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GEOCHEMISTRY OF FELSIC ROCKS AROUND KOLAR SCHIST BELT, KARNATAKA

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CERTIFICATE

This dissertation entitled 'Geochemistry of felsic rocks around Kolar Schist Belt' embodies the work carried out at the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi. This work has not been submitted in part or in full for any degree or diploma of any university.

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CONTENTS

CHAPTER-I

INTRODUCTION

The ancient shield areas of the earth are being investigated to understand the processes that were operating in the early history of the earth. The concentration of metallic and nonmetallic deposits in the Archean shield areas are as a result of these geological processes. In the Archean shield areas a major portion of the crust ($\sim$80%) is composed of granitic rocks which are mostly over 2.5 b.y. old (Goodwin 1976). The crust by the end of Archean was similar to that of the present day crust in terms of total mass and amount of sialic material. The crustal evolution thus involved generation of large amount of sialic/granitic material, which make up the continents over a period of time, essentially within Archean (Goodwin, 1976).

There are different opinions/theories about the processes involved in the evolution of the crust. The differences among these processes involve (a) energetics that initiated the crust forming processes and the mode of crust forming processes themselves. Some argue that the differentiation of the core by sinking of Fe - FeS, and enrichment of radioactive material (such as U and Th) at the fringe of the earth were responsible for supply of energy (heat) to melt the mantle, and thus initiated differentiation of the mantle (Ramamurthy, 1976; Shaw, 1976).

The continuous impact of meteorites is believed to have heated the outer layers of the earth's crust and thus initiated melting and differentiation of the mantle; thus the 'giant impacting' triggered the volcanisms which formed continental nucleii and in successive periods it expanded to form the ancient continents. It is suggested that the giant impacting of mateorites took place after the differentiation of the earth's core and just before and during the differentiation of the sialic crust (Green, 1972; Goodwin, 1976).

Among the various processes put forth for the crustal evolution, the differences arise in whether the primitive crust was ultrabasic, basic, Anorthositic or granitic. But all agree in the crustal formation by differentiation of the mantle and successive volcanism by the heat supplied either by core formation or meteoritic impacting apart from the radioactive source as discussed above. The suggested protocrustal materials are

a. Mafic and ultramafic crust
b. Anorthositic crust and
c. Sialic crust.

Recently much attention has been paid to the study of geochemistry involving major, trace and rare-earth elements and isotopes of granitic rocks of Archean shield areas towards understanding the nature, origin and evolution of the crust.

The early Archean shield areas are characterised by the presence of greenstone belts surrounded by granitic rocks, some of which are intrusive into greenstone belts and some probably formed basement on which green- 7 stone belts were evolved. Greenstone belts include ultramafic + mafic ± acid volcanic ± sedimentary lithological associations. Some are dominated by mafic and ultramafics with minimum of sediments and other are dominated by sediments with subordinate amount of mafic volcanics. These belts are thus commonly referred to as greenstone-granite complexes. The greenstone-granite complexes are being studied for various reasons primarily to understand the evolution of greenstone-granite complexes and therefore the crustal evolution in general and to understand the mineralizations associated with these complexes. It is well known that GSB are known for their Fe, Cr, Ni, Cu, Au, Zn deposits and the adjoining granitic rocks for their U, Th, Be, Sn mineralization. Because these mineral deposits are integral part of rock-systems present in these complexes understanding the petrogenesis of these rock systems is very basic in scientific mineral resources study.

The evolution of the granite-greenstone complexes probably lasted over a period of 1.2 b.y. (3.8 - 2.6 b.y) and terminated by a major thermal event in all the shield areas. In this period it is believed that the siamatic nature of the crust changed to sialic and this may be connected with the evolution of greenstone belts (Glikson, 1976). Further, the isotope measurements have proved that the volcanics and granites have formed in the same period of time (with maximum time span of 100 m.y) and the development of granite-greenstones complexes was repeated several times (Moorbath, 1976).

Though the greenstone belts of the world are similar, Ⓐ they have marked differences. Such differences could possibly be either due to the time-period of their formations or due to differences in geological processes. Such differences are usually recognized from the chemistry of rocks and from the type of associated mineralization. The later suggestion is evidenced by the fact though several greenstone belts are recognized in India (Naqvi et al., 1978), none of them are known for magmatic Nickel sulphide deposits, whereas, in other shield areas Ni sulphide deposits are associated with ultramafic-mafic dominated GSB. This may be because of various factors involved in magma generation like amount of melting, depth of melting, the type of melting involved and the temperature of melting of the source rock to produce the rocks comprising greenstone belts (Rajamani, 1982). Hence a study involving the granite greenstone belts should be aimed to understand the processes involved in the evolution of these belts, in order to understand the mineralization processes.

The granitic rocks of the shield areas have evolved at various periods during Precambrian just as the GSB. Sutton (1979) suggested that great volumes of igneous rocks, mostly granitic, were added to the continental crust and named these events as 'Chelogenic cycles' or shield forming cycles. He further suggested that extensive plutonic activity affected the crust periodically and in between the active periods the crust remained relatively inactive as cratons. The older periods of intrusive activity are thought to be extensive as infered from the geological mapping and age determinations. A relationship between these periods of crustal additions and changes in polar wander path has been established (Irving and Mc. Glynn, 1976; Sutton, 1979). Based on isotopic age determination, Moorbath (1976) grouped the intrusive episodes at 3800-3500, 2900-2600, 1900-1600, 1200-900 and 600 m.y. The global tectonics in these periods were of same style differing in the intensity, however, (Moorbath, 1976).

It is interesting to see the geochemical evolution of the granitic rocks over a period of time (3.8 to 2.5 b.y) during Archean. In Barberton greenstone-granite complex two distinct cycles of granite evolution are recognized based on geochemistry (Viljoen and Viljeen 1969). The earlier cycle dated at 3200-3400 m.y. is one of tonalites and granodiorites with higher Na/k ratios. Whereas the later cycle is of high Potassium granites with low Na/K ratios. The later high K granites are shown to be chemically more evolved and well fractionated. Based on field evidences and geocloronological investigations, the granites of the Rhodesian Archean craton are divided into three units. These granites were emplaced at $\geq$ 3.6 b.y., 3.4 b.y. and 2.6 b.y. (Wilson et al., 1978). These granitic rocks also show systematic decrease in Na/k ratios as the granitic evolution proceeded.

The granites and gneisses of Greenland are well studied and the oldest gneisses are recognized and dated in this area. Based on age data, the Archean granitic rocks of this area can be grouped into 3800-3600, 3100-2900, and 2500 m.y. old gneisses and granites.

In Greenland, the oldest granitic rocks are mainly quartzo-felsdpathic ortho-gneisses. These rocks are dated by Rb-Sr, U-Pb and Pb-Pb methods and fall between 3600-3800 m.y. (Moorbath et al., 1975; Hurst et al., 1975; Black et al., 1971; Baadsgards, 1973). The 3700 m.y. old

Amitsoq gneisses posses some unique geochemical characteristics. These rocks are poor in K, Rb, Y, Zr, Nb, Ba and Cu and rich in Ca and Sr. Also they show very high Fe_2O_3/MgO, high SiO_2/Al_2O_3, high model quartz, low U and Th and Y decreasing as Ca decreases (Lambert and Holland, 1974, 1976). The gneisses dated around 3100-2900 m.y. are found extensively and mostly magmatic origin and a small portion of this has been considered to be as a result of reworking of an older crust. (Moorbath, 1975). These gneisses have lower Na/K ratio, higher Rb/Sr and higher Ba/Sr ratio when compared to the Amitsoq gneisses.

Among the youngest Archean granites, the Qorgut granite is important and well studied (Mc. Gregor, 1973). This is homogeneous and potash rich granite and dated as 2520 ± 90 with Sr^{87}/Sr^{86} initial = 0.209 ± .007 by Moorbath and Pankhurst (1976). Similar ages are reported for post granulite, K-rich intrusions in Seglak and Labrador (Bridgwater _et_ _al_., 1975). These rocks are suggested as products of partial melting of earlier sialic material (Bridgwater _et._ _al_., 1978). These youngest granites have very low Na/K ratio and very high Rb/Sr and Ba/Sr ratios. In Greenland, the increase of K_2O from 3.7 b.y. old gneisses to 3.0 b.y. old gneisses is moderate whereas from 3.0 b.y. to 2.5 b.y. old gneisses is very high. Similarly Ba/Sr and Rb/Sr ratios show sympathetic behaviour, with a steep increase between 3.0 to 2.5 b.y. old gneisses suggesting some change in the crust building processes in that region.

In W. Australia, a trend similar to that of Greenland has been observed from the data on Archean granitic rocks given by Glikson and Sheraton (1972). In Canadian Shield though there is some variation in the geochemistry of the granitic rocks, the change is relatively less. This is evidenced from the major and trace element data on the granitic rocks of this region given by Harris and Goodwin (1976), Hillary and Ayres (1980); and Nisbitt (1980). However, terrains in the Archean of N.W. Scotland, the granitic rocks do not show any such significant trend of chemical evolution as a function of time (Robinson and Windley 1978, 1980; Pride and Mucke, 1980).

The Archean rocks are well exposed at various regions in Peninsular India. Among these regions, the Dharwar craton has been studied intensively for a long time. In this craton several greenstone belts are identified (Naqvi _et al_., 1978). These greenstone belts are surrounded by vast stretch of granitic rocks and some granitic intrusions are also seen within and around the belts. These archean granitic rocks are composite and migmatitic nature. Further these gneisses are believed to have intruded at various stages of crustal evolution in the Dharwar region. Secular geochemical variations, like decrease in Na/K ratio, depletion of Ca and Mg and increase in Th are observed for the gneisses and granites of this region also (Divakara Rao et al., 1974, Shaha 1979).

The Kolar Schist Belt has been recognized as a true greenstone belt in Dharwar craton. This belt is well known for gold mineralization and mining. This belt is surrounded by migmatitic Peninsular Gneisses and is also intruded by granitic rocks. The Peninsular Gneisses surrounding the Kolar schist belt are thought to have several components, possibly with different mineralogy and chemistry and emplaced at various stages of crustal evolution around Kolar schist belt. Based on the field study of the gneisses and granites on the western side of Kolar schist belt, Granath and Rajamani (1982) grouped the gneisses as:

(a) veined polydeformed older gneisses; (b) metasedimentary gneisses; (c) migmatitic gneisses; (d) Granodiorite-diorite gneisses and (e) granites.

The association of U and Th mineralization with particular type of granitic rocks could be because of processes responsible for their evolution (Sutton, 1979). ⑤ Recently intensive efforts are made to understand the petrogenesis of granitic rocks and processes responsible for concentration of U, Th, Be and other elements of great economic and strategic importance. Abnormally high U and Th contents in the gneisses around KGB are reported (Rao and Rao 1977) and this may be related to the evolution of these rocks in particular and crust around this region in general. Hence I have made an attempt to investigate these felsic rocks around KGB, using major and trace elements, in order to understand their origin and possible relation to Kolar Greenstone Belt.

CHAPTER-II

REGIONAL GEOLOGY OF DHARWAR CRATON

1. Regional Setting:

The Archean granites and gneisses occur in three major provinces constituting the Indian shield and they are (a) Dharwar Province, (b) Singhbhum-Orissa iron ore province and (c) Bundelkhand-Rajasthan Province (Saha, 1979). The Dharwar craton is separated from others by younger sedimentary formations (Gondwanas) of Narmada-Sone and Godavary rift valley systems. The North-western portion of the Dharwar craton is covered by Deccan traps. Dharwar craton is mostly composed of early Precambrian rocks. It also contains Protozoic, Mesozoic and Tertiary rocks as well. The Mesozoic to Tertiary rocks are found at the edge of the craton along the coastal belt. The Cuddapah basin of Protozoic age is located at the North-eastern portion of the craton. The above mentioned geological features are shown in fig. 2.1.

2. Regional Structures and Tectonics:

In Dharwar Craton, most of the schist belts are considered as synclines infolded into the basement (Iyengar 1976). An anticlinal axis of regional dimension has been conceived in between Shimoga and Chitradurga schist belts by Pichamuthu (1951). The Peninsular

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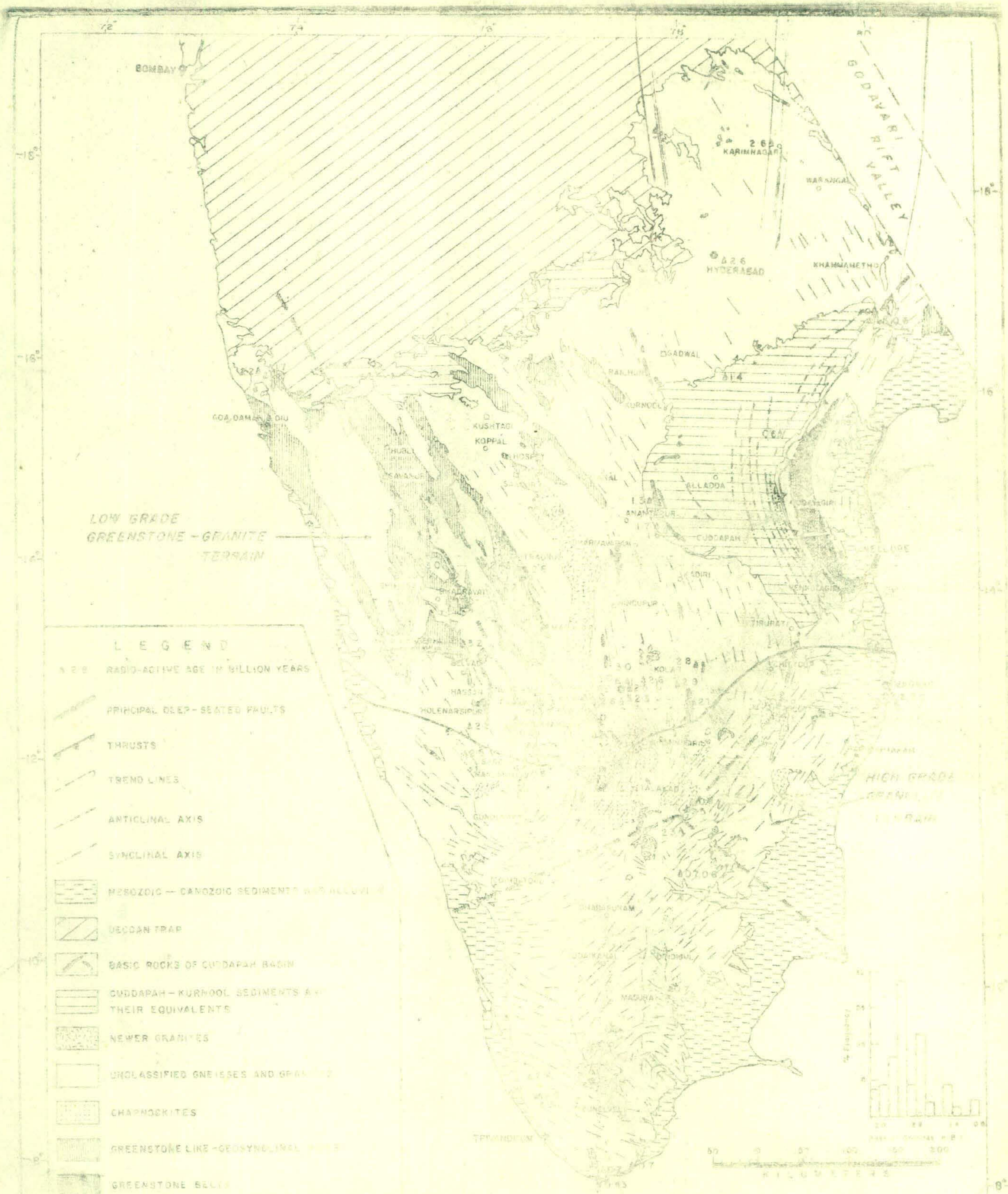


Fig. 1. Geological map of southern peninsular India, showing the four successive geological settings, high and low-grade me[illegible] structural trends and radioactive ages. The inset shows the frequency distribution of the available radioactive ages of granitic [illegible] over the region.

(Naqvi et al 1978)

Fig. 2.1.

Gneisses exposed along this anticlinal axis was were considered to be intrusive into the schist belts assuming that this axis does not represent geographic ridge of pre-Bababudan age (Iyengar, 1976). In the northern part of the Craton, the schist belts strike WNW and swings to NNW and N-S in the central part. In the southern part the strike becomes SSW to SW. The regional structural trends in Dharwar craton, in general are arcuate with the concave side facing west and south west and terminating at the Arabian sea coast (Narayanaswamy, 1971; Iyengar, 1976). The important structural elements are presented in fig.2.1.

Chadwick et al., (1978) studied the structural elements of Sargur, Holenarasipur and Chitradurga schist belts and identified L and S tectonics and related structures, leading to three phases of deformation Sg D_1; Sg D_2; and Sg D_3 in the older Sargur group and Dh D_1; Dh D_2 and Dh D_3 in the younger Dharwar super group. They found that the strains and timing of various phases relative to metamorphism are similar in both the groups and matched Sg D_1 = Dh D_1; Sg D_2 = Dh D_2 and Sg D_3 = Dh D_3. However, the presence of unconformities between older Sargur group and the younger Dharwar super groups lead the authors to suggest that the tectanometamorphic fabrics in Sargur rocks are over printed and rotated into parallelism with structures in Dharwar rocks at Holenarasipur and Chittaldurga during younger Dh D_1 and Dh D_2 deformation. Their structural studies further showed that tectanometamorphic events affected a wide area with similar timing.

Structural studies on Sargur supracrustal rocks by Janardhan et al., (1979) revealed four major fold episodes and associated fault movement and polymetamorphic, polydeformational nature of the terrain. They traced structural continuity of the Sargurs into the highgrade granitic terrain, South of Sargurs. Their study implies continuity of the low grade gneisses of north to high grade terrain of south as granulitic rocks (Charnockites) along with the associated supracrustals. ⑥

Based on the structural and metamorphic relationship among Sargurs, Peninsular gneisses and Dharwar supra crustals Chadwick et al., (1981) concluded that Peninsular gneisses were injected in a series starting with polyphase gneisses and concluding with Chikmangalur granite (and thier equivalent granitoids of Ghatti Hosahalli area) within a time span of 100 m.y. This caused the scattering and migmatisation of Sargur rocks. Further these Peninsular Gneisses form the basement to the Dharwar supra crustals. Their study shows that the younger greenstone belts/geosynclinal piles are laid on Peninsular Gneisses and thus the environment and possibly the tectonics of the younger greenstone belts are different from the true greenstone belts.

The greenstone belts on Eastern side of Dharwar craton (Kolar, Ramagiri, Hutti, etc.) are classified as ④ true greenstone belts (Naqvi, 1976; Radhakrishna, 1976). Naqvi *et al.*, (1978) and Radhakrishna (1976) included Sargur schists in the true greenstone belts. Ramakrishnan *et al.*, (1976) and Swaminath *et al.*, (1976) classified the greenstone belts in western block as Dharwar type and the ones in the Eastern block as Keewatin type. A third group has been distinguished and christined as Sargur group comprising Sargur Schists (Viswanatha and Ramakrishnan (1976). This is considered as the oldest among Dharwar supracrustals and equivalent to ancient supracrustals of W. Greenland. The identification of Sargurs as a separate group has strong implications on the evolution of Dharwar craton as a whole and evolution of greenstone belts, as this envisages three stage development.

3. Metamorphism:

A gradational increase in metamorphism from North to South in Dharwar Craton is recognized by Pichamuthu

(1951, 1962 and 1965). The metamorphism begins with greenschist facies passing through amphibolite facies to the granulite facies as evidenced by the low grade gneisses in the central region and granulitic (Chrnockitic) rocks at the southern margin. Viswanatha and Ramakrishnan (1976) divided the Dharwar craton into Eastern and Western blocks based on metamorphic grade of Sargur schists and differences in the greenstone belts. Recently Rollinson <u>et al</u>., (1981) studied the mineral chemistry of Sargur schists on Eastern and Western blocks and showed that the Eastern block obtained maximum temperature of $750^{\circ}C$ and $850^{\circ}C$ and a maximum pressure of 7 kb; the western block, however, reached a maximum temperature of $790^{\circ} \pm 50^{\circ}C$ and a pressure of 13 ± 2 kb suggesting relatively thicker crust on the Western side during Dharwar. Further this data suggest a maximum crustal thickness of 45 Km and there was a maximum difference of 20 Km in crustal thickness between Eastern and Western blocks. Thus, the metamorphic grade in the Dharwar craton increased both from North to South and from east to west.

