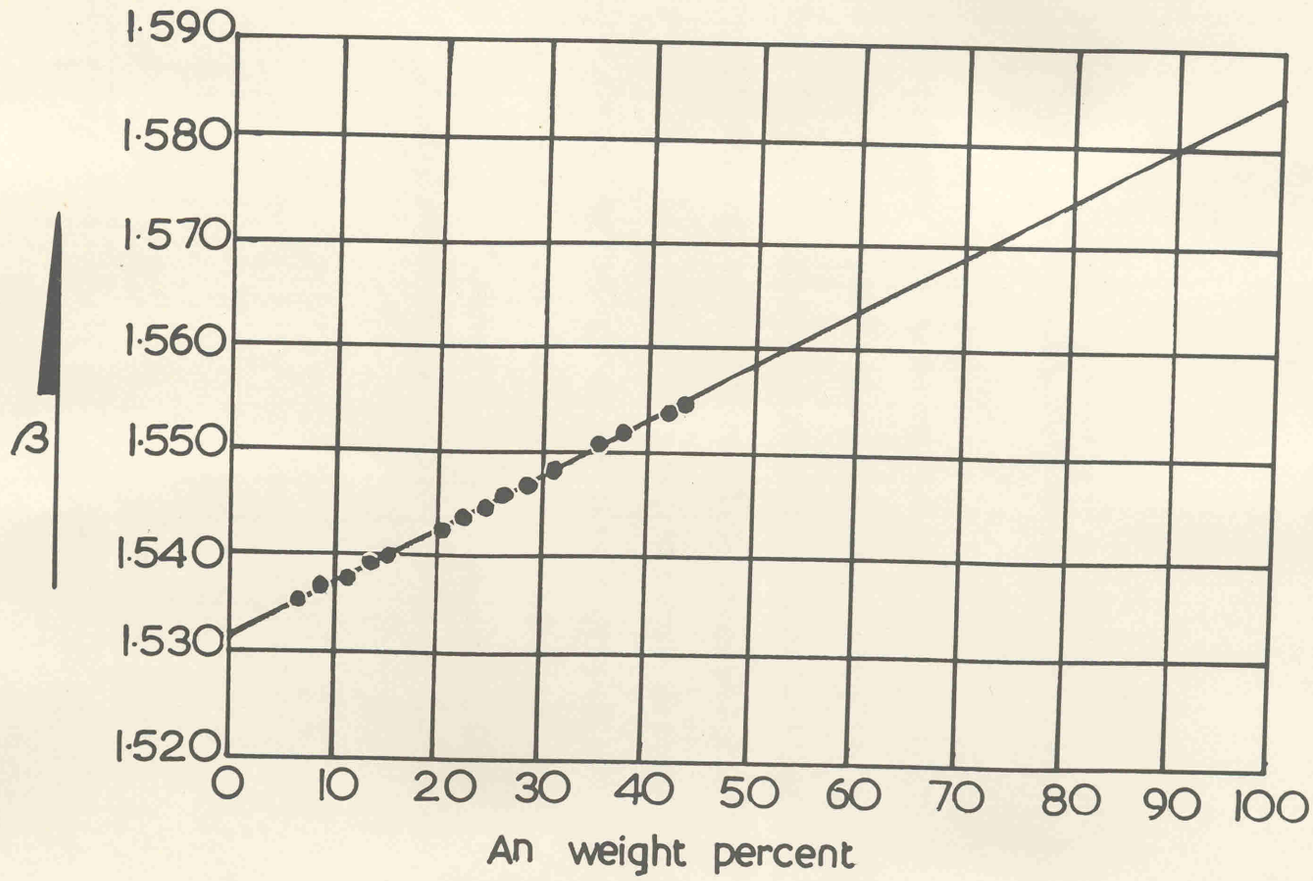
FIG : 4

FIG : 5

FIG : 6

Explanation of Plate-21

Diagram showing variation in "B" with composition in Plagioclases. Dots on diagram represent individual Ladakh granite plagioclases.



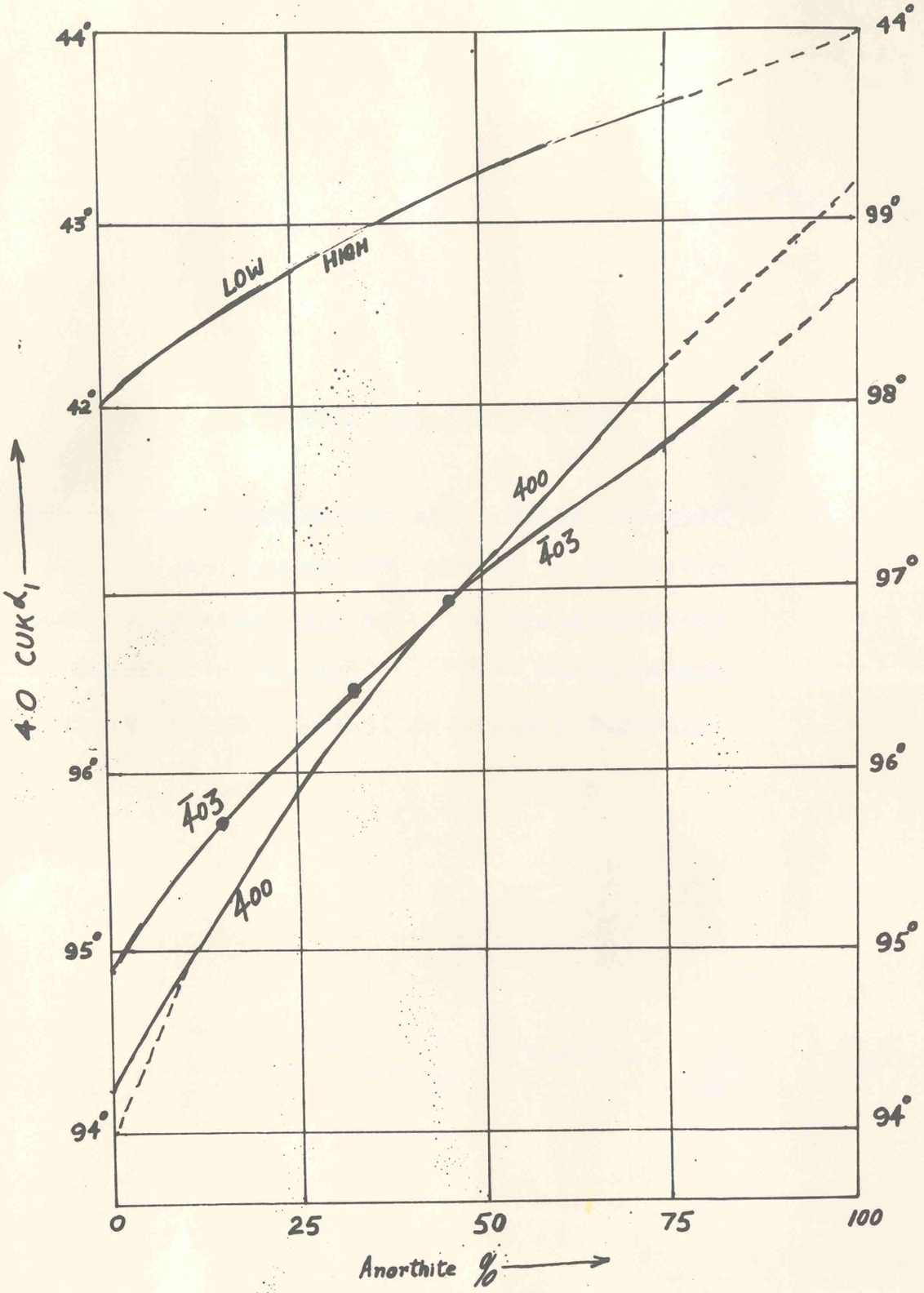
Variation in β with composition in plagioclase

PLATE-21

Explanation of Plate - 22

Bivariate diagram showing the relationship of 4θ peak positions of $\bar{2}01$, 400 and $\bar{4}03$ reflections and the anorthite content of plagioclases (after Vishwanathan,1971). Ladakh Granite plagioclases plot on one of the curves (Dots in the diagram) from which the anorthite content of the plagioclases could be easily estimated.

