CHAPTER-7

PETROGENESIS

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7.1 GENERAL

In this chapter, based on the synthesis of the entire field, petrographic and chemical data, reconstruction of the successive geological events, which probably took place in the study area, is discussed. Possible models for the origin and evolution of the various lithological units of the area around Tiruchirapalli in particular, and the granulite terrain as a whole in general, are discussed taking in to consideration the results of similar studies carried at granulite terrains elsewhere.

7.2 GRANULITES

The problem of origin of granulites is considered under the following subheadings

Igneous or sedimentary nature of the protolith

Mode of protolith formation

Metamorphism and Retrogression

7.2.1 IGNEOUS OR SEDIMENTARY NATURE OF PROTOLITH

The geochemical characters observed in granulites, namely the positive values of discriminant function (Shaw 1972), (except for those with MgO more than 6% which according to Jahn and Zhang (1984) are non controversially igneous) are magmatic. The plotting of samples in igneous fields on the binary plot of K_2O/Al_2O_3 vs Na_2O/Al_2O_3 (Fig.7.1) also suggests the protolith of these granulites to be magmatic. Other geochemical evidences like the presence of normative diopside in these rocks and their $Al_2O_3/(CaO+Na_2O+K_2O)$ ratio of less than 1.1 also imply igneous parentage rather than sedimentary precursors (Chappel and White, 1974). Moreover, the plots show igneous trends not only on Larsen's variation diagram (Fig.6-1) but also on the ternary plots of cations (Fig.6-15) and ortho-para discrimination diagram (Fig.6-11) after Tarney (1972).

The petrographic features such as combined Carlsbad and albite twins in plagioclase feldspar, existence of zoned structures in them, subhedral to euhedral character of sphene and apatite grains and presence of sub-ophitic texture are in support of igneous parentage for these rocks. It is relevant to point out here that relict sedimentary structures have not been observed in the field. Moreover, in the

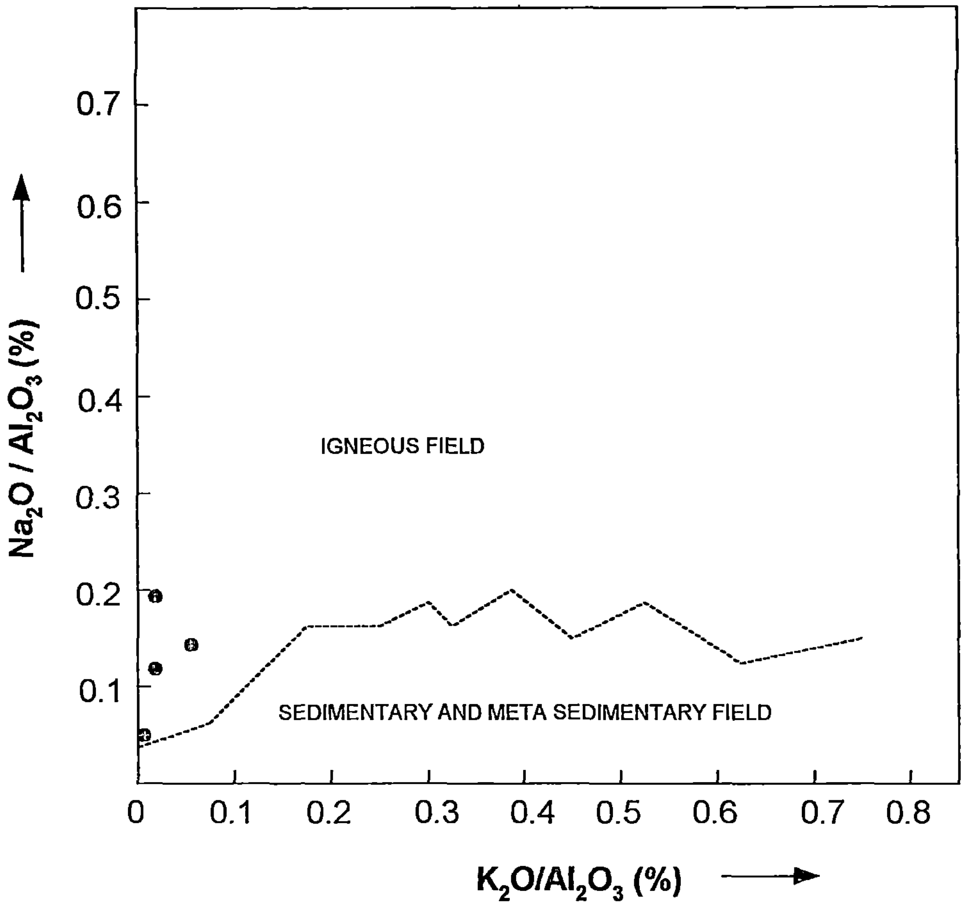

FIGURE 7-1 K_2O/Al_2O_3 vs Na_2O / Al_2O_3 VARIATION DIAGRAM

(GARVEL AND MACKENZIE, 1971)

● BASIC GRANULITES OF TIRUCHIRAPALLI

magma discrimination diagrams the basic granulites occupy tholeiitic composition. Their basic igneous nature is also brought out by a silica content of more than 47 percent.

