

PETROLOGICAL STUDIES OF SOUTH EASTERN  
PART OF KAPLAS GRANITE MASSIF,  
DODA DISTT, KASHMIR HIMALAYAS

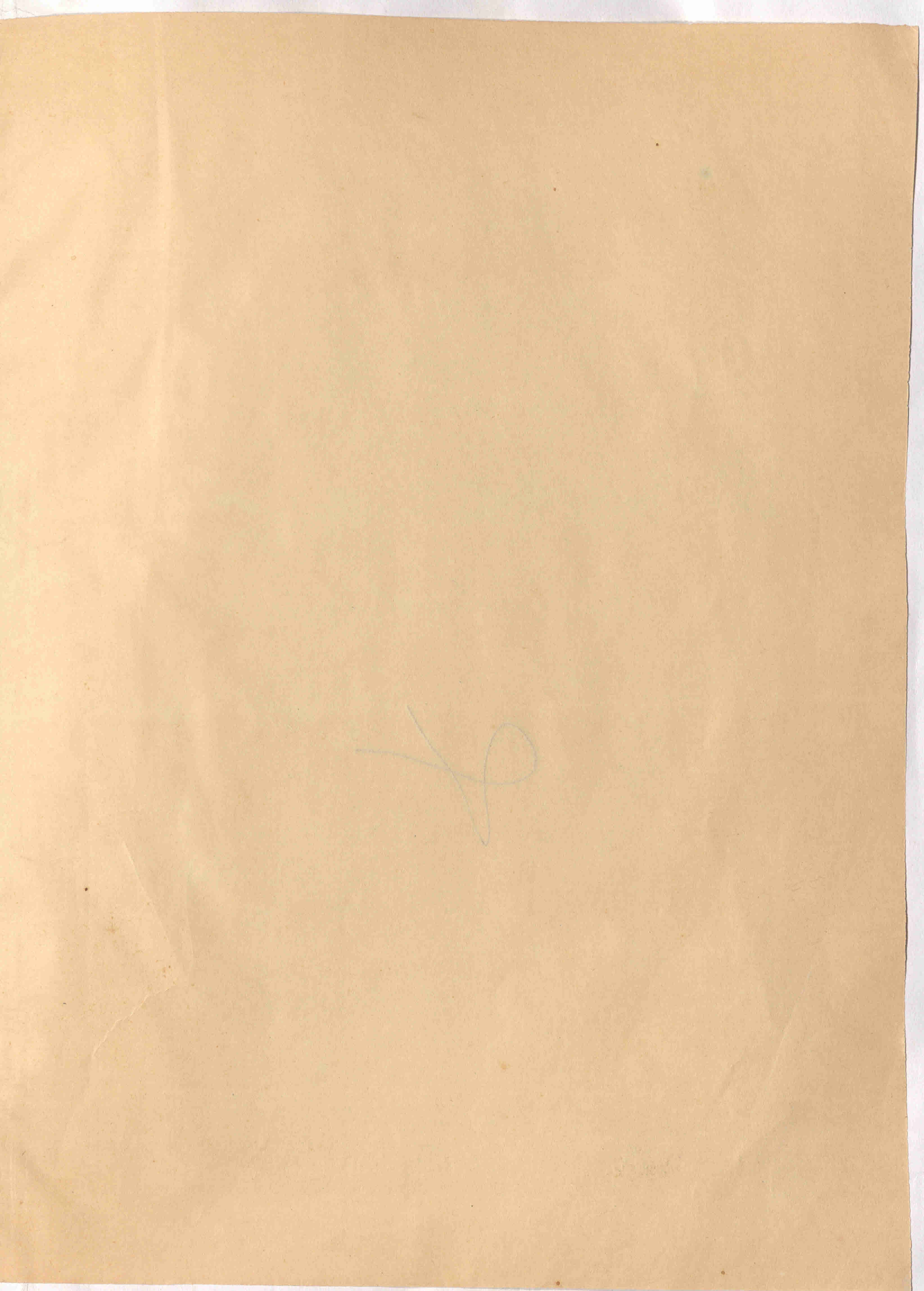
BY  
SURINDER KUMAR SHARMA

Ph. D. THESIS  
SUBMITTED TO  
UNIVERSITY OF JAMMU

FACULTY OF SCIENCE  
POST GRADUATE DEPARTMENT OF GEOLOGY  
UNIVERSITY OF JAMMU  
JAMMU-180001

1981





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CERTIFICATE

Certified that

- (i) the thesis embodies the work of Shri Surinder Kumar Sharma and is worthy of consideration for the award of Ph. D. degree ;
- (ii) the candidate worked under my supervision for the period required under the statutes of the University of Jammu, Jammu ;
- (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 his research in the department.

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*To My*  
**REVERED**  
**FATHER**

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## CHAPTER I

### INTRODUCTION

\*\*\*\*\*  
\* I. GENERAL \*  
\*\*\*\*\*

The lofty Himalayan mountains, which have been a perennial source of inspiration to the geologists and others from India and abroad, conceal in them a long chain of geological events in an unbroken succession, faithfully preserving the relicts of each event for the geologists to ponder over. Tectonically being a new feature of the crust, it is not so simple as it looks. On the other hand, its problems are also as lofty as the mountains themselves. This is a classic ground for the study of poly-metamorphic events aided with magmatism. The Himalayan rocks throw a challenge to the ingenuity of the earth scientists of the world, many of whom have devoted their entire lives in unravelling the mysteries of geological problems associated with Himalaya. Looking back in time one has to go right to the earliest periods of earth history, much before the geosynclines with thick sediments in them came on the stage of Himalayan scene. To simplify the matter for the sake of introduction, the first phase of metamorphism and magmatism is represented by the Precambrian progressive metamorphism and granitization of central crystalline gneisses and its equivalents which are characteristics of Higher Himalaya. Nanga Parbat area epitomises the history of

metamorphism.

The second phase is represented by Hercynian prograde metamorphism, which is less profound than the earlier one, producing second generation of prograde index minerals, through crystallisation and remobilisation of older rocks.

Whereas the third phase is the phase of Himalayan metamorphism characterised by large scale thrusting and associated dynamic and retrogressive metamorphism.

The pre-Himalayan and Himalayan granitic rocks are represented by granite gneisses, biotite granite, and tourmaline granite respectively which broadly fall under two major types as recorded by Pascoe (1964) and Valdiya (1962). The first group is represented by porphyritic biotite granite, granitic gneisses and mixed gneisses occurring almost completely amidst the Precambrian or doubtful Palaeozoic rocks in Punjab, Ladakh Karakoram, Kumaon and eastern Himalaya associated with high grade metamorphic rocks and as a rule, with the thrust (Desio, et al., 1964) and related with Hercynian orogeny (Pascoe, 1964). The second group includes younger Tertiary granite, including both tourmaline-granite and hornblende-granite, occurring as discordant intrusive in the sediments, and are believed to represent the latest phase of completely mobilized material intruded from the deeper levels into the

upper horizons (Gansser, 1964). They occur in the northern part of Himalaya e.g., in Bhutan, Nepal and Dras.

The present studies relate to Kaplas Granite Massif, named after Kaplas peak (Lat.  $32^{\circ} 51' 50''$  ; Long.  $75^{\circ} 41' 00''$ ), falling in Kashmir Himalaya. This granitic massif is considered to occur as an elongated dome shaped intrusive body covering an area of about 400 sq.km. (Sharma et al., 1973), extending from southeast of Khalani (Lat.  $33^{\circ} 08' 20''$  ; Long.  $75^{\circ} 31' 00''$ ) in the northwest to Budwar (Lat.  $32^{\circ} 45' 08''$  ; Long.  $75^{\circ} 46' 27''$ ), northwest of Bani in the southeast, along the Seoj Dhar and from southeast of Bhadarwah to northeast of Dudu across the Seoj Dhar. The axis of dome corresponds, in general, with the regional strike NW - SE.

Generally, it is observed that a small deviation in the study of complex problems, connected with the geological evolution of a terrain, ultimately leads to multiplication of complexities, sometimes upto the point of no return. Such happens only, when little attention is paid to the problems which rather appear monotonous and for which answers are also taken for granted. Exactly, this is what has happened in the area of present studies. Owing to its inaccessibility, ruggedness of terrain and stupendous heights, this area has not been paid much attention by the earlier workers. Thus the

area for all practical purposes has been left unattended which is substantiated by the fact that very limited published work exists regarding the geology of present study area.

From the initial stages of geological studies, only brief touch has been given to the stratigraphic position of the area, not much substantive work has been done especially from a petrological and geochemical standpoint. The author would, therefore, not hesitate to mention here that this is the first attempt in this direction and as such, though very limited in scope, does provide data which would be of immense help for the future workers and a tool to elucidate the controversies created on account of numerous interpretations and origin of the rock formations occurring in the present area.

\*\*\*\*\*  
 \* II. AIM AND SCOPE \*  
 \*\*\*\*\*

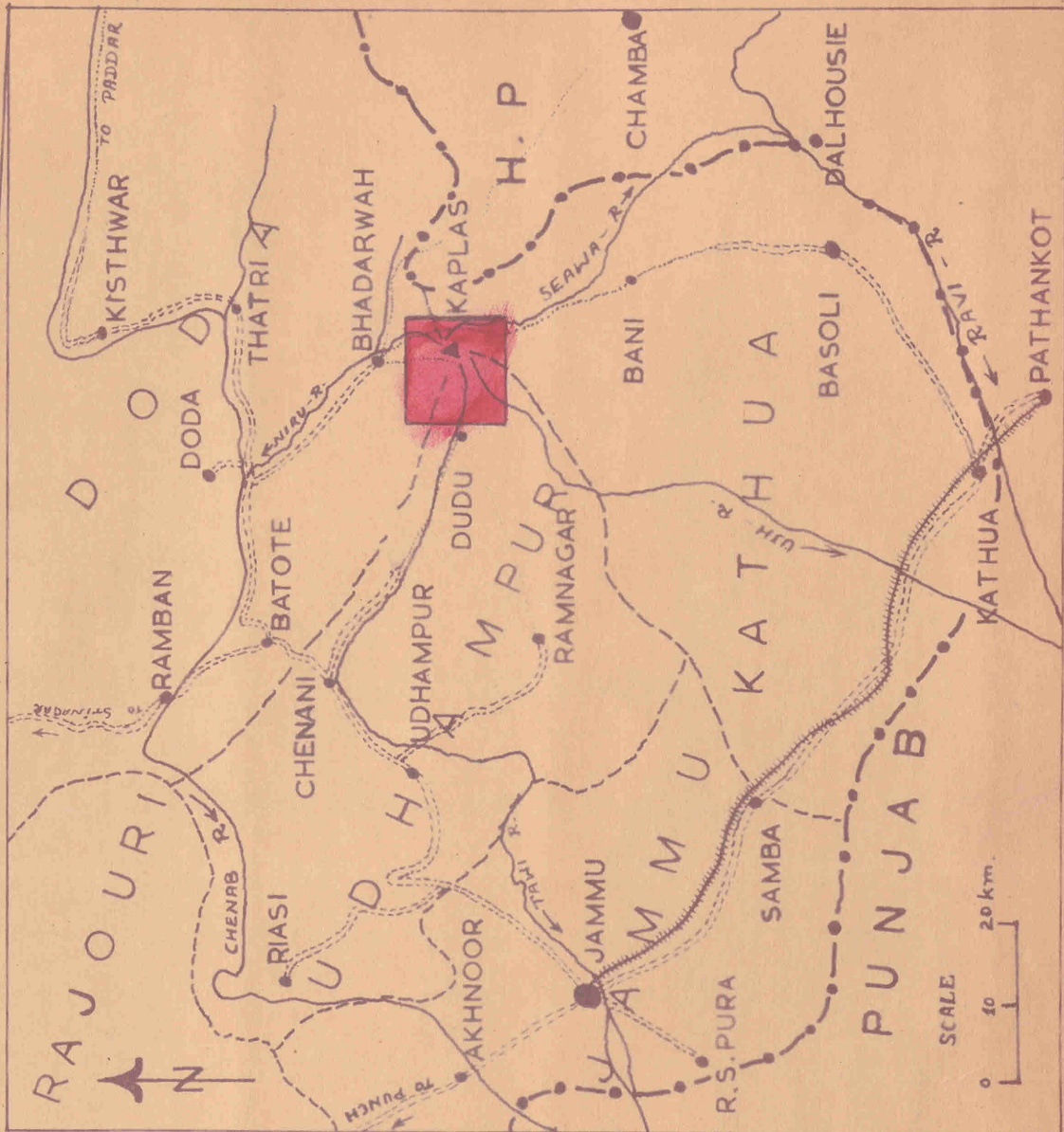
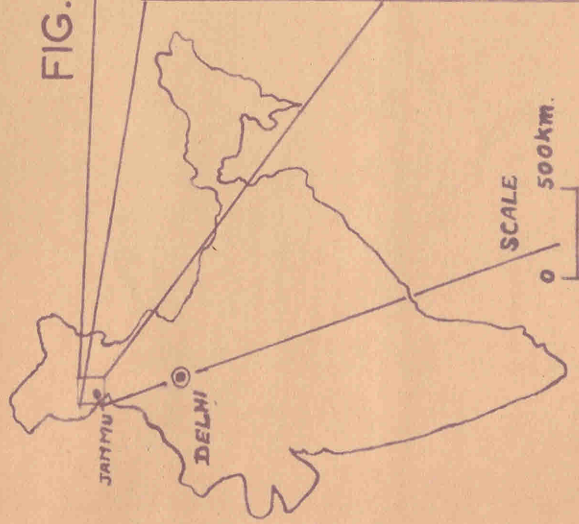
Most of the earlier workers concentrated their work on the present area from stratigraphic point of view. The present work, however, has been undertaken to study the geochemistry of southeastern part of Kaplas Granite Massif and its relationship with the country rocks. The chief aim of the present study is to collect the quantitative geochemical data which could be of great help in revealing

the true identity of these rocks and to work out the mineralogy and chemistry including the study of the behaviour of major as well as trace elements present in the rocks from one phase to another and also the cause of their migration. An attempt has also been made to correlate the chemical characteristics with mineralogy on the one hand, and the initial composition and the resulting chemical gradient on the other. Thus, the present work is limited to investigations directly related to the above aim, leaving out of its domain such generalized studies which have little bearing on the present problem. In matter of stratigraphic correlations, the present work does not make any new contribution other than what will throw light on the nature and status of the granitic rocks of this region.

\*\*\*\*\*  
 \* III. LOCATION OF THE AREA \*  
 \* \*\*\*\*\*

The area under reference is situated in Bhadarwah, Ramnagar and Basoli tehsils of Doda, Udhampur and Kathua districts respectively of Jammu and Kashmir state. It is delimited by Lat.  $32^{\circ} 45'$  to  $32^{\circ} 55'$  N. and Long.  $75^{\circ} 35'$  to  $75^{\circ} 48'$  E. and covering about 362 sq.km. area. The area comes under (1 : 50,000 scale) Survey of India Toposheet No. 43 P/9 and 43 P/13. The nearest town is Bhadarwah, which lies at the foot of Kaplas peak, is well connected by an all

FIG. 1. LOCATION MAP SHOWING THE AREA OF STUDY



- STATE BOUNDARY
- DISTRICT BOUNDARY
- RAILWAY LINE
- VEHICULAR ROADS
- MULE PATHS
- RIVERS
- AREA OF STUDY

Explanation of Plate 1

- A. A Panormic<sup>a</sup> view of the Kaplas range, camera facing east.
- B. A close panormic<sup>a</sup> view of the Kaplas range, camera facing northeast.



A



B

weather Jammu-Bhadarwah road. There is no other motorable road in the area. There are, however, few mule tracks, locally known as "Pagh Danddi". The mention may be made of the most common and popular tracks, Dudu-Seoj-Bhadarwah and Bhadarwah-Sarthal-Bani, which are the only means of transportation by mule or head loads in the area of present study. The location of the area of study is shown in Fig. 1. Panoramic views of a portion of the Kaplas area are shown in Plate 1, A & B.

\*\*\*\*\*  
 \* IV. PHYSIOGRAPHY \*  
 \*\*\*\*\*

The area under present investigations, lies north of Punjal Thurst and south of Pir Panjal Range, and forms part of lesser Himalaya. It shows few of the physiographically interesting landforms. The present area, in general, is mountainous with rugged topography consisting of high ranges, deep valleys, gently sloping meadows, steep slopes and escarpments etc. It has got an altitude ranging from 1900 m to 4341 m above m.s.l. The area under reference consists of major and minor ranges, most of which cut another in an oblique manner and meeting almost at one particular point, Kaplas peak (4341 m) showing, in general, a radial pattern of ranges (Fig. 2).

The most prominent range in the area of present studies

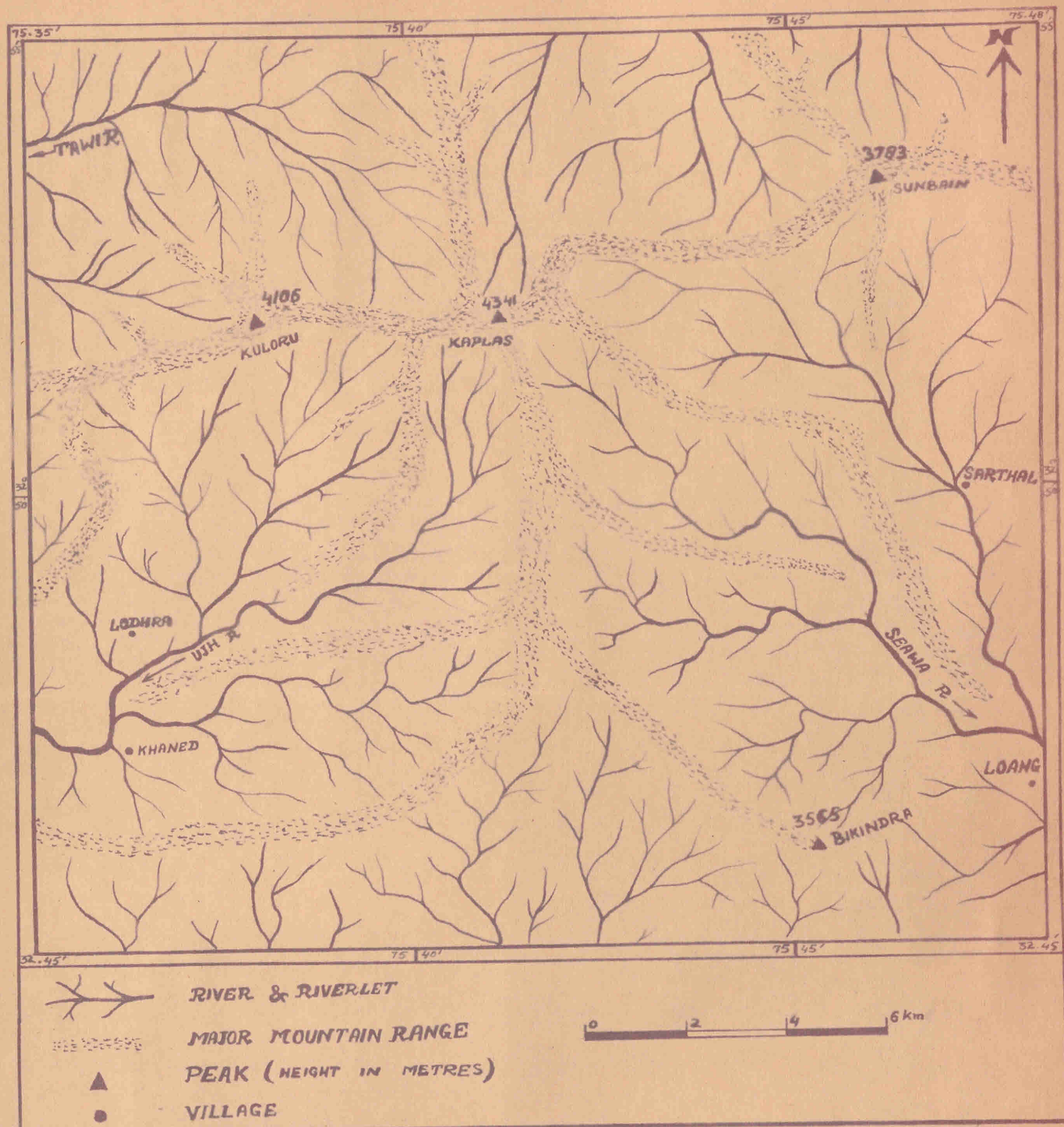
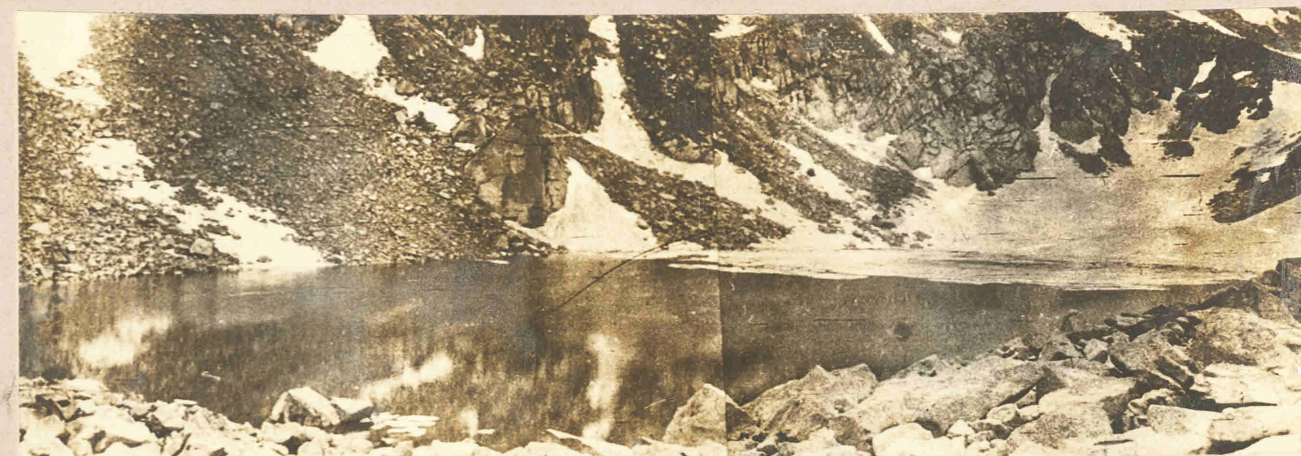


FIG.2. PHYSIOGRAPHIC MAP OF THE AREA OF STUDY

Explanation of Plate 2

- A. A view of the Kali Kund.
- B. A view of Kaplas Kund.
- C. Field photograph depicting the gorge cut by river Seawa (Locality : Kharkala).
- D. Field photograph showing striated Glacial boulder of Kaplas Granite (Locality : S.W. of Dabar).



B



A



D



C

is the Kaplas Range trending in an east-west direction and to which joins number of minor ranges. In between the ranges, deep gorges and valleys are also noticeable. This range, which is considered to be the continuation of Dholadhar Range, acts as a watershed between the Neru river flowing on its northern side and Tawi and Ujh on its southern side. Kaplas peak (4341 m) is the prominent feature which demarcates the boundary of three tehsils Bhadarwah, Ramnagar, Basoli falling in the Doda, Udhampur and Kathua districts respectively (Fig.1).

\*\*\*\*\*  
 \* V. DRAINAGE OF KAPLAS AREA \*  
 \*\*\*\*\*

The area is striven all over with drainage courses of prominent dendritic type, but the overall radial drainage pattern is the typical feature observed in the physiographic map of the present area (Fig. 2). There are numerous consequent, subsequent and obsequent streams out of which four are considered to be the major namely Tawi, Neru, Seawa and Ujh, all of which originating from the area surrounding Kaplas peak. A mention may be made of few streams occurring in the study area.

The common popular river of the region is Tawi which takes its origin at Kalikund (3703 m, Plate 2,A), proceeds towards west, joined by many tributaries, and after flowing

through Chenani near Udampur impounded for power generation and further running through Jammu it finally joins river Chenab.

The Neru is another important river which originates from the Kaplas kund (3982 m, Plate 2,B), is joined by many streamlets originating from SeoJ and Ramtund area and finally, merges into river Chenab near Pull Doda.

The river Seawa is the outcome of the combined waters of five tributaries viz., Nauwa, Thalli, Khori and Panheru-da-Nal\*. Seawa has its origin in the ChhatarGali. It is joined by another big tributary, Nauwa Nal near Garar Pher from south-east, then it follows southernly course exactly through the contact of Bhadarwah Slate and Kaplas Granite and is further joined by Thalli Nal south of Sarthal. It takes southernly trend and cuts a gorge (Plate 2,C) near Kharkala and is joined by another tributary Panheru-da-Nal which is fed by the streams like Bimled Nal etc. and then flows through contact of slates and phyllites ultimately joins the river Ravi in H.P.

River Ujh is the outcome of confluence of two tributaries viz., Deni Nal and Sai Nal. The perennial source of water in the tributaries is provided by the snow-clad peaks of Kuloru,

---

\* Nal : Locally for small tributary.

Kaplas and Bikindera. Deni Nal flows southwest of Kaplas peak and meets Sai Nal near Punara after following the course through tehsil Ramnagar it flows through Kathua district and lastly enters to Pakistan.

\*\*\*\*\*  
 \* VI. GLACIATION \*  
 \*\*\*\*\*

The area under discussion has undergone active glaciation. The Seoj Dhar region represents an excellent example of main U-shaped valley, along which Bhadarwah-Dudu mule track runs, joined by several subsidiary U-shaped hanging valleys in Khuriyari-Kanji-Kalikund nala area, where terminal moraines and medial moraines are also observed in the form of crecent shaped hills. Several well polished hillocks and facettted huge blocks of porphyritic Kaplas Granitic Rocks are also noticed (Plate 2,D). A mention may be made of another typical U-chaped glaciated valley occurring in the Lodhra-Punara area with thick terrace deposits.

Similarly Sarthal valley is also one of the excellent example of a broad U-shaped valleys in the area under reference with huge rounded and facettted boulders. The typical features of active glaciation are also observed in Agali and west of Tipri, falling on Bhadarwah-Bani mule track, with well deposited morainial material.

\*\*\*\*\*  
 \*\* VII. AGRICULTURE \*\*  
 \*\*\*\*\*

As already referred to the Kaplas Range is the highest in the present area. It has got very thin soil cover. Due to its steep slopes and unavailability of water for irrigation at such altitudes, cultivation is very difficult.

Agriculture in this region is confined only to the lower reaches of mountainous terrain and the adjoining alluvial plains, where irrigational facilities are available viz., at Sarthal, Chunchili, Loang, Lodhra, Punara and Khaned. Paddy and Maize are the main crops of this area.

\*\*\*\*\*  
 \*\* VIII. FLORA AND FAUNA \*\*  
 \*\*\*\*\*

Flora : The flora of the present area is very interesting and is present in variegated form due to variation in the essential parameters viz., rainfall, lithology, altitude and topography. Important trees found in the area are pine, deodar, kail, fir, birch, oak, chestnut rhododendron etc. Flora 3000 m above the tree line is scanty and no significant vegetation is noticeable. Only alpine type shrub and grasses are recorded at higher altitudes.

Fauna : The principal fauna found in the area are mostly

wild animals. There are black and brown bears, foxes, lizards and snakes generally in the forested portion of the area. In the higher reaches only snow leopards and white eagles are present.

\*\*\*\*\*  
 \* IX. CLIMATE \*  
 \*\*\*\*\*

The area experiences a pleasant temperate climate. The higher elevations of the area remain snow covered for about six months (November to April) while the lower heights remain snow covered for about four months (November to February) in a year. Rains are quite frequent. Rainy season starts by the end of June and continue till the middle of September and rain fall is high during this period. There are five seasons very well demarcated from one to another :

- i. Spring season between March to May ;
- ii. Summer in the months of May and June ;
- iii. Rainy season between the months of July and September ;
- iv. Autumn season in the months of October and November ; and
- v. Winter extends from December to February. Summer and rainy months are favourable for the field work.

\*\*\*\*\*  
 \* X. POPULATION \*  
 \*\*\*\*\*

As already mentioned the area of study is highly elevated. Due to its dizzy heights, snow clad peaks and adverse climatic conditions, it is very difficult for the people to become habitat of this region. Only in summer season Gujjars, Gadies and Bakarwals visit the meadows of higher reaches for grazing their livestock and sheep flocks. They live in temporary huts during summer season and in winter season come down to the lower reaches, where climatic conditions are relatively favourable. A mention may be made of few villages which comparatively have good population. They are Lodhra, Punara, Khaned, Sukad, Loang and Chunchili.

\*\*\*\*\*  
 \* XI. A BRIEF RESUME' OF THE PREVIOUS WORK \*  
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A brief resumé of the work carried out by the earlier workers on the granitic and other associated country rocks occurring in the area under reference and also in surrounding areas is given in a chronological order in the following pages.

Stolizcka (1866), who was one of the earlier workers, was the first to give a detailed account of the geological formations of Kashmir, and designated the granitic rocks

occurring in the area as "Central Gneiss". He considered them to be of Archaean age.

Lydekker (1876), one of the pioneer geologists of the 19th century, during the course of his work in the eastern and western part of the area of present investigations, concluded that the area is covered by crystalline schists and Triassic Formations.

McMahon (1885) on the basis of his work in and around Basoli, Bani and Bhadarwah area, considered the Bhadarwah Slate of Silurian age. They lie unconformably over the Central Gneiss (Kaplas Granite) and succeeded by the conglomerates of Upper Silurian age.

Hayden (1915) regarded the granites and hornblende schists and gneisses of Gilgit area to be of metamorphic origin.

Middlemiss (1931) during the course of his work in Kishtwar region, reported the occurrence of hornblende and biotite gneisses composing mineralogically of quartz, feldspars, biotite and hornblende.

Wadia (1931) has shown that the present area is covered by the rocks of Dogra slate and by the unfossiliferous rocks

of Palaeozoic age. Later in (1932) during his field work in the Nanga Parbat area he reported the occurrence of gneissose granite and tourmaline-hornblende granite and regarded them to be of metamorphic origin.

Misch (1949), while working in the Nanga Parbat area reported the gradual gradation of the Salkhala (Pre-cambrian) to coarse-grained granitic gneisses and regarded them as mostly metamorphosed Salkhala. He recorded in the area the presence of three major metamorphic zones, starting from low grade metamorphism to extreme granitization. The different minerals entering the composition of these granitized rocks, according to him, are quartz, potash feldspars, oligoclase, biotite and muscovite. Garnet has also been reported from the granites occurring in the area.

Gansser (1964) has shown that the Doda-Bhadarwah region is covered up by the rocks belonging to the Salkhala and Dogra slate group with a thin band of Panjal Trap. He regarded the Central Gneiss as the older formation.

Kapoor (1964) during his field session in the area northwest of Bhadarwah, reported the occurrence of phyllites, schists and granitic gneisses belonging to Salkhala.

Ukai and Kimura (1965), who made a detailed work on the granitic rocks of the Karakoram Range, concluded that the granitic rocks of the area of metamorphic origin. These leucocratic rocks, which are medium to coarse-grained in size, composed of quartz, feldspars, biotite and muscovite along with accessory like zircon, sphene, apatite and garnet.

Wakhaloo (1968) reported granite gneisses of east of Mari Sudar river near Bhandakut, Kishtwar area to be of metamorphic origin.

Munshi (1969) during the course of his research investigations around Kangan, in Kashmir, reported the occurrence of granodiorites and regarded them to be of intrusive nature. The different minerals entering into its composition are quartz, plagioclases, Potash feldspars, biotite and muscovite. Tourmaline is also found in these rocks at places. Oxides of iron are also present in them as accessory minerals.

Wakhaloo and Bhatia (1970) during the course of field work near Digdaul on the Jammu-Srinagar National Highway, reported the grey coloured granitic exposures, which are gneissose, medium to coarse-grained in nature, and the minerals constituting these rocks, according to him, are quartz, potash feldspars, plagioclases and biotite, alongwith zircon, epidote, apatite, sphene, calcite and opaque minerals.

Wakhaloo and Dhar (1970) and Dhar (1972) reported the occurrence of granitic rocks from Kishtwar area. They are of light grey to dark grey in colour and medium to coarse-grained in texture. They considered these rocks to be of intrusive nature.

Ray (1972), while dealing with Himalayan problems connected with the orogenic movements in the Himalaya, concluded that a melt of partial and complete fusion of crustal rocks must have been formed at 10-40 km depth, which ultimately in the form of granites and the associated rocks reached the present surface through uplift in the solid state.

Sharma, et al. (1973) gave a detailed account of stratigraphy and tectonics of Doda-Bhadarwah-Basangarh region, and referred to the Central Gneiss of McMahon (1885) as Kaplas Granite.

Didwal (1975) during the course of his detailed investigations in Bhala and Dedni area, reported the granitic rocks are of intrusive nature. He considered them to be <sup>of</sup> anatectic origin.

Uppal (1978), while working on Hant area Baramulla district, Kashmir emphasized that the "Hant Granite" is of

magmatic origin.

Gupta (1979) during the course of his research work in KaziNag area, Kashmir, regarded the Kazi Nag Granites to be of magmatic origin. The different minerals entering into the composition of these granites, according to him, are quartz, sodaline feldspars, alkalifeldspars, biotite, muscovite and tourmaline alongwith magnetite and ilmenite as opaque minerals.

Bhandari and Singh (1979) conclude that granites of Kaplas-Khal-Dedni area are of intrusive nature and have been intruded into the meta-sediments of Salkhala *formation* and Dogra Slate.

\*\*\*\*\*  
 \* XII. THE PRESENT WORK \*  
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In its manner of approach, the present work differs very much from the earlier works on the area under reference. The present work is first quantitative geochemical approach towards the study of properly sampled granitic rocks and associated country rocks. In this way, it is essentially different from the previous works of this region. The salient features of the present work may be summarized below :

- i. During the course of present work the area under

reference has been mapped on 1 : 50,000 scale on the basis of delineating in it various litho-units, dipstrike and joints pattern. Systematic collection of samples in the field by employing proper methods of sampling was also done.

ii. For the purpose of petrographic study 2V and An content of mineral grains, using five axis universal stage, were determined. The standard curves of Slemmons (1962) were used for this purpose. Modal composition of stained uncovered thin section (Bailey, et al., 1960) of rocks were determined with the help of Swift's point counter.

iii. Use of better techniques of analyses whose precision and accuracy are predetermined and statistically worked out against International Standards.

iv. Study of the behaviour of both the major as well as the trace elements occurring in these rocks on the basis of a much larger number of analyses than hitherto included in any of the previous studies.

v. Quantitative study of the role of the all the variable phases involved in the evolution of granitic rocks of the present study area.

vi. Finally, correlation of all the available data obtained from field, petrographic, chemical, and mineralogical studies and the statistical interpretation of the results.

\*\*\*\*\*  
\* XIII. ORDER OF PRESENTATION \*  
\*\*\*\*\*

The present work from the point of view of clarity in presentation can be divided into different chapters dealing with the individual aspect of problem concerned.

In the first chapter the problem has been introduced, the location of the area followed by the aim and scope of the present work as well as its limitations set forth. A general background of previous work has also been given together with the salient features of the present work.

The second chapter deals with regional geology and also includes geological succession and set up of present area. The petrographic studies with all possible details of Kaplas granitic rocks and associated rocks in the area under reference have been given in chapter third.

The fourth chapter deals with the methods employed in the field and laboratory for working out this problem together with an outline of the precision and accuracy and standard used.

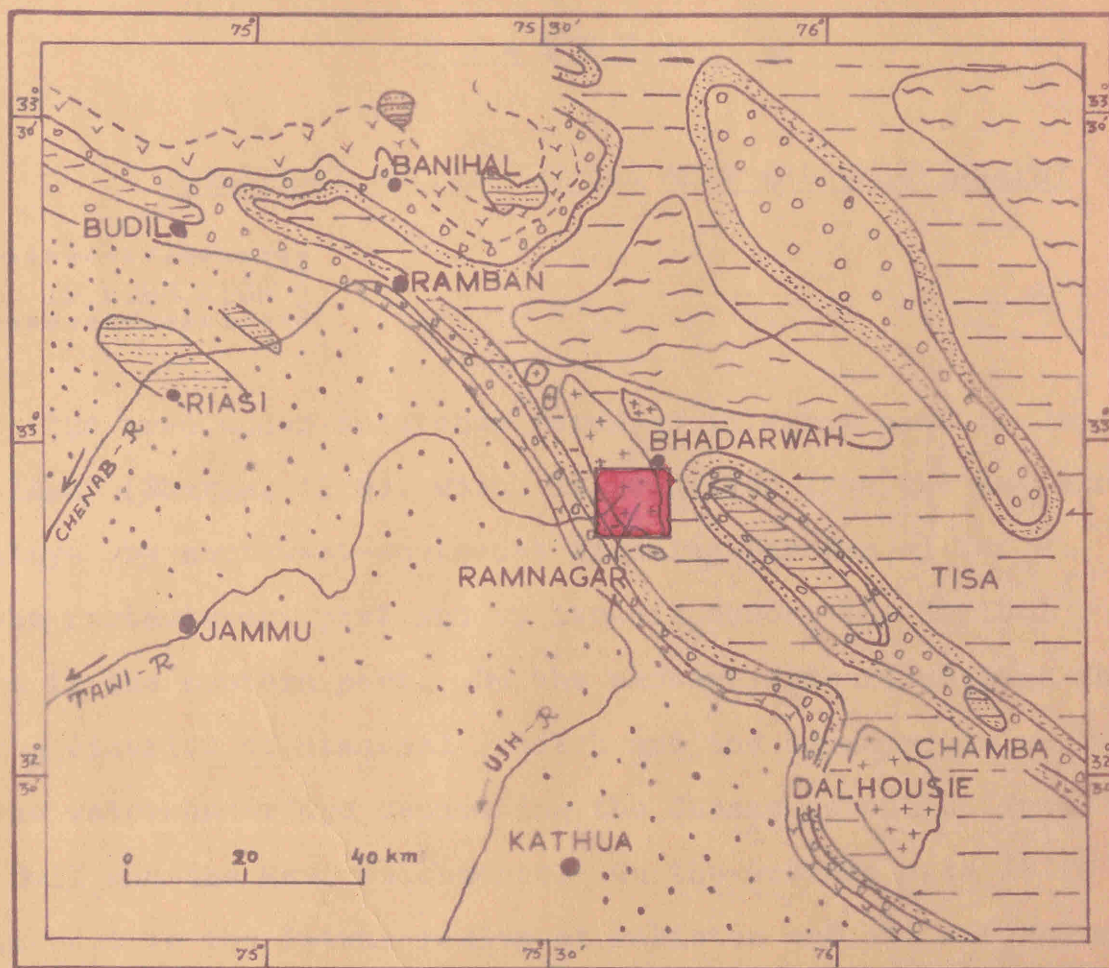
whereas chemical characteristics and the geochemical problems arising therein have been critically examined and discussed in chapter fifth.

Chapter sixth contains the chemical and mineralogical correlation, while in the seventh chapter behaviour of trace elements have been dealt.

The interpretation and discussion part of the present work is included in eighth chapter, which starts with a description of basic ideas and background, and eventually deals with the bulk transfer and adjustment of composition during the formation of granite massif.


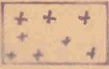
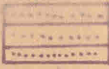



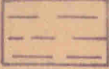


The last chapter encompasses with a summary of the present observations and important conclusions arrived at during the period of study.

Thus from what has been said above, it will be clear that the present studies are of restricted nature and no attempt has been made to generalise the results. To what bare truth these data point out is the only tool with which the writer has tried to build up this framework and indeed only the posterity can judge how far this framework can stand the "weathering agent of geological concepts and ideas".



(AFTER SHARMA, 1975)

## INDEX

- |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
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**FIG 3 REGIONAL GEOLOGICAL MAP**

## CHAPTER II

### GEOLOGICAL SETTING OF THE AREA AND STRATIGRAPHY

\*\*\*\*\*  
\* I. INTRODUCTION \*  
\*\*\*\*\*

The area under reference forms an integral part of Jammu Himalaya (Sharma, 1976), which is separated from the Kashmir Himalaya by northwest-southeast trending Pir Panjal Range in the northwestern part and by its off shoot, the Saribal Range in the eastern part. On the eastern side it adjoins the Chamba district of Himachal Pradesh and the boundary is marked by the watershed-ridge separating the Chenab catchment from the Suil and the Ravi catchments. On the western side it is contiguous to the Potwar region of Pakistan and its extension is delimited by the southerly flowing Jehlum (Sharma, op.cit.)

The regional setting of the area indicated above has been shown in regional geological map fig. 3 (after Sharma 1975), wherein the geology of the region under investigation is also shown. The Dogra Slate (Bhadarwah Slate) are present all around the granite massif. They are of great thickness especially towards the southeast and east of the granite massif, whereas towards west of the body, they are not that much thick as compared to the southeast and east of the

granite massif. In the area adjoining the northeastern and southwestern of the granitic body, there are small isolated granitic bodies, which are considered to be the cupolas of the main granitic body (Sharma, 1973; Didwal, 1975). The Salkhala are also present towards the northeast of the main intrusive body but have not been included in present investigations. The Salkhala are composed mostly of schists and phyllites with bands of limestone. Dogra Slate (Late Precambrian) are composed of slates and graywackes. The contact between the Salkhala (Early Precambrian) and the Dogra Slate is not clear and it is on the basis of metamorphism that the two are distinguishable from each other, the former showing high grade of metamorphism, while the latter shows metamorphism of lesser degree.

\*\*\*\*\*  
 \*\* II. STRATIGRAPHY \*\*  
 \*\*\*\*\*

Stratigraphically, Jammu Himalaya represent almost a complete stratigraphic set up of rock groups ranging in age right from Precambrian to Triassic, but with breaks here and there. The following is the stratigraphic sequence of rocks given in Table-1, which has been worked out on the basis of order of superpositions, mutual field relationship of different rocks, their lithological characters, structure, grade of metamorphism and fossil content.

Table-1

<u>Formation</u>	<u>Lithological description</u>	<u>Age</u>
Alluvium and terrace deposits	Buff coloured shales, loam and fluvioglacial deposits.	Pleistocene and Recent
Murree	Red and grey shale and sandstone.	Oligocene to Mid. Miocene.
----- Murree Thrust -----		
Kaplas Granite	Massive and foliated coarse-grained granite	Post-Carboniferous
Panjal Trap	Massive, Schistose, amygdaloidal vesicular trap with thin intertrappean fossiliferous shales.	Upper-Carboniferous
Katari Gali Formation	Dark Carbonaceous, ferruginous and calcareous shale and slates.	Middle-Carboniferous
Langera Conglomerate	Boulder bed, conglomerate, conglomeric and gritty quartzite, pebbly, phyllite with thin bands of limestone.	Lower-Carboniferous
Seawa Para-Gneiss	Quartzitic, banded, streaky, augen para gneiss with quartzite slate partings.	Devonian
Sunbain Quartzite	Coarse grained grey, greenish grey, buff brown coloured quartzite, at places gritty, pebbly and conglomeric.	
Bhadarwah Formation	Bhadarwah Slate Garnet phyllites	Cambro-Silurian

A brief stratigraphic account of each of the rock groups is given below :

Bhadarwah Formation

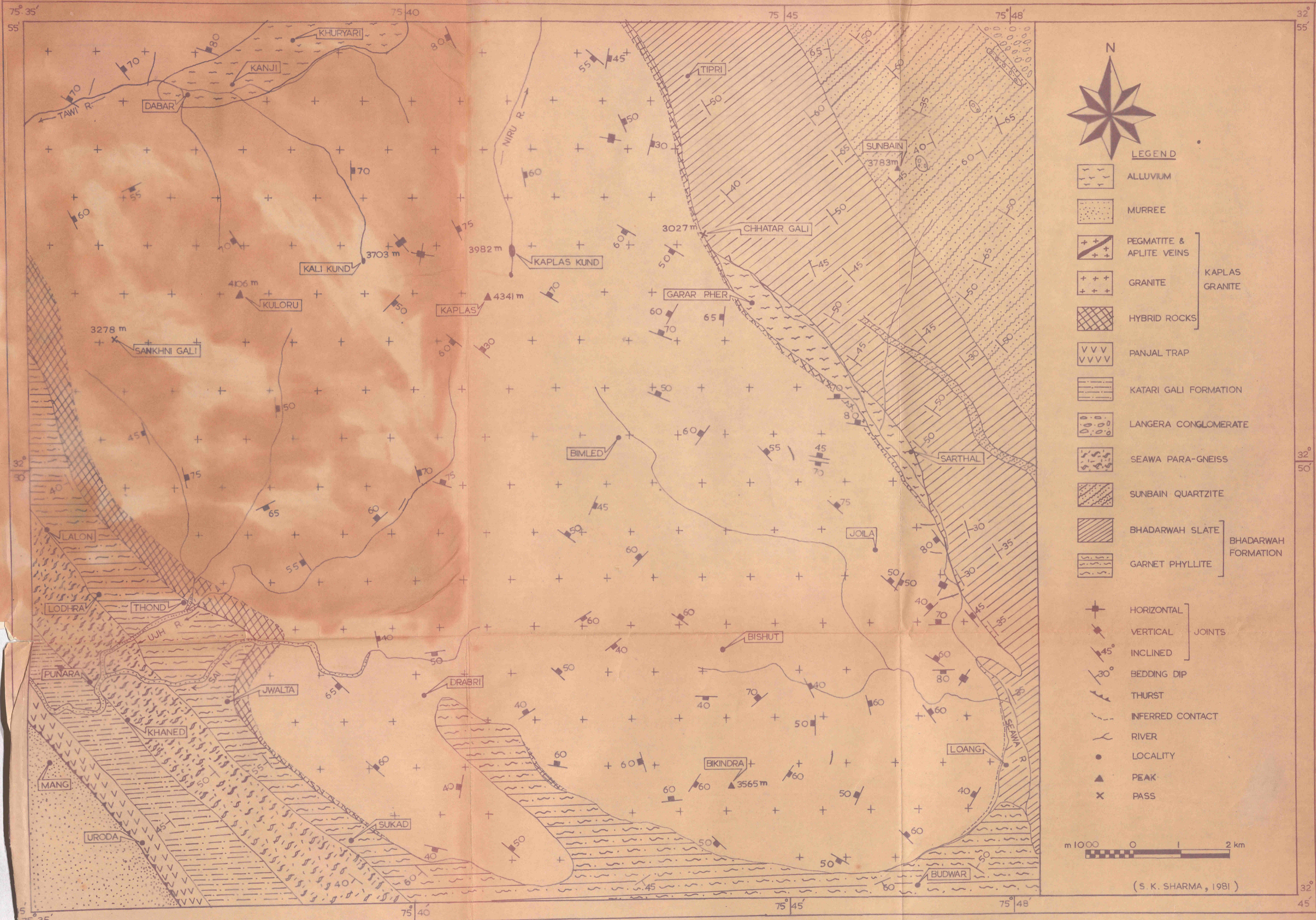
This formation as a whole includes a group of rocks which have been named after the town Bhadarwah (Lat.  $32^{\circ} 59'$  ; Long.  $75^{\circ} 43'$ ) (Kapoor 1973). The rocks of Bhadarwah Formation show a great deal of textural as well as vertical facies variation. Lateral gradation of slates into quartzitic slates and quartzites is commonly noted. Similarly the gradation of slates into chloritic phyllites and garnet phyllites is also commonly met with.

The rocks of Bhadarwah Formation have been divided into two members showing distinct lithological characters (Sharma, et al., 1973) are as under :

- i. Garnet Phyllites,
  - ii. Bhadarwah Slates.
- 
- i. Garnet Phyllites

Garnet phyllites comprise sheeny grey and steel grey colour, shining lusture and with minor crinkly folds.

GEOLOGICAL MAP OF THE KAPLAS AND ADJOINING AREAS, KASHMIR HIMALAYA



LEGEND

- ALLUVIUM
  - MURREE
  - PEGMATITE & APLITE VEINS
  - GRANITE
  - HYBRID ROCKS
  - PANJAL TRAP
  - KATARI GALI FORMATION
  - LANGERA CONGLOMERATE
  - SEAWA PARA-GNEISS
  - SUNBAIN QUARTZITE
  - BHADARWAH SLATE
  - GARNET PHYLLITE
- KAPLAS GRANITE
- BHADARWAH FORMATION
- HORIZONTAL JOINTS
  - VERTICAL JOINTS
  - INCLINED JOINTS
  - BEDDING DIP
  - THRUST
  - INFERRED CONTACT
  - RIVER
  - LOCALITY
  - PEAK
  - PASS



(S. K. SHARMA, 1981)

Explanation of Plate 3

- A. Field photograph showing the exposures of Bhadarwah Slate (Locality : North of Sarthal).
- B. Field photograph showing an outcrop of Bhadarwah Slate (Locality : Chhater Gali).
- C. Field photograph showing quartzitic band in Bhadarwah Slate (Locality: North of Chhater Gali).



A



B



C

The chief mineralogical constituent present in these rocks is garnet, which is brown to chocolate in colour, ranging in size from pin head to oil seed, at places they occur in the form of clusters. These rocks are well exposed southeast of granitic massif at Lodhra-Lalon area in Ujh valley, where they comprise chlorite-phyllite and with incipient development of garnet. Phyllites show foliation with a strike varying from  $N 25^{\circ} W$  to  $S 25^{\circ} E$  and  $N 45^{\circ} E$  to  $S 45^{\circ} N$  with the dips  $40^{\circ} SW$  and  $65^{\circ} SE$  respectively. These rocks are considered to be Cambro-Silurian in age (Sharma, 1973). These are well demarcated in the geological map of the area (Fig.4).

ii. Bhadarwah Slate

The term Bhadarwah Slate is introduced after Bhadarwah town (Sharma, 1973), where slates are well exposed adjoining to the area of present investigations (Plate 3,A & B). They comprise grey, dark grey and buff coloured slates generally showing cleavage development parallel to the bedding. At places, they contain lenticular bands of dirty white coarse-grained quartzite as seen at Ghatti (Lat.  $32^{\circ} 50'$  ; Long.  $75^{\circ} 47'$ ) near Sarthal and 100 m north of Chhatargali (Plate 3,C). At Tipri and Sapnagri, slates are highly carbonaceous and assume coaly appearance.

The Bhadarwah Slate, as shown in the geological

map (Fig. 4) are crop out northeast of Kaplas Granite which along its contact with granite are disturbed, puckered and crenulated. The Bhadarwah Slate extend southeasterly towards Chamba in Himachal Pradesh, where they are referred to as Chamba Slates (Sharma, 1973). These are considered to be equivalent to Jutogh Formation of Simla (Sharma, 1969). Wadia (1931) considered that the area under present investigations is covered with Dogra Slate and correlated them with the slates of Kishenganga Titwal area, which are of Cambro-Silurian age.

#### Sunbain Quartzite

Bhadarwah Slates are followed in succession (Table-1) by coarse-grained, greyish dirty, white, brownish and greenish quartzites at places with quartzitic slates. These rocks are well exposed in Sunbain ridge, eastern side of Mount Kaplas (Fig. 4) and have been designated as Sunbain Quartzite and occur as passage bed between the underlying Bhadarwah Slate and overlying Langer Conglomerate (Sharma, et al., 1973, 1975; Sharma, 1976).

To the southeast of Bhadarwah, these rocks extend from Sunbain towards Kalethu ridge which forms the boundary between Bhadarwah and Chamba and watershed between Suil and Seawa. In the Markhad-Sunbain area, these rocks

comprise thinly banded sequence of quartzites and quartzitic slates which are gritty and pebbly. These hard massive quartzites are repeated several times between Padri Gali to Sunbain due to folding. In Bajju-Bag, these rocks comprise thinly bedded rhythmic sequence of coarse-grained white quartzites and greenish quartzitic slates which at places are gritty and even contain Lenticular bands of conglomerates. Several such lenticular bands have also been observed in Sappnagri-Bhadarwahi Got. On the basis of lithological characters and stratigraphic position the Sunbain Quartzite, after correlations with their equivalents in different areas, have been considered to be the equivalent of Muth Quartzite of Kashmir.

#### Seawa Para-Gneiss

A group of rocks which comes next in the stratigraphic sequence given in Table-1, has an excellent development in the valley of Seawa river. These have been referred to as the Seawa Para-Gneiss (Sharma, et al., 1973; Sharma, 1975). This band is a sedimentary and metamorphic facies variant of the Sunbain Quartzite and quartzitic slates of Devonian age. They consist of banded, streaky augen, mylonitised quartzose porphyritic gneisses. These rocks show a great variation in lithological characters and granularity

from coarse-grained augen gneiss to gneissic quartzites. In the coarse-grained augen gneisses, the augens of quartz and feldspars are wrapped around by the minerals biotite and chlorite, which form the chief mafic constituents entering into the composition of these rocks. At places, large flakes of biotite are also developed as seen near Dhaman on the ridge connecting Kamlogh Gali with Dari Gali. Seawa Para-Gneiss band is very well developed between Kamlogh Gali and Punara (Fig. 4), beyond which it shows lateral facies variation into calcareous massive and gritty quartzites and slates, which after a distance of about 2 km, again becomes gneiss as seen on the ridge west of Khaned. Towards northwest they laterally grades into calcareous, massive and flaggy quartzites, gritty quartzites and slates with lenticular bands of quartzose gneisses.

Several field evidences, such as its strike extension over a long distance, its occurrence as a marker of stratigraphic horizon, presence of interbedded slates and quartzite bands, presence of bedding planes and its gradational relationship with overlying and underlying rocks suggest that the Seawa Gneiss is a para-gneiss formed due to the transformation of arkosic quartzo-feldspathic metasediments by emanations from the closely located granite massif such as Kaplas Granite which have emplaced along the core of the Kaplas

anticline (Sharma, 1975).

According to Sharma (op.cit.) the Seawa Para-Gneiss extends towards Sundernagar in Satluj valley Himachal Pradesh and has been referred to as Manjrot Gneiss, belonging to Jutogh Formation which have been considered to be the strike continuation of the Seawa Para-Gneiss (Srikantia and Sharma, 1969). Similar thick para-gneiss band in Kulu-Rampur belt has been referred to as Gahr Para-Gneiss of Devonian age (Sharma, 1969).

From Table-1 it is clear that lithologically and stratigraphically, the lateral variations of the Seawa Para-Gneiss are comparable with Sunbain Quartzite as both the groups grade downward into Bhadarwah Slate and upward into carbonaceous slates and limestone which in turn are overlain by Panjal Trap indicating that the Seawa Para-Gneiss and its variants are of Devonian age (Sharma, 1975).

#### Langer Conglomerate

The Sunbain Quartzite grade upward into Langer Conglomerate which are named after the village Langer (32° 52' N ; 75° 52' E) in Himachal Pradesh (Sharma, et al., 1973). The Langer Conglomerate shows a great variation in its

lithological characters and varying in thickness from about 40 m near Padri Gali, Markhad to about 400 m in Chota Baju Bag. On the basis of the size of phenoclasts and phenoclast-matrix relationship, it has been grouped under the categories of boulder beds, conglomerates, conglomeratic quartzites, pebbly and gritty phyllites and greywackes. The phenoclasts consist of white grey and purple highly metamorphosed quartzites, vein quartz, platy pellets of slate which are embedded in the coarse grained arenaceous, argillaceous and calcareous matrix. The size of phenoclasts varies from a granule to a big boulder, but generally they are of the size of pebbles and cobbles. The coarser fractions are generally well rounded, while the finer fractions are sub-rounded to sub-angular. Sorting is fair to poor and interstitial space is fitted up with grit, sand and argillaceous material. The ratio between the phenoclasts and the matrix is highly variable ranging from 4:1 to 9:1 ratios.

On the basis of its lithological characters, overall association and stratigraphic position, Langera Conglomerate has also been correlated with the Jaunsar Conglomerate, Blaini Conglomerate, Boulder slates of Garhwal and Tanakki boulder bed of western Kashmir and Hazara areas. The Langera Conglomerate is of Upper Devonian to Lower Carboniferous age as it is overlain by the fossiliferous

Katari Gali Formation containing Lower to Middle Carboniferous fossils. It thus occupies Lower Carboniferous age (Sharma, et al., 1975; Sharma, 1976).

Katari Gali Formation

This formation comprises dark calcareous, carbonaceous, siliceous, ferruginous shale-slates with lenses and bands of cream and grey coloured slaty limestone in the upper part and khaki and black well cleaved slates with bands of greyish quartzites and quartzitic slates in the lower part.

In Uroda area, these rocks are highly carbonaceous and ferruginous and containing pyrite disseminations. The leaching of pyrite has imparted a rusty appearance to the rocks due to limonite encrustations. The bleached shale bands at places are highly puckered and contain fossil like impressions. The limestone occur in the form of lenticular bend assuming tremendous thickness in the Uroda beyond which it gradually lenses out. In lower part these rocks comprise khaki and black slates with great variation in thickness. At places, they are paper thin and usually crumble down into small pieces. These slates become quartzitic and even contain bands of dark grey banded quartzites, which show gradational relationship with the underlying Seawa Para-Gneiss



as observed in the ridge southeast of Khaned. Towards Basantgarh, these rocks are highly carbonaceous and calcareous and has coaly and slaggy appearance (Sharma, 1976).

The lithological characters of these rocks, their fossil assemblage suggest that these rocks are identical to Katari Gali Formation of Bhallesh area which are Middle Carboniferous age (Kapoor, 1973).

#### Panjal Trap

Panjal trap which is one of the members of Panjal volcanics is next in the stratigraphic sequence occurring in the area under reference. The trap band has been traced from Uroda Nal area which can be seen from the geological map of study area (Fig. 4). This band is thin and comprises massive and schistose trap which at places is vesicular and amygdaloidal. The trap at places, is highly epidotised and at places, light green epidote occur in the form of vein.

