CHAPTER VI

GRANITIC ROCKS

The granitic rocks that are intrusive into the Delhis, constitute the most important formation of the study area. Occupying almost two-third of the area these rocks, show much variation in their texture and mineralogy, and these in turn, have reflected in the topography of the granitic terrain. The granites have been broadly classified into two main types:-

(1) Coarse foliated gneissic granite occupying the flat low-lying terrain.

(2) Massive unfoliated granite forming conspicuous hills and massifs.

The massive type shows typically intrusive relationship with the metasediments as well as the gneissic granite. The two varieties represent the "Sheet-complexes" and "Massive Stocks" respectively of Heron (1953, p. 349) both being two stages of the Erinpura granite activity. In the subsequent pages, the author has given a detailed account of these two varieties of Erinpura granite and from his study it is evident that while the foliated variety comprises para-gneisses of migmatitic origin, the bodies of massive granite, forming hills and tors are post tectonic late igneous intrusions.

GNEISSIC GRANITE

Extensive soil covered plain terrain lying between Idar and Vadali contain these foliated granites. The exposures are rare, and its presence is established on the basis of:-

(1) A few scattered exposures in the cultivated fields.

(2) Outcrops fringing the hills of the massive granite.

(3) Samples obtained from recently dug wells.

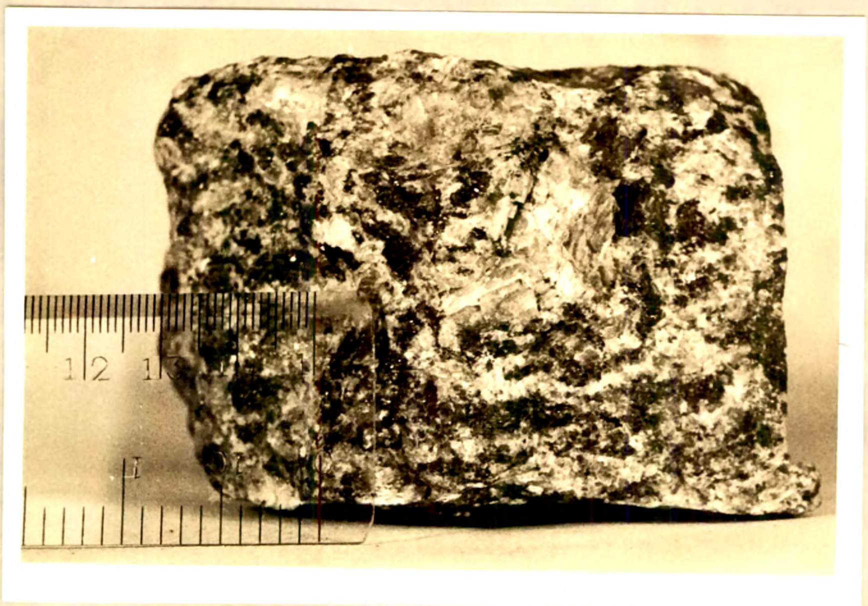
The exposed portions of this variety are highly weathered and it is very difficult to obtain their fresh unaltered samples. However, such exposures ideally reveal the coarse and foliated nature of the rock and also its bulk mineral content, consisting mainly of quartz, feldspar and biotite. These gneissic granites are quite often porphyroblastic. As has already been mentioned earlier (Chapter IV) these granites gradually merge into the biotite gneisses of Delhi system.

The rock shows weathering upto a depth of 7 m. below which relatively fresh and unaltered samples are obtained. These samples have proved very valuable in knowing the original nature of the rock. Unfortunately, on account of non-availability of representative samples from all over the area, author was considerably handicapped in carrying out detailed petrographic and chemical studies of this variety. However, the data available has been adequate enough to present a well defined picture of the nature and evolution of this rock.

Petrography and Chemistry

In hand specimen the rock is seen as coarse grained, porphyritic gneiss with quartz, feldspar and biotite (Plate-VI.1). The feldspar is seen in the groundmass

PLATE-VI.1



Gneissic granite showing development of feldspar porphyroblast (Loc: W. of Kamboya) and also forming phenocrysts (porphyroblasts). Under the microscope, it shows large euhedral to subhedral crystals of plagioclase embedded in an equigranualr groundmass comprising of quartz, plagioclase, microcline biotite and muscovite. The mica characterises the gneissic foliation.

The relative percentages of the various minerals are somewhat variable because this gneissic granite is a product of migmatisation of biotite-schists, and depending upon the degree of migmatisation, the mineral content varies. The transformation of schists into gneissic granite has been found to consist of two stages - an early one comprising a sodic phase and the late being potassic. Thus, the proportion of plagioclase and microcline too shows much variation and with progressively increasing potash the rock is seen to contain more and more microcline.

Plagioclase is an oligoclase (An_{21-24}) and is the dominant feldspar, occuring both as small grains in the foliated groundmass or as well formed porphyroblasts. It typically shows the polysynthetic twinning on albite law. The porphyroblasts are seen growing without any orientation and lie half-hazardly. They contain tiny inclusions of muscovite and quartz and show some alteration to sericite. An interesting feature of these porphyroblasts is their replacement by microcline (Plate-VI.2).

Microcline is variable and depends on the degree of addition of potash in the rock. Generally, it is confined to the groundmass of the rock and occurs as anhedral interstitial grains, showing sutured contacts with quartz. The microcline also occurs occasionally as porphyroblasts and in almost all such cases it is seen to have developed by a progressive replacement of plagioclase. Myrmekitic texture is frequently seen along the contacts of microcline and plagioclase. It is recognised by its typical cross-hatching.

Biotite is the dominant mica; it forms tufts of small flakes and a faint parallelism of these tufts characterises the gneissic foliation. The mineral shows typical cleavage and pleochroism in shades of brown.

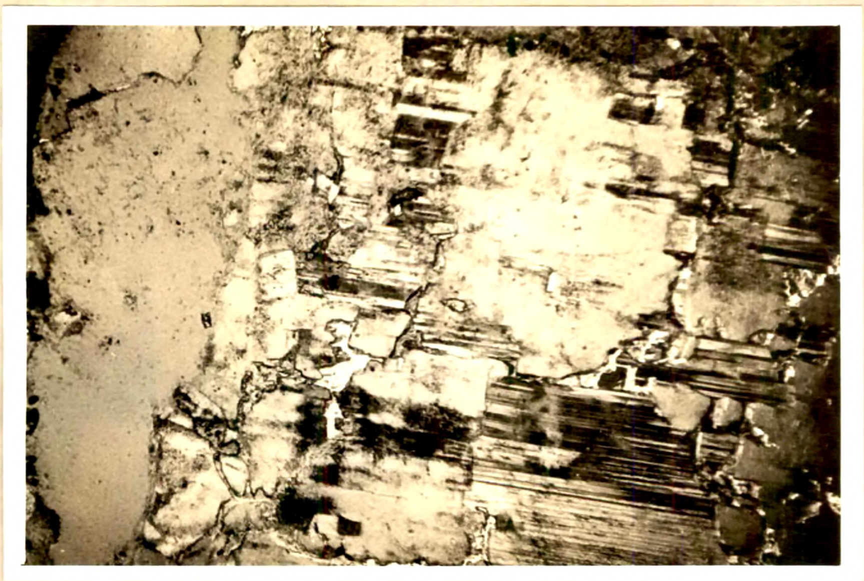
X = yellow

Y = Z = greenish brown

$X < Y = Z$

Biotite together with muscovite also occurs as tiny inclusions in feldspar porphyroblasts.

PLATE-VI.2



Photomicrograph(X80) of gneissic granite showing replacement of plagioclase by microcline.

Muscovite is in a very subordinate amount and occurs as long flakes intergrown with biotite. Some muscovite is derived from biotite. Tiny specks of muscovite are quite common as inclusions in the feldspar porphyroblasts.

Zircon, apatite and sphene are the common accessory minerals.

The Table-VI.1 gives the chemical analyses of the representative samples of the gneissic granites. From the petrographic and chemical details, it will be seen that in composition, these gneisses are somewhat richer in Na_2O and almost granodioritic.

Mode of Origin

The migmatitic origin of these gneissic granite is ideally revealed by its field occurrence, petrography and chemistry. The author has already described the various stages through which the metapelites of Delhi system have passed to ultimately give rise to an almost granitic rock. The transformation of a biotite schist into almost a granite, has been brought about by the metasomatic action of the granites prior to their actual intrusion. This early metasomatic phase of the granite

TABLE-VI.1

CHEMICAL ANALYSES OF GNEISSIC GRANITE

Wt. %	213/148	250	289/200	659
SiO_2	71.71	71.65	71.36	72.02
TiO_2	00.42	00.29	00.48	00.45
Al_2O_3	15.23	14.87	16.48	15.46
Fe_2O_3	01.20	01.20	00.50	00.98
FeO	01.78	03.98	01.99	02.01
MgO	00.54	00.56	00.63	00.52
MnO	00.23	00.21	00.21	02.08
CaO	01.32	01.70	01.42	00.29
Na_2O	03.57	03.99	03.59	03.99
K_2O	03.07	02.51	03.04	03.21
P_2O_5	00.09	00.07	00.04	00.07
Total	99.16	101.03	99.74	101.08
Kohler-Raaz values:				
qz	62.69	58.21	61.32	-
F	19.97	23.92	18.74	-
fm	17.73	17.87	19.94	-
Niggli values:				
si	377.00	335.80	365.00	-
al	47.00	41.00	49.50	-
fm	18.00	24.70	15.70	-
c	07.24	08.40	07.68	-
alk	27.89	26.00	27.00	-
Values for Ossan's diagram:				
Al	17.24	16.48	17.67	15.78
C	02.64	03.36	02.73	03.94
Alk	10.12	10.16	09.60	10.28

action is represented in the gneissic granite while the late intrusive magmatic bodies are seen cutting the early foliated granite. The early granitic rocks are richer in soda as compared to the late intrusive bodies rich in potash. The progressive replacement of plagioclase by microcline, typically suggests that the transformation of schists into gneisses comprised an early sodic phase to be followed by a late potassic phase which immediately preceded the intrusion of potash granites. The author has discussed the various aspects of this migmatisation in the following pages.

The transformation of the Delhi pelitic schists (now seen as biotite-gneisses only) into coarse porphyroblastic gneissic granite, was obviously brought about by the increasing metasomatic action of alkali rich emanations originating from the subterranean and progressively rising granitic magma. The process of migmatisation consisted of an early sodic phase and a late potassic phase. The mineralogical changes leading to the transformation of garnet-mica-schist into foliated granite have been summarised below:

Stage - I   Appearance of plagioclase and increase in the amount of quartz.

<u>Stage - II</u> Increase in the size and content of plagioclase with corresponding increase in quartz content and decrease of biotite.

<u>Stage - III</u> Appearance of microcline in the groundmass; decrease in biotite content. Plagioclase porphyroblastic.

<u>Stage - IV</u> Progressive replacement of plagioclase porphyroblasts by microcline.

Variation in the Modal percentages of the important constituents with increasing granitisation, are given in the Table-VI.2. The variation diagram based on the above (Fig.-VI.1) ideally illustrates the trend of the mineralogical changes.

<u>Evidence of migmatisation</u>: The author has rallied a number of evidences to establish the nature and course of migmatisation. These are summarised below:

<u>Field evidences</u>:

(1) The gneissic granite grades imperceptibly into the biotite gneisse.