7.2.2 MODE OF PROTOLITH FORMATION

The mode of formation of protolith of granulites can be accounted for by any one of the following mechanisms. The residuum, left after the removal of granite magma from intracrustal partial melts, may give felsic charnockitic representatives. The basic granulite exhibits a hydrous mineralogical characteristic of granulite facies metamorphism. The occurrence of basic granulites as lenses and sill type bodies in gneisses points to their emplacement as viscous bodies. The major element composition like SiO_2, Al_2O_3 MgO and FeO of these granulites is suggestive of their derivation from a more basic magma. Field et al (1980) and Holland and Lambert (1975), have advocated the deep crustal fractionation of dacitic magma. However, the protoliths of the granulites may be produced by fractional crystallization of wet basaltic magma (Barker and Arth 1976). It may also be possible to produce such rocks during partial melting of a mafic source rich in hornblende with or without garnet (Weaver and Tarney, 1983:Condie et al, 1982).

The processes of extraction of granitic magma from the parent rock, which leaves a granulite residue, will also make depletion of LIL elements in granulites (Fyfe 1973; Pride and Muecke 1980). However, many authors (Wells 1979; Weaver 1980) are not in favour of this theory since the granulites studied by them in various areas are not fully explained by this mechanism. One of the main reasons for this is that the low-grade gneisses representing the transition zone do not have negative europium anomaly (Condie et al., 1982). But the granitic gneisses in Tiruchirapalli have positive europium anomaly and hence it appears that the Fife's model will hold good for them. But as pointed out by Fife (1973), the ratios of Ba/Sr as calculated from the tables show such variations between granitic gneisses and granulite and hence the later could be a residuum of granitic melt. It may also be noted that according to Fyfe (1973), the granulites of this model have Eu enriched pattern slope but the granulite investigated in the study area is having no Eu anomaly. Field et al., (1980), from the geochemical model enumerated that the REE pattern is consistent with an essentially primary fractionation processes involving the separation of cumulus phase (LIL deficient) from andesitic - dacitic magma emplaced directly under the high grade conditions, with the normal LIL element rocks crystallizing from the residual melt. This model does not explain the low HREE and the positive Eu anomaly of the siliceous gneisses of the area. Moreover, a crustal fractionation model requires strontium to be enriched in the plagioclase cumulates and the incompatible Ba has to be depleted. But such trends in the distribution of trace elements have not been noted in the granulites under study.

Regarding the origin, according to the model visualized by deep crustal fractionation of dacitic magma, charnockites are produced directly from magmatic crystallization at depth. However, the present study and a number of other studies on the South Indian charnockites have shown that they are metamorphic. It is also an accepted fact, as indicated by many workers (Holland 1900; Barbey et al., 1986) that direct magmatic crystallization processes form charnockites. But, Newton and Hansen (1983) argued that the proportion of uniquely magmatic charnockite is probably small. However in the study area, the calc alkaline trend exhibited by them clearly demonstrates their igneous origin. Miyashiro (1972), explained the tholeiitic and alkaline volcanism in terms of the rate of plate subduction, " Tholeiites resulting when the rate is high, alkaline when it is low and, Shoshonite when the rate is minimum". Charnockites of the study area have major and trace element chemistry broadly comparable to the charnockites from other granulite terrains (Weaver 1980; Kaiyi et al., 1985). These rocks with their different field characters, variation in colour textural patterns and grain size suggest more than one phase of formation. One group of rocks are having melanocratic color index, with more ferromagnesian mineral content and elevated abundances of MgO, FeO and CaO, while, light colored and lesser amounts of ferromagnesian minerals and more of alkali feldspar, zirconium and yittrium with low MgO characterize the other late stage charnockites.

