MINERALOGY AND GEOCHEMISTRY OF KOGA SYENITES, CARBONATITES AND FENITES BUNER, NW PAKISTAN

By

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Dedicated to the everlasting affection of my deceased parents that keep me going.

APPROVED BY

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ABSTRACT

The Koga complex is composed of alkali granite, alkali syenite and nepheline syenite. The syenite and nepheline syenite are intruded and fenitized by carbonatite and ijolites at different places. The ijolites and carbonatites are exposed mainly in the western part of Koga complex.

Amongst the mafic minerals in the Koga syenite, the fenitic Na-pyroxene show trends of crystallization from acmitic to diopsidic and/or hedenburgitic components. Which is reversed to the magmatic trend. The fenitic amphibole shows a trend from magnesio - arfvedsonite to richterite which is opposite to the magmatic subsolidus trend. The fenitic alkali feldspar solid solution series in the Koga fenitized syenite are anomalously low albite and maximum microcline. Temperature for this solid solution series is suggested as 350-500C in contrast to the magmatic feldspar for which temperature is 800-1000C.

From the whole rock geochemistry and petrography of Koga complex it is suggested that the carbonatite has produced two types of fenites: 1. Na-fenites and 2. K-fenites. Both the type of fenites show great deferences in their Ba, Sr, Nb and Th contents. K-fenites are depleted in REE as compared to the unfenitized rocks whereas Na-fenites show enrichment of REE.

The composition of Na-pyroxenes, Na-amphiboles, feldspars and whole rock geochemistry of Koga compex suggests that the rocks have been fenitized by the solution emanating from at least two carbonatites which have different Na/K ratios.

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CHAPTER 1

INTRODUCTION

Carbonatite achieved geological importance only about 30 years ago, largely through the impact of work in Scandinavia and Africa. Broger (1921) worked on carbonatites at Fen in South Norway and suggested that Carbonatites owed their origin to metasomatic hydrothermal replacement. Broger's work was strongly disputed by Bowen (1924). But Saether (1957) re-established the Broger's work and demonstrated that calcite-rich rocks could have all the characteristics of intrusive magmatic bodies and they alkali metasomatize (fenitize) their host rocks. The rocks which develop as a result of metasomatism due to carbonatites are called fenites and the process is termed as fenitization. Extensive work has been done on fenitization of rocks by a number of authors (Mckie, 1966; Verwoerd, 1966; Sutherland, 1969; Currie and Eurguson, 1971; Cooper, 1971; Woolley et al., 1972; Gittins et al., 1975; Vartiainen and wooley, 1976; Le Bas, 1977; Ferguson et al., 1978; Vartiainen, 1980; Gittins and Mckie, 1980; Rubie and Gunter, 1986; Viladkar, 1980,1986; Kresten and Morogan, 1986; Mian and Le Bas, 1986; 1987), but the process is not well understood because it depends on different factors including, nature of fenitizing fluids, variation in mineralogical composition, texture, chemical reactivity, the state of oxidation and particularly permeability of the country rock. Fenitization mainly effects the structure and composition of the individual mineral.

In Pakistan three main occurrences of carbonatites has been reported so far, (1) Loe Shilman Carbonatite Complex, (2) Silai Patti Carbonatite Complex (3) Narinji Kandau Carbonatites of Ambella Granitic Complex. An appreciable work has been done on the fenitization around the Loe Shilman Carbonatites and Silai Patti Carbonatites by Mian and Le Bas, 1986; 1987; and Le Bas et al., 1987. The authors have described the effect of fenitization on micas, and Na-amphiboles. Very little has been published on the fenites around Naranji carbonatite. To know the effects of fenitization on the Syenites at Koga area has been selected. These Syenites surround the Naranji Kandau Carbonatites of Ambella Granitic Complex.

The Ambella Granitic Complex is an intrusive batholith in the alkaline igneous province of Peshawar plain. It is composed of a varied assemblage of granite, alkali granite, quartz syenite, alkali-quartz syenite, syenite, alkali-syenite, feldspathoidal syenites, carbonatites, ijolites and related rocks of Koga Complex (Saddiqui et al., 1968).

The Koga alkaline complex is an oval shaped body of about 40 sq. km (Fig.1.1). It is emplaced in Chingalai gneisses to the east and metasediments to the north and west. It is composed of alkaline rocks ranging from undersaturated aegirine and feldspathoidal-bearing syenites to slightly oversaturated biotite-bearing normarkites (Saddiqui, 1967). The complex has been intruded by carbonatites, ijolites, lamprophyre dykes, pegmatitic and aplitic veins. The carbonatite rocks are confined to the western part of the syenite body and occur in the form of lenses, pockets and veins that may vary from a few meters to a few centimeters in thickness, with lengths of upto a few meters. The host rock at Narinji Kandau is Nepheline syenite. In the vicinity of carbonatites fenitization has taken place.

PREVIOUS STUDIES

The Ambela granitic complex occupies the core of an anticline in the Swabi-Chamla sedimentary group (Saddiqui, 1965). The feldspathoidal syenites and associated rocks of the Koga area, and Naranji Carbonatites were firstly reported by Saddiqui (1967). Latter on, Saddiqui et al. (1968) described three main petrological types in the Koga area:

3. Feldspathoidal syenite
2. Peralkaline syenites and granites or Babaji syenite
1. Calc-alkaline Chingalai granodiorite gneisses

They suggested that the rocks of the Koga and Babaji area were the products of a peralkaline syenitic magma which became undersaturated and was emplaced as a viscous mush with alkaline feldspar crystals suspended in a liquid capable of crystallizing nepheline. On the basis of petrography and preliminary geochemistry, Saddiqui (1965) also suggested that the Shewa Formation (the so-called Shewa-Shahbaz Garhi Complex) may be related to Koga feldspathoidal syenites and related rocks.

Colson (1936) correlated the alkaline granitic rocks of Warsak with Shahbaz Garhi. Subsequently Kemp and Jan (1970) considered that these rocks along with the alkaline rocks in Koga and Terbela, constitute an alkaline igneous province. Later on, Kemp and Jan (1970) and Kemp (1973) concluded that the rocks of the alkaline igneous province were the product of magmatism associated with rifting, caused partly by rebound relief tension or compression release. The rifting event, activating the alkaline magmatism, thought to be late Cretaceous or Early Tertiary, followed collision between the Indo-Pak plate and Island arc.

Engineers Combine Limited (1977) presented a detailed account of the petrography and geochemistry of the Koga Nepheline syenites. A classification scheme based on alkali-feldspar content, texture, mineralogy and colour indices was presented for these rocks. The carbonatites of Narinji Kandau, fenites of Koga, Lamprophyres of Bibi Derai and acidic dykes and zoned pegmatites near and within Koga Syenites were also described. Based on the report, Chaudhry et al. (1981) described the petrology and geochemistry of these rocks and suggested that the rocks were emplaced along a zone of weakness developed south of MMT in the sequence as Babaji Soda granites, pulaskite, nepheline syenite, feyalites, sodalite syenite, fenite and carbonatite.

Rafiq (1987) described the Ambela granitic complex and divided the rocks into three main groups, I. granites and alkali granites, II. quartz-syenites and alkali-quartz-syenites and III. basic dykes. The author suggested that the major and trace element variation show fractionation of silicic parental magma (from granites to alkali granites of group I) generated by partial melting within the lower crust. He further suggested that during the later phases, the partial melts of the crust were continuously contaminated by influx from the activated upper mantle and progressive desilicification of magma led to the formation of quartz-syenites, syenite and feldspathoidal syenites. It is proposed that the initiation of partial' melting occurred predominantly in the lower crust in response to crustal swelling.

Le Bas et al. (1987) assigned an age of 315±15 Ma for the Babaji Syenites and 297±4 Ma for the Koga Syenite. The authors proposed that the small difference is because the Koga syenite cuts the Babaji syenite and granite, and all belong to Ambela Complex. So they suggested that there must have been alkaline igneous activity in carboniferous period which had not been previously appreciated by Kemp and Jan (1970) and Kemp (1973).

OBJECTIVES

Not much work has been done on Koga Syenites specifically with respect of fenitization. Therefore, the objectives of the present study are:

1. to know the nature of fenitizing fluids emanating from

carbonatite/ijolite and its effects on the surrounding rocks.

2. To distinguish the composition of the fenitic pyroxene and amphiboles from that of magmatic pyroxene and amphibole and,

3. To distinguish the structure and composition of the fenitic feldspar from the magmatic feldspar.

4. To describe the geochemistry of fenitized and un fenitized rocks, and established the various processes/parameters which cause and influence fenitization.

CHAPTER 2

GEOLOGICAL SETTING

INTRODUCTION

The northern part of Pakistan has been divided into three geological domains separated by two suture zones (Tahirkheli and Jan 1979; Tahirkheli et al., 1979)

1. Eurasian plate in the north,
2. Kohistan Island arc in the middle, and
3. Indian plate in the south.

The northern margin of the Indian Plate is marked by the Inner zone or Hazara zone of the Lesser Himalayas. The igneous rocks of the zone comprises Mansehra-Nausen and Nanga Parbat gneisses, Swat Lahore granitic gneisses and Alkaline igneous province of Peshawar Plain. Alkaline igneous province trending WSW-ENE and extending for about 200 km in northern Pakistan consisting of alkaline and peralkaline intrusions and hypabasal rocks has been described by Kemp & Jan (1970, 1980) and Kemp (1973).

REGIONAL GEOLOGY

Most of the geological features developed in the northern part of Pakistan are the products of Collision of Eurasian plate with Indian plate, 55 m.y. ago (Powell, 1979). The collision occurred due to northwards subduction of Tethys ocean floor under the Eurasian plate. The Kohistan island arc was formed in response to this subduction during Cretaceous and was sandwitched between the Eurasian and Indian continents during Early Tertiary. The northern and southern boundaries of the Kohistan island arc are marked by two branches of Indus Suture Zone. The northern one is called as Main Karakoram Thrust (MKT) which separates the Kohistan arc from the Eurasian plate, and the southern one is called as Main Mantle Thrust (MMT) along which the Kohistan island arc wedged with Indian plate (Tahirkheli et al., 1979).

In the south of the Kohistan arc occurs a series of southward directed nappes, and tight to recumbent folds. The series is bounded by MMT in the north and Main Boundary Thrust (MBT) in the south. The belt was classified as inner zone or Hazara zone of lesser Himalayan belt (Tahirkheli, 1982). This zone marks the northern margin of the Indian plate with Precambrian to paleozoic rock sequence. These are thrusted southwards with the formation of complex structures such as the Hazara-Kashmir syntaxis, western arc, and Indus re-entrant (Calkin et al., 1975).

The igneous rocks exposed in the lesser Himalayan belt (inner zone) comprises granite gneisses, granite and pegmatites called as Mansehra-Nausen and Nanga Parbat gneisses to the east, and Swat-Lahore granite gneisses to the west of the Indus river. In the south of the Swat granitic gneisses lies the alkaline igneous province of Peshawar plain (Kemp and Jan, 1970).

The alkaline igneous province of the Peshawar plain extends over a distance of 200 Kilometers along the northern and northwestern margins of Peshawar plain, from Loe Shilman in the west through Warsak, Mohmand-Malakand Agencies, Ambella, upto Terbella in the east or even upto Mansehra (Fig.2.1). The alkaline province includes Shilman Carbonatite Complex, Warsak alkaline granites, Silai Patai Carbonatite Complex, Malakand Carbonatite, Shewa Shahbaz Garhi Complex, Ambella alkaline complex and Terbella alkaline complex.

Compositionally the rocks of the alkaline igneous province ranges from highly saturated granites to undersaturated feldspathoidal syenites. Besides these small gabbroic intrusions, dolerite and metadolerite dykes, albites and carbonatites are sporadically distributed throughout the province.

The west central part of the Ambella granitic complex is occupied by the feldspathoidal syenites, ijolites, carbonatites, and related rocks which constitute the Koga Syenites(Fig.2.2).

The origin of the rocks of the alkaline igneous province of Peshawar plain is attributed to extentional type environments (rift/graben-related) during Tertiary time (Kemp and Jan 1970, 1980; Kemp, 1973, 1983). The authors suggested the production of alkaline magma as a result of "Rebound release tension". During the process of subduction of Indian plate, continental deep crustal fractures were formed as a result of siesmic gap and relict forces. When the episode of compressional forces was over, parallel tension fractures were produced near the Main Mantle Thrust (MMT). Simultaneously continental crust melted producing an alkaline magma. Rafiq (1987) suggested that the Ambella granitic complex might be the product of an epicrustal phenomena in structural pattern (crustal swell) within the crustal basement before the disintigration of Gondwana land began.

Le Bas et al., (1987), proposed that in northern Pakistan strongly alkaline and carbonatitic magmatism occurred in two periods, one in Carboniferous (c. 300 M.a) and the other in oligocene (31+2 M.a). The Tertiary carbonatites (Loe Shilman and Silai Patti Carbonatites) are emplaced as sheets along fractures now interpreted as thrust planes. This negates the proposal (Kemp and Jan, 1970) that there was alkaline magmatism near Peshawar which was associated with rift during the Tertiary. The Carboniferous Carbonatite at Koga (Le bas et al.,(1987) confirms to normal interplate magmatism.

LOCAL GEOLOGY

Koga Carbonatite Complex is associated with Ambella granitic Complex. The rock constituents are nepheline-syenite, quartz-syenite, alkali-syenite, ijolite, carbonatites and associated fenites (Fig.1.1). In the north of the complex lies alluvium laid down by the Chamla river and its tributaries. In the west and southwest occur peralkaline oversaturated syenite and granites. In the east and southeast lies the Chinglai gneisses.

In the field it is difficult to distinguish between the nepheline syenite, alkali-syenite and quartz-syenite of the Koga Complex. Their contact relationship is little difficult to determined. However, on the whole the Koga Syenites have an irregular and sharp contact with the Babaji syenites. At some places shearing can also be observed. Apophyses of the Koga syenites with chilled margins, cut the Chinglai gneisses and Babaji syenite. Xenoliths of the Babaji syenite and Chinglai gneisses occur within Koga Syenites.

The colour of the Koga syenite is whitish, light grey and dark grey on fresh surface and on weathering surface it is grey to rusty grey depending upon the composition of the rock. Exfoliation weathering is prominent in the area (Photo.1,2) due to which spherical blocks of the rocks has been formed. These blocks occur in the form of huge boulders on the outcrop.

The rocks show marked heterogenity with respect to its composition, lithology and texture. The grain size varies from fine to coarse. Coarser variety is more leucocratic. The coarse grained and fine grained varieties are intermingled with each other. The patches and veins of the coarse-grained rock occur in the fine-grained rocks and vice versa (Photo.3,4,5,6). Pegmatites and aplitic veins are intruded in to the Koga syenites.

Feldspar, nepheline, sodalite, pyroxene, biotite and ore minerals can be recognized in the handspecimen. In an area of about one square kilometer near Koga Village and at places in Miane Kandau the nepheline syenite contains garnet. The garnet has been developed only within the coarse-grained leucocratic part (Fig.7). In the rest of the area the garnet is not found. A detailed work is required to know the nature and origin of this garnet.

IJOLITES

Ijolites have been found at various places (near Narinji Kandau, Bagosh Sar, Shpala, and Nawe Kalli) in Koga Syenites (Fi g.2.2). These occur in the form of pockets and lenses. These are fine to medium grained, and dark black or brownish black in colour. Usually traversed by the veins of albite and pyroxene and also having albite at the contact with syenites. Pyroxene, nepheline and alkali-feldspar can be distinguished in handspecimen.

CARBONATITES

Koga Carbonatites are sporadically distributed within syenite and occur in the form of pocket, lenses and veins. Mostly they are exposed to the western part of the syenite (Narinji Kandau, Shpala and near Nawe Killi). These ranges in size from a few centimeters to about 45 meters in width with length of up to 120 meters. The veins of carbonatite cut across Koga syenites.

The Carbonatites are medium to coarse-grained and generally lack foliation. These are white on fresh surfaces but due to weathering changes to brownish or rusty-white-soft material. In field pyroxene, feldspar and ore minerals can be distinguished.

FENITES

The Koga syenites have been fenitized by carbonatites and/or ijolite. The two types of fenitization can be distinguished by petrographic and chemical studies. In the field the rocks colour shows a kind of backing effect which may be called turbidity. This turbidity of the felsic minerals, which are mostly feldspars is found in the low grade fenite and its intensity increases in the medium grade rocks, while is diminished in the high grade rocks (cape rock and Narinji Kandao). At the contact with carbonatite intrusion large pyroxene needles are found which are approximately at right angle to the wall of the intrusion.

In the case of ijolite white rims of feldspar have been developed along the contact of ijolite with syenites. Detail study of fenites is given in the following chapters.

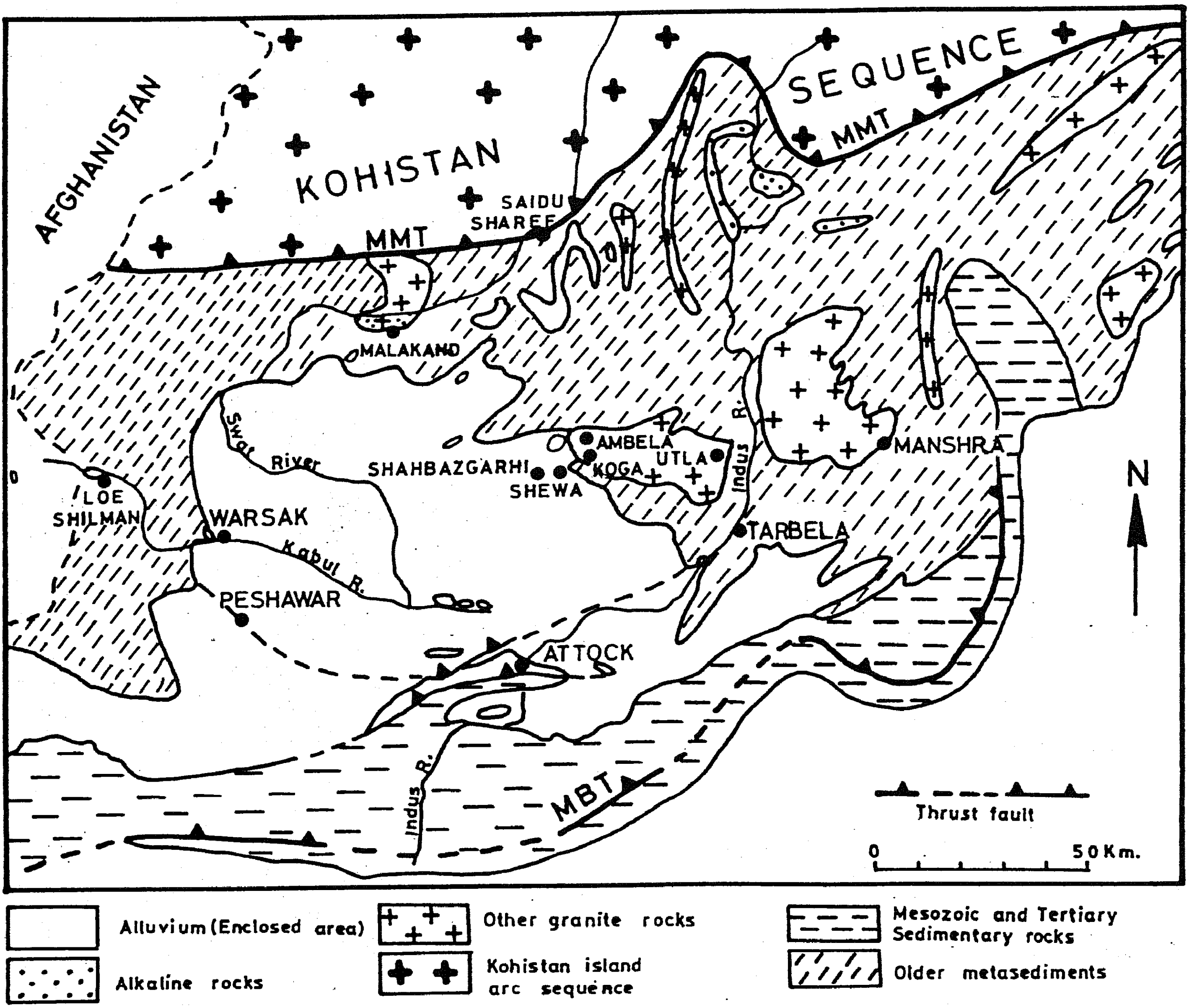
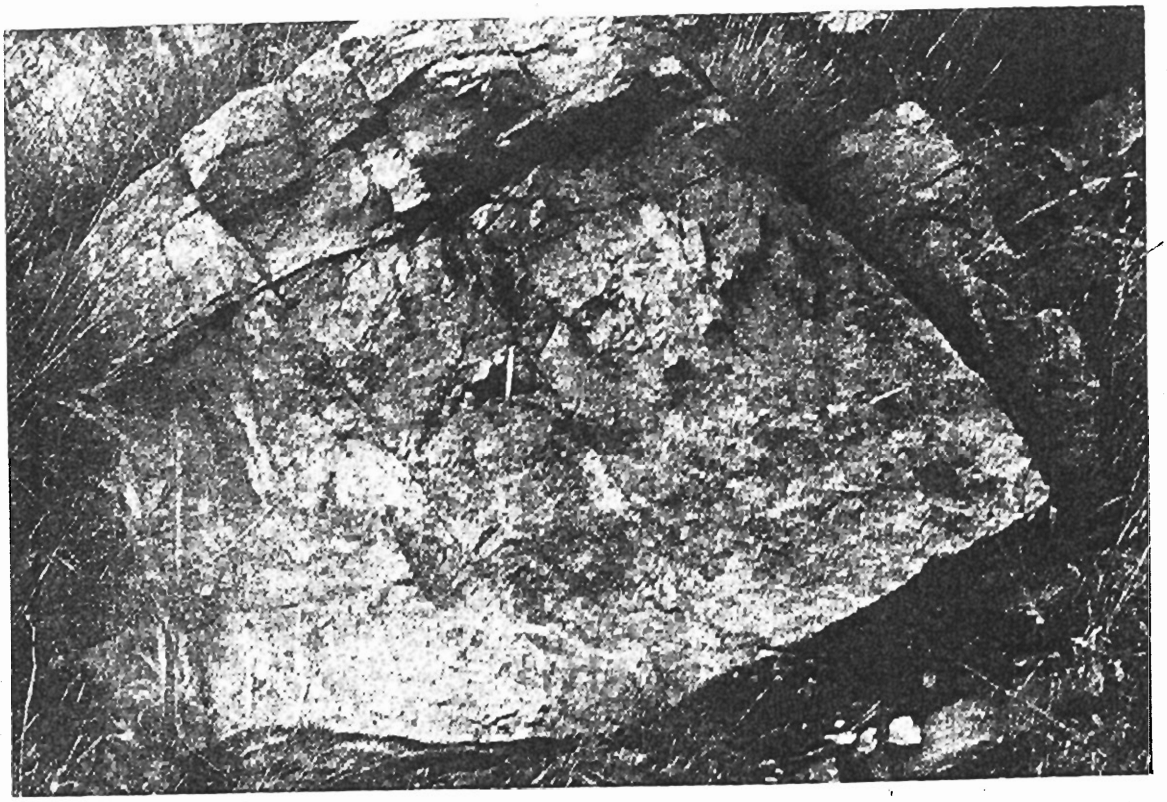
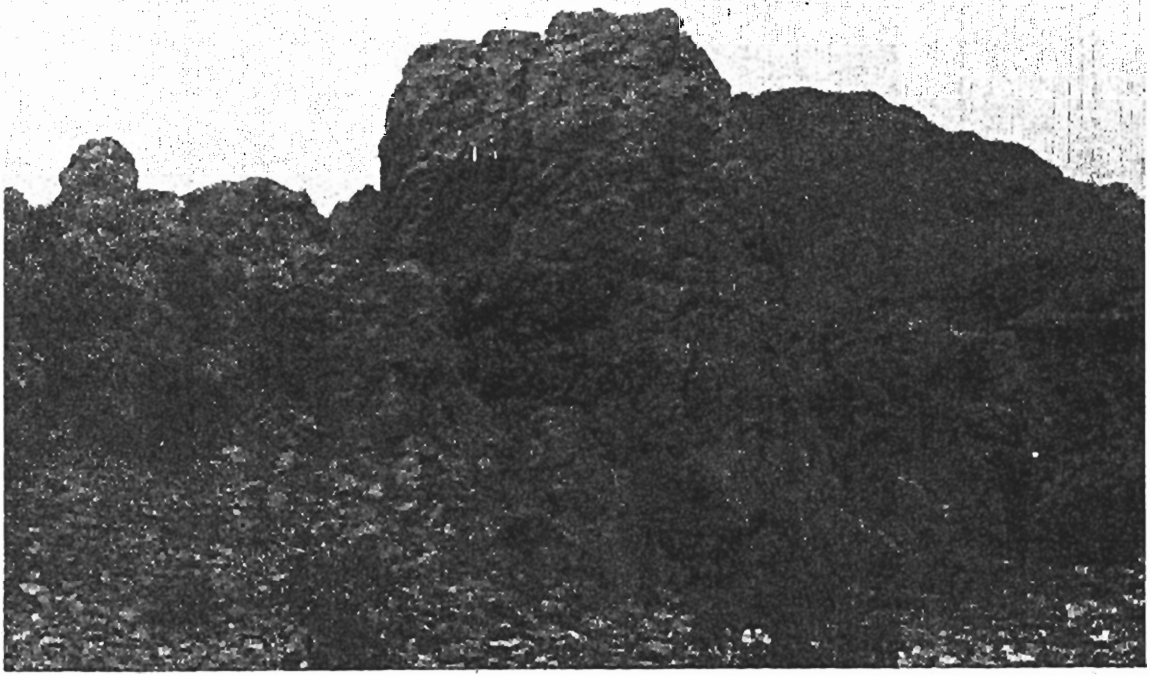


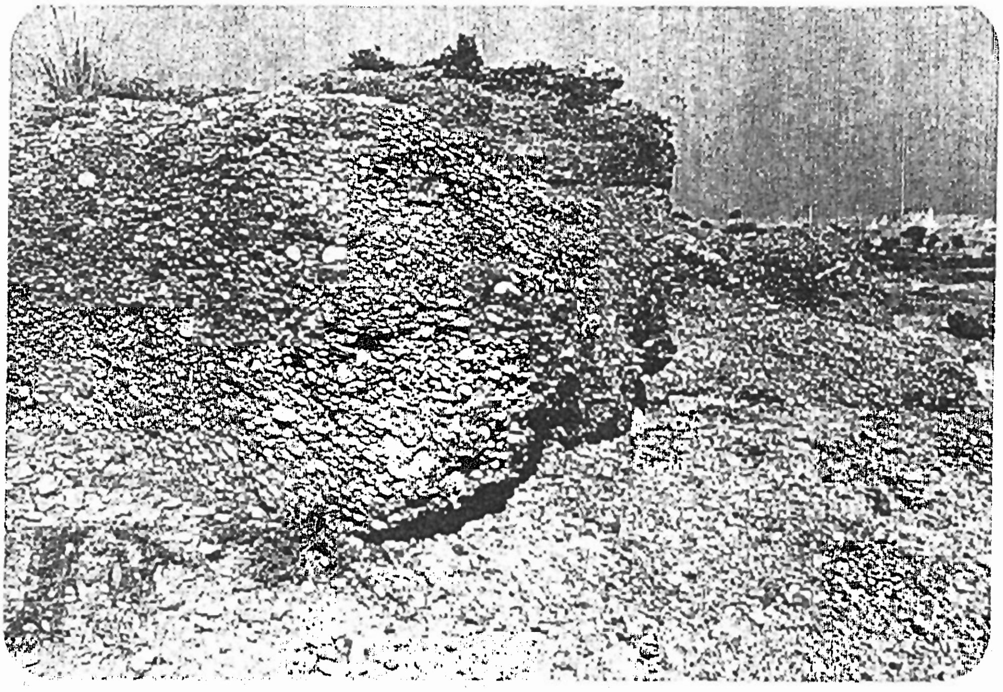
Fig.1.1 A regional Geological Map of the Peshawar plain and surrounding hill ranges showing the position of various alkaline complexes (after Kemp and Jan, 1979). MMT main mantle thrst and MBT main boundary thrust.



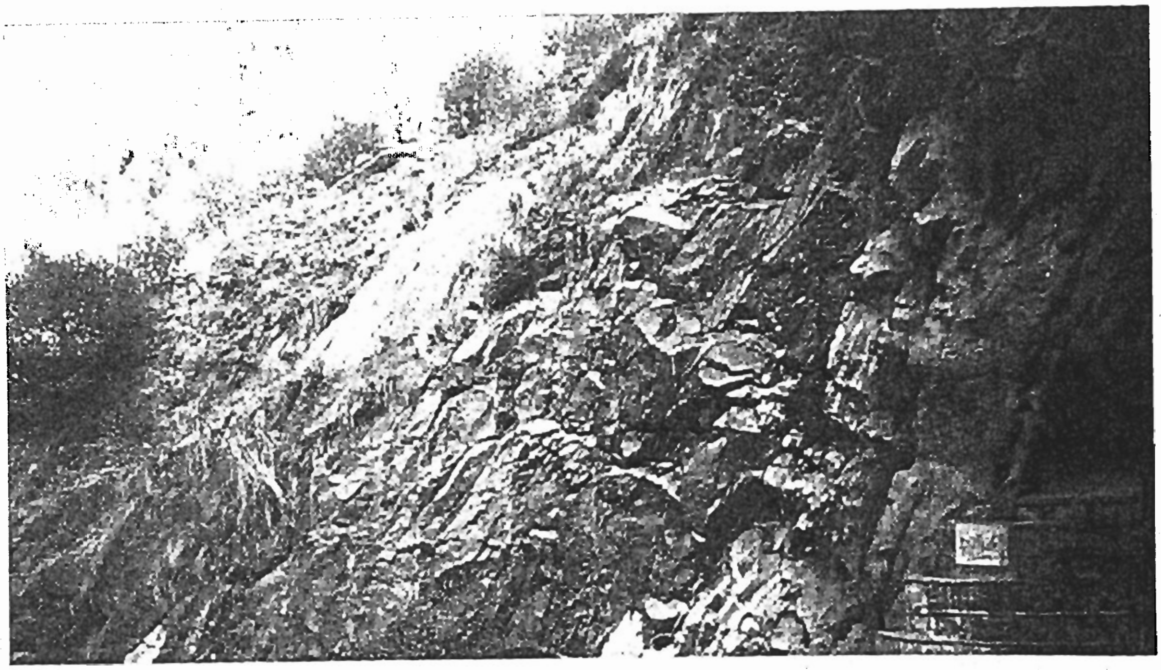
Photograph-2.1. Nepheline-Syenite of Koga showing exfoliation weathering.



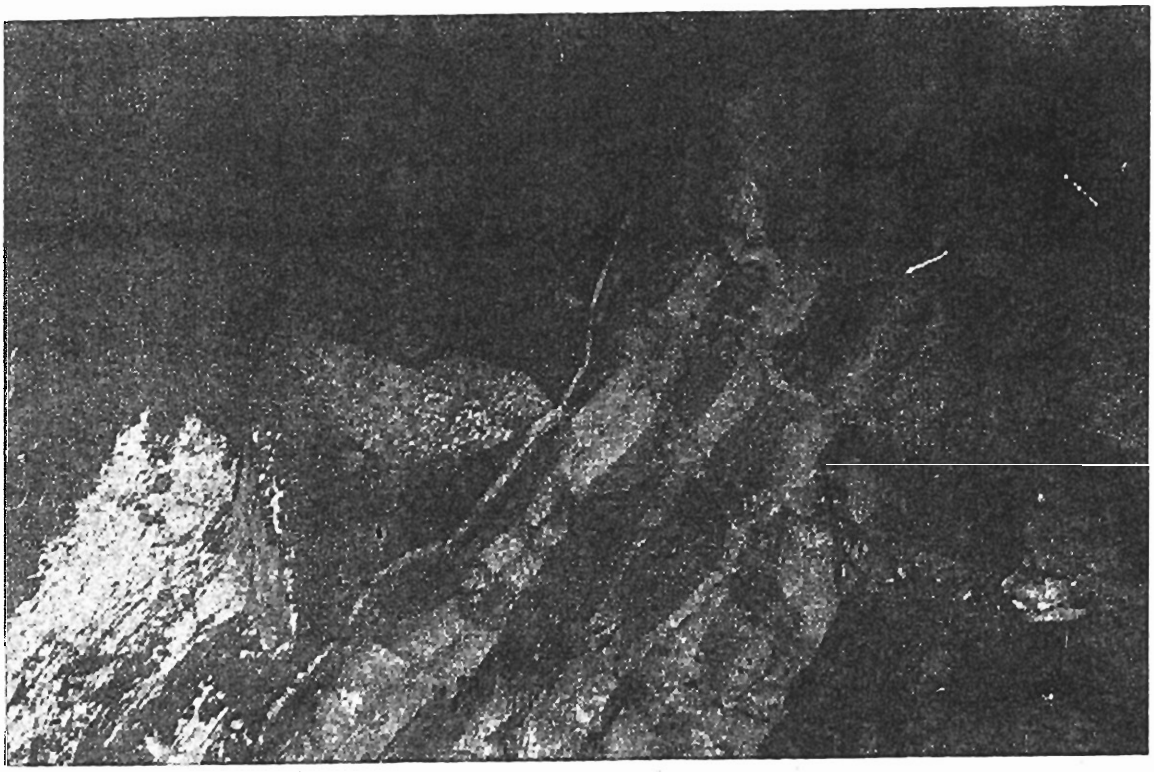
Photograph-2.2. Rounded boulders of Nepheline-Syenites showeing exfoliation weathering.



