GEOCHEMISTRY AND GENESIS OF LATERITE IN PARTS OF CANNANORE DISTRICT, NORTH KERALA

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CERTIFICATE

This is to certify that this thesis is an authentic record of research work carried out by Sri Narayanaswamy, M.Sc. under my supervision and guidance in the Centre For Earth Science Studies, Thiruvananthapuram for the Ph.D. degree of the Cochin University of Science and Technology and no part of it has previously formed the basis for the award of any other degree in any university.

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ABSTRACT

The term 'laterite' was coined by Francis Hamilton Buchanan in 1800 to denote a building material used in the Malabar region of Kerala. Since then occurrences of this material have been described from many regions of the tropics. Presence of various mineral deposits/occurrences associated with the laterites contribute to the general economy of the warm, humid parts of the world. Problems of laterite utilisation has more often been discussed from the agronomic point of view, and in recent times the importance of laterites in civil engineering and hydrological studies is rapidly increasing.

Besides these economic factors, lateritisation process is closely linked to landform evolution, and the subject matter of tropical geomorphology is concerned mainly with the study of this process and its products.

Kerala is the type area for laterites, and a substantial portion of it is occupied by lateritic cover of varying thickness, developed over rocks of different composition and age. The major soil type of Kerala belongs to the lateritic variety, and hydrogeological conditions here among others, are also controlled by the nature and extent of weathering profile development. It is, therefore, of paramount importance to understand the nature and course of development of the weathered rock mantle over various rock units in terms of their genesis and potential application.

In this backdrop, and in the absence of comprehensive and detailed information on laterite profile development over various rock units pertaining to the Kerala region, the present study on laterites was undertaken, with the prime object of characterising the course of laterite profile development over rocks of different composition and age through mineralogical, geochemical and geomorphic approaches.

The thesis consists of six chapters. Definition and classification of laterites, together with the concepts on laterite genesis as evolved through time are described in the first chapter. Status of laterite research, objectives of the present study and methodology are also projected.

The general geologic and geomorphic setting of the Kerala region, followed by a detailed account of the geology, structure and geomorphology of the Cannanore district is the subject matter of the second chapter.

Thirty laterite profiles developed over various lithological units like charnockite, gneisses, fuchsite quartzite, ultramafites, quartz-mica-schist, anorthosite, gabbro, granophyre, alkali syenite and sedimentary formation have been described in detail. Specific gravity of the laterites vary from 1.72 over charnockite to 2.41 over the sedimentaries. Two lateritisation cycles, namely pre-Warkalli and post-Warkalli based on this study.

Stability of minerals during weathering applicable for the study area has been established. Pyroxenes are the first minerals to undergo alteration during weathering in the area, while quartz remains stablest of all. Variation diagrams of major elements in laterite profiles studied show two stages in the development of laterite over charnockite, gabbro - granophyre, ultramafites, gneisses, alkali syenite and fuchsite quartzite; and three stages over sedimentaries and anorthosite. Out of the total discernible trends in the profiles, the first stage is marked by rapid depletion of silica, lime, magnesia and alkalies and enrichment of Al_2O_3 , Fe_2O_3 and TiO_2 . The second stage is marked by a gradual depletion of SiO_2 , CaO, MgO, Na_2O and K_2O with enrichment of Al_2O_3 , Fe_2O_3 and TiO_2. In the third stage as observed in the case of anorthosite and sedimentaries, rapid depletion of silica and partial removal of ferric iron with residual enrichment of alumina is noticed.

Variation diagrams of trace elements show enrichment of V, Cr, Co, Ni and Cu whereas Ba and Zn show depleting trend during lateritisation process. Ni enrichment is noticed in laterite profiles over ultramafites. Geochemical mobility series of elements during weathering over various lithological units have also been calculated. The elemental behaviour during weathering has been attributed to change in pH regime. Water geochemistry data indicate that kaolinite is the stable phase in the weathering milieu of rocks of the study area. REE patterns suggest that laterites in general are depleted in REE abundances compared to the parent rocks except in Ce and Eu values. Similarity of REE patterns of parent rocks and overlying laterites suggests that bed rock character in unexposed areas can be elucidated using REE patterns of laterites.

The major factors influencing the course and consequence of laterite profile development in the study area are suggested to be the bed rock character and topographic features to a limited extent. Prolonged rock-water interaction resulted in varying pH regimes in the rock provenances, influencing differential mobility and enrichment of elements leading to Fe or Al rich laterites. Five planation surfaces have ben identified in the area, and these are related to various stages of laterite profile development. The most extensive planation surface supporting thick laterite profiles (P_3) occurs at an elevation of 60-160 m. Laterite is also seen at lower levels. The major economic mineral associated with the lateritisation process in the area is the china clay deposit at Palayangadi, derived from weathering of peraluminous gneisses. This is overlain by a thick column of sedimentary kaolins.

It has been concluded that the course of laterite genesis on different rock types is not similar, though their physical appearance is similar.

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Chapter 1

INTRODUCTION

1.1. DEFINITION AND CLASSIFICATION - A REVIEW OF LITERATURE ON LATERITE GENESIS

Laterite was first reported by Dr. Francis Hamilton Buchanan from Angadipuram in Kerala (India) on 20-21 December, 1800, while on a journey through the countries of Mysore, Canara and Malabar (Buchanan, 1807). Buchanan observed a type of weathered material used for building, which was an indurated clay with full of cavities and pores, containing a large quantity of iron in the form of red and yellow ochre. It was very soft when fresh and could be cut with any iron instrument. When exposed, it became hard and resisted air and water much better than any bricks. He coined the term - "Laterite" to designate this material. In Latin "laterite" means brickstone and it is equivalent of the vernacular terms '*iticacullu*' or '*vettucullu*'. However, there exists some dispute in regard to the authorship of the term "laterite". Prescott is of the opinion that Babington (1821) was the first to use the term scientifically.

Laterite is a characteristic weathering product, first discovered in India and later found in the whole of the tropical belt. Fermor (In Fox, 1936) characterised Buchanan's laterite as 'lithomargic laterite' and even in part as 'lateritic lithomarge' while the high-level laterites of the Deccan were termed as the finished products - fully formed laterite. Initially, geologists were interested in the study of laterite as a rock, and on account of its relationship with bauxite. Later, during the first half of the twentieth century pedologists got interested in the study of laterite, as the upper parts of laterite profile were referred to as "soil forming", and they regarded it as their domain of investigation. Occurrence of laterite at the surface was believed to be due to the removal of "soil". Soon, those who described laterite as a rock qualified this by saying that it was a weathered or altered rock or, it was the product of alteration or weathering of an original rock.

Buchanan realized the disadvantage of using specific word for a material whose analytical characters were poorly known, and used the words laterite and brickstone indiscriminately during the period 1807 to 1814. It was only towards the end of his life he restricted the use of the term 'laterite' to a material of soft consistency which hardened on exposure to air. It can thus be seen that the term 'laterite' was applied originally to a particular type of rock with a remarkable property. Descriptions on these lines are found in the works of Newbold (1844, 1846). Lake (1890) reviewed a considerable number of studies on Indian laterites, formed over various rock types. Babington (1821), Benza (1836), Cole (1838), Clark (1838), Wingate (1852), Kelaart (1853), Blanford (1859), Buist (1860), King and Foote (1864), Wynne (1872), Theobald (1873), Mallet (1883) and Voysey (1833) were also associated with the laterite studies during the nineteenth century.

Though the alteration product developed on a particular rock type and with specific physical properties, was originally termed as laterite, it soon became axiomatic on account of its diverse origins, that too in various regions. The difficulties in the use of the term became apparent with the mention that in some cases lithomarge/mottled clays may also harden on exposure to air (Blanford, 1959; Kellog, 1962). Really, Du Preez (1949) and Sherman (1952) eliminated from Buchanan's definition the requirement of hardness. However, the property of absolute hardness rather than the ability to harden has gained popularity.

The chemical characterisation of laterite was attempted by Mallet (1883) who suggested that laterite was ferruginous and/or aluminous, although Buchanan had already drawn attention to the high iron content. It was Bauer (1898) who established the main chemical characteristics of laterites and suggested that these have elevated contents of Fe_2O_3, Al_2O_3 and low SiO_2 based on analysis of laterite from Seychelles. Presence of aluminium hydroxides and low silica values enabled comparison of these laterites with bauxites. A little later, Warth and Warth (1903) published chemical analysis of Indian laterites. While some of these laterites contained small amounts of alumina, others were rich in iron oxides. Others contained large amounts of aluminium oxide with relatively poor iron content. Similar results were obtained from other parts of tropical regions (Du Bois, 1903; Holland, 1903). Thus chemical composition of laterites seemed to offer a good criterion for a comprehensive definition of laterite compared to Buchanan's definition.

Since many of the tropical weathering products and soils are enriched in alumina, this criterion has been used to define laterite. Holland (1903) reported that the alumina in laterite exists as it does in bauxite in the form of oxides, while Fermor (1911) stated that laterite must contain besides hydrated iron oxide, oxides of aluminium and titanium, and recognized several kinds of lateritic weathering products namely lithomarge, true laterite, lateritic rocks, siliceous laterites, bauxite and iron ore. Fox (1923) stressed that if the laterite contains enough hydrated alumina which can be used as aluminium ore, it should be called bauxite. Warth and Warth (1903) considered that laterite is identical to bauxite. Thus, there has been considerable dispute as to whether the term laterite be discarded in favour of the term bauxite (Scrivenor, 1932). At this juncture, it became imperative that laterite should be defined either in terms of iron enrichment or of desilicification. The definition based on desilicification is however not free from constraints. If the synonimity of lateritisation with desilicification is accepted, a material characterised by kaolin could be considered as an example of incomplete process of lateritisation as kaolin could further be desilicified (McFarlane, 1976). Clays and hydrates normally occur together in varying proportions in laterite, and bauxite may occur as segregations (Bishopp, 1937; Dey, 1942) and as one of the constituent units of the laterite profile (Fox, 1933; Karunakaran and Sinha Roy, 1971). This clearly shows that laterite has been recognised as a product of weathering by which desilicification takes place and an enrichment in either alumina or iron or both results (Fermor, 1911; Humbert, 1948; King, 1962). Thus, within the broad perspective of the definition, silicious, ferruginous or aluminous varieties of laterite have been suggested (Scrivenor, 1937). As lateritisation or desilicification results in the progressive change in the proportions of silica and sesquioxides of the weathered material, the ratios of SiO_2, Fe_2O_3 and Al_2O_3 are considered to provide a basis for laterite definition. Martin and Doyne (1930) stipulated that if $SiO_2 : Al_2O_3$ ratio is less than 1.33, the material should be termed as laterite and for lateritic soils the ratio should be 1.33 to 2.0. Later they modified the upper limit of this ratio for laterite at 2.2. Karunakaran and Sinha Roy (1971) and Sinha Roy (1967) proposed that materials having $Fe_2O_3 : Al_2O_3$ ratio less than 1.33 be termed as ferruginous laterite, while those with $Fe_2O_3 : Al_2O_3$ rather less than 1 and $SiO_2 : Al_2O_3$ ratio less than 1.33 as aluminous laterite. Since all the chemical - mineralogical classifications proposed hitherto ignored factors such as the intensity of the weathering conditions, type and composition of the parent rocks that generally determine the ultimate composition of the weathering products etc., no satisfactory and universally acceptable classification could be so far arrived at. More recently proposed definitions particularly by pedologists ignoring the chemical criteria, are woven around the morphological - physical characteristics including those of the indurated products.

Considering the inadequacies of the existing classifications, Schellmann (1981) proposed a new classification for laterite formed on different rock types. "Laterite fields" developed over various rock types have been shown on SiO_2-Al_2O_3-Fe_2O_3 ternary diagrams (Schellmann, 1981, 1986).

1.2. GENESIS OF LATERITES

Like the definition, the genesis of laterite has also precipitated much debate and controversy. Until the first quarter of the twentieth century, laterite was regarded as a rock type. The earliest description of Newbold (1844) and Bain (1852) characterised it as a "purplish, or brick red rock prevalent in the tropics, but unknown in Europe. In Australia its affinity to "desert sandstone" delayed the acceptance of the rock name in Australian geological context (Mallet, 1883; Prescott and Pendleton, 1952). Wetherell (1906) considered laterite as a sedimentary formation. Models suggesting the activities of nitrifying bacteria (Holland, 1903), and termites (Erhart, 1951) have not evoked much support. However, most of the early workers who unreservedly believed laterite to be a rock, emphasising that laterites has a residuum (Babington, 1821; Clark, 1838; Benza, 1936) formed by complex processes of physico-chemical weathering leading to the concentration of sesquioxides and removal of silica and alkalies (Russell, 1889; Harrison, 1911; Hartman, 1955). Further they suggested that under conditions of tropical weathering the alteration of basic or intermediate rocks at or close to water table under conditions of more or less perfect drainage results in nearly complete removal of Si, Ca, Mg, K, Na oxides, leaving a residuum of alumina, iron oxides, some altered feldspar, secondary quartz and resistant minerals. Two phases of mobility of the elements were implied in the process of residuum accumulation: (1) the residual components became mobile and were precipitated in immobile or related immobile form, (2) this mobility which was certainly less than that of the component completely washed away, was short lived, and led to accumulation or precipitation.

Maclaren (1906) stressed the importance of ground water in the formation of laterite and stated that laterites are not the result of *in situ* decomposition of rocks, but a replacement of decomposition products by ground water. Marbut (1932) suggested that the thickness of laterite zone is the width of the scene of the fluctuation of the water table. The source of enrichment of the ground water is considered to be located below the laterite horizon. Laterite as a precipitate also stemmed from the recognition of pallid zones that generally underlie the true laterite. This led to the recognition of a higher degree of mobility of the accumulated materials than was formerly thought of, suggesting that the concentration was due to the higher mobility (Campbell, 1917).

After the formulation of the concept of laterite being a precipitate (Campbell, 1917), numerous chemical studies on mobilisation and reprecipitation were carried out mostly by pedologists (Britton, 1925; Deb, 1949) and others reinforcing the former suggestion. This led to the description of laterite either as a soil horizon or resulted in a chemical rather than physical definition of laterite. However, this was not readily accepted by geologists (Pendleton and Shrasuvana, 1946). At the same time, a study of Hawaiian laterites by Sherman (1952) concluded that as a consequence of extensive chemical weathering in the tropics the sequence of changes involve derivation of hydrated oxides from secondary alumino silicate clay minerals that are formed due to alteration of primary minerals. Silica is leached out, leaving behind free oxides of iron and aluminium, while titanium hydroxide is brought to the zone of dehydration by capillary action

Although laterite formation was largely aided by capillary action (Holmes, 1914; Woolnough, 1927) and considered to be one of the mechanisms that plays an important role in the formation of duricrusts (Stamp, 1961; Loughnan *et al.*, 1962), it was later disputed by Goudie (1973). The concept involving the combined effect of capillarity and water table fluctuations in essence suggests the upward migration of enriched solutions with the seasonal rise of water table and their precipitation near the upper limits of the range of fluctuations (Pendleton, 1941), the efficacy of which was even emphasised by Fox (1923), who suggested that colloids are generated during chemical weathering and these are precipitated in the laterite zone.

Recent thinking, especially after the 1960's, through interpretation of precise data exposes the inadequacies of many of the basic assumptions upon which rested the previous theories of laterite origin as a precipitate. Occurrence of laterite in varied geological environments, generally under conditions of low relief, made geomorphologists make a synthesis between the old model of down-wasting with residual accumulation, and the later model of precipitation in a planation surface profile. The distribution of laterite under anomalous conditions requires something more than climatic change to explain its occurrence. This led geomorphologists to believe that weathering profile development, including the thickness of the profile is dependent on the topographical conditions existing on a peneplain or on a remnant of a dissected peneplain, having implications on landscape evolution. Association of laterite development with planation surfaces has been unequivocally established in many parts of the tropics (Vaidyanadhan, 1967; McFarlane, 1976; Subramanian and Mani, 1981; Karunakaran and Sinha Roy, 1981).

In short, research on laterite in tropics invariably recognises the precipitationary aspect of laterite, and the essentially residual accumulation under favourable conditions of planation.

1.3. STUDIES ON LATERITES FROM KERALA

Dr. Francis Buchanan described and coined the term laterite in 1800, within the territory of Kerala. Since then it has been a subject of scientific controversy. Furthermore, the laterite of Buchanan's type area in Angadipuram has been later found to vary in composition from limonitic hematite to argillaceous or siliceous limonite (Scrivenor, 1937) and represents a halfway product between kaolinised parent rock and bauxite (Dey, 1954). Fox (1936) indicated the presence of detrital components in the laterite of this area. Chemical analyses of laterite of this area were reported by Chacko (1919) and later by Fox (1936). Lake (1933) described a series of laterite occurrences from Malabar area. Fox (1936) and Dey (1954) studied Buchanan's laterite of Malabar, and Stephens (1961) described the structural features of the laterites from Angadipuram. Gopalaswamy and Nair (1975) worked out the micromorphological aspects of Kerala laterites. Studies on mineralogy, geochemistry, genesis and relationship to landform evolution have been attempted by many workers in the recent years (Gopalakrishnan and Nair, 1976; Sinha Roy, 1979; Subramaniyan *et al.*, 1980, 1981; Karunakaran and Sinha Roy, 1981; Mallikarjuna *et al.*, 1981; Nair and Thomas Mathai, 1981; Raghavan Nambiar *et al.*, 1981; Sambandam and Prasad, 1981; Ghosh, 1982a,b, 1983; Ghosh and Narayanaswamy, 1982; Soman, 1982; Sambandam and Nair, 1982; Ghosh, 1986; Narayanaswamy, 1986; Narayanaswamy and Ghosh, 1987; Rajendran and Narayanaswamy, 1987; Soman and Slukin, 1987).

1.4.SIGNIFICANCE OF THE PRESENT STUDY

Although a considerable amount of work on laterites of Kerala, on their geomorphic significance, mineralogy and genesis have been carried out, a systematic geological, geomorphological, mineralogical and geochemical study of laterites developed over various lithological units in one region was lacking. Discerning of the geochemical course and consequence of laterite profile development and its relation to landform evolution was also lacking. In addition, studies on the occurrences of exogenic mineralisations in Kerala associated with weathering profiles also remained fully unattended to. With this background and with aims of achieving these objectives the present study was initiated. The Cannanore district of north Kerala was chosen, since the laterites were relatively less investigated and the weathering profiles developed over a diverse variety of rocks.

1.5. LOCATION

The study area falls within longitudes 75°10' - 75°56' and latitudes 11°40' - 12°18'.

1.6. METHODOLOGY

1.6.1. Field studies included

a) Preparation of geomorphic map of the study area and map showing the distribution of laterite (scale 1:50000); b) Field checking of compiled geological map of the study area (scale 1:50000) and c) Laterite profile description and systematic collection of samples from the profiles developed over various litho units.

1.6.2. Laboratory investigations included

a) Petrography of bed rocks and laterites (90 thin sections)

b) Mineralogical analyses using:

i) X-ray diffraction (XRD) - 38 Nos.

ii) Infra Red Spectroscopy for 7 clay mineral samples.

iii) Differential thermal analysis for 7 clay mineral samples.

iv) Scanning Electron Microscopy for clay minerals - 12 Nos.

v) Specific gravity determinations of laterite and weathered rock samples - 40 Nos.

c) Geochemical analyses:

i) Major and trace element geochemistry - (124 samples from 30 profiles)

ii) Rare Earth Element geochemistry (9 samples from 3 profiles covering 3 rocks types).

1.7. PHYSIOGRAPHY OF THE AREA

The area of investigations falling within the Cannanore district is flanked to the east by hills of the Western Ghats and to the west by the Arabian Sea. The maximum elevation of the area is 1156 meters at Cherumudi. Physiographically the area can be divided into three longitudinal units namely, the low-lands (<10 m) the midlands (<100 m) and the highlands (>100 m). Area wise, the low land unit constitutes 6% of the total area, the mid land region covers 54% and the high land region covers 40% of the total area.

1.8. CLIMATE

Climate of the area is hot and humid with temperatures varying between 16°C and 37°C. Mean daily maximum temperature is about 33°C with mercury shooting to the maximum during the months of April and May. Night temperatures are lowest in the months of December and January, being about 20°C. On individual nights of these months temperatures may drop to 16°C. The average annual rainfall is 3488 mm, of which 80% precipitation occurs during the south-west monsoon, and the rest during the north-east monsoon season.

1.9. VEGETATION

The ghat region of the area, barring the reserved forests are under rubber plantation. Coffee plantation exists at a few places, mostly on steep slopes. The skeletal plateau areas and scrub lands with gravel beds are under cashewnut, grass, medicinal and aromatic grass species. The narrow valleys though at higher elevations are also under cultivation, predominantly for plantation crops like coconut, arecanut and nutmeg in patches. Ginger and turmeric are cultivated on raised beds.

The midland region consisting of laterite plateau is planted with rubber and cashewnut. On hill slopes coconut is cultivated. Tapioca is cultivated in border areas. The broad valleys are cultivated for paddy, banana and vegetables. The dissected laterite plateau of the lowland is mostly cultivated for coconut and cashewnut on the top of mounds. Coconut and arecanut are also raised in narrow valleys. The broad valleys are cultivated for rain fed paddy followed by vegetables and banana.

Chapter - 2

GEOLOGIC AND GEOMORPHIC SETTING

2.1. REGIONAL GEOLOGY

The Kerala region constitutes an important segment of the western passive continental margin of the Indian shield, and is bounded by Western Ghats on the east and the Arabian sea on the west. The rock types found in this region can be grouped into: (i) the Precambrian rocks (ii) the Tertiary formations and (iii) the Recent to sub-Recent sediments (Fig. 1). The generalised geological succession of the various rock formations of Kerala is given in Table-1.

2.1.1. Precambrian rocks

These are the most widely spread rock types in Kerala. The rocks falling within this age are referred under (a) Khondalite Group (b) Charnockite Group (c) Sargur Group and (d) Dharwar Group of rocks. Rocks of these groups are intruded by basic and ultrabasic rocks (e) and granites and related rocks (f).

(a) The khondalite group consists of light coloured, fine to medium grained, of garnet - sillimanite schists containing varying amounts of graphite, and some quartz and orthoclase. In khondalites, sillimanite occurs as hair like needles, as also broken crystals; graphite forms nests or pockets; and calcite, biotite and rutile are generally present (Pichamuthu, 1967). In Kerala, the khondalites have been identified and mapped for the first time by Jacob during 1965-'66. These rocks traversed by narrow bands of pyroxene granulites and charnockite make up the southern part of Kerala between Punalur - Adoor and Cape Comerin (Now in Tamil Nadu - Narayanaswami, 1967) and parts of the Palghat district.

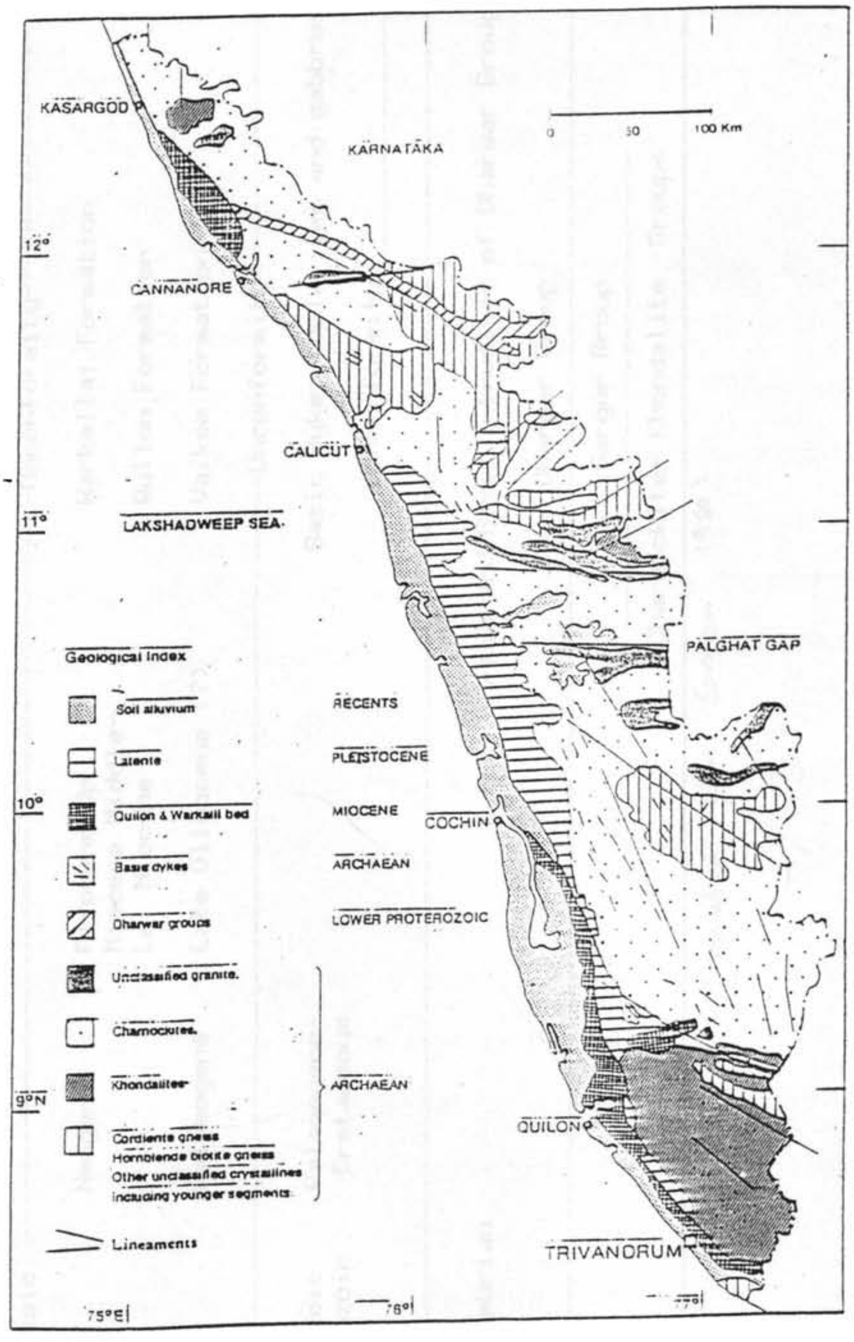


Fig.1 Generalised geological map of Kerala (after GSI, 1976).

Table 1: Generalised geological succession of various rock formations of Kerala

Geological-Time units			Lithostratigraphic Units
Era	Period	Epoch	
Cenozoic	Quaternary		Soil, Alluvium, beach sands, limeshell, peat beds, calcareous clay with shells, etc.
			Unconformity
	Neogene	Pliocene-Up Miocene Middle- Lr. Miocene	Warkallai Formation Quilon Formation
	Palaeogene	Late Oligocene (?)	Vaikom Formation (?)
			Unconformity
Cenozoic -Mesozoic	Palaeogene- Cretaceous		Basic dykes (dolerites and gabbros)
			Unconformity
Precambrian			Acid and Basic intrusives of Dharwar Group
			Dharwar Group
			Sargur Group
			Charnockite- Khondalite Groups

(modified after Soman 1980)

In Trivandrum district, the khondalites are interbanded with garnetiferous - biotite gneiss, leptynite and narrow bands of charnockite (Jacob, 1967). Graphite mineralisation associated with sillimanite gneisses around Vellanad, and chrysoberyl associated with pegmatites are characteristic features of the khondalite group of rocks of this region (Gopalakrishnan and Raju, 1976). In Quilon district the khondalite are intruded by swarms of pegmatites and the region is highly sheared (Jacob, 1976). In parts of Kottayam district, lenticular bands of garnet-sillimanite gneiss along with garnet-biotite gneiss and cordierite are observed (Thampi and Selvan, 1972). Lenticular bands of crystalline limestone and calc-granulites occur interbanded with these rocks in Palghat, Quilon, Kottayam and Trivandrum districts.

Crawford (1969) has reported four Rb-Sr whole-rock model ages for these rocks, and the values range from 2155 to 3070 m.y. Chacko *et al.* (1987) reported a poorly defined Rb-Sr isochron age of 2100 m.y. for the khondalite from south Kerala. The recent U-Pb Zircon ages indicate 2200 m.y. (Soman *et al.*, under publication).

(b) The charnockite group of rocks are the predominant rock type in Kerala and are well exposed in the central and northern parts of the state. The charnockite group in Kerala consists of (i) lenses of hypersthene - diopside - hornblende - magnetite- biotite rocks (pyroxenites, ultrabasic charnockites), (ii) lenses, bands and schlieren of hypersthene - diopside - granulites (basic charnockites), (iii) hypersthene - diopside - hornblende - biotite gneisses and migmatites (intermediate charnockites), and (iv) lenticular sheets, bands and layers of hypersthene bearing quartzo-feldspathic alaskite granites (acid charnockites). The prevalent rocks in the erstwhile Cochin province is the intermediate charnockite and the acid rocks occur in the peripheral regions

of the intermediate rock exposures (Chattergee, 1974). The intermediate charnockite types are met where the felspathic and acid charnockites are in migmatitic association with the basic granulites (Mahadevan, 1964).

The charnockites with narrow bands of pyroxene granulites and magnetite - quartz rocks are the most widespread group of rocks in Cannanore, Kozhikode, Palghat, Trichur, Kottayam and Quilon districts. These rocks also constitute the high ranges of Western Ghats and extend to the Nilgiri massif. In the Wynad region, tongues of unfoliated charnockites frequently cross the foliation of the older gneisses and are mainly intermediate to basic varieties (Damodaran, 1958). In Nilambur Valley, Kozhikode district, magnetite - quartzite, pyroxene and hornblende granulites and charnockite gneiss constitute the charnockite group (Sarwarkar, 1980). In Trichur region, the charnockite and the associated interbanded rock types are well foliated (Mahadevan, 1964). In Tiruvalla area, this is interbanded with pyroxene granulites and cordierite gneiss. In the Periyar Valley region in Idukki and Kottayam districts, pyroxinites, alaskites, magnetite - quartzites and calc - granulites constitute the charnockite group (Nair and Selvan, 1976). The acid and intermediate charnockites in Quilon district are migmatites and are layered (Jacob, 1976). In the eastern fringes of the Western Ghats, the charnockites have undergone intense folding and migmatisation (Mahadevan, 1964). The charnockites in many places are intruded by granites, dolerites and pegmatites.

The foliation is, in general, poorly developed, and its regional strike is NW-SE to WNW-ESE having a steep dip of 50-85 dominantly towards SW and SSE. There is a swerve in the above regional strike to ENE-WSW and finally to NE-SW in Wynad, Silent Valley and Attapadi Valley area flanking the

Anamalai - Palani hill range, and in Periyar lake area flanking the Varshanad hill range (Narayanaswami, 1976).

Occurrence of incipient charnockite from Ponmudi within the Khondalite group of rock has been reported recently (Ravindra Kumar *et al.*, 1985). This observation has dispelled the presumption that incipient charnockite is characteristic of the transitional zone, and that it is absent further south of the regional orthopyroxene isograde in south India.

Incipient charnockites are generally coarse - grained compared to the host rocks and occur as patches, veins or structures with green appearance. In incipient charnockites, apart from the mineralogy of garnet-biotite gneisses (garnet + biotite + K-feldspar + plagioclase + quartz + graphite), orthopyroxene is noticed. Depending on individual cases and on the pervasiveness of transformation, the modal proportion of orthopyroxene varies. The texture is homogeneous granoblastic with no preferred orientation. Incipient or arrested charnockite occurrence is identified normally by the following criteria. (i) cross-cutting relation to the gneissic foliation. Emanating from these patches are tongues of charnockite spread parallel to foliation (ii) coarse grained crystallised nature of charnockites which generally obliterate the gneissic foliation; only in rare cases the relict foliation is still preserved. (iii) Warping and doming of adjacent gneissic foliation with the development of charnockite and (iv) common contact with shears (S. Kerala: Ravindra Kumar and Chacko, 1986; Ravindra Kumar *et al.*, 1990).

Interrelationship between the rocks of the charnockite group, and other prominent rocks of the Archeans is not yet clear. In Walayar, Palghat district, the khondalites structurally overlie the charnockites (Murthy *et al.*, 1976). Radiometric age determination by Rb-Sr method of a charnockite sample from Ayoor has given an age of 2155 m.y. and another sample from Kizhaikonam, Trivandrum district has given 2780 m.y. (Crawford, 1969). The charnockites of the Nilgiri hills, which are the extension of the charnockites of Kerala and has given an age of 2635 ± 125 m.y. (Crawford, 1969). Odom (1982) has reported U-Pb zircon ages of 2930 ± 50 m.y. for charnockites from Nedumannur area. The incipient charnockite (Ponmudi) has been dated at 540 m.y. by U-Pb methods (Srikantappa *et al.*, 1985).

Biotite - hornblende gneisses and cordierite gneisses are seen closely associated with charnockites and khondalites in Kerala. Narrow zones of biotite - hornblende gneiss and gneisses of granitic composition are well exposed in the Wynad - Nilambur - Kozhikode region, Attapadi Valley, Palghat gap area and Munnar - Periyar - Todupuzha - Muvattupuzha region in northern and central Kerala (Narayanaswami, 1976). Quartz, feldspar, biotite and/or hornblende are the essential minerals. These are formed as a result of retrograde metamorphism of charnockites under conditions of upper amphibolite to hornblende facies (Mahadevan, 1964).

Garnet-sillimanite gneiss passes into a garnet-gneiss with the disappearance of sillimanite and increase in the amount of feldspar; with cordierite as an essential constituent, the rock becomes cordierite - garnet gneiss (Chatterjee, 1974). In Kerala, cordierite gneisses associated with khondalites and charnockites are developed along Achankovil shear zone (Jacob, 1976). These are exposed at Konni, Thiruvalla and Kottayam. In the Thiruvalla area, these are seen to occur as bands in the charnockite rocks. The rocks here are foliated and the general trend of foliation is NW-SE with steep dips. The cordierite gneisses here are tightly folded about a NNW-SSE axis and there are a numerous canoe folds in the exposures, into the noses of which the feldspathic charnockitic material has permeated. The charnockite - cordierite - gneiss sequences is veined by pink granite and pegmatites (Mahadevan, 1964, Sinha Roy *et al.*, 1984). In south Kerala two generations of cordierite are present. The first generation cordierite is parallel to the metamorphic foliation. The second generation cordierite occur as caronas about embayed garnet grains. From the study of mineral association and reaction texture, Chacko *et al.* (1987) and Santhosh (1987) have suggested that cordierite producing reaction was caused by isothermal decrease of pressure during uplift. Cordierite bearing gneiss from Achankovil has yielded a Rb-Sr age of 670 ± 8 m.y. Santhosh and Drury, 1988).

(c) Sargur group: In Kerala, the schistose formations are represented by the high grade schists of Sargur and low grade Schists of Dharwar, both being southward extension into Wynad of the corresponding groups of southern Karnataka. The Sargurs show higher grade of metamorphism, migmatisation and a more complex tectonic imprint (Nair *et al.*, 1975) than the Dharwars.

These two groups were till recently known as the Dharwar group designated to include all the crystalline schists comprising both metavolcanics and metasediments (Foote, 1886). But later studies in Karnataka necessitated the sub-division of this group into: (i) Sargurs: to represent the lower members of the Dharwar (Viswanatha and Ramakrishnan, 1976). (ii) Dharwars: to represent the younger members of the same.

In Wynad, the Sargur group is represented by bands of quartz-mica schists with kyanite, quartz-sericite schists, quartz - magnetites, quartzites and meta-ultramafics. Several linear bands and broadly parallel linear belts of these high grade schists and ultramafic enclaves trending NNW-SSE extend into Cannanore district and occur as isolated bands within the granulitic and gneissic terrain stretching from Sultan's Battery and Manantoddy in the Wynad plateau to Taliparamba and Payyanur, and in the eastern parts of Kasargod district. Their contact with the gneisses is generally concordant due possibly to coaxial folding, high grade metamorphism and intense migmatisation.

(d) Dharwar group: The younger Dharwar schists, overlying the sargur schists, consist of oligomict conglomerates, current bedded quartzites, quartz-mica schists and biotite-quartzites forming an interlayered sequence. The polymictic conglomerates recorded near Kuthuparamba occupy the basal portions of the quartz-mica schists and unconformably overlie the older formation of charnockites. The conglomerate near Vengad village with primary sedimentary structures indicates that the rocks to the west are comparable to the low-grade Dharwar supergroup of Karnataka (Nair *et al.*, 1975; Nair, 1976; Nambiar, 1985; Ravindra Kumar and Narayanaswamy, 1987).

The metamorphic grade of the Dharwar schists is lower amphibolite to greenschist facies. Two directions one NNW-SSE, representing the Dharwar orogeny, and the other NNE-SSW probably linked to the Eastern Ghats orogeny, are recognised in the low-grade schists.

(e) Basic and ultrabasic rocks: These rocks are reported from a number of places in Kerala. Basic gabbro bodies are reported from Kartikulam, Adakkathodu, Karrang and at Ezhimala in Cannanore district (Nair *et al.*, 1975; Nair, Varadan and Venkataramana, 1976). The basic intrusives in this area include minor patches of anorthositic differentiates and diorites. The Attapadi shear zone is conspicuously marked by the occurrence of a host of basic and

ultrabasic rocks, consisting of peridotite, pyroxenite, gabbro, leucogabbro and anorthosite (Lahiri *et al.*, 1976; Sinha Roy and Radhakrishna *et al.*, 1983) In Quilon district, ultrabasic rock of dunite composition has been reported from Punalur along a minor shear zone parallel to the Achankovil Shear (Jacob, 1976). K-Ar whole rock age of basic dykes from the Agali-Coimbatore area has been reported as 2030 ± 65 m.y. (Radhakrishna *et al* ., 1989a).

(f) Granites, pegmatites and quartz veins: The Precambrian crystallines are invaded by several late Proterozoic intrusives of acidic and alkaline composition. They include pink and grey granites at Kalpetta, Ambalavayal, Tovarimalai, Angadimogara, Chengannur, Munnar, Achankovil, Iddukki project area; syenites (Sholayar, Peralimala, etc granophyre (Ezhimala) and Anorthosite (Perinthatta). K-Ar ages of 512 ± 20 and 560 ± 30 m.y. have been reported for Kalpetta and Ambalavayal granites respectively (Nair *et al.*, 1985).

Numerous pegmatites and quartz veins traverse the Precambrian rocks and are common in south and southwest Wynad, in parts of Trivandrum, Quilon and Palghat districts. Some pegmatites in Trivandrum host gem quality chrysoberyl. K-Ar dating of these pegmatites in south Kerala gives an age of 460 m.y. (Soman *et al.*, 1982). Recently, dating of mica in pegmatites from Palghat region has yielded age which range from 484 to 512 m.y. suggesting a retrogressive metamorphic event (Soman *et al.*, 1990). Gold bearing quartz rocks/veins occur in the gneisses/amphibolites in south and southwest Wynad. They cut across the foliation of the gneisses running NNW-SSE. The reefs which are milky white in colour occur either contiguous to the country rocks or separated from them by a selvage of talcose schist, quartz breccia and limonite. The biotite gneiss and hornblende gneiss are usually the country rock for the quartz reefs.