TABLE-VI.2

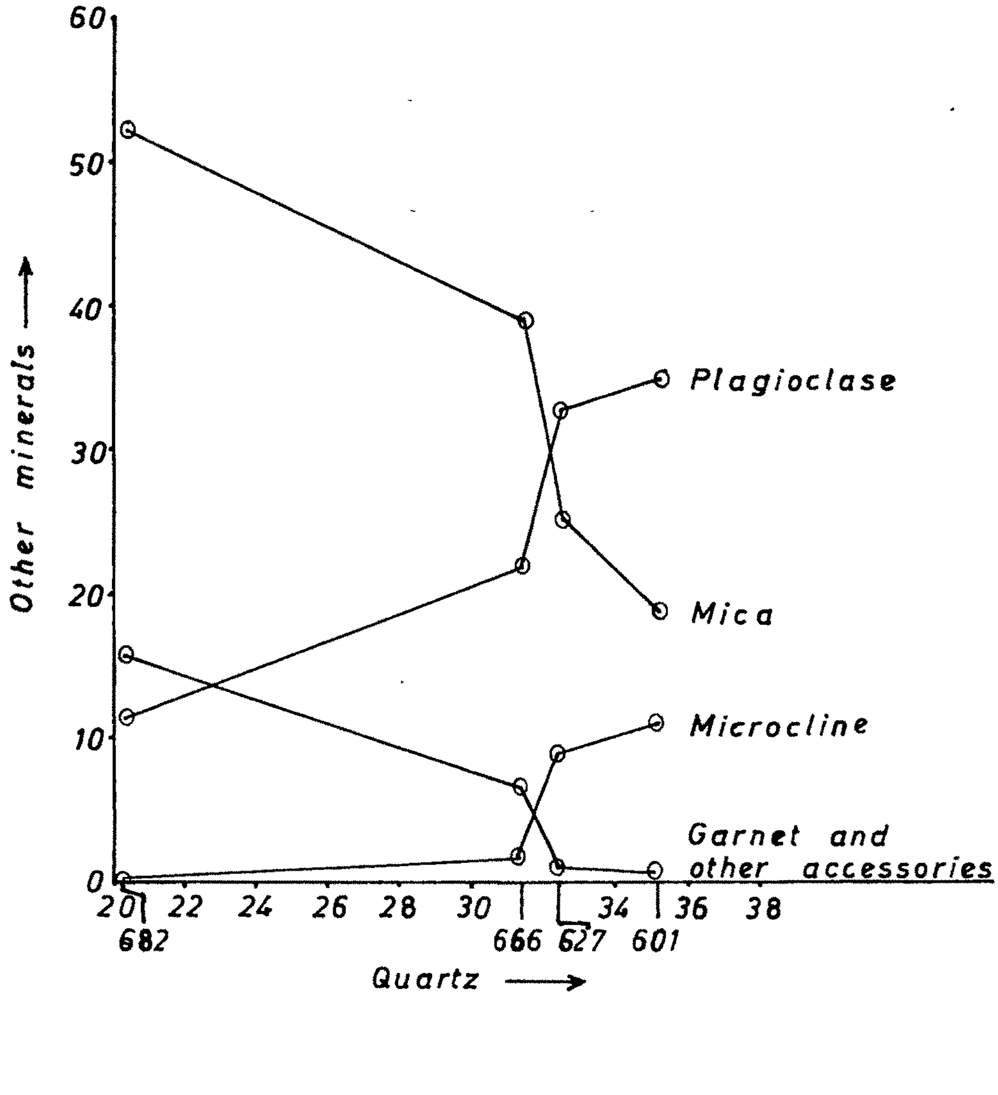
MODAL ANALYSES OF BIOTITE-GNEISSES

Minerals	Felds-pathised garnet-mica schist	Per-meation gneiss	Sub-augen gneiss	Augen gneiss
	682	666	627	601
Quartz	20.38	31.44	32.52	35.17
Plagioclase	11.57	21.92	33.25	35.05
Microcline	-	01.56	09.13	11.01
Mica	52.31	39.00	25.21	18.78
Garnet and other accessory content	15.74	06.64	01.22	00.67
Total	100.00	100.56	101.33	100.67

Analyst: Paresh Raval

Fig.- VI. 1.

Mineral variation diagram of biotite-gneisses



(2) The transition of schist to granite has been caused by the increasing feldspar (and quartz) content. Not only the amount of feldspar goes up, but the size of the feldspars also increases. This cannot be explained by any other mechanism except gradual metasomatic addition of feldspathic material from the nearby granitic source.

(3) There are frequent layers of relict schists and quartzites inside the migmatite zone. The trends of these 'skialiths' are identical with those of the neighbouring country rocks.

Microscopical evidences:

Thin sections ideally reveal a perfect transformation of schists into granite through various transitional stages. The original rock is seen progressively changing to feldspathised schist, permeation gneiss, sub-augen gneiss, augen-gneiss and finally to a porphyroblastic foliated granite. The porphyroblasts of plagioclase show replacement by microcline. Secondly, the metasomatic origin of porphyroblasts is supported by the presence of abundunt inclusions of biotite, muscovite and quartz.

Chemical evidences:

The chemical analysis of the selected rocks (Table-VI.3) representing various stages of migmatisation, when plotted on the variation diagram (Fig.-VI.2), give a very clear indication of the chemical changes brought about by metasomatism. The trends of the percentages of SiO_2, Al_2O_3, Fe_2O_3, FeO, TiO_2, MgO, CaO, Na_2O and K_2O from the feldspathised schists to porphyroblastic foliated granite, reveal the trend of the chemical changes. It is seen that SiO_2 shows a gradual increase though the addition is quite small. Al_2O_3 shows little change. Na_2O tends to increase steadily. K_2O indicates an initial decrease, suggesting that no potash was added in the early stages of the migmatisation. Once it appears, it shows a progressive rise; this is due to the arrival of potash following the soda. During the migmatisation, first plagioclase feldspar appeared and gradually increased and this is reflected in the increase of Na_2O and CaO. With the advent of microcline during the last stage of migmatisation, K_2O shows an increase while CaO declines.

TABLE-VI.3

CHEMICAL ANALYSES OF SELECTED ROCKS SHOWING MIGMATISATION

Wt. %	Feldspathised schist	Permeation gneiss	Sub-augen gneiss	Augen gneiss	Gneissic granite
	Averages of 682 & 683	Average of 56/69 & 666	627	601	659
SiO_2	66.31	68.10	69.00	70.01	72.02
TiO_2	00.92	00.78	00.67	00.60	00.45
Al_2O_3	15.20	16.03	16.02	16.50	15.46
Fe_2O_3	03.00	02.04	01.85	01.05	00.98
FeO	05.09	04.32	03.20	01.39	02.01
MgO	02.40	01.83	01.10	00.99	00.52
MnO	01.30	00.77	00.57	00.45	00.29
CaO	02.00	02.25	02.41	02.55	02.08
Na_2O	01.33	01.95	03.01	03.49	03.99
K_2O	03.10	02.90	02.75	02.99	03.21
P_2O_5	00.03	00.05	00.05	00.04	00.07
Total	100.68	101.02	100.63	100.06	101.08
Q	39.19	37.84	35.13	33.60	32.17
L	37.28	43.48	52.04	58.04	61.04
M	23.53	18.69	12.89	08.49	06.79

Values for the diagram after Hejtman:

K_2O	35.97	29.80	24.79	10.53	25.36
Na_2O	23.59	30.77	39.67	49.12	47.10
CaO	40.44	39.43	35.54	40.35	27.54
K_2O	16.00	18.75	24.59	35.55	40.70
MgO	30.00	27.88	22.95	27.33	12.00
Fe_2O_3+FeO +MnO	54.00	53.37	52.46	37.12	47.30

TABLE-VI.4

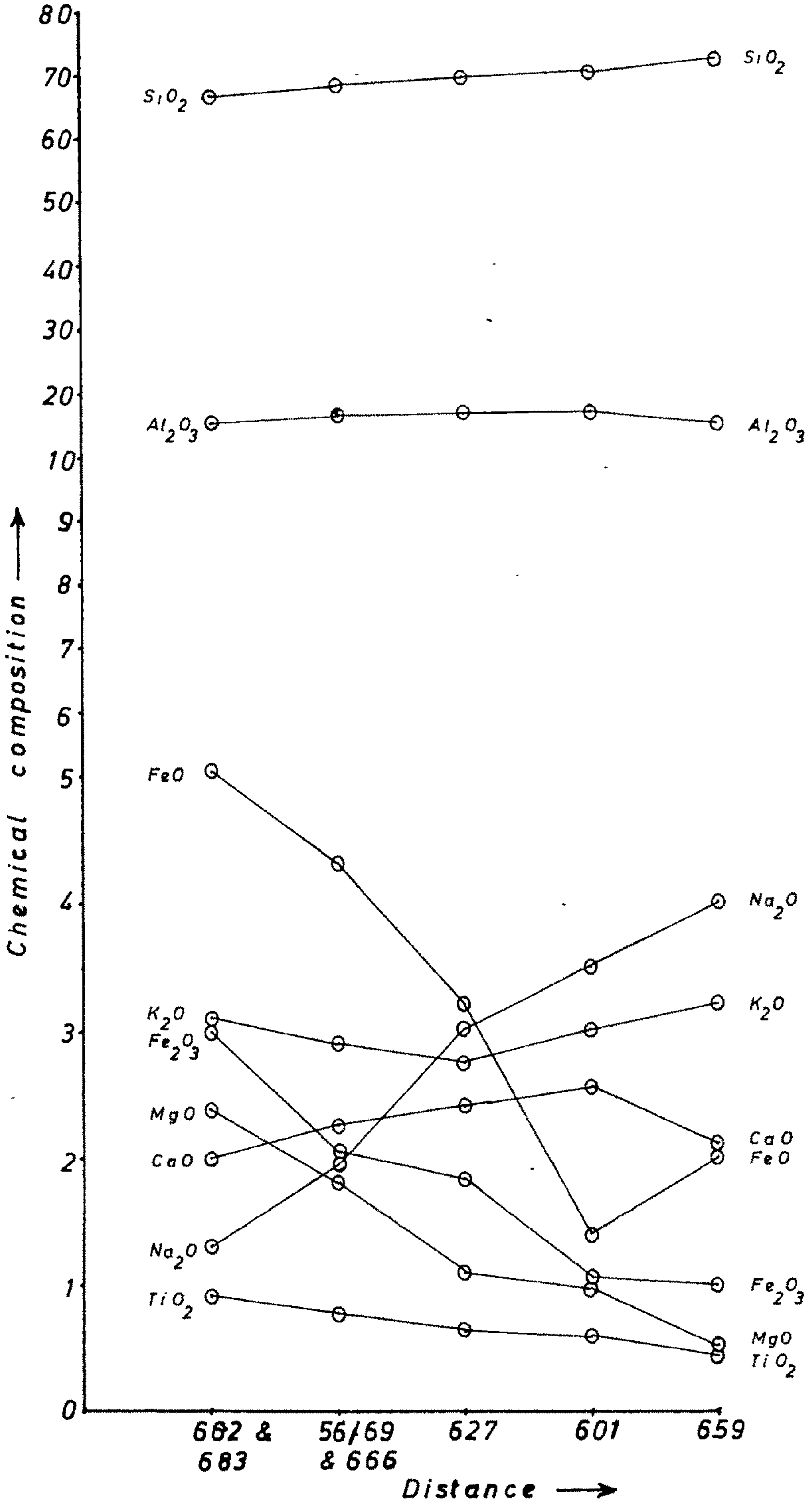
ALKALI ALUMINA RATIO

	Felds-pathised schist 682 & 683	Permeation gneiss 56/69 & 666	Sub-augen gneiss 627	Augen gneiss 601	Gneissic gnaiite 659
Na_2O/Al_2O_3	0.08	0.12	0.18	0.21	0.25
K_2O/Al_2O_3	0.20	0.18	0.17	0.17	0.20
$\frac{Na_2O+K_2O}{Al_2O_3}$	0.28	0.30	0.35	0.38	0.45