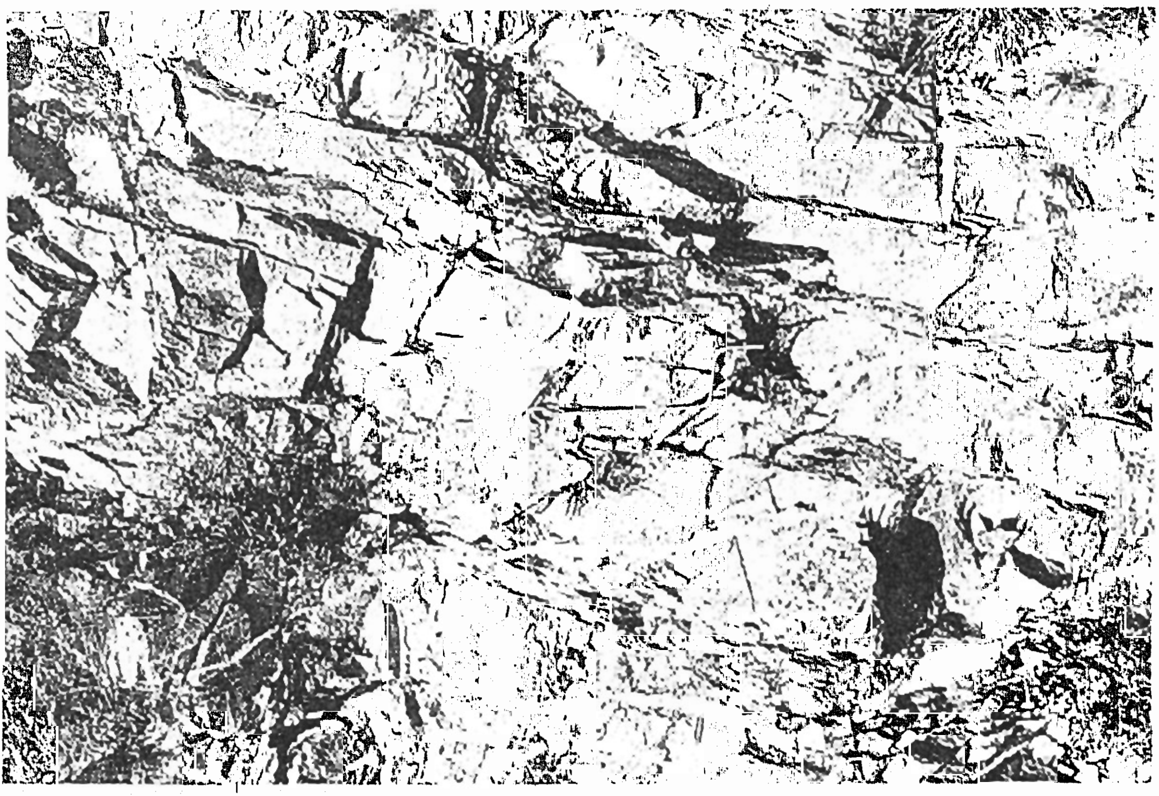
Photograph-2.3. Patch of coarse-grained syenites within fine-grained syenites.



Photograph-2.4. Veins of coarse-grained syenites cross-cutting fine-grained syenites.



Photograph-2.5. Patch of fine-grained rock within coarse-grained rock.



Photograph-2.6. Veins of fine-grained material within coarse-grained rock.

Photograph-2.7. Presence of garnet only along the coarse-grained leucocratic syenites near Koga village

CHAPTER 3

PETROGRAPHY OF KOGA SYENITES

INTRODUCTION

The geological region of Buner, Swat in which Koga syenite lies, consists of low to high grade metamorphics (Swat-Chamla metasedimentary group) which are cut by various igneous intrusions (Ambella granitic complex). The Ambella granitic complex has been emplaced into the core of an anticline in Swat-Chamla metasedimentary group (Saddiqui, 1965). The Koga syenites occur in the south western part of the Ambella granitic complex. Petrographic features of the Koga syenites have been described by Saddiqui et al., (1968) and Chaudhry et al., (1981).

Saddiqui et al., (1968) divided, the rocks of the Koga area, into three main petrographical types: (a) Chingalai granodiorite gneisses, (b) Babaji syenites and (c) Koga syenites. The Chingalai granodiorite gneisses includes granitic to granodioritic gneisses with dykes of aplite and diorite. The Babaji syenites consist of a rather varied assemblage of alkali granite, quartz-bearing aegirine-augite and arfvedsonite nordmarkites and quartz-free aegirine-augite syenites and aplites. These rocks are characterized by a general peralkaline nature with a granitoid texture. The rocks of the Koga syenites are silica undersaturated and composed of feldspathoids such as nepheline, cancrinite and sodalite. The two major types of nepheline syenites suggested by Saddiqui et al. are foyaites and litchfieldites and the minor varieties are nepheline-cancrinite-syenite, sodalite, hydromuscovite syenite, and pegmatite. Besides, these syenites the other rock types include carbonatite, fenites and lamprophyres.

Chaudhry et al., (1981) described almost the same rock unites as established by Saddiqui et al., (1968). Chaudhry et al., (1981) divided pegmatites into pulaskite and syenite pegmatite, different zones within pegmatite have also been [illegible] albites in the area.

Le Bas et al., (1987) described the petrography of these Koga rocks which were analysed for Rb/Sr isotopic ratios. They reported ijolite intrusion in the Koga nepheline syenites near Naranji Kandau. According to them some of the ijolites near Naranji Kandau are metasomatized by the Carbonatite. This Carbonatite metasomatism of ijolites suggest that some carbonatites are later than the ijolites.

The present study of Koga syenites has been done with respect to fenitization by the Carbonatite intrusions at different localities. Sixty five samples were selected by the petrographic study on the basis of which the Koga syenite can be divided into following units:

1. Alkali granite
2. Alkali syenites
3. Nepheline syenites
4. Ijolites

5. Carbonatites

6. Fenites

ALKALI-GRANITE

Alkali granite is located at a very few localities (about half a mile in the east of Naranji Kandao as small intrusions). It is also found in boulders near Nawe Killi.

The alkali-granite is medium to coarse-grained and has hypidiomorphic texture. It is composed of perthite, quartz, aegirine-augite, biotite and magnetite.

Perthite (55%) occurs as phenocrysts, containing inclusions of ore and is slightly Kaolinized. Qtz (45%) fine- to coarse-grained, anhedral and highly fractured. At places gives wavy extinction and contains inclusions of biotite and aegirine-augite.

Biotite (1-2%) is dark brown and occurs as medium to coarse subhedral flaks, in association with ore and aegirine-augite. Aegirine-augite is dark-green to yellowish-green, contains inclusions of ore. Magnetite (2%) is dark black, medium to coarse-grained, does not show any alteration.

ALKALI-SYENITES

Alkali Syenites form the most dominant rock unites of the Koga syenites particularly from Koga to Naranji Kandau. These rocks are fine to coarse-grained, hypidiomorphic and at places are porphyritic. Sporadically these are fractured and show iron leaching along the fractures. Alkali syenites comprise of albite, microcline, perthite, pyroxene (aegirine-augite), biotite, ore, zircon, apatite and sericite (table 3.1).

Albite and microcline form about 30-75% of the whole rock. Both minerals occur in the form of phenocrysts contain inclusions of ore and apatite. In the groundmass the feldspars are fresh while, phenocrysts are corroded at the margins and both the feldspars are sericitized. Perthite is microcline microperthite (0-60%) and occurs as subhedral phenocrysts.

Pyroxene (4-15%, table 3.1)is aegirine-augite and has colourles to light green pleochroism. The grains are anhedral and mostly associated with ore. Biotite (2-3%) occurs as greenish-brown subhedral flaks. Ore mineral (1-4%) is magnetite occurs in the form of subhedral to euhedral crystals. It also occurs as massive core to the pyroxene and biotite.

Zircon (0-2%) has subhedral to euhedral crystals. Rarely, it is associated with ore. Apatite occurs in traces as subhedral to euhedral inclusions within feldspars.

NEPHELINE-SYENITES

Nepheline Syenites are sporadically distributed within the area as small intrusive bodies and veins. A relatively large body is found about 200 to 300 meters in the west of Miane Kandau, and a small body is found about 1.75 to 2 km in the south east of Narinji Kandao,near Bagosh Sar.These rocks are dark-grey to whitish grey, medium to coarse-grained and hypidiomorphic. It is composed of perthite (50-60%), nepheline (5-9%), Muscovite (20-25%), biotite (1-2%), ore (2%), zircon, sphene and sericite is found in traces (Table 3.1).

Perthite is medium to coarse-grained, at places fractured and mostly making triple junctions. Perthite is commonly fresh but at places shows kaolinization and sericitization. Nepheline grains are coarse and euhedral to subhedral. Small nepheline grains also occur in a few rocks as interstitial in perthite. The nepheline and perthite grains are crushed at the boundaries.

The micaceous minerals are muscovite and biotite. Muscovite occurs in the form of large flaks and shows corroded boundaries. Biotite is green to brownish-green and is associated with ore. The flaks of biotite also occur within muscovite and cross-cut the muscovite cleavages. The Al_2O_3 content of biotite is about 18-19% in the nepheline syenite of Miane Kandau (see Table 3.2) which shows that it is of magmatic origin Speer (1984). The ore is magnetite (see Table 3.3) which is massive and coarse-grained. Zircon and sphene have euhedral to subhedral crystals and occur in association with ore. Sericite occurs as alteration product within perthite.

IJOLITES

Ijolite intrusions have been reported by Le Bas et al., (1987) at different localities in Koga. During this study a few more ijolites have found between Bagosh Sar and Naranji Kandau. These occur in the form of dykes and veins cross-cutting the Koga syenites and nepheline syenites. One of the biggest intrusion (about 400 meters long and 1.5 meters wide) is exposed at a distance of about 50 meters in the north east of Naranji Kandau. The other small bodies and showings are found at following localities:

1. In the south east of Naranji Kandau at about 45 meters distance.

2. At the north eastern margin of Naranji Kandau Carbonatite (Le Bas et al. 1987).

3. At a distance of about 35-40 meters in the southwest of Nawe Killi Village.

The ijolites are dark black to brownish black, medium-grained intrusive bodies and in turn intruded by albite veins. Ijolites are composed of nepheline (55-60%), pyroxene (25-30%), sphene (5-8%), calcite (2%), apatite (1-4%), zircon (1-3%) and ore (1-2%) Table 3.1.

Nepheline is medium to coarse-grained, anhedral to euhedral. At places the margins of nepheline are dusty. Nepheline contains inclusions of zircon and ore. Pyroxene has grass-green to yellowish-green, anhedral to subhedral grains. The pyroxene shows zoning at places, the dark-green core is rimed by the yellowish-green margin. The green core is diopsidic while the rim is hedenbergitic in composition (see table 3.4). Sphene has subhedral to euhedral crystals associated with nepheline and pyroxene. Apatite and zircon grains are euhedral and occurs as inclusion in nepheline.

Fenitized ijolite (Kn-44) in the field shows white bends and veins of feldspar. In thin section these are composed of augite, nepheline, cancrinite/ vishnevite, sphene, k-feldspar and calcite. Nepheline is altered to cancrinite/vishnevite. K-feldspar is interstitial and is metasomatically introduced and it has high barium content (1.7 wt%) which is characteristic of k-feldspar associated with the Koga carbonatite (Le Bas et al. 1986).

CARBONATITES

The carbonatite of Koga are typical sovites, made up of medium to coarse-grained calcite. It shows saccharoidal texture and generally lack the permanent orientation of the minerals. But at places orientation of pyroxene, and apatite can be found. It is composed of calcite (75-85%), apatite (7-8%), sphene (5-6%), ore (0-2%) and pyroxene (3%) Table 3.1.

The calcite is well cleaved, equigranular and subhedral to euhedral. Dusty calcite is also common and sometimes present in the matrix between the clear calcite grains. Apatite occurs as euhedral prismatic crystals. It is usually found in two habits: (a) small isolated avoid-shaped grains within calcite, (b) idomorphic prisms form aggregates. Some of the grains are fractured.

Pyroxene has euhedral to subhedral grains containing inclusions of calcite, apatite and ore. It has been altered to ore along the cleavages.

FENITES

Fenites are the most common rocks in the Koga syenites particularly in the western part of the Koga rocks and around Narinji Kandau. This fenitization is due to the intrusions of carbonatite, which showings are common in and around the Naranji Kandau (see Fig.2.2). The effects of fenitization are observed by the petrographic study, geochemistry of the rocks, mineralogy and X-ray differaction study of the feldspars. The intensity of fenitization is highly variable and proper zones of fenitization can not be marked on the map. This is due to the textural heterogenity of the igneous rocks, sporadical distribution of the fenitizing bodies or the distance from the source rocks of the fenitized rocks.

Two main types of fenites has been observed in the studied area. 1. Potassic-fenites 2. sodium-fenites. This difference in the types of fenites may be due to the difference in the origin of fenetizing solutions. These solutions may be emanated by morte than one solution of carbonatite intrusion having different Na/K ratio.

POTASSIC FENITES (low Na/K)

Potassic fenites are most common in the studied area particularly, in the surroundings of Naranji Kandau carbonatite. These are medium to coarse-grained, hypidiomorphic, porphyritic (at places) and are traversed by the veins (1 mm to 1 cm). The veins contain calcite + biotite + ore and calcite + microcline + biotite (Photograph 3.1,3.2). These potassic fenites are composed of perthite, albite, microcline, Cancrinite/vishnevite, natrolite, aegirine-augite, biotite, calcite, zircon, sphene, ore and rarely nepheline (Table 3.5).

On the basis of textural and mineralogical studies the potassic fenites can be divided into:

a) low grade fenites

b) medium grade fenites

c) high grade fenites.

The most dominant felsic mineral in these fenites is perthite which is medium to coarse-grained and occurs as subhedral to euhedral crystals. The k-feldspar within perthite is turbid. This turbidity is present in the low grade fenites, increases upto medium grade fenites, and decrease again in the high grade fenites close to the carbonatite contact. These high grade fenites are fresh, very coarse-grained k-feldspar rocks (normally called orthoclasite) are present in the cape rocks on top of the carbonatite at Naranji Kandau. This type of change in the turbidity can also be seen in thin section (section No.kn-35, kn-47). In which one vein passes through perthite the k-feldspar in the perthite becomes turbid but when second vein, which cross-cut the first vein, the k-feldspar in the vicinity of second vein becomes clear and the k-feldspar of the first vein becomes turbid. Such turbidity in the feldspar is also observed in the syenitic fenites of Sokli, Finland (Vartiainen and Woolley, 1976) and Kangankunde Carbonatite, Malawi (Woolley, 1969). Woolley (1969) suggested that this turbidity may be the result of a change in the ratios of alkalies in feldspars.

A rim of albite around the perthite is observed. This rim is partially developed and is single around the perthite of low grade fenites while, it is completely developed and becomes double in the medium grade and in the high grade fenites. The characteristic feature of the rims is that the rim around one perthite grain is in optical continuity with the albite of the adjacent perthite and the rim around the other perthite is in optical continuity with the albite of the first grain (Fig.3.3,3.4). Such rim of albit around perthite is also observed in nepheline syenites of south Greenland (Stephenson, 1976), in the fenites of north and south Ruri (Dixon and Collins, 1977) and in Sillai Patti fenites (Mian, 1986). The nature and behavior of the two rims is not fully understood different suggestions are given only for the single rim around perthite.

1. The albite rim is formed due to unmixing and recrystallization of the initial homogeneous feldspar in the presence of sufficient supply of volatile materials (Tuttle and Bowen, 1954). The outcoming albit crystallized around the

adjacent grain of perthite (Butt, personal cummunication).

2. This behavior of the rim may be due to the carlsbad twinning of albite within the rim.

These suggestions can explain the behavior of one rim around perthite but the behavior of the double rim is difficult to explain.

In high grade fenites k-feldspar and perthite are fresh, very coarse-grained, subhedral to euhedral. Medium-grained k-feldspar is present interstitially, with coarse-grained perthite. These interstitial k-feldspars shows microcline twinning. However, twinned or untwinned small grains of albite are also present in the coarse-grained perthite.

Pyroxene is aegirine-augite in composition which is shattered and corroded at the margins and along the cleavages. In medium grade fenites it has been altered to biotite along the cleavages and at the margins (photograph 3.8,3.9). The vein of calcite when passes through pyroxene it forms biotite. In high grade fenites pyroxene shows zonning (photograph 7) and its composition changes from core towards the margins table (4.2). Biotite is reddish brown to green in colour and is associated with ore and pyroxene.

Zircon is euhedral to subhedral and occurs as isolated grains as well as a worm-like structure along vein which shows that zircon may have moved (Photograph 3.10a, 3.10b). This represent that even zircon can be moved during fenitization. Sphene is subhedral to euhedral and is associated with ore and other mafic minerals.

Nepheline is rarely found in low grade fenites which has been altered to k-feldspar and at places contains minute flaks of biotite. Quartz is also rare in low grade fenites and has been altered at the margins to biotite. The formation of microcline from quartz is not observed, which may be due to the availability of water in the environments.

SODIUM-FENITES (High Na/k)

In handspecimen the sodium-fenites are same as potassic-fenites (see k-fenites). These are found near the Nawe Killi and in the north of Bagosh Sar in the vicinity of ijolite. These are fresh and not turbid as the k-fenite are. The rocks are traversed by albite veins and are medium to coarse-grained, hypidiomorphic, composed of perthite, albite, pyroxene, ore,biotite, Na-amphibole and rarely nepheline.

Perthite has same textural features as in the case of potassic fenites. But in the case of sodium fenites the perthite is traversed by the veins of fine-grained albite. Small grains of pyroxene sometime present in these veins of albite (Photograph 3.11,3.12). Needles of newly formed pyroxene occurs within perthite. Fine-grained albite mostly with albite twinning occurs interstitially. Pyroxene is yellowish to dark green associated with ore and biotite. Biotite and ore has been altered to pyroxene (photograph 3.13,3.14). The needles of pyroxene seems to radiat from a common center of ore (photographs 15,16), which is the typical occurrence of fenitic pyroxene, as in Uyi fenites (Le Bas, 1977) and Homa mountain fenitized granites (Clark et al. 1977).

Nepheline rarely found in the low grade fenites and has euhedral to subhedral grains,. containing abundant needles of pyroxene which are oriented randomly. Nepheline has also been replaced by albite. Cancrinite/veshnuvite and natrolite are the common alteration products of nepheline (photograph 18,19). Nepheline is diminished in the high grade fenites.

POTASIUM-SODIUM FENITES

In Koga fenites some rocks show both types (potassium- and sodium-fenites) of fenitization. In these rocks textural and mineralogical features of both the fenites can be observed. The rocks are found near Nawe Killi (Kn-272, Kn-251, Kn-247,, Kn-276) and near Bagosh Sar (Kn-32, Kn-23).

The potasium-sodium fenites are traversed by the veins which are found in potassic-fenites (calcite + biotite + ore, and calcite + microcline + biotite) and also by the veins found in sodium fenites (calcite + pyroxene + ore and albite).

Table 3.2. ANALYSES OF BIOTITE FROM NEPHELINE SYENITES.

Analyses No.	1	2	3
Sample No.	K-4P	K-4P2	K-12
SiO_2	32.321	33.046	32.906
TiO_2	2.714	2.572	0.201
Al_2O_3	18.177	19.054	19.069
FeO*	29.288	26.290	25.184
MnO	1.531	1.962	1.943
MgO	1.286	1.390	0.327
CaO	0.062	0.014	0.903
Na_2O	0.634	1.197	5.008
K_2O	9.461	8.848	6.661
Total	96.474	94.323	92.002

No. of ions on the basis of 22 oxygens.

Si	5.227	5.314	5.425
Ti	0.330	0.311	0.025
Al	3.465	3.611	3.706
Fe	3.961	3.535	3.472
Mn	0.210	0.267	0.271
Mg	0.310	0.333	0.080
Ca	0.011	0.002	0.159
Na	0.199	0.373	1.601
K	1.952	1.815	1.401

*Total iron as FeO.

Table 3.3. ANALYSES OF MAGNETITE FROM NEPHELINE SYENITES.

Analyses No.	1	2
Sample No.	K4P3	K4P4
SiO2	0.379	0.429
TiO2	0.249	0.182
Al2O3	0.142	0.003
Cr2O3	0.033	—
FeO	94.341	96.163
MnO	0.241	0.245
MgO	0.278	—
CaO	0.031	0.079
Na2O	0.614	0.272
K2O	0.065	0.071
Total	96.343	97.464

No. of ions on the basis of 32 Oxygens.

Si	0.149	0.167
Ti	0.073	0.053
Al	0.065	0.002
Cr	0.010	—
Fe	30.889	31.323
Mn	0.080	0.081
Mg	0.162	—
Ca	0.013	0.033
Na	0.466	0.206
K	0.032	0.035

Table 3.4. ANALYSES OF PYROXENE FROM IJOLITES AT KOGA.

Analyses No.	1	2	3	4
Sp.No.	K330 MIO	K330 MAR	K23A MID	K23A MAR
SiO2	47.15	51.01	53.69	49.11
FiO2	1.58	0.32	0.23	0.57
Al2O3	4.10	1.64	0.110	1.47
Fe2O3	7.34	9.38	0.35	8.58
FeO	1.97	7.09	3.13	9.52
MnO	0.17	0.58	0.00	0.70
MgO	11.58	8.07	16.46	6.92
CaO	23.76	19.98	24.79	19.54
Na2O	0.99	2.94	0.36	2.86
Total	98.64	101.01	99.10	99.22

No. of ions on the basis of 6 oxygens.

	1	2	3	4
Si	1.794	1.929	1.985	1.915
Ti	0.045	0.009	0.006	0.017
Al	0.184	0.073	0.003	0.068
Fe3	0.210	0.267	0.010	0.250
Fe2+	0.063	0.224	0.097	0.310
Mn	0.006	0.019	0.000	0.023
Mg	0.657	0.455	0.907	0.402
Ca	0.969	0.809	0.982	0.816
Na	0.073	0.215	0.026	0.216
Na	9.1	23.5	2.5	22.7
Mg	82.2	49.8	88.1	42.3
Fe+2+Mn	8.6	26.6	9.4	34.9

TABLE 3.1 MODAL COMPOSITON OF THE ROCKS FROM KOGA

Anal #	1	2	3	4	5	6	7	8	9	10
Sample #	K-86	K - 6	K-30	K-219	K-4	K-32	Kn-44	K-104a	K-104b	Kn-43
Albite	—	45	35	20	—	—	—	—	—	—
Microcline	—	30	45	10	—	—	—	—	—	—
Perthite	55	10	—	60	60	45	—	20	—	—
Nepheline	—	—	—	—	25	35	30	20	33	60
Quartz	45	—	—	—	—	—	—	—	—	—
Pyroxene	1	—	15	4	—	15	32	55	50	25
Biotite	1	—	3	3	2	2	—	—	—	—
Muscovite	—	Tr	Tr	—	—	—	—	1	—	—
Sericite	—	Tr	Tr	—	—	—	—	1	—	—
Ore	2	4	1	3	3	3	—	3	2	2
Calcite	—	—	—	—	—	—	10	—	—	2
Sphene	—	—	—	—	—	—	3	—	11	6
Apatite	—	Tr	Tr	Tr	—	—	5	—	4	4
Zircon	—	2	—	—	—	—	2	—	—	1
Amphibole	—	—	—	—	—	—	—	—	—	—
Cancrinite	—	—	—	—	—	—	18	—	—	—

Alkali-granite analysis # 1.

Alkali-synite analysis # 2,3,4.

Nepheline-synite analysis # 5,6.

Ijolites analysis # 7,8,9,10.

TABLE 3.1 Continued.

Anal. #	11	12	13
Sample #	Kn - 41	K - 257	K - 14
Albite	-	-	-
Microcline	-	-	-
Perthite	-	-	-
Nephiline	55	-	-
Quartz	-	-	-
Pyroxene	35	3	-
Biotite	-	-	-
Ore	2	2	Tr
Calcite	-	80	88
Sphene	5	6	5
Apatite	-	8	7
Zircon	3	-	-
Amphibole	-	-	-

Ijolite analysis # 11.

Carbonatites analysis # 12,13.

TABLE 3.5 MODAL COMPOSITION OF THE FENITIZED ROCKS FROM KOGA SYENITE

Anal.#	1	2	3	4	5	6	7	8	910	11	12	
Kn-	27	237	277A	24	265	274	278	K-24	K-25	25	29	35
Albite	12	–	–	16	25	–	5	–	–	–	13	5
microcline	–	31	–	–	–	–	–	–	–	–	–	–
Perthite	63	60	68	65	65	88	72	54	67	75	64	91
Nepheline	–	–	30	–	–	–	–	20	–	–	–	–
Quartz	10	3	–	15	–	–	8	10	15	–	–	–
Aegerine	2	–	–	1	–	5	2	3	6	18	14	–
Biotite	–	–	–	–	–	–	–	–	–	2	2	2
Ore	4	2	–	–	–	–	–	6	2	2	–	3
Calcite	1	–	–	–	–	–	–	–	–	2	6	–
Sphene	–	Tr	–	–	–	2	–	2	Tr	–	–	–
Apatite	–	–	–	–	–	–	–	–	1	1	1	–
Zircon	–	–	–	–	–	–	–	–	–	–	–	–
Amphibole	–	–	–	–	–	–	–	–	–	–	–	–
Cancrinite	–	–	–	–	–	–	–	–	–	–	–	–

Low-grade K-fenites analysis # 1,2.3.

Medium-grade K-fenites analysis # 4,5,6,7,8,9.

High-grade K-fenites analysis # 10,11,12.

TABLE 3.5 Continued.

Anal.#	13	14	15	16	17	18	19	20	21	22
Sample #	Kn-48	Kn-257	K-10	k-13	K-14	K-18	Kn-36	Kn-47	Kn-253	Kn26
Albite	-	14	25	-	-	5	8	12	-	7
Microcline	-	-	5	-	-	75	-	-	-	-
Perthite	68	70	42	82	59	10	27	80	25	52
Nephiline	-	-	-	2	15	-	43	-	-	4
Quartz	-	2	-	-	-	-	-	-	-	-
Aegrine	12	3	7	-	10	-	7	6	5	15
Biotite	2	2	10	5	4	3	2	-	-	-
Ore	3	-	8	10	5	4	-	1	-	2
Calcite	5	1	-	-	-	3	Tr	Tr	Tr	4
Sphene	2	-	-	-	4	-	1	-	-	3
Apatite	-	-	-	-	-	-	1	-	-	-
Zircon	-	1	-	-	1	-	Tr	-	-	-
Amphibole	-	-	-	-	Tr	-	-	-	-	-
Cancrinite	8	-	3	-	-	-	-	-	70	3

High-grade K-fenites analysis # 13,14,15,16,17,18.

High-grade Na-fenites analysis # 19,20,21,22.

TABLE 3.5 Continued.

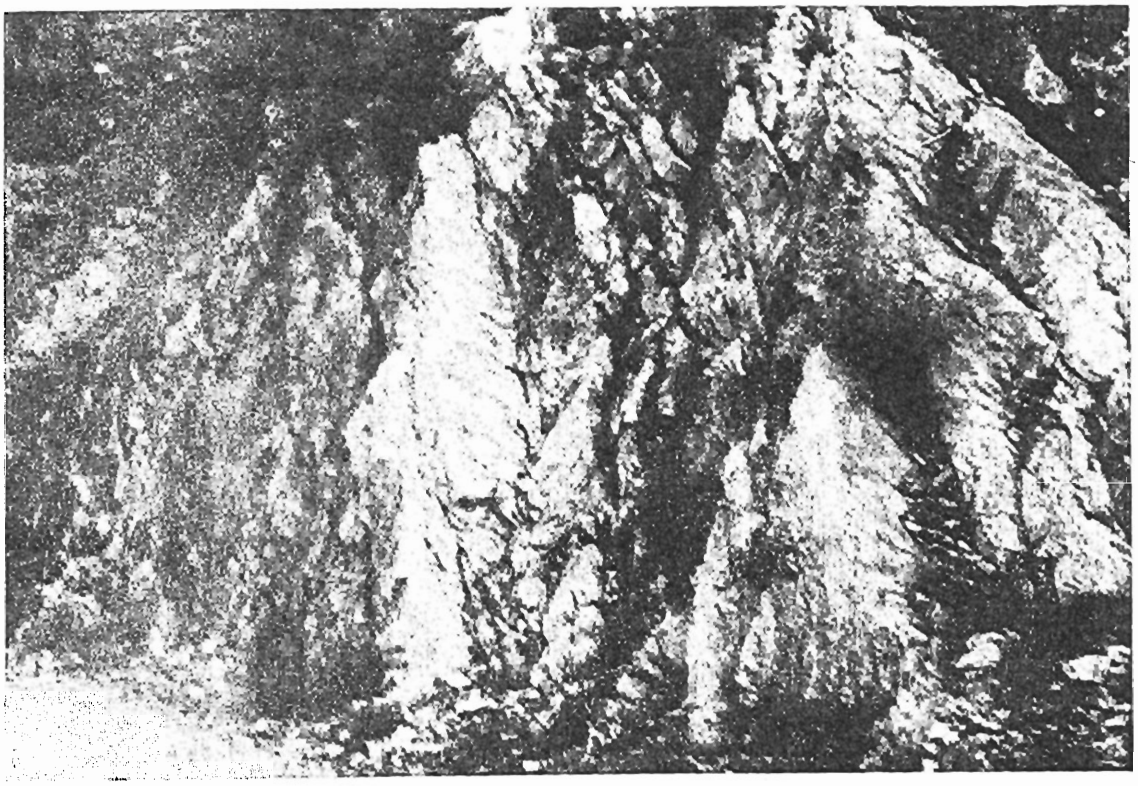
Anal. #	23	24	25	26	27	28	29	30	31	32	33	34
Sample #	Kn263A	Kn30	Kn239	Kn253	Kn22	Kn272	Kn251	K7	K26	Kn23	Kn247	Kn276
Albite	6	14	2	37	10	13	8	10	-	3	-	25
Microcline	-	-	-	-	3	-	-	5	-	-	-	5
Perthite	65	70	88	70	81	64	60	57	67	87	75	57
Nephilene	-	-	-	-	-	-	-	-	-	-	5	-
Quartz	-	-	-	-	-	-	-	-	-	-	-	-
Pyroxene	24	13	8	13	5	20	4	15	15	5	10	8
Biotite	1	-	-	6	-	1	1	5	6	2	3	2
Ore	2	-	2	1	-	1	1	4	8	3	3	3
Calcite	1	-	-	-	-	2	3	-	-	-	2	-
Sphene	2	1	-	-	1	-	-	1	2	-	2	-
Apatite	-	2	-	-	-	-	2	-	-	Tr	-	-
Zircon	Tr	-	-	1	-	-	-	1	1	-	-	-
Amphibole	-	-	-	-	-	-	-	-	1	-	-	-
Cancrinite	-	-	-	-	-	-	20	-	-	-	-	-

High-grade Na-fenites analysis # 23.

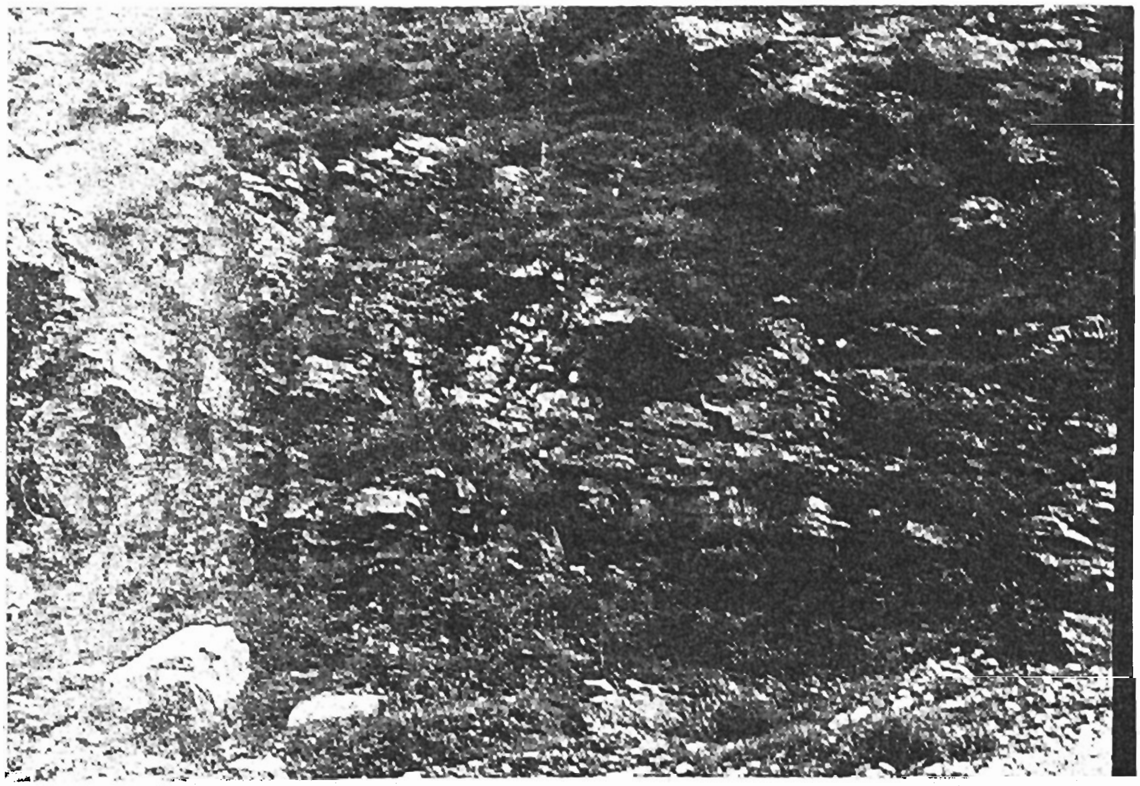
Medium-grade Na-fenites analysis # 24,25,26,27.

High-grade Potasium-Sodium-fgenites analysis # 28,29,30,31.