2.1.1. Dolerite dykes

Dolerite dykes are generally oriented parallel to the major lineaments trending NNW-SSE, NE-SW and ENE-WSW. Basic sills and dykes are seen as intrusives between Muvattupuzha and Cheruvalli. Basic dykes are also reported from Nilambur valley, from parts of Quilon district and from Idamalayar dam site (Sarwarkar, 1980; Jacob, 1976). Dolerite and dykes are also reported from Nedumannur, Kuttimud and Anakudi areas of Trivandrum district (Panchanathan, 1979). An unsheared sample of dolerite dyke is dated to be 75 ± 25 m.y. (Subramanian, 1976). Recent age determinations of the dykes from south Kerala yield 59 m.y. with initial Ar^{40}/Ar^{36} ratio close to 510 (Furnes *et al* 1983).

2.1.2.Tertiary formation

The tertiary sedimentary formations of Kerala unconformably overlie the Precambrians. The Tertiary sedimentary basin extend from Cape Comerin to Manjeswar and is the southern most one among the chain of Tertiary basins along the west coast of Indian Peninsula. Extending as a narrow belt along a major part of the Kerala coast, the on-land part of this basin contains essentially Neogene and Quaternary sediments comprising a series of variegated sandstone and clays with lenticular seams of lignite (Warkalli formation). These are underlain by more compact sands and clays with fragments and thin beds of limestone that are called Quilon formation. However, recent studies of the lithology of these sediments by C.G.W.B. workers supported by exploratory bore hole data indicate that the upper Tertiary sediments in Kerala consist of three distinct formations (Raghava Rao, 1975). The Warkallis with a thickness of nearly 80 m. are underlain by the

Quilon Formation, having a maximum thickness of 70 m. These are underlain by a thick sequence of sediments called the Vaikom beds (Raghava Rao, 1975)

2.1.3. Quaternary formations

Subrecent formations consisting of a great thickness of sand with shell fragments, sticky black clays, peat beds of both marine and fluvial environments occur in the low-lying areas between Quilon, Kayamkulam, Kottayam, Ernakulam and Ponnani and also between Cannanore and Nileswar. These are separated from the Tertiary rocks by a polymict pebble bed seen almost throughout Kerala. It consists predominantly of pebbles and cobbles, composed chiefly of quartz and quartzite.

2.1.4. Laterite

Kerala is the type area for laterite and it is from Angadipuram of Kerala that Buchanan (1807) described laterite. It is a product of intense sub-aerial weathering of rocks involving leaching of alkalis, bases and silica with complementary enrichment of alumina, iron and some of the trace elements. Laterite covers around 60 percentage of the exposed surface area of Kerala and occurs as capping on the crystalline rocks and the Tertiary sediments. It is highly porous and shows gradations in composition from ferruginous to aluminous types. When pure enough to be used as an ore of aluminium, the laterite is termed as bauxite. In Kerala, bauxite occurrences are reported from Kasargod (Ananthapura Gudda, Narayana Gudda, Nileswar), Cannanore (Palayangadi), Quilon and Trivandrum districts. The prominent among them being those located at Nileswar.

Laterites in Kerala are generally classified into two major groups in terms of their genetic relation. (i) primary/high-level laterite as used for *in situ* weathering products (ii) secondary laterite/ detrital/ low-level laterite formed by partial or complete consolidation of transported lateritic material.

Laterites distributed all through Kerala doesn't belong to one period, since the lateritisation process is continuous from Cretaceous to Holocene with intense spells of lateritisation. Mallikarjuna *et al.* (1981) proposes three spells of lateritisation in Kerala, (i) lateritisation of the crystalline rocks during pre-Oligocene times before the deposition of Tertiary formations. (ii) lateritisation during post-Tertiary times as evidenced, by the lateritisation of the top Tertiary sediments, and (iii) during post Pleistocene period as evidenced by lateritisation of pebble beds, sand and alluvium. However, the first two spells of lateritisation have been reported from Cannanore and adjoining areas (Rajendran and Narayanaswamy, 1987; Narayanaswamy, present work), and south Kerala (Soman and Slukin, 1987). Palaeomagnetic studies of laterites from Kerala have confirmed pre and post Tertiary lateritisation periods (Schmidt *et al.*, 1983).

2.1.5. Recent deposits

These deposits include fringes of parallel sand bars and sandy flats alternating with marshy lagoonal clays and beach sand deposits. Raised sand beaches composed of reddish sandy loam known as 'teris' which are of aeolian origin are seen at places in Kasargod and Trivandrum.

2.2. GEOMORPHOLOGY

Four distinct geomorphic zones could be recognised in the Kerala region, namely 1) the highlands ranging in altitude from nearly 600 m and more, (2) mid lands from 300 to 600 m, (3) the lowlands from 30 to 300 m and (4) the coastal strip with lagoons (locally known as 'kayals') and sand dunes. The altitudinal range in the state is asymmetric with the maximum area of about 24,000 km^2 (62 percent of the total area of 39,000 km^2) falling within the 0-300 m altitudinal range (Sinha Roy and Mathai, 1979).

The most prominent geomorphological feature of the state, and one of the important orographic features of the peninsular India is the Western Ghats. The Western Ghats fringe western coast from the Tapti estuary to Cape Comerin. This hill range plays a critical role in the climate of south India. The highest elevation is attained at the Anamudi peak (2,695 m) which is the highest peak in Western Ghats. Except for the prominent break in the Palghat area, the Western Ghats and the highland terrain of Kerala are extensive from south to north. Palghat Gap is the major break within the Western Ghats having a width of about 30 km and extends in a E-W direction over a distance of 80 km. This conspicuous feature in the landscape of the peninsular shield connects the West Coast with the peninsular region of the east. Another minor break is in the Ariankavu - Shencottah region. The gap here coincides with a major WNW-ESE lineament.

Another important geomorphic feature of the state is the Wynad plateau which bounds the Nilgiri in the north. This surface formation at 900 - 950 m with a general slope towards east and north-east forms part of the most extensive land systems of peninsular India. Linear hillock of magnetite quartzite at Pandallur and Devala and granitic domes around Kalpetta and Tovarimalai are identified as erosion outliers of the Wynad Surface (Pardhasaradhi and Vaidyanadhan, 1974).

Planation surfaces with polycyclic development is well evidenced in Kerala. These surfaces fit roughly in the scheme of major land forms of the peninsular India, viz, the early Gondwana (2,580 m), Indian (180-600 m) and Godavari (180-540 m) (King, 1950). Vaidyanadhan (1967) identified 5 planation surfaces at 2,400 m, 1800 m, 900 m, 600 m and at 360 m in areas south of 15 N latitude. Pardhasaradhi and Vaidyanadhan (1974) have identified two geomorphological surfaces in the Kerala region adjoining the Nilgiri surface, namely, the Wynad surface at 900 - 950 m and the Malabar upland surface at about 75 m. According to Demongeot (1975), there are only two surfaces in the Palghat Gap: (1) up to 75 m towards the coast with a lateritic cover and (2) the lower one, representing the present coastal plains. Thirugnanasambandam (1976) identified five erosion surfaces in central Kerala with altitudinal ranges from 550 m at the top to 15 to 75 m at the lowest and considered that these cyclic assemblages of landforms are due to regional uplift of the region causing base level changes, resulting in the dissection of earlier surfaces and rotation of new surfaces. On a regional scale in Kerala, Murthy *et al.* (1976) recognised five surfaces between 1500 and 60 m. Based on field studies the first two surfaces have been reconstructed from laterite remnants. In broad conformity with these surfaces, Sinha Roy (1979) identified four surfaces at 1200 - 1300 m, 150-200 m, 60-100 m and 20-50 m. These surfaces have variable angle and slope towards west and their hinge zone has been suggested roughly in the coastal strip.

Recent studies by Narayanaswamy and Chattopadhyaya (1991) have identified 5 surface in Cannanore district traceable at altitudes of 0-20 m, 20-60 m, 60-160 m, 160-220 m and >220 m. Above 220 m the only notable surface is at an altitudinal range of 750-900 m which represents the Wynad plateau.

The drainage pattern of the region is in conformity with the physiographic divisions with the summit of the Western Ghats forming the watershed between the drainage systems of the west coast and that of the Tamil Nadu plains. There are 41 west flowing rivers in Kerala, the majority of which are drained by 6 order streams. Most of the rivers follow the structural trends of rocks (Sinha Roy, 1979).

Another striking feature in the landscape of Kerala is the occurrence of a large number of estuaries and lagoons along the coastline. There are 27 estuaries and some of these are elongated and parallel to coast line. Occurrence of mud banks is another peculiar feature of the Kerala coast.

2.2.GEOLOGY OF THE CANNANORE DISTRICT

Cannanore district is located in the northern part of Kerala, within longitudinal 75°10' to 75°56' and latitude 11°40' to 12°18' (Fig. 2). The major rock types of this area are granulites, gneisses and high and low grade schists. Granulites consist of pyroxene granulites and charnockite with its variants. The gneisses are mainly granitic within which occur enclaves of sillimanite - kyanite bearing schists, fuchsite quartzite with occasional barite association as well as meta - ultramafites and amphibolites, which are

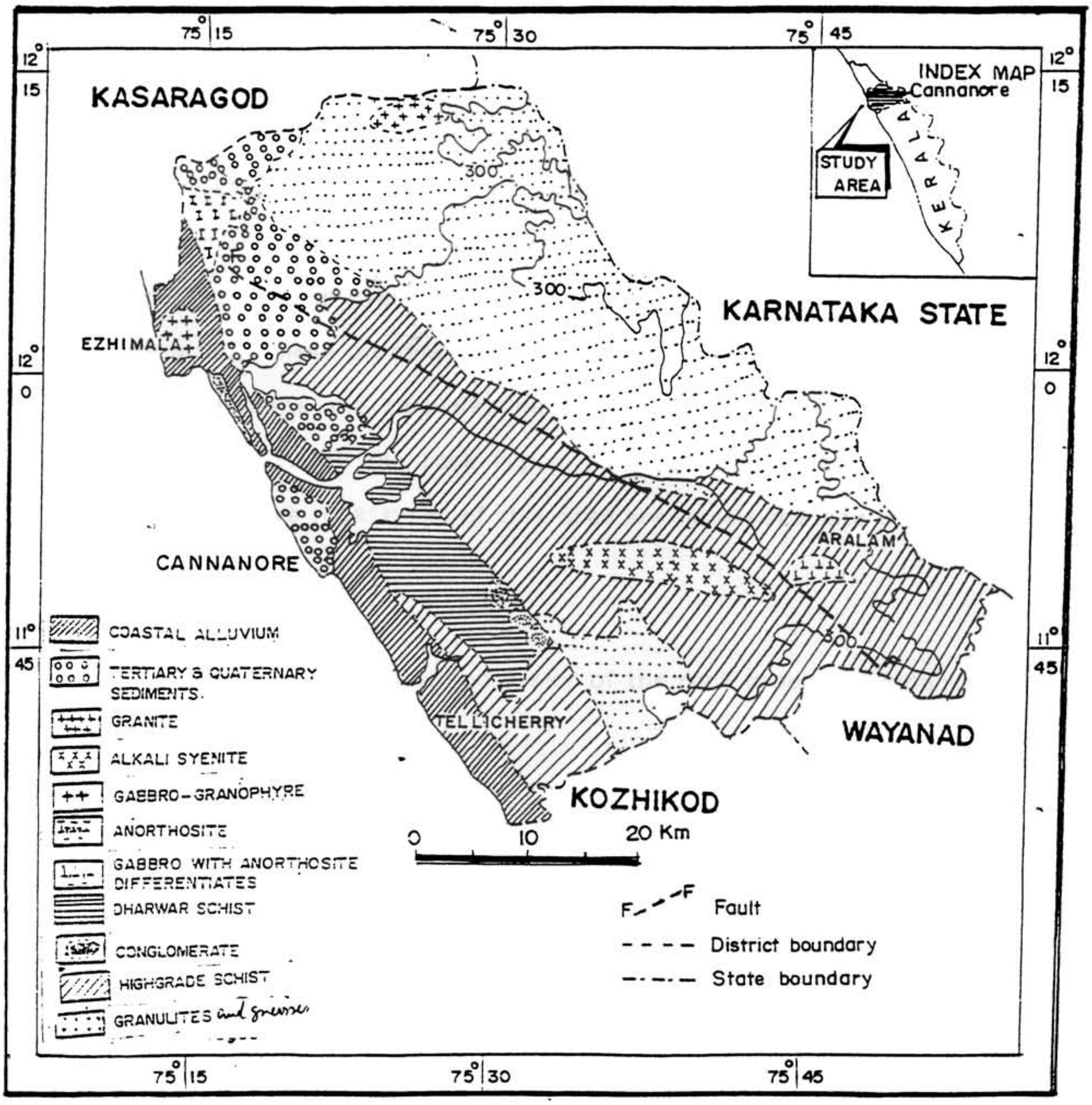


Fig.2 Geological map of Cannanore District (modified after Rao, 1973; I,1976; Nair et al., 1980;Nair and Vidyadharan, 1982).

equivalents of the Sargur's of southern Karnataka, and are locally designated as Manantoddy schist belt (Nair *et al.*, 1975). The low grade schists noted to the west of the region are referred as Vengad group. This group consists of basal conglomerates and low grade schists are seen in the southwestern portion of the area and are equivalent of the Dharwar group of rocks. A gabbro body at Adakkatodu trending in a general east - southeast direction is exposed parallel to a major fault designated as Bavali lineament (Nair *et al.*, 1975). Massive anorthosite occurrences at Perinthatta and Kadannapalli, and the Ezhimala gabbro - granophyre complex are also exposed along this lineament. A major syenite body at Peralimala is located in the central part of the area. These plutons have intruded the schist belt indicating a post-kinematic alkaline and calc-alkaline magmatism. A number of dolerite dykes cut across almost all the rock types. Tertiary sediments fringe the coastal zone. The entire rock types of this area are lateritised and covers an extensive area.

Generalised geological succession of the rock types of Cannanore district is given below: (Table. 2).

(Table. 2).

Generalised geological succession of the rock types of Cannanore district

Formation/Group	Lithology
Quaternary to recent sediments	Sand, silt, mud
Warkalli group (Tertiary)	Laterite, clays, sand, grit, and lignite beds
Intrusives	Dolerite Alkali Syenite Gabbro-granophyre Anorthosite
Vengad Group (equivalents of Dharwar Super Group)	Quartz-mica schists, Migmatites, conglomerates
~~Unconformity~~~~~	
Rocks of Manantoddy schist belt (equivalent of Sargurs)	Granite-gneiss (migmatite Quartz-mica-kyanite-schist Magnetite-quartzite/sillimanite Quartzite, Meta-ultramafics/amphibolites
~~Unconformity~~~~~	
	Granulites and gneisses

Since the area is generally covered by laterite/soil, contacts are not visible and hence the observations made on weathered rocks and soil/laterite profiles were also utilised to delineate the various lithological units.

2.3.1. Granulites and related gneisses

These include charnockitic gneiss and hornblende gneiss and are exposed towards the eastern portion of the area (Fig. 2). Exposures are seen around Alcheri, Kitcheri and north of Pariyaram.

Megascopically, charnockite is medium to coarse grained, melanocratic to leucocratic with large feldspar, and quartz grains. In thin sections, it exhibits hypidiomorphic to xenomorphic texture. Hypersthene is the dominant pyroxene with traces of augite. Felsic minerals include quartz, K-feldspar and plagioclase. Plagioclase composition ranges from albite to oligoclase. K-feldspar include orthoclase and microcline. Coarse grained perthitic intergrowths are common. Myrmikitic - inter-growths are also seen. Alteration of pyroxene is seen along the cleavage planes and fractures to hornblende and to chlorite at places. Zircon and magnetite occur as accessories.

The hornblende gneisses extending from Kuthuparamba to Periya and further south-east of the study area or of uniform nature and are devoid of layering. Hornblende gneiss is medium to coarse grained, and is mesocratic to melanocratic, containing hornblende, feldspars and minor amounts of quartz. The rock shows granulitic texture at places. Hornblende rich xenoblastic texture is common. The original high calcic feldspars seem to be recrystallised into high sodic feldspars, epidote and little calcite. The gneisses are traversed by numerous quartz veins.

The gneisses exposed to the east of Tellicherry and around Mattanur are migmatitic. These are generally hornblende - biotite gneisses with patches of linear bands of amphibolites and hypersthene gneisses within them. Good exposures are noticed all along the Pazhassi canal passing through Mattanur, Peravur and Palayanad. The rock is medium grained, mesocratic to melanocratic and consists of hornblende, biotite, feldspars and quartz. Quartz and feldspar are seen in equal amounts. Parallel arrangement of biotite alternating with quartzose felsic layers define the gneissocity. Biotite is highly altered with serrated margins. Plagioclase and potash feldspar constitute nearly 20-30 modal percentage of the rock. Plagioclase is well twinned. Sericitisation and kaolinisation are common in feldspars. Zircon and magnetite are the accessory minerals.

Rocks of the high-grade schists, known as Wynad - Sargurs (Manantoddy schist belt) are exposed towards south central parts of the area with a WNW-ESE trend. Quartz - mica - kyanite schists, magnetite and fuchsite bearing quartzite, and sillimanite gneiss form dominant rock types of this group. Mica schists are exposed around Kuthuparamba, Kottiyur and Mattanoor. Quartzites form minor bands within schists and gneisses. Meta - ultramafites and amphibolites occur as numerous bands within hornblende gneisses and schists to the north and south of Peralimala. Exposures are seen around Nedungom and Aicheri near Sreekantapuram of Taliparamba taluk. The lithology of this part of the schist belt comprises mafic - ultramafic rocks represented mainly by pyroxene granulites, metaperidotites, and rarely by serpentinites, and tremolite - actinolite - talc schists. These rocks are invaded by granites, resulting in the migmatitic gneiss development with numerous enclaves of mafic-ultramafic rocks and schists (Nambiar, 1982).

Fuchsite bearing quartzite is an important unit of the high grade supracrustal rocks in the study area. The rock is fine grained and leucocratic quartz, feldspars and fuchsite mica are the major mineral assemblages.

Thin section studies show quartz grains with sutured grain boundaries which are recrystallised and are of medium size. Small grains exhibit triple junctions and polygonal outlines and at place they show deformation bands. Fuchsite mica constitute 10-20 modal percentage of the rock is pale green to pale brown under transmitted light and shows feeble pleochroism. It occurs in a linear fashion. Muscovite mica, barite and zircon with rare sphene form the accessory mineral assemblage, chlorite also occur in minor quantity.

The pyroxenite is melanocratic, medium to coarse grained and xenoblastic rock, consisting predominantly of pyroxene, epidote, feldspar with minor hornblende. The pyroxenes are fractured. The plagioclase is of andesine-labradorite composition. Alteration of pyroxene to hornblende is observed. Biotite, magnetite and ilmenite form the accessories.

The metaultramafite is melanocratic, coarse grained rock, at times fibrous with interlocking texture and altered. It consists of talc, actinolite, tremolite, chlorite and iron ores.

Bands of amphibolites are found occurring interlayered with quartz-mica-kyanite schists. Generally they also occur as enclaves within granulites and migmatites.

The rock is melanocratic, medium to coarse grained and xenoblastic. It consists predominantly of hornblende and plagioclase feldspar. Quartz and zoisite are seen in thin section. Hornblende is well cleaved, dark green in colour with light yellow to dark green pleochroism. Minor alteration is noted along their margins. Plagioclase is the dominant feldspar mineral with good twinning. Occasional clinopyroxene is diopsidic with pale yellow to yellowish green pleochroism. Quartz is intergranular ranging in proportion from 5 to 10 modal percentage of the total mineral abundance.

2.3.2. Vengad Group

Rocks of the Manantoddy schist belt are overlain unconformably by Vengad group, consisting of conglomerate at the base followed by quartz - mica - schists interlayered with micaceous quartzite. The contact of the Vengad group rocks with the older rocks is tectonic as evidenced by the presence of crushed conglomerate near Kuthuparamba (Nair *et al.*, 1980).

The Vengad conglomerates divides the supracrustals into two distinct litho-tectonic cycles, separated by a major break in sedimentation, and gains its significance in deciphering the stratigraphic succession (Nair, 1980). The conglomerate bed which occupies the base of the Vengad group occurs as patches extending over ten kilometres in a general NW-SE direction till it is truncated in the south east (Nair, 1976). It is found to overlie the gneisses to the east. The best exposures are observed along the Anjarakandi river section south of Vengad. The foliation in the matrix trends N 50 W - N 70 W with steep westward dip of about 65 . Graded bedding is recorded with the diminishing of pebbles towards west (Nair, 1980). The conglomerate is interbedded with and overlain to the west by quartz-sericite schists. Granulites and hornblende biotite gneisses form the basement to the conglomerate. Two phases of deformation are recorded in the conglomerate and overlaying schists

(Nambiar, 1985). Petrography of the conglomerate shows that the pebbles consists of vein quartz, quartzite, quartz-mica schist and granite. Quartzite pebbles are the dominant type (more than 75 percentage of the total). Pebbles are well smoothened and oval in shape (Fig. 3) The presence of pebbles of quartz-mica schist (~ 15 %) and granite (~ 5 %) indicates the polymictic character. Deformation following deposition is evident from the alignment, stretching, elongation of quartz pebbles and crenulation and mylonitisation of the matrix.

Quartz - mica schist pebbles are petrographically distinct from quartzite in having abundant sericite (~ 15-20 %). Both types contain rounded zircons, altered biotite, epidote and carbonates as accessories.

Granitoid pebbles show plagioclase and microcline feldspars in addition to quartz and mica. Myrmekitic intergrowths between plagioclase and microcline are common. Quartz grains are equigranular consequent on recrystallisation during deformation. Sericite is abundant swerving around quartz and feldspar grains.

The matrix of the conglomerate is composed dominantly of muscovite and quartz. At places it grades on to arkosic composition. An elongated fabric of quartz and muscovite is prominent (Fig.4) often giving rise to parallel alternate layers of quartz-mica rich portions. Aggregation of quartz and quartz - feldspar minerals, probably representing micropebbles of quartzite and granite are also seen defining knife shape boundaries with the matrix (Fig.5). The pebble to matrix ratio varies from 70:30 to 20:80 (Ravindra Kumar and Narayanaswamy, 1987).

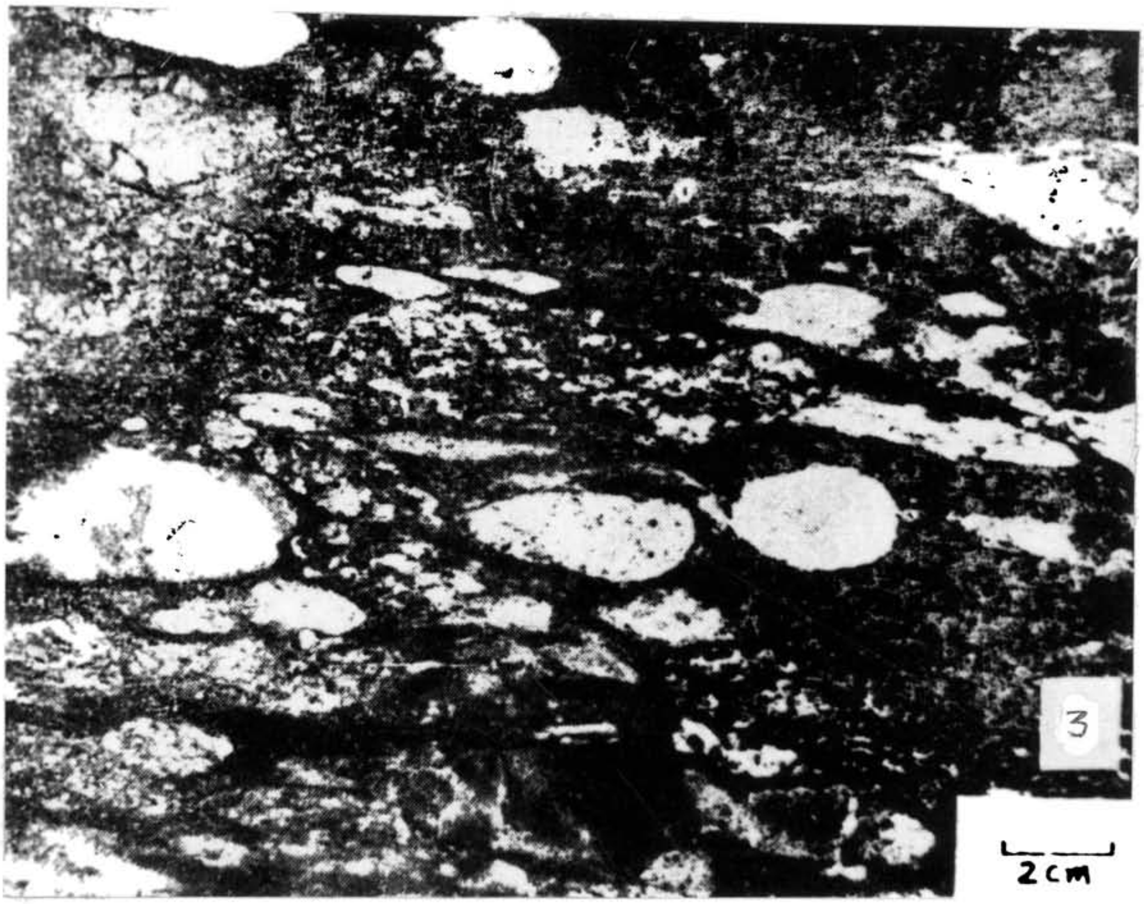


Fig.3 Photomicrograph of well smoothened and oval shaped pebbles in conglomerate: Note the schistocity defined by ribbon quartz and mica flakes, crossed nicol x 25.

Fig.4 Photomicrograph of tounge-shaped and elongated quartz in conglomerate, crossed nicol x 25.

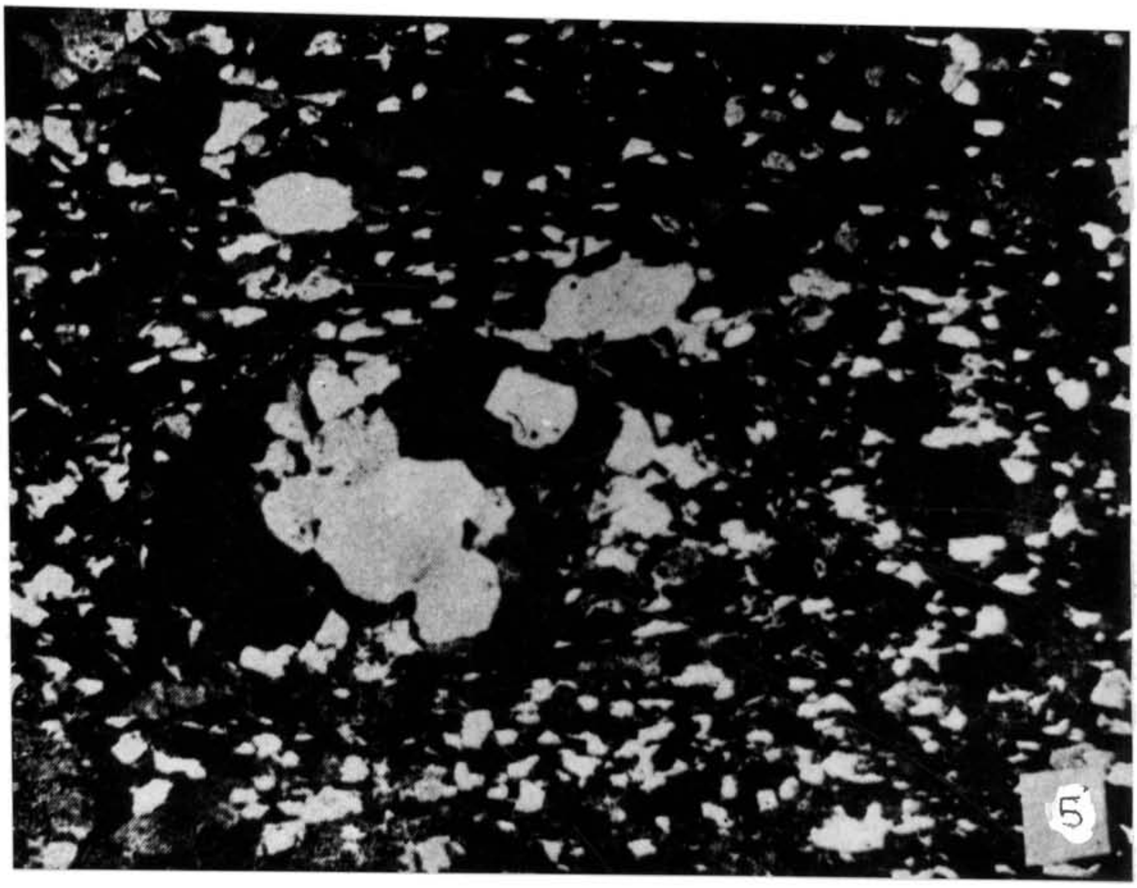


Fig.5 Photomicrograph of a micro quartzite pebble in matrix; Note the polygonal outline of quartz in the pebble and sharp contact between pebble and matrix. Crossed nicol x 25.

Geochemistry of the quartzite pebbles show low abundance of alumina, iron and magnesium The plot falls in the field of sublithic arenite. The composition of the quartzite pebbles is comparable to that of quartzites from the basement rocks, ie quartzite from Manantoddy Schist Belt (Ravindra Kumar and Narayanaswamy, 1987).

The quartz-mica schist pebbles are less silicic and have higher alumina, iron, magnesium and alkalies than quartzite pebbles and suggest a lithic arenite to subarkose composition. The granitoid pebbles have Na_2O/K_2O ratio less than 0.5 suggesting granitic composition.

The matrix composition of Vengad conglomerate suggests a mixture of composition of various pebbles and plots between the composition of quartzite, quartz-mica schist and granite pebbles, and indicates arkosic nature. In the absence high mafic contents, a dominant sialic source of the conglomerate is suggested (Ravindra Kumar and Narayanaswamy, 1987).

2.3.3. Quartz-mica -schist

It is noticed as thin linear bands within the granulites as well as migmatites. All the rock types of the older metamorphic complex of this area are found interlayered with this schist and have sharp contact at many places.

The rock is melanocratic with fine grained nature. Quartz and muscovite are the major minerals. Planar features are well represented by the alignment of quartz and sericite as fine needles along with muscovite. Feldspars (microcline, perthite and plagioclase), chlorite, amphibole, ilmenite, zircon, and leucoxene are found as accessories. Quartz shows recrystallisation features. Quartz, feldspar and amphiboles occur also as aggregates and as lenticular streaks at places.

Several intrusive bodies of anorthosite, gabbro-granophyre, alkali syenite and granite are seen within the linear Wynad schist belt in Cannanore district. Regular alignment of these igneous plutons along the Bavali lineament is suggested as being due to differentiation and emplacement from a single parent magma (Ravindra Kumar, 1986).

2.3.4. Anorthosite

Vidhaydharan *et al.* (1977) reported the occurrence of elliptical-shaped, massif anorthosite emplaced in the pyroxene granulite-charnockite rocks, around Perinthatta, northwest of Taliparamba in Cannanore district. The body has an aerial extent of more than 50 sq.km. The contact relationship with the country rock is not clear and appears to be sharp. The anorthosite is non-layered and is highly deformed with very coarse grained plagioclase laths. The alignment of the plagioclase laths are crude and has a general E-W direction. Regional dips in the surrounding rocks are observed towards the anorthosite body suggesting that the anorthosite was emplaced into a synform structure (Vidyadharan *et al.*, 1977). The anorthosite body is covered largely by laterites (Narayanaswamy, 1986). However, good exposures are seen around Kovumal, Kuruveli, Alakkad, Kankol and at Peralam.

The rock is extremely coarse grained, composed mainly of grey plagioclase with pyroxene and magnetite as minor constituents. Plagioclase megacrysts of about 10 to 12 cm in length are observed and some of them show play of colours. Apatite is ubiquitous and forms an important accessory mineral. Brown biotite, zircon also occur occasionally. Hornblende and chlorite occur as alteration products of pyroxenes.

Plagioclase feldspar has bimodal distribution as megacrystals and as ground mass. Majority of the plagioclase crystals are untwined. Wherever twinning is present, twin lamellae show intra-granular termination and bending. Twinning is more common in megacrystals compared to ground mass. Plagioclase of labradorite variety shows play of colours in reflected light and is restricted towards west of the body. Plagioclase at many places occurs as microperthite indicating that the potash feldspar component is also significant. Microperthite is common in border zones, whereas antiperthite is seen in the central part of the anorthite body.

Pyroxenes constitute a minor amount in the anorthosite which include both clino (Augite) and orthopyroxene (enstatite). Invariably pyroxenes enclose crystals of apatite and opaques along cleavages and cracks. Pyroxenes show alterations to hornblende, biotite and chlorite.

Biotite occurs as reaction rims around opaques in addition to secondary biotite which occurs as an alteration product.

The chemical characteristics of anorthosites are comparable to massif anorthosites. The chemistry also indicates calc-alkaline composition of the anorthosites. The low K_2O content, cumulate plagioclase and the mafics in anorthosite favour a deep environment of origin, favouring the general concept that anorthosites are mantle derivatives (Ravindra Kumar, 1986).

2.3.5. Gabbro bodies

In the study area occur at Ezhimala and at Adakkatodu. At Ezhimala, the gabbro is associated with granophyre and granite. The gabbro is exposed at the foot of the hill on the south eastern side and in the middle of the eastern flank of the granophyre body. The rock is coarse grained at the southern side in contact with the granophyre. Grain size decreases towards the eastern side of the body. At Adakkatodu, a metagabbro body is seen as intrusive into the basement gneisses and schistose rocks. The contact relationship is not clear.

The rock is typical-sub-ophic to ophitic in texture and consists of plagioclase feldspar and pyroxene as major constituents.

Plagioclase (60 %), clinopyroxene (20-30 %), hornblende (5-10 %) and biotite (~ 2 %) constitute the modal mineral assemblage of the gabbro. The anorthite content in plagioclase ranges between 55-75 (labradorite composition). The anorthite content in the zoned grains decrease from core to the rim ie. about 80-85 percent to 60-65 percent, thus it is normal zoning with bytownite core with labradorite rim. The twinning is as per Albite and Manebach law.

The pyroxenes which constitute the mafic content are mostly clinopyroxenes with few grains of orthopyroxenes. The clinopyroxenes are augite and diopsidic augite in composition. Hypersthene and enstatite form the orthopyroxene with well developed euhedral nature. Two sets of cleavages intersect almost at 90°. The pyroxenes show alteration along cleavage planes and fractures to hornblende and chlorite. Biotite is also seen in some cases. The alteration is more pronounced towards the southern portion of the body.

Occasionally, primary hornblende is seen interlocked with pyroxene. Hornblende also occurs as interstitial to plagioclase laths with blebs of anhedral magnetite.

Accessory minerals noticed are magnetite, apatite, and quartz, minor amounts of sphene, epidote and calcite are also noticed. Magnetite occurs as inclusions in quartz as well as separate grains. Apatite is needle to prismatic with well developed crystal faces. Quartz is seen in minor amounts.

Geochemical studies of the gabbro show a dominant calc-alkaline to slightly tholeitic nature (Ravindra Kumar, 1986).

2.3.6. A conspicuous igneous body of granophyre

It occurs around Mount Dilli at Ezhimala (Varadan and Venkataramana, 1976). Generally known as Ezhimala complex near Payyanur in Cannanore district, this body covers an area of 6 by 3 km and the whole body is oriented in a N15°W - S15°E direction. The granophyre is associated with gabbro and granite is commonly known as Ezhimala gabbro granophyre complex (Varadan and Venkataramana, 1976).

The granophyre shows typical granophyric texture (Fig. 6) with intergrowth of quartz and feldspar. Quartz and potash feldspar form the ground mass with phenocrysts of potash feldspar and a few zoned plagioclase feldspars. Pyroxenes are the main ferro-magnesian mineral with magnetites, apatite, epidote, fluorite, sphene and zircon as accessories.

Fig.6 Photomicrograph showing granophyre texture. Crossed nicol x 25.

Quartz is found mostly as intergrowths with potash feldspars and occasionally as phenocrysts. Quarts is clear, inclusions of magnetite are uncommon. The shape varies from small vermicular to large anhedral grains.

Feldspars are dominated by orthoclase with minor amounts of plagioclase. K-feldspars show kaolinisation, sericitisation and chloritisation. However plagioclase feldspars are comparatively clear. Phenocrysts of potash feldspar is found in minor amounts and in few places these form core around which the intergrowth of orthoclase and quartz are seen.

The plagioclase is albite to oligoclase in composition and shows twinning (according to Albite law).

The main mafic constituent of the granophyre is clinopyroxene (augite and diopside) with minor amounts of orthopyroxene (enstatite and hypersthene). The alteration of these pyroxenes to amphiboles (occasionally to biotite) and to chlorite can be seen in a few grains along the boundaries, cleavages and cracks.

Based on geochemical (SiO_2 varying between 61.96 % and 76.62%) and mineralogical (relative proportions of K-feldspar and plagioclase) consideration, Sinha Roy and Ravindra Kumar (1986) identified the different rock types of Ezhimala complex in the felsic end of the suite and considered it to comprise a petrologic range of gabbro - tonalite - trondhjemite - granite.

The unique feature of the granophyre is the presence of vugs filled with various secondary minerals and exhibits typical granophyric texture.

Minor outcrops of rapakivi granite are noted in the southern portion of the granophyre body. The granite here shows two textural types. The major one being a light pink granite with less mafics showing gradational relationship with the greyish coloured porphyritic variety. The granite is medium grained with equigranular texture. Quartz and feldspars form the major constituents. Feldspar is mostly orthoclase with few grains of plagioclase. Pyroxene is the mafic mineral present. The accessory minerals include magnetite, calcite, apatite and sphene.

Quartz is seen as blebs of phenocrysts in pink varieties and is fresh and clear with occasional tiny inclusions of magnetite.

Feldspars include both orthoclase (mostly) and plagioclase (few grains). Both the feldspars are clouded due to kaolinisation and chloritisation. Clouding is less in pink granite as compared to grey granite.

Clinopyroxene is the major ferromagnesian component with augitic and diopsidic composition A few grains of orthopyroxene (hypersthene and enstatite) is also seen. The pyroxenes are seen altered to hornblende, biotite and chlorite at cleavages and cracks. The granite-granophyre of Ezhimala has yielded a Rb-Sr isochron age of 678 m.y. (Nair and Vidyadharan, 1982).

Another major igneous pluton cropping out in Cannanore district is the peralimala syenite. This body covers an area of about 80 km^2 occurring from south-eastern part of Mattanur to Kanichar. It has a linear extension with a length of 20 km and an average width of 4 km (Sukumaran, 1984; Ravindra Kumar and Sinha Roy, 1985). This pluton is enveloped by high grade schists.