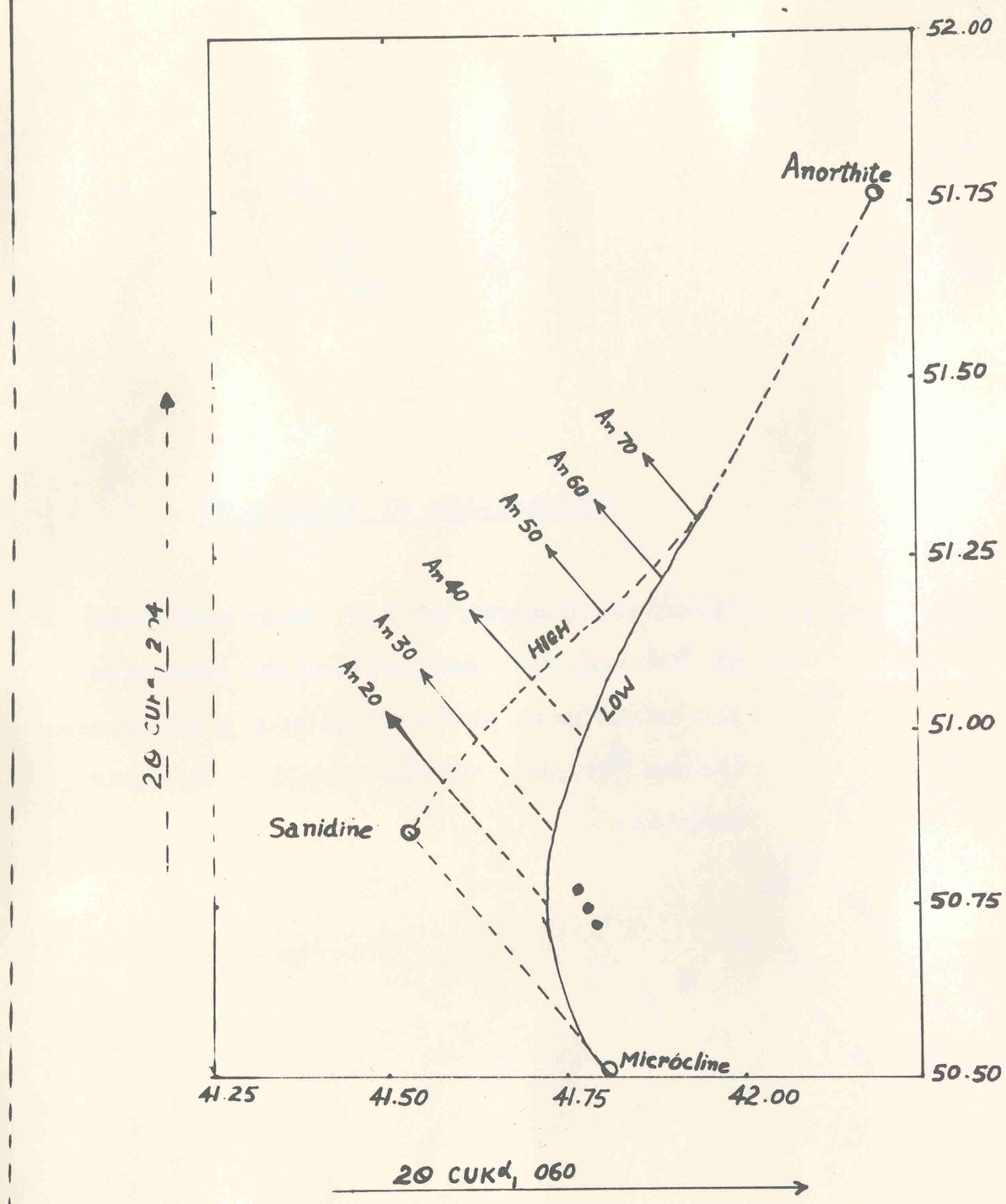
PLATE-22


44°
43°
42°
96°
95°
94°
44°
99°
98°
97°
96°
95°
94°
LOW
HIGH
400
403
403
400
0
25
50
75
100
Anorthite %
4 0 CUKα_1

Explanation of Plate - 23

Diagram showing the relationship of 2θ peak positions of $\bar{2}04$ and 060 reflections and the structural state of the plagioclases (after Vishwanathan, 1971). Dots on the diagram represent individual Ladakh Granite plagioclases.

PLATE-23


52.00
51.75
51.50
51.25
51.00
50.75
50.50
Anorthite
An 70
An 60
An 50
An 40
An 30
An 20
HIGH
LOW
Sanidine
Microcline
41.25
41.50
41.75
42.00
2θ CuKα1, 274
2θ CuKα1, 060

Explanation of Plate - 24

Bivariate diagram of 2 θ peak positions of $\bar{2}04$ and 060 reflections to determine the structural state of alkali - feldspars (After Wright, 1968). Alkali - feldspar samples.

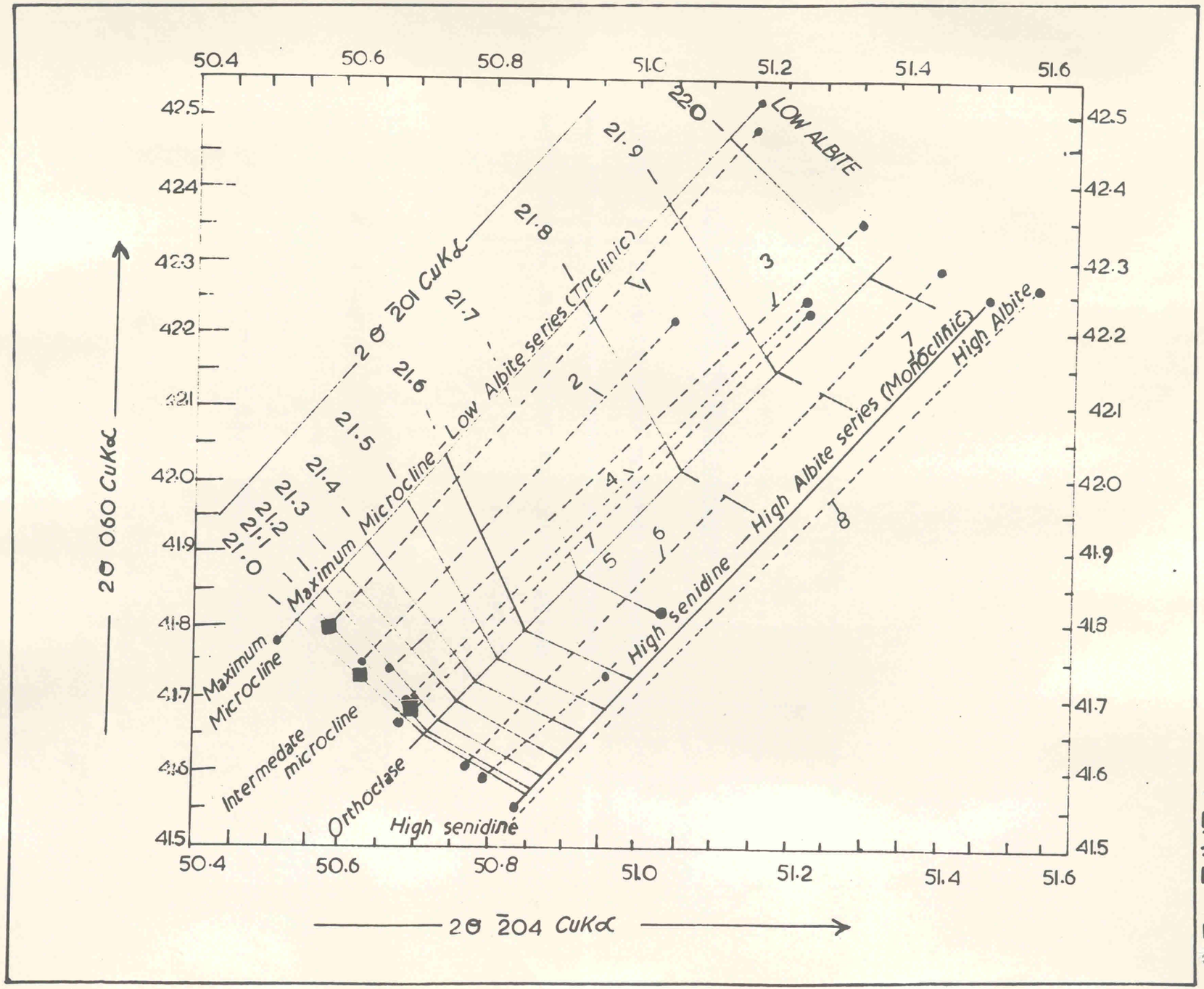
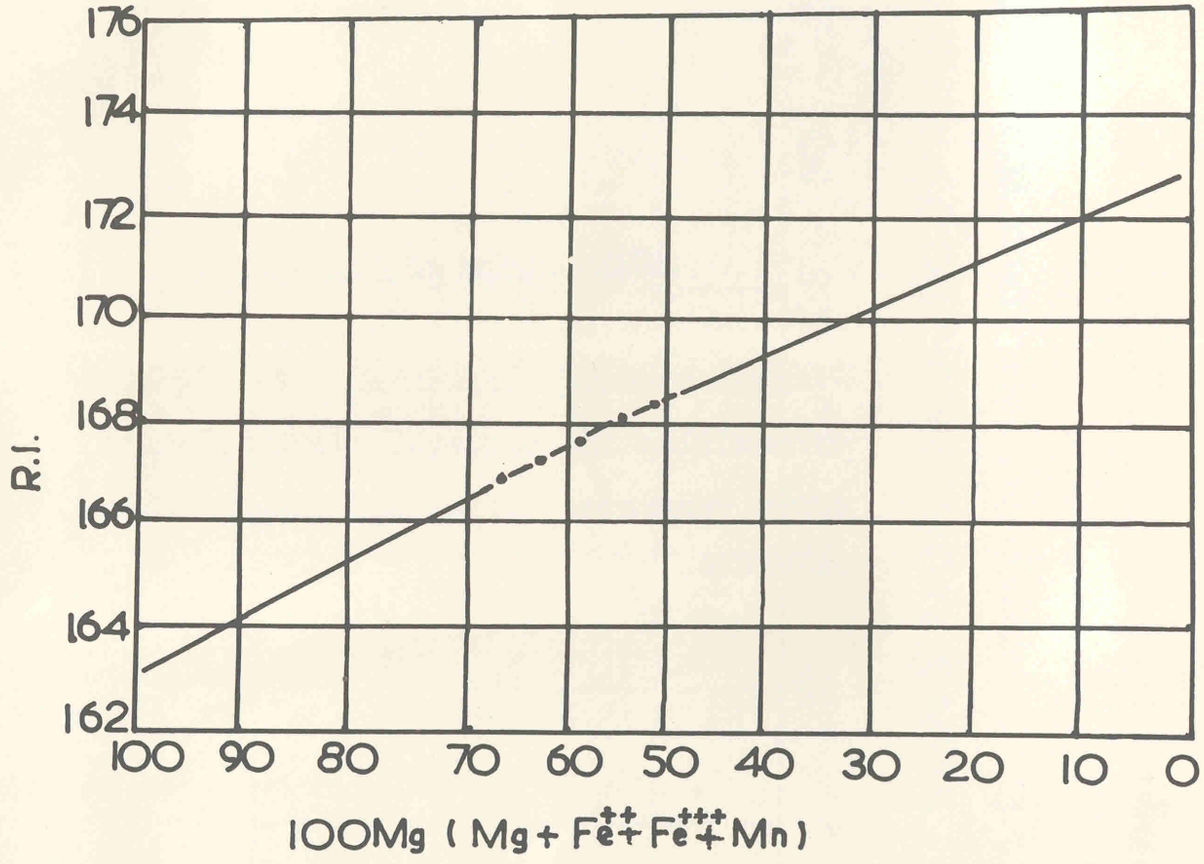