It comprises hard, massive to schistose rocks of greenish grey to dark grey colour. It is generally fine-grained but at places, medium to coarse-grained and shows porphyritic texture. At places it is highly vesicular and amygdaloidal. It is, generally, very hard and massive, but in the marginal

portions it is of phyllitic and schistose nature.

The Panjal Trap band can be traced all along the Murree Thrust from Mandi-Sundernagar area in Himachal Pradesh (Srikantia and Sharma, 1969). Wadia (1928) mapped Panjal Trap in Mandi-Surnkot valley Thanna Mandi area in Jammu and Kashmir and assigned the Upper Carboniferous age to it. Gupta (1971) in his Ph.D. thesis has also assigned the same age. Sharma (1976) correlated this band with Mandi-Darla volcanics of Mandi area of Himachal Pradesh.

#### Kaplas Granite Massif

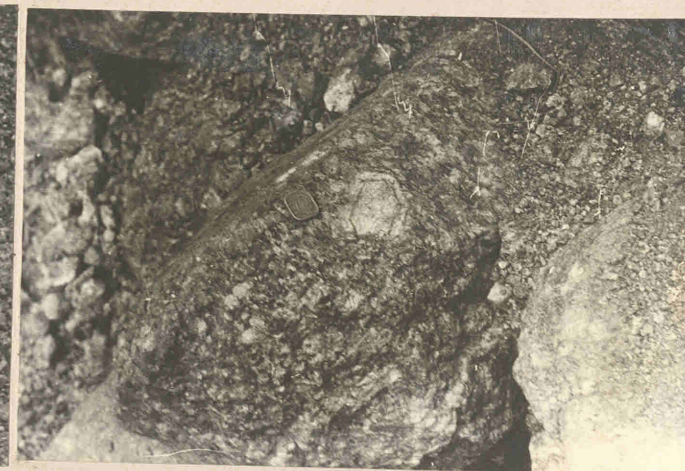
Kaplas Granite which represents one of the Himalayan granites is extensively developed in and around mount Kaplas and as such referred to as Kaplas Granite. It has a batholithic dimension and it extends from southeast of Khalani in the northwest to Budwar northwest of Bani in the southeast. It occurs in the form of elongated dome, which rises to an elevation of 4341 m above the m.s.l. in the Central part and to 1800 m above the m.s.l. in the peripheral areas. The axis of the dome corresponds to the regional strike which trends in NW-SE direction. The northwestern portion of granite massif is not included in the present work. The southeastern half which covers an area of about 200 sq.km, is the subject matter of the

Explanation of Plate 4

- A. Field photograph showing acicular development of tourmaline in granite (Locality : Joila).
- B. Field photograph showing zoning in feldspar in coarse-grained granitic rock (Locality : East of Joila).
- C. Field photograph showing zoned feldspar in coarse-grained granitic rock (Locality : Chunchili).
- D. Field photograph showing an outcrop of coarse-grained porphyritic granitic rock (Locality : West of Marali Ka Got).



A



B



C



D

present investigations. The granite body can be seen in geological map fig. 4.

The granitic rocks which come under the area of reference are, generally, massive, highly jointed, coarse-grained, porphyritic with aplitic and pegmatitic veins. A thin zone of hybrid rocks is formed all along the contact of emplaced granitic rocks and host rocks. A detailed description about the field occurrence and mutual relationship of the rocks of Kaplas Granite Massif is given below :

#### Granitic Rocks

The Kaplas granitic rocks are, in general, massive highly jointed and show a great variation in granularity, from fine-grained homogeneous to coarse-grained porphyritic. These rocks show variation in colour, which depends upon the composition of feldspars and more on the concentration of the biotite. Muscovite is scarce being present only in subordinate amount. The granites contain large prismatic shape phenocrysts of feldspar at places measuring 8-14 cm long in a coarse-grained matrix consisting of quartz, feldspars, micas and at places, tourmaline also occurring as radiating needles as seen near Joila (Plate 4,A). The feldspar phenocrysts generally occur scattered with their longer axis pointing in different

directions, but at certain places in the peripheral portion of the granitic body, they occur aligned parallel to each other. The plagioclase phenocrysts at places show megascopic twinning and zoning (Plate 4, B & C), as indicated by slight colour difference between the outer and inner zones. Very coarse-grained porphyritic granite has also been observed near Thulpu, in Chunchili-Kurdwa area (Plate 4, D). The grain size decreases in the central portion as compared to the peripheral portion.

#### Xenoliths

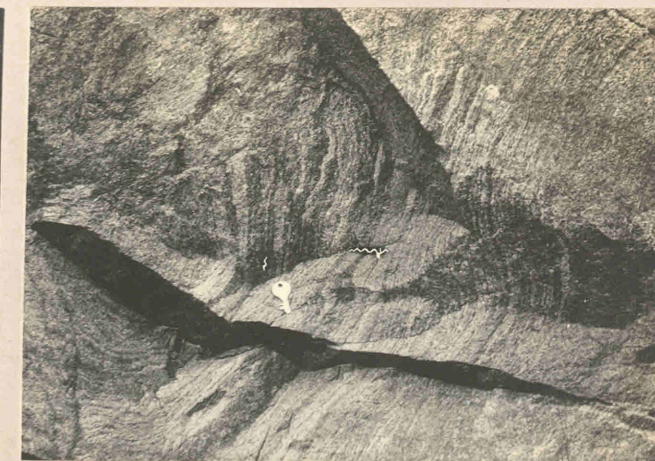
The Kaplas Granite abounds in metasedimentary foreign xenoliths, occurring not only in the marginal hybrid zone but also in central part of the granitic body. The foreign xenoliths comprise quartz, quartz-schists, slates and phyllites mostly belonging to the rocks of Bhadarwah Formation. All of these xenoliths are of sedimentary rocks showing original sedimentary characters such as bedding plane, banding, colour and composition. Some of these xenoliths have sharp margins and are not affected by the surrounded granitic rocks, while others show gradational contact with the granitic rock in which they are wrapped. Xenoliths vary in size from 5 cm to 5 m in length. They are generally very hard and slaggy in appearance due to baking effect and because of differential hardness

Explanation of Plate 5

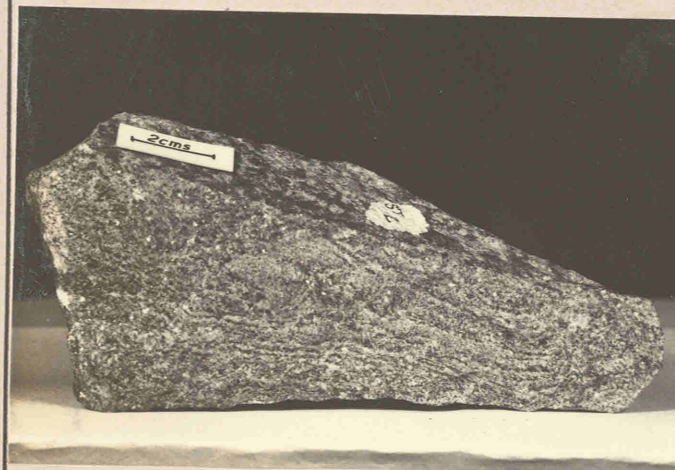
- A. Field photograph showing ptigmatic folding in migmatite like hybrid rock (Locality : Sankhni Gali).
- B. Field photograph showing stictolithic structure in hybrid rock, (Locality : Sankhni Gali).
- C. A handspecimen of migmatitic hybrid rock showing pinching and swelling character.
- D. Field photograph showing exposures of hybrid rocks (Locality : Sarthal).
- E. Field photograph showing xenoliths of Bhadarwah Slate in the hybrid rocks (Locality : Kharkala).
- F. Field photograph showing intersecting veins of aplite in coarse-grained porphyritic granites (Locality : N.W. of Chunchili).



A



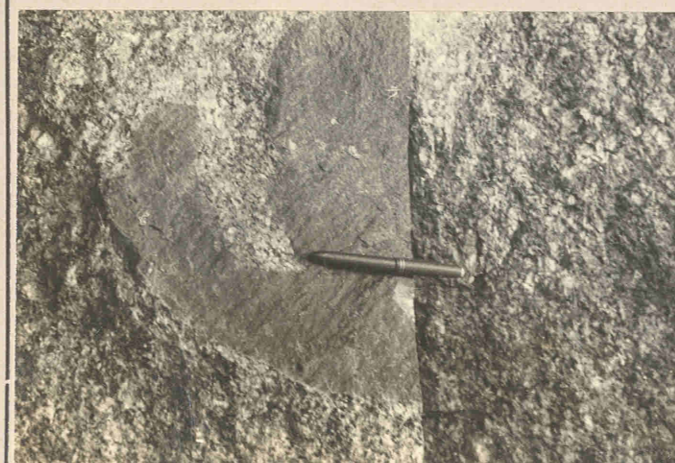
B



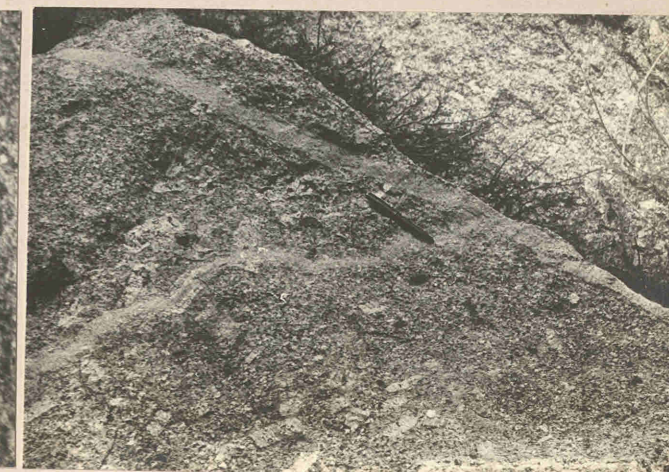
C



D



E



F

protrude out very prominently. The removal of these protruding xenoliths results in the formation of hollows as observed at few places in the area under present investigation.

### Hybrid Rocks

All around the Kaplas Granite Massif there occurs a zone which has been described as a mixture of granitic and slaty and quartzitic host rocks of Bhadarwah Formation. The latter at many places being wholly or partially granitized and blended with the granite on one side and country rock on the other. This zone is always present but its width varies from a few metres as seen near Sukad, Loang, Duggan to about 100 metres as observed west of Tipri and it is about 700 to 800 metres west of Sankhni Gali area. In Sankhni Gali area these rocks comprise quartzose banded, streaky, augen gneisses. At places, ptygmatic folding is also observed (Plate 5,A). The linear arrangement of minerals especially biotite and feldspars even showing the alternating bands of biotite is conspicuous (Plate 5,B). The feldspars also show parallel as well as at random arrangement of prismatic crystals ranging in thickness from fraction of a cm to about one centimeter. Besides this, features like pinching and swelling are also noted (Plate 5,C). The prominent exposures of this type are observed at Sundri and Jwalta area.

In Sarthal area, the mixed type of rock exposures are observed very commonly (Plate 5,D). This mixed type of rock is of similar mineralogical composition as the granite but only difference is that the calcareous and carbonaceous slaty xenoliths are present in them (Plate 5,E).

#### Aplite and Pegmatite Veins

Aplite Veins : Commonly occur as streaks, bands and as intersecting veins (Plate 5,F) in the coarse-grained porphyritic granite as observed in Kharkala area. They range in thickness from few cms to about 1/2 metre. They comprise very fine-grained white coloured material consisting of quartz and feldspars with subordinate amount of muscovite.

Pegmatite Veins : They occur in the form of narrow veins, at places intersecting, ranging in thickness from few centimetres to 1/2 metre in the coarse-grained porphyritic granite. They consist mainly of coarse-grained quartz, feldspars (microcline etc.) alongwith subordinate amount of muscovite and occasional presence of black mica, and also sometimes with tourmaline.

#### Murree

The Murree occurs all along the Murree Thrust on

Explanation of Plate 6

- A. Field photograph showing alluvium cover over hybrid rocks (Locality : Gharar Pher).
- B. Field photograph showing prominently developed vertical joints in Kaplas Granite (Locality : Khorinala).
- C. Field photograph showing well developed inclined joints in Kaplas Granite (Locality : Joila).



A



B



C

the sub-thrust side. This formation is composed of reddish clay with bands of reddish, greyish and greenish sandstone. These are well developed in Ujh valley in Mang-Churerh area, where these are found alongwith the bands of conglomerates.

### Alluvium and Terrace Deposits

The Pleistocene deposits in the area under reference are represented by the terrace deposits. They comprise glaciated boulders embedded in the clays. They range in size from small boulder to boulders of very big size, as seen at Kanji, Khuryari and also along the course of Ujh river at Kudvah, Lodhra and Punara area.

The Recent deposits are mostly alluvium confined to the river terraces occurring in the area under reference. They are grey brown clays as seen at Tipri and Garar Pher (Plate 6, A) northwest of Kaplas and also at Loang situated south of mount Kaplas.

\*\*\*\*\*  
\* III. STRUCTURE \*  
\*\*\*\*\*

The most striking structural features of the area under present investigations are (i) Murree Thurst (ii) Joints.

Murree Thurst : It is a tectonic plane along which the pre-Tertiary rocks have travelled to rest over the Tertiary rocks. It lies in southwest of the mount Kaplas (Sharma, 1976). On the up-thurst side of this tectonic plane the rocks comprise massive vesicular and amygdaloidal trap. On the Sub-thrust side they comprise bring red clay stones, shales which, at places, are slickensided.

Joints : Joints are present in almost whole of the granitic body. Double set of joints, inclined, horizontal and vertical (Plate 6, B & C) are seen near Joila.

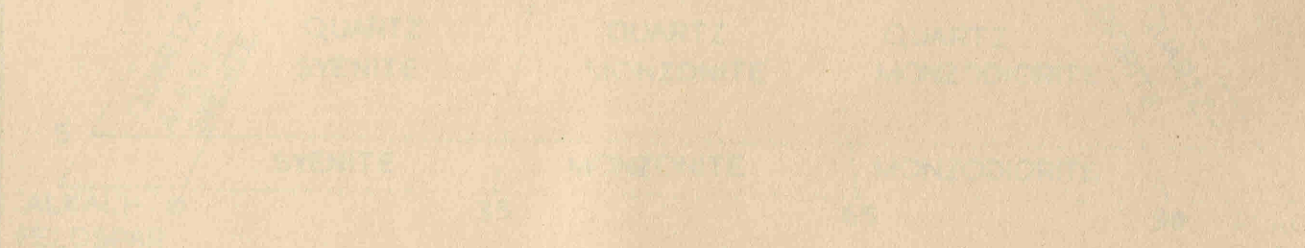


FIG. 5. VARIATION IN THE MODAL COMPOSITION OF GRANITIC ROCKS OF KAPLAS BASED UPON THE CLASSIFICATION OF STRECKEISEN (1974)

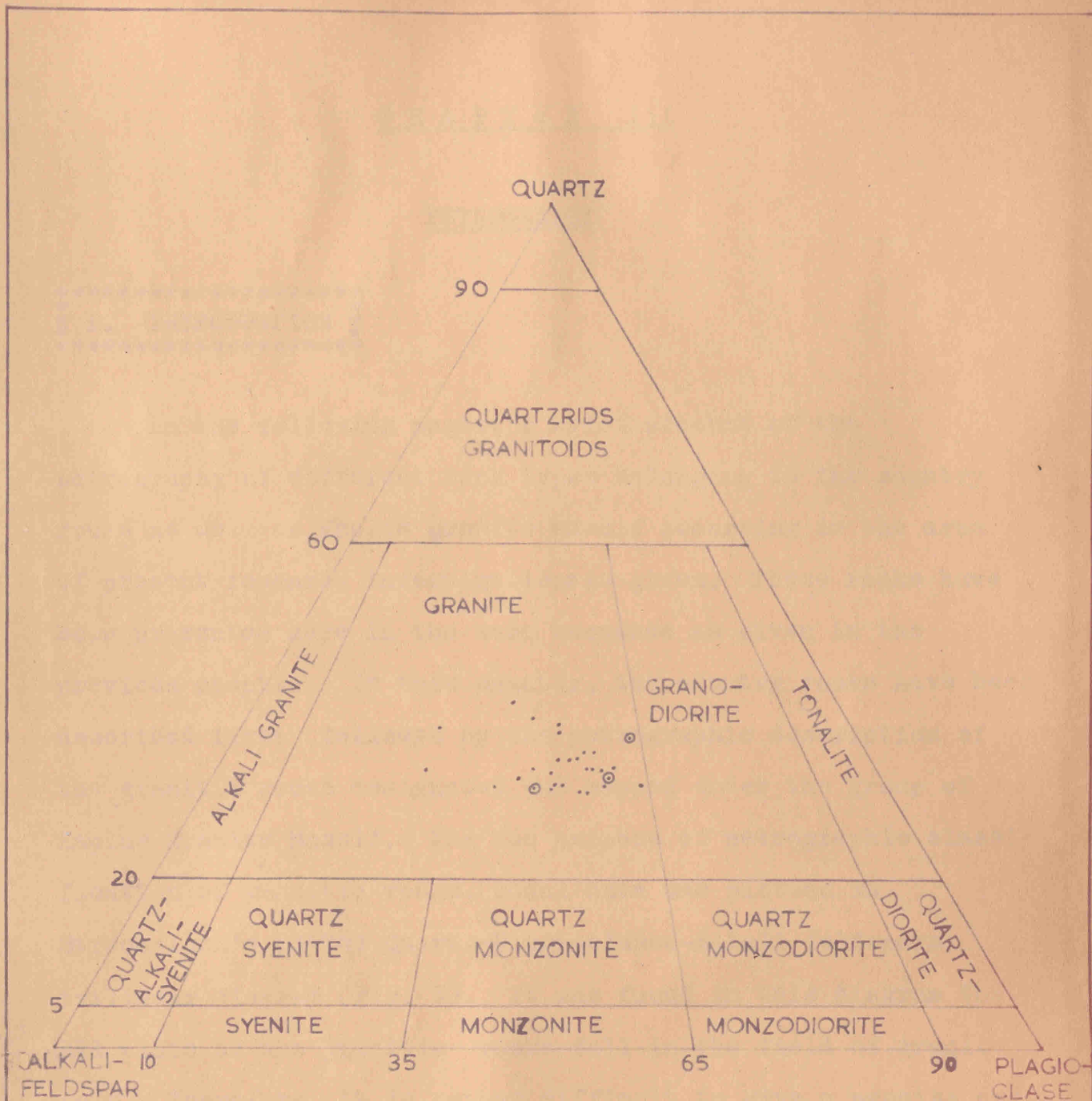


FIG. 5. VARIATION IN THE MODAL COMPOSITION OF GRANITIC ROCKS OF KAPLAS BASED UPON THE CLASSIFICATION OF STRECKEISEN (1974)

## CHAPTER III

### PETROGRAPHY

\*\*\*\*\*  
\* I. INTRODUCTION \*  
\*\*\*\*\*

In the following pages, a brief account of the petrography of different rock types belonging to the country rocks as well as Kaplas Granite Massif occurring in the area of present research investigations is given. These rocks have been presented here in the same sequence as given in the previous chapter. In this chapter, the country rocks have been described first followed by the petrographic description of the granitic rocks designated and mapped under the group of Kaplas Granite Massif. For the purpose of petrographic classification of granitic rocks, modal data was plotted in Streckeisen's (1974) Quartz-Plagioclases-Alkali feldspars trilinear diagram (Fig. 5). It was found in this diagram that all plots of the granitic rocks fall in the field of granite only. Therefore, it is rather difficult to give a precise and clear cut petrographic classification of present granitic rocks. Taking into consideration these limitations, an attempt has been made to classify these rocks petrographically on the basis of different mineral assemblages. The present classification, forms the back bone of this work, therefore, is a broad and

Exolanation of Plate 7

- A. A handspecimen depicting linear arrangement to garnet grains in the garnet phyllites.
- B. Photomicrograph showing sieve texture in garnet phyllite. Ordinary Light (x45).
- C. A handspecimen showing quartz vein in chloritic slate.
- D. Photomicrograph showing fine-grained slaty texture in slate. Ordinary Light ((x 45).
- E. Photomicrograph showing euhedral crystals of pyrite in slate. Ordinary Light (x 45).
- F. Photomicrograph of quartzite showing sericitized feldspar grains. Crossed nicols (x 45).



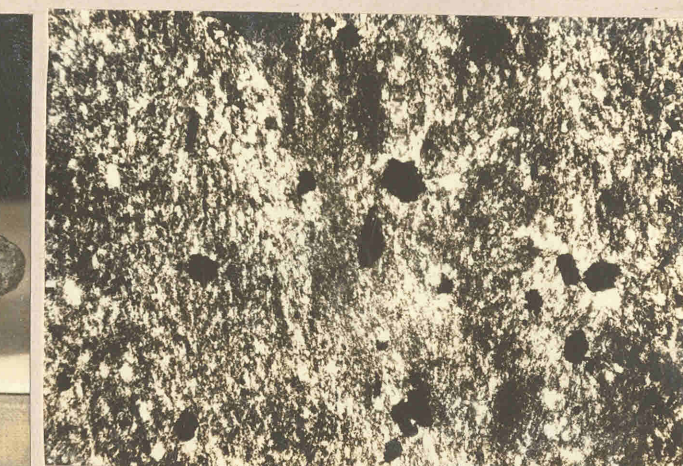
A



B



C



D



E



F

descriptive type of classification, which is primarily based on qualitative as well as quantitative approach.

\*\*\*\*\*  
 \* II. PETROGRAPHY OF COUNTRY ROCKS \*  
 \*\*\*\*\*

Garnet Phyllites

These rocks are fine-grained, steel grey to greenish grey in colour and show silky sheen of the cleavage surface due to coarser texture of mica. Megascopically, these rocks show phyllitic texture, which is well exhibited on the broken surfaces of the rock samples belonging to this group. Porphyroblasts of garnet, rounded to sub-rounded "mustard seed" size with brown colour are commonly embedded in fine-grained matrix of these rocks. At places, these porphyroblasts are in linear arrangement (Plate 7, A). These rocks have got an average sp.gravity of about 2.69.

Microscopically, quartz is the chief mineralogical constituent occurring as fine-grained, anhedral, rounded and sub-rounded grains with irregular borders, and in most of the cases showing undulatory extinction indirectly indicating the effects of strain developed in the quartz grains. Feldspar grains, which occur in subordinate amount in the fine-grained matrix are completely sericitized. Linear arrangement is

well exhibited by strongly pleochroic, green coloured elongated sub-hedral flakes of chlorite, which at places show wavy extinction alongwith fine-grained flakes and scales of muscovite. Reddish iron stained chlorite flakes are not uncommon. Porphyroblasts of pink coloured garnet are distinctly and prominently noticed. It occurs as medium-grained sub-hedral to euhedral hexagonal crystals and usually enclosing subrounded quartz grains which form sieve texture (Plate 7,B). They are surrounded by chlorite and muscovite. The common accessories present in these rocks are zircon, rutile, epidote, tourmaline and iron-ores.

### Slates

The slates, which are fine-grained derivatives of argillaceous sediments, are carbonaceous, ferruginous and chloritic in nature and show black, rusty brown and green colour respectively. Megascopically, they exhibit well developed slaty cleavage, with individual laminations parallel to the bedding plane ranging in thickness from 0.05 to 1 mm. At places, laminations are folded with the intrusion of quartz veins (Plate 7,C). The average sp.gravity of these rocks is about 2.71.

Under the microscope, the minerals are arranged parallel to the cleavage planes, and exhibit distinctly well

developed slaty texture (Plate 7,D), and are cemented with different types of cementing material viz. siliceous, argillaceous and ferruginous, in different types of rocks. Quartz which is the chief mineral present in these rocks, occurs as fine-grained anhedral grains with abundantly developed undulatory extinction. They are embedded in fine-grained matrix. Fine dusty particles are invariably seen, but the red coloured iron stained grains are rare. Chlorite is one of the minerals, which have been flattened, rotated and elongated in the plane of cleavage have resulted in the slaty cleavage. It is green coloured and pleochroic and changing its colour from green to shades of greenish yellow. The chloritic slates are green because of the higher proportion of chlorite and epidote. The mineral biotite is present in subordinate amount which in few flakes partially altered to chlorite. Muscovite flakes and scales are not uncommon. Plagioclase grains, which are in most of the cases untwinned, are sericitized. Plagioclase grains are covered up with carbonaceous matter, which makes very difficult to identify, are commonly present in the carbonaceous slates. Few fine-grained plagioclase laths showing polysynthetic and albite law twinning are invariably seen. Pyrite euhedral cubic crystal (Plate 7,E) are abundantly noticed, especially in green coloured chloritic slates. Tourmaline, rutile and zircon are the common accessory minerals present in these rocks.

### Quartzites

Quartzites occurring in the area of present investigation, are fine to medium grained, greenish, greyish and brownish in colour showing granoblastic texture. A peculiar vitreous luster, especially along the freshly broken surfaces, has been noticed. On an average the sp.gravity is about 2.68.

Under the microscope, these rocks show allotriomorphic granular texture. The grains are angular to subangular with sutured margins and show quartzitic texture (Plate 7, F). Quartz is the chief mineralogical constituent of quartzites. It occurs as fine-grained anhedral grains, generally, with corroded and serrated borders and contain magnetite as inclusions. Oscillatory extinction is frequently noticeable in them. Feldspars which are rather difficult to identify, are altered to sericite. Grains showing twinning are very rare. Fine-grained muscovite flakes and scaly masses are commonly seen in these rocks. At places, these flakes are stained to red colour because of the alteration of magnetite. Green chlorite, which is pleochroic commonly seen as irregular shaped masses, especially in the green coloured quartzites. In the case of grey quartzites, a linear arrangement is exhibited by the black coloured carbonaceous matter.

Among the accessories, zircon is the most common accessory which is present in six-sided euhedral crystals. Tourmaline, magnetite and hematite are other accessories.

### Panjali Trap

The effusive rocks of the study area are the lava, generally, known as Panjal Trap, which are mostly of andesitic composition. Both massive as well as vesicular varieties of Panjal Trap are seen in the area under present investigations. The vesicles, in case of vesicular variety, are filled up with minerals such as secondary quartz, Jasper, zeolite etc. These rocks are greenish grey and dark grey in colour. The minerals chlorite and epidote present in these rocks have imparted, in general, pistachio-green colour. They are fine grained and have an average specific gravity of about 2.82.

Under microscope, these rocks show sub-ophitic to ophitic texture, but the inequigranular variety shows porphyritic texture which is also common. The following minerals have been identified in these rocks. The medium-grained plagioclases are the chief mineralogical constituent occurring as phenocrysts embedded in the groundmass consisting chiefly of plagioclases, epidote and sericite which is the common alteration product of plagioclases. Augite is

Explanation of Plate 8

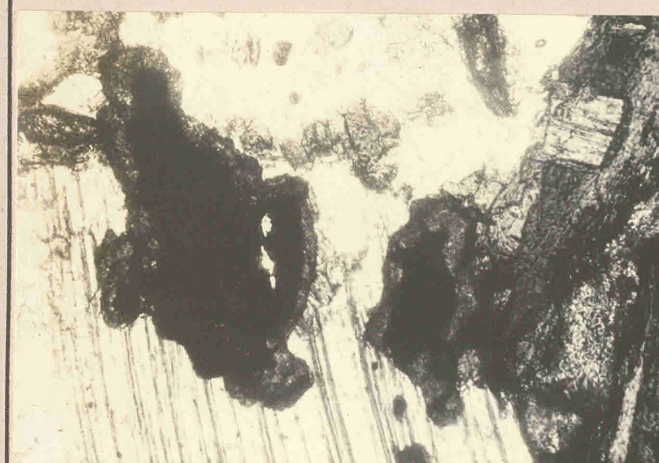
- A. A handspecimen of augen gneiss showing ophthalmic structure.
- B. Photomicrograph of augen gneiss showing well developed ophthalmic structure. Crossed nicols (x 45).
- C. Photomicrograph showing the leucoxene karnel around the illmenite grain. Ordinary Light (x 120).
- D. Photomicrograph of quartz grains showing mortar texture and also depicting undulatory extinction in granitic rock. Crossed nicols (x 45).
- E. Photomicrograph of a braided perthite in granitic rock. Crossed nicols (x 45).
- F. Photomicrograph of granitic rock showing a plagioclase lath containing lobate grain of microcline depicting antiperthitic texture. Crossed nicols (x 45).



A



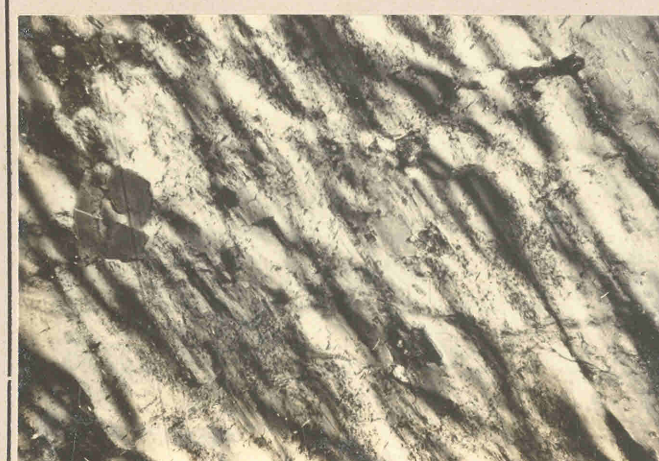
B



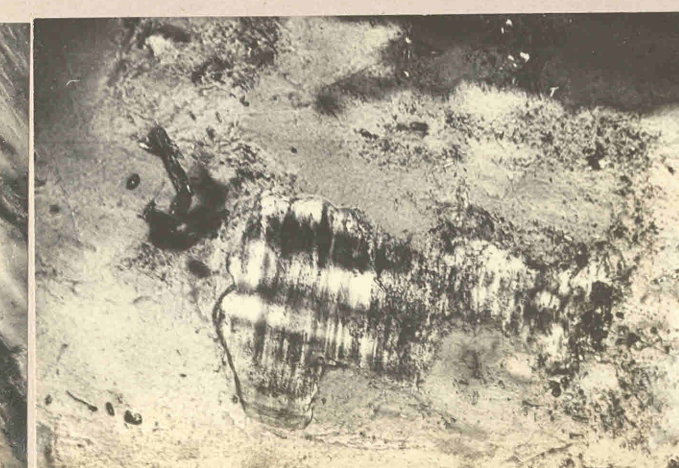
C



D



E



F

the chief Fe-Mg mineral occurring as sub-hedral, medium-grained doubly cleavage prismatic grains frequently showing ophitic and sub ophitic texture. Uralite (hornblende), the common alteration product, especially along the margins is present in these rocks. Magnetite and ilmenite commonly altered to Leucoxene along the borders are noticed as opaque minerals. In few rocks, cavities are filled up with green glass which is usually altered to prochlorite.

#### Gneisses

Megascopically, these rocks are coarse-grained exhibiting well developed foliation texture by the elongated prisms or bands of brown biotite and muscovite with a mosaic of granulose mass, which marks gneissose structure. In augen gneisses, augen texture (Plate 8,A) is abundantly seen, which is formed by wrapping around of minerals quartz and feldspars by minerals biotite and muscovite. The augens are of variable shapes, ranging from elongated to bird's eye-shaped lenses. On an average the specific gravity of these rocks is about 2.69.

Microscopically, augen texture is abundantly seen in these rocks (Plate 8,B). Both eye shaped as well as sub-rounded augens are worthy to note. The augens of plagioclases are mostly untwinned, but only few of them show lamellar albite

type twinning which sometimes altered to sericite. The augens of alkali-feldspars mostly of perthitic nature. The mineral quartz is also present in these rocks. It occurs as medium-grained grains which are cracked, crushed along the margins exhibiting wavy extinction. Biotite, the most important ferromagnesian mineral, is in linear arrangement around the feldspar augens. It is strongly pleochroic, changing its colour light brown to dark brown. It is usually with broken borders and pierced with the fine-grained flakes of muscovite. Pleochroic halos are not uncommon. Muscovite flakes are seen to occur in the subordinate amount, which at places show typical well developed oscillatory extinction. The accessories recorded are hornblende, magnetite and ilmenite. At places, ilmenite is altered to Leucoxene, especially along the margins, forms karnel structure (Plate 8,C).

\*\*\*\*\*  
 \* III. PETROGRAPHY OF GRANITIC ROCKS \*  
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On the basis of the mineral associations, their proportion and their grain size, Kaplas Granite has been classified into different groups. Their modal data are given in Table III (1-6). The groups are as under :

- (i) Coarse-grained quartz-perthite-albite-microcline-biotite granitic rocks.

(ii) Medium-grained quartz-microcline-perthite-oligoclase-biotite granitic rocks.

(iii) Coarse-grained quartz-perthite-albite-oligoclase-biotite granitic rocks.

(iv) Medium-grained quartz-perthite-oligoclase-albite-muscovite/biotite granitic rocks.

(v) Coarse-grained quartz-albite-oligoclase-perthite-biotite granitic rocks.

(vi) Fine-grained quartz-perthite-oligoclase-albite-biotite granitic rocks.

(vii) Hybrid rocks.

(i) Coarse-grained quartz-perthite-albite-microcline-biotite granitic rocks

This group includes generally the light grey coloured coarse-grained holocrystalline rocks which show graphic texture. Megascopically, the minerals entering into their composition are quartz, feldspars and biotite. Under microscope, the following minerals entering into the rocks of

this group are identified.

Quartz is the common mineral which occurs in two generations, one is represented, generally, by coarse-grained, cracked, fissured, irregular sub-hedral and anhedral grains with broken and corroded borders. As a rule, they occupy the interstitial spaces of the earlier formed minerals. As a result, mortar texture is commonly noticed (Plate 8,D). Another characteristic feature is the frequent presence of the undulatory extinction (Plate 8,D) indirectly indicating the effect of stress created by diastrophic movements. They show grey first order of interference colour. They contain dusty inclusions of iron oxide, which are irregularly arranged all over the grains. Fine-grained inclusions of muscovite and biotite are rarely seen. The second type quartz is fine-grained, sub-rounded and is quite fresh. It occurs in the fissures and cracks developed in the primary quartz. It is, generally, devoid of inclusions.

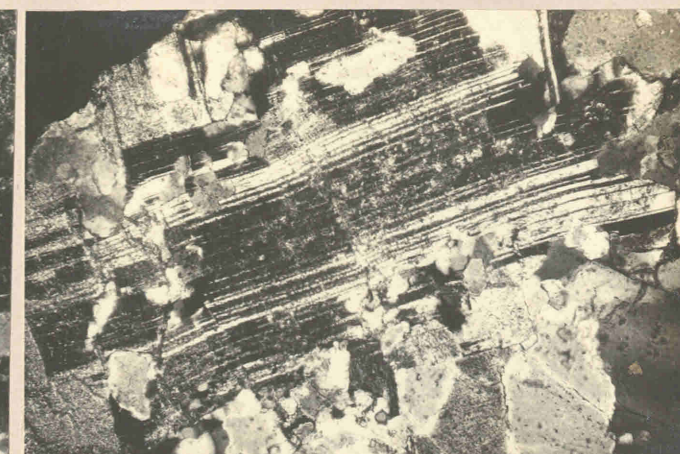
Perthite is the chief alkali-feldspar occurring as medium to coarse-grained anhedral grains with broken borders. Few banded and dislocated grains have also been noticed. The most common perthite is braided perthite (Plate 8,E) but string and film perthites are also present. Sometimes antiperthite is also seen, where cross-hatched

Explanation of Plate 9

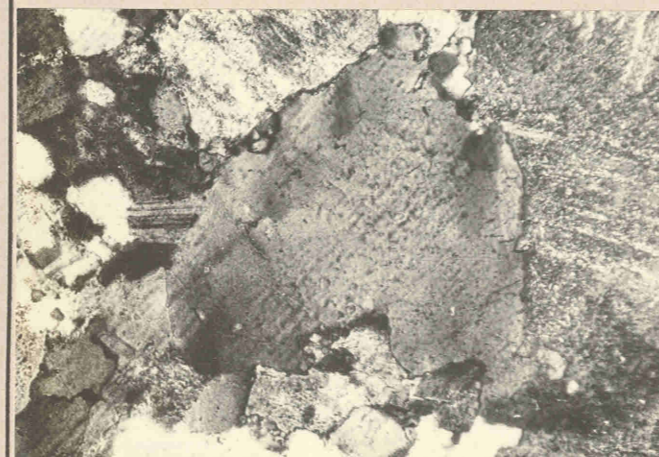
- A. Photomicrograph of granitic rock showing cross-hatched twinning of microcline and plagioclase grains depicting zoning which has been indicated by central sericitized portion. Crossed nicol (x 45).
- B. Photomicrograph of granitic rock showing kink bend in twin lamellae of plagioclase lath. Crossed nicols (x 45).
- C. Photomicrograph of granitic rock showing clouding in plagioclase lath. Crossed nicols (x 60).
- D. Photomicrograph of granitic rock showing pleochroic halos in biotite flake. Crossed nicols (x 45).
- E. Photomicrograph of muscovite showing criss-cross habit along with intergrowth of biotite flakes in rock. Cross nicols (x 45).
- F. Photomicrograph of granitic rock depicting cross-hatched twinning in microcline lath. Cross nicols (x 45).



A



B



C



D



E



F

microcline grain is enclosed within the tabular albite lath showing polysynthetic twinning (Plate 8,F). At places microperthite is also seen. They are generally kaolinized. The few of the cracked grains contain veinlets of secondary quartz. Muscovite and quartz inclusions are rarely found.

Few microcline grains have also been observed in these rocks. They are medium-grained, anhedral grains showing cross-hatched twinning (Plate 9,A) with white and grey interference colours of first order.

Plagioclase is represented by albite ( $An_{5-8}$ ,  $2V + 78$ ). It occurs as coarse-grained, sub-hedral to anhedral grains with severely corroded borders. Banded grains are also noticed, (Plate 9,B). Most of them are untwinned, but the grains showing polysynthetic twinning following albite and albite-carlsbad laws are not uncommon. Generally, they are altered to sericite. Sericite, in few of the completely sericitized grains, covers whole of the grain and marks the original characters of albite. The laths of this mineral show grey interference colours of first order. Commonly they contain irregularly arranged fine-grained inclusions of magnetite, quartz and muscovite. Plagioclase zoning although rare, but is very prominently developed in these rocks (Plate 9,A). Clouding of the feldspars is also seen here (Plate 9,C). Pitchamuttu (1959) has believed that some of the

clouded plagioclases may be formed by palingenesis ( or rheomorphism).

Biotite is the chief ferro-magnesian mineral occurring as medium-grained sub-hedral to anhedral tabular flakes with well developed basal cleavage. Flakes without cleavage have also been noticed. Most of them are bended, broken, dislocated exhibiting at places intergranular tendency. They are pleochroic changing their colour from brown to greenish brown and sometimes with yellow green tinges. Under crossed nicols, they show straight extinction parallel to the cleavage planes and exhibit interference colours of second order. The most conspicuous feature in rocks of this group is the partial alteration of biotite to yellowish green mineral chlorite. This usually starts at margins of biotite flakes. The central portion is almost fresh. The basal cleavage is well retained in chlorite. The pleochroic halos, which are formed by radioactive bombardment during the orogenic time, are not uncommon. (Plate 9,D).

Muscovite is another mineral of mica group occurring in subordinate amount. The flakes of this mineral are colourless commonly occur as medium and medium to coarse-grained which have been greatly affected by the diastrophic activities. Bended, broken, folded and interpenetrated grains which marks

criss-cross habit (Plate 9,E) are commonly observed. In most of the cases they commonly occur in the association of biotite. They have got well developed perfect basal cleavage and show shades of peacock interference colours of upper second order.

Magnetite is the common accessory mineral which is in black colour occurs as small anhedral irregular shaped grains aligned along the cleavage planes of the partially altered biotite. It commonly occurs as inclusion in essential minerals.

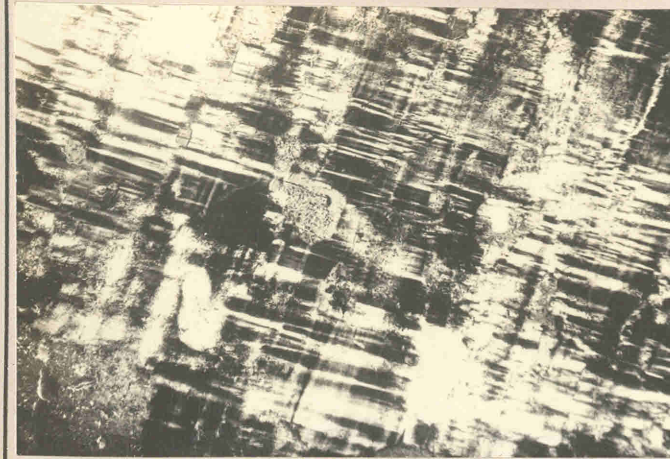
(ii) Medium-grained quartz-microcline-perthite-oligoclase-biotite granitic rocks

The rocks of this group are medium-grained, light grey in colour and show hypidiomorphic texture. In thin sections, following minerals alongwith their detail optical characters have been established.

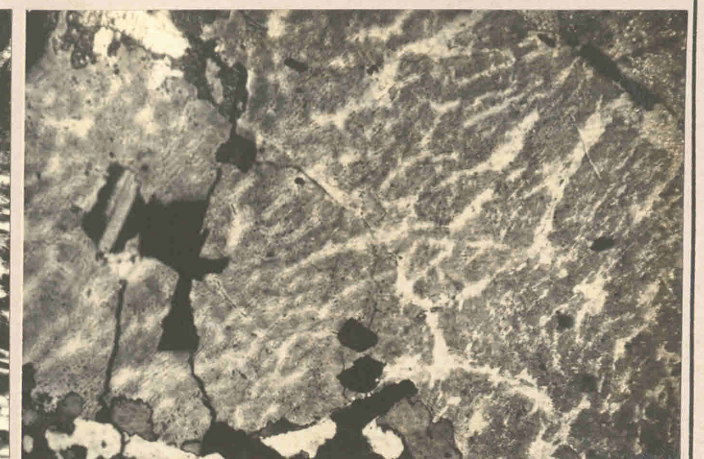
Quartz is commonly found to occur as medium-grained anhedral grains, usually cracked and with irregular borders, and show grey and light yellow interference colours of first order. Wavy extinction is common. Another common tendency is that the coarse grains are surrounded by fine crushed quartz which exhibit mortar texture (Plate 8,D). Dusty

Explanation of Plate 10

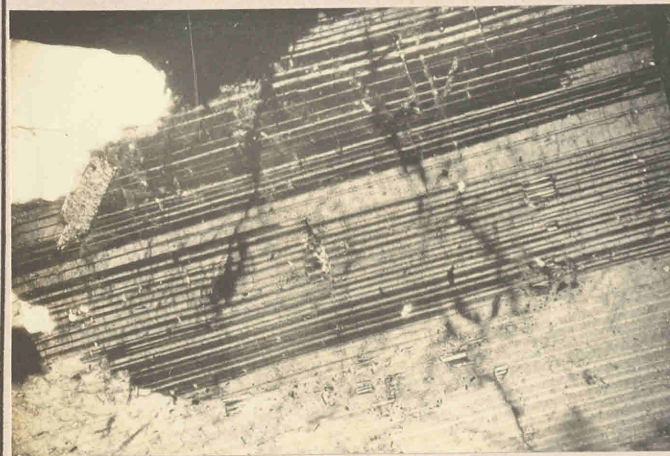
- A. Photomicrograph of granitic rock exhibiting cross-hatched twinning in microcline lath. Crossed nicols (x 45).
- B. Photomicrograph of granitic rock exhibiting vein perthite alongwith enclosed lath of plagioclase showing albite twinning. Crossed nicols (x 60).
- C. Photomicrograph of granitic rock exhibiting lamellar twinning in plagioclase lath.
- D. Photomicrograph of granitic rock exhibiting sericitized plagioclase lath. Crossed nicols (x 45).
- E. Photomicrograph showing the development of myrmekite at the margins of feldspars in granitic rock. Crossed nicols (x 45).
- F. Photomicrograph of granitic rock showing banded and broken flakes of biotite. Ordinary Light (x 45).



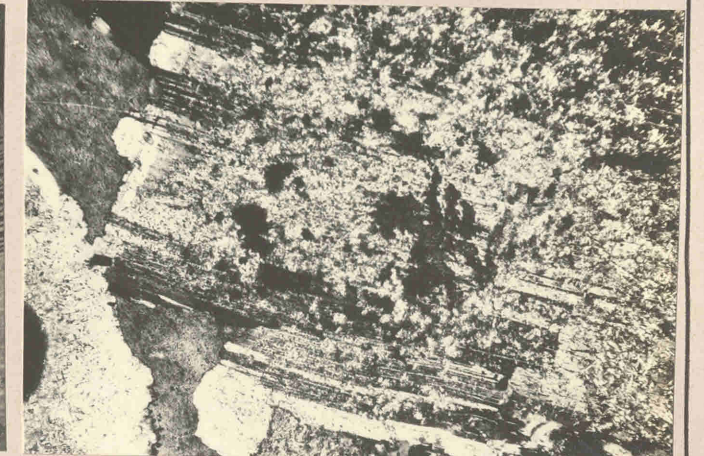
A



B



C



D



E



F

inclusions in linear arrangement have usually been observed.

Secondary quartz grains are observed to occur in the fissures formed in primary quartz. It is ~~as~~ fine-grained, anhedral grains and also exhibits serrate texture.

Microcline ( $2V$ ,  $-77^{\circ}$ ) is the chief alkali-feldspar. It usually occurs as medium-grained to coarse-grained subhedral and anhedral grains with irregular and severly broken borders. The most conspicuous feature is the cross-hatched twinning (Plate 9,E ; 10,A), which is frequently and prominently developed. Generally, microcline laths are kaolinized, sometimes even masking whole of the grain and giving cloudy appearance of earthy brown colour. Perthite is the other alkali-feldspar, which is not commonly found to occur in the rocks of this group. It commonly occurs as coarse-grained, cracked sub-hedral to anhedral grains with irregular borders showing first order grey interference colour. In most of the cases it is braided perthite but vein perthite and patch perthites are not uncommon (Plate 10,B).

Oligoclase ( $An_{13-15}$ ,  $2V + 84^{\circ}$ ) is the prominent plagioclase observed in these rocks. It occurs as medium to

coarse-grained subhedral porphyroblasts, usually fissured and with corroded and broken borders. In most of the twinned laths polysynthetic twinning (Plate 10,C), following albite law is noticed but, on the other side most of the oligoclase grains have also been found to be untwinned. They are commonly altered to sericite (Plate 10,D), which sometimes masks the whole grain concealing the original identity of the mineral. They commonly enclose the inclusions of fine-grained muscovite and quartz.

The other plagioclase is the albite ( $An_{5-8}$ ,  $2V + 79^{\circ}$ ) which is present in very smaller proportion. It occurs as medium-grained anhedral laths. Most of the grains are untwinned. Twinned grains showing polysynthetic twinning following albite law are not uncommon. Generally, they are sericitized. In few cases, only central part has been observed affected, while the outer part is almost fresh which indicate zoning (Plate 9,A). Myrmekite, which is the result of replacement of potash feldspar to soda feldspar with addition of soda and release of silica, forms a cauliflower like appearance (Plate 10,E) is commonly observed in the rocks of this group.

Biotite is seen to occur as brown coloured, medium to coarse-grained sub-hedral flakes with well developed

basal cleavage. Anhedral, bended flakes which are interpenetrating to each other are not uncommon (Plate 10,F). They are strongly pleochroic, changing their colour from dark brown-brown-light green. Grains with pleochroic halos sometimes with wavy extinction have also been observed. Alteration of biotite into chlorite particularly along the margins is noticed. Medium-grained subhedral flakes of colourless muscovite, generally, having broken borders are observed to occur in association with the mineral biotite, and at places, piercing and interpenetrating to them (Plate 10,F).

Magnetite is the chief opaque mineral occurring as black coloured, shapeless inclusions into the mineral biotite and muscovite. Apatite is another accessory mineral which is present very rare.

(iii) Coarse-grained quartz-perthite-albite-oligoclase-biotite granitic rocks

The granitic rocks included in this group are represented by dirty white and grey coloured rocks. These are inequigranular and hypidiomorphic texture, in general. Under microscope, the following minerals have been identified and are described as under.

Quartz occurs in two generations, one as porphyroblasts which show oscillatory extinction. At places, crushing of grains into fine-grained resulting to mortar texture (Plate 8,D). Fine dusty iron oxide inclusions are also seen in them. Another generation is the secondary quartz which is quite fresh and occurs in veins, fissures and cracks developed during the diastrophic movements in the grains of primary quartz and perthite (Plate 11,A).

Alkali-feldspar present in this group is mostly perthite, only few grains of orthoclase with carlbad twinning, enclosed within the perthite lath are observed. Perthite occurs as coarse-grained subhedral laths showing string, vein and braid types of perthitic growths (Plate 10,B). The process of kaolinization has played a vital role in transferring perthite into earthy brown matter, kaolin. Secondary quartz veins in the fissured perthitic grains are also noticeable (Plate 11,A).

Albite ( $An_{6-7}$ ,  $2V +79$ ), the chief plagioclase, occurs as medium to coarse-grained, subhedral and anhedral laths. In most of the cases they are untwinned but the grains showing well developed albite twinning are not rare. Sericite is the common alteration product which is mostly active in these laths (Plate 10,D). At places, central portion of the grain is sericitized while the outer remained unaffected which

indicate sort of zoning (Plate 9,A). Few broken and bended grains are also seen which indirectly indicate the strain effect of diastrophic movements (Plate 9,B).

Oligoclase ( $An_{15}, 2V + 85$ ) is the second plagioclase entering into the composition of these rocks. *Few grains with* lamellar twinning *are* noticed. Sericitization is very intensive, which at places masks over whole of the lath.

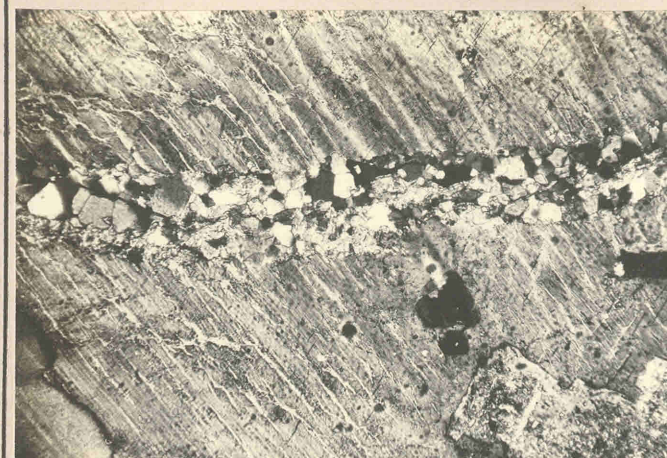
Biotite occurs as brown coloured sub-hedral flakes with frayed margins. They show strong pleochroism, changing their colour brown to green. At places, the laths are dislocated, displaced and interpenetrated to each other (Plate 10,F). Pleochroic halos are abundantly noticed in central portion of the lath (Plate 9,D) while on the margins alteration to chlorite is observed. Flakes of muscovite with good basal cleavage are present in subordinate amount. At places, scaly masses of muscovite interpenetrated with the biotite flakes which again indicate the effect of stress on these minerals. Magnetite is commonly present as inclusion in these minerals.

(iv) Medium-grained quartz-perthite-oligoclase-albite-muscovite/biotite granitic rocks.

In this group, the rocks are medium grained,

Explanation of Plate 11

- A. Photomicrograph of granitic rock showing secondary quartz in vein perthite. Crossed nicols (x 45).
- B. Photomicrograph of granitic rock showing well developed micrographic intergrowth of quartz and feldspars. Crossed nicols (x 45).
- C. Photomicrograph of granitic rock exhibiting carlsbed twinning in alkali-feldspar lath. Crossed nicols (x 45).
- D. Photomicrograph of granitic rock showing broken and microfaulted sericitized plagioclase lath. Crossed nicols (x 45).
- E. Photomicrograph of granitic rock showing distorted twin lamellae in plagioclase lath. Crossed nicols (x 45).
- F. Photomicrograph of granitic rock showing broken and interpenetrated flakes of muscovite. Crossed nicols (x 45).



A



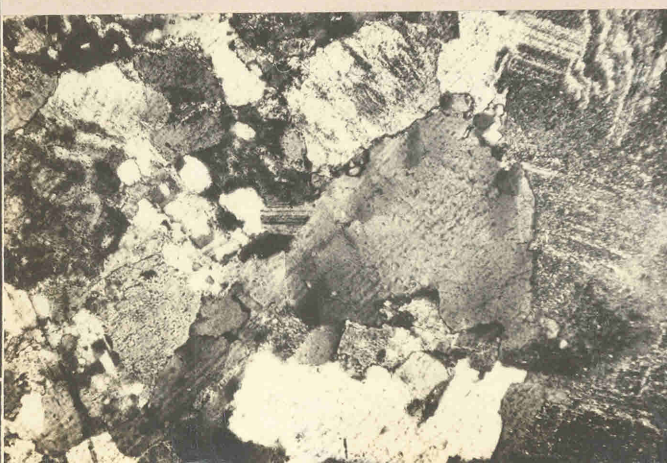
B



C



D



E



F

dirty white in colour, holocrystalline and hypidiomorphic in texture. Megascopically, they consist chiefly of quartz and feldspar with other accessory minerals. Under microscope, they are described as under.

Quartz is the last formed mineral which occurs in this group as anhedral grains usually with irregular borders. They commonly show undulatory extinction which is the characteristic of effect of strain developed in them. Simultaneous growth of quartz and feldspars which forms graphic texture (Plate 11,B) is quite frequent. At places, secondary quartz is also seen in veins.

The chief alkali-feldspar entering into the composition of these rock is perthite. It occurs as medium-grained subhedral and anhedral laths exhibiting typically developed perthitic growths of patch, vein and string types, sometimes micro-perthite type. Grains showing carlsbad twinning over shadowed by perthitic growth are also observed (Plate 11,C). The cracked grains veined with secondary fine-grained quartz are not rare. Few microcline subhedral grains showing cross-hatched twinning (Plate 10,A) are also noticed. They have generally been kaolinized.

Plagioclase, which most commonly present is

oligoclase ( $An_{15-20}$ ,  $2V + 87$ ). It occurs as medium-grained tabular laths frequently exhibiting lamellar twinning (Plate 10,C). Bended and broken grains are not rare. Few of laths show distorted albite type twinning (Plate 11,E).

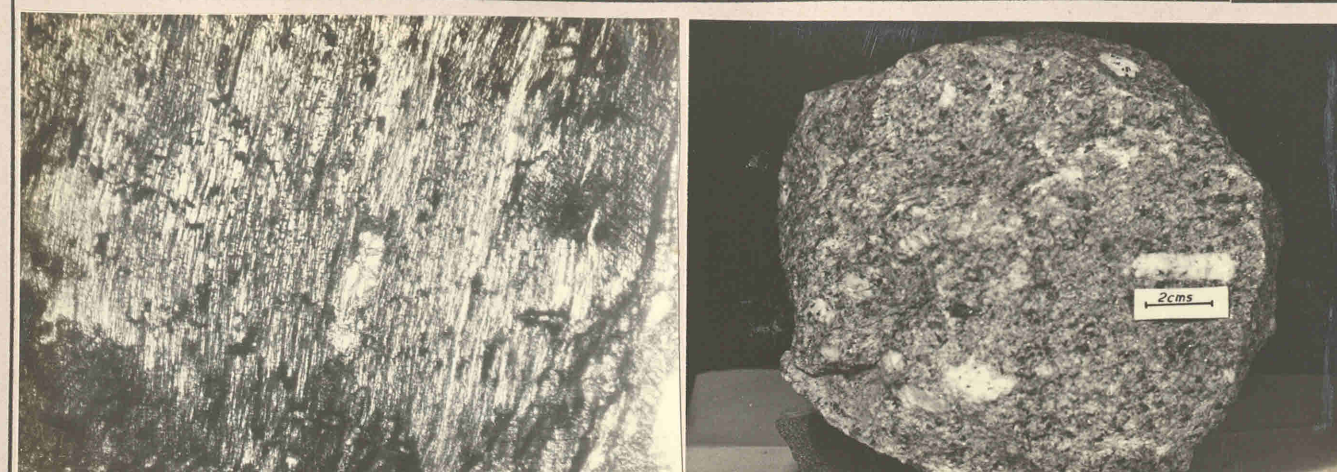
Albite ( $An_{5-7}$ ,  $2V + 79$ ) is the second type of plagioclase, which is present in small proportion in these rocks. Laths of this mineral mostly show twinning of albite type. Few broken laths (Plate 11,D) are also observed which indirectly indicating the diastrophic activities.

Muscovite is commonly seen in association with biotite. It occurs mostly as sub-hedral flakes with well developed basal cleavage. Bended grains with broken borders and having intergranular tendency, showing oscillatory extinction are not uncommon (Plate 11,F). Magnetite grains scattered all over muscovite are noticed.