Analyst: Paresh Raval

Fig.— VI. 2

Chemical variation diagram

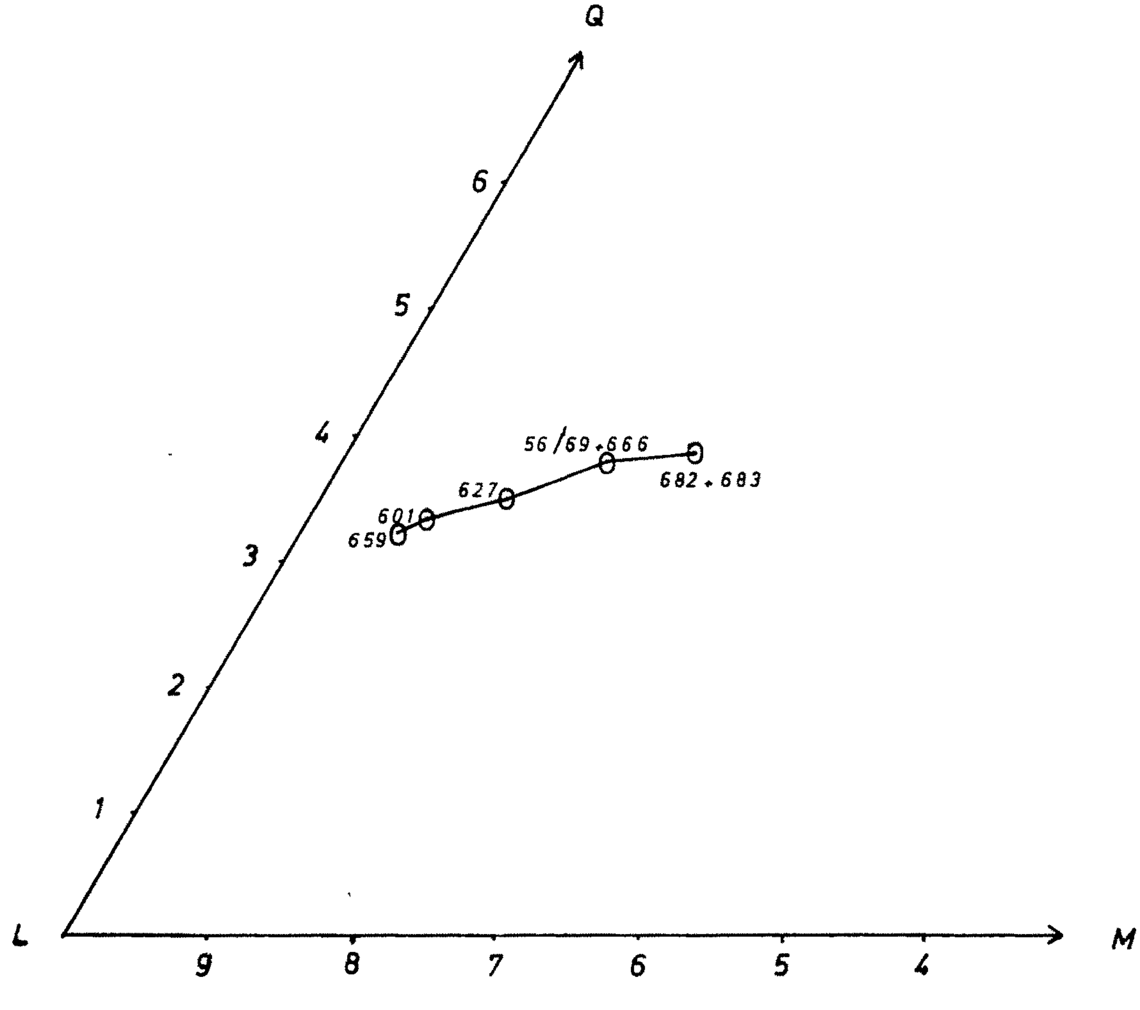


Q-L-M values calculated from the analyses given in Table-VI.3 when plotted on Von Wolff's diagram (Fig.-VI.3) reveal that with increasing migmatisation, the free quartz (Q) percentage shows steady decrease while those of leucocratic minerals increased. This supports the limited external supply of silica and appreciable addition of alkalies.

Following Billings (1938), the author worked out the ratios between the alkalies and the alumina in the five representative rocks (Table-VI.3) showing different stages of migmatisation, which are given in Table-VI.4. From this table, it becomes clear that Na_2O/Al_2O_3 ratio steadily increases, indicating progressive enrichment in soda. On the other hand K_2O/Al_2O_3 ratio progressively shows a decline until the last stage of migmatisation (gneissic granite) in which the K_2O/Al_2O_3 shows a slight increase. Total alkalies also increase.

The above mentioned chemical criteria, suggest that the process of migmatisation was brought about mainly by the addition of alkalies. The transformation started with addition of soda, which was at a quite later period joined by potash.

Fig—VI. 3



Von Wolff's Q-L-M diagram for migmatites

Mechanism and cause of migmatisation: In the present area, the introduced components of the migmatites migrated from outside into the host, and were supplied by the nearby body of granitic magma. Injection of actual igneous melt does not appear to have taken place, and perhaps the emanations formed a diffuse system of ions which migrated through pore fluids. Various criteria point towards a gradual metasomatic alteration of schists into granite, the transformation having been brought about by the passage through solid rocks, of a stream of interchanging constituents. It also appears that in bringing about the migmatisation hydrothermal solutions played a somewhat subordinate role. The relative scarcity of sericitisation and chloritisation during this transformation clearly indicates the paucity of water. In a region of active orogeny, where sediments have been subjected to high temperatures and different types of stresses, ideal conditions would exist for initiating ionic migration. Thus regional metamorphism, migmatisation and emplacement of granite bodies - all these formed a connected sequence of events closely related to the Delhi orogeny.

MASSIVE UNFOLIATED GRANITE

This type includes massive granites which occupy hills and tors, and are distinctly intrusive into the foliated granites. These unfoliated rocks have obviously risen cutting through the gneissic type. These late granites are different from the earlier ones in respect of not only in the mode of occurrence, but also in their structure, texture, mineralogy and chemistry.

In contrast to the gneissic granites, which are generally much weathered and hardly have any topographic expression, these late granite masses are exposed as fresh and unaltered hard rocks, forming conspicuous rugged hills of various sizes and heights. It shows shades of creamy white, pink, buff and grey colour and much variation in texture. On the basis of grain size textural variation and mode of occurrence, these massive unfoliated granites have been subdivided into the following five different varieties.

1. Coarse pink and grey biotite granite.
2. Medium-grained muscovite granite.
3. Granite porphyry.
4. Microgranite.
5. Aplite.

Coarse Biotite Granite

This variety is the most dominant and forms most of the hills. Its mafic content is represented by biotite but at places especially where this has been contaminated by the fragments of, mafic rock, some hornblende is also recognised (Plates-VI.3 & 4). The prominent exposure, of this variety comprise the hills around Idar, and at villages of Sabalwad, Dentroli, Vasai, Nadri, Vehrabar, Naranpara and Gulabpara. An interesting feature of these intrusive bodies is seen along their junction with the grey foliated types. Here the rock is seen to show a patchy grey and pink appearance, very clearly indicating mixing of the two types. This phenomenon is ideally seen near village Vehrabar in the west.

Under the microscope, this variety is seen to contain quartz, microcline, oligoclase and biotite. These minerals form a holocrystalline aggregate of equigranular subhedral grains (Plate-VI.5). The potash feldspar dominates over the plagioclase and quite often perthitic intergrowth is recorded. The most common are the vein perthites typically indicating igneous origin.

PLATE-VI.3

Coarse biotite granite (Loc: Idar).

PLATE-VI.4

Variety of coarse biotite granite containing hornblende (Loc: Kawa).

PLATE-VI.5

Photomicrograph (X60) of coarse [illegible]
granite.

Biotite is the only mica though stray flakes of muscovite are not ruled out. Some hornblende crystals are also present in the rocks contaminated by the mafic rock. The percentages of the various constituent minerals of this coarse granite are given in the Table-VI.5.

Medium-grained Muscovite Granite

This variety is not very common and is encountered only in the main Idar exposures. It occupies small portion within the mass of the biotite bearing variety and obviously represents the residual solutions of the magma rich in silica and alkalies. The rock is less compact and less hard than the previous one. Exposed surfaces are much weathered. The rock is flesh coloured and various minerals are easily identifiable in hand specimen. The minerals present in this variety are quartz, microcline, oligoclase and muscovite. Biotite is very rarely present. The main bulk of the rock comprises of quartz and feldspars, the muscovite though conspicuous is quite subordinate. The texture is granitic and the intergrowths of quartz, microcline and oligoclase are very common. Inclusions of plagioclase in quartz and microcline are also recorded. Muscovite generally forms skeletal and irregular flakes growing in the interstices (Plate-VI.6).

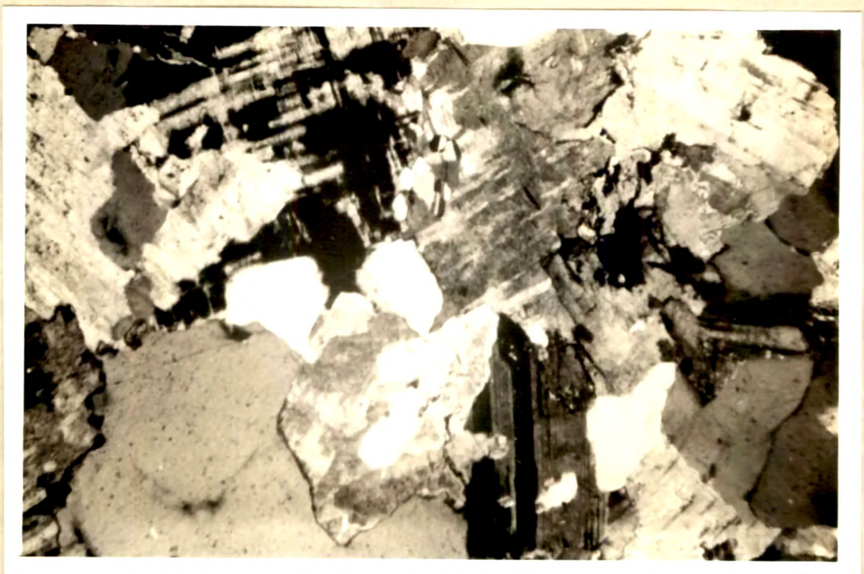
TABLE-VI.5

MODAL ANALYSIS OF COARSE GRANITE

Minerals	32/43	33/45	100/93	A-229	301	406
	%	%	%	%	%	%
Quartz	35.29	44.28	31.27	29.31	34.43	30.94
Potash feldspar	49.20	36.33	50.26	56.08	43.24	50.15
Plagioclase	11.34	11.00	11.54	09.98	13.84	12.97
Biotite	02.89	07.76	03.86	03.56	03.97	04.27
Accessory minerals	01.29	00.64	03.05	01.06	03.51	01.65

Analyst: Paresh Raval

PLATE-VI.6



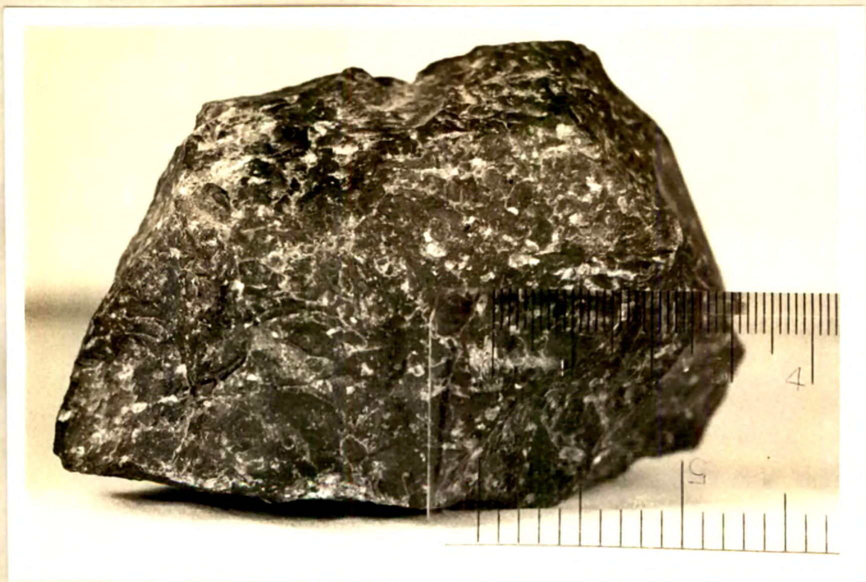
Photomicrograph (X80) of medium-grained muscovite granite showing granitic texture.