Within this broad framework, individual schist belts may have different patterns of metamorphism as in Bababudan Group where a progressive decrease in metamorphism form the margin to the core of the belt is noticed (Viswanatha and Ramakrishnan, 1981). Kolar schist belt has experienced low pressure regional metamorphism and they have reached middle amphibolite facies at the margin. (Ramakrishnan et al., 1976; Viswanatha and Ramakrishnan, 1981). Rajamani et al., (1981) based on the study of chemistry of amphiboles, plagioclase and sulphides of the four varieties of metabasalts of Kolar schist belt, suggested middle to upper amphibolite facies for the Kolar amphibolites and further noted that there is no difference in metamorphisms between the amphibolites within the belt. Sarkasanahalli association formed as enclaves near KSB are considered to be equivalent to Sargurs. Narayanan Kutty and Ananta Iyer (1977) estimated a temperature of 600-650°C at 3 to 5 kb for critical rock parageneisis of Sarkasanahalli association.

The gneisses close to the schist belts have apparently undergone the same degree of metamorphism as that of the schist belts. The Closepet granite region is considered to have reached 600-700°C and 3 kb during Dharwar regional metamorphism as evidenced by the Cord + Hyp + Gedrite + Sill + Gt assemblage commonly noticed (Srinivas and Srinivasan, 1974).

4. Granitic Rocks in Dharwar Stratigraphy:

The stratigraphy of Dharwar craton has been revised continuously on accumulation of new evidences ever since the first statigraphy proposed more than a century ago. In this chapter a few stratigraphic models proposed recently based on current thinking and new evidences are discussed. Among these, five stratigraphic models are presented in Table 2.1a,b,c,d and e.

Before the infusion of the 'greenstone-granite belt' concept among the geologists working in Dharwar craton, the craton was considered as a single entity and various components within a greenstone belt are assigned to various divisions in the Dharwar stratigraphy and Peninsular gneiss was considered as a single unit. Later this stratigraphy was revised considerably by Radhakrishnan (1964) who assigned gneisses as basement and introduced the series concept in the Dharwar stratigraphy. Nautiyal (1966) recognized that Peninsular Gneisses were polyphase and assigned them to various positions in Dharwar stratigraphy (Table 2.1a).

Iyengar (1976) classified various schist belts under Vanivilas, Aimangala and G.R. Halli-Ranibennur Groups. He first introduced Mercara group to include

Table 2.1: Stratigraphic Models Proposed for Dharwar Craton

[a] Nautiyal (1966)

DHARWAR (Proterozoic)	
Upper	Quartz veins
	Sandstones, greywakes, shales, calc phyllites
	- Unconformity--
	Younger granites
Middle	Conglomerates, quartzites, limestones, dolomites, greywakes, shales, ironstones, pillow lavas.
	-Decollement
	Champion gneiss, diapir granites
Lower	Acid to ultrabasic intrusives
	Metagreywackes, chloritif and graphitic schists, metavolcanics, quartzites
	- Thrust -
	Anatectic granites and migmatites (Closepet)
ARCHAEAN	
Upper	Sillimanite-kyanite-garnet schists, amphibolites, epidiorites, ultrabasics, porphyry dykes
	- Thrust -
	(Peninsular Gneissic Complex)
Lower	(Gneisses with xenoliths of older metasediments and amphibolites)
	- Thrust -
	Refused gneisses
	Charnockites, pyroxene granulites, calc granulites, garnet amphibolites
	Original crust not recognisable due to repeated palingenesis.

Table 2.1 (contd.)

[b] Srinivasan and Sreenivas (1976)

DHARWAR GROUP

G.R. Halli Sub-group

Closepet granite

Peninsular gneiss (s.s.)

Champion gneiss

Chitradurga Sub-group

Dodguni Sub-group

Bababudan Sub-group

Nuggihalli Sub-group

Peninsular gneiss
(fundamental and remobilised gneisses)

Biligirirangan-Sargur Group

(Charnockites, Khondalites and chromiferous ultramafics)

Table 2.1 (contd...

[c] Radhakrishna and Vasudev (1977)

Dharwar Super-Group	Ranibennur Group
	Chitradurga Group
	Bababudan Group

Generation of granulitic mobile belt through reworking of older crust

Peninsular gneisses
Sargur Schist Complex
Base not recognised

TH-1066

Table 2.1 (contd...

[d] Naqvi (1981)

Chitradurga Group

2.6 - 2.4 b.y.
Granitic activity
Chert, sericitic phyllite
Metavolcanics
Chlorite schist
Greywacke conglomerates (K.M. Kere)
Greywacke
Greywacke conglomerate (Aimangala)
Arkose-grit
Greywacke conglomerate (Talya)

Bababudan Group

Kaldurga conglomerates
Quartzite (BMQ)
Argillite schist
Mafic flows
Mafic flows with interlayers amphibole-garnet schist
Chlorite schist
Orthoquartzite (fuchsitic at places)
Basal conglomerate

----- Unconformity -----

Javanahalli Group

Dykes
Quartz
Veins
Pegmatites
Granites
Fuchsite-quartzite
Ultramafic-schist
Ortho-amphibolites
Para-amphibolites interbedded with carbonate, calcsilicates etc. para-gneisses

- -

[contd...

Table 2.1 [d] contd...

Holenarasipur Group

Krishnarajpet	Holenarasipur	Nuggihalli	Ghattihosahalli
	Tonalitic and Trondhjemitic activity (3500 million years)		
Dunite, amphibolite Fuchsite quartzite Hornblende schist Tremolite-actionlite schist; 95% of the area consists of basic ultrabasic rocks	Dunite, Fuchsite quartzite, high Al Mg, Sediments Hornblende schist tremolite-actionlite-schist, serpentinite, peridotite; 60-70% of area is made up of basic/ultrabasic rocks	Titaniferous magnetite Dunite, Fuchsite-Quartzite Hornblende schist Tremolite-actionlite-schist, serpentinite, peridotite; 80% of the area is made up of ultrabasic rocks	Fuchsite quartzite Barytes Tremolite-actionlite-schist, serpentinite, amphibolite; 80% of the area is made up of ultra-basic rocks
	BASEMENT ? ? ? ?		

Table 2.1 (condt...

[e] Swami Nath and Ramakrishnan (1981)

		Western Block		Eastern Block
DHARWAR SUPER-GROUP	Chitradurga Group	Hiriyur Formation		
		Ingaldhal Volcanics		
		Vanivilas Formation		
		------ Unconformity ------		
	Bababudan Group	Mulaingiri Formation	KOLAR GROUP	Gold Field Volcanics
		Santaveri Formation		Champion Gneiss
		Allampur Formation		Yerrakonda Formation
		Kalasapura Formation		
		--------Unconformity---------		
		PENINSULAR GNEISS (3000 m.y.)		
SARGUR GROUP		Ultramafic-mafic complex and anorthosites		Sakarsanahalli Association
		Ironstones, amphibolites and pyribolites		
		Marbels and calc silicate rocks		
		Metapelites with kyanite, staurolite, garnet, sillimanite, graphite and corundum.		
		Fuchsite (± sillimanite, kyanite) quartzite locally with baryte beds and chromite layers		

highly altered schists. The recent classification of Dharwar stratigraphy by Srinivasan and Srinivas (1976), Radhakrishna and Vasudev (1977), Naqvi (1981), Swaminath and Ramakrishnan (1981) are presented in Tables 2.1b,c, d and e. In the above stratigraphic models, though recent findings are incorporated, some problems remain to be solved as reflected by differences among these models. Some models include part or whole of Sargur schists in the Dharwar group and in the other models, Sargurs are grouped as older and separated from the Dharwar group by an unconformity. The position of Kolar schist belt also remains controversial. One important aspect of all the models is that polyphase nature of the Peninsular gneisses is appreciated and as far as possible various components are identified and classified accordingly, at least locally. The Dharwar stratigraphy can be further improved by identifying various units in the gneisses and granites by geochemical and geochronological studies and asscertaining the relationship between schists and adjoining gneisses.

5. Granitic Rocks and High Grade Granulites:

The charnockites were considered as intrusions into the Dharwars and younger than Peninsular gneisses by the early workers (Smeeth 1916, Pichamuthu 1967).

Later, Charnockites were regarded as earliest geosynclinal rocks/mobile belts (Narayana Swamy 1966, 1975; Nautiyal, 1966; Srinivasan and Srinivas, 1972) and later thrust over the Dharwar block and separated from type Dharwar rocks by a thrust running close to the Southern border of Karnataka state (Iyengar 1976).

Based on field and petrographic studies at Kabbaldurga, Pichamuthu (1961) proved that gneisses were transformed to Charnockites and this is supported by the results of latter workers (Ziauddin and Yadav, 1975; Ramiengar, 1978; Janardhan _et al._, 1982 abst.). The charnokitisation of gneisses was attributed to metasomatism and deepseated plutonic metamorphism by above authors. Recently Friend (1981) suggested dehydration of H_2O, influx of CO_2 are responsible for charnockitisation at lower levels and accumulation of H_2O at higher levels causing crustal fusion. The metamorphic event around 2600 m.y. (Venkatasubramanian 1974) is considered to have affected both high and low grade terrains (Chadwick _et al._, 1981) with varying intensity.

The recent findings suggest that the charnockites are nothing but continuation of low grade gneisses and probably represent an older component of Peninsular gneisses. Pichamuthu (1976) suggested that the Charnockites have originated from lower/deeper crustal rocks and thus form the basement.

6. Granitic Rocks and Greenstone Belts:

The gneisses and granites are little studied and understood in Dharwar craton. Even today the map of Dharwar craton fig. 2.2 shows all the granitoids as either unclassified gneisses and granites or as Peninsular Gneisses but for the demarcation of Closepet granites. Recently some geochronological and geochemical studies are carried out and they are mostly of prilimanary in scope. However, with available data new concepts on gneisses and granites and their relationship with schist belts are postulated (Srinivas and Srinivasan 1974, Pichamuthu 1976, Radhakrishnan 1974, Divakara Rao et al., 1974, Swaminatha et al., 1981).

Srinivas and Srinivasan (1976) classified the granitoids of Dharwar craton into three main units, i.e.,

1. A migmatitic complex with more homogeneous granite phase namely Peninsular gneisses;
2. Island like granitoid intrusions in greenstone belts and;
3. A series of coarse grained porphyritic granites called closepet granites.

with the recent findings of greater 3300 m.y. old gneisses from Dharwar craton (Beckinsale et al., 1980) there is a possibility of older rocks existing at least in patches,

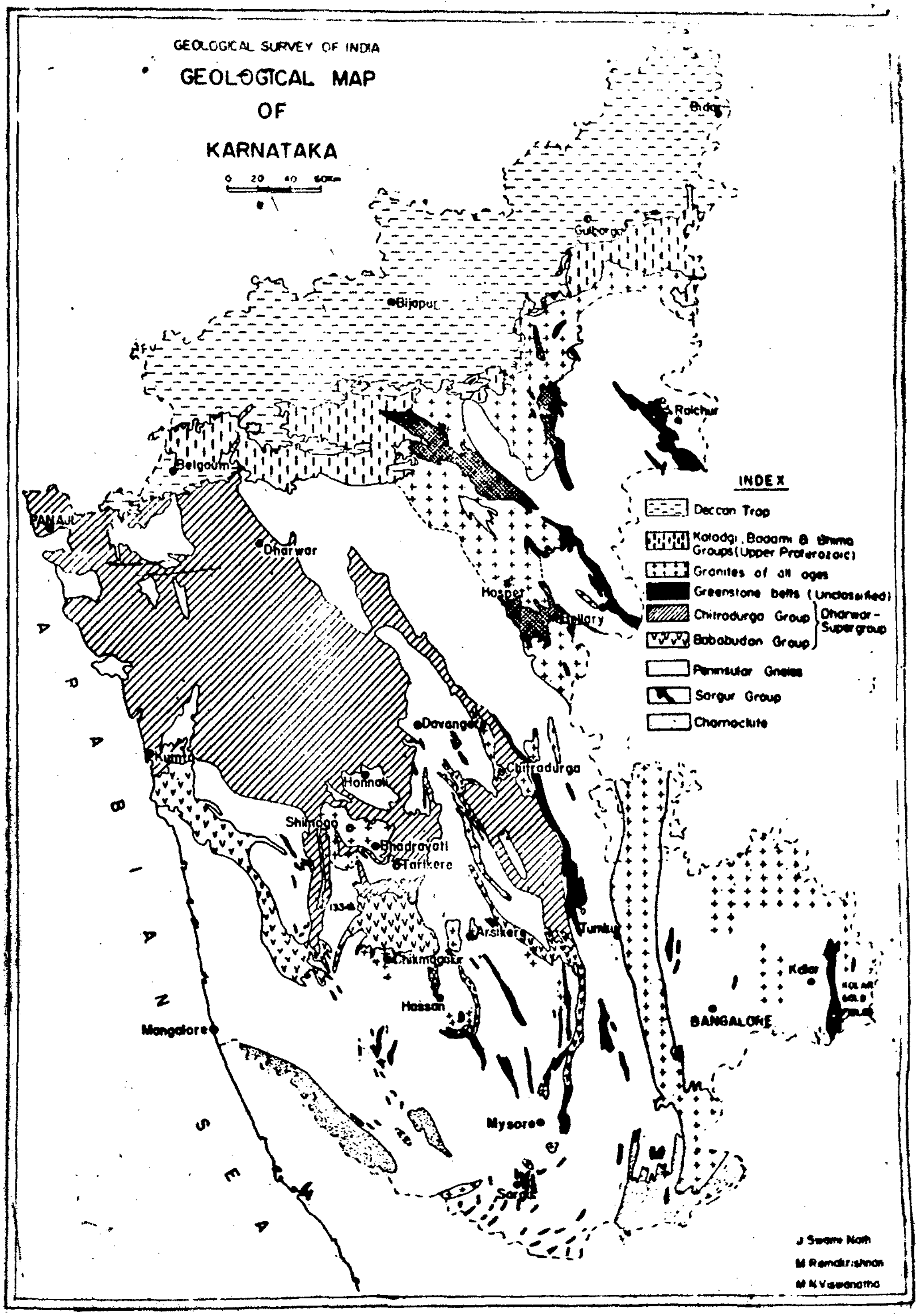

GEOLOGICAL SURVEY OF INDIA
GEOLOGICAL MAP
OF
KARNATAKA
0 20 40 60Km
Bidar
Gulbarga
Bijapur
Raichur
Belgaum
PANAJI
Dharwar
Hospet
Bellary
Davangere
Chitradurga
Kumta
Honnali
Shimoga
Bhadravati
Tarikere
Arsikere
Tumkur
Chikmagalur
Hassan
Kolar
KOLAR GOLD FIELDS
BANGALORE
Mangalore
Mysore
Sargur
ARABIAN SEA
INDEX
Deccan Trap
Kaladgi, Badami & Bhima Groups (Upper Proterozoic)
Granites of all ages
Greenstone belts (Unclassified)
Chitradurga Group
Bababudan Group
Dharwar-Supergroup
Peninsular Gneiss
Sargur Group
Charnockite
J Swami Nath
M Ramakrishnan
M N Viswanatha

Fig. 2.2

in the migmatitic gneisses. Hence, the early precambrian granitoids of Dharwar craton can be broadly classified into 4 types. In this light, the relationship between various important schist belts and granitoids are considered below.

Rocks of Sargur schist belt are found as enclaves in migmatised gneisses and banded gneisses (Iyengar, 1976, Viswanatha and Ramakrishnan 1981). The basement for the Sargurs are still speculative and a component of Kabini gneisses could be the basement (Janardhan *et al.*, 1979). Chadwick *et al.*, (1979, 1981) consider simatic basement with small nucleii of sialic rocks older than 3000 m.y. for the Sargur rocks. Similarly the basement for Nuggihalli and Krishna-rajpet belts still remain unresolved (Ramakrishnan 1981, Pichamuthu 1974, Varadarajan and Pande 1965).

The basement for the true greenstone belts lying in the Eastern block is still speculative. The gneisses and granites are considered as intrusives by some and basement by others. However, there are granites within the greenstone belts showing clear intrusive relationship as that of Patna and Bisanathan granites in the KGB (Bhalla *et al.*, 1978). Generally the contacts between gneisses and schists are obscure and screened by numerous pegmatites.

On the other hand, the younger greenstone belts/ geosynclinal piles of the Western block are laid unconformably on the older migmatitic gneissic complex as evidenced by the structural studies (Chadwick et al., 1979; 1981), field studies (Dhurva Rao et al., 1972, Bhaskara Rao and Ahmad 1982) and recent geochronological studies (Beckinsale et al., 1980).

From the above discussions it is evident that the oldest granitoids > 3300 m.y. do exist in the Dharwar craton and they may be considered as primitive crustal material (primitive sialic nucleii) within simatic crust. The later migmatitic gneisses may have intrusive relationship with older greenstone belts which needs to be confirmed and their equivalents in western block could be the basement for the younger greenstones. The porphyritic and more potassic granites could be later intrusives into the schist belts as well as into the older gneisses.

7. Geochemistry of Granitic Rocks:

In Dharwar craton, the earliest formed granitic rocks are considered to be tonalitic (Saha 1979) as the granitic pebble from Kolar Gold Field conglomerate gave tonalitic composition (Srinivas and Srinivasan 1974). The Geochemistry Group of N.G.R.I (1977) suggested the earliest granitic rocks could be trendjhemitic. Further, the Working Group suggested that the plutonic activity has changed to tonalitic to granodioritic and lastly to granitic. Ample evidence is available for systematic increase in K and Th and depletion of Ca and Mg with the evolution of younger granitic rocks (Divakara Rao et al., 1974; Syedali and Divakara Rao, 1980; Srinivas and Srinivasan, 1974; Saha, 1979; Jayaram et al., 1982 abst.). However, Srinivas and Srinivasan 1976) noted that the available Rb/Sr, K/Na ratios do not give a cogent picture of granitic crustal evolution. This may be owing to the paucity of dates available, and lack of systematic precise analysis on critically chosen samples.

It is interesting to note that the intrusive Patna granite in KGB shows higher Th-U contents of 18 and 7 ppm with higher U/K ratio compared to other Archean granitic rocks (Rao and Rao 1977). Further Th and U contents of granitic rocks on the Eastern side of KGB are 7.4 ppm and 2.7 ppm and Th/U = 2.7, falling in the normal range from typical granitic rocks. On the west of KGB Th and U are 15.5 and 1.2 ppm resulting in very high Th/U ratio = 12.7 which is anomolous. The K contents are apparently similar on both sides. Also anomolously high enrichment of Th and U are noted in the grey series of Hyderabad with 70-125 ppm of Th and 5.1 - 13.4 ppm of U, with high Th/U and U/K ratio. They show good correlation with petrological subgroups (Rao and Rao, ibid). Sutton (1979) noted that there is close relationship between uranium deposits and Precambrian rocks in their vicinity and they are generally not seen in the vicinity of very oldest precambrian rocks. This may have some bearing on the crustal evolution and distribution of U in granitic rocks when considering younger age of Hyderabad granites (Ca 2000 m.y.).

8. Geochronology:

Reliable age determinations available for the rocks of Dharwar craton are presented in fig2.3 in the form of a histogram showing the distribution of ages for various types of granitic rocks (Data for metabasalt are not represented on the account of their unreliability due to the LIL depletion). The data for the histogram is taken from: Venkata Subramanian *et al.*, (1969), Sarker (1968), Crawford (1969), Venkatasubramanian *et al.*, (1971), Venkatasubramanian and Narayanasamy (1974a, 1974b), Jayaram *et al.*, (1976), Balasubramanian *et al.*, (1976), Bhalla *et al.*, (1978), Monard *et al.*, (1982), Bhaskara Rao (1982), Beckinsale *et al.*, (1980), Beckinsale *et al.*, (1982), Recent review on this subject is presented by Sarkar (1980).