50.4
50.6
50.8
51.0
51.2
51.4
51.6
42.5
42.4
42.3
42.2
42.1
42.0
41.9
41.8
41.7
41.6
41.5
2θ 060 CuKα
2θ 204 CuKα
2θ 201 CuKα
22.0
21.9
21.8
21.7
21.6
21.5
21.4
21.3
21.2
21.1
21.0
LOW ALBITE
Low Albite series (Triclinic)
Maximum Microcline
High Albite series (Monoclinic)
High Albite
High senidine
Maximum Microcline
Intermedate microcline
Orthoclase
High senidine
1
2
3
4
5
6
7
8

PLATE- 24

Explanation of Plate - 25

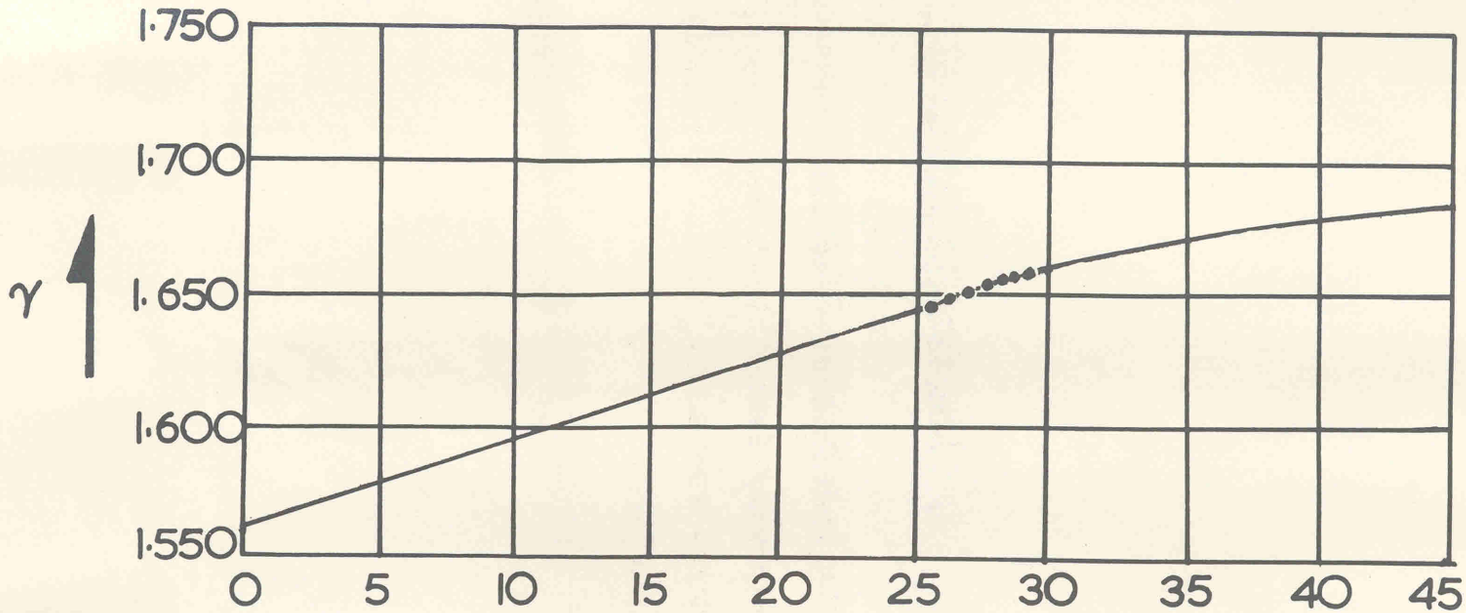
Diagram showing variation in 'γ' with composition in Hornblende. Dots on the curve represent values for Ladakh granite hornblende.

PLATE-25


176
174
172
170
168
166
164
162
R.I.
100 90 80 70 60 50 40 30 20 10 0
100Mg (Mg + Fe++ Fe+++ Mn)

Explanation of Plate - 26

Diagram showing variation in 'γ' with composition in biotites. Dots on the curve represent values for Ladakh Granite biotites.



Weight % FeO+2 (Fe_2O_3+TiO_2)

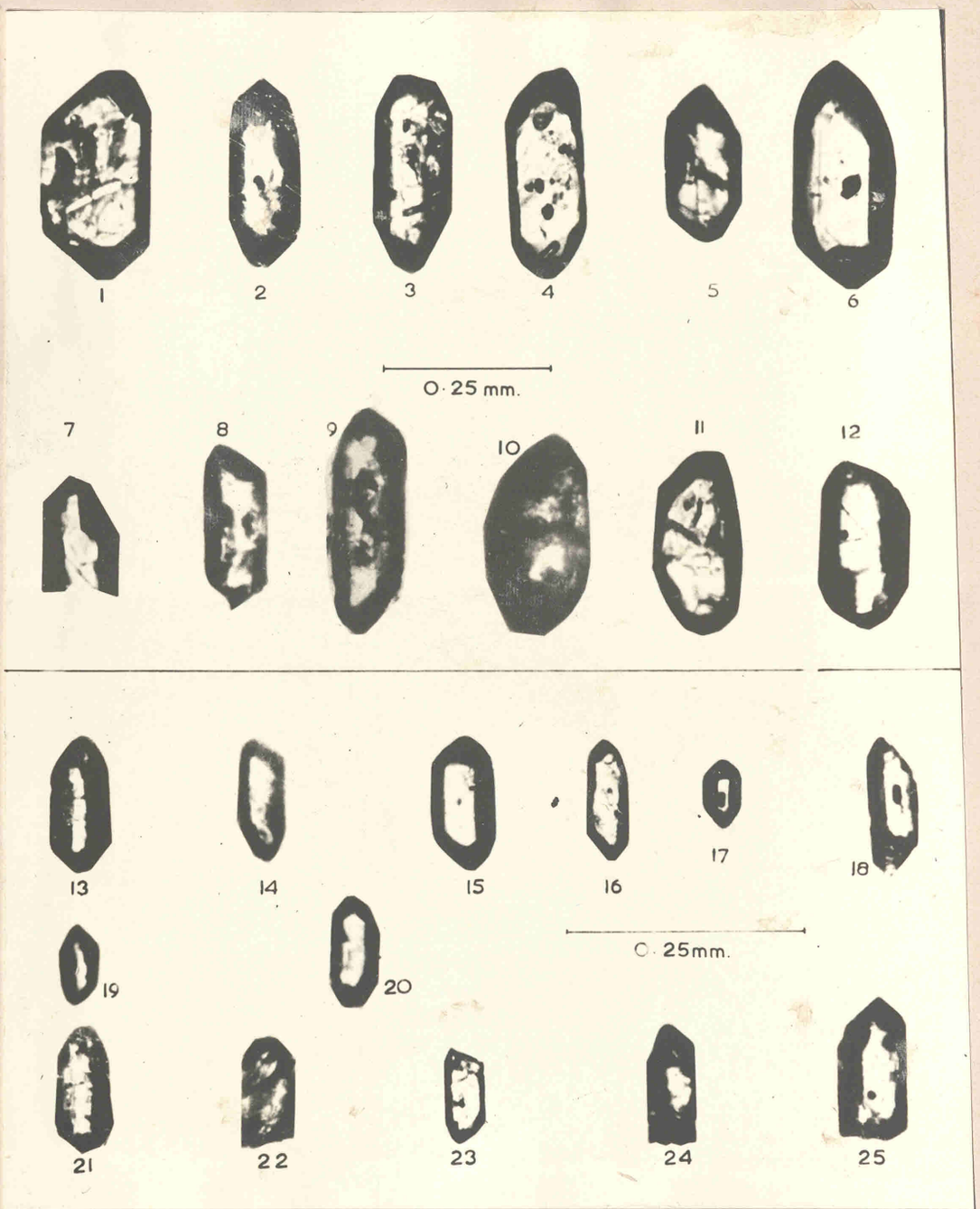
FIG-1. Variation in γ with composition in Biotite

PLATE-26

Explanation of Plate - 27

Zircons from granitic rocks of the study area.