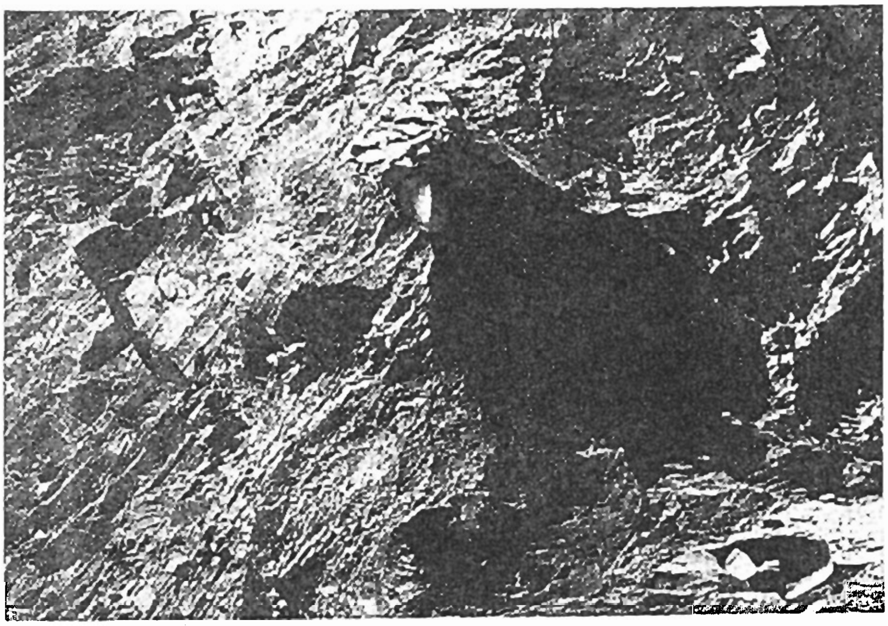
Medium-grade Potasium-Sodium-fenites analysis # 32,33,34.



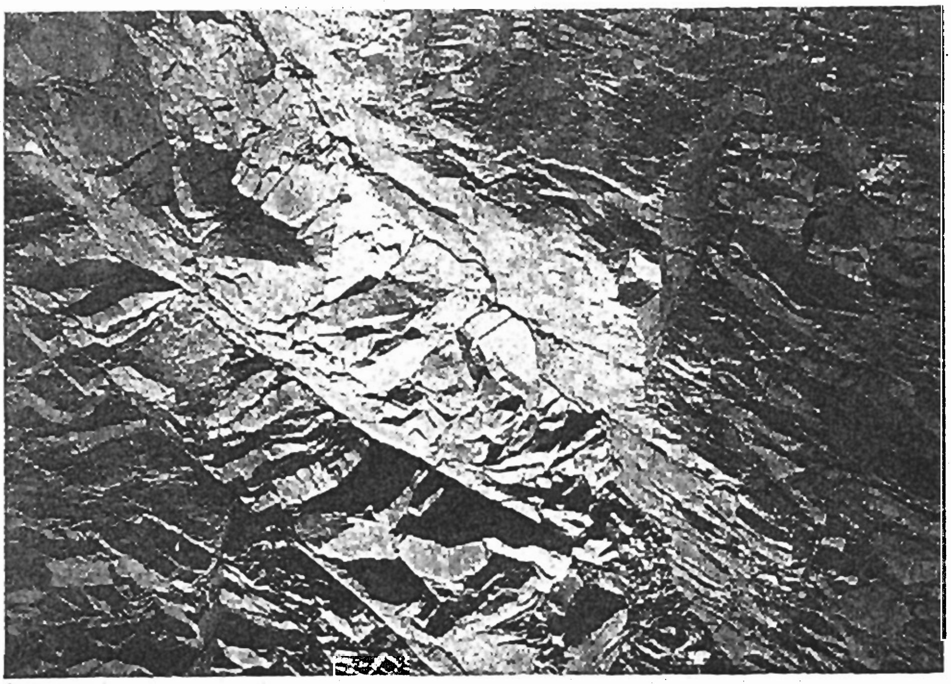
Photograph-3.1. Photomicrograph of fenites from Koga syenites showing the veins of biotite+microcline+calcite+ore (crossed nicols, magn.x25).



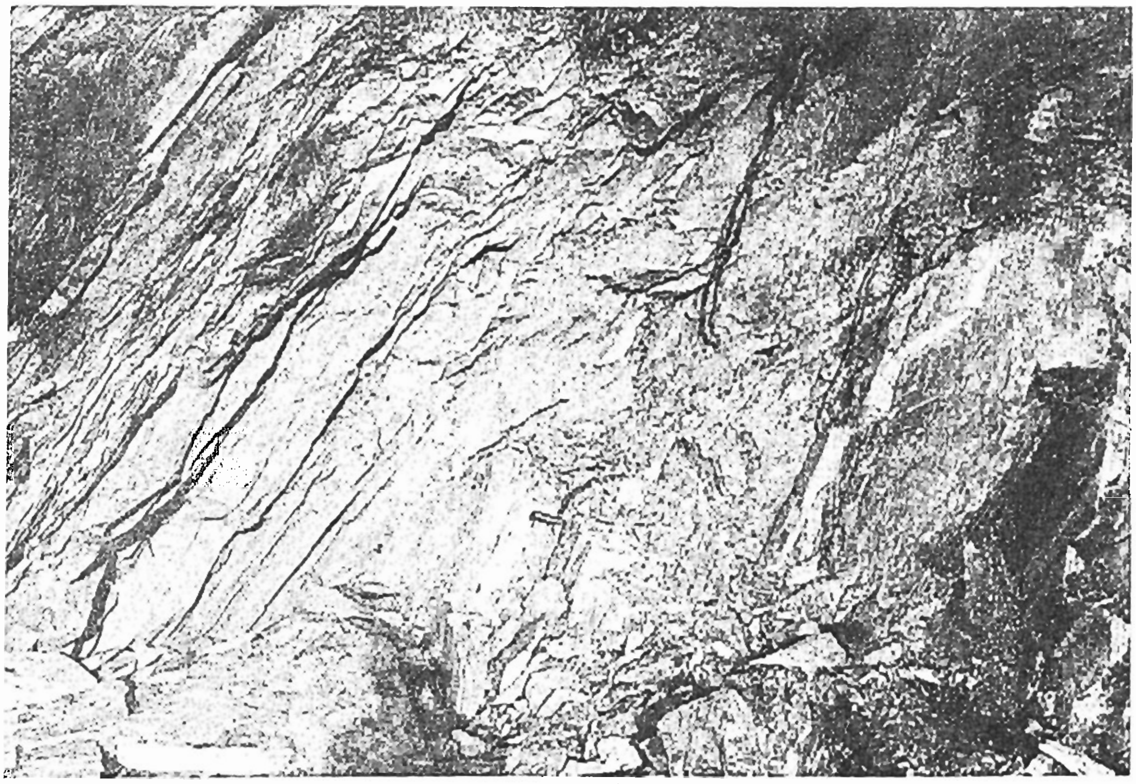
Photograph-3.2. Photomicrography of fenites from Koga syenites showing the vein of biotite+microcline (crossed nicols, magn.x25).



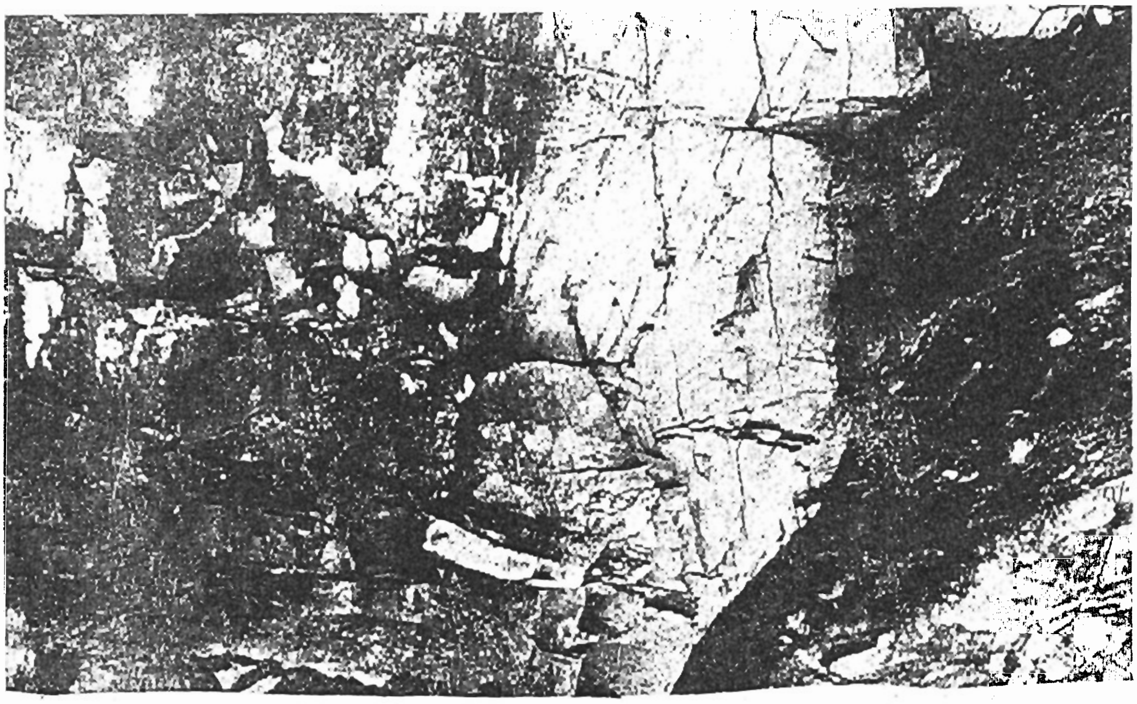
Photograph-3.3. Photomicrograph of potassium-fenites (Kn-25) from the Koga syenites showing the rim of albite around perthite (Crossed Nicols, magn.x25).



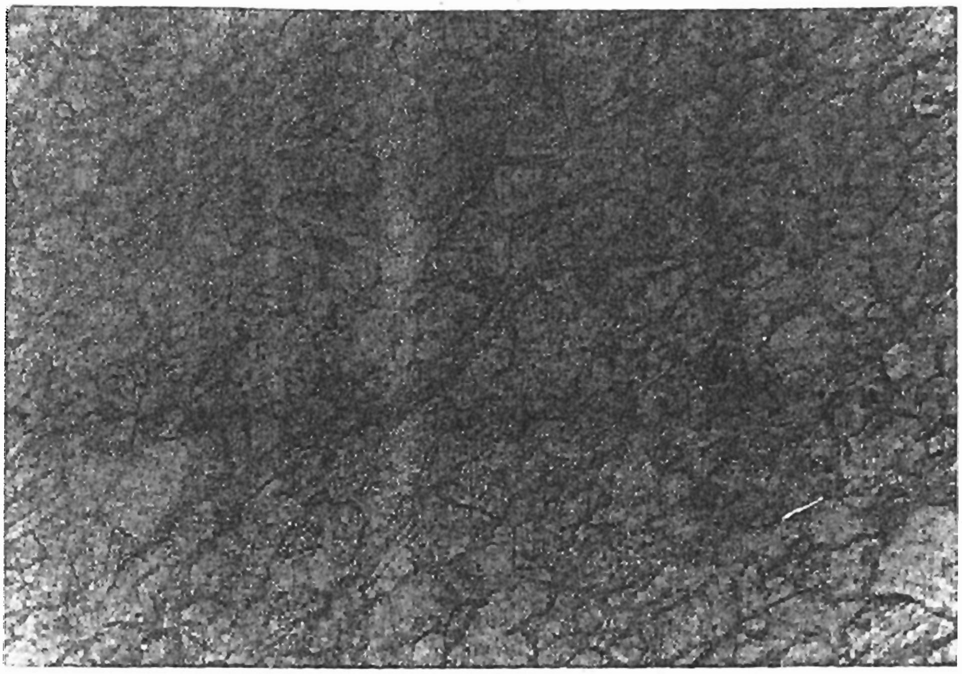
Photograph-3.4. Photomicrograph of potasium fenites from Koga Syenites showing the rim of albite (Alb) around perthite (Per). Calcite vein can also be seen along the margin of perthite. Photograph-3.2 is rotated clock vice to this position.



Photograph-3.5. Photomicrograph of sodium fenites (Kn'-239A) from Koga Syenites. Only one rim of albit developed arround perthite, which may be expelled out of the same perthite grain by exsolution. (Cross nicols, magn.x25).

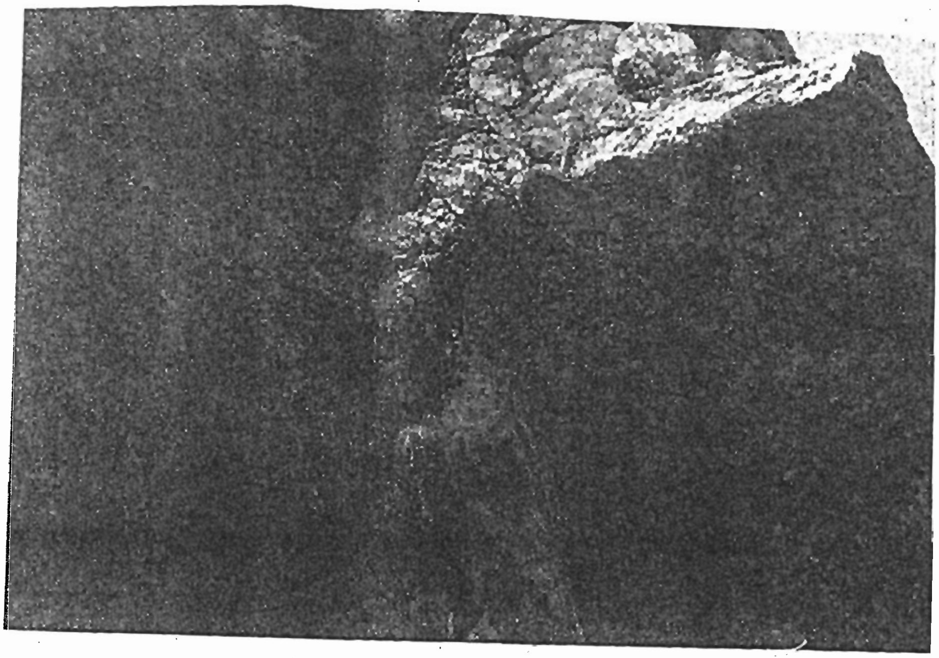


Photograph-3.6. Photomicrograph of sodium-fenite from Koga Syenite. Only one rim of albit is developed. (Crossed nicols, magn.x25).

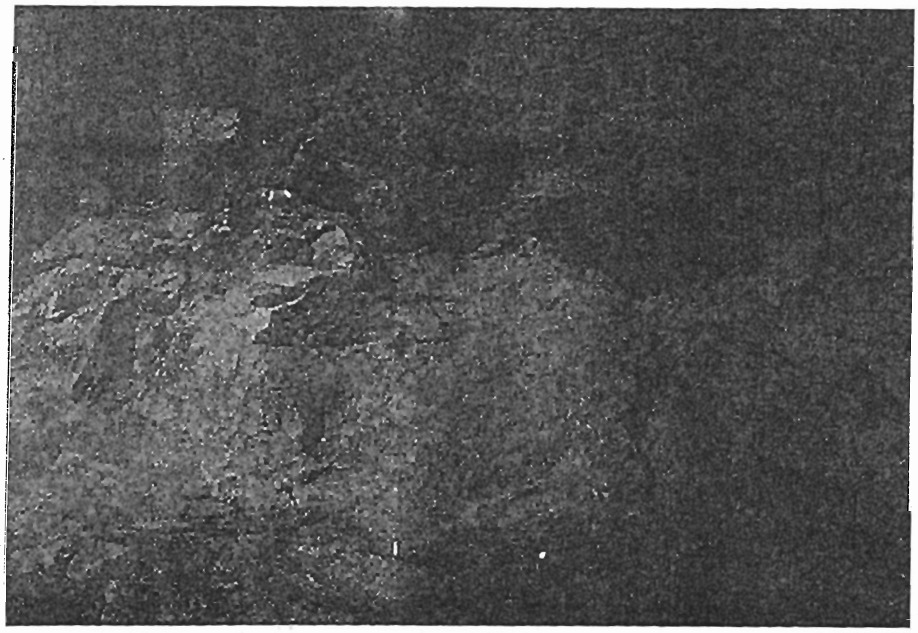


Photograph-3.7. Photomicrograph of pyroxene present in the high grade fenites (K-18) in the cape rock at Naranji Kandau showing that the relict pyroxene is green and arround which a dusty -dark brown rim has been developed. Arround the dusty rim yellowish-brown pyroxene is developed as a result of k-fenitizating (Low Na/K) solutions emanating from the Carbonatite. (Plane light, magn.x65).

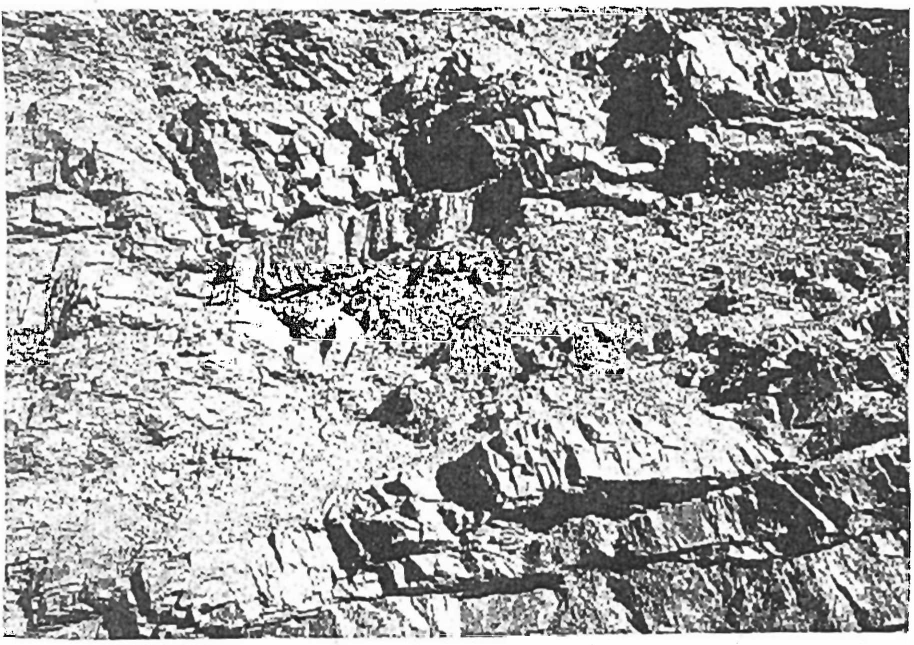
Photograph-3.8. Photomicrograph of fenites (K-12) from Koga syenites, the pyroxene has been altered along the margins to biotite. (Crossed nicols, magn.x25).



Photograph-3.9. Photomicrograph of fenites (Kn-257A) from Koga Syenites, the carbonatite veins when touches pyroxene, forms biotite. (Plane light, magn.x65).



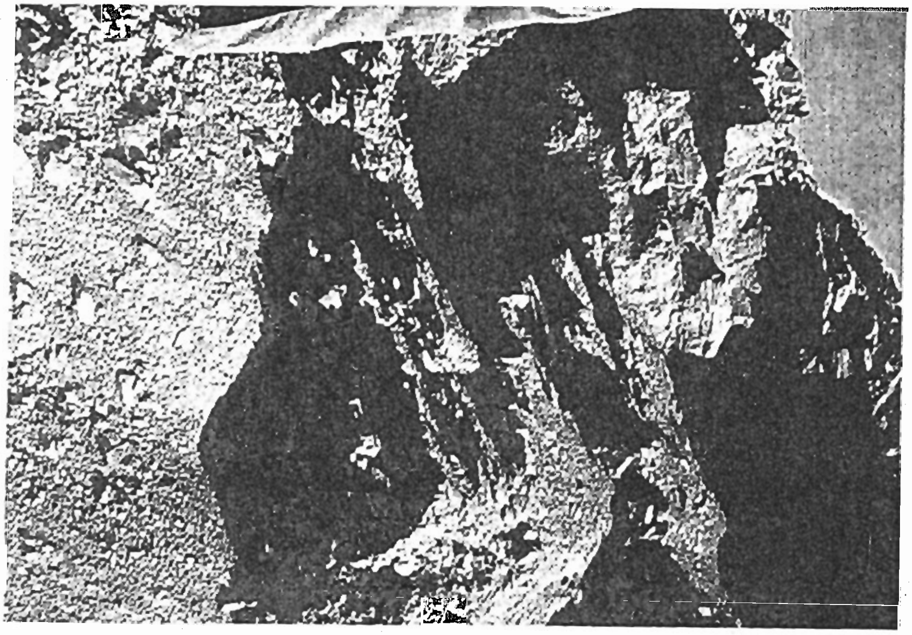
Photograph-3.10a. Photomicrograph of fenites (K-8) from Koga Syenites in which zircon occur in the form of worm-like structure in metasomatic vein, which may show the flow of zircon during fenitization. (Plane light, magn.x25).



Photograph-3.10b. Photomicrograph of fenites (K-8) from Koga Syenites showing the zircon accurring along the veins passing through perthite. (Crossed nicols, magn.x25).

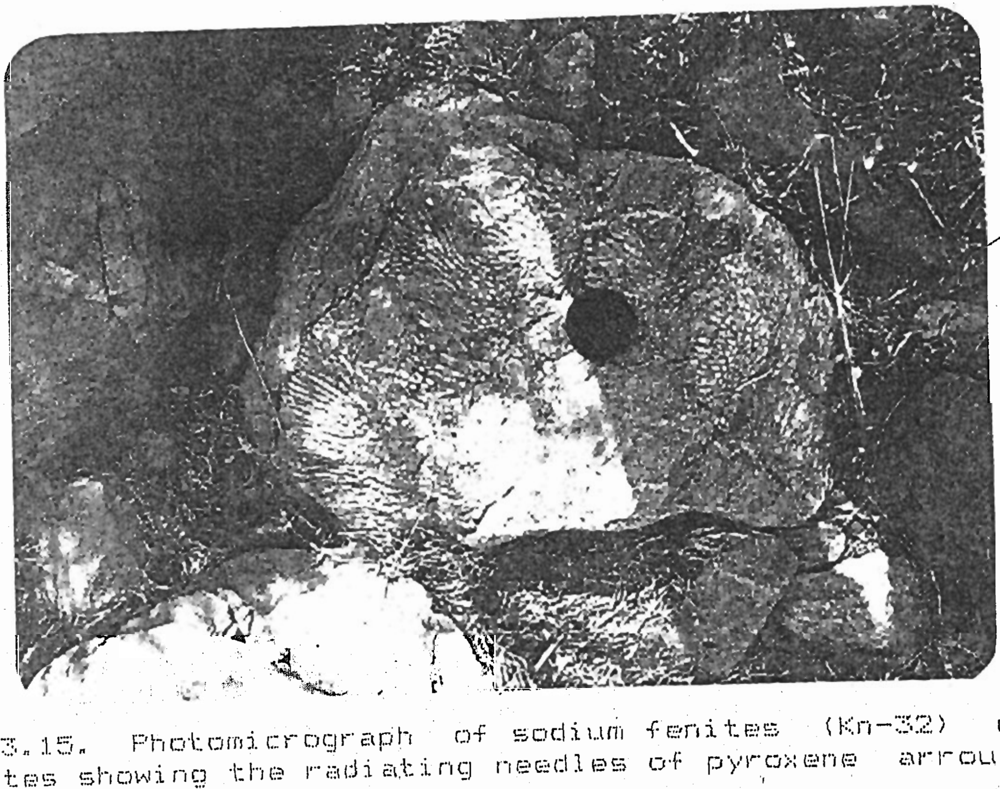
Photograph-3.11. Photomicrograph of fenites of Koga Syenites, the vein of albite traversed accross perthite. (Crossed nicols, magn.x25).

Photograph-3.12. Photomicrograph of Koga Syenites showing the veins of albite+ore and pyroxene+ore+albit. (Crossed nicols, magn.x25).



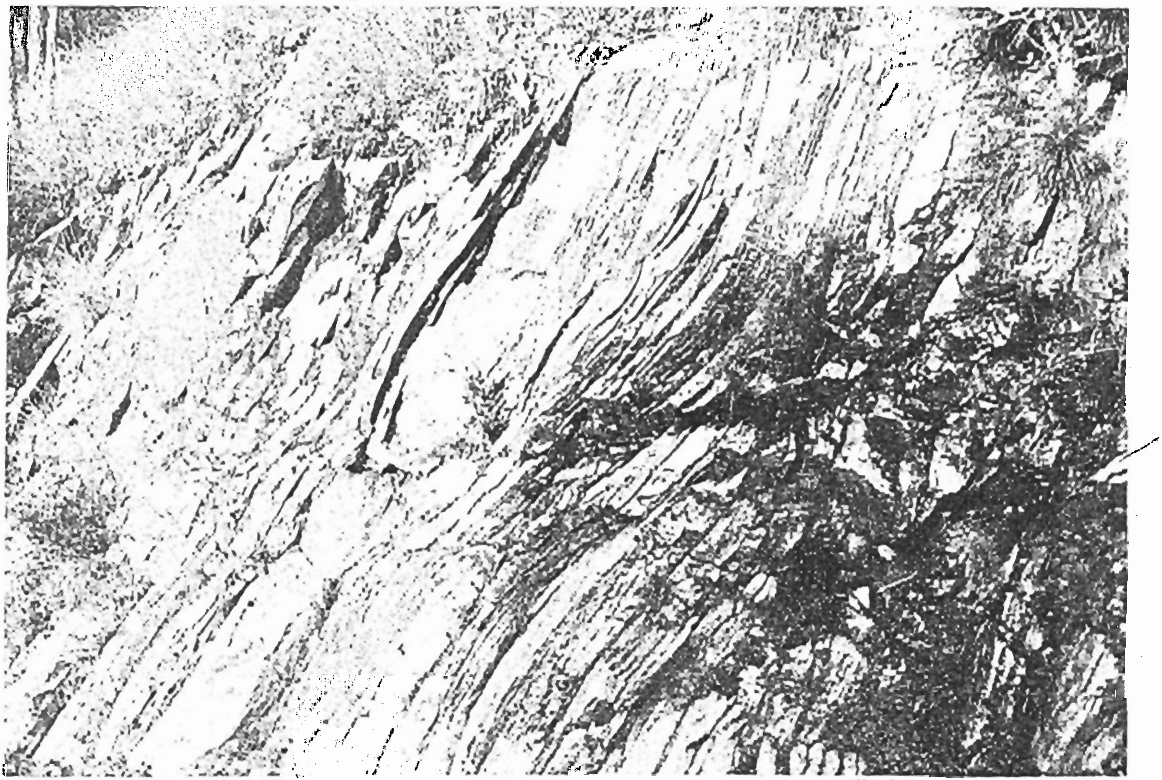
Photograph-3.13. Photomicrograph of sodium fenites (Kn-257) of Koga Syenites showing the formation of pyroxene at the expens of biotite during sodium fenitization (Plane light, magn.x65).

Photograph-3.14. Photomicrograph of fenites (Kn-257) of Koga Syenites showing the formation of pyroxene (Plane light, magn.x65).

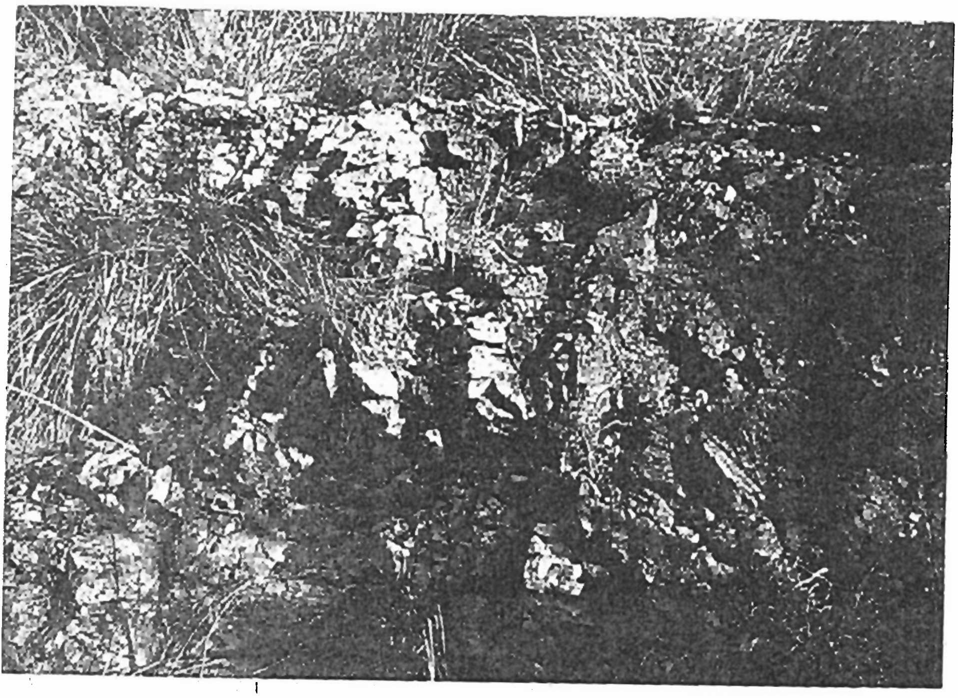


Photograph-3.15. Photomicrograph of sodium fenites (Kn-32) of Koga Syenites showing the radiating needles of pyroxene arround ore. (Plane light, magn.x25).

Photograph-3.16. Photomicrograph of fenites from Koga Syenite same as that of photograph 15. (Plane light, magn.x25).



Photograph-3.17. Photomicrograph of fenites (Kn-36) from the Koga Syenites showing the replacement of nepheline by the sodic amphibole. (Plane light, magn.x65).



Photograph-3.18. Photomicrograph of fenites showing the natrolite and cancrinite. (Crossed nicols, magn.x65).

CHAPTER 4

SODIC PYROXENES AND AMPHIBOLES FROM KOGA SYENITES

INTRODUCTION

Carbonatites are typically surrounded by the metasomatic aureoles, which develop as a result of metasomatism of country rocks by the carbonatite fluids emanating during the emplacement. Although many authors (Mckie, 1966; Currie and Ferguson, 1971; Le Bas, 1977; Vartiainen, 1980; Viladkar, 1980; Wolley, 1982; Rubie and Gunter, 1983 and Mian and Le Bas, 1986,1987,1988) have made extensive studies of fenitization by carbonatites but the process is still not well understood. This is partly because of the uncertainties of the nature of the fenitizing fluids, but also because of the variation in mineralogical composition, texture, chemical reactivity, the state of oxidation and permeability of the country rocks. At Koga in NW Pakistan carbonatites and/or ijolites are intruded and fenitized the syenitic rocks.

To understand the process of fenitization in general and behaviour of Na-pyroxene and Na-amphibole (Pyroboles) in particular, samples are collected from different syenitic rocks of Koga. This chapter presents the variation in the chemistry of pyrobole as a result of fenetic fluids emanating from the carbonatite. The chemistry of other minerals present in the syenitic rocks and whole rock chemistry is discussed in later chapters.

GEOLOGICAL SETTING

The Koga syenites occupy the eastern part of the Ambella granitic complex of alkaline igneous province, NW Pakistan and located at the border of Swat and Mardan District near Koga village at a distance of about 35 miles in northeast of Mardan. The syenitic rocks constitute an oval-shaped body (about 40 sq. kms) and are emplaced in Chinglai gneisses to the east and granites and syenites in the north and west (Fig.1.2). The rock unites of Koga are alkali-syenites, nepheline-syenites, ijolites, carbonatites and associated fenites.

The Koga syenites and carbonatites are first reported by Siddiqui et al., (1967). Chaudhry et al., (1981) described the preliminary petrology and chemistry of these rocks and suggest the emplacement of magma along a weak zone developed south of Main Mantle Thrust in the sequence as Babaji Soda granite, pulaskite, nephelinitic syenites, foyaite, sodalite syenite, and carbonatites and their fenites. Rafiq (1987) suggested the generation of magma by partial melting of the lowewr crust, contimination during later phases by the influx from the activated upper mantle and progressive desilicification of the magma which led to the formation of the quartz syenite, syenite and feldspathoidal syenites. Le Bas et al., (1986) give the preliminary petrography of the Babaji Syenites and Koga syenites ands suggest an age of 315+15 Ma for Babaji Syenites and 297+4 Ma for Koga syenites on the basis of Rb-Sr isotopic ratios.

PETROGRAPHY AND MINERALOGY

Detailed petrography of the syenitic rocks, carbonatites and ijolites and their fenites is presented in chapter 3. However, petrography of the original Na-pyroxenes and Na-amphiboles (Pyroboles) in the syenites, nepheline-syenites and the fenitic pyroboles which formed as a result of metasomatizing fluids emanating from the carbonatites and/or ijolites discussed below.

Amongst the pyroboles, pyroxene is more abundant in the unfenitized rocks both in the central and marginal rocks at Koga. The pyroxene in the unfenitized syenites is fine to medium-grained, subhedral and is yellowish green in colour. In the low grade fenites it is medium-grained, yellowish-brown in colour and corroded and altered along the margins and cleavages. The change in the colour from yellowish-green to yellowish-brown increases with the intensity of fenitization. In the high grade fenites pyroxene shows zoning, where the relict yellowish-green pyroxene is surrounded by yellowish-brown pyroxene (photograph 3.7). The core is sometime dusty. The dusty brown rim arround the relict green pyroxene is interpreted as the reaction rim between the original pyroxene of the protolith and fenitizing fluids, low in Na/k ratios emanating from the carbonatite.