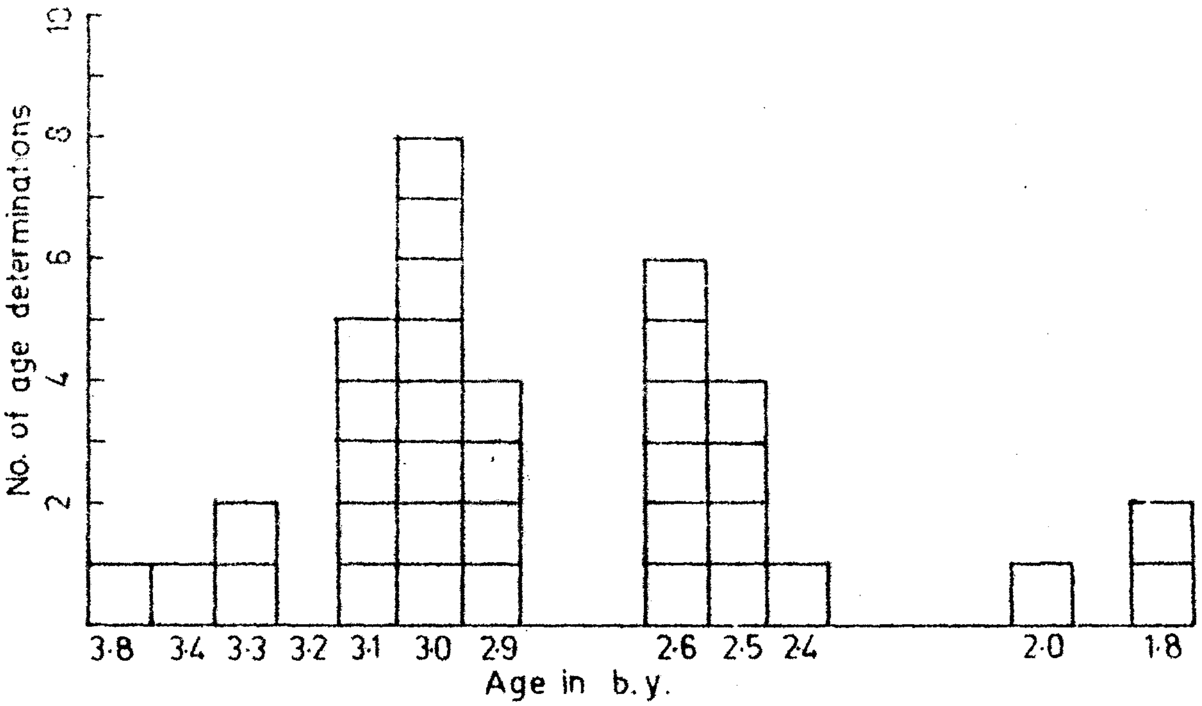


Figure 2.3: Histogram showing distribution of ages in the rocks of Dharwar Craton.

Almost all the ages are determined using Rb/Sr wholerock method. The new ages around 3.3 b.y. are recently made available for the gneisses. Monhad et al., (1982) have reported as crude age Ca 3.8 b.y. for one subgroup of low Al gneisses with extremely low Rb content near Holinarasipur schist belt. The initial Sr^{87}/Sr^{86} ratios for the gneisses older than 3.3 b.y. are extremely low and they have been considered as derived from the mantle (Beckinsale et al., 1980, Monhad 1982). Some of the rocks in 2.9 - 3.1 b.y. range show low IR and others high IR, falling well above the mantle growth line. The rocks with low IR are generated from mantle or lower crust with short crustal residence time; the rocks with high IR may represent either reworked crustal material or they have undergone alkali metasomatism causing enrichment of Sr^{87} (Bridwater and Collerson, 1977; Moorbath, 1977). If the former is the case, then the gneisses with high IR could have originated by reworking of older sialic crustal material.

The majority of rocks around 2.5 b.y. are with higher IR suggesting reworking of early crustal material and the others representing magmas derived from the lower crust/mantle. Further the shape of the histogram shows two major tectono-magmatic events. The gneisses

> 3.3 b.y. represent the early formed granitic rocks. During 2.9 - 3.1 b.y. period volumunous sialic material was added to the crust, possibly scattering the oldest schists (Sargurs). The 2.5 to 2.6 b.y. period represents fresh additions to crust and reworking/fusion of granitic materials already existing, and regional metamorphic event. Chadwick *et al.*, (1978, 1981) and Janardhan (1979) suggested a regional metamorphic event at 2600 m.y. coinciding with the geochronological evidence.

CHAPTER-III

PETROGENESIS OF GRANITIC ROCKS - A GEOCHEMICAL APPROACH

3.1 General Considerations:

The origin of granitic rocks is a complex subject and several processes such as magmatic, anatectic, metasomatic and metamorphic are believed to generate rocks of granitic composition. The above mentioned processes individually or combinedly may give rise to single product - granite. Winkler (1967) has shown that anatexis of sediments could give rise to granitic melts. Based on experimental evidence and a statistical survey of the composition of granitic rocks, Tuttle and Bowen (1958) suggested magmatic origin of granites. Recent developments in geochemistry of granitic rocks and experimental petrology have shown that granitic melts can be generated by partial melting of a variety of rocks in a broad range of P, PH_2O and T conditions. Trace element geochemistry of granitic rocks along with their petrography, major element chemistry and field geology have shown to be very useful in terms of reducing the possible models of petrogenesis to a few (Hanson, 1978).

A granitic rock crystallized from a melt, could have been derived by one or other of following processes as suggested by Hanson (1978):

1. Partial melting of mantle,
2. Basaltic rocks,
3. Other granitic rocks,
4. Rocks of intermediate composition and,
5. Sedimentary rocks.

The melts thus derived could have undergone differentiation and other alterations including assimilation. Trace element approach involves testing of the above mentioned models quantitatively for a given suite of granitic rocks.

3.2 Trace Element Theory:

The quantitative approach involving trace elements to granite petrogenesis is made possible by determinations of mineral melt distribution co-efficient (Kd) for granitic system. The Kd can be expressed as

$$Kd_i = \frac{\text{weight fractions of a trace element i in the mineral}}{\text{weight fraction of the trace element i in the melt}}.$$

Under equilibrium conditions, the Kd is independant of relative proportion of melt and mineral and the concentration of the trace element considered as it follows

TABLE 3.1

Definitions of Symbols and Terms Used

X^i = weight fraction of phase i in the solid

Kd^i = mineral/melt weight distribution coefficient of a trace element for phase i

D = bulk distribution coefficient of a given trace element for residual mineral phases at time of separation of melt and residue;

$$D = \sum_{i}^{n} X^i Kd^i$$

D_o = bulk distribution coefficient of a given trace element at the onset of melting

þ^i = fractional contribution of phase i to the liquid

$P = \sum_{i}^{n} \text{þ}^i Kd^i$

C_o = weight concentration of a trace element in parent.

C_L = weight concentration of a trace element in a derived melt.

C_s = weight concentration of a trace element in the residual mineral phases.

$D = C_s/C_L$

F = weight fraction of melt relative to original parent.

Henry's law. The Kd is influenced by temperature, composition of the mineral and melt, pressure and volatile content. The bulk distribution co-efficient (D) of a trace element between residue and melt under equilibrium conditions can be calculated using the relation

$$D = \Sigma_{i}^{n} X^{i} Kd^{i}$$

Trace element modelling involves mainly three stages, i.e., (1) Melting, (2) Crystallization and (3) Transportation. Any one or a combination of (these processes) above three stages can be considered in trace element modelling, depending upon the nature of the rock (plutonic or volcanic, etc.). The style of melting can be modal, non modal or incongruent. Apart from this, there are three types of melting as described below:

a. Batch melting: throught the melting, the liquid remains in equilibrium with the residual solids and the melt is removed on termination of further fusion.

b. Fractional melting: small fractions, as they melt, are continuously and completely removed and stored in a magma chamber, and

c. Continuous melting: as melting takes place, small fractions of melt are removed and stored in a magma chamber, However, the melt is not completely removed and a portion of it is always in contact with the residual solids.

Shaw (1977) has shown that, the trace element behaviour among various styles of melting, the modal, non-modal, and incongruent melting is almost similar. But the trace element contents in the melt differ considerably depending upon the type of melting considered like batch melting, fractional melting or continuous melting. Among these various types of melting, the batch melting appears to be reasonable. The first formed melt contains volatiles and fluids. Once these are removed, the residue becomes dry and the solidus of the residue is increased, terminating further melting (Hanson 1978). Particularly for the generation of acidic melts, presence of volatiles and fluids is essential (Wyllie <u>et</u> <u>al</u>., 1976). Therefore, only batch melting will be considered in further discussions.

The equations for batch melting as given by Shaw (1970) is

$$\frac{C_L}{C_o} = \frac{1}{D_o + F(1-P)} \quad \ldots \quad (1)$$

This equation can be rewritten as,

$$\frac{C_L}{C_o} = \frac{1}{(D_o - PF) + F} \quad \ldots \quad (2)$$

In the above equations, D_o and P are constants, provided, Kd and melting proportions of phases are kept constant and none of the phases reacted out. Once a phase has reacted out, new values for D_o and P should be calculated and inserted in the equation. For varying Kds and melting proportions, equation given below can be used,

$$\frac{C_L}{C_o} = \frac{1}{F + D(1-F)} \quad \ldots \quad (3)$$

D is affected by melting components that are solid solutions, pressure ($D \alpha P$) and temperature ($D \alpha \frac{1}{T}$) [Shaw 1977].

Neuman et al., (1954, quoted by Hanson, 1978) established the relation between the concentration of an element in fractionated melt (C_L) and parent melt (Co) as:

$$\frac{C_L}{C_o} = F^{(D-1)} \quad \ldots \quad (4)$$

Apart from melting and fractional crystallization, our knowledge of the effect of assimilations, contaminations and any other changes on magma during emplacement (transport) is very little. Some attempts are made to understand the changes a magma undergoes while passing through pores of rocks or solid cummulates (commonly referred as 'Zone refining') [Shaw 1977].

3.3 Trace Element Behaviour and Application:

The equation (3) for batch melting shows that concentration of a trace element in the melt (C_L) relative to the source (Co) is dependent only on bulk distribution coefficient (D) and extent of partial melting (F); from this equation, we can show that for lower extents of melting, and if D >> F,

$$\frac{C_L}{C_o} = \frac{1}{D}$$

Similarly as D approaches 0, $\frac{C_L}{C_o}$ approaches $\frac{1}{F}$. The changes in C_L/C_o for D ranging from 0 to 10 and for varying extents of melting are shown in Fig. 3.1

The equation (4) for fractional crystallization also shows that concentration of a trace element in liquid (C_L) is a function of D and F.

Similar to partial melting, as D approaches zero,

$$\frac{C_L}{C_o} \longrightarrow \frac{1}{F}.$$

But if D > 1, unlike partial melting, fractional crystallization depletes the trace element from the melt considerably. Fig.3·2 shows how C_L/C_o varies with F and D during fractional crystallization.

From Fig.3·1 and 3·2, we can infer, that an element with very low D(D -> O) varies considerably with the low extents of melting upto 40% and an element with high D(D >> F) does not show much variation. Whereas during fractional crystallization the element with high D varies considerably as shown in fig.3·2 Thus by selecting a trace element with low D and plotting it against an element with high D for a suit of rocks as in the fig3·3, we can know whether the suit of comagmatic rocks are as a result of partial melting or fractional crystallization.

As discussed earlier, the bulk distribution coefficient is a function of type and proportion of various minerals in the residue/crystallizing cummulates and their Kds. The possible residual minerals or cummulates during partial melting/differentiation to form acidic melt are plagioclase, K-feldspar, quartz, hornblende, clinopyroxene, hypersthene, olivine, biotite or phlogopite, muscovite, cordeirite or sillimanite scapolite, oxides, sulphides, apatite and other accessory minerals (Hanson, 1978). Among the above mentioned minerals, Kds (for K, Rb, Sr, Ba and REE) are available for K. feldspar,

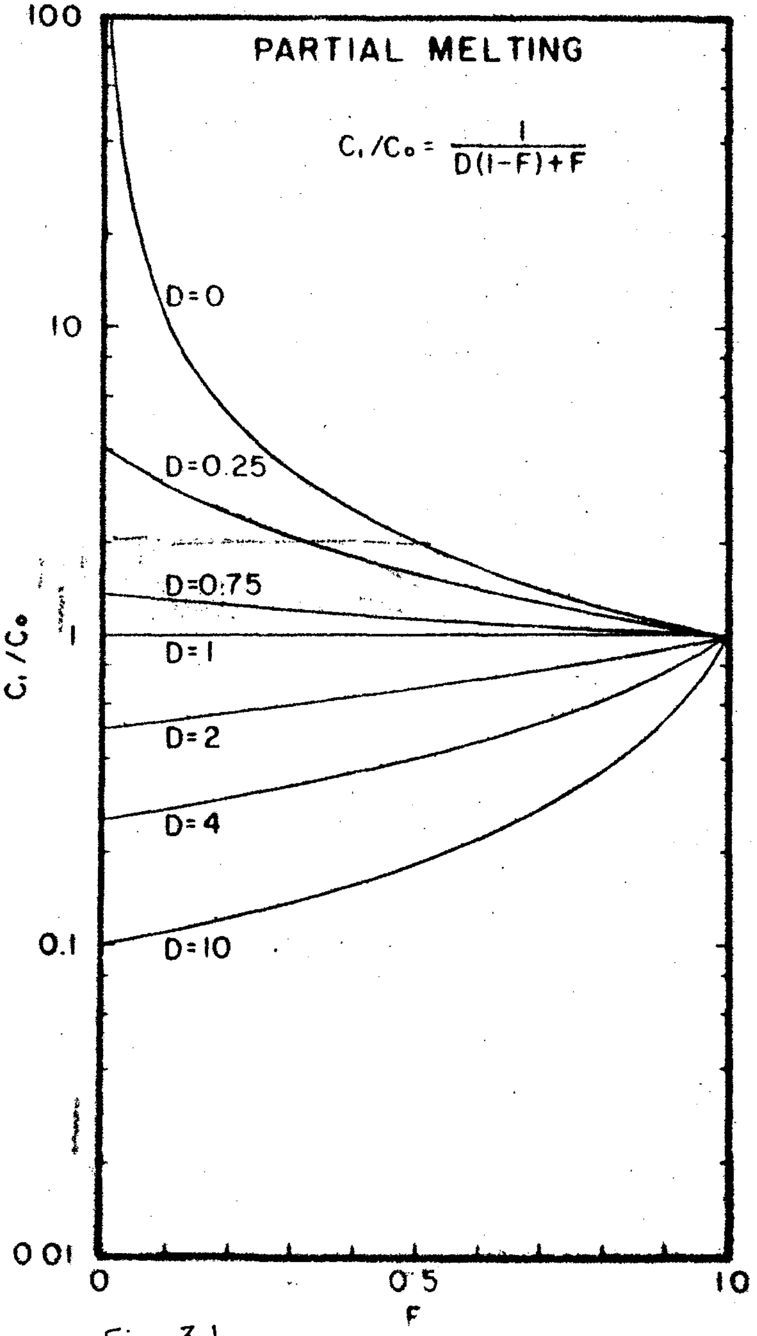

PARTIAL MELTING
$C_l/C_o = \frac{1}{D(1-F)+F}$
D=0
D=0.25
D=0.75
D=1
D=2
D=4
D=10
100
10
1
0.1
0.01
C_l/C_o
0
0.5
1.0
F

Fig. 3·1

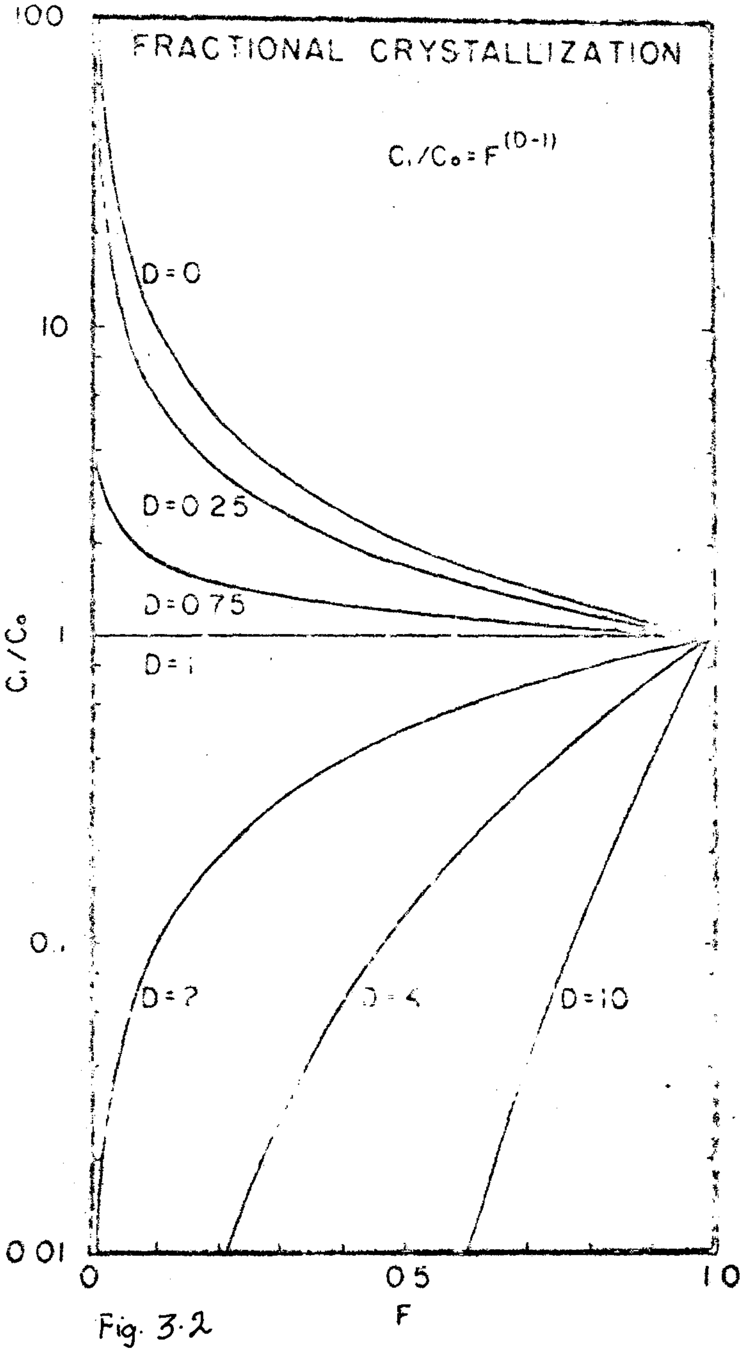

FRACTIONAL CRYSTALLIZATION
$C_l/C_o = F^{(D-1)}$
D=0
D=0.25
D=0.75
D=1
D=2
D=4
D=10
100
10
1
0.1
0.01
C_l/C_o
0
0.5
1.0
F

Fig. 3·2

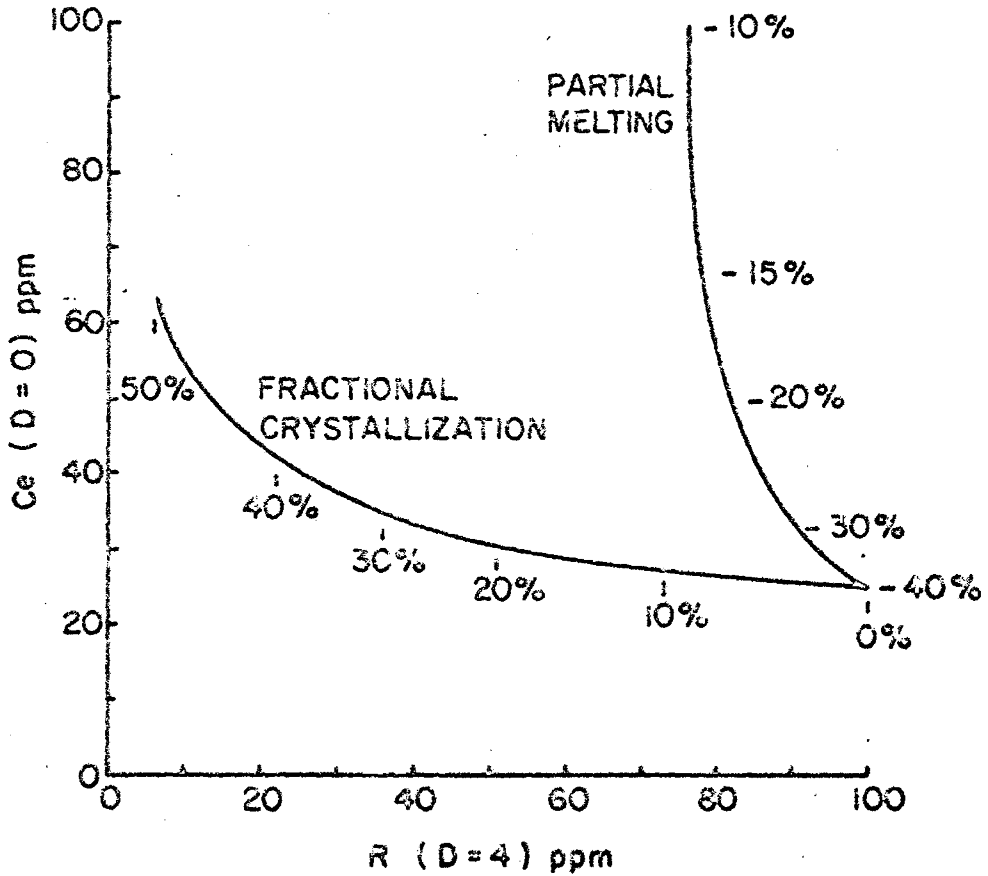

100
80
60
40
20
0
0
20
40
60
80
100
Ce (D = O) ppm
R (D = 4) ppm
PARTIAL MELTING
-10%
-15%
-20%
-30%
-40%
FRACTIONAL CRYSTALLIZATION
50%
40%
30%
20%
10%
0%

Fig. 3·3

anorthoclase, garnet, hypersthene, clinopyroxene, hornblende and biotite. Though Kds are not available for minerals like quartz, kyanite and sillinanite, it can be assumed as zero (Hanson, 1978).