The two-charnockite groups recognized in the field show distinct litho-contact relationships and petrography contrasting levels of immobile elements and molecules like CaO, MgO, Zr, and Y also specify characters. The CaO –Y relationship in the charnockites (Fig.7.2) demonstrates the origin of their protoliths by magmatic processes (Lambert and Holland 1974). The increase in Zr-Y (Fig.6.20) in these charnockites and an increase in Cr-Ni (Fig.7.3) in basic granulites suggest a probable similar origin for them. This view

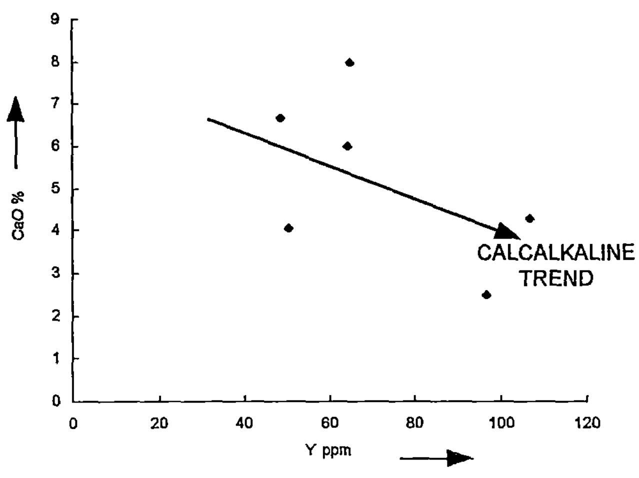

FIGURE 7 - 2 CaO vs Y DISTRIBUTION

◆ CHARNOCKITES FROM TIRUCHIRAPALLI

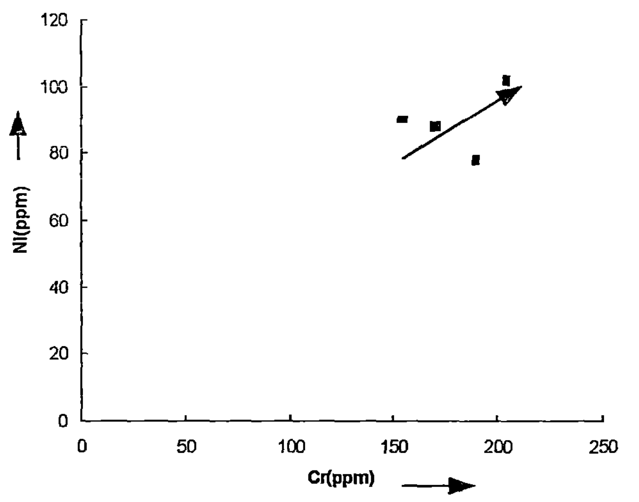

FIGURE 7 - 3 Cr vs Ni PLOT

■ BASIC GRANULITES FROM TIRUCHIRAPALLI

is also supported by Yb-Y (Fig.6.27) linear relationship observed in these rocks.

The significance of K/Rb ratios in understanding the fractionation process in magmatic series is clearly realized and this ratio has been used in many granulite terrains to find out the source rock characters and fractionation processes (Sheraton 1970; Drury 1973; Collerson 1975; Sighinolfi and Gorgoni 1978;). The low Rb and high K/Rb values in granulite facies rocks suggest that the lower crust is deficient in rubidium relative to the upper crust (Field and Clough 1976; Rudlick et al., 1985). In upper crustal rocks K/Rb ratio shows higher values (Shaw 1968). Many Precambrian granulite terrains show a sharp increase in this ratio with decrease in K. Infact, K/Rb ratio of 1000 or more are reported from many shield areas (Tarney and Windley 1977). The K/Rb ratios in the basic granulites of Tiruchirapalli area are as high as 2300, indicating depletion of both K and Rb and relatively strong depletion in Rb. The charnockites on the other hand have uneven enrichment of K and Rb, resulting in K/Rb ratios similar to the upper crustal averages. The charnockites with higher K/Rb values also have higher Zr (799 ppm) and Y (72 ppm) values.

It has been suggested that Ba behaves coherently with K and Rb during geochemical events and consequently K/Ba may be more reliable indicator than K/Rb ratio for indicating prior depletion of the terrain. As a corollary, Rb-Sr dating systems in such terrains may considerably be affected and should be used with caution (Allen 1979). The K-Ba relationship in basic granulites and charnockites of the present study area (Fig.7.4) points to the depletion of the LIL elements in the former and subsequent enrichment of both K and Ba in the latter.

As the REE are generally immobile during metamorphism and metasomatism, their abundance in a rock could be taken as index to represent the actual concentration levels in the source rocks (Henderson, 1984). However, a little modification of REE distribution in granulite facies of metamorphism has been demonstrated by Green et al., (1972). They have also indicated from Sm-Nd systematics of Lewisian gneisses that REE are not mobilized during granulite facies metamorphism. However, Collerson and Fryer (1978), explained that HREE depletion in the granulites might be the result of action of CO_2 rich fluids upon them. This view of depletion of HREE due to CO_2 metasomatism does not hold good for the basic granulites and