Na-amphiboles are abundant in the fine to medium-grained syenites and nepheline syenites. These syenites and nepheline syenites occur along the contact with Babaji granite and syenites. Na-amphibole in unfenitized rocks is taramite, which is fine to medium-grained, subhedral and is mostly parallel to foliation. These taramites are unzoned and has strong absorption. The pleochroism scheme is a = yellowish-brown, β = greenish-brown and g = bluish-green. The biotite also occur in the form of needles parallel to the febrics.

The amphibole in the low grade fenites is medium-grained, and mostly parallel to the primary foliation but at places the overgrowth of the amphibole crosscut the foliation. The amphibole is zoned and zoning can be sewen also in thin section. The core of the amphibole is taramite which has the same plewochroism as described above apart from the which is now pale brown. The margin is kataphorite and the pleochroic scheme is a = yellowish-green, β = greenish-blue, and g = greenish-yellow to orange. Needles of amphibole can also be found which radiat from the zoned amphibole. The amphibole in the medium-grade fewnites is formed in granitic rocks. These granitic rocks are present as xenoliths in the syenitic rocks between Nawe Killi and Naranji Kandau, and are composed of quartz, perthite and muscovite. These granitic rock are foliated. the foliation is marked by the parallel alighment of quartz and perthite. The amphibole and pyroxene formed as clusters and from these clusters Na-amphibole radiates. The radiating grains of amphibole cross-cut the foliation. Relict quartz is present sometimes in the middle of the cluster of amphibole and pyroxene. New k-feldspar which is fresh and untwined are formed at the expense of quartz ands muscovite.

The newly formed amphibole in the granitic xenoliths is magnesio-arfredsonite which shows iron leaching along the cleavages. The amphibole is zoned in thin section but little variation is present in the chemistry. The pleochroic scheme is a = greenish blue, β = pale-indigo, g = greenish-yellow.

COMPOSITION OF PYROBOLES

The pyroxene from the Koga granites and syenites is aegirine-augite and amphibole is taramite, ketaphorite and magnesium arfredsonite (IMA nomenclature; Leak, 1978). Analyses of pyroboles (three or four crystals per sample and two or more spots per crystal) were performed on polished thin sections with Jeol superprobe JCX-703 using wave length dispersive system and 15 Kv voltage. ZAF correction was applied through a computerized programme. Tables 4.1 and 4.2 gives the representative analyses of the core and margins of the pyroxene and amphibole for each sample respectively. The data for pyroxene is recalculated on the basis of six oxygens and four cations and for amphibole recalculation scheme is on basis of 23 oxygens and 13 cations.

Na-pyroxene is one of the important mineral present in syenite and nepheline syenite formed during magmatic process. The composition of these pyroxenes have been studied in detailed in such type of rocks. Different authors have given different trends for magmatic pyroxenes. Magmatic pyroxene in syenitic rocks ranges in composition from diopsitic to aegirine augitic in syenetic rocks fractionate during magmatic emplacement (Yogi, 1953; Taylor and King, 1967; Varet, 1969; Gomes et al., 1970; Stephenson, 1972; Platt and Woolley, 1986; Mian, 1987).

The composition of magmatic pyroxene from Koga syenite and nepheline syenite follows similar trend as given by Stephenson (1972) for nepheline syenites of south Qoroq Centre, south greenland. The pyroxene from Koga nepheline syenite along the contact with Babaji granites and syenites, along the road to Miane Kandau, show trend from hedenbergitic aegirine-augite (Na-Mg=1) to aegirine-augite (Na-Mg=0) in core and margin of the grain respectively. In the coarse-grained rock present in the middle of Koga syenites little variation is present in the composition of magmatic pyroxene. Although this variation is small but the trend is the same from diopside or hedenbregite to aegirine. In the Fig.4.1 the parameter Na-Mg in atom per formula unit is used by the Stephenson (1972) has been chosen as a fractionation trend during the emplacement of different types of rocks.

The above parameter in Fig.4.1 has been chosen as a dsegree of intensity of fenitization by alkaline fluids which emanated from the carbonatite having different Na/k ratio. The fenitic pyroxene shows a reverse trend on Fig.4.1 with increasing degree of intensity of fenitization. The composition of the relict green pyroxene is aegirin in the core in which Na-Mg is approximately 1 while in the overgrown brown pyroxene Na-Mg decreases to 0.5. Ca and Fe^{2+} decreases in magmatic pyroxene with fractionation while

Fe^{3+} increases. In fenetic pyroxene Ca and Fe^{2+} increases. Similarly Na+K increases with the decrease of Mg ratio (100 Mg/(Mg,Fe,Mn) in the magmatic pyroxene, showing a fractionation trend during the evolution of syenites and nepheline syenites (Fig.4.2). The fenetic pyroxenes show a reverse trend. With the increase of Mg ratio Na+K decreases. Some of the analyses show little but a reverse trend than that of the magmatic pyroxene.

The state of oxidation increases during fractionation in most of the magmatic pyroxenes. At Koga Fe^{2+} and Mg decreases and F^{3+} increases with the fractionation of pyroxene from the early to late stage intruded rocks. However, some pyroxene show a reverse trend i.e., with the increase of intensity of fenitization by the carbonatites Mg and Fe^{2+} increases with respect to Fe^{3+}. Again some of the rocks show little variation but reverse than that of magmatic pyroxene (Fig.4.3).

Fig.4.4, shows two different trends. One is for magmatic pyroxene and the other is for fenetic pyroxene. The magmatic pyroxene data is in accordance with the data of magmatic pyroxene of south Qoroq alkaline rocks represented by Stephenson (1972). While, the fenetic pyroxene gives reverse trend and moves toward Fe-Mg rich boundary on Na+k-Fe-Mg diagram (Fig.4.4).

Fig.4.5a, shows the magmatic fractionation trend of Na-pyroxene in Koga syenites and nepheline syenites. The composition of magmatic pyroxene shows an increase in the actmitic component with increasing fractionation in most of the rocks particularly from the marginal rocks of Koga. The pyroxene in coarse-grained syenites ands nepheline syenites from the middle of the complex although show little variation from diopsidic to acmitic component but the same as that of magmatic pyroxene. However, the fenitic pyroxenes in sample K-14,K-18, K-25, K-34, K-318 show a reverse trend from acmitic to diopsidic component in both fenitized syenites and granitic rocks (Fig.4.5a). The fenitic pyroxenes show two different trend one in samples k-18 and k-318 in which diopsidic component increases with little increase in hedenbergitic component while, in sample k-34 both diopsidic and hedenbergitic components increases almost equally. These trends are interpretted as the result of the variation in Na/k ratio of the fenitizing fluids, low in the first trend and high for second trend. The trend similar to the second trend is also reported by Kresten and Morogan (1986) for the pyroxene from the Fen Complex. The authors suggested the ijolite-type magma for the fenetization of these rocks.

The magmatic and fenitic pyroxenes from Koga are compared with the published data of other magmatic pyroxenes. Fig.4.5b, shows a similar trend from diopsidic to acmitic component for magmatic pyroxene. The opposite and reverse trend for fenitic pyroxene is shown in which diopsidic component increasing with increase of fenitization by the alkaline fluids emanating from the carbonatites. The reverse trends given by Kresten and Morogan

(1986) are also presented.

The Na-amphybole like Na-pyroxene is a common mineral present in alkaline igneous rocks particularly in granites and syenites. The magmatic Na-amphibole mostly occur in the marginal nepheline syenites is taramite. These amphiboles are unzoned and show little variation in chemistry and optical properties.

In granites and syenites which are intruded by carbonatites, fenitic Na-amphibole is common when the carbonatitic fenetizing fluid is high in Na/k ratio. The fenetic amphibole have been studied in detail in granites and syenites which are intruded by carbonatites and ijolites (Sutherland, 1969; Vartiainen and Woolley, 1976; Vartiainen, 1980; Hogarth and Lapointe, 1984; Mian and Le Bas, 1986).

Representative analyses of original amphiboles and amphiboles form as a result of fenitization in granitice and syenitic rocks are given in table.4.2. The Na-amphiboles from the marginal medium-grained rocks are taramite. These show little variation in optical properties and chemistry and show no sign of metasomatism. Therefore, these amphiboles are interpretted as formed by magmatic processes. However, Na-amphiboles present in some coarse-grained syenites and fenitized granites show variation in optical properties and chemical composition. Mg increased with respect to Fe^{2+} while Na+K remain constant with the increase of intensity of fenitization (Fig.4.6). The interpretation of fenitized Na-amphibole is supported by the newly formed amphiboles in granitic xenoliths in syenites in which Mg reaches to maximum.

The increasing oxidation trend shown by the fenetic amphiboles contrast with the magmatic trend for the Na-amphibole (Fig.4.7). Strong and Taylor (1984) show that with the progressive crystallization of peralkaline magmas, the Na-amphiboles progress from barrosite through richterite to arfredsonite, whereas in the highly fenetized rocks at Koga Na-amphiboles show a revers trend from magnesio-arfvedsonite to richterite, which is a reverse trend as compared to magmatic subsolidus trend.

Hogarth and Lapointe (1984) gave two separate evolution trends for amphiboles from fenites at Cantley, Quebec, Magnesio-arfvedsonite from biotite gneiss; and magnesio-ricbeckite from pyroxene gneiss (MA and MR respectively, Fig.4.8). They suggested that magnesio-arfvedsonite and riebeckite make solid-solution series with winchite as shown by dotted lines (Fig.4.8). Mian and Le Bas (1986) gave solid solution trend from magnesio-arfvedsonite to magnesio-riebeckite (solid line, Fig.4.8). While at Koga fenitic amphiboles show an increase in monovalent cations (Na+K) from magmatic to fenetic amphiboles as a result of which the vacancies in A site increases with the increasing intensity of fenitization.

The variation in (Na+K) content from magmatic amphibole to fenetic amphibole in Koga granite and syenites show a smooth rise as Mg ratio increases (Fig.4.9; low in unfenitized syenites and high in fenitized syenites and granites). Similar trend is given by Mian and Le Bas (1986) for the Na-amphiboles of Loe Shilman. Amphiboles from Loe Shilman and Koga, both show an increase in Mg ratio with the increasing degree of intensity of fenitization.

The slope of the straight line given by plotting the Mg-ratio against MgO for fenetic Na-amphiboles from Koga is steeper than that for magmatic Na-amphiboles (Fig.4.10). Data for magmatic amphiboles are taken from Deer et al., (1963) and coldwell syenites igneous complex in Ontario, Canada (Mitchell and Platt, 1982). This type of kinking between unfenetized and fenetized Na-amphiboles was first reported by Vartiainen and Woolley (1976) from Sokli, Finlands. According to Mian and Le Bas (1986) this kinking at about 30 Mg ratio between magmatic and fenetic amphiboles is a product of differing oxidation states, with that in the metasomatic rocks being the high. Therefore, the kinking in the slope in amphiboles from Koga is also interpretted as the result of difference in the state of oxidation in magmatic and fenetic amphiboles.

DISCUSSION

The behavior of pyroxene and amphibole is not well undserstood during the fenitization by carbonatite. However, it is suggested that there are two types of fenetic pyroxenes: (1) when pyroxene is not present in the protolith before fenitization as in shale/slates and phyllites at Loe Shilman, then the newly formed pyroxene may not shuow much variation in the chemistry and optical properties in the less and highly fenitized rocks. This is due to the newly formed nuclii in equilibrium with the carbonatitic fenetizing fluids. This equilibrium may be present in contact with carbonatite or within carbonatite. Such type of pyroxenes are present in the granitic xenolith (K-318) in which pyroxenes grow radially and are formed at the expanse of quartz during the emanation of fenitizing fluids by the carbonatite. In this case very little change in composition is present because there was originally no pyroxene 2) when pyroxene is present in the protolith, then the overgrowing pyroxene does not require any nucleous for their crystallization. In this case fenetic pyroxene grows arround the original or already present pyroxene. During the overgrowth the original pyroxene (magmatic or metamorphic) is also attacked by the fenitizing fluids and a change occurs in the composition and optical properties of the original relict pyroxene. The original pyroxene of the protolith is preserved (K-18, as yellowish green see chapter 3). The second possibility is favourd for the fenitic pyroxene at Koga because the pyroxene is already present in nepheline syenite.

The pyroxene compositional trends for the alkaline rocks are shown in Fig.4.5b. Which represent the cooling history of the alkaline rocks. In this figure all the trends move towards acmite end member. The reverse trend (i.e. from acmite to diopside) is not reported during fractional crystallization of the alkaline magma. The reverse trends which are observed in the individual grain of pyroxene from Koga syenites, suggest the fenitization of pyroxene by the carbonatite. The two reverse trends, one (K-14, K-18) from acmitic to diopsidic end and the other (k-34) from acmitic to hedenburgitic end, are interpretted as the result of variation in Na/K ratio by different carbonatite intrusions. The carbonatite which fenitized the K-34, is more Na-rich than the carbonatite fenitizing K-14 and K-18. In other words the Naranji Kandau carbonatite is more potassic. This is supported by the whole rocks chemistry (see chapter 6). The behavior of the second carbonatite (i.e. having high Na/k ratio is almost same as that of the amphibole carbonatite at Silai Patti (Mian personal communication). Different types of carbonatite have not been identified in the field. However, it is suggested on the basis of petrography and pyroxene analyses that there might be at least two different intrusions of carbonatite. Amongst these two carbonatites one is exposed at Naranji Kandau, in which the Na/K ratio was low and the other in which Na/K ratio was high is not exposed. The third possibility of Na-fenitization by the ijolite can not be ignored as ijolite does only Na-fenitization. But the author favours the possibility that there may be another carbonatite which emanated alkaline fluids high in Na/K ratio. This is because there are a few thin dikes of ijolite but a lot of carbonatite exposures, although small, are present in the western part of Koga syenites and nepheline syenites Na-fenitization by the carbonatite instead of ijolite is favoured also because the capacity of fenitization by the carbonatite is more intense and more widespread due to the free alkalis present in the carbonatite magma while, in ijolites the alkalis are present in more stable minerals.

In contrast to the magmatic and fenitic pyroxenes, Na-amphibole does not suggest two possible carbonatite intrusions with different Na/K ratios. It is also not possible to suggest whether the fenitic amphiboles are formed by Na-fenitizing fluids emanating from carbonatite or ijolites. This is because Na-amphiboles were not seen in the carbonatite or in the highly fenitized rocks near Naranji Kandau Carbonatite plug. However, two different trends suggesting of two carbonatites, different in Na/K ratios, can be seen in the whole rock chemistry.

CONCLUSION

The study of pyroboles from Koga syenites suggests:

1) fenitization of the rocks by the fluids emanating from carbonatite intrusions.

2) The fenetic pyroxene shows the trend of evolution from acmitic to diopsidic component which is reverse to the trend of evolution for magmatic pyroxene.

3)The composition of pyroxene further suggests that the Koga rocks have been intruded by at least two carbonatite intrusions having different Na/K ratios.

4)The fenitic Na-amphibole shows trend from magnesio-arfvedsonite to richterite which is also opposite to the magmatic subsolidus trend.

5)The amphibole composition shows an increase in MgO ratio with increasing intensity of fenitization and crystallization of fenitic amphibole under strong oxidation state. However, Na-amphibole occurs only in the Na-fenitized syenites.

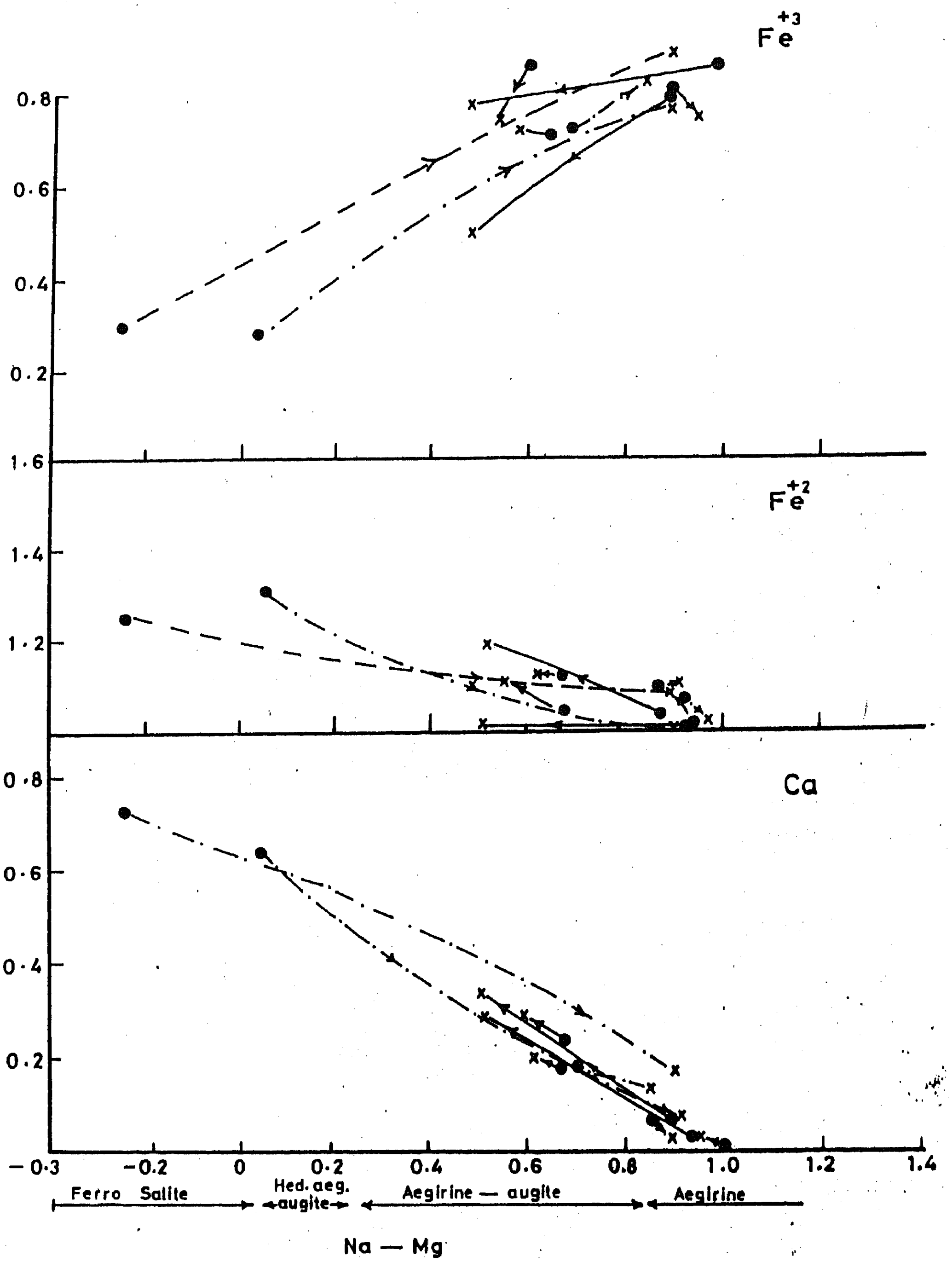


Fig.4.1 Plot of Ca. Fe^{2}+ and Fe^{3+} against (Na–Mg) of the pyroxene showing that composition of magmatic pyroxene from Koga and South Qoroq alkaline rocks change from hedenburgite to aegirine while the fenitic pyroxenes of Koga syenite shows an opposite trend from aegirine to aegirine augite. (–.–.–>)=magmatic pyroxene of Koga syenite (–.–.–>) = pyroxene of South Qoroq, (–) = fenitic pyroxene of Koga. Crosses = margin, dots =core, of the pyroxene grains.

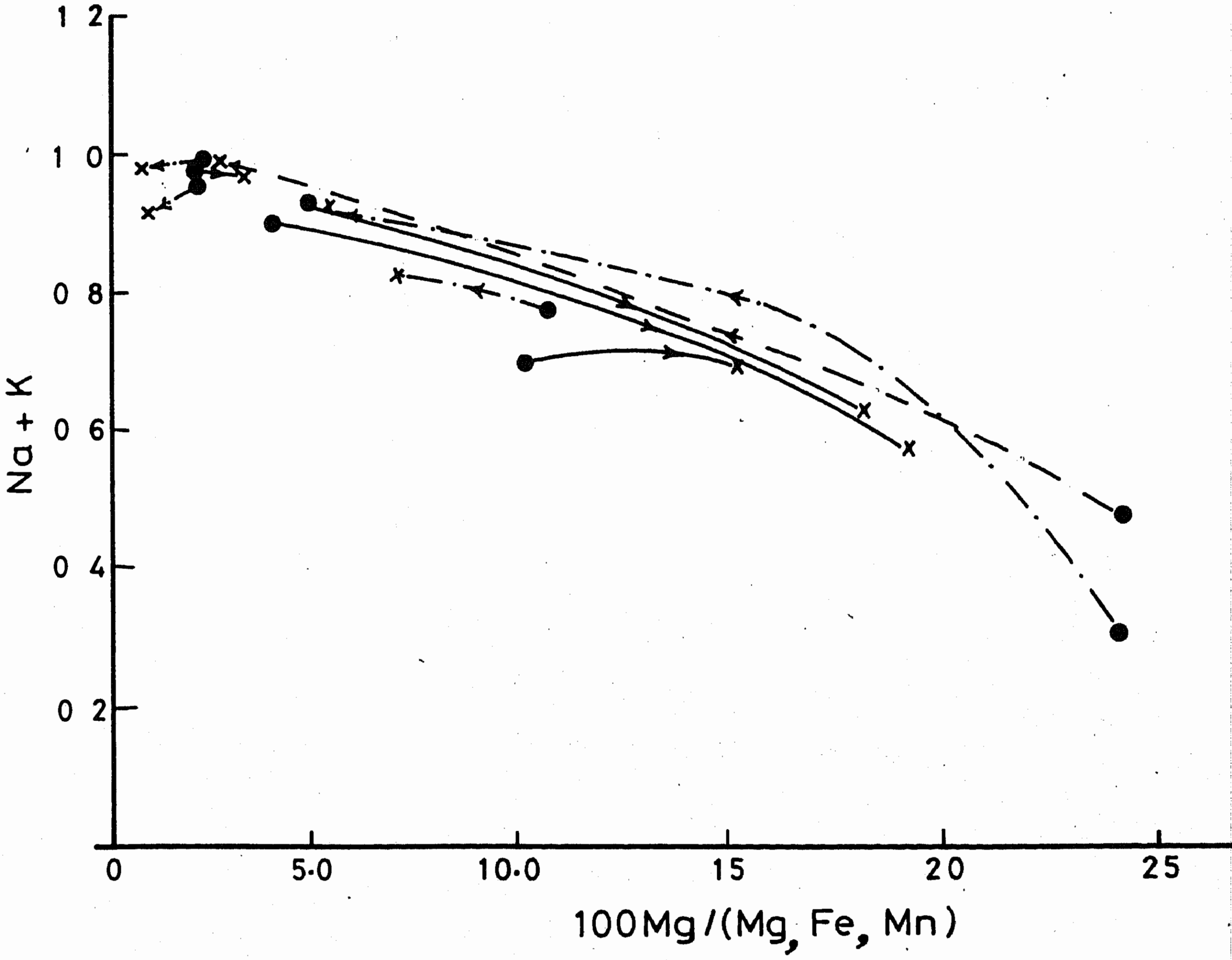


Fig.4.2 Mg/(Mg+Fe Mn) vs. (Na+K) for magmatic and fenitic pyroxenes. The fenitic pyroxene shows a decrease in (Na+K) and increase in Mg ratio with the increase of fenitization. While magmatic pyroxene shows reverse trend. Symbols and trend as for Fig.4.1.

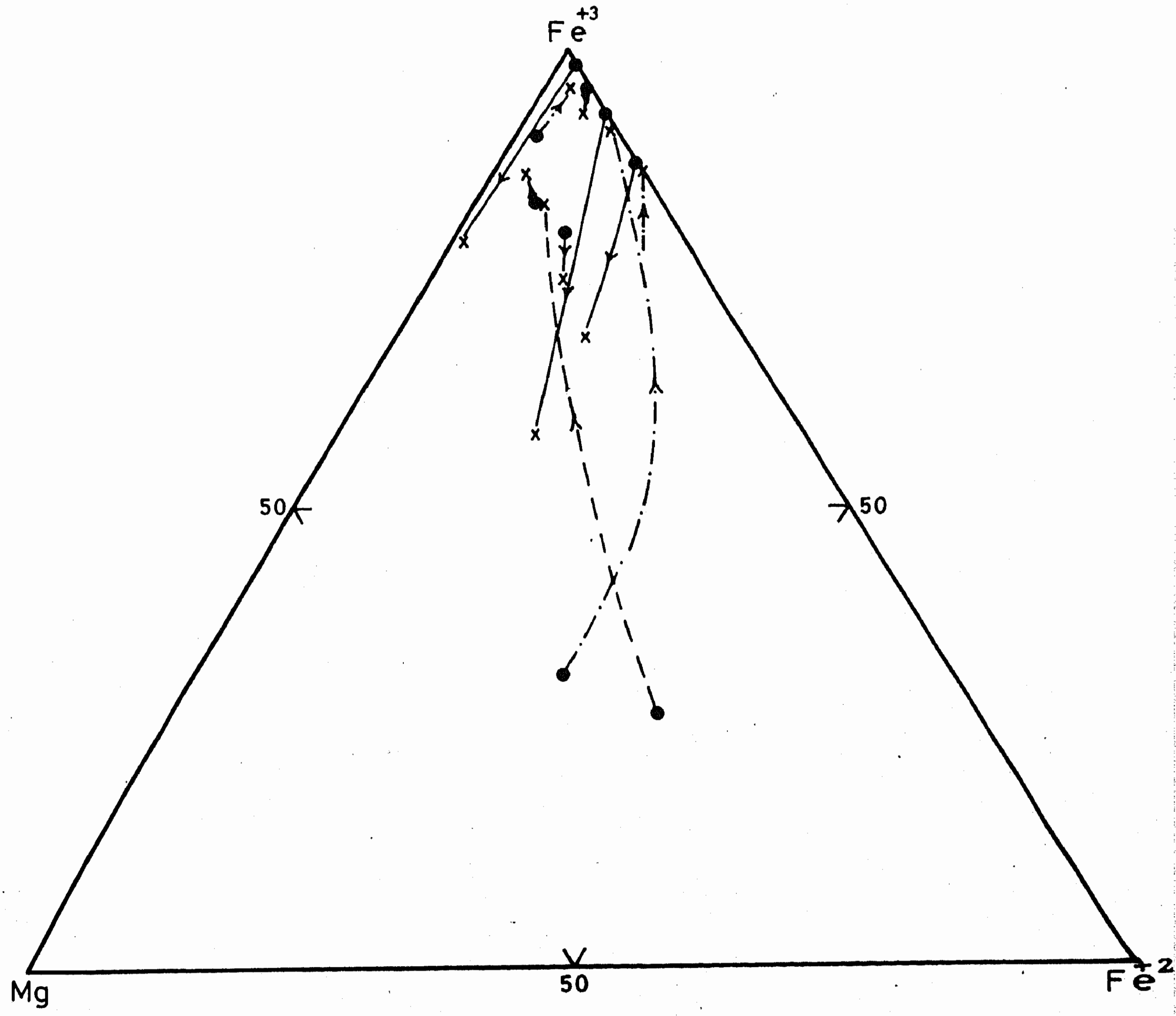


Fig.4.3 Plot of Koga pyroxene in terms of Fe^{2+} – Fe^{3+} –Mg which shows Mg and Fe^{2+} increases with respect to Fe^{3+} in fenitic pyroxenes while, reverse in the case of magmatic pyroxenes.Symbols and trends as for Fig.4.1.

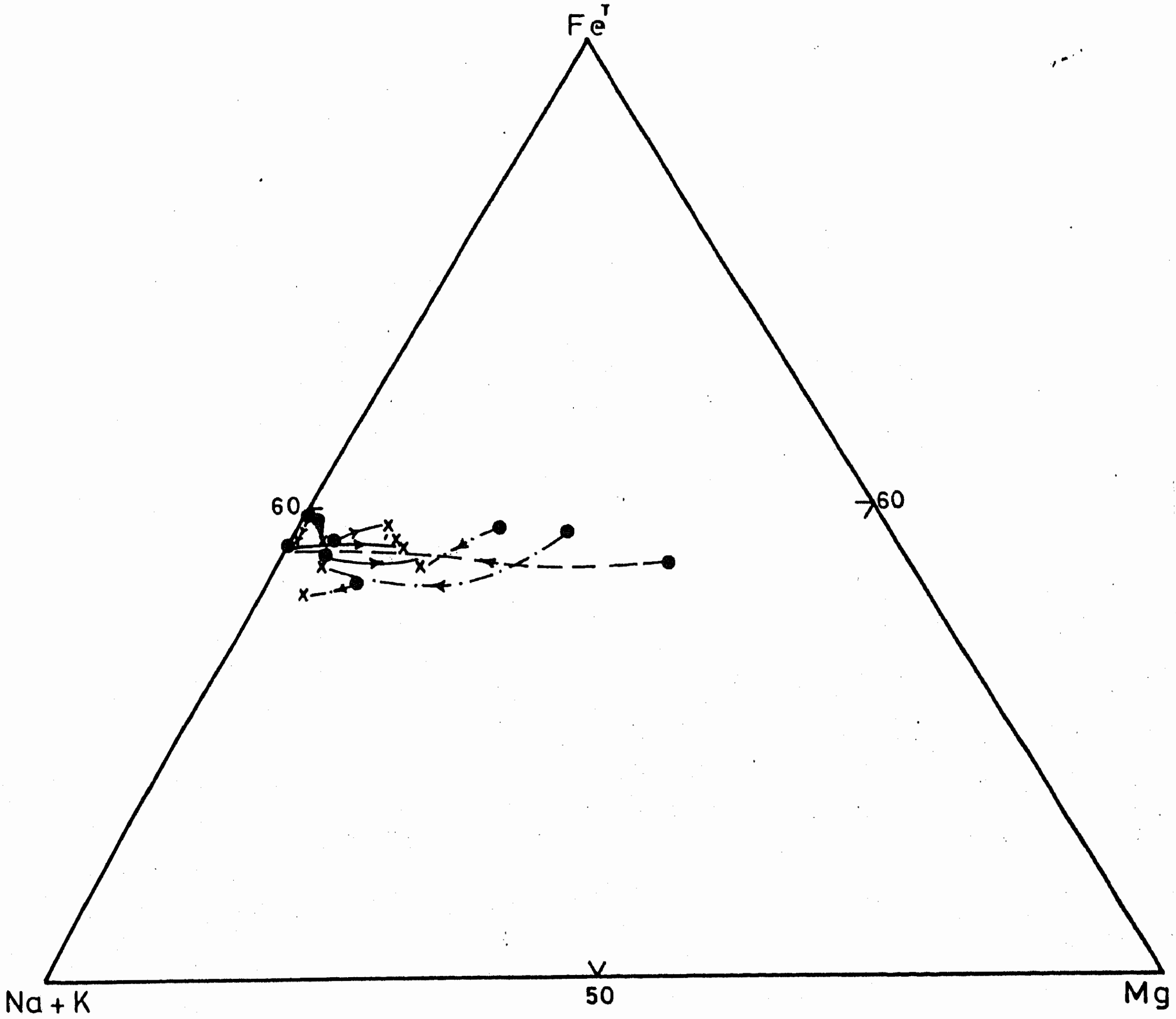
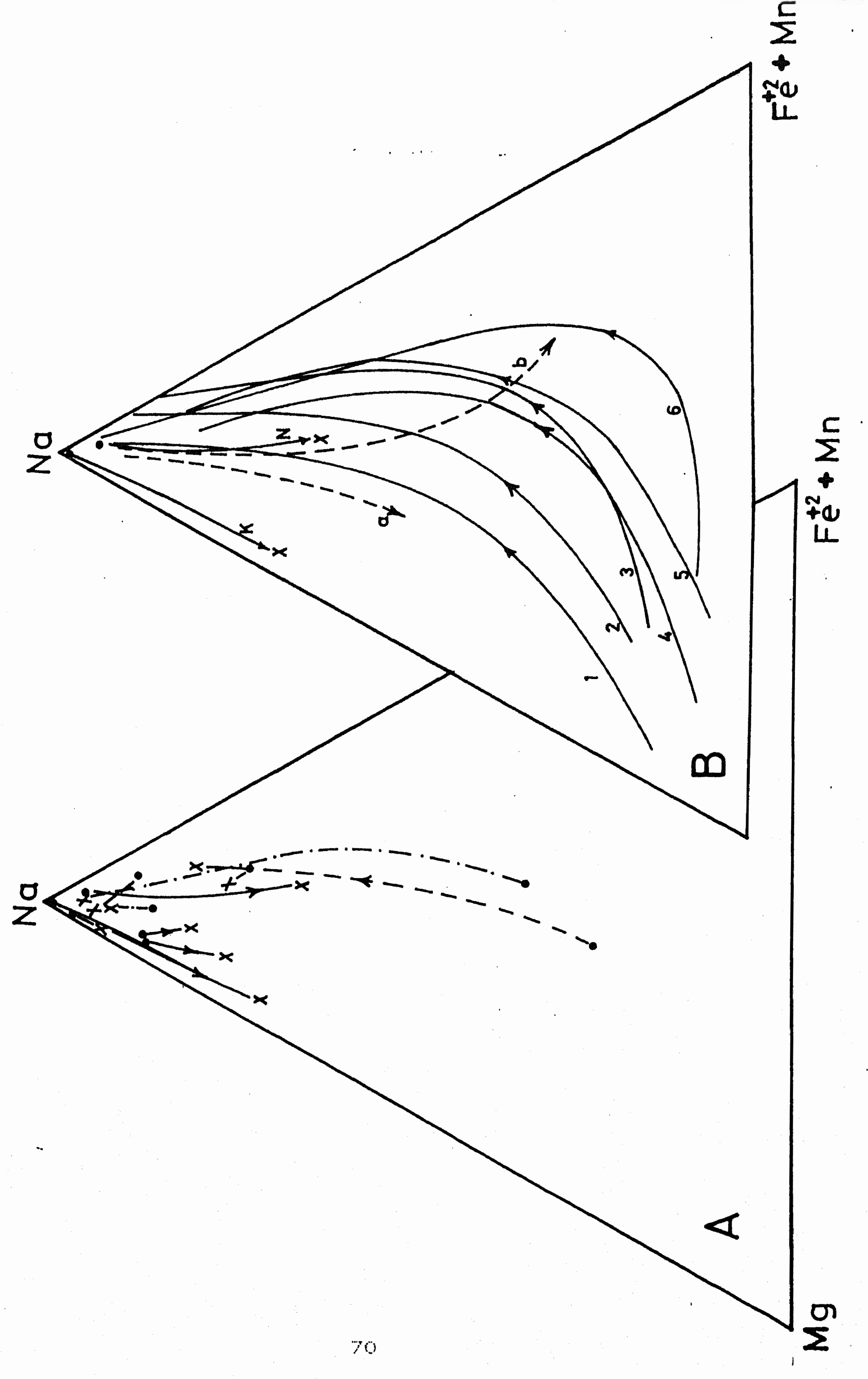


Fig.4.4 Plot of Koga pyroxene in terms of (Na+K)-FeT-Mg showing that magmatic pyroxenes of Koga and South Qoroq moves towards FeT-Mg rich side while fenitic pyroxenes composition moves opposite. Symbols and trends as for Fig.4.1.