Granite Porphyry

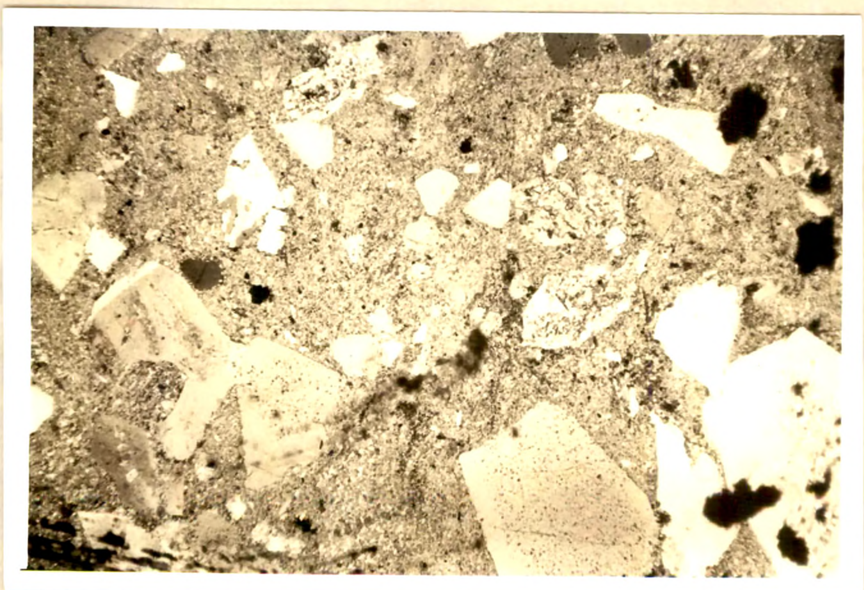
The porphyry is the hypabyssal equivalent of the biotite granite and has been recorded only at two places. It forms conspicuous hills near Vasai and Posina in the east and is seen intruding the foliated granite and quartzite. It typically resembles the porphyry of Jalor area (Malani age) and is dark coloured compact fine-grained rock with abundant phenocrysts of quartz and feldspar (Plate-VI.7). Quartz is recognised by its greasy lusture while the feldspar crystals are pink and euhedral.

Another occurrence of this porphyry is recorded from within the Idar outcrop of biotite granite. It is seen exposed at the S.E. end of this granitic exposure and is somewhat coarser than the one described above. However, there are ample points of similarity between the two outcrops, to be included together. The Idar outcrop is somewhat lighter in colour, tending to be grey and the groundmass is crystalline. The phenocrysts are identical. The contact of this porphyritic rock is rather transitional with the biotite granite, and it is quite evident in the field that both the types have a common magmatic origin.

PLATE-VI.7



A. Dark coloured compact fine-grained granite porphyry. (Loc.: Vasai)

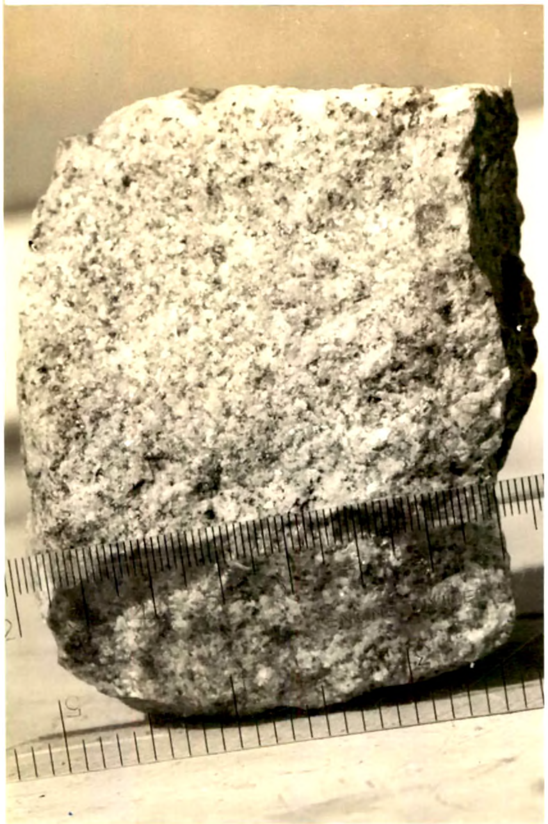


B. Photomicrograph (X30) of granite porphyry showing phenocrysts of quartz and feldspars.

Microgranite

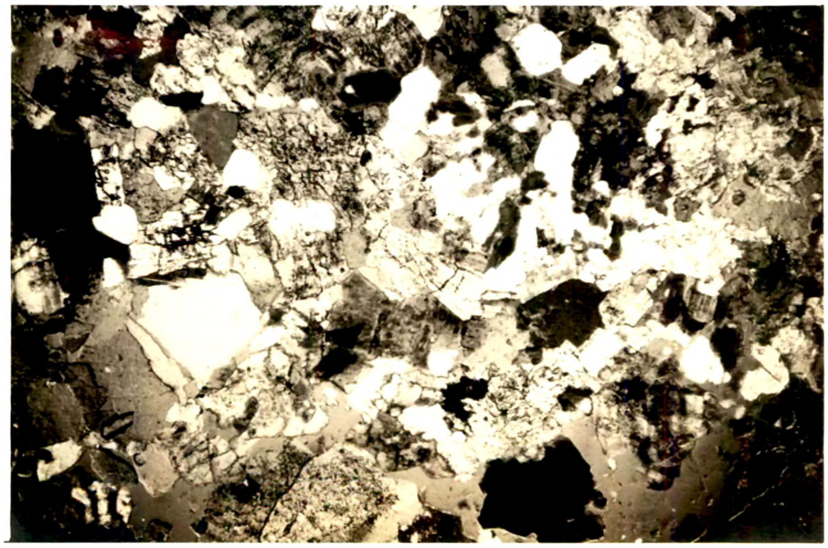
This variety of granite forms narrow veins and dykes cutting the entire granitic terrain comprising both foliated and massive types. Of course they are better recognised in the exposures of the massive granites. The constituent rock is light pink, cream or buff coloured of medium to fine grain (Plate-VI.8). The sizes of the dykes or veins are variable but they never exceed 2 m. in thickness. Their contact with the massive rock is quite sharp and well defined. This microgranite is mainly a quartz-feldspar rock with some biotite. The rock shows a granitic texture with frequent intergrowth of quartz and feldspar (Plate-VI.9). The minerals are quartz microcline, orthoclase, oligoclase and biotite. The microgranite differs from the coarse-grained biotite granite in being fine-grained and with a smaller biotite content. Otherwise, it is in no way different from the massive granite. An interesting feature of this rock is frequent presence of a microcline showing traces of carlsbad twinning (Plate-VI.10) obviously, such grains indicate inversion of orthoclase to microcline.

PLATE-VI.8



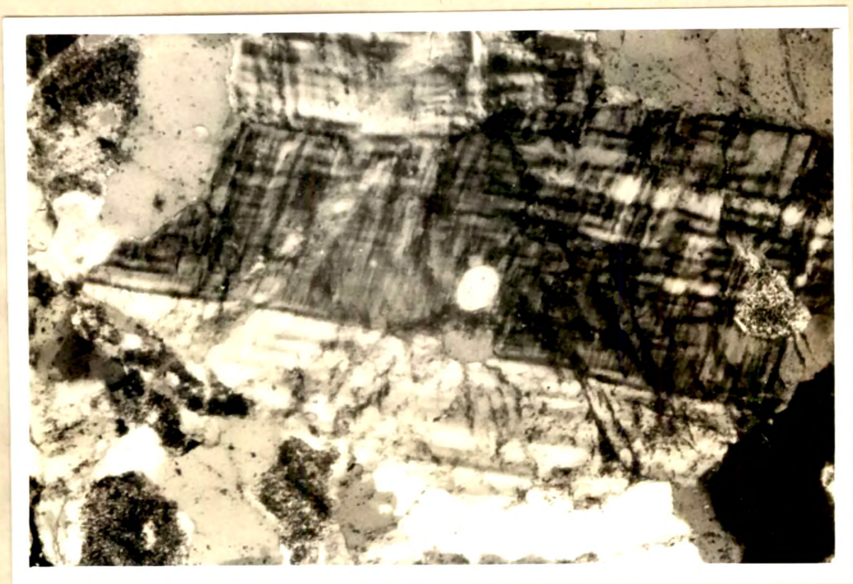
Microgranite (Loc: Kawa).

PLATE-VI.9



Photomicrograph (X70) of microgranite
showing granitic texture.

PLATE-VI.10



Photomicrograph (X70) showing inversion of orthoclase to microcline.

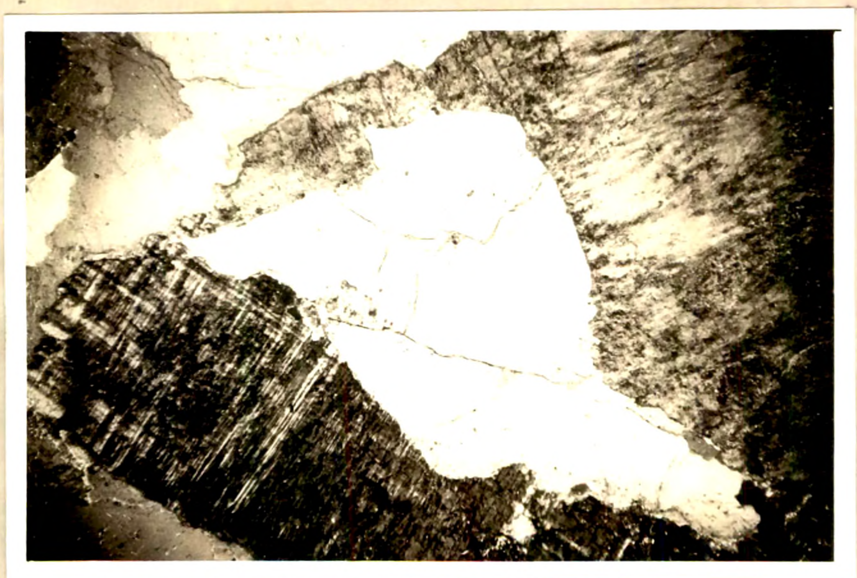
Aplite

This variety is confined to the calc-gneisses and occurs as veins and dykes. Varying in thickness from a few cm. to a metre or two, these aplite veins form concordant bodies along the bedding of the calc-gneisses and follow all the fold patterns. A close scrutiny in the field and their subsequent petrographic study reveal that these aplites were intruded along the already folded calc-gneisses and are mostly post-folding in age. Aplite veins cutting across the bedding are also sometimes noted, and in one case it is seen containing xenoliths of the calc-gneiss (Plate-VI.11). The rock is medium-grained, saccharoidal and of milky white colour. It is totally devoid of mafic minerals and consists almost entirely of quartz and feldspars. In thin sections the rock shows a granitic texture (Plate-VI.12). While quartz is the dominant mineral, the feldspars both microcline and oligoclase are present and the relative proportions of the two feldspars is quite variable though on the whole microcline predominates. Inter-growth of quartz and feldspar and of microcline and oligoclase is frequent and inclusion of oligoclase in microcline and vice-versa are, occasionally recorded. While microcline is fresh and unaltered, the oligoclase is always somewhat clouded

PLATE-VI.11

Xenolith of calc-gneiss in aplite (Loc: N. of Nadri).