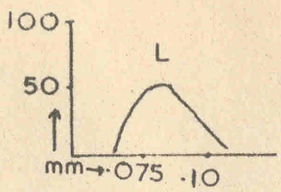
PLATE— 27

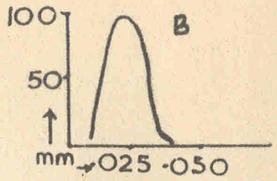

1
2
3
4
5
6
0·25 mm.
7
8
9
10
11
12
13
14
15
16
17
18
19
20
0·25mm.
21
22
23
24
25

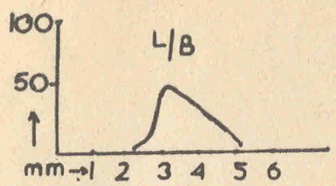
Explanation of Plate - 28

Size frequency curves for Zircons of granites.

SAMPLE NO: 1







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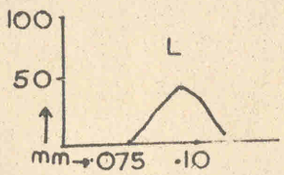
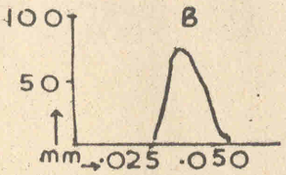
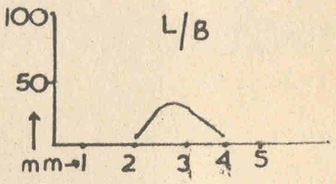
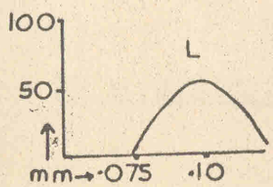
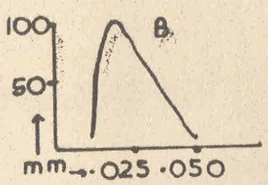


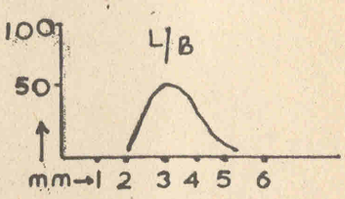




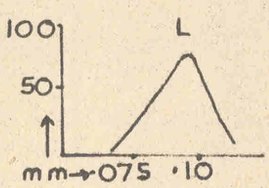
SAMPLE NO: 3

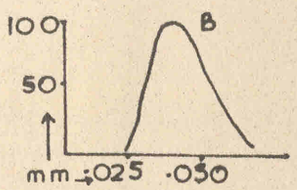


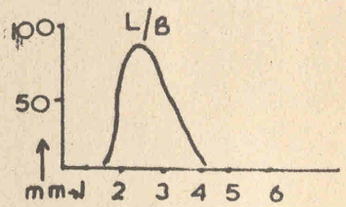




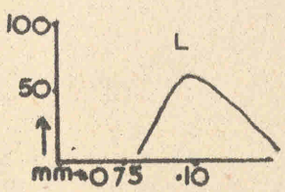
SAMPLE NO: 4

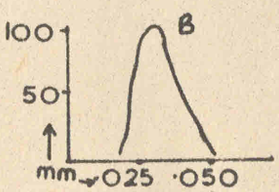


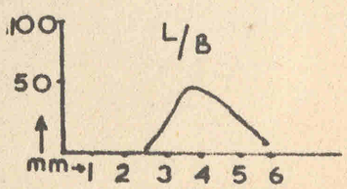




SAMPLE NO: 5



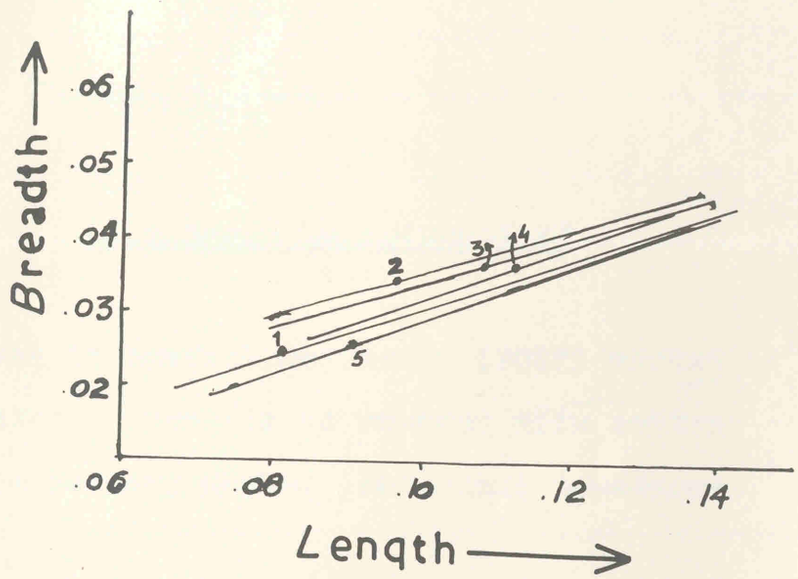




Explanation of Plate - 29

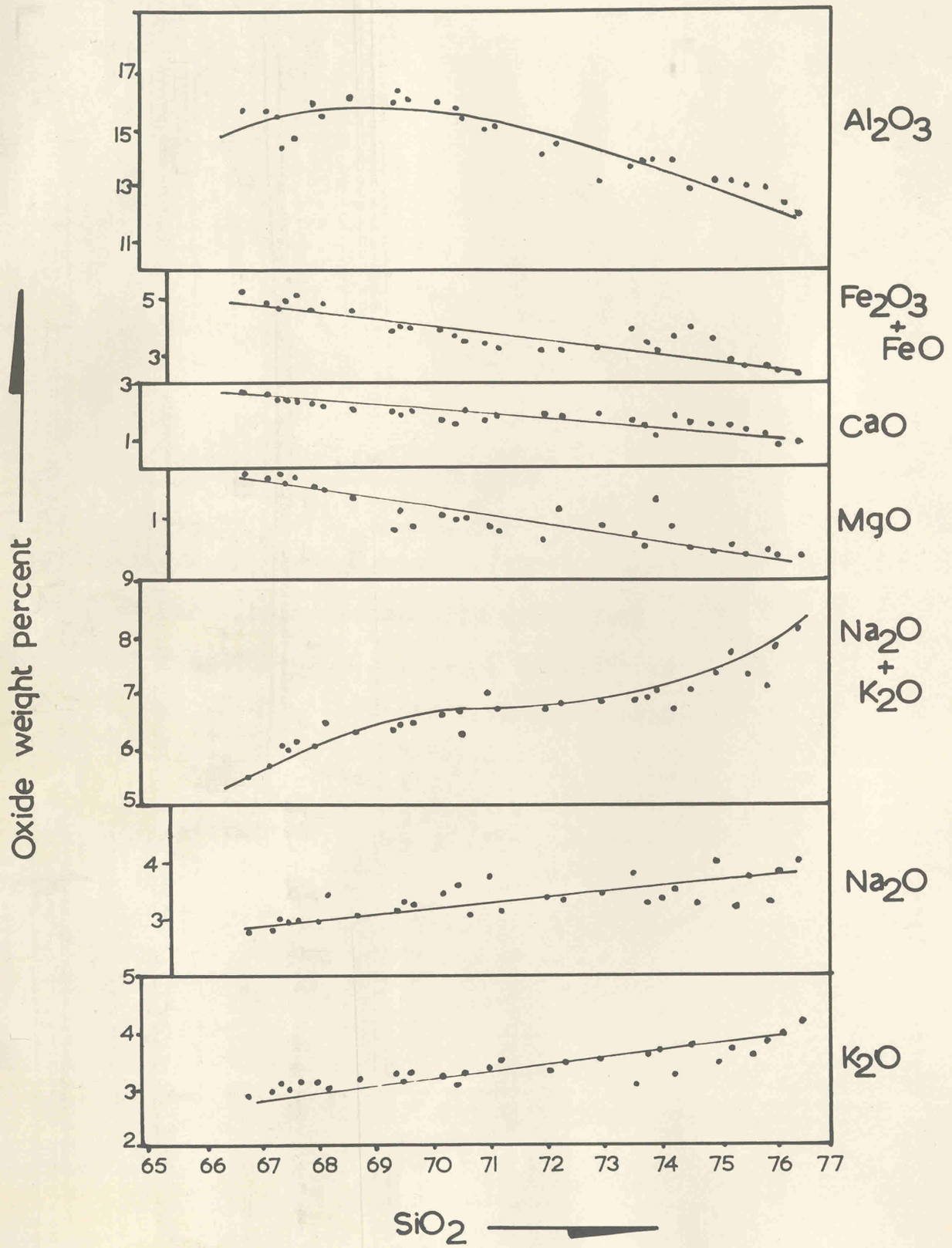
R.M.A's for Zircons of granites.