Thin section studies of the syenite show k-feldspar as the principal mineral constituent with minor amounts of plagioclase, aegerine augite and quartz. K-feldspar is significantly high (70-90% modally). The potash feldspars are dominantly microcline perthites (Fig. 7). Braid, string and vein perthites are common (Fig. 8). Quartz is recrystallised in highly deformed varieties and usually occurs as interstitial to feldspar plates. Hornblende is deep green in colour with greenish yellow to deep green pleochroism. At places feebly pleochroic aegerine augite with deep green colour is observed. Sphene with subhedral to rounded grains having wedge shape are randomly distributed sometimes rimming apatite. Traces of carbonates and zircons are also encountered.

High K_2O content (~ 13%) is unique of this syenite. Based on geochemical and mineralogical studies an attempt has been made to explain the origin to be a mantle source of magma enriched in K_2O (Ravindra Kumar and Sinha Roy, 1985).

Later intrusives of basic (dolerite) composition have been found cutting all the earlier formations. Best exposure are noticed at Vengad, north of Kuthuparamba, Kirachchi and on the banks of Anjarakandi puzha, apart form these a few dykes occur within gabbro-granophyre complex at Ezhimala. The dykes occur in three district orientations (NNW-SSE, NW-SE and NW-SW). The rock is medium grained melanocratic. The texture is ophitic to sub-ophitic. Augite, plagioclase (andesine-labradorite) with minor hornblende, chlorite and iron ores constitute the mineral assemblage. The dykes have been attributed a transitional composition between abyssal and plateau basalts (Radhakrishna *et al.*, 1991) based on geochemical data.

Fig.7 Photomicrograph of microcline in Alkali Syenite showing cross hatched twinning. Crossed nicol x 25.

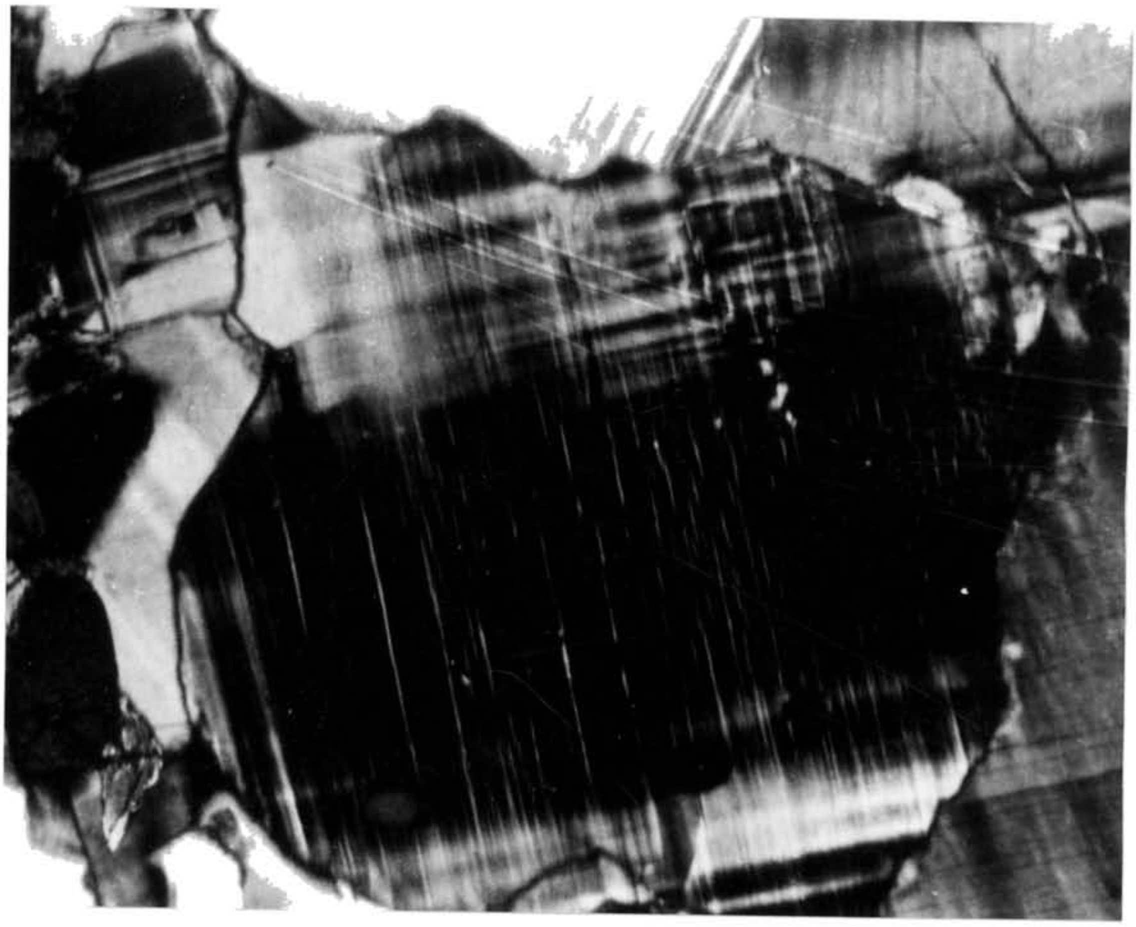


Fig.8 Photomicrograph of vein perthite undergoing merichimsatia in alkali syenite. Crossed nicol x 25.

The sedimentary formation in Cannanore district consists of clay, grits and lignite belonging to the Warkalli group which overlie the weathered basement rocks. Good exposures of these sedimentary formations are seen all along the coast. Interbed lignite-clay assemblage, suggesting marshy conditions of deposition are seen near the coast about 3 km at Cannanore, Meenkunnu and Palayangadi areas.

Interbedded loose, friable sandstone and clay sequence representative of deposition along river mouth is noted along road cuttings in Perumba, Vellur and further north.

At places like Valapatanam and Andur pebbles of vein quartz lying on weathered schistose rocks are overlain by ferruginous grit and laterites. In Koram and Cheemeni areas sub rounded pebbles of quartz and gneisses are seen lying below the variegated clay-sand stone sequence.

2.3.7. Quaternary to Recent Sediments

Lime shell and black clay occurrences are exposed in low lying paddy fields which represent the extinct lagoons, are seen stretching between Payyanur to Nileswar. Radiocarbon dates of lime shells from Payyanur (4490 ± 90 Y.B.P & 4370 ± 100 Y.B.P) and peat sample from Tellicherry (7230 ± 120 Y.B.P) has shown that the period of deposition of peat was prior to shell beds (Rajendran *et al.*, 1989).

The upper portion of all the rock types described from Cannanore district are lateritised. Detailed descriptions of laterites developed over these rock types are given in chapter - 3. Soil and alluvium area seen over laterite capping. Beach sands are seen along the coast and the alluvial sands in river beds.

2.4. STRUCTURE AND TECTONIC FEATURES

Planar and linear structures of different generations are observed in the study area, Primary planar structures like bedding. (S_1) are observed in the formation of the Vengad Group, revealed by non-pebbly horizons. Strike of S_1 structure is N65°W - S65°E with steep dips. Secondary planar structures like foliation (S_2) are preserved in all rock types of the area.

Around Tellicherry - Kuthuparamba, the mica schists and gneisses show trends mainly in a NNW-SSE direction. East of Kuthuparamba, the granulites have a general E-W strike of foliation. In the north-eastern part of the area and beyond, migmatites show broad E-W, trend lines, showing local swings to NNE-SSW and NNW-SSE directions.

Small-scale isoclinal folds (F_1) defined by S_1 are the earliest recognisable structures of the area. Such folds are observed in Palayad in the canal cutting and along the Anjarakandi river at Maruvambayi etc.

East of Kuthuparamba the hypersthene gneisses and the schists have been found folded along an E-W to ENE-WSW major antiform (Nair *et al.*, 1975)structure (F_2) with steep easterly plunge. North of Kuthuparamba, a synformal structure is observed. The Peralimala granite pluton is elongated parallel to the axial trace of this fold. The E-W fold axis seems to have suffered some refolding around NE-SW axes, as seen by swerves of the strike directions. The latter are asymmetrical, tight folds with moderate plunges towards NE and are the F_3 folds of the area Another set of NW-SE asymmetrical open folds (F_4) with low moderate plunges towards SE are also observed in the area.

Brittle deformation structures of the area include fault fractures observed north-east of Kuthuparamba, where the conglomerates and the schists of the Vengad formation have been brought of against the pyroxene granulite and hornblende - biotite gneisses, having foliation trends at right angles to that of the schists. The contact is also marked by a breccia zone. Further north around Iritty, the abrupt disappearance of the amphibolites of the High Grade Schists along the river course has been attributed to faulting. The western continuation of the shear zone of the Bavali lineament in this area is marked by development of slickensides as exposed in the quarry section at Kunot (Nair, 1980).

LANDSAT images of 12,500 scale (Band 5, 7 and false colour composites) were studied by visual interpretation techniques. The lineaments identified using the above technique was transferred to topographic maps using a Carl Zeiss sketchmaster and cultural features were filtered out as far as possible. The lineament map (Raghavan and Narayanaswamy, 1987) of the area is given in Figure 9. Limited field checks were carried out to verify the lineaments. The lineaments observed in the area are mainly due to incised fractures/shears of varying dimensions, dykes, differential erosion and vegetation. The highland region in Cannanore exhibit lineament pattern more clearly and towards the lowland regions the lineament density decreases due to various obscuring factors which include extensive soil and laterite cover, vegetation and cultivated land. Rose diagrams (Fig. 10) show that NNW-SSE.

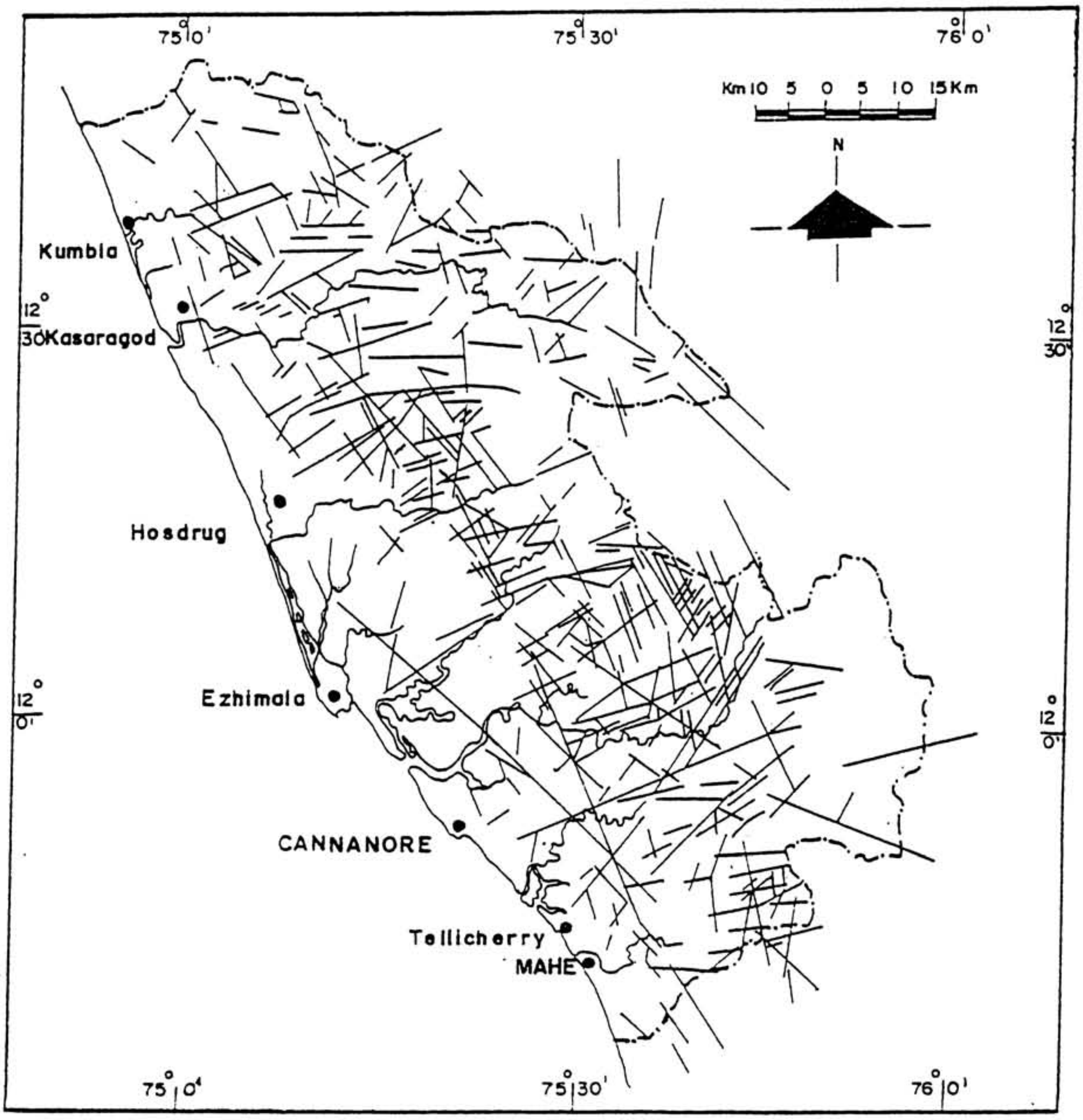


Fig.9 Lineament map of Cannanore district and adjoining areas.

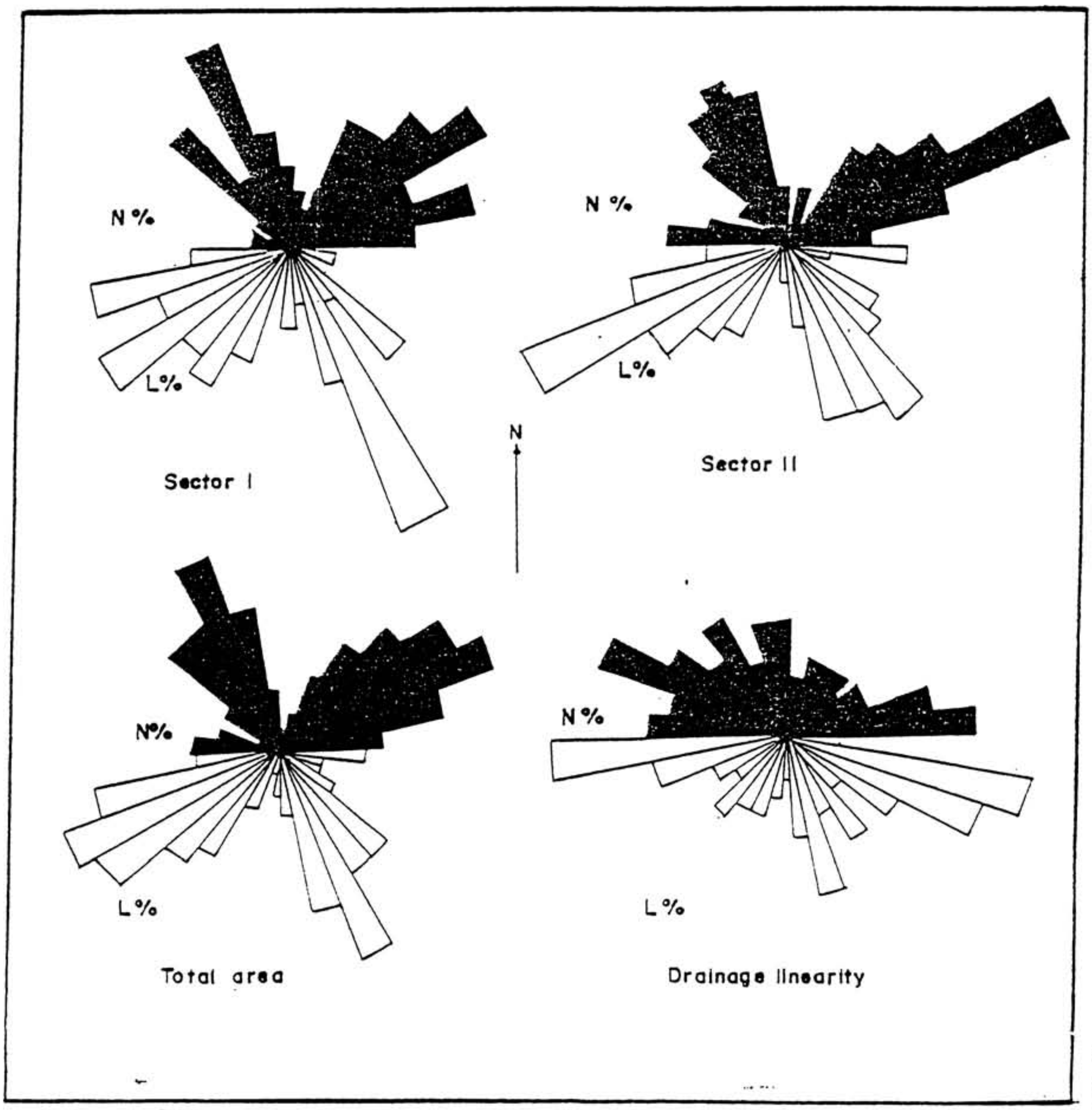


Fig.10 Rose diagrams of lineaments of the Cannanore region.
(N% = number percent; L% = length percent)

NW-SE, ENE-WSW and NE-SW linear features are predominant. The lineament density and intersection density maps (Fig. 11) show two prominent anomalies in the area NE and SE of Ezhimala. Distribution of lineaments in different azimuth classes are shown in Figure 12.

2.5. GEOMORPHOLOGIC SETTING OF THE STUDY AREA

The study area is marked by unique features ranging from coastal beach of very low relief in the west to the high hills with conspicuous relief in the east. Located between the sea and the Western Ghats, the area has been subjected to different exogenous processes leading to the present day geomorphic configuration. Lateritisation has influenced the landform evolution to a great extent. The following morphogenetic processes could be identified in this area.

Marine
Fluvio-Marine/Estuarine
Fluvial and Denudational weathering

Different geomorphic units have been demarcated under each of these process and described in chapter 5. Influence of some other processes are also evident. Table. 3 given below shows geomorphic units under each of these process.

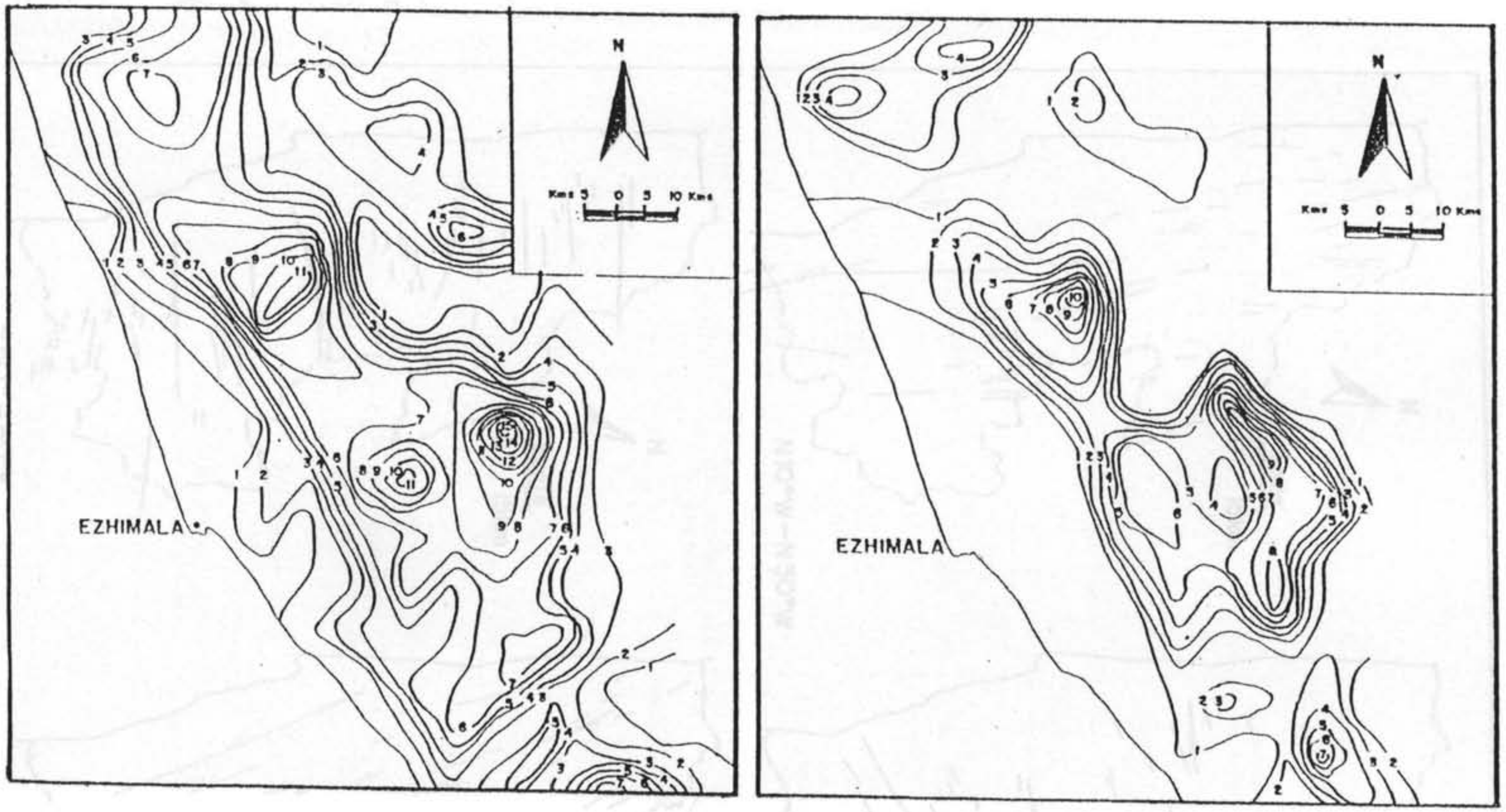


Fig.11 Isolineament density and Isolineament intersection maps for the Cannanore region.

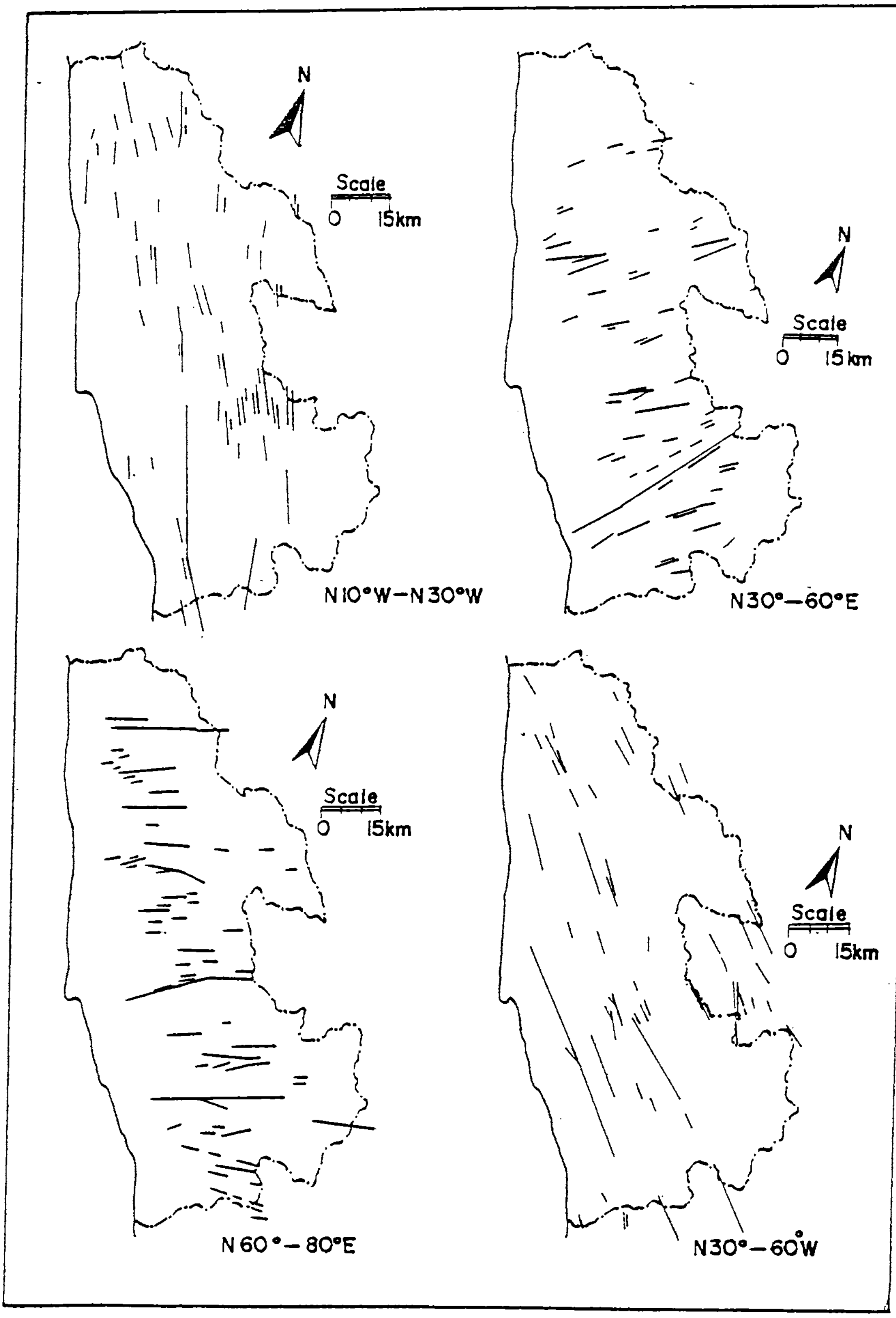


Fig.12 Distribution of lineaments in different azimuth classes.

TABLE 3

Process	Geomorphic units		Characteristics
	Main units	Sub units	
Marine		Beach (C_2)	Narrow, accretional beach including some aeolian deposits
	Coastal plain	Coastal cliff ($C1$)	Erosional, lateritic
		Coastal plain - lateritic (C_{3-1})	Erosional, probably the lowest plantation surface
		Coastal plain - alluvium (C_{3-2})	Depositional, includes mud/tidal flats and paleo beaches
Aluvio-marine/estuarine	Fluvio-tidal channel and swamps	Partially isolated brackish marsh (B_2)	Regularly inundated
		Tidal channel (B_3) also known as back water islands within tidal channel	Braided bars
Fluvial	Flood plain and terraces	Flood plain including lowest terrace	Regularly flooded area during monsoon
		Terraces	Depositional terraces at higher level than the flood plain
		Alluvial plains	Normally away from the main river course
Denudational weathering	Flat to rolling plain	Gently rolling	Low relief, slope $<5^{\circ}$
		Undulated	Low to medium relief, slope $<10^{\circ}$
	Denudational hills and slopes	Isolated hills and slopes	Structurally controlled, steep sided
	Lateritic mesa	Lateritic mesa	Almost flat table like with slope 5°
	Denudated hills and mountain	Ridges, highly undulated terrain	Flat, elongated slope $<5^{\circ}$, Western Ghat hills, scarp slopes

Spatial distribution of these units highlights that considerable area of Cannanore district is subjected to denudational processes. Depositional units i.e., fluvial units are marked in patches. Even a major river like Valapatanam does not show continuous flood plain. The river valleys that almost follow the lineaments cutting across the laterite are narrow, steep sided but flat bottomed. This indicates the dominance of scarp retreat in landform development.

Five planation surfaces demarcated (oldest to recent are P_1 to P_5. P_3 surface (60 - 160 m) is characterised by the presence of laterite mesa (plate 1) and covers a major part of the area. The P_1 surface is distinguished by the surface denudational process and is mostly stripped of the laterite cover in the upper slope and some laterite remnants are observed in the shoulder slope. The P_2 surface, also with laterite cover, mostly occurs as bounding slope to the P_1 surface and gradually merges with the P_3 surface. The P2 surface can be equated to the unit of denudational hills and slope. P_4 surface occurs as flood plain valley bottom, and terraces incised on to the P_3 surface along the rivers. P_5 surface is generally the aggradational plain consisting of coastal deposits in the western part and alluvial and colluvial deposits in the eastern valley bottoms and flood plains. Along the coast the P_5 surface exhibits hard laterite crust cover which marine terrace is exposed in some areas. The foregoing discussion on geomorphology indicates that lateritisation had wide ranging impact on landform evolution of the area.

Chapter 3

LATERITES OF THE CANNANORE DISTRICT

Laterites of the study area are characterised by their development over a wide variety of lithologies ranging from granulite/gneiss, through schists of the Sargur/Dharwar groups and rocks of the Tertiary sedimentary formations, to intrusive phases like anorthosite, gabbro - granophyre, alkali - syenite etc. Further, the laterite formation is confined to an altitude below 300 m in the eastern part of the region, while towards the coast, they are observed even below 1 m. Well preserved laterite mesas covering most of the area are seen between 60 to 160 m interval.Along the coast hard laterite cover is exposed as marine terraces. The distribution of laterite in the Cannanore district is shown in Figure 13.

3.1. TERMINOLOGY

Laterites are generally classified into two major groups in terms of their genetic relation i.e. (i) primary/high level laterite is the term used for in-situ weathering products (ii) secondary/detrital/low-level laterite for that formed by partial or complete consolidation of transported lateritic material. As mentioned above, the concept of high-level and low-level laterite in terms of genetic classification is not tenable because low- level laterites are not always detrital or secondary in nature (Karunakaran and Sinha Roy, 1971) which has more relevance to Kerala region as the in-situ laterites including those of Buchanan's type area occur in relatively low level.

Each zone of the laterite profile has its own distinctive character which is highlighted by varying morphologic characteristics, mineralogy and chemistry. It is difficult to give a purely morphological, physical or chemical definition of laterite as this term covers a variety of aspects of tropical

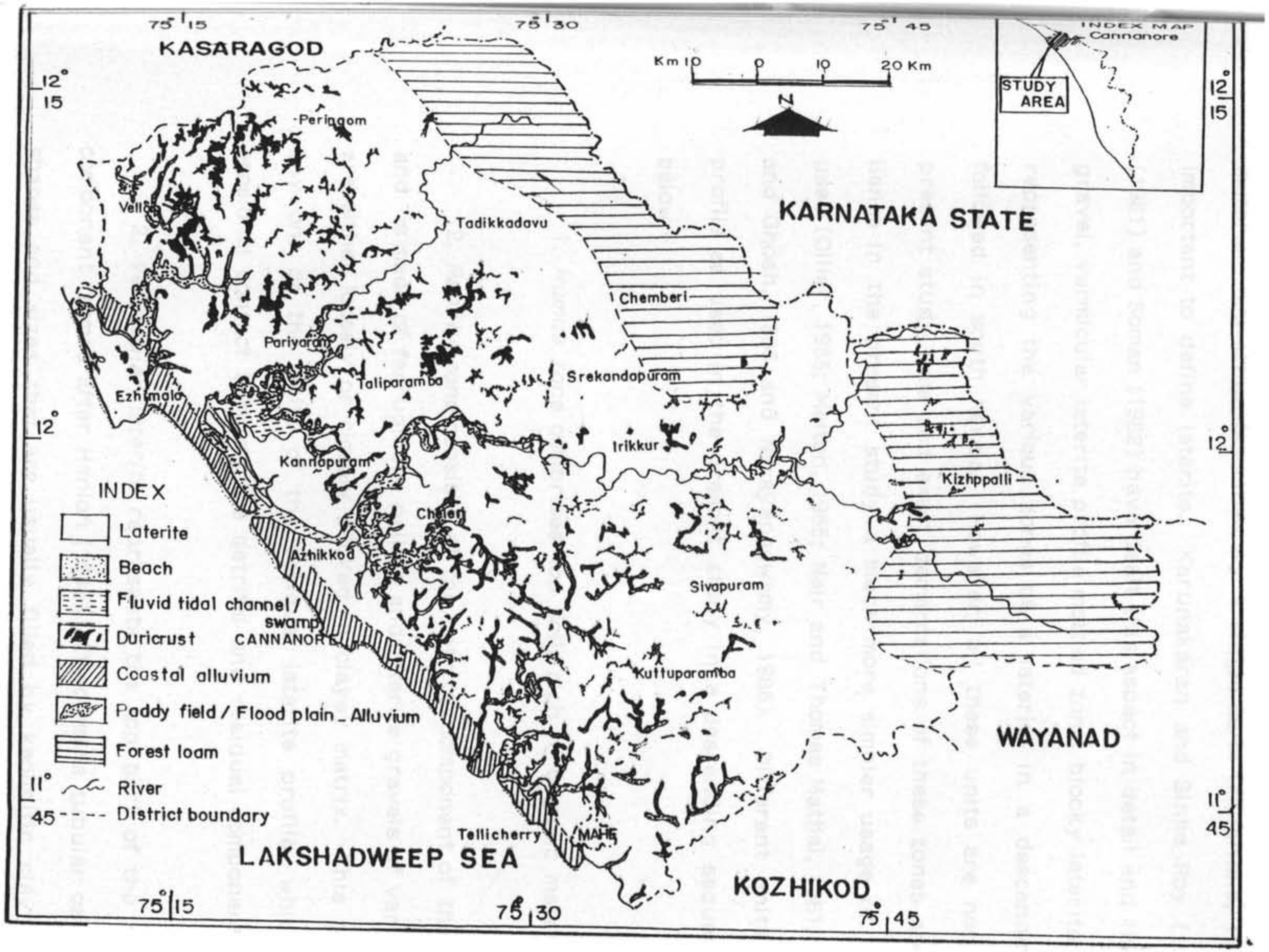


Fig.13 Map showing distribution of laterite in Cannanore district.

weathering. One of the major difficulties in terminology is that different materials are often described by a single term (Mcfarlane, 1976), hence it is important to define laterite. Karunakaran and Sinha Roy (1979), Sinha Roy (1981) and Soman (1982) have dealt this aspect in detail and the terms lateritic gravel, vermicular laterite profile mottled zone, blocky laterite and pallid zone representing the various zones of a laterite in a descending sequence is followed in south Kerala. However, all these units are not noticed in the present study area and exact demarcations of these zones are also difficult. Hence in the present study a much more simpler usage of the names were used (Ollier, 1965; Melton, 1965; Nair and Thomas Mathai, 1981; Narayanaswamy and Ghosh, 1985 and Narayanaswamy, 1986). Different units of the laterite profile as used in the present study in a descending sequence are defined below:-

1. *Humus zone* comprises top soil, rich in organic material.

2. *Pebbly zone* consists of the detrital component of the laterite profile and is made of ferruginous pellets and laterite gravels of various shapes that are either loosely or closely packed in clayey matrix. This zone may overlie any one of the units of the residual laterite profile, which signifies the erosional contact between the detrital and residual components.

3. *Vermicular laterite* represents the top part of the residual laterite component termed after Hanlon (1945). It contains tubular cavities of various shapes and sizes that are usually filled by kaolinitic clay (Fig. 14). The thickness of this zone is highly variable.

4. *Pallid zone* comprises kaolinitic clay pockets or bands. The

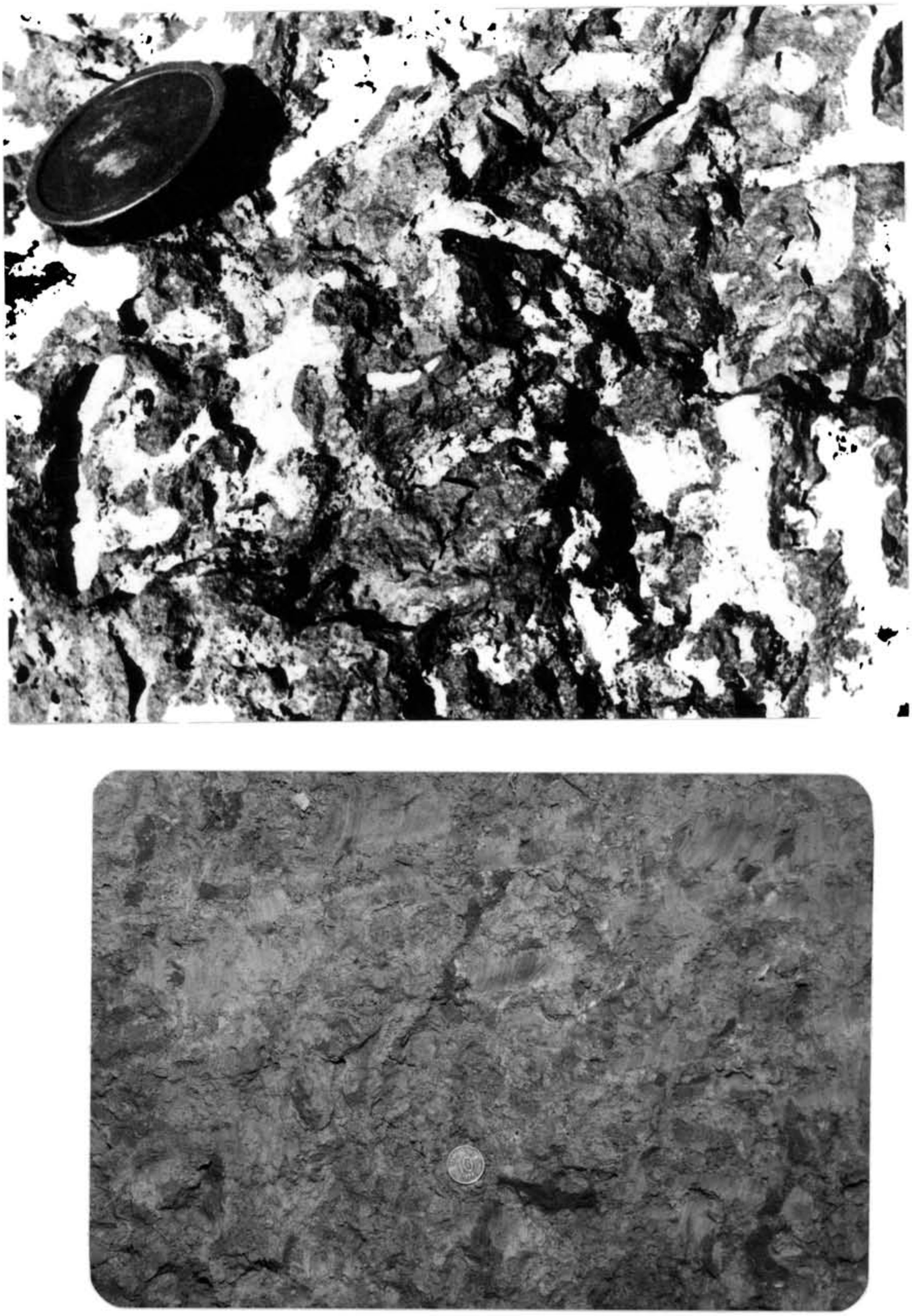


Fig.14 Vermiform laterite showing tubular cavities filled with Kaolinitic clay (a) black and white photograph (b) colour photograph. Crossed nicol x 25.

Fig.15 Field photograph showing relict structures in weathered parent rock.

Laterites owe their colour to iron oxides in various states of hydration and hence the estimation of colour gives a rough idea of composition (Fig. 15 shows different shades of laterites).