PLATE-VI.12



Photomicrograph (X80) of aplite.

due to alteration. The mica, biotite or muscovite is significantly absent though some tiny muscovite flakes as alteration product of feldspar may be occasionally present.

Quartz-Veins

The final stages of the granite activity are presented by numerous quartz-veins, quartz-feldspar veins and pegmatites. On the whole these are not very frequent but their number is adequate enough to need a mention. The author observed that the mineral content of these pegmatitic veins was dependent on the rocks in which they occur, and appear to be more of the nature of metasomatic seggregations.

Mineralogy

In the accompanying table (Table-VI.6) the mineralogy of the different varieties enumerated above, is summarised and their relative proportions have been given. The characters of the different minerals present in the granitic rock have been briefly discussed below:

Quartz is an important constituent of all the varieties, and depending on the texture of the rock types, it shows wide variation in its grain size. In

TABLE-VI.6

RELATIVE STUDY OF DIFFERENT VARIETIES OF MASSIVE GRANITE

Properties	Coarse biotite granite	Medium-grained muscovite granite	Granite porphyry	Micro granite	Aplite
Colour	Pink, occasionally grey	Flesh	Grey	Buff	White
Mode of occurrence	Massifs, hills, tors and bosses	Hills	Hills and hillocks	Veins and dykes	Veins, occassionally forming knolls and mounds
Texture	Holocrystalline, hypidiomorphic, equigranular coarse grained (4 to 5 mm). Often perthitic	Holocrystalline equigranular subhedral grains of medium size (1-2 mm).	Hypocrystalline inequigranular porphyritic. Phenocryst (2-3 mm).	Holocrystalline hypidiomorphic-granular. Medium size grains (0.5 to 1.5 mm). Show micrographic texture.	Holocrystalline xenomorphic-granular or aplitic. Fine to medium grained (0.4 to 1 mm). Graphic intergrowth common.
Mineral composition essential	Quartz, microcline oligoclase, biotite. (Hornblende in contaminated granites)	Quartz, microcline oligoclase, muscovite.	Quartz, microcline, orthoclase, oligoclase, biotite.	Quartz, microcline orthoclase, oligoclase biotite.	Quartz, microcline oligoclase.

most cases it forms irregular anhedral grains showing sutured contact with other minerals. Intergrowth of quartz and feldspar is almost universal.

Potash feldspar is the most dominant mineral and both orthoclase and microcline are present but of the two, the latter predominates. In the biotite and muscovite granites, orthoclase is generally absent, but it is quite common in the micrograpites and the porphyries. Microcline is readily distinguished by its cross-hatching. The orthoclase shows a very distinct carlsbad twinning. Thin sections of micrograpite contain abundant potash feldspar, almost all are microcline with well defined cross-hatching but relict carlsbad twinning indicates the inversion of orthoclase to microcline during the cooling of the rock itself. Microcline is present in all varieties and occurs in the form of irregular anhedral to subhedral grains. It shows a wide range of size variation. Even in coarse rocks, its grain size varies considerably. In porphyries, it forms phenocrysts, while in aplites it is seen intimately intergrowing with oligoclase. In the main massive variety, the veins and patches of oligoclase in microcline are so frequent that the mineral is almost a microcline perthite. Orthoclase is mostly restricted to microgranite and porphyries. In the former rock, it occurs as subhedral to anhedral crystals, showing carlsbad twinning. Quite often, in these rocks a superimposition of cross-hatching is observed. In the porphyries, this mineral forms almost euhedral crystals. In the absence of twinning the mineral has been identified by 'Na-Cobaltinitrate' staining, optical angle 2V = 70°, low relief and $n <$ balsam.

Plagioclase is an oligoclase (An_{12-14}) and is universally present. It is lesser in amount as compared to potash feldspar. Its intergrowth with microcline has given rise to perthites. The mineral mostly shows twinning on albite and carlsbad laws. In massive coarse variety of granite, occasional inclusion of plagioclase within perthite shows ideal myrmekite developed along its borders. Its alteration to sericite is common and is noted in all samples.

Biotite is another important constituent, and is always present in the coarse massive variety as well as in the microgranite. Of course, its proportion is much less in microgranite. It is quite conspicuous in the porphyries. The biotite forms random flakes or cluster and shows strong pleochroism from straw yellow to dark brown.

X = straw yellow

Y = Z = dark brown

$X < Y = Z$.

In the porphyries, however, its colour is somewhat greenish and shows pleochroism from greenish brown to brown. Inclusions of zircon and apatite are common in bigger flakes. It also occurs as small inclusions within feldspars.

Hornblende is only occasionally recorded especially in the rocks which have been contaminated by mafic rocks. It generally occurs as broken small fragmentary grains of green colour. Pleochroism is well marked in shades of green. Cleavage is not readily recognized on account of the small size of the grains.

Muscovite occurs in very subordinate amount in all varieties except in the muscovite bearing granite. In the latter variety, it is seen forming skeletal irregular flakes occupying interstitial space between quartz and feldspar grains. In rest of the varieties only stray small flakes of muscovite are seen either in association with biotite or as inclusions in feldspar. Some fine flakes of muscovite could be derived from the recrystallisation of sericite, the alteration product of feldspars.

Accessory minerals are zircon, apatite, sphene and magnetite. All these occur as tiny grains.

Chemistry

From the chemical analyses of a few selected samples of the different varieties of late granites given in Table-VI.7, it is seen that the rocks show variation in composition, but are always richer in K_2O as compared to Na_2O.

Contact Metamorphism

Contact metamorphic effects of the intrusive granite is restricted to only a few localised spots. At some places where calc-gneisses are seen intruded by small bosses and stocks of biotite granite, hornfelsic rocks containing corundum and wollastonite have developed. The details of these hornfelses have been discussed earlier (Chapter IV). Contact effects on pelitic rocks are uncommon as this intrusive granite has rarely come

TABLE-VI.7

CHEMICAL ANALYSES OF MASSIVE GRANITES

Wt. %	Coarse Biotite Granite	Micro-granite	Coarse Biotite Granite			Micro-granite	Porphyry	Coarse biotites	Muscovite granite
	21/27	26/33	37/49	207/144	A-229	245	269	301	320
SiO_2	74.69	75.93	72.77	74.87	75.55	77.31	72.86	75.53	73.02
TiO_2	00.23	00.15	00.32	00.11	00.13	00.14	00.46	00.15	00.14
Al_2O_3	13.63	13.56	13.91	13.27	12.76	13.36	13.52	13.02	14.86
Fe_2O_3	00.84	00.45	00.64	00.40	00.68	00.50	01.60	00.92	00.78
FeO	01.48	00.59	02.91	01.27	01.19	02.39	03.98	01.38	01.79
MgO	00.52	00.31	00.58	00.54	00.52	00.99	00.54	00.33	00.43
MnO	00.07	00.05	00.08	00.07	00.05	00.06	00.14	00.05	00.06
CaO	00.84	00.71	01.41	01.40	00.70	01.26	01.40	00.49	00.62
Na_2O	03.34	03.61	02.99	03.45	03.45	03.61	02.43	03.35	03.80
K_2O	04.65	04.52	05.30	04.65	05.60	04.30	04.40	04.69	04.24
P_2O_5	00.12	00.11	00.09	00.12	00.07	00.10	00.07	00.10	00.26
Total	100.40	99.99	101.00	100.15	100.70	100.73	101.40	100.01	100.00

Niggli values:

si	423.47	463.90	-	420.80	432.76	-	-	451.20	395.00
al	45.24	48.89	-	47.73	43.00	-	-	45.56	47.40
fm	15.30	7.68	-	12.90	13.01	-	-	14.00	14.60
c	4.76	4.80	-	8.89	4.46	-	-	3.20	3.58
alk	34.70	38.90	-	35.00	39.50	-	-	37.10	34.40

Kohler-Raaz values:

qz	-	-	-	-	-	64.55	-	66.94	61.09
F	-	-	-	-	-	26.67	-	24.39	30.68
fm	-	-	-	-	-	08.78	-	08.67	08.23
Q	-	-	-	-	-	-	-	-	32.29
L	-	-	-	-	-	-	-	-	63.72
M	-	-	-	-	-	-	-	-	05.83

Values for Ossan's diagram:

Al	-	-	-	-	-	-	-	15.88	16.65
C	-	-	-	-	-	-	-	01.12	01.25
Alk	-	-	-	-	-	-	-	13.00	12.10

Analyst: Paresh Raval

Contd...

TABLE-VI.7 (Contd.)

Wt. %	Coarse Bio-granite	Porphyry	Coarse biotite granite		Muscovite granite		Granite with hornblende		
	334	402-A	402-B	406	422	458	484	585	634
SiO_2	76.30	70.01	75.15	78.17	73.70	75.34	70.26	67.33	74.91
TiO_2	00.12	00.33	00.19	00.12	00.16	00.14	00.50	00.49	00.17
Al_2O_3	13.61	14.15	12.15	13.07	14.62	13.76	14.66	15.00	13.19
Fe_2O_3	00.60	01.20	00.64	00.64	00.48	00.36	01.00	01.70	00.80
FeO	01.28	03.60	01.80	01.59	00.80	00.99	04.59	04.40	01.79
MgO	00.40	00.56	00.22	00.30	00.21	00.24	00.76	00.68	00.99
MnO	00.06	00.11	00.05	00.05	00.05	00.06	00.11	00.11	00.05
CaO	00.55	01.35	00.65	00.98	00.69	01.16	01.28	02.05	01.12
Na_2O	03.70	03.98	03.85	02.00	04.30	03.25	03.50	02.97	03.13
K_2O	04.30	05.40	06.00	02.90	05.10	04.93	04.50	04.90	04.90
P_2O_5	00.09	00.09	00.11	00.08	00.24	00.11	00.02	00.07	00.13
Total	101.01	100.78	100.86	99.90	100.35	100.34	101.25	99.70	101.18

Niggli values:

si	446.80	320.68	427.30	-	427.90	439.00	329.00	299.00	400.00
al	46.70	37.90	40.60	-	47.50	47.80	40.00	38.08	41.60
fm	12.80	22.24	13.00	-	7.30	9.10	26.40	24.00	19.00
c	3.50	6.32	3.90	-	4.31	7.40	6.26	9.89	6.45
alk	37.1	33.5	42.70	-	40.86	37.00	29.00	26.00	32.85