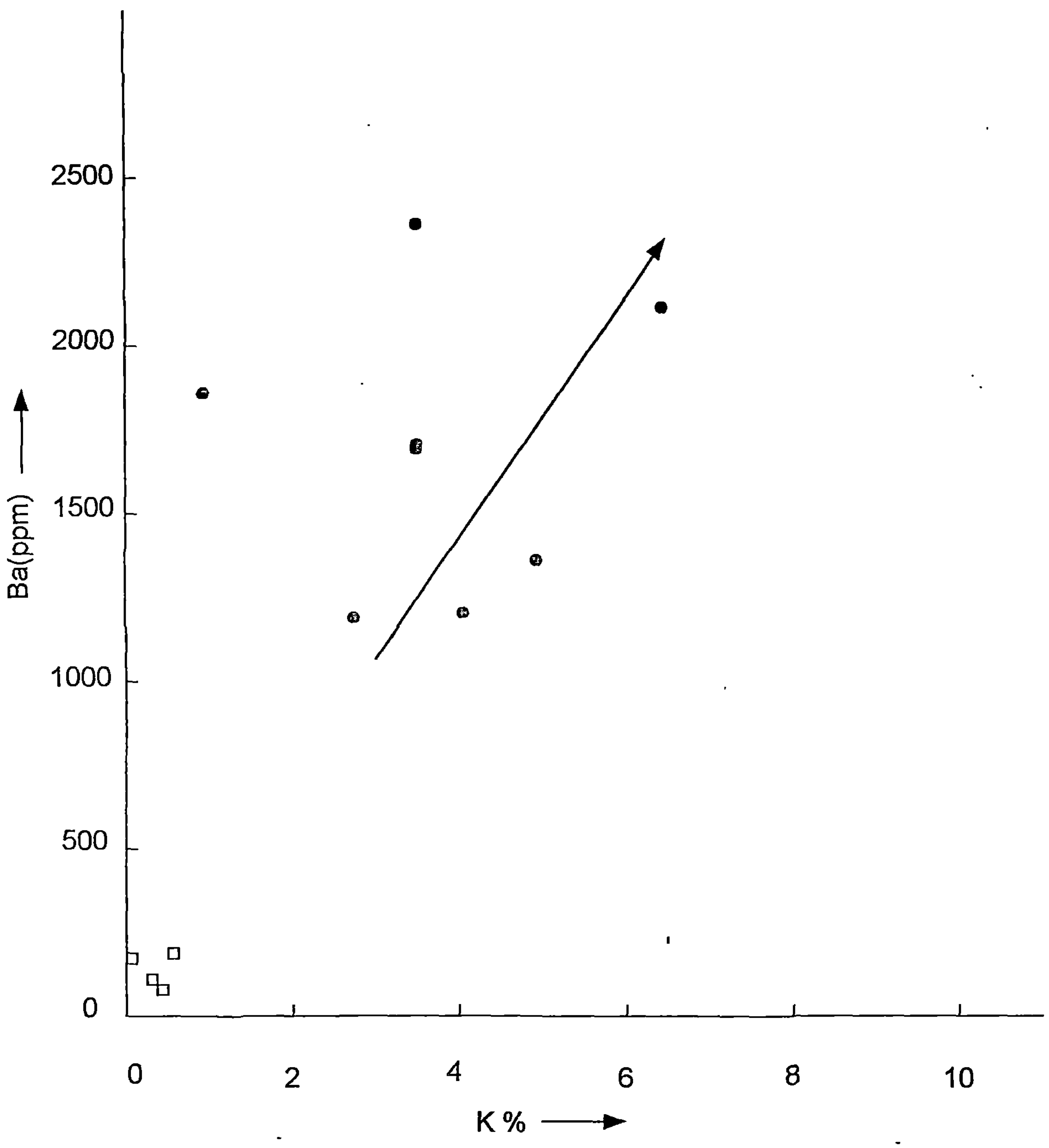

FIGURE 7 - 4 K vs Ba DISTRIBUTION

● CHARNOCKITES FROM TIRUCHIRAPALLI

□ BASIC GRANULITES FROM TIRUCHIRAPALLI

charnockites of the study area, while considering the K/Rb, and Ce/Yb ratios.

Generally REE prefer enrichment in a liquid medium than in a solid phase. By and large it shows selective enrichment in different types of minerals. Garnet admits HREE readily but not LREE. Apatite accepts both HREE and LREE. Feldspar normally takes Eu better than other REE. Comparatively Ca rich pyroxenes incorporate the REE more readily than Ca poor pyroxenes or olivine. Thus in the late-forming phases of a fractionally crystallizing liquid, the REE absorption is very selective.