A quantitative approach to trace element modelling involves testing of various models. A granitic melt can be generated from a variety of sources as mentioned earlier. To test whether a suite of granitic rocks are derived by partial melting of one or other sources, the modal mineralogy of the source and trace element content of the source should be known. For example, based on field geological and geochemical considerations, we believe that a certain rock with 20% quartz, 10% K feldspar, 50% plagioclase and 20% hornblende could be the source, and we know trace element abundances (for K, Rb, Sr. Ba, etc.) in this rock. Bulk distribution co-efficient (D) can be calculated using the relation

$$D = \sum_{i}^{n} X_i \, Kdi.$$

The trace element content (C_L) in the liquid for various extents of melting can be calculated using the equation 3. By comparing the observed trace element contents and their ratios in the rock of interest and the calculated trace element contents and ratios in the melt, We can understand if our presumed source was possible or not. If possible the extent of partial melting and the fractional crystallization and the nature of the residue and cummulate minerals.

The trace element ratios, particularly K/Rb ratios are widely used in petrogenetic modelling. Although both K and Rb are incompatible elements, the bulk distribution co-efficient of potassium (D_K) for almost any residual mineralogy is greater than that of Rb. As a result, K/Rb ratio in the initial melt is decreased relative to the parent during lower extents of melting. As the melting proceeds, the K/Rb ratio in the melt increases and approaches the parent ratio. Applying this to granitic system granitic melt generated by lower extents of partial melting of a basaltic source should have lower K/Rb ratio than the source basalt itself. For example let us consider a tholeiite having 0.23% K, 5 ppm Rb and K/Rb = 460 with modal composition of 10% Qtz, 45% Pb and 45% Hb, undergoing partial melting. Considering batch melting in the modal proportion, using equation (3), the concentration of K, Rb and K/Rb ratio in the melt for various extents of melting can be calculated: 1% of melt will have K/Rb = 190.9 and 20%

melt will have K/Rb = 385.5, K = .87% and Rb = 22.5 ppm. A tonalite with K/Rb = 365, K = 1% and Rb = 27 ppm could have been generated by partial melting of tholiitic source; whereas a quartz - monzonite with K/Rb = 134, K = 3.2% and Rb = 242 cannot be generated by partial melting of a normal tholeiitic source. Probably the quartz monzonite could have been generated from a source with higher K, Rb and lower K/Rb ratio than the tholeiite considered above. Similarly Rb/Sr and Sr/Ba ratios can be used to infer petrogenesis of granitic rocks.

The trace element modelling can be applied to understand the petrogenesis of granitic rocks in a meaningful way by combining field observations, petrography and major and trace element data. Further, data like initial isotope ratios and geochronology on the same rocks and on same samples may throw much light on the evolution of granitic rocks. Reviews on trace element application to petrogenesis of igneous rocks are given by Arth (1976) and Allegre and Minster (1978). A review on application of trace element modelling particularly to petrogenetic problems pertaining to granitic rocks is given by Hanson (1978).

CHAPTER-IV

PRESENT STUDY

4.1 Field Work:

The field work was carried out in two legs during February 1981 and June 1981. In the first leg six traverses are made on the eastern side of Kolar Greenstone belt. The western side of the belt was covered by four traverses in the second leg. A portion of felsic gneisses (Peninsular Gneisses) west of KGB has been already mapped by Granath and Rajamani (1982).

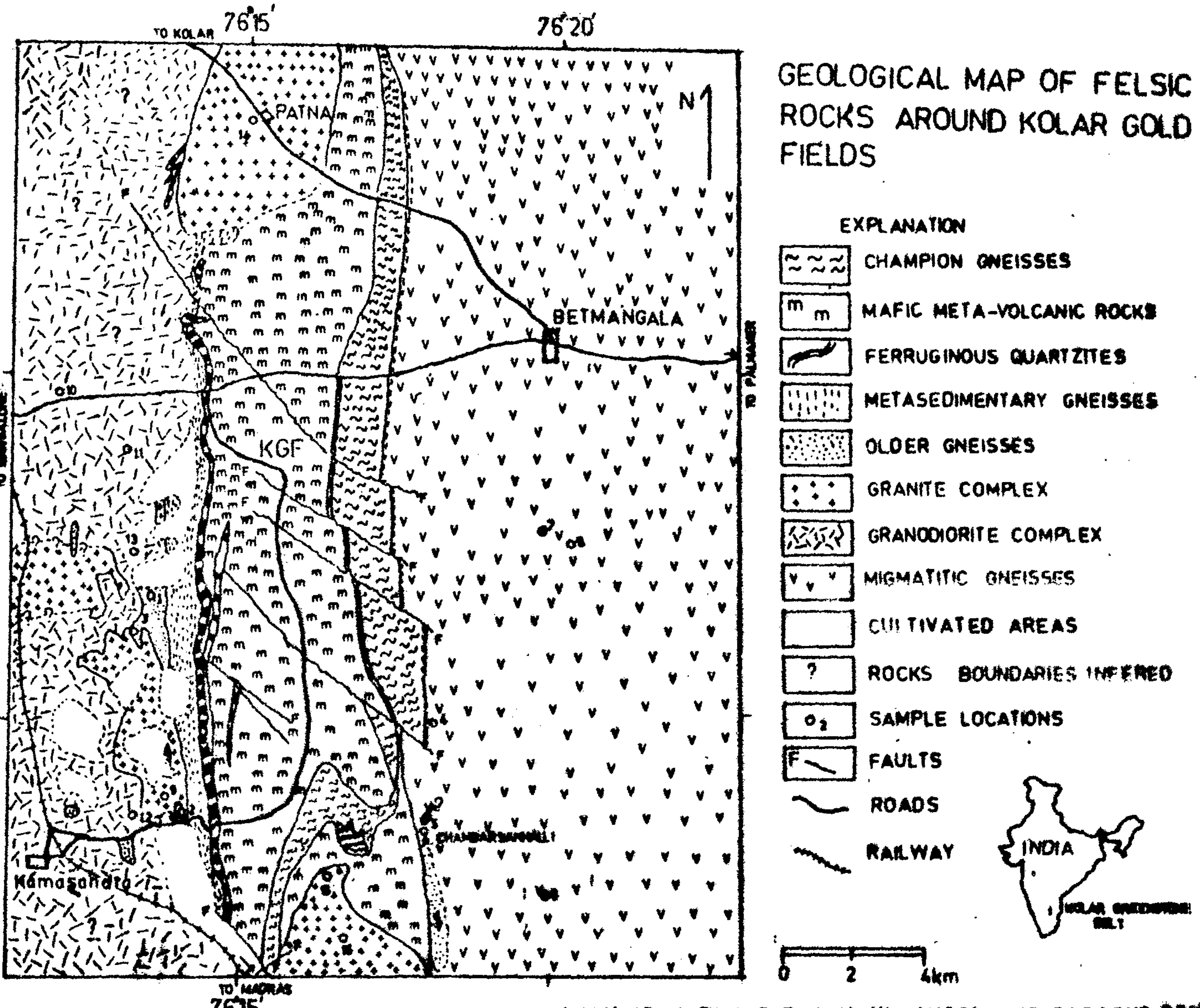
In this preliminary field work, an attempt has been made to distinguish and map various components of felsic rocks around central part of Kolar greenstone belt. On the Western side of the belt four types of gneisses are identified. A thin band of quartzo-feldspathic metasedimentary gneiss with amphibolite enclaves is noticed immediately adjoining the iron formation. These metasedimentary gneisses have foliation trending N-S and dipping 70 to 80° E as noted by Granath and Rajamani (1982). Further West, three types of gneisses are recognized. The polydeformed, highly veined and complexly folded gneisses occur as large enclaves within the granitic and granodioritic gneisses. Because the deformational history recorded in this unit possibly predates the main KGB event, the polydeformed gneisses are thought to be older than other gneisses (Granath and Rajamani, 1982). N.W. of Dod Valagmadi, older gneisses and granodioritic intrusives are seen. The granodioritic intrusives include mafic xenolithis and are cut by aplytic dykes. The granodioritic intrusives are migmatitic at places. S.W. of Chik Karimakanhalli a patch of older gneiss is seen. Adjoining this, migmatitic granodioritic gneisses are seen. Often it becomes difficult to distinguish older gneisses from migmatitic granodioritic gneisses based on the field criteria. Once we have geochronology data on these rock types then it would be possible to clearly demonstrate the occurrence of older gneiss on the Western side of the belt.

On the Eastern side of the belt, East of the Champion gneisses rocks similar to older gneisses occur as a small mappable unit extending from Ballegre Betta hills to the South of Chambarsanhalli. It is important to mention here that on the Eastern side, the older gneiss in addition to their highly veined and polydeformed nature is also compositionally layered. This unit is surrounded by migmatitic gneisses and just as on Western side, they become indistinghishable. The eastern side of KGB is otherwise covered by granodioritic gneisses, often migmatitic in nature. The Bisanatham granites show intrusive relationship to the schist belt as well as to the migmatitic granodiorite gneisses on the eastern side. The Patna granite is intrusive into the belt and has mafic inclusions of varying size and shape. A map is prepared showing field relationship between various types of felsic rocks (see map 1). For the present work, older gneisses, migmatitic gneisses and intrusive gneisses are studied.

Representative samples weighing about 15 Kg are collected from each component of the felsic rocks around KGB. Care was taken to avoid weathered and altered surfaces and only fresh rocks were chosen as samples. The sample locations are given in the map 1 . The same samples are being used for radioactive dating.

4.2 Petrography:

In hand specimen, the felsic rocks around KGB are leucocratic medium to coarse gained, equigranular, holocrystalline and gneissic. Characteristic features recognized in the field for polydeformed older gneisses, migmatitic gneisses and intrusive gneisses are reflected in their petrography as described below.



GEOLOGICAL MAP OF FELSIC ROCKS AROUND KOLAR GOLD FIELDS

After VISWANATHA (1981) GRANATH AND RAJAMANI (1982) AND PRESENT STUDY

Map1.

1. Older gneisses: In thin sections, the older gneisses are medium grained, equigranular, holocrystalline and gneissic. All the grains appear to be crushed and quartz grains with rounded corners are seen (fig4·1-4·5) suggesting possible sedimentary origin. In the three rocks studied, quartz, plagioclase, microcline, muscovite, sillimanite are common with or without garnet. The mafic minerals are sparse and they constitute less than 3% of the mode (fig 4·5). The older gneisses are characterised by possible relict sedimentary features and high grade metamorphic mineral assemblage of Cordierite-Sillimanite-Garnet-Orthoclase-quartz subfacies of amphibolite facies.

2. Migmatitic gneisses: The migmatitic gneisses are coarse grained, equigranular, holocrystalline and granoblastic. Plagioclase felspars are coarse grained and homoblastic. Quartz and K. feldspars are medium grained and fill the interstices of plagioclase feldspars (fig4·6). The plagioclase feldspars are generally idiomorphic whereas quartz and K-feldspars are xenomorphic fig.4·6 . Drop like quartz inclusions are seen in feldspars (fig4·6-4·7). Weak zoning in feldspars is also common. The migmatitic gneisses are mainly composed of plagioclase, quartz, orthoclase, biotite and hornblende. Twining in plagioclase feldspars is less common in most of the cases. The mafic minerals make up about 5 to 13% of mode.

Intrusive Gneisses: The intrusive gneisses are coarse grained, equigranular, holocrystalline and gneissic. Bending of cleavage planes are noticed in biolite and in rare cases in feldspars suggestive of high stress conditions (fig4·8-4·11). Plagioclase feldspars show good twining . The intrusives are composed of plagioclase, quartz, orthodase, biotite and hornblende. The mafic minerals make up 3 to 15% of the mode. Zircon is the common accessory mineral and is generally found as inclusions in biotite, for example, in the Patna Granite (VR3-1)(fig. 4·14).

4.3 Petrochemistry:

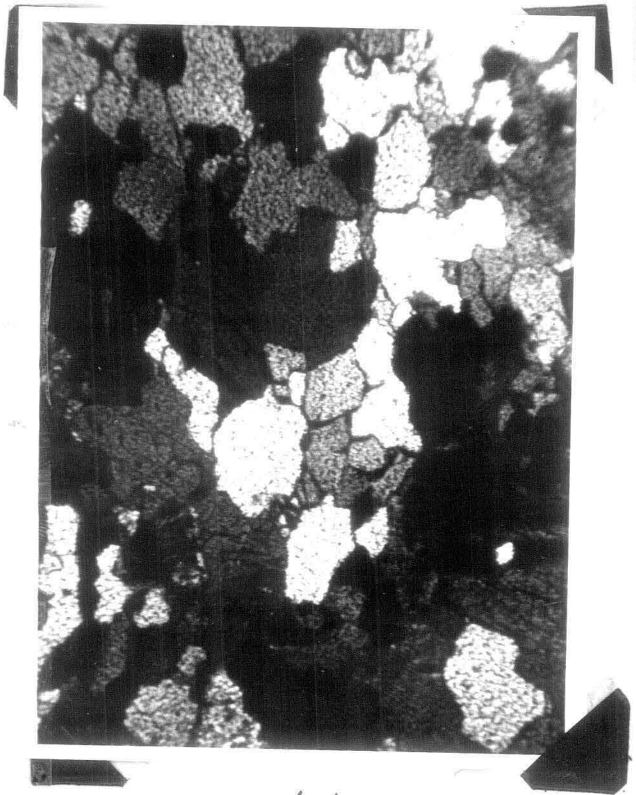
Based on field criteria and petrography a minimum of three components of felsic rocks (Peninsular Gneisses) around KGB were identified. The main objectives of this study are (a) to see whether there are any differences among the various components of felsic rocks around KGB in terms of their geochemistry and (b) to understand the petrogenesis of these rocks using their major and trace element chemistry. Therefore these rocks were analysed for their major and trace element contents. The analysis was carried out on 3 older gneisses, 7 migmatitic gneisses and 6 intrusive gneisses samples.

Figure 4.1: Quartz grains with rounded corners in an older gneiss sample (23-4). 6.3 x 8X. Crossed Nicols.

Figure 4.2: Microcline perthite and quartz grains with rounded corners 6.3 x 8X. Crossed Nicols

Figure 4.3: Quartz grains with rounded corners - 6.3 x 8X Crossed Nicols.

Figure 4.4: Quartz grains with rounded corners in an older gneiss sample (23-6). 12.5 x 8X. Crossed Nicols.



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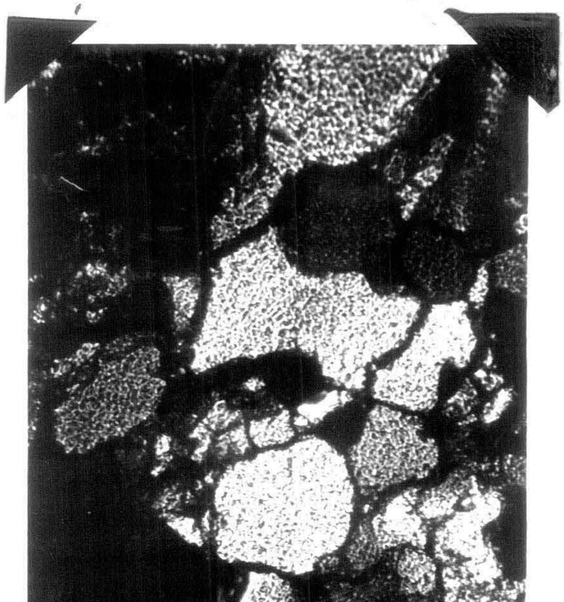

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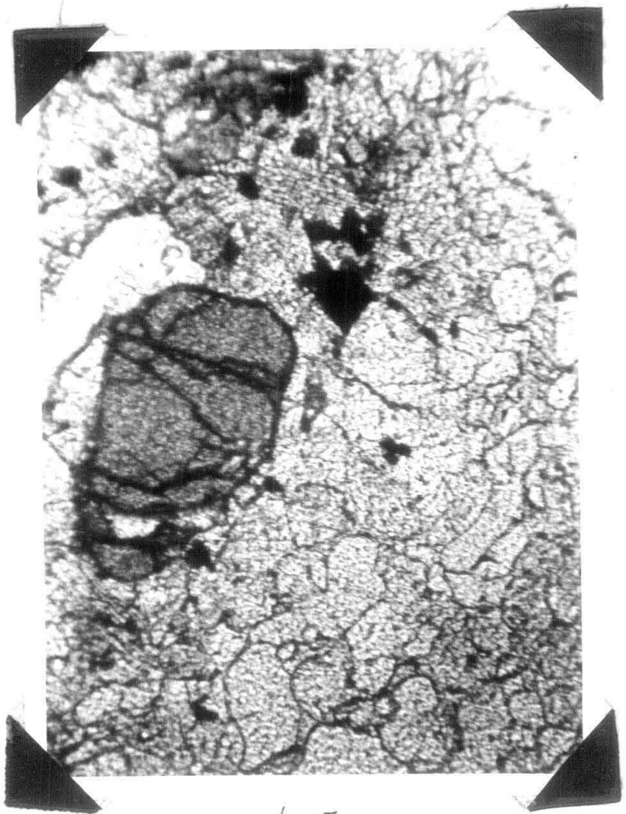
Figure 4.5: Garnet and sillimanite along with rounded quartz grains in an older gneiss (28-1).
6.3 x 8X. Parallel Nicols.

Figure 4.6: Idiomorphic plagioclase feldspars, xenomorphic quartz and drop-like quartz inclusions in feldspar.
6.3 x 8X. Crossed Nicols.

Figure 4.7: Drop-like quartz inclusions in a coarse feldspar grain. Medium grained quartz and feldspar are also seen.
6.3 x 8X. Crossed Nicols.

Figure 4.8: Biotite showing bent cleavage planes in an intrusive gneiss (23-3).
12.5 x 8X. Crossed Nicols.