Biotite is the dark brown ferro-magnesian mineral, which occurs in brown and greenish brown coloured flakes, is not so commonly present in the granitic rocks of this group. It shows strong pleochroism of brown to greenish brown colour. It is invariably altered to green coloured chlorite especially along the margins. Pleochroic halos (Plate 9,D) are not uncommonly present in this mineral. At places,

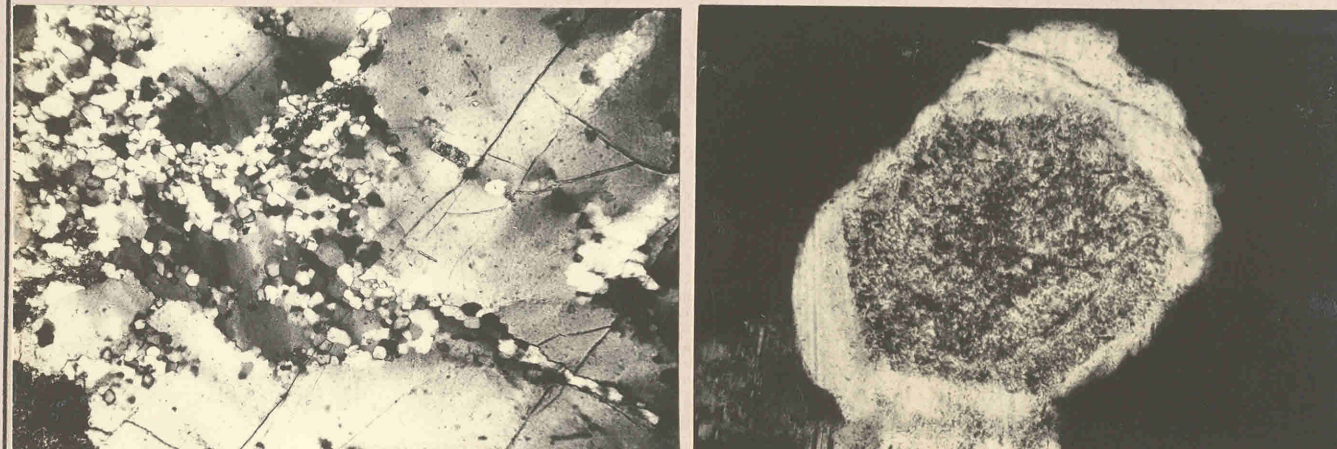
Explanation of Plate 12

- A. Photomicrograph of granitic rock showing magnetite concentration along the cleavage planes of biotite. Ordinary light (x 45).
- B. A handspecimen of coarse-grained porphyrite granitic rock.
- C. Photomicrograph of quartz grains showing the development of mortar texture and undulatory extinction in granitic rock. Crossed nicols (x 45).
- D. Photomicrograph showing hexagonal zoned plagioclase grain in granitic rock. Crossed nicols (x 45).
- E. Photomicrograph of granitic rock showing rod type perthetic growth. Crossed nicols (x 45).
- F. Photomicrograph of granitic rock exhibiting perthite lath in which plagioclase grain with reverse zoning is enclosed. Crossed nicols (x 45).



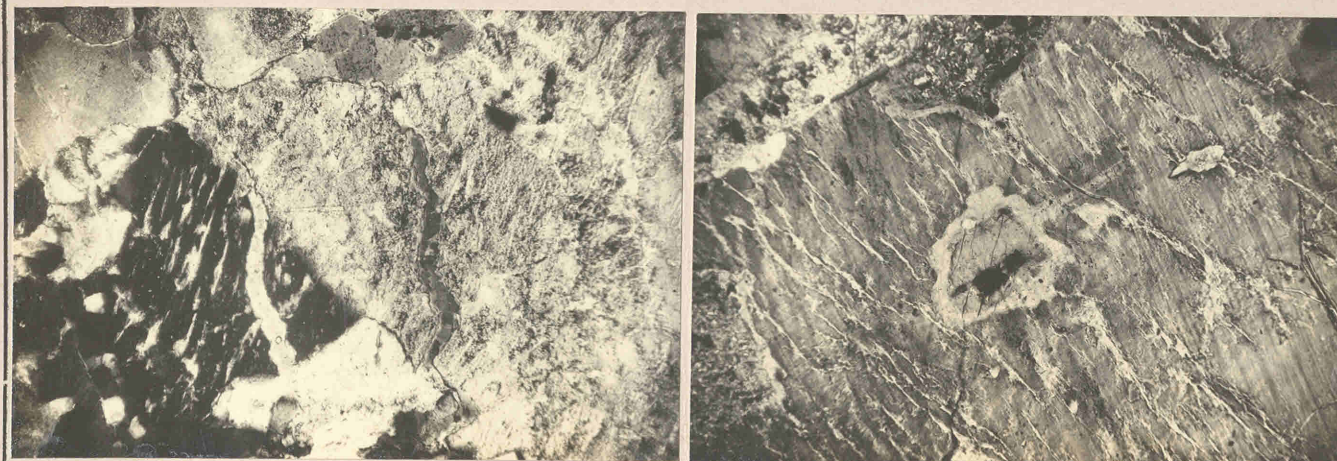
A

B



C

D



E

F

interpenetrated flakes alongwith muscovite needles are not rare. The inclusions of opaque mineral magnetite are very prominently present (Plate 12,A). Sometimes these inclusion altered to hematite.

v. Coarse-grained quartz-albite-oligoclase-perthite-biotite granitic rocks

Megascopically, the rock samples included in this group are coarse-grained, light grey in colour, and show, in general, well developed porphyritic texture (Plate 12, B) with porphyroblasts of plagioclases and alkali-feldspars. Almost complete hexagonal euhedral crystals of zoned feldspar (Plate 4, B & C in Chapter II) are easily identified with unaided eyes in these rocks. In thin sections, these rocks are described as below.

Quartz is the most common mineral in all the granitic rocks. It occurs as coarse-grained anhedral grains, which are usually cracked and have got very irregular and broken borders. In most of the cases, the crushing of coarse grains along the borders to fine-grained grains is a common phenomena which result to the mortar texture (Plate 12,C). The undulatory extinction is also not uncommon. All these features indicating indirectly the effects of strain developed

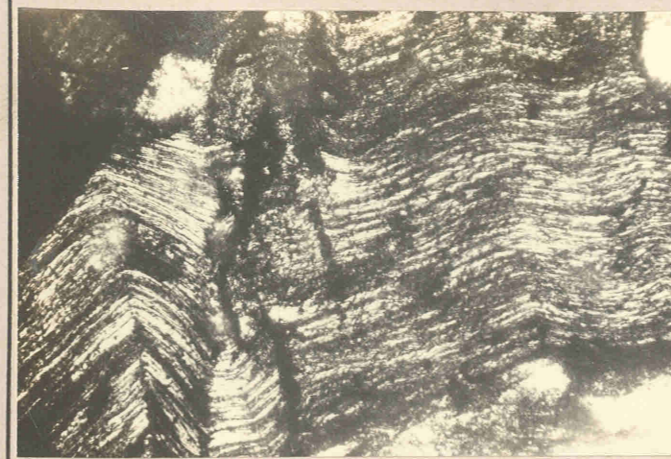
during the orogeny on the mineral quartz. The fresh quartz with sutured borders is commonly formed in veins of primary quartz and perthite (Plate 11,A).

Two types of plagioclases are present in these rocks. The chief plagioclase is the albite ( $An_{5-8}$ ,  $2V + 79^\circ$ ) and other one is oligoclase ( $An_{15-20}$ ,  $2V + 81^\circ$ ). They are found, in general, as coarse-grained sub-hedral tabular laths having irregular broken borders. In most of the cases they occur as untwinned grains but grains showing lamellar twinning are also common (Plate 9,B; 10,C). Distorted albite twinning is also seen especially in banded laths. At places, the process of sericitization is so intense that even whole of the grains are masked by sericite and it becomes difficult to reveal their true identity. In few grains, central portion is sericitized whereas the outer portion is unaffected resulting to the zoning in plagioclase (Plate 12,D) but, carlsbad twinning is observed in whole of the grain. Myrmekitic texture is also observed at few places (Plate 10,E).

Like the plagioclases, two types of alkali-feldspars are present in these rocks. The chief being the perthite occurring comparatively in higher proportion. Perthite is found to occur as coarse-grained, elongated tabular laths showing micro, braid, patch and string type of perthitic growths (Plate 12,E). Generally, they are altered to kaolin. Perthite

Explanation of Plate 13

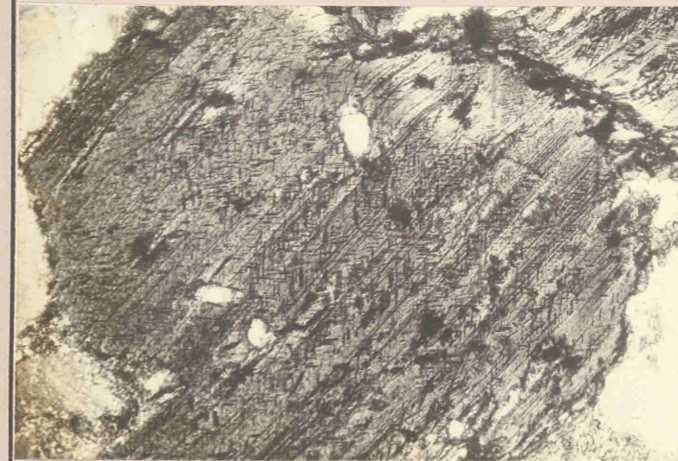
- A. Photomicrograph of granitic rock showing crinkly folded biotite flake. Ordinary light (x 120).
- B. Photomicrograph of granitic rock showing sagenitic texture and pleochroic halos in bended biotite flakes. Ordinary light (x 45).
- C. Photomicrograph of granitic rock showing sagenitic texture and pleochroic halos in biotite flake. Ordinary light (x 70).
- D. Photomicrograph of biotite flake depicting sagenitic texture. Ordinary light (x 45).
- E. Photomicrograph of granitic rock showing rod type perthitic growth. Crossed nicols (x 45).
- F. Photomicrograph of granitic rock showing fan-like appearance in muscovite flakes. Crossed nicols (x 45).



A



B



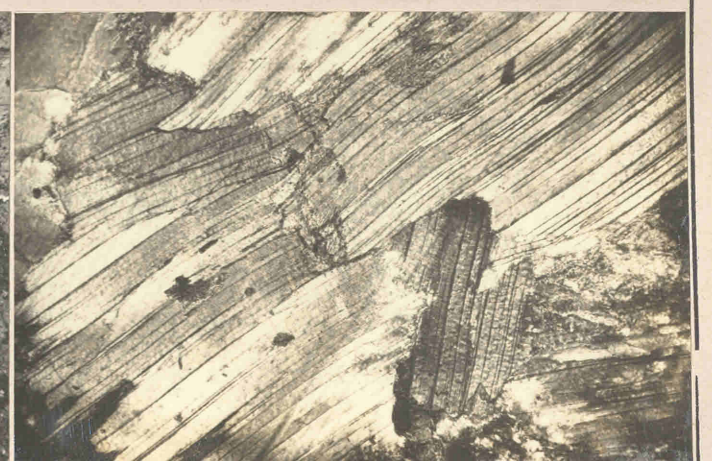
C



D



E



F

grains completely masked by kaolin are oftenly observed. In most of the cases, reverse zoning (Plate 12,F) is noted in perthitic laths. The second type of alkali-feldspar is microcline, which occurs as coarse-grained laths exhibiting cross-hatched twinning is very rarely present.

Biotite, which is of brown colour, occurs as coarse-grained flakes. They have got well developed basal cleavage and are strongly pleochroic. They show straight extinction, whereas bended broken grains show oscillatory extinction (Plate 13, A & B) indicating strain effects on the mineral biotite. Sagenitic texture has also been observed in few of the flakes (Plate 13, B, C & D). The alteration of biotite into chlorite particularly on the margin is very common but the presence of pleochroic halos is also not uncommon. Muscovite, in colourless flakes, is found to occur in association with biotite. At places, these flakes are interpenetrated to each other in criss-cross habit. Few flakes also observed to occur in scaly masses. They exhibit their typical peacock interference colours of upper second order. The inclusions of magnetite and ilmenite are commonly present. Few inclusions are altering to Leucoxene are also observed in these rocks (Plate 8,C).

vi. Fine-grained quartz-perthite-albite-microcline-biotite granitic rocks

The rocks included in this group are fine-grained, equigranular and hypidiomorphic in texture. Under microscopic examination, the minerals entering into the composition of these rocks are described below.

Quartz is the common mineral in the mineralogical composition of these rocks. The chief characteristic feature of this mineral is the low refractive index with first order of grey interference colours. Wavy extinction is commonly noted in the grains of this mineral. Secondary quartz has also been identified in these rocks. It occurs mostly in interstitial spaces, sometimes also with scaly masses of muscovite.

Among the alkali-feldspars, perthite, is most commonly seen in the rocks of this group. It occurs as subhedral laths which show different types of perthitic growth viz. micro, vein, patch perthite etc. (Plate 13, E). Few small subhedral to anhedral microcline grains are also seen to occur in these rocks. They show its typical cross hatched twinning. Few of the grains are altered to kaolin which is the common alteration product of alkali feldspars.

The chief plagioclase present in the rocks of this group is albite ( $An_{6-9}$ ,  $2V + 79^\circ$ ), which occurs in fine-grained, subhedral grains with frayed borders. The process of sericitization is only active in the central part of these grains whereas the peripheral portion remain unaffected. The broken and bended grains showing albite law of twinning are oftenly observed. The inclusions of biotite and muscovite are present.

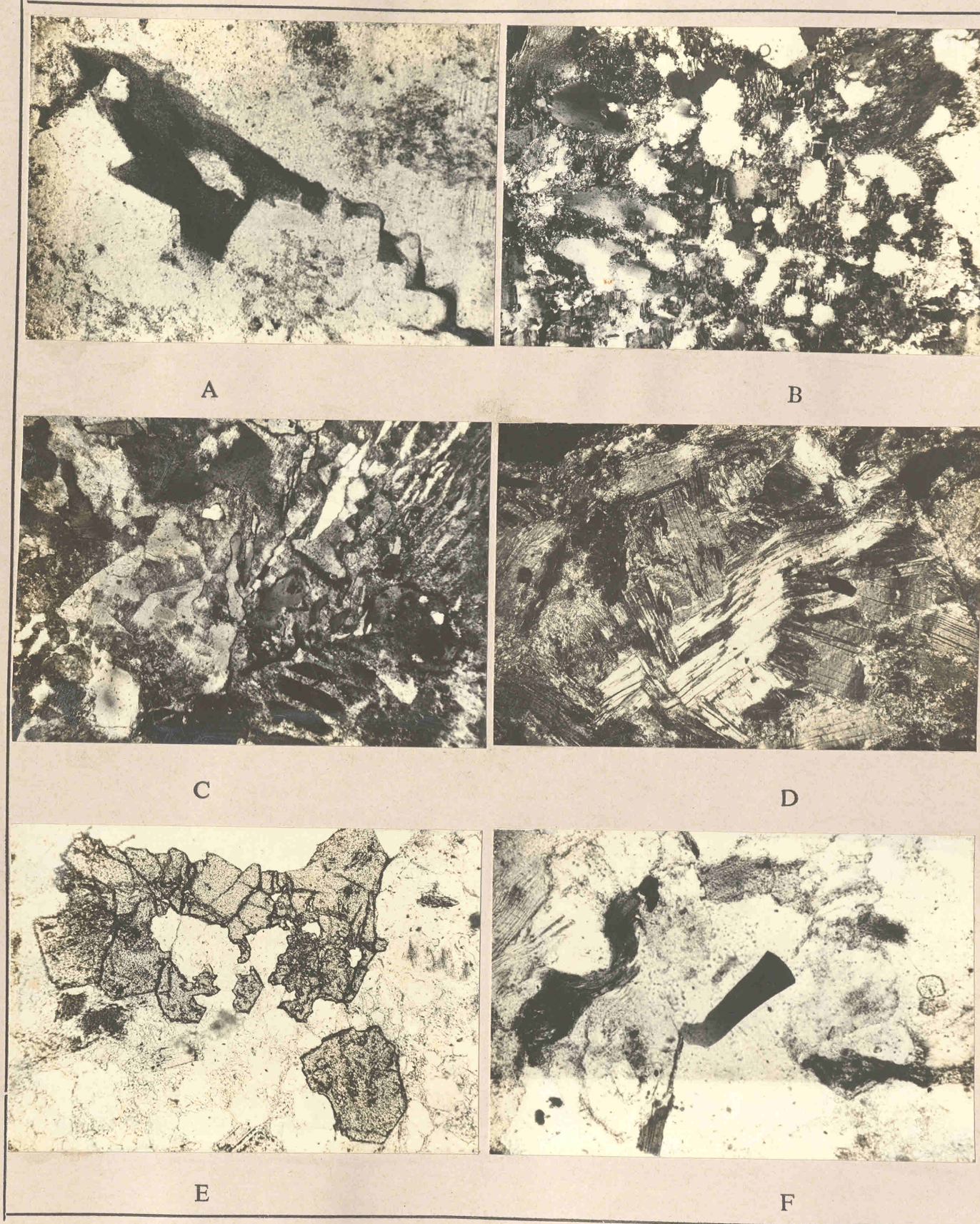
Biotite is the chief ferro-magnesian mineral which occurs flaky to tabular habit. It is in coffee brown colour and show pleochroism through brown to tints of leaf-green colour. Green colour is seen at the margins of flakes which indicates incipient stage of alteration. The scaly masses of muscovite present in subordinate amount are also observed. Few flakes interpenetrated to each other and give rise to fan-like appearance (Plate 13,F). The inclusions of iron oxides are also present.

#### Hybrid Rocks

The rocks belonging to this group are medium-grained and light grey to dark grey in colour. They occur as thin band all around the granitic body and have been considered to be formed by the mixture of country rocks and the granitic

Explanation of Plate 14

- A. Photomicrograph of slate xenolith present in the hybrid rock. Ordinary light (x 45).
- B. Photomicrograph of hybrid rock showing quartz grains partly masked with carbonaceous matter. Crossed nicols (x 45).
- C. Photomicrograph of hybrid rock showing graphic intergrowth of quartz and feldspars. Crossed nicols (x 45).
- D. Photomicrograph of muscovite flakes showing criss-cross development in hybrid rock. Crossed nicols (x 45).
- E. Photomicrograph of skeletal garnet grains in hybrid rock. Ordinary light (x 45).
- F. Photomicrograph of hybrid rock showing magnetite grains partly altered to hematite. Ordinary light (x 45).



melt (Sharma, 1973). At places, the grains are in linear arrangement which result into migmatite type rocks (Plate 5,C). Under the microscopic studies, the rocks show linear texture. In few rocks, samples the xenoliths of slate have also been observed (Plate 14, A). The minerals which are identified in these rocks are as under.

Quartz, which occurs as medium-grained, anhedral grains usually cracked, broken and has sutured margins. Undulatory extinction is much prevalent indicating the strain effects on quartz grains. Presence of secondary quartz is also noted. At places, quartz grains are masked by the carbonaceous matter (Plate 14, B). Simultaneous formation of quartz and feldspars resulting to graphic growth has also been observed (Plate 14, C).

Plagioclase is represented by albite ( $An_{5-8}$ ,  $2V + 79^\circ$ ). It occurs as medium to coarse-grained subhedral to anhedral grains. Mostly they are untwinned grains, only few show twinning following the albite law of twinning. Sericite is the common alteration product. In few grains sericitization is so intensive that masks over whole of the grain, while the others covered by carbonaceous matter are commonly observed. Myrmekitic texture is also seen but very rarely present in these rocks (Plate 10,E).

Muscovite, which is not of common occurrence, is seen to be as medium-grained, subhedral, colourless flakes. They show straight extinction. Few curved, broken interpenetrated flakes having criss-cross habit, show wavy extinction (Plate 14,D). Few green colour flakes of biotite are also observed in association with muscovite flakes. Small scaly masses of muscovite are also seen.

Among the accessories, garnet is the most common accessory as sub-hedral grains but few grains with skeletal frame work have also been observed (Plate 14,E). It is isotropic under the crossed nicols. Another important accessory is magnetite which occurs as anhedral grains. Few of the grains altering to hematite have also been seen (Plate 14, F). The other accessories which commonly observed are tourmaline, zircon and ilmenite.

#### Aplites

Aplites are fine-grained, white coloured rocks consisting of quartz and feldspar, occurring almost in equal proportions. Microscopically, they are described as under.

Quartz is the most important mineral which occurs as medium-grained fractured anhedral grains. Serrate texture

is seen at the borders. In few of the rock samples belonging to this group myrmekitic texture has also been noted.

The chief plagioclase is albite, which generally occurs as sub-hedral laths. In most of the cases, the grains are untwinned, but the grains which show albite law of twinning are also present. Sericite, is the common alteration product of this mineral, is commonly present.

Microcline is the chief alkali feldspar present in these rocks. As a rule, they show typically and prominently developed cross-hatched twinning. Few of the laths are altered to earthy brown matter maolin. Perthite is the other alkali-feldspar which is mostly of micro-perthite type present in these rocks.

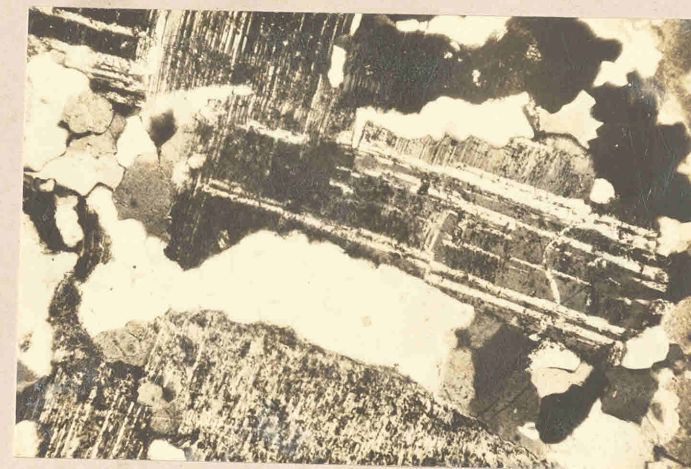
Muscovite is the common mica which occurs in the composition of these rocks. It is colourless, show straight extinction and occurs in scaly masses. Few greenish brown coloured biotite flakes are also noticed in association with the muscovite. They are strongly pleochroic and contain inclusions of iron oxides particularly of opaque mineral magnetite.

Explanation of Plate 15

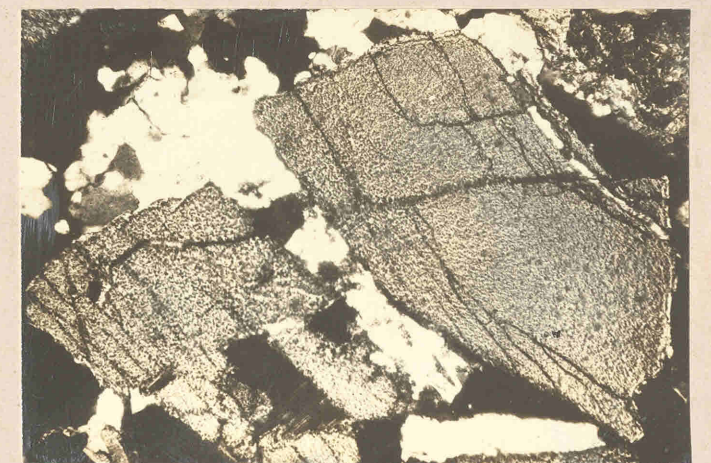
- A. A handspecimen of pegmatite depicting the presence of black coloured tourmaline.
- B. Photomicrograph of pegmatite exhibiting interpenetrated plagioclase laths showing lamellar twinning. Crossed nicols (x 45).
- C. Photomicrograph of pegmatite showing tourmaline grains with irregular cracks. Crossed nicols (x 45).



A



B



C

### Pegmatites

They are white coloured, coarse-grained rocks exhibiting typical developed pegmatitic structure. They occur as veins in the granitic rocks of area under reference. Megascopically, they consist of coarse-grained quartz and feldspar alongwith the spangle of muscovite and biotite and at places tourmaline also (Plate 15,A). In thin sections, following minerals have been recognised.

The mineral quartz occurs as coarse-grained, anhedral grains which usually cracked and crushed along the margins. Few of the grains showing undulatory extinction are also noted. Secondary quartz is also seen in veins of perthite.

The alkali-feldspars present in these rocks are mostly microcline and microcline perthite, but the chief alkali-feldspar is microcline which show its typical character cross-hatch twinning (Plate 10,A). Perthite is second type of alkali-feldspar occurring comparatively in lesser proportion.

The main plagioclase is the oligoclase ( $An_{15-20}$ ,  $2V + 85^{\circ}$ ). They found to occur as coarse-grained subhedral tabular laths and show lamellar twinning. At places, laths

are interpenetrating to each other (Plate 15,B). Few albite laths following albite law of twinning are also seen. Sericite is commonly present in few of the laths.

Muscovite is the common platy mineral present in the pegmatites. It is also seen to occur in scaly masses, showing its typical peacock interference colours. Few brown coloured, strongly pleochroic, subhedral isolated grains of biotite with fine-grained muscovite flakes has also been seen.

Tourmaline is chief accessory mineral occurring as green coloured, coarse to medium-grained, sub-hedral grains. They show high relief, cleavage absent but irregular fractures are commonly present (Plate 15,C). It shows straight extinction and green to pinkish interference colours which are the characteristics of Schörlite (tourmaline). The other accessory mineral is magnetite, which occurs as inclusions in other minerals.

A brief petrographic description of different country rocks and granitic rocks of the area of present investigations has been outlined above. In table III-(1 to 6) the modal composition of different granitic rock groups are presented. An attempt has been made to give also the average data of the initial and subsequent stages in table III-7 which

Table III-1

Modal Analyses (volume percentage) of coarse-grained  
quartz-perthite-albite-microcline biotite granitic rocks.

Specimen number	R <sub>24</sub>	L <sub>13</sub>	K <sub>32</sub>	T <sub>7</sub>	B <sub>15</sub>	K <sub>52</sub>
Quartz	29.25	29.90	37.96	29.88	33.30	28.81
Alkali-feldspars (Perthites and microperthites)	31.72	34.53	30.05	26.02	26.35	32.37
Plagioclases (Oligoclase to albite)	28.65	29.22	24.25	33.56	29.54	27.27
Biotite	6.38	4.35	5.01	6.57	7.04	7.63
Muscovite	3.47	1.59	2.14	3.39	3.28	3.50
Others including magnetite etc.	0.53	0.41	0.59	0.58	0.49	0.42

Table III-2

Modal Analyses (volume percentage) of medium-grained  
quartz-microcline-perthite-oligoclase-biotite granitic rocks.

Specimen number	R <sub>57</sub>	R <sub>12</sub>	R <sub>8</sub>	R <sub>21</sub>	R <sub>5</sub>
Quartz	31.89	29.46	30.97	36.51	36.28
Alkali-feldspars (Perthites and microperthites)	30.24	37.83	26.01	29.43	28.01
Plagioclases (Oligoclase to albite)	31.98	27.06	36.99	26.45	30.34
Biotite	4.28	4.23	4.42	3.95	3.92
Muscovite	1.12	1.14	1.21	2.98	1.18
Others including magnetite etc.	0.49	0.28	0.40	0.68	0.27

Table III-3

Modal Analyses (volume percentage) of coarse-grained quartz-perthite-albite-oligoclase-biotite granitic rocks.

Specimen number	S <sub>46</sub>	B <sub>4</sub>	L <sub>18</sub>	B <sub>16</sub>
Quartz	29.88	31.53	35.79	32.78
Alkali-feldspars (Perthites and microperthites)	25.71	28.48	29.01	25.84
Plagioclases (Oligoclase to albite)	36.86	32.08	31.00	34.58
Biotite	5.38	5.29	3.10	4.52
Muscovite	1.47	1.95	0.63	1.72
Others including magnetite etc.	0.70	0.67	0.47	0.56

Table III-4

Modal Analyses (volume percentage) of Medium-grained quartz-perthite-oligoclase-albite-muscovite/biotite granitic rocks.

Specimen number	S <sub>51</sub>	S <sub>30</sub>	K <sub>55</sub>	S <sub>57</sub>	B <sub>21</sub>	T <sub>19</sub>	R <sub>52</sub>	K <sub>8</sub>	S <sub>59</sub>
Quartz	28.90	32.12	35.21	29.29	30.32	27.82	28.67	30.08	29.22
Alkali-feldspars (Perthites and microperthites)	34.26	44.42	38.99	26.72	25.46	29.11	31.41	25.95	32.98
Plagioclases (Oligoclase to albite)	31.28	20.72	19.28	37.74	37.29	35.96	33.40	36.83	33.62
Biotite	3.95	1.79	3.70	3.85	4.10	4.09	4.96	4.14	2.61
Muscovite	1.19	0.84	2.46	2.00	2.56	2.69	1.16	2.55	1.17
Others including magnetite etc.	0.42	0.11	0.36	0.40	0.27	0.33	0.40	0.45	0.40

Table III-5

Modal Analyses (volume percentage) of coarse-grained  
quartz-albite-oligoclase-perthite-biotite granitic rocks.

Specimen number	T <sub>22</sub>	T <sub>8</sub>	C <sub>7</sub>	T <sub>23</sub>	B <sub>20</sub>
Quartz	32.69	32.58	27.87	31.60	31.78
Alkali-feldspars (Perthites and microperthites)	20.59	20.71	23.18	25.88	27.84
Plagioclases (Oligoclase to albite)	36.08	35.31	39.53	31.93	32.88
Biotite	6.67	6.12	5.75	6.96	5.02
Muscovite	3.25	3.98	3.40	2.97	1.92
Others including magnetite etc.	0.72	1.30	0.27	0.66	0.56

Table III-6

Modal Analyses (volume percentage) of fine-grained quartz-perthite-oligoclase-albite-biotite granitic rocks.

Specimen number	R <sub>30</sub>	R <sub>23</sub>	K <sub>24</sub>
Quartz	28.18	28.98	30.11
Alkali-feldspars (Perthites and microperthites)	28.77	33.74	30.94
Plagioclases (Oligoclase to albite)	35.53	30.48	31.54
Biotite	5.25	4.22	4.79
Muscovite	1.78	1.61	2.15
Others including magnetite etc.	0.49	0.97	0.47

Table III-7

Addition and/or subtraction of respective modal constituents in different groups.

Group Stages	I		II		III		IV		V		VI	
	Ini-tial	Mean Subst.	Ini-tial	Mean Subst.	Ini-tial	Mean Subst.	Ini-tial	Mean Subst.	Ini-tial	Mean Subst.	Ini-tial	Mean Subst.
Quartz	29.25	31.98	31.89	33.30	29.88	33.37	28.90	30.34	32.69	30.96	28.18	29.54
Alkali-feldspars*	31.72	29.86	30.24	30.32	25.71	27.78	34.26	31.88	20.59	24.40	28.77	32.34
Plagioclases**	28.65	28.77	31.98	30.21	36.86	32.55	31.28	31.86	36.08	34.91	35.53	31.01
Biotite	6.38	6.12	4.28	4.13	5.38	4.30	3.95	3.65	6.67	5.96	5.25	4.50
Muscovite	3.47	2.78	1.12	1.63	1.47	1.43	1.19	1.93	3.25	3.07	1.78	1.88
Iron oxide minerals	0.53	0.50	0.49	0.41	0.70	0.57	0.42	0.34	0.72	0.70	0.49	0.72
Quartz	+ 2.73		+ 1.41		+ 3.49		+ 1.44		- 1.73		+ 1.36	
Alkali-Feldspars*	- 1.86		+ 0.08		+ 2.07		- 2.38		+ 3.81		+ 3.57	
Plagioclases**	+ 0.12		- 1.77		- 4.31		+ 0.58		- 1.17		- 4.52	
Biotite	- 0.26		- 0.15		- 1.08		- 0.30		- 0.71		- 0.75	
Muscovite	- 0.69		+ 0.51		- 0.04		+ 0.74		- 0.18		+ 0.10	
Iron oxide minerals	- 0.03		- 0.08		- 0.13		- 0.08		- 0.02		+ 0.23	

\* Perthites and microperthites.

\*\* Oligoclase to albite.

Table III-8

Average Modal data of different granitic rock groups.

Minerals	Group I	Group II	Group III	Group IV	Group V	Group VI
Quartz	31.52	33.02	32.50	30.18	31.30	29.09
Alkali-feldspars (including perthite and microperthite)	30.17	30.30	27.26	32.14	23.65	31.15
Plagioclases (oligoclase to albite)	28.75	30.56	33.63	31.79	35.15	32.52
Biotite	6.16	4.16	4.57	3.69	6.10	4.75
Muscovite	2.90	1.53	1.44	1.85	3.10	1.85
Others including magnetite	0.50	0.43	0.60	0.35	0.70	0.64



## CHAPTER IV

### SAMPLING AND ANALYTIC TECHNIQUES

\*\*\*\*\*  
\* I. INTRODUCTION \*  
\*\*\*\*\*

Collection of proper samples in the field and sample preparation in the laboratory play a vital role in the accuracy and interpretation of chemical data. Samples collected at random cannot be taken to give true representation and many a time data based on stray samples lead to contradictory interpretations. This aspect of the problem has been quantitatively dealt with and discussed by Sinha (1956), Engel and Engel (1958), Pitcher and Sinha (1958) and Samal and Wager (1960). With rapid advancement in analytic techniques, it is now possible to deal with a larger number of samples than hitherto included in geochemical studies. Yet, all these precise and advance methods become almost futile if the representative nature of the material under study is not first assured. Despite this importance of field sampling, no single method of sampling has been evolved which could be safely adopted as universal for all types of geological studies. In sampling, each arearepresents its own special problems depending upon the geological setting, availability of fresh outcrops, structural and tectonic complexities, banding etc. For

instance, when working in a metamorphic terrain, metamorphic changes are to be quantitatively determined, both grid as well as bulk and composite sampling have to be adopted.

It has been observed that a careful selection of some appropriate method of sampling may well reduce the possibility of errors. Keeping these problems in view, the methods adopted in the present studies are also described below.

\*\*\*\*\*  
 \*\* II. FIELD SAMPLING \*\*  
 \*\*\*\*\*

For the present study, after a preliminary reconnaissance of the entire area, an orientation survey was carried out during the first field trip. Partial chemical analyses of samples was carried out and it was found that grid method of sampling with a convenient grid interval of 2 m to 5 m was fairly satisfactory to represent the salient chemical and mineralogical differences. In some remote and inaccessible parts of the area it was hardly possible to collect samples at a fixed grid because of the reasons already mentioned. Therefore, collection of samples across vertical profiles was limited to approachable grid intervals. In this work skill of local labour helped a lot. In the selection of samples, weathered and stray samples were avoided. Bulk method of sampling, sometimes samples weighing not less than 3 kg was found suitable

especially for the coarse-grained prophyritic granitic rocks.

Thus, the present writer feels the samples collected both by grid as well as bulk method, provide a good basis for working out the petrochemistry of these rocks.

\*\*\*\*\*  
 \* III. LABORATORY SAMPLING \*  
 \*\*\*\*\*

It is very difficult to do the chemical studies of all the samples collected from the field, therefore, a preliminary petrographic study of each group of samples had to be first carried out before the selection of material for chemical analysis. The preparation of samples in the laboratory is also not free from difficulties much precaution has to be taken to save them from contamination at the various stages of the process.

The samples collected from the field were halved, each weighing about 500 gms. One half was preserved for preparation of thin sections and petrographic studies, while the other half was bulked and used for analyses. The samples selected for analyses were thoroughly cleaned, dried and broken to pea-nut-size on a hard steel plate with hard steel hammer. Preliminary reduction of bulk was done at this stage by "coning and quatering" method. The small pieces of the reduced bulk

were crushed in a steel mortar to about -40 mesh and bulk was further reduced to half or quarter depending upon the original quantity by "coning and quatering" method. The remaining material was finally pulverised to fine powder (-300 mesh) in an agate mortar. Sieving at this stage was, however, avoided to check metallic contamination.

\*\*\*\*\*  
 \* IV. PETROGRAPHIC METHOD \*  
 \*\*\*\*\*

About 250 thin sections were studied for detailed petrographic observation of different types of rocks. Modal analyses, 'An' content and 2V of the minerals of the selected samples were determined. For the modal analysis, uncovered slides of granitic rocks were stained to distinguish the plagioclases and K-feldspars following the method after Bailey et al. (1960). Plagioclase was stained brick red with a solution of potassium rhodizonate whereas, K-feldspar took yellow colour with the solution of sodium cobaltinitrite, and then volume percentage of various minerals present in them determined with the help of point counter (Chayes, 1956).

An-content following symmetrical extinction angle and 2V of the plagioclases were determined on a five-axis universal stage, and results determined by plotting the data on the standard curves of Naidu (1958), Slemmons (1962). The mean error

of this method was found to be about  $\pm 2$  per cent 'An'.

\*\*\*\*\*  
 \* V. ANALYTICAL TECHNIQUES \*  
 \*\*\*\*\*

(i) Major Elements

The chemical analyses of the rocks were carried out by Rapid Methods of Silicate Analysis (Shapiro and Bronnock, 1952, 1956 and 1962), with suitable changes. Details of these techniques have been discussed, besides Shapiro and Bronnock (op.cit.), by Sinha (1956) and Mall (1967) and hence these are not repeated here. Briefly the method involves preparation of two solutions 'A' and 'B' of a known quantity of rock powder for the determination of major elements. The solution 'A' is used for determination of  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  while solution 'B' is used for determination of  $\text{TiO}_2$ ,  $\text{Fe}_2\text{O}_3$  (total iron)  $\text{MnO}$ ,  $\text{MgO}$ ,  $\text{CaO}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{P}_2\text{O}_5$ .

All the oxides except  $\text{K}_2\text{O}$ ,  $\text{Na}_2\text{O}$ ,  $\text{CaO}$ ,  $\text{MgO}$  and  $\text{FeO}$  were spectrochemically determined on Carl Zeiss Jena 'Uvispeck' spectrophotometer (Model Q 1, Germany make). The optimum conditions of the instrument in course of present work were as follows :

- |    |                                           |   |                                                                                                                                                                                                   |
|----|-------------------------------------------|---|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. | Source of light for steady transmission   | - | Tungsten Lamp (6V).                                                                                                                                                                               |
| 2. | Monochromator for selection of wavelength | - | Interference scatter filter.                                                                                                                                                                      |
| 3. | Wave length range                         | - | 380 $\mu$ to 700 $\mu$ with vernier adjustment for precise measurement upto 0.1 $\mu$ in the interference filter.                                                                                 |
| 4. | Mean silt width                           | - | 100 A.C for 100 A.E.                                                                                                                                                                              |
| 5. | Cell arrangement                          | - | Four equi-dimentional rectangular cells of fused silica kept at a time in the rack.                                                                                                               |
| 6. | Photo cells                               | - | Two inter-changeable tubes housed in special cases and marked 'Red sensitive and Blue sensitive' covering wave length ranges from 380 $\mu$ to 600 $\mu$ and 600 $\mu$ to 700 $\mu$ respectively. |
| 7. | Reception                                 | - | A spot light galvanometer pointer with linear scale, measuring absorbance or transmission as desired.                                                                                             |

The alkalies were determined on Carl Zeiss AAS-I Atomic Absorption Spectorophotometer by following Emission mode, CaO and MgO were determined volumetrically by titrating against versene using Erichrome Block-T as an indicator. Whereas FeO was determined by the usual classical dichromate method with sodium-diphenyl sulphonate as an internal indicator.  $H_2O^+$  was

determined by modified penfield's method.

(ii) Trace Elements

Quantitative determination of the trace elements was done by using the carl Zeiss AAS-I Atomic Absorption spectrophotometer. Details of the assemblage of this unit and the optimum conditions of the present work are given below :

1. Description of the Instrument

The AAS-I Atomic Absorption Spectrophotometer is self-contained instrument accommodating the following units:

- a. Gas supply unit with gas-washer cylinder (1,22) the two pressure reducing stages (41, 47, 57) safety valve (42) and flow meters (9,10,11).
- b. Atomizer - Burner unit (2).
- c. Hollow cathode Lamps in Lamp turret (91).
- d. Optical system with change over device for conversion from single to tripple pass (tube with imaging optics ( 92 ).

- e. Amplifier and indicating unit (105).
- f. Power supply for photomultiplier and current stabilizer for hollow cathode lamps.
- g. Facility for automatic measuring compensation (Autozero).

2. Measuring principle and operating mode

This instrument provides absorption as well as emission relative measurements. The data are compared with standard curves of samples of known composition and concentration.

The liquid sample is atomized and aerosol is supplied to the acetylene/air or propane airflame. In the flame the dissolved elements are brought to their ground state. The atoms preferably absorb radiation of those wave lengths, which correspond to the transition from the ground state. The resonance line necessary for absorption is supplied by a hollow cathode lamp of very small band width, the cathode of which consists of the element to be detected. Constant operating conditions of flame and lamp provided, the quantitative laws of spectrophotometry also apply for atomic absorption :

$$E = \text{Log } \frac{1}{v}$$

$$v = \frac{\phi_e}{\phi_i}$$

$$\therefore E = \text{Log } \frac{\phi_i}{\phi_e}$$

where E = absorbance.

v = internal transmittance.

e = emitted light current.

i = incident light current.

### 3. Optimum condition used in the present work

#### a. Spectral dispersion :

Grating monochromator - Ebertmount

Focal length - 500 mm

Slit width - 0 to 2 mm  
continuously  
adjustable

Slit height - 20 mm

Coupled entrance and exist slit :

Precision deffraction - Plane  
grating

Ruled Area - 54 mm x 54 mm

Number of grooves - 1300 /mm

Dispersion - 1.5nm/mm

Blaze wave length - 300 nm

Range - 190 to 800 mm

## b. Order filters :

Order filters - WK 38(GG13)  
from 400 nm.

## c. Gas Control System :

Two stage pressure reducer for  
compressor air :

First stage for connection to high  
pressure gas cylinder.

High - pressure gauge.

The light of back ground radiator is attenuated by atomic absorption and then reflected to the detector via the grating monochromator.

After being amplified, the signal is demodulated, averaged through a time constant and then displayed. The scale value of the matter is a measure of the concentration of the element to be detected. This value is related to full scale deflection for non-attenuated light of the hollow cathode lamp.

The hollow cathode lamp is modulated with alternating current (300 Hz.). The amplifier responds only to this a.c. signal, so that measuring errors through non-modulated flame back ground radiation are eliminated.

In emission mode, those atoms are utilized which are in excited state. Their number depends on flame temperature and on the excitability of the element. In most cases it is smaller than the number of atoms in ground state. The excited atoms are capable of emitting radiation which is a typical for the element. The light signal emitted in the flame is directed to the monochromator, modulated at 300 Hz by a chopper placed in front of the detector.

Table IV-a

(Optimum conditions of AAS-I used in the present work)

Element	Wavelength	Photomultiplier	Grain	Fuel
Cu	324.75	4	2	Air/Acety Lene
Cr	357.9	4	2	" "
Zn	219.9	4	2	" "
Fe	248.4	4	2	" "
Mg	285.2	4	1	" "
Ca	422.7	5	2	" "
Mn	279.5	4	2	" "

\*\*\*\*\*  
 \* VI. STANDARDS USED \*  
 \*\*\*\*\*

Both synthetic and natural standards were used with each batch of analyses to check the accuracy and precision of the

analytical data. All the determinations were carried out against G<sub>2</sub>, GSP-1 and BCR-1, the three international standards supplied by the United States Geological Survey (USGS), Washington. Synthetic standards were also prepared in the laboratory from 'Analar' grade and extra pure chemicals, for the determination of following oxides :

<u>Oxide determined</u>	<u>Standard Used</u>
TiO <sub>2</sub>	Titanium dioxide.
Fe <sub>2</sub> O <sub>3</sub>	Ferrous ammonium sulphate.
FeO	" " "
MnO	Manganese dioxide.
MgO	Magnesium metal.
CaO	Calcium carbonate.
Na <sub>2</sub> O	Sodium chloride.
K <sub>2</sub> O	Potassium chloride.
P <sub>2</sub> O <sub>5</sub>	Calcium Phosphate.

For trace element work also the two natural standards GSP-1 and G<sub>2</sub> were used.

\*\*\*\*\*  
 \*\* VII.      PRECISION AND ACCURACY OF THE RESULTS \*\*  
 \*\*\*\*\*

As a check for reproducibility of the results as also the precision and accuracy of the present techniques of Rapid Methods of Silicate Analysis, a number of replicate analyses of the standard rock GSP-1 were carried out. The standard deviation and relative error calculated from the replicate data was well within the statistical range as discussed by Fairbairn and others (1951), Fairbairn (1953) and represented by the data given in Table IV-b.

The following statistical abbreviations have been used in this table.

n	=	number of observations.
$\bar{X}$	=	arithmatic mean.
d	=	deviation of an individual observation from the arithmatic mean.
S	=	Standard deviation $\sqrt{\frac{\sum d^2}{n - 1}}$
$\bar{Sx}$	=	Standard error = $\frac{S}{\sqrt{n}}$ , the error of the arithmatic mean.
C	=	relative deviation = $\frac{S}{\bar{X}} \times 100.$
E	=	relative error = $c/\sqrt{n}$

Table IV-b

Precision and reproducibility of chemical data.  
(Standard GSP-1)

Oxides	1	2	3	4	$\bar{X}$	S	S $\bar{X}$	C	E
SiO <sub>2</sub>	67.27	67.36	67.42	67.28	67.35	.070	.040	.104	.060
TiO <sub>2</sub>	0.69	0.66	0.63	0.68	0.66	.025	.014	3.787	2.186
Al <sub>2</sub> O <sub>3</sub>	15.11	15.25	15.14	15.13	15.17	.067	.038	.441	.254
Fe <sub>2</sub> O <sub>3</sub>	1.77	1.77	1.80	1.76	1.78	.021	.012	1.179	.680
FeO	2.30	2.31	2.33	2.28	2.31	.025	.014	1.082	.624
MnO	0.04	0.04	0.03	0.04	0.04	.002	.001	5.000	2.886
MgO	0.95	0.96	0.91	0.98	0.95	.036	.021	3.789	2.187
CaO	2.03	2.04	2.09	2.01	2.05	.040	.023	1.951	1.126
Na <sub>2</sub> O	2.88	2.80	2.78	2.91	2.83	.070	.040	2.473	1.427
K <sub>2</sub> O	5.48	5.53	5.57	5.42	5.51	.077	.044	1.397	0.806
P <sub>2</sub> O <sub>5</sub>	0.28	0.29	0.31	0.27	0.29	.020	.011	6.896	3.981

1 - Recommended values for GSP-1 by Flanagan (1969).

2 to 4- Analyses by the present author.

\*\*\*\*\*  
\* VIII. PRESENTATION OF RESULTS \*  
\*\*\*\*\*

Like sampling and analytic techniques, the choice of presentation of geochemical data plays an important role in geochemical studies. Sometimes serious errors in interpretation can arise by a wrong selection of the method of presentation. This problem has been discussed from time to time by petrologists as well as geochemists, who depending upon the nature of the results, have suggested various methods both for graphic and tabular presentation. All these methods can broadly be classified into two groups, the one in which no consideration of volume changes during the process or processes involved is given, while the other where the data are presented with suitable modifications with regard to the volume changes. No attempt is made here to discuss the detail of each method, as it would serve little purpose, and for the present work, only a survey of the relative merits of important and widely used methods would be sufficient.

Niggli (1948) suggested molecular units as the basis of presentation of chemical data, while in the same year Barth proposed the idea of standard unit cell composed of 160 oxygen atoms for showing the chemical changes. This idea of Barth has been seriously criticised on the basis of volume changes in the metasomatic and metamorphic processes by Rosenquist (1949) Brajnikov (1949) and Eskola (1954). Eskola (op.cit.) recommended

the use of ionic percentage instead of molecular units, Poldervaart (1953) advanced the concept of Silica-Alumina tetrahedra for the purpose of presentation. Green and Poldervaart (1960) have compiled these methods and their relative precision discussed in detail. Besides the above, several other methods on the basis of cation percentage, number of cation per cc of rock, gm metal per 100 cc of rock have been used from time to time. It is not possible to give a bias in favour of any one of these methods, as the choice of the method of presenting data depends upon the nature of study, the accuracy aimed at, the magnitude of the changes involved and also the ultimate aim of the work. Patwardhan (1965) after reviewing most of the prevalent methods concluded that the weight-percent-oxide method is still most useful as it involves no tedious calculations and further it can directly be correlated with the normative data on the one hand the mineral analysis on the other. Thus, despite the several vicissitudes which the weight-percent-oxide system of presentation of analytic data has undergone, its usefulness and validity has not been minimised. In the present work, therefore, the chemical data have been presented on this basis.

As regards graphic presentation, opinions differed from time to time and new methods using several premises have been introduced. The silica-variation diagrams and the ternary diagrams are still undoubtedly preferred and have proved their

usefulness for presentation of chemical changes and variations during magmatic evolution. Indirectly the magnitude of the process responsible for chemical changes is also indicated. However, the chief difficulty with silica-variation diagrams is that, it does not give any idea of the changes in space. As such in the present work both binary and ternary diagram, which have an obvious advantage, have been used. They demonstrate at very first sight not only the nature of the chemical variation but also the magnitude of the changes, in space. Indirectly the process responsible for these chemical changes is also indicated in many cases, which may be noticed in the chapter of discussion.

In the following pages, the analytic data of both major as well trace elements<sup>of</sup> different rock types are presented along with the corresponding C.I.P.W. norms. Each table thus contains the chemical analyses, norms, oxide ratios Niggli value as well as the trace-elements of the rocks.

Table IV-1

Chemical composition of the coarse-grained quartz-perthite-albite-microcline-biotite granitic rocks\*.

Specimen number	Major elements (weight per cent)							Trace elements (parts per million)							
	R <sub>24</sub>	L <sub>13</sub>	K <sub>32</sub>	T <sub>7</sub>	B <sub>15</sub>	K <sub>52</sub>	Average	R <sub>24</sub>	L <sub>13</sub>	K <sub>32</sub>	T <sub>7</sub>	B <sub>15</sub>	K <sub>52</sub>	Average	
SiO <sub>2</sub>	68.92	70.52	70.97	70.97	71.22	71.38	70.66	Cr <sup>3+</sup>	20	15	15	5	25	20	17
TiO <sub>2</sub>	0.49	0.19	0.19	0.40	0.34	0.22	0.31	Co <sup>2+</sup>	12	10	12	8	8	12	10
Al <sub>2</sub> O <sub>3</sub>	14.01	14.86	15.29	13.47	13.45	13.78	14.15	Ni <sup>2+</sup>	10	4	10	6	8	8	8
Fe <sub>2</sub> O <sub>3</sub>	1.07	0.73	0.62	0.79	0.84	0.94	0.83	Rb <sup>+</sup>	150	200	150	150	175	150	<163
FeO	1.66	1.10	1.22	1.66	1.69	1.21	1.42	Sr <sup>2+</sup>	75	75	50	30	50	40	53
MnO	0.04	0.03	0.05	0.05	0.03	0.04	0.04	Ba <sup>2+</sup>	960	680	540	840	920	520	743
MgO	1.52	0.66	0.83	0.83	1.22	0.55	0.94	<u>Cation ratios</u>							
CaO	1.27	1.23	1.21	1.15	1.38	1.38	1.27	(Co/Fe <sup>2+</sup> )x10 <sup>3</sup>	0.93	1.17	1.26	0.62	0.61	1.27	0.90
Na <sub>2</sub> O	5.00	5.10	4.50	5.50	5.40	5.00	5.08	Co/Ni	1.20	2.50	1.20	1.33	1.00	1.50	1.25
K <sub>2</sub> O	4.08	4.38	3.46	3.46	3.05	4.38	3.80	(Ni/Mg)x10 <sup>3</sup>	1.09	1.02	2.04	1.22	1.09	2.42	1.42
P <sub>2</sub> O <sub>5</sub>	0.28	0.14	0.19	0.18	0.22	0.13	0.19	K/Rb	225	181	191	191	144	242	194
H <sub>2</sub> O <sup>+</sup>	0.61	0.46	0.58	0.52	0.53	0.54	0.54	Rb/Sr	2.00	2.66	3.00	5.00	3.50	3.75	3.05
Total	98.95	99.40	99.11	98.98	99.37	99.55	99.23	K/Ba	35	53	53	34	27	69	42
<u>Norms (CIPW)</u>								Sr/Ba	0.08	0.11	0.09	0.03	0.05	0.07	0.07
Q	19.26	20.46	27.30	22.02	23.22	22.20	22.56	Ba/Rb	6.40	3.40	3.60	5.60	5.25	3.46	4.57
Or	24.46	26.13	20.57	20.57	18.35	26.13	22.24	<u>Niggli values</u>							
Ab	42.44	42.97	38.25	46.63	45.59	42.44	42.97	al	37.95	43.45	45.73	39.40	38.60	40.66	41.07
An	3.34	4.73	5.00	1.67	3.34	1.95	4.45	fm	21.05	11.61	14.33	16.72	19.00	13.25	15.77
C	-	-	2.24	-	-	-	-	c	6.37	6.55	6.40	6.27	7.31	7.53	6.85
Di	1.11	0.46	-	2.75	2.26	3.43	0.89	alk	34.63	38.39	33.54	37.61	35.09	38.56	36.31
Hy	4.72	2.42	3.55	2.72	3.98	0.90	3.32	si	318.28	349.70	360.67	353.13	347.08	358.43	350.60
Mt	1.62	0.93	0.93	1.16	1.16	1.39	1.16	k	0.35	0.36	0.34	0.29	0.27	0.37	0.33
Il	0.91	0.46	0.46	0.76	0.61	0.46	0.61	mg	0.61	0.52	0.54	0.46	0.55	0.44	0.53
Ap	0.67	0.34	0.34	0.34	0.34	0.34	0.34	<u>Modified Larsen Differentiation Index (MDI)</u>							
<u>Oxide ratios</u>								MDI	12.29	13.34	12.56	12.60	11.89	13.42	12.68
Na <sub>2</sub> O/K <sub>2</sub> O	1.23	1.16	1.30	1.59	1.77	1.44	1.34	<u>Location of the analysed samples</u>							
K <sub>2</sub> O/Na <sub>2</sub> O	0.83	0.86	0.77	0.63	0.56	0.88	0.75	R <sub>24</sub>	(32° 54' 43" ; 75° 36' 32") ; L <sub>13</sub> (32° 47' 15" ; 75° 46' 05")						
Na <sub>2</sub> O/CaO	3.94	4.15	3.72	4.78	3.91	3.62	4.00	K <sub>32</sub>	(32° 54' 52" ; 75° 40' 03") ; T <sub>7</sub> (32° 49' 47" ; 75° 38' 15")						
Na <sub>2</sub> O/total alkalis	0.55	0.54	0.56	0.61	0.64	0.53	0.57	B <sub>15</sub>	(32° 48' 22" ; 75° 41' 35") ; K <sub>52</sub> (32° 53' 12" ; 75° 39' 15")						
CaO/total alkalis	0.14	0.13	0.15	0.13	0.16	0.15	0.14	* All samples dried at 110° C.							
Na <sub>2</sub> O/(CaO+Na <sub>2</sub> O)	0.797	0.805	0.788	0.827	0.796	0.783	0.800								





Table IV-4

Chemical composition of the medium-grained quartz-perthite-oligoclase-biotite-muscovite/biotite granitic rocks.\*

Specimen number	Major elements (weight per cent)										Trace elements (parts per million)											
	S <sub>51</sub>	S <sub>30</sub>	K <sub>55</sub>	S <sub>57</sub>	B <sub>21</sub>	T <sub>19</sub>	R <sub>52</sub>	K <sub>8</sub>	S <sub>59</sub>	Average	S <sub>51</sub>	S <sub>30</sub>	K <sub>55</sub>	S <sub>57</sub>	B <sub>21</sub>	T <sub>19</sub>	R <sub>52</sub>	K <sub>8</sub>	S <sub>59</sub>	Average		
SiO <sub>2</sub>	70.06	70.97	72.27	72.77	72.77	73.03	73.40	73.72	73.98	72.55	Cr <sup>3+</sup>	5	10	5	10	10	15	5	20	10		
TiO <sub>2</sub>	0.10	0.08	0.30	0.12	0.21	0.22	0.08	0.27	0.08	0.16	Co <sup>2+</sup>	14	10	10	6	8	12	16	12	10	10	
Al <sub>2</sub> O <sub>3</sub>	15.81	15.52	15.38	15.75	15.30	14.72	14.78	14.83	14.38	15.16	Ni <sup>2+</sup>	6	6	8	6	6	8	8	4	8	7	
Fe <sub>2</sub> O <sub>3</sub>	0.43	0.30	0.70	0.45	0.43	0.74	0.35	0.54	0.32	0.47	Rb <sup>+</sup>	175	175	150	200	175	200	200	200	200	186	
FeO	0.86	0.59	0.72	0.50	0.80	0.77	0.54	0.54	0.58	0.66	Sr <sup>2+</sup>	50	20	40	50	50	50	75	50	50	48	
MnO	0.05	0.04	0.04	0.05	0.05	0.04	0.05	0.06	0.04	0.04	Ba <sup>2+</sup>	340	260	400	300	400	360	400	320	320	344	
MgO	0.77	0.69	0.41	0.55	0.33	0.28	0.25	0.41	0.28	0.44	Cation ratios											
CaO	0.46	0.88	0.50	0.46	0.83	1.22	0.88	0.65	0.85	0.75	(Co/Fe <sup>2+</sup> )10 <sup>3</sup>	2.12	2.17	1.78	1.53	1.29	2.00	1.42	2.85	2.22	1.96	
Na <sub>2</sub> O	4.10	4.30	4.00	4.10	3.84	3.20	3.52	4.16	4.80	4.00	Co/Ni	2.33	1.66	1.25	1.00	1.33	1.50	0.75	3.00	1.25	1.42	
K <sub>2</sub> O	5.60	5.29	4.48	4.28	3.79	4.08	4.32	3.34	4.38	4.40	(Ni/Mg) 10 <sup>3</sup>	1.30	1.46	3.33	1.81	3.00	4.70	5.33	1.60	4.70	2.69	
P <sub>2</sub> O <sub>5</sub>	0.19	0.20	0.34	0.25	0.35	0.38	0.36	0.38	0.24	0.30	K/Rb	265	250	248	177	179	169	179	138	181	196	
H <sub>2</sub> O <sup>+</sup>	0.58	0.52	0.48	0.54	0.48	0.52	0.49	0.46	0.48	0.51	Rb/Sr	3.50	8.75	3.75	4.00	3.50	4.00	2.66	4.00	4.00	3.85	
Total	99.01	99.38	99.62	99.82	99.18	99.20	99.02	99.36	100.41	99.44	K/Ba	136	168	93	118	78	94	89	86	113	106	
											Sr/Ba	0.14	0.07	0.10	0.16	0.12	0.14	0.18	0.15	0.15	0.14	
											Ba/Rb	1.94	1.48	2.66	1.50	2.28	1.80	2.00	1.60	1.60	1.85	
											Norms (CIPW)											
Q	22.26	23.04	30.48	30.56	34.62	36.30	35.16	35.64	27.00	30.48												
Or	33.36	31.14	26.69	25.58	22.24	24.46	25.58	19.46	26.13	26.13												
Ab	34.58	36.15	34.06	34.58	31.96	27.25	29.34	35.63	40.35	34.06	al	47.11	47.06	50.00	50.99	51.55	50.00	51.60	51.06	46.84	49.67	
An	1.67	3.61	0.83	1.67	2.22	3.34	1.95	0.83	3.61	1.95	fm	11.85	9.29	9.60	9.21	8.93	9.38	6.41	8.45	6.64	8.67	
C	2.35	1.43	3.57	3.77	4.18	3.67	3.67	3.98	0.41	3.06	c	2.74	4.95	2.98	2.96	4.81	7.29	5.69	4.22	5.32	4.33	
Di	-	-	-	-	-	-	-	-	-	-	alk	38.30	38.70	37.42	36.84	34.71	33.33	36.30	36.27	41.20	37.33	
Hy	3.22	2.49	1.40	1.93	1.59	1.36	1.26	1.13	1.49	1.63	si	355.0	366.2	399.0	399.0	416.8	422.6	435.2	432.7	409.6	403.0	
Mt	0.70	0.46	0.93	0.70	0.70	0.93	0.46	0.70	0.46	0.70	k	0.48	0.45	0.43	0.41	0.40	0.46	0.45	0.34	0.38	0.42	
Il	0.15	0.15	0.61	0.15	0.46	0.46	0.15	0.61	0.15	0.30	mg	0.58	0.65	0.48	0.64	0.40	0.37	0.43	0.56	0.44	0.55	
Ap	0.34	0.34	0.67	0.34	0.67	1.01	1.01	1.01	0.34	0.67												
											Oxide ratios											
Na <sub>2</sub> O/K <sub>2</sub> O	0.73	0.81	0.89	0.96	1.01	0.78	0.81	1.24	1.09	0.91	MDI	14.75	14.39	14.36	14.21	13.67	13.70	14.21	13.52	14.36	14.13	
K <sub>2</sub> O/Na <sub>2</sub> O	1.36	1.23	1.12	1.04	0.98	1.27	1.23	0.80	0.91	1.10	Location of the analysed samples											
Na <sub>2</sub> O/CaO	8.91	4.88	8.00	8.91	4.63	2.62	4.00	6.40	5.65	5.33	S <sub>51</sub>	(32° 51' 10"; 75° 40' 50");					S <sub>30</sub>	(32° 49' 35"; 75° 43' 44")				
Na <sub>2</sub> O/total alkalis	0.42	0.45	0.47	0.49	0.50	0.44	0.45	0.55	0.52	0.48	K <sub>55</sub>	(32° 52' 32"; 75° 39' 40");					S <sub>57</sub>	(32° 51' 25"; 75° 42' 25")				
CaO/total alkalis	0.05	0.09	0.06	0.05	0.11	0.17	0.11	0.09	0.09	0.09	B <sub>21</sub>	(32° 49' 16"; 75° 40' 42");					T <sub>19</sub>	(32° 50' 56"; 75° 37' 15")				
Na <sub>2</sub> O/(CaO+ Na <sub>2</sub> O)	.899	.830	.888	.899	.822	.724	.800	.864	.849	.842	R <sub>52</sub>	(32° 55' 00"; 75° 39' 10");					K <sub>8</sub>	(32° 53' 12"; 75° 40' 42")				
											S <sub>59</sub>	(32° 50' 30"; 75° 43' 06");										

\* All samples dried at 110°C.