La/Yb and Ce_N/Yb_N are considered as indices of fractionation. In the study area the average La/Yb ratio for charnockites (30.3) is higher than that of basic granulites (4.3). Similarly the average Ce_N/Yb_N ratio is higher in charnockites (8.7) and lower in basic granulite (1.95). Hubbard and Whitley (1979), have visualized the retrogressive change in REE contents, concentrated in the various litho units of plutons in the Varberg region of Southwest Sweden. Pride and Muecke (1980) have also provided REE evidence for the possible existence of genetic link between granulites and granitoids. This contention is reinforced by the rational nature of the REE change with bulk compositional differentiation from basic to acid granulites with increase in total REE (Key and Wright, 1982). Thus it is inferred, in the study area, that the charnockites are comparatively more fractionated than the basic granulites.

A comparison of REE data of charnockites of Tiruchirapalli with that of the type area from Madras (Weaver 1980) has revealed a few important differences between them. The charnockites of the study area show higher abundant levels of total REE instead of lower concentration of Pallavaram charnockites. Similarly basic granulites are also enriched in total REE content with higher Ce_N/Yb_N ratio compared to the basic granulites described from Madras (Griffith J.B et al., 1987), indicating more fractionation of REE. More over, Weaver (1980) has inferred a non-homogeneous source for Madras charnockites. But the basic granulites and charnockites of Tiruchirapalli are the products of a relatively homogeneous source.

The charnockites of the study area show geochemically a calc – alkaline trend. The basic granulites and the charnockites of the Tiruchirapalli exhibit compositional gradation in many of the major and trace elements and REE. The compositional variation in between the basic granulites and the charnockites suggests that both are derived from same source but at different levels of differention. In fact the basic granulites are the least fractionated with tholeiitic affinity and the charnockites are more fractionated with calc-alkaline affinity. It is also inferred that the regional metasomatic activity has affected the granulites considerably.

7.3 AMPHIBOLITES

In the AFM plot (Fig.7-5) the amphibolites fall in calc alkaline field. But the plots of Na_2O+ K_2O vs SiO_2 (Fig.6-31) assign tholeiitic composition for their protolith. It is pertinent to point out here that Coulon and Thrope (1981) stated that in nature there is no clear distinction between the tholeiitic and alkaline rocks. While discussing the K content of volcanic rocks, Jakes and White (1972) have concluded that the tholeiitic association has a relatively low K_2O. Moreover, the Archaean tholeiitic rocks are low in potash irrespective of their tectonic environment (Brooks and Hart, 1974). Considering, therefore, the value of low K_2O content of mostly less than 3.55% (minimum value of 0.66%) for the amphibolites of the study area a tholeiitic protolith is more likely. The shift of plots towards the calc-alkaline field (Fig.7.5) and a slightly elevated abundance of alkalies in the amphibolites, may be due to the infused alkalis from later calc-

