CHAPTER IV

PETROGRAPHY

In a highly metamorphosed terrane as that of Central Crystallines of Higher Kumaun Himalaya, most of the original characteristics, of the pre-existing or parent rocks have been obliterated but their mineralogy and textures reveal quite an interesting petrogenetic story. The granitoid rocks, as already stated, form an important component of these crystallines. Their petrographic details are very illuminating. They show significant variation in texture and mineralogy, and based on these factors, they are divisible into streaky gneisses, augen gneisses, porphyroblastic gneisses, granitic gneisses and granites. This nomenclature is based on a similar classification given by Merh and Vashi (1965) for the granitic rocks of Almora nappe around Ranikhet. Besides these, schists of various types including feldspathic schists, micaceous quartzites and amphibolites which are found associated with the granitoid rocks have also been studied.

About 150 fresh rock samples of varying lithologies of the study area were selected for thin section studies, collected from different horizons and locations. In the following pages a concise account of the description of few representative thin sections of granitoids and associated rocks are furnished.

PHYLLONITES AND CHLORITE SCHISTS

The phyllonites as well as chlorite schists occur in a linear narrow belt along the MCT zone. Thin section studies of these reveal the preponderance of recrystallised minerals over the cataclastic matrix. The phyllonites and the chlorite schists are typically retrograded rocks of the thrust zone indicating metamorphic downgrading of the mica schists. The main minerals are quartz, chlorite and sericite, which occur in varying proportions. Usually sericite dominates over the chlorite. The sericite rich variety has been termed as phyllonite while those which contain chlorite have been described as chlorite schists. The chlorite schists are greenish grey in colour while phyllonites are yellowish brown in colour. The quartz grains are crushed and granulated, the grain size reducing to less than 0.1 mm. The proportion of quartz, chlorite and sericite vary from rock to rock. Sericite appears to have derived from muscovite, while the chlorite is from biotite and garnet. In some sections, partly altered relict garnets are observed.

MICA SCHISTS

In most of the thin sections of mica schists muscovite predominates. However, in some thin sections biotite marks the principal mica. Muscovite sometimes shows brownish yellow tinge and feeble pleochroism, pointing to a small content of iron in it. Biotite is reddish brown in colour and shows characteristic pleochroism. In some sections, micas of two generation have been observed. Mica of the first generation is parallel to schistosity while of the second generation is oblique to it. Quartz occurs either as discrete grains closely associated with parallel flakes of micas or as segregated layers and lenses of sutured grains, alternating with or enclosed by tufts of mica. The average size of quartz grains varies from 0.2 to 0.5 mm. Some quartz grains show faint strain shadows. Unstrained quartz or those with sutured boundaries indicate recrytallization. Garnet occurs as porphyroblastic grains, varies in size from about 0.1 mm to 5 mm, and reveals interesting metamorphic data. It is pale reddish and pinkish, and is of almandine variety. It generally shows numerous tiny inclusions of quartz and magnetite arranged in various patterns, straight parallel, spiral, semicircular and random arrangements well developed crystals without inclusions are also common. Fracturing, leaching of iron oxide and alteration into chlorite are also frequently observed. Some garnets appear to have grown in two stages, and thus show the phenomenon of 'garnet in garnet'. The feldspar grains are observed in close association with quartz. The plagioclase grains show polysynthetic twinning and distinct cleavage, their An content being of about 25 % . Chlorite occurs as porphyroblasts and alteration product of biotite/garnet. The former appears to have developed during Himalayan metamorphism, while the latter is related to the retrogression that accompanied the thrust movement. Sericite is another product of retrogression having been derived from muscovite. Besides these, zircon, epidote and opaques comprise the accessory minerals of mica schists.

MICACEOUS QUARTZITES

These are medium grained rocks, composed predominantly of quartz with a subordinate amount of muscovite (Plate IV.1). They exhibit faint foliation. Quartz shows a mosaic of intergrown grains with tiny flakes of muscovite uniformly interspersed in it. The slightly elongated grains and the parallel orientation of mica flakes define the foliation. At times even skeletal garnet remains are observed along with opaques as accessory minerals (Plate IV.2).

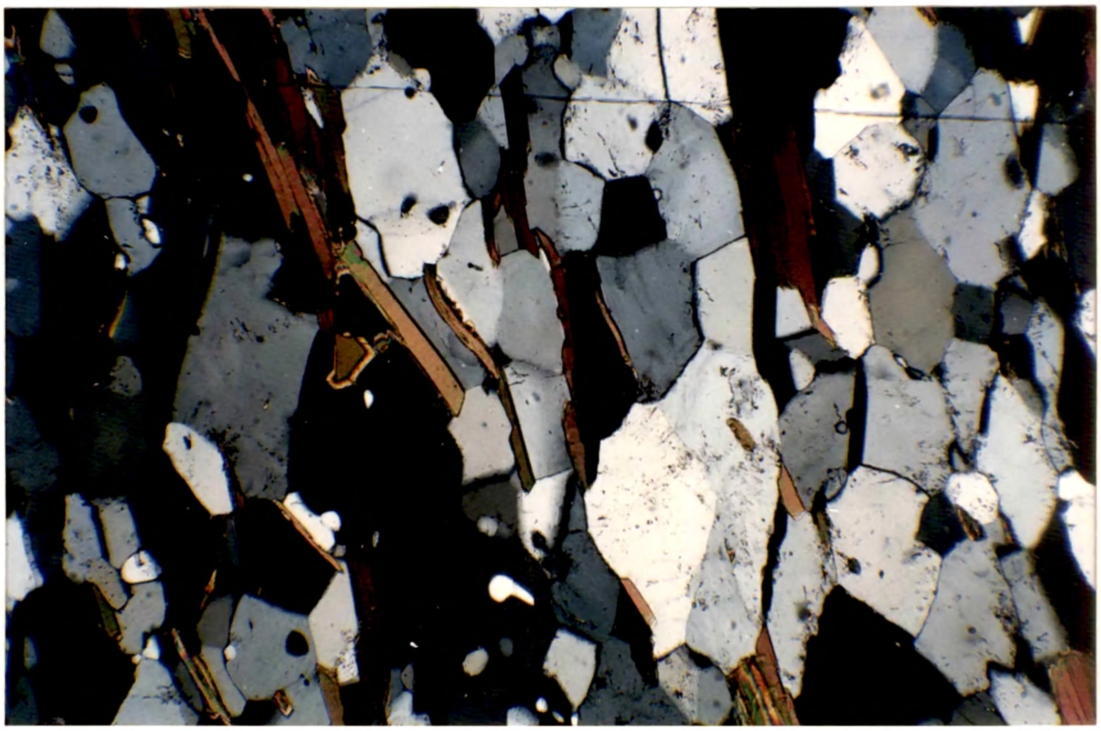

Plate IV.1 Photomicrograph showing texture of micaceous quartzite (Crossed Nicols X 60)

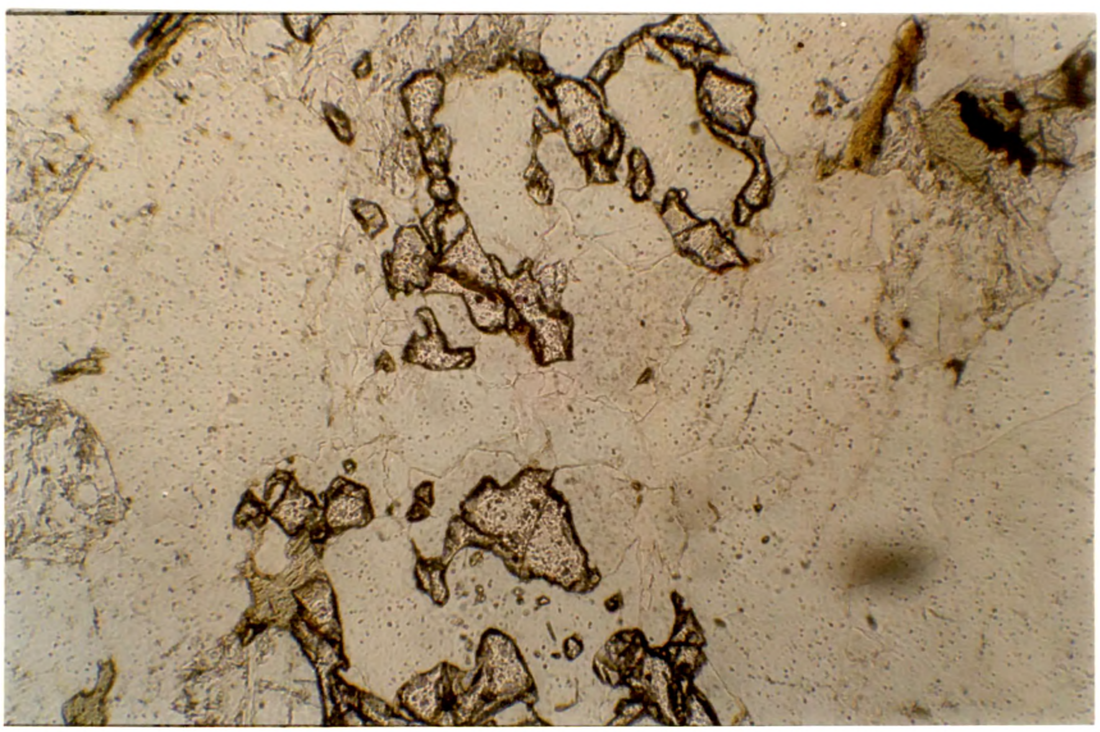

Plate IV.2 Photomicrograph showing skeletal garnets in micaceous quartzite (Plane Polarised light X 60)

AMPHIBOLITES

These are coarse to medium grained dark coloured rocks mainly consisting of hornblende, biotite, epidote, muscovite, chlorite, plagioclase, quartz and sphene. Hornblende occurs as strongly pleochroic, equant, lenticular grains. Biotite shows strong cleavage and pleochroism. Epidote group of minerals (pistacite, zoicite and clinozoicite) are almost invariably present, though in subordinate amounts. Plagioclase (An 25-50) occurs typically as equant or lenticular grains exhibiting multiple twinning. The grains are considerably saussuritized and sericitized. Quartz is mostly present but in very small proportion and always occurs interstitially. Magnetite, rutile and sphene are the common accessories.