Table IV-5

Chemical composition of the coarse-grained quartz-albite-oligoclase-perthite-biotite granitic rocks.\*

Specimen number	Major elements (weight per cent)						Trace elements (parts per million)						
	T <sub>22</sub>	T <sub>8</sub>	C <sub>7</sub>	T <sub>23</sub>	B <sub>20</sub>	Average	T <sub>22</sub>	T <sub>8</sub>	C <sub>7</sub>	T <sub>23</sub>	B <sub>20</sub>	Average	
SiO <sub>2</sub>	70.22	70.36	70.56	70.68	71.93	70.75	Cr <sup>3+</sup>	20	20	20	20	5	17
TiO <sub>2</sub>	0.24	0.22	0.30	0.19	0.18	0.22	Co <sup>2+</sup>	8	14	10	16	16	13
Al <sub>2</sub> O <sub>3</sub>	13.85	15.12	15.03	15.44	13.91	14.67	Ni <sup>2+</sup>	4	8	8	8	6	7
Fe <sub>2</sub> O <sub>3</sub>	1.13	1.01	0.67	1.04	0.87	0.94	Rb <sup>+</sup>	175	200	175	175	225	190
FeO	1.66	1.53	1.34	1.13	1.17	1.37	Sr <sup>2+</sup>	50	50	75	50	25	50
MnO	0.05	0.04	0.05	0.05	0.04	0.05	Ba <sup>2+</sup>	560	600	560	400	540	532
MgO	0.83	0.83	0.64	0.97	1.11	0.87	<u>Cation ratios</u>						
CaO	1.15	1.00	1.27	0.50	0.92	0.97	(Co/Fe <sup>2+</sup> )x10 <sup>3</sup>	0.62	1.17	0.96	1.81	1.75	1.22
Na <sub>2</sub> O	5.00	5.50	3.84	4.80	5.20	4.87	Co/Ni	2.00	1.75	1.25	2.00	2.66	1.85
K <sub>2</sub> O	4.28	3.36	4.53	4.58	4.38	4.23	(Ni/Mg)x10 <sup>3</sup>	0.80	1.60	2.10	1.37	0.89	1.34
P <sub>2</sub> O <sub>5</sub>	0.20	0.17	0.23	0.17	0.12	0.18	K/Rb	202	139	214	217	161	185
H <sub>2</sub> O <sup>+</sup>	0.61	0.68	0.57	0.58	0.50	0.59	Rb/Sr	3.50	4.00	2.33	3.50	9.00	3.80
Total	99.22	99.82	99.03	100.13	100.33	99.71	K/Ba	63	46	67	95	67	66
							Sr/Ba	0.09	0.08	0.13	0.12	0.05	0.09
							Ba/Rb	3.20	3.00	3.20	2.28	2.40	2.80
							<u>Niggli values</u>						
Q	20.70	21.54	27.30	22.74	21.42	22.32	al	39.54	42.77	45.65	44.68	40.24	42.35
Or	25.58	20.02	26.69	27.24	26.13	25.02	fm	17.44	15.90	13.36	15.38	16.27	15.88
Ab	42.44	46.63	31.96	40.35	44.01	41.39	c	6.10	5.20	7.14	2.66	4.73	5.30
An	2.50	4.17	5.56	1.67	1.39	4.17	alk	36.92	36.13	33.85	37.28	38.76	36.47
C	-	0.82	1.84	1.94	-	0.51	si	340.12	339.02	365.22	348.52	354.73	346.76
Di	2.07	-	-	-	1.79	-	k	0.36	0.29	0.44	0.39	0.36	0.36
Hy	3.05	3.82	3.05	3.32	3.26	3.65	mg	0.46	0.49	0.46	0.60	0.62	0.52
Mt	1.62	1.39	0.93	1.39	1.16	1.39	<u>Modified Larsen Differentiation Index (MDI)</u>						
Il	0.46	0.46	0.61	0.46	0.30	0.46	MDI	13.15	12.52	13.44	13.85	13.49	13.30
Ap	0.34	0.34	0.34	0.34	0.34	0.34	<u>Location of the analysed samples</u>						
							T <sub>22</sub> (32° 52' 53"; 75° 35' 58");	T <sub>8</sub> (32° 50' 00"; 75° 37' 52")					
							C <sub>7</sub> (32° 54' 25"; 75° 42' 04");	T <sub>23</sub> (32° 54' 06"; 75° 41' 45")					
							B <sub>20</sub> (32° 48' 49"; 75° 40' 48");						
							<u>Oxide ratios</u>						
Na <sub>2</sub> O/K <sub>2</sub> O	1.17	1.64	0.84	1.05	1.18	1.15	<u>Location of the analysed samples</u>						
K <sub>2</sub> O/Na <sub>2</sub> O	0.86	0.61	1.18	0.95	0.84	0.87	<u>Location of the analysed samples</u>						
Na <sub>2</sub> O/CaO	4.35	5.50	3.02	9.60	5.65	5.02	<u>Location of the analysed samples</u>						
Na <sub>2</sub> O/total alkalis	0.54	0.62	0.46	0.51	0.54	0.54	<u>Location of the analysed samples</u>						
CaO/total alkalis	0.12	0.11	0.15	0.05	0.10	0.11	<u>Location of the analysed samples</u>						
Na <sub>2</sub> O/(CaO+Na <sub>2</sub> O)	0.813	0.846	0.750	0.905	0.849	0.833	<u>Location of the analysed samples</u>						

\*All samples dried at 110°C

Table IV-6

Chemical composition of the fine-grained quartz-perthite-oligoclase-biotite granitic rocks.  
-albite-

Specimen number	Major elements (weight per cent)				Trace elements (parts per million)				
	R <sub>30</sub>	R <sub>23</sub>	K <sub>24</sub>	Average	R <sub>30</sub>	R <sub>23</sub>	K <sub>24</sub>	Average	
SiO <sub>2</sub>	70.20	71.64	72.28	71.37	Cr <sup>3+</sup>	5	15	5	8
TiO <sub>2</sub>	0.56	0.38	0.21	0.38	Co <sup>2+</sup>	10	12	16	13
Al <sub>2</sub> O <sub>3</sub>	14.09	14.50	14.67	14.42	Ni <sup>2+</sup>	8	6	4	6
Fe <sub>2</sub> O <sub>3</sub>	1.48	0.77	1.22	1.16	Rb <sup>+</sup>	200	200	200	200
FeO	2.12	1.73	1.46	1.77	Sr <sup>2+</sup>	25	50	25	33
MnO	0.05	0.05	0.06	0.05	Ba <sup>2+</sup>	520	500	500	507
MgO	0.97	0.41	0.33	0.57	Cation ratios				
CaO	1.42	1.27	1.08	1.26	(Co/Fe <sup>2+</sup> )x10 <sup>3</sup>	0.60	0.88	1.40	0.94
Na <sub>2</sub> O	4.48	4.16	3.52	4.05	Co/Ni	1.25	2.00	4.00	2.16
K <sub>2</sub> O	2.81	3.71	3.71	3.41	(Ni/Mg)x10 <sup>3</sup>	1.37	2.40	2.00	1.76
P <sub>2</sub> O <sub>5</sub>	0.25	0.27	0.32	0.28	K/Rb	116	154	154	141
H <sub>2</sub> O <sup>+</sup>	0.63	0.51	0.49	0.54	Rb/Sr	8.00	4.00	8.00	6.00
Total	99.06	99.40	99.35	99.26	K/Ba	44	61	61	56
Norms (CIPW)					Sr/Ba	0.05	0.10	0.05	0.06
Q	28.56	29.58	35.22	31.08	Ba/Rb	2.60	2.50	2.50	2.53
Or	16.68	21.68	21.68	20.02	Niggli values				
Ab	38.25	35.63	29.34	34.58	al	40.83	44.80	47.21	43.92
An	5.28	4.73	3.89	4.45	fm	21.30	14.20	15.08	17.45
C	1.63	1.84	3.57	2.35	c	7.40	7.25	6.56	6.85
Di	-	-	-	-	alk	30.47	33.75	31.15	31.78
Hy	4.25	2.98	2.25	3.12	si	346.15	376.66	394.75	370.40
Mt	2.09	1.16	1.86	1.86	k	0.29	0.36	0.41	0.35
Il	1.06	0.76	0.46	0.76	mg	0.44	0.29	0.27	0.35
Ap	0.67	0.67	0.67	0.67	Modified Larsen Differentiation Index (MDI)				
Oxide ratios					MDI	11.66	13.06	13.35	12.69
Na <sub>2</sub> O/K <sub>2</sub> O	1.59	1.12	0.95	1.19	Location of the analysed samples				
K <sub>2</sub> O/Na <sub>2</sub> O	0.63	0.89	1.05	0.84	R <sub>30</sub> (32° 53' 55"; 75° 35' 38"); R <sub>23</sub> (32° 54' 20"; 75° 36' 27") K <sub>24</sub> (32° 52' 35"; 75° 40' 45");				
Na <sub>2</sub> O/CaO	3.15	3.27	3.26	3.21					
Na <sub>2</sub> O/total alkalis	0.61	0.53	0.49	0.54					
CaO/total alkalis	0.19	0.16	0.15	0.17					
Na <sub>2</sub> O/(CaO+Na <sub>2</sub> O)	0.759	0.766	0.765	0.763					

\* All samples dried at 110°C.

Table IV-7  
Chemical composition of hybrid rocks.\*

Specimen number	Major elements (weight per cent)				Trace elements (parts per million)				
	S <sub>28</sub>	S <sub>33</sub>	S <sub>35</sub>	Average	S <sub>28</sub>	S <sub>33</sub>	S <sub>35</sub>	Average	
SiO <sub>2</sub>	71.47	72.54	72.96	72.32	Cr <sup>3+</sup>	20	10	10	13
TiO <sub>2</sub>	0.32	0.18	0.15	0.22	Co <sup>2+</sup>	8	10	10	9
Al <sub>2</sub> O <sub>3</sub>	15.24	15.58	15.38	15.40	Ni <sup>2+</sup>	8	6	4	6
Fe <sub>2</sub> O <sub>3</sub>	0.81	0.44	0.39	0.55	Rb <sup>+</sup>	125	190	200	172
FeO	1.47	0.61	0.45	0.84	Sr <sup>2+</sup>	60	40	25	42
MnO	0.04	0.03	0.04	0.04	Ba <sup>2+</sup>	380	300	260	313
MgO	0.69	0.39	0.28	0.45	<u>Cation ratios</u>				
CaO	0.58	0.48	0.63	0.55	(Co/Fe <sup>2+</sup> )x10 <sup>3</sup>	0.70	2.12	2.85	1.38
Na <sub>2</sub> O	4.03	3.90	3.97	3.97	Co/Ni	1.00	1.66	2.50	1.50
K <sub>2</sub> O	3.50	3.78	4.26	3.85	(Ni/Mg)x10 <sup>3</sup>	1.95	2.60	2.35	2.22
P <sub>2</sub> O <sub>5</sub>	0.22	0.35	0.35	0.31	K/Rb	232	165	176	186
H <sub>2</sub> O*	0.58	0.63	0.68	0.63	Rb/Sr	2.08	4.75	8.00	4.12
Total	98.95	98.91	99.54	99.13	K/Ba	76	104	135	102
					Sr/Ba	0.15	0.13	0.09	0.13
					Ba/Rb	3.04	1.57	1.30	1.82
					<u>Niggli values</u>				
					al	48.06	52.94	51.36	50.67
					fm	15.81	8.30	7.14	10.40
					c	3.23	3.12	3.74	3.36
					alk	32.90	35.64	37.76	35.57
					si	384.19	418.34	413.61	404.36
					k	0.36	0.39	0.41	0.39
					mg	0.44	0.56	0.47	0.48
					<u>Modified Larsen Differentiation Index (MDI)</u>				
					MDI	13.19	13.85	14.26	13.78
					<u>Oxide ratios</u>				
					<u>Location of the analysed samples</u>				
Na <sub>2</sub> O/K <sub>2</sub> O	1.15	1.03	0.93	1.03	S <sub>28</sub>	(32° 51' 08" ; 75° 45' 00").			
K <sub>2</sub> O/Na <sub>2</sub> O	0.87	0.97	1.07	0.97	S <sub>33</sub>	(32° 50' 50" ; 75° 45' 20").			
Na <sub>2</sub> O/CaO	6.95	8.12	6.30	7.22	S <sub>35</sub>	(32° 50' 40" ; 75° 45' 45").			
Na <sub>2</sub> O/total alkalis	0.54	0.51	0.48	0.51					
CaO/total alkalis	0.08	0.06	0.08	0.07					
Na <sub>2</sub> O/(CaO+Na <sub>2</sub> O)	0.874	0.890	0.863	0.878					

\* All samples dried at 110°C.

Table IV-8  
Chemical composition of country rocks.\*

Specimen number	Major elements (weight per cent)						Trace elements (parts per million)				
	L <sub>5</sub>	N <sub>10</sub>	T <sub>1</sub>	B <sub>19</sub>	N <sub>9</sub>	Average	T <sub>1</sub>	B <sub>19</sub>	N <sub>9</sub>	Average	
SiO <sub>2</sub>	63.32	64.92	65.41	65.88	66.30	65.17	Cr <sup>3+</sup>	15	5	10	10
TiO <sub>2</sub>	0.82	0.85	0.58	0.86	0.66	0.75	Co <sup>2+</sup>	10	12	12	11
Al <sub>2</sub> O <sub>3</sub>	14.86	15.78	17.07	17.31	17.01	16.41	Ni <sup>2+</sup>	7	8	8	8
Fe <sub>2</sub> O <sub>3</sub>	4.26	2.49	1.37	2.03	2.79	2.59	Rb <sup>+</sup>	175	200	200	192
FeO	4.50	3.29	3.06	2.52	2.79	3.23	Sr <sup>2+</sup>	60	25	50	45
MnO	0.04	0.04	0.04	0.04	0.06	0.04	Ba <sup>2+</sup>	660	420	420	500
MgO	1.06	1.22	1.27	0.77	0.44	0.95	Cation ratios				
CaO	0.76	1.14	1.00	0.74	0.76	0.88	(Co/Fe <sup>2+</sup> )x10 <sup>3</sup>	0.42	0.61	0.55	0.43
Na <sub>2</sub> O	1.96	1.96	1.75	1.54	1.89	1.82	Co/Ni	1.42	1.50	1.50	1.37
K <sub>2</sub> O	4.67	4.67	3.72	3.91	3.73	4.14	(Ni/Mg)x10 <sup>3</sup>	0.92	1.73	3.07	1.40
P <sub>2</sub> O <sub>5</sub>	0.12	0.24	0.16	0.13	0.17	0.16	K/Rb	176	162	154	179
H <sub>2</sub> O*	3.04	3.26	3.71	3.67	3.36	3.41	Rb/Sr	2.91	8.00	4.00	4.25
Total	100.01	99.86	99.15	99.40	99.96	99.55	K/Ba	46	77	73	68
							Sr/Ba	0.09	0.06	0.12	0.09
							Ba/Rb	3.77	2.10	2.10	2.60
							Norms (GIPW)				
Q	29.28	30.36	35.94	39.42	38.34	34.62					
Or	27.80	27.80	21.68	22.80	21.68	24.46					
Ab	16.77	16.77	14.67	12.58	16.24	15.20					
An	3.06	4.73	4.17	2.78	3.06	3.61					
C	5.41	5.71	8.77	9.69	8.77	7.65					
Di	-	-	-	-	-	-					
Hy	6.16	5.64	6.76	3.48	2.82	5.17					
Mt	6.26	3.71	2.09	3.02	4.18	3.71					
Il	1.52	1.67	1.22	1.67	1.37	1.37					
Ap	0.34	0.34	0.34	0.34	0.34	0.34					
							Oxide ratios				
Na <sub>2</sub> O/K <sub>2</sub> O	0.42	0.42	0.47	0.39	0.50	0.44					
K <sub>2</sub> O/Na <sub>2</sub> O	2.38	2.38	2.13	2.54	1.97	2.27					
Na <sub>2</sub> O/CaO	2.57	1.72	1.75	2.08	2.48	2.07					
Na <sub>2</sub> O/total alkalis	0.30	0.30	0.32	0.28	0.34	0.31					
CaO/total alkalis	0.11	0.17	0.18	0.14	0.14	0.15					

Location of the analysed samples

L<sub>5</sub> (32° 47' 45" ; 75° 47' 44").  
N<sub>10</sub> (32° 53' 30" ; 75° 43' 50").  
T<sub>1</sub> (32° 50' 25" ; 75° 35' 15").  
B<sub>19</sub> (32° 49' 10" ; 75° 35' 48").  
N<sub>9</sub> (32° 53' 45" ; 75° 44' 20").

\*All samples dried at 110°C.

Table IV-9

Average composition of the different rocks of the study area.

	Group I (6)*	Group II (5)*	Group III (4)*	Group IV (9)*	Group V (5)*	Group VI (3)*	Hy. rocks (3)*	Country rocks (5)*
SiO <sub>2</sub>	70.66	70.59	70.15	72.55	70.75	71.37	72.32	65.17
TiO <sub>2</sub>	0.31	0.20	0.22	0.16	0.22	0.38	0.22	0.75
Al <sub>2</sub> O <sub>3</sub>	14.15	14.99	14.60	15.16	14.67	14.42	15.40	16.41
Fe <sub>2</sub> O <sub>3</sub>	0.83	0.79	1.00	0.47	0.94	1.16	0.55	2.59
FeO	1.42	0.97	1.41	0.66	1.37	1.77	0.84	3.23
MnO	0.04	0.03	0.05	0.04	0.05	0.05	0.04	0.04
MgO	0.94	0.95	0.92	0.44	0.87	0.57	0.45	0.95
CaO	1.27	0.76	0.99	0.75	0.97	1.26	0.55	0.88
Na <sub>2</sub> O	5.08	4.44	3.86	4.00	4.87	4.05	3.97	1.82
K <sub>2</sub> O	3.80	4.87	5.01	4.40	4.23	3.41	3.85	4.14
P <sub>2</sub> O <sub>5</sub>	0.19	0.19	0.21	0.30	0.18	0.28	0.31	0.16
H <sub>2</sub> O*	0.54	0.49	0.61	0.51	0.59	0.54	0.63	3.41
Total	99.23	99.27	99.03	99.44	99.71	99.26	99.13	99.95
<u>Norms (CIPW)</u>								
Q	22.56	23.16	24.90	30.48	22.32	31.08	32.70	34.62
Or	22.24	28.91	29.47	26.13	25.02	20.02	22.80	24.46
Ab	42.97	37.20	32.49	34.06	41.39	34.58	34.06	15.20
An	4.45	3.06	4.17	1.95	4.17	4.45	1.11	3.61
C	-	1.33	1.33	3.06	0.51	2.35	4.18	7.65
Di	0.89	-	-	-	-	-	-	-
Hy	3.32	3.19	3.75	1.63	3.65	3.12	1.76	5.17
Mt	1.16	1.16	1.39	0.70	1.39	1.86	0.93	3.71
Il	0.61	0.46	0.46	0.30	0.46	0.76	0.46	1.37
Ap	0.34	0.34	0.34	0.67	0.34	0.67	0.67	0.34
<u>Oxide ratios</u>								
Na <sub>2</sub> O/K <sub>2</sub> O	1.34	0.91	0.77	0.91	1.15	1.19	1.03	0.44
K <sub>2</sub> O/Na <sub>2</sub> O	0.75	1.09	1.30	1.10	0.87	0.84	0.97	2.27
Na <sub>2</sub> O/CaO	4.00	5.84	3.90	5.33	5.02	3.21	7.22	2.07
Na <sub>2</sub> O/total alkalis	0.57	0.48	0.44	0.48	0.54	0.54	0.51	0.31
CaO/total alkalis	0.14	0.08	0.11	0.09	0.11	0.17	0.07	0.15
Na <sub>2</sub> O/(CaO+Na <sub>2</sub> O)	0.800	0.853	0.795	0.842	0.833	0.753	0.878	0.674
<u>Modified Larsen Differentiation Index (MDI)</u>								
MDI	12.68	13.91	13.81	14.13	13.30	12.69	13.78	12.36

\* Number of samples analysed given in brackets.

## CHAPTER V

### CHEMICAL CHARACTERISTICS AND VARIATIONS

\*\*\*\*\*  
\* I. INTRODUCTION \*  
\*\*\*\*\*

The petrographic description and classification of the rocks included under the head "Kaplas Granite" have been described in the previous chapter, where it can be seen that there is quite a substantive mineralogical variation in different groups of the granitic rocks. The present chapter, which deals with the chemistry of the different granitic groups and their characteristics, has been devoted with a view to providing a basis for the interpretation in the forthcoming chapters. The same procedure of grouping and sequence of description as has been adopted in the previous chapter, has been followed here also. In the first part of this chapter, chemical variations as met within the individual groups have been described, while in the later part a general description of the chemical behaviour of major elements occurring in the granitic rocks belonging to the Kaplas Granite Massif as a whole, is dealt with.

\*\*\*\*\*  
 \* II. CHEMICAL CHARACTERS AND VARIATIONS \*  
 \*\*\*\*\*

Group I

Coarse-grained quartz-perthite-albite-microcline-  
 biotite granitic rocks

The chemical analyses of the rocks belonging to this group are given in Table IV-1. The C.I.P.W. norms, oxide ratios and Niggli values are also included in this table. The chief chemical characteristics of the rocks observed individually in this group is their higher soda and lime content. Soda which is always more than the potash, does not show conspicuous increase or decrease. It may be noted that soda is maximum at stage 4, whereas potash is maximum at stage 2 of this group. Lime goes on decreasing upto stage 4, but shows sudden increase in the later stages. The values of magnesia are at par with the corresponding values in other rock groups.  $Al_2O_3$ , which shows progressive increase in the initial stages of this group, behaves rather erratically in the later stages. Total iron which is maximum at stage 2, is almost similar to the one met with in Group V, but comparatively less than the corresponding values in groups III and VI, and higher than the groups II and IV.

The norms of these rocks which are also included in Table IV-1, are exceedingly interesting as can be seen from the

variations in the values of 'Q' molecules in the different stages of this group, despite the fact that there is not much difference in the values of  $\text{SiO}_2$  in these rocks. The maximum 'Q' is at stage 3. Similarly, 'An' molecules behave altogether in a different manner. Their values are not at par with their respective chemical composition in the analyses. The obvious reason for this is disparity in the  $\text{Al}_2\text{O}_3$  values. The value of 'Ab' and 'Or' molecules are at par with the corresponding value of soda and potash in the Table IV-1. Another interesting feature of the norms of this group is the presence of 'C' molecules, which is because of high  $\text{Al}_2\text{O}_3$  proportions. As far as 'Di' and 'Hy' molecules are concerned, they correspond with CaO and FeO values in the chemical analyses at different stages of this group. 'Ap' remains almost constant.

As regards the oxide ratios, the ratio  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  which is always more than 1, shows a little decrease in the beginning but shows progressive increase upto stage 5 and then again decrease in the last stage. In comparison to the other groups, this ratio is maximum in these rock whereas ratio  $\text{K}_2\text{O}/\text{Na}_2\text{O}$  behaves altogether in a different way having its minimum value in this group. The ratio  $\text{Na}_2\text{O}/(\text{Na}_2\text{O} + \text{K}_2\text{O})$  derived from the analytic data and the ratio  $\text{Ab}/(\text{Or} + \text{Ab})$  derived from the normative values are maximum in this group as compared to the other granitic rock groups.

Group IIMedium-grained quartz-microcline-perthite-  
oligoclase-biotite granitic rocks

Table IV-2 shows the chemical analyses, C.I.P.W. norms, oxide ratios and Niggli values of the rocks included in this group. A closer scrutiny of the chemical data of this group reveals that as compared to the rocks of group I they have a lower  $\text{SiO}_2$ , total iron,  $\text{CaO}$ ,  $\text{Na}_2\text{O}$  and  $\text{H}_2\text{O}^*$  values while all other chemical constituents such as alumina, magnesia, potash are present comparatively in higher proportions.

When the chemical variations in this group are observed, some interesting features come out. It is seen that  $\text{MgO}$  and  $\text{TiO}_2$  show a progressive decrease with the increase of  $\text{SiO}_2$  in the initial stages of this group but in the later stages there is slight increase of  $\text{MgO}$ . Lime behaves in antipathetic manner to magnesia. Total alkalis are maximum in this group as compared to other groups.  $\text{Al}_2\text{O}_3$  behaves rather erratically.

Normatively, the rocks of this group have appreciably higher values of 'Q' molecules than in the group I. This is because of lesser amount of soda present in the rocks of this group. 'Ab', 'Or' and 'An' molecules do not correspond with

corresponding values of their chemical constituents in the analyses. It is obviously because of the higher values of  $Al_2O_3$ . 'C' molecules, with the exception of stage 3, are found invariably in all other stages of this group. Their increase or decrease corresponds with erratic attitude of  $Al_2O_3$  in the analyses. As far as 'Di' molecules are concerned, these are present only in the stage 3 of this group, distinctly because of the lime left over after the formation of 'An' molecules. The values of 'Hy' and 'Ap' molecules are at par with the group I.

The ratio  $Na_2O/K_2O$  has got comparatively less values than group I.  $Na_2O/CaO$  shows a progressive decrease in the initial stages of formation of rocks of this group, and shows slight increase in the last stage. This ratio is also comparatively higher than group I. The ratios  $Na_2O/K_2O + Na_2O$  and  $CaO/Na_2O + K_2O$  has low values than group I, and the ratio  $Na_2O/CaO + Na_2O$  is maximum in comparison to this ratio in other groups.

### Group III

#### Coarse-grained quartz-perthite-albite-oligoclase-biotite granitic rocks

The chemical analyses of the rocks of this group are given in Table IV-3 where C.I.P.W. norms, oxide ratios and Niggli

values are also included. The average chemical analysis of the rocks of this group show that silica and soda have lesser values whereas the values of  $K_2O$  and  $H_2O^*$  are comparatively more in comparison to all other groups. For instance, when a comparison is made with groups I and II, it is seen that total iron,  $K_2O$ ,  $P_2O_5$  and  $H_2O^*$  are more while soda, magnesia and total alkalis are in lesser amounts in the rocks included here. Another chemical characteristic feature of the rocks of this group is the erratic behaviour of  $Al_2O_3$ . Total (ferrous and ferric) iron shows progressive decrease with the increase of silica. The values of  $TiO_2$ ,  $MgO$  and  $K_2O$  progressively decreases but show a slight increase in the later stages. The values of lime and soda are at par with the corresponding values in other groups. The most conspicuous feature is that  $Na_2O$  is found always in lesser amounts than  $K_2O$ , while the total alkalis are comparable with the groups I and II.

Few interesting features are noticed in C.I.P.W. norms. It is observed here that these rocks are not much different chemically, but the values of 'Q' molecules do not correspond with the  $SiO_2$  values in chemical analyses. For instance, the  $SiO_2$  proportion in the last stage of formation of these rocks is maximum, but, in the norms we find at this stage that the 'Q' molecules have got less value in comparison to the initial stages of this group. It can be explained by the fact that high

proportions of alkalis and low proportion of  $Al_2O_3$  have ultimately affected the 'Q' molecules ultimately. 'Or' molecules are slightly higher and 'Ab' molecules are lesser in this group as compared to the rocks of groups I and II. This is obviously because of the corresponding higher  $K_2O$  and lower  $Na_2O$  values in the chemical analyses. The absence of 'C' molecules and presence of 'Di' molecules in last stage of this group is only because of the deficiency of alumina. 'Hy' molecules, which are present invariably in all the stages, show progressive decrease with increase of  $SiO_2$  and corresponding with the decrease of FeO in chemical analyses. 'Ap' is found to remain constant in all the stages.

The ratio  $Na_2O/K_2O$ , unlike the groups I, V and VI, is always less than one and also comparatively lesser than all other groups, while ratio  $K_2O/Na_2O$  is antipathetic to the ratio  $Na_2O/K_2O$ . Both ratios  $Na_2O/Na_2O + K_2O$  and  $Na_2O/CaO + Na_2O$  are less in this group as compared to the rocks of I and II groups but ratio  $CaO/Na_2O + K_2O$  is more here than in the group II.

#### Group IV

Medium-grained quartz-perthite-oligoclase-albite-muscovite/biotite granitic rocks

Table IV-4 shows the chemical analyses of the rocks belonging to this group. The C.I.P.W. norms, oxide ratios and

Niggli values have also been included here. The rocks of this group show very interesting conspicuous chemical behaviour. For instance, it is observed that  $\text{SiO}_2$  on an average is always higher than all other granitic rock group.  $\text{Al}_2\text{O}_3$ , as usual shows, an erratic behaviour, but it has comparatively higher values than all other groups. The values of total iron (Ferrous and Ferric), magnesia and lime are conspicuously and distinctly lower than the corresponding values in other groups.  $\text{Na}_2\text{O}$  is found here in lesser amount than in I, II and V groups and more than in group III and almost equal in average of VI group. In most of the stages of this group  $\text{K}_2\text{O}$  is greater than  $\text{Na}_2\text{O}$ , whereas  $\text{K}_2\text{O}$  is maximum at stage I and  $\text{Na}_2\text{O}$  is maximum at stage 9.  $\text{H}_2\text{O}^+$  is at par with the corresponding values of other groups.

The important point to note in the norms of this group is progressive increase of 'Q' molecules upto stage 6 and then a decrease in the last stages. This disparity can be explained by the higher values of lime and total alkalis, which consumed silica for the formation of 'Or', 'Ab', 'An' molecules. Another peculiar characteristic feature of this group is the universal presence of 'C' molecules and total absence of 'Di' molecules in the norms of these rocks. This is because of the higher value of  $\text{Al}_2\text{O}_3$  and deficiency of lime during the different stages of the formation of the rocks belonging to this group.

As far as oxide ratios are concerned, the ratio  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  is less than one but comparatively its values are more than group III whereas  $\text{K}_2\text{O}/\text{Na}_2\text{O}$  is antipathetic in behaviour to  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratio. The other ratios for instance,  $\text{Na}_2\text{O}/\text{Na}_2\text{O} + \text{K}_2\text{O}$ ,  $\text{CaO}/\text{Na}_2\text{O} + \text{K}_2\text{O}$ ,  $\text{Na}_2\text{O}/\text{CaO} + \text{Na}_2\text{O}$  are at par with the corresponding ratios of other groups.

#### Group V

##### Coarse-grained quartz-albite-oligoclase-perthite-biotite granitic rocks

The chemical analyses along with C.I.P.W. norms, oxide ratio and Niggli values of these rocks have been shown in table IV-5. The important characteristic feature of this group is that there is no progressive increase or decrease in any of the oxide.  $\text{Al}_2\text{O}_3$ , as usual, show erratic behaviour. Here in this group soda, only with the exception of stage 3, is always more than potash. It is comparable with the corresponding values in groups I and VI. The values of the lime and magnesia are at par with that of group III.

Normatively 'Q' molecules show lesser value than in group IV but it is at par with the values found in groups I, II and III. 'C' molecules are present invariably but, comparatively

in lesser amounts than group IV. Its absence in the initial and final stage is because of low  $Al_2O_3$  values. 'Di' molecules, which are present only in the first and last stage of this group, are also due to lesser value of  $Al_2O_3$ . 'Hy' molecules found in this group are higher than in group IV, because of the higher magnesia value. Magnetite is also more than group IV due to higher content of ferric iron. 'Ap' remains constant in all the stages of the rocks belonging to this group.

The ratio  $Na_2O/Na_2O + K_2O$  is at par with I and VI groups and comparatively more than other groups, while ratio  $CaO/Na_2O + K_2O$  is comparable with corresponding values of other groups.

#### Group VI

##### Fine-grained quartz-perthite-oligoclase-albite granitic rocks

In table IV-6 the chemical analyses of the rocks of this group along with C.I.P.W. norms, oxide ratios and Niggli values are shown. The very interesting feature of these rocks is that with the increase of silica, there is progressive decrease of  $MgO$ ,  $CaO$ ,  $Na_2O$  and  $TiO_2$  whereas  $Al_2O_3$ ,  $K_2O$  and  $P_2O_5$  are antipathetic in behaviour when compared to other groups. The

total iron and titania are higher and  $K_2O$  much less than in all other group.  $Na_2O$  exceeds to  $K_2O$  in most of the stages in this group with the results that ratio  $Na_2O/K_2O$  is always more than 1 and the ratio  $K_2O/Na_2O$  is antipathetic to ratio  $Na_2O/K_2O$ . The ratio  $CaO/Na_2O + K_2O$  is comparatively higher whereas ratio  $Na_2O/CaO + Na_2O$  is low in this group as compared to the corresponding values of all other groups. The ratio  $Na_2O/Na_2O + K_2O$ , is at par with group I and V.

Normatively, the 'Q', 'Or' molecules show progressive increase with the increase of  $SiO_2$  and  $K_2O$  values in the analyses, whereas the 'Ab' and 'An' molecules show progressive decrease with the increasing silica. Another conspicuous feature is the total absence of 'Di' molecules. This can be explained by the fact that whole of the lime, which is the prime chemical constituent of diopside, is being consumed for the formation of normative anorthite. 'Ap' is comparatively more here than in other groups, and it remains constant in all the stages of this group.

#### Hybrid Rocks

In table IV-7 three analyses of hybrid rocks have been included. These rocks, in general, are in high percentages of  $Al_2O_3$ , and low in lime and magnesia.  $K_2O$  increases with

increase of silica while  $\text{Na}_2\text{O}$  remains almost constant. Total alkalis are comparable with alkalis present in group VI of granitic rocks. Like the groups I, V and VI of granitic rocks here also  $\text{Na}_2\text{O}$  is more than  $\text{K}_2\text{O}$ . C.I.P.W. norms do not show any peculiarity except that the 'An' molecules are present in low proportion and the absence of 'Di' molecules like in the granitic rock groups IV and VI. The progressive decrease of 'Hy' molecules corresponding with the decrease of magnesia and ferrous iron in the chemical analyses.

The oxide ratios do not show any noticeable change in these rocks. The ratios  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  and  $\text{Na}_2\text{O}/\text{Na}_2\text{O} + \text{K}_2\text{O}$  show progressive decrease with the increase of silica. The ratio  $\text{K}_2\text{O}/\text{Na}_2\text{O}$  behaves in an opposite manner.

#### Country Rocks

In order to visualize the chemical variations in the country rocks surrounding the granite massif and their effects on the granitic rocks five rock samples of these were analysed chemically. After a careful consideration of the chemical data, which is given in table IV-8, it is seen that these rocks when compared to hybrid rocks are low in silica and soda content whereas  $\text{H}_2\text{O}^*$  and alumina are present in fairly high amounts, with the exception of ferruginous slates, which

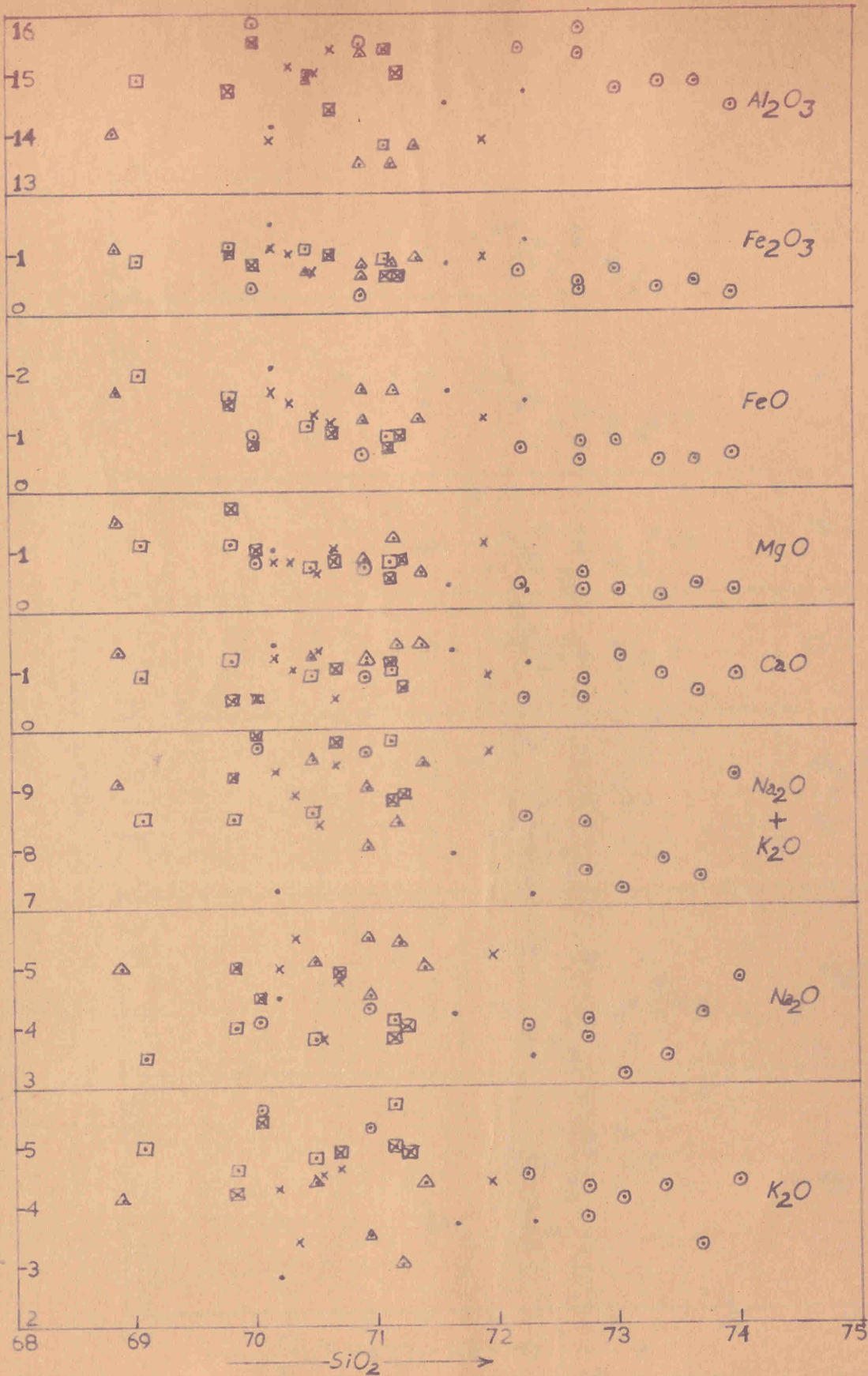
have got high total iron content. The interesting feature, however, is an overall similarity in the chemical analyses. Another noticeable character is the high proportion of  $H_2O^+$  in these rocks which is one of the chief mobilizers. Its proportion is more in the rock samples which are quite away from the contact of the granitic rocks where the amount of  $H_2O^+$  goes on decreasing in the rock samples nearer the granite contact.

As far as C.I.P.W. norms are concerned, the most interesting feature is the presence of 'C' molecules in very high proportion in all the stages of these rocks. It is obviously because of high proportion of  $Al_2O_3$  in the chemical analyses. The ratio  $Na_2O/K_2O$  which is always less than one, is in very low proportion as compared to other different rocks. The ratio  $K_2O/Na_2O$  behaves in an antipathetic manner.  $Na_2O/Na_2O + K_2O$  ratio is comparable with the ratio of other rocks.

\*\*\*\*\*  
 \* III. SUMMARY \*  
 \*\*\*\*\*

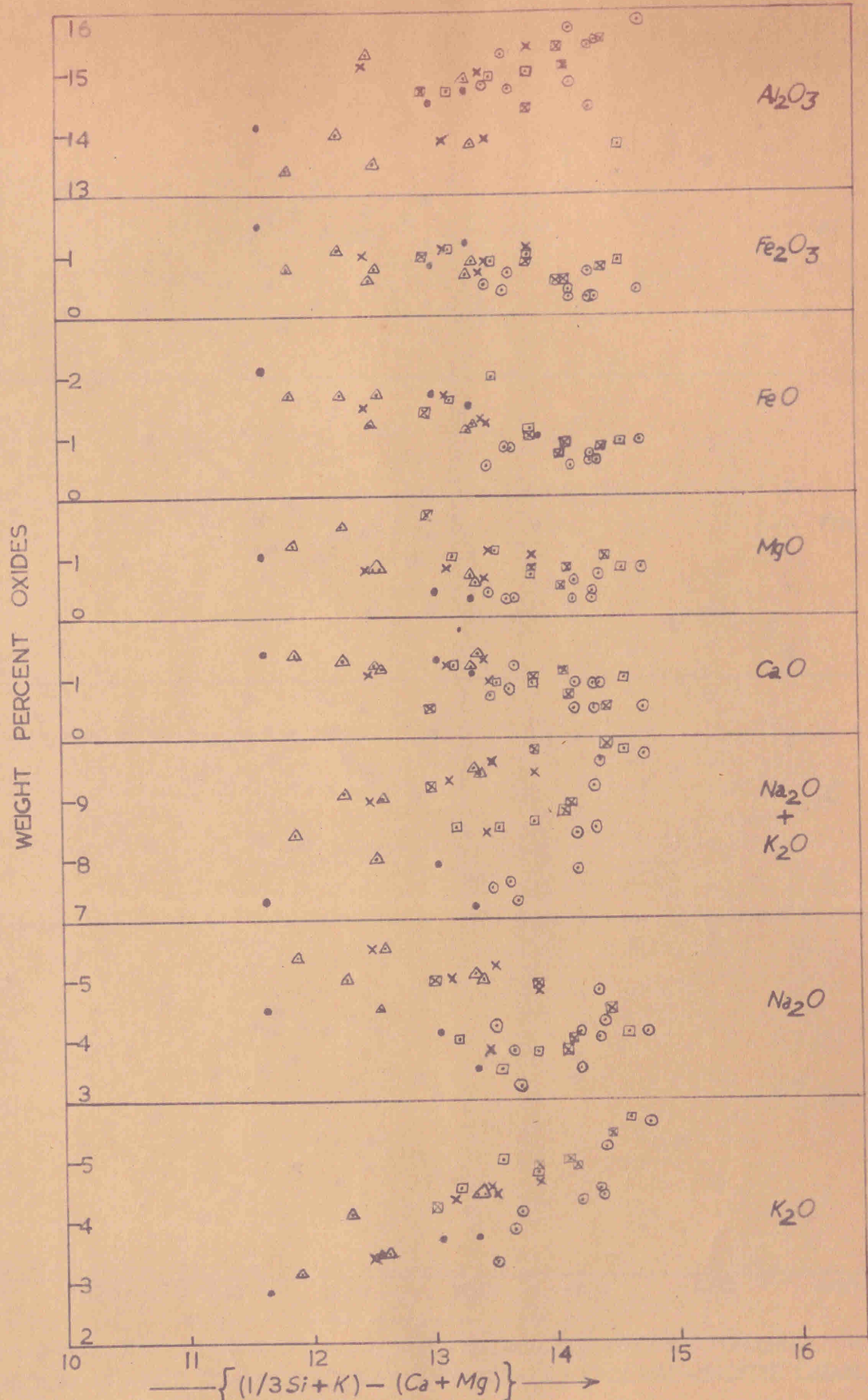
The rock-wise chemical variation for the chief granitic rock groups has been described above. In the present section, an attempt has been made to plot all rocks together to see their mutual as well as overall relationship and sequence of appearance of different granitic rock groups. The main purpose of this type of study is, therefore, to find out any clue or clues

WEIGHT PERCENT OXIDES



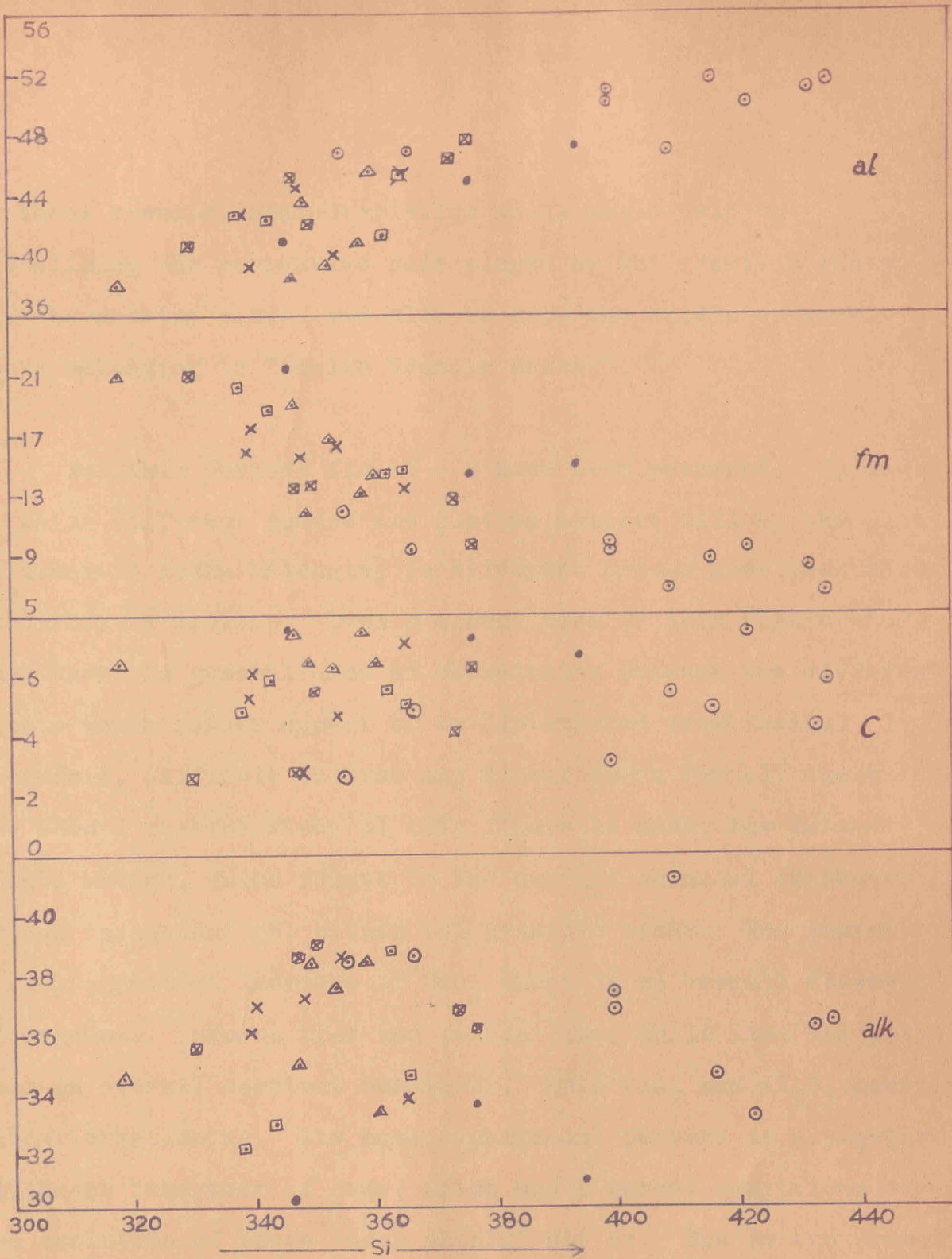
- △ COARSE-GRAINED QZ-PERTHITE-ALBITE-MICROCLINE-BIOTITE GRANITIC ROCKS
- ▣ MEDIUM-GRAINED QZ-MICROCLINE-PERTHITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS
- COARSE-GRAINED QZ-PERTHITE-ALBITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS
- MEDIUM-GRAINED QZ-PERTHITE-OLIGO-ALB - MUSCOVITE/BIOTITE GRANITIC ROCKS
- × COARSE-GRAINED QZ-ALBITE-OLIGOCLASE-PERTHITE-BIOTITE GRANITIC ROCKS
- FINE-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE-BIOTITE GRANITIC ROCKS

FIG.6 SILICA VARIATION DIAGRAM OF KAPLAS GRANITIC ROCKS



- △ COARSE-GRAINED QZ-PERTHITE-ALBITE-MICROCLINE-BIOTITE GRANITIC ROCKS
- ◻ MEDIUM-GRAINED QZ-MICROCLINE-PERTHITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS
- ◻ COARSE-GRAINED QZ-PERTHITE-ALBITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS
- MEDIUM-GRAINED QZ-PERTHITE-OLIGO-ALB-MUSCOVITE/BIO GRANITIC ROCKS
- x COARSE-GRAINED QZ-ALBITE - OLIGO-PERTHITE - BIOTITE GRANITIC ROCKS
- FINE-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE-BIOTITE GRANITIC ROCKS

FIG.7 VARIATION DIAGRAM OF DIFFERENT OXIDES PLOTTED AGAINST MODIFIED LARSEN DIFFERENTIATION INDEX (AFTER NOCKOLDS & ALLEN, 1953)



- △ COARSE-GRAINED QZ-PERTHITE-ALBITE-MICROCLINE-BIOTITE GRANITIC ROCKS
- ⊠ MEDIUM-GRAINED QZ-MICROCLINE-PERTHITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS
- COARSE-GRAINED QZ-PERTHITE-ALBITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS
- MEDIUM-GRAINED QZ-PERTHITE-OLIGO-ALB-MUSCOVITE/BIO GRANITIC ROCKS
- × COARSE-GRAINED QZ-ALBITE-OLIGO-PERTHITE-BIOTITE GRANITIC ROCKS
- FINE-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE-BIOTITE GRANITIC ROCKS

FIG.8 NIGGLI VARIATION DIAGRAM

in these chemical characteristics which could help in visualizing the respective role played by the granitic rocks and the country rocks, and also to know the origin of granitic rocks belonging to "Kapas Granite Massif".

For this purpose fig. 6 - 8 have been prepared. In fig. 6, in which different oxides are plotted against silica, the plots of granitic rocks belonging to different groups have been shown by different indices. Even a casual view of this figure shows that there is general lack of correlation between the different points which rather appear to be distributed erratically. It is, therefore, difficult to draw any linear curve for all these rocks. But when a careful study of this figure is made, few interesting points emerge, which relate to the overall chemical characteristics and variations met within the granitic rocks. For instance, with progressive increase of  $\text{SiO}_2$  there is an overall decrease of magnesia, ferrous iron and ferric iron, while lime and potash show an overall constant behaviour. Both  $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$  behave rather erratically. The most significant feature is altogether different behaviour of soda, which under normal conditions of the evolution of these rocks should not be. But in the present case it rather shows steady decrease indicating indirectly the point in favour of magma not in true sense of igneous origin.

In fig. 7 where different oxides have been plotted against

$(1/3Si + k) - (Ca + Mg)$  Modified Larsen Differentiation Index (MDI) after Nockolds and Allen (1953). The most important point in this figure is the clustering of plots of different oxides. For instance, in case of  $Na_2O$ , in this figure, the points of different granitic rocks cluster together revealing that stock parentage of these rocks were similar. Moreover, this peculiar type of behaviour of plots is because of the reason that this element was less mobile, and is still lying at the same composition level.

In fig. 8 the Niggli's values of alk, c, fm and al are plotted against Si. With the progressive increase of Si, al shows an overall increase, whereas fm shows an overall decrease and C remains almost constant. The significant point is the attitude shown by the alk, which again behaves altogether in similar manner as it has been noticed in figs. 6 & 7. Moreover, the clustering of points, which has been also observed in earlier figure, can be seen here also, which again supports the views already discussed above.

Few of the different significant features, which have emerged on the basis of above discussion may be summarised as under :

- (i) That each granitic rock group shows its own chemical

characteristics.

(ii) That some of the chemical constituents such as  $TiO_2$  and  $Al_2O_3$  show, generally, an erratic attitude, while lime and potash show a constant behaviour.

(iii) That ferrous iron, magnesia and ferric iron show an overall decrease with progressive increase of silica during the different stages of the formation of these rocks.

(iv) That soda behaves altogether in a different manner.

(v) Fig. 6 - 8 show, in general, the peculiar behaviour of clustering of plots of different oxides, which reveals that the mobility of the constituents was not high for their easy movement during the evolution of these rocks, and are still lying at the same composition level. Moreover, it strongly supports the view that the stock parentage of these rocks was similar.

Before closing this chapter, it will be useful to summarise in the tabular form the salient points of chemical behaviour of these granitic rocks. Table V-1 has been prepared for this purpose. It denotes an increase and/or decrease of chemical constituents met with in the individual group.

Table V-1

Increase and or decrease of chemical constituents with respect to initial and subsequent stages during the evolution of the granitic rocks.