3.3. SPECIFIC GRAVITY

The specific gravity of laterites from the study area varies between 1.72 and 2.41. The variation is consistent with the chemical composition. The specific-gravity of oxidised forms are higher than that of hydrated forms. Comparison of apparent density is useful in estimating the intensity of leaching of materials. Old duricrusts are denser than recent duricrusts. It is also found that looser the structure of the laterite, lower is the density.

3.4. LATERITE PROFILE DESCRIPTIONS

Laterite profiles developed over different lithological units (charnockite, gneisses, fuchsite-quartzite, ultramafites, quartz-mica schists, anorthosite, gabbro, granophyre, alkali syenite, and sedimentary formation) have been studied and the various units were demarcated from 30 representative locations and the these profiles are shown in Figs. 16A, B, and C.

3.4.1. Laterite profiles over charnockites

Since charnockites form the major rock type in the study area, *in situ* development of laterites were examined at several places for mineralogical and for geochemical studies, and results from four such profiles are presented here. In general, the profiles vary from 3.8 to 9.9 m in thickness (Fig.16 A, profiles 1 to 4). A generalised picture of the profiles indicates a humus zone (0.3 - 0.9 m) underlain by a 0.4 m thick pebbly zone (in one section only) which contains ferruginous pellets in clay matrix. It is underlain by vermicular laterite (1.5 - 3 m), which is the top portion of the profile with tubular cavities of various shapes and sizes that are usually filled with kaolinitic clay. A hard ferruginous crust is seen above this zone at two places (profile No. 2 and 3, Fig. 16). The cross sections of the vermicules consist of alternating layers of gibbsite and hematite grown around released silica. It is followed by a thin layer of lithomarge (0.2- 0.5 m thick). Further below completely weathered, partly weathered and fresh parent rocks occur. The boundaries between different zones are gradational. All the units are not found in all the profiles (eg. profile No.1 and 4) have humus zones which is missing in profile nos. 2 and 3, where a hard duricrust is exposed. Lithomarge clay zone appears to be a conspicuous unit in laterite profiles over charnockite. Sampling for analysis was restricted to certain zones.

3.4.2. Laterite profiles over gneiss

Laterite profiles developed *in situ* over gneisses have a laterite cover of 2.7 m. Details of the weathering units are shown in Figure 16A (profiles 5 and 6). In general the profiles developed over gneisses are seen devoid of humus zone and hard duricrust, at the top, instead the laterite column (2.1 to 2.7 m) is noticed. This zone is underlain by a thin veneer (0.3 m) of lithomarge, which is noticed in one profile only (Fig. 16A profile 6). This is followed by completely weathered (0.6 to 1.2 m) and partly weathered rocks (0.9 to 0.2 m). Fresh rock is noticed in all the profiles. *in situ* profiles have structural continuity of the bed rock from one zone to another.

3.4.3. Laterite profiles over fuchsite quartzite

The hill Tumbeni is composed of fuchsite quartzite. The fuchsite quartzite body has dimensions of 6 x 1 m. The entire hill is lateritised. Sketch of the profile studied is given in figure 16A, profile No 7. The *in situ* profile consists of a pebbly zone of 0.3 m thickness, underlain by vermiform laterite (1.5 m). Fuchsite mica is visible and distributed sporadically in this zone, below which a thin layer of lithomarge (0.3 m) is present. This is followed by completely weathered (0.45 m) and partly weathered zones (0.6 m). Fresh fuchsite quartzite rock is exposed upto a depth of 4.5 m.

3.4.4. Laterite profiles over ultramafites

Ultramafic rocks occur around Sreekandapuram. The major rock varieties are talc-tremolite schist and pyroxenites. Five profiles exposed around Sreekandapuram, were studied in detail, out of which sampling was done at three locations, (profile Nos. 8,9 and 10 - two over schists and one over pyroxenite). The profile thickness ranges from 3 to 6 m and shows textural continuity from bed rock to laterite.

The profile has a thin layer of humus zone (0.2 to 0.3 m) with ferruginous pebbles/lateritic gravels in clayey matrix in one of the profiles. This zone is underlain by vermiform laterite. The thickness of this zone ranges from 3 to 6 m. Tubular cavities of various shapes are filled by kaolinite, and also show alternate layers of gibbsite and limonite. This zone is underlain by a layer of lithomarge of 0.45 m thickness (in one profile only No. 10) Completely weathered, partly weathered and fresh parent rock units are exposed towards the bottom. The sketches of the studied profiles are given in figure 16A, profile 8 to 10.

3.4.5. Laterite profiles over quartz-mica-schist

Quartz mica schist occurs as linear bands within the granulites as well as migmatites. Two fully developed laterite profiles were selected for the study (Fig. 16B, profile Nos 11 and 12) which have continuity of textural features suggesting the *in situ* nature. The profile consists of a pebbly zone of 0.2 is followed by vermiform laterite of 1.5 to 3 m. This is followed by completely weathered (0.15 to 0.8 m) and partly weathered zones (0.15 to 0.5 m). Fresh rock is exposed upto to a depth of 0.8 to 1.5 m.

3.4.6. Laterite profiles over anorthosite

A thick capping of laterite is seen developed over anorthosite at Perinthatta. Four profiles were selected for the present study. All units of the synoptic profile are present in the laterite developed over this rock unit. The profiles indicate a humus zone (0.5 m) at the top, followed by a lateritic gravel bed consisting of ferruginous pellets in clay matrix (1.5 m). It is underlain by hard duricrust (4.5 m) at one place (profile No. 13), followed by vermiform laterite (4.5 m) showing tubular cavities of various shapes. A thin layer of lithomarge (0.5 m thick) is also observed in most of the profiles, occurring below the vermiform laterite zones. Further below weathered (2.5 m) and fresh rocks occur (Narayanaswamy, 1986). Sketches of the laterite profiles over anorthosite with sample locations are given in figure 16B (profiles 13 to 16) and figure 17.

3.4.7. Laterite profiles over gabbro-granophyre rock units

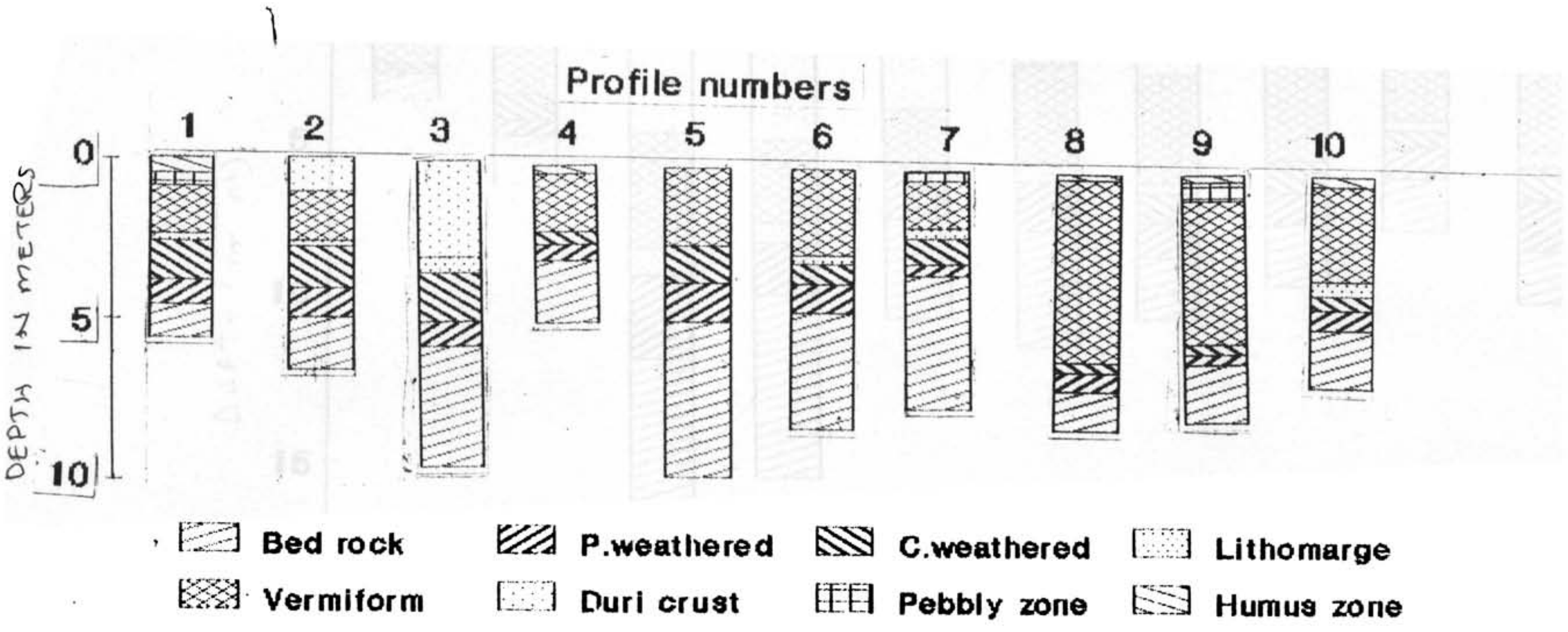


Fig.16A Sketches of laterite profiles developed over different rock units: profile Nos. 1 to 4 : over charnockite, 5 & 6: over hornblende-biotite-gneiss, 7: over fuchsite quartzite, 8-10: over ultramafites.

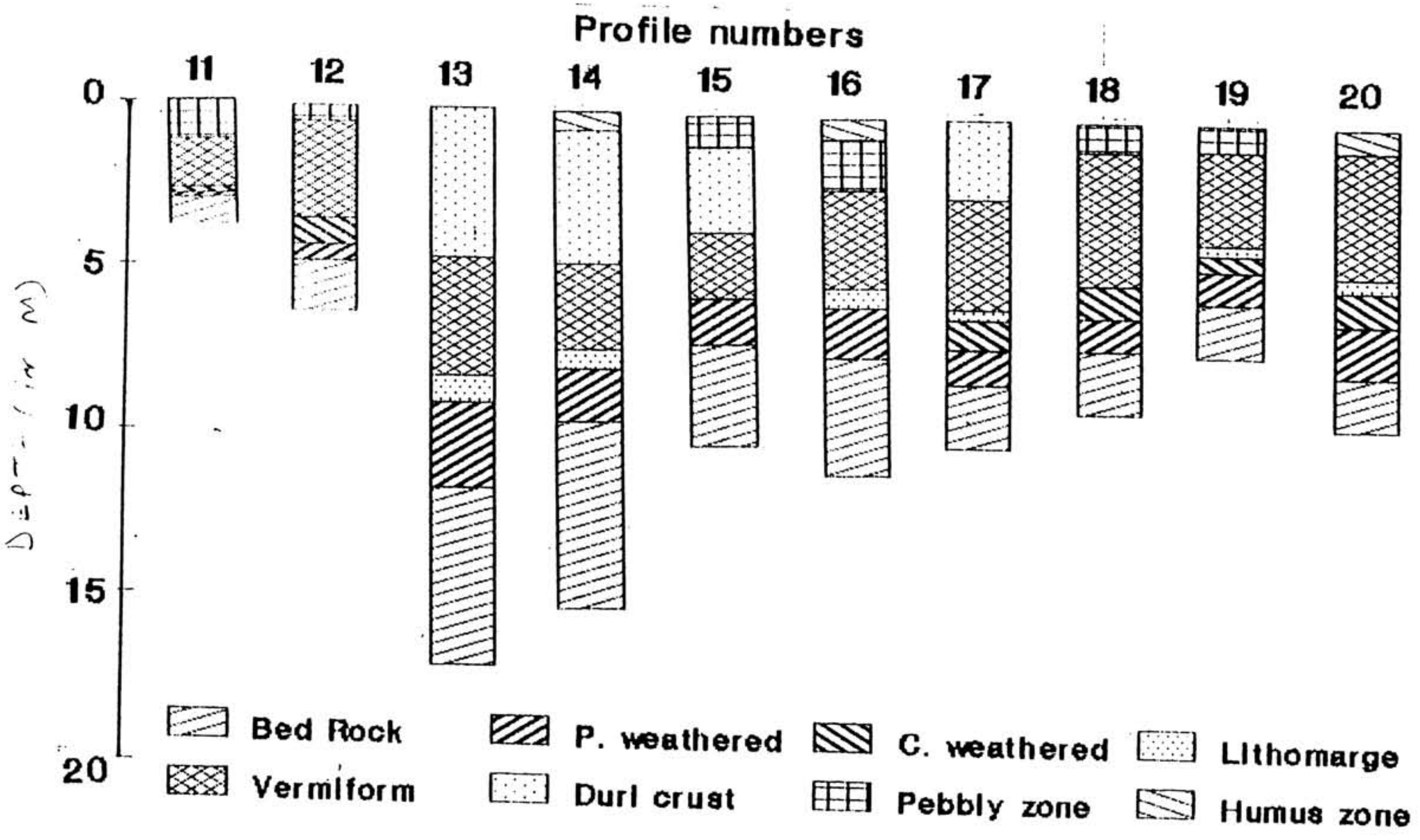


Fig.16B Sketches of laterite profiles 11 and 12 : over quartz- mica-schist, 13 to 16 : over anorthosite, 17 to 20 : over gabbro.

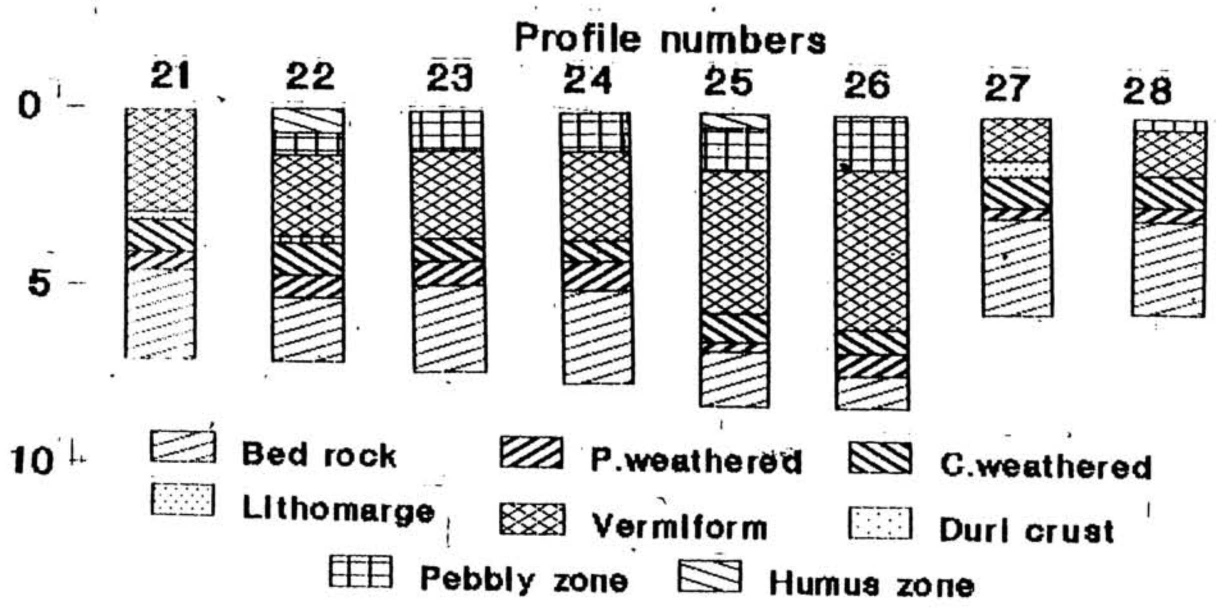


Fig.16C Sketches of laterite profiles 21 to 26 : over granophyre, 27 and 28 : over Alkali syenite

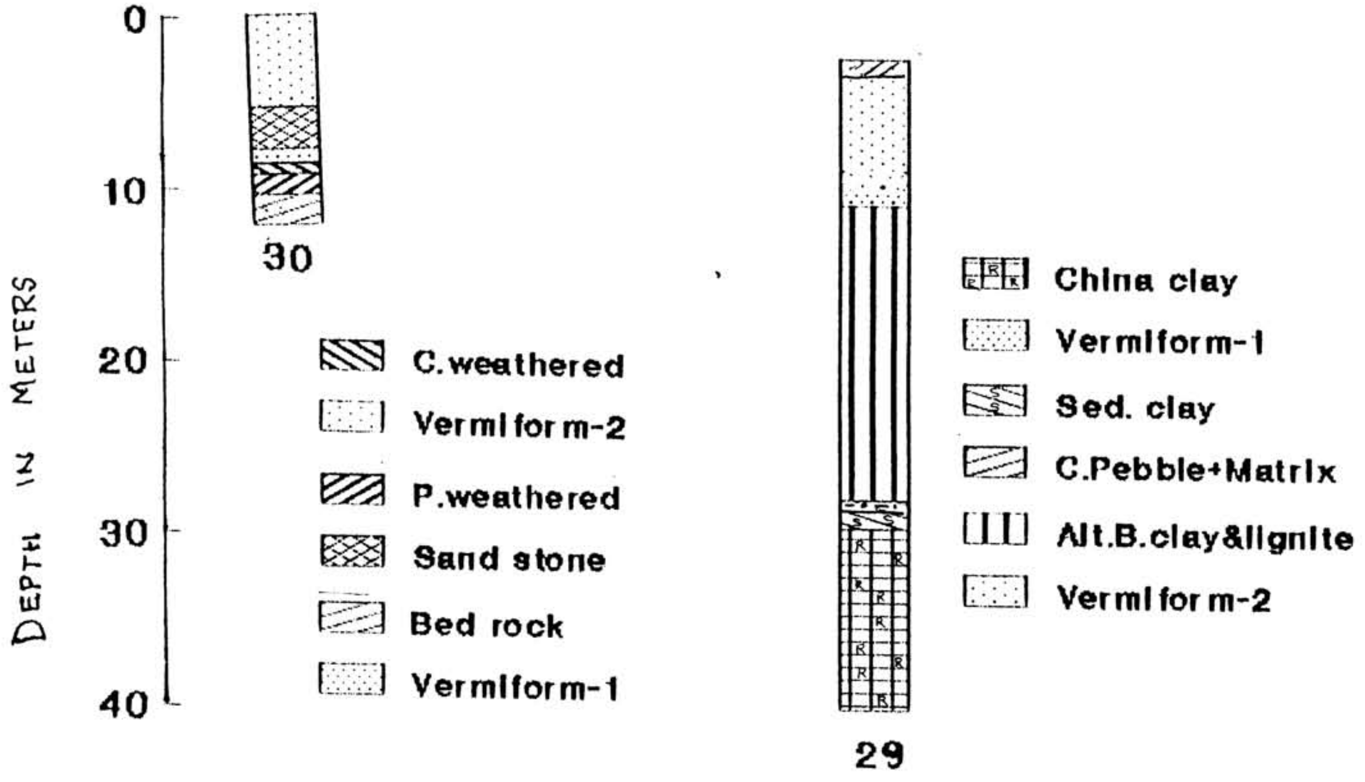


Fig.16D Sketches of laterite profiles 29 and 30 : over sedimentary formations.

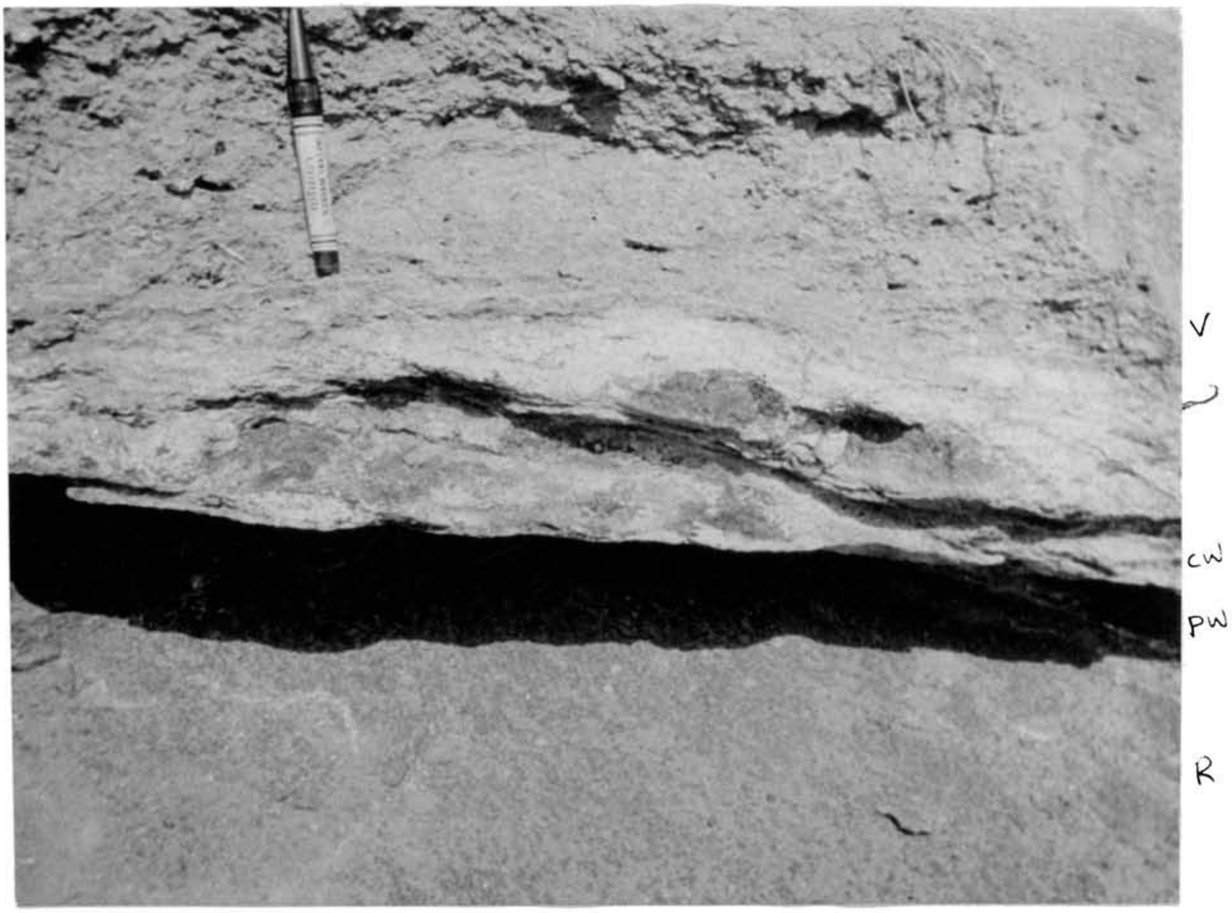


Fig.17 Field photograph showing inter relationship between various units of the laterite profile over anorthosite. R = parent rock, PW = partly weathered CW = completely weathered and V = vermiform laterite.

Generalised picture of the residual profiles developed over this rock units at Ezhimala with thickness of the compositional units are given in figure 16B (profile no 17 to 20: gabbro) and 16C (profile 21 to 26: granophyre). The generalised picture shows a humus layer (0.5 - 1 m thick), followed by hard ferruginous crust (2.5 m) in the profile over gabbro, while it is absent in laterite profiles developed over granophyre. This zone is underlain by a thick cover of vermicular laterite (4.75 m), exhibiting typical vermiform texture with tubes of various shapes filled by kaolinitic material. Further below is a thin layer of lithomarge seen in most of the profiles. Further below, completely weathered, partly weathered and fresh parent rocks are seen. Boundaries between various zones of the laterite profiles are gradual (Fig. 18, gabbro) and Fig. 19 (granophyre).

3.4.8. Laterite profiles over alkali syenite

Laterite profiles developed over alkali syenite body at Peralimala are almost devoid of humus layer. However the pebbly zone (0.2 to 0.3 m) with ferruginous pellets in clay matrix is noticed. This is underlain by a 1.2 m thick vermiform laterite exhibiting tubular cavities filled with kaolinite. A thin layer of lithomarge (0.6 m) is seen further below. Completely weathered, partly weathered and fresh rocks occur towards the bottom. Sketches of the laterite profiles are given in figure 16C (profile 27 and 28).

3.4.9. Laterite profiles over sedimentary formations

Laterite profile over sedimentaries are well exposed in the study area at (a) Palayangadi and (b) Tellicherry. The profiles consist of two components (i) *in situ* (residual) and (ii) transported (secondary) laterites.

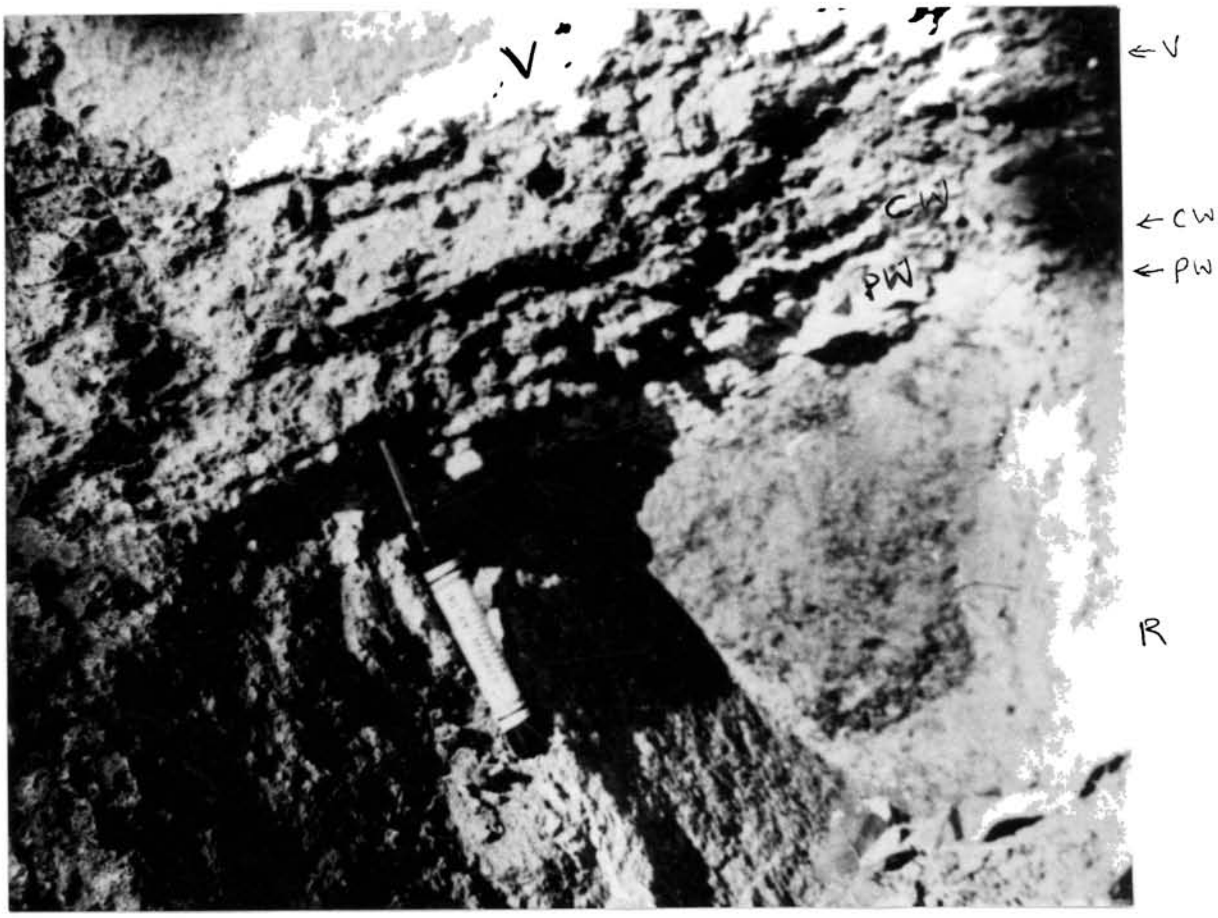


Fig.18 Field photograph showing interrelationship between various units of the laterite profile over gabbro. R = parent rock, PW = partly weathered CW = completely weathered and V = vermiform laterite.

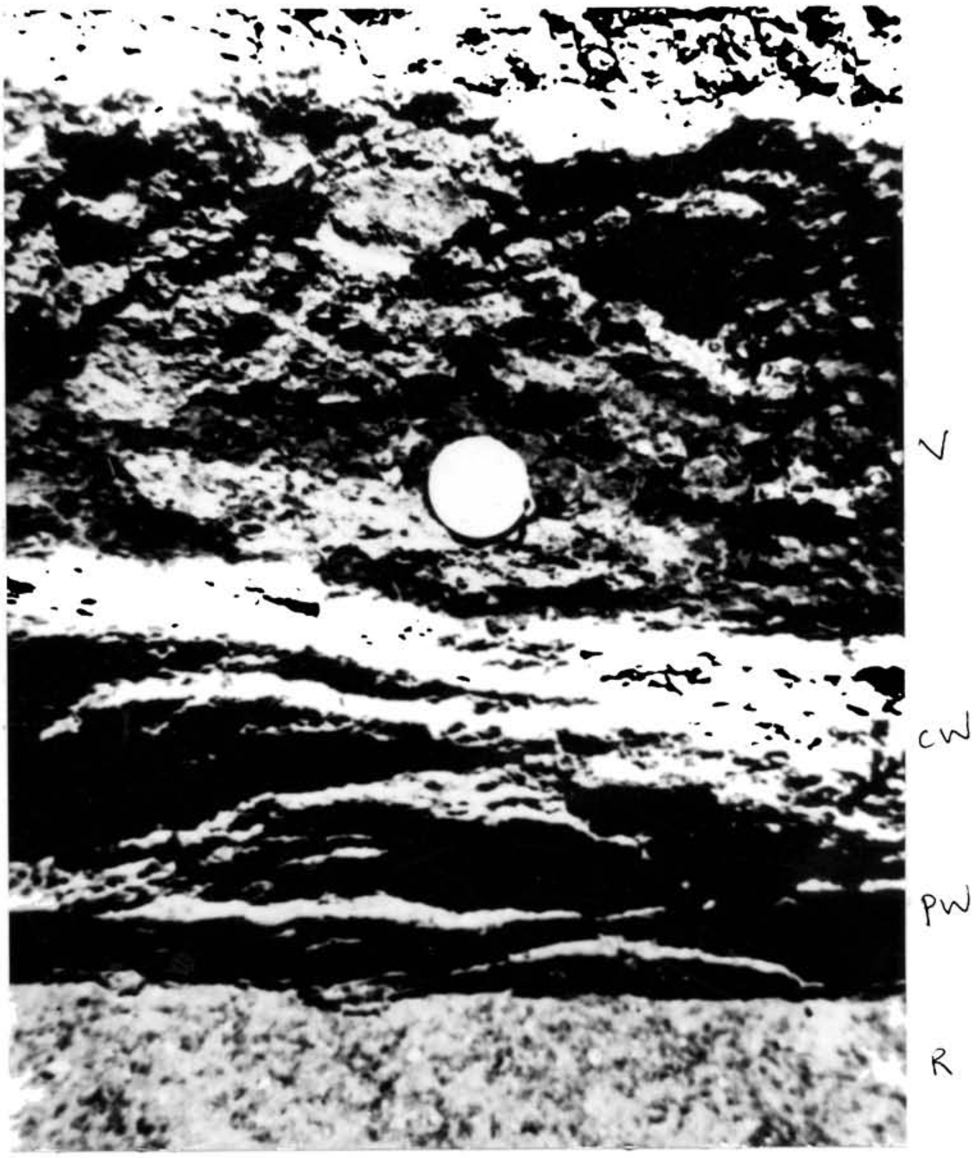


Fig.19 Field photograph showing interrelationship between various units of the laterite profile over granophyre. R = parent rock, PW = partly weathered CW = completely weathered and V = vermiform laterite.

a) *Laterite profile at Palayangadi* : Sketch of the studied profile at Palayangadi is given in Figure 16D (profile 29). The sedimentary sequence has a thickness of 38 m out of which the top 7.25 m is composed of laterite. The upper most part of the lateritised portion (about 0.6 m) consists of cemented pebbles of ferruginous material. This is followed by a thick laterite zone (6.65 m). The upper part of this zone is hard whereas the lower portion is soft. This is followed below by a sequence of alternating lignite and ball clay layers of 0.5 - 2 m each with a cumulative thickness of 19.5 m. A 3 m china clay layer of sedimentary origin is found further below, the top of which shows symptoms of lateritisation. This zone is followed by primary clay (8.25 m). Figure 20 shows a synoptic view of the profile. The basement rock is not exposed at the profile site.

b) *Laterite Profile at Tellicherry*: The profile at Tellicherry cliff section is unique as the development of *in situ* laterite over biotite gneiss-migmatite and on the overlying sedimentary rocks are very well preserved. The profile exposes the bed rock upto 1.8 m above sea level, over which 1.2 m thick partly weathered and 0.6 m thick completely weathered rocks are exposed. Further up, a 0.9 m thick laterite column is seen. This laterite layer is overlain by a 2.4 m thick sandstone bed and an upper laterite bed of 5.4 m thick. The sandstone bed shows graded bedding and ripple marks. The sketch of the profile is given in figure 16D (profile 30).

3.5. LATERITISATION CYCLES IN CANNANORE DISTRICT

Occurrence of *in situ* laterites, developed over the Precambrians and over the overlying Tertiary sediments suggests that the laterites occurring

Fig.20 Field photograph showing the laterite profile at Palayangadi.

throughout the district belong to two periods of formation. The two types can be distinguished mineralogically and geochemically also (as will be discussed in chapter 4). Based on these observations two lateritisation cycles have been reported from the area (Mallikarjuna *et al.*, 1981 Rajendran and Narayanaswamy, 1987). This is also consistent with the observations that two cycles of lateritisation occurred in south Kerala (Raghava Rao, 1975, Soman and Slukin, 1985). Observation at the Palayangadi clay section also substantiate this view. Age wise, the cycles may be attributed to pre-Warkalli and post-Warkalli times.

Chapter 4

MINERALOGY AND GEOCHEMISTRY

4.1. MINERALOGY

Mineralogical composition of the laterites and associated clays of the study area was established through the combination of a number of determinative techniques such as petrographical investigations, X-ray diffraction, Differential Thermal Analysis, Scanning Electron Microscopy and Infra Red Spectroscopy.

X-ray analyses using powder diffraction method was carried out on a Phillips PW 1730 X-ray generator. The samples were analysed with the following instrument settings: The 420 mesh fraction of the laterite samples were scanned at 5 to 65° (2θ) with Cu Kα target and Ni filter operated at 40 KW and 20 mA with chart a speed of 2°/minute.

As revealed by petrographical observations, all the silicate minerals have been transformed to a mixture of goethite, hematite and kaolinite in laterite samples developed over charnockite. Alteration begins along cleavage planes, grain boundary and cracks. It has been further observed that pyroxenes have been altered to goethite while feldspars gave rise to kaolinite. Quartz is cracked, eroded and disintegrated. Alteration of pyroxenes precedes that of feldspars (Fig.21). Monazite and zircon are the accessory minerals. X-ray diffractograms substantiate the presence of goethite, kaolinite, quartz, gibbsite, vermiculite and monazite (Fig. 22A).

Petrographic observations of laterite developed over gneiss also reveal that all the silicate minerals have been transformed to a mixture of Fe and Al oxides and hydroxides. Hornblende and biotite have been altered to goethite and hematite while feldspars have given rise to kaolinite. Quartz fragments, corroded and cracked are seen within Fe-Al oxide/hydroxide mass, and the cracks have been filled with Fe-material. Alteration of pyroxenes precedes that of feldspar, hornblende, and biotite.

X-ray diffractograms indicate presence of kaolinite, quartz, gibbsite, goethite, and vermiculite (Fig. 22B).

Laterite over fuchsite quartzite is characterised by the formation of opaque minerals from fuchsite and other mafic minerals. Quartz is cracked, and corroded. Alteration of mafics precedes that of feldspar and fuchsite mica. Presence of kaolinite, quartz, gibbsite, goethite, vermiculite, barium muscovite and barite is indicated by XRD (Fig. 22C).

Thin section examination of laterite developed over ultramafic rocks reveal that pyroxene, tremolite, and actinolite are altered to goethite, hematite and kaolinite. X-ray diffractograms (Fig. 22D) indicate the presence of kaolinite, quartz 'gibbsite, goethite, vermiculite, garnierite, maghemite and illite. Alteration of pyroxenes is earlier than that of actinolite and tremolite. Quartz is the most resistant mineral in the rock.

In laterites developed over quartz-mica schists, silicate minerals have been transformed to Fe and Al oxides/hydroxides. Hornblende is altered to goethite while feldspar has given rise to kaolinite. Quartz is cracked and corroded and the cracks are filled with Fe-material. Desilication of kaolinite is also noticed.

X-ray diffractograms indicate the presence of kaolinite, quartz, gibbsite, goethite, and zircon (Fig. 22E).

Fig.21 Photomicrograph showing alteration of pyroxenes preceding that of feldspar in charnockite. Crossed nicol x 25.

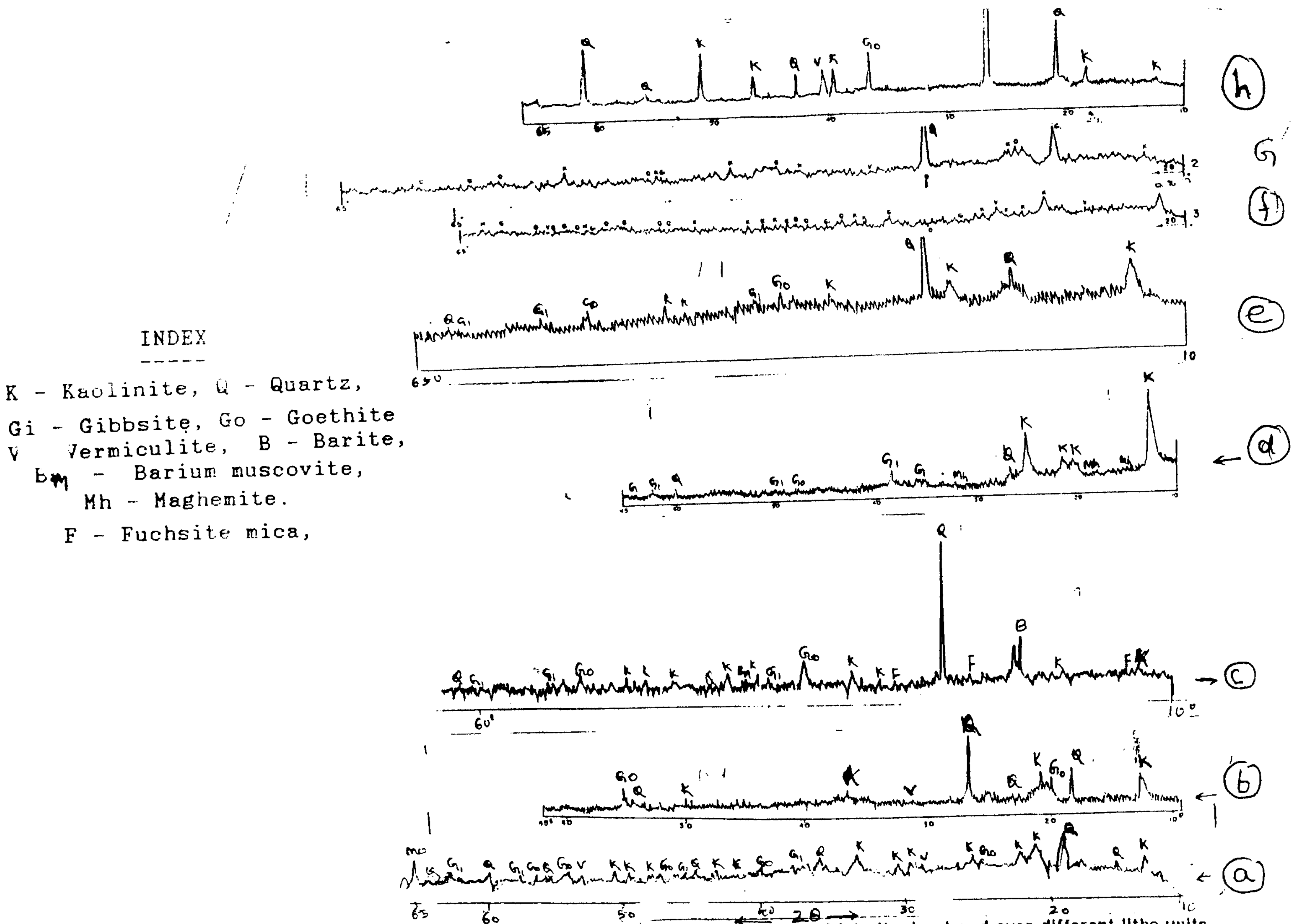


Fig.22 X-ray diffractograms of laterite developed over different litho units.
(a) over charnockite (b) over gneiss (c) over fuchsite quartzite (d) over ultramafites (e) over quartz- mica-schist (f) over gabbro (g) over granophyre (h) over alkali syenite.