GRANITOIDS

The granitoids constitute the most predominant rocks of the Central Crystallines (the Axial zone of Himalaya). The granitoids also form an important component of the various crystalline thrust sheets of the Lesser Himalaya, viz Almora, Baijnath, Askot, Dharamgarh and Chhiplakot, resting as outlier over the younger Himalayan metasediments. The granitoids have been classified as streaky gneisses, augen gneisses, porphyroblastic gneisses, granitic gneisses and granites.

Streaky gneisses are fine to medium grained and are highly foliated. They exhibit various deformational textures due to their nearness to the thrust zone. The augen gneisses are distinguished by the development of numerous auge of feldspar (Plate IV.3). They are medium to coarse grained rocks. The auge tend to be of larger size than the matrix and have grown by pushing apart of the foliation or by engulfing the pre-existing minerals (quartz and mica), auge of both plagioclase and K-feldspar are recorded; however the former predominates. In the porphyroblastic gneisses, the auge are replaced by well formed subhedral to euhedral grains of feldspar, most of which are of K-feldspar. Quite often plagioclase is seen being replaced by K-feldspars (Plate IV.4). The sizes of the porphyroblasts vary greatly ranging from 2 cm to 6 cm to 10 cm x 15 cm even. Most of the porphyroblasts are seen lying parallel to the foliation, but those oblique or across the foliation are also not uncommon. There is not much difference in granitic gneisses and granites, both are same but, for a very obscure and crude foliation exhibited by granitic gneisses. These are both medium to coarse grained rocks. All the above mentioned granitoid varieties are mainly composed of quartz, plagioclase, K-feldspar, muscovite and biotite. Some of the augen gneiss occurrences contain well formed garnets and blades of kyanite. Accessory minerals are tourmaline, apatite, zircon and opaques.

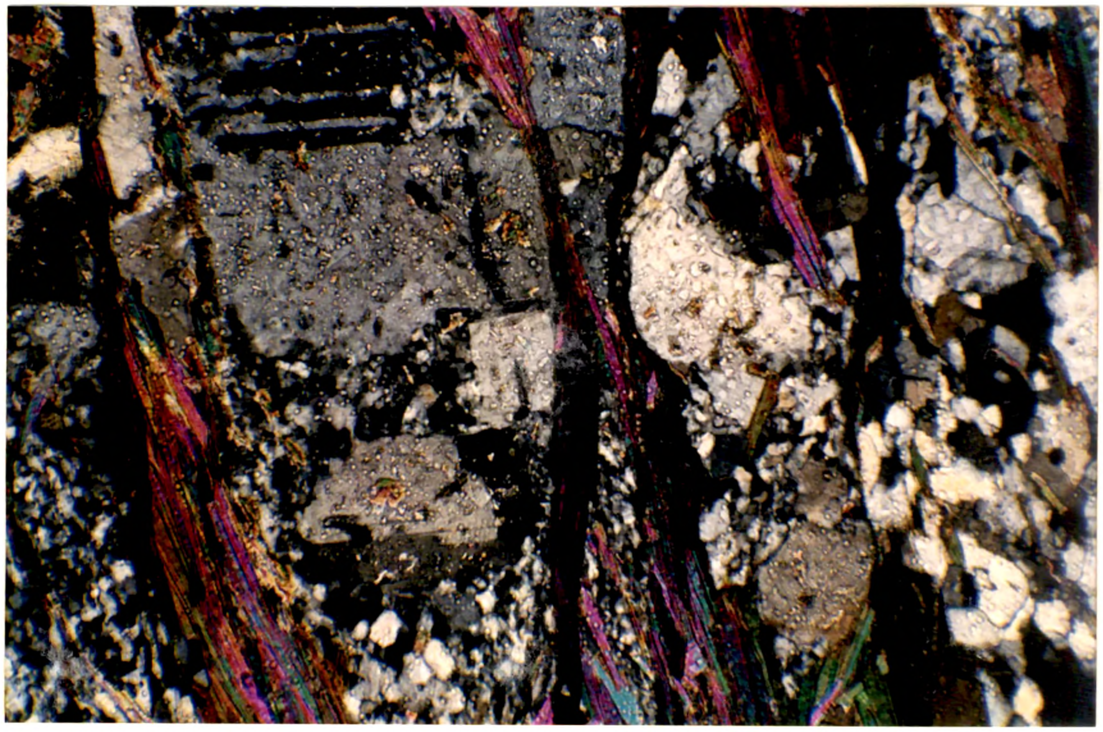

Plate IV.3 Photomicrograph showing texture of augen gneiss (Crossed Nicols X 60)

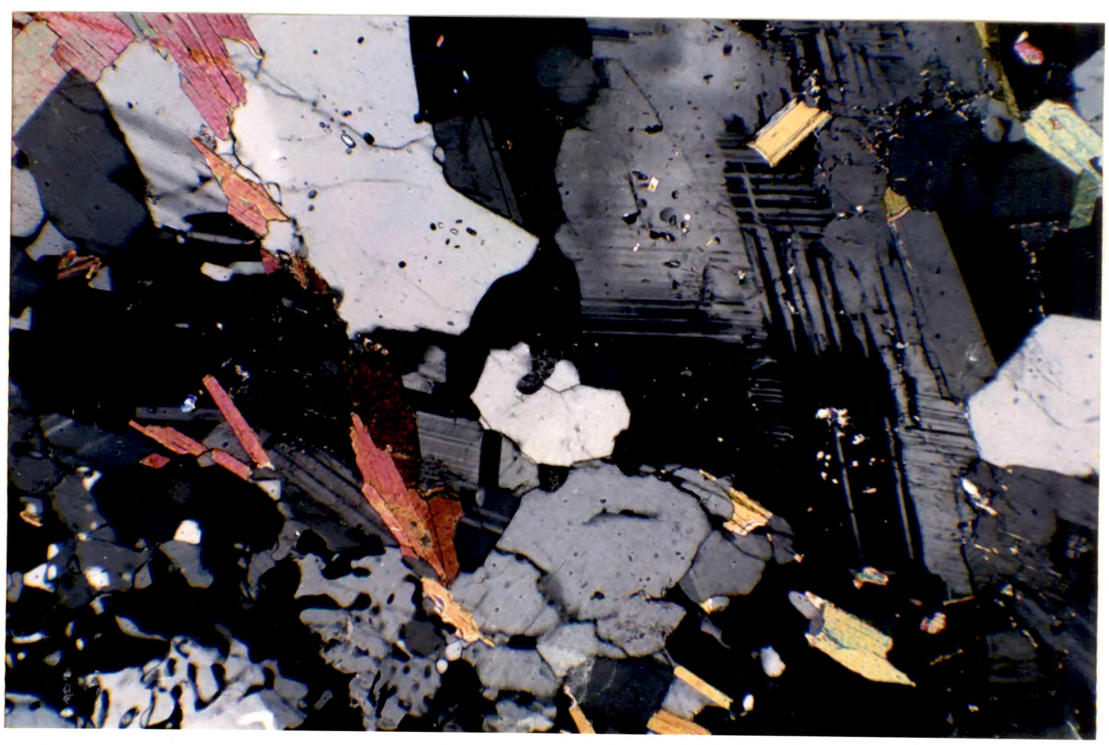

Plate IV.4 Photomicrograph showing replacement of plagioclase by K-feldspar in augen gneiss (Crossed Nicols X 60)

Quartz is the main constituent of all the varieties of granitoid rocks. It occurs as euhedral grains showing undulose extinction. Especially in the streaky gneisses it is highly pulverised and granulated, exhibiting effects of deformation. It shows sutured contact with adjoining mineral grains (Plate IV.5). In the augen, porphyroblastic and granitic gneisses, it is found arranged parallel to the main schistosity. It also occurs as inclusions in plagioclase and K-feldspar as well as in garnet porphyroblasts and represents the original quartz. Quartz formed subsequent to metamorphism and granitisation shows preferred orientation with it's longer axis parallel to the foliation. In augen and porphyroblastic varieties this quartz shows undulose extinction and development of deformation lamellae. The original granulated quartz has often recrystallised into large clear crystals. While recrystallising often, it has intergrown with the adjacent sheared plagioclase resulting into myrmekitic intergrowth. In gneisses it exhibits strain shadows and also interlocking boundaries with adjacent mineral grains (Plate IV.6).