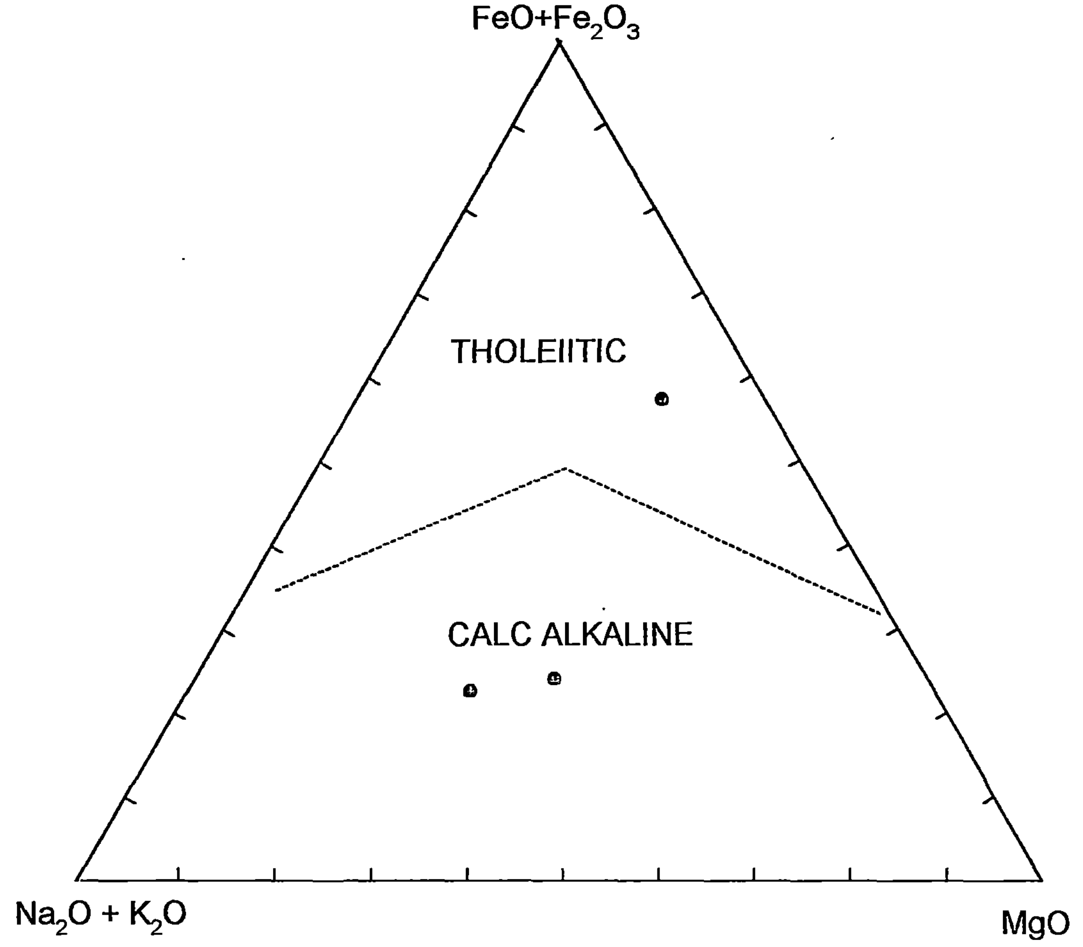

FIGURE 7 - 5 A F M DIAGRAM.
(IRVINE & BARAGER, 1971)

● AMPHIBOLITES FROM TIRUCHIRAPALLI

alkaline melt related to the metasomatic activity. The following models have been formulated to account for the origin of tholeiitic rocks. They include;

1.Tholeiites were derived from source materials and physico-chemical conditions similar to those of komatiites, but by lower extents of melting.

2.Tholeiites were formed from fractional crystallization of parental komatiitic magma.

3.Tholeiities were derived from shallow levels but from sources similar to those of komatites (Basaltic Volcanism Study Project, 1981).

In addition, while studying the Kolar schist belt, Rajamani et al., (1989), opined that the tholeiites were derived from Archaean asthenosphere by low and variable extents of partial melting.

If tholeiiltes are assumed to the formed from a later stage of fractionation from komatiitic sources, the Fe content of tholeiites should be greater than that of komatiites. But the Fe content of the amphibolites of Tiruchirapalli is strikingly less than that of komatiites of type area. Moreover, the amphibolites, when compared to komatiitic rocks are found richer in TiO_2. If the amphibolites are the products of fractional crystallization of komatitic magma then TiO_2 content in them must have been otherwise. As supporting evidence, a relatively high MgO and low Al_2O_3 of the amphibolites of Tiruchirapalli are the confirming factors of their derivation not through fractional crystallization of komatitic magma. Hence, the theory to account for the development of tholeiitic magma based on the association with komatiitic magma is ruled out. However, the tholeiitic affinity of the amphibolite samples can be discerned by comparing their trace element composition with that of known established basalts. For example the average concentration of Sr (281 ppm) compare well with the concentrations typical of oceanic tholeiites (Condie 1976). Similarly Cr and Ni values though appearing to be mobilized, (237 and 140 ppm respectively) match well with the tholeiitic basalts province of Western Australia (Glicksen, 1983). Subrahmanyam et al., (1981), reported cobalt content for Deccan basalt, which is similar to that the study area (43 ppm). Moreover the REE pattern slopes (Fig.6.33) of these amphibolites are in accordance with most of the Archaean metabasalts, which show enriched, or depleted LREE and flat or sloping HREE with small negative Eu anomaly (Iyer et al., 1980: Condie, 1981).

From the above discussions, it is inferred that the protoliths of the amphibolites of Tiruchirapalli may be a part of the basaltic magma. This magma during its fractionation has given rise to a melt of gabbroic or noritic composition, which got intruded at places into the metasediments, the digestion of which can be accounted for their compositional changes. However, the infusion of a later metasomatic activity has also affected the original composition of the amphibolites.

7.4 GNEISSES

Gneisses are the predominant litho units exposed within the study area. The foliated gneissic structure, general concordant relationship, merged and transitional contacts among them, development of augen structure and migmatized styles of folding are the products of regional metamorphism associated with granitoid intrusion. All along the shield areas throughout the world, such common features in gneisses are well documented and they are syntectonic in origin.