In anorthosite profiles, all the silicate minerals have been transformed to a mixture of Fe and Al oxides and hydroxides during weathering. Pyroxene has been altered to goethite. Feldspars have been transformed to kaolinite, while brown biotite has also given rise to goethite. Quartz is corroded, and cracked. Alteration of feldspar precedes that of biotite and pyroxene (augite) . Further, desilication of kaolinite to gibbsite is also observed (Fig.22) Al oxides-hydroxides predominate over Fe oxides-hydroxides. Presence of quartz, kaolinite, gibbsite, goethite and vermiculite are also indicated in XRD.

In laterite developed over gabbro, as revealed by petrological observations, all the silicate minerals have been transformed to a mixture of Fe and Al oxides and hydroxides. Alteration of pyroxenes to goethite, feldspars to kaolinite and disintegration of quartz through cracking and corrosion have given rise to the laterite. Alteration of pyroxene is earlier than that of feldspar (Fig.23). X-ray diffractograms substantiate the presence of kaolinite, quartz, gibbsite, goethite, and vermiculite (Fig.21 F). Goethite concentration is found to be more in this rock type than in granophyre which is also consistent with the geochemistry data.

Transformation to laterite over granophyre is characterised by the presence of a mixture of goethite and hematite formed on transformation of pyroxenes, and of kaolinite after feldspars. Quartz is found to be cracked, corroded and disintegrated. Alteration of pyroxenes precedes that of feldspar (Fig.24)

X-ray diffractograms substantiate the presence of kaolinite, quartz, goethite, gibbsite and vermiculite (Fig.21 G).

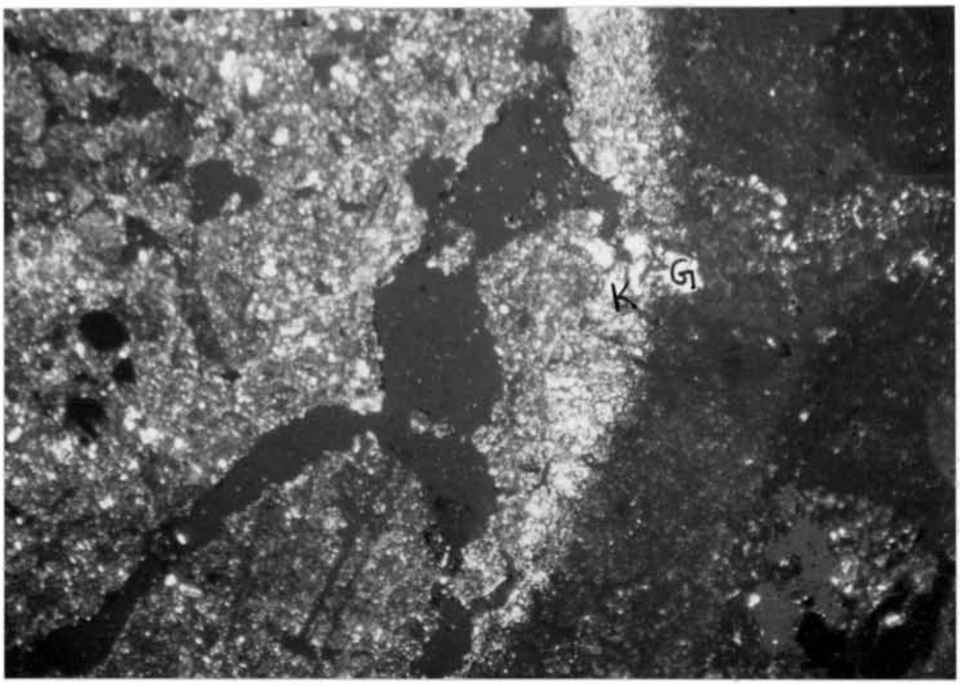


Fig.23 Photomicrograph showing desilication of Kaolinite(k) to gibbsite(G).
Crossed nicol x 25.

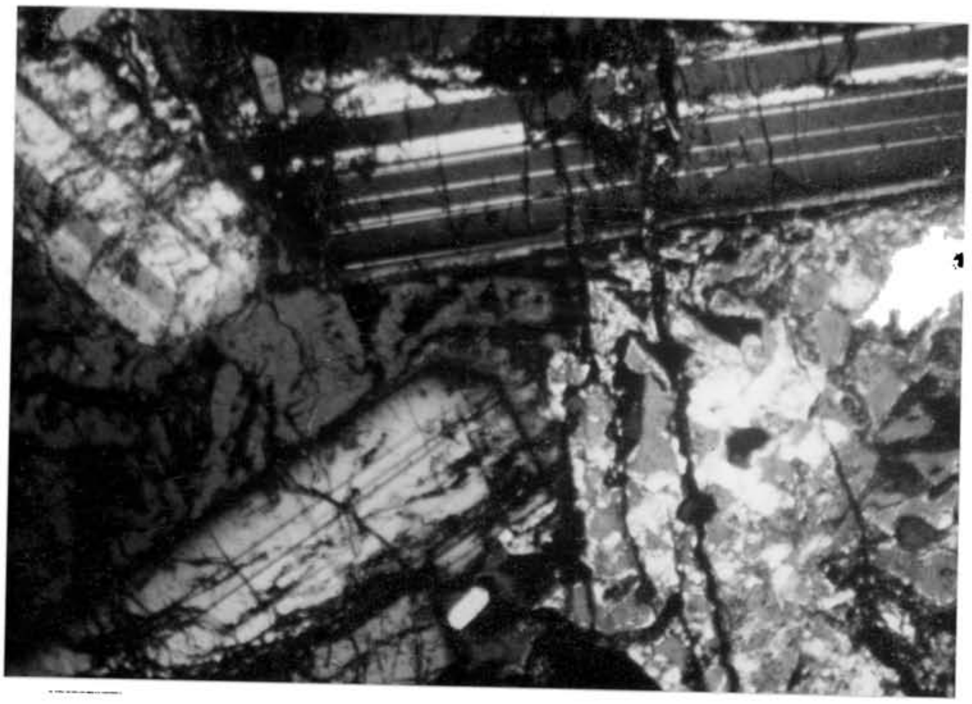


Fig.23A Photomicrograph showing pyroxene alteration in gabbro. In this rock also alteration of pyroxene proceeds that of plagioclase.
Crossed nicol x 25.

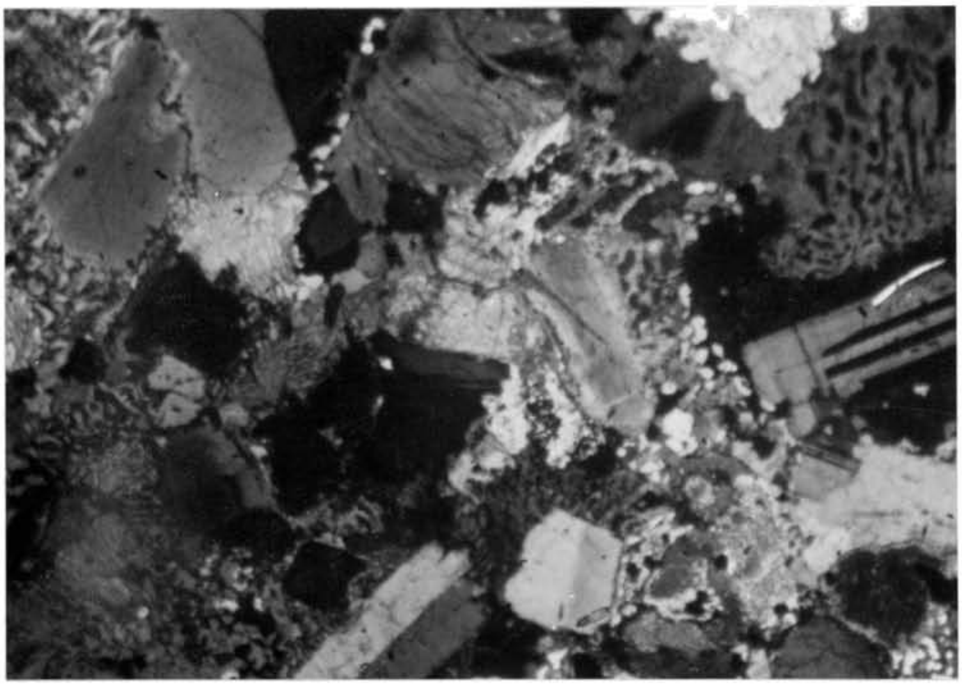


Fig.24 Photomicrograph showing alteration of pyroxene which also preceds alteration of feldspar in granophyre. Note : feldspar grains (F) are less altered than pyroxenes(P). Crossed nicol x 25.

Petrographical observation of laterite developed over alkali syenite indicates that all the silicate minerals have been transformed to a mixture of Fe and Al oxides and hydroxides. It has ben noticed that kaolinite is pseudomorphous after feldspars. Aegerine is altered to goethite. Alteration of feldspars precedes that of aegerine.

X-ray diffractogram substantiate the presence of kaolinite, gibbsite, goethite etc. (Fig.21 H).

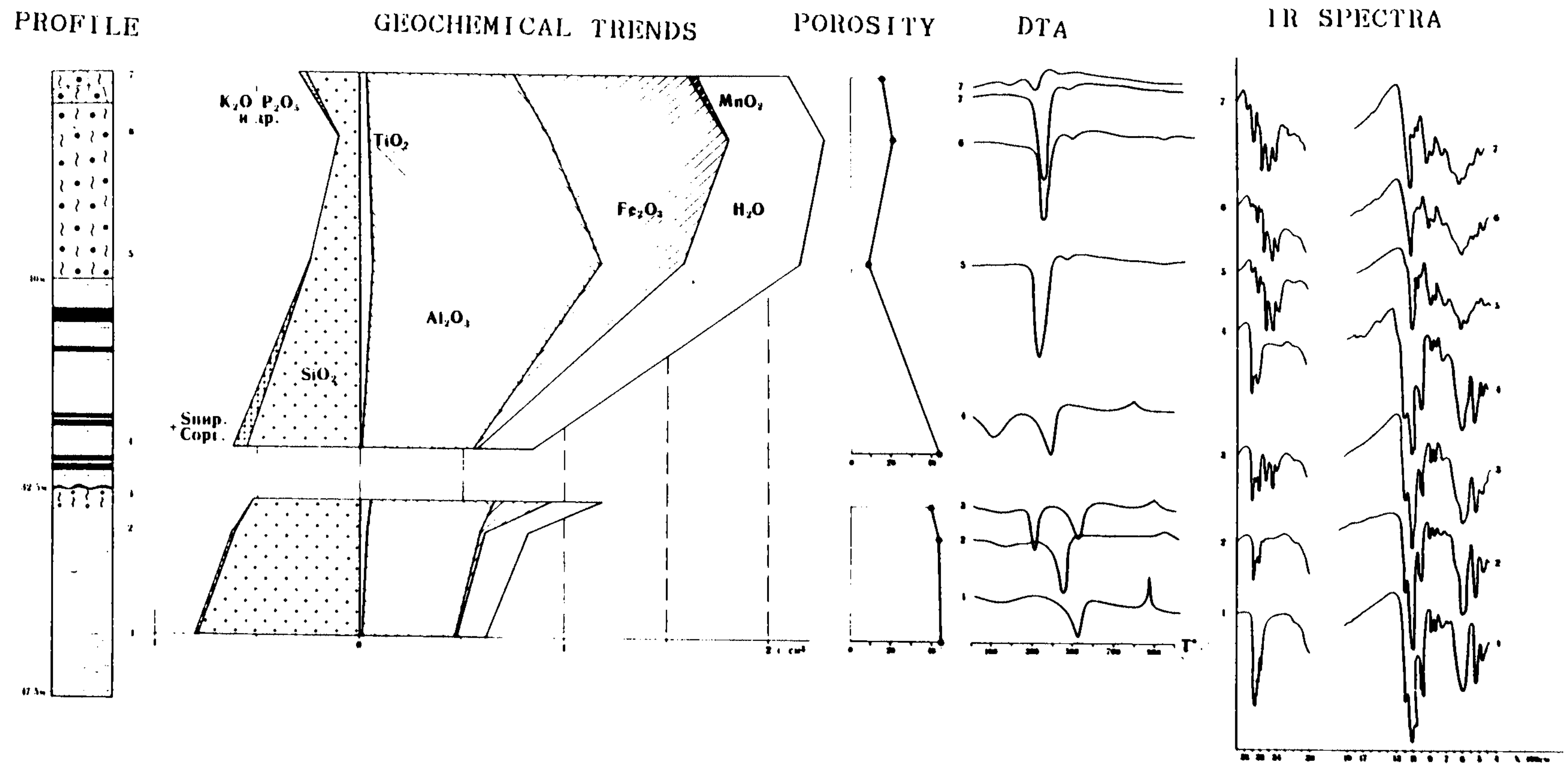
4.1.1. Profiles over Tertiary sediments

Laterite profile over Tertiary sediments is characterised by the occurrence of bauxitic patches towards the upper and lower portions of the profile. Further the underlying bed rocks have been modified to good quality china clays, during the pre-Tertiary weathering episode.

Detailed mineralogical analyses of the entire profile over Tertiary sequence and the underlying kaolinised bed rock (at Palayangadi) have been attempted and the results together with geochemical characteristics are summarised below:

The primary clay at the base of the Tertiaries as exemplified by DTA (Fig.25) and XRD (Fig.26) data, consists of kaolinite with DTA endothermic and exothermic peaks at 530° C and 790° C and with its characteristics XRD peaks at 7.09 A and 3.56 A respectively . IR spectroscopy also substantiates the finding. Manifestation of an endothermic depression just before the exothermic peak in DTA curve is attributed to the well crystalline nature of the kaolinite (Grim, 1968) which is also substantiated by SEM (Fig.27).

Fig. 25 Cumulative geochemical characteristics of the laterite profile over Tertiary sediments, Palayangadi, together with porosity, DTA and IR data. Numbers from 1 to 7 indicates the sample numbers, locations of which are shown in the profile spectra.



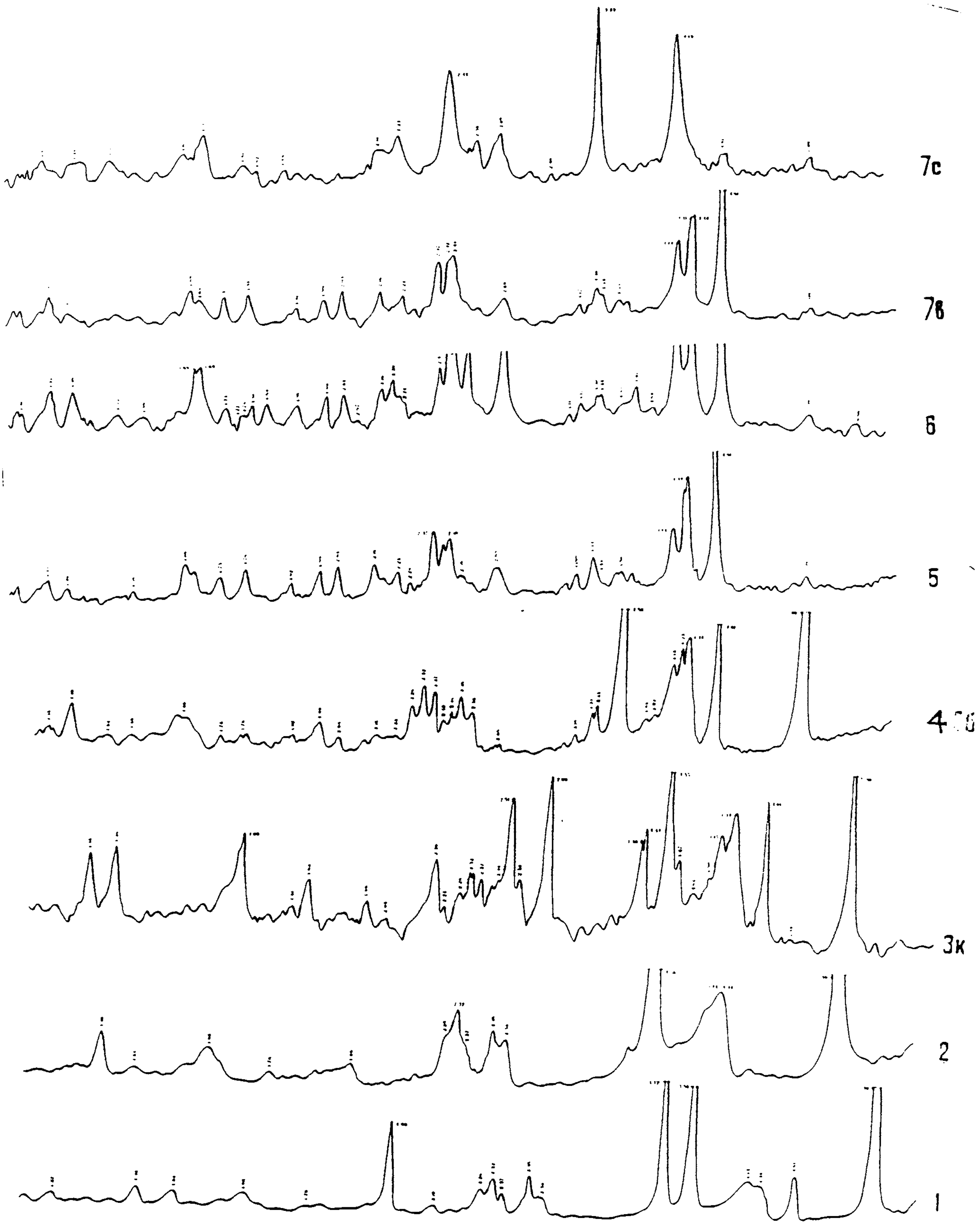


Fig.26 X-ray diffractogram of laterite profile over Tertiary sediments at Palayangadi : primary clay (1), secondary clay(2), laterite(3), ball clay(4), laterite (bauxitic patch; (5), laterite (6), aluminous laterite/bauxite(7B&C).

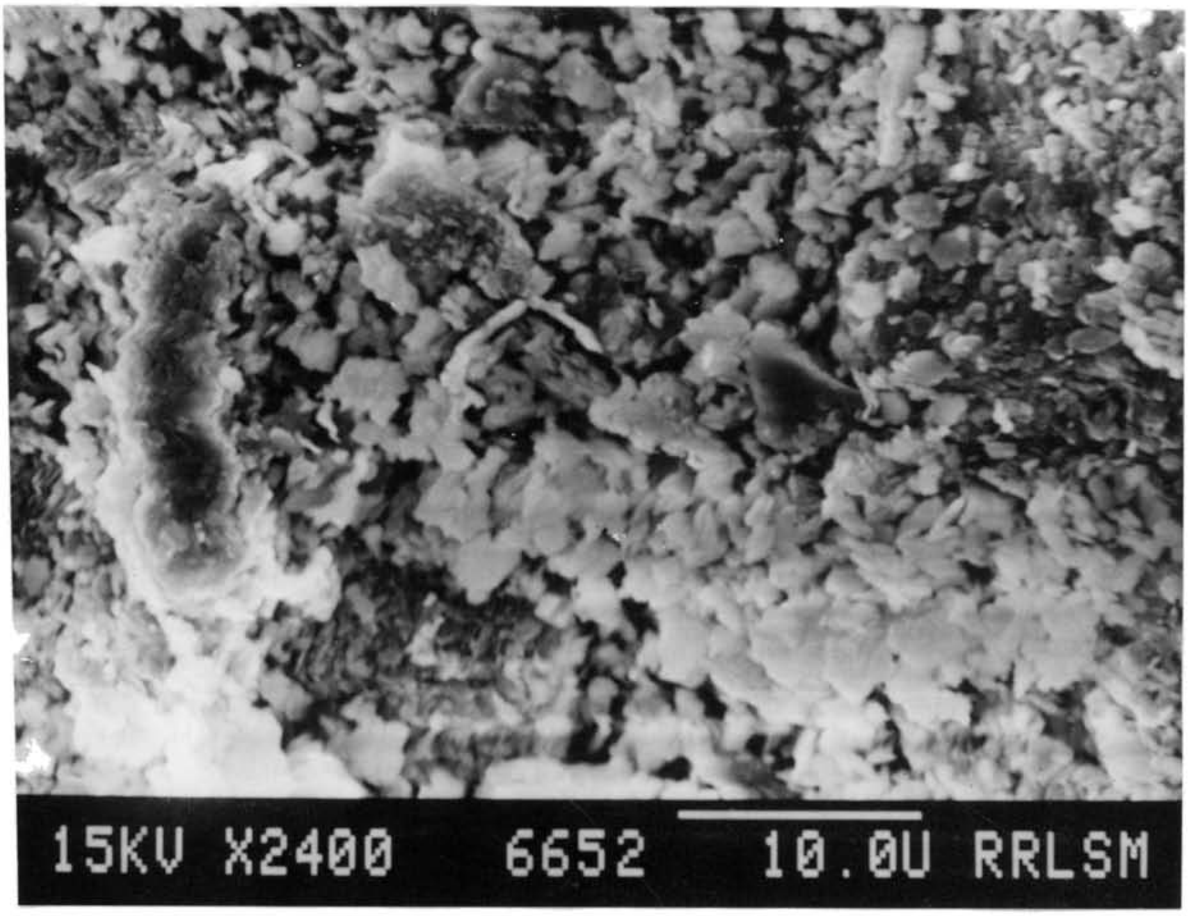


Fig.27 SEM photomicrograph of primary clay showing well crystalline kaolinite.
Scale shown on photograph.

The overlying sedimentary kaolin also consists of kaolinite as indicated by XRD, DTA and IR (Figs.25(2),26(2). Relatively poorer crystalline nature of this kaolinite is exemplified by the XRD and DTA peaks and SEM (Fig.28).

Further up in the profile a part of the china clay with red-stains and vermiform texture shows evidences of leaching. XRD (Fig.26(3)) and IR (Fig. 25(3)) data indicate the presence of kaolinite with traces of gibbsite and quartz. This is also substantiated by DTA data (Fig. 25(3), 26(3)). Poorly ordered nature of the clay is indicated by the peak characteristics. Geochemical data on the clays from this patch further support the presence of gibbsite, with Al_2O_3 values touching 40.74 wt% (Table-4)

Ball clay from the Tertiary sequence consists of disordered kaolinite (Fig.25 sample-4) which is also supported by SEM data (Fig.29).

The overlying laterite horizon mostly consist of gibbsite and contains two patches of bauxite (Fig.25 sample areas 5 and 7). Gibbsite is the major mineral with XRD (Fig.26) peak at 4.81 A and the characteristic IR (Fig.25) doublet peaks at 3395-3380 cm^{-1} suggesting its well crystalline nature (Fig.25, sample 5 and 7). DTA curve with endothermic peak at around 300 C substantiate the presence of gibbsite (Fig.25 samples 5 and 7). This is also consistent with the geochemical data (Table-4). However, the sample 6 in the same horizon, indicates a total less alumina content, though the mineralogy remain the same. The other prominent mineral is goethite. In the uppermost portion (Fig.26, sample-7) goethite, quartz, traces of gibbsite and hematite are the major minerals. Zircon and sillimanite are the accessory minerals.

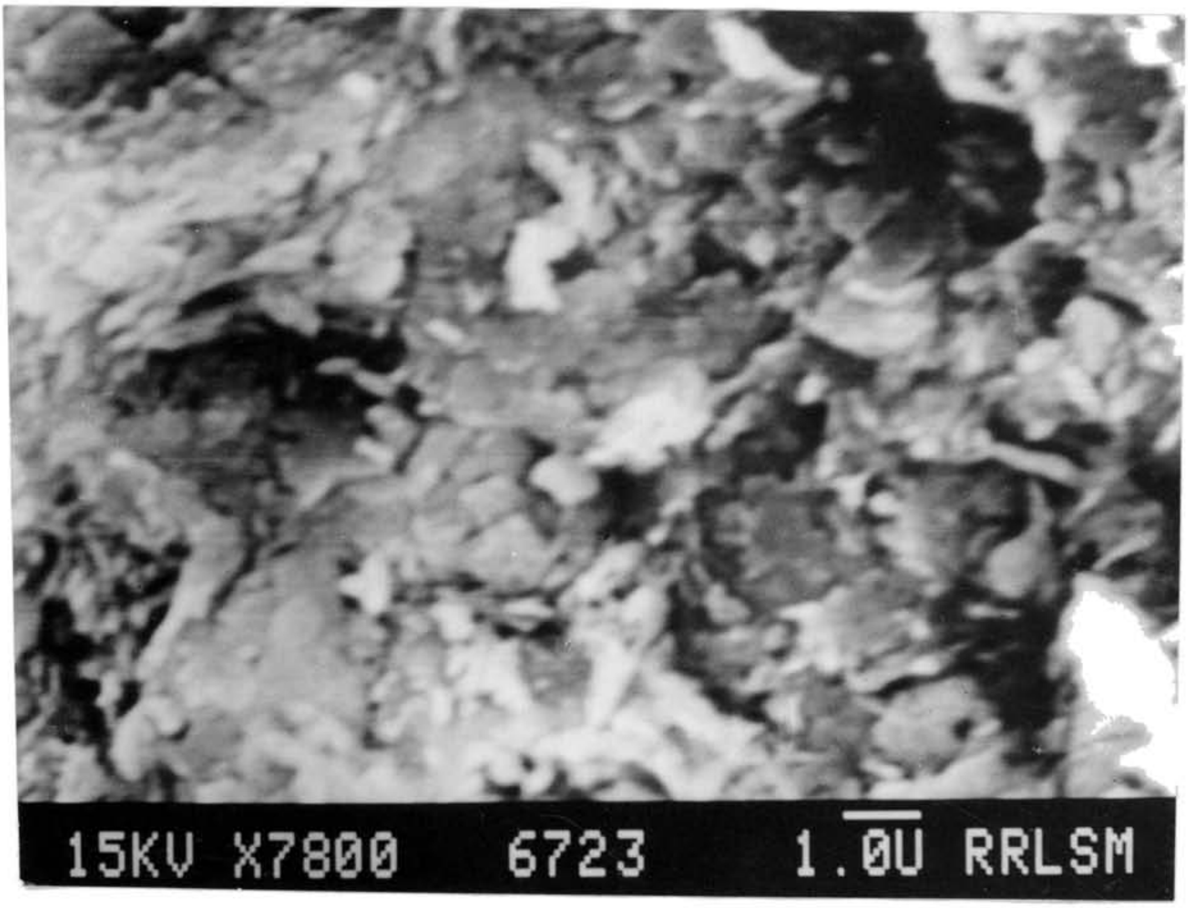


Fig.28 SEM photomicrograph of secondary clay showing poor crystalline Kaolinite. Scale shown on photograph.

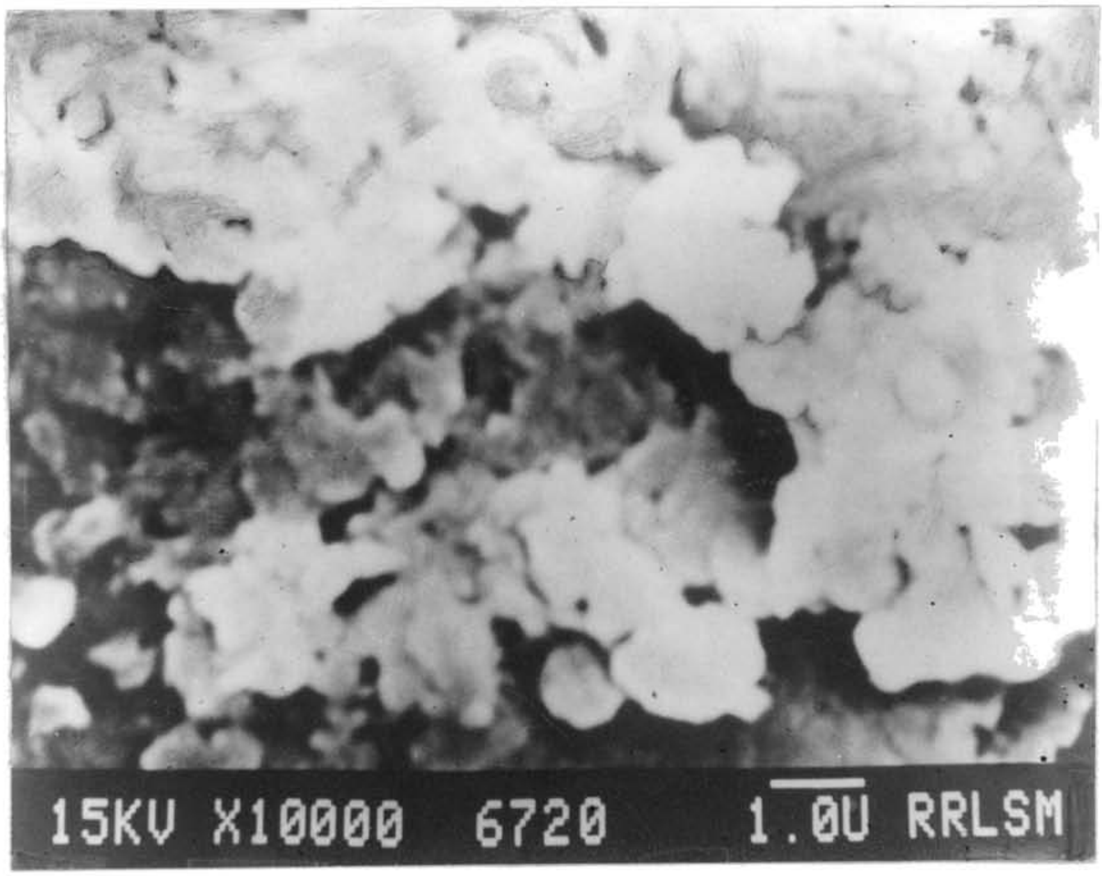


Fig.29 SEM photomicrograph of ball clay showing the disordered nature kaolinite. Scale shown on photograph.

Table 4 Chemical composition (wt %) of kaolins and associated laterites, Palayangadi, north Kerala.

	IK-1	IK-2	IK-3		IK-4	IK-5		IK-6	IK-7	
			red	white		brown	Yellow		black	brown
SiO_2	56.41	41.92	27.94	33.02	36.95	4.63	15.53	4.16	16.07	5.22
TiO_2	0.41	1.74	2.71	3.23	0.74	1.75	3.55	1.6	0.83	1.9
Al_2O_3	32.2	37.84	29.54	40.74	35.9	46.28	46.28	36.94	17.24	45.01
Fe_2O_3	0.57	1.71	27.16	5.67	1.22	20.61	12.17	37.66	46.54	22.96
Fe(Pyritic)	nil	0.18	nil	nil	2.37	nil	nil	nil	nil	nil
MnO	Trace	0.01	0.02	0.02	0.01	0.01	0.02	0.02	2.3	0.1
MgO	0.09	0.14	0.03	0.06	0.24	0.01	0.06	0.02	0.16	0.03
CaO	0.04	0.02	0.03	0.04	0.17	0.02	0.04	0.03	0.05	0.03
Na_2O	0.05	0.04	0.05	0.05	0.04	0.03	0.05	0.05	0.08	0.06
K_2O	0.38	0.23	0.07	0.2	0.09	0.1	0.23	0.02	0.36	0.01
H_2O-	0.47	2.01	1.45	0.92	4.8	1.1	0.5	1.16	3.27	1.06
H_2O+	9.85	12.55	11.42	15.53	12.64	24.62	20.54	18.28	10.44	23.08
CO_2	0.01	0.23	0	0.02	0.01	0.12	nil	nil	0.01	0.01
P_2O_5	0.1	0	Trace	Trace	nil	0.31	nil	nil	1.24	0.65
S(Pyretic)	nil	0.21	nil	nil	2.71	nil	nil	nil	nil	nil
SO_3	nil	0.75	nil	nil	0.77	nil	nil	nil	nil	nil
C(org)	0.13	0.46	nil	nil	0.81	nil	nil	nil	nil	nil

IK-1 = white kaolin, IK-2 = Gray kaolin, IK-3 = Lateritised, IK-4 = Gray kaolin, IK-5 = Bauxite, Black with mangeneferous cement, IK-6 = Laterite, IK-7 = Laterite.

4.2 GEOCHEMISTRY OF LATERITE PROFILES

Laterite and bauxite are the residual products derived from a wide variety of parent rocks by intense chemical weathering under strongly oxidising and leaching conditions. Minerals in the rocks when exposed to atmosphere, becomes vulnerable to reaction by water, oxygen and carbon dioxide. Water penetrates through pores, cleavages and other micro openings in the minerals and dissolves the more soluble constituents. The residue becomes progressively enriched in the less soluble constituents as well as in oxygen and hydroxyl groups as the process intensifies. During weathering process, various groups of anions and cations are deposited in a similar environment depending on their like properties (also see Fig. ; Cartledge, 1928; Goldsmidt, 1937, 1938). The behaviour of elements during weathering has been discussed by several workers (Goldsmidt, 1937; Krauskoff, 1967 etc). The chemical changes that take place at different stages in the decomposition of the parent rock during weathering can be traced by comparing the chemical composition of the weathered product with that of the fresh rock. The relative enrichment of an element during this process is accomplished either by the formation of a stable secondary product or by loss of less stable elements. Thus during the process of lateritisation a progressive change in the ratio of silica and sesquioxide is significant. Hence, the ratio of SiO_2 , Fe_2O_3 and Al_2O_3 is taken as base to define the laterite (Schellmann, 1981).

In this chapter geochemical trends of weathering profiles developed over different parent rock types from Cannanore district are discussed with the prime object of discerning the geochemical course and consequence of weathering process in various lithologies. Due to reasons of clustering in some of the geochemical diagrams,certain trace elements have not been plotted, though they have been included in the Tables. In total 123 samples were analysed representing 30 profiles. Details of analytical procedure are given in appendix-II.

4.2.1. Profiles over charnockite

The laterite profiles developed over charnockite show gradational contacts between the different units (Fig.16 A, profile 1 to 4). Major and trace elemental compositions are presented in Tables 5 and 6 respectively. Plots in the ternary diagram (SiO_2 - Fe_2O_3 - Al_2O_3) characterise the rock as moderate to strongly lateritised (Fig.30). Al_2O_3 values in the laterite zone range from 27.03 to 33.14 wt% and Fe_2O_3 from 21.77 to 31.42 wt%. Variation diagrams of the major and trace elements are shown in (Figs.31 A to 31 D). They show a general depletion of SiO_2 , FeO, MgO, K_2O, Na_2O and CaO and complimentary enrichment of Al_2O_3 , Fe_2O_3 and TiO_2 . Slight increase of K_2O values towards the upper portion of the profile may be attributed to incongruent dissolution of feldspars during weathering. Depletion of SiO_2 , FeO, MgO, and Na_2O is gradual towards the upper portion of the profiles. The trace elements show a general rapid enrichment of V, Ga, Ni and CO in the lower parts of the profile, followed by gradual increase in the upper portions. Zn, Ba and CO show general depletion trend. The concentration patterns of Cr and Ni may be controlled by the abundance of kaolinite in the profile units, as kaolinite can accommodate considerable amounts of Cr, and Ni through adsorption (Mc Laughlin, 1959) . Ba follows the trend of K, which is consistent with the geochemical affinity of the two elements (Goldsmidt, 1954).