Plagioclase forms a major constituent of salic minerals and is seen as subhedral grains. Often it is found as tiny grains around K-feldspar phenocrysts. Generally plagioclase shows diffused margins with muscovite and biotite and is observed slightly altered to colourless mica (Plate IV.7). The anorthite content varies between 20% to 35%. No zoning is observed however it exhibits polysynthetic twinning. The effect of deformation on plagioclase

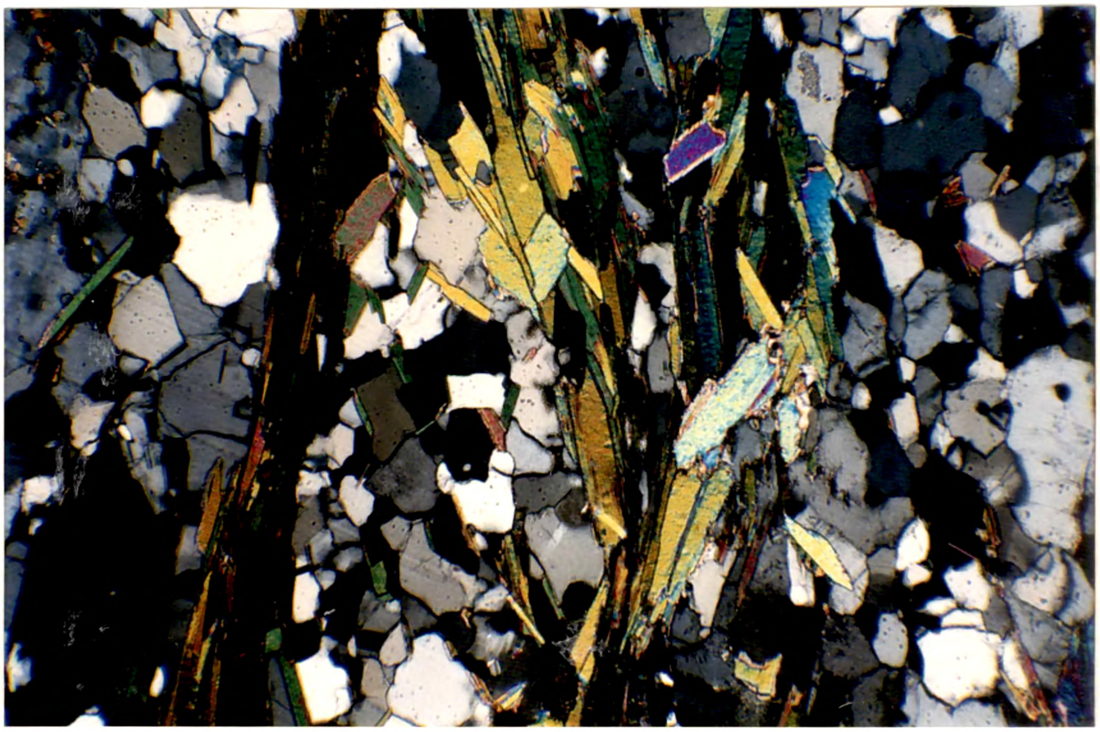

Plate IV.5 Photomicrograph showing sutured grain contacts in augen gneiss (Crossed Nicols X 60)

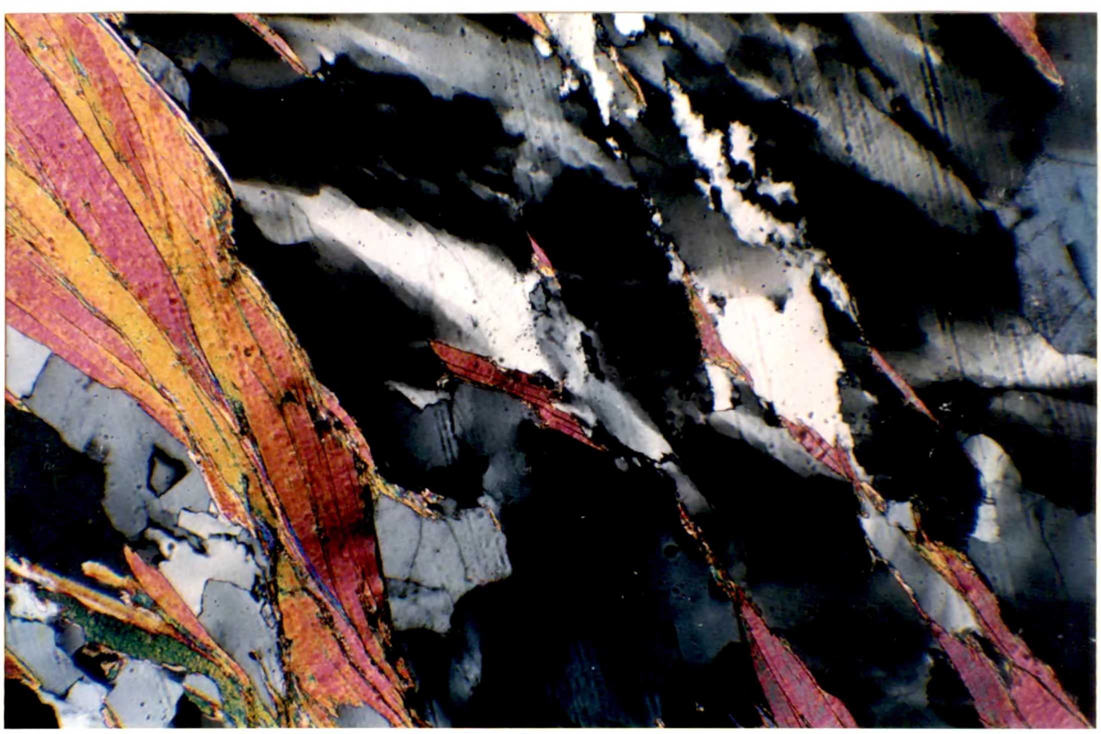

Plate IV.6 Photomicrograph showing strain shadows in quartz (Crossed Nicols X 60) is conspicuous in some samples, where plagioclase is fractured and bent (Plate IV.8). Development of glide twinning is common in highly deformed patterns. Frequently along the fractures, quartz has plastically squeezed in (Plate IV.9). In the streaky and augen gneisses plagioclase grains exhibit widespread sericitization and saussuritization (Plate IV.10). In augen and porphyroblastic gneisses it even occurs as auge and porphyroblasts. Many of these plagioclase auge have been replaced by K-feldspar. In some varieties the plagioclase appears to have recrystallised. However, it is difficult to distinguish between the early and late generations of plagioclase. The late plagioclase has probably contributed to the formation of plagioclase rim around K-feldspar phenocrysts. Perhaps some perthite intergrowth owe their origin to this phenomenon (Plate IV.11). Plagioclase grains also exhibit myrmekitic growth with quartz.

K-Feldspar grains are mostly sub-idioblastic to irregular in outline. These are frequently surrounded by myrmekite (Plate IV.12). In augen gneisses and porphyroblastic gneisses most of the phenocrysts are composed of feldspars. The proportion and size of these also increases from streaky gneisses to augen gneisses and further much more in porphyroblastic gneisses. The K-feldspar is found almost fresh and unaltered, sieved with tiny grains of plagioclase, quartz and mica (Plate IV.13). The porphyroblasts are usually surrounded by a rim of plagioclase and myrmekite which in turn have been wrapped by mica flakes. Rare perthitic intergrowth