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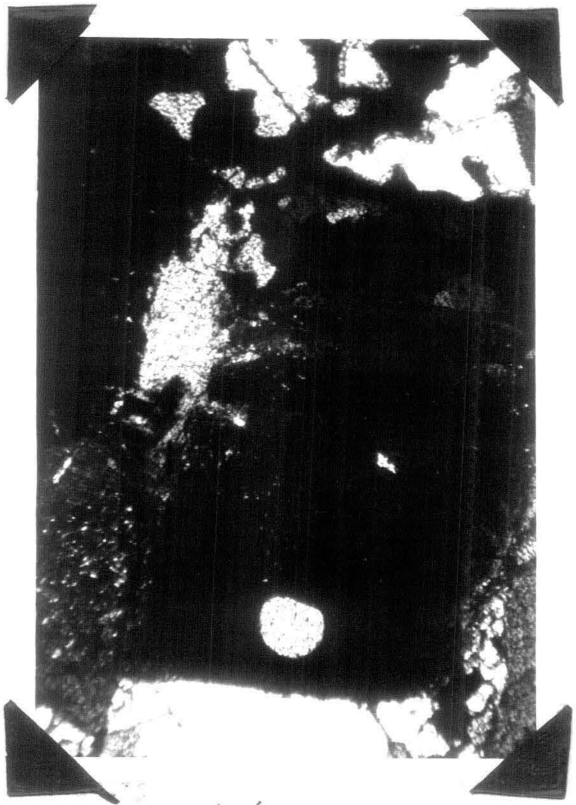

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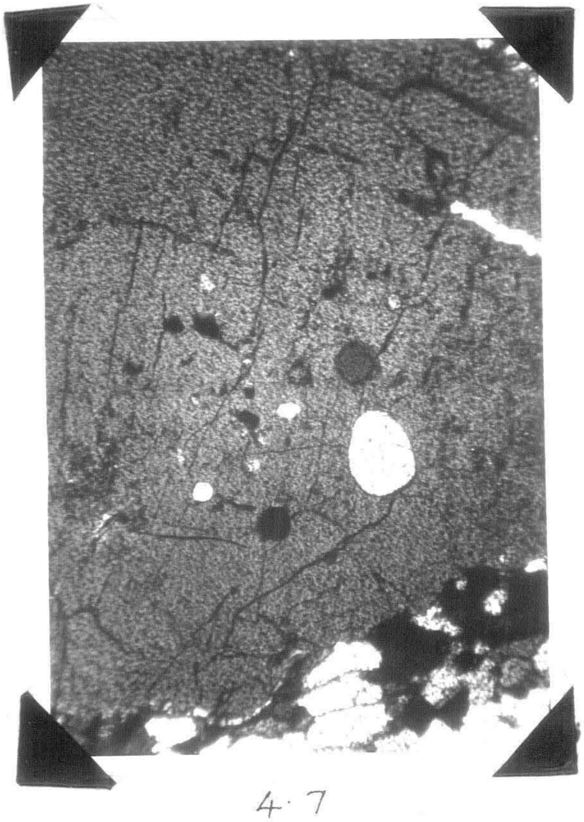

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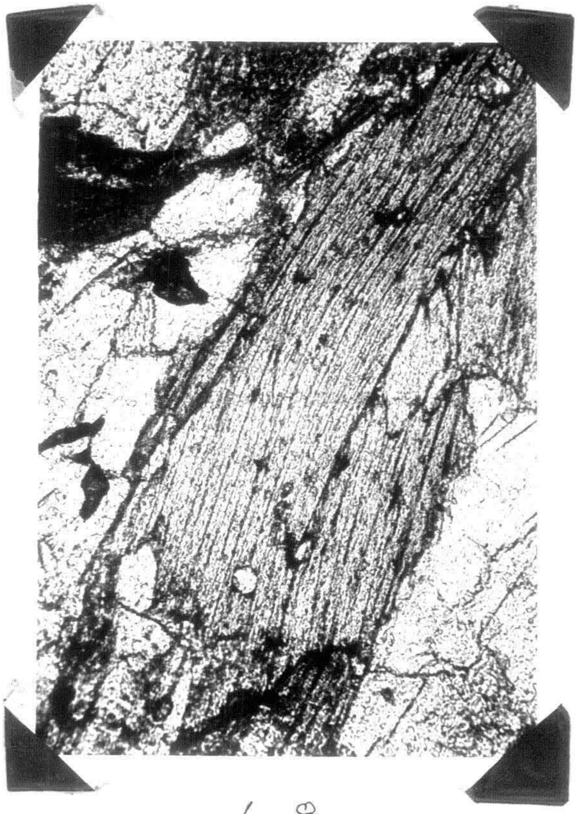

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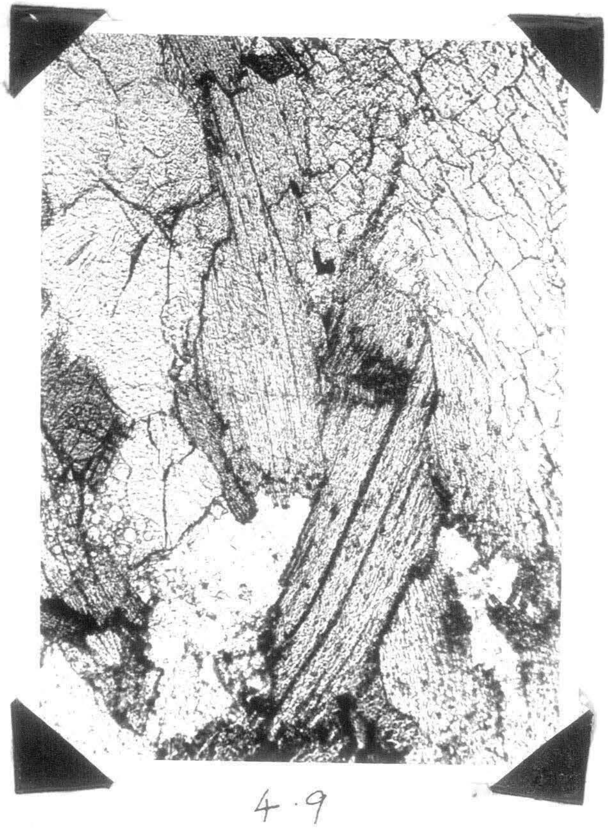
Figure 4.9: Biotite showing bent cleavage planes in an intrusive gneiss (20-3)
12.5 x 8X Crossed Nicols.

Figure 4.10: Biotite showing bent cleavage planes in an intrusive gneiss (23-1).
6.3 x 8X. Crossed Nicols.

Figure 4.11: Feldspar grain showing bent fracture/cleavage in an intrusive gneiss (23-3).
6.3 x 8X. Crossed Nicols.

Figure 4.12: Microcline perthite (braid) in an intrusive gneiss (VR3-1)
6.3 x 8X. Crossed Nicols.



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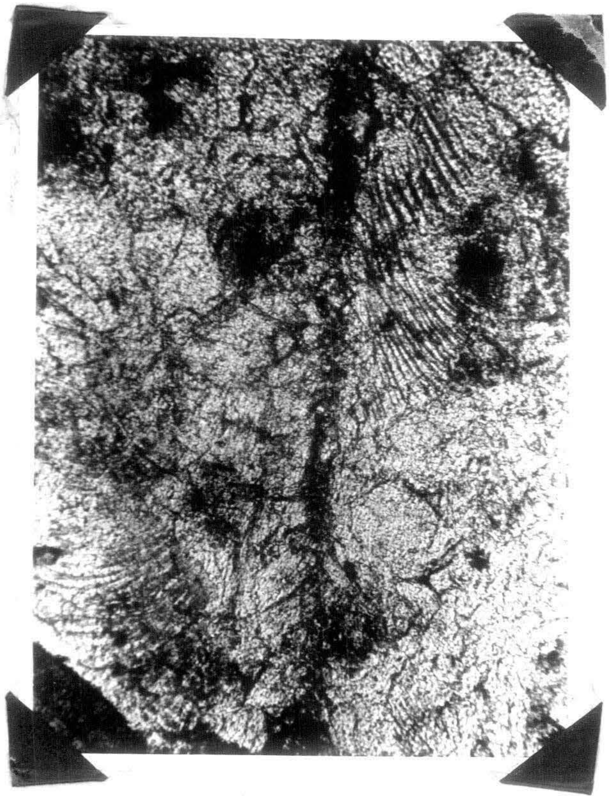

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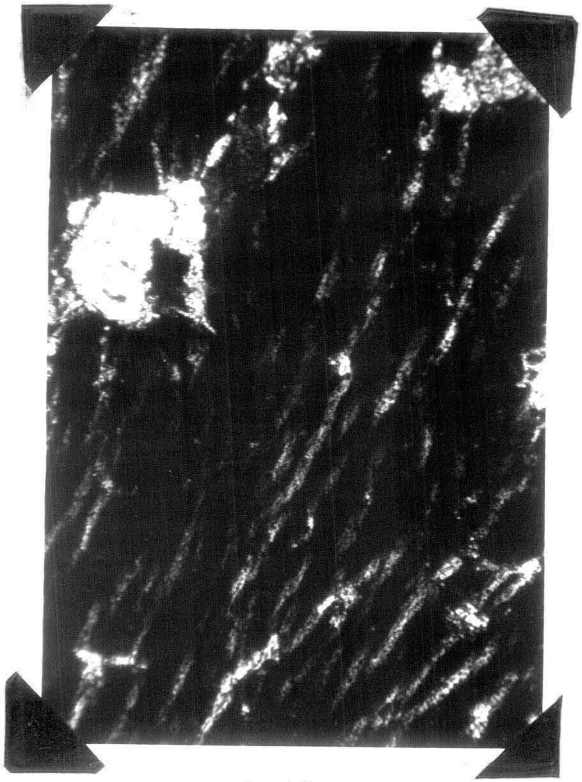


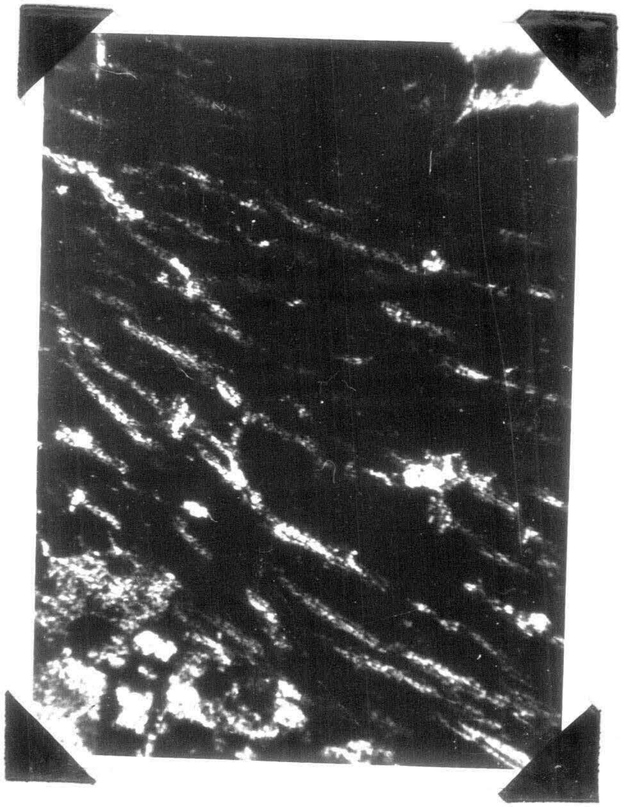
4·12

Figure 4.13: Microcline perthile (braid) in another intrusive gneiss.

6.3 x 8X. Crossed Nicols.

Figure 4.14: Idiomorphic zircon inclusions in biolite

25 x 8X. Crossed Nicols.



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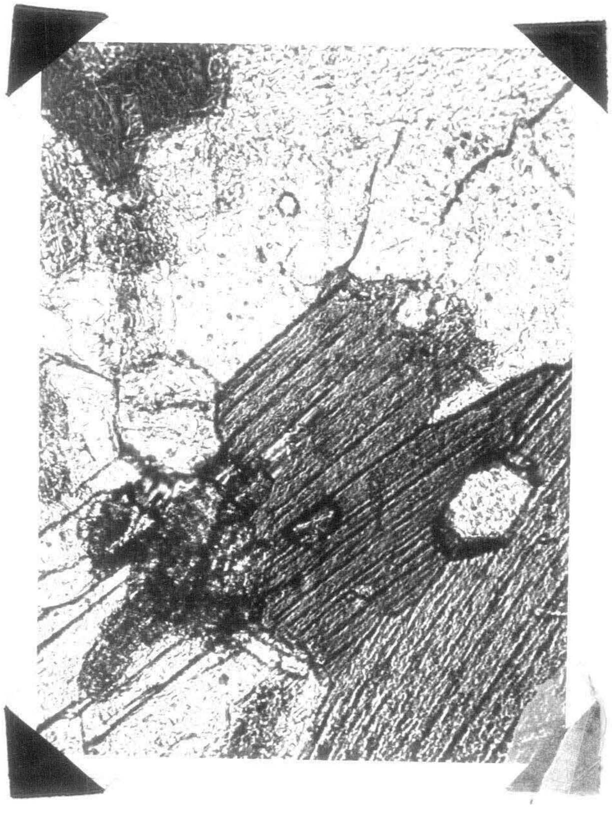


4·14

SiO_2, Al_2O_3, TiO_2 and Fe_2O_3 (total) have been determined by 'Spectronic 20' spectrophotometer, following the procedure given by Shapiro and Burnock Brannock (1962). The Fe_2O_3(T) was again determined using 'Pye Unicam' AAS on the same sample solutions. CaO has been determined by titration following the procedure given by Shapiro and Burnock (1962). MgO and MnO have been analysed 'Pye Unicam' AAS while Na_2O and K_2O have been determined in the emission mode using the same AAS. P_2O_5 was determined by XRF. The major element analytical data are included in Table 4·1 .

Nb, Zr, Y, Sr, and Rb have been determined by X-ray flourescence method at SUNY, Stony Brook, by Prof. Gil Hanson. Ba, Pb, Cu and Ni have been determined using 'Variant Tectron' AAS on the sample solutions of 1000 x dilution. The trace element data are presented in Table 4·2 .

The major element analyses was carried in duplicate by wet chemical methods on a few samples Twelve samples were also analysed by XRF method at Airborne Mineral Survey and Exploration Wing of G.S.I., Bangalore to check the precision and accuracy of data generated at our laboratory. The XRF analysis was done on portions of homogenized sample powders prepared for major and trace element analysis. The XRF data on these rocks are presented within paranthesis in Table 4·1 . All the analysis have been carried out using appropriate standards, USGS standards G-2 and GSP-1 and Mn-68, Arth and Hanson (1975) as working standards. The normative composition of these rocks are also included in Table 4·3 .

Table 4.1: Major element content of felsic rocks around Kolar Greenstone Belt (in weight %)

	OLDER GNEISSES			MIGMATITIC GNEISSES						
Sample No.	23-4	23-6	28-1	VR2-26	VR1-27	VR3-27	VR5-28	VR5-28	VR3-29	VR1-30
	1	2	3	4	5	6	7	8	9	10
SiO_2	74.79 (73.71)	74.65 (73.36)	74.95 (73.34)	76.60 (71.33)	72.12 (71.30)	71.15 (69.68)	75.06 (72.56)	69.59	70.51 (69.87)	72.95 (69.91)
Al_2O_3	15.60 (13.91)	16.01 (13.25)	15.62 (13.37)	15.21 (14.93)	15.49 (14.75	15.37 (15.09)	15.51 (14.41)	16.71	15.76 (15.23)	16.12 (16.06)
TiO_2	0.10 (0.11)	0.09 (0.10)	0.20 (0.21)	0.22 (0.25)	0.20 (0.24)	0.22 (0.24)	0.18 (0.20)	0.77	0.0.33 (0.34	0.30 (0.32)
$Fe_2O_3(T)$	1.65 (1.46)	1.75 (1.64)	2.00 (1.76)	2.40 (2.30)	2.45 (2.27)	2.40 (2.26)	1.80 (1.77)	4.55	2.75 (2.56)	2.45 (2.38)
MgO	0.04 (0.00)	0.19 (0.00)	0.24 (0.26)	0.61 (0.69)	0.56 (0.35)	0.68 (0.49)	0.33 (0.19)	0.63	0.78 (0.55)	0.71 (0.60)
MnO	0.06 (0.08)	0.04 (0.06)	0.03 (0.04)	0.04 (0.06)	0.05 (0.07)	0.04 (0.05)	0.02 (0.04)	0.09	00.05 (0.05)	(0.03) (0.04)
CaO	1.11 (1.18)	1.21 (0.99)	1.62 (1.00)	2.70 (2.42)	2.33 (2.33)	2.64 (2.79)	1.94 (1.86)	2.94	2.43 (2.65)	2.55 (3.10)
Na_2O	4.74 (4.64)	4.23 (3.91)	2.32 (2.44)	3.23 (4.82)	4.01 (4.22)	4.14 (4.91)	3.56 (4.14)	4.23	3.74 (4.51)	4.23 (4.80)
K_2O	3.11 (3.72)	3.56 (4.21)	4.92 (5.86)	2.37 (2.78)	2.31 (2.65)	1.94 (2.19)	3.00 (3.64)	3.50	2.08 (2.27)	2.94 (1.44)
P_2O_5	(0.078)	(0.143)	(0.057)	(0.083)	(0.069)	(0.076)	(0.061)		(0.116)	(0.101)
TOTAL	101.20 (98.89)	101.75 (97.66)	101.91 (98.34)	103.38 (99.66)	99.52 (98.25)	98.56 (97.78)	101.40 (98.87)	103.01	98.43 (98.15)	102.28 (98.75)

Table 4.1 (contd...

Sample No. →	INTRUSIVE GNEISSES					
	20-3	21-6	19-4	VR3-1	23-1	23-3
	11	12	13	14	15	16
SiO_2	64.86 (64.69)	66.41 (65.94)	76.52 (74.81)	74.71	73.01	75.31
Al_2O_3	15.31 (14.48)	15.58 (15.20)	16.08 (13.47)	15.99	16.84	16.28
TiO_2	0.49 (0.49)	0.52 (0.56)	0.05 (0.07)	0.39	0.32	0.32
$Fe_2O_{3(T)}$	4.85 (4.73)	4.95 (4.84)	1.3 (1.17)	2.95	2.51	2.29
MgO	2.97 (2.31)	2.21 (1.74)	0.00 (0.00)	0.55	0.53	0.48
MnO	0.09 (0.10)	0.8 (0.09)	0.03 (0.05)	0.07	0.04	0.03
CaO	3.70 (3.91)	4.00 (3.85)	1.11 (1.19)	1.45	1.85	1.22
Na_2O	3.34 (3.91)	3.96 (4.18)	3.18 (3.72)	4.05	4.00	3.78
K_2O	2.26 (2.79)	1.55 (1.76)	3.64 (4.25)	3.15	3.6	4.06
P_2O_5	(0.265)	(0.168)	(0.04)	ND	ND	ND
TOTAL	97.87 (97.68)	99.98 (98.23)	101.91 (98.73)	102.92	102.7	103.77

Table 4.2: Trace element content of felsic rocks around Kolar Greenstone Belt (in ppm)

	OLDER GNEISSES			MIGMATITIC GNEISSES						
Sample No	23-4	23-6	28-1	VR2-26	VR1-27	VR3-27	VR5-28	VR5-28	VR3-29	VR1-30
	1	2	3	4	5	6	7	8	9	10
Ni	9	8	8	9	9	9	8	10.7	9	9
Cu	26	22	17	35.5	36	19	40	6.6	24	19
Pb	38	26	42	21	23	21	28	33	73	28
Nb	6.7	23.5	N.D.	24.7	88.5	5	8.5	ND	5.2	3.1
Zr	68.5	110.8	ND	82	69.9	74.4	78.2	ND	134	103
Y	21.8	87.8	ND	7.5	7.0	6.7	6	ND	8,1	8.4
Rb	107	117.6	DN	111	110	83.7	107	ND	77.6	40.4
Ba	377.8	629.6	755.5	944.4	1101.8	944.4	1038.9	ND	912.9	629.6
Sr	130	143.8	118	522	522	672	558	793	381	509
K	25,818	29,554		19,675	19,177	16,103	24,888		17,267	24,407
K/Rb	240.8	251.3		177.7	174.3	192.4	233.6		222.5	604.1
Rb/Sr	0.82	0.82	ND	0.21	0.21	0.12	0.19		0.2	0.08

ND: Not Determined.

Table 4.2 (contd...

	INTRUSIVE GNEISSES					
Sample No. →	20-3	21-6	19-4	VR3-1	23-1	23-3
Ni	19	15	8	10	10	9
Cu	33	19	28	23.7	16	42
Pb	33	28	26	28	30	28
Nb	8.8	7.9	3.7	ND	ND	ND
Zr	150	151	42.7	ND	ND	ND
Y	23.4	20.1	6.9	ND	ND	ND
Rb	86.5	60.4	117	ND	ND	ND
Ba	818.5	566.6	118.5	1007.4	692.6	692.6
Sr	574	497	234	397	627	553
K	18,762	12,867	30,218			
K/Rb	216.9	213.0	258.3			
Rb/Sr	0.15	0.12	0.5			

ND: Not Determined.

Table 4.3: Normative Composition of felsic rocks around Kolar Greenstone Belt

	OLDER GNEISSES			MIGMATITIC GNEISSES						
Sample No.	23-4	23-6	28-1	VR2-26	VK1-27	VR3-27	VR4-28	VR5-28	VR3-29	VR1-30
	1	2	3	4	5	6	7	8	9	10
Qtz	32.2	32.5	38.0	40.1	32.7	32.1	37.6	22.68	33.3	29.7
Or	18.4	21.1	28.9	13.9	13.9	11.7	17.8	20.6	12.2	17.2
Ab	39.8	35.6	19.4	27.2	34.2	34.6	29.9	35.6	31.4	35.6
An	5.6	6.1	8.1	13.3	11.7	13.1	9.5	14.7	12.0	12.8

Table 4.3 (contd...

Sample No.→	INTRUSIVE GNEISSES					
	20-3	21-6	19-4	VR3-1	23-1	23-3
	11	12	13	14	15	16
Qtz	22.2	23.2	41.1	33.8	30.1	33.4
Or	13.3	8.9	21.7	18.9	21.1	23.9
Ab	28.3	33.5	26.7	34.1	34.1	31.9
An	18.4	19.7	5.6	7.2	9.2	6.1

CHAPTER-V

DISCUSSION

The felsic rocks in and around Kolar greenstone belt possibly contain at least three components, including, polydeformed older gneisses, migmatitic gneisses and intrusive gneisses. The older gneisses are traced on the western side of the belt as enclaves within and along the eastern margin of the intrusive bodies (Granath and Rajamani, 1982) and also possibly on the eastern side. The migmatitic gneisses occur on both sides of the belt. The intrusive gneisses occur as diapiric domes adjoining the metavolcanics at the North Western and South Eastern end of the belt (Patna and Bisanattam intrusives) and as elongated plutons on the western side of the belt.