Geochemical budget calculations reveal that nearly 65% of SiO_2 , 84% of Na_2O, 90% of K_2O ,78% of FeO and 89% of MgO are lost in the conversion of

Table 5: Major element composition of laterite profiles. R: Bed rock; PW: Partly weathered; CW: Completely weathered; V, V1 & V2: Vermiform laterite; C, C1 & C2: Duri crust CC: China Clay, `` **S1,S2:Sedimentary clay**'' ,SST: Sandstone. BC: Ball clay

Description of Profiles:- 1-4:Charnockite: 5-6:Gneiss; 7:Fuchsite quartzite 8 to 10: Ultramafites: 11-12: Schist; 13-16: Anorthosites: 17-20: Gabbro: 21-26: Granophyre; 27-28: Alkali syenite; 29-30: Sedimentary formations
nd: Not determined, LOI: Loss on ignition, MOI: Moisture

Profile Number	Sample Descpn.	SiO2	Fe2O3	Al2O3	FeO	CaO	MgO	Na2O	K2O	TiO2	P2O5	LOI	MOI
1	R	45.88	14.43	14.78	-nd-	9.87	5.32	3.60	0.70	2.14	0.30	0.45	0.42
	PW	41.56	9.98	23.98	1.33	2.24	1.45	1.42	0.96	0.90	0.32	10.21	4.86
	CW	35.67	12.91	28.05	0.25	1.57	1.13	0.08	0.07	0.64	0.36	12.84	6.34
	V	31.82	21.77	27.03	0.29	0.90	0.65	0.88	0.12	0.84	0.42	12.33	2.86
2	R	53.08	9.56	16.31	-nd-	5.16	0.97	6.19	3.84	2.14	0.88	0.08	
	PW	45.16	8.19	18.88	0.81	2.69	0.48	9.82	2.34	0.98	1.43	3.80	4.97
	V	27.06	18.49	29.07	0.43	0.90	0.16	1.16	0.24	1.72	0.48	12.59	7.16
	C	15.95	30.05	30.09	0.25	0.90	0.16	-nd-	0.12	1.90	0.84	15.54	2.59
3	R	60.07	13.08	11.88	-nd-	5.50	3.70	2.30	0.91	0.61	-nd-		0.24
	PW	48.91	5.50	28.12	1.55	4.14	0.73	0.40	0.73	0.92	0.17	5.52	2.67
	CW	25.49	5.28	43.31	0.43	0.34	0.16	0.23	0.03	0.29	0.08	23.03	0.55
	V	14.06	27.21	32.53	0.36	0.45	0.24	0.53	0.07	0.81	0.54	18.38	4.55
4	R	65.48	7.16	13.42	-nd-	3.82	2.90	4.10	1.30	0.52	-nd-		
	PW	50.84	2.47	22.42	1.80	2.58	1.05	2.76	0.34	0.51	0.07	8.08	6.72
	CW	29.71	10.78	34.16	0.50	0.78	0.32	0.29	0.07	1.05	0.12	16.09	5.48
	V	12.34	31.42	33.14	0.25	0.34	0.24	0.30	0.14	1.58	0.32	18.16	1.56
5	R	75.30	2.09	14.96	1.21	0.26	0.01	5.18	0.12	0.32	-nd-	0.42	
	PW	57.34	4.05	19.88	0.68	2.47	1.64	3.37	2.94	0.29	-nd-	4.89	2.19
	V	36.60	10.56	31.10	0.11	0.90	0.48	0.78	0.32	0.68	-nd-	14.48	4.05
6	R	67.23	7.24	15.04	3.74	0.41	0.02	3.77	0.07	1.25	-nd-	1.07	
	PW	43.82	8.07	22.99	1.65	3.36	1.44	0.90	0.46	1.23	0.38	9.94	0.38
	V	38.83	11.78	27.03	1.08	1.34	0.64	0.33	0.26	1.33	0.27	12.60	0.27
7	R	66.94	0.72	16.82	0.29	1.12	0.32	0.35	1.35	0.24	-nd-	0.73	0.06
	PW	61.18	18.20	10.71	0.14	0.40	0.30	0.39	0.35	0.84	-nd-	5.01	2.03
	V	22.64	46.23	16.78	0.13	0.35	0.26	0.28	0.26	1.22	-nd-	10.36	0.61
8	R	53.60	7.99	5.73	1.60	2.06	25.03	1.40	0.30	0.06	-nd-	1.87	0.36
	PW	32.50	8.38	18.35	1.51	2.02	20.60	1.10	0.22	0.10	-nd-	12.60	0.50
	V	30.05	28.11	22.36	0.29	0.45	0.32	0.94	0.15	0.53	-nd-	10.68	4.77
9	R	49.01	11.67	6.12	5.17	11.20	11.52	1.97	0.14	0.83	0.05	0.98	0.32
	PW	37.58	25.76	10.20	3.84	7.62	4.32	1.54	0.10	1.37	0.25	4.50	1.75
	V	13.39	54.26	12.24	0.04	0.90	0.48	1.31	0.04	0.91	0.92	11.41	3.58
10	R	53.58	12.19	1.53	1.37	1.34	26.08	0.79	0.05	0.06	0.15	1.96	0.33
	PW	37.60	12.45	19.37	3.20	1.79	24.00	1.04	0.19	0.15	-nd-	8.88	0.22
	CW	36.20	16.82	15.20	1.08	1.34	14.08	0.91	0.01	0.06	-nd-	2.61	0.18
	V	31.00	22.42	29.24	0.18	0.90	0.96	0.51	0.08	0.34	-nd-	11.10	3.12
11	R	54.28	7.29	17.35	3.13	1.12	3.74	1.11	0.23	0.65	0.22	9.57	0.22
	PW	49.36	13.75	7.14	3.47	2.02	16.28	0.98	0.01	0.73	0.33	5.26	0.18
	V	34.43	19.18	26.04	0.25	1.12	0.48	0.95	0.36	0.81	0.30	12.81	2.88
12	R	67.25	5.45	14.51	2.30	0.13	0.44	4.21	0.05	0.07	-nd-	4.78	
	PW	53.12	4.93	17.84	4.60	2.02	5.00	1.06	0.28	0.59	0.24	9.08	0.24
	V	41.45	21.43	21.35	0.22	0.90	0.16	0.46	0.13	1.91	0.24	10.72	0.24
13	R	54.72	1.08	21.23	1.77	12.30	0.50	4.80	0.14	0.56	-nd-	-nd-	-nd-
	PW	35.08	2.47	32.63	0.36	2.69	0.64	1.30	0.77	0.36	0.06	11.56	10.84
	V	27.75	7.59	39.26	0.29	0.45	0.16	0.19	0.10	1.18	0.15	18.04	4.42
	C1	9.38	23.53	39.76	0.40	0.34	0.08	0.46	0.18	1.71	0.49	21.77	1.82
	C2	13.73	21.47	39.26	0.36	0.45	0.16	0.27	0.15	1.62	0.36	20.62	1.70
14	R	55.16	0.75	21.22	1.63	12.11	0.83	5.30	0.18	0.33	-nd-	-nd-	-nd-

	PW	31.02	12.06	31.10	0.57	1.12	0.26	3.18	1.97	0.65	0.33	14.66	2.96
	V1	25.19	21.16	30.06	0.43	1.12	0.20	1.84	0.25	0.88	0.44	12.18	6.02
	C	27.13	17.07	35.01	0.22	0.67	0.16	1.85	0.37	0.76	0.31	12.72	3.40
15	R	55.88	0.83	21.56	1.39	11.93	0.42	5.40	0.24	0.36	-nd-	1.00	1.00
	PW	30.05	23.51	16.85	4.63	2.69	1.77	1.21	0.28	2.66	1.34	7.68	6.90
	V	26.11	28.77	23.98	0.29	0.90	0.48	1.07	0.28	1.45	1.17	10.78	4.66
	C	14.04	28.39	33.18	0.07	0.90	0.40	0.78	0.11	2.03	0.18	16.88	3.07
16	R	54.68	0.97	21.84	1.71	11.40	0.82	5.30	0.25	0.42	-nd-	1.00	1.00
	PW	36.41	8.87	30.68	2.10	1.98	0.78	1.15	0.41	0.81	0.20	10.78	5.70
	V	25.57	21.03	36.71	0.32	0.45	0.31	0.63	0.21	1.31	0.44	13.88	3.10
17	R	46.76	6.37	16.28	5.03	13.46	5.97	2.79	0.07	1.34	0.15	0.73	0.36
	PW	33.39	8.01	23.54	3.56	6.51	3.06	1.35	0.05	0.97	0.27	9.66	8.87
	CW	18.07	14.24	32.65	1.80	2.24	2.26	1.07	0.05	1.12	0.36	17.61	8.33
	V	33.18	15.19	27.05	0.68	1.35	1.13	0.81	0.12	0.96	0.37	12.37	6.60
	V1	33.28	13.57	28.59	0.29	1.12	0.65	0.88	0.26	1.14	0.21	13.14	6.32
	V2	26.15	21.51	28.08	0.40	1.12	0.48	1.04	0.36	1.55	0.48	13.84	4.65
	C1	18.27	37.37	25.04	0.14	0.90	0.48	1.16	0.03	1.48	1.06	12.33	1.42
	C2	7.26	41.16	27.05	0.40	0.90	0.65	1.33	0.03	1.71	1.28	15.59	2.60
18	R	46.85	6.70	16.80	5.53	11.44	7.25	2.64	0.10	1.50	0.26	0.17	0.15
	PW	24.59	17.88	25.00	1.98	2.24	2.58	1.14	0.45	1.26	0.25	13.64	8.43
	CW	23.49	18.65	32.51	1.01	1.12	0.81	0.67	0.47	1.61	0.42	13.47	5.65
	V1	23.23	25.26	28.58	0.47	0.90	0.64	1.24	0.39	1.94	0.40	14.46	3.02
	V2	21.04	23.91	36.69	0.32	0.90	0.48	1.11	0.27	1.89	0.36	10.03	2.21
19	R	48.92	7.94	4.06	0.15	13.46	3.55	2.68	0.06	1.26	0.16	0.23	0.17
	PW	45.66	8.11	17.83	3.05	12.56	3.71	2.50	0.18	1.07	0.26	2.77	1.53
	CW	30.68	14.70	25.00	1.44	2.47	2.10	1.90	0.12	1.35	0.31	12.17	6.98
	V	27.82	16.57	29.69	0.43	1.12	0.64	1.21	0.19	1.50	0.26	13.06	6.97
20	R	50.49	8.33	12.24	8.01	6.95	3.39	3.87	0.84	2.36	1.26	1.17	0.75
	PW	33.75	22.03	20.93	2.36	2.57	1.29	2.10	0.23	0.95	0.33	9.71	3.32
	CW	43.51	11.83	20.40	1.98	2.24	0.97	1.74	0.95	1.66	0.64	8.36	4.77
	V	22.07	23.25	29.93	1.98	1.57	0.48	1.55	0.23	2.35	0.40	11.00	4.37
21	R	70.55	4.08	11.24	2.19	2.10	0.41	4.79	2.70	0.62	0.32	0.38	0.22
	PW	59.41	5.51	19.37	0.79	0.78	1.03	3.14	0.78	0.78	0.07	5.93	2.94
	V	25.33	32.20	19.88	2.12	0.56	0.32	0.50	1.12	2.69	0.84	11.15	4.04
22	R	71.11	3.91	11.97	2.07	1.89	0.38	4.28	3.01	0.71	0.18	0.48	0.21
	PW	64.17	4.11	17.33	0.34	1.01	0.32	1.46	3.17	0.99	0.66	4.44	2.47
	V	29.71	23.15	27.05	0.22	0.67	0.30	0.85	0.42	1.87	0.44	11.01	4.17
23	R	72.26	3.92	11.24	2.35	1.44	1.65	3.10	3.12	0.15	0.26	0.10	0.18
	PW	58.70	4.87	20.39	0.58	1.68	0.72	2.03	3.37	1.04	0.14	4.13	1.93
	V	15.19	42.58	21.41	0.14	0.56	0.16	0.65	0.16	2.00	0.73	12.68	2.95
24	R	68.08	3.72	14.52	1.60	2.10	1.60	4.30	2.45	1.06	0.28	0.08	0.12
	PW	60.03	6.64	17.84	1.51	0.71	0.40	3.24	2.42	1.32	0.16	3.23	1.94
	V	34.04	19.58	28.55	0.22	0.56	0.24	0.16	0.27	1.41	0.23	11.50	2.96
25	R	71.47	3.50	12.22	2.30	0.45	0.52	4.59	2.12	0.77	0.29	0.11	0.22
	PW	60.83	5.66	16.41	0.32	0.90	0.48	1.34	1.81	0.94	0.13	8.99	2.70
	CW	48.04	8.35	3.08	0.36	0.67	0.32	0.20	0.12	1.12	0.19	14.76	1.50
	V	34.44	23.63	2.45	0.22	0.12	0.32	0.87	0.37	1.11	0.48	11.62	4.30
26	R	65.57	4.01	13.34	3.12	4.12	1.64	3.54	1.74	0.91	0.34	0.48	0.36
	PW	55.90	5.65	20.86	2.01	2.40	0.39	1.32	2.41	1.32	0.58	4.31	2.42
	V	27.19	27.56	30.12	0.22	0.67	0.32	1.11	0.26	1.69	0.40	13.50	3.64
27	R	59.21	2.45	13.97	1.26	3.39	1.13	3.28	13.89	0.30	-nd-	0.71	1.00
	PW	57.33	0.46	23.46	0.02	2.02	0.48	4.83	6.56	0.16	0.08	2.71	1.43
	CW	45.05	2.27	28.04	0.25	1.12	0.48	1.69	6.60	0.19	0.04	7.11	3.49
	V1	44.14	6.44	28.04	0.02	0.90	0.48	1.12	3.47	0.41	0.08	9.55	4.94
	V2	33.16	31.28	17.85	0.11	1.12	0.80	1.04	3.20	0.38	0.50	8.03	1.86
28	R	61.42	1.77	13.46	1.14	2.82	0.40	5.14	12.68	0.14	-nd-	0.42	1.00
	PW	60.64	0.40	22.39	0.14	1.57	0.48	3.01	9.69	0.14	0.04	0.45	0.10
	V	35.83	16.66	26.52	0.07	0.90	0.32	0.90	2.78	0.91	0.19	10.95	3.65

29	CC	46.91	1.08	35.69	0.11	0.45	0.16	0.16	0.25	0.48	0.01	13.38	1.28
	S_1	50.29	6.67	27.61	0.47	0.45	0.24	0.04	0.14	1.60	0.11	11.05	1.39
	S_2	39.56	7.63	32.63	0.40	0.45	0.32	0.08	0.15	2.49	0.08	13.31	2.90
	V	26.91	12.68	37.73	0.22	0.40	0.16	0.14	0.11	3.51	0.22	16.39	1.07
	BC	39.24	2.64	32.12	1.15	0.57	0.16	0.10	0.07	1.25	0.07	16.25	5.98
	C1	7.76	19.23	44.35	0.14	0.34	0.24	0.19	0.08	2.91	0.31	23.01	1.08
	C2	4.46	33.89	34.67	0.40	0.34	0.16	0.27	0.05	2.80	0.48	19.80	1.86
30	R	56.29	5.49	18.35	1.51	5.61	1.93	4.46	0.62	0.58	0.22	2.67	1.04
	PW	56.25	6.41	20.90	0.76	1.57	1.13	1.41	0.39	0.74	0.24	8.50	1.36
	V1	42.89	13.89	26.03	0.10	0.90	0.32	0.75	0.10	0.86	0.22	12.28	1.73
	SST	44.34	9.40	26.53	0.14	0.67	0.32	0.77	0.03	0.95	0.12	15.88	0.44
	V2	30.64	24.66	26.51	0.14	0.62	0.32	0.64	0.09	0.95	0.44	12.57	0.31

Table 6 : Given after page 66

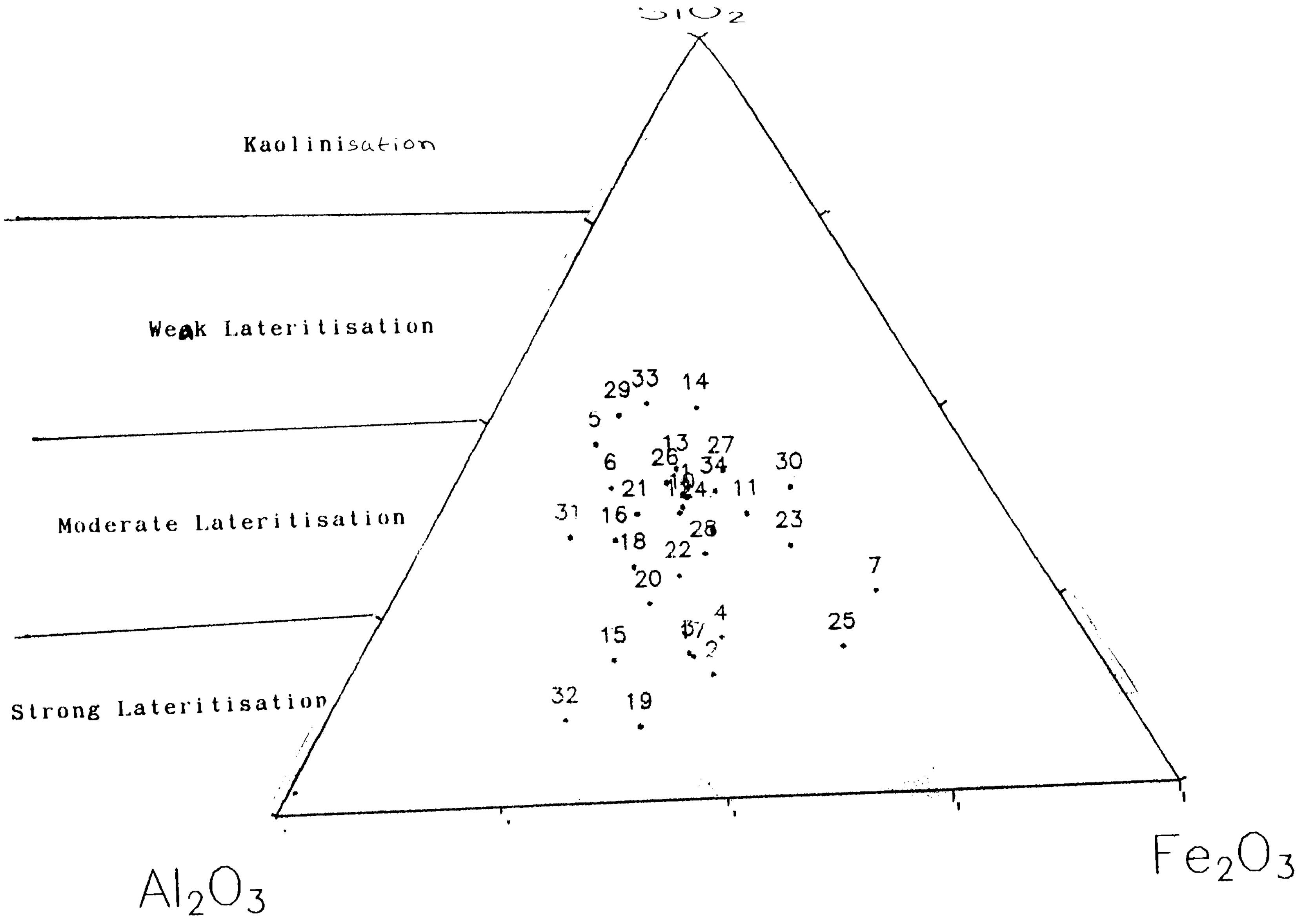
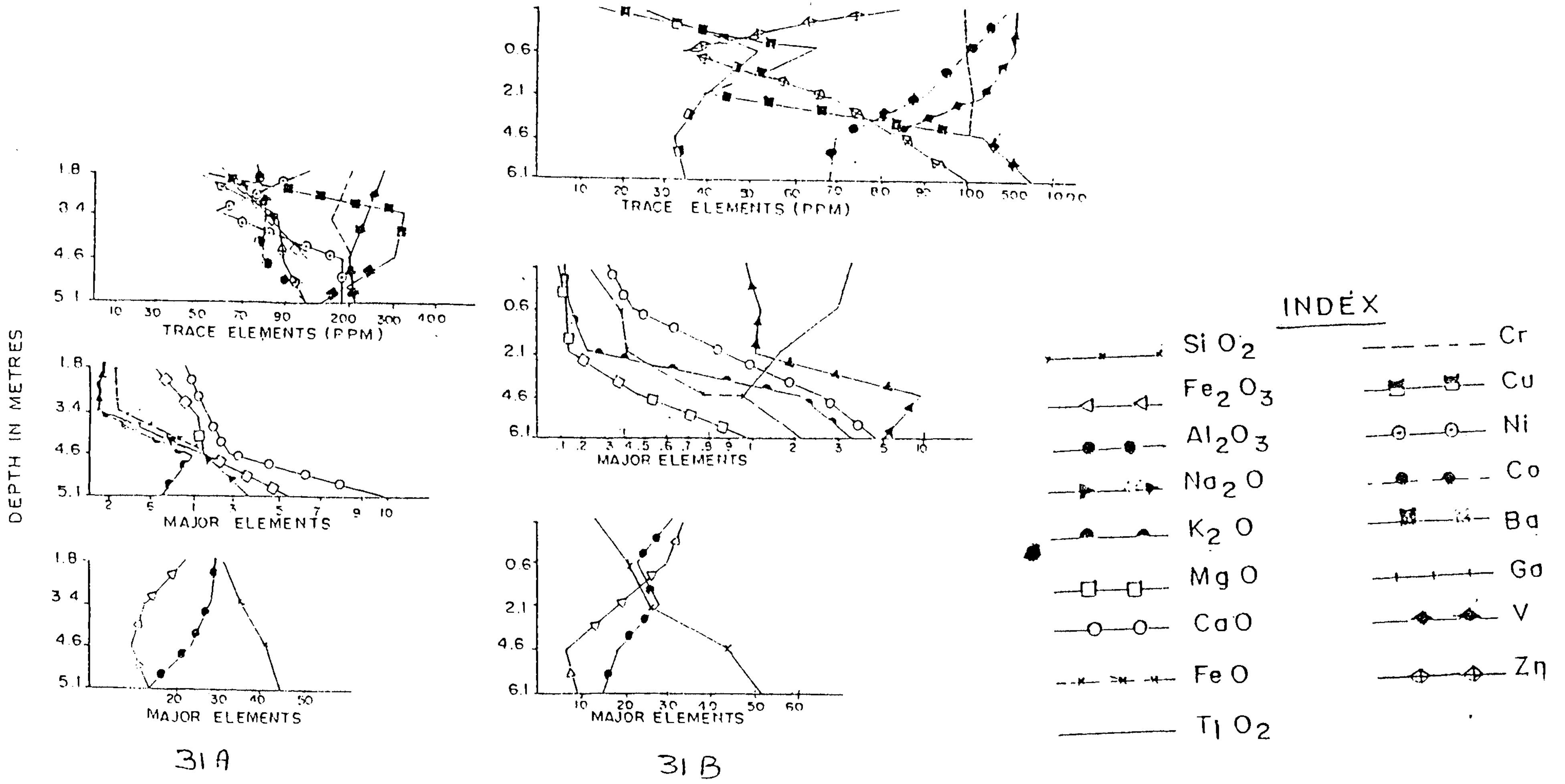


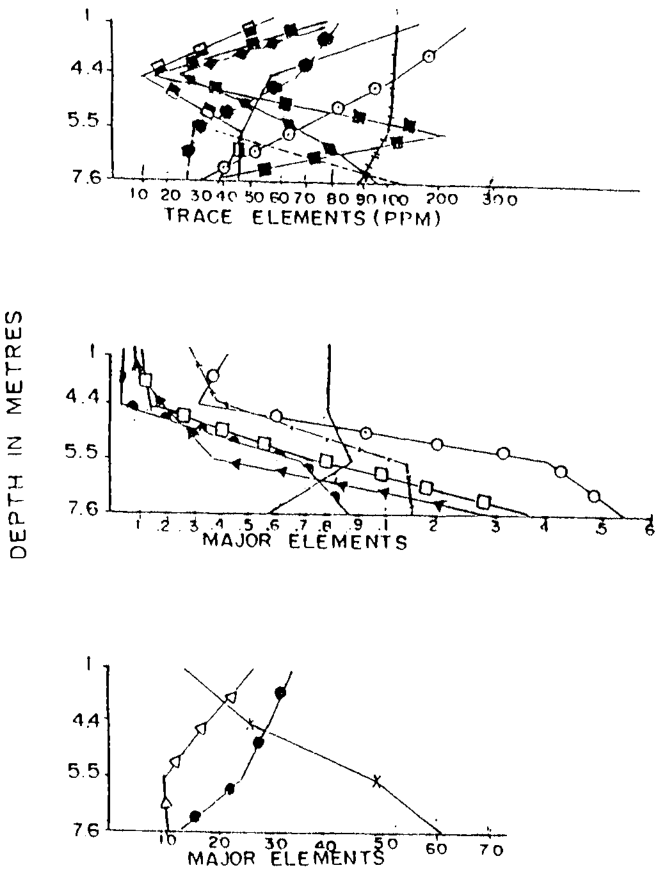
Fig.30 SiO_2-Al_2O_3-Fe_2O_3 ternary diagram showing maturity of laterites developed over different lithounits (after Schellemann, 1981).



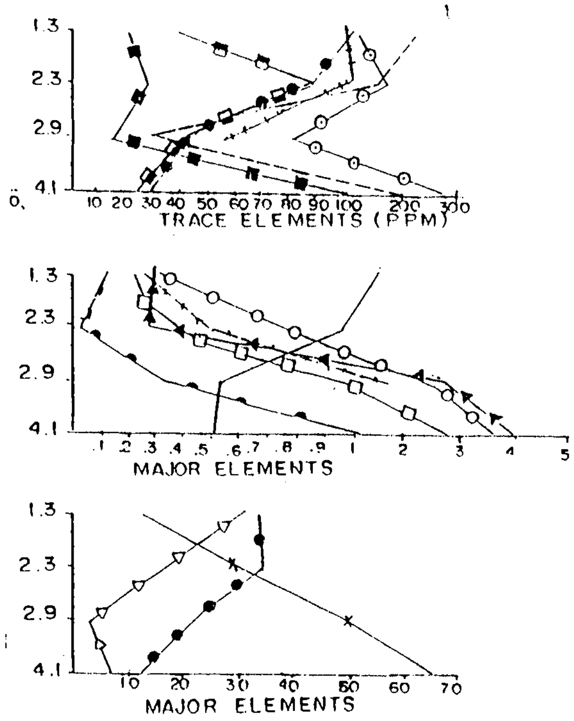
31 A

31 B

Fig.31 Major and trace element variation diagrams of laterite profiles over charnockite(31A to 31D).


DEPTH IN METRES
1
4.4
5.5
7.6
10 20 30 40 50 60 70 80 90 100 200 300
TRACE ELEMENTS (PPM)
.1 .2 .3 .4 .5 .6 .7 .8 .9 1 2 3 4 5 6
MAJOR ELEMENTS
10 20 30 40 50 60 70
MAJOR ELEMENTS

31 C


1.3
2.3
2.9
4.1
10 20 30 40 50 60 70 80 90 100 200 300
TRACE ELEMENTS (PPM)
.1 .2 .3 .4 .5 .6 .7 .8 .9 1 2 3 4 5
MAJOR ELEMENTS
10 20 30 40 50 60 70
MAJOR ELEMENTS

31 D

parent rock to laterite, whereas the concentration ratio of Al_2O_3 and Fe_2O_3 in the weathering crust is 2.2 and 2.48 respectively. The solubility series for charnockite is found to be Mg> K> Ca> Na> Fe> Si for most of the profiles.

4.2.2. Profiles over hornblende-biotite gneiss

The studied profiles have 9.6 to 9.1 m thickness. The profiles show gradual contacts and the sketches are shown in Fig.16 A, profile 5 and 6). Ternary diagram of SiO_2 - Fe_2O_3 - Al_2O_3 was used to characterise the maturity of the laterites. This indicates that the rock is weakly lateritised (Fig.30). The variation diagrams of major and trace elements (Fig.32 A & B) show depletion of SiO_2 , FeO, MgO, CaO, Na_2O and K_2O during lateritisation process with complimentary enrichment of Al_2O_3 , Fe_2O_3 and TiO_2 . Trace elements V, Ga, Cr and Ni show enrichment, whereas Ba, Zn and Cu show depletion. As in other profiles, the lower part is marked by sudden depletion of SiO_2 ,Na_2O, CaO, MgO and FeO. Gradual depletion trends are discernible in the upper portion of the profiles. Chemical budget of the fresh rock to laterite conversion shows.92.63.% SiO_2 , 84.94.% Na_2O, 81.1% FeO are lost. The concentration ratio of Al_2O_3 and Fe_2O_3 is 1.94 and 3.34 respectively.

4.2.3. Fuchsite quartzite

Fuchsite quartzite forms an important unit of the high grade supracrustals of Manantoddy schist belt in Cannanore district and is noticed around Sreekandapuram. At Thumbeni, where the entire hill is composed of this rock type showing *in situ* laterite development, it is found in association

Table 6: Trace element composition (ppm) of laterite profiles. R: Bed rock; PW: Partly weathered; CW: Completely weathered;v V1 & V2: Vermiform laterite; C, C1 & C2: Duri crust CC: China Clay, **S1,S2:Sedimentary clay,** SST: Sandstone. Bc: Ball cla
Description of Profiles:- 1-4:Charnockite; 5-6:Gneiss; 7:Fuchsite quartzite 8 to 10: Ultramafites; 11-12: Schist; 13-16: Anorthosites; 17-20: Gabbro; 21-26: Granophyre; 27-28: Alkali syenite; 29-30: Sedimentary formations

Profile Number	Sample Descp	Cr	Cu	Ni	Co	Ba	Ga	V	Pb	Zn
1	R	nd	nd	nd	112	152	24	220	44	101
	PW	206	112	187	80	312	26	200	20	90
	CW	156	83	187	82	332	48	240	42	93
	V	206	53	198	78	42	56	280	36	46
2	R	60	35	80	68	854	54	70	18	105
	PW	140	32	96	70	522	78	80	24	114
	V	178	40	102	91	44	88	260	16	86
	C	480	25	149	120	14	740	740	14	34
3	R	154	45	90	27	32	30	310	3	98
	PW	38	48	114	30	210	68	nd	114	77
	CW	60	14	120	68	12	118	nd	14	26
	V	163	77	254	84	60	116	nd	116	79
4	R	220	24	88	27	107	nd	165	7	162
	PW	127	40	80	42	14	56	180	60	70
	CW	156	89	178	86	28	118	230	74	73
	V	218	38	218	110	20	100	340	134	48
5	R	6	11	57	200	nd	24	60	82	38
	PW	29	28	37	44	160	30	160	102	52
	V	42	89	82	56	82	88	240	106	66
6	R	175	72	151	51	106	122	200	34	18
	PW	230	58	229	88	118	118	320	44	14
	V	327	62	284	80	92	126	340	42	14
7	R	147	13	64	69	3026	50	180	118	12
	PW	420	59	106	120	94	40	320	56	110
	V	457	208	236	206	704	94	400	108	125
8	R	616	13	639	271	nd	56	60	172	90
	PW	73	24	1830	101	122	66	120	68	65
	V	1315	67	740	102	144	94	240	40	47
9	R	2116	56	310	82	8	nd	300	22	132
	PW	3248	92	321	128	16	nd	520	26	131
	V	3632	268	446	179	78	nd	560	42	154
10	R	451	12	520	115	nd	13	11	48	69
	PW	476	18	836	129	22	20	76	112	nd
	CW	1100	16	1458	105	64	48	80	92	102
	V	929	26	440	85	92	58	120	52	97

11	R	586	19	371	65	34	30	120	20	61
	PW	1988	47	2124	124	nd	14	120	20	191
	V	591	101	303	68	38	40	360	36	61
12	R	67	2	130	260	nd	20	60	214	42
	PW	491	14	446	68	40	26	120	24	82
	V	365	22	134	82	14	38	140	40	56
13	R	78	46	42	11	190	nd	47	2	97
	PW	12	19	68	80	226	nd	91	162	104
	V	87	32	142	68	78	nd	104	40	40
	C1	398	43	120	74	56	nd	100	54	49
	C2	145	17	138	88	30	nd	106	1	90
14	R	85	17	35	9	28	nd	60	1	90
	PW	20	25	46	86	240	nd	81	28	66
	V1	130	41	60	93	72	nd	260	34	71
	C	76	39	50	83	66	nd	160	32	63
15	R	160	69	37	11	29	nd	26	5	172
	PW	64	273	77	135	100	nd	300	11	175
	V	293	47	60	114	50	nd	440	18	55
	C	420	78	44	127	20	1	33	32	nd
16	R	116	11	55	15	64	nd	82	12	59
	PW	241	29	131	76	83	nd	280	24	81
	V	394	26	110	127	44	nd	410	31	37
17	R	371	22	207	nd	40	nd	nd	52	69
	PW	233	83	156	111	78	nd	nd	38	79
	CW	269	93	194	124	94	nd	nd	14	68
	V	148	85	66	98	166	nd	nd	32	72
	V1	197	77	203	95	172	nd	nd	16	69
	V2	233	83	129	99	42	nd	nd	28	53
	C1	177	21	73	120	12	nd	nd	20	35
	C2	411	20	183	127	18	nd	nd	26	31
18	R	310	27	230	nd	36	nd	nd	62	78
	PW	199	154	218	nd	208	nd	nd	42	124
	CW	202	91	210	nd	90	nd	nd	44	78
	V1	205	92	158	nd	50	nd	nd	54	60
	V2	239	82	130	nd	44	nd	nd	54	55
19	R	396	30	211	nd	44	nd	nd	58	71
	PW	184	96	166	nd	124	nd	nd	38	107
	CW	210	97	216	nd	58	nd	nd	44	73
	V	310	84	202	nd	48	nd	nd	40	54
20	R	160	22	158	nd	186	nd	nd	74	158
	PW	366	138	255	nd	260	nd	nd	72	nd
	CW	46	57	100	nd	176	nd	nd	34	150
	V	56	44	135	nd	72	nd	nd	60	121
21	R	48	33	45	6	36	nd	nd	17	134
	PW	22	76	36	26	564	nd	nd	60	nd
	V	33	19	120	102	58	nd	nd	48	79

Table · (contd..)

Profile Number	Sampl Descp	Cr	Cu	Ni	Co	Ba	Ga	V	Pb	Zn
22	R	71	41	43	8	38	nd	nd	21	128
	PW	80	17	22	10	140	nd	nd	132	13
	V	60	43	80	94	300	nd	nd	44	58
23	R	166	10	52	4	33	nd	nd	26	77
	PW	45	56	186	30	396	nd	nd	138	57
	V	756	48	106	60	38	nd	nd	142	nd
24	R	171	20	60	13	25	nd	nd	71	195
	PW	18	28	36	16	390	nd	nd	120	24
	V	118	25	100	38	48	nd	nd	86	180
25	R	178	13	82	48	384	nd	nd	56	120
	PW	9	15	5	57	282	nd	nd	22	63
	CW	25	18	15	79	34	nd	nd	46	99
	V	36	32	96	90	29	nd	nd	26	71
26	R	180	25	80	78	85	nd	nd	21	40
	PW	70	11	38	84	190	nd	nd	16	71
	V	94	34	94	109	60	nd	nd	40	93
27	R	45	58	26	30	nd	nd	80	18	nd
	PW	33	21	118	626	nd	120	46	14	nd
	CW	37	16	138	70	548	nd	160	54	27
	V1	88	21	68	304	240	46	31	nd	nd
	V2	175	36	146	88	322	nd	421	1	nd
28	R	45	49	14	18	nd	nd	83	20	nd
	PW	54	32	123	62	584	48	120	44	120
	V	333	74	195	75	204	66	480	60	33
29	CC	49	114	110	14	34	100	nd	174	113
	S1	832	104	132	14	40	94	nd	74	85
	S2	461	28	224	28	50	70	nd	142	58
	V	515	38	174	40	42	108	nd	154	86
	BC	556	27	282	78	42	104	nd	72	175
	C1	832	48	142	112	30	142	nd	154	92
	C2	1387	37	102	78	28	148	nd	72	nd
30	R	230	5	89	50	198	16	100	22	101
	PW	193	48	61	76	281	100	140	101	45
	V1	207	43	113	54	52	220	200	45	nd
	SST	239	17	88	51	46	12	14	16	14
	V2	359	79	162	56	46	340	280	43	43

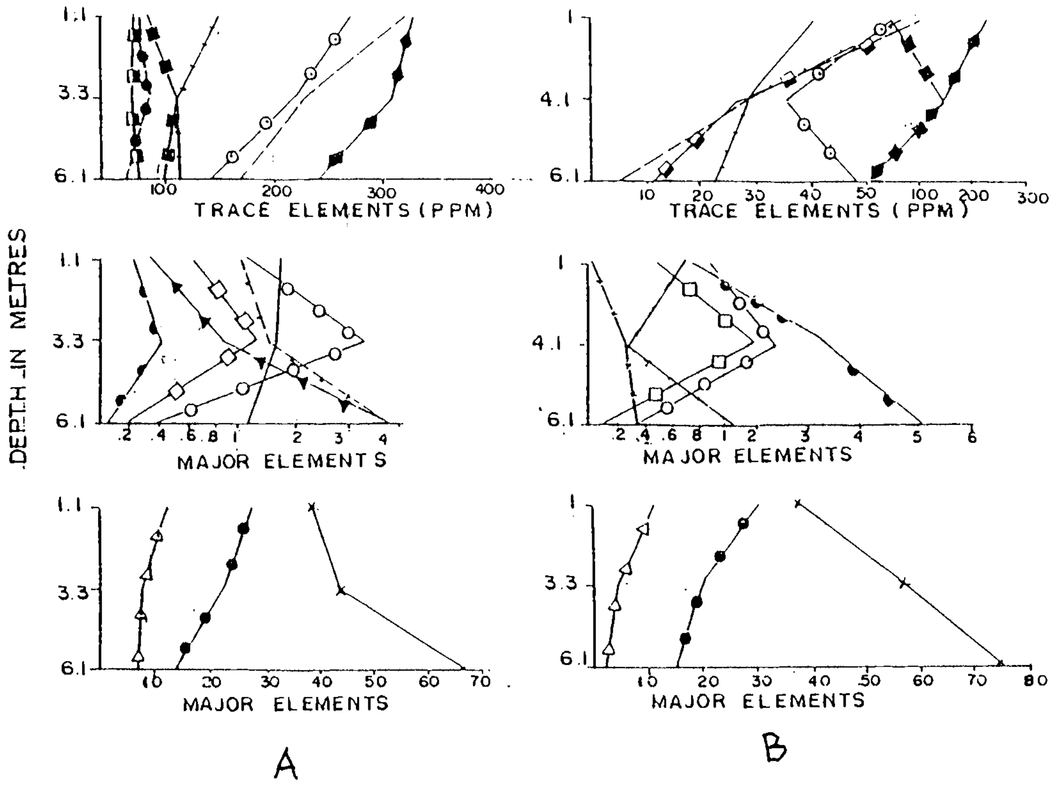


Fig.32 Major and trace element variation diagrams of laterite profiles over hornblende-biotite-gneiss (32A & 32B).

with barite. The sketch of the studied profile is given in Fig.16, profile 7).

The major and trace elemental composition from the various zones of the profile is given in Table 5 and 6 respectively. Plots in the ternary diagram SiO_2 - Al_2O_3 - Fe_2O_3 (Schellmann, 1981) indicate it to be moderately lateritised (Fig.30). The variation diagrams of major and trace element composition (Fig.33) show depletion of SiO_2 , FeO, MgO, CaO, K_2O, and Na_2O with enrichment of Al_2O_3 , Fe_2O_3 and TiO_2 during the lateritisation process, (i.e from bed rock to vermicular laterite). Trace elements V, Cr, Ni and Co are seen enriched along with sesquioxides and TiO_2 , whereas Ba, Zn and Cu are depleted. This trend is in conformity with the theoretical trends as suggested by Hardy and Folletsmith (1931). Two stages during the genesis of laterite over fuchsite quartzite can be discerned from the variation diagrams. In the first stage, there is a rapid depletion of SiO_2 , MgO, CaO, K_2O and Na_2O and trace elements Ba, Zn and Cu, with corresponding enrichment of Al_2O_3 , Fe_2O_3 and TiO_2 and trace elements V, Cr, Ni and Co. In the second stage depletion is gradual with corresponding enrichment of sesquioxides. Chemical budget of the fresh rock to laterite conversion reveals that nearly 2/3 of SiO_2, 69% of CaO, 19% of MgO, 20% of Na_2O and 81% of K_2O are lost during weathering. The concentration ratios of Al_2O_3 , Fe_2O_3 and TiO_2 are 0.99%, 64.2% and 5.08 respectively.

The solubility series in fuchsite quartzite is found to be K> Ca> Si> Fe> Na> Mg.