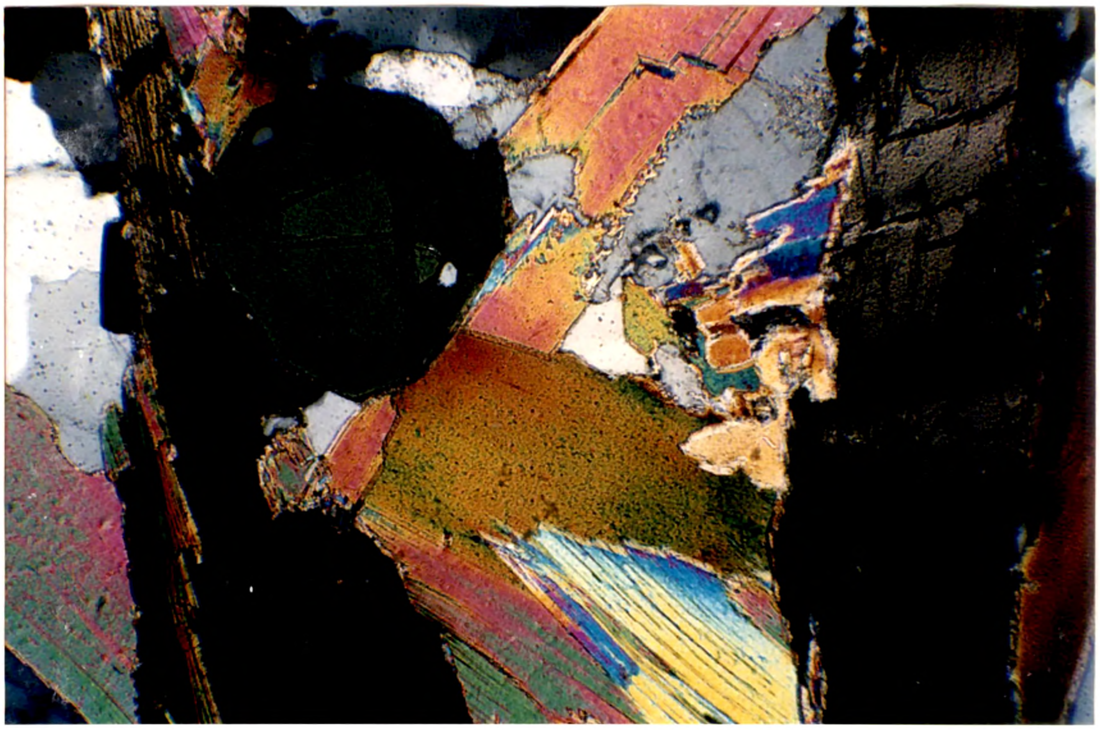

Plate IV.7 Photomicrograph showing diffused margins between plagioclase and mica (Crossed Nicols X 60)

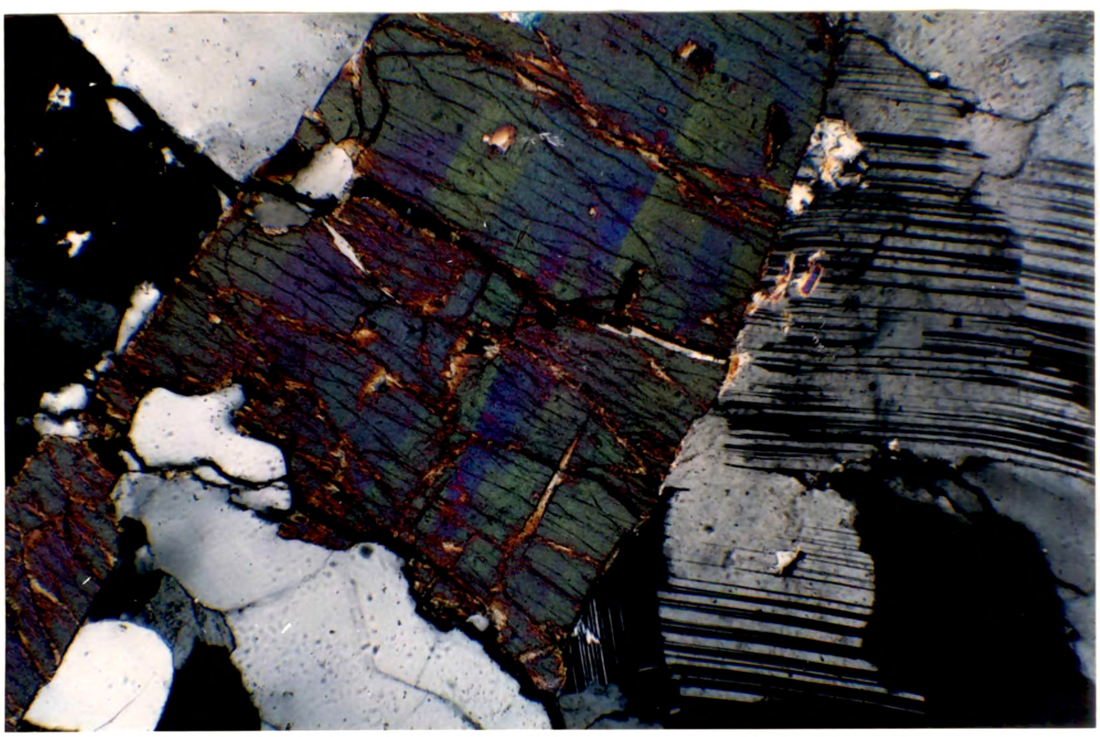

Plate IV.8 Microphotograph showing deformed plagioclase lamellae in granitic gneiss (Crossed Nicols X 60)

Plate IV.9 Photomicrograph showing squeezed quartz along micro-fractures (Crossed Nicols X 60)

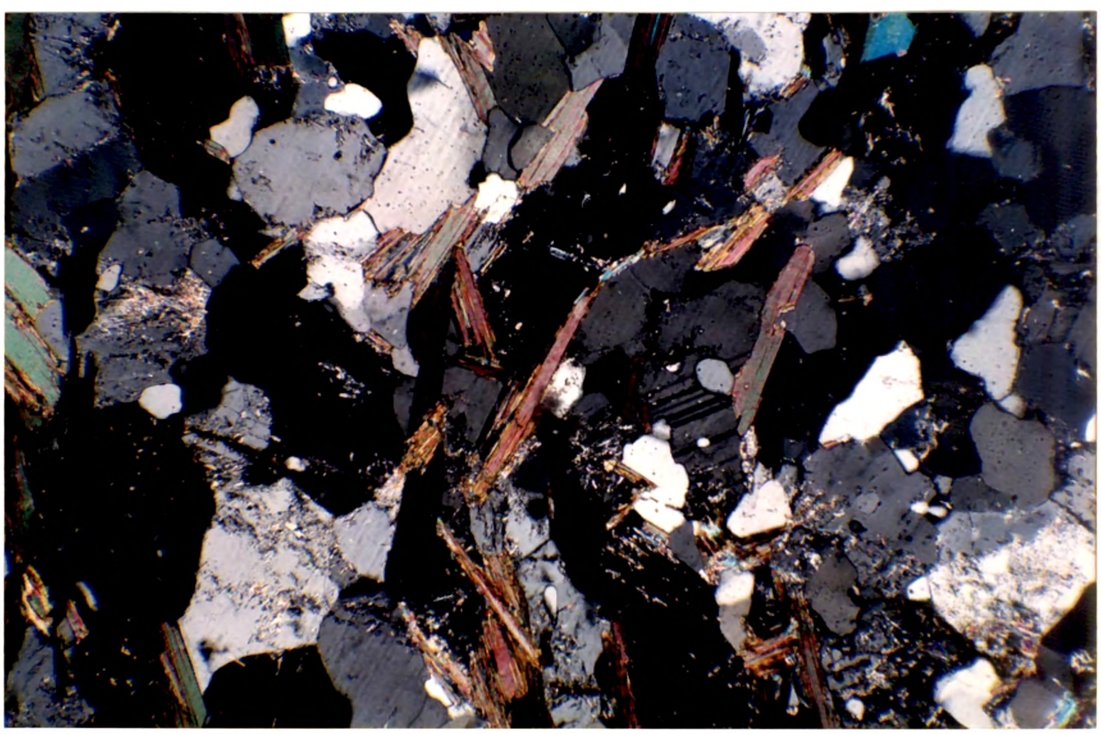

Plate IV.10 Photomicrograph exhibiting sericitization and saussuritization in augen gneiss (Crossed Nicols X60)

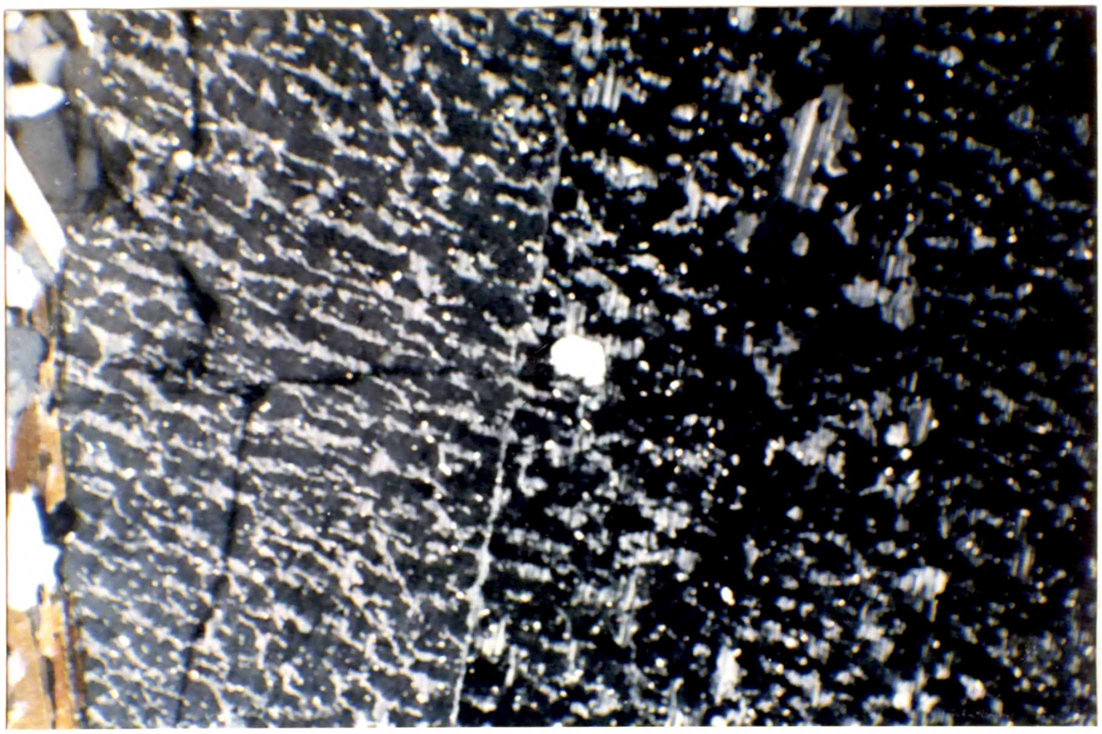

Plate IV.11 Photomicrograph showing perthite intergrowth in augen gneiss (Crossed Nicols X 60)