Petrographically the older gneisses are medium grained, equigranular rocks, with possible relict sedimentary texture. Quartz grains with rounded corners are observed in three rocks studied. Further these gneisses are characterised by the presence of metamorphic minerals such as sillimanite and garnet, thus indicating high grade of metamorphism. The migmatitic gneisses are characterised by coarse grained homoblastic plagioclase feldspars and medium grained quartz and k-feldspars.

The plagioclase feldspars are generally idiomorphic whereas, the K-feldspars and quartz are xenomorphic filling the interstices of former. The mafic minerals include biotite and hornblende. Weak zonning and droplike quartz inclusions are seen in feldspars suggestive of migmatization (Menhert, 1968). The intrusives are coarse grained, equigranular, holocrystalline and gneissic, essentially composed of albite, quartz, microcline, hornblende and biotite. The cleavage planes in hornblende and biolite are bent suggestive of high stress conditions. Pertite and microcline are common in these rocks.

Although we recognized three components among the felsic rocks, based on field and petrography, the major element geochemistry, particularly the Q-Qr-(Ab + An) normative plot shows the rocks are granodioritic in nature except three rocks (28-1, 19-4 and 23-1) that fall in quartz monzonite field (fig 5.1). In the K_2O-Na_2O-CaO diagram, the rocks plot in a broad field as shown in fig 5.2 ranging from tonalite to quartz monzonite. No particular grouping of intrusives or migmatites is seen.

The granitic rocks plotted in FeO-Alk-MgO diagram show a Calc-alkaline trend (fig 5.3). The Calc-alkaline trend shown by granitic rocks around KGB is similar to that of Amitsoq gneisses and kaapvaal tonalites. In their Na_2O and K_2O content, most of the rocks are similar to the granodiorites and two of the intrusives (19-4 and 23-1) are similar to quartz monzonites reported in the literature. None of them show typical tonalitic Na_2O/K_2O ratio although two granodioritic intrusives (20-3, and 21-6) and two migmatitic gneisses (VR1-2) and (VR3-27) have near tonatitic Na_2O/K_2O ratios (> 2) [fig 5.4].

With increasing SiO_2, Na_2O contents of these rocks do not change whereas K_2O as well as $K_2O + Na_2O$ show a positive correlation (fig 5.5). MgO, CaO and Fe_2O_3 contents of these rocks show a marked decrease with increasing SiO_2 in all the rock types (fig 5.6). The intrusive granites and gneisses do not show any significant change in the TiO_2 content with increasing silica, although a general decreasing trend is observed (fig 5.7). Tarney (1976) plotted TiO_2 contents of Archean metasediments and metaigneous rocks against SiO_2 and showed that metasediments have higher TiO_2 for given SiO_2. On this basis he has given fields for igneous and metasedimentary rocks. It is interesting to note some of our intrusive granitic rocks (VR3-1, 23-1 and 23-3) which are clearly intrusive into the KGB fall in the metasedimentary field.

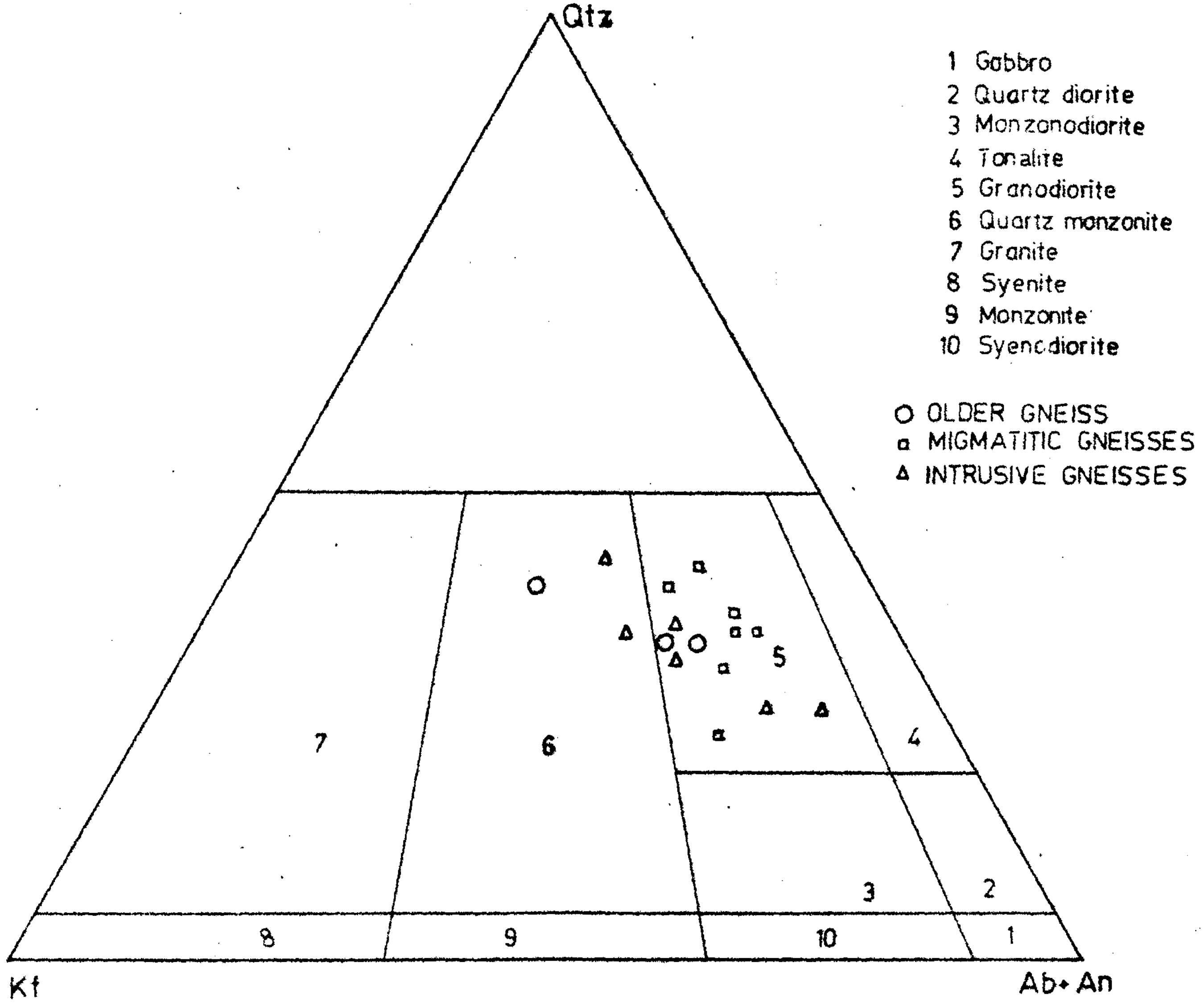


Figure 5.1 Normative Qtz–Kf–(Ab+An) plot of felssic rocks around Kolar schist belt.

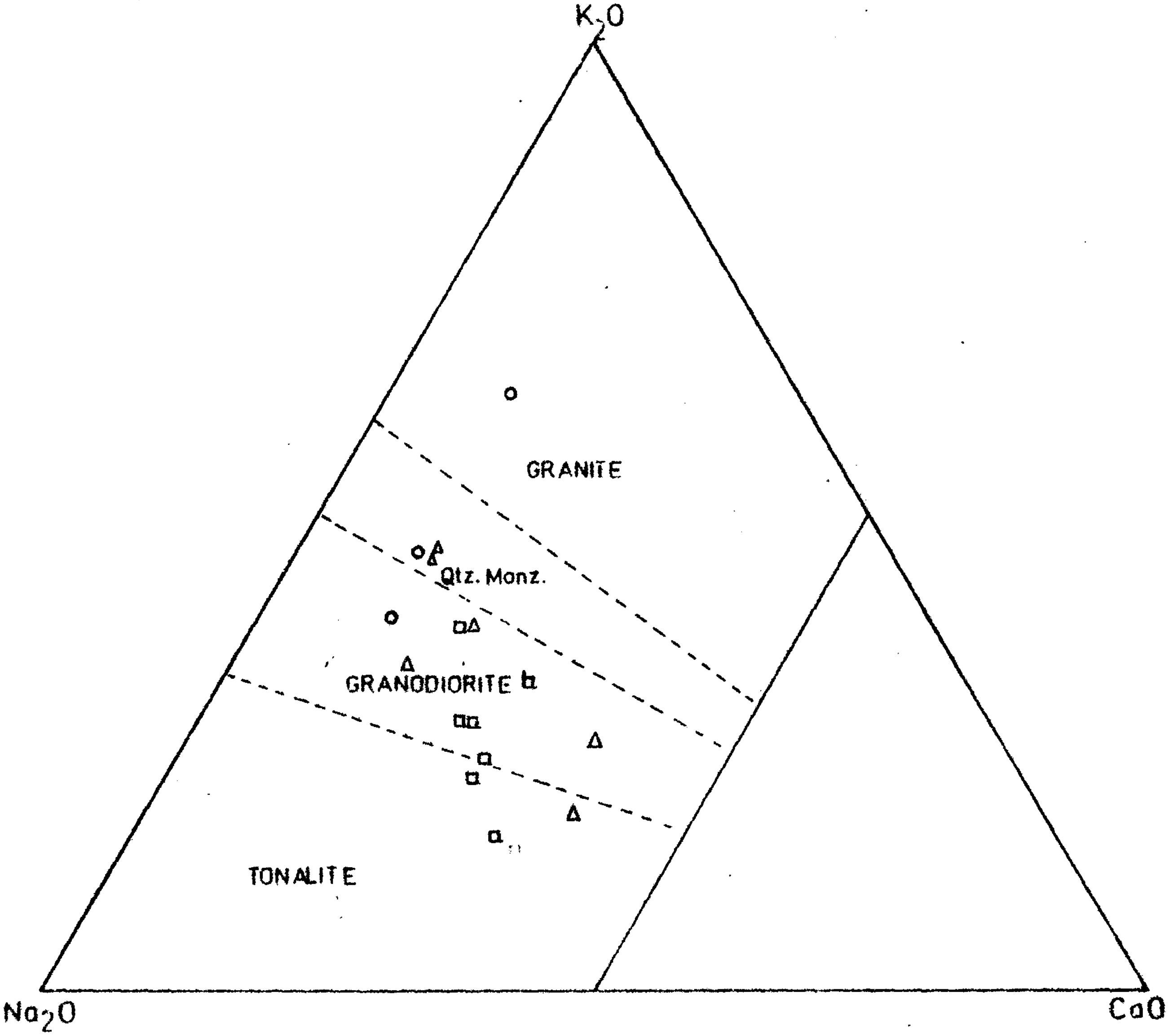


Figure 5.2: Plot of K_2O - Na_2O - CaO for felsic rocks of Kolar schist belt

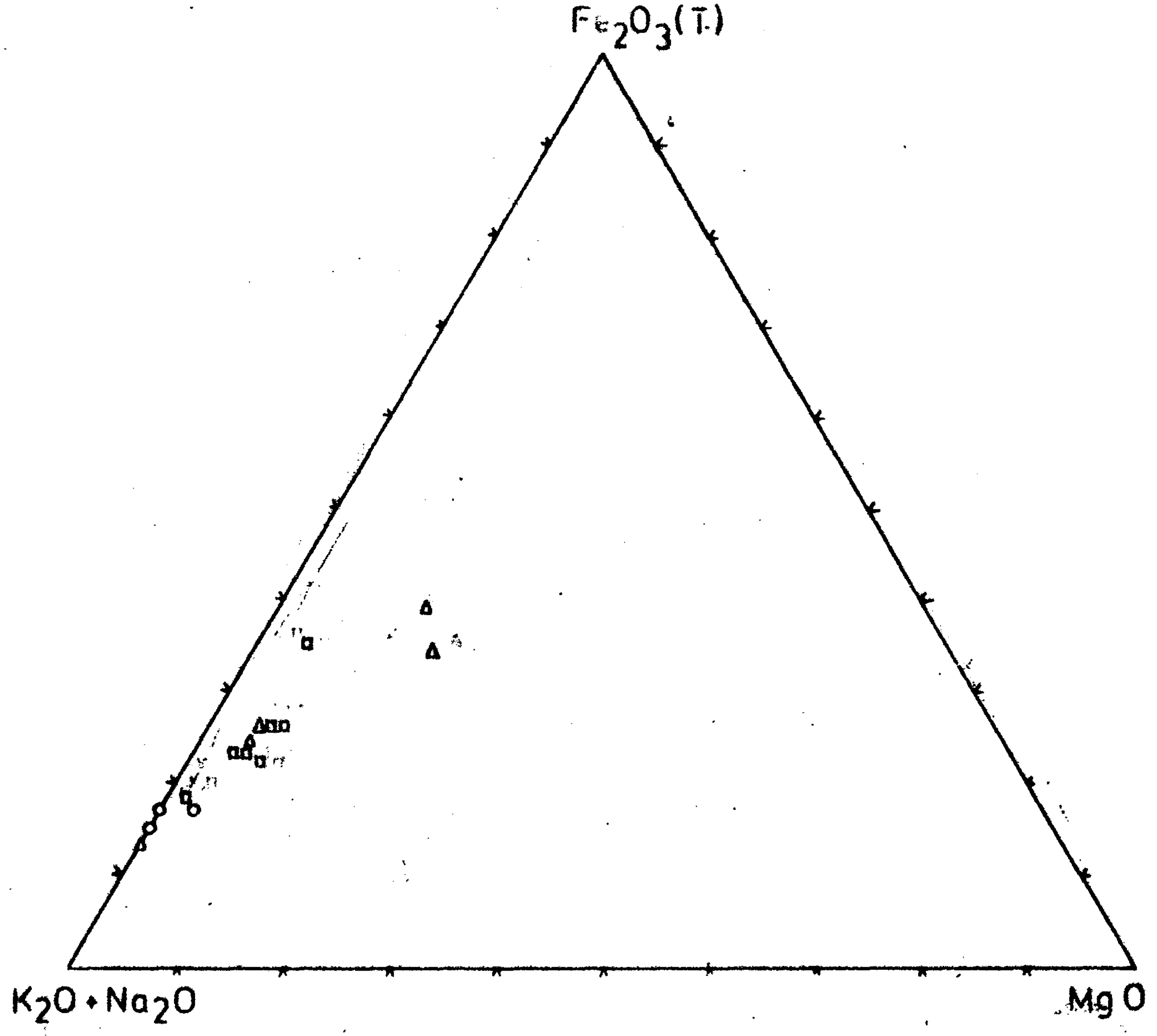


Figure 5.3: Felsic rocks of Kolar schist belt showing calc-alkaline trend in AFM plot.

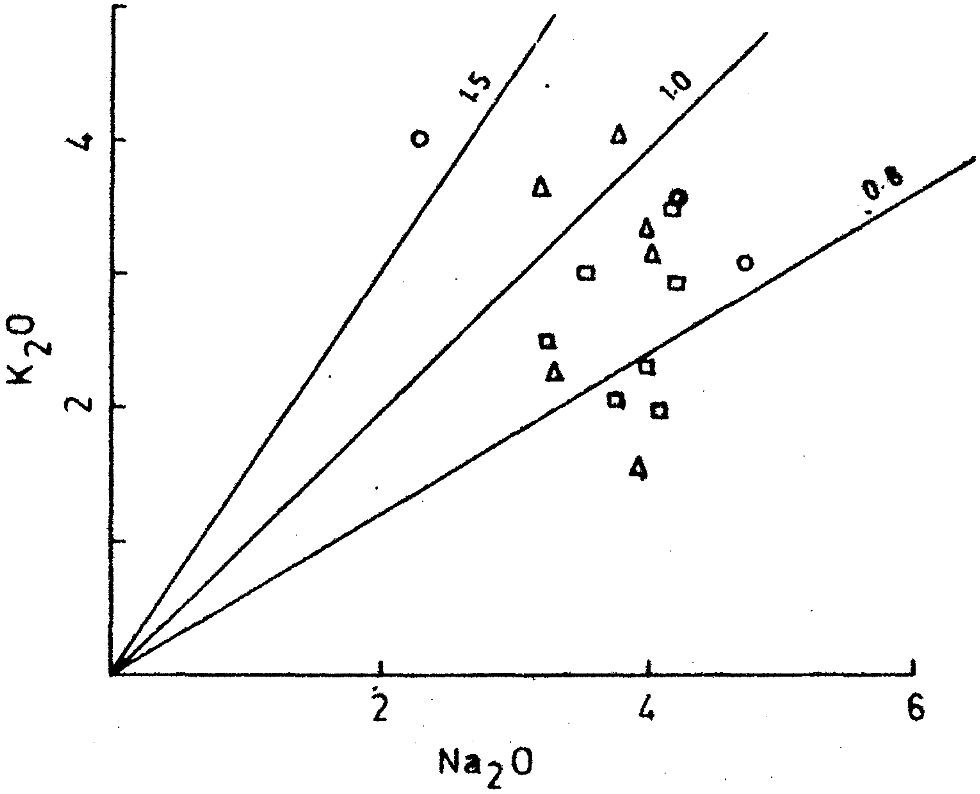


Figure 5.4: Plot of K_2O verse Na_2O for felsic rocks around Kolar schist belt

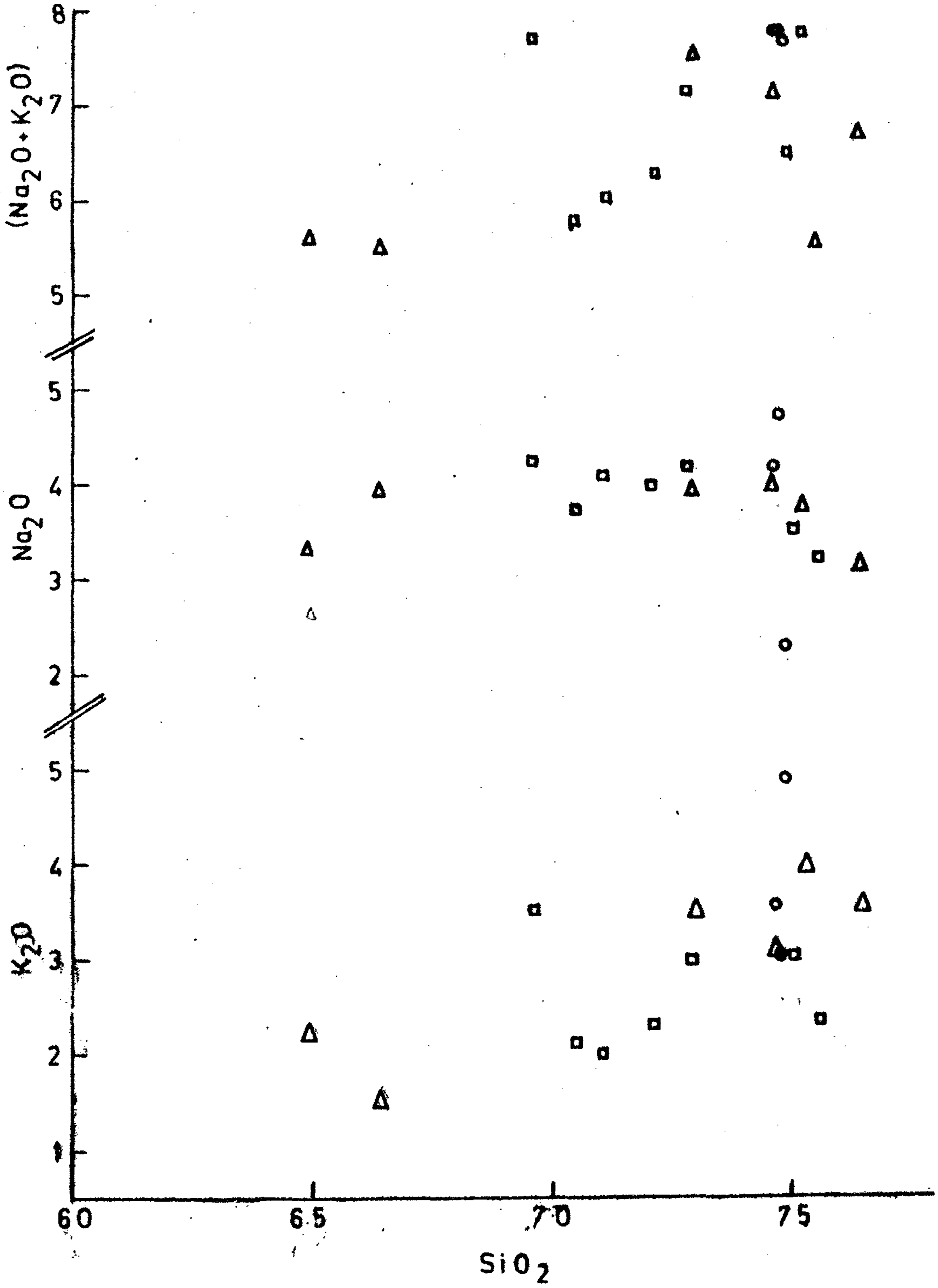


Figure 5.5: Plot of K_2O, Na_2O and $(K_2O + Na_2O)$ verse SiO_2 for felsic rocks of KSB.