4.2.4. Profiles over ultramafic rocks

This rock occurs as thin bands within the schistose layers. Of the studied profiles two are from talc - tremolite - actinolite schists and one from

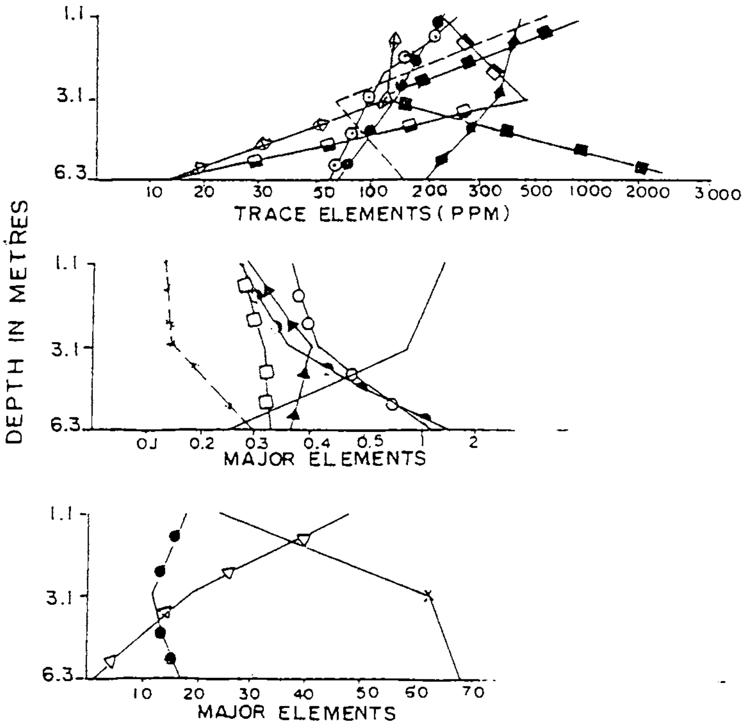


Fig.33 Major and trace element variation diagrams of laterite profile over fuchsite quartzite.

pyroxenites. They vary in thickness from 6.6 to 7.8 m. with a relatively thick laterite column (5.7 m). Sketches of the profiles are presented in Fig.16 A, profile 8 to 10).

Tables 5 and 6 contain the major and trace element composition of the studied profiles. These are moderately lateritised (Fig.30), as per the classification of Schellmann (1981). The variation diagrams of the major and trace element data (Fig. 34 A to C) are comparable with those from other profiles of the study area. However, these laterites have higher concentration of nickel (maximum 740 ppm). Chemical budget calculation of fresh rock to laterite conversion reveals that nearly 45% of SiO_2 , 75% of CaO, 97% of MgO, 81% of FeO, 61% of K_2O and 21% of Na_2O are lost during the process of lateritisation. Concentration ratios of Al_2O_3 is 2.63 and Fe_2O_3 is 3.34. The mobility series of elements are in the order of Mg> Fe> Ca> K> Si> Na.

4.2.5. Profiles over quartz-mica-schist

This rock type is found as thin linear bands within granulites as well as migmatites . The profile thickness of *in situ* laterite varies from 3.1 to 3.8 m with laterite thickness of 1.2 to 3 m. The different compositional units of the profile are presented in Fig.16 B, profile 11 and 12). Major and trace element compositions are given in Table 5 and 6 respectively. The plots in the ternary diagram of SiO_2-Fe_2O_3-Al_2O_3 fall in the field of weakly lateritised zone (Fig.17). The variation diagrams of major and trace elements (Figs.35 A & 35 B) show depletion of SiO_2 , MgO, K_2O, Na_2O, and enrichment of Al_2O_3 , Fe_2O_3 and TiO_2 . Trace elements V, Ga, Cu, Cr and Ni get enriched whereas Ba and Zn show a depleting trend during the process of lateritisation. The variation diagrams show two stages in the genesis of laterite over schists. The first

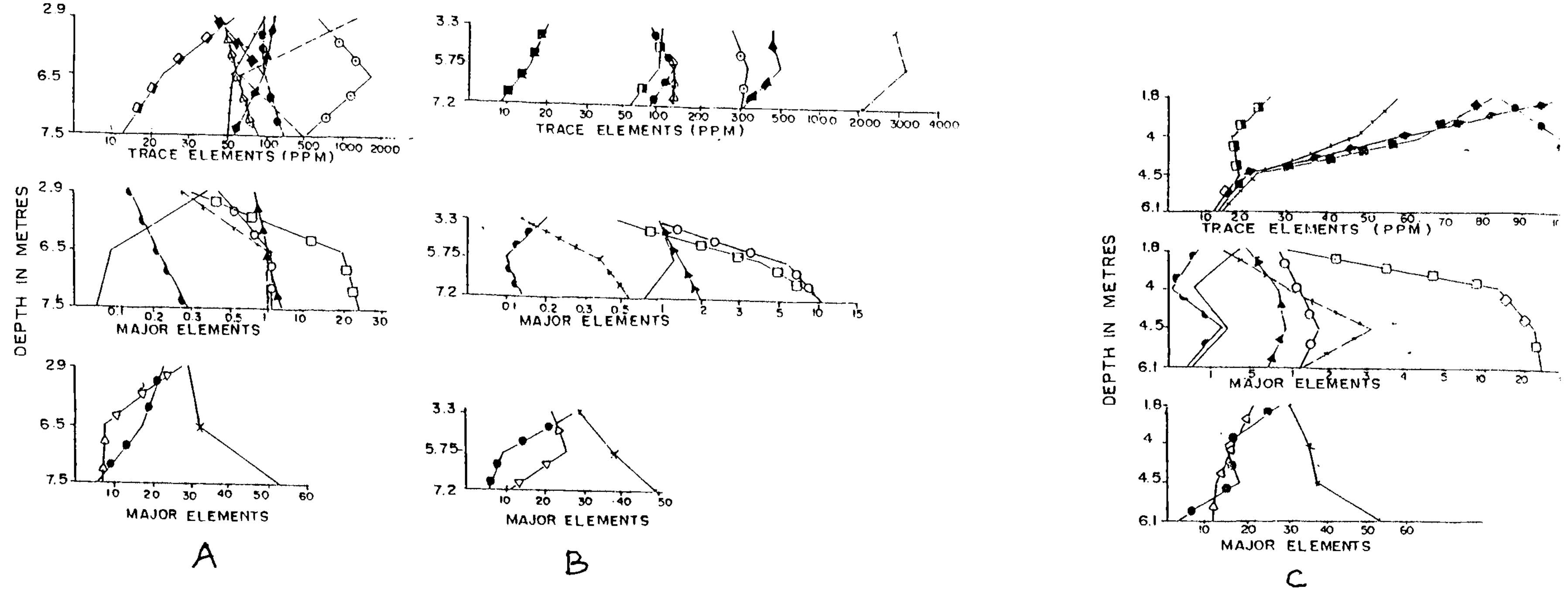


Fig.34 Major and trace element variation diagrams of laterite profiles over ultramafites (34A to 34C).

stage shows a rapid depletion of SiO_2 , CaO, MgO and K_2O with slight increase in Na_2O and FeO. Chemical budget of the fresh rock to laterite conversion reveals that nearly 37.67% of SiO_2 , 75% of MgO and 91% of FeO are depleted. Al_2O_3 and Fe_2O_3 show concentration ratios of 1.49 and 3.28 respectively. The solubility series for quartz - mica - schist is found to be Fe> Mg> Na> Si.

4.2.6. Profiles over anorthosite

The laterite developed over the massif anorthosite body at Perinthatta has been lateritised. Profiles vary in thickness varying from 10.1 to 17 m. Different compositional units of the profiles are shown in Fig.16 B, profile 13 to 16). Major and trace elemental composition of these profiles are presented in Tables 5 and 6. Al_2O_3 content in the laterite zones ranges from 26.71 to 39.26 wt.%, with a silica value of 54.68% to 55.88% wt%.

Variation diagrams of the major and trace elements compositions of the profiles (Figs.36, profiles 36 A to D) show three stages during the formation of laterite. The first stage is marked by a rapid depletion of SiO_2 , FeO, CaO, MgO and Na_2O, and the second stage by a gradual depletion of SiO_2 , FeO, CaO, and Na_2O. In the third stage, depletion of SiO_2 and enrichment of Al_2O_3 are gradual, and the Al_2O_3 values attains significant level close to bauxite content. Trace elements V, Co and Ni show general enrichment whereas Ba and Zn show depletion during the lateritisation process. Geochemical calculations reveal that nearly 58.06% of SiO_2 , 94.83% of CaO, 53.92% of MgO and 70.5% of Na_2O are lost during weathering. Al_2O_3 and Fe_2O_3 shows concentration ratio of 1.68 and 25.11 respectively. Solubility series of anorthosite during weathering is found to be Ca > Fe > Na > Si > K > Mg.

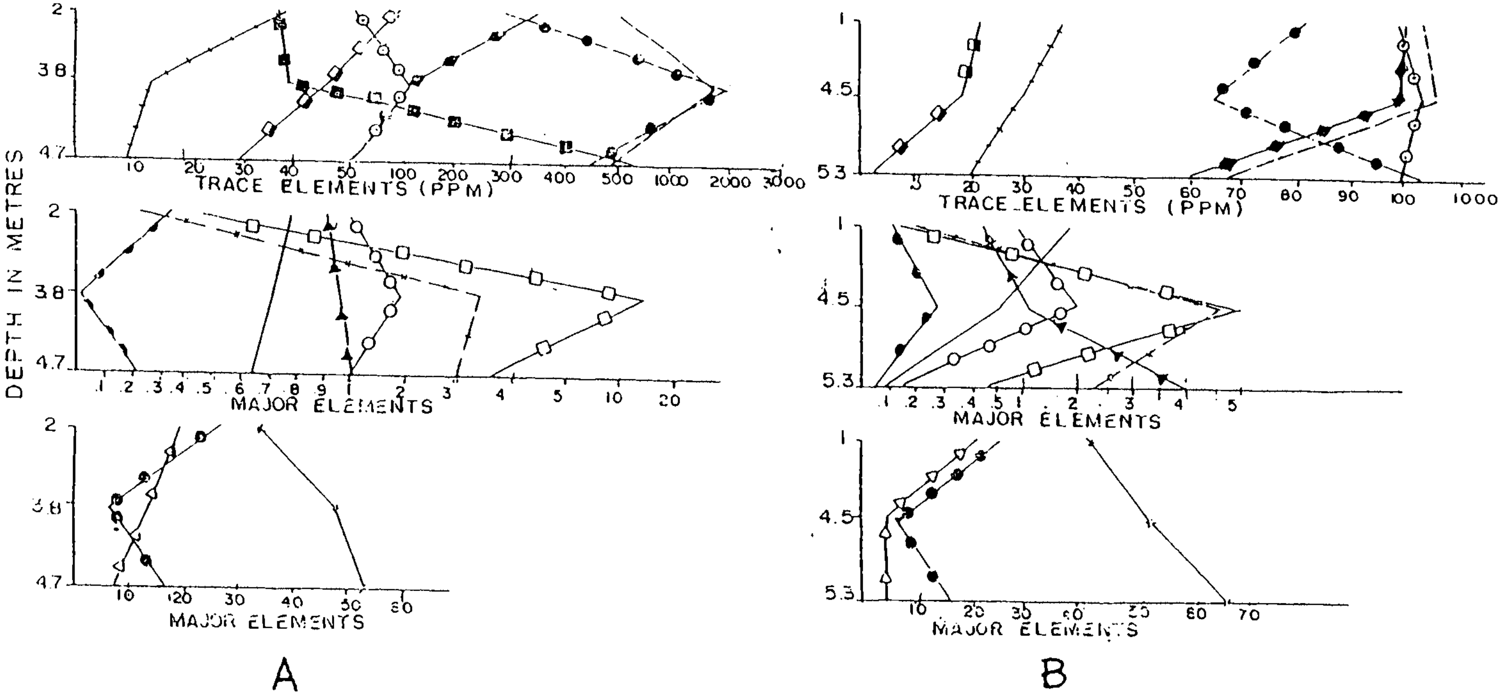


Fig.35 Major and trace element variation diagrams of laterite profiles over quartz-mica-schist (35A and 35B).

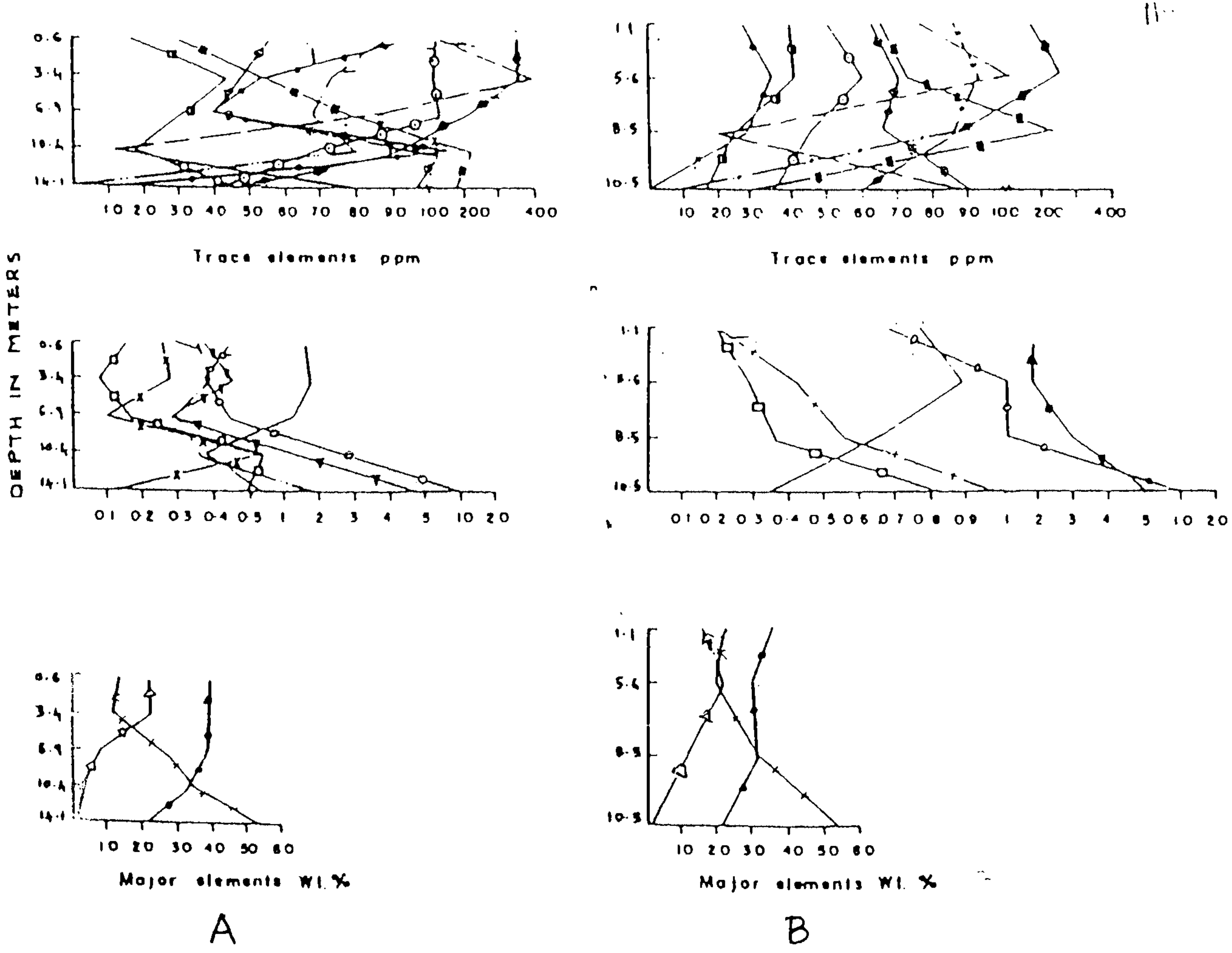


Fig.36 Major and trace element variation diagrams of laterite profiles over anorthosite (36A to 36D).

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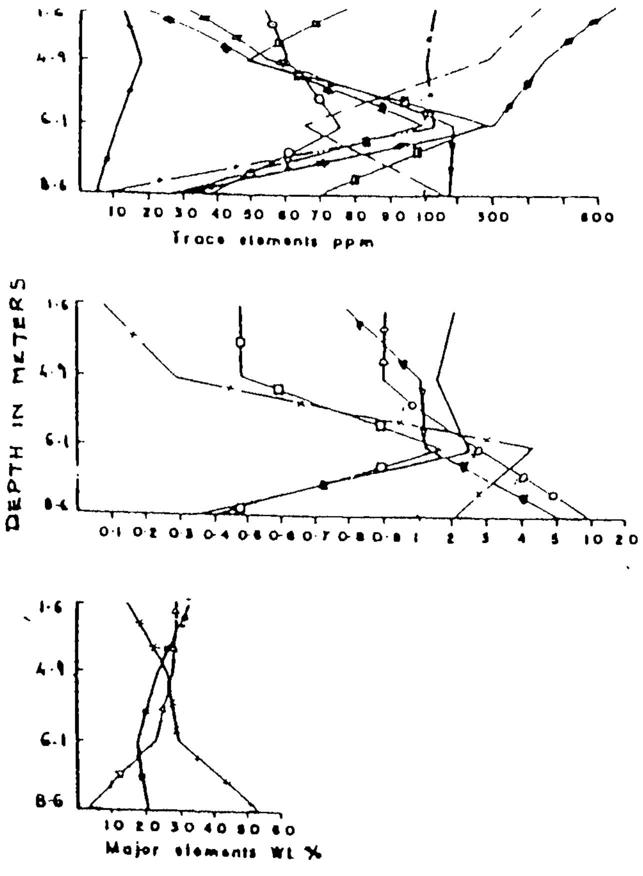
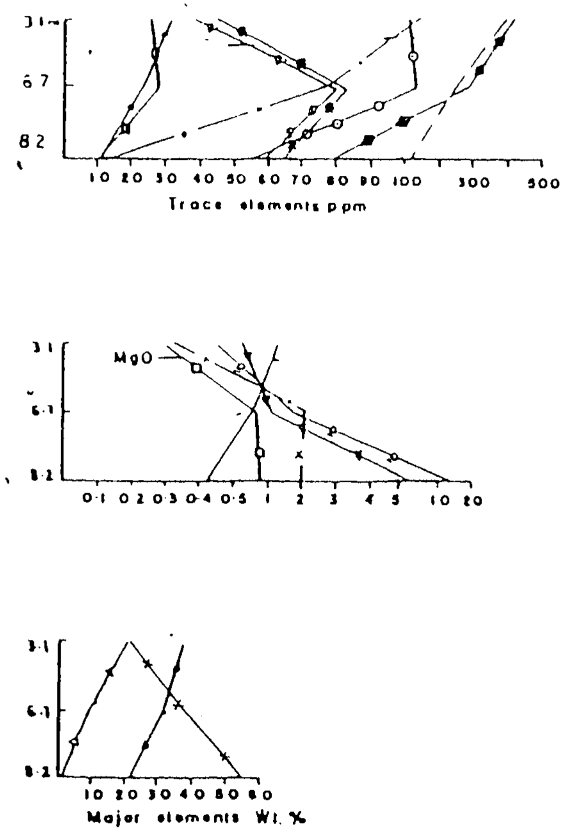

DEPTH IN METERS
1·6
4·9
6·1
8·6
10 20 30 40 50 60 70 80 90 100 300 600
Trace elements ppm
0·1 0·2 0·3 0·4 0·5 0·6 0·7 0·8 0·9 1 2 3 4 5 10 20
Major elements Wt. %

C


3·1
6·7
8·2
10 20 30 40 50 60 70 80 90 100 300 500
Trace elements ppm
MgO
6·1
0·1 0·2 0·3 0·4 0·5 1 2 3 4 5 10 20
10 20 30 40 50 60
Major elements Wt. %

D

4.2.7. Profiles over gabbro

This rock forms a prominent unit of the Ezhimala gabbro - granophyre complex. The studied profiles vary in thickness from 7.1 to 10 m (Fig.16 B, profiles 17 to 20). Major and trace element data of the studied profiles are presented in Tables 5 and 6 respectively. Based on maturity index, the laterite can be termed as moderate to strongly weathered. Variation diagrams are given in Figs.37 A to D. The first stage of weathering in gabbro is characterised by rapid depletion of SiO_2 , FeO, CaO, MgO, and Na_2O with complimentary enrichment of Al_2O_3 and Fe_2O_3 . The trace elements V, Ni and Cr show relative enrichment, whereas Ba and Zn are depleted. Gradual depletion trends of SiO_2 , FeO, MgO, CaO, and Na_2O are observed in the second stage of weathering with the trace elements V, Ni, and Cr also showing relative enrichment compared to the trends in granophyre. Chemical budget calculation during the process of conversion of bed rock to laterite show a loss of 49.65% of SiO_2 , 88.23% of CaO, 89.15% of MgO and 77% of Na_2O. Al_2O_3 and Fe_2O_3 concentration ratios are 3.22 and 3.7 respectively. Solubility series for gabbro is found to be Ca> Fe> Na> Si> K> Mg>.

4.2.8. Profiles over granophyre

This rock also forms a conspicuous unit of the Ezhimala gabbro-granophyre complex. The laterite profiles vary in thickness from 7.1 to 8.2 m. Different compositional units have been measured and are shown in Fig.16 C, profiles 21 to 26. In the ternary diagram of Schellmann (1981) they plot in the fields of moderate to strong weathering (Fig.30).

The major and trace element data for the profiles are given in Tables

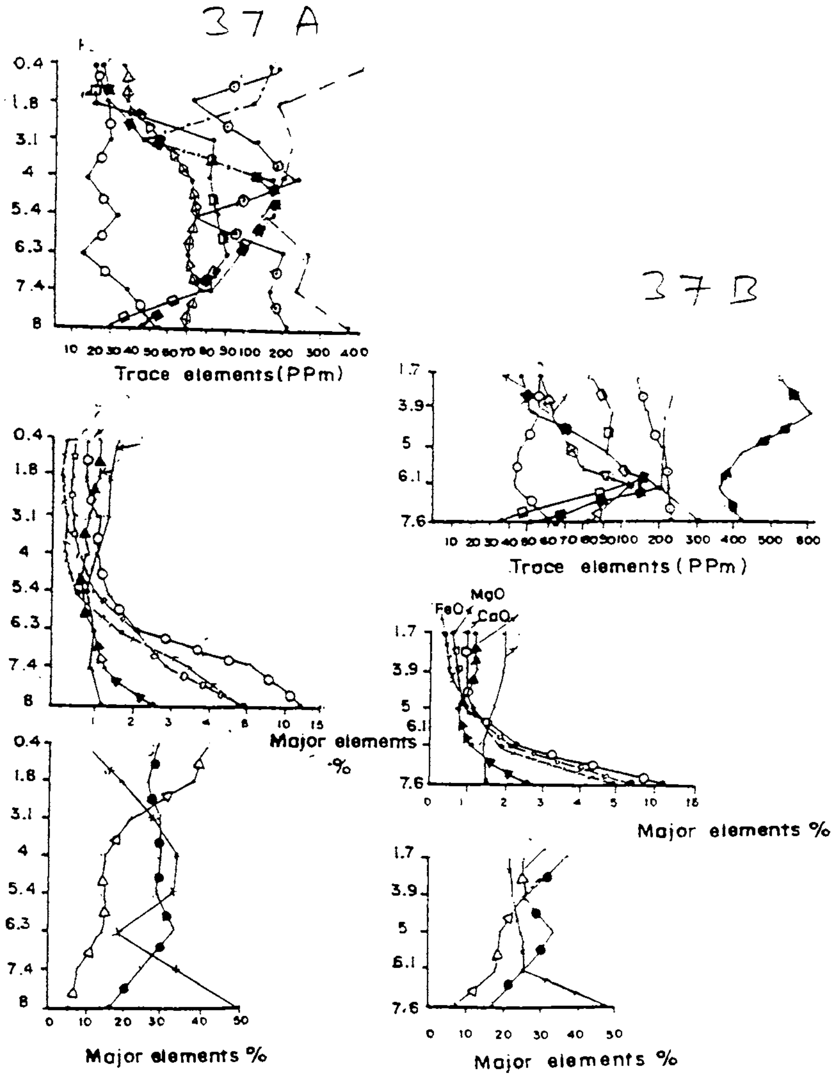


Fig.37 Major and trace element variation diagrams over laterite profiles over gabbro (37A to 37D).

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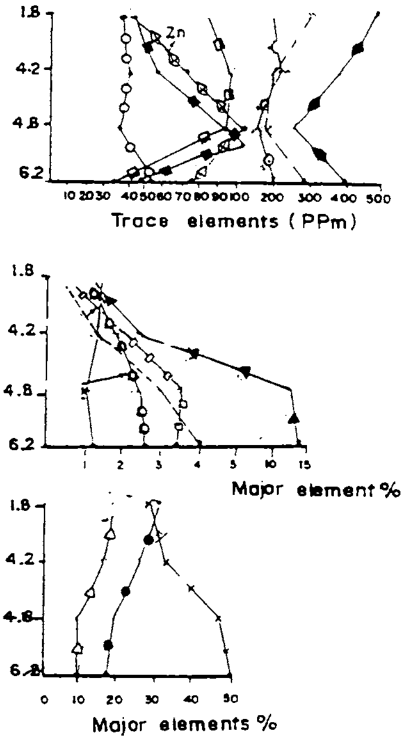
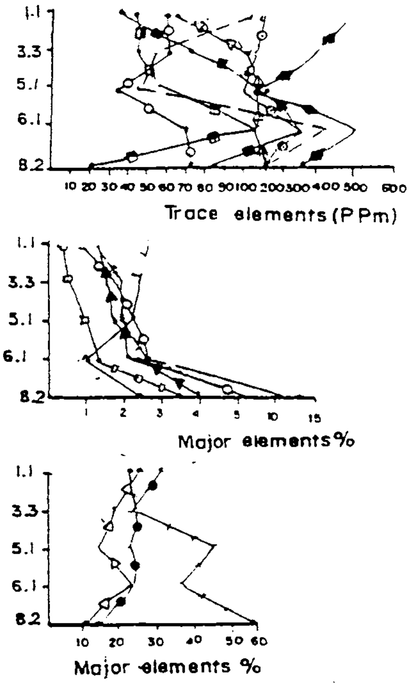
37 c


1.8
4.2
4.8
6.2
Zn
10 20 30 40 50 60 70 80 90 100 200 300 400 500
Trace elements (PPm)
1.8
4.2
4.8
6.2
1 2 3 4 5 10 15
Major element %
1.8
4.2
4.8
6.2
0 10 20 30 40 50
Major elements %

37 D


1.1
3.3
5.1
6.1
8.2
10 20 30 40 50 60 70 80 90 100 200 300 400 500 600
Trace elements (P Pm)
1.1
3.3
5.1
6.1
8.2
1 2 3 4 5 10 15
Major elements %
1.1
3.3
5.1
6.1
8.2
10 20 30 40 50 60
Major elements %

5 and 6 respectively. The variation diagrams of the major and trace element composition (Figs.38 A to F) show two stages during the process of weathering. The first stage is marked by a rapid depletion of Na_2O and MgO with gradual but steady enrichment of Fe_2O_3 and a relatively rapid TiO_2 enrichment along with trace elements Cr, Ni and Co in the lower part of the profile. Ba and Zn show general depletion. Silica depletion is slower in the second stage. Al_2O_3 behaviour is more or less steady in both the stages.

Chemical budget calculation reveals that nearly 60.26% of SiO_2 , 71.5% of CaO, 56.2% of MgO, 82.45% of Na_2O, 82.67% of K_2O and 73.39 of FeO are lost during the conversion of the bed rock to laterite, Al_2O_3 concentration ratio of 1.94 and Fe_2O_3 concentration of 7.24 are noticed in the weathering crust. Since this profile is close to the gabbro body, the higher Fe_2O_3 concentration ratio may be attributed due to lateral movement from the gabbro also. The solubility series of the major elements in granophyre is K > Na > Fe > Ca > Si > Mg.

4.2.9. Profiles over alkali-syenite

The investigated profiles have thickness of 5.5 m. Sketches of the profiles are given in Fig.16 C, profiles 27 and 28).

The major and trace element compositions are given in Tables 5 and 6 respectively. SiO_2 - Fe_2O_3 - Al_2O_3 ternary diagram plots indicate weak to moderate lateritisation (Fig.30). Variation diagrams of major and trace elements (Figs.39 A & B) indicate gradual depletion of SiO_2 , CaO, MgO, Na_2O and K_2O, and gradual enrichment of Al_2O_3 , Fe_2O_3 and TiO_2 in the profiles. No discernible pattern in enrichment/depletion of trace elements are seen in the diagrams.

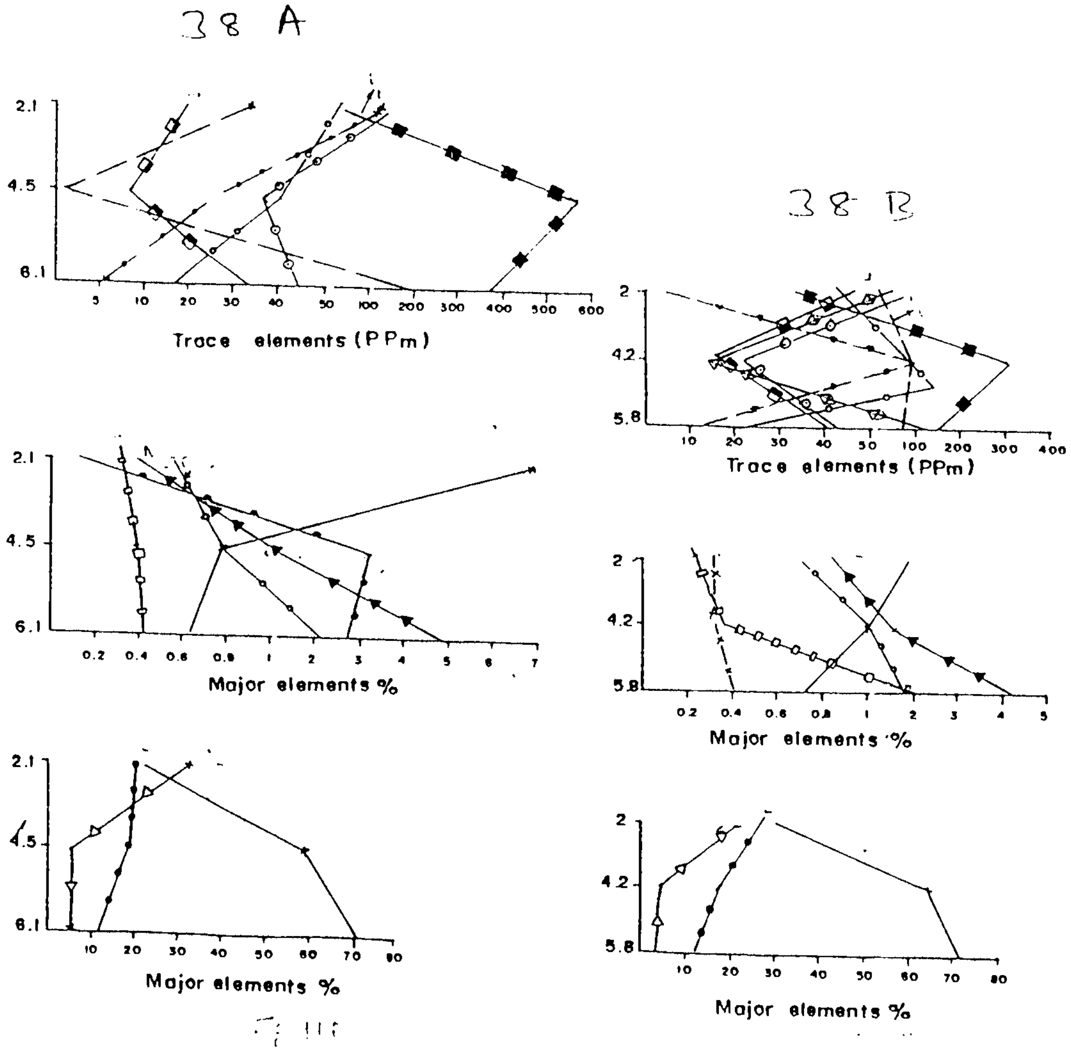


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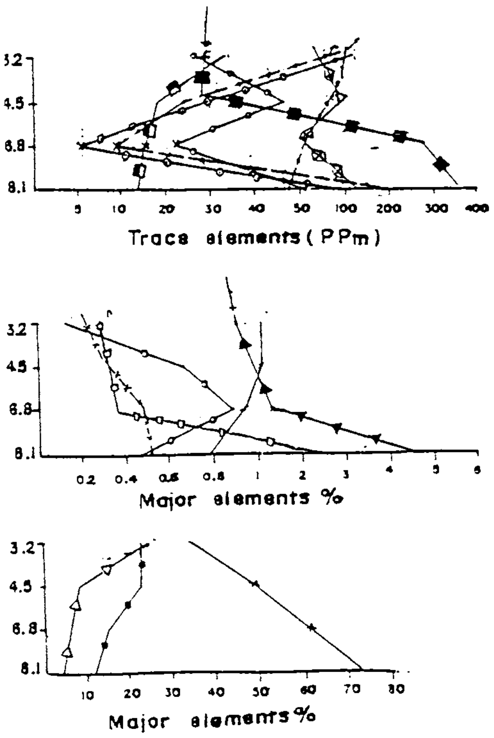
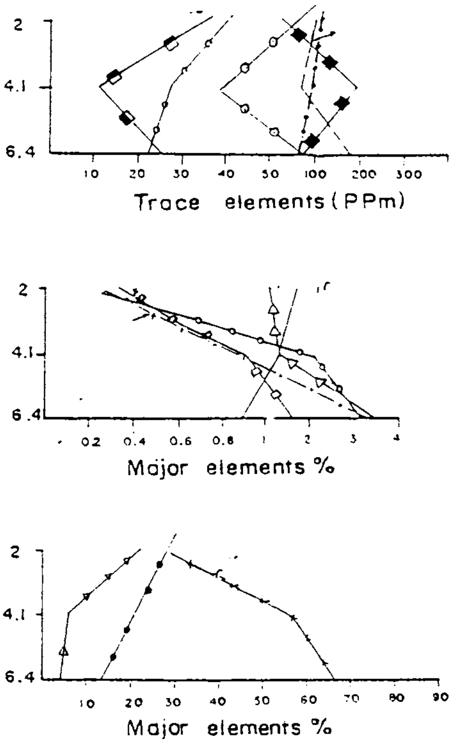
Fig.38 Major and trace element variation diagrams of laterite profiles over granophyre (38A to 38F).

38 C



38 D



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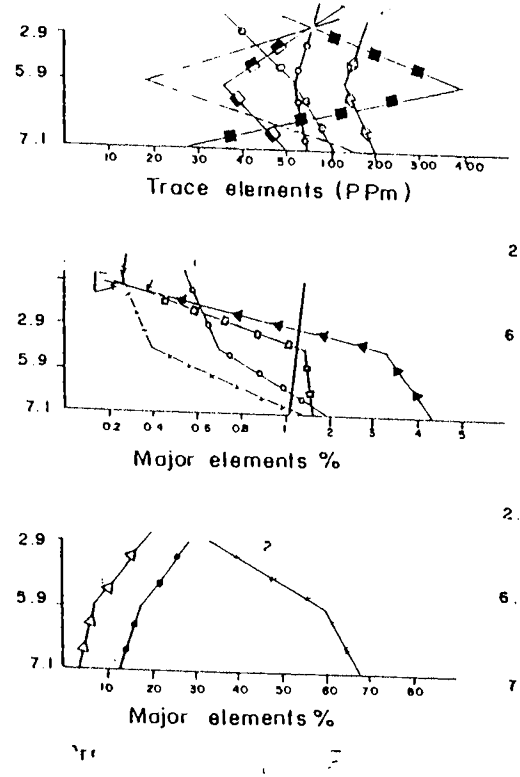
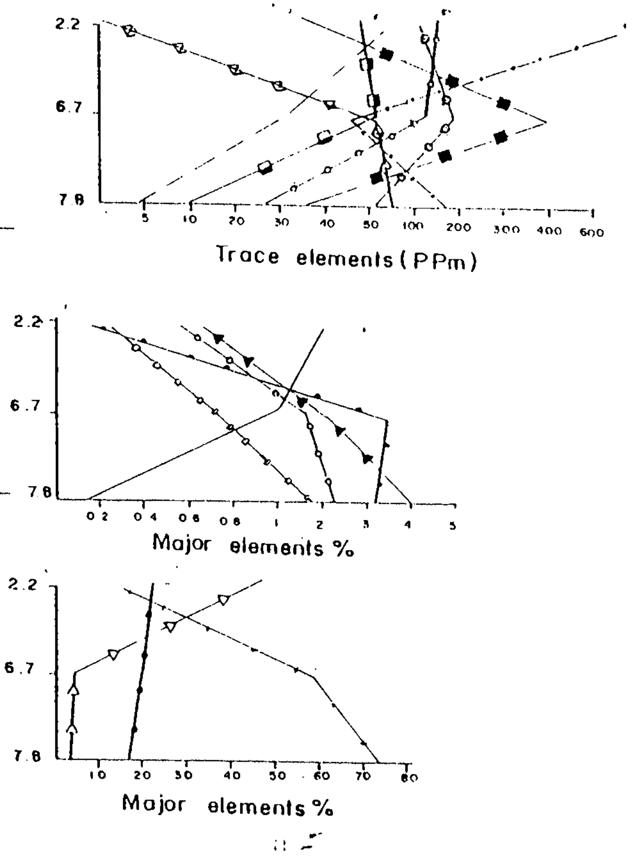
38 E


2.9
5.9
7.1
10 20 30 40 50 100 200 300 400
Trace elements (PPm)
2.9
5.9
7.1
0.2 0.4 0.6 0.8 1 2 3 4 5
Major elements %
2.9
5.9
7.1
10 20 30 40 50 60 70 80
Major elements %

38 F


2.2
6.7
7.8
5 10 20 30 40 50 100 200 300 400 600
Trace elements (PPm)
2.2
6.7
7.8
0.2 0.4 0.6 0.8 1 2 3 4 5
Major elements %
2.2
6.7
7.8
10 20 30 40 50 60 70 80
Major elements %

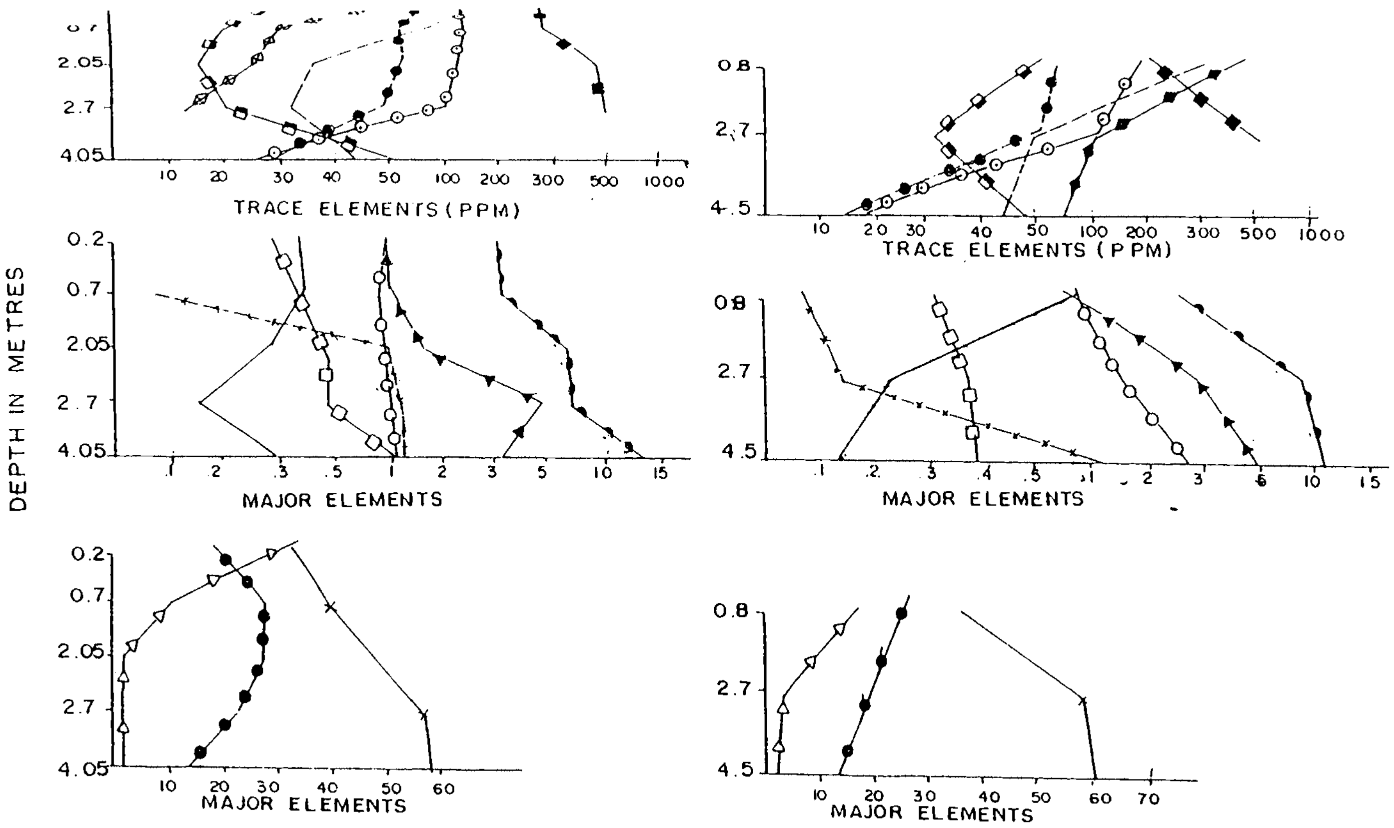


Fig.39 Major and trace element variation diagrams of laterite profiles over alkali-syenite (39A and 39B).