Fig.4.5a Plot of Koga pyroxenes in terms of Ac-Di-Hed showing the decrease of acmite relative to diopside with the increasing degree of intensity of fenitization. Symbols and trends as for Fig.4.1.

Fig.4.5b Pyroxene trend in Koga syenites (N=Na-fenitized and K=K-fenitized) is compared with published data alkali pyroxene trends a,b) Fen Complex, southern Norway (Kresten and Morogan, 1986); (1) Auvergne, France (Varet, 1969); (2) Itapirapua, Brazil (Gomes et al., 1970); (3) Chambe, Mulanji, Malawi (Platt and Woolley, 1986); (4) Uganda (Tyler and King, 1967); (5) South Greenland (Stephenson, 1972).



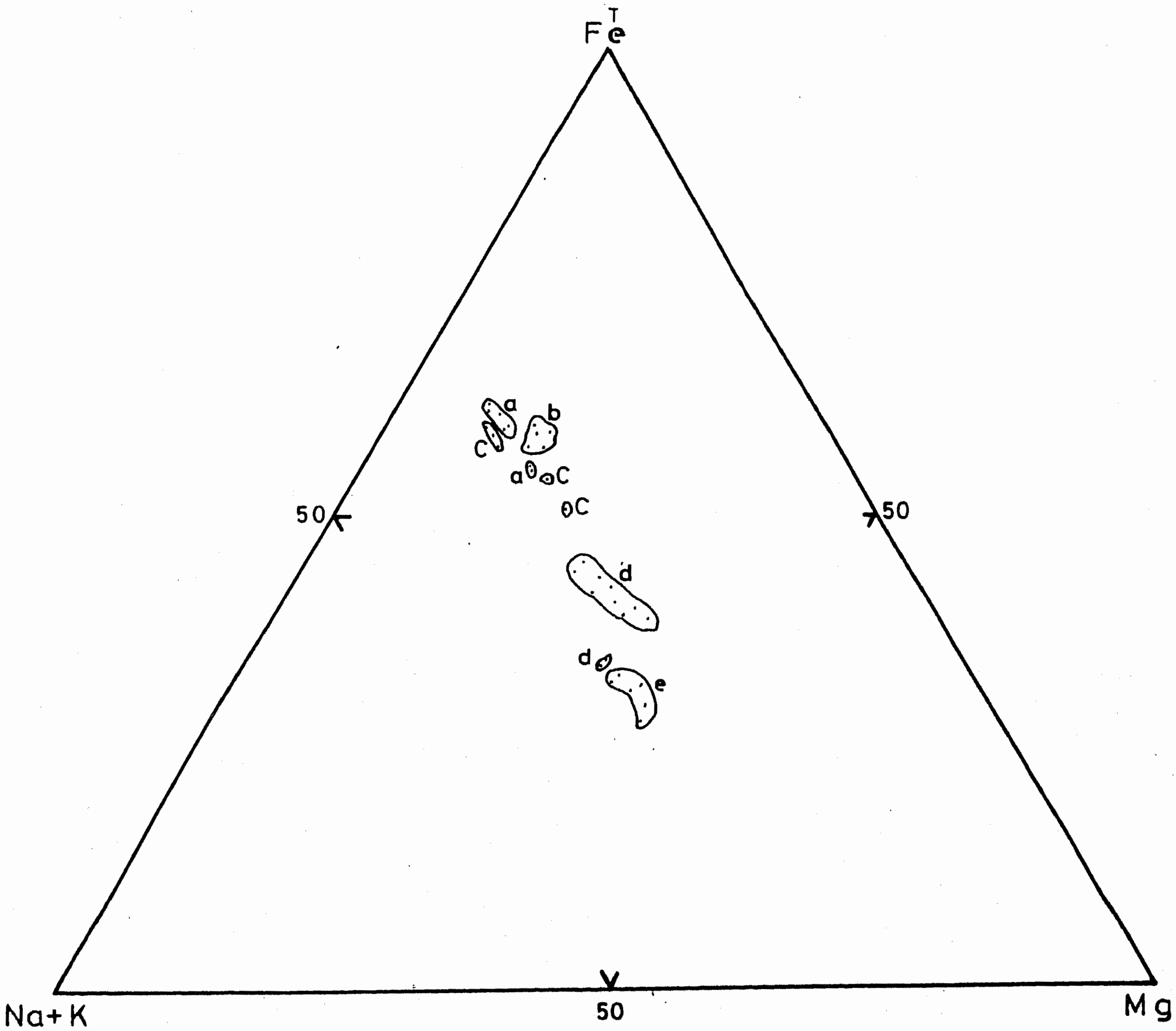
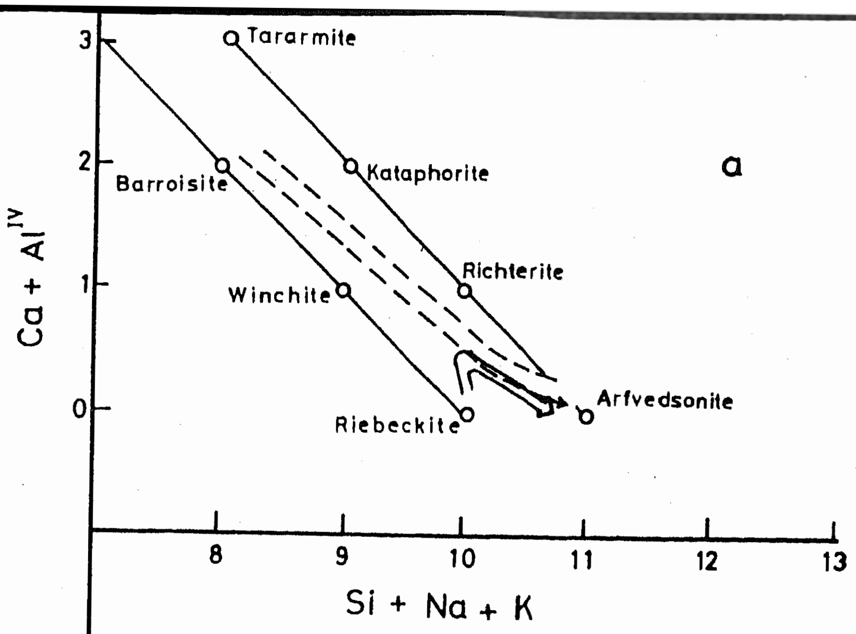


Fig.4.6 Plot of amphiboles from Koga syenites in terms of(Na+K)-FeT-Mg showing that Mg increases with respect to FeT while (Na+K) remains constant with the increase of intensity of fenitization. a= magmatic amphibole (K-1), b= low grade fenites (K-2), C= medium grade fenite (K-34), d=(K-3), and e= (318) high grade fenites .



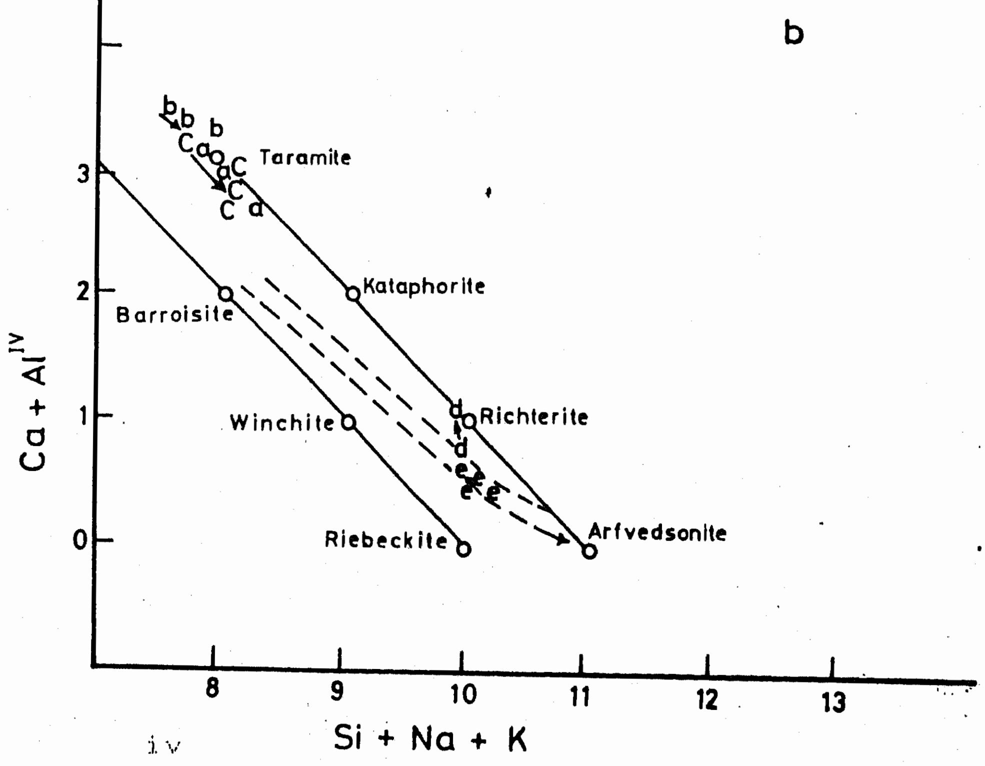


Fig.4.7a $(Ca+Al^{iv})$ vs. $(Si+Na+K)$ plot after Strong and Taylor (1984), showing the magmatic-subsolidus trend for Na-amphibole (dashed arrows) and compared with he fenitic amphiboles from least to the highly fenitized slates and phyllites from Loe Shilman.

Fig.4.7b The magmatic Na-amphibole (taramite) from Koga shows a normal fractionation trend while, fenitic Na-amphibole shows a reverse trend from arfvedsonite to richterite apposite to magmatic trend given by Strong and Taylor (1984). a= magmatic Na-amphibole (K-1), b= Na-amphibole from low grade fenites (K-2), c=Na-amphibole from medium grade fenites (K-34), d & e = Na-amphibole from high grade fenites from Koga rocks.

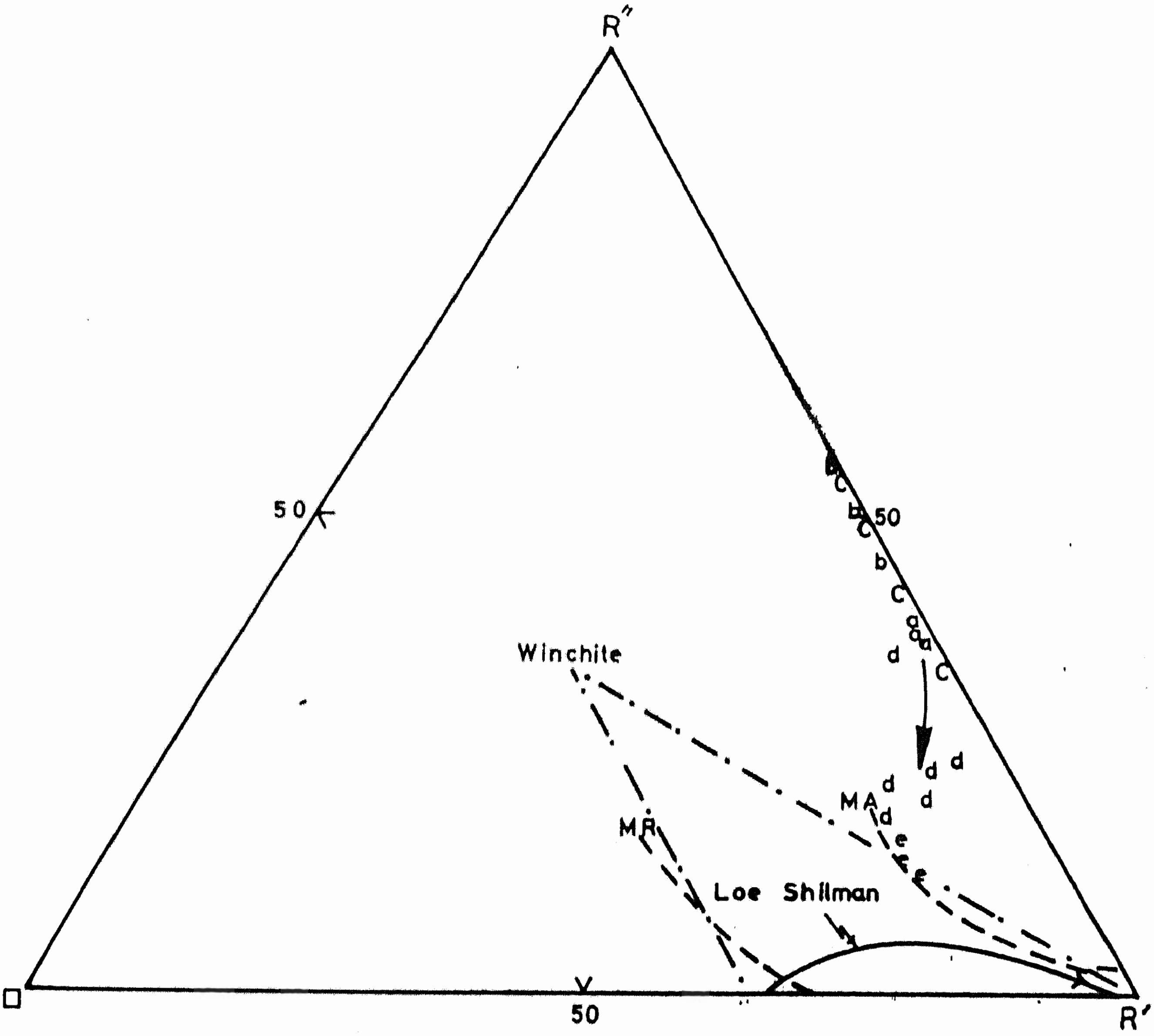


Fig.4.8 The Na-amphiboles (a to e) from Koga syenites plotted with respect to monovalent cations R', divalent cations in B site R", and vacancies (0) in A site. Also shown (as dashed lines) are the fenites trends in gneisses and the solid solution series between magnesio-arfvedsonite (MA) and magnesio-riebeckite (MR) with winchite (dotted lines) as given by Hogarth and Lapoit (1984). Solid line shows the trend of fenitic amphibole of Loe Shilman (Mian and Le Bas, 1986) and arrow shows the trend of fenetic amphiboles from Koga syenites. Symboles as for figure 4.6.

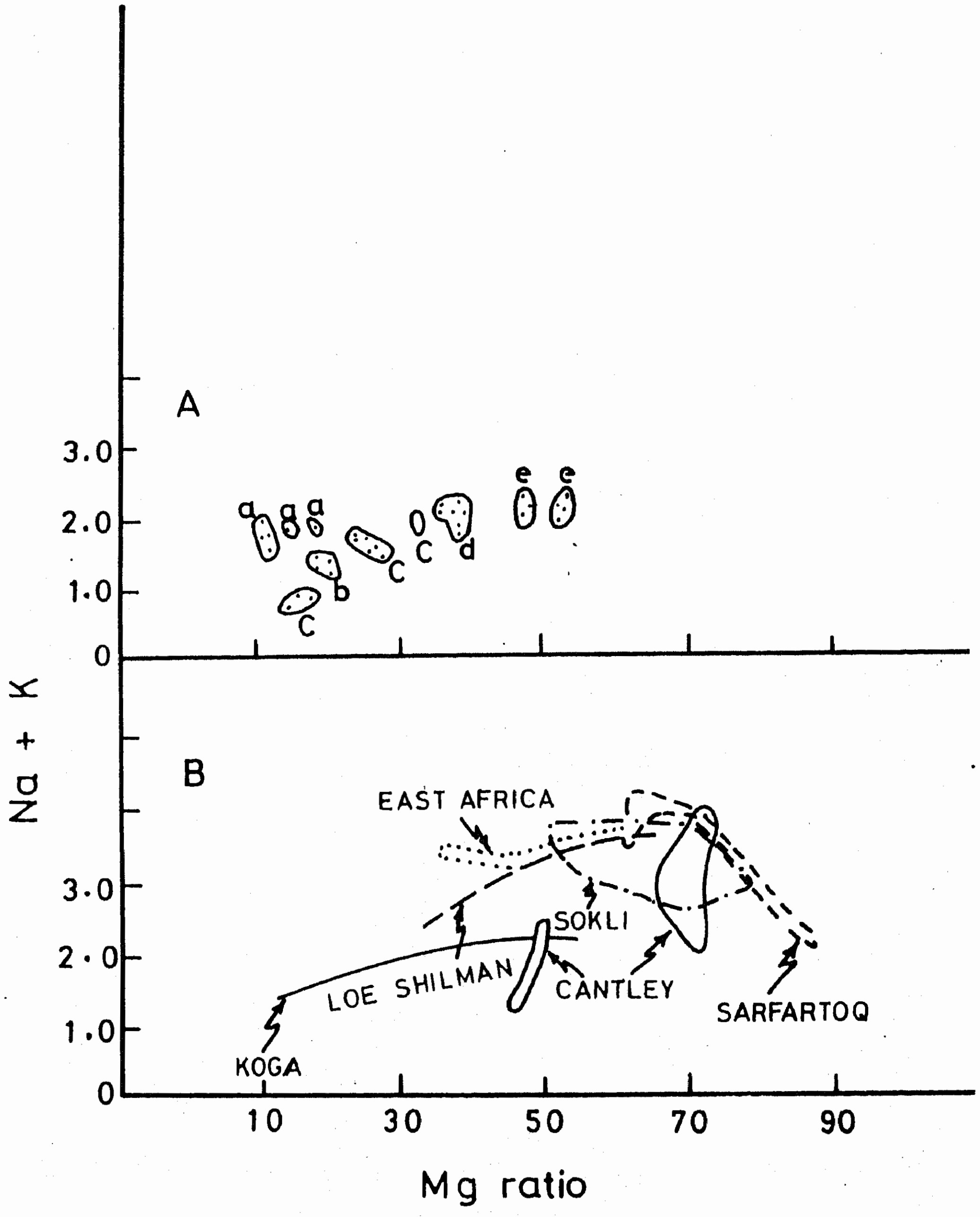


Fig.4.9 Plot of Mg ratio against Na+K (A) for amphibole in fenites at Koga, showing regular increase in Na+K with increasing Mg ration; (B) the trend for amphibole from Loe Koga syenites in compared with fenitic amphibole from Loe Shilman (Mian and Le Bas, 1986). Sokli, Finland (Vartianen and Woolley, 1986); Sarfartoq, West Greenland (Secher and Larsen, 1980); Cantley, Quebec (HOgarth and Lapoite, 1984) and from East Africa (Sutherland, 1969). Symbols as for Fig.4.6.

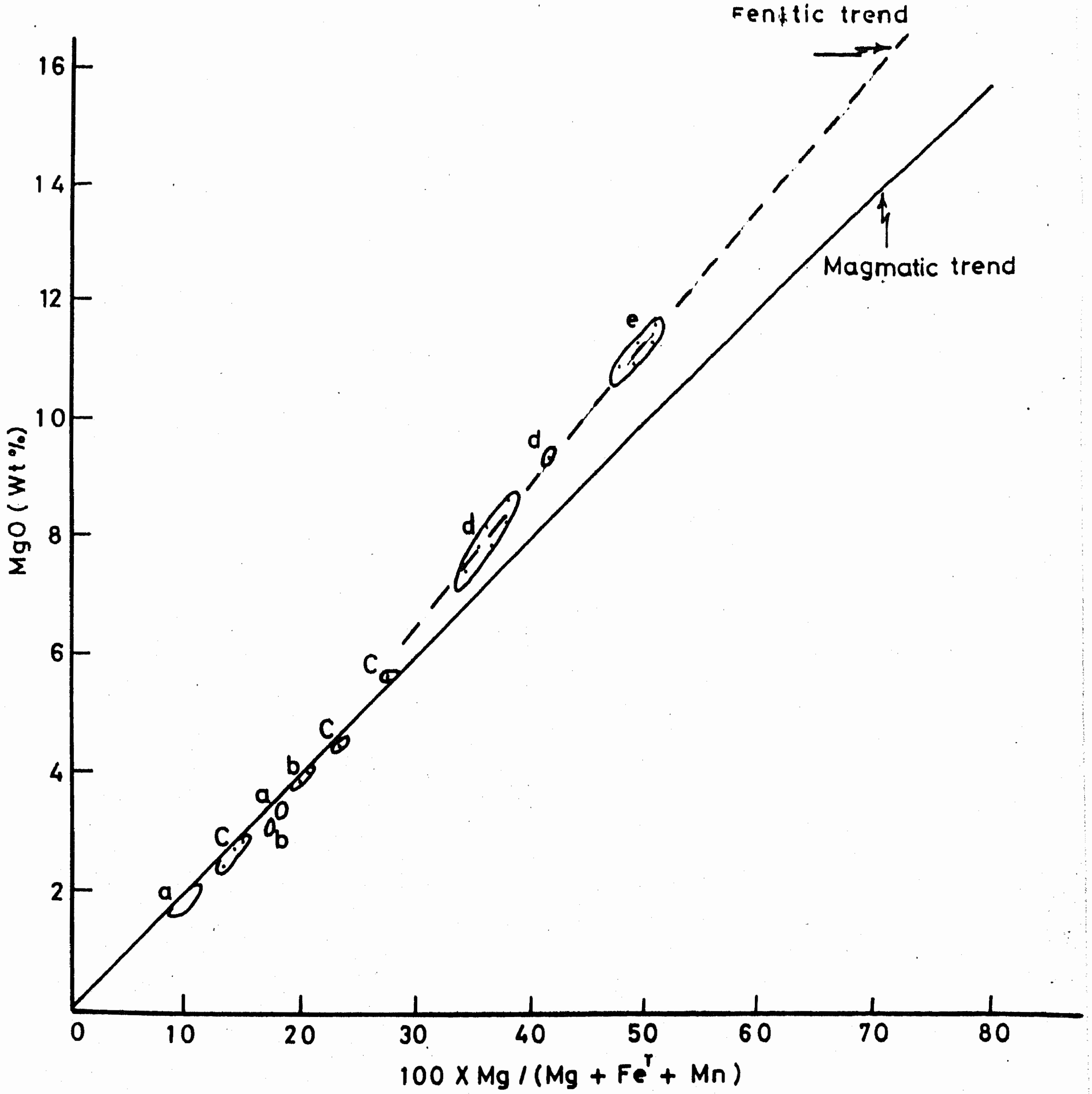


Fig.4.10 MgO vs MgO ratio plots after Mian and Le Bas (1986) distinguishing the trends of magmatic and fenitic amphiboles. Symboles as for figure 4.6.

Table 4.1. Analyses of pyroxene from Koga syenites.

Analyses No.	1	2	3	4
Sample No.	K5P1A1(MID)	K5P1A2(MAR)	K6P2A1(MID)	K6P2A2(MAR)
SiO2	53.140	54.190	52.460	53.200
TiO2	00.040	00.080	00.370	00.110
Al2O3	02.320	05.575	01.700	05.050
Fe2O3	27.180	26.790	27.840	26.800
FeO	03.760	00.860	02.150	00.010
MnO	00.270	00.020	00.530	00.170
MgO	00.450	00.130	00.200	00.250
CaO	01.290	00.370	01.640	00.640
Na2O	12.320	13.650	12.500	13.430
Total	100.770	101.850	99.390	99.670

No.of ions on the basis of 6 Oxygen.

Si	02.012	01.989	02.013	01.995
Ti	00.001	00.002	00.011	00.003
Al	00.104	00.249	00.077	00.223
Fe3+	00.774	00.740	00.804	00.756
Fe2+	00.119	00.026	00.069	00.000
Mn	00.009	00.001	00.017	00.005
Mg	00.025	00.007	00.011	00.014
Ca	00.052	00.015	00.067	00.026
Na	00.904	00.971	00.930	00.977
Na	85.500	96.600	90.500	98.000
Mg	02.400	00.700	01.100	01.400
Fe2+Mn	12.100	02.700	08.400	00.600

Table 4.1 Continued.

Analyses No.	5	6	7	8
Sample No.	K6P2F1(MID)	K6P2F2(MAR)	K7P4A1(MID)	K7P4A2(MAR)
SiO2	52.640	54.380	52.620	52.700
TiO2	00.130	00.070	00.130	00.180
Al203	01.980	06.170	03.980	04.000
Fe2O3	30.750	24.910	25.260	25.360
FeO	00.000	00.560	02.790	03.110
MnO	00.340	00.040	00.280	00.170
MgO	00.470	00.000	00.820	00.550
CaO	00.890	00.060	01.800	01.110
Na2O	13.670	13.880	12.130	12.310
Total	100.900	100.100	99.810	99.640

No.of ions on the basis of 6 Oxygen.

Si	01.988	02.015	01.992	01.999
Ti	00.004	00.002	00.004	00.005
Al	00.088	00.269	00.178	00.179
Fe3+	00.873	00.695	00.720	00.724
Fe2+	00.000	00.017	00.088	00.099
Mn	00.011	00.001	00.009	00.005
Mg	00.026	00.000	00.046	00.031
Ca	00.360	00.002	00.073	00.045
Na	01.001	00.997	00.890	00.906
Na	96.400	98.200	86.100	87.000
Mg	02.500	00.000	04.500	03.000
Fe2+Mn	01.100	01.800	09.400	10.000

Table 4.1 Continued.

Analyses No.	9	10	11	12
Sample No.	K12P2X1(MID)	K12P2X2(MAR)	K12P3X2(MID)	K12P3X4
SiO2	51.14	52.77	51.18	52.78
TiO2	0.47	0.32	0.31	0.17
Al2O3	1.08	1.78	1.61	1.77
Fe2O3	18.17	26.76	9.48	18.75
Feo	5.83	0.10	9.58	2.75
MnO	1.32	0.32	1.34	0.78
MgO	2.71	1.98	5.18	4.57
CaO	9.24	4.30	15.34	9.10
Na2O	8.14	11.64	4.68	8.58
Total	98.71	99.71	98.70	99.31
	No. of ions on the basis of 6 oxygen.			
Si	1.989	1.997	1.991	2.004
Ti	0.014	0.009	0.009	0.005
Al	0.077	0.079	0.074	0.079
Fe3+	0.532	0.762	0.278	0.536
Fe2+	0.190	0.003	0.312	0.087
Mn	0.043	0.010	0.044	0.025
Mg	0.157	0.112	0.300	0.259
Ca	0.385	0.174	0.039	0.370
K	0.614	0.854	0.353	0.632
Ma	61.10	87.20	35.00	63.00
Mg	15.70	11.40	29.70	25.80
Fe2+Mn	23.20	1.40	35.30	11.20

Table 4.1 Continued.

Analyses No.	13	14	15	16
Sample Nop.	K12P3X4	K12P3X6	K12P3X7(MAR)	K16P3A1(MID)
SiO2	53.06	53.01	53.53	49.763
TiO2	0.28	00.33	0.27	0.311
Al2O3	2.11	3.76	3.52	0.976
Fe2O3	22.62	21.82	27.19	18.060
FeO	2.05	2.84	0.00	4.850
MnO	0.44	0.35	0.14	0.909
MgO	3.29	1.22	0.88	4.393
CaO	6.31	3.60	2.19	12.021
Na2O	10.20	11.57	12.94	6.62
Total	100.37	98.52	100.66	97.069

No. of ions on the basis of 6 oxygen.

Si	1.997	2.021	1.999	1.951
Ti	0.008	0.009	0.008	0.010
Al	0.094	0.169	0.155	0.045
Fe3+	0.641	0.626	0.764	0.533
Fe2+	0.065	0.091	0.000	0.159
Mn	0.014	0.004	0.004	0.030
Mg	0.185	0.069	0.049	0.258
Ca	0.254	0.147	0.088	0.505
Na	0.744	0.855	0.937	0.504
Na	73.90	83.30	94.60	53.030
Mg	18.30	6.80	5.00	27.039
Fe2++Mn	3.80	9.90	0.40	19.932

Table 4.1 Continued.

Analyses No.	17	18	19	20
Sample No.	K16P3A2	K16P3A3(MAR)	K16P2A1(MID)	K16P2A2
SiO2	50.403	51.629	49.704	50.029
TiO2	0.190	0.228	0.487	0.061
Al2O3	0.826	0.686	1.286	1.254
Fe2O3	19.770	29.520	15.260	14.630
FeO	3.900	0.000	7.070	7.660
MnO	0.834	0.341	0.823	0.799
MgO	4.151	0.227	4.597	4.649
CaO	10.207	0.337	14.980	14.911
Na2O	7.545	13.327	5.304	5.134
Total	95.956	95.149	97.991	97.761

No. of oins on the basis of 6 Oxygen.

Si	1.972	1.992	1.933	1.949
Ti	0.006	0.007	0.014	0.002
Al	0.038	0.122	0.059	0.051
Fe3+	0.582	0.857	0.447	0.429
Fe2+	0.128	0.000	0.230	0.249
Mn	0.020	0.004	0.027	0.026
Mg	0.242	0.013	0.266	0.270
Ca	0.428	0.014	0.624	0.622
Na	0.573	1.997	0.400	0.388
Na	59.044	98.272	43.327	41.535
Mg	24.954	1.304	28.845	28.918
Fe2++Mn	16.002	0.424	27.828	29.547

Table 4.1 Continued.

Analyses No. Sample No.	21 K16P2A3(MAR)	22 K22P4A1(MID)	23 K22P4A2(MAR)	24 K24P1A1(MID)
SiO2	52.683	51.395	51.691	53.48
TiO2	0.281	0.988	0.340	0.26
Al2O3	4.326	0.824	2.170	2.66
Fe2O3	27.060	26.910	23.86	25.67
FeO	0.170	2.830	4.330	1.41
MnO	0.000	1.030	0.322	0.34
MgO	0.433	1.232	0.544	2.38
CaO	0.575	2.300	0.571	4.08
Na2O	13.288	11.507	11.974	11.43
Total	96.30	96.417	93.462	99.90
No. of ions on the basis of 6 oxygen.				
Si	1.994	1.992	2.046	2.012
Ti	0.008	0.029	0.010	0.001
Al	0.193	0.037	0.101	0.118
Fe3	0.771	0.785	0.709	0.676
Fe2+	0.005	0.092	0.143	0.044
Mn	0.000	0.034	0.011	0.011
Mg	0.024	0.071	0.032	0.134
Ca	0.023	0.096	0.024	0.164
Na	0.975	0.865	0.919	0.834
Na	97.043	81.476	83.166	81.60
Mg	2.431	6.694	2.885	13.0
Fe2++Mn	0.525	11.830	13.949	5.4

Table 4.1 Continued.

Analyses No.	25	26	27	28
Sample No.	K24P1A2(MAR)	K26P1A1(MID)	K26P1A2	K26P1A3(MAR)
SiO2	54.27	51.464	51.081	51.993
TiO2	0.14	0.000	0.059	0.257
Al2)3	3.95	1.290	1.571	4.299
Fe2O3	25.67	24.320	25.380	2.960
FeO	0.00	3.950	3.020	4.710
MnO	0.24	0.753	0.877	0.250
MgO	1.40	1.955	1.721	1.110
CaO	2.59	4.385	4.123	2.712
Na2O	13.11	10.299	10.553	11.217
Total	101.39	96.041		95.518

No. of ions on the basis of 6 oxygen.

Si	2.004	2.002	1.988	2.009
Ti	0.004	0.000	0.002	0.008
Al	0.172	0.059	0.072	0.196
Fe3+	0.713	0.712	0.743	0.609
Fe2+	0.000	0.129	0.098	0.152
Mn	0.008	0.025	0.029	0.008
Mg	0.077	0.113	0.10	0.064
Ca	0.102	0.183	0.172	0.112
Na	0.939	0.777	0.796	0.840
Na	91.7	74.466	77.805	78.940
Mg	7.6	10.860	97.753	6.005
Fe2++Mn	0.7	14.694	12.442	15.056

Table 4.1 Continued.

Analyses No.	29	30	31	32
Sample No.	K14P2D1(MID)	K14P2D7(MAR)	K18P1A1(MID)	K18P1A2
SiO2	53.080	53.930	52.231	53.200
TiO2	00.400	00.270	00.048	00.090
Al2O3	01.260	02.700	04.155	01.160
Fe2O3	30.070	28.620	31.530	31.590
FeO	00.000	00.630	00.000	01.090
MnO	00.040	00.100	00.000	00.050
MgO	00.510	00.770	00.047	02.840
CaO	00.920	01.030	00.100	05.720
NaO	13.320	13.230	14.811	10.830
Total	99.600	101.290	101.922	102.570

No.of oins on the bases of 6 Oxygen.