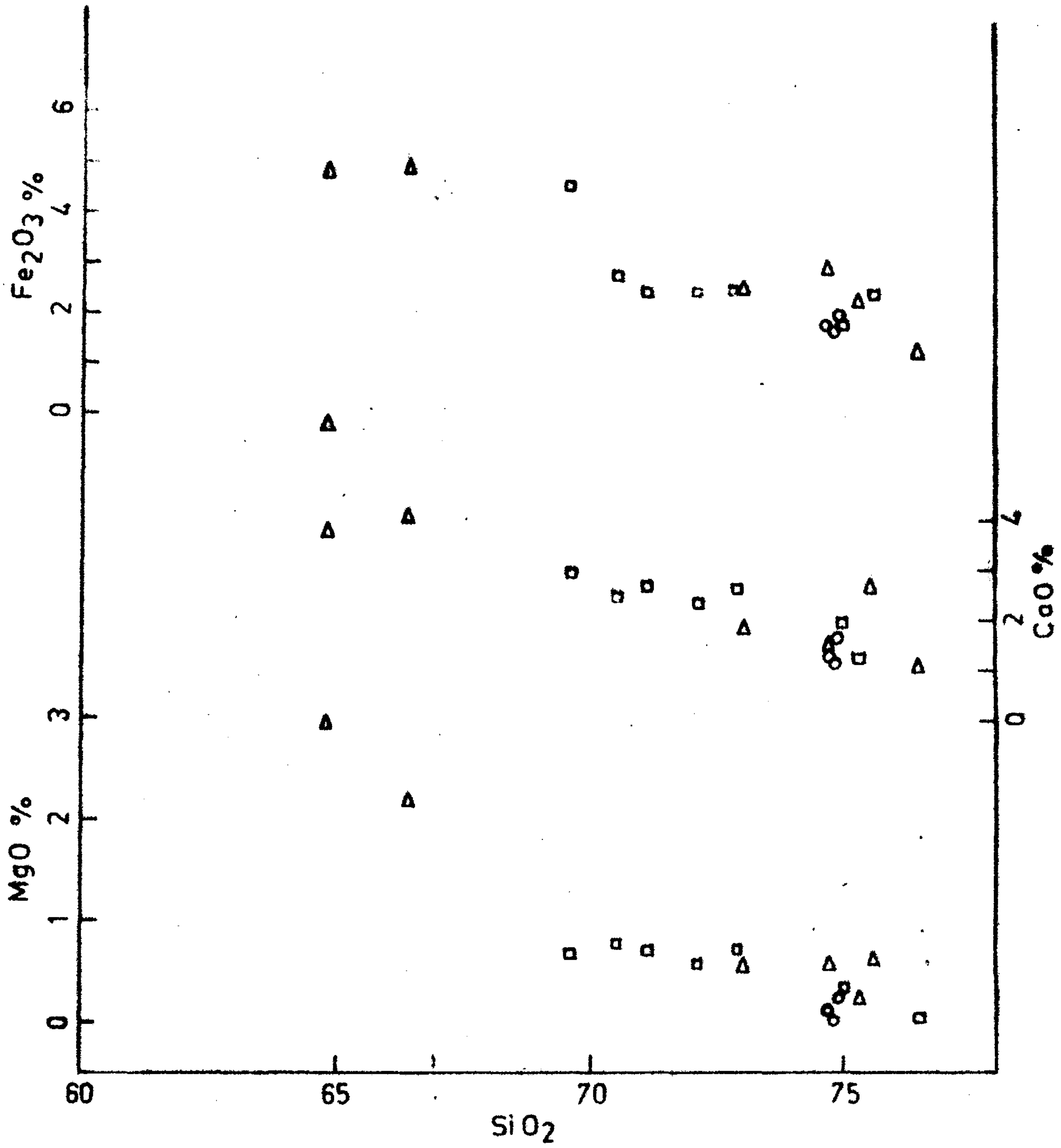


Figure 5.6: Plot of MgO, CaO and Na_2O verses SiO_2 for felsic rocks of KSB.

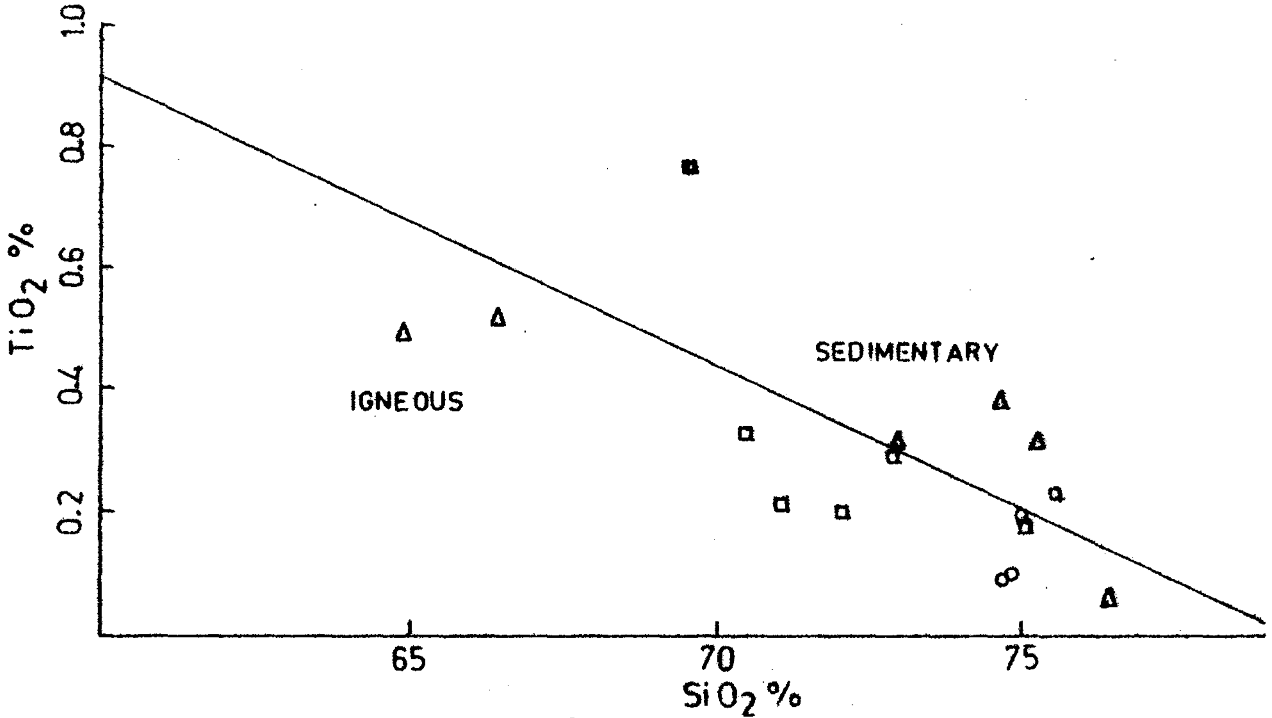


FIGURE 5.7: TiO$_2$ VERSE SiO$_2$ PLOT WITH IGNEOUS AND SEDIMENTARY FIELDS (AFTER TARNEY, 1976).

Rest of the rocks fall in the igneous field.

The MgO mole percent is below 3.5 and most of rocks have MgO mole percent < 1.5. The FeO mole percent ranges from 1 to 3.5 but most of the rocks have < 2%. The FeO and MgO mole percentages show positive correlation (fig 5.8). All the plots fall well below 0% melting line of periodolitic mantle as given by Hanson and Langmuir (1978). Therefore these rocks could not be partial melts of the mantle.

In addition to major elements, trace elements are useful in petrogenetic studies. The trace element content of felsic rocks around KGB vary widely. The trace element content and ratios of felsic rocks of various shield areas are presented along with the data for felsic rocks around KGB in Table 5.1 for comparison. The Rb concentration in the felsic rocks around KGB varies from 40.4 to 118 ppm and particularly the intrusives have Rb concentrations varying from 60.5 to 117 ppm which is comparable to that of granodiorites and quartz monzonites of N.E. Minnesota and granodioritic Amitsoq gneisses. Sr and Ba contents are also comparable to that of granodioritic and quartz monzonitic gneisses of other shield areas. The K/Rb ratio of the intrusive rocks around KGB ranges from 180–260 and is comparable

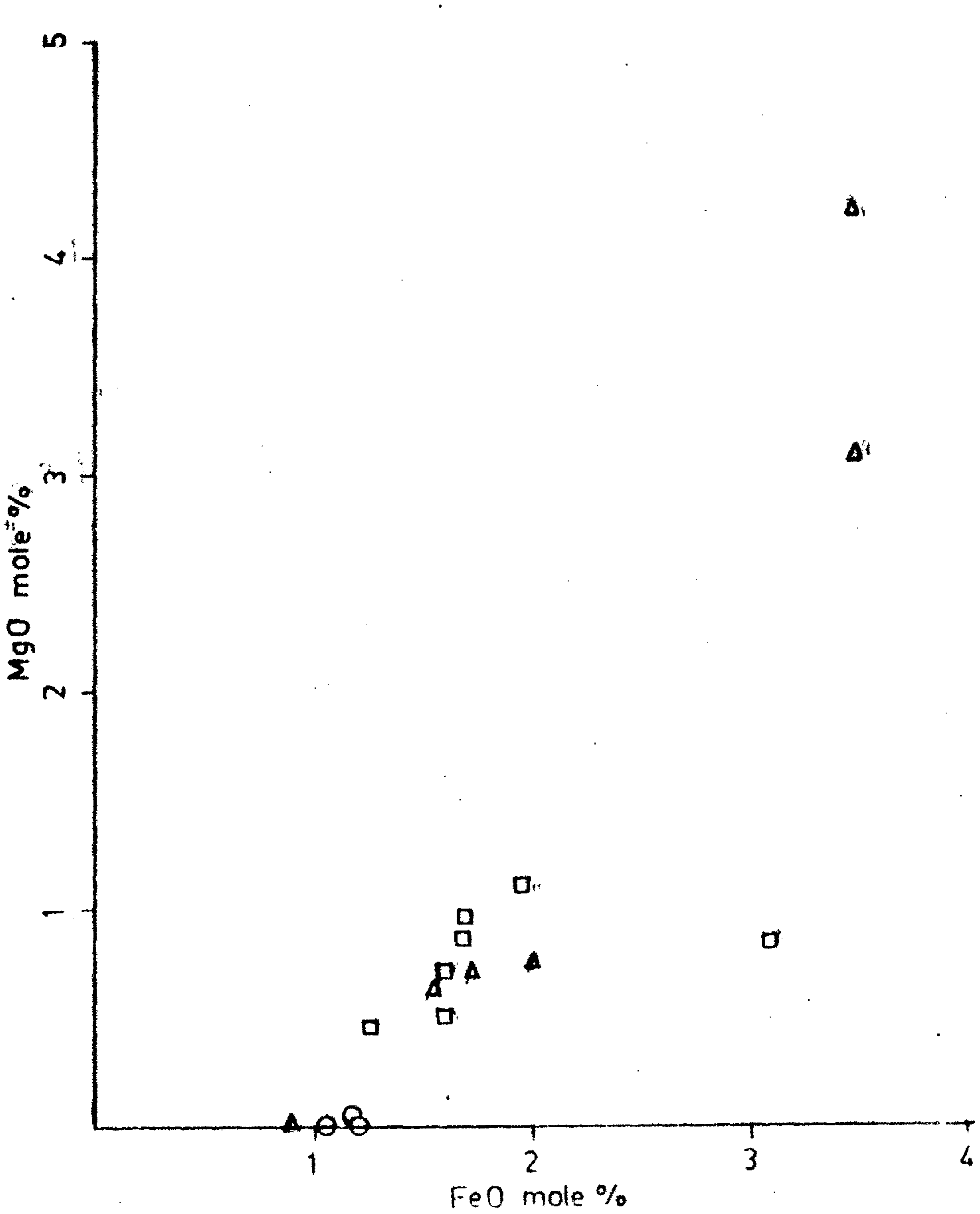


Figure 5. 8: Plot of FeO mole % verse MgO mole % for felsic rocks around Kolar shist belt

Table 5.1: Trace element content and ratios for felsic rocks in various shield areas and around KGB (in ppm).

Rock		N.E. Min.	Zimb-Rhod	N.W. Scot Scourie	S.Africa	N.W. Ont. Canada	Greenland	KGB Felsic	KGB intrusives and migmatites	KGB older gneisses
		1	2	3	4	5	6	7	8	9
	Ton	26-46	20-44	3-7.2	35	78	30			
Rb	Gd	74	-	34-44	196	-	94	40-118	40-117	107-118
	QMG	67-242	-	42-62	-	-	53			
	Ton	471-1127	325-523	436-480	563	-	218			
Sr	Gd	991	-	250-354	483-1263	-	300	118-672	234-672	130-144
	QMG	116-290	-	161-333	-	-	230			
	Ton	334-459	-	337-518	170	-	420			
Ba	Gd	1017	-	708-1216	360-700	-	100	378-1102	630-1102	378-756
	QMG	448-807	-	321-776	-	-	390			
	Ton	-	124-309	103-158	120	-	146			
Zr	Gd	-	-	117-149	64-350	-	80	43-151	43.151	69-111
	QMG	-	-	27-68	-	-	410			

Table 5.1 (contd...

		1	2	3	4	5	6	7	8	9
	Ton	-	-	0.5 -10.5	5.2	-	11			
Y	Gd	-	-	0.7-1.1	18-32	-	-	6-87.8	6-23.4	22-87.8
	QMG	-	-	10.9	-	-	-			
	Ton	-	-	1.8-4.2	-	-	5			
Nb	Gd	-	-	1-3	-	-	-	3.1-88.5	3.1-88.5	6.7-13.5
	QMG	-	-	-	-	-	-			
	Ton	254-625	224-361	1000-1903	271	140	352,			
$\frac{K}{Rt}$	Gd	341	-	840	197-238	-	129	174-604	174-604	241-251
	QMG	134-275	-	-	-	-	462			
	Ton	.01-.059	.06-.08	.006-.02	0.06	-	.09			
$\frac{Rb}{Sr}$	Gd	.075	-	.12-.14	.16-.25	-	.31	.08-.82	.08-.5	0.82
	QMG	.57-1.58	-	.26-.19	-	-	.23			
	Ton	1.35-2.78	-	1.29-.93	3.31	-	.52			
$\frac{Sr}{Ba}$	Gd	.974	-	.35-.29	1.34-1.8	-	3	.18-.82	.29-.12	.18-.24
	QMG	.24-.36	-	.50-.43	-	-	.59			

Data Source: 1. Arth and Hansen (1975); 2. Condie and Allen (1980);
3. Rollinson and Windley (1980); 4. Glikson (1976);
5. Hillary and Ayres (1980); 6. Bridgwater, Collerson and Myres (1978).

to the granodioritic gneisses of South Africa and to the quartz-monsonites of N.E. Minnesota. Rb/Sr ratios of felsic rocks around Kolar are comparable to that of granodioritic gneisses of S. Africa; Scouric, N.W. Scotland, and granodioritic Amitsoq gneisses. The Pb content of the felsic rocks on KGB varies from 21 to 73 ppm and is higher than the concentration of Pb observed for high grade Archean gneisses of Scotland (Drury 1978). The Cu and Ni content of the felsic rocks around KGB seem to be normal when compared to the Amitsoq gneisses of Greenland (Bridgewater et al., 1978).

Recent developments in trace element geochemistry have made possible quantitative petrographic modelling using mineral-melt distribution coefficient (Kd) available for few trace elements (Table 5.2) applicable to granitic system. The composite nature of the Archean granitic rocks places constraints on geochemical modelling involving trace elements. Further, it is not understood clearly whether the elements have remained immobile during various processes that have affected these oldest rocks, since Archean. Changes in trace-element concentrations, particularly LIL elements (K, Rb, U, Th and Cs) are reported during metamorphism and metasomatism (Rollinson and Windley 1980, Bridgwater and Collerson 1977). Vocke et al., (1982), however, have shown that

Table 5.2: Kd, values on few trace elements for common rock forming minerals and D values for a parent with 45%hb, 45% Pl and 10% Qtz.

Element	Garnet	Hyper-sthene	Clino-pyro-rene	biolite	K-felds	Anortho clase	Hornblende		Plagioclase			D
	(1)	(1)	(2)	(2)	(2)	(3)	(1)	(1)	(1)	(1)	(2)	
K	0.020	0.0023	0.037	(5.63)*	(1.49)*	-	0.081	0.065	0.10	0.076	0.263	0.0815
Rb	0.0085	0.0027	0.032	3.26	0.659	0.45	0.041	0.0077	0.041	0.016	0.048	0.0279
Sr	0.015	0.0085	0.516	0.120	3.87	5.57	0.22	0.094	4.4	1.45	2.84	2.079
Ba	0.017	0.0029	0.131	6.36	6.12	5.04	0.044	0.054	0.31	0.30	0.36	0.1593

1. Nagasawa and Schnetzler (1971); 2. Philpotts and Schnetzler (1970); 3. Sun and Hansen (1976)

Data source: Hansen (1978).

low temperature hydrothermal fluids do not alter the REE pattern significantly. In the following discussion, the felsic intrusive rocks around KGB are assumed to have remained as 'closed system' with respect to trace elements, and a quantitative approach is made to understand the petrogenesis of these rocks, particularly the intrusive gneisses.

Why?

Granitic melts can be generated by partial melting of mantle, basaltic rocks, rocks of intermediate composition, granitic rocks and sedimentary rocks (Hanson, 1978). Assuming the melt thus derived has undergone least differentiation and other alterations, possible source can be suggested. The rocks of tonalitic chemistry associated with the older greenstone belts are thought to have been generated by partial melting of mafic component of the greenstone belt itself (metavolcanics or subducting oceanic crust). The Kolar greenstone belt is believed to be one of the true ancient greenstone belts and, as we have seen earlier, the felsic intrusives associated with this belt have varying chemistry falling in near tonalitic to quartz monzonitic fields (fig 5.1 and 5.2). Further among the various component of the felsic rocks, certainly the intrusives would have crystallized directly from the melt. Therefore, some of the intrusives around KGB can also have similar origin. Hence to test this possible model, I have assumed a tholeiitic rock with trace element concentration similar to that of metavolcanics of KGB (see Table 5.3) as parent with a modal mineralogy of 45% Hb, 45% Pl and 10% Qtz. Melting of this source is assumed to be non-modal in the proportion 10% Hb; 40% Pl and 50% Qtz. and a simple case of batch melting, $\frac{C_L}{C_o} = \frac{1}{(D_o - PF) + F}$, given by Shaw (1970) is used. The concentration of various trace elements (K, Rb, Sr and Ba) and their ratios for various extents of melting are given in Table 5.4.

K, Rb and Ba are incompatible elements for the residue considered here, with D values much less than 1 (Table 5.2). Therefore for lower extents of melting, the conc. of these incompatible elements in the melt should be several times higher than the source because $C_L = \frac{C_o}{F}$ when $D << 1$. Also, as the extent of melting (F) increases the concentrations of these elements decrease and approach the concentration in the original source (C_o); i.e., $C_L = C_o$ as $F \longrightarrow 1$. Though K and Rb are incompatible elements, the K/Rb ratio is lowered in the melt since bulk distribution co-efficient (D) for Rb is lower than K ($D_{Rb} < D_K < D_{Ba} < 1$). However,

Table 5.3: Average major and trace element content of Amphibolites from Kolar Greenstone Belt

Major element	Average conc. (wt.%)	Trace element	Average conc. in ppm (n=11)
SiO_2	53.73	V	258.45
TiO_2	0.95	Y	20.36
Al_2O_3	14.32	Zr	58.2
FeO	10.56	Rb	4.91
MgO	6.88	Sr	123.09
CaO	11.24	Ba	87.0
K_2O	0.11		
Na_2O	1.69		
Total	99.68		

Source: V. Rajamani (Personal Communication).