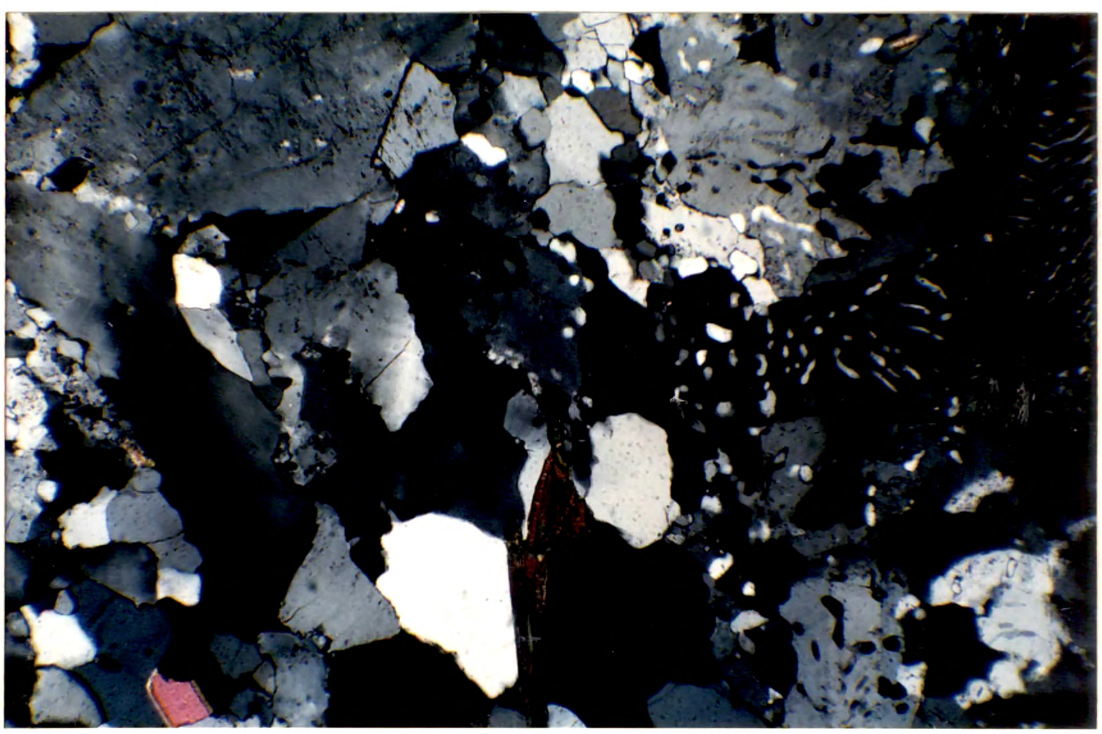

Plate IV.12 Photomicrograph showing myrmekitic texture in augen gneiss (Crossed Nicols X 60) is observed as plagioclase usually occurring in the form of veins and is often finely twinned. The K-feldspar porphyroblasts show considerable variation in twinning, extinction and optic axial angle. Cross-hatching is better developed in the K-feldspar of the granitoid rocks, however some porphyroblasts reveal relict carlsbad twinning. In less deformed areas, the K-feldspar is almost unhatched and with the increasing effect of deformation, the microclinization also increases (Plate IV.14). From thin section studies one observes that the cross-hatching is initiated around inclusions, along perthitic veins and along borders and fractures and with increasing deformation, it progressively extends to the other parts of the crystal. Most of the porphyroblasts show beginning of microclinisation around inclusions formed due to the shearing phenomenon. Most of the cross-hatched feldspar have 2Vx ranging from 50^0 - 70^0 which is generally high and is characteristic of granitised varieties (Karanth, 1977). Replacement of plagioclase by K-feldspar is noticed very conspicuously in augen and porphyroblastic gneisses. Parallelism between twin lamellae of plagioclase and K-feldspar and optical continuity between the plagioclase inclusions and the plagioclases lying outside, commonly indicate the replacement phenomenon (Plate IV.15).

To confirm the triclinic nature of K-feldspar in granitoids X-ray data for one sample (M1) from the Central Crystalline was obtained with a Philips X-ray diffractometer (Model Pw 1729) with

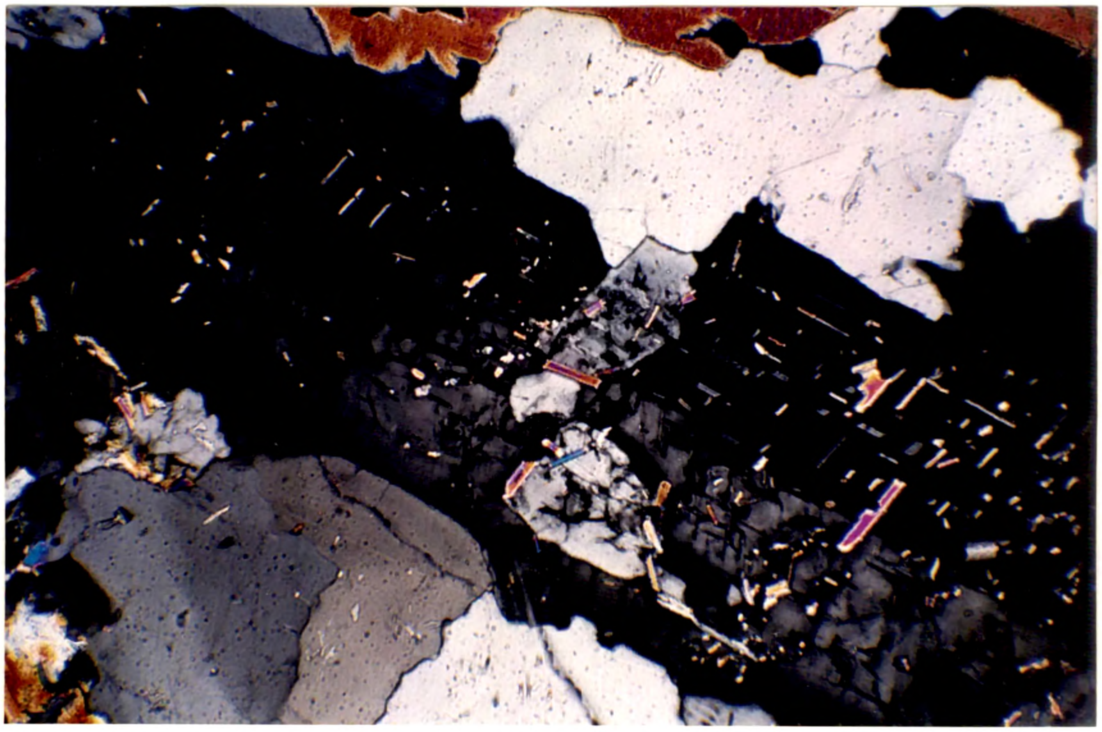

Plate IV.13 Photomicrograph of a sieved K-feldspar in porphyroblastic gneiss (Crossed Nicols X 60)