SI	02.021	02.009	01.900	01.922
Ti	00.011	00.008	00.001	00.002
Al	00.057	00.119	00.177	00.049
Fe+3	00.861	00.803	00.857	00.859
Fe+2	00.000	00.020	00.000	00.033
Mn	00.001	00.003	00.000	00.001
Mg	00.029	00.043	00.003	00.153
Ca	00.038	00.040	00.004	00.221
Na	00.983	00.956	01.038	00.759
Na	97.000	93.600	99.727	80.196
Mg	02.900	04.200	00.273	16.170
Fe2+Mn	00.100	02.200	00.000	03.634

Table 4.1 Continued.

Analyses No.	33	34	35	36
Sample No.	K18P1A3	K18P1A4(MAR)	K25P4A1(MID)	K25P4A2
SiO_2	53.356	53.390	49.851	52.426
TiO_2	00.024	00.030	00.233	00.171
Al_2O_3	00.995	01.190	02.840	02.517
Fe_3O_2	28.120	24.320	26.810	25.480
FeO	00.000	00.760	00.000	01.490
MnO	00.103	00.100	00.625	00.810
MgO	03.972	04.450	01.690	02.005
CaO	07.215	08.640	08.927	05.586
Na_2O	10.361	09.500	09.790	10.750
Total	101.146	102.280	98.463	99.004

No.of oins on the bases of 6 Oxygen.

	33	34	35	36
Si	01.952	01.976	01.900	01.970
Ti	00.001	00.001	00.007	00.009
Al	00.043	00.052	00.128	00.112
Fe^{3+}	00.774	00.675	00.769	00.721
Fe^{2+}	00.000	00.023	00.000	00.047
Mn	00.003	00.003	00.200	00.026
Mg	00.216	00.246	00.096	00.112
Ca	00.287	00.343	00.365	00.225
Na	00.735	00.682	00.723	00.783
Na	76.931	71.477	86.167	80.915
Mg	22.688	25.743	11.437	11.575
Fe^{2+}+Mn	00.351	02.779	02.397	07.511

Table 4.1 Continued.

Analyses No.	37	38	39	40
Sample No.	K25P4A3(MAR)	K34P1C1(MID)	K34P1C3(MAR)	K34P3A1(MID)
SiO2	53.188	51.140	52.756	53.230
TiO2	00.014	01.301	00.175	00.807
Al2O3	02.448	03.171	03.300	03.610
Fe2O3	22.060	16.590	18.470	24.390
FeO	04.400	06.110	04.390	02.790
MnO	00.591	00.295	00.420	00.028
MgO	02.600	02.635	02.724	00.662
CaO	06.438	08.535	07.716	01.771
Na2O	09.871	08.702	09.432	12.550
Total	100.037	96.976	97.666	97.421

No. of ions on the basis of 6 Oxygen.

Si	01.990	02.054	02.095	02.131
Ti	00.000	00.039	00.005	00.240
Al	00.108	00.150	00.154	00.170
Fe3+	00.621	00.482	00.528	00.692
Fe2+	00.138	00.197	00.139	00.088
Mn	00.019	00.010	00.014	00.001
Mg	00.145	00.158	00.161	00.038
Ca	00.258	00.367	00.318	00.076
Na	00.716	00.678	00.726	00.974
Na	70.365	64.517	69.346	88.027
Mg	14.252	14.996	15.379	3.452
Fe2+Mn	15.383	20.487	15.275	8.521

Table 4.1 Continued.

Analyses No. Sample No.	K34P3A2(MAR) 41	K318P1A1(MID) 42	K318P1A2 43	K318P1A3(MAR) 44
SiO2	52.962	53.450	52.130	53.710
TiO2	00.730	00.360	00.210	00.190
Al2O3	03.743	02.320	01.210	02.220
Fe2O3	27.840	27.530	26.090	24.964
FeO	00.070	03.480	02.090	05.160
MnO	00.143	00.280	00.830	00.640
MgO	00.706	01.130	02.480	01.440
CaO	01.578	02.340	04.620	03.330
Na2O	13.038	11.960	10.630	11.080
Total	98.090	102.890	100.300	102.730

No. of oins on the basis of 6 Oxygen.

Si	02.116	01.984	01.985	01.999
Ti	00.032	00.010	00.006	00.005
Al	00.176	00.102	00.055	00.097
Fe3+	00.783	00.769	00.748	00.699
Fe2+	00.002	00.108	00.067	00.161
Mn	00.005	00.009	00.027	00.020
Mg	00.042	00.062	00.141	00.080
Ca	00.068	00.093	00.189	00.133
Na	01.010	00.861	00.785	00.799
Na	95.351	82.756	77.044	75.382
Mg	03.992	06.004	13.800	07.556
Fe2+Mn	00.657	11.240	09.157	17.062

Table 4.2. CHEMICAL ANALYSES OF Na-AMPHIBOLES FFROM KOGA ROCKS.

Analyses No.	1	2	3	4	5
Sample No.	K1P1(MID)	K1P2	K1P3	K2P3(MID)	K2P3(MAR)
SiO2	38.040	36.890	37.100	36.800	37.080
TiO2	0.780	0.380	0.600	1.120	0.370
Al2O3	11.620	13.630	13.350	10.420	12.540
Fe2O3	2.200	4.450	5.260	5.050	9.290
FeO	21.270	23.590	24.500	21.560	18.170
MnO	1.190	1.000	1.380	1.600	1.280
MgO	3.140	1.050	1.670	3.640	3.130
CaO	6.700	6.740	6.670	9.940	7.520
Na2O	4.190	3.990	4.220	3.310	3.500
K2O	1.890	3.230	3.110	1.860	2.980
Total	91.020	95.950	97.860	94.990	95.870

No. of ions on the basis of 23 Oxygens.

Si	6.424	6.050	6.009	6.092	6.020
Aliv	1.576	1.950	1.991	1.908	1.98
Alvi	0.737	0.684	0.557	0.125	0.419
Ti	0.099	0.047	0.073	0.139	0.045
Fe3+	0.280	0.549	0.641	0.629	1.135
Fe2+	3.004	3.235	3.318	2.689	2.468
Mn	0.170	0.139	0.189	0.224	0.176
Mg	0.790	0.501	0.403	0.898	0.758
Ca	1.212	1.184	1.157	1.710	1.308
Na	0.788	0.816	0.843	0.290	0.632
Na	0.584	0.453	0.482	0.772	0.470
K	0.407	0.676	0.643	0.393	0.617
Vacancy in A site	0.009	0.00	0.00	0.00	0.00
Mg ratio	18.61	11.32	8.855	18.39	16.70

Table 4.2 Continued.

	6	7	8	9
	K2P3E(MID)	K2P3E2(MAR	K2P2H1(MID)	K2P3H2(MAR)
SiO2	37.410	37.850	38.610	37.400
FiO2	1.390	1.250	1.220	0.570
Al2O3	10.760	11.200	11.200	11.790
Fe2O3	6.160	7.520	8.860	9.270
FeO	21.220	20.360	19.860	18.220
MnO	1.280	1.470	1.370	1.360
MgO	3.870	3.620	4.150	3.790
CaO	9.480	9.150	9.250	8.450
Na2O	3.520	3.390	3.650	3.620
K2O	1.770	1.940	1.880	2.000
Total	96.520	97.750	99.60	96.460

No. of ions on the basis of 23 Oxygens.

	6	7	8	9
Si	6.053	6.051	6.002	6.022
Aliv	1.947	1.949	1.978	1.978
Alvi	0.105	0.051	0.081	0.259
Ti	0.169	0.150	0.143	0.069
Fe+3	0.746	0.905	1.040	1.123
Fe+2	2.871	2.722	2.590	2.453
Mn	0.175	0.199	0.181	0.185
Mg	0.933	0.863	0.965	0.910
Ca	1.643	1.567	1.546	1.458
Na	0.357	0.433	0.454	0.542
Na	0.747	0.618	0.650	0.588
K	0.365	0.396	0.374	0.411
Vacancy in A site	0.00	0.00	0.00	0.00
Mg ratio	19.75	18.39	20.20	19.93

Table 4.2 Continued.

	10 K2P3A1(MID)	11 K2P3A2(MAR)	12 K2P3A3(MAR)	13 K34K1A1(MID)	14 K34K1A2(MAR)
SiO_2	37.280	36.730	36.970	42.190	37.350
TiO_2	1.390	1.300	1.530	0.850	0.460
Al_2O_3	10.150	10.419	10.710	13.300	12.880
Fe_2O_3	7.390	6.590	6.160	2.330	9.880
Feo	19.670	29.170	21.210	18.750	17.630
MnO	1.490	1.500	1.360	1.360	1.140
MgO	3.830	3.730	3.840	4.690	3.030
CaO	8.750	8.930	9.380	7.640	6.590
Na_2O	3.520	3.600	3.640	3.930	4.020
K_2O	1.720	1.740	1.880	1.780	3.130
Total	95.190	94.700	96.680	96.820	96.110

No. of ions on the basis of 23 Oxygens.

	10	11	12	13	14
Si	6.114	6.072	6.008	6.523	6.029
Aliv	1.886	1.928	1.992	1.477	1.971
Alvi	0.076	0.100	0.059	0.947	0.479
Ti	0.171	0.162	0.187	0.099	0.056
Fe3+	0.912	0.819	0.754	0.271	1.200
Fe2+	2.697	2.789	2.882	2.425	2.380
Mn	0.207	0.210	0.187	0.178	0.156
Mg	0.936	0.919	0.930	1.081	0.729
Ca	1.537	1.582	1.633	1.266	1.140
Na	0.463	0.418	0.367	0.734	0.860
Na	0.656	0.736	0.780	0.444	0.398
K	0.360	0.367	0.390	0.351	0.645
V. A site	0.00	0.00	0.000	0.158	0.00
Mg ratio	19.70	19.41	19.57	27.33	16.32

Table 4.2 Continued.

	15 K34P3B1(MID)	16 K34P3B4(MAR)	17 K34P4A1(MID)	18 K34P4A2(MAR)	19 K34P4A3(MAR)
SiO2	38.180	38.780	39.160	38.190	38.450
TiO2	0.730	0.310	0.700	0.330	0.920
Al2O3	13.240	12.710	10.960	11.850	10.730
Fe2O3	8.060	8.410	6.860	7.600	6.050
FeO	18.930	20.250	18.890	19.710	21.010
MnO	1.130	1.250	1.070	1.070	1.330
MgO	2.390	2.480	4.400	3.990	3.660
CaO	6.330	6.500	7.580	7.650	8.390
Na2O	3.970	4.450	4.250	4.380	4.090
K2O	3.000	3.350	2.130	3.040	1.910
Total	95.490	98.490	96.000	97.810	96.530

No. of ions on the basis of 23 Oxygens.

Si	6.147	6.147	6.283	6.095	6.210
Aliv	1.853	1.853	1.717	1.905	1.790
Alvi	0.659	0.522	0.356	0.324	0.253
Ti	0.088	0.037	0.084	0.040	0.112
Fe+3	0.976	1.003	0.828	0.913	0.735
Fe+2	2.548	2.685	2.534	2.631	2.837
Mn	0.154	0.168	0.145	0.145	0.182
Mg	0.574	0.586	1.052	0.949	0.881
Ca	1.092	1.104	1.303	1.308	1.452
Na	0.908	0.896	0.697	0.692	0.548
Na	0.331	0.472	0.625	0.663	0.733
K	0.616	0.677	0.436	0.619	0.394
V.A site	0.053	0.000	0.000	0.000	0.000
Mg ratio	13.86	13.20	23.06	20.47	19.00

Table 4.2 Continued.

	20 K3P1A1(MID)	21 K3P1A2(MID)	2 K3P1A3(MAR)	23 K3P2A1(MID)	24 K3P2A4(MAR)
SiO2	51.220	50.060	50.520	53.090	52.390
TiO2	00.360	00.870	00.420	00.300	00.110
Al2O3	01.320	01.630	01.490	01.510	01.000
Fe2O3	12.000	12.232	10.450	10.090	10.002
FeO	13.880	13.530	14.120	14.980	13.200
MnO	01.390	01.430	01.350	01.200	03.800
MgO	07.840	07.660	07.730	08.480	09.390
CaO	02.630	02.580	02.970	02.900	03.800
Na2O	06.340	06.300	05.820	06.610	05.660
K2O	01.290	01.310	01.350	01.320	01.390
Total	98.270	97.600	96.220	99.970	98.420

No. of ions on the basis of 23 Oxygens.

Si	07.694	07.587	07.733	07.766	07.787
Aliv	00.306	00.413	00.267	00.234	00.213
Alvi	00.000	00.000	00.002	00.026	00.000
Ti	00.041	00.099	00.048	00.033	00.012
Fe3+	01.356	01.394	01.204	01.110	01.121
Fe2+	01.744	01.715	01.807	01.832	01.640
Mn	00.177	00.184	00.175	00.149	00.184
Mg	01.756	01.731	01.764	01.849	02.081
Ca	00.432	00.419	00.487	00.455	00.605
Na	01.577	01.581	01.513	01.545	01.395
Na	00.270	00.270	00.214	00.330	00.236
K	00.247	00.253	00.264	00.246	00.264
V.in A	00.180	00.115	00.425	00.233	00.500
Mg ratio	34.880	34.448	35.630	37.420	41.139

Table 4.2 Continued.

	25 K3P7A3(MID)	26 K3P7A2(MAR)	27 K318P1(MID)	28 K318P2(MAR)	29 K318P3(MAR)
Si02	49.510	50.930	52.630	52.200	54.600
Ti02	00.720	00.310	00.120	00.160	00.170
Al203	01.470	01.750	01.070	00.690	00.920
Fe203	09.570	12.810	10.150	09.430	08.600
Fe0	14.200	12.390	08.070	09.740	08.720
Mn0	01.290	01.550	02.180	02.290	02.440
Mg0	08.100	08.300	11.600	10.790	12.800
Ca0	03.420	03.050	02.650	02.410	02.730
Na20	05.760	05.870	06.460	06.430	06.930
K20	01.360	01.380	01.660	01.260	01.870
Total	95.400	98.340	96.650	95.490	99.800

No. of oins on the basis of 23 Oxygens.

	25	26	27	28	29
Si	07.660	07.618	07.814	07.877	07.844
Aliv	00.340	00.382	00.186	00.123	00.156
Alvi	00.000	00.000	00.001	00.000	00.000
Ti	00.084	00.035	00.013	00.018	00.018
Fe3+	01.114	01.441	01.134	01.071	00.930
Fe2+	01.837	01.550	01.002	01.229	01.047
Mn	00.169	00.196	00.274	00.293	00.297
Mg	01.868	01.851	02.568	02.427	02.741
Ca	00.567	00.489	00.422	00.390	00.421
Na	01.433	01.511	01.578	01.610	01.579
Na	00.295	00.191	00.282	00.270	00.352
K	00.268	00.263	00.314	00.243	00.343
V. in A	00.180	00.315	00.404	00.437	00.270
Mg ratio	34.880	36.730	51.590	48.350	54.650

CHAPTER 5

FELDSPAR CHEMISTRY

ABSTRACT

At least two carbonatite intrusions,having different Na/K ratios, have fenitized the Koga syenites.The carbonatite with high Na/K ratio has produced Na-fenites while, the other formed K-fenites.

XRD study of low albite indicates that changes occur in the structural state of albite with increasing grade of fenitization. The Na-feldspar in the unfenitized rocks is low albite while, in the fenitized rocks is anomalous low albite. The degree of orderness increases with the increas of intensity of fenitization.

The K-feldspar is maximum microcline in both the fenitized and unfenitized rocks. The tie lines between the co-existing Na- and K-feldspars deviate from the generally agreed magmatic trend.

INTODUCTION

Feldspar are the most important minerals in igneous, metamorphic and metasomatic rocks. In metasomatic rocks fenitic feldspars are formed as a result of K and Na fenitizing fluids emanating from the carbonatites and / or ijolites. A lot of work has been done on the chemistry and structure of the magmatic feldspars but very little work is available on the metasomatic feldspars; especially on their structural state.

Siemiat Kowska and Martin (1975) have suggested that the fenitic albite in the Mississagi quartzite, Sudbury area, Ontario, is well ordered and has 2Q(131)-2Q(131) values

(Cu K radiation), close to the values proposed for ordered pure albite by Martin (1969). While albite in the Loe Shilman is anomalously low albite, (Mian and Le Bas, 1988). The authors also observed that the co-existing Na-and K-feldspars showed some deviation from normal tielines present in the coexisting igneous feldspars given by Wright (1967) and others (e.g Mian and Le Bas, 1988). These workers demostrated that the k-feldspars and anomalously low albite constitute reverse zonationin contrast to the temprature gradient. The reverse zonation at Loe Shilman fenites has been interpreted as the result of superimposed fenitization by later ankeritic carbonatite (Mian and Le Bas, 1988).

The Koga syenites were intruded by sporadic intrusions of carbonatite and minor ijolites. Two types of fenites are dominanted in the area: one is potassium fenite and the other is sodium fenite. There are some rocks in which both types of fenitization can be observed: these results from the k- and Na-fenitization of syenites and nepheline syenites at Koga. The most dominant minerals are alkali-feldspars which occur as perthite, albite-rimed around perthite, and veins of albite and microcline both within the whole-rock and in perthite of the protolithic syenites and nepheline syenites.

GEOLOGICAL SETTING

The Koga syenites occupy the eastern part of the Ambella granitic complex of the alkaline igneous province, NW Pakistan wich is located at the border of Swat and Mardan District near Koga village at a distance of about 35 miles northeast of Mardan. The syenitic rocks constitute an oval-shaped body (about 40 sq. kms) and are emplaced in Chinglai gneisses to the east and granites and syenites in the north and west (Fig.1). The rock unites of Koga are alkali-syenites, nepheline-syenites, ijolites, carbonatites and their fenites.

The Koga syenites and carbonatites are first reported by Siddiqui et al., (1967). Chaudhry et al., (1981) described the preliminary petrology and chemistry of these rocks and suggest the emplacement of magma along a weak zone developed south of Main Mantle Thrust in the sequence as Babaji Soda granite, pulaskite, nephelinitic syenites, foyaite, sodalite syenite, and carbonatites and their fenites. Rafiq (1987) suggested the generation of magma by partial melting of the lowewr crust, contiminated during later phases by the influx from the activated upper mantle and progressive desilicification of the magma which led to the formation of the quartz syenite, syenite and feldspathoidal syenites. Le Bas et al., (1986) give the preliminary petrography of the Babaji Syenites and Koga syenites and suggested an age of 315+15 Ma for Babaji Syenites and 297+4 Ma for Koga syenites on the basis of Rb-Sr isotopic ratios.

PETROGRAPHY

Alkali feldspars in the Koga syenites are albite (sodium feldspar) and maximum microcline (potash feldspar). Albite

(Ab93 to Ab99) rims perthite, and ocurs in veins which cut the perthite, (see chapter 3). The albite in the rims are mostly fine-grained and untwinned ;they form aggregates arround perthite. Vein albite is also fine-grained and is commonly associated with calcite, pyroxene (acmite) and ore. The composition of albite is essentially constant,with only Fe showing significant variation (Table 5.2). XRD determinations show that this albit is low albite (2θ value = 27.90).

K-feldspar is maximum microcline is indicated by the 1oo intensity peak 2θ value 27.45. The triclinicity of maximum microcline or albite can not be determined by the Goldsmith and Laves method (1954) (=12.5 (d131-d131) due to the 2θ value of (131) plane of albite overlaping with the 2θ(131) plane of maximum microcline. However, this overlap of (131) of maximum microcline and albite in the area of maximum triclinicity suggests that these feldspars are well ordered and K-feldspar plots as maximum microcline whilst albite plots as anomalusly low albite. Wave dispersive microprobe results show that barium reaches peak cocentrations in the maximum microcline around Naranji Kandau fenitized rocks (Mian personal communication).

X-RAY POWDER DIFFRACTION DATA OF FELDSPARS

About one hundred samples were used for X-ray differaction study of feldspar. Selective X-ray diffraction data is given (table 5.2). Feldspar was separated from the other minerals and then analysed.There are problems distinguishing between low albite and acmite because the (331) and (330) planes of acmite have 2θ value 42.6 may interfere with the 2θ value of (060) of the low albite. The peak position was measured at the estimated centre line of the top 1/3 of the peak. Pure CaF2 was used as a standard for the XRD work. Three X-ray powdered patterns for (204) and (060) were run for each sample using Cu radiation at 1/min for one run and 1/4 per min for two runs. The error calculated is based on the minimum and maximum of the three diffraction patterns (see table 5.2).

2θ values for (204) and (060) planes of alkali-feldspars are plotted (Wright,1968).The plot (Fig.1) shows albite in unfenitized rocks has a 2θ (060) value of 42.4 and in the low grade fenites the value ranges from 42.4 to 42.5. In medium-grade fenites these values range between 42.5 to 42.55 while in the high grade fenites these range between 42.55 to 42.8. This increase from 42.4 to 42.8 shows that the albite of high grade fenites, (especially in the sodium fenites), is more ordered as compared to the albite of low grade fenite, (particularly from albite in unfenitized rocks). This suggests that the albite in the highly fenitized rocks formed at a temperature lower than the albite present in the unfenitized rocks. In contrary to (060) little variation is present in (204) values which range between 50.1 and 50.16.

The K-feldspar which is maximum microcline plots mostly within the field suggested for maximum microcline. The tielines can be drawn between the coexisting Na- and K-feldspars but these tielines deviate from the generally agreed magmatic trend (Wright, 1967). This type of deviation from the magmatic tielines trend is also observed by Mian and Le Bas (1988) between the coexisting K-feldspars and anomanously low albite in Loe Shilman fenites.

DISCUSSION

The XRD study of low albite in the Koga syenites indicates that changes occur in the structural state of albite with increasing grade of fenitization. Magmatic albite or unfenitized albite (k-4) from Koga syenites plots as normal low albite (Fig.5.1) having a 2Q value for (060) plane of 42.4, whilst albite from fenites of Koga plots as anomalous low albite. The 2Q value for (060) is 42.5 in the low grade fenites and reaches upto 42.8 in the high grade fenites.

The degree of orderness also increases with the increasing grade of fenitization. The magmatic albite and albite from low grade fenites are less ordered whilst, high grade fenites are relatively highly orderd (e.g Cape rocks of the Naranji Kandau carbonatite, which indicate a low temperature gradiant near the intrusion). Generally the highest temperatures within a fenite environment are proximal to the source of fenitization.At Koga the low temperature albite proximal to source ofis obtained. This is due to the fact that the albite was initially present as magmatic albite in the Koga syenites, forming at higher temperatures of 800 -1000 C,(Mian personal communication). The temperature of the carbonatites at Koga, Shilman and Silai Patti is determined by Mian and Le Bas (in prep.) as 350-500 C. this suggests that the albite which was proximal the source of fenitization has been most affected by the low tempertature (350-500) fenitizing fluids. The orderness of albite decreases as the temperature and intensity of fenitization decreases. As a result the low grade fenites and unfenitized rocks preserved orignal less ordered (magmatic) low albite (Fig.5.1).

CONCLUSION

The study of feldspar from Koga syenites, nepheline syenites, and fenites sugests that;

1) the magmatic alkali feldspars in the Koga syenites are low albite and maximum microcline whilst fenitic Na-feldspar is anomalous low albite.

2) The degree of orderness also increases with the increasing grade of fenitization.

3) In the low grade fenites albite has retained its original structure whilst, in the high grade fenites it has become more ordered.

4)The tie lines between the co-existing Na- and K-feldspar deviat from the generally agreed *magmatic* trend.

Fig.5.1 The structure state of Na-feldspar and k-feldspar in Koga syenites, showing low albite of fenitized rocks plots as anomalously low albite and tie lines between maximum microcline and anomalously low albite deviate from the tie lines existing between magmatic maximum microcline and low albite (after Wright, 1968). = magmatic albite o = albite from low grade fenites = albite from medium grade fenites = albite from high grade fenites.

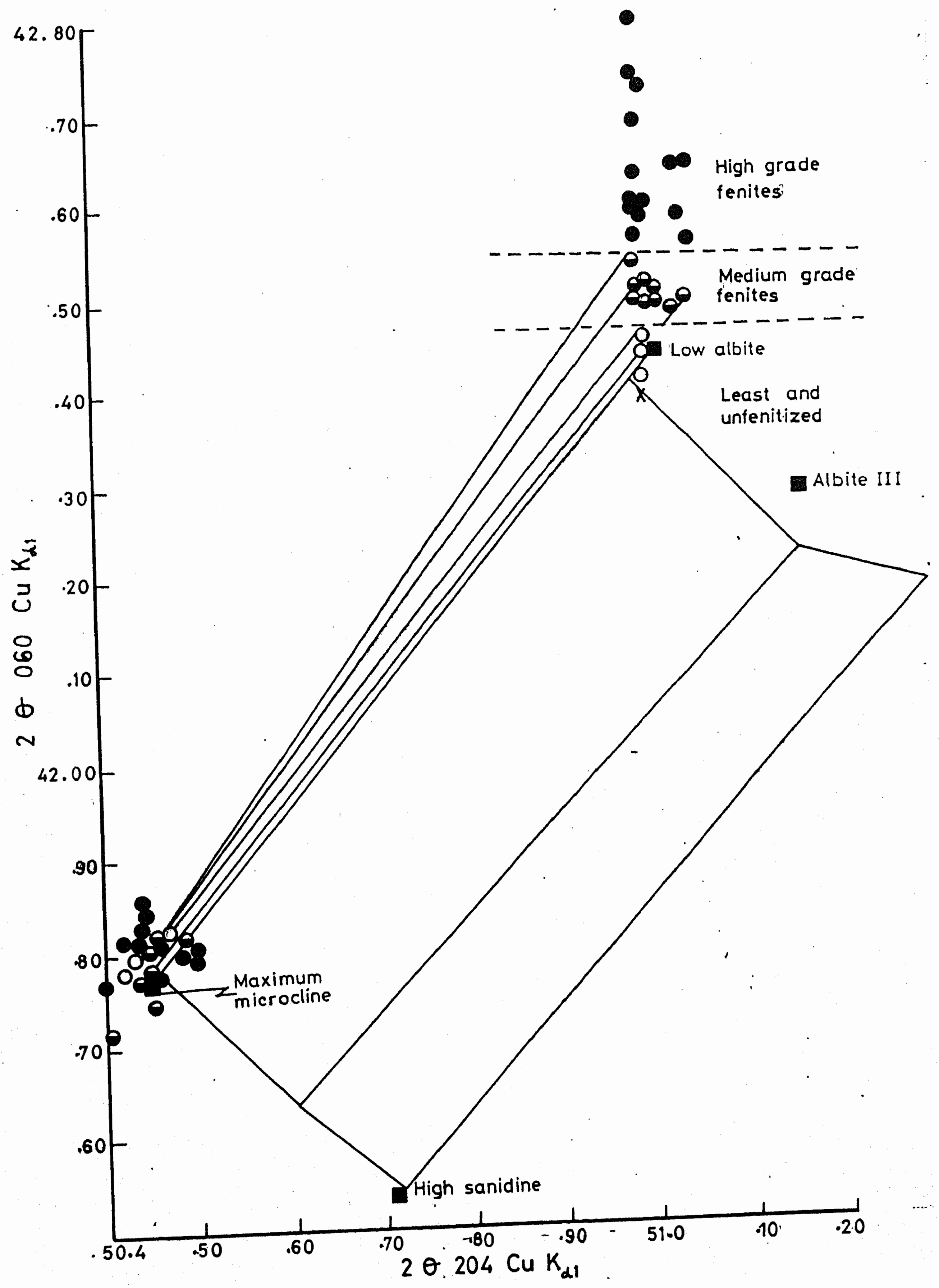


Table 5.1 XRD data of K-feldspar frome koga syenites.

Anal.NO.	1	2	3	4	5	6
Sample No.	K-4	Kn-27	Kn-237A	Kn-277A	Kn-23	Kn-24
$2\theta(060)$	41.750	41.800	41.800	41.770	41.800	41.850
	(00.010)	(00.010)	(00.015)	(00.010)	(00.020)	(00.010)
$2\theta(204)$	50.600	50.500	50.560	50.460	50.500	50.600
	(00.015)	(00.015)	(00.020)	(00.020)	(00.010)	(00.010)

XRD data of Na-feldspar from Koga syenites.

Anal.NO.	1	2	3	4	5	6
$2\theta(060)$	42.400	42.400	42.460	42.410	42.550	42.500
	(00.025)	(00.015)	(00.015)	(00.030)	(00.010)	(00.010)
$2\theta(204)$	51.100	51.100	51.100	51.100	51.100	51.150
	(00.020)	(00.025)	(00.015)	(00.015)	(00.030)	(00.010)

Alkali-feldspar from unfenitiezed rock; analyses No.1.

Alkali-feldspar from low grade fenites;analyess No.2,3,4.

Alkali-feldspar from medium grade fenites;analyses No.5-21.

Alkali-feldspar from high grade fenites;analyses No.22-46.

Table 5.1 Continued.

Anal.No.	7	8	9	10	11	12
Sample No.	Kn-30	Kn-51	Kn-239a	Kn-247	Kn-257B	Kn-265
2θ(060)	41.820	41.800	41.740	41.800	41.820	41.750
	(00.015)	(00.002)	(00.015)	(00.030)	(00.015)	(00.010)
2θ(204)	50.570	50.580	50.440	50.560	50.580	50.550
	(00.015)	(00.001)	(00.020)	(00.010)	(00.015)	(00.010)

XRD data of Na-feldspar from Koga syenites.

2θ(060)	42.530	42.500	42.540	42.500	42.500	42.500
	(00.030)	(00.050)	(00.040)	(00.010)	(00.050)	(00.025)
2θ(204)	51.120	51.150	51.100	51.100	51.100	51.100
	(00.025)	(00.025)	(00.015)	(00.015)	(00.050)	(00.015)

Table 5.1 Continued.

Anal.No.	13	14	15	16	17	18
Sample No.	KN-268	Kn-270	Kn-272	Kn-274	Kn-276	Kn-277B
2θ(060)	41.850	41.780	41.800	41.800	41.720	41.850
	(00.025)	(00.025)	(00.015)	(00.015)	(00.015)	(00.015)
2(204)	50.480	50.550	50.460	50.580	50.500	50.500
	(00.015)	(00.015)	(00.015)	(00.015)	(00.015)	(00.030)

XRD data of Na-feldspar from Koga syenites.

2θ(060)	42.500	42.500	42.500	42.500	42.500	42.500
	(00.025)	(00.025)	(00.050)	(00.050)	(00.015)	(00.015)
2θ(204)	51.100	51.100	51.100	51.150	51.100	51.100
	(00.015)	(00.015)	(00.015)	(00.015)	(00.015)	(00.010)

Table 5.1 Continued.

Anal.No.	19	20	21	22	23	24
Sample No.	K-22	K-14	K-26	Kn-25	Kn-26	Kn-29
2θ(060)	41.800	41.810	41.810	41.820	41.850	41.810
	(00.015)	(00.025)	(00.015)	(00.030)	(00.025)	(00.025)
2θ(204)	50.560	50.510	50.660	50.550	50.600	50.550
	(00.025)	(00.015)	(00.015)	(00.015)	(00.025)	(00.015)

XRD data of Na-feldspar from Koga syenites.

2θ(060)	42.500	42.500	42.520	42.590	42.600	42.660
	(00.015)	(00.030)	(00.025)	(00.010)	(00.015)	(00.040)
2θ(204)	51.100	51.160	51.160	51.100	51.100	51.160
	(00.015)	(00.015)	(00.015)	(00.010)	(00.010)	(00.030)

Table 5.1 Continued.

Anal.No.	25	26	27	28	29	30
Sample No.	Kn-33	Kn-34	Kn-35	Kn-36	Kn-44	Kn-45
2θ(060)	41.850	41.800	41.850	41.830	41.800	41.750
	(00.025)	(00.025)	(00.025)	(00.015)	(00.025)	(00.025)
2θ(204)	50.550	50.600	50.500	50.500	50.550	50.500
	(00.013)	(00.013)	(00.015)	(00.015)	(00.015)	(00.015)

XRD data of Na-feldspar from Koga syenites.

2θ(060)	42.640	42.750	42.550	42.600	42.75	42.800
	(00.004)	(00.050)	(00.010)	(00.010)	(00.015)	(00.010)
2θ(204)	51.100	51.100	51.100	51.100	51.100	51.100
	(00.010)	(00.030)	(00.010)	(00.030)	(00.010)	(00.010)

Table 5.1 Cotinued.

Anal.No.	31	32	33	34	35	36
Sample No.	Kn-47	Kn-54	Kn-56	Kn-57	Kn-237C	Kn-239
2θ(060)	41.800	41.800	41.850	41.800	41.770	41.800
	(00.025)	(00.025)	(00.025)	(00.010)	(00.025)	(00.015)
2θ(204)	50.600	50.500	50.580	50.500	50.560	50.560
	(00.015)	(00.010)	(00.015)	(00.015)	(00.015)	(00.100)

XRD data of Na-feldspar from Koga syenites.

2θ(060)	42.700	42.600	42.600	42.620	42.560	42.660
	(00.020)	(00.025)	(00.025)	(00.010)	(00.010)	(00.015)
2θ(204)	51.100	51.150	51.150	51.150	51.100	51.160
	(00.010)	(00,020)	(00.025)	(00.015)	(00.015)	(00.020)

Table 5.1 Continued.

Anal.No.	37	38	39	40	41	42
Sample No.	Kn-251	Kn-253	Kn-261	Kn-263A	K-7	K-10
2Θ(060)	41.810	41.800	41.810	41.810	41.78	41.86
	(00.025)	(00.025)	(00.025)	(00.025)	(00.025)	(00.025)
2Θ(204)	50.610	50.600	50.560	50.560	50.640	50.610
	(00.030)	(00.015)	(00.010)	(00.015)	(00.015)	(00.015)
	XRD data of Na-feldspar from Koga syenites.					
2Θ(060)	42.600	42.600	42.560	42.560	42.560	42.570
	(00.015)	(00.010)	(00.025)	(00.015)	(00.015)	(00.025)
2Θ(204)	51.100	51.100	51.100	51.100	51.160	51.170
	(00.025)	(00.015)	(00.015)	(00.015)	(00.015)	(00.015)

Table 5.1 Continued.