Table 5.4: Trace element concentrations and ratios in original tholeiitic source and in melts derived by various extents of melting (in ppm)

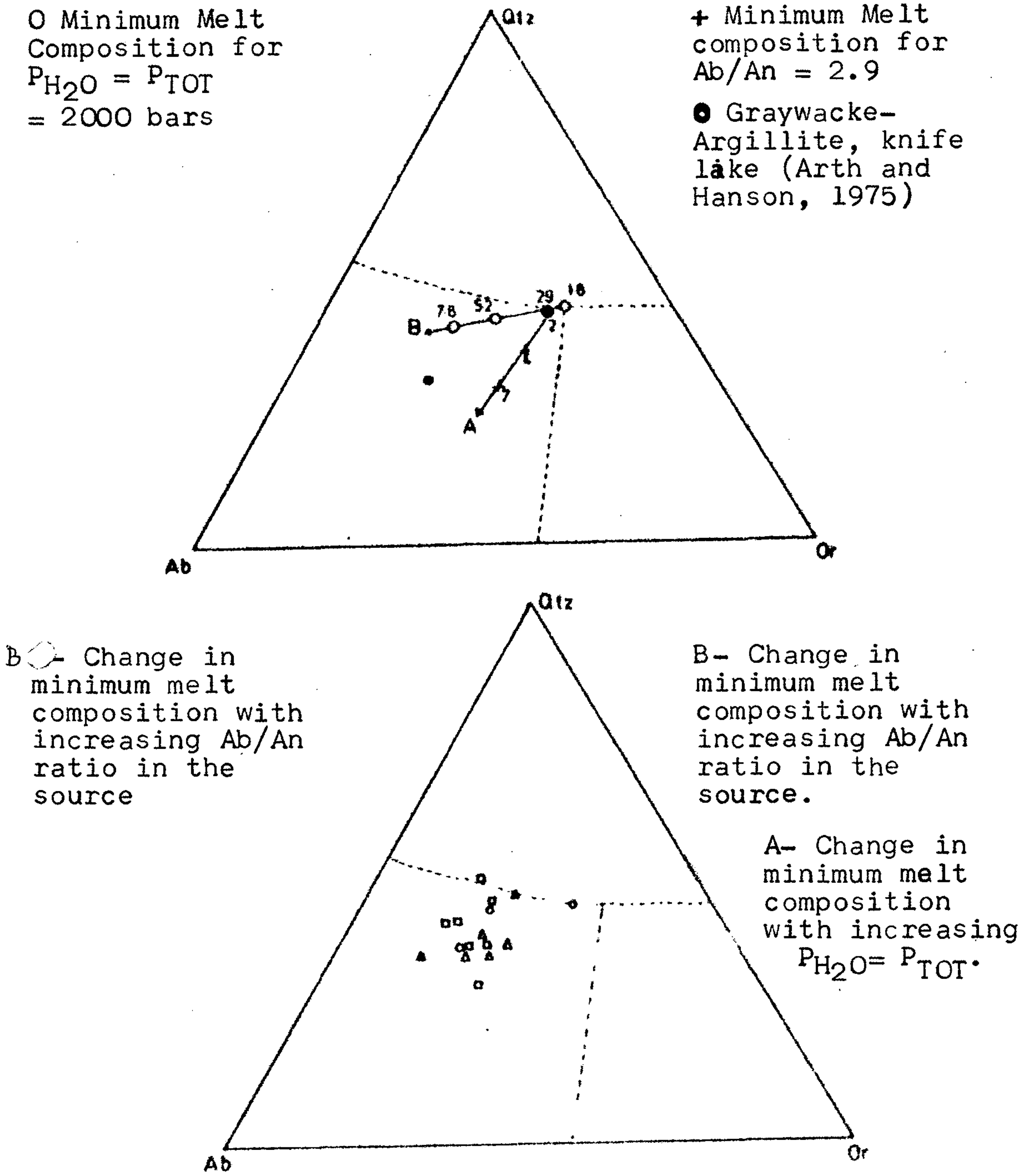
% Melt	K	Rb	Sr	Ba	K/Rb	Rb/Sr	Sr/Ba
Original	1,500	5	123	87	300	0.04	1.41
1%	16,480	132.65	59.39	517.81	124.2	2.23	0.11
2%	14,920	105.29	59.78	492.27	141.7	1.76	0.12
3%	13,629	87.29	59.84	469.13	156.1	1.46	0.13
5%	11,619	65.05	60.30	428.83	178.6	1.08	0.14
10%	8,489	39.73	61.48	352.99	213.7	0.65	0.17
15%	6,688	28.60	62.70	299.96	233.9	0.46	0.21
20%	5,517	22.34	63.98	260.78	247.00	0.35	0.25
G.d. 20.3	18,762	86.5	574.0	818.5	216.9	0.15	0.70
21.6	12,867	60.4	497.0	566.6	213.04	0.12	0.88
Q.M. 19.4	30,218	117.0	234.0	818.5	258.3	0.5	0.29

as the percentage of melting increases, the K/Rb ratio increases and approaches the original value. Since Sr is a compatible element with $D > 1$, the conc. of Sr in the liquid for lower extents of melting is lower than the source.

By comparing the K/Rb ratios of intrusives, and melts formed for various extents of melting, we may infer that the intrusives could have been formed by > 10% melting of a tholeiitic parent. However, the K concentration in the intrusives are high. Similarly the concentration of Rb, Sr and Ba in the intrusives are higher than the concentrations of these elements expected for 10% melting. The Rb/Sr ratios for intrusives are high; whereas the Sr/Ba ratios are far lower. The Concentration of these trace elements and their ratios observed in quartz monzonitic intrusive gneisses(19-4) are again not comparable to concentration and ratios calculated for various percentages of melting of amphibolitic source. Therefore, partial melting of amphibolites similar to Kolar amphibolites for the genesis of intrusive gneisses around KGB does not appear to be a possible model. However, the granodiorites (20-3, 21-6) have 2.21 to 2.97% MgO, 4.85 to 4.95% Fe_2O_3(T) 3.7 to 4% CaO 64.86 to 66.41% SiO_2 and near tonalitic Na_2O/K_2O

ratio suggesting a basic parent. Fractional crystallization of plagioclase and a mafic phase (Hb, Cpx or Opx) from the tonalitic melt may enrich the melt in K, Rb and Ba. But the fractionation will also deplete Sr and increase the acidity of the melt, which are contrary to what we observe in these rocks. Possibly the tonalitic melt generated by 10 to 15% partial melting of tholeiitic parent could have been contaminated by granitic rock/melt at deeper levels, thus slightly affecting the major elements and increasing K, Rb and Ba moderately and Sr significantly to the observed levels. On the other hand the K, Rb, Sr and Ba contents and their ratios observed in the granodioritic intrusives can also be explained by their origin involving partial melting of an heterogeneous crust of intermediate composition.

The felsic rocks of quartz monzonitic chemistry are thought to have been derived by partial melting of graywacke (Arth and Hanson, 1975). Winkler (1974) has given the minimum melt composition of the granitic melts on melting graywacke at various pressures (P_{H_2O}) and for various Ab/An ratios (fig 5.9a). The average composition of the graywacke with Ab/An = 2.9 (Arth and Hanson, 1975) is plotted in the fig 5.9b. Assuming that no phase has reacted out completely, the composition of



O Minimum Melt Composition for $P_{H_2O} = P_{TOT}$ = 2000 bars

+ Minimum Melt composition for Ab/An = 2.9

● Graywacke-Argillite, knife lake (Arth and Hanson, 1975)

B O- Change in minimum melt composition with increasing Ab/An ratio in the source

B- Change in minimum melt composition with increasing Ab/An ratio in the source.

A- Change in minimum melt composition with increasing $P_{H_2O} = P_{TOT}$.

Figure 5.9a: Projections onto the Q-Ab-Or plane of minimum melt compositions in the system Q-Ab-An-Or-H_2O for P_{H_2O} = 2000 bars with different Ab/An ratios and different pressures keeping Ab/An=2.9 (Winkler 1967, 1974

5.9b: Q-Ab-Or plot for felsic rocks around KSB, showing projected cotectic lines and minimum melt composition for Ab/An=2.9 and P_{H_2O} = 4000 bars the melt formed by melting a graywacke of above chemistry should be eutectic composition. From fig. 5.9 we can infer that all the intrusive graintes do not fall in the region expected for the melt derived by simple partial melting of graywacke. Particularly the quartz monzonitic intrusive (19-4) falls away from the eutectic composition. Further, the intrusive rocks occupy large areas and to generate these volumunous bodies, the source also should have occupied large areas. For example, a granitic intrusive of 5 Km on a side has a volume of 125 Km^3 or more, If this body is considered to have derived by 10% partial melting, the parent should have had at least a volume of 1250 Km^3 or a block with ~ 10.77 Km on a side. But, around KGB, we do not have graywacke of any extent and hence it is not possible to consider the graywacke as source for the intrusives. Further, the Rb content of the intrusives range from 60 to 117 ppm and they cannot be generated by melting graywacke/metasediments with similar or higher Rb content.

The above discussion has narrowed the probable source materials for the felsic intrusives to mantle and continental crust. Recent experimental studies have shown that it is difficult to generate even tonalitic and andesitic magmas from the mantle as primary melts

(Wyllie et al., 1976). Therefore, the Kolar intrusives that are granodioritic to quartz monzonitic in composition cannot be derived from mantle. The rocks of granodioritic composition can be generated in the crust with moderate water content at temperature attained during regional metamorphism (Wyllie et. al., 1976). From the observed geochemical characteristics of felsic intrusives of KGB and from the experimental evidence, it is possible that these intrusives could have been generated from a heterogenous source in the continental crust.

The migmatitic gneisses are essentially granodioritic in compositions (fig 5.1) and in major and trace element content they are comparable to the granodioritic intrusives, The migmatitic gneisses pose severe constraints in geochemical modelling on the account of complex origin. The migmatitic gneisses of various terrains are attributed to one or more processes, as given below:

1. lit-par-lit injection of granitic magma along foliation planes of already existing rock (Pitcher and Berger, 1972) or magmatic injection at various stages of fractional crystallization (Condie and Allen, 1980).
2. anatexis of crustal rocks (Winkler 1974, Menhert 1968).

3. Metasomatism (Brown 1967).
4. Subsolidus metamorphic differentiation, with a locally closed system by mechanical or chemical processes (Oslen, 1977 and Yardley, 1978).

The nature of the migmatization process that has affected a given terrain can be determined using criteria suggested by Yardley (1978). They are:

1. field correlation between a migmatite and its premigmatization equivalent and their differences in bulk composition,
2. bulk composition of leucocratic veins and layers in the migmatite with the initial melt composition in experimental studies and
3. textural and mineralological criteria and distribution of major and minor elements in paleosomes and neosomes.

Though we have extensive migmatitic complex around KGB, we were not able to locate its pre-migmatization equivalent to carryout comparative study. The migmatites sampled at various localities both in western and eastern sides of KGB are similar in mineralogy, major element and trace element chemistry. The above observation suggests that the migmatization episode, perhaps involving more than one processes, dominated over the rocks of roughly similar lithology.

The migmatitic gneisses, in their major and trace-element (Chemistry) content are comparable to the intrusive granodiorites, Hence, agmatization or mixing of already existing rocks by granodiontic magma, to give migmatites may not be a viable process. Further, repeating the same arguments given for intrusive granodiorites, migmatites cannot be generated by partial melting of amphibiolites. Their low K, Rb and Y and high Sr content compared to the archean metasediments and the absence of extensive metasediments around KGB preclude the possibility of vast migmatitic complex produced by anatexis of sedimentary rocks. The migmatitic gneisses could have been generated by anatexis or subsolidus metamorphic differentiation of already existing crustal material with some sedimentary component.

The older gneisses differ from other rocks in their texture, mineralogy, major and trace-element content. The older gneisses are characterised by possible relict sedimentary feature and high grade metamorphic mineral assemblage like sillimanite and garnet. The polydeformed older gneisses when compared to the granodioritic intrusives and migmatitic gneisses have lower MgO, Sr, and higher Y, Rb, and K contents and higher Zr/TiO_2 and Y/TiO_2 ratios (fig 5.10) characteristic of sediments. Therefore, the older gneisses could probably represent sediments, metamorphosed to Sillimanite-Anorhite-cordierite-orthclase-Qtz sub facies of amphibolite facies, derived from prexisting crust.

The geochemical nature of the intrusives, migmatites and older gneisses indicates the presence of pre-existing crust as their percussors. Such a pre-existing crust could have been tonalitic in chemistry as suggested for other shield areas. However, we were not able to trace rocks of definitic tonalitic chemistry representing the pre-existing crust around Kolar Greenstone belt. The high U and Th contents in the felsic rocks around KGB indicate their origin by reowrking of continental crust, since the rocks derived directly from the tholeiite/basaltic source cannot have high U and Th. Preliminary study on Rb and Sr isotopes revealed Sr^{87}/Sr^{86} initial ratio of 0.704 c.a. for the intrusive gneisses of 2.5 to 2.7 b.y. old (Rajamani, Personal communication). This high Sr^{87}/Sr^{86} initial ratio again suggests their origin by remobilization of continental crust. Thus based on major and trace-element chemistry of older gneisses, migmatitic gneisses and

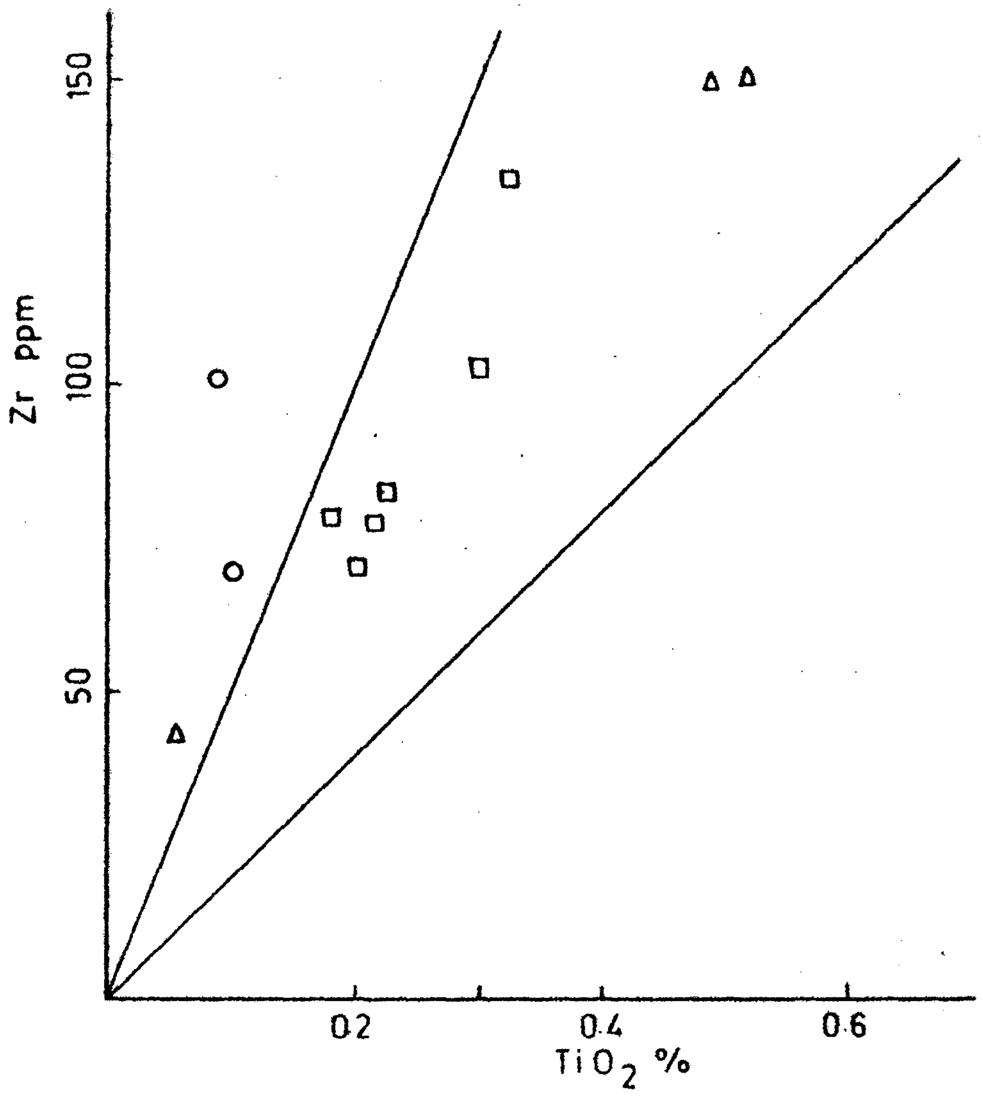


Figure 5.10 (a): Plots of Zr and Y verse TiO_2 for felsic rocs around Kolar schist belt.

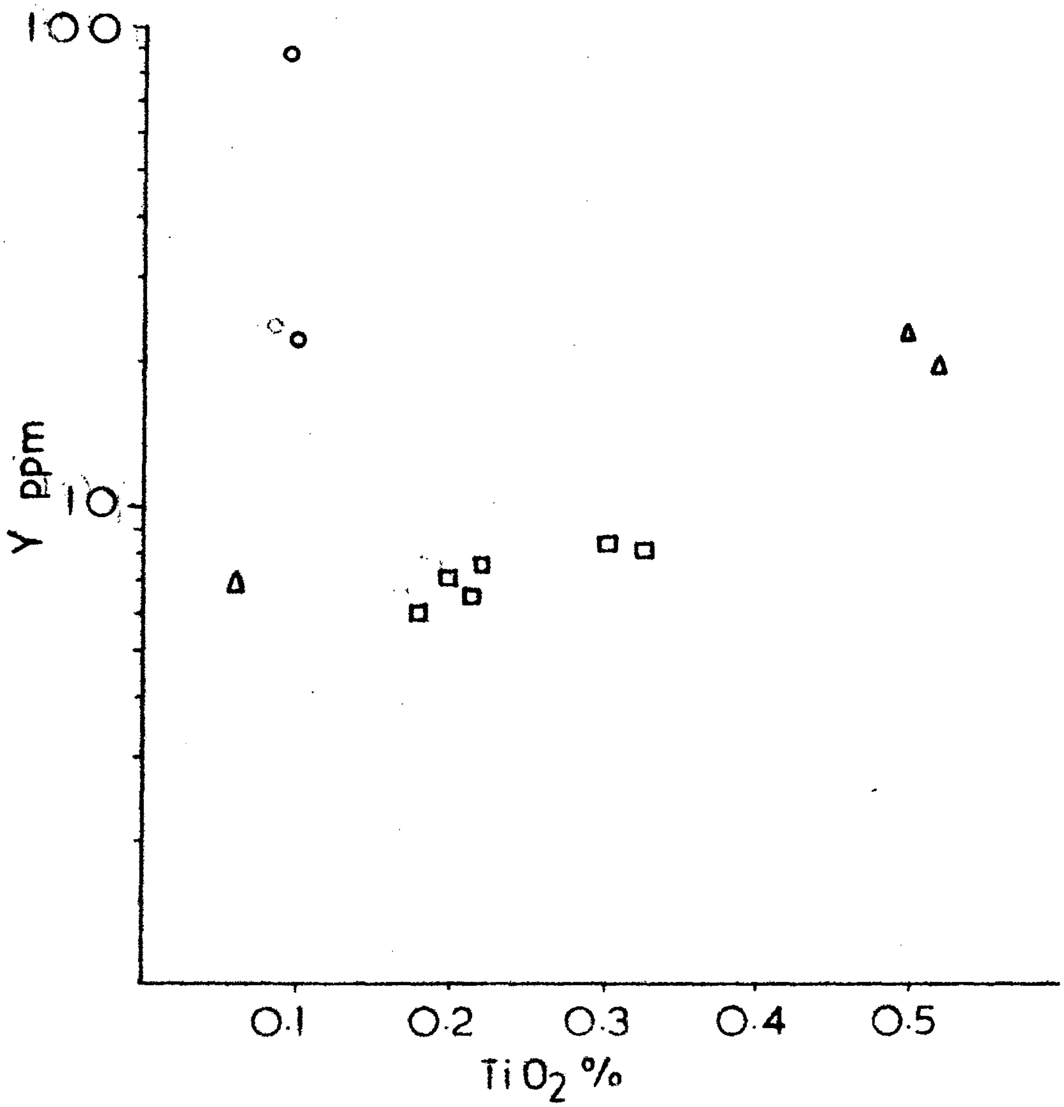


Figure 5·10 (b). Plot of Y verse TiO_2 for felsic rocks around Kolar Schist Belt.

intrusive gneisses, we suggest presence of pre-existing continental crust in this region. Possibly this pre-existing continental crust could have been the basement on which Kolar greenstone belt was evolved.

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