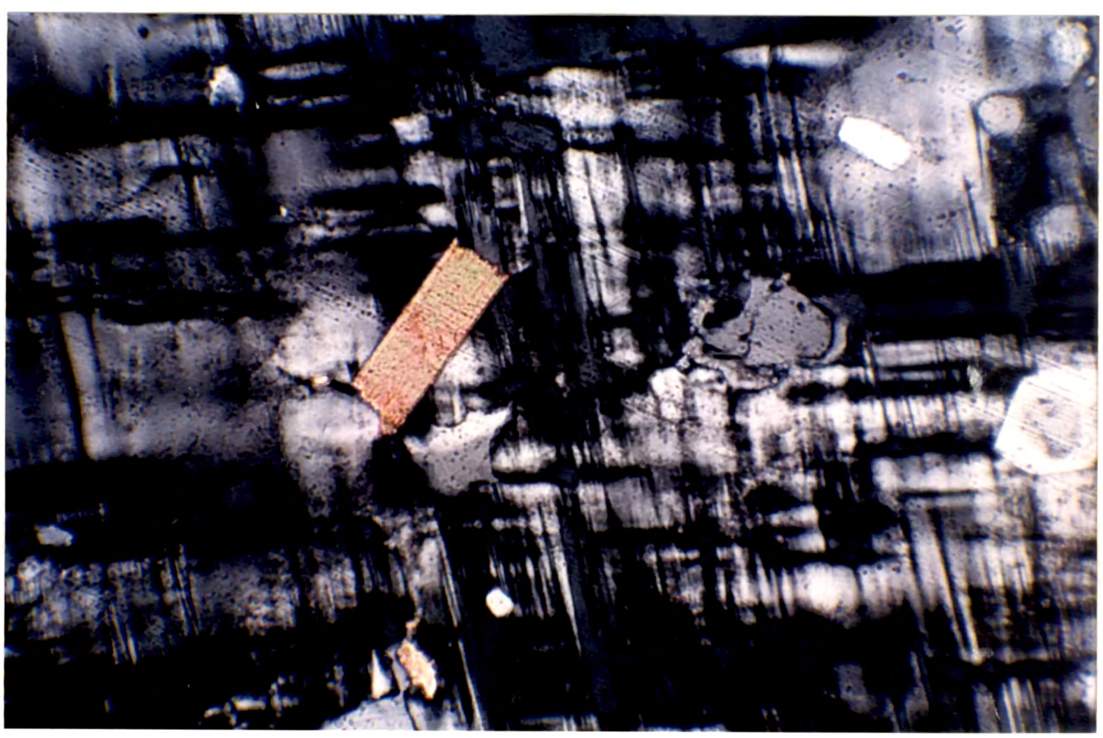

Plate IV.14 Photomicrograph of a cross-hatched K-feldspar in granitic gneiss (Crossed Nicols X 60)

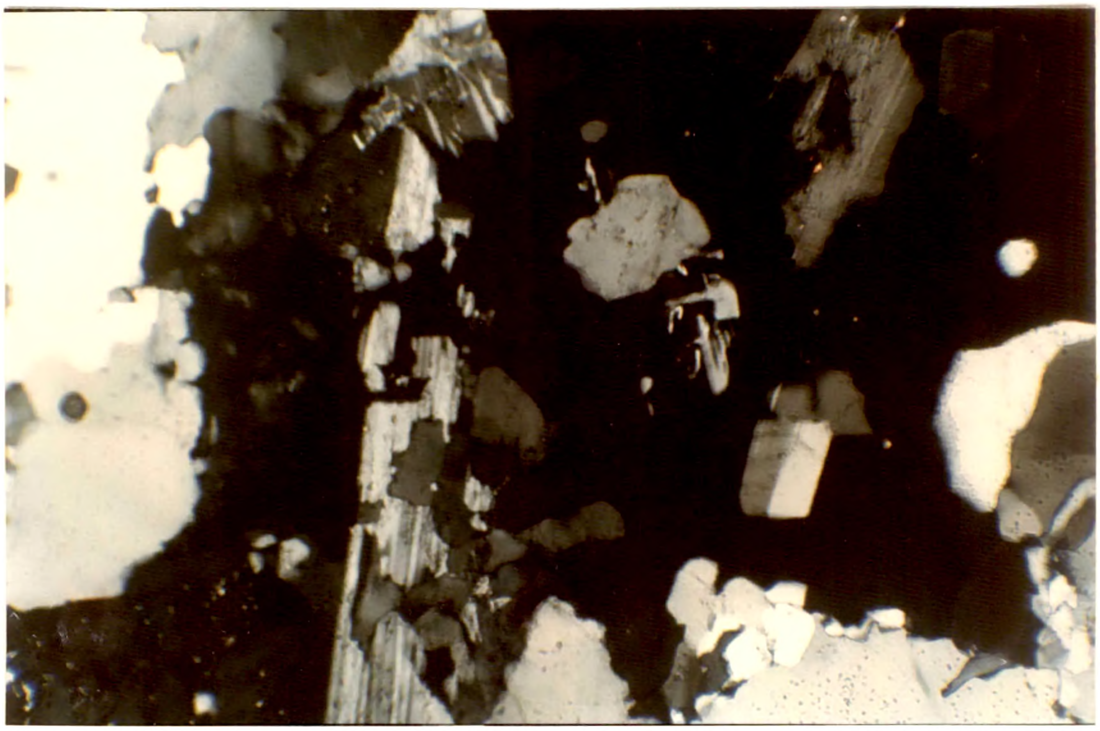

Plate IV.15 Photomicrograph showing parallelism between plagioclase and K-feldspar in granitic gneiss (Crossed Nicols X 60)

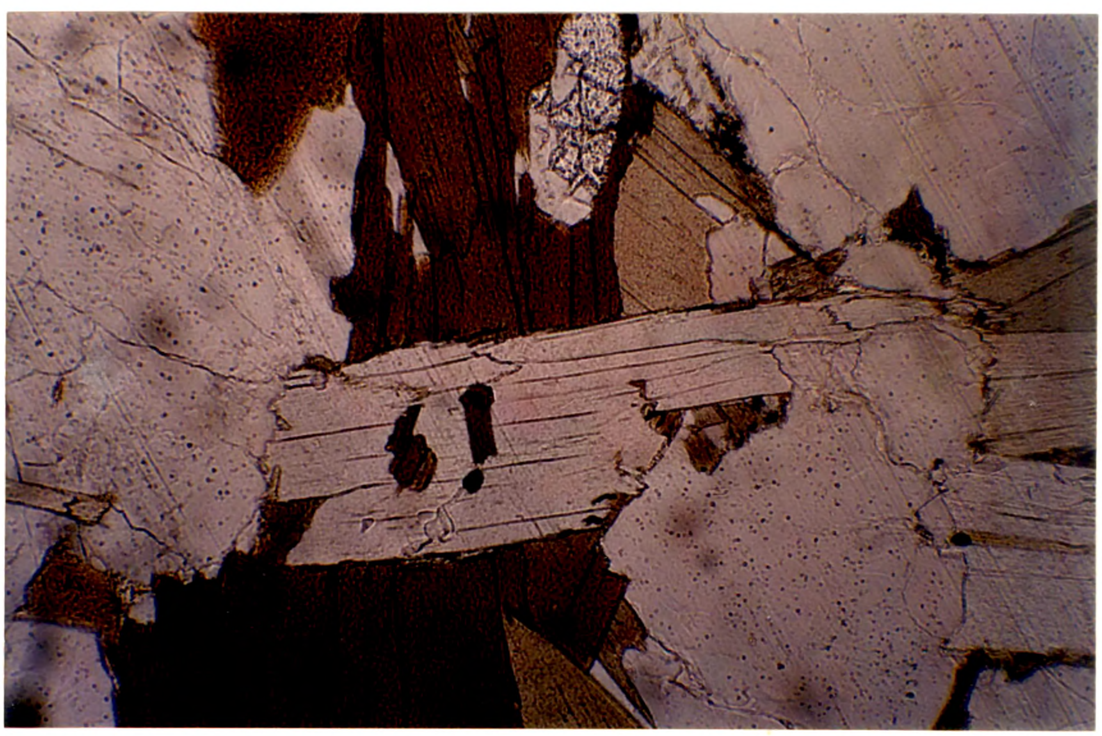

Plate IV.16 Photomicrograph showing muscovite lying oblique to the foliation in augen gneiss (Plane Polarised light X 60) a Ni filter using Cu α radiations at Wadia Institute of Himalayan Geology, Dehradun.

About 1/2 kg of the granitoid sample was crushed in tema mill and homogenised and then sieved using sieves of 120, 60, 40 and 20 mesh size. -60 to + 120 mesh size fraction thus obtained was retained. This fraction was then washed thoroughly and dried and further passed through the isodynamic separator under the following conditions :

Side slope — 15^0

Forward slope — 10^0

Current < 0.8 amps for separating magnetic fraction.

< 1.5 amps for the non-magnetic fraction.

50 gm of separated non-magnetic fraction is then added to diluted bromoform of known specific gravity and centrifuged at 5000 rpm. Alkali feldspars are thus separated and washed with acetone for removal of bromoform. Thus finally separated fraction of about 95% pure alkali - feldspar is then crushed into very fine powder in an agate mortar.

To achieve a proper understanding of feldspar relationships it is not only necessary to characterise them according to chemical composition but also according to their structural state. Hence, using the technique of rapid X-ray diffraction method the structural state of one sample was confirmed. For this, XRD pattern of sample M1 was obtained (Fig. IV.1). From this 2θ and d values were obtained and assigned 6 hkl planes (Table IV.1). Then precise direct lattice parameters a, b, c, α, β, γ and reciprocal lattice parameters a^*, b^*, c^*, α^*, β^* and γ^* were determined. Using these parameters aluminum in Tetrahedral sites T_1O, T_1m, T_2O and T_2m was thus determined (Jowhar, 1989), as given in Table IV.2. Then by comparison with given values of alkali-feldspar and by plotting 2θ $\bar{2}04$ against 2θ 060 CuKα values on graph given by Wright (1968) it was revealed that the alkali feldspar is of potassic phase and of intermediate microcline triclinic type.