Anal.No	43	44	45	46
Sample No.	K-12	K-13	K-14	K-25
$2\theta(060)$	41.760	41.810	41810	41.810
	(00.015)	(00.010)	(00.010)	(00.015)
$2\theta(204)$	50.630	50.570	50.710	50.660
XRD data of Na-feldspar from Koga syenites.				
$2\theta(060)$	42.590	42.550	42.610	42.610
	(00.010)	(00.015)	(00.015)	(00.015)
$2\theta(204)$	51.140	51.160	51.200	51.160
	(00.025)	(00.010)	(00.010)	(00.015)

Table 5.2 Analyses of Na-feldspar from Koga syenites.

Analysis NO.	1	2	3	4	5
Sample No.	K-4	K7P1	K34P1	K34P2	K25
SiO2	68.499	67.727	67.935	68.801	67.609
TiO2	00.000	00.000	00.057	00.031	00.134
Al2O3	19.374	19.478	19.571	19.426	19.366
FeOT	00.000	00.177	00.059	00.155	00.322
MgO	00.000	00.092	00.011	00.000	00.014
CaO	00.021	00.217	00.183	00.063	00.049
Na2O	10.269	10.871	10.973	10.733	10.903
K2O	01.391	00.024	00.178	00.082	00.132
Total	99.609	98.704	99.013	99.314	98.662

No. of oins on the basis of 23 Oxygens.

Si	12.033	11.970	11.971	12.050	11.970
Ti	00.000	00.000	00.008	00.004	00.018
Al	04.012	04.058	04.065	04.010	04.041
Fe	00.000	00.026	00.009	00.023	00.048
Mg	00.000	00.024	00.003	00.000	00.004
Ca	00.004	00.041	00.035	00.012	00.009
Na	03.498	03.725	03.749	03.644	03.743
k	00.312	00.005	00.040	00.018	00.030

Table 5.3 Analyses of K-feldspar from Koga syenites.

Analysis No.	1	2	3	4	5
Sample No.	K-4	K-7	K25	K34	K19
SiO2	64.431	64.327	64.247	64.384	64.385
Al2O3	18.419	17.867	18.641	18.381	18.758
Fe2O3	00.146	00.046	00.061	00.171	00.017
MgO	00.058	00.000	00.141	00.211	00.216
CaO	00.126	00.101	00.033	00.107	00.000
Na2O3	00.538	00.484	00.481	00.838	00.574
K2O	16.639	16.578	16.155	15.993	16.497

No. of oins on the basis of 23 Oxygens.

Si	11.924	12.000	11.887	11.906	11.877
Al	04.018	03.928	04.063	04.006	04.079
Fe3	00.023	00.015	00.009	00.026	00.003
Mg	00.016	00.000	00.039	00.058	00.059
Ca	00.025	00.200	00.007	00.021	00.000
Na	00.193	00.175	00.172	00.300	00.205
K	03.929	03.945	03.811	03.773	03.882

CHAPTER 6

GEOCHEMISTRY

INTRODUCTION

carbonatites are characteristically surrounded by an aureole of metasomatic country rocks. This type of metasomatism is known as fenitization. The country rocks in which carbonatites are intruded are commonly granite and syenite which show various degrees of metasomatism by the development of metasomatic minerals and loss of original texture. The intensity of fenitization in these coarse-grained country rocks, does not correlate with distance from the carbonatite contact. This is because the fenitizing fluids penetrate through joints and fractures and fenitize the adjacent rock to varying degrees. Extensive work has been done on the fenitization of granites e.g (McKie, 1960; Curri and Ferg uson, 1971; Ferguson et al., 1978; Le Bas, 1977; Vartiainen, 1980; Vartiainen and Woolley, 1976; Rubie and Gunter, 1983; Kresten and Morogan,1986), but in Pakistan very little work has been done on the fenitization of granite and syenite and no work is available on the fenites of the Koga Syenites, Ambella granitic complex.

Koga Syenites occupy the west central part of the Ambella granitic complex of the alkaline igneous province. These are emplaced within the chinglai gneisses to the east, and metasediments to the north and west. It constitutes an oval shaped body (about 40 sq km) and consists of alkali granites, alkali syenites, nephelene syenites, ijolites, carbonatites and associated fenites. The carbonatite rocks are exposed in the western part of the syenitic body and occur in the form of a main plug at Naranji Kandau and as lenses, pockets and veins, which vary from a few centimeters to a few meters. Small bodies of ijolite crop outare near Shpala, Bagosh Sar, and Nawe Killi.

Koga syenites show two types of fenitization (see chapter-3) K- and Na-fenitization: the combined effects of these two have been observed. These fenites were formed due to the fluids emanating from carbonatites and/or ijolite.

The propose of this chapter is to describe the geochemistry of fenitized and unfenitized rocks, and established the various processes/parameters which cause and influence fenitization.

MAJOR ELEMENT GEOCHEMISTRY

Seventy three samples were analyesed for both major and trace elements by the X-ray flouresence spectroscopy usinng pressed powder samples.Whole rock major element geochemistry of the Koga syenite and fenites are given in Table.6.1. Fig.6.1 is a plot of Si, K, Al and Mg against Na, using the value for 100 anionic cell for unfenitized rocks and K and Na fenites.

Si shows a slight increase in the high grade fenites of two distinct fenitic groups, produced by the K- and Na-fenitizing fluids (Fig.6.1). This increase in Si is due to the formation of feldspar at the expense of nepheline in the fenitized nepheline syenites. Si may be taken from Babaji granite, the patches of the unfenitized granites which are found within Koga syenites. The slight increase or decrease of Si in the medium and high grade fenites is due to the variation in the proportion of albite and K-feldspars as well as the total amount of the these feldspars. K increases with respect to Na from less to more strongly K-fenitized rocks but remains constant or slightly decreases in the case of Na-fenitized rocks (Fig.6.2).

Al remains approximately constant between 12-13 in the K-fenites except Kn-29. In the Na-fenites Al ranges from 11.8 to 12.8 (Fig.6.3) with exception of Kn-32 and Kn-36: these show a relatively high Al content which is due to cumulus nepheline. The variation in Al content of the two groups corelates with the variation in the proportion and modal aboundance of biotite, pyroxene and feldspars.

In the Koga syenite it is difficult to find an unfenitized sample, especially in the traverses followed by the author. Only samples K-4 and K-32 of nepheline syenite near Mian Kandau appear to be unfenitized, (petrographic evidence) it is likely that the orignal rocks were syenite or nepheline syenite: fenitization may have changed the rocks to syenites.

If one consider quartz syenites and granites as to be the protolith rocks on Qz-Nep-Ks diagram (Fig.6.4a) the path Ia will be followed by K-fenites and Ib will be followed by Na-fenites. On the other hand if nepheline syenite is the protolith rock then the K-fenitization will move the composition of rock along the path IIa and Na-fenitization will move the composition along path IIb. In this case enrichment of alkalis and SiO_2 take place. The dotted line show the superimposition of both the type of fluids.

TRACE AND REE ELEMENT GEOCHEMISTRY

Trace element data of the Koga fenites and carbonatites are given in the Table 6.5 and plotted as normalized multi-element variation diagrams (Fig.6.5).Fig.6.5a and 6.5b are the plots of K- and Na-fenites respectively. Both the type of fenites show great differences in their Ba, Sr, Ni and Th contents, which are the best distinguishing elements between the K- and Na-fenites. In fig.6.5a, K-fenites show an increase in their Ba and Sr content and decrease in Nb and Th. Which reflects a high content of K and low Na because Ba can easily replace K. The K-fenites have a similar trace element pattern to that of the average Naranji Kandau Carbonatite (Fig.6.5a). This sugests that the source for K-fenitization is the Naranji Kandau carbonatite.

IN fig.6.5b Na-fenites show a decrease in Ba and increase in Nb and Th which reflects high Na content. the Na can be replaced by Nb that is why Nb is high in Na-fenites. Ce concentrations are slightly higher in the Na-fenites. The trace element pattern of Na-fenites is completely different to that of K-fenites and the Narinji Kandau carbonatite.This suggests that another source is responsible for the fenitization. Both fenites have similar trace element compositions for most of the remaining elements.Zr concentrations are higher in both fenites relative to the carbonatite;the original Zr is equal to the carbonatite.

The chondrite normalized plot of REE of Koga rocks has been plotted (Fig.6.6). All samples are LREE enriched and have an even slope from the LREE to the HREE. The carbonatite is particularly enriched with La_N concentration of 100xchondrite and Lu_N cocentration of 80xchondrite. The fenites have lower absolute concentration of REE but pattern is similar to the REE pattern of carbonatite.K-fenites have a positive Ce anamoly,which sugests low oxegen fugasity conditions (Moller, Marteani, and Schilley,1980).As compared to the unfenitized rocks (K-4) the K-fenites are depleted in the REE and the La/Yb ratio is 17.2. The La/Yb ratio of K-fenite is 17.2. The Na-fenites show enrichment of REE as compared to the unfenitized nepheline syenites (K-4). The La/Yb ratio of Na-fenites is 25.4. They do not shows any Eu anomaly. Ijolite gives a negative Eu anomaly and La/Yb ratio (89.98) which indicates that the REE pattern of ijolite is quite different than the Na-fenites. Therefore, the possibility of ijolite as a source of fenitization for Na-fenites is ruled out.

DISCUSSION

Fenitization is a process of alkali-metasomatism that occurs around intrusions of ijolite, nepheline, syenites, carbonatite and related type rocks (Heinrich, 1966; Le Bas, 1977). The process characteristically involves a loss or replacement of quartz, growth of sodic pyroxene and/or sodic amphibole, biotite and growth or recrystallization of alkali-feldspar. The addition of alkalis is important, and one of the main variable of fenitization is the Na/K ratio of the metasomatic assemblage (Rubie and Cunter, 1983). No difficulty arises when completely new minerals are formed which were not present in the protolith. But in the case of mineral which were present in the protolith change in their chemistry as a result of metasomatic fluids, difficulty sometimes arises to distinguish between the original and metasomatic minerals and to interpret the effect of fenitization by the alkaline fluids. Similarly, in such rocks where more than one carbonatite or carbonatite and ijolite both intrudes, the kind of metasomatism can be difficult to distinguish.

All the type of rocks after passing through the processes of fenitization, eventually changes to syenites, orthoclasites or albitites, depending upon the intensity and nature of fenitizing fluids. Therefore, if the protolith rocks are syenites then in many cases it becomes difficult to show the fenitization on the basis of geochemistry only because if a fenitizing source has the same Na/k ratio as that of syenite then the whole rock major element geochemistry behavior will be the same as that of the unfenitized rock but there will be difference in thin sections. The unfenitized rock will show magmatic texture while the fenitized rock will show replacement texture.

The whole rock chemistry of Koga fenites show variation in K, Na, Si, Al, and trace elements study indicates two type of fenitization (1) K-fenitization which is due to carbonatite mainly by Naranji Kandau carbonatite which is the main exposed intrusion in the area. (2) Na-fenetization which may be due to an other intrusion of carbonatite, which is not exposed or due to ijolite. the K-fenite shows increase in K while in Na-fenites K remains constant or slightly decreases. Si shows slight increase in both the cases. Al is more or less constant in both the type of fenites.

A few rocks (Kn-23, Kn-247, Kn-251, Kn-272, Kn-276) which petrographically represent both the types of fenitization and their chemistry is also intermediate between the two types of fenites. These rock represent superimposition of both the type of fenites. It is difficult to distinguish that which type of fenitization is earlier and which one is latter. Because both the mineral pyroxene and biotite are present in the protolith and it requires a more detail work.

The trace elements Ba and Sr show an increase in the k-fenites while Nb and Th shows increase in the Na-fenites. This difference in the trace element data clearly suggests different sources for the fenitization of these two type of fenites

(Fig.6.5). The pattern of k-fenite is similar to that of sovite while, the Na-fenites differs.

The mobility of the REE in the granites and quartzite during metasomatism by the alkaline fluids has been discussed in detail by Mineyew (1963), Martin et al., 1978 and Viladkar et al. (1986). REE content of fenites depend upon the composition of the host rock and composition of the invaded liquid. LREE enrichment was noted in the fenitized quartzite in the Borran lan complex, Scotland (Martin et al., 1978). In contrast, little difference in REE content between fenitized and unfenitized country rocks occurs around a lymprophyric dike at Seabrook Lake (Cullers and Medavis, 1977). There, the fenitized parts are depleted in HREE compared to the unfenitized sample. One extremely fenitized sample at an other location at seabrook Lake is very much depleted in HREE as compared to unaltered country rocks. The total REE of Sillai Patti granite gneisses decrease and its Eu anomaly is also diminished as compared to Malakand granite (Mian, 1986).

However, in Koga fenites the REE content is dependent on the REE in the fenitizing sources. The K-fenites are depleted in REE while Na-fenites are enriched which indicate two different sources for the fenitization of Koga rocks. One source is carbonatite which is exposed at Naranji Kandau while the other one may be carbonatite or ijolite. But the REE pattern of ijolite is quite different from that of Na-fenite (Fig.6.6). Therefore, it is interpreted that there is an other carbonatite intrusion in the area, emanated fluid rich in Na/k ratio which is not exposed at the surface and has fenitized the country rocks.

CONCLUSION

The study of geochemistry of the Koga syenites gives the following results.

1) The Koga syenites are intruded by carbonatites as plugs and veins which have produced two types of fenites:

   1. K-fenites
   2. Na-fenites

2) The superimposition of the k- over Na-fenites or vice versa is difficult to establish because of the cross-cutting relation of the fenitic veins.

3) The original rocks were either alkali granites or nepheline syenites which have been altered to syenites by the fenitization.

4) Si has been slightly increased in both the types of fenites.

5) K is increased in K-fenites and remains somewhate constant in Na-fenites.

6) Al is almost constent in all the fenites.

7) Both the types of fenites show great differences in their Ba, Sr, Nb and Th contants. K-fenites show an increase in Ba and Sr contents and decrease in Nb and Th , Which reflect a high content of K and low Na.

8) REE pattern shows that k-fenites are depleted as compared to the unfenitized rocks. The positive Ce anomaly of k-fenites in

the trace element patterns suggest that the k-fenites are formed under the environments of low state of oxidation.

9) Na-fenites show enrichment of REE and the REE pattern of Na-fenites is quite different from the REE pattern of ijolites which suggests that Na-fenites are formed by the effect of fluids emanating from another carbonatite (rich in Na) which is not exposed arround Koga.

Fig.6.1 Plot of Na vs K for Koga syenites. = unfenitiz nepheline syenite. = low grade k-fenites = medi grade k-fenites = high grade k-fenites. =low gra Na-fenites, o= medium grade Na-fenites, = high gra Na-fenites, o = medium grade both type of fenites, high grade both type fenites.

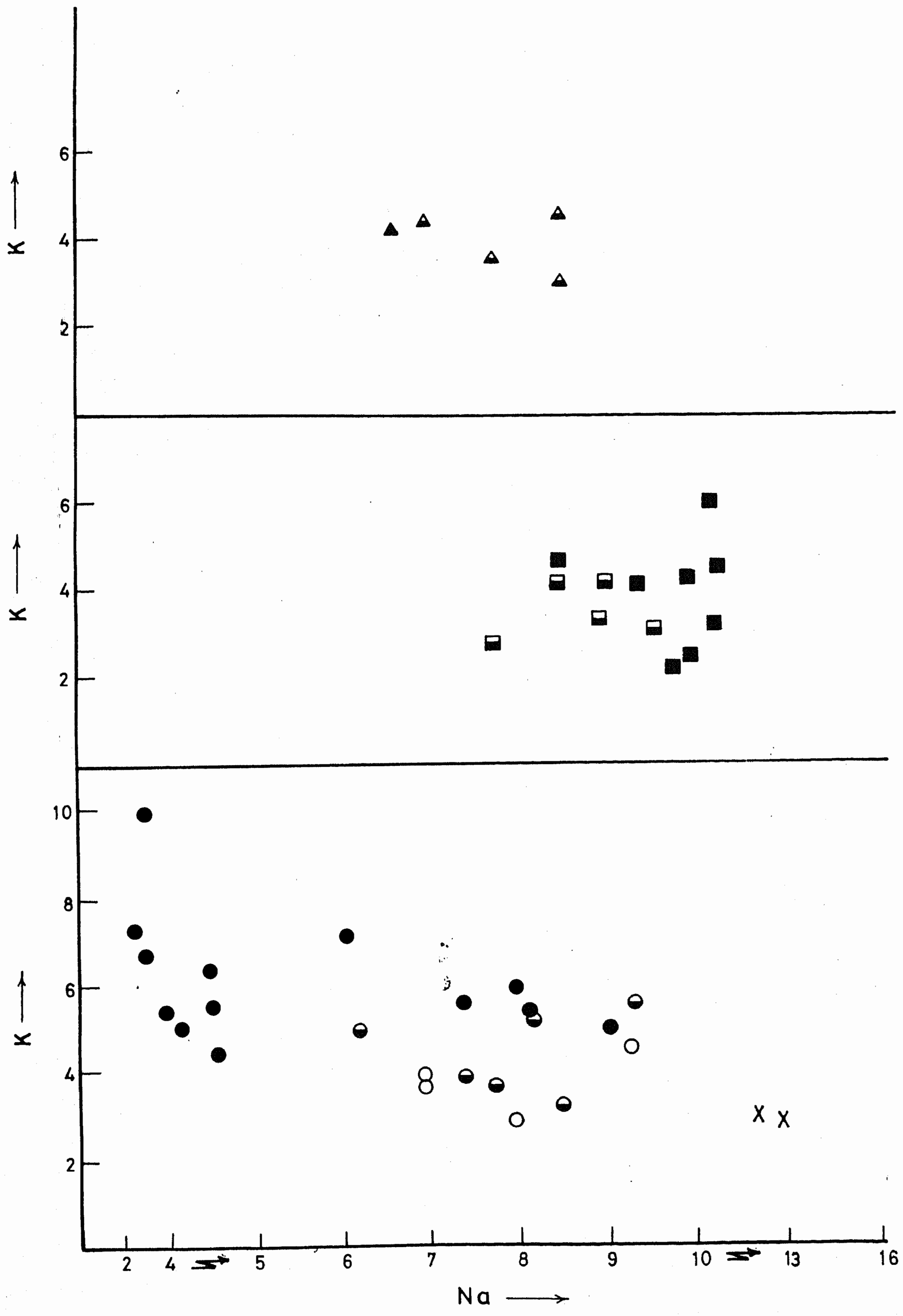


Fig.6.2 Plot of Na vs Si for Koga syenites. Symboles as Fig.6.1.

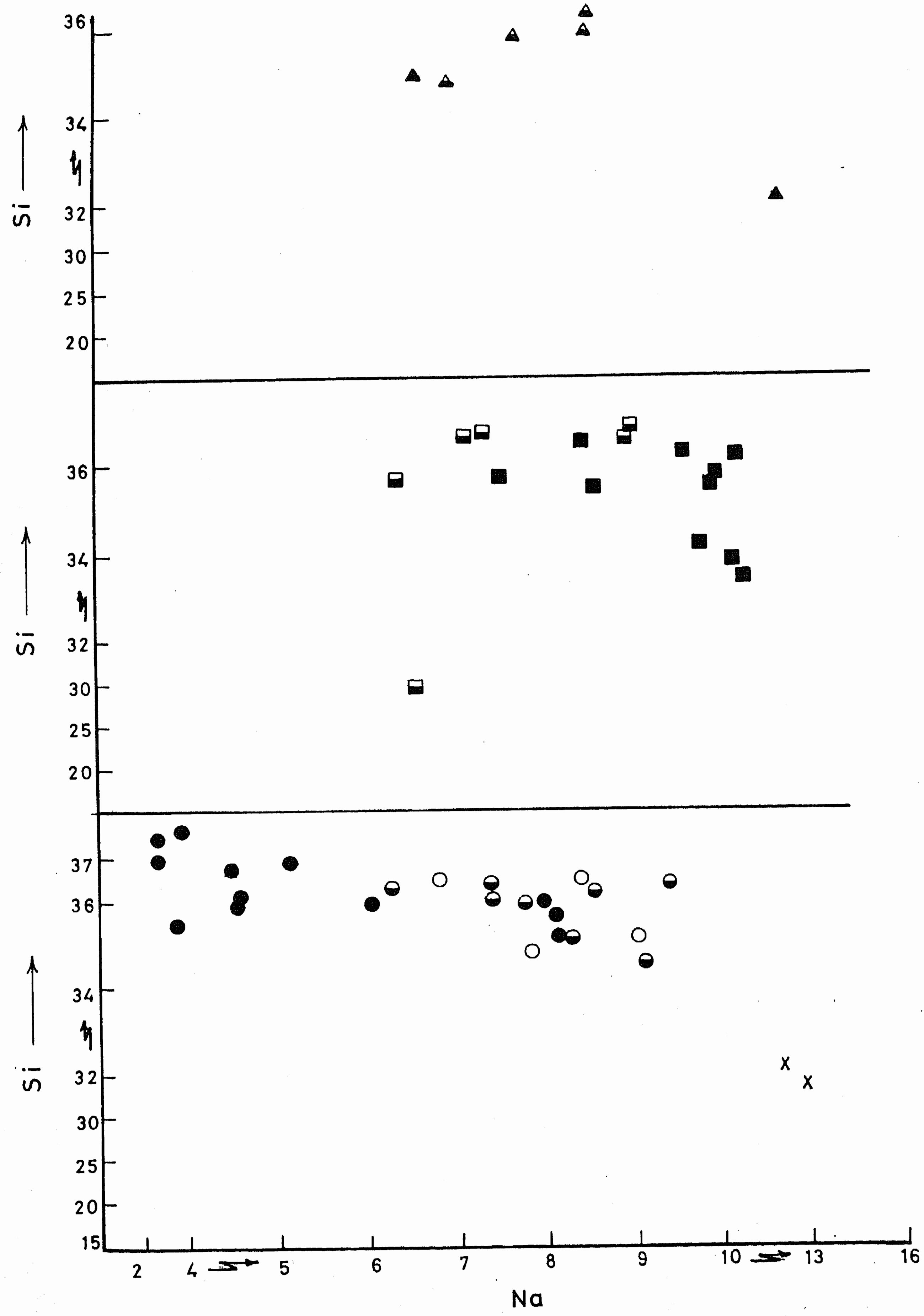


Fig.6.3 Plot of Na vs. Al for Koga syenites. Symboles as
Fig.6.1.

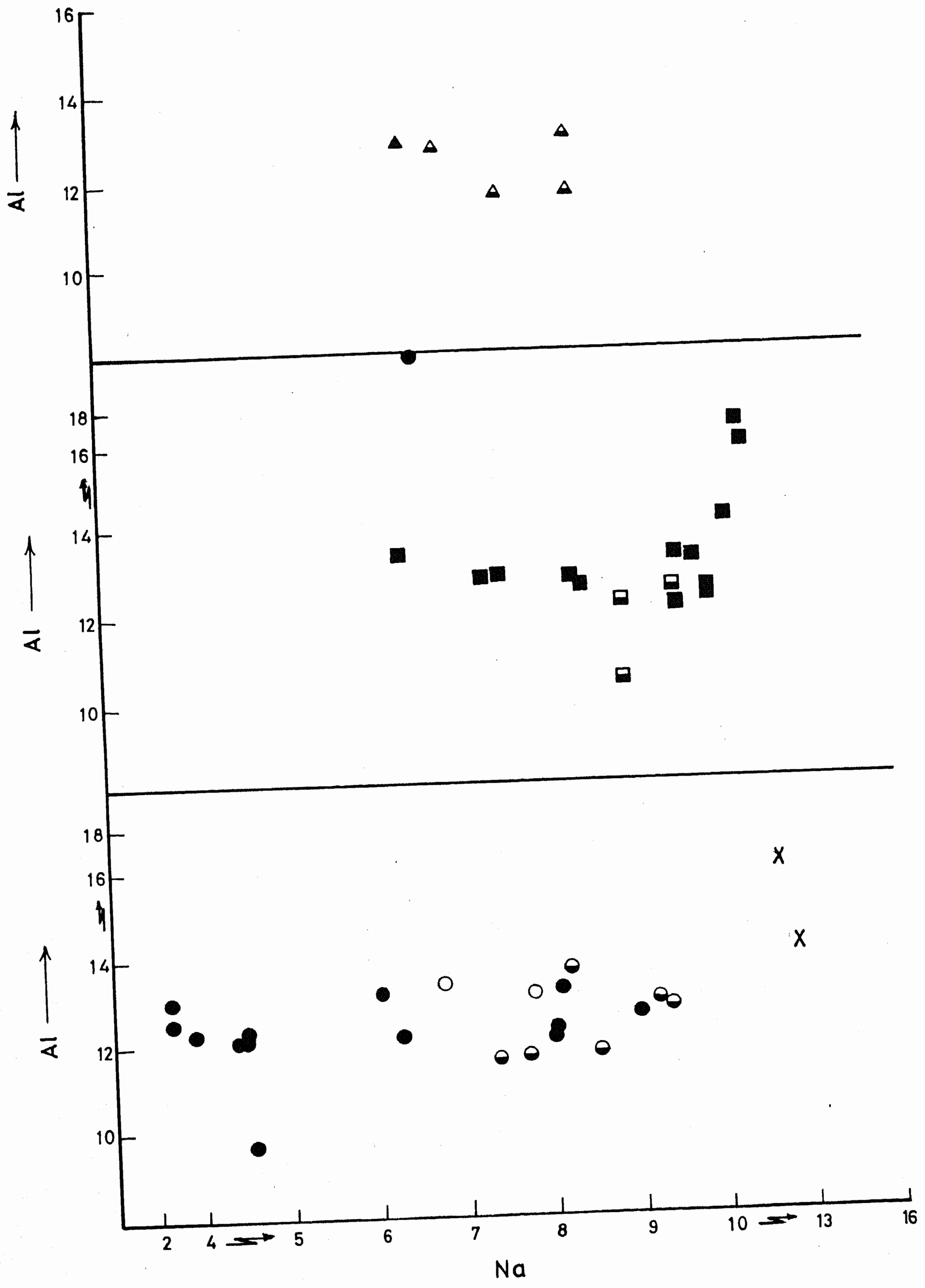


Fig.6.4 Plot of the Koga syenites in part of the wt% normati system quartz-nepheline-kalsilite. (a) showing th suggested trends of fenitization for k-fenites Ia=fenitization of quartz syenite, Ib=fenitization nepheline syenites. (b) showing the suggested trends Na-fenitization. Symbols are as for Fig.6.1.

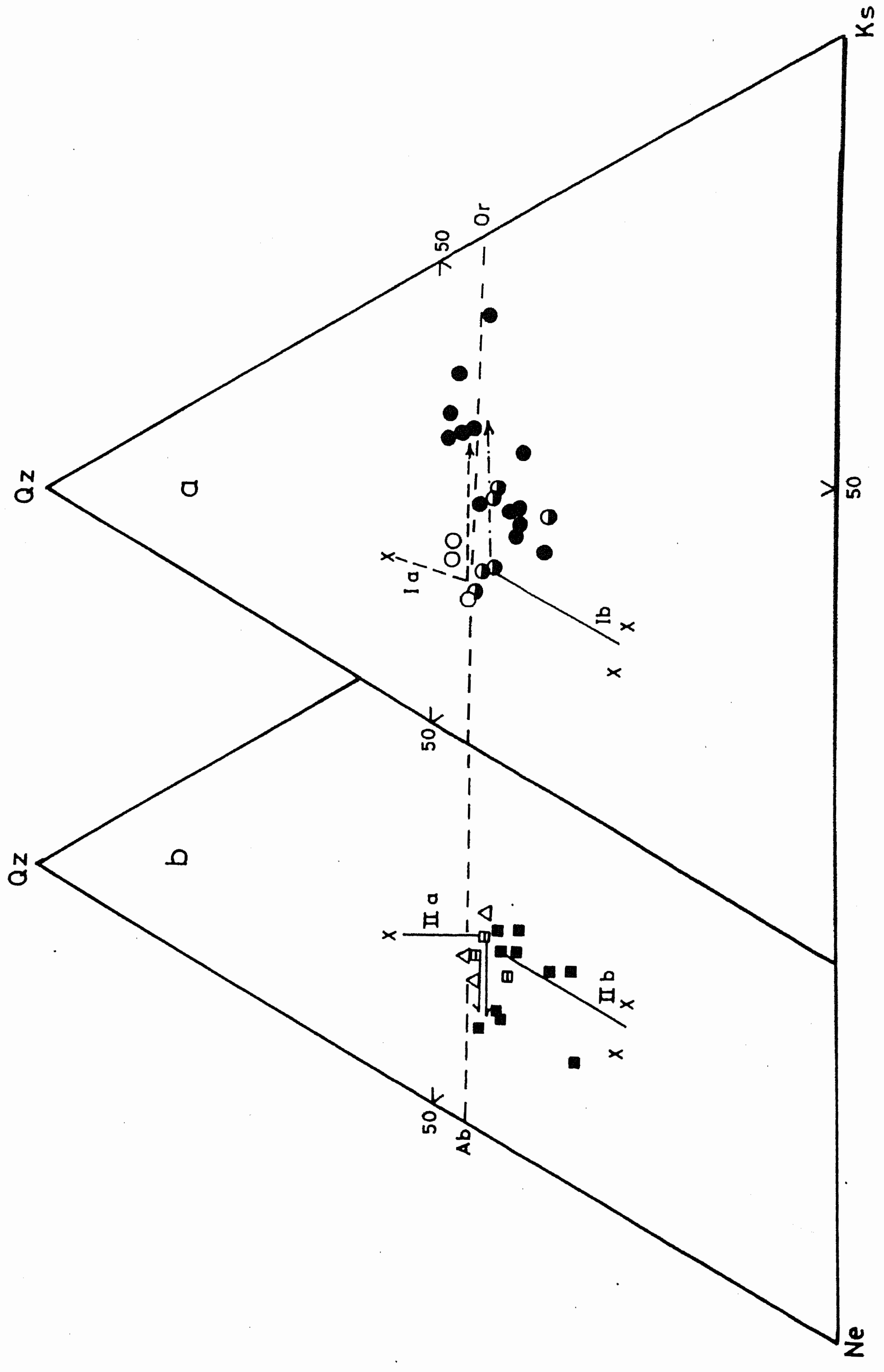
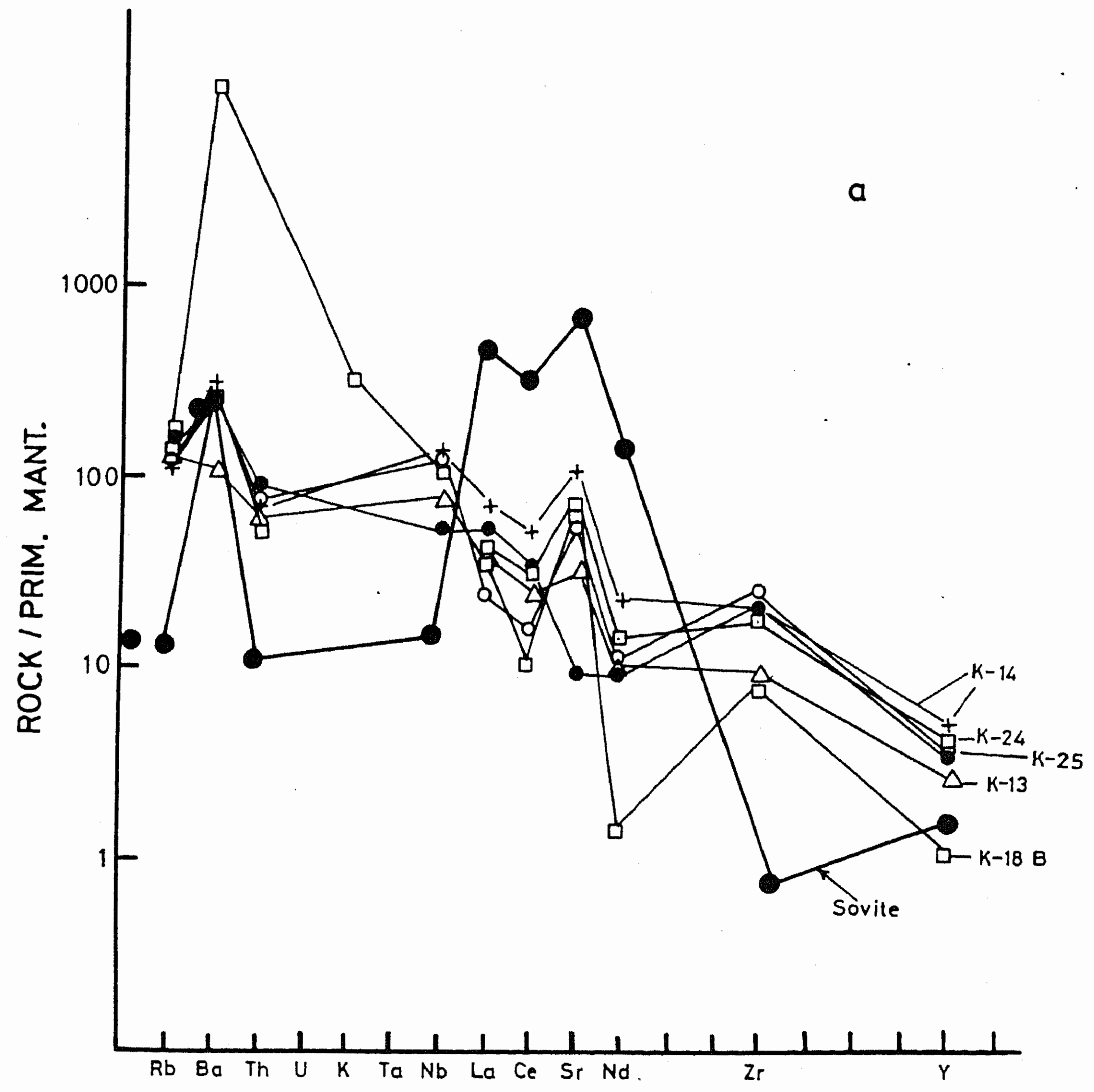
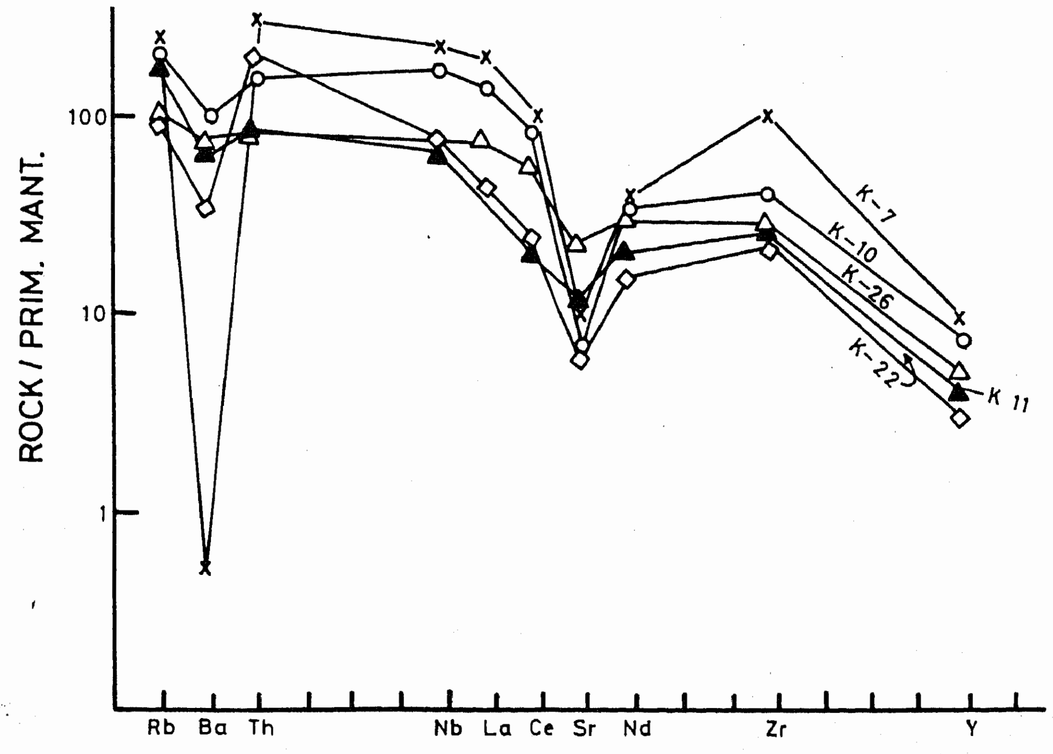


Fig.6.5a Primodial Mantle-normalized trace element spectra for k-fenites (open circles) and mean of five carbonatites (closed circle) at Koga. K-fendites shows similarity with Naranji Kandau Carbonatite.