The discrimination diagrams plotted (Fig. 6.37) have established the igneous parentage of the gneisses. The ortho nature of the precursors (Werner, 1987) of these gneisses is also brought about in P_2O_5 / TiO_2 ratio vs MgO /CaO ratio in figure (7.6). It can be noted

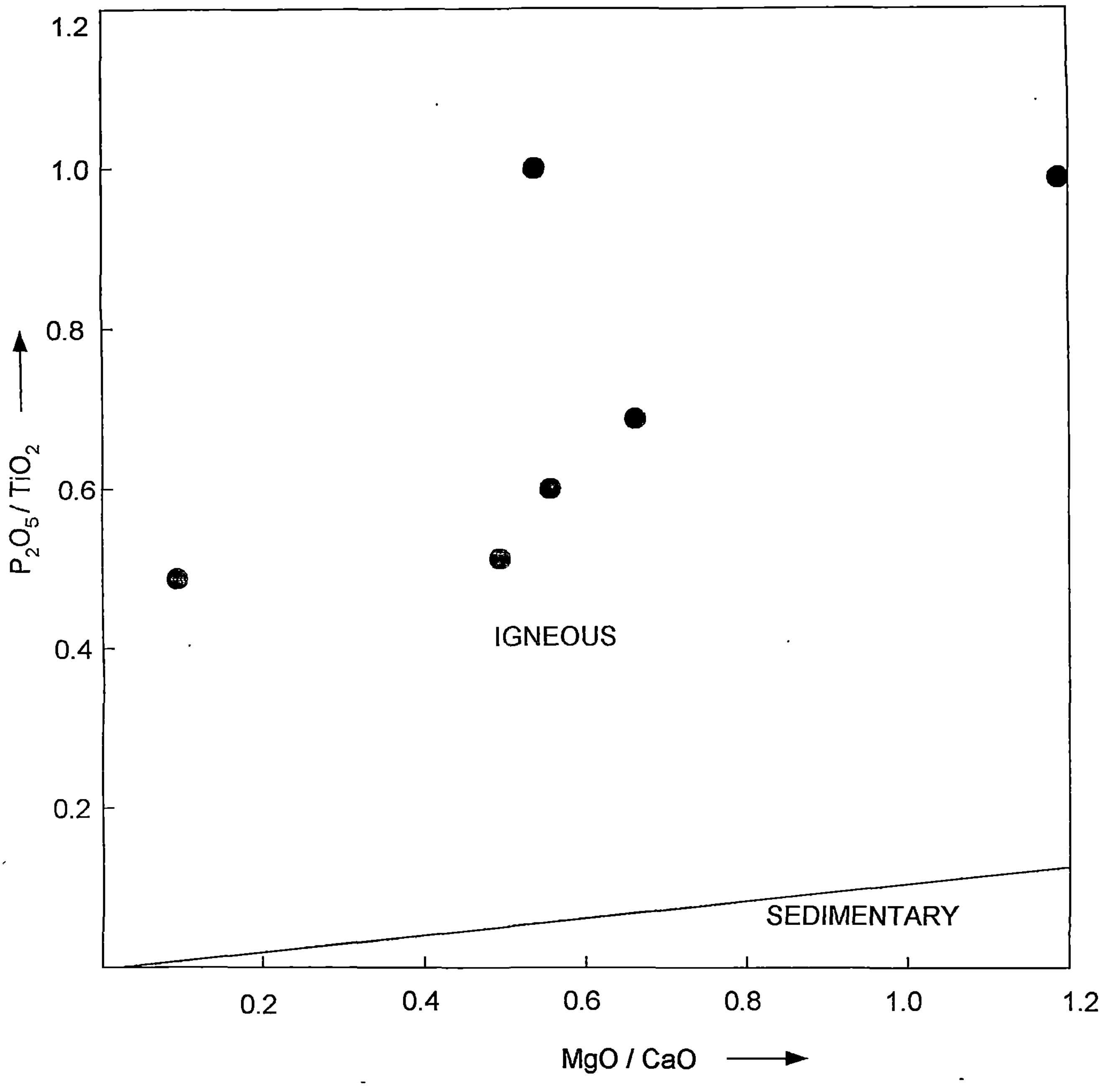

FIGURE 7 - 6 MgO / CaO vs P_2O_5 / TiO_2 PLOT
(WERNER ,1987)

● GNEISSES FROM TIRUCHIRAPALLI

from the plots (Fig.6.34, 6.35& 6.36) that the gneisses record a wide compositional range falling within the fields of granite and granodiorite. The compositional variation with Na_2O / K_2O value, mostly less than one, is considered here as an effect of K enrichment due to regional metasomatism.

In the AFM diagram (Fig.6.38) invariably all gneisses occupy the calc alkaline field. Petrogenesis of the high-grade gneisses has remained a controversy among petrologists and has currently many competing concepts pertaining to their origin and evolution. Newton (1987), has advocated that there are four hypotheses regarding the formation of protoliths including;

(a). Hot spot hypothesis

(b). Intercontinental subduction

(c). Continent scale under thrusting

(d). Continental collision and subsequent thickening hypothesis

Since field, petrographic and geochemical evidences do not indicate or favour any CO_2 metasomatic activity; the Hotspot hypothesis cannot be accepted for the generation of Tiruchirapalli gneisses. The extensive and sediment dominated high-grade gneissic terrains of the ancient shield cannot be explained by the continental margin under-plating model (Passchier et al., 1991). Thompson (1989) has advanced an attractive hypothesis that the crust is first thinned during several tens of million of years by extension, leading to basin formation, sedimentation, and related igneous intrusion. Subsequently the tectonic stacking brought down the crustal materials, enabling it possible for supracrustal sequences to be pushed down to considerable depth where melting can take place at high temperature and pressure conditions.