Muscovite flakes are observed in all varieties of granitoid rocks. It predominates over biotite. It is found defining the foliation planes in streaky, augen porphyroblastic and granitic gneisses. It is generally found enveloping auge and porphyroblasts in augen and porphyroblastic gneisses. Muscovite is observed as colourless grains with generally straight edges and shows faint but perceptible pleochroism in some sections. Some flakes are found superimposed obliquely over the main foliation (Plate IV.16). In the streaky gneisses muscovite is observed altered to sericite. It is also observed as inclusions within some plagioclase and K-

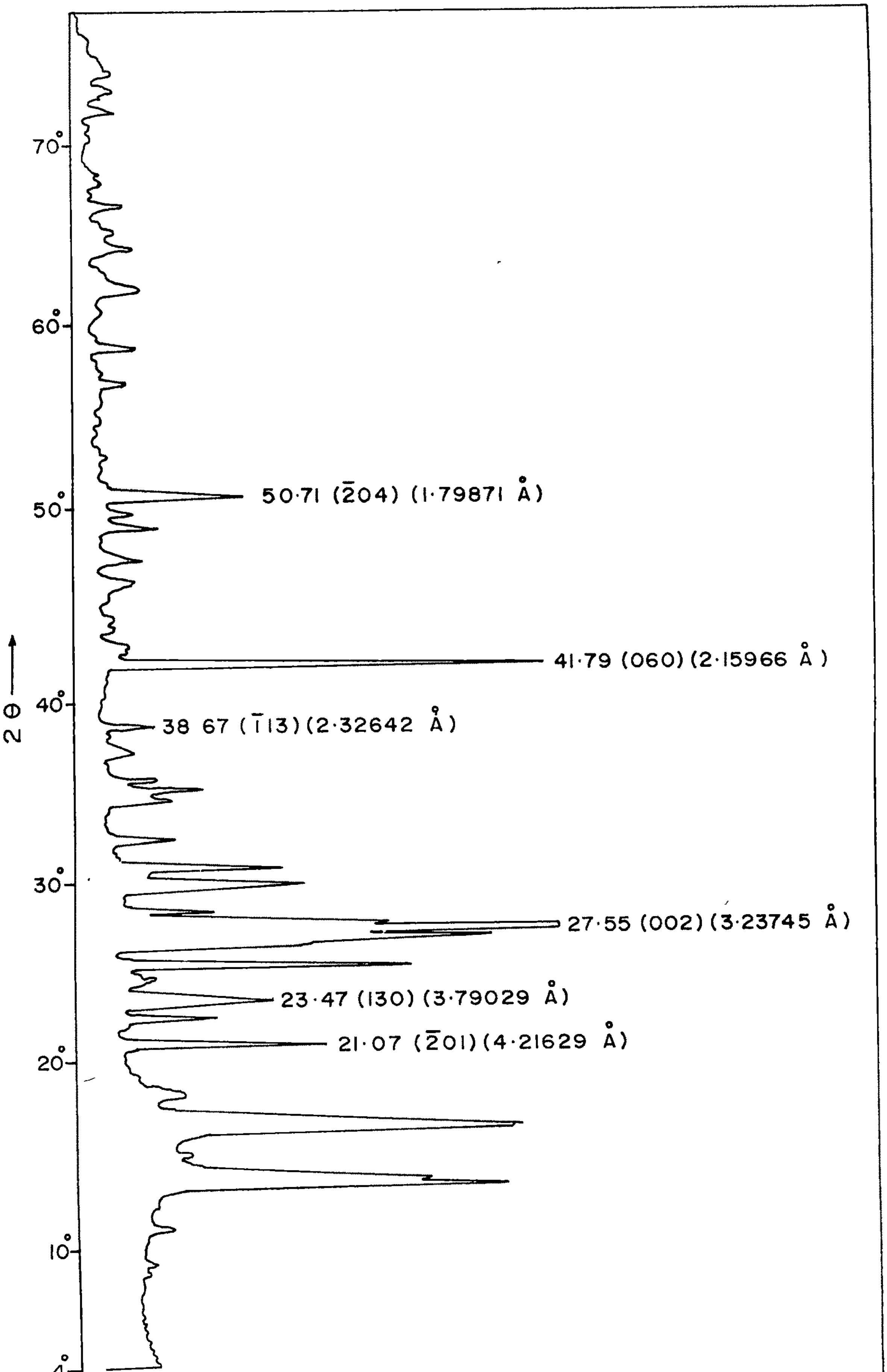

Fig IV.1 Diffractogram of sample no. M1

Table IV.1 : 2θ and d values of alkali feldspar from Central Crystallines.

hkl	2θ Cuk α	d Spacing (A^0)
$\bar{2}01$	21.07	4.21629
130	23.47	3.79029
002	27.55	3.23754
$\bar{1}13$	38.67	2.32642
060	41.79	2.15966
$\bar{2}04$	50.71	1.79871

Table IV.2 : Unit cell parameters of alkali feldspar from Central Crystallines

a = 8.56334	α = 89.94	
b = 12.95920	β = 115.86	V = 718.51 A^0
c = 7.19601	γ = 89.31	
a^* = 0.12979 A^{0-1}	α^* = 90.40	
b^* = 0.07717 A^{0-1}	β^* = 64.13	V^* = 0.00139 A^{0-3}
c^* = 0.015444 A^{0-1}	γ^* = 90.80	
Δbc^* = 0.9082	AlT_1O = 0.598	AlT_1m = 0.310
$\Delta\alpha^*\beta^*$ = 0.2881	AlT_2m = 0.046	AlT_2O = 0.046

feldspar porphyroblasts. A general decrease in muscovite flakes is observed from streaky gneisses to granites.

Biotite though more abundant in mica schists is found to show a decrease in the granitoid rocks. Strongly pleochroic grains of biotite are observed aligned parallel to the main foliation. They show light yellow to dark yellow pleochroism with pleochroic haloes developed due to degeneration around zircons. It is generally found altered to greenish chlorite and iron oxides. Biotite is also found as inclusions in plagioclase and K-feldspar porphyroblasts (Plate IV.17). It exhibits highly irregular and shredded margins with plagioclase. Some biotite flakes are also observed superimposed over the main foliation plane of the granitoid rocks.

Garnet is found as well developed porphyroblasts of 1 mm to 2 mm size. They are light pinkish in colour and are seen in some of the augen gneiss and granite occurrences. These garnets are free of inclusions and are quite fresh. Often they exhibit fracturing and are seen altered to greenish chlorite along cracks and margins (Plate IV.18). They are sometimes found as clusters in granites.

Kyanite occurs only in one of the augen gneiss band. It is seen as bluish coloured mineral of perfectly bladed nature and aligned parallel to the gneissic foliation (Plate IV.19). It has high refractive index and shows perfect two set cleavage at 90^0.

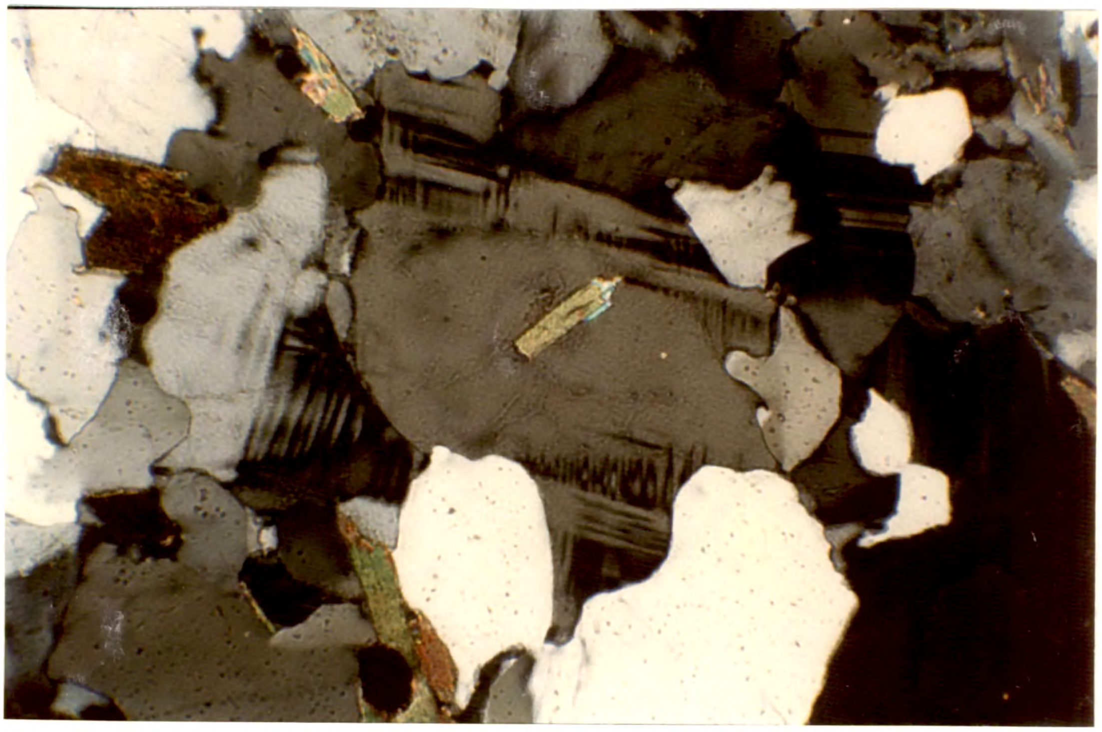

Plate IV.17 Photomicrograph showing biotite inclusion in K-felspar in granitic gneiss (Crossed Nicols X 60)

Plate IV.18 Photomicrograph showing garnets altering to chlorite in garnetiferous augen gneiss (Plane Polarised light X 60)

Tourmaline occurs as euhedral crystals in granite. It shows a characteristic light blue to dark blue pleochroism, exhibits high relief and shows inclusions of quartz (Plate IV.20).