Kohler-Raaz values:

qz	66.94	-	-	-	-	67.14	-	-	64.03
F	24.88	-	-	-	-	26.72	-	-	26.41
fm	08.18	-	-	-	-	06.14	-	-	09.56
Q	40.82	-	-	-	-	-	-	26.55	-
L	57.68	-	-	-	-	-	-	63.24	-
M	03.90	-	-	-	-	-	-	09.27	-

Values for Ossan's diagram:

Al	16.03	-	-	-	-	-	-	-	15.42
C	01.20	-	-	-	-	-	-	-	02.39
Alk	12.77	-	-	-	-	-	-	-	12.19

Analyst: Paresh Raval

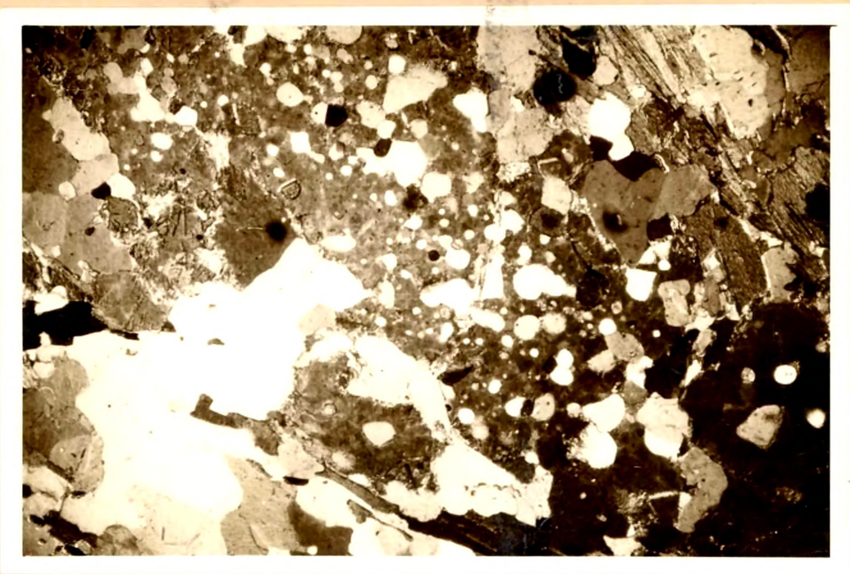
in contact with biotite schists directly. The author, however recorded a small patch of hornfelsic rock in gneissic granite, which was seen to contain some cordierite (Plate-VI.13). It appears that this cordierite bearing hornfels represents contact metamorphic derivative of migmatised biotite schists caught up in the granite.

DISCUSSION

The study of the granitic rocks in all its aspects has led the author to arrive at following conclusions, which throw much light on the pre-Cambrian geology of Gujarat and Rajasthan in general:-

(1) The foliated and massive granites both belong to the same igneous activity related to the Delhi orogenic upheaval. The fact that the various types of unfoliated granite show intrusive relationship with the foliated granite, need not be taken to consider them as representing two igneous episodes. The author is in full agreement with Heron (1953) on this point and the doubts raised by Sharma (1953) can be adequately answered if the two varieties are taken as early and late phases of Erinpura granite.

PLATE-VI.13

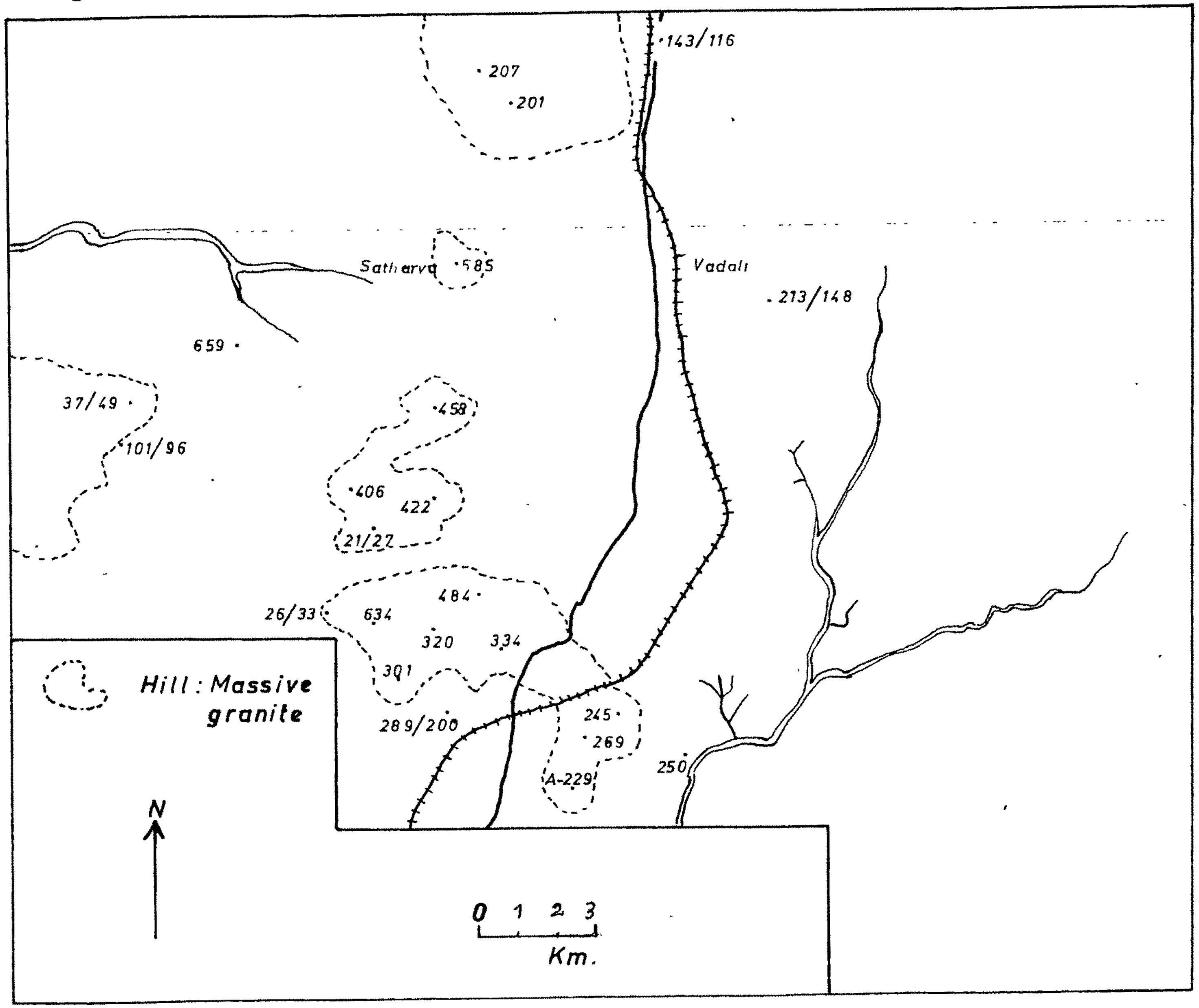


Photomicrograph (X30) of biotite-gneiss showing development of cordierite.

(2) The two varieties, each showing distinct mode of occurrence, structure and mineralogy, very clearly point out to the fact that while the foliated variety is a product of mostly metasomatic transformation of biotite-schists due to granitic emanations, the massive unfoliated granite represents intrusive magmatic bodies that arose cutting through the granitised metasediments. Thus, a relative age-relationship is easily established - the gneissic granite being early and perhaps in part synkinematic (with reference to Delhi orogeny) and the intrusive bodies being post-kinematic. The chemical data also confirms the above idea. The early phase characterised by the foliated granites is relatively richer in Na_2O as compared to the massive granite. The enclosed figures (Fig.-VI.4&5) ideally show the Na_2O-K_2O proportion in the granites from different parts of the area. Also the chemical data when plotted on various diagrams, clearly brings out the fact that the foliated gneissic granites are of metasomatic origin while the later massive variety is typically igneous (Figs.-VI.6,7&8).