Fig.6.5b Primodial Mantle -normalized trace element spectra for Na-fenites . Na-fenites do not show any similarity with Naranji Kandau carbonatites.





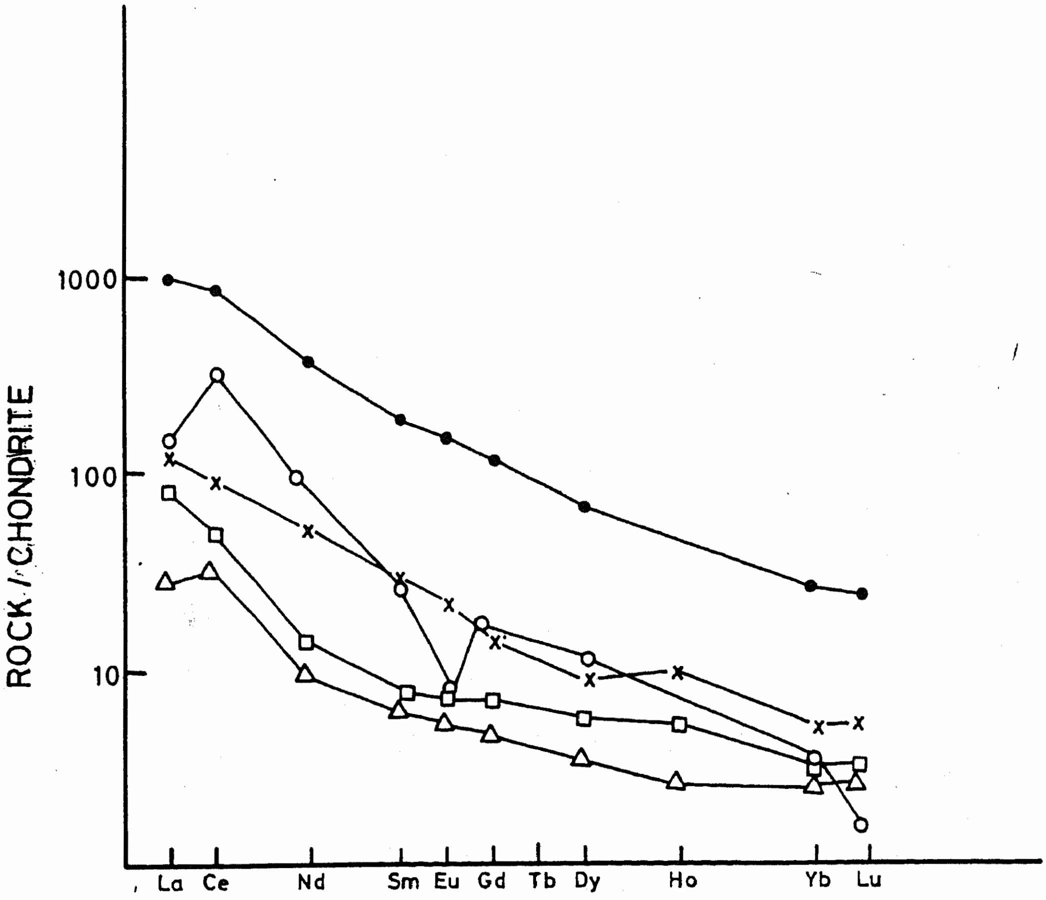


Fig.6.6 Chondrite-normalized REE spectra for unfenitized nepheline syenite (open squares), Na-fenites (crosses) and k-fenites (open triangles) at Koga and compared with the REE of the carbonatites (close circle) and ijolite (open circles) at Koga.

TABLE 6.1. XRF analyses of unfenitized rocks of Koga Syenites.

Analyses No.	1	2
Sample No.	K-4	Kn-32
SiO_2	55.30	57.15
TiO_2	00.15	0.18
Al_2O_3	24.27	25.71
Fe_2O_3	3.00	0.72
FeO	0.00	0.00
MnO	0.00	0.63
MgO	0.05	0.00
CaO	0.80	1.08
Na_2O	11.80	11.05
K_2O	4.55	4.71
P_2O_5	0.02	0.06
Total	100.04	100.29
	C.I.P.W. NORMS	
Qz	0.00	0.00
Co	0.00	0.00
Or	26.72	39.52
Ab	30.68	18.36
An	0.00	0.83
Lc	0.00	0.00
Ne	37.36	40.63
Ac	0.00	0.00
Wo	01.16	1.05
Di	00.96	1.74
Ol	0.00	0.00
Mt	2.55	0.69
Il	0.30	0.30
Ap	0.00	0.00
Qtz	27.01	25.86
Ne	56.96	51.34
Ks	16.02	22.80

TABLE 6.2. XRF analyses of K-fenitized rocks of Koga syenites.

Analyses No.	1	2	3	4	5
Sample No.	Kn-27	Kn-237A	Kn-277A	Kn-265	Kn-51
SiO_2	62.19	63.97	64.09	63.53	66.45
TiO_2	0.29	0.25	0.32	0.16	0.21
Al_2O_3	20.18	18.49	17.91	17.5	5.60
Fe_2O_3	4.18	0.83	0.51	1.32	4.89
FeO	0.00	0.00	0.00	0.00	0.00
MnO	0.15	0.00	0.02	0.01	0.06
MgO	0.10	0.46	0.47	0.00	0.25
CaO	1.16	1.84	1.096	1.08	2.15
Na_2O	7.31	6.36	6.22	8.74	3.84
K_2O	3.99	4.91	5.51	4.94	5.68
P_2O_5	0.07	0.10	0.08	0.12	0.40
Total	99.62	97.21	96.23	97.40	99.53

C.I.P.W NORMS

Qz	0.00	4.11	4.43	0.00	17.55
Co	0.00	0.00	0.14	0.00	0.00
Or	47.32	28.95	32.29	34.51	33.40
Ab	34.22	54.02	52.45	57.56	32.52
An	0.00	7.23	4.64	0.28	7.79
Lc	0.00	0.00	0.00	0.00	0.00
Ne	13.57	0.00	0.00	4.33	0.00
Ac	2.77	0.00	0.00	0.00	0.00
Wo	1.28	0.00	0.00	1.51	0.00
Di	2.48	0.77	0.00	1.58	0.00
Ol	0.00	0.00	0.00	0.00	0.00
Mt	2.78	0.46	0.00	0.69	3.01
Il	0.61	0.31	0.61	0.15	0.46
Ap	0.00	0.00	0.31	0.00	0.93
Qtz	45.75	47.50	47.56	42.82	56.15
Ne	38.85	33.61	31.87	36.84	21.11
Ks	15.40	18.89	20.58	20.34	22.74

TABLE 6.2. CONTINUED.

Analyses No.	6	7	8	9
Sample No.	K-24	Kn-24	Kn-239A	K-14
SiO_2	59.00	63.53	63.51	59.50
TiO_2	0.47	0.28	0.11	0.60
Al_2O_3	18.60	17.50	19.18	18.40
Fe_2O_3	2.77	3.22	0.99	3.30
FeO	0.00	0.00	0.00	0.00
MnO	0.100	0.06	0.02	0.12
MgO	0.33	0.00	0.20	0.34
CaO	2.25	0.537	1.20	2.95
Na_2O	8.22	7.710	7.76	8.00
K_2O	7.38	7.610	5.83	6.40
P_2O_5	0.00	0.00	0.00	0.00
Total	99.12	100.45	98.8	99.61
		C.I.P.W NORMS		
Qz	0.00	0.00	0.00	0.00
Co	0.00	0.00	0.00	0.00
Or	43.42	45.09	34.51	37.85
Ab	25.35	39.14	57.56	30.86
An	0.00	0.00	0.28	0.00
Lc	0.00	0.00	0.00	0.00
Ne	15.82	4.65	4.33	15.11
Ac	4.62	5.54	0.00	5.54
Wo	2.29	0.00	1.51	3.45
Di	3.97	2.48	1.58	4.71
Ol	0.00	0.31	0.00	0.00
Mt	0.00	0.00	0.69	0.00
Il	0.91	0.61	0.15	1.21
Ap	0.31	0.00	0.00	0.31
Qtz	35.90	42.08	42.82	36.37
Ne	34.93	29.09	36.84	37.97
Ks	29.19	28.83	20.34	25.66

TABLE 6.2. **CONTINUED**

Analyses No.	10	11	12	13
Sample No.	K-25	Kn-56	Kn-94A	Kn-98
SiO_2	61.50	62.08	63.54	62.28
TiO_2	0.400	0.71	0.40	0.43
Al_2O_3	19.01	18.75	18.15	17.98
Fe_2O_3	3.84	3.33	2.84	5.69
FeO	0.00	0.00	0.00	0.00
MnO	0.09	0.08	0.00	0.20
MgO	0.08	0.00	0.47	0.68
CaO	0.95	0.90	1.33	2.71
Na_2O	7.52	7.47	5.77	3.47
K_2O	6.59	6.94	6.96	7.30
P_2O_5	-	0.06	0.12	-
Total	99.98	100.26	99.58	100.74

C.I.P.W NORMS

	10	11	12	13
Qz	0.00	0.00	0.44	0.00
Co	0.00	0.00	0.00	0.00
Or	38.97	41.20	41.20	43.42
Ab	42.35	39.34	48.78	29.37
An	0.00	0.00	3.06	11.69
Lc	0.00	0.00	0.00	0.00
Ne	10.02	9.94	0.00	0.00
Ac	2.31	5.08	0.00	0.00
Wo	0.71	0.81	0.00	0.00
Bi	2.67	2.23	2.17	1.40
Ol	0.00	0.00	0.00	0.00
Mt	1.85	0.23	2.08	3.70
Il	0.76	1.37	0.76	0.76
Ap	0.00	0.00	0.31	0.00
Qtz	39.67	39.58	44.88	48.65
Ne	36.08	34.54	29.23	20.13
Ks	24.24	25.87	25.89	31.22

TABLE 6.2. CONTINUED.

Analyses No.	14	15	16	17
Sample No.	K-25	Kn-29	Kn-26	Kn-104
SiO_2	62.01	61.28	62.64	63.96
TiO_2	0.20	0.24	0.16	0.25
Al_2O_3	18.00	13.89	19.73	17.96
Fe_2O_3	3.50	7.90	2.75	2.18
FeO	0.00	0.00	0.00	0.00
MnO	0.11	0.20	0.08	0.50
MgO	0.36	0.37	0.00	0.33
CaO	1.50	4.57	0.58	1.50
Na_2O	7.30	4.02	6.89	4.10
K_2O	7.33	7.69	7.85	8.60
P_2O	-	-	-	-
Total	100.31	100.16	99.97	99.38

C.I.P.W NORMS

Qz	0.00	0.00	0.00	0.00
Co	0.00	0.00	0.00	0.00
Or	43.42	45.65	46.21	51.22
Ab	33.30	28.32	37.70	34.62
An	0.00	0.00	0.00	5.01
Lc	0.00	0.00	0.00	0.00
Ne	10.00	0.00	9.13	0.00
Ac	6.01	5.08	3.23	0.00
Wo	0.00	3.95	0.00	0.00
Di	6.42	11.38	2.48	0.53
Ol	0.00	0.00	0.10	0.00
Mt	0.00	3.01	0.69	1.62
Il	0.46	0.46	0.30	0.46
Ap	0.00	0.00	0.00	0.62
Qtz	39.18	45.61	40.01	46.70
Ne	32.40	20.22	31.76	20.89
Ks	28.42	34.18	28.22	32.42

TABLE 6.2. CONTINUED.

Analyses No.	18	19	20	21
Sample No.	Kn-95	Kn-100	K-18B	K-18C
SiO_2	65.54	61.61	61.87	65.82
TiO_2	0.11	0.28	0.19	0.01
Al_2O_3	18.25	17.61	19.34	18.47
Fe_2O_3	0.00	0.25	1.04	0.48
FeO	0.00	0.00	0.00	0.00
MnO	0.00	0.03	0.02	0.00
MgO	0.30	0.08	0.07	0.00
CaO	1.07	3.43	1.53	0.00
Na_2O	3.57	2.44	5.44	2.34
K_2O	9.21	9.54	9.60	13.84
P_2O_5	0.00	-	-	-
Total	98.05	95.27	99.10	100.96
		C.I.P.W. NORMS		
Qz	6.61	5.61	0.00	0.22
Co	0.00	0.00	0.00	0.00
Or	54.56	56.23	56.78	8134
Ab	30.42	20.45	27.80	17.83
An	5.29	9.18	0.00	0.00
Lc	0.00	0.00	0.00	0.00
Ne	0.00	0.00	9.94	0.00
Ac	0.00	0.00	0.00	0.92
Wo	0.00	2.63	2.90	0.00
Di	0.00	0.43	0.43	0.00
Ol	0.00	0.00	0.00	0.00
Mt	0.00	0.00	0.69	0.00
Il	0.15	0.61	0.30	0.00
Ap	0.00	0.31	0.00	0.31
Qtz	48.16	47.71	39.41	43.78
Ne	17.99	13.47	26.45	9.67
Ks	33.85	38.83	34.13	46.55

Low grade K-fenites; Analyses No.1,2,3.
Medium grade K-fenites; Analyses No.4-7.
High grade K-fenites; Analyses No.8-12.

TABLE 6.3. XRF ANALYSES OF NA-FENITIZED ROCKS OF KOGA SYENITES

Analyses No.	1	2	3	4	5
Sample No.	Kn-30	K-22	K-26	K-7	K-263B
SiO_2	62.05	65.01	63.50	62.29	63.20
TiO_2	0.47	0.07	0.25	0.29	0.51
Al_2O_3	18.03	18.01	18.70	18.75	17.90
Fe_2O_3	5.49	1.75	2.74	3.29	2.24
FeO	0.00	0.00	0.00	0.00	0.00
MnO	0.25	0.08	0.11	0.19	0.12
MgO	0.11	0.26	0.24	0.21	0.82
CaO	1.21	0.40	1.12	1.14	1.85
Na_2O	7.89	8.20	8.78	7.76	8.63
K_2O	4.27	5.80	4.34	6.41	3.01
P_2O_5	0.07	-	-	0.02	0.00
Total:	99.84	99.58	99.78	100.35	98.28
			C.I.P.W NORMS		
Qz	1.02	0.00	0.00	0.00	0.00
co	0.00	0.00	0.00	0.00	0.00
Or	25.05	34.51	25.61	37.85	17.81
Ab	53.50	56.58	59.46	42.22	68.31
An	0.00	0.00	0.00	0.00	1.39
Lc	0.00	0.00	0.00	0.00	0.00
Ne	0.00	2.02	6.71	10.09	2.49
Ac	7.85	2.77	2.31	4.16	0.00
Wo	0.00	0.00	0.00	0.12	0.58
Di	5.40	0.87	3.95	4.56	5.08
Ol	0.00	1.11	0.03	0.00	0.00
Mt	0.00	0.00	0.93	0.69	1.62
Il	0.91	0.15	0.46	0.61	0.91
Ap	0.00	0.31	0.31	0.00	0.00
Qtz	45.69	43.85	41.74	39.59	44.01
Ne	36.42	35.09	42.41	36.55	44.57
Ks	17.87	21.06	15.85	23.86	11.42

TABLE 6.3. CONTINUED.

Analyses No.	6	7	8	9
Sample No.	K-12	Kn-33	K-11	Kn-261
SiO_2	58.50	64.36	61.90	63.52
TiO_2	0.70	.10	0.16	0.47
Al_2O_3	19.00	19.97	19.00	18.29
Fe_2O_3	5.80	0.00	3.08	3.61
FeO	0.00	0.00	0.00	0.00
MnO	0.10	0.04	0.07	0.10
MgO	0.20	0.12	0.10	0.44
CaO	1.20	0.87	0.50	1.75
Na_2	08.70	8.81	8.90	9.16
K_2O	5.60	6.09	6.00	3.12
P_2O_5	-	0.00	-	-
Total	99.80	100.36	99.71	100.46
	C.I.P.W NORMS			
Qz	0.00	0.00	0.00	0.00
Co	0.00	0.00	0.00	0.00
Or	32.84	36.18	35.63	18.37
Ab	35.64	51.01	42.61	66.74
An	0.00	0.00	0.00	0.00
Lc	0.00	0.00	0.00	0.00
Ne	16.80	9.59	11.58	5.33
Ac	6.01	0.00	5.08	0.92
Wo	0.00	1.51	0.00	1.39
Di	5.06	0.65	2.20	4.37
Ol	0.09	0.00	0.79	0.00
Mt	1.62	0.00	0.00	2.08
Il	1.37	0.15	0.30	0.91
Ap	0.00	0.00	0.00	0.00
Qtz	35.78	40.30	38.87	42.59
Ne	42.33	38.46	38.59	45.87
Ks	21.89	21.25	22.54	11.54

TABLE.6.3. CONTINUED.

Analyses No.	10	11	12	13
Sample No.	Kn-44	Kn-253A	Kn-263A	Kn-36
SiO_2	55.25	56.99	64.02	60.11
TiO_2	0.05	0.12	0.10	0.13
Al_2O_3	19.37	23.35	18.80	22.10
Fe_2O_3	0.49	2.14	0.37	0.00
FeO	0.00	0.00	0.00	0.00
MnO	0.06	0.03	0.00	0.05
MgO	0.25	0.00	0.43	0.00
CaO	2.41	4.93	1.32	0.91
Na_2	09.21	9.40	9.63	10.31
K_2O	8.90	3.47	3.75	6.45
P_2O	0.03	0.00	0.00	0.00
Total	96.02	100.43	98.42	00.06

C.I.P.W NORMS

	10	11	12	13
Qa	0.00	0.00	0.00	0.00
Co	0.00	0.00	0.00	0.00
Or	52.33	20.60	22.27	37.85
Ab	66.95	38.02	63.86	34.62
An	0.00	11.13	0.00	0.00
Lc	0.00	0.00	0.00	0.00
Ne	23.51	22.59	6.32	23.50
Ac	0.92	0.00	0.46	0.00
Wo	4.07	5.11	1.39	1.86
Di	1.80	0.99	2.63	0.00
Ol	0.00	0.00	0.00	0.00
Mt	0.15	1.62	0.00	0.00
Il	0.00	0.30	0.15	0.30
Ap	0.00	0.00	0.00	0.00
Qtz	31.14	32.41	42.06	33.53
Ne	32.95	53.18	44.26	44.70
Ks	35.92	14.41	13.69	22.30

Medium grade Na-fenites; Analyses No.1-3.
High grade Na-fenites; Analyses No.4-13.

TABLE 6.3. XRF analyses of Na-K-fenitized rocks of Koga syenites

Analyses No.	1	2	3	4	5
Sample No.	Kn-276	Kn-272	Kn-251	Kn-23	Kn-247
SiO_2	63.46	62.48	60.88	65.05	60.36
TiO_2	00.45	0.63	0.84	0.26	1.36
Al_2O_3	17.31	17.11	18.87	19.09	18.72
Fe_2O_3	4.17	3.96	4.17	0.32	4.19
FeO	0.00	0.00	0.00	0.00	0.00
MnO	0.15	0.14	0.15	0.00	0.08
MgO	0.37	0.60	0.55	0.47	0.00
CaO	1.45	1.80	1.75	1.53	1.97
Na_2O	7.75	6.93	5.91	7.81	6.23
K_2O	4.37	4.97	5.84	6.13	6.17
P_2O_5	0.11	0.12	0.16	0.10	0.16
Total	99.59	98.74	99.12	98.20	99.24

C.I.P.W. NORMS

Qz	0.00	0.00	0.00	0.00	0.00
Co	0.00	0.00	0.03	0.00	0.00
Or	25.61	29.50	34.51	36.18	6.74
Ab	63.77	58.26	49.83	55.46	46.85
An	0.00	0.83	7.70	0.56	4.73
Lc	0.00	0.00	0.00	0.00	0.00
Ne	0.69	0.26	0.00	5.75	3.31
Ac	0.46	0.00	0.00	0.00	0.00
Wo	0.43	0.43	0.00	0.00	1.70
Di	4.43	4.99	0.00	0.00	0.00
Ol	0.00	0.00	0.53	0.00	0.00
Mt	2.78	2.78	3.01	0.00	2.32
Il	0.91	1.21	1.67	0.91	2.58
Ap	0.31	0.31	0.31	0.31	0.31
Qtz	44.72	44.72	44.74	42.14	43.23
Ne	39.12	39.12	32.00	36.75	32.86
Ks	16.16	16.16	23.25	21.11	23.91

Table 6.4. Analyses of unfenitized Nephiline Synite recast in Cations per 100 oxygens anions

Anal.No.	1	2
Sample No.	K-4	Kn32
Si	32.08	31.92
Ti	00.12	00.14
Al	16.61	17.73
Fe3+	01.39	00.28
Fe2+	00.00	00.00
Mn	00.32	00.28
Mg	00.00	00.00
Ca	00.35	00.67
Na	13.12	12.62
K	03.28	03.54

Table 6.5. Analyses of K-fenites recast in cations per 100 oxygen anions.

Anal.No.	1	2	3	4	5
Sample No.	Kn-27	Kn-237A	Kn-277A	Kn-265	Kn-51
Si	34.78	36.867	37.180	36.387	35.841
Ti	00.12	00.034	00.139	00.067	00.097
Al	31.09	12.543	12.250	12.688	12.040
Fe^{3+}	01.99	00.345	00.209	00.552	02.254
Mn	00.071	00.000	00.069	00.006	00.031
Mg	00.00	00.381	00.418	00.000	00.228
Ca	00.684	01.143	00.662	00.643	01.410
Na	07.81	07.068	06.970	09.410	04.558
K	05.61	03.603	04.044	03.500	04.436

Low grade K-fenites;1,2,3.

Medium grade K-fenites;4,5,6,7.

High grade K-fenites;8-21.

Table 6.5 Continued.

Anal.No.	6	7	8	9	10	11
Sample No.	K-24	Kn-24	Kn-239A	K-14	Kn-25	Kn-56
Si	34.629	35.124	36.587	34.641	35.144	35.883
Ti	00.207	00.116	00.046	00.263	00.168	00.297
Al	12.866	13.564	12.625	12.625	13.228	12.282
Fe^{3+}	01.223	01.340	00.416	01.446	01.616	01.392
Mn	00.050	00.028	00.009	00.059	00.043	00.038
Mg	00.289	0.000	00.167	00.295	00.067	00.000
Ca	01.415	00.318	00.718	01.840	00.569	00.536
Na	09.354	08.133	08.403	09.031	08.152	08.048
K	05.526	05.368	04.154	04.754	04.700	04.920

Table 6.5 Continued.

Anal.No.	12	13	14	15	16	17
Sample No.	Kn-94A	Kn-98	K-25	Kn-29	Kn-26	Kn-104
Si	36.281	35.483	35.621	35.875	35.933	36.735
Ti	00.172	00.184	00.086	00.106	00.067	00.108
Al	12.214	12.073	12.186	9.584	12.903	12.157
Fe^{3+}	01.220	02.439	01.513	03.480	01.150	00.942
Mn	00.000	00.097	00.054	00.099	00.038	00.024
Mg	00.400	00.578	00.308	00.323	00.000	00.283
Ca	00.814	01.654	00.923	02.867	00.345	00.923
Na	06.388	03.833	08.131	04.563	07.426	04.566
K	05.070	05.306	05.372	05.743	05.568	06.301

Table 6.5 Continued

Anal. No.	18	19	20	21
Sample No.	Kn-95	Kn-100	K-18B	K-18C
Si	37.572	36.820	35.850	37.409
Ti	00.047	00.126	00.083	00.004
Al	12.331	12.404	13.216	12.372
Fe^{3+}	00.000	00.112	00.454	00.205
Mn	00.000	00.015	00.010	00.000
Mg	00.256	00.071	00.061	00.000
Ca	00.657	02.196	00.950	00.000
Na	03.968	02.827	06.116	02.579
K	06.736	07.274	07.101	10.035

Table 6.6 Analysis of Na-fenites recast in cations per 100 oxygen anoins.

Anal.No.	1	2	3	4	5	6
Sample No.	Kn-30	K-22	K-26	K-7	Kn-2638	K-12
Si	36.611	36.838	35.986	35.927	36.128	34.039
Ti	00.207	00.030	00.107	00.117	00.214	00.306
Al	10.388	12.028	12.490	12.344	12.060	13.030
Fe^{3+}	02.422	00.746	01.168	01.364	00.964	02.540
Mn	00.124	00.038	00.053	00.067	00.058	00.044
Mg	00.096	00.220	00.203	00.168	00.699	00.173
Ca	00.760	00.243	00.680	00.671	01.133	00.748
Na	08.968	09.009	09.647	08.386	09.565	09.815
K	03.194	04.193	03.138	04.562	02.195	04.157

Medium grade Na-fenites;1,2,3.

High grade Na-fenites;4-13.

Both type fenites;14,15,16,17,18.

Table 6.6 Continued.

Anal.No.	7	8	9	10	11	12
Sample No.	Kn-33	K-11	Kn-261	Kn-44	Kn-253A	Kn-263A
Si	36.207	35.512	35.757	33.884	32.661	36.130
Ti	00.042	00.069	00.199	00.023	00.051	00.042
Al	13.244	12.847	12.135	14.004	15.772	12.505
Fe^{3+}	00.000	01.330	01.529	00.226	00.923	00.157
Mn	00.019	00.034	00.048	00.031	00.015	00.000
Mg	00.101	00.086	00.369	00.228	00.000	00.362
Ca	00.524	00.307	01.055	01.584	03.027	00.798
Na	09.610	09.900	09.998	10.952	10.445	10.866
K	04.370	04.391	02.241	06.964	02.537	04.140

Table 6.6 Continued.

Anal.No.	13	14	15	16	17	18
Sample No.	KN-36	Kn-276	Kn-272	Kn-251	Kn-23	Kn-247
SI	33.440	36.122	35.966	35.046	36.428	34.871
Ti	00.054	00.193	00.273	00.364	00.198	00.591
Al	16.462	11.616	11.612	12.806	13.041	12.750
Fe^{3+}	00.000	01.786	01.716	01.106	00.080	01.822
Mn	00.024	00.073	00.068	00.073	00.029	00.039
Mg	00.000	00.314	0.515	00.472	00.000	00.000
Ca	00.542	00.884	01.110	01.079	00.489	01.219
Na	10.928	08.554	07.736	06.596	08.496	06.978
K	04.578	03.174	03.650	04.288	04.388	04.548

TABLE. 6.7. REPRESENTATIVE TRACE ELEMENTS (ppm) IN THE ROCKS OF KOGS SYENITES.

Analyses No.	1	2	3	4	5
Sample No.	K-24	K-14	K-25	K-18B	K-22
Rb	134	104	122	156	101
Ba	2047	2387	1906	7983	297
Th	5	6	7	-	23
K	61265	53129	60850	79694	48149
Nb	74	88	63	57	47
La	33	56	19	56	33
Ce	62	97	32	92	66
Sr	1695	2590	1289	4144	139
Nd	21	32	13	31	22
Zr	206	238	277	133	239
Ti	2818	3597	1199	779	420
Y	20	24	19	19	14

1,2,3,4= Represetative analyses of K-fenitized rocks of Koga.
5,6,7,8= Representative analyses of Na-fenitized rocks of Koga.
9= Unfenetized nepheline syenite of Koga.
10= Mean of eight sovites of Koga.

TABLE 6.7. CONTINUED.

Analyses No. 6 7 8 9 10

Sample No.	K-26	K-07	K-11	K-04	Sovite
Rb	101	184	161	140	13.4
Ba	590	133	472	36	1527
Th	8	29	8	9	1.1
K	36028	53213	49809	37772	-
Nb	44	148	54	35	9.4
La	56	147	29	42	342
Ce	101	215	47	58	615
Sr	509	212	331	213	14542
Nd	39	52	15	15	204
Zr	301	1147	297	274	8
Ti	1499	739	59	899	-
Y	20	57	21	16	77.4

TABLE 6.8. REE (ppm) ANALYSES OF ROCKS FROM KOGA SYENITES

Analyses No.	1	2	3	4	5
Sample No.	K-4	K-26	K-18B	Ijolite	Sovite
La	29.0	37.7	12.232	164.4	332
Ce	45.6	8.5	28.704	326	744
Pr	3.2	7.7	2.498	25.76	-
Sm	1.5	5.4	1.273	21.5	37.4
Eu	0.52	1.62	0.288	6.77	11.5
Gd	1.22	4.01	1.004	18.47	30.4
Dy	0.96	2.72	0.711	12.04	19.7
Ho	0.35	0.81	0.127	2.31	-
Er	0.74	1.56	0.458	6.98	-
Yb	0.44	0.96	0.36	3.71	5.8
Lu	0.08	0.15	0.559	0.58	0.8
Ce/Yb	65.90	39.27	33.98	44.31	57.0
La/Lu	362.5	251.3	21.88	283.4	415

1= Unfenitized nepheline syenite from Koga.
2= Na-fenitized rock of Koga.
3= K-fenitized Cape rock of Naranji Kadou carbonatite.
4= Mean of four ijolites from Koga.
5= Mean of three sovites from Koga, NW Pakistan.

CHAPTER 7

SUMMARY OF CONCLUSION

The main mineralogical and petrological conclusions which are drawn from the work described in this thesis are as follows:

1. The petrographic study of Koga syenites suggests that the rocks in the studied area are alkali-granite, alkali-syenites, nepheline syenites, ijolites, carbonatites and fenites.

2. Fenites are of two types i. potassium-fenites, ii. sodium-fenites. Effects of these two types are also present.

3. The magmatic pyroxene shows normal trend of crystallization from diopsidic to acmitic component while fenitic pyroxene shows a reverse trend which is from acmitic to diopsidic and/or hedenbergitic component. The composition of pyroxene further suggests that the Koga rocks have been intruded by at least two carbonatite intrusions having different Na/k ratios.

4. The fenitic amphibole shows a trend from magnesio-arfvedsonite to richterite which is opposite to the magmatic subsolidus trend. The amphibole composition shows an increase in MgO ratio with increasing intensity of fenitization and crystallization of fenitic amphibole under strong oxidation state.

5. The magmatic alkali-feldspars in the Koga syenites are low albite and maximum microcline while fenitic Na-feldspar is anomalously low albite. The degree of orderness o low albite

increases with the increasing grade of fenitization. The magmatic albite is formed at about 800 -1000 C while, the temperature for the formation of low albite is about 350-500 .C i.e. the temperature of fenitizing fluids.

6. The study of pyroboles, feldspars and geochemistry of the Koga syenites suggests that the rocks have been intruded by at least two carbonatite intrusions which have different Na/k ratios. One carbonatite intrusion having low Na/k ratio is exposed at Naranji Kandau while, the other intrusion which has high Na/k ratio is not exposed or / not observed by the author.

7. The possibility of Na-fenitization by the fluids emanating from the ijolite intrusions has been ruled out on the basis of study of pyriboles, and geochemistry of the whole rocks especially trace elements and REE.

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