RMA's FOR ZIRCONS IN GRANITIC ROCKS



Explanation of Plate - 30

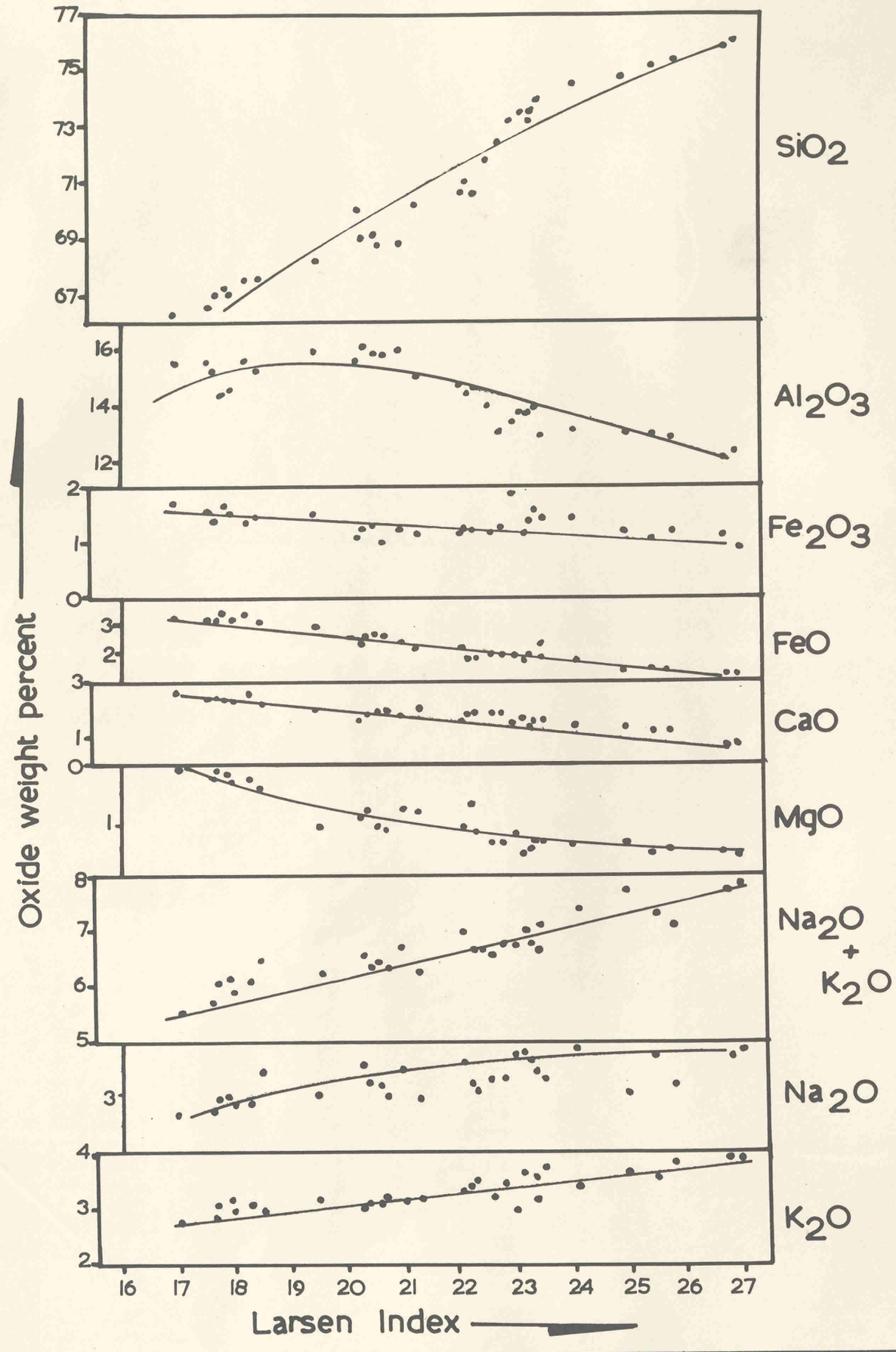
Harker (1909) variation diagram of several oxides with respect to silican. Dots represent individual Ladakh granite samples.


Oxide weight percent
17
15
13
11
Al_2O_3
5
3
Fe_2O_3 + FeO
3
1
CaO
1
9
MgO
8
7
6
5
Na_2O + K_2O
4
3
Na_2O
5
4
3
2
K_2O
65 66 67 68 69 70 71 72 73 74 75 76 77
SiO_2

Explanation of Plate - 31

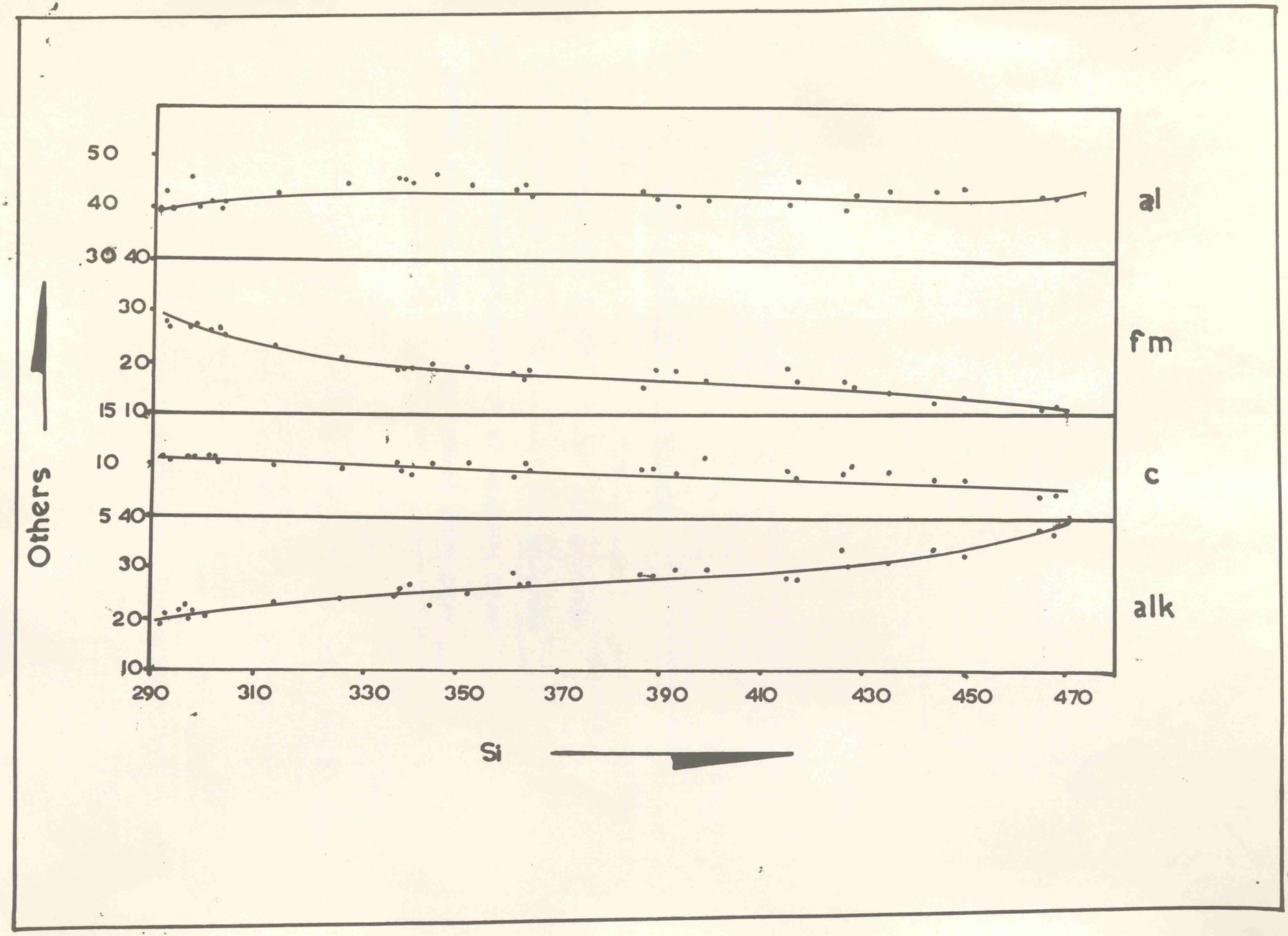
Larsen (1938) variation diagram showing the relationship of several oxides with respect to "Larsen Index". Dots represent individual Ladakh Granite samples.

PLATE-31


77
75
73
71
69
67
SiO2
16
14
12
Al2O3
2
1
0
Fe2O3
3
2
FeO
3
1
0
CaO
1
MgO
8
7
6
5
Na2O + K2O
3
Na2O
4
3
2
K2O
Oxide weight percent
16
17
18
19
20
21
22
23
24
25
26
27
Larsen Index

Explanation of Plate - 32

Niggli (1954) variation diagram showing the relationship of several Niggli molecules with respect to Si molecule. Dots represent Ladakh Granite individual samples.