The proposal of Thompson (1989) proposal suits well for explaining the development of Tiruchirapalli gneisses. The fractional crystallization of the basaltic magma so generated yielded residual liquids of calc alkaline nature that formed a part of the precursors of the gneisses. The subduction of the sediments in the basin, their melting in the calc alkaline melts and syn-tectonic emplacement completed the story of formation of the gneisses.

7.5 METASEDIMENTARIES

The occurrence of small bands of calc granulites in the gneisses and charnockite suite of rocks along with quartzite indicates that the provenance has been changing during the deposition of the sediments. The chemistry of calc granulites also indicates LIL elemental depletion in them as well as the role of mafic rocks in their formation as indicated by the magnesia rich calc granulites. However, Serdyuchenko (1975) has visualized and recorded the formation of calc granulites originally as evaporates in shallow marine facies environment. Katz (1978), advocated a model according to which the precursors of the metasediments of the granulites belt of South India were conceived to have formed in fault bounded ensialic linear zones with an older migmatite basement, which may represent intercratonic aulocogens. Based upon these, shallow water environment of deposition and a stable cratonic source are inferred. The association of metavolcanic and metasedimentary sequences in granulites terrain has also been unequivocally evidenced (Narayanaswamy, 1975), while studying the charnockite series of Holland (1900) and khondalite series of Walker (1902). Barbey and Cuney (1982) have reported the association of metasedimentary and metavolcanic litho units in Lapland–Fennoscandia. Divakara Rao (1983) suggested that the metasedimentary rocks were deposited in marginal basins separated from one another under different Ph and Eh conditions.

From the geochemical characters and concentrations, it is inferred that the calcareous sediments become calc-gneiss and calc-granulite, and arenaceous sediments become quartzite.

7.6 EVIDENCES OF METAMORPHISM

The following field, petrographic and geochemical observations from the area of research are suggestive of metamorphism. The observations are: the presence of granulitic texture in the rocks, the nematoblastic texture in amphibolites, the absolute freshness of nearly all the constituent minerals, the appearance of greasy luster on the fresh surfaces of charnockites, (Leelanantham, 1961), occurrence of antiperthitic texture with oriented blebs, intense pleochroism in hypersthenes (Howie, 1955) and the unsystematic variation of trace elements like Rb, Sr and Ba (Condie, 1976).

7.7 RETROGRESSION

Prograded charnockites have been reported from the areas like Kabbal Durga Dharmapuri and Thiruvannamalai (Allen et al., 1985). However, from the granulite terrains of South Kerala there are reports of charnockites in the making and charnockites in the breaking in the same locality (Srikantappa, 1985: Ravindrakumar et al., 1985: Santosh and Yoshida 1986; Santosh 1991). Instances of charnockite breaking have been noticed in the building–stone quarries in and around Rettamalai and Edamalaipatti Pudur. Similar phenomena have been observed on a regional scale in and around area around Thuvakkudi and Kuttimalai in the northeast and central part of the study area respectively. Evidences in favor of such retrogression include the breaking down of clinopyroxene to garnet and magnetite and formation of hydroxyl minerals such as biotite and hornblende around hypersthene.

7.8 GEOCHRONOLOGICAL DATA

Geo-Chronological and Pressure-Temperature-Time studies have not been carried out in the present work. However data are available regarding P-T condition of formation of the rocks of the adjoining areas. The estimated pressure and temperature from several widespread granulite localities with in the Kodaikkanal and Nagerkoil Blocks, located due south of the present study area indicate that metamorphic conditions were largely in the low pressure granulite field (5 ± 1 kb, 700 ± 20° C, Wightman, 1986). The granulitic rocks of Dharmapuri area have also recorded pressures of 5 to 6 kb and temperatures between 730 and 775 ° C (Rameswararao et al., 1991). For the rocks of Mathukkarai area 5.5kb pressure and 760 ± 30 ° C temperature have been reported (Srikandappa et al., 1990). The granulites of Shevaroy have been subjected to a pressure of 7.4 kb and a temperature of 680 ± 55 ^{o} C. The area of study is therefore likely to have under gone metamorphic conditions of 6 ± 1 kb pressure and 650 ± 100 ^{o} C temperature. Al-Mg rich supracrustal enclaves from the Manapparai area, which are occluded within massive charnockite, yield a metamorphic temperature of 890 ± 40°C and pressure of 7.5 ± 0.5 kb (Charan et al, 1998).