Oxide	Group I			Group II			Group III			Group IV			Group V			Group VI		
	Initial stage	Subsequent stage	Increase(+) decrease(-)	Initial stage	Subsequent stage	Increase(+) decrease(-)	Initial stage	Subsequent stage	Increase(+) decrease(-)	Initial stage	Subsequent stage	Increase(+) decrease(-)	Initial stage	Subsequent stage	Increase(+) decrease(-)	Initial stage	Subsequent stage	Increase(+) decrease(-)
SiO <sub>2</sub>	68.92	71.01	+2.09	69.88	70.78	+0.90	69.08	70.50	+1.42	70.06	72.86	+2.80	70.22	70.88	+0.66	70.20	71.96	+1.76
TiO <sub>2</sub>	0.49	0.27	-0.22	0.30	0.17	-0.13	0.34	0.19	-0.15	0.10	0.17	+0.07	0.24	0.22	-0.02	0.56	0.30	-0.26
Al <sub>2</sub> O <sub>3</sub>	14.01	14.17	+0.16	14.67	15.07	+0.40	14.92	14.49	-0.43	15.81	15.08	-0.73	13.85	14.87	+1.02	14.09	14.58	+0.49
Fe <sub>2</sub> O <sub>3</sub>	1.07	0.78	-0.29	0.96	0.75	-0.21	0.93	1.03	+0.10	0.43	0.48	+0.05	1.13	0.90	-0.23	1.48	0.99	-0.49
FeO	1.66	1.37	-0.29	1.46	0.85	-0.61	2.03	1.21	-0.82	0.86	0.63	-0.23	1.66	1.29	-0.37	2.12	1.60	-0.52
MgO	1.52	0.82	-0.70	1.66	0.77	-0.89	1.10	0.86	-0.24	0.77	0.40	-0.37	0.83	0.89	+0.06	0.97	0.37	-0.60
CaO	1.27	1.27	± 0	0.46	0.83	+0.37	0.92	1.01	+0.09	0.46	0.78	+0.32	1.15	0.92	-0.23	1.42	1.18	-0.24
Na <sub>2</sub> O	5.00	5.10	+0.10	5.00	4.30	-0.70	3.52	3.97	+0.45	4.10	3.99	-0.11	5.00	4.83	-0.17	4.48	3.84	-0.64
K <sub>2</sub> O	4.08	3.75	-0.33	4.18	5.04	+0.86	5.02	5.00	-0.02	5.60	4.25	-1.35	4.28	4.21	-0.07	2.81	3.71	+0.90
P <sub>2</sub> O <sub>5</sub>	0.28	0.17	-0.11	0.18	0.20	+0.02	0.21	0.21	± 0	0.19	0.31	+0.12	0.20	0.17	-0.03	0.25	0.29	+0.04
H <sub>2</sub> O*	0.61	0.53	-0.08	0.55	0.48	-0.07	0.68	0.59	-0.09	0.58	0.50	-0.08	0.61	0.58	-0.03	0.63	0.50	-0.13

## C H A P T E R      V I

### CHEMICO - MINERALOGICAL CORRELATION

\*\*\*\*\*  
\* I. INTRODUCTION \*  
\*\*\*\*\*

The chemical variations and characteristics of different granitic rock groups belonging to "Kaplas Granite Massif" have been dealt with in the previous chapter. The petrographic and mineralogical data have also been discussed before. But nothing so far has been mentioned about the relation of these chemical changes with regards to the mineralogy of the rocks concerned. In the present chapter, an attempt has been made to correlate the chemical variations with respect to the reconstituted mineralogy of the rocks of the different groups. For this purpose table VI-1 has been prepared which gives an abstract summary of chemical and modal data in the form of addition and subtraction of the chemical and their corresponding mineralogical constituents. It must, however, be stated here that owing to alteration of different minerals entering into the composition of these rocks and also the coarse-grained porphyritic nature of some of the rocks, the present modal data cannot be so accurate as the chemical analyses. It can at best give approximation of the correlation between the chemistry and mineralogy of these rocks. However, for the purposes of ascertaining the overall

Table VI-1

Abstract summary of chemical and modal data in form of addition and subtraction of constituents with respect to initial stages of each series.

Oxides	Group I		Group II		Group III		Group IV		Group V		Group VI	
	Chemical	Modal	Chemical	Modal	Chemical	Modal	Chemical	Modal	Chemical	Modal	Chemical	Modal
SiO <sub>2</sub>	+2.09	Qz.* +2.73	+0.90	Qz. +1.41	+1.42	Qz. +3.49	+2.80	Qz. +1.44	+0.66	Qz. -1.73	+1.76	Qz. +1.36
		Alk- <sup>*</sup> feld. -1.86		Alk-feld +0.08		Alk-feld +2.07		Alk-feld -2.38		Alk-feld +3.81		Alk-feld +3.57
Al <sub>2</sub> O <sub>3</sub>	+0.16	Plag. <sup>£</sup> +0.12	+0.40	Plag. -1.77	-0.43	Plag. -4.31	-0.73	Plag. +0.58	+1.02	Plag. -1.17	+0.49	Plag. -4.52
Total iron	-0.58	Bio. <sup>@</sup> -0.26	-0.82	Bio. -0.15	-0.72	Bio. -1.08	-0.18	Bio. -0.30	-0.60	Bio. -0.71	-1.01	Bio. -0.75
MgO	-0.70	Musc. <sup>\$</sup> -0.69	-0.89	Musc. +0.51	-0.24	Musc. -0.04	-0.37	Musc. +0.74	+0.06	Musc. -0.18	-0.60	Musc. +0.10
CaO	+0.00		+0.37		+0.09		+0.32		-0.23		-0.24	
Na <sub>2</sub> O	+0.10	Iron ) oxide ) mine- ) -0.03 ral )	-0.70	Iron ) oxide ) mine- ) -0.08 ral )	+0.45	Iron ) oxide ) mine- ) -0.13 ral )	-0.11	Iron ) oxide ) mine- ) -0.08 ral )	-0.17	Iron ) oxide ) mine- ) -0.02 ral )	-0.64	Iron ) oxide ) mine- ) +0.23 ral )
K <sub>2</sub> O	-0.33		+0.86		-0.02		-1.35		-0.07		+0.90	

\*Qz. = Quartz.

\*\*Alk-feld = Alkali feldspars.

<sup>£</sup>Plag. = Plagioclases.

<sup>@</sup>Bio. = Biotite. <sup>\$</sup>Musc. = Muscovite.

sequence of mineral paragenesis in relation to arising chemical gradients and also for finding out the stability relationship of the minerals concerned, it serves well.

\*\*\*\*\*  
 \*\* II. CORRELATION BETWEEN MINERALOGICAL AND CHEMICAL \*\*  
 \*\* COMPOSITION OF THE DIFFERENT GROUPS \*\*  
 \*\*\*\*\*

Group I

Coarse-grained quartz-perthite-albite-microcline-  
 biotite granitic rocks

The chemical analyses of the rocks included in this group are given in table IV-1 and their modal composition in the table III-1. Table VI-1 shows the addition and subtraction of the respective chemical and mineralogical constituents. This table has been prepared for ready reference. As can be seen from this table only total iron, magnesia and potash show a decrease while  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  and  $\text{Na}_2\text{O}$  show an increase. Lime remains constant. In the mineralogy, quartz and plagioclases show an increase. The corresponding chemical constituents namely  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  and  $\text{Na}_2\text{O}$  also mark an increase. Similarly the decrease in iron oxide minerals and biotite is reflected in the analyses by a similar decrease in the total iron and magnesia content of these rocks. However, there is a significant anomaly in the chemical and modal

data. For instance, potash marks decrease and correspondingly there is a loss in the alkali-feldspars and muscovite, but the magnitude of decrease of alkali-feldspars cannot be justified with the decrease of  $K_2O$ . The only explanation for this anomaly is that in the alkali-feldspars quite a lot of Na might have gone in solid solution. Keeping this point in view, the chemical and mineralogical data of the rocks included in this group are fairly comparable.

#### Group II

##### Medium-grained quartz-microcline-perthite- oligoclase-biotite granitic rocks

The complete chemical analyses of the rocks of this group has been given in table IV-2 while their modal data in table III-2. In table VI-1, the abstract summary of addition and subtraction of the chemical and modal constituents with respect to initial stage of each group has been given. It may be seen from table VI-1 that the minerals which show an increase in this group are quartz, muscovite and to some extent alkali-feldspars. The corresponding chemical constituents  $SiO_2$ ,  $K_2O$  and  $Al_2O_3$  also register an increase.

The decrease of magnesia and total iron is reflected

in the concomitant decrease in the biotite and iron oxide minerals of the mode. Again with the decrease of  $\text{Na}_2\text{O}$  there is decrease in plagioclases but on the other side  $\text{CaO}$  is increasing. The only explanation which can be given for the increase of  $\text{CaO}$  and decrease of  $\text{Na}_2\text{O}$  in the present case is that the plagioclase may be more calcic, of oligoclase type in the later stage. In this regard the rocks of this group differ from the rocks included in Group I.

### Group III

#### Coarse-grained quartz-perthite-albite-oligoclase-biotite granitic rocks

The chemical analyses of the rocks of this group have been given in table IV-3 while their modal analyses in table III-3. The different chemical constituents which show the addition include silica, lime and soda while subtractions are registered by alumina, total iron, magnesia and to some extent potash as noted in table VI-1.

In the mode, the increase in quartz is comparatively more as compared to the increase in silica in analysis. The only explanation which can be given for the increase of quartz is that the plagioclase, which might have been more acidic in the earlier

stages, might have become calcic in the later stages thus releasing the excess silica in the form of quartz. In ratification with this point, it may be seen that lime marks an increase in the later stage. The decrease of  $Al_2O_3$  in the analysis is of an order befitting the decrease of plagioclases in the mode, but the decrease of  $Na_2O$  is quite contrary with this particular decrease. On the other hand, the decrease in  $K_2O$  with the increase of alkali-feldspars is quite puzzling one and is a serious anomaly in the present correlation. The best explanation for this is that the decrease of  $K_2O$  is befitting with concomitant decrease of muscovite, and moreover, alkali-feldspar which is mostly of perthitic nature, might have been responsible for the consumption of soda.

The decrease of total iron is well explained by the decrease of iron oxide minerals in the mode and so also the decrease of magnesia and decrease of biotite. But it must be stressed here that this is purely a qualitative correlation as there is a lot of difference in the magnitude of chemical and mineralogical changes.

Group IVMedium-grained quartz-perthite-oligoclase-albite-muscovite/biotite granitic rocks

The chemical analyses of the rocks included in this group are shown in table IV-4 and their modal composition in table III-4. The addition and subtraction of the chemical and modal constituents with respect to initial stage of each group has been given in table VI-1. The nature of the chemical changes represented by the rocks of this group are very characteristic. The chemical changes in this group include addition of  $\text{SiO}_2$  and  $\text{CaO}$ , while there is decrease of all other chemical constituents namely  $\text{Al}_2\text{O}_3$ , total iron,  $\text{MgO}$ ,  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$ . The decrease of total iron and magnesia is very remarkable. Corresponding to these chemical changes there is decrease in the mafic as well as iron oxide minerals. Surprisingly, despite the subtraction of soda in the analysis, plagioclases in the mode mark an increase. It, therefore, indicates that the later stage plagioclases are substantially more calcic. This idea is further ratified with the increase of lime in the chemical analysis shown in the table VI-1.

Further, the decrease of alumina and  $\text{K}_2\text{O}$  is connected with the decrease of alkali feldspars. But more interesting

feature is that there is increase of muscovite in the mode, which is not concomitant with the decrease of potash. The possible explanation for this anomaly is that during the course of evolution of these rocks some potash might have been utilized by muscovite. Also this anomaly may be due to the perthitic nature of the alkali-feldspar occurring in the later stage of the formation of these rocks.

#### Group V

##### Coarse-grained quartz-albite-oligoclase-perthite-biotite granitic rocks

The complete chemical analyses as well as mineralogical data of the rocks belonging to this group are given in table IV-5 and table III-5 respectively. The summary of addition and subtraction of chemical and mineralogical constituents is shown in table VI-1. The chemical additions include silica, alumina and magnesia while subtraction of the oxide is registered by total iron, CaO, Na<sub>2</sub>O and K<sub>2</sub>O. It has been observed that this is the only group in which MgO shows an increase, while in all other groups, it has registered a decrease. The increase of silica and magnesia in the analysis and decrease of quartz and biotite in the mode is a serious anomaly in the present chemico-mineralogical correlation. Even taking in view

that the modal data are not so statistical, this disparity is quite significant and rather inexplicable under the present circumstances. It may likely be that some of the quartz grains might have been eaten up by the hydrofluoric acid fumes during the course of staining of uncovered thin sections or may be that some quartz grains might have been mistaken for alkali feldspars during the modal analyses of the rocks included in this group. But this is hardly a correct and complete explanation. What appears, therefore, in the present context is that the alkali-feldspars, which might have been more acidic consumed more silica in the later stages of evolution of these rocks. The addition of alkali-feldspars is further confirmed by the addition registered by the oxide alumina. Yet another explanation may be given here for the present anomaly is that some quartz micro veins, which are not uncommonly seen in the coarse-grained plagioclase laths, might have been responsible for taking the excess silica. Another serious anomaly observed in the present case is that there is increase of magnesia, while biotite shows a decrease in the mode. However, such a behaviour can well be explained by the fact that a part of the Mg might have been substituted by  $\text{Fe}^{2+}$  during the evolution of these rocks. The decrease of  $\text{Na}_2\text{O}$ ,  $\text{CaO}$  and  $\text{K}_2\text{O}$  is reflected with the corresponding decrease in the plagioclases and muscovite contents shown in the mode.

Group VIFine-grained quartz-perthite-oligoclase-albite-  
biotite granitic rocks

The abstract summary of chemical and modal analyses of these rocks has been given in table VI-1, which is based on the data already shown in complete form in the table IV-6 and table III-6 respectively. It may be seen from the table VI-1 that the chemical constituents namely silica, alumina and potash show an increase, while total iron, magnesia, lime and soda mark a decrease. In other words, most of the chemical changes observed here are similar to those met within the rocks included in group V, except MgO and K<sub>2</sub>O. Thus magnesia, which had marked an increase in the previous instance, has registered a decrease in the present case, while potash which had registered decrease in the rocks of previous group shows an increase here. The corresponding changes in mineralogy, to be noted in the present case, are decrease in biotite and increase in alkali-feldspars and muscovite. The increase of Al<sub>2</sub>O<sub>3</sub> also supports the addition of alkali-feldspars. The decrease of soda and lime in the chemical analyses corresponds with the analogous decrease of plagioclases. But a disparity is noted in iron oxide minerals which show an addition with subtraction of total iron. As it has been discussed before that modal data are not so accurate because

of the obvious reasons already referred, this disparity is quite significant. It may be that some of the very fine pleochroic halos, which are commonly seen in biotite under microscope and which are sometimes very difficult to identify even under high magnification of microscope, might have been mistaken for iron oxide minerals during the course of volume percentage determination. But it is not an appropriate explanation for this disparity. The only answer which can be put forward to explain this anomaly, is the formation of mineral chlorite at the expense of biotite. The alteration of biotite particularly along the margins to chlorite is noted in the rocks belonging to this group. Moreover, magnetite which is the chief iron oxide mineral occurring in these rocks and which has been released during course of transformation of biotite to chlorite may be an appropriate explanation for the disparity noted above.

In the above pages of the present chapter, an attempt has been made to correlate the chemico-mineralogical changes established in different group, which have been involved in the formation of the granitic rocks belonging to the Kaplas Granite Massif. From the nature of observation, and moreover, from the lack of correlation in few instances, the following salient features, which emerge out of the above correlation, are noted below :

- (i) The process, responsible for bringing about the chemical and corresponding mineralogical changes, has been same in the formation of granitic rocks belonging to the different groups;
- (ii) The chemical changes, which are observed in the different groups of these rocks, are directly related to the original lithology of the parent rocks prior to the formation of melt of granitic composition;
- (iii) The addition and subtraction of the chemical constituents have not been of the same order/magnitude in different stages of these rock groups; and
- (iv) Complete equilibrium in all the cases has not been attained. Some disparities has also been noted. This suggest possibilities of solid solution and presence of metastable phases in some of the rock systems.

The above cited significant points, which emerged out from the chemico-mineralogical correlationship of the granitic rocks,

make the paragenetic history of these rocks a complex one, and it becomes necessary to review the chemical and mineralogical changes on the basis of other premises as well. This has been dealt within the chapter of discussion.

## C H A P T E R      V I I

### DISTRIBUTION AND BEHAVIOUR OF TRACE ELEMENTS

\*\*\*\*\*  
\* I. INTRODUCTION \*  
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The data concerning the major elements occurring in the various rocks of the area under present investigations have been dealt with in Chapter V. In the present chapter, an attempt has been made to discuss the distribution and behaviour of the trace elements occurring in these rocks and their chief constituent minerals. The trace elements, unlike the major elements, in general, are not capable of forming steep chemical gradients, and as such they reveal in a better manner than their corresponding major elements the sequence of changes during the evolution of granitic as well as invaded rocks. Tables IV-1 to IV-8 show the trace-element data (ppm) of various rocks, whereas table VII-1 includes average trace element content expressed in parts per million (ppm).

\*\*\*\*\*  
\* II. DISTRIBUTION OF THE TRACE ELEMENTS \*  
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The distribution-pattern of the trace elements occurring in the different groups of the rocks of the area is given below:

Table VII-1

Average trace element content in different rocks of the area of study.  
(in parts per million)

	Group I (6)*	Group II (5)*	Group III (4)*	Group IV (9)*	Group V (5)*	Group VI (3)*	Hybrid rocks (3)*	Country rocks (3)*
Cr <sup>3+</sup>	17	15	12	10	17	8	13	10
Co <sup>2+</sup>	10	10	10	10	13	13	9	11
Ni <sup>2+</sup>	8	6	7	7	7	6	6	8
Rb <sup>+</sup>	163	160	169	186	190	200	172	192
Sr <sup>2+</sup>	53	47	50	48	50	33	42	45
Ba <sup>2+</sup>	743	508	580	344	532	507	313	500
	Coarse-grained Qz- perthite-ab-microcline -biotite granitic rocks.	Medium-grained Qz- microcline-perthite- oligo-biotite granitic rocks.	Coarse-grained Qz- perthite-albite-oligo- -biotite- granitic rocks.	Medium-grained Qz- perthite-oligo-albite muscovite/biotite granitic rocks.	Coarse-grained Qz-ab- oligo-perthite-biotite granitic rocks.	Fine-grained qz- perthite-oligo-albite biotite granitic rocks.		

\* Number of samples analysed given in brackets.

Chromium : All the granitic rocks of various groups of the present area are unusually rich in chromium, as can be seen from table VII-1. Among themselves, chromium is maximum in the rocks included in the group I, where average chromium content is upto 17 ppm. The content of chromium of the group I is comparable with the rocks of group V, whereas granite rocks included in the groups II, III, IV and VI are rather poorer in their chromium content. It can be seen from tables IV-1 to 8 that there is no overall increase or decrease of chromium in the granitic rock groups. Hybrid rocks are also poor in chromium content but its proportion is comparable with some of the granitic rock groups having low chromium concentration. The significant feature of this element is that the country rocks occurring in the study area have got very low chromium content in comparison to the granitic rocks.

Cobalt : The maximum distribution of cobalt is found in the granitic rocks of the groups V and VI and next in the sequence come country rocks, the granitic rocks of other groups and in the last hybrid rocks. Among the granitic rocks of groups I to IV, cobalt is more or less uniformly distributed. Tables IV-1 to 8 show the distribution of cobalt in individual rock groups. Like chromium, cobalt also does not show any progressive increase or decrease except in the granitic rock belonging to groups III and VI. The rocks of the former group

show decrease whereas those of the latter show an increase. The cobalt content in hybrid rocks is conspicuously interesting. It is seen from table IV-7 that the concentration of cobalt in the hybrid rocks goes on increasing from granitic rocks to its contact with country rocks.

Nickel : Like cobalt, nickel is present in all the rocks, but always in low concentrations. As a matter of fact, the rocks belonging to different groups are comparatively poor in cobalt as well in nickel content which can be seen from table VII-1, where average of cobalt data (in ppm) is shown. Nickel, in the granitic rocks and also the hybrid and country rocks, does not show much variation and is more or less evenly distributed. The maximum average concentration of nickel (8 ppm) is found in the granitic rocks, included in group I, whereas the granitic rocks belonging to group VI as well as hybrid rocks have got minimum concentration of nickel. From the tables IV-1 to 8, it is noticed that granitic rocks of group VI and hybrid rocks show a progressive decrease, while no conspicuous increase or decrease is observed in the rocks of other various groups. The distribution of nickel in the country rocks is noticeable. Apart from slight increase in the initial stage it remains almost constant in the latter stages.

Rubidium : It is present in the different rocks of the

study area in an appreciable amount. Table VII-1 show the average rubidium data. As can be seen from this table that there is not much variation in the rubidium values. Its values range between 160 to 200 ppm. The maximum concentration (200 ppm) on an average is noted in rocks included in the group VI, followed in the sequence by country rocks and other granitic rocks. The minimum average concentration of rubidium is 160 ppm noted in the granitic rocks belonging to group II. Tables IV-1 to 8 show the group-wise distribution of rubidium in the different rocks. With the exception of the rocks belonging to group VI and the hybrid and country rocks, no conspicuous increase or decrease is seen. Rubidium remains constant in the rocks of group VI whereas it shows progressive increase in the case of hybrid as well as country rocks.

Strontium : Strontium, though occurs in subordinate amount, is present in all the rocks of the present area. Table VII-1, which includes average strontium values, shows that strontium is maximum in the granitic rocks of group I whereas the minimum concentration is observed in the granitic rocks of group VI. Tables IV-1 to 8 show, in general, the distribution of strontium in individual rocks belonging to different groups. The concentration of strontium ranges between 20 ppm to 75 ppm. With the exception of the granitic rocks of group III and the hybrid rocks, the distribution of strontium is of erratic nature. The

rocks included in group III show constant distribution of strontium whereas its concentration decreases with progressive increase of silica in case of hybrid rocks. A peculiar type of behaviour is noticed when the strontium data of hybrid rocks are scrutinized. It is seen here (Table IV-7) that the hybrid rocks have got lesser concentration of strontium than the average strontium content in the granitic rocks, but its concentration is almost equal to the strontium concentration of the country rocks. In other words, when strontium data of hybrid rocks are scrutinized, it is observed that strontium shows an overall decrease from the granitic rocks to country rocks.

Barium : Like strontium, the concentration of barium is also maximum in granitic rocks of group I which can be seen from table VII-1 where the averages of each rock group are shown. Concentration of barium in individual rocks belonging to different groups is given in tables IV-1 to 8. It is seen here that except in few cases, barium does not show any conspicuous increase or decrease with the increase of silica. Only in the rocks of group VI it shows decrease upto stage 2 and then it remains constant. Similar type of attitude has been noticed in the country rocks also. The behaviour of barium is quite interesting in the hybrid rocks. It progressively decreases with the progressive increase of silica.

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 \* III. BEHAVIOUR OF THE TRACE ELEMENTS \*  
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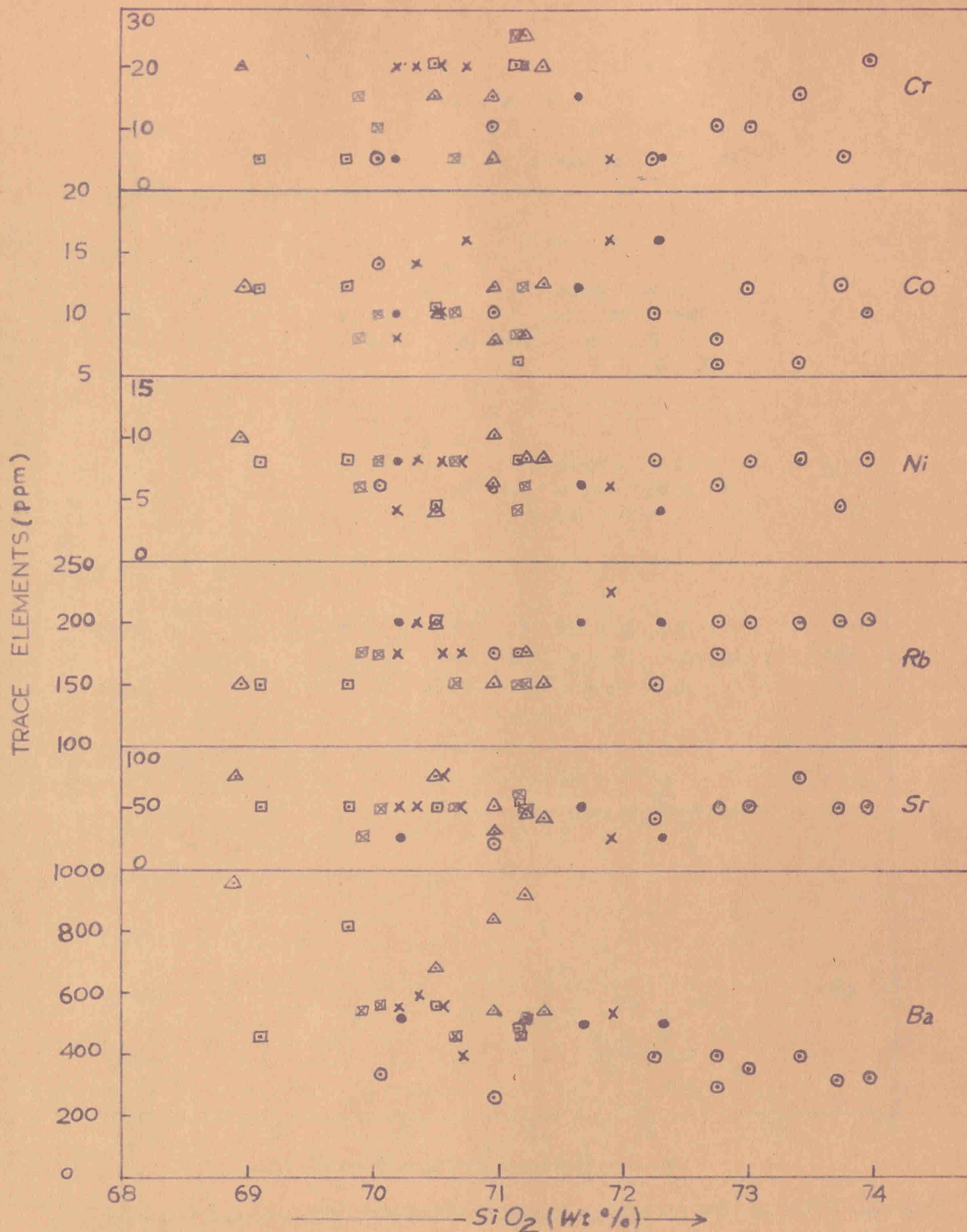
After discussing the distribution of the trace elements in the rocks of various groups, an attempt has been made in this section to study in detail the overall behaviour of the trace elements in the granitic rocks of the area under reference. This all has been done as under :

Chromium : ( $\text{Cr}^{3+}$ , ionic radius = 0.64 Å, e = 1.6)

Chromium is less abundant constituent in the upper lithosphere, its distribution in most of the granitic rocks belonging to the different groups is not uniform. But, the more striking point is the overall higher concentration of chromium in these granitic rocks. The average chromium content of granite is between 2 to 6.8 ppm (Rankama and Sahama, 1950, p. 621). Goldschmidt (1937b) gave an average ranging between 2-10 ppm in granite which is very low in comparison to the chromium content present in the granitic rocks of study area. The average  $\text{Cr}^{3+}$  content in present case ranges between 8 to 17 ppm, but in some individual samples the chromium concentration goes even upto 25 ppm. Grohmann (1965) gave an average of 25 ppm  $\text{Cr}^{3+}$  for 122 granitic rocks of Austria. The peculiarity in the geochemistry of  $\text{Cr}^{3+}$  is considered to be its diadochic behaviour with ferric iron ( $\text{Fe}^{3+}$ , r=0.67 Å, e=1.8) in silicates, its lower electronegativity being considered to be responsible for its high concentration

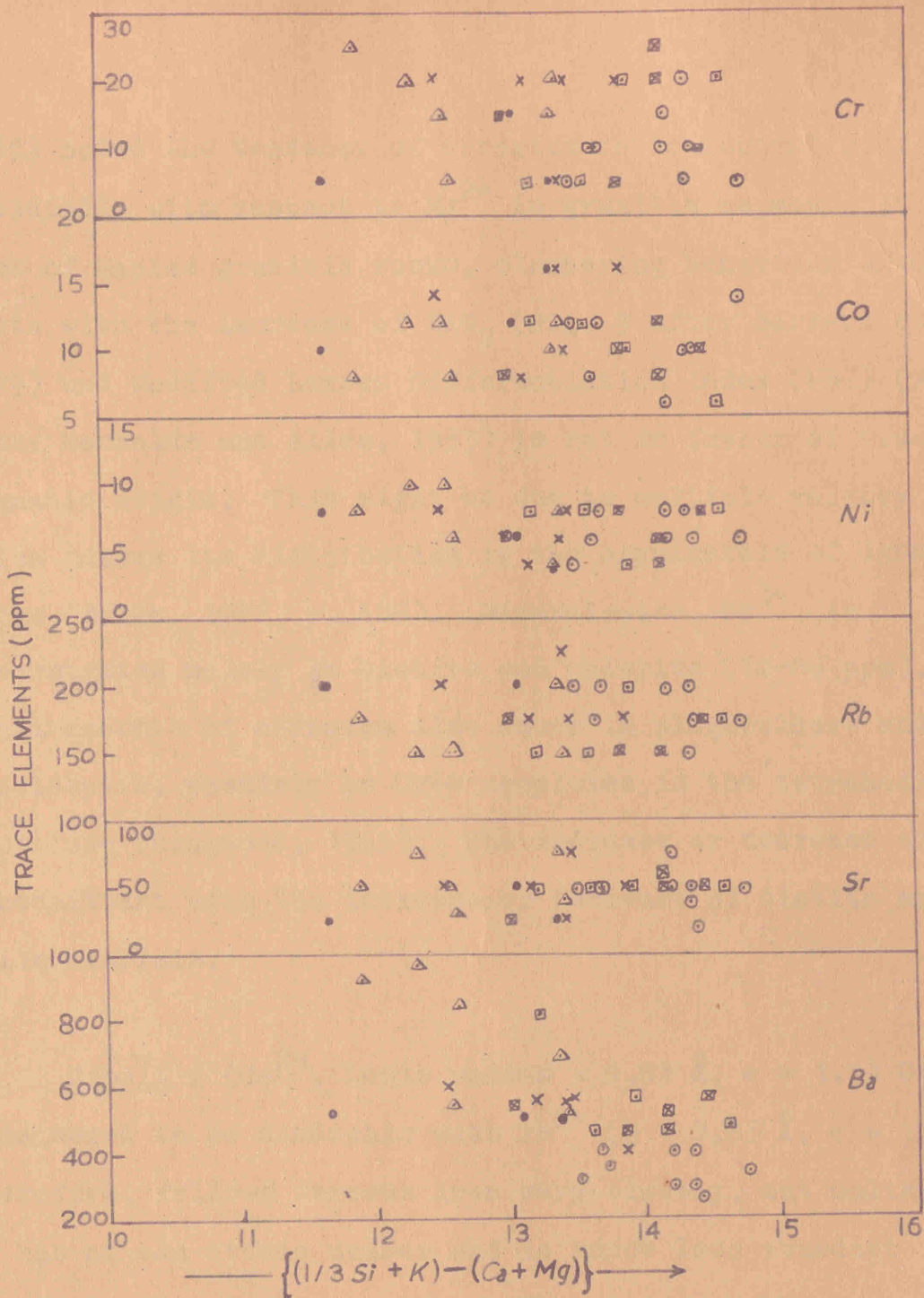
in the early crystallized constituents (Ringwood, 1955). The chemical analyses show that ferric iron, which bears the closest affinity among the major elements to  $\text{Cr}^{3+}$ , is seen to occur in appreciable quantities. Similarly, the modal analyses of granitic rocks (Table III-8) show the presence of the minerals biotite and magnetite—the ideally suited structures for the adjustment of chromium. Despite these favourable considerations, the overall high concentration of  $\text{Cr}^{3+}$  can only be due to the enrichment in  $\text{Cr}^{3+}$  of the older rocks, prior to the formation of granitic melt. When the physico-chemical factors, which govern the geochemistry of  $\text{Cr}^{3+}$ , are taken into consideration, it is seen that a higher temperature favours the concentration of  $\text{Cr}^{3+}$  (Rankama and Sahama, 1950; Goldschmidt, 1954; Smith, 1962).

It is rather difficult to explain the higher chromium content in the present case. In this connection, the observations of Ringwood (1955, p.199) show that the relatively higher concentration of  $\text{Cr}^{3+}$  with respect to  $\text{Fe}^{3+}$  is primarily due to "the smaller electronegativity of  $\text{Cr}^{3+}$  (1.6) as compared to  $\text{Fe}^{3+}$  (1.3)". The rocks included in group VI contain lesser  $\text{Cr}^{3+}$  but have got higher  $\text{Fe}^{3+}$  content. Similarly, rocks of the Groups I and II contain more  $\text{Cr}^{3+}$  but lesser ferric iron. Similar type of relationship has also been observed in rocks of other groups. Some earlier workers (Carr and Turekian, 1962; Siedner,



- △ COARSE-GRAINED QZ-PERTHITE-ALBITE-MICROCLINE-BIOTITE GRANITIC ROCKS
- ⊠ MEDIUM-GRAINED QZ-MICROCLINE-PERTHITE-OLIGOCLASE-BIO GRANITIC ROCKS
- COARSE-GRAINED QZ-PERTHITE-ALBITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS
- MEDIUM-GRAINED QZ-PERTHITE-OLIGO-ALB-MUSCOVITE/BIO GRANITIC ROCKS
- × COARSE-GRAINED QZ-ALBITE-OLIGO-PERTHITE-BIOTITE GRANITIC ROCKS
- FINE-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE-BIOTITE GRANITIC ROCKS

FIG.9 VARIATION DIAGRAM OF TRACE ELEMENTS  
 PLOTTED AGAINST SILICA (AFTER BARKER et al., 1979)



- △ COARSE-GRAINED QZ-PERTHITE-ALBITE-MICROCLINE-BIOTITE GRANITIC ROCKS
- ▣ MEDIUM-GRAINED QZ-MICROCLINE-PERTHITE-OLIGOCLASE-BIO GRANITIC ROCKS
- ▢ COARSE-GRAINED QZ-PERTHITE-ALBITE-OLIGO - BIOTITE GRANITIC ROCKS
- MEDIUM-GRAINED QZ-PERTHITE-OLIGO-ALB-MUSCOVITE/BIO GRANITIC ROCKS
- × COARSE-GRAINED QZ-ALBITE-OLIGO-PERTHITE - BIOTITE GRANITIC ROCKS
- FINE-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE - BIOTITE GRANITIC ROCKS

FIG. 10 VARIATION DIAGRAM OF TRACE ELEMENTS PLOTTED AGAINST MODIFIED LARSEN DIFFERENTIATION INDEX (AFTER NOCKOLDS & ALLEN, 1953)

1965) noted the tendency of chromium to be concentrated residually with respect to  $Mg^{2+}$  in granitic magmas. In the case of Kaplas granitic rocks, clustering behaviour of  $Cr^{3+}$  plots with the increase of  $SiO_2$  (Fig. 9 after Barker, et al., 1979) and Modified Larsen Differentiation Index (MDI) (Fig. 10 after Nockolds and Allen, 1953) is not in favour of true magmatic origin. This might be due to multiple valency of  $Cr^{3+}$ , which causes its distribution in the oxyminerals of igneous rocks (Smith, 1962, p. 403). Mineral-wise,  $Cr^{3+}$ , is concentrated mainly in biotite and chlorite (10-85 ppm), but small amounts of chromium also occur in plagioclases and k-feldspars, possibly as Cr-O complexes in the tetrahedral in positions (Ringwood, 1955). The increase or decrease of  $Cr^{3+}$  is concomittant with the increase or decrease of biotite and iron-oxide minerals.

Cobalt : ( $Co^{2+}$ , ionic radius = 0.82 Å,  $e = 1.7$ ) Cobalt is considered to be diadochic with  $Fe^{2+}$  ( $r = 0.83$  Å,  $e = 1.65$ ). It, therefore, follows ferrous iron very closely, but unlike iron, it has an odd atomic number and is hence less abundant in nature than the element ferrous iron. The studies of Newhouse (1936) and Ramdohr (1940) showed that igneous rocks contain, as a rule, small quantities of common sulfide minerals e.g., pyrite, which form the seat of Co-Ni. However, cobalt found in the igneous rocks is incorporated in silicate minerals, being concealed in

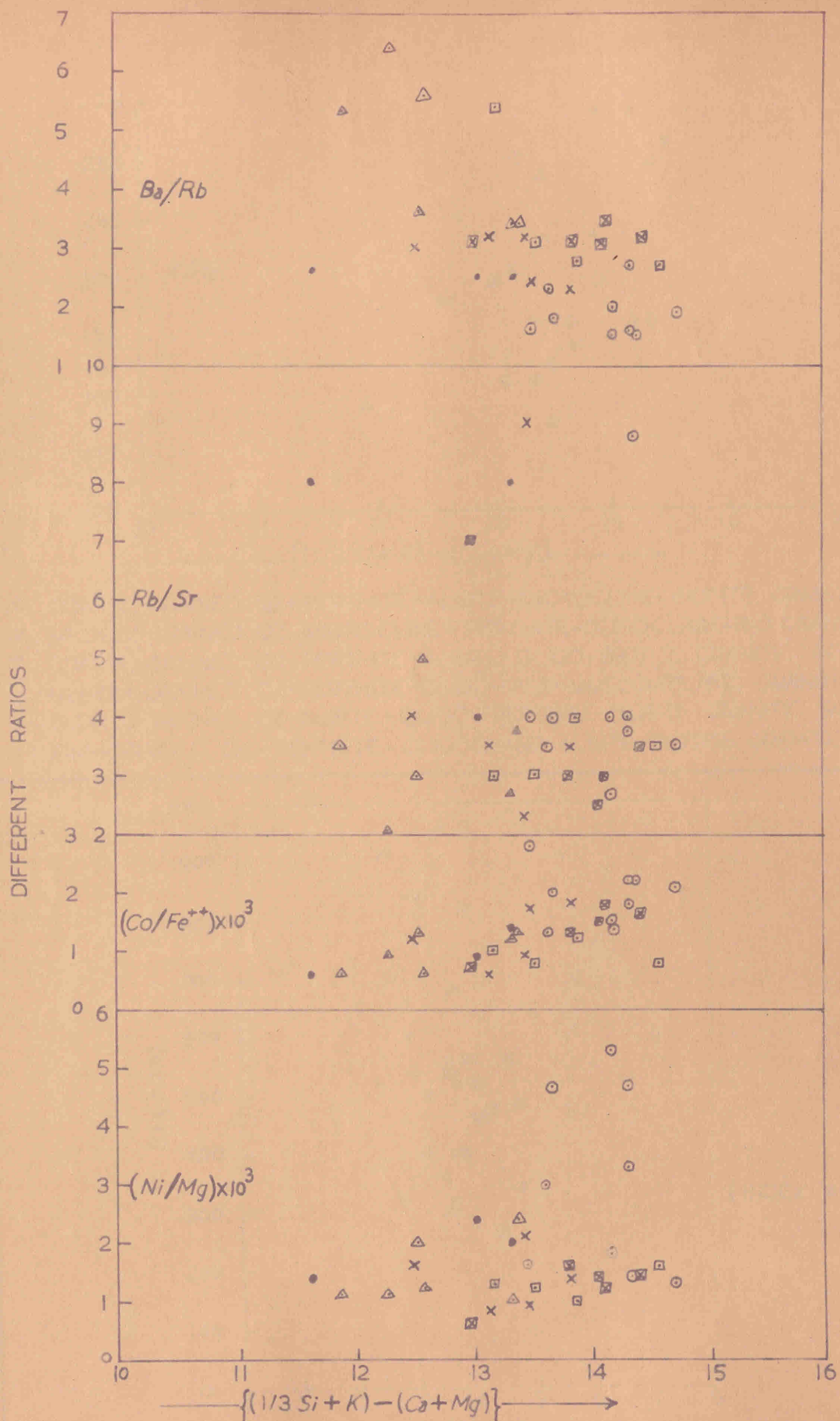
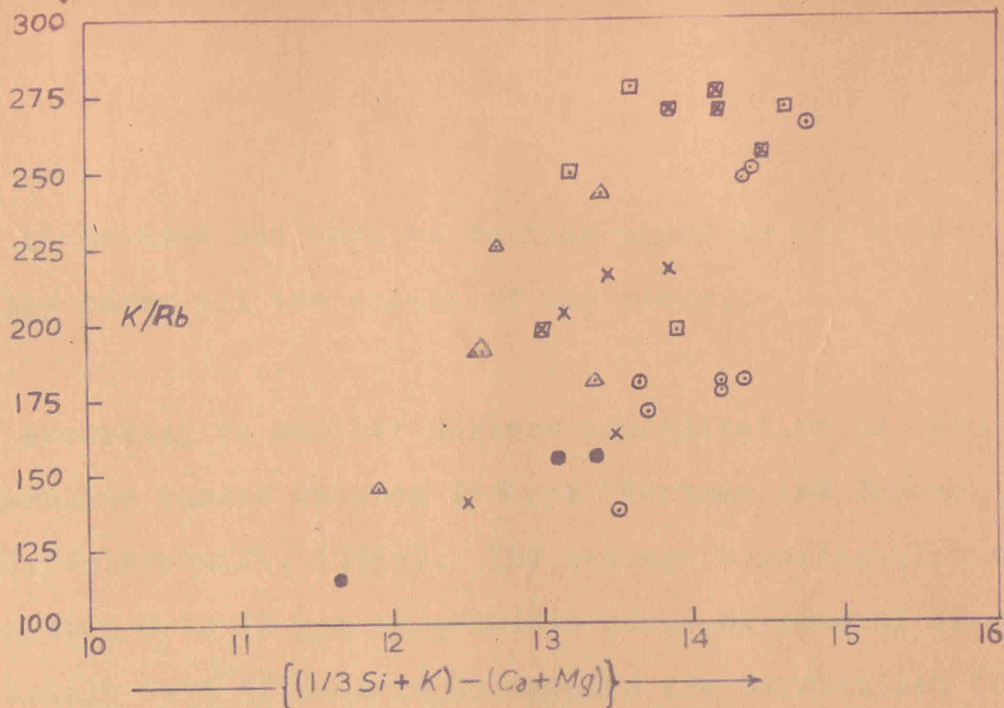
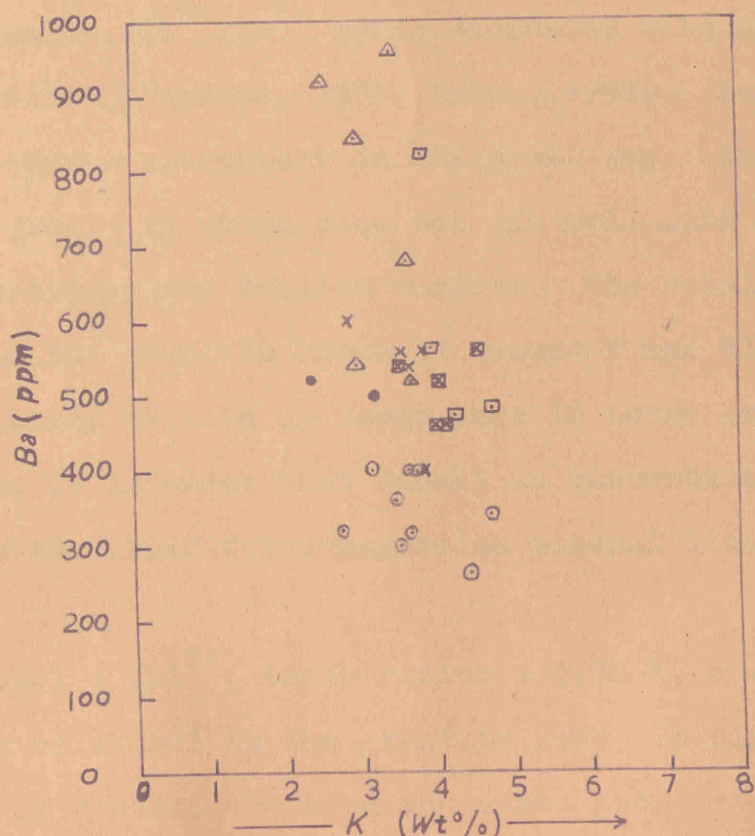


FIG. II VARIATION DIAGRAM OF DIFFERENT RATIOS PLOTTED AGAINST MODIFIED LARSEN DIFFERENTIATION INDEX (AFTER NOCKOLDS & ALLEN, 1953)

(CONTINUATION OF FIG.11)



- △ COARSE-GRAINED QZ-PERTHITE-ALBITE-MICROCLINE-BIOTITE GRANITIC ROCKS
- ▣ MEDIUM-GRAINED QZ-MICROCLINE-PERTHITE-OLIGOCLASE-BIO GRANITIC ROCKS
- ▢ COARSE-GRAINED QZ-PERTHITE-ALBITE-OLIGO-BIOTITE GRANITIC ROCKS
- MEDIUM-GRAINED QZ-PERTHITE-OLIGO-ALB-MUSCOVITE/BIO GRANITIC ROCKS
- x COARSE-GRAINED QZ-ALBITE-OLIGO-PERTHITE-BIOTITE GRANITIC ROCKS
- FINE-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE-BIOTITE GRANITIC ROCKS



(INDEX AS IN FIG.11)

FIG.12 DIAGRAM SHOWING RELATION BETWEEN BARIUM AND POTASSIUM CONCENTRATION (AFTER SAHA et al,1968)

their structures and when no sulfide minerals are present, the silicate carry all the cobalt of the rocks.

According to earlier workers concentration of cobalt in the granites ranges between 2-8 ppm (Rankama and Sahama, 1950, p. 682; Goldschmidt, 1937a). The average concentration of cobalt ranges from 9 to 13 ppm in granitic rocks of present area, but when cobalt data of individual samples are scrutinized (Tables IV-1 to 6) then it is observed that maximum  $\text{Co}^{2+}$  concentration is 16 ppm. Figures 9 and 10 show the relationship of cobalt with  $\text{SiO}_2$  and MDI.

Normally,  $\text{Co}^{2+}/\text{Fe}^{2+}$  ratio decreases with increasing fractionation (Ringwood, 1955; Mason, 1958). But in the present case it behaves altogether in different way. An overall increase is noted (Fig. 11) which does not fit well with the observations put forwarded by the earlier workers. The cobalt concentration is more in the granitic rocks of groups V and VI (Tables IV-5 & 6). Similarly biotite is found more in these groups (Table III-8). Therefore, it is clear that cobalt is concentrated and incorporated within ferro-magnesian mineral biotite.

Nickel : ( $\text{Ni}^{2+}$ , ionic radius = 0.78 Å,  $e = 1.7$ ) The behaviour of nickel in the granitic rocks is similar to the attitude of cobalt. In both the cases there is no conspicuous

increase or decrease with the increasing  $\text{SiO}_2$  (Fig. 9) and increasing MDI (Fig. 10). More than  $\text{Co}^{2+}$ ,  $\text{Ni}^{2+}$  show a geochemical affinity for  $\text{Mg}^{2+}$  ( $r = 0.78 \text{ \AA}$ ,  $e = 1.2$ ) and  $\text{Fe}^{2+}$  ( $r = 0.83 \text{ \AA}$ ,  $e = 1.65$ ) because of similarity of ionic radii in the former and ionic charge in latter. The behaviour of nickel is usually interpreted on the basis of the concept that it is camouflaged by magnesium in the crystal lattice. Later it has been argued by Ringwood (1955) that nickel follows  $\text{Fe}^{2+}$ , rather than magnesium. According to relative bonding energies, magnesium and nickel should show marked preferential entry into a given crystal lattice with respect to  $\text{Fe}^{2+}$  (Nockolds, 1966). But it is evident that nickel replaces magnesium diadochically in mineral structures and becomes enriched therewith, and moreover, nickel has a tendency to become enriched in the early crystallised magnesium and ferro-magnesian minerals (Rankama and Sahama, 1950, p. 683). In granites, nickel is almost quantitatively adjusted in biotite structure. When trace-element data of the present granitic rocks are scrutinised (Table VII -1), it is observed that the rocks of group I contain on an average high concentration of  $\text{Ni}^{2+}$  (8 ppm) whereas low concentration (6 ppm) is seen of the rocks included in group II. In brief its concentration corresponds with the proportion of biotite present in the granitic rocks of different groups. Another interesting thing which may be noted here is that ( $\text{MgO} + \text{FeO}$ ) content in the rocks of group I is more in comparison to their content in the rocks of group II,

which is an appreciable variation to justify the variation noted in the case of  $\text{Ni}^{2+}$ . Similar type of phenomenon has also been observed in other granitic rock group. According to previous data of Goldschmidt (1937) Rankama and Sahama (1950, p.682) the average concentration of nickel in granitic rocks ranges from 2 to 8 ppm, which fully corresponds with the nickel concentration of the granitic rocks of present area. The country rocks, contain higher concentration of nickel (8ppm) which may be explained by the fact that these rocks contain minerals like chlorite and biotite in which  $\text{Ni}^{2+}$  is incorporated in their structures.

The ratio Co/Ni behaves erratically and is always less than 4. Coming to the ratio Ni/Mg, normally, it decreases with increasing fractionation (Ringwood, 1955; Mason, 1958), but an increasing trend of Ni/Mg has been noted by Siedner (1965) in a syenite-rhyolitic suite of rocks. Fig. 11 shows that only few plots are scattered otherwise this ratio shows constant behaviour which indicates that the stock parentage was of same composition level during the evolution of these granitic rocks.

Rubidium : ( $\text{Rb}^+$ , ionic radius 1.47 Å,  $e = 0.8$ ) Rubidium which is one of the heavy alkali metals, occurs constantly alongwith cesium in nature. As far as its manner of occurrence is concerned, it is incorporated in the silic minerals during

crystallization and resembles potassium chemically  $K^+$  ( $r = 1.33 \text{ \AA}$ ,  $e = 0.8$ ). Because of its large ionic size,  $Rb^+$  is admitted into potassium minerals and it forms no independent mineral of its own. It follows that the most important minerals, where rubidium is incorporated, are micas and K-feldspars, but, when biotite and muscovite co-exist in the rocks then  $Rb^+$  seems to enter into the structure of biotite, but maximum concentration is found in the mineral muscovite (Goldschmidt, 1958). The average concentration of  $Rb^+$  in the granites is 830 ppm (Goldschmidt, et al., 1934). According to Rankama and Sahama (1950, p.437) this concentration should be in between 455-910ppm. But, the concentration of rubidium in the Kaplas granitic rocks ranges from 150 to 225 ppm (Tables IV 1-8) which is much lower than that investigated by the earlier workers.

After visualizing the table VII-1 it has been observed that granitic rocks of groups I and II contain lesser concentration of  $Rb^+$  (160 ppm), whereas rocks included in groups V and VI have got higher (200 ppm) rubidium content. This peculiar type of variation may be explained by the fact that rocks belonging to group I contain lesser proportion of mica in comparison to group V (Table III-8). Moreover, in the rocks of group II, alkali-feldspars are seen to occur in lesser proportion than in the rocks of group VI (Table III-8). It has already been discussed that rubidium is incorporated with potassium. Secondly,

plagioclases of the granitic rock groups V and VI, which are more sericitized, and where rubidium probably has replaced  $K^+$  in the sericitic alteration products, which contain appreciable concentration of  $Rb^+$ . Saha, et al. (1968) explained in a similar way that mineralwise,  $Rb^+$  is found to be concentrated in the minerals K-feldspars and biotite, but an appreciable proportions may also be expected in the sericitized plagioclases where it has replaced  $K^+$  in the alteration product sericite.

From figures 9 and 10 it is observed that rubidium does not show any conspicuous increase or decrease but it approximately remains constant even with increasing  $SiO_2$  (Barker, et al., 1979), and MDI (Nockolds and Allen, 1953). In fig. 11 where ratios  $Rb/Sr$  and  $Ba/Rb$  are plotted against MDI, it is seen that they show clustering of points with increasing MDI and no linear trend is observed. Condie (1969) used  $K/Rb$  ratio in the Laramie batholith and explained that this ratio in this batholithic body slightly decreases or remains approximately similar. But this ratio in the present case behaves in a rude manner (Fig. 11).

Strontium : ( $Sr^{2+}$ , ionic radius = 1.12 Å,  $e = 1.0$ ) It is geochemically characterized by the fact that no independent strontium mineral is known which is formed during the main stage of crystallization. The bulk of strontium is concealed in the rock-forming minerals of igneous rocks. The geochemistry of

strontium in the igneous rocks is controlled chiefly by its corresponding major elements  $\text{Ca}^{2+}$  ( $r = 0.99 \text{ \AA}$ ,  $e = 1.0$ ) and partly by  $\text{K}^+$  ( $r = 1.33 \text{ \AA}$ ,  $e = 0.8$ ) (Mason, 1958). The ionic size of  $\text{Sr}^{2+}$  indicates that it can proxy for either calcium or potassium, being admitted into calcium minerals (higher ionic radius) or captured by potassium minerals (higher charge). This phenomenon is well explained by Goldschmidt's "admittance" theory, which says that  $\text{Sr}^{2+}$  is "admitted" into the smaller calcium lattice, but is "entrapped" in the potassium lattice which has a large radius ( $1.33 \text{ \AA}$ ).  $\text{Sr}^{2+}$  is camouflaged in some of the Ca-bearing minerals, chiefly the plagioclase feldspars. It may well be captured by potassium in K-bearing minerals e.g., potash-feldspars. Mineral-wise, plagioclases are the chief host for strontium, but part of  $\text{Sr}^{2+}$  is also adjusted in the K-feldspar (microcline perthite), suggesting replacement of potassium by strontium in the K-feldspar, but not in biotite where the proportion of  $\text{Sr}^{2+}$  is below the detection limit.

The average strontium concentration in granites as found by Turekian (1956) is about 282 ppm. According to Noll (1934) it is about 90 ppm. Sahama (1945 c) gave an average of  $\text{Sr}^{2+}$  for Rapakivi granites of about 100 ppm. Table VII-1 shows the average  $\text{Sr}^{2+}$  content of different granitic rock groups which ranges from 33 ppm to 53 ppm. It has been observed from this table that  $\text{Sr}^{2+}$  concentration is more in the granitic rock

groups II, III, IV and V in comparison to  $\text{Sr}^{2+}$  concentration in the rocks belonging to group VI which has been incorporated proportionally in the structures of plagioclases (Table III-8). For instance, the proportion of plagioclases in Table III-8 for the rocks of group VI is more but has got lesser proportion of strontium (Table VII-1). This can be explained by the fact that the plagioclases occurring in the granitic rocks of group VI are more albitic, a fact which has already been discussed in the previous chapter. When plagioclase is albitic, it means that it is going to have lesser proportion of calcium in its structure, with the result that very less quantity of strontium could be adjusted alongwith calcium present in the plagioclase. In the case of rocks belonging to group I, the position is altogether reverse. The proportion of plagioclase is less (Table III-8) whereas the concentration of  $\text{Sr}^{2+}$  is high (Table VII-1). The explanation for this unusual behaviour can be that the plagioclase might have been lime-rich, and a part of the strontium might have been captured by the potassium of alkali feldspars.

For the purpose of ascertaining the overall behaviour of strontium in the Kaplas granitic rocks different diagrams have been prepared. In the figures 9 and 10 where strontium data is plotted against silica (Barker, et al., op.cit.) and MDI (Nockolds and Allen, op.cit.). It has been seen that trend remains approximately constant. The ratio  $\text{Rb}/\text{Sr}$  remains more or

less uniform with increasing MDI (Fig. 11).

Barium : ( $\text{Ba}^{2+}$ , ionic radius = 1.35 Å,  $e = 0.85$ ) It is known to be diadochic with potassium,  $\text{K}^+$  ( $r = 1.33$  Å,  $e = 0.8$ ). Barium does not substitute for calcium in significant quantities because the difference in the size of ionic radii is too great. In terms of the overall geochemical cycle, barium most closely resembles strontium which is another alkaline-earth trace element of smaller ionic size. Von Engelhardt (1936) has shown on the basis of his works that only small amount of barium enters into calcium minerals, the bulk of the element is captured by potassium minerals owing to the smaller difference in the charge between the barium and potassium ions. Goldschmidt (1954) explained that the igneous rocks, which have been formed through the process of fractional crystallization, are expected to be low in barium in the early differentiates which are poor in potassium content.

Like strontium, barium undoubtedly is the most important habitat in feldspar structure in igneous rocks. Strontium is present both in the plagioclases and the potash-feldspars, but significant amounts of barium are found only in potash-feldspars. The substitution of  $\text{K}^+$  in the feldspar structure by  $\text{Sr}^{2+}$  and  $\text{Ba}^{2+}$  is analogous to the  $\text{Na}^+$ - $\text{Ca}^{2+}$  diadochy. Noll (1934) and Von Engelhardt (1936) have shown that the content of strontium and

barium in potash-feldspars really depend upon the temperature of formation. The potash-feldspar formed during the early steps of the crystallization interval contain, as a rule, more strontium and barium than do the potash-feldspar last to crystallized, in which potassium is enriched.

Von Engelhardt (1936) found that  $Ba^{2+}$  content in the granites is about 430 ppm. Sahama (1945 b) gave an average of about 670 ppm. In addition to this he also gave the average for the Rapakivi granites as 900 ppm. The average barium concentration in the case of present granitic rocks varies from 500 to 743 ppm, (Table VII-1). The average content in the country rocks is about 500 ppm, which is comparable with the average content (500 ppm) given for shales by Vinogradov (1956) and Puchelt (1967). It has also been observed that in the early cumulative rocks, both  $Ba^{2+}$  and  $K^+$  occur in very poor quantities (Nockolds and Mitchell, 1948). In the present granitic rocks,  $Ba^{2+}$  rather behaves erratically. It has got an overall decreasing tendency with increasing  $SiO_2$  (Barker, et al., op.cit.) and MDI (Nockolds and Allen, op.cit.) (Figs. 9 and 10). When an attempt is made to correlate the  $Ba^{2+}$  content with the content of K-bearing minerals, it may be observed from table III-8 that with the exception of few minerals i.e., alkali-feldspars, muscovite and biotite, there is no other mineral appreciably rich in  $K^+$ , but the trend of these minerals, in general, is antipathetic to the

Ba content. In fig. 12, where  $Ba^{2+}$  concentration is plotted against potassium it has been seen that plots do not show any linear trend. The only explanation which can be put forward for such behaviour is the lack of appropriate structures to accommodate  $Ba^{2+}$  in the absence of potassium bearing minerals.