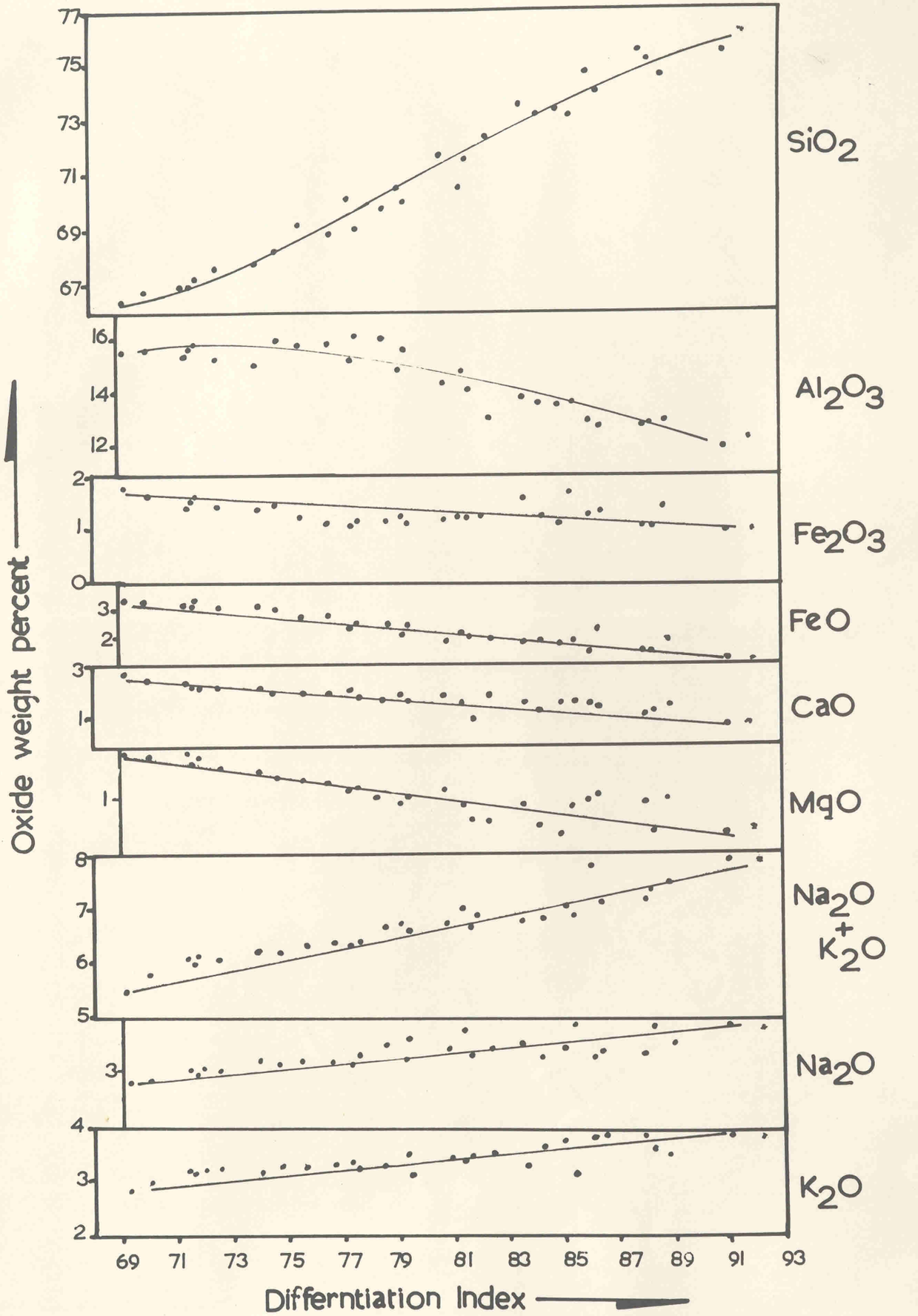

50
40
30 40
30
20
15 10
10
5 40
30
20
10
Others
290
310
330
350
370
390
410
430
450
470
Si
al
fm
c
alk

PLATE—32

Explanation of Plate - 33

Thorton and Tuttle (1960) variation diagram showing the relationship of several oxides with respect to "Differentiation Index". Dots represent individual Ladakh Granite samples.

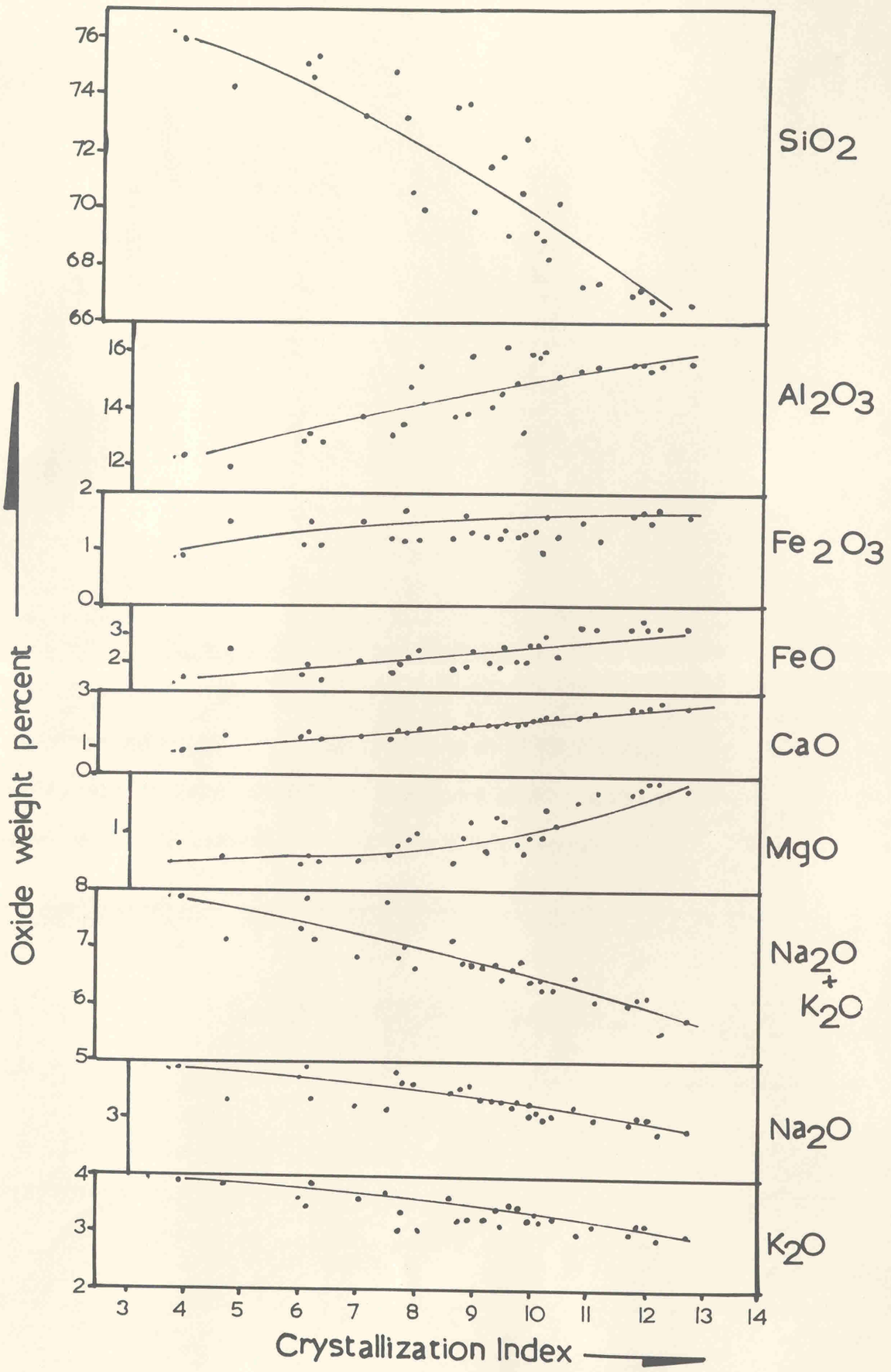
PLATE- 33


77
75
73
71
69
67
SiO2
16
14
12
Al2O3
2
1
0
Fe2O3
3
2
FeO
3
1
CaO
1
MgO
8
7
6
5
Na2O + K2O
3
Na2O
4
3
2
K2O
Oxide weight percent
69 71 73 75 77 79 81 83 85 87 89 91 93
Differntiation Index

Explanation of Plate - 34

Poldervaart and Parker (1964) variation diagram showing several oxides with respect to "Crystallization Index". Dots indicate individual Ladakh Granite samples.