Map showing location of samples of granitic rocks chemicaly analysed

Fig.— VI. 4a



Map showing Soda Potash relationship in the granitic rocks of Idar area

Fig. — VI. 4b

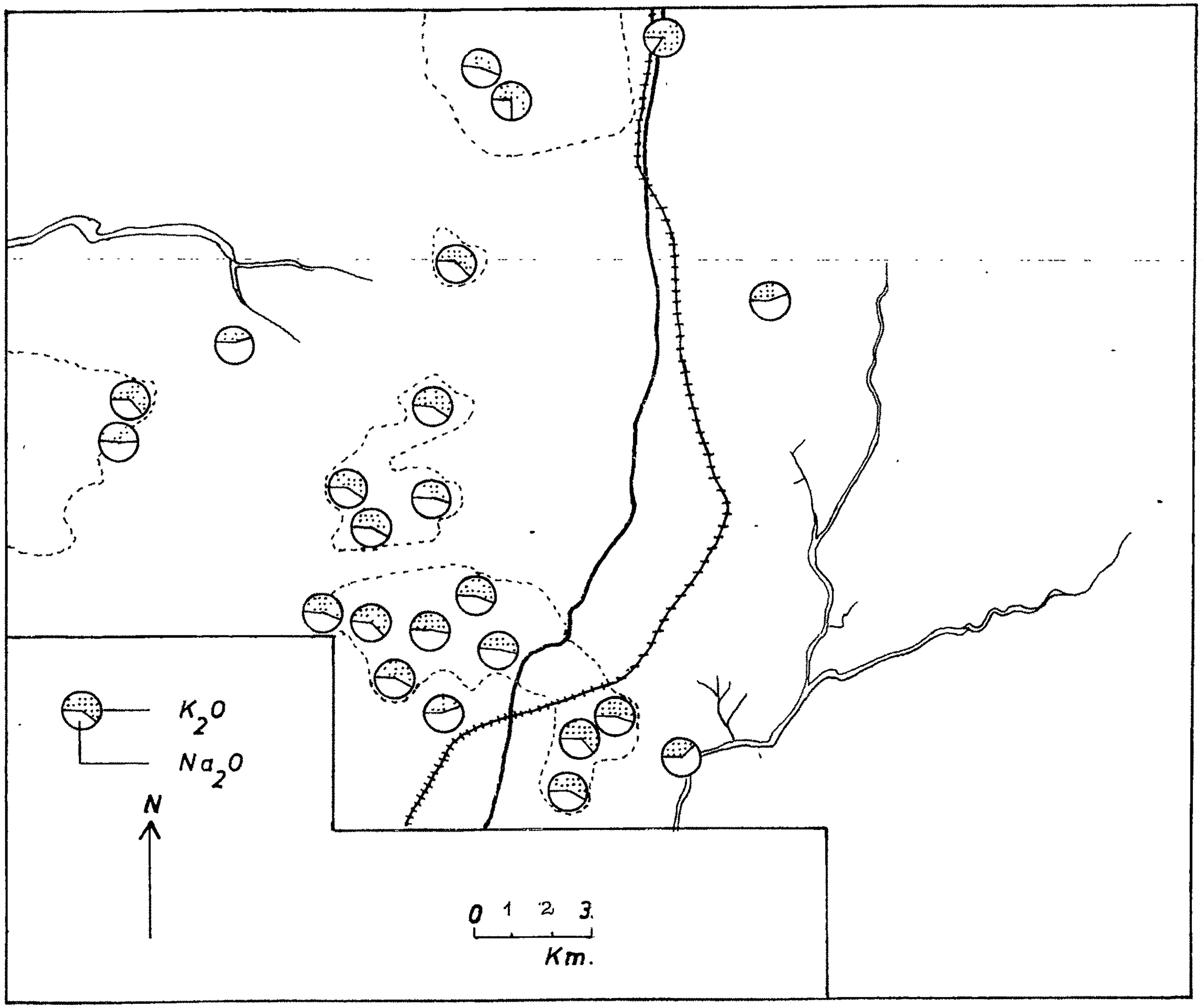


Fig.—VI. 5

Relative proportion of Na_2O & K_2O in granitic rocks

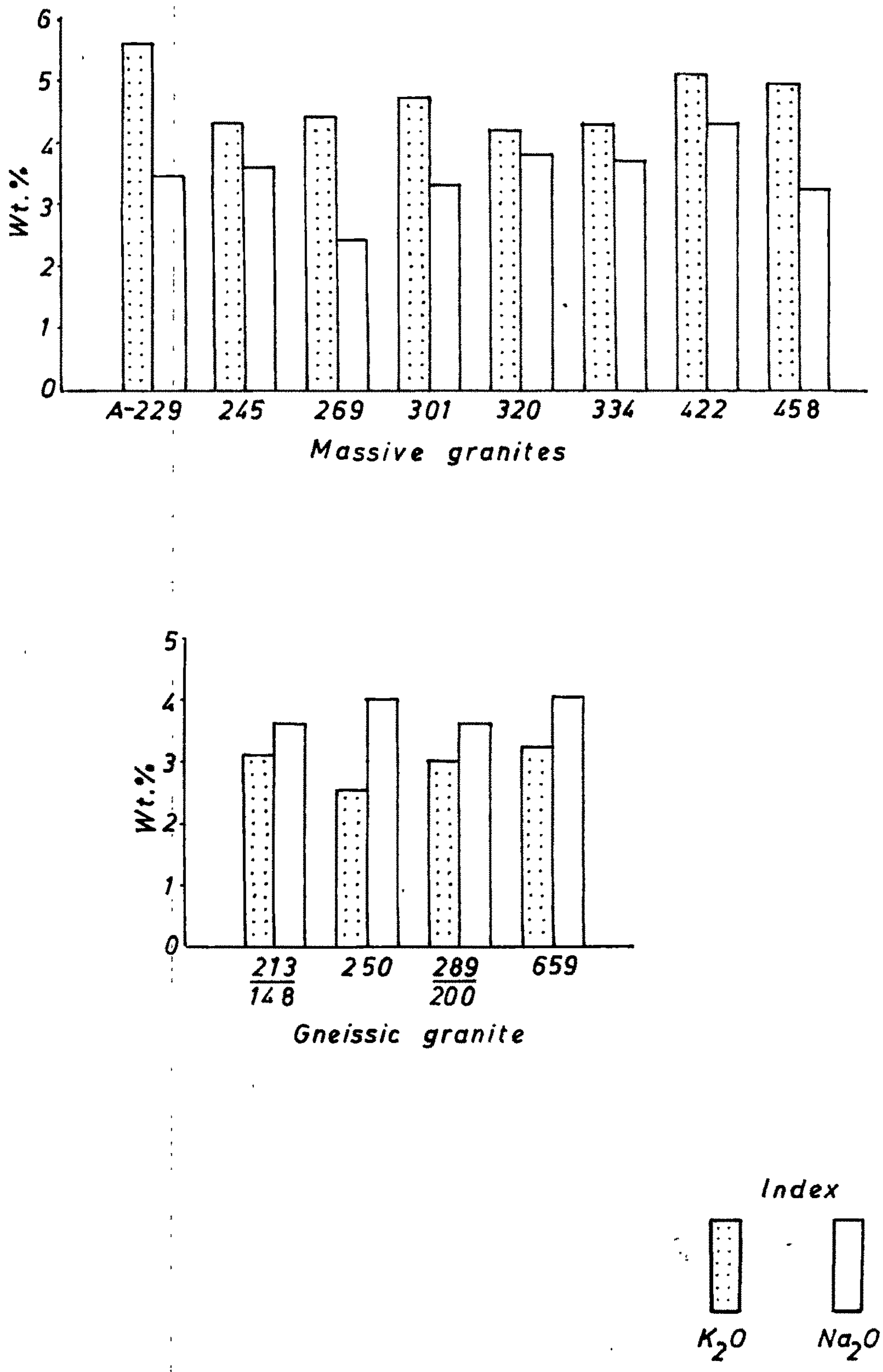
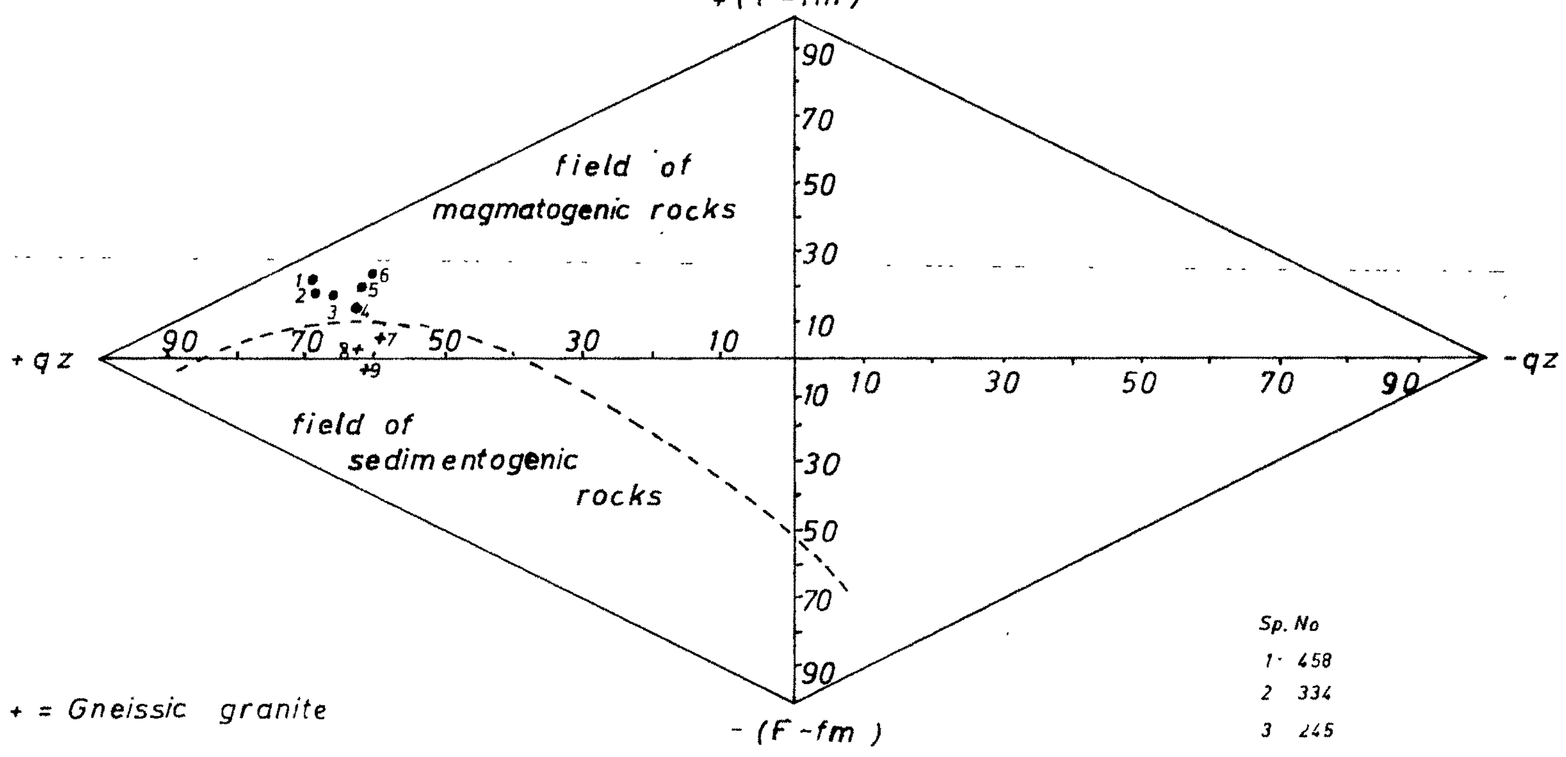