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 \* IV. GENERALISED SUMMARY OF THE BEHAVIOUR OF TRACE \*  
 \* ELEMENTS DURING THE EVOLUTION OF GRANITIC ROCKS \*  
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The geochemistry of the chief trace elements occurring in the rocks of the present study area has been described above and the details of their behaviour with respect to the prevailing physio-chemical conditions, relative mobility, their relation with the corresponding major elements and their choice for appropriate mineral structures have been given. Previous workers have pointed out that, in general, the distribution behaviour of the trace elements is controlled by corresponding major elements of similar size and valence. Goldschmidt (1937) has, in this context, formulated the well known principles of camouflage, capture and admission. While confirming to some extent Goldschmidt's generalizations regarding particle size, co-ordination, valence etc., there are some significant departures from his as well as other's results so far as the behaviour of the above referred trace elements in the case of present granitic rocks is concerned. It has been found that the relationship of the trace

elements with their corresponding major elements is very limited and have their own zones of maximum concentration. The chief reasons for this behaviour of the trace elements is that such elements occur in very low concentration and, moreover, they hardly get any opportunity to form any chemical gradient, if proper time is not allowed to them, with the result, that they get localised. Secondly, the trace elements, unlike the major elements, are not capable of adjusting to the newly changed conditions and migrate accordingly but are left over there in their original positions.

After discussing the geochemistry of trace elements, the author is now in a position to give a generalized summary of the behaviour of trace elements :

$\text{Cr}^{3+}$  : Occurs chiefly in the biotite and only very small amounts of chromium occurs in plagioclases. It is also present in magnetite. It replaces  $\text{Fe}^{3+}$  ions or is camouflaged by them. It is concentrated chiefly in granitic rocks included in group I.

$\text{Co}^{2+}$  : In comparison to the country rocks, the granitic have got comparatively higher  $\text{Co}^{2+}$  content. Among the granitic rock group, the

higher cobalt content is seen in the rocks of groups V and VI. It has been substituted for  $Mg^{2+}$  chiefly in the structures of ferromagnesian minerals. But more preferably it has also been adjusted alongwith the  $Fe^{2+}$  in the mineral magnetite.

$Ni^{2+}$  : Like cobalt, it is also present mainly in the structures of the minerals biotite and magnetite where it is incorporated alongwith  $Fe^{2+}$ . It is evenly distributed in all the different granitic groups.

$Rb^{+}$  : Concentrated maximum in the rocks belonging to group VI. It is admitted into the  $K^{+}$  ions in the potassium-bearing minerals, like alkali-feldspars, muscovite and to some extent in the plagioclase structure.

$Sr^{2+}$  : Occurs chiefly in the plagioclase and K-feldspar structures. It is admitted into the  $Ca^{2+}$  ions and has maximum concentration in the granitic rocks in comparison to that of country rocks.

$Ba^{2+}$  : Its concentration is higher in granitic rocks in comparison to that of the country as well as hybrid rocks. But its maximum concentration is in the granitic rocks of group I. On account of its higher charge,  $Ba^{2+}$  is captured mainly by  $K^+$  in the alkali-feldspar structures.

Beside the above cited summarized interpretation of individual trace elements, there are much more significant features yet to be discussed. For instance the overall behaviour of all the trace elements during the evolution of granitic rocks belonging to Kaplas Granite Massif. Trace elements, when considered together alongwith certain major elements, may be useful in determining the feasibility of formation of granitic rocks by the partial melting of the older rocks especially valuable ratios in this respect are the K/Rb, Ca/Sr, Rb/Sr, Ba/Sr, Ba/K and Ba/Rb (Taylor and Heier, 1960 ; Taylor, 1965; White, 1966).

The different trace elements which are shown in table IV-1 to 6 are plotted against  $\left\{ (1/3Si + K) - (Ca + Mg) \right\}$  MDI in fig. 10. In this fig. Cr, Co, Ni, Rb and Sr do not show any linear trend, the points are clustered together in a very smaller field, whereas Ba shows an overall decrease towards the more acidic end. From the table VII-1 it has been observed that there

is higher Cr and Ba content in the granitic rocks in comparison to that of country rocks, which further indicates that granitic rocks have been formed of the material having different chemical composition than that of country rocks. The ratios K/Rb, Ba/Rb, Rb/Sr, Ni/Mg, Co/Ni and Co/Fe as noted in table IV-1 to 6 (Fig. 11) remain approximately same. Such relationship of the ratios in the granitic rocks suggests that these rocks could have been derived by the partial melting of the parent rocks prior to the melt (Condie, 1969). It seems that in the present case the K/Rb ratio is low when compared to the 'normal' K/Rb ratio of the crustal rocks (Ahrens and others, 1952; Heier and Adams, 1963). The low K/Rb ratio in the present case is the result of the mode of formation of the granites by the process of anatexis (Albuquerque, 1971). However, such ratios could be the result of fractional crystallization of the mafic magma or perhaps by granitization; therefore, these ratios alone are not sufficient to support a partial melting origin of granitic rocks in the present case. Therefore, for this purpose, points which should be elucidated are of great importance, as further discussion will reveal in the subsequent chapter of discussion.

## CHAPTER VIII

### DISCUSSION

\*\*\*\*\*  
\* I. INTRODUCTION \*  
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The geological setting, petrographic characters of the rock types, variations in their chemical as well as mineralogical composition and the behaviour of the trace elements in the different granitic rocks of the area have been described in the preceding chapters, wherein an attempt was also made to correlate the mineralogical and chemical variations. These studies, which reveal interesting and significant features and have bearing on some fundamental petrogenic problems, seems to be very useful in providing a substantive background for a discussion of the geochemistry of these rocks. In the present chapter, while discussing the geochemistry of different granitic rocks, which are included in "Kaplas Granitic Massif", an attempt has also been made to give the sequence of crystallization and also the nature of granitic magma.

Before dealing with the more intricate problems, it is essential first to visualise the sequence of appearance of the different cation-molecules and also the nature and magnitude of the chemical changes involved during formation of different

Table VIII-1

Recalculated values of the granitic rocks : group I.

Specimen number	Recalculated values for fig. 13		Recalculated values for fig. 14		Recalculated values for fig. 15		Recalculated values for fig. 16			
	SiO <sub>2</sub>	K <sub>2</sub> O	CaO	K <sub>2</sub> O	Na <sub>2</sub> O	SiO <sub>2</sub>	Alk	FeO	MgO	CaO
R <sub>24</sub>	88.36	5.23	12.27	39.42	48.31	84.86	11.18	37.30	34.16	28.54
L <sub>13</sub>	88.15	5.47	11.48	40.90	47.62	86.22	11.59	36.79	22.07	41.14
K <sub>32</sub>	89.92	4.38	13.20	37.73	49.07	87.59	9.82	37.42	25.46	37.12
T <sub>7</sub>	88.79	4.33	11.38	34.22	54.40	86.06	10.86	45.61	22.80	31.59
B <sub>15</sub>	89.39	3.83	14.04	31.03	54.93	86.21	10.23	39.39	28.44	32.17
K <sub>52</sub>	88.39	5.42	12.82	40.71	46.47	86.46	11.36	38.54	17.52	43.94

Recalculated value of the granitic rocks : group II.

Specimen number	For fig. 17		For fig. 18		For fig. 19		For fig. 20		
	SiO <sub>2</sub>	K <sub>2</sub> O	CaO	K <sub>2</sub> O	SiO <sub>2</sub>	Alk	FeO	MgO	
R <sub>57</sub>	88.38	5.29	4.77	43.36	51.87	85.00	11.17	40.78	46.37
R <sub>12</sub>	87.62	6.75	4.81	51.92	43.27	85.68	12.11	35.53	42.94
R <sub>8</sub>	87.83	6.08	9.27	45.32	45.41	85.83	11.89	36.36	28.67
R <sub>21</sub>	89.01	6.24	11.39	50.30	38.31	87.71	10.83	29.82	21.61
R <sub>5</sub>	88.91	6.10	7.20	51.04	41.76	87.05	10.86	36.14	34.87

Recalculated value of the granitic rocks : group III.

Specimen number	For fig. 21		For fig. 22		For fig. 23		For fig. 24		
	SiO <sub>2</sub>	K <sub>2</sub> O	CaO	K <sub>2</sub> O	SiO <sub>2</sub>	Alk	FeO	MgO	
S <sub>46</sub>	89.00	6.47	9.73	53.06	37.21	85.51	10.57	50.12	27.16
B <sub>4</sub>	89.13	5.80	11.89	47.05	41.06	86.16	10.51	42.11	27.63
L <sub>18</sub>	89.12	6.03	9.27	50.26	40.47	87.09	10.63	41.20	25.84
B <sub>16</sub>	87.90	7.04	9.17	52.83	38.00	85.98	11.84	33.82	30.18

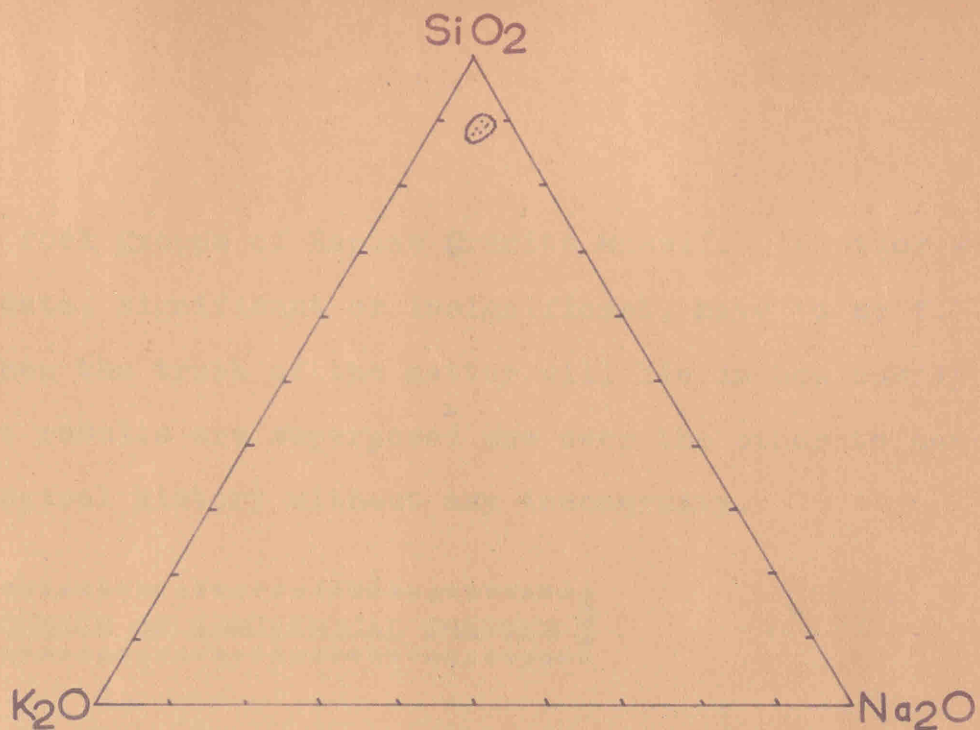


FIG.13  $\text{SiO}_2\text{-K}_2\text{O-Na}_2\text{O}$  DIAGRAM OF COARSE-GRAINED QZ-PERTHITE-ALBITE-MICROCLINE-BIOTITE GRANITIC ROCKS

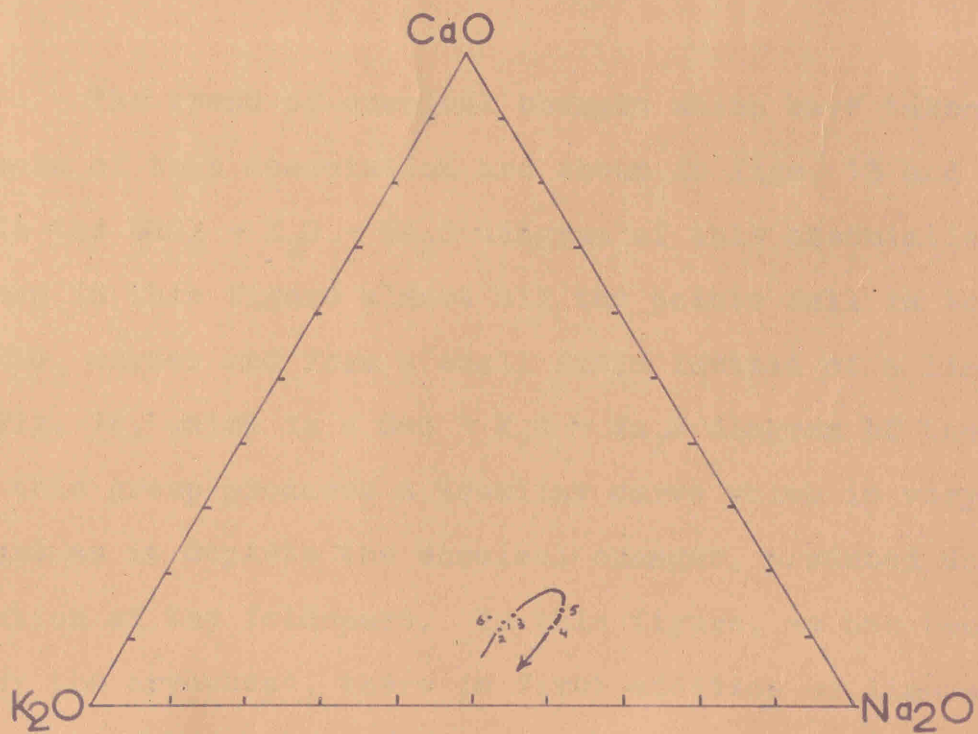


FIG.14  $\text{CaO-K}_2\text{O-Na}_2\text{O}$  DIAGRAM OF COARSE-GRAINED QZ-PERTHITE-ALBITE-MICROCLINE-BIOTITE GRANITIC ROCKS

granitic rock groups of Kaplas Granite Massif. In other words, all the data, significant or insignificant, have to be fitted in and then the truth of the matter will lie in how easily the different results are superposed one over the other to complete the geological history without any incongruity.

\*\*\*\*\*  
 \* II. SEQUENCE OF GEOCHEMICAL CHANGES \*  
 \*\*\*\*\*

Group I

Coarse-grained quartz-perthite-albite-microcline-  
 biotite granitic rocks

The trend of chemical changes which have taken place in the rocks of this association are shown in figs. 13 and 16. Fig. 13 is the  $\text{SiO}_2 - \text{K}_2\text{O} - \text{Na}_2\text{O}$  diagram of this association. As can be seen in this figure almost all the points fall in the extreme  $\text{SiO}_2$  corner and form a small field instead of a linear trend. Fig. 14, which is a  $\text{CaO} - \text{K}_2\text{O} - \text{Na}_2\text{O}$  diagram of the rocks of this group produces a peculiar curve which is very significant as it depicts the chemical changes, produced during the formation of the feldspars. In this figure, as has been denoted by the arrowhead, there is first addition of lime and soda but loss of potash in the earlier stages followed by the sudden decrease of former constituents and increase in the latter.

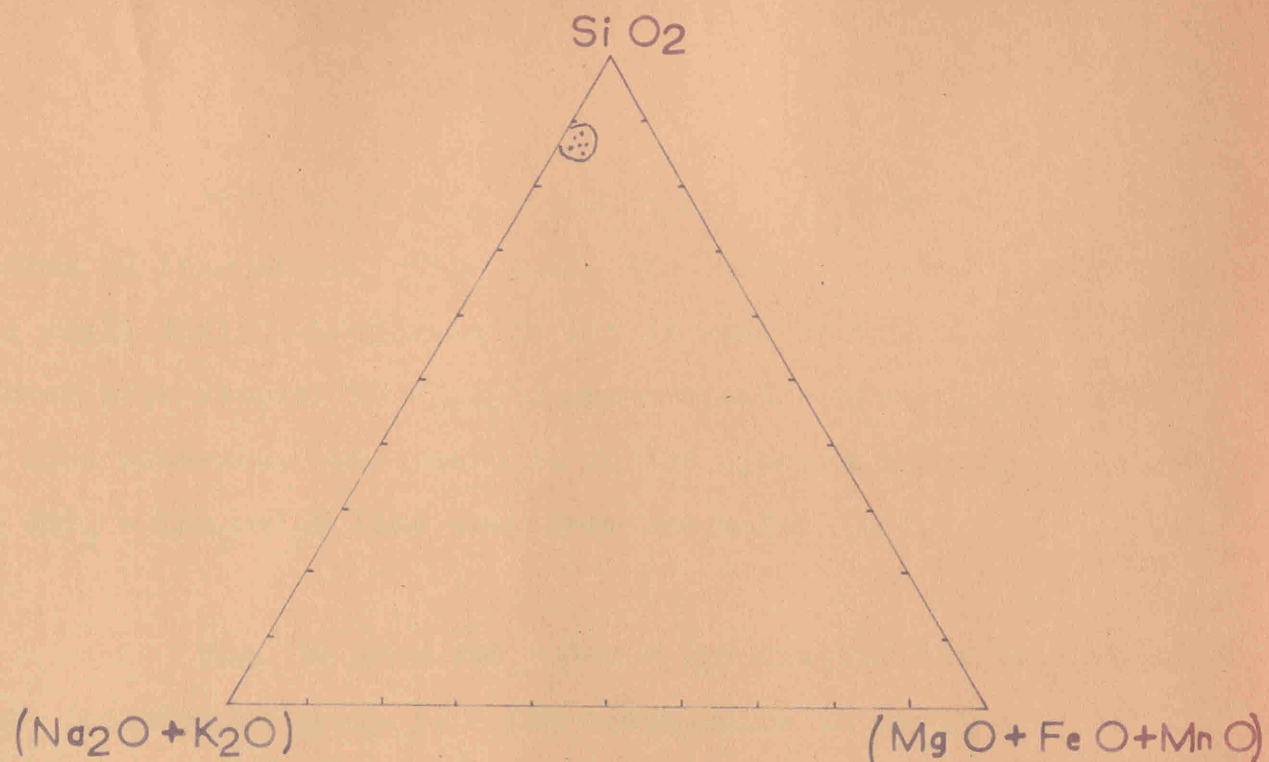


FIG. 15  $\text{SiO}_2$ -ALK -MAFIC DIAGRAM OF COARSE-GRAINED QZ-PERTHITE-ALBITE-MICROCLINE-BIOTITE GRANITIC ROCKS

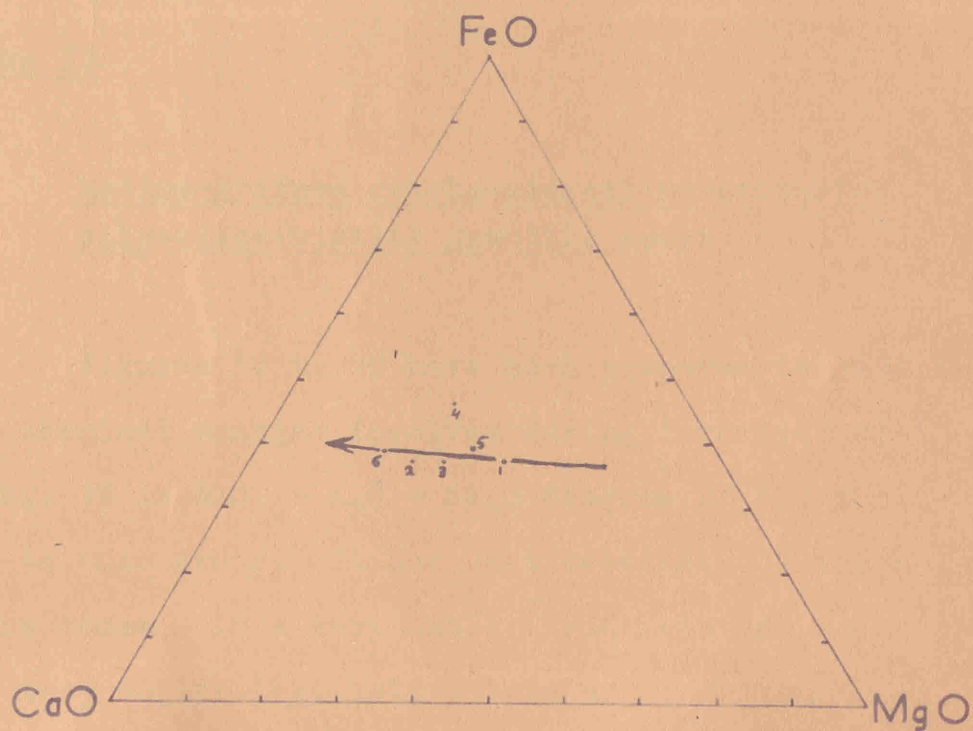


FIG. 16  $\text{FeO}$ - $\text{CaO}$ - $\text{MgO}$  DIAGRAM OF COARSE-GRAINED QZ-PERTHITE-ALBITE-MICROCLINE-BIOTITE GRANITIC ROCKS

Fig. 15 is  $\text{SiO}_2 - (\text{Na}_2\text{O} + \text{K}_2\text{O}) - (\text{MgO} + \text{FeO} + \text{MnO})$  diagram of this group. Here again the points cluster together in a small field, which lies in the extreme corner of  $\text{SiO}_2$ . However with respect to fig. 13 where similar type of behaviour was also observed, this field is on the opposite side i.e., near the  $\text{SiO}_2 - (\text{Na}_2\text{O} + \text{K}_2\text{O})$  line away from the mafic line.

Fig. 16 is a  $\text{FeO} - \text{CaO} - \text{MgO}$  diagram for the granitic rocks included in group I. The trend, which is denoted by an arrow head, denotes a progressive decrease of  $\text{MgO}$  (from points 1 to 6) and a conspicuous increase in  $\text{CaO}$  whereas  $\text{FeO}$ , shows a very slight increase.

### Group II

#### Medium-grained quartz-microcline-perthite-oligoclase-biotite granitic rocks

Figures 17 to 20 have been prepared to know the nature of chemical changes involved during formation of these rocks. Fig. 17 is  $\text{SiO}_2 - \text{K}_2\text{O} - \text{Na}_2\text{O}$  diagram of the rocks belonging to this group. It has been seen that all the points in this figure occur in a very small field near the silica apex. Moreover, they denote that both potash and soda remain more or less constant.

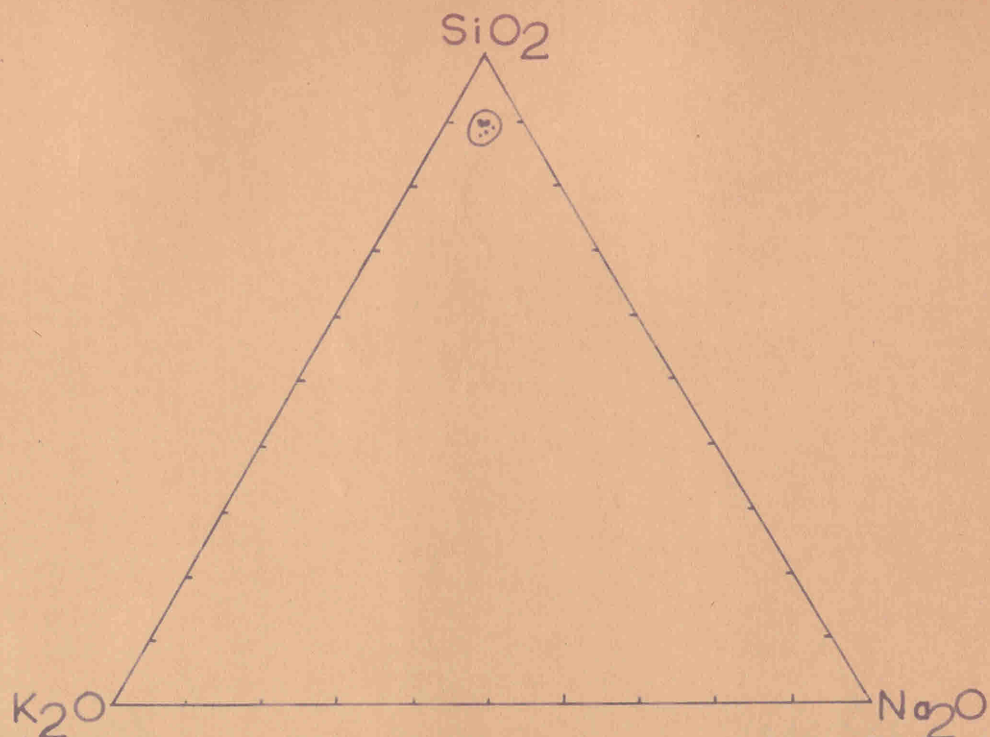


FIG. 17  $\text{SiO}_2$ - $\text{K}_2\text{O}$ - $\text{Na}_2\text{O}$  DIAGRAM OF MEDIUM-GRAINED QZ-MICROCLINE-PERTHITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS

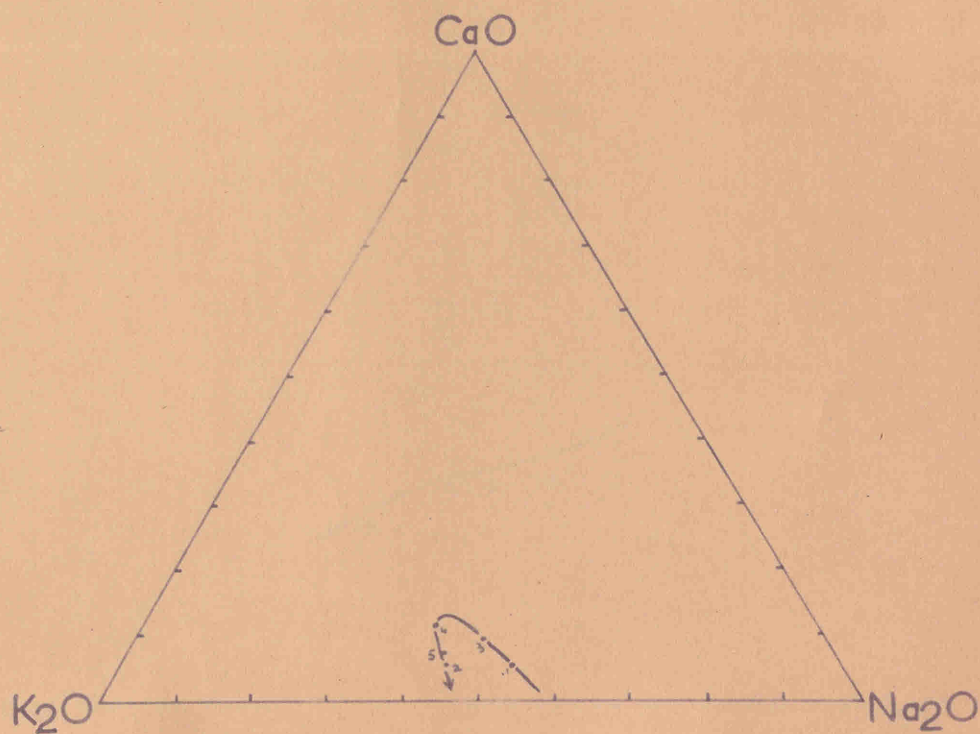


FIG. 18  $\text{CaO}$ - $\text{K}_2\text{O}$ - $\text{Na}_2\text{O}$  DIAGRAM OF MEDIUM-GRAINED QZ-MICROCLINE-PERTHITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS

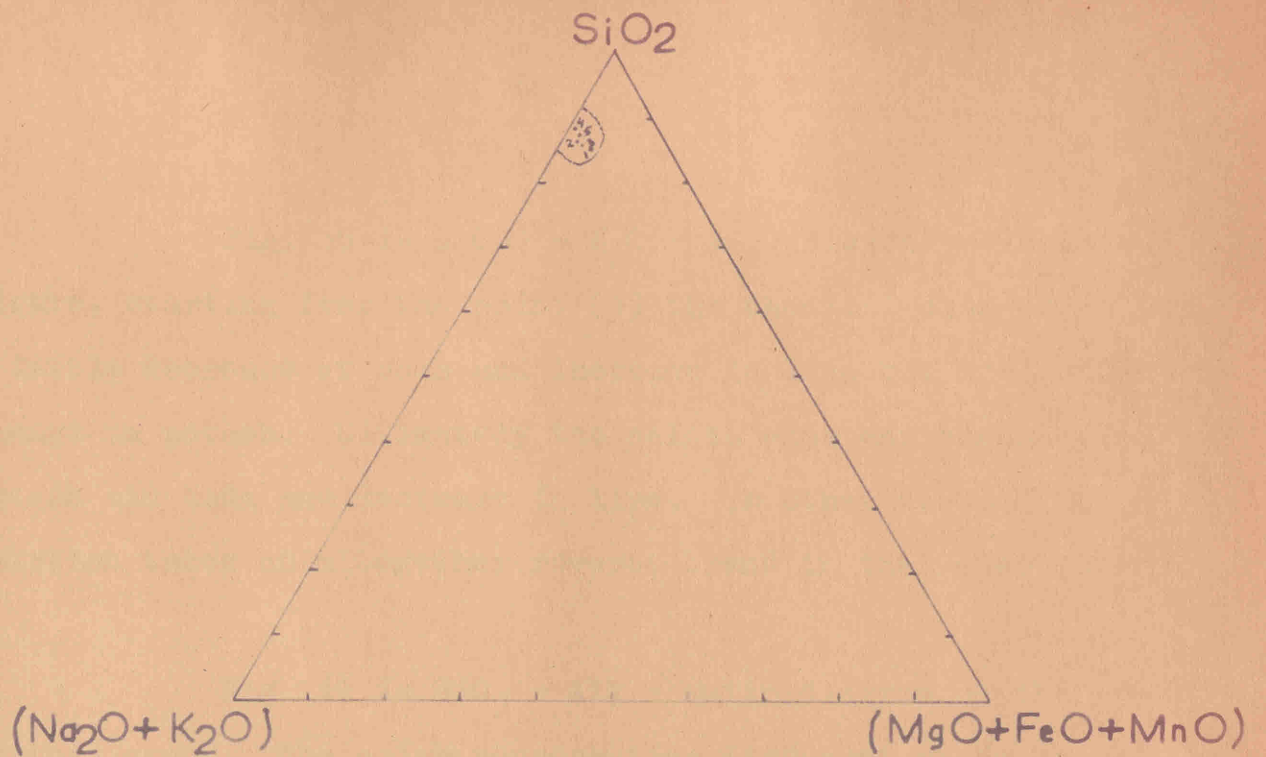


FIG. 19  $\text{SiO}_2$ -ALK-MAFIC DIAGRAM OF MEDIUM-GRAINED QZ-MICROCLINE-PERTHITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS

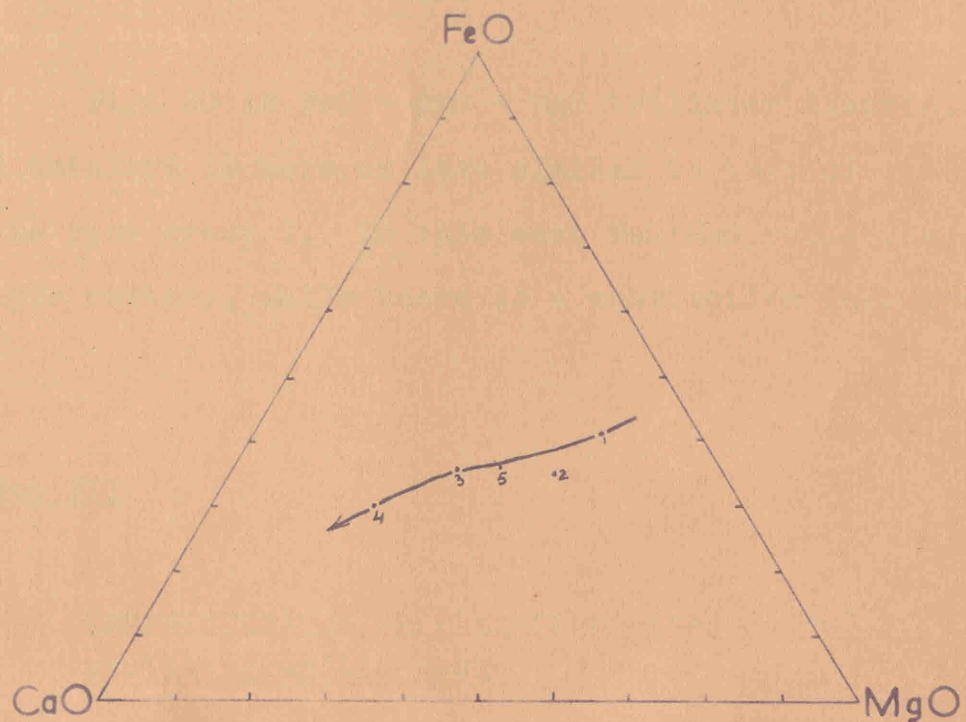


FIG. 20  $\text{FeO}$ - $\text{CaO}$ - $\text{MgO}$  DIAGRAM OF MEDIUM-GRAINED QZ-MICROCLINE-PERTHITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS

Fig. 18 is a  $\text{CaO} - \text{K}_2\text{O} - \text{Na}_2\text{O}$  diagram. In this figure, starting from the point (1) the chemical changes follow a little decrease of soda and increase in lime but negligible change in potash. Ultimately the points show enrichment of potash and soda and decrease in lime. In other words, the reaction takes an altogether reverse trend in the later stages.

Fig. 19 is  $\text{SiO}_2 - \text{Alk} - \text{Mafic}$  diagram of the rocks of this group. The points representing different rocks do not form any linear pattern. On the other hand, they occur in a narrow small field situated near the silica apex and very close to the base line of mafic constituents.

Fig. 20 is  $\text{FeO} - \text{CaO} - \text{MgO}$  trilinear diagram. Here the trend obtained is more or less similar to that of a fig. 16 of granitic rock group I. In this case  $\text{FeO}/\text{MgO}$  ratio remains more or less constant, while there is a substantive increase in lime.

### Group III

#### Coarse-grained quartz-perthite-albite-oligoclase-biotite granitic rocks

Fig. 21 to 24 have been prepared to study the chemical changes involved in the formation of the rocks of

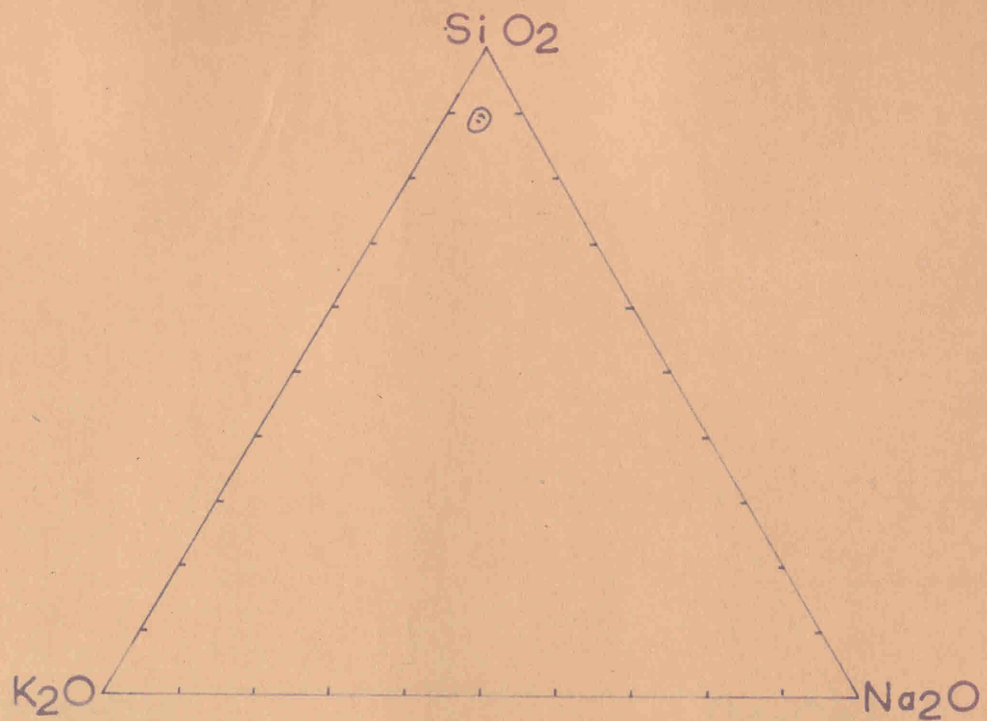


FIG. 21  $\text{SiO}_2\text{-K}_2\text{O-Na}_2\text{O}$  DIAGRAM OF COARSE-GRAINED QZ-PERTHITE-ALBITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS

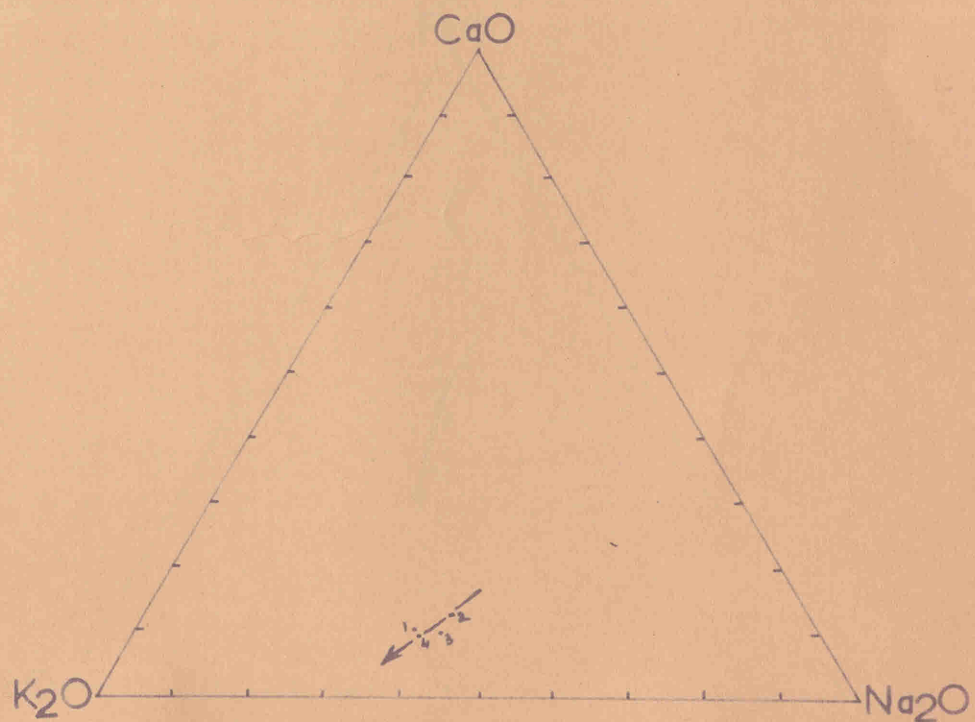


FIG. 22  $\text{CaO-K}_2\text{O-Na}_2\text{O}$  DIAGRAM OF COARSE-GRAINED QZ-PERTHITE-ALBITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS

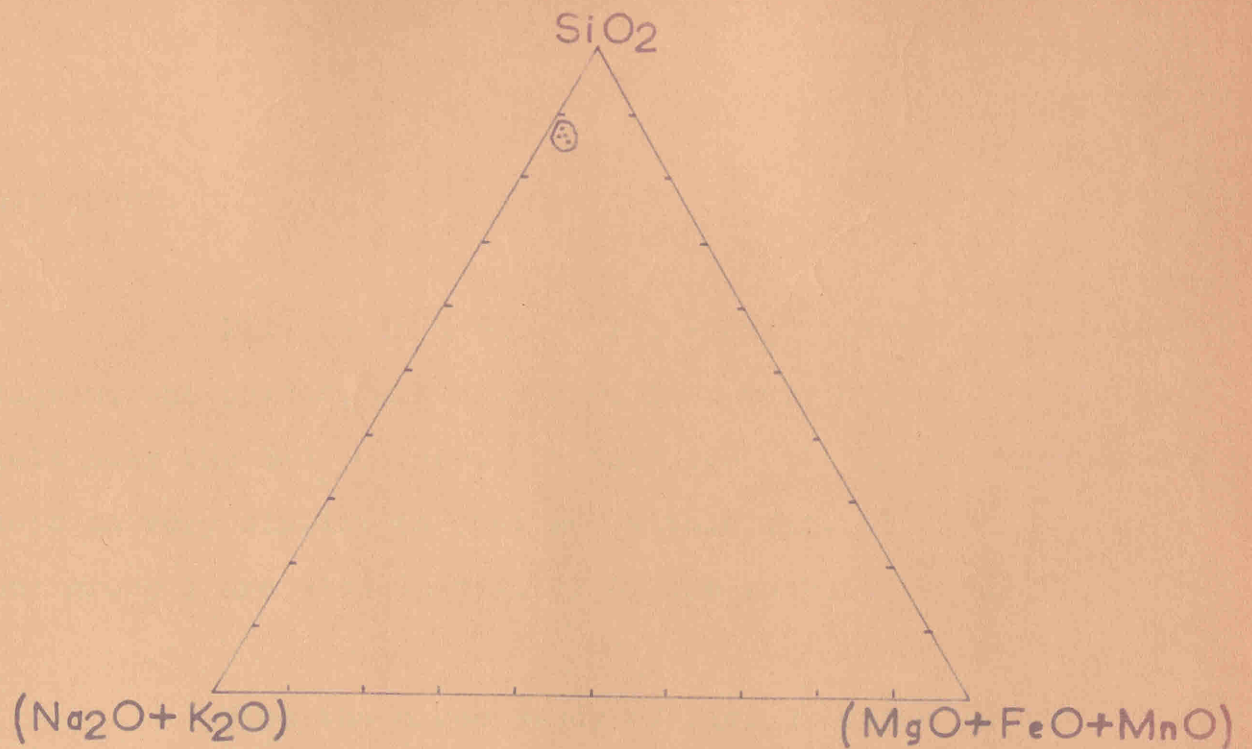


FIG. 23  $\text{SiO}_2$ -ALK-MAFIC DIAGRAM OF COARSE-GRAINED QZ-PERTHITE-ALBITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS

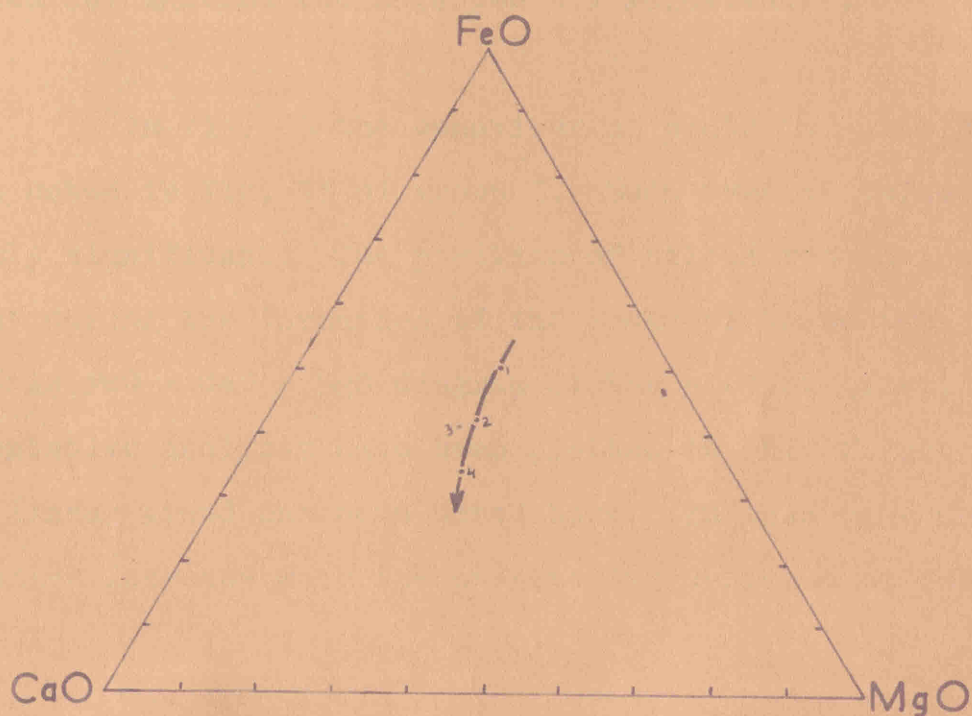


FIG. 24  $\text{FeO}$ - $\text{CaO}$ - $\text{MgO}$  DIAGRAM OF COARSE-GRAINED QZ-PERTHITE-ALBITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS

this group.

Fig. 21 is a  $\text{SiO}_2 - \text{K}_2\text{O} - \text{Na}_2\text{O}$  diagram. In this diagram, the points, are clustered in a very narrow restricted field near the  $\text{SiO}_2$  corner. In this respect the position of the plots is very similar to that met within fig. 13 of granitic rock group I and also in fig. 17 of the rocks of group II.

From the close study of fig. 22 which is  $\text{CaO} - \text{K}_2\text{O} - \text{Na}_2\text{O}$  diagram, is seen that the linear trend, which is shown by arrowhead, marks a progressive increase of potash and decrease of  $\text{Na}_2\text{O}$  and  $\text{CaO}$ . This trend is quite comparable with the trend suggested for igneous rocks (Green and Poldervaart, 1958).

In fig. 23 the behaviour of plots is quite similar to that noted in fig. 15 of group I. Such type of relationship is highly significant. The position of silica remains nearly constant during the formation of the rocks of these two groups. Fig. 24 is  $\text{FeO} - \text{CaO} - \text{MgO}$  diagram of the present group. Four representative analyses have been plotted in this figure and a single linear trend has been noted here. In this case  $\text{CaO}$  shows progressive increase with the progressive decrease of  $\text{FeO}$  and  $\text{MgO}$ .

Table VIII-2

Recalculated values of the granitic rocks : group IV.

Specimen number	Recalculated values for fig. 25		Recalculated values for fig. 26		Recalculated values for fig. 27		Recalculated values for fig. 28					
	SiO <sub>2</sub>	K <sub>2</sub> O	Na <sub>2</sub> O	CaO	K <sub>2</sub> O	Na <sub>2</sub> O	SiO <sub>2</sub>	Alk	Mafic	FeO	MgO	CaO
S <sub>51</sub>	87.84	7.02	5.14	4.53	55.12	40.35	86.03	11.91	2.06	41.15	36.84	22.01
S <sub>30</sub>	88.10	6.57	5.33	8.40	50.53	41.07	86.68	11.71	1.61	27.32	31.94	40.74
K <sub>55</sub>	89.50	5.55	4.95	5.57	49.89	44.54	88.22	10.35	1.43	44.17	25.17	30.68
S <sub>57</sub>	89.68	5.27	5.05	5.20	48.42	46.38	88.47	10.19	1.34	33.11	36.43	30.46
B <sub>21</sub>	90.51	4.71	4.78	9.81	44.80	45.39	89.20	9.35	1.45	40.82	16.84	42.34
T <sub>19</sub>	90.94	5.08	3.98	14.35	48.00	37.65	89.72	8.94	1.34	33.92	12.34	53.74
R <sub>52</sub>	90.35	5.32	4.33	10.09	49.54	40.37	89.43	9.55	1.02	32.34	14.97	52.69
K <sub>8</sub>	90.78	4.11	5.91	7.98	40.98	51.04	89.65	9.12	1.23	33.75	25.63	40.62
S <sub>59</sub>	88.96	5.27	5.77	8.47	43.67	47.86	88.01	10.92	1.07	33.92	16.37	49.71

Recalculated values of the granitic rocks : group V.

Specimen number	For fig. 29		For fig. 30		For fig. 31		For fig. 32					
	SiO <sub>2</sub>	Alk	SiO <sub>2</sub>	Alk	SiO <sub>2</sub>	Alk	SiO <sub>2</sub>	Alk				
T <sub>22</sub>	88.33	5.38	6.29	11.02	41.04	47.94	85.59	11.31	3.10	45.61	22.80	31.59
T <sub>8</sub>	88.81	4.24	6.94	10.14	34.08	55.78	86.20	10.86	2.94	45.54	24.70	29.76
C <sub>7</sub>	89.40	4.74	4.86	13.18	46.99	39.83	87.15	10.34	2.51	41.23	19.69	39.08
T <sub>23</sub>	88.38	5.72	6.00	5.06	46.36	48.58	85.97	11.41	2.62	43.46	37.31	19.23
B <sub>20</sub>	88.25	5.37	6.38	8.76	41.72	49.52	85.80	11.43	2.77	36.56	34.69	28.75

Recalculated values of the granitic rocks : group VI.

Specimen number	For fig. 33		For fig. 34		For fig. 35		For fig. 36					
	SiO <sub>2</sub>	Alk	SiO <sub>2</sub>	Alk	SiO <sub>2</sub>	Alk	SiO <sub>2</sub>	Alk				
R <sub>30</sub>	90.59	3.63	5.78	16.30	32.26	51.44	87.06	9.04	3.90	47.01	21.51	31.48
R <sub>23</sub>	90.10	4.67	5.23	13.90	40.59	45.51	87.69	9.63	2.68	50.73	12.02	37.24
K <sub>24</sub>	90.90	4.67	4.43	13.00	44.64	42.36	88.84	8.89	2.27	50.87	11.50	37.63

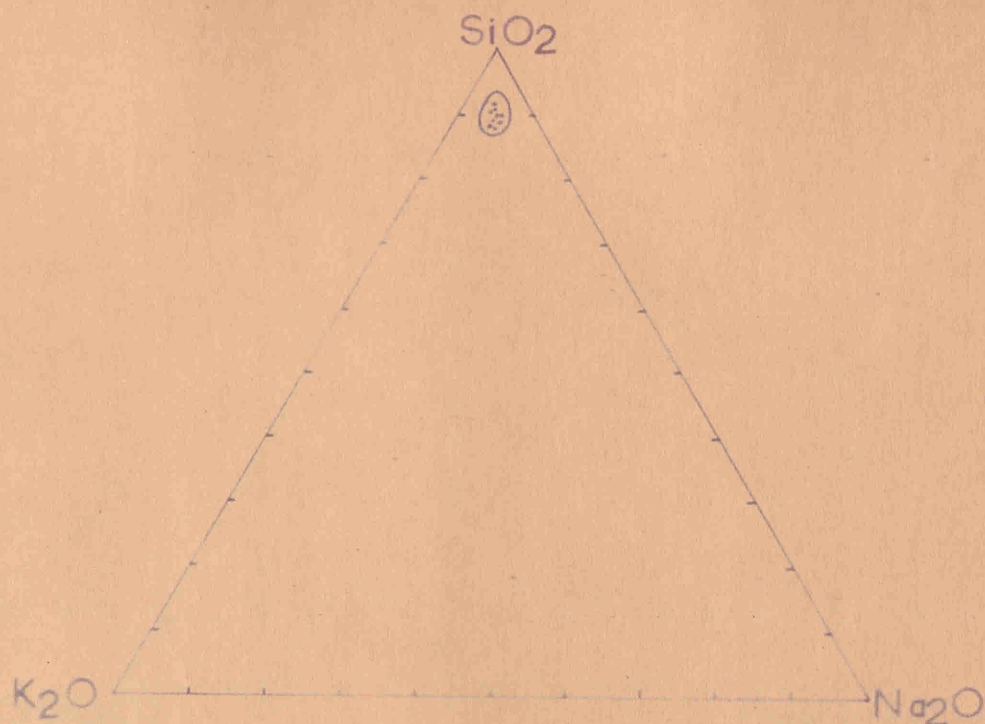


FIG. 25  $\text{SiO}_2$ - $\text{K}_2\text{O}$ - $\text{Na}_2\text{O}$  DIAGRAM OF MEDIUM-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE-MUSCOVITE/BIOTITE GRANITIC ROCKS

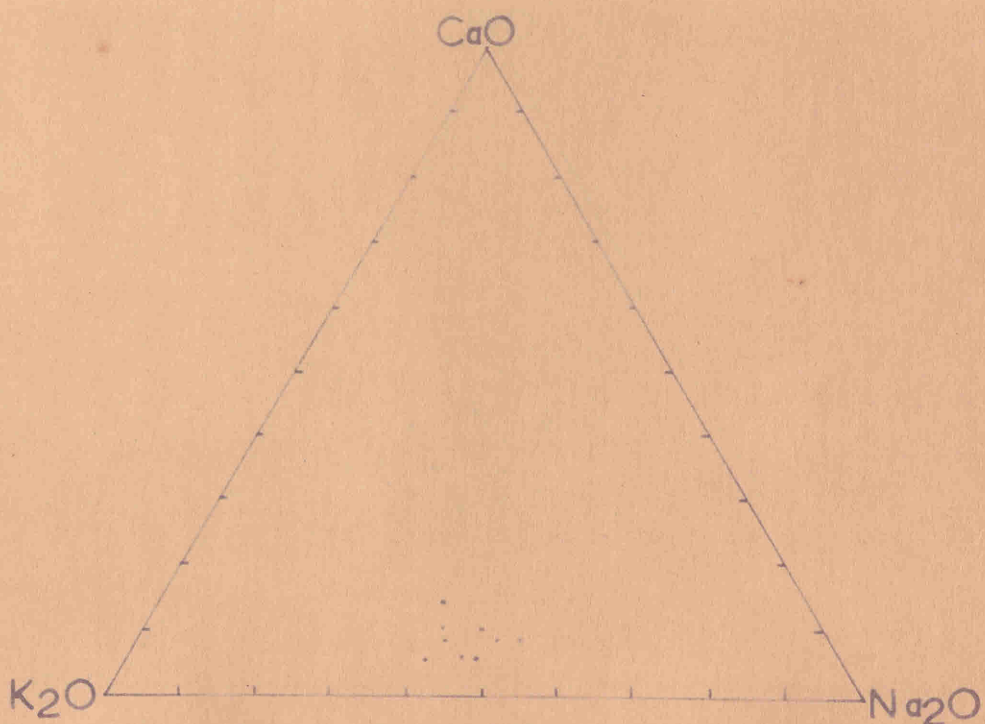


FIG. 26  $\text{CaO}$ - $\text{K}_2\text{O}$ - $\text{Na}_2\text{O}$  DIAGRAM OF MEDIUM-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE-MUSCOVITE/BIOTITE GRANITIC ROCKS

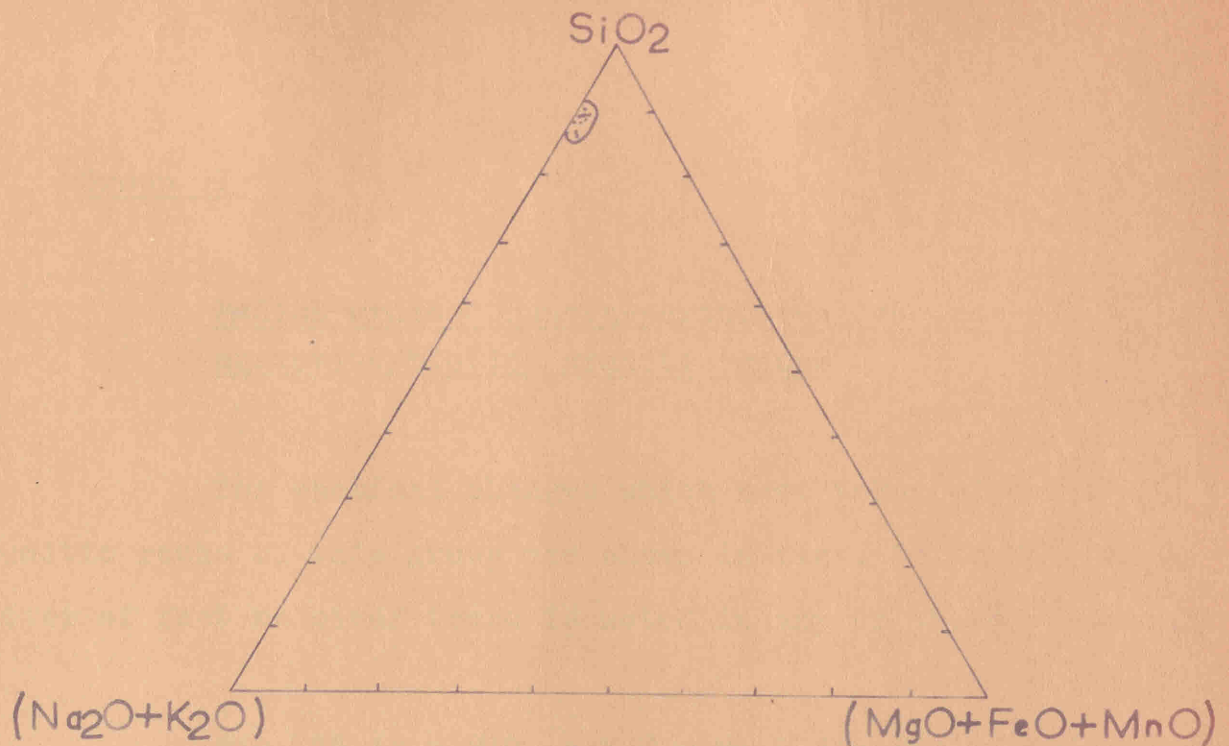


FIG. 27 SiO<sub>2</sub>-ALK-MAFIC DIAGRAM OF MEDIUM-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE-MUSCOVITE / BIOTITE GRANITIC ROCKS

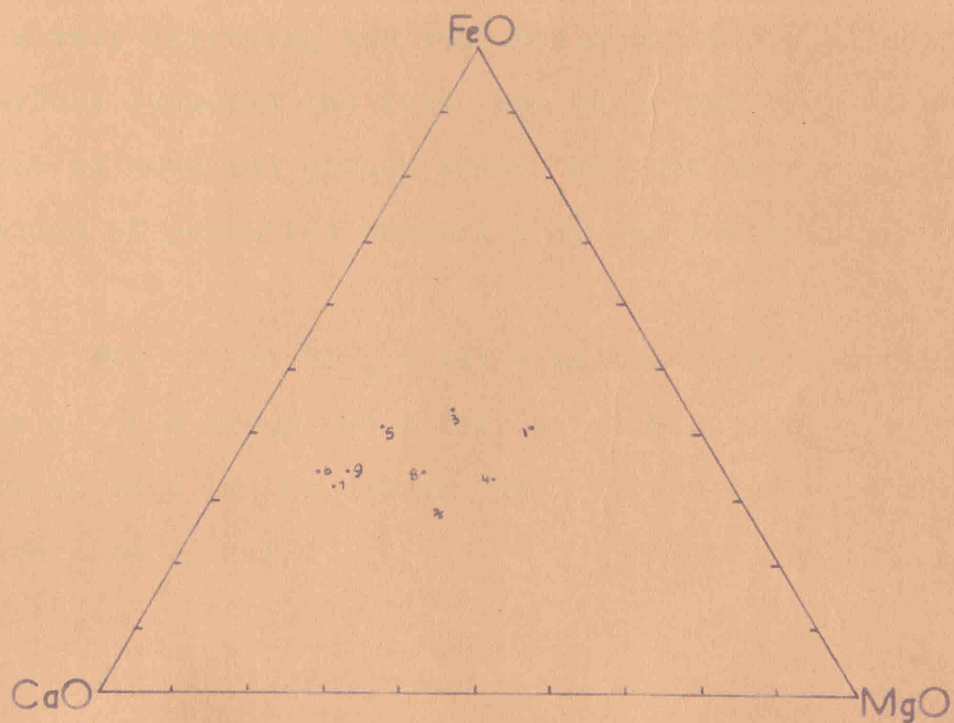


FIG. 28 FeO-CaO-MgO DIAGRAM OF MEDIUM-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE-MUSCOVITE / BIOTITE GRANITIC ROCKS

Group IVMedium-grained quartz-perthite-oligoclase-albite-muscovite/biotite granitic rocks

The chemical changes which have taken place in granitic rocks of this group are shown in figs. 25 to 28. As a matter of fact no clear trend is noted in any of these figures.