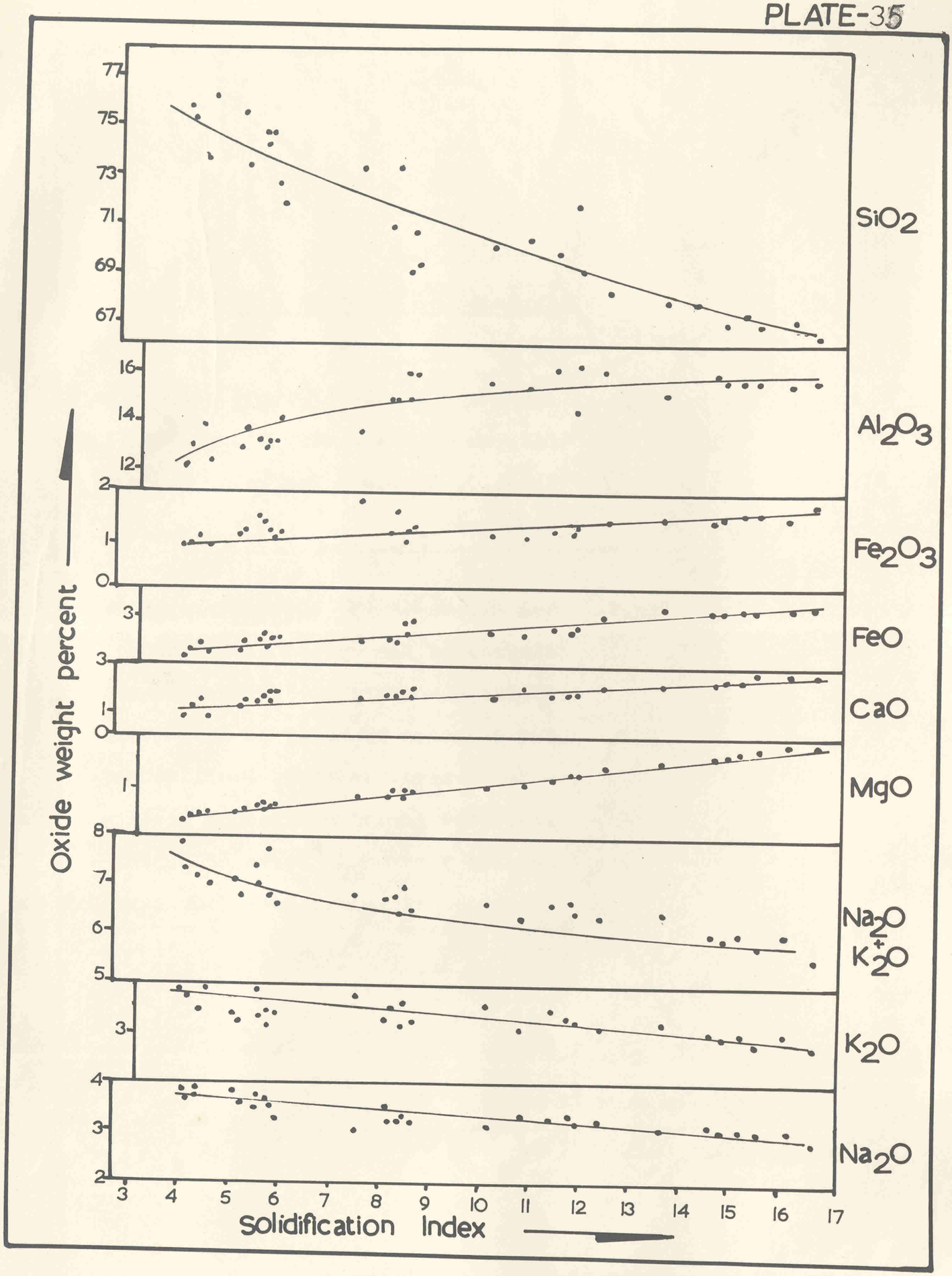
PLATE-34


Oxide weight percent
SiO2
Al2O3
Fe2O3
FeO
CaO
MgO
Na2O + K2O
Na2O
K2O
Crystallization Index
3 4 5 6 7 8 9 10 11 12 13 14

Explanation of Plate - 35

Kuno (1968) variation diagram showing several oxides with respect to "Solidification Index". Dots represent individual Ladakh granite samples.

PLATE-35


Oxide weight percent
Solidification Index
SiO2
Al2O3
Fe2O3
FeO
CaO
MgO
Na2O + K2O
K2O
Na2O

Explanation of Plate - 36

Fig.1 Bowen and Tuttle's (1958) ternary phase diagram of the system SiO_2 - $NaAlSi_3O_8$ - $KAlSi_3O_8$ at 2,000 bar water vapour pressure.

Fig.2 Vol Platen (1965) quarternary phase diagram of the system of Quartz - Albite - Anorthite - Orthoclase in the presence of water at 2,000 bar water vapour pressure. Small dots represent individual Ladakh Granite samples plotted in terms of Quartz - Albite - Orthoclase normative composition.

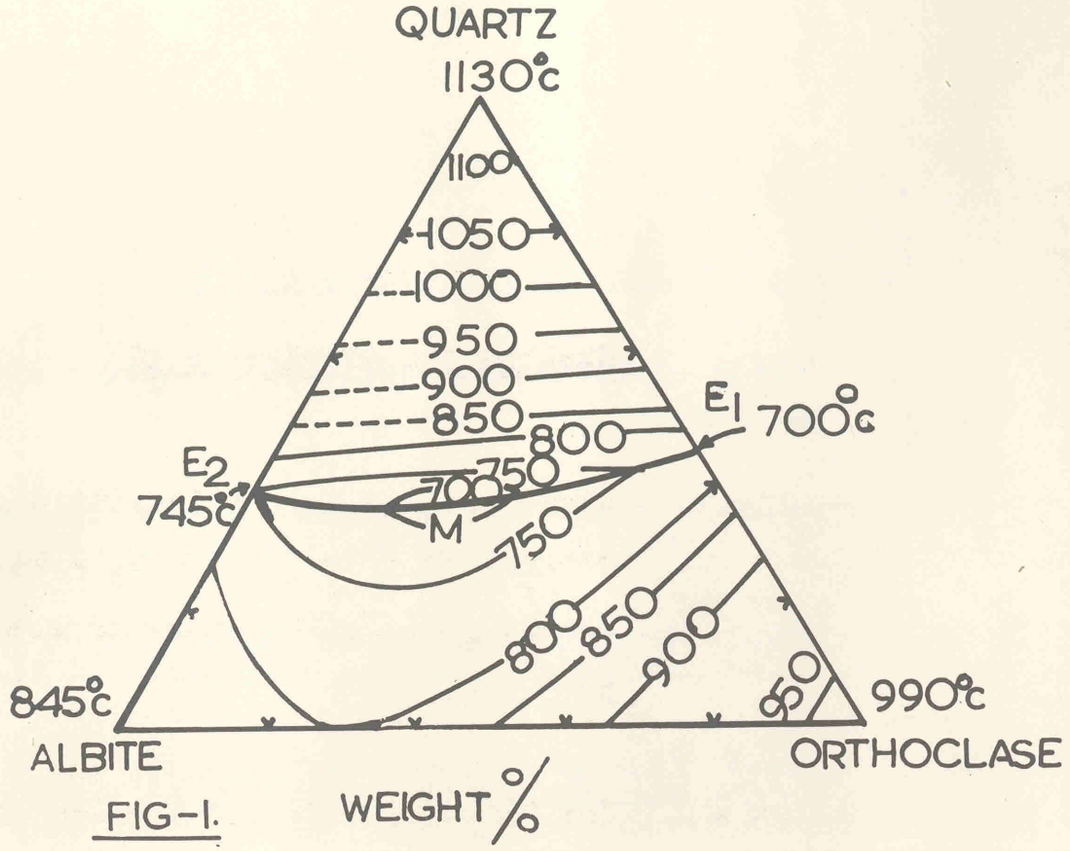

QUARTZ
1130°c
1100
1050
1000
950
900
850
800
750
700
E1
700°c
E2
745°c
M
750
800
850
900
950
845°c
990°c
ALBITE
ORTHOCLASE
WEIGHT %

FIG-1.

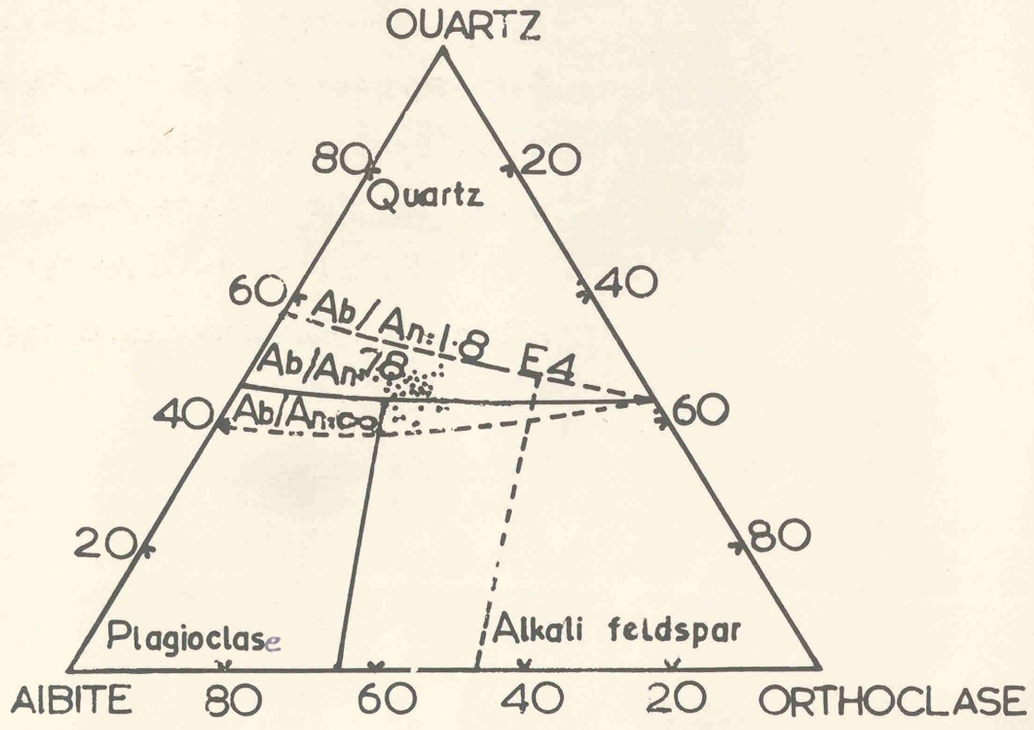

OUARTZ
80
20
Quartz
60
40
Ab/An:1:8
E4
Ab/An:8
40
Ab/An:∞
60
20
80
Plagioclase
Alkali feldspar
AIBITE
80
60
40
20
ORTHOCLASE

FIG-2

Explanation of Plate - 37

Family of triangular variation diagrams after Green and Poldervaart (1958).