Besides these minerals, zircon, apatite and iron oxides are the associated accessories. Apatite occurs as prismatic as well as basal sections, the latter are perfect euhedral isotropic grains; zircons are well rounded in outline. Iron oxides occur as small irregular grains.

Petrographic studies of the granitoid rocks reveal that excepting the granites all the other varieties viz. streaky, augen, porphyroblastic and granitic gneisses are foliated and including granites show marked difference in the texture, granularity and mineralogy. The granularity increases from streaky gneisses confined to the thrust zones, to augen gneisses and then to porphyroblastic gneisses in the north towards Trans Himadri Thrust. Even within the same variety, the granularity and the sizes of the auge and porphyroblasts are variable. Mineralogically, on going northwards the granitoids become richer in feldspar particularly K-feldspar. Replacement of plagioclase by K-feldspar is a common, yet noteworthy phenomenon. Plagioclase is found to have An content ranging from 20 - 35% and shows polysynthetic twinning. The granitoids of the study area have a slightly high 2Vx values indicating role of granitisation in their formation. Karanth (1977) also reported higher values of 2Vx for the granitised

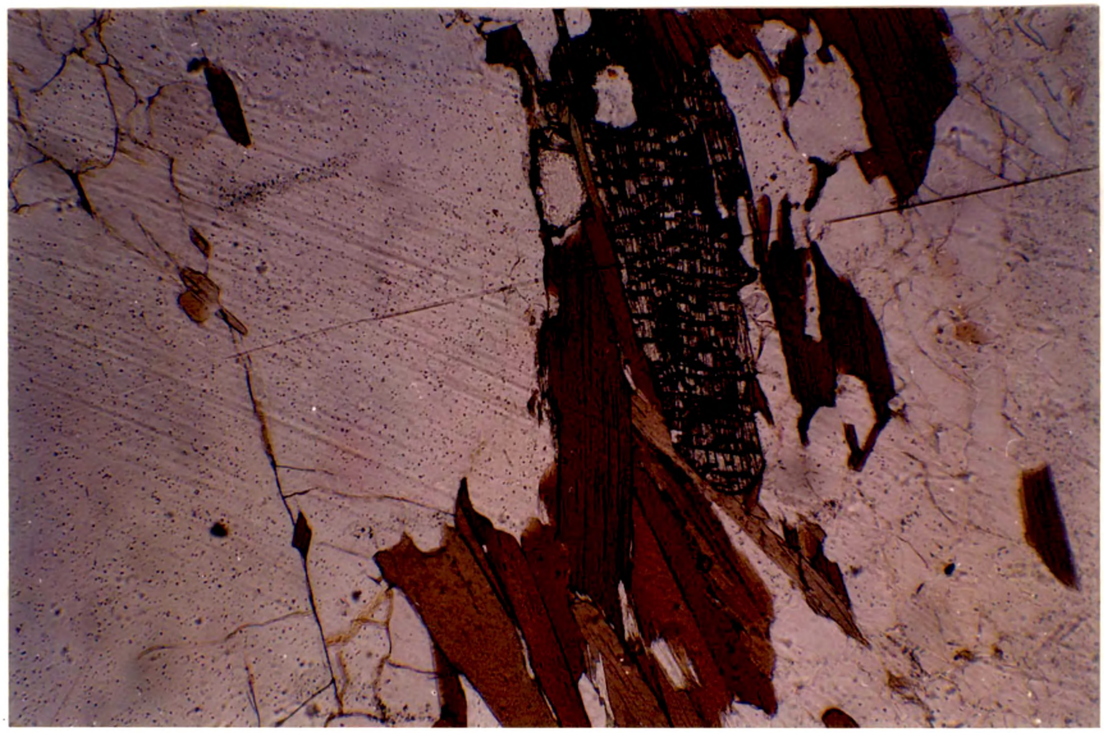

Plate IV.19 Photomicrograph showing kyanite aligned along the gneissic foliation in garnetiferous kyanite gneiss (Plate Polarised light X 60)

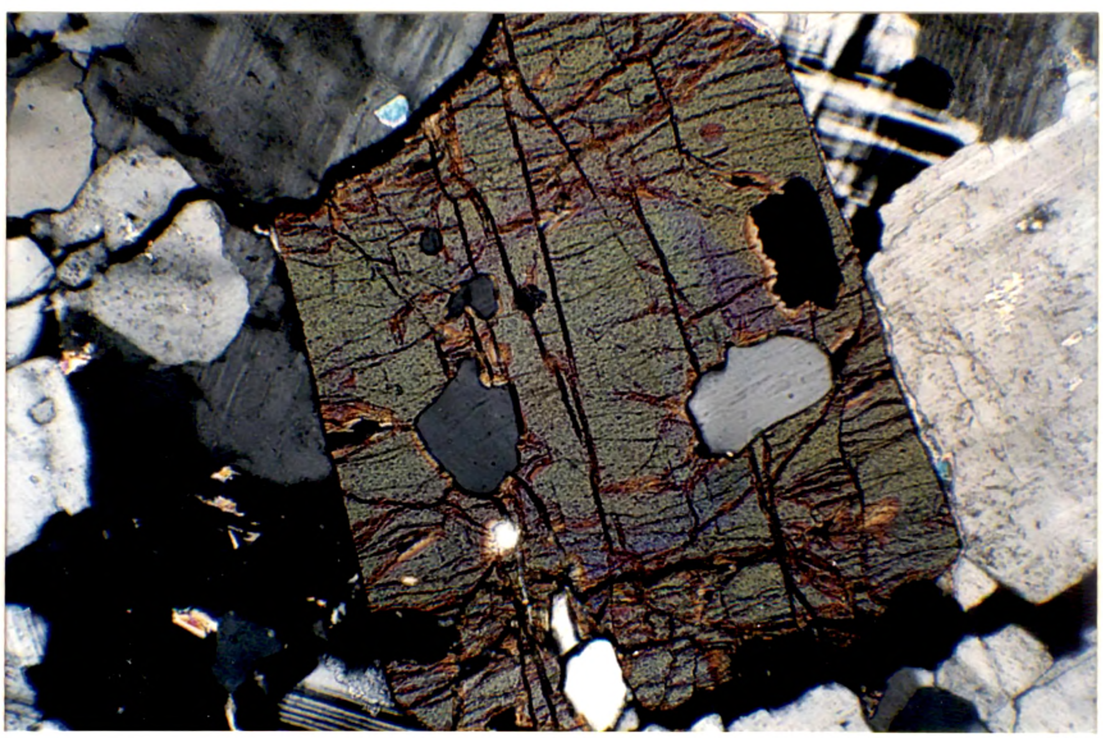

Plate IV.20 Photomicrograph showing tourmaline with quartz inclusions in granitic gneiss (Crossed Nicols X 60) gneissic granites of Almora. The granitoids also exhibit a preponderance in muscovite over biotite mica like adjacent mica-schists. Garnets and tourmaline are also found associated with these granitoid rocks. Zircon found in these granitoid rocks are of subrounded nature indicating a relict sedimentary parentage.

The above observations point towards granitisation through fluid medium as the likely explanation for the evolution of the granitoid rocks of the study area. Frequent replacement of one mineral by the other, sutured grain boundaries, presence of hydrous silicates, absence of variation in the An content of plagioclase point to an active participation of liquid diffusion in rocks (Eskola, 1932; Hietanen, 1954). Of the various kinds of metasomatic changes noticed, the replacement phenomenon of plagioclase by K-feldspar is fairly accepted (Anderson, 1928; Reynolds, 1946; Engel and Engel, 1958). Das (1971, 1979) and Powar (1972, 1983) have also concluded that the gneisses of Eastern Kumaun Himalaya have been formed due to introduction of permissive emplacement of 'granitic melt' along privileged paths. Several Himalayan geologists have postulated on advancing soda front with preceeding potassic front leading to profuse microclinisation, as the possible cause of migmatisation in the evolution of these rocks (Pande, 1956; Saklani, 1970, 1973; Rao and Kumar, 1981).