Fig. 25 is a  $\text{SiO}_2 - \text{K}_2\text{O} - \text{Na}_2\text{O}$  diagram of this group. Like the other groups, it is observed here also that no linear trend is formed except a very small field near the silica apex. Fig. 26, which is  $\text{CaO} - \text{K}_2\text{O} - \text{Na}_2\text{O}$  diagram of this group, produces a very diverging and scattering behaviour of points. This behaviour supports the view that there has been mutual replacement of soda and potash which had ultimately resulted in the formation of perthites occurring in the rocks of this group.

Fig. 27 is  $\text{SiO}_2 - \text{Alk} - \text{Mafic}$  diagram of these rocks. Once again in this group the different points cluster together in a field which lies in the extreme  $\text{SiO}_2$  corner and very close to the base line of mafic.

Fig. 28 is  $\text{FeO} - \text{CaO} - \text{MgO}$  diagram. As can be noted here the trend is not at all linear, but points are widely

scattered, denoting an oscillating behaviour. These results are very significant and they point out that the melt from which these rocks have been formed were more or less similar in composition but this oscillation, is due to the tectonic disturbances which was present during the evolution of these rocks. When the figures 26 and 28 are scrutinised in relation to figs 25 and 27, where different plots form narrow fields in the extreme silica corner of the respective triangular diagrams. This becomes apparent that in all these reactions the  $(\text{Si}, \text{Al-O}_4)$  tetrahedra has remained more or less undisturbed and whatever additions and subtractions of the cations have been taken place, have been established in the original framework of the silicate lattice.

#### Group V

##### Coarse-grained quartz-albite-oligoclase-perthite-biotite granitic rocks

Fig. 29 is  $\text{SiO}_2 - \text{K}_2\text{O} - \text{Na}_2\text{O}$  diagram of the rocks of group V, which is characterised by the assemblage quartz-albite-oligoclase-perthite-biotite. Here like the previous groups all points fall in the extreme  $\text{SiO}_2$  corner of the triangle and form a field instead of any linear trend.

Fig. 30 is a  $\text{CaO} - \text{K}_2\text{O} - \text{Na}_2\text{O}$  diagram. The trend

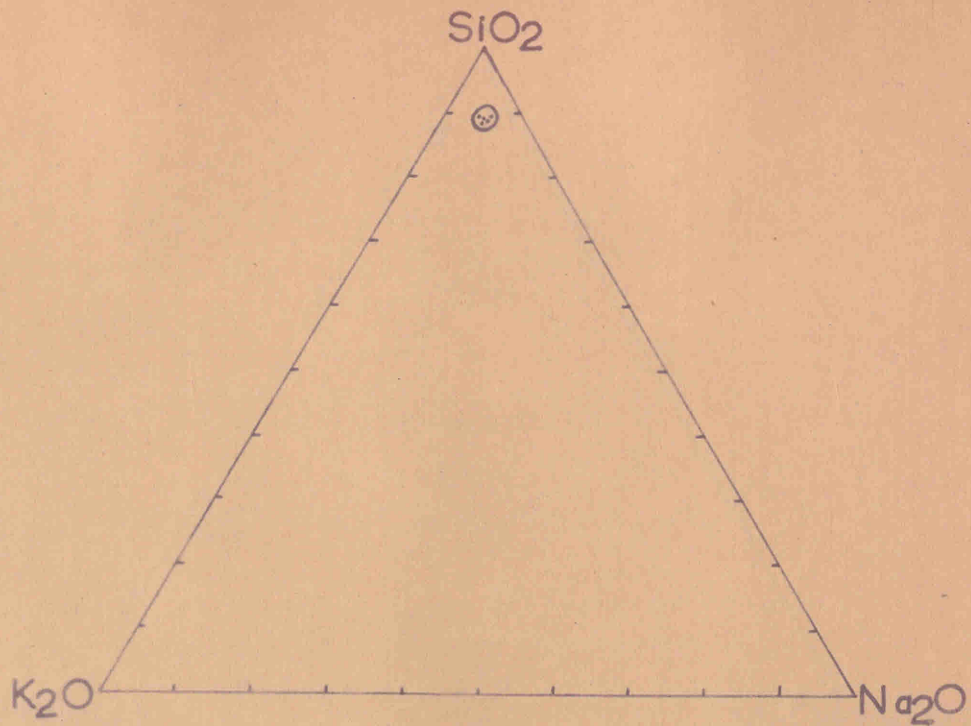


FIG. 29  $\text{SiO}_2\text{-K}_2\text{O-Na}_2\text{O}$  DIAGRAM OF COARSE-GRAINED QZ-ALBITE-OLIGOCLASE-PERTHITE-BIOTITE GRANITIC ROCKS

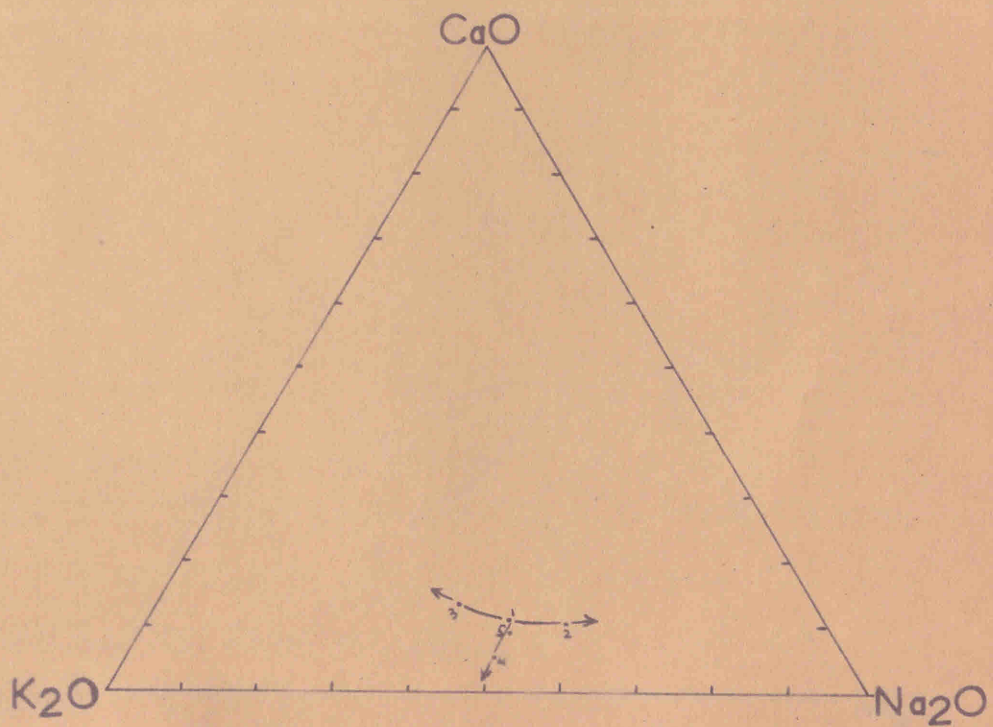


FIG. 30  $\text{CaO-K}_2\text{O-Na}_2\text{O}$  DIAGRAM OF COARSE-GRAINED QZ-ALBITE-OLIGOCLASE-PERTHITE-BIOTITE GRANITIC ROCKS

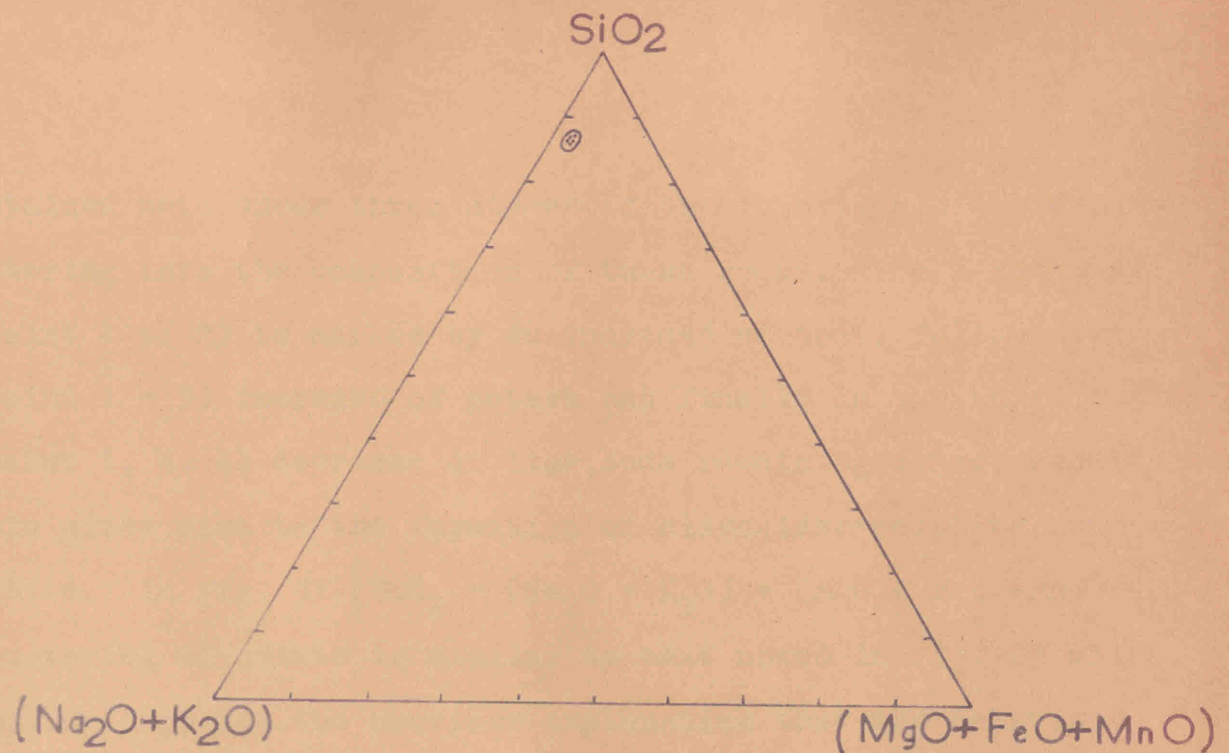


FIG. 31  $\text{SiO}_2$ -ALK-MAFIC DIAGRAM OF COARSE-GRAINED QZ-ALBITE-OLIGOCLASE-PERTHITE-BIOTITE GRANITIC ROCKS

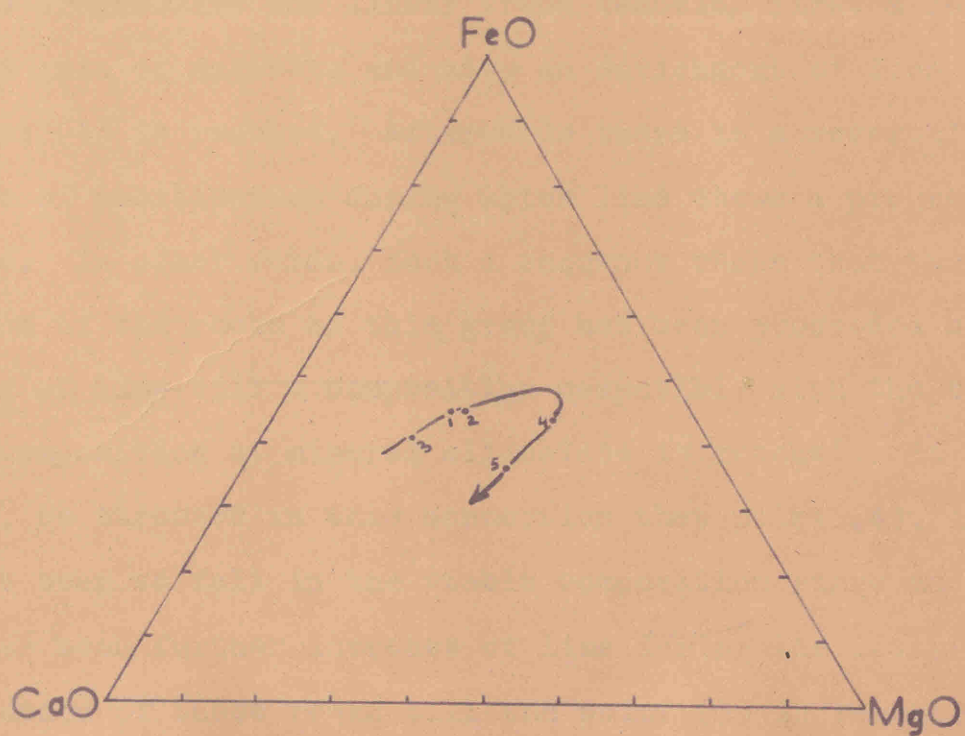


FIG. 32  $\text{FeO}$ - $\text{CaO}$ - $\text{MgO}$  DIAGRAM OF COARSE-GRAINED QZ-ALBITE-OLIGOCLASE-PERTHITE-BIOTITE GRANITIC ROCKS

obtained here shows three stages of the formation of feldspars entering into the composition of these rocks. The first stage (point 1 to 2) is marked by an increase of soda, followed by (point 1 - 3) increase of potash and finally in the third stage (point 1, 5, 4) decrease of lime, soda remaining almost constant. This gives rise to the formation of oligoclase-perthite and albite. In fig. 31  $\left\{ \text{SiO}_2 - (\text{Na}_2\text{O} + \text{K}_2\text{O}) + (\text{MgO} + \text{FeO} + \text{MnO}) \right\}$  clustering of points is similar to that noted in fig. 29 which further supports the previous explanation that the behaviour of alkalis with respect to silica is constant.

Fig. 32 is a FeO - CaO - MgO diagram. In this case there is progressive and linear trend denoting first a loss of lime and gain of magnesia and also an enrichment of iron till the point (4) is reached. Afterwards there is a reversal of the sequence of mobilisation during which lime shows a progressive increase. In other words, such a sequence shows that the formation of the rocks of this group has been proceeded by the decrease of lime till a composition compatible with the stoichiometric composition of mineral oligoclase is reached. It must, however, be stressed in this connection that point (4), in fact, does not seem to fall in the stable composition range and that there has been further increase of lime during the latter stages of evolution of these rocks till the point (5) is reached.

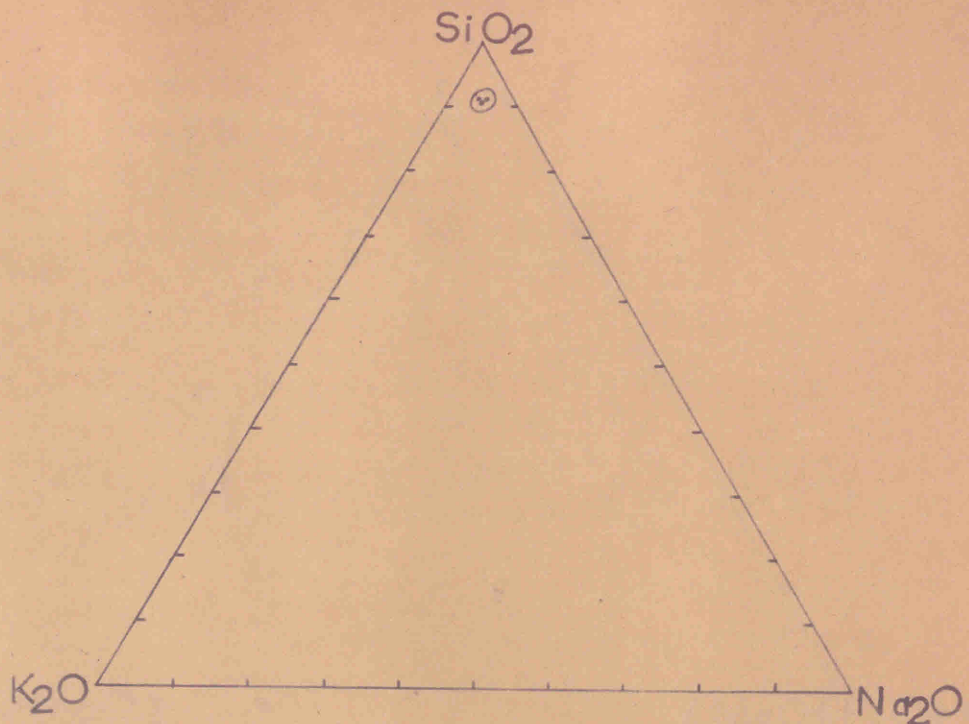


FIG. 33  $\text{SiO}_2\text{-K}_2\text{O-Na}_2\text{O}$  DIAGRAM OF FINE-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE-BIOTITE GRANITIC ROCKS

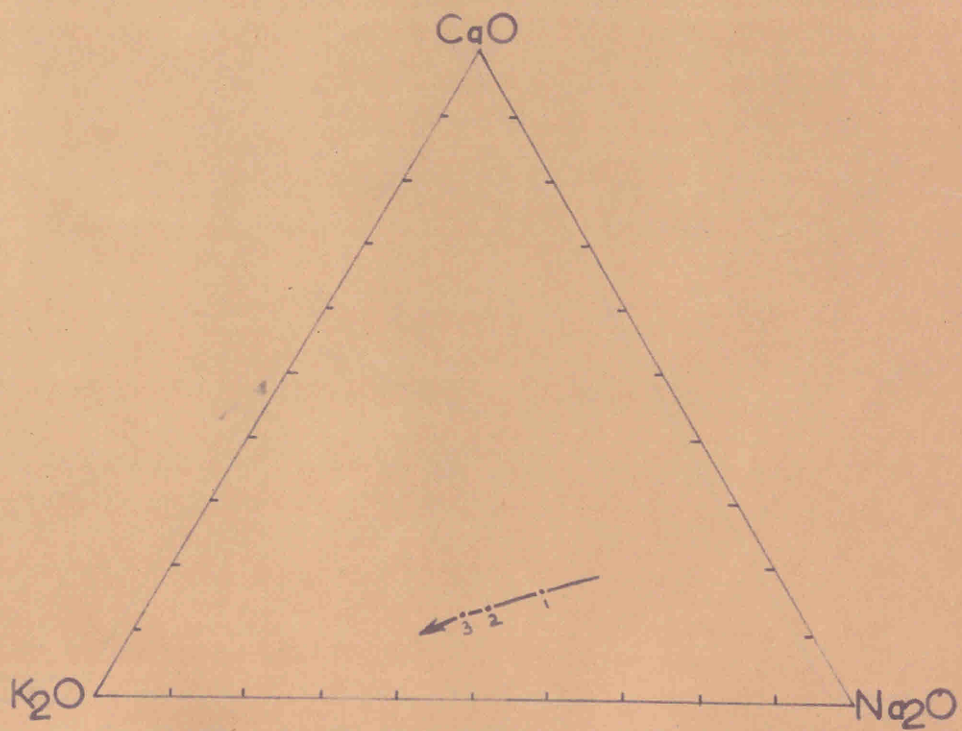


FIG. 34  $\text{CaO-K}_2\text{O-Na}_2\text{O}$  DIAGRAM OF FINE-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE-BIOTITE GRANITIC ROCKS

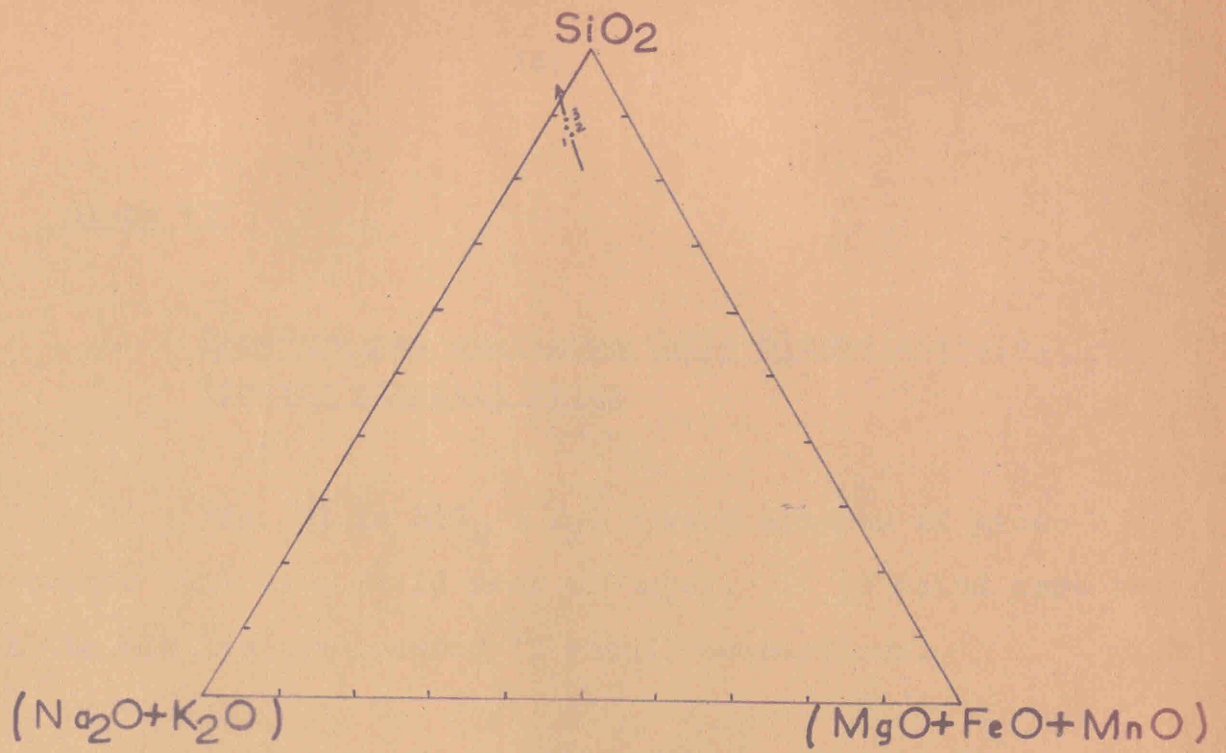


FIG. 35 SiO<sub>2</sub>-ALK-MAFIC DIAGRAM OF FINE-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE-BIOTITE GRANITIC ROCKS

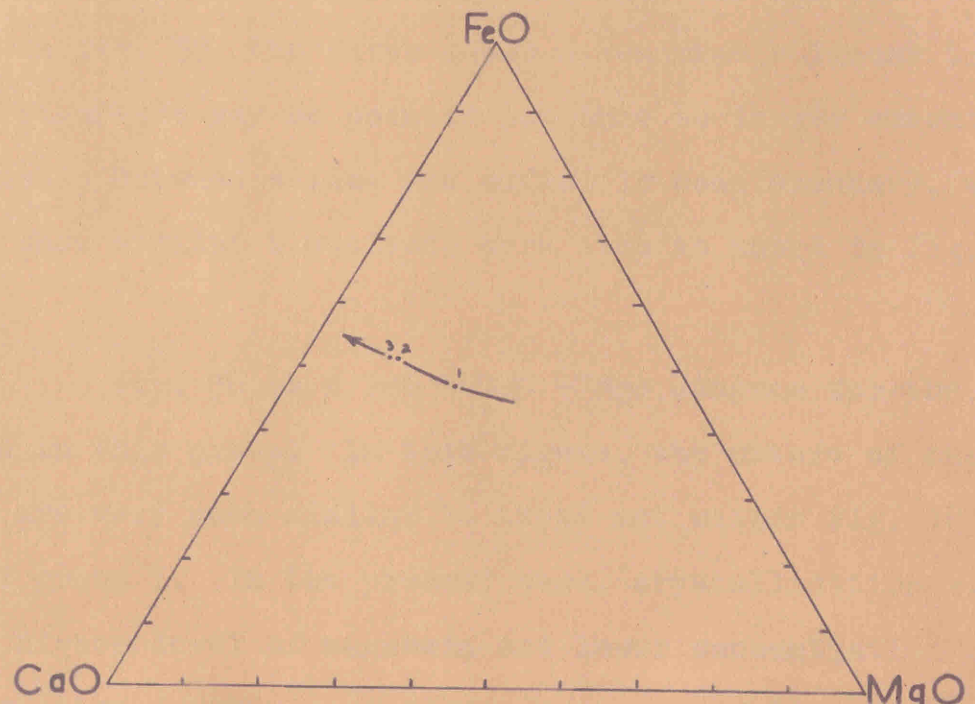


FIG. 36 FeO-CaO-MgO DIAGRAM OF FINE-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE-BIOTITE GRANITIC ROCKS

Group VIFine-grained quartz-perthite-oligoclase-albite-  
biotite granitic rocks

Fig. 33 is  $\text{SiO}_2 - \text{K}_2\text{O} - \text{Na}_2\text{O}$  diagram of group VI. The points fall in a field near SiO apex. It is noted here that both the alkalis are present in equal proportions.

Fig. 34, shows very peculiar linear trend which marks progressive decrease of lime and soda whereas potash shows an increase. The trend line, obtained in this figure, is comparable with the trend recommended for the igneous rocks. However in fig. 35, the curve shows a remarkable linear trend. In this figure, it may be pointed out that to larger extent the relationship between silica and mafic is complementary, whereas alkalis show similar attitude here also as noted in fig. 33.

Fig. 36 is a  $\text{FeO} - \text{CaO} - \text{MgO}$  diagram for the rocks included in this group. In this figure, the nature of chemical changes are very much similar to those met within fig. 16 of the rocks of group I. In the present case, crystallisation starts at much higher level of magnesia and lower concentration of iron and lime then marks a progressive increase of lime with a slight increase in ferrous iron.

Table VIII-3

Recalculated values of the averages of granitic rock groups

Group	Recalculated values for fig. 37			Recalculated values for fig. 38			Recalculated values for fig. 39			Recalculated values for fig. 40		
	SiO <sub>2</sub>	K <sub>2</sub> O	Na <sub>2</sub> O	Alk	Mafic	CaO	K <sub>2</sub> O	Na <sub>2</sub> O	Or	Ab	An	
I	88.84	4.78	6.38	10.84	2.93	12.51	37.44	50.05	31.93	61.68	6.39	
II	88.35	6.10	5.55	11.38	2.38	7.55	48.33	44.12	41.80	53.78	4.42	
III	88.77	6.35	4.88	10.90	2.92	10.04	50.81	39.15	44.56	49.13	6.31	
IV	89.62	5.44	4.94	10.23	1.39	8.20	48.09	43.72	42.05	54.81	3.14	
V	88.60	5.30	6.10	11.08	2.79	9.63	42.01	48.36	35.45	58.64	5.91	
VI	90.54	4.33	5.13	9.19	2.94	14.45	39.11	46.44	33.90	58.56	7.54	

Group	Recalculated values for fig. 42			Recalculated values		
	FeO	MgO	CaO	Qz	Or	Ab
I	39.12	25.90	34.98	25.70	25.34	48.96
II	36.19	35.45	28.36	25.94	32.38	41.67
III	42.47	27.71	29.82	28.67	33.93	37.40
IV	35.68	23.78	40.54	33.62	28.82	37.56
V	42.61	27.18	30.21	25.15	28.19	46.65
VI	49.17	15.83	35.00	36.27	23.36	40.36

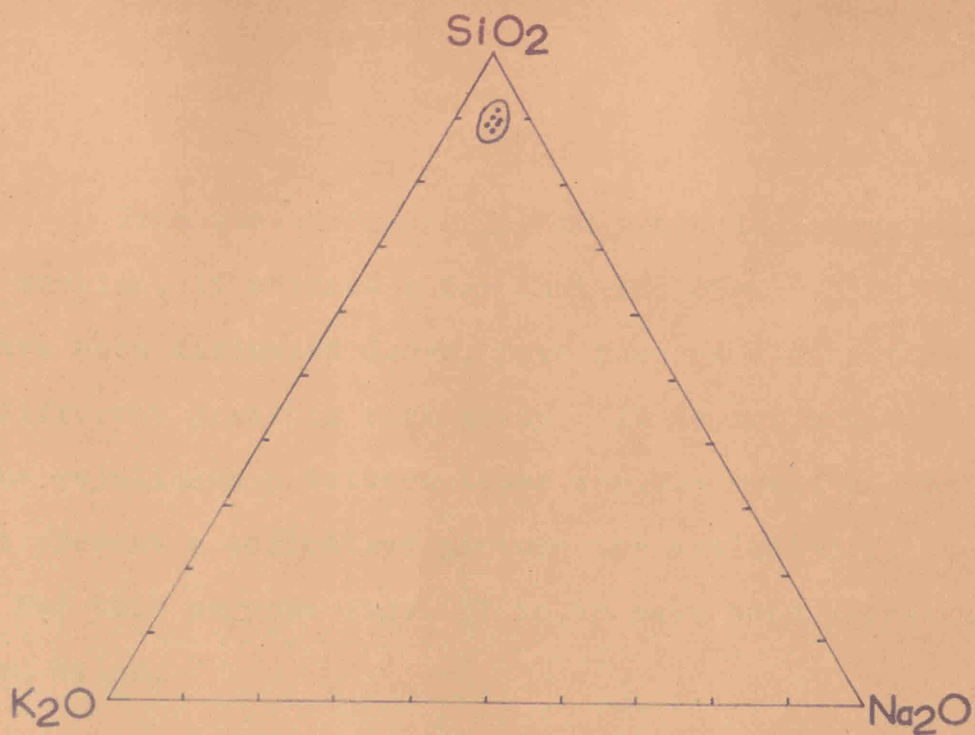


FIG. 37  $\text{SiO}_2$ - $\text{K}_2\text{O}$ - $\text{Na}_2\text{O}$  DIAGRAM OF THE DIFFERENT GRANITIC ROCKS (AV. COMP.)

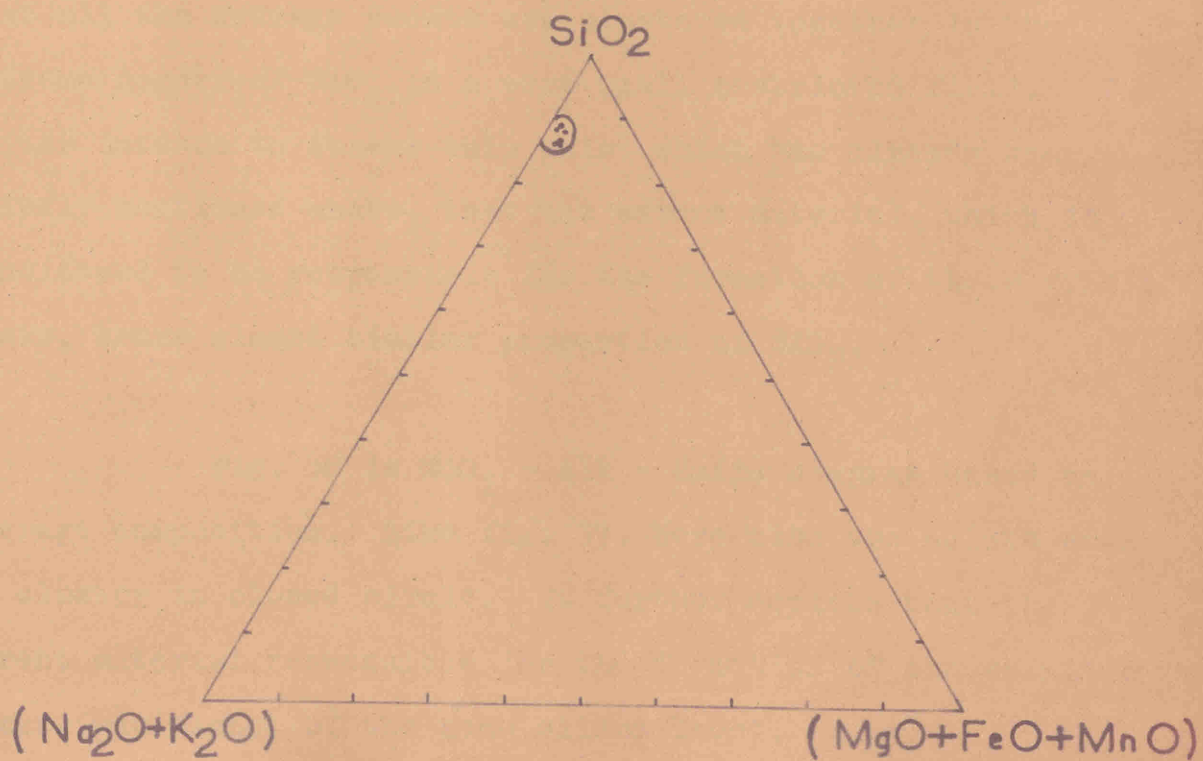


FIG. 38  $\text{SiO}_2$ -ALK-MAFIC DIAGRAM OF THE DIFFERENT GRANITIC ROCKS (AV. COMP)

From what foregoes in the preceding paragraphs of this section, it becomes clear that the chemical changes which have been discussed above, have been of different nature in the different granitic rock group. It is now proposed to study the relationship between these various granitic rock groups so as to present a collective picture the evolution of these rocks. For this purpose figs. 37 to 42 have been prepared and discussed below.

Fig. 37 is based on the average composition of all the granitic rock groups, plotted in  $\text{SiO}_2 - \text{K}_2\text{O} - \text{Na}_2\text{O}$  diagram. This is highly interesting and significant diagram as it shows that all the average points are clustered together in the extreme corner of  $\text{SiO}_2$  in a very small restricted field. The writer intends to stress this point which has already been briefly mentioned above, that the parent material, which is considered to be responsible for the formation of these granitic rocks, bears almost similar proportion of  $\text{SiO}_2$ .

Fig. 38 is  $\text{SiO}_2 - \text{Alk} - \text{Mafic}$  diagram based on average composition. Like fig. 37, here also the points seem to cluster in closed circle. It further depicts that the parent material responsible for the formation of the granitic rocks, was almost of the same silica level.

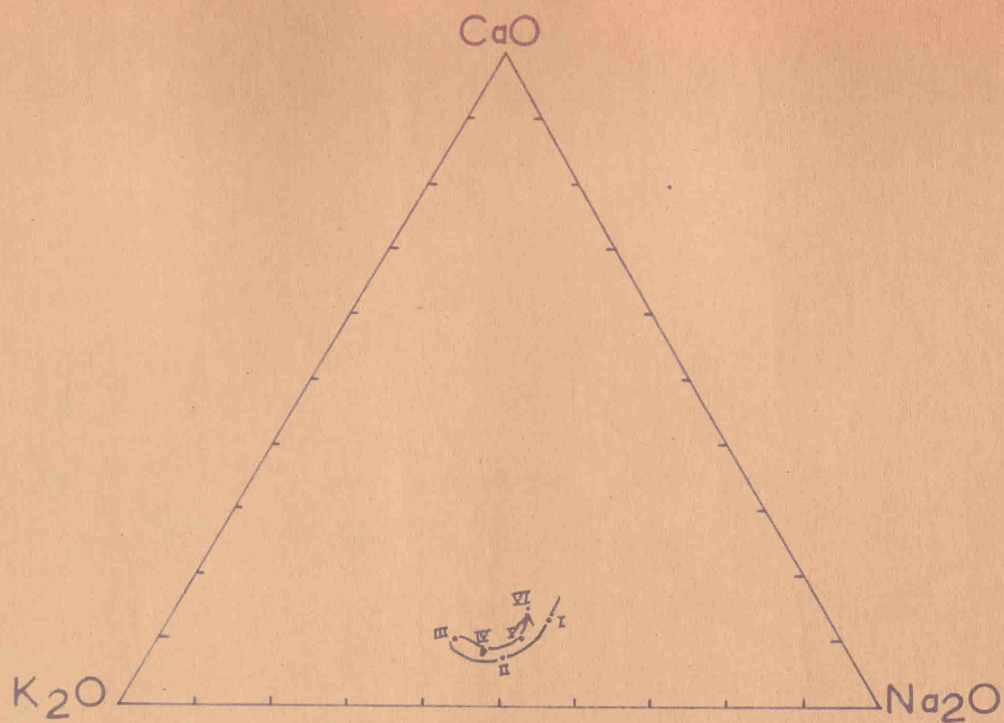


FIG. 39 CaO-K<sub>2</sub>O-Na<sub>2</sub>O DIAGRAM OF THE DIFFERENT GRANITIC ROCKS ( AV. COMP. )

- I ▲ COARSE-GRAINED QZ-PERTHITE-ALBITE-MICROCLINE-BIOTITE GRANITIC ROCKS
- II ☒ MEDIUM-GRAINED QZ-MICROCLINE-PERTHITE-OLIGOCLASE-BIO GRANITIC ROCKS
- III □ COARSE-GRAINED QZ-PERTHITE-ALBITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS
- IV ○ MEDIUM-GRAINED QZ-PERTHITE-OLIGOCLASE-ALB-MUSCOVITE/BIO GRANITIC ROCKS
- V X COARSE-GRAINED QZ-ALBITE-OLIGO-PERTHITE-BIOTITE GRANITIC ROCKS
- VI • FINE-GRAINED QZ-PERTHITE-OLIGO-ALBITE-BIOTITE GRANITIC ROCKS

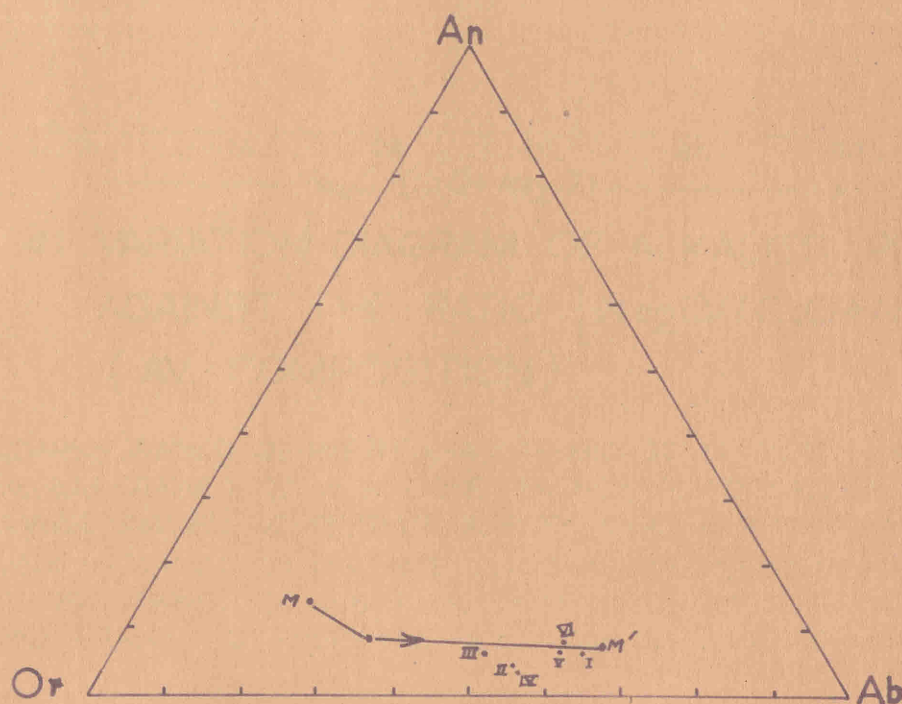


FIG. 40 NORMATIVE DIAGRAM

PLOTS OF AVERAGE GRANITIC ROCK GROUPS OF KAPLAS GRANITE MASSIF IN THE Or-Ab-An SYSTEM. THE LINE M-M' REPRESENTS EXPERIMENTALLY ESTABLISHED MINIMUM MELT COMPOSITIONS (RECALCULATED TO CATION PERCENTAGES). THE ARROW DENOTES INCREASING Ab/An RATIOS AT P<sub>H<sub>2</sub>O</sub> = 2Kb ( TUTTLE AND BOWEN, 1958; LUTH *et al.*, 1964; VON PLATEN, 1965 AND VON PLATEN & HÖLLER, 1966).

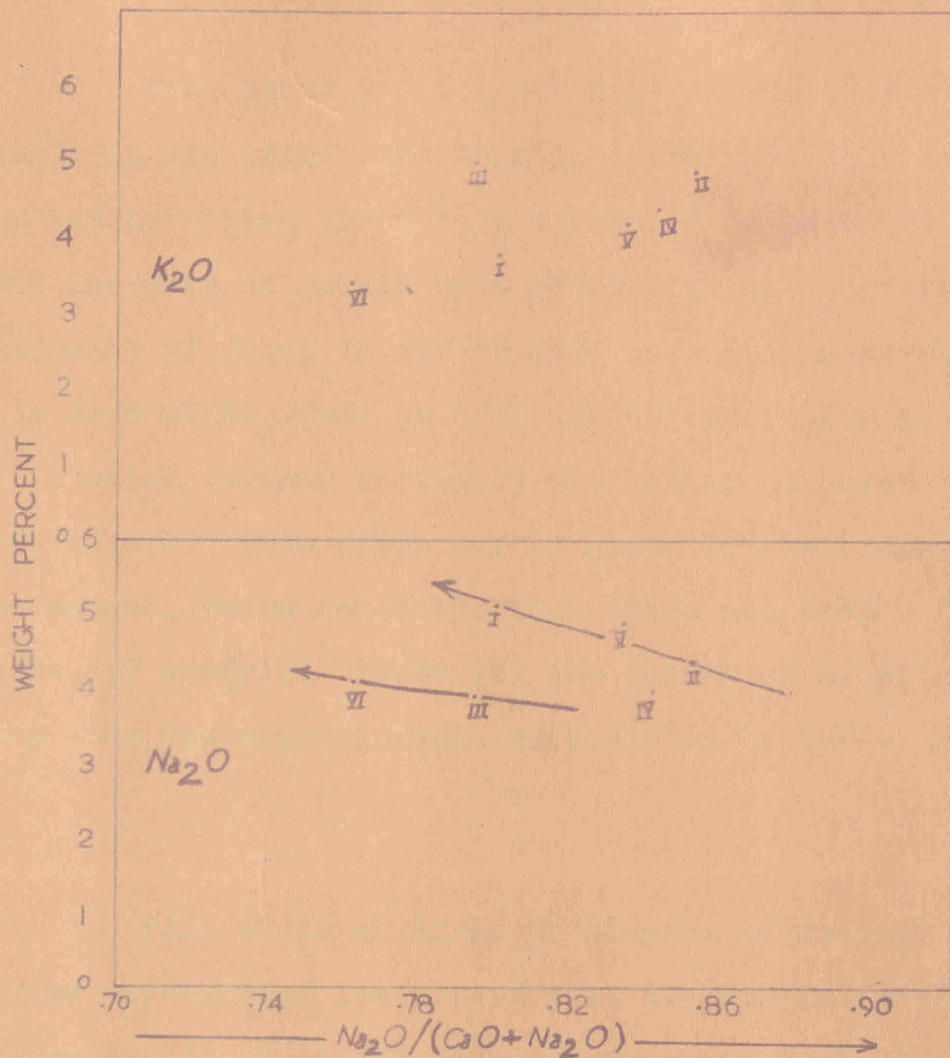


FIG. 41 VARIATION DIAGRAM OF ALKALIES PLOTTED AGAINST THE RATIO  $\left\{ \frac{Na_2O}{(CaO+Na_2O)} \right\}$  (AV. COMPOSITION)

- I  $\Delta$  COARSE-GRAINED QZ-PERTHITE-ALBITE-MICROCLINE-BIOTITE GRANITIC ROCKS
- II  $\boxtimes$  MEDIUM-GRAINED QZ-MICROCLINE-PERTHITE-OLIGOCLASE-BIO GRANITIC ROCKS
- III  $\square$  COARSE-GRAINED QZ-PERTHITE-ALBITE-OLIGO-BIOTITE GRANITIC ROCKS
- IV  $\odot$  MEDIUM-GRAINED QZ-PERTHITE-OLIGO-ALBITE-MUSCOVITE/BIO GRANITIC ROCKS
- V  $\times$  COARSE-GRAINED QZ-ALBITE-OLIGO-PERTHITE-BIOTITE GRANITIC ROCKS
- VI  $\bullet$  FINE-GRAINED QZ-PERTHITE-OLIGO-ALBITE-BIOTITE GRANITIC ROCKS

Fig. 39 is CaO - K<sub>2</sub>O - Na<sub>2</sub>O diagram, which is remarkable in its trend line starting from the rocks of group I it is noted here that there is progressive decrease of lime and soda and increase of potash upto group II which indicates that the feldspars of group II are of more perthitic nature, and then there is loss of Na<sub>2</sub>O and gain of CaO together with potash upto group III which further indicates that plagioclases of this group are more calcic. From group III to group VI the trend behaves in reverse manner, which indicates that there has been a fresh accession of soda rich liquid for the formation of plagioclases entering into the mineralogical composition of these granitic rocks.

Fig. 40 is an An-Ab-Or diagram of average normative data. The outstanding feature of this diagram is that granitic rock group I, III, V and VI lie close to the An<sub>10</sub> line, while plots of the other granitic rock groups are away from this line. In other words, the granitic rock groups I, III, V and VI seem to lie close to the composition of the original melt (**M-M'**) whereas the other granitic rocks appear to have been derived by subsequent enrichment of albite and/or orthoclase in relation to anorthite.

There is yet another way of looking at the behaviour of soda and potash than the one discussed above. Fig. 41 where oxides Na<sub>2</sub>O and K<sub>2</sub>O are plotted against the ratio Na<sub>2</sub>O/(CaO+Na<sub>2</sub>O)

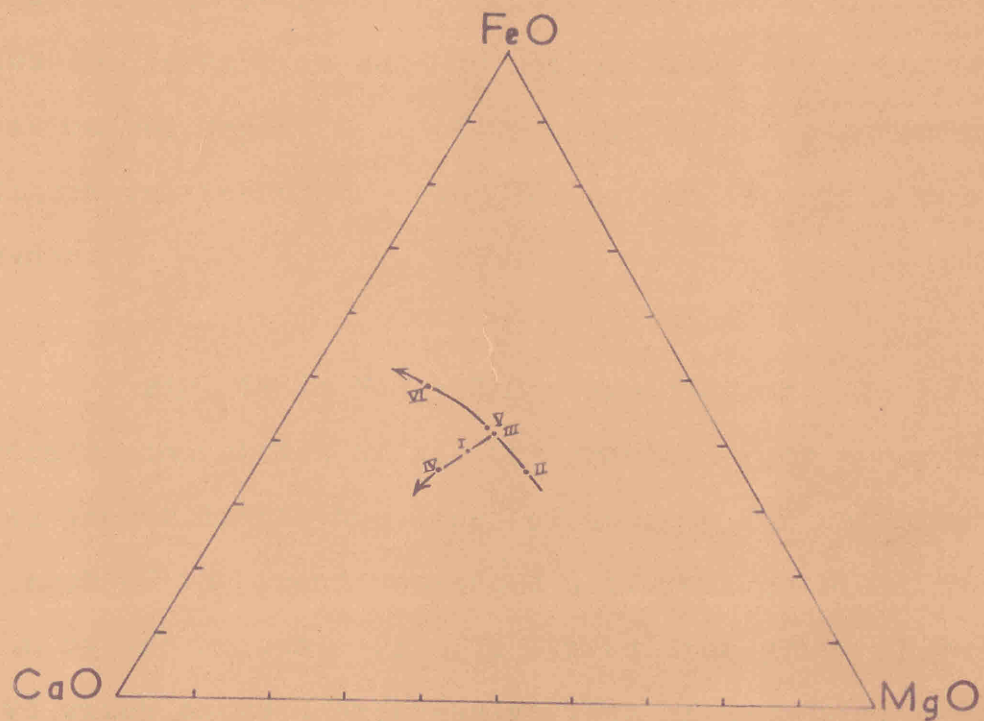


FIG. 42 FeO-CaO-MgO DIAGRAM OF THE DIFFERENT GRANITIC ROCKS (AV. COMP.)

- I  $\Delta$  COARSE-GRAINED QZ-PERTHITE-ALBITE-MICROCLINE-BIOTITE GRANITIC ROCKS
- II  $\boxtimes$  MEDIUM-GRAINED QZ-MICROCLINE-PERTHITE-OLIGOCLASE-BIO GRANITIC ROCKS
- III  $\square$  COARSE-GRAINED QZ-PERTHITE-ALBITE-OLIGOCLASE-BIOTITE GRANITIC ROCKS
- IV  $\odot$  MEDIUM-GRAINED QZ-PERTHITE-OLIGO-ALB-MUSCOVITE/BIO GRANITIC ROCKS
- V x COARSE-GRAINED QZ-ALBITE-OLIGO-PERTHITE-BIOTITE GRANITIC ROCKS
- VI  $\bullet$  FINE-GRAINED QZ-PERTHITE-OLIGOCLASE-ALBITE-BIOTITE GRANITIC ROCKS

shows average plots of various granitic rock groups. In this figure oxide  $\text{Na}_2\text{O}$  shows two trend lines. In one of the trend lines soda marks an increase from granitic rock group III to the group VI with decreasing ratio. Again at second stage a conspicuous increase in soda is noted, which indicates that there is mutual replacement of Ca by Na in the plagioclases. In this figure the behaviour noted for potash is only a related phenomenon.

Fig. 42 is FeO - CaO - MgO diagram. It is based on the average composition of all the granitic rock groups. The chemical trends denote two lines of descent for the granitic rocks, each of the trend possesses different chemical gradient as shown by the arrows. (i) It starts from group II goes to group VI which shows a progressive loss of magnesia, gain in ferrous iron and more or less constancy of lime, (ii) the trend bifurcates from the average point of group III and proceeds upto plot of group IV. In this case there is an increase of CaO and loss of FeO whereas magnesia remains constant.

The above type of fluctuating trend denotes constant struggle for equilibrium in the system.

\*\*\*\*\*  
\* III. NATURE AND MAGNITUDE OF CHEMICAL CHANGES \*  
\*\*\*\*\*

On the basis of above discussion, the present writer is in position to give certain significant features regarding the sequence of geochemical changes involved during the evolution of these rocks. These are mentioned as below.

(i) The sequence of crystallization has been of oscillatory nature.

(ii) The proportion of silica in these granitic rocks seems to be similar.

(iii) The trend line in different groups with different chemical gradients indicates the mutual replacement of potash and soda. Moreover, it has been observed in several rock groups that there has been enrichment of sodic phase over the calcic phase.

(iv) There are two stages of addition of soda denoting fresh arrival of soda-rich liquids.

(v) There are two trends of reconstitution of mafic minerals as given below :

Phase I through the process of diffusion at an elevated temperature when the phase Fe and Ca have been separated.

Phase II coincides with the fresh arrival of soda rich liquid when the earlier formed basic plagioclases have been transformed into sodic plagioclases.

(vi) Invariably during the chemical transformations the overall (Si, Al-O<sub>4</sub>) co-ordination has been maintained and the ensuing chemical transformations appear to have taken place within the framework of the original silicate structure, the changes in the latter being due to addition and subtraction of cations of different size.

The above mentioned features which are based on the present findings require a quantitative assessment of the chemical gradient of each group belonging to granitic rocks of the study area. For this purpose various diagrams have been used by different workers. It is proposed to discuss the results in the light of these in the next section.

\*\*\*\*\*  
 \* IV. APPLICATION OF EXPERIMENTAL DATA FOR \*  
 \* THE ORIGIN OF GRANITIC MAGMA \*  
 \*\*\*\*\*

The earlier views that had been held till the late fifties on the origin of granites were confined to two schools of thoughts between 'transformists' and 'magmatists'. Winkler (1958) provided much new data about the remelting of sediments, including those of graywacke composition by the process of anatexis. The term 'Anatexis' was introduced by Sederholm (1907). It is remelting of deep seated rocks which takes place at relatively low temperature,  $650^{\circ}\text{C}$  at 4 to 5 kilobar pressure. Experimental investigations by Wyllie and Tuttle, (1958, 1959, 1961a, 1961b) Winkler (1965) and Von Platen (1965) show that partial melting of clay, shale, graywacke and gneisses could produce large volume of melt of batholithic dimension in the presence of water. Melting begins in these rocks as soon the eutectic temperature is reached. The resulting melt, at eutectic conditions, is in equilibrium with alkali-feldspars, plagioclases, quartz and gaseous phase.

It is observed that granites formed anatectically cluster near the temperature-minimum (eutectic) of the system Qz-Or-Ab. Von Platen (op.cit.), Winkler (1967) and James and Hamilton (1969) have stressed the importance of 'An content in the partial melting of granitic rocks. Their studies reveal that

the addition of 'An' as a component in the "granite system" has an opposite effect to that of increasing pressure. The richer the 'An' content of the parent rocks, the greater the 'Or' content of the first liquid formed.

Melting investigations on gneisses and granites have thus led to the conclusion that the first liquid produced by partial melting is granitic in composition. With the rise in temperature about 50 per cent of the rock is melted, resulting in a progressive change in the liquid composition towards the rocks of intermediate composition (Winkler, 1967; Brown and Fyfe, 1970; Büsch, et al., 1974). It is observed that granitic magma upto  $An_{39}$  could be formed by such partial melting (Winkler, 1967; Ghose, 1974b).

#### Initial Melting at Grain Boundaries

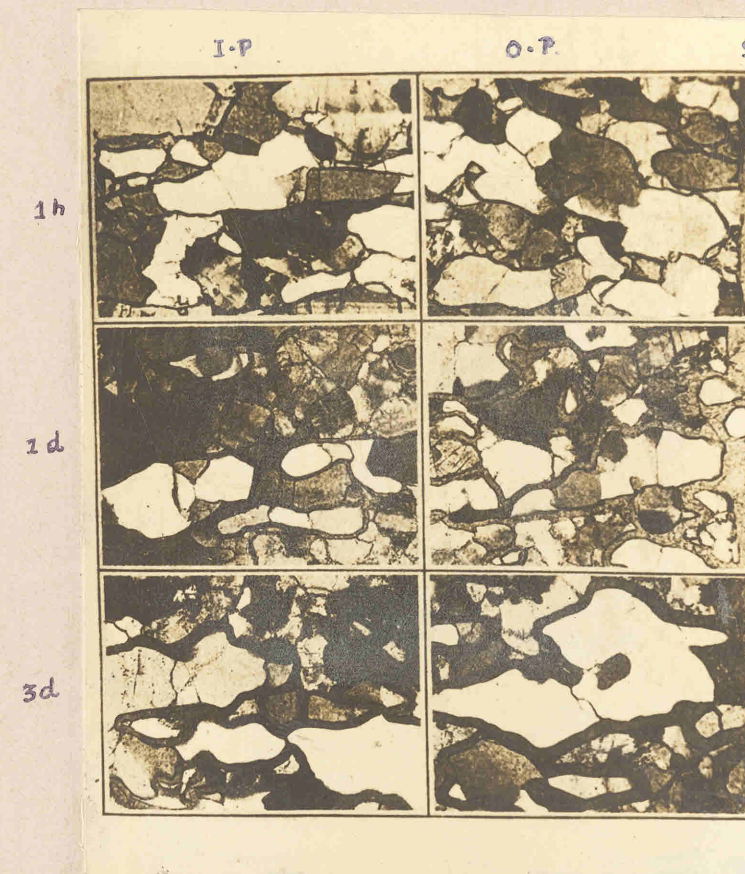
Kranck and Oja (1960) have carried out experiments on the natural rocks to see if there are any possibilities of anatexis for such rocks. The results obtained are extremely interesting and promising. First of all, during the progressive heating of quartzo-feldspathic rocks, first signs of glass are always seen at the boundary between alkali-feldspar and quartz, and slightly later between plagioclase and quartz (Plate 16). A more realistic approach of investigating the melt formed at the

Explanation of Plate 16

Sequence of hydrothermal melting experiment of a gneiss at constant pressure and temperature showing a varying degree of melting with respect to time in different parts of the samples (after Mehnert et al., 1974).

Note : The initial melting between the boundaries of quartz (clear white) and feldspar (turbid).