Fig.1 Triangular variation diagram for the combination of Ca, Al, and (Na + K).

Fig.2 Three component variation diagram for the combination of Mg, Fe(Total) and Al.

Fig.3 Triangular variation diagram for the combination of Fe(Total), Al and (Na + K).

Fig.4 Three component variation diagram for the combination of Mg, Al and (Na + K).

Fig.5 Triangular variation diagram for the combination of Mg, Ca and Fe (Total).

Fig.6 Three component variation diagram for the combination of Mg,Fe(Total and (Na + K).

Fig.7 Triangular variation diagram for the combination of Mg, Ca and Al.

Fig.8 Three component variation diagram for the combination of Mg, Ca and (Na + K).

Fig.9 Triangular variation diagram for the Combination of Ca, Fe(Total) and Al.

Fig.10 Three component variation diagram for the combination of Ca, Fe (Total) and Na + K).

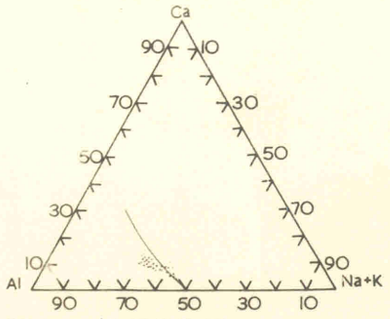


FIG-1. Ca, Al, Na+K System.

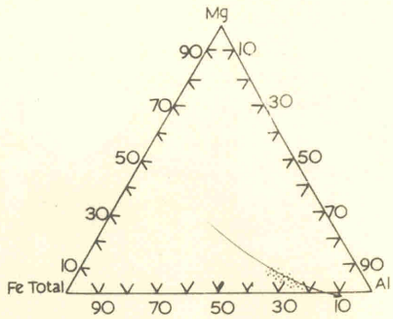


FIG-2. Mg, Fe Total, Al System.

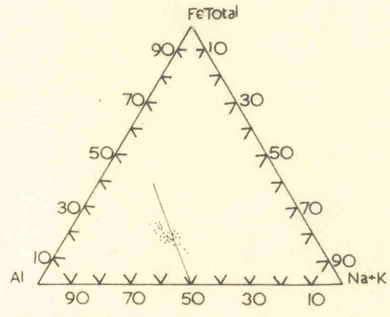


FIG-3 Fe Total, Al, Na+K System.

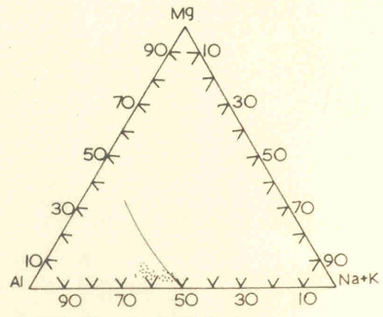


FIG-4 Mg, Al, Na+K System.

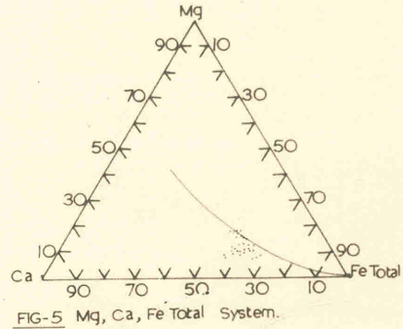


FIG-5 Mg, Ca, Fe Total System.

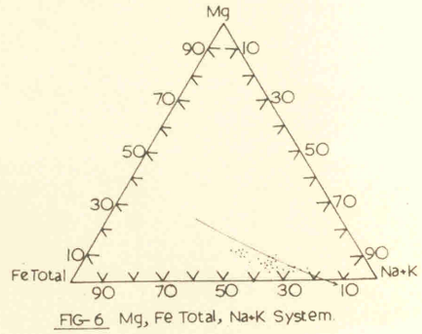


FIG-6 Mg, Fe Total, Na+K System.

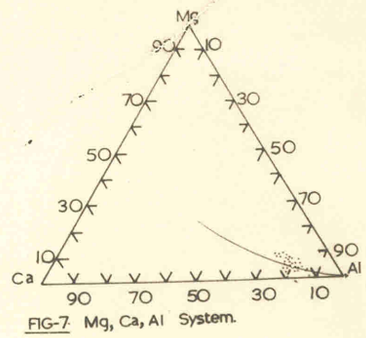


FIG-7 Mg, Ca, Al System.

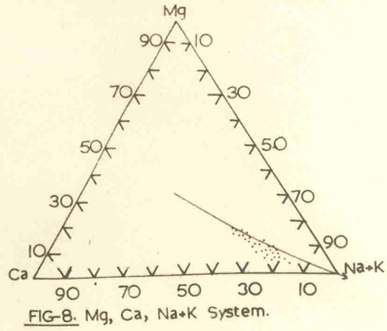


FIG-8. Mg, Ca, Na+K System.

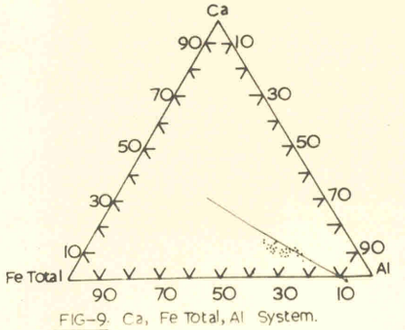


FIG-9. Ca, Fe Total, Al System.

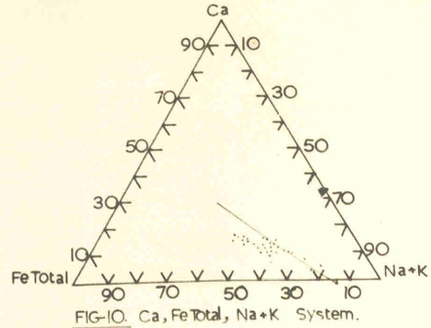


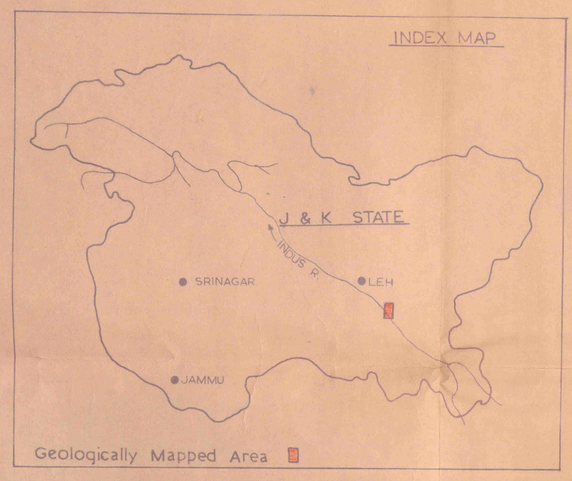
FIG-10. Ca, Fe Total, Na+K System.

GEOLOGICAL MAP OF THE AREA AROUND SAKTI, LADAKH DISTRICT, J & K STATE.

Scale

0 1 2 3 4 5 km.

INDEX MAP



Geologically Mapped Area

INDEX

- Fluvial — River Alluvium
- Fluvioglacial — Moraines
- S.St and Shale — Tuchik Formation
- Basal Conglomerate — Tuchik Formation
- Monzogranite — Ladakh Granite
- Granodiorite — Ladakh Granite
- Tonalite — Ladakh Granite

- Dip & Strike
- Joint
- Foliation
- Vertical Joint
- River & Rivulets
- Places
- Peaks, Height in metres
- Contact
- Probable Contact

— AJAY KUMAR SAPRU, 1982

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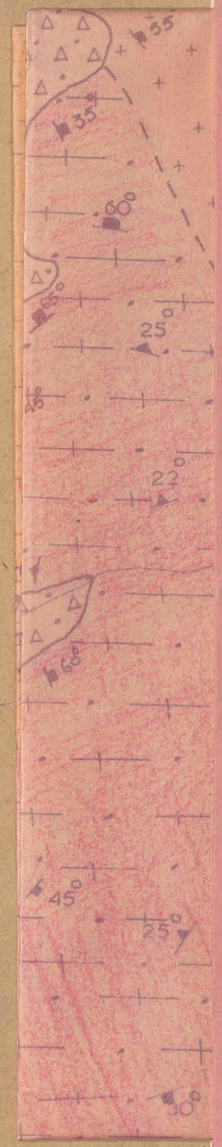

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PLATE 38