Fig - VI.6



+ = Gneissic granite

• = Massive granite

KÖHLER - RAAZ DIAGRAM

Sp. No	
1	458
2	334
3	245
4	301
5	634
6	320
7	250
8	213\148
9	289\200

Al–C–Alk diagram
based on Ossan's system

Fig. — VI. 7

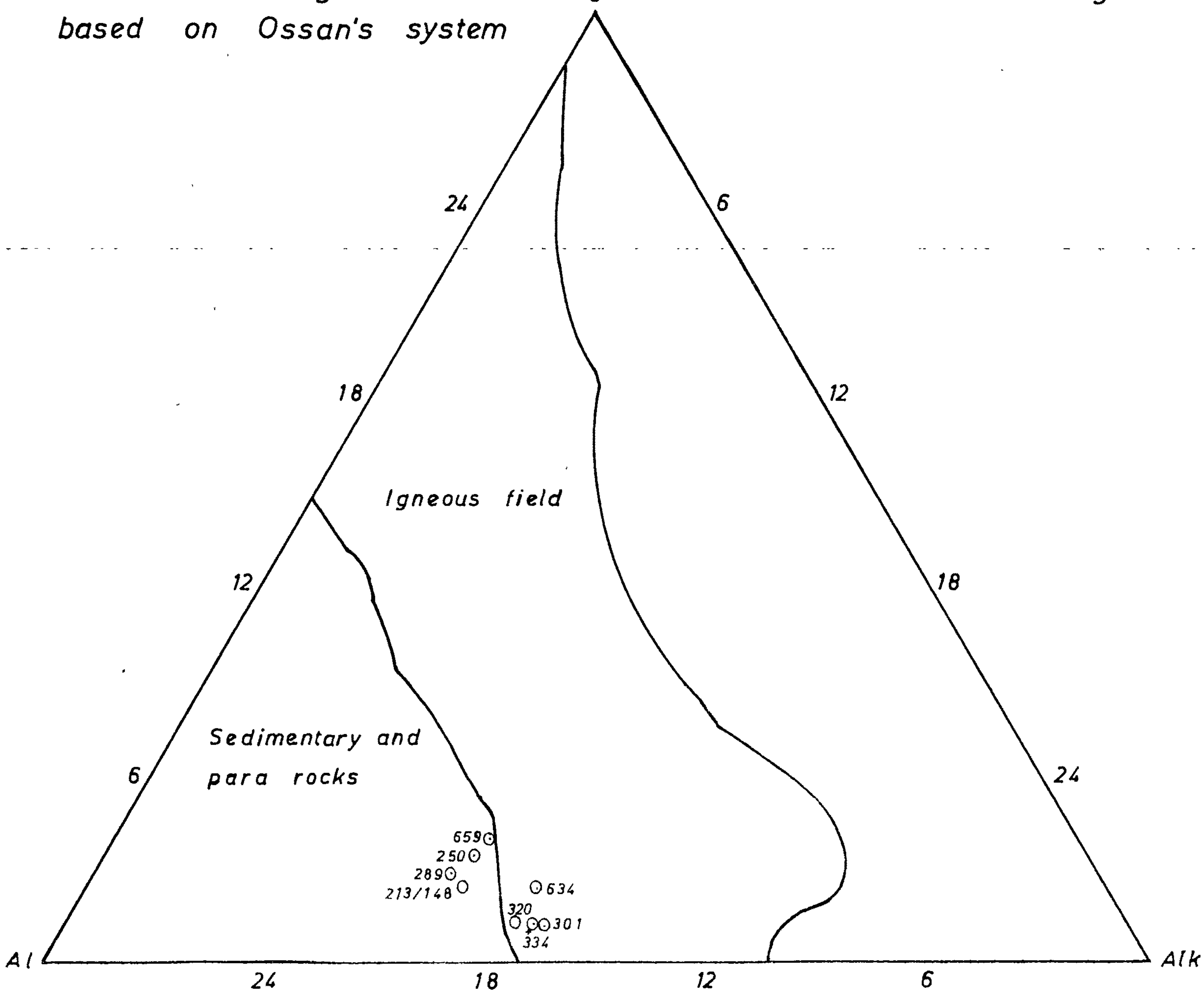
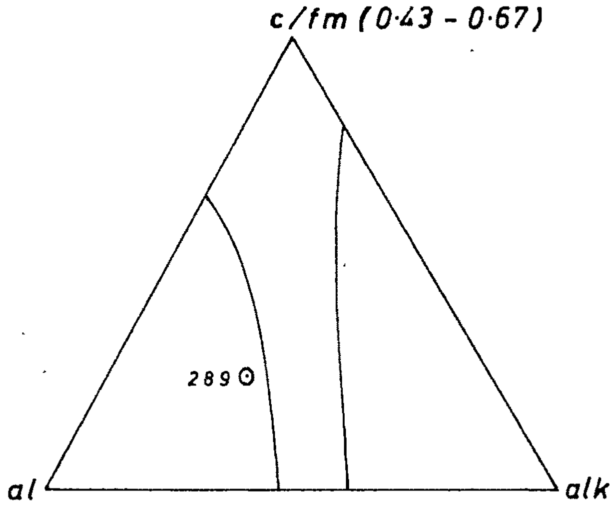
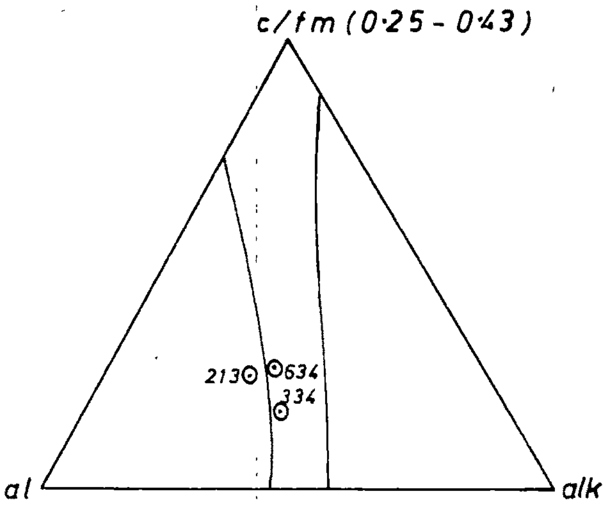
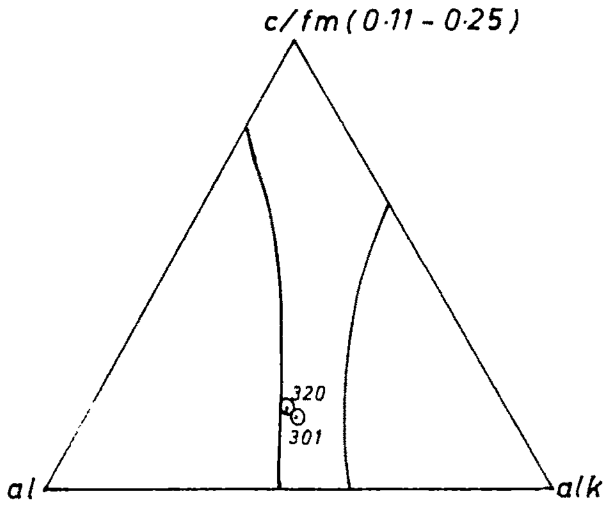


Fig.— VI. 8

c/fm — al — alk diagram of Niggli







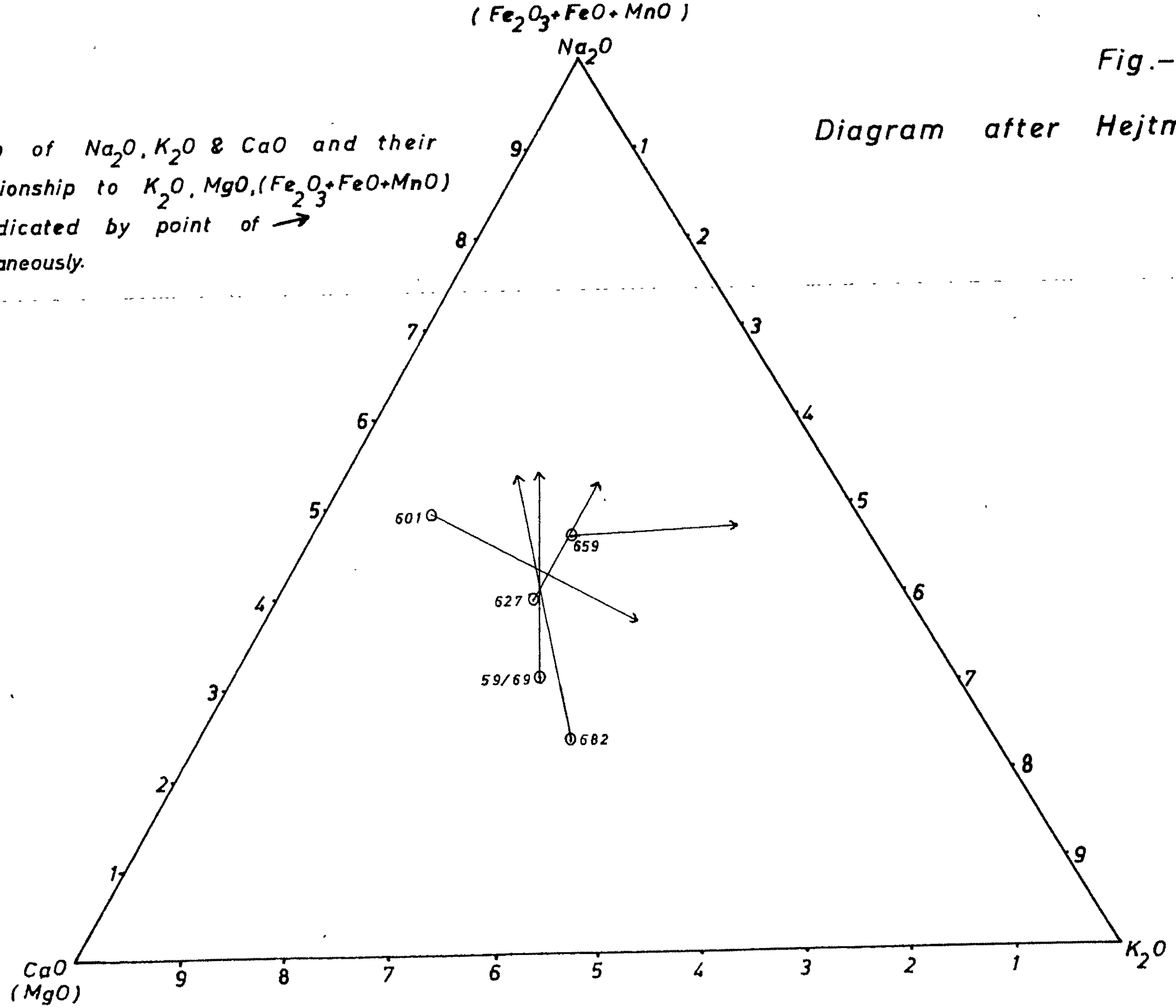
(3) The metasomatism that transformed the schists into gneisses and finally into gneissic granite, for the most part was dominantly sodic. It was only at quite a later date (the stage at which potash feldspar appeared as porphyroblasts) that potassic emanations become important. This soda-potash sequence is ideally reflected in the different variation diagrams of chemical and mineral constituents. In the accompanying diagram (Fig.-VI-9) after Hejtman (1956) also shows this point quite clearly and further indicates the trends of the depletion of mafic content.

(4) The earlier metasomatic phase of granite activity, affected the earlier pelitic and the basic rocks. The biotite-schists were gradually transformed into a gneissic granite. The dolerites intruding into the Delhis, were converted into epidiorites, such that they still preserve their igneous textures but mineralogically show much alteration. Pyroxenes have been fully or partly changed to hornblende and chlorite, and feldspars show partial saussuritisation.

Fig.– VI.9

Diagram after Hejtman

⊙ = Ratio of Na_2O, K_2O & CaO and their relationship to K_2O, MgO, (Fe_2O_3+FeO+MnO) is indicated by point of → simultaneously.



(5) The late intrusive phase of potash granite affected the pre-existing rocks in several ways. Its most important effect is seen in the development of calc-silicate hornfels in the vicinity of granite intrusions in calc-gneisses. Development of corundum, wollastonite and idocrase typically illustrates the effects of contact metamorphism of granite on calcareous meta-sediments. Occasional development of cordierite in caught up patches of biotite schist also indicates a similar effect on pelitic rocks. The intrusive granite has affected the mafic rocks in two ways: (1) Fragments of epidiorites have been assimilated bodily giving rise to progressively hornblende and biotite rich patches of contaminated granites (2) Along the contact with bigger mafic mass of Kawa, potassic emanations have entered the basic rock and given rise to extensive oval-shaped porphyroblasts of potash feldspar set in a dark matrix comprising of partly altered pyroxene and plagioclase. Extensive development of biotite porphyroblasts in the Kawa rock also indicates contact effects accompanied by the addition of potassic constituents to the basic rock from the granite.

(6) Finally, it has been concluded that the various granitic types, foliated, coarse massive, micro-granite, aplite and porphyry, all comprise different phases of one single acid igneous activity related to the Delhi orogeny.

(7) Having established that the foliated granites are migmatitic while the massive types richer in potash have intruded them, it is automatically concluded that the two granitic types do not indicate any difference in age or magma type, but the succession is a clear indication of the two stages of granite activity in an orogenic setting. As regards the veins of microgranites and aplites, these typically represent the final stages of granite intrusion. These veins, having arisen along folded calc-gneisses, give an erroneous impression of their being involved in Delhi folding and this phenomenon perhaps misled Middlemiss (1921 p.32) who considered the aplites to have been intruded prior to folding. The author has conclusively observed that the potassic aplite veins devoid of ferromagnesian minerals originated out of the main massive intrusive mass of granite. Also the microgranite and the porphyry show clear evidence of gradational relationship with the

non-foliated granites. These post-Delhi granitic rocks considered equivalent to the Erinpura granites, show wide-spread development in the region and the various granitic rocks described by other workers in the neighbouring areas may belong to this igneous activity only.

(8) The author finds himself in full agreement with the observation of Middlemiss (1921 p.126,129) that the porphyries and the coarse granites comprise one single acid igneous activity. But he is not inclined to correlate these granites with those of Malani age. Heron (1953) has rightly considered the granites of Idar to be equivalent to the Erinpura granites. As regards the Coulson's findings in Sirohi area, where he mapped two granites - one of Erinpura granite age and the other of Malani age, it appears that this two-fold classification may not be valid. Coulson (1933) correlated his late granite with Idar granite of Middlemiss and assigned them Malani age mainly on the basis of the associated porphyries which resembled those of Malani igneous phase. The author is of opinion that Erinpura granites have quite frequently given rise to porphyries and this criteria can hardly be applied for classifying the granites of the region. It is most probable that all granites in N. Gujarat and S. Rajasthan belong to one single acid igneous activity of post-Delhi age, equivalent to the Erinpura granite.