N.B. I.P.= Inner part.  
 O.P.= Outer part.  
 S = Surface.  
 h = hour,  
 d = day(s).



grain boundaries in various metamorphic rocks at elevated temperature and estimating the composition of the melt by microprobe analysis has been initiated by Mohnert, et al. (1973) and Büsch, et al. (1974). They ascribed that melting begins at the boundaries of quartz/alkali-feldspar or quartz/plagioclase contacts, "where the quantitative relationship  $\text{SiO}_2\text{-NaAlSi}_3\text{O}_8\text{-KAlSi}_3\text{O}_8$  allows minimum melting conditions" this is achieved, generally, at the outermost margins of K-feldspar and sodic to calcic plagioclase against quartz.

#### Phase Relationship in the Qz-Or-Ab-An System

The phase relations in the quaternary system Qz-Or-Ab-An where  $\text{H}_2\text{O}$  is at a constant pressure, have been discussed by Winkler (1967, 1974), to explain the genesis of granitic magma (Fig. 43). In this figure points  $E_1$ ,  $E_2$ ,  $E_3$ ,  $E_4$  and  $E_6$  represent binary eutectic or Qz-Ab, Qz-An, Qz-Or, An-Or and Ab-Or edges of the tetrahedron respectively. The space of the tetrahedron is divided by three cotectic surfaces. A large cotectic surface  $E_1\text{-}E_2\text{-}E_5\text{-}P$  separates the quartz space from the plagioclase space. A small cotectic surface ( $E_5\text{-}E_3\text{-}P$ ) separates the quartz space from the alkali-feldspar space. A further cotectic surface ( $E_4\text{-}E_6\text{-}P\text{-}E_5$ ) separates the alkali-feldspar space from the large plagioclase space. Accordingly, there are three cotectic surfaces along which Quartz+plagioclase + melt, Quartz+alkali-feldspar+melt and alkali-feldspar +

plagioclase+melt coexist (together with gaseous phase). These three cotectic surfaces intersect in a cotectic line P-E<sub>5</sub>, which indicates the compositions of the melts coexisting with Quartz+plagioclases+alkali-feldspars+gaseous phase. The cotectic line begins at 'P' ternary eutectic of the system Qz-Ab-Or and passes with very gentle inclination through the 'An' poor region of the tetrahedron to the ternary eutectic E<sub>5</sub> of the system Qz-An-Or. A direction P-E<sub>5</sub> of the cotectic line corresponds to increasing temperature (Winkler and Lindemann, 1972). A rise in temperature from the beginning of melting with increasing An-content under isobaric condition was also suggested by James and Hamilton (1969). As a consequence, the melt composition formed at the beginning of anatexis will be different at more advanced stage although the three solid phases still coexist with the melt. Thus, from the beginning of melting with increasing temperature, the composition of the melt will follow the direction E<sub>5</sub> at a given pressure. It is only when one of these solid phase disappears or consumed at an elevated temperature, that the melt would leave the cotectic line P-E<sub>5</sub> and proceed along one of the cotectic surfaces, e.g. quartz-plagioclase, quartz-alkali-feldspar and plagioclase-alkali-feldspar, provided the temperature is sustained. Therefore, the relative amount of three solid phases quartz-K-feldspar and plagioclase will not only decide the trend of progressive melting but also the ultimate fate of the granitic

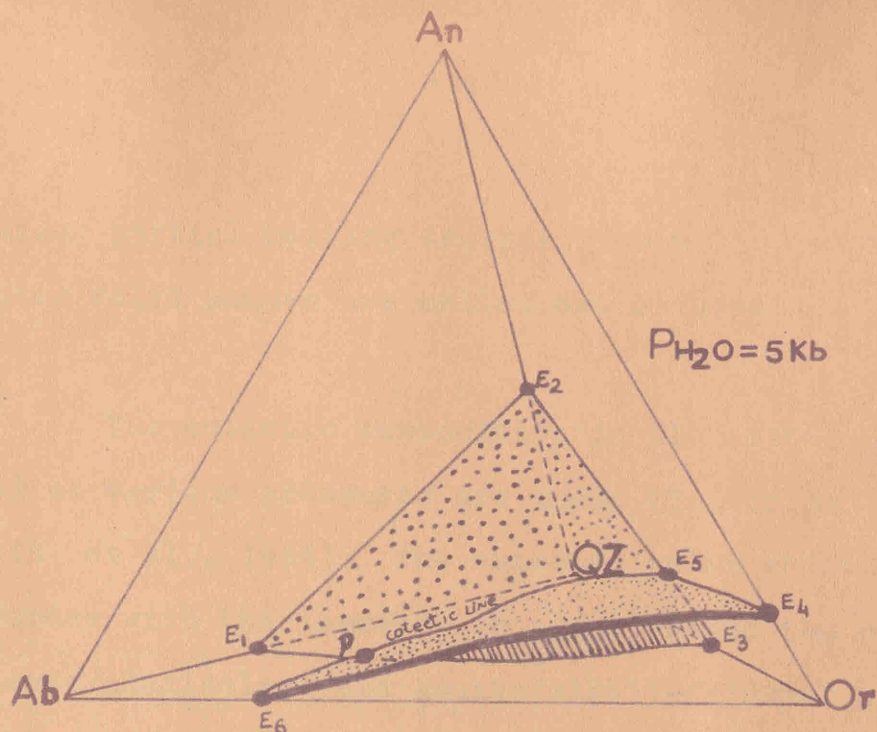


FIG. 43 SYSTEM Qz-Ab-Or-An. DIAGRAMMATIC PHASE RELATIONS AT A GIVEN H<sub>2</sub>O PRESSURE.  
(AFTER WINKLER, 1976)

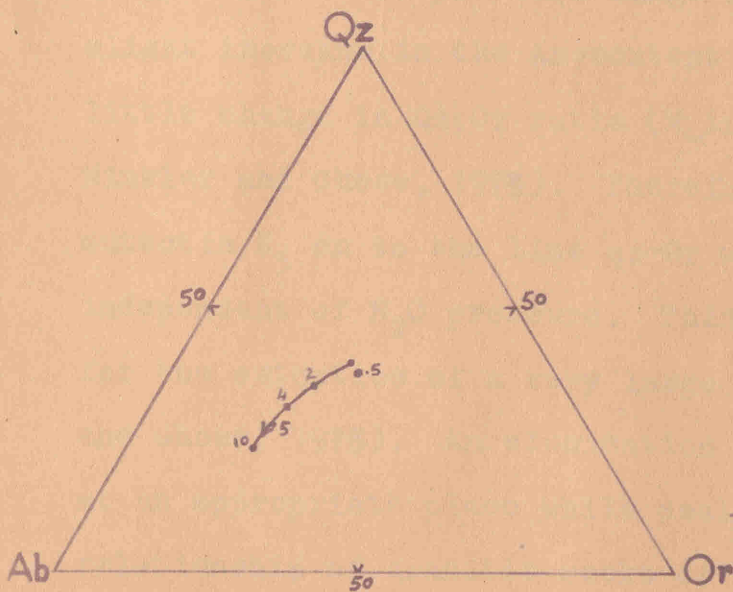


FIG. 44  
EUTECTIC COMPOSITION IN  
THE SYSTEM Qz-Ab-Or AT  
VARIOUS PRESSURES.  
(AFTER TUTTLE AND BOWEN 1958  
AND LUTH *et al.*, 1964)

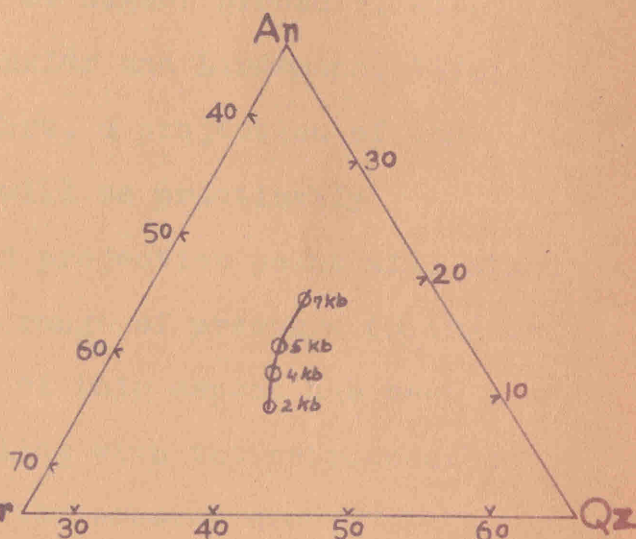


FIG. 45  
EUTECTIC COMPOSITION  
IN THE SYSTEM Qz-Or-An  
AT H<sub>2</sub>O 2, 4, 5 & 7 kb.  
(AFTER WINKLER AND LINDEMANN,  
1972 AND WINKLER & GHOSE 1973)

magma during partial melting depending upon the order in which three solid phases are melted out or used up.

The eutectic composition in the system Qz-Or-Ab (Fig. 44) at various pressures are known (Tuttle and Bowen, 1958; Luth, et al., 1964). The eutectic point shifts towards the Ab corner with the increase in pressure and the cotectic lines Quartz/plagioclase and quartz/alkali-feldspar are shifted towards the Ab-Or side.

The eutectic composition of the system Qz-Or-An (Fig. 45) for the pressure range from 2 to 7 kilobars shows a slight increase in the An-content at higher pressure, with little change in Qz:Or ratio (Winkler and Lindemann, 1972; Winkler and Ghose, 1973). Therefore, a projection of the eutectic  $E_5$  on to the line qz-Or will be practically independent of  $H_2O$  pressure. This projection point will stand for the eutectics of a very large range of pressure (Winkler and Ghose, 1973). An elucidation of this aspect has been made at an appropriate place while dealing with the petrogenetic relationship of granitic rocks of the present area.

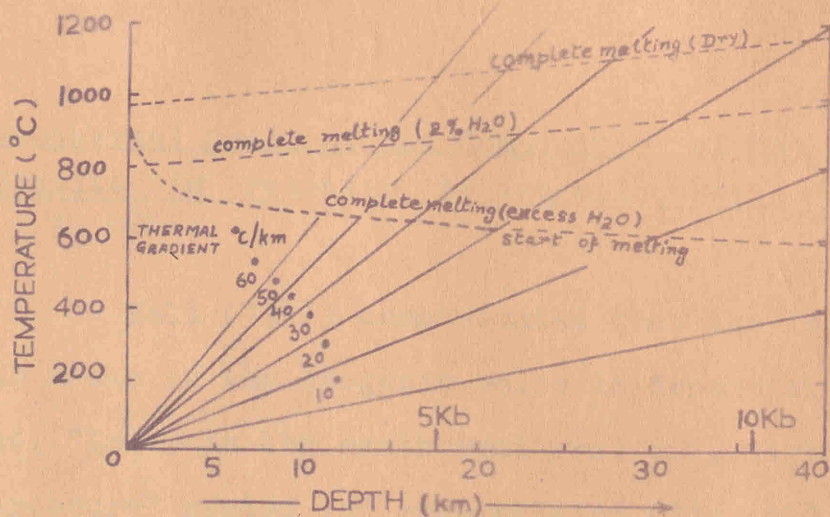


Fig. 46 The variation in melting temperatures of the minimum melting constituents of granites with pressure and depth. (After Tuttle and Bowen, 1958; Hall, 1971)

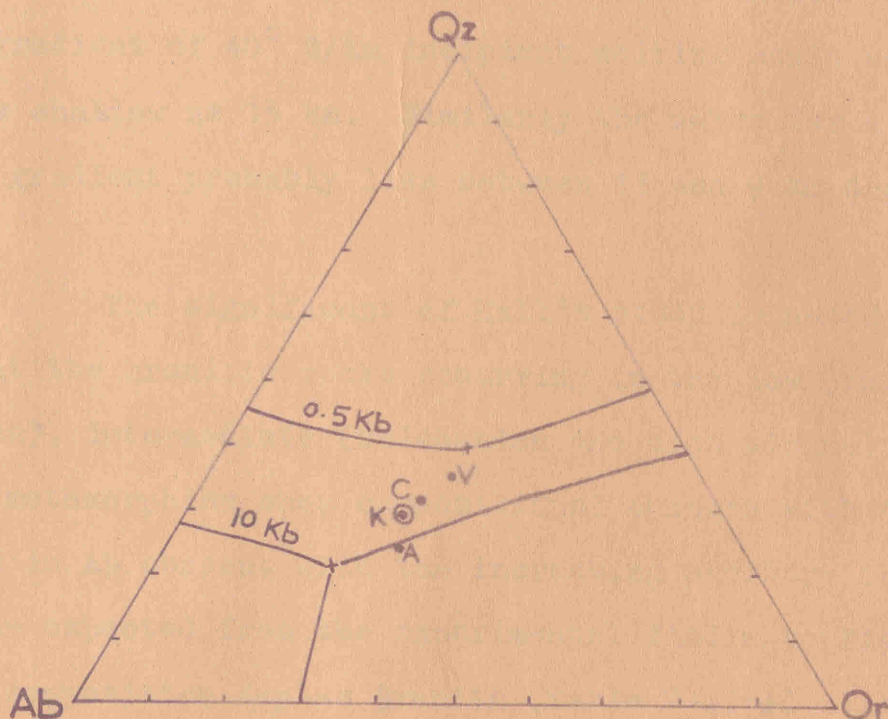


Fig. 47 Plot of the compositions of the average Variscan (V), Caledonian (C) and Alpine (A) Granite in the system Qz-Or-Ab (after Hall, 1971). Crosses indicate the isobaric minima at water pressure of 0.5 and 10 kb (Tuttle and Bowen, 1958; Luth, Johns and Tuttle, 1964). Average composition of Kaplas Granite (K) is also shown.

Geothermal Gradient and Composition of the Present  
Granite in relation to orogenic belt

Hall (1971) demonstrated that the formation of granitic rocks in the orogenic belts is dependent on geothermal gradient, "Lower is the geothermal gradient, higher is the water pressure" needed for rock melting (Fig. 46). Tuttle and Bowen (1958) estimated that with a geothermal gradient of  $30^{\circ} \text{C}/\text{km}$  the partial melting of sediments might start to yield a biotite granitic magma with  $640^{\circ} \text{C}$  temperature at the depth of 21 km. With a gradient of  $40^{\circ} \text{C}/\text{km}$  incipient melting could occur at a depth as shallow as 15 km. Similarly the value for a  $50^{\circ} \text{C}/\text{km}$  initial gradient probably lies between 13 and 9 km depth.

The significant of Hall's study is noted by the fact that the granitic rocks occurring in the low (Variscan or Hercynien), intermediate (Caledonian and high Alpine) pressure type of metamorphism show compositional changes with an increase in Ab content with the increasing pressure (Fig. 47) as to the expected from the experimental findings (Fig. 44). The average composition Kaplas Granite (Table VIII-5) plot lies in between the Caledonian and the Alpine types (Fig. 47).

Genesis of the Granitic Rocks of the Present Area

For knowing the genesis of granitic rocks of Kaplas

Table VIII-4

Recalculated values of the granitic rocks.

Specimen number	Recalculated values for fig. 48			Recalculated values for fig. 50			Normative for fig. 49	
	Qz	Or	Ab	Or	Ab	An	Plagio- clase	Colour index
R <sub>24</sub>	22.35	28.38	49.25	34.82	60.42	4.76	7.30	8.36
L <sub>13</sub>	22.84	29.17	47.97	35.39	58.20	6.41	9.92	4.27
K <sub>32</sub>	31.70	23.88	44.41	32.23	59.93	7.84	11.56	4.94
T <sub>7</sub>	24.68	23.05	52.26	29.87	67.71	2.42	6.83	8.01
B <sub>15</sub>	26.64	21.05	52.30	27.28	67.76	4.96	4.39	6.18
K <sub>52</sub>	24.45	28.78	46.75	37.05	60.18	2.76	3.46	7.39
R <sub>57</sub>	23.48	28.38	48.13	36.19	61.39	2.42	3.79	7.55
R <sub>12</sub>	23.29	34.75	41.95	44.78	54.05	1.17	2.12	4.42
R <sub>8</sub>	22.59	31.83	45.57	39.56	56.64	3.80	6.29	5.09
R <sub>21</sub>	30.57	33.30	36.11	44.54	48.31	7.15	12.89	2.94
R <sub>5</sub>	29.44	32.39	38.16	43.97	51.80	4.23	7.54	3.97
S <sub>46</sub>	30.19	34.97	34.82	47.21	47.01	5.78	10.96	7.31
B <sub>4</sub>	29.14	31.39	39.45	40.57	50.98	8.45	14.22	6.40
L <sub>18</sub>	31.01	32.43	36.55	44.36	49.99	5.65	10.15	4.53
B <sub>16</sub>	24.72	37.27	38.00	47.96	48.90	3.14	6.03	5.42
S <sub>51</sub>	24.67	36.98	38.33	47.92	49.68	2.40	4.61	4.07
S <sub>30</sub>	25.50	34.47	40.01	43.92	50.99	5.09	9.08	3.10
K <sub>55</sub>	33.41	29.25	37.33	43.34	55.31	1.35	2.38	3.94
S <sub>57</sub>	33.75	28.16	38.07	41.37	55.93	2.70	4.61	2.78
B <sub>21</sub>	38.97	25.04	35.98	39.42	56.64	3.94	6.50	2.75
T <sub>19</sub>	41.24	27.79	23.96	44.43	49.50	6.07	10.92	2.75
R <sub>52</sub>	39.03	28.40	32.57	44.98	51.59	3.43	6.23	1.87
K <sub>8</sub>	39.28	21.45	39.27	34.80	63.72	1.48	2.28	2.44
S <sub>59</sub>	28.88	27.95	23.17	37.28	57.57	5.15	8.21	2.10
T <sub>22</sub>	23.33	28.83	47.83	36.27	60.18	3.55	5.56	7.20
T <sub>8</sub>	24.42	22.70	52.87	28.27	65.84	5.89	8.21	5.67
C <sub>7</sub>	31.76	31.05	37.18	41.57	49.77	8.66	14.82	4.59
T <sub>23</sub>	25.17	30.15	44.67	39.33	58.26	2.41	3.97	5.17
B <sub>20</sub>	23.39	28.53	48.07	36.53	61.53	1.94	3.06	6.51
R <sub>30</sub>	34.20	19.97	45.81	27.70	63.53	8.77	12.13	7.49
R <sub>23</sub>	34.04	24.95	41.00	34.95	57.43	7.62	11.72	4.90
K <sub>24</sub>	40.83	25.13	34.02	39.48	49.43	7.09	11.71	4.57
Average of (Normative) plagioclase & Colour Index :							9.05	5.04

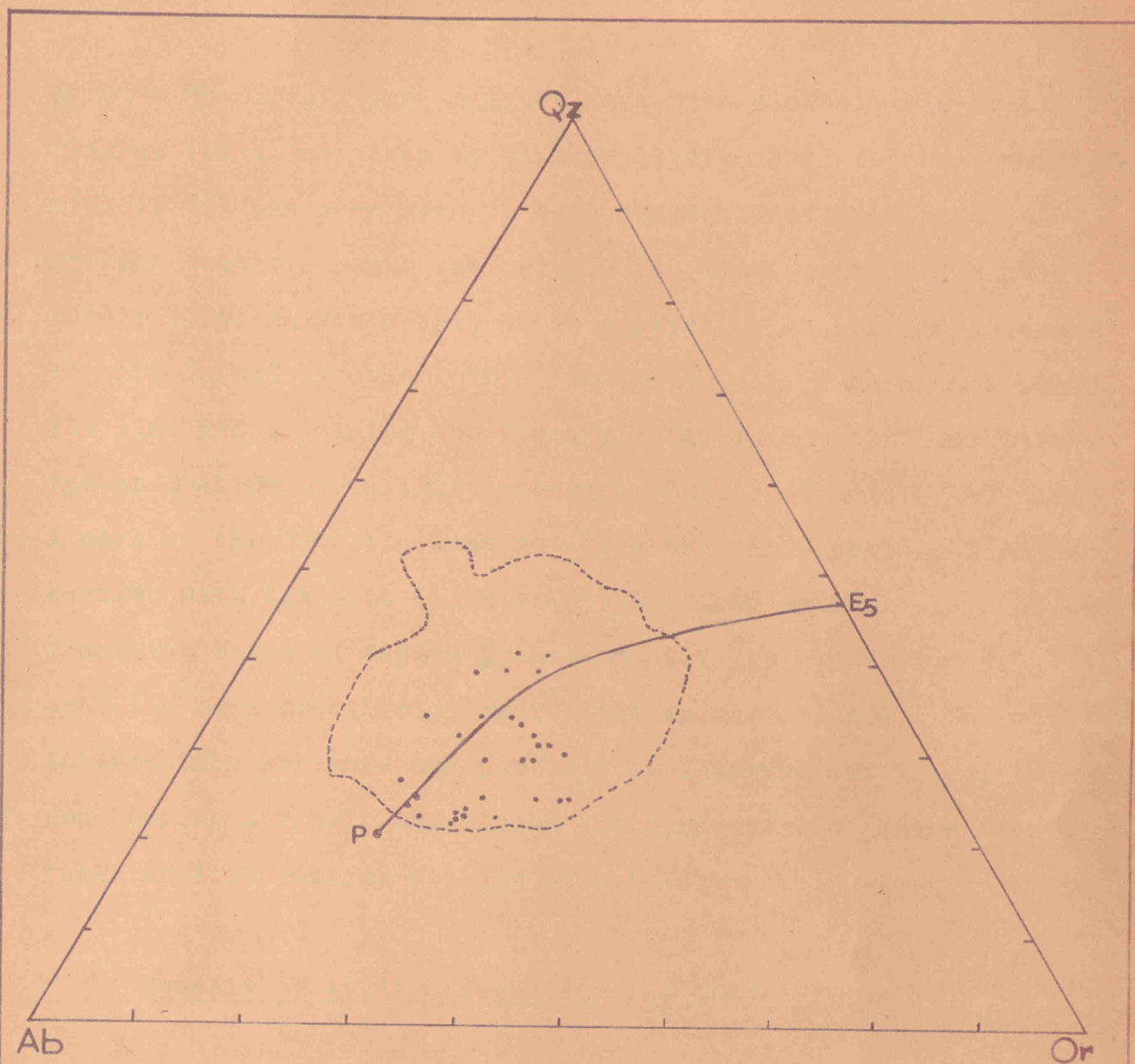


FIG. 48 Qz-Or-Ab NORMATIVE DIAGRAM SHOWING PLOTS OF KAPLAS GRANITIC ROCKS. THE DASHED LINE MARKS THE COMPOSITIONAL FIELD OF GRANITIC ROCKS (AFTER WINKLER, 1974).

Granite Massif all the analyses have been plotted in Q-Ab-Or diagram (Fig. 48) given by Winkler (1967; 1974) for the granitic system. It has been seen in this diagram that the plots of present granitic rocks fall within the close contour. Winkler (1967; 1974) suggests that it is apparent that the composition of melt formed by experimental anatexis falls within this field. The line P-E<sub>5</sub>, joining the ternary cotectic compositions in the system Q-Ab-Or at various pressures (0.5, 2, 4 and 10 Kb) forms a part of the cotectic line at which the three principal phases coexist with the melt (Winkler, 1974). The maximum plots of the granitic rocks of Kaplas Granite Massif lie close to the cotectic line relatively towards the Ab corner, i.e., formed at intermediate pressure and possibly at intermediate temperature and thereby strongly suggesting the derivation of these granitic rocks by differential melting of the tectogene.

#### Genesis of Aplite, Pegmatite and Quartz Veins

The genesis of aplite and pegmatitic quartz and quartz feldspar veins could be shown as a corollary to the above findings in the experimental data. For instance, if the Ab/An ratio of the melt becomes low enough than required for the granite composition, aplite phase is bound to appear and such a composition, will obviously be close to the main cotectic line, though nearer the Ab-corner of Q-Ab-Or diagram (Ghose and

Chakraborty, 1978).

### Role of Water in the Anatectic Melt

Besides temperature and composition of the source rock, water plays most important role for the initial melting of the rocks in the anatectic process. An earlier model suggests that intergranular fluid medium facilitates the migration of elements (Wegmann, 1935; Ramberg, 1962). However, Büsch, et al. (1974) demonstrated that migration of water takes place not only along the grain boundaries, but also along the cleavages and cracks. It was shown by these authors that melting takes places even in discontinuous parts (Plate 16) for instance, around the inclusions, occurring in the mineral grains between quartz/feldspar contacts, provided the heating is raised above the eutectic temperature and existence of quartz/feldspar contacts.

Experimental evidences indicate that solubility of water in the silicate melts increases with increasing pressure which also has a great influence in depressing the melting temperature of granite. Even a small amount of water present can produce partially anatectic rock (Mehnert 1968; Marmo, 1971), provided the original composition is sufficiently close to that of granite. Higher the temperature above the solidus and the

water content of rock undergoing melting, greater is the dimension of melt formed.

Recently, Brown and Fyle (1970) have suggested that in the absence of free water, the OH-bearing minerals of a **gneiss** supply water for the formation of melt. Thus the source of water at the lower crust are mainly by hydroxyl bearing minerals and the water released by many dehydration reactions. On the whole the following principle of formation of anatectic rocks can be established : the temperature and the water content of the crust show an inverse relationship, i.e., from the surface downward temperature increases, whereas the water content generally decreases. Thus the amount of the newly formed anatectic melt would increase at deeper levels with rising temperature, whereas the increasing water content would facilitate the formation of the anatectic melt at much higher levels.

#### Formation of Hybrid Zone on the Margins of Granite

It is generally agreed that hybrid rocks, which are developed at the contact of Kaplas Granite Massif is admixture of granitic component with the host rock, are formed at the time of emplacement by the process of granitization (Sharma, 1975). The idea of soaking of country rocks by granitic fluid is supported by Michel Levy (1893), Lacroix (1899 & 1900), Termier

(1904 & 1912), Sederholm (1907, 1913, 1923 & 1926), Wegmann (1935 & 1936), Barth (1952), Read (1957), Mehnert (1968), Pande et al. (1968) and Wakhaloo et al. (1971). These granite fluids, which are named as 'ichors' or 'granitic juices' of Sederholm and 'filter colonies' by Termier or 'emanations' by Read, have played a major role in the process of granitization of these hybrid rocks. This phenomenon has commonly been observed very close to the contact of granitic rocks with the country rock where granitic magma is contaminated with the xenoliths of host rocks, and the rocks ultimately formed from it are of hybrid origin. When such hybrid rocks are intruded by residual water rich silicate melt (pegmatite magma) show intricate ptygmatic folding resulting into the formation of migmatitic type of rocks (Plate 5,A) as seen near Khaned. The enrichment of volatile matter like boron vapour in granitic juice has given rise to the formation of tourmaline in the hybrid rock. In the microscopic study sutured margins, myrmekitic growth and inclusions of earlier minerals in the porphyroblasts of feldspar support the replacement relations between the minerals of different generations, in these rocks. Transformation of ilmenite into leucoxene has also been observed in few cases. All these facts strongly suggest that hybrid rocks were formed by admixture of country rocks and granitic rocks by the process of assimilation and granitization. According to Mehnert (1968) the process of granitization is operative till

the anatectic melt begins to migrate from the place of origin.

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 \* V. PRESENT STATUS OF GRANITIC ROCKS OF STUDY AREA \*  
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The geological history of the present area starts with the period of first sedimentation as back as late Pre-cambrian. The sediments upto late Paleozoic (Carboniferous) appear to have undergone strong folding for the first time with an orogenic movements corresponding to the world-wide Hercynian orogeny when the sediments were folded into tight isoclinal folds. This was accompanied with large scale regional metamorphism, converting the pelitic sediments to low grade slates and phyllites. The arkosic quartz-feldspathic metasediments were converted into Seawa Para-Gneiss (Sharma, 1975).

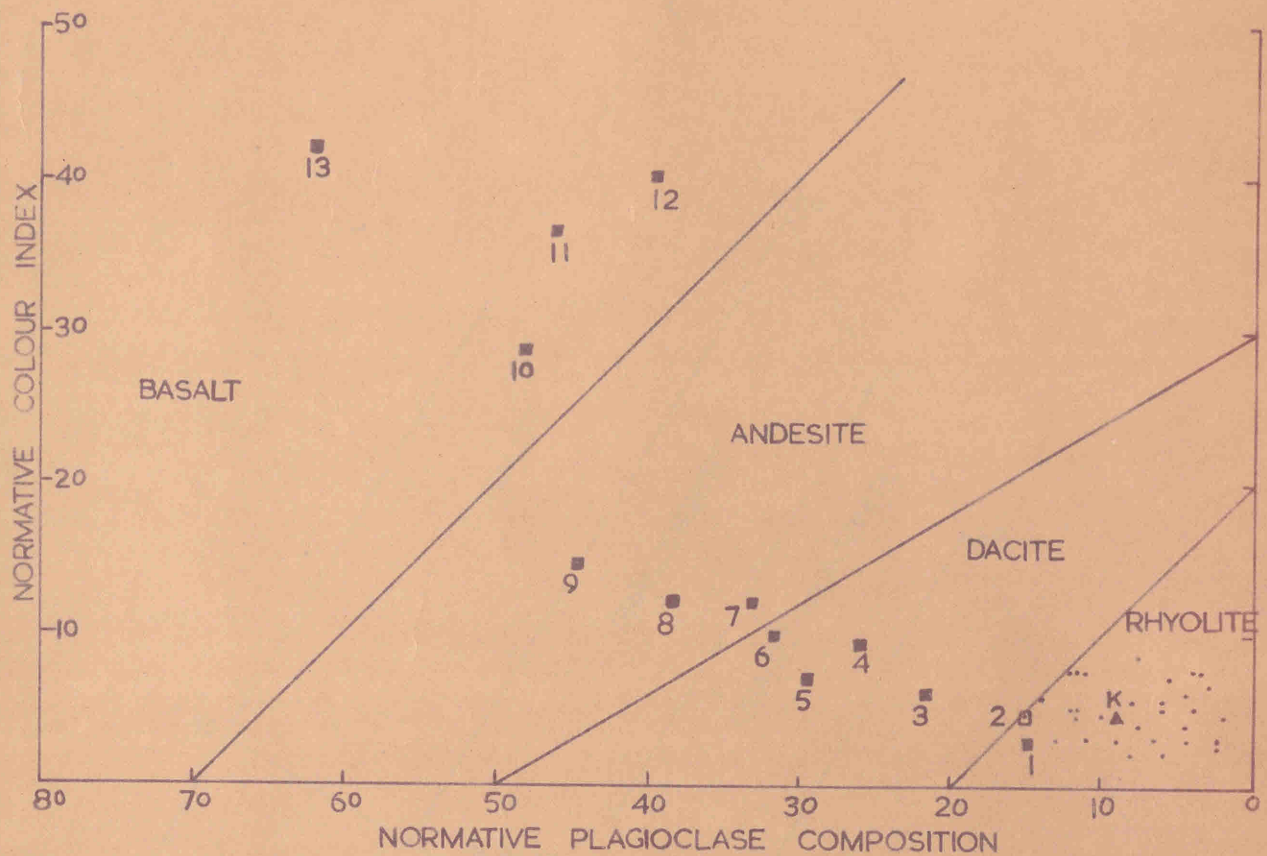
This Hercynian orogenic activity heralded the event of an anatectic phase at the deeper levels, when it has been shown that it was greatly helped both by composition (very near to eutectic) as well as appropriate temperature, and melting of the felsic followed by the mafic constituents took place.

The low melting fractions, comprising quartz and feldspars, were the first mineral constituents to be melted with the release of pressure by any diastrophic movement resulting in the formation of magma. This is in agreement with the observations

of Lacy (1960), who on the basis of laboratory investigations on granitic melts, has dealt with the structure properties and behaviour of such melt. According to him granite liquid originates at depth of 28 to 30 kms with 2 per cent initial water and thermal gradient  $32^{\circ}$  c/km at temperature about  $925^{\circ}$  c.

He further mentions that the portion of strata above the generation of the melt, acquires plasticity in response to elevated temperatures and the tectonic stresses involved in the orogeny create upward buldge below which granitic melt arises in a diapiric fashion. That anatexis was in fact a corollary to the chemical and thermal gradient, is proved by the isolated, yet large occurrence of granitic rocks in this region as a whole.

The anatectic phase was responsible for the derivation of these granitic rocks viz. the granites and aplite/pegmatite. As illustrated before, the eutectic composition after yielding the granites was soon enriched relatively in its aqueous phase resulting into relative increase in silica yielded the aplites and pegmatites. The present writer believes that the difference between different granitic rock groups is chiefly mineralogical and different degree of melting when the magma had passed to eutectic composition and, therefore, all groups are genetically related and the entire process for the formation has been one alone.



NOCKOLDS' (1954) AVERAGES: 1-BIOTITE GRANITE; 2-AVERAGE ALKALI GRANITE; 3-BIOTITE ADAMELLITE; 4-BIOTITE TONALITE; 5-BIOTITE GRANODIORITE; 6-AVERAGE GRANODIORITE; 7-HORNBLLENDE-BIOTITE GRANODIORITE; 8-AVERAGE TONALITE; 9-HORNBLLENDE-BIOTITE TONALITE; 10-HORNBLLENDE-BIOTITE DIORITE; 11-AVERAGE DIORITE; 12-AVERAGE THOLEIITIC ANDESITE; 13-AVERAGE GABBRO  
 (▲), AVERAGE OF KAPLAS GRANITIC ROCKS

FIG. 49 DIAGRAM SHOWING THE PLOTS OF GRANITIC ROCKS OF KAPLAS GRANITE MASSIF

(AFTER NOCKOLDS, 1954)

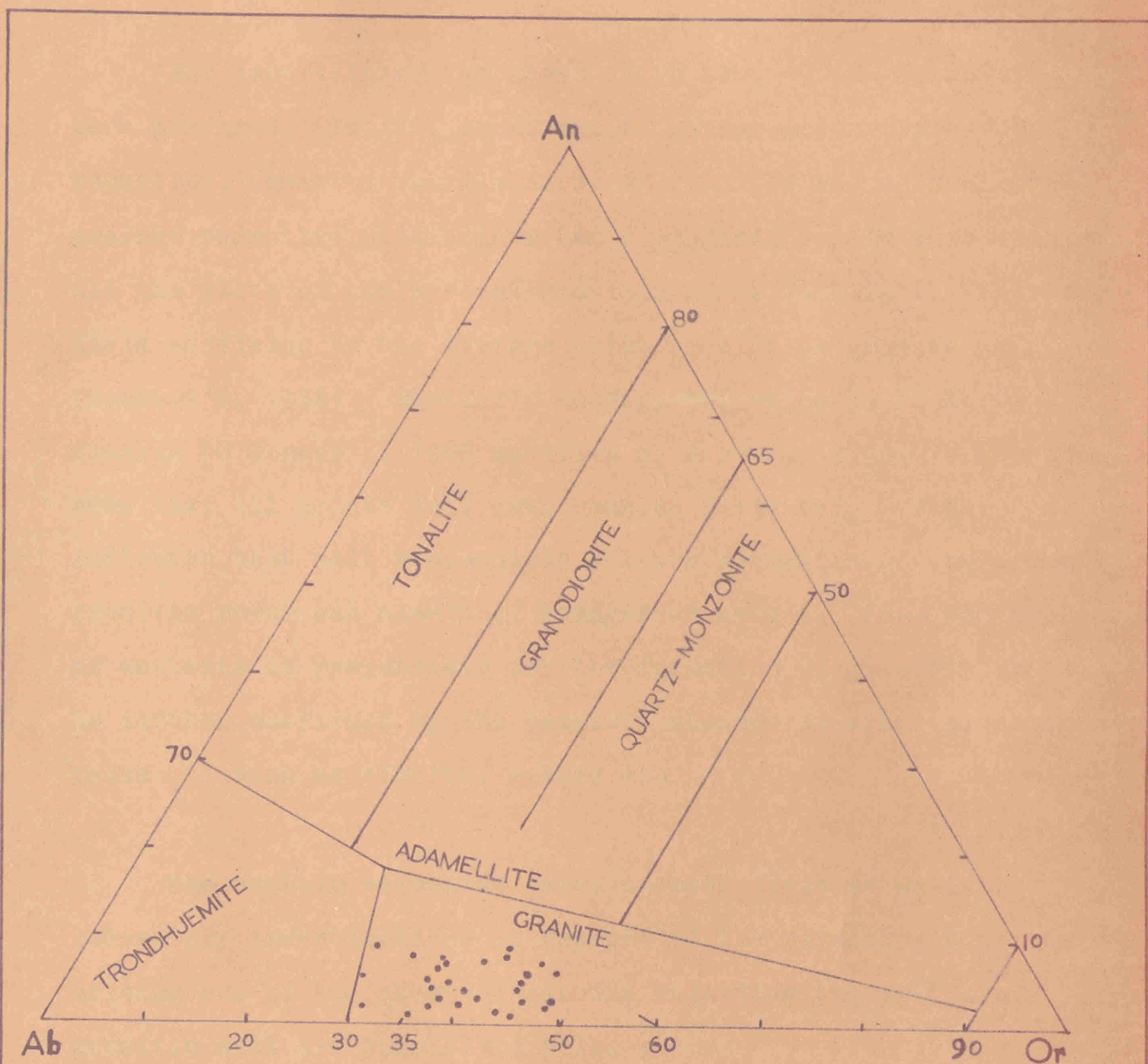


FIG. 50 Or-Ab-An NORMATIVE DIAGRAM SHOWING PLOTS OF KAPLAS GRANITIC ROCKS.

(AFTER O'CONNOR, 1965 & MODIFICATION OF BARKER, 1979)

For ascertaining the above facts fig. 49 and 50 have been prepared. In fig. 49 normative colour index (Pyrexene, magnetite, Hematite and ilmanite) of granitic rocks is plotted against normative plagioclase ( $An \times 100 / Ab + An$ ). In this diagram all the plots of the present granitic rocks fall in the rhyolite field adjoining to the average point of biotite granite (Nockold's, 1954). Similarly in fig. 50, which is An-Ab-Or diagram (O'Connor, 1965 modified by Barker, 1979), it has been seen that all points fall into granite field only. This indicates that melt responsible for the formation of the present granitic rocks was almost of homogenous nature. Thus the process of anatexis is responsible for the formation of granitic rocks is further confirmed by the complete absence of other plutonic rocks such as diorite, gabbro etc.

The certain evidences based on both field as well as laboratory investigations in support of the significant points arising out of the above discussion regarding the origin of granitic melt are summarised below :

(i) The Kaplas Granite Massif shows concordant relationship with Bhadarwah Formation and its axial elongation is along the tectonic axis, due to which they are included under the heading of synkinematic granite (Raguin, 1965).

(ii) Presence of xenoliths of country rocks (Bhadarwah Formation) in the granitic body, particularly along its marginal zones.

(iii) Presence of tongues into host rocks (near Chunchli) and apophyses and cupolas in the surrounding areas.

(iv) Formation of tourmaline along the contact between granitic body and the host rocks.

(v) Reverse zoning in few plagioclase laths.

(vi) The plagioclase feldspars show besides albite and pericline type of twinnings, the combined carlsbad-albite type of twinning and also interpenetration.

(vii) Presence of graphic intergrowth in the marginal areas.

(viii) The development of myrmekitic and perthitic and antiperthitic textures.

(ix) Presence of clouded feldspar and sutured texture.

(x) Bending of biotite, muscovite and plagioclase laths.

(xi) Presence of undulose extinction in quartz which indicate strong deformation.

(xii) Presence of sagenitic texture in the biotite.

(xiii) Presence of more soda than potash in the analytical data.

All the above referred points led to the conclusion that the generation of magma is apparently connected with the process of anatexis, which have been operative at considerable depth. Didwal (1975) in his Ph.D. thesis submitted to Jammu University has concluded that Bhala and Mundella granites, which are the cupolas of Kaplas Granite Massif, have been originated by the process of anatexis.

Therefore, in all probability the granitic rocks of Kaplas Granite Massif are synkinematic with Hercynian orogeny (Sharma, 1976). They have been derived from the partial melting of tectogene, by the process of anatexis.

\*\*\*\*\*  
 \* VI. RELATIONSHIP AND COMPARISON OF KAPLAS GRANITE \*  
 \* WITH OTHER GRANITES OF KASHMIR HIMALAYA \*  
 \*\*\*\*\*

The process goes for enough weither as Migma or as Magma,

the granitic material may move into higher levels of the crust and produce the batholithic granite body depending upon the mobility of the granitic material - there might be granites and granites. Though there may be granites and granites, some of them are of one kind and some of them are other type.

If granites are igneous then we have to consider the proposals concerning the origin of granitic magma. These proposals fall into two groups, in the first the granitic magma is primary, in the second it is derived from partial melting.

As far as Himalayan granites are concerned Ray (1972) provides that a multilayered sedimentary cover of 20 km thick overlying a single layered basement of about 40 km thick, shortened about 50 per cent during the Himalayan orogeny or orogenies. Buckling down of the crust due to thrusting of recumbent folding brought the rocks to the conditions melting of Himalayan crust, and thus melt produced granites in Himalaya (Pascoe, 1949; Valdiya, 1962; Ray, 1972).

Two major types of granites have been recorded in the Himalaya (Pascoe, 1964 and Valdiya, 1962). They are as under:

(i) Tertiary granites ; (ii) Porphyritic biotite granite, granitic gneisses related to the Hercynian orogeny

Table VIII-5

Average chemical composition of some Kashmir Himalayan granites (weight per cent oxide).

No. of Analyses Oxides	Hant	Kazi Nag	Ladakh	Kaplas
	(5)*	(3)*	(9)*	(32)*
SiO <sub>2</sub>	75.21	75.22	70.28	71.01
TiO <sub>2</sub>	0.36	0.27	0.44	0.30
Al <sub>2</sub> O <sub>3</sub>	11.91	12.91	14.57	14.67
Fe <sub>2</sub> O <sub>3</sub>	1.21	0.72	1.35	0.86
FeO	1.55	1.50	2.39	1.27
MnO	-	-	-	0.04
MgO	0.52	1.09	1.10	0.78
CaO	1.24	1.31	1.93	1.00
Na <sub>2</sub> O	3.98	4.82	3.25	4.38
K <sub>2</sub> O	3.10	2.64	3.36	4.29
P <sub>2</sub> O <sub>5</sub>	-	-	-	0.22
H <sub>2</sub> O <sup>+</sup>	0.63	0.18	0.76	0.55
H <sub>2</sub> O <sup>-</sup>	0.15	0.13	0.50	-
Normative values Recalculated to hundred				
Qz.	41.1	35.71	46.27	29.22
Or.	20.6	18.13	24.94	28.68
Ab.	38.3	46.16	34.79	42.10

Hant : Uppal(1978).  
 Kazi Nag: Gupta(1979).  
 Ladakh : Sapru(1981).  
 Kaplas : Present author.

\* Number of analyses for which average is given.

(Pascoe, 1964). Mutual exclusion on the major occurrences of these two types suggests a separation in their source of origin and a contrast between two granites is broadly as between 'Alpine type' and 'Hercynian type' granites in Europe (Zwart, 1967 in Ray, 1972).

The average chemical analyses of granites of Kashmir Himalayas has been presented in table VIII-5, wherein the average analyses of Hant, KaziNag, Ladakh granites and the granite of the present area have also been given for comparison. The salient chemical differences between these and present granite are given here. When this comparison is made with other granites of Himalayas, it is found that Kaplas granite are rich in Alumina and total alkalis.

Wadia (1934) has referred about the ring of intrusive granite bodies that encircle the area of deposition of the Paleozoic rocks of Kashmir. The granitic bodies of KaziNag and Hant form some of the important exposures of these rocks. During the course of their work on the granites of Hant (Uppal, 1977) and KaziNag (Gupta, 1979) are of the opinion that bodies are synchronized with Caledonian orogeny.

Moreover, Uppal (op.cit) Gupta (op.cit.) have proved that there is zonal arrangement of granitic rocks from the centre

(+) CROSSES INDICATE THE ISOBARIC MINIMA AT H<sub>2</sub>O PRESSURE OF 0.5 & 10 kb (TUTTLE & BOWEN, 1958; LUTH, JOHNS & TUTTLE, 1964)

AVERAGE OF

- H• HANT GRANITE
- KN• KAZI-NAG GRANITE
- L• LADAKH GRANITE
- K• KAPLAS GRANITE

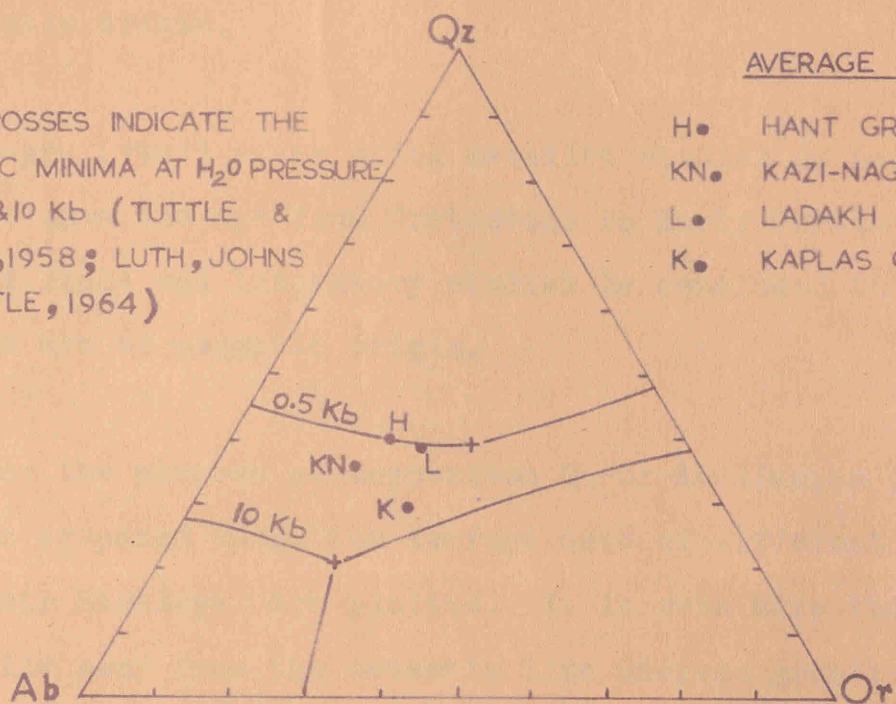


FIG. 51 Qz-Or-Ab NORMATIVE DIAGRAM SHOWING AVERAGE PLOTS OF DIFFERENT GRANITES OF KASHMIR HIMALAYA.

to periphery, where granite is in centre and granodiorite is along the periphery, in Hant and Kazinag Granite Massifs respectively. They are of the opinion that these massifs are of magmatic origin.

Sapru (1981) after doing detailed studies of Ladakh Granite, gave the age from Cretaceous to Early Tertiary. On the basis of field and laboratory studies he concluded that these granites are of magmatic origin.

For the purpose of comparison Qz-Or-Ab diagram (Fig.51) has been prepared where the average data of different granites of Kashmir Himalaya are plotted. It is seen here that all other points lie away from the cotectic line whereas granitic rocks of present area lie close to the cotectic line relatively towards the Ab corner indicating that they have been formed at intermediate pressure and possibly at intermediate temperature as well. Therefore, these rocks not only differ in their depth of formation but also in other field and microscopic evidences.

As far as field and microscopic evidences are concerned Kaplas Granite differ with other massifs because of the presence of hybrid zone along the margins of granitic body and moreover, another common difference is the presence myrmekitic texture which have not been reported from any of the above referred

granitic massifs occurring in Kashmir Himalaya .

From whatever petrographic and chemical observations made available in this work, it may be stated that though there are basic differences between the different components of the Kaplas Granite and other granites of Kashmir Himalaya, in so far as the material for all these granites has been derived from the crustal layers, they are in fact genetically related. The present differences are therefore, only related to the time, space and modus operandi of these granites.

## CHAPTER IX

### SUMMARY AND CONCLUSIONS

The present work deals with the petrological studies of Kaplas Granite Massif, named after the peak 'Kapas', falling in Kashmir Himalaya. The area under study is delimited by Lat.  $32^{\circ} 45'$  to  $32^{\circ} 55'$  N and Long.  $75^{\circ} 35'$  to  $75^{\circ} 48'$  E with an altitude ranging from 1,900 m 4,341 m above mean sea level.

It has been observed that the country rocks have been folded into a broad NW-SE anticline, the axis of which is occupied by the granitic rocks. The oldest group of rocks occurring in the present area is the Bhadarwah Formation equivalent to Lower Palaeozoics. It consists of slates and garnet bearing phyllites and is overlain by the Sunbain Quartzite of Devonian age.

Petrographic studies of the different rock types show subtle yet diagnostic variations in the different rocks. For the purpose of petrographic classification of the granitic rocks of present area, modal data has been plotted in Qz-Pl-alkali-felds diagram and was found that all plots fall in granitic field only. These rocks, therefore, classified on the basis of different mineral assemblages into six groups,

which have been described in chapter III.

The detail petrographic description of each of granitic rock group was worked out and the minerals entering into composition of these groups viz. quartz, soda-lime feldspars, alkali-feldspars, biotite, muscovite and tourmaline with magnetite and ilmenite were studied in detail.

In the present work representative samples of each rock group were analysed. In addition to the major elements, the trace element have also been determined for these rocks.

The rock analyses, while confirming to a large extent the petrographic observations, show certain significant characteristics which have been dealt within chapter of chemical characteristics and variations. It has been shown there that the behaviour of the different chemical constituents is different in different granitic rock groups. But the overall chemistry of the granitic rocks provides very revealing facts. Soda decreases with the increasing silica presents a very peculiar behaviour. On the basis of clustering type of behaviour of plots a common parentage for these rocks has been chemically indicated having almost same composition level.

When the chemical variations of the different granitic

rock groups are correlated with their corresponding mineralogy a few significant points emerge. For instance, the chemico-mineralogical correlation shows that the chemical changes, which are observed in different groups of these rocks, are directly related to the original lithology of the parent rocks prior to the formation of melt of granitic composition. Further, it has been established that a complete equilibrium in all the cases has not been attained. The present results demonstrate that in most of cases the (Si, Al-O<sub>4</sub>) tetrahedron lattice has not been disturbed to any large extent and whatever additions and subtractions of the other cations have taken place, have been established in the original framework of the silicate lattice.

Trace element studies of the granitic rocks of the present area shows certain significant conclusions. In general, the distribution behaviour of the trace elements is controlled by the corresponding major elements of similar ionic size and valence. It has been found that the relationship of the trace elements with their corresponding major elements is very limited and many a times the trace elements have their own zones of maximum concentration. The concentration of chromium and barium is more in granitic rocks than the country rocks whereas the nickel is minimum in granitic rock and maximum in the invaded rocks. On the basis of these observations, it has been concluded that granitic rocks have not been transformed from the country rocks

and the material responsible for the formation of these rocks were different than the host rocks. Further, it has been noted in the present case K/Rb ratio is low in comparison to the 'normal' K/Rb ratio of the crustal rocks. It leads to the conclusion that present granitic rocks are formed by the process of anatexis of deeper crustal material.

The field, petrographic and chemical data have been scrutinised and interpreted on the bases of different premises in the preceding chapter of discussion, where the sequence of geochemical changes have been dealt with. The important conclusions arrive at may be summarised as below :

That the chemical changes noted in particular cases are indicative of mutual replacement of potash and soda, which ultimately resulted in the formation of perthites.

That there are two stages of addition of soda denoting fresh arrivals of soda rich liquids from the depths.

That there are two trends for the constitution of mafic minerals each coinciding with the addition of soda stages.

The experimental results provide some interesting data

that lead to the conclusion that melt which has been considered responsible for the formation of granitic rocks in the present case is distinctly of anatectic origin. The experimental data fit well in the (Qz-Or-Ab) diagram (Fig. 48) and also go to prove the genetic relationship between the different granitic rock groups.

The geochemical history of evolution of the present granitic rocks has been elucidated in detail in the chapter of discussion and it has been shown there that these rocks were formed in the syntectonic period at eutectic composition and under pressure between 4 to 6 kilobar in the orogenic belt of intermediate geothermal gradient. The  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratio supports this view.

From the results obtained in the preceding section, it may be said that the major orogeny accompanying geosynclinal regions is commonly composed of several episodes of deformations and uplifts. Moreover, they also reflect the variance of transfer of heat in normal geothermal gradient with time and consequently on the nature and composition of granitic magma formed by fusion of tectogene.

Given below are the significant points which arise out of the preceding discussions :

(i) Breaking and bending of biotite and muscovite flakes, and interpenetration of plagioclase laths indicate that these have been formed from a melt undergoing tectonism. This places the granitic rocks belonging to Kaplas Granitic Massif into synkinematic group related with the Hercynian orogeny.

(ii) The presence of hybrid zone and a number of ghost enclaves of earlier rocks within the granite body are also indicative of the involvement of a melt. The zoning in the plagioclases with calcic cores supports this contention that the evolutionary trend marks stages (chiefly two) of crystallisation is an undoubted fact in support of the origin of these rocks from a melt derived from deeper crustal layers.

The average composition of granitic rocks belonging to Kaplas Granite Massif is different from the other granites occurring in Kashmir Himalaya . However, the difference seems related to the stage of development viz. synkinematic, post and late kinematic. The present writer believes that granitic rocks of Kaplas Granite Massif are only outwardly different from the other granites referred to above, while in depth they are all alike.

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\* ACKNOWLEDGEMENTS \*  
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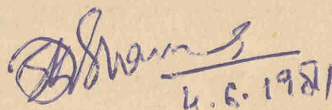
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2.6.1981

(Surinder Kumar Sharma)

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APPENDIX

Locality	Latitude			Longitude		
	o	'	"	o	'	"
Baju Bag Gali	32	53	10	75	48	05
Bani	32	42	30	75	49	00
Barnud	32	45	00	75	37	00
Basantgarh	32	48	40	75	33	00
Bhadarwah	32	59	00	75	43	00
Bhadarwahi Got	32	53	45	75	47	40
Bikindra	32	46	20	75	44	20
Bimled	32	50	16	75	42	50
Bishut	32	47	40	75	44	10
Budwar	32	45	08	75	46	27
Chhatar Gali	32	52	45	75	43	50
Chil	32	53	20	75	33	30
Chinali	32	51	15	75	35	00
Chunchili	32	47	20	75	47	37
Dabar	32	54	10	75	37	08
Deri Gali	32	42	00	75	43	00
Dinbial	32	50	15	75	45	30
Drabrhi	32	47	17	75	40	10
Dugan	32	43	50	75	45	10
Gau gali	32	49	00	75	47	45
Ghatti	35	50	28	75	48	20
Ghori Got	32	50	32	75	44	18
Gunoduru	32	55	00	75	39	00
Gurdanda	32	54	00	75	45	30
Jangilot	32	51	00	75	45	35
Jimuth	32	52	28	75	35	01
Joila	32	49	00	75	46	12
Jwalta	32	47	20	75	37	35
Kalethu	32	50	45	75	49	50

Locality	Latitude			Longitude		
	o	'	"	o	'	"
Kali Kund	32	52	15	75	39	20
Kamlogh Gali	32	45	30	75	39	30
Kanji	32	54	24	75	37	47
Kaplas Peak	32	51	50	75	41	00
Kaplas Kund	32	52	30	75	41	20
Katari-di-Gali	32	57	00	75	48	15
Katias	32	48	30	75	46	05
Khaleni	33	08	20	75	31	00
Khaned	32	47	15	75	36	00
Kharkala	32	48	15	75	47	08
Khuryari	32	54	41	75	38	15
Kudvah	32	47	30	75	36	52
Kugughat	32	52	50	75	35	05
Kuloru	32	52	05	75	37	52
Kurdwa	32	47	05	75	47	42
Langera	32	52	20	75	51	40
Loang	32	46	30	75	48	00
Lodhra	32	48	30	75	36	00
Machranth	32	45	45	75	38	30
Mang-sang	32	46	45	75	35	30
Marali-ka-Got	32	53	32	75	43	40
Markhad	32	54	20	75	48	18
Mothe-ra-Talab	32	51	30	75	49	10
Natun	32	55	00	75	46	00
Nauwa	32	51	45	75	45	15
Padri Gali	32	55	00	75	48	00
Punara	32	47	30	75	35	30
Ranmatha	32	54	00	75	35	00
Sankhni Gali	32	51	20	75	36	10
Sapnagri	32	51	40	75	45	40
Sarthal	32	50	00	75	46	45
Sawan Kund	32	48	40	75	43	00

Locality	Latitude			Longitude		
	o	'	"	o	'	"
Sunbain	32	53	10	75	46	30
Seoj or Nakka Gali	32	55	00	75	40	00
Sevijiri	32	53	38	75	36	00
Sukad	32	45	45	75	39	15
Talab Gali	32	50	00	75	51	50
Thalli	32	51	50	75	47	15
Thond	32	48	30	75	37	05
Thulpu	32	53	52	75	36	23
Tipri	32	54	28	75	43	38
Udak	32	51	45	75	48	45
Urkun	32	49	34	75	44	23
Uroda	32	45	40	75	36	45

Abbreviations of Normative Components

<u>Symbols</u>	<u>Components</u>
Qz	Quartz
Or	Orthoclase
Ab	Albite
An	Anorthite
C	Corundum
Di	Diopside
Hy	Hypersthene
Mt	Magnetite
It	Ilmenite
Ap	Ap <sup>a</sup> tite

Locality	Latitude			Longitude		
	o	'	"	o	'	"
Sumbain	32	53	10	75	46	30
Seoj or Nakka Gali	32	55	00	75	40	00
Sevijiri	32	53	38	75	36	00
Sukad	32	45	45	75	39	15
Talab Gali	32	50	00	75	51	50
Thalli	32	51	50	75	47	15
Thond	32	48	30	75	37	05
Thulpu	32	53	52	75	36	23
Tipri	32	54	28	75	43	38
Udak	32	51	45	75	48	45
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Ap	Ap <sup>a</sup> ite