Geochemical calculation reveals that nearly 42.83 % of SiO_2 , 81.88% of CaO, 24.6% of MgO, 75.39% of Na_2O, 88.25% of K_2O and 92.56% of FeO are lost during the conversion of bed rock to laterite. Al_2O_3 and Fe_2O_3 show concentration ratios of 1.63 and 11.09 respectively. The solubility series of elements during the process of weathering is found to be Fe> K> Ca> Na> Si> Mg.

4.2.10. Profiles over sedimentary formation

The profiles developed over the sedimentary formation assume significance as the processes leading to the formation of china clays in Kerala are intimately associated with lateritisation process. One of the studied profiles has thick beds of china clays of residual and secondary origins. Further, these profiles also enable to identify various cycles of lateritisation in the region. The sketches of the profiles are given in Fig.16 D , profiles 29 & 30). Thickness of these profiles vary from 12.3 m. at Tellicherry to 38 m. at Palayangadi.

Major and trace element compositions of these profiles are given in Tables 5 and 6 respectively. The primary laterite developed over biotite gneiss at Tellicherry, at the base of the sedimentaries is weakly lateritised as per the classification of Schellmann (1981), whereas the primary laterite developed over the basement rock at Palayangadi and the second cycle *in situ* laterite developed over sandstone at Tellicherry show that they are moderately lateritised. The second cycle *in situ* laterite developed over sedimentary formation at Palayangadi shows strong lateritisation trend (Fig. 17A).

Variation diagrams of major and trace element compositions of the laterite profiles over Tertiaries (Fig.40 A & B) show that the laterite at the top and the bottom is marked by rapid depletion of SiO_2 , K_2O, Na_2O and FeO with complimentary enrichment of Al_2O_3 , Fe_2O_3 and TiO_2 . Data on middle portions of the profile do not indicate any trend comparable to that observed in laterite profiles developed over basement rocks of the study area. Trace elements show enrichment in the laterite over gneiss and sandstone at Tellicherry. At Palayangadi no distinct trend of trace element behaviour is discernible, except for Cr.

Geochemical features of the profile (at Palayangadi) have been summarised in figure 25 (also see Table) indicating the enrichment values of Al_2O_3 towards the laterite horizon. The leached portion close to the base of the sedimentary column also shows alumina enrichment. Fe_2O_3 progressively gets enriched towards the upper portion. Silica depletion is more towards the lower horizons. As can be seen from Table-4, separate analyses of the brown/red and white/yellowish portions of the laterite samples yield slightly different Al_2O_3 values in the bauxite patches, while in the hard crust, the black coloured samples are richer in Fe_2O_3 than the brown varieties indicating that even colour can be an effective compositional criterion in the area.

4.2.11. Element distribution contour maps

Geochemical data on major elements (SiO_2 , Al_2O_3 , Fe_2O_3 , CaO, MgO, Na_2O, K_2O, TiO_2 and LOI) obtained from the present study were also utilised to prepare element distribution contour maps for the area. Fig.41 A to 41 C relate to element distribution in the bed rock, Fig.42 A to 42 I in the weathering zone (partly weathered and completely weathered zones in the

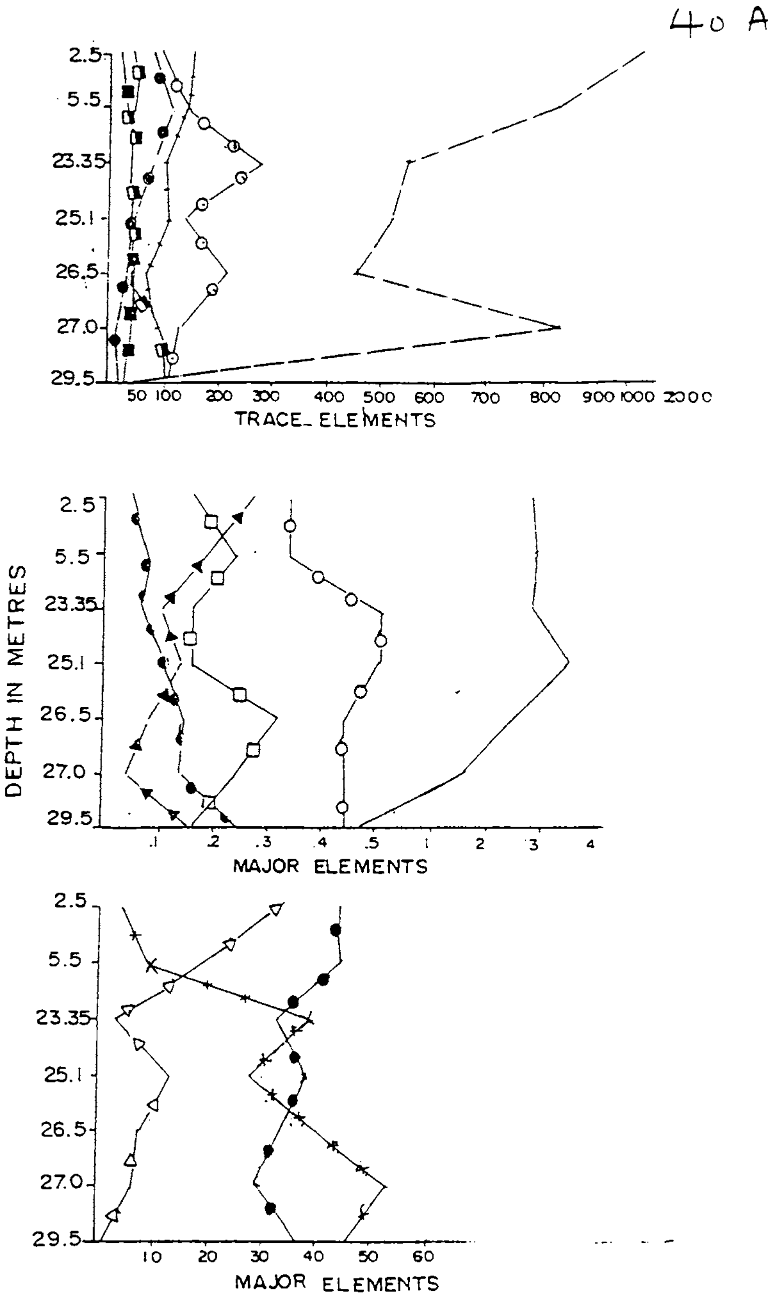
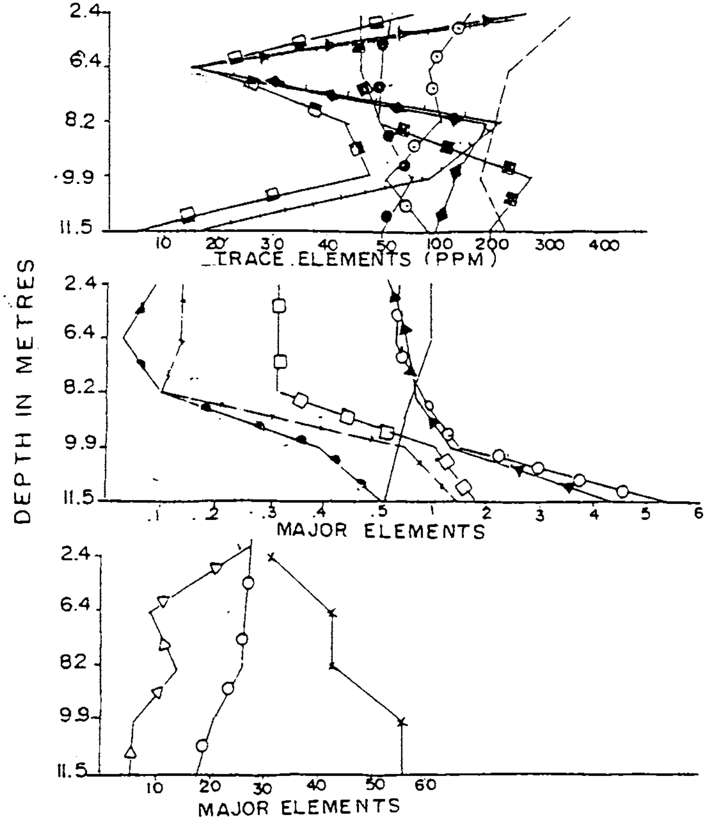


Fig.40 Major and trace element variation diagrams of laterite profiles over sedimentary formation (40A and 40B).

(Contd ....)

40B


2.4
6.4
8.2
9.9
11.5
10
20
30
40
50
100
200
300
400
TRACE ELEMENTS (PPM)
DEPTH IN METRES
2.4
6.4
8.2
9.9
11.5
.1
.2
.3
.4
.5
1
2
3
4
5
6
MAJOR ELEMENTS
2.4
6.4
8.2
9.9
11.5
10
20
30
40
50
60
MAJOR ELEMENTS

synoptic profile), and Fig.43 A to 43 I in the laterite. These maps show substantial variation and may be used for guiding future investigations on geochemical soil/mineral survey.

4.3. CONCLUSIONS

1. The results from the studied laterite profiles (Table 5 and 6) when compared with those from the parent rock clearly indicate that Al_2O_3 , Fe_2O_3 and TiO_2 are enriched with varying intensities.

2. Concentration ratios of Fe_2O_3 in various lithological units range from 2.48 in charnockite to 11.45 in the sedimentary formations. The ratios are still higher in anorthosite (21.11). In fuchsite quartzite rock type the ratio attains the value of 64.2, possibly indicating that the weathering of this rock generally leads to iron-rich laterites due to the insolubility of iron in the weathering crust, a phenomenon observed in the schistose rocks of the Western Ghats. Further the iron-poor rock types show higher Fe_2O_3 enrichment ratios than the iron-rich varieties.

3. Alumina in the studied laterites occurs as hydrated oxide mostly as kaolins as a result of desilication of the alumino-silicates and their transformation. Other oxides like SiO_2 , MgO, Na_2O and K_2O etc are removed substantially from the parent rock.

Concentration ratios of Al_2O_3 range from 0.99 in fuchsite - quartzite to 3.22 in gabbro, which is slightly lower than that of Fe_2O_3 . In the

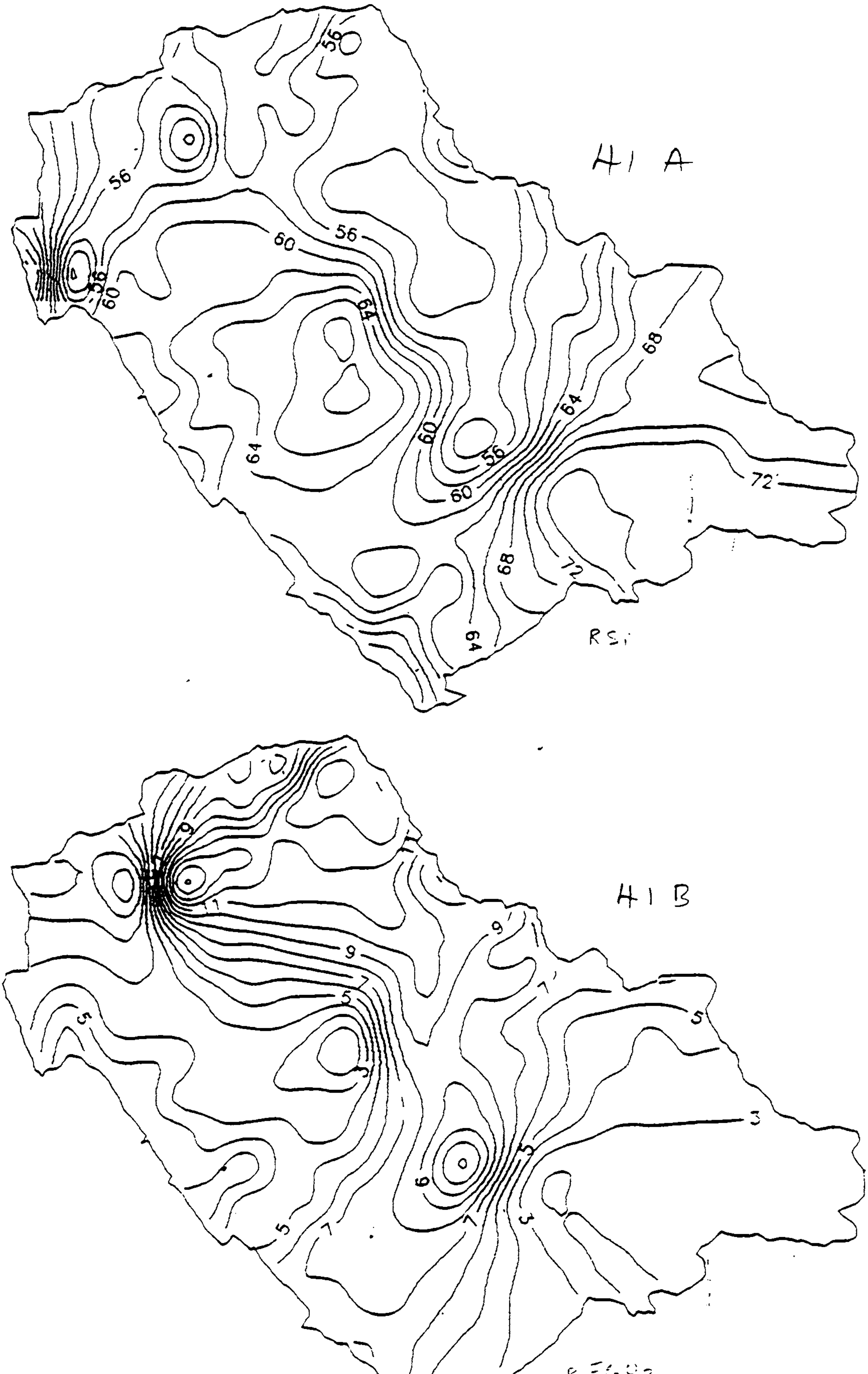
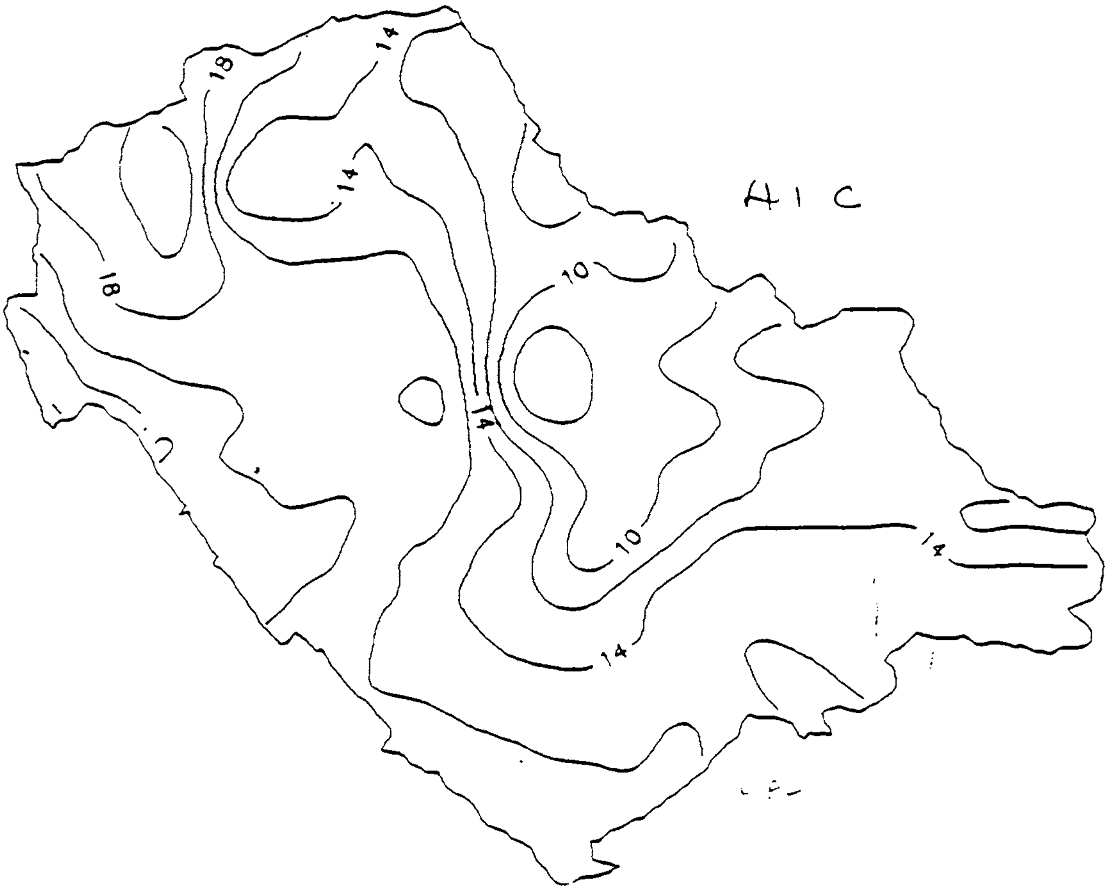
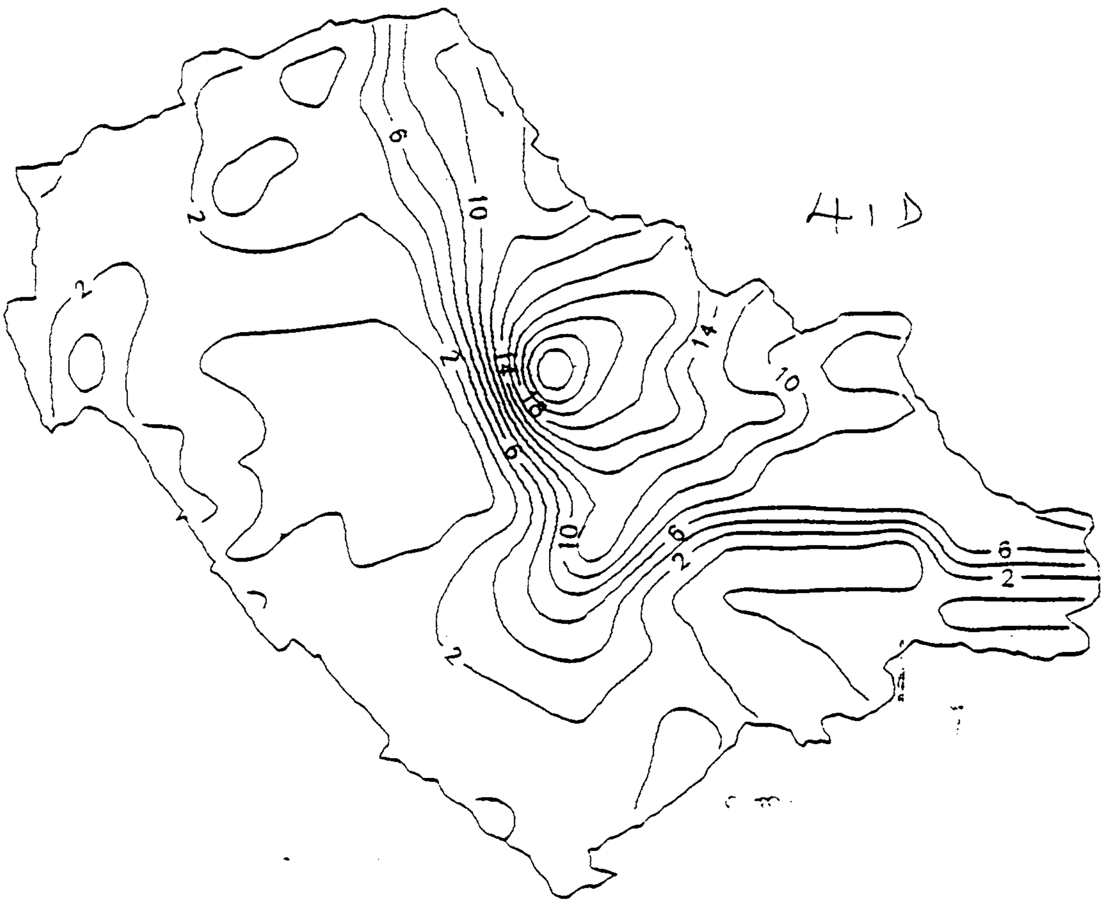


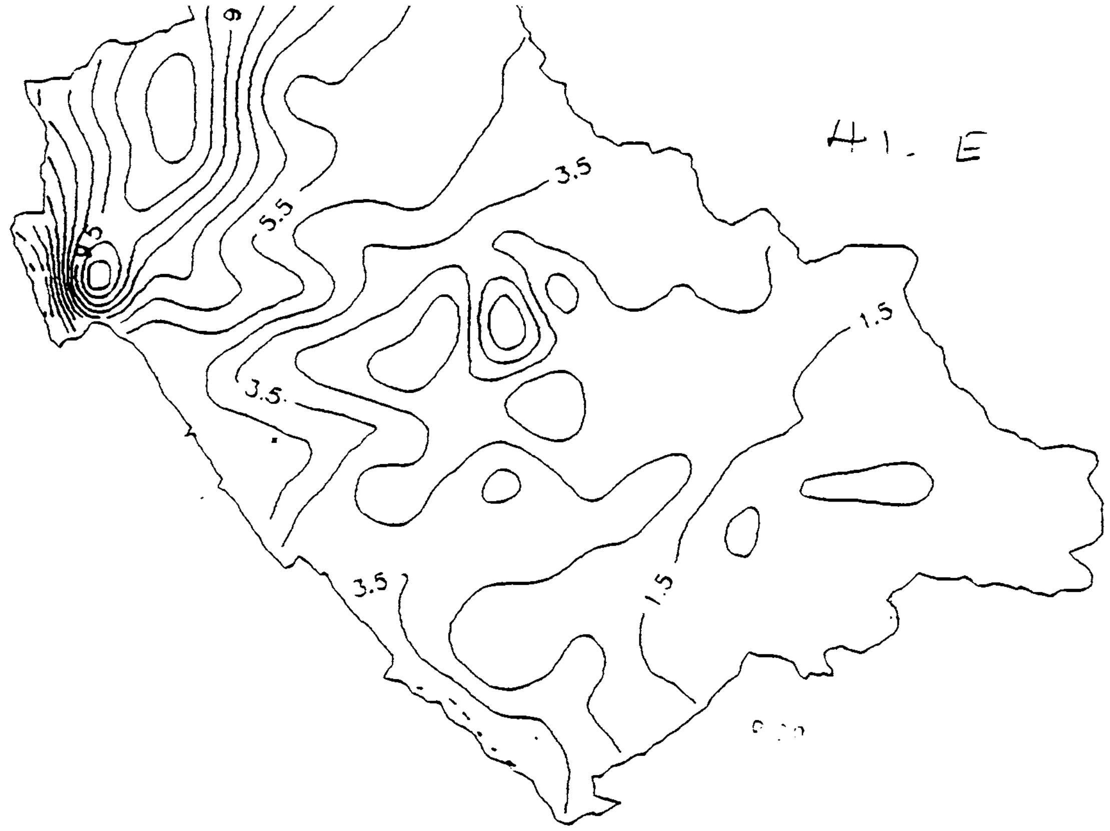
Fig.41 Major element distribution contour maps of Cannanore dis- trict based on bed rock data (41 A : SiO$_2$, B : Fe$_{203}$ C : Al$_2$O$_3$, D : MgO, E CaO, F : Na$_2$O, G : K$_2$O, H : TiO$_2$, I : LOI.



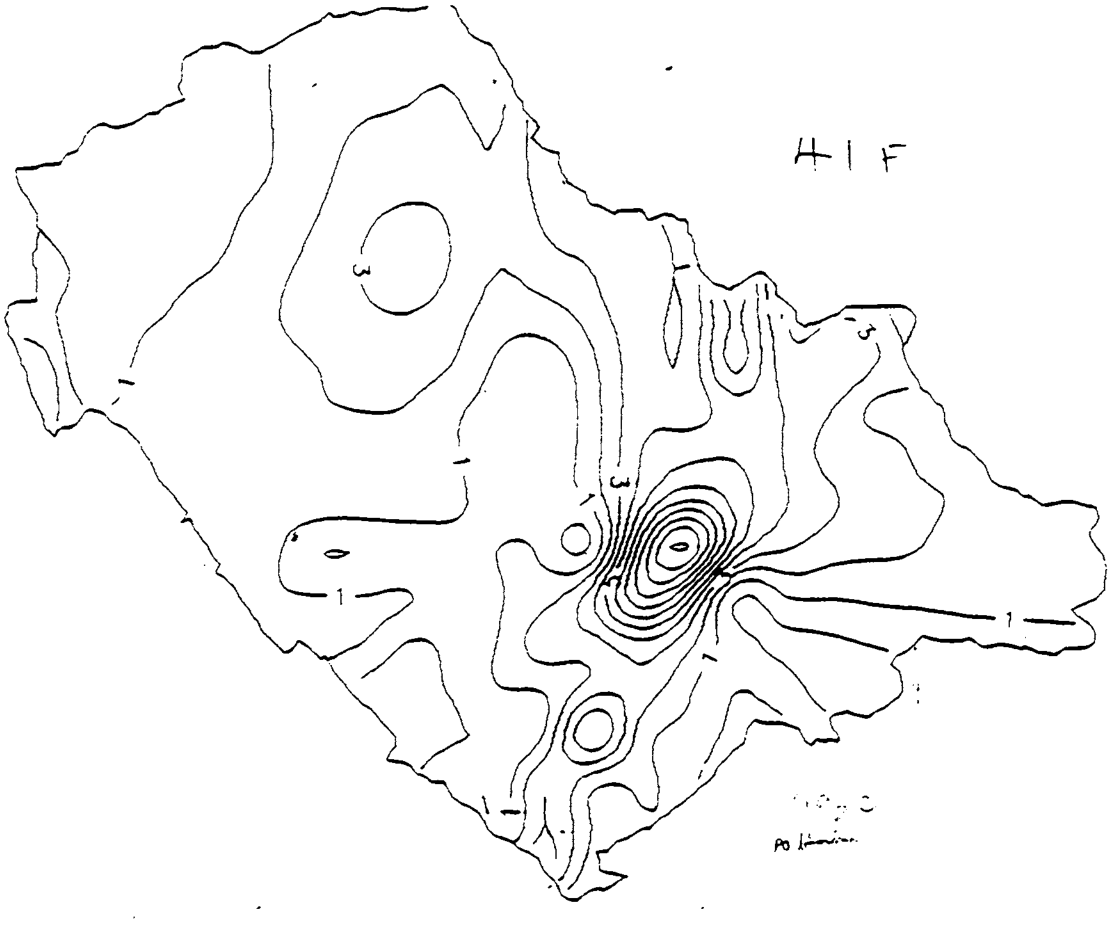
41C



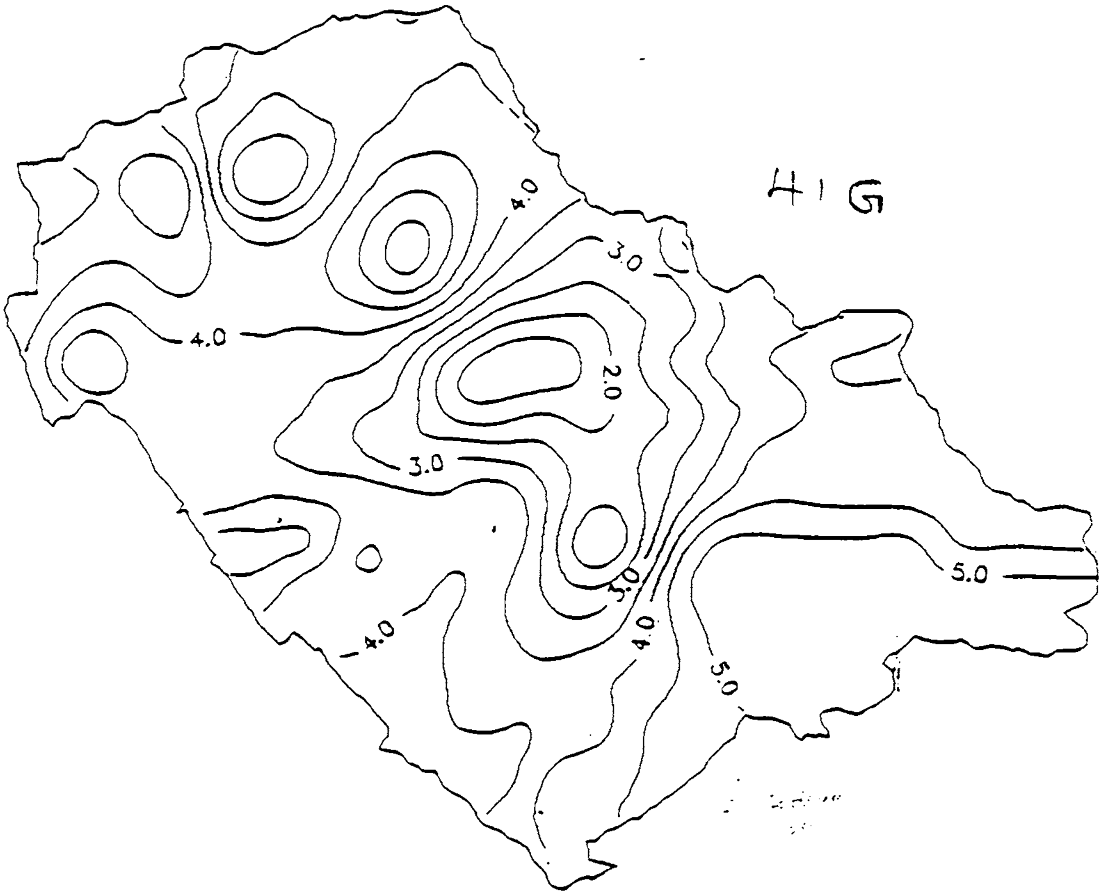
41D



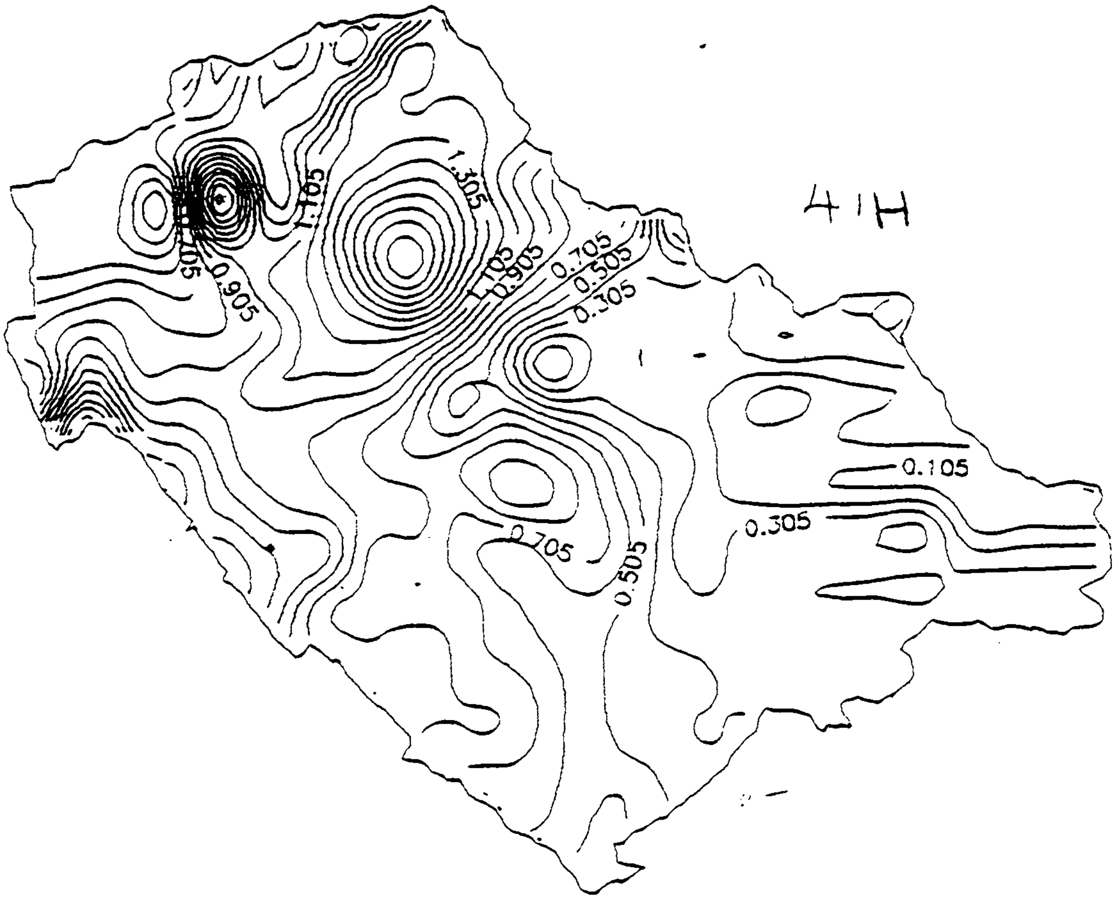
41. E



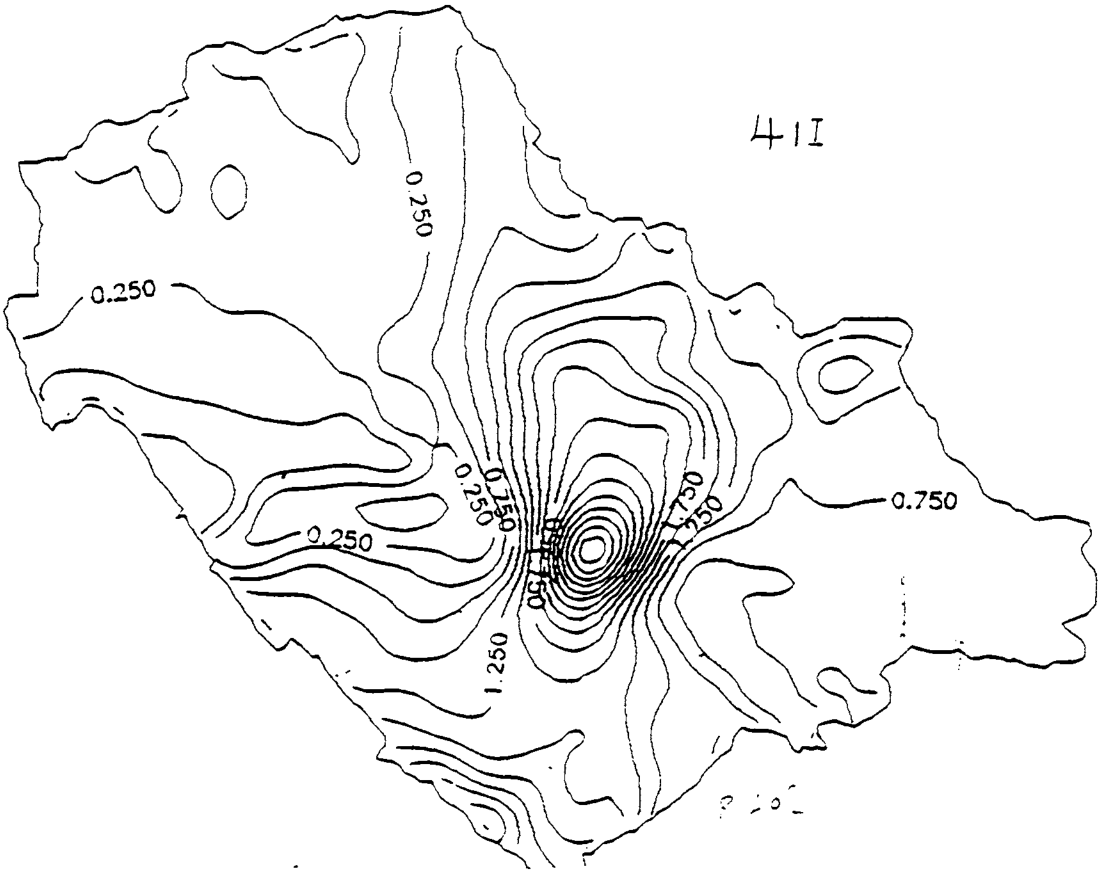
41 F


4.0
3.0
4.0
2.0
3.0
5.0
4.0
4.0
5.0
5.0

41G


1.305
1.105
0.905
0.705
0.505
0.305
1.105
0.905
0.905
0.105
0.705
0.505
0.305
0.105

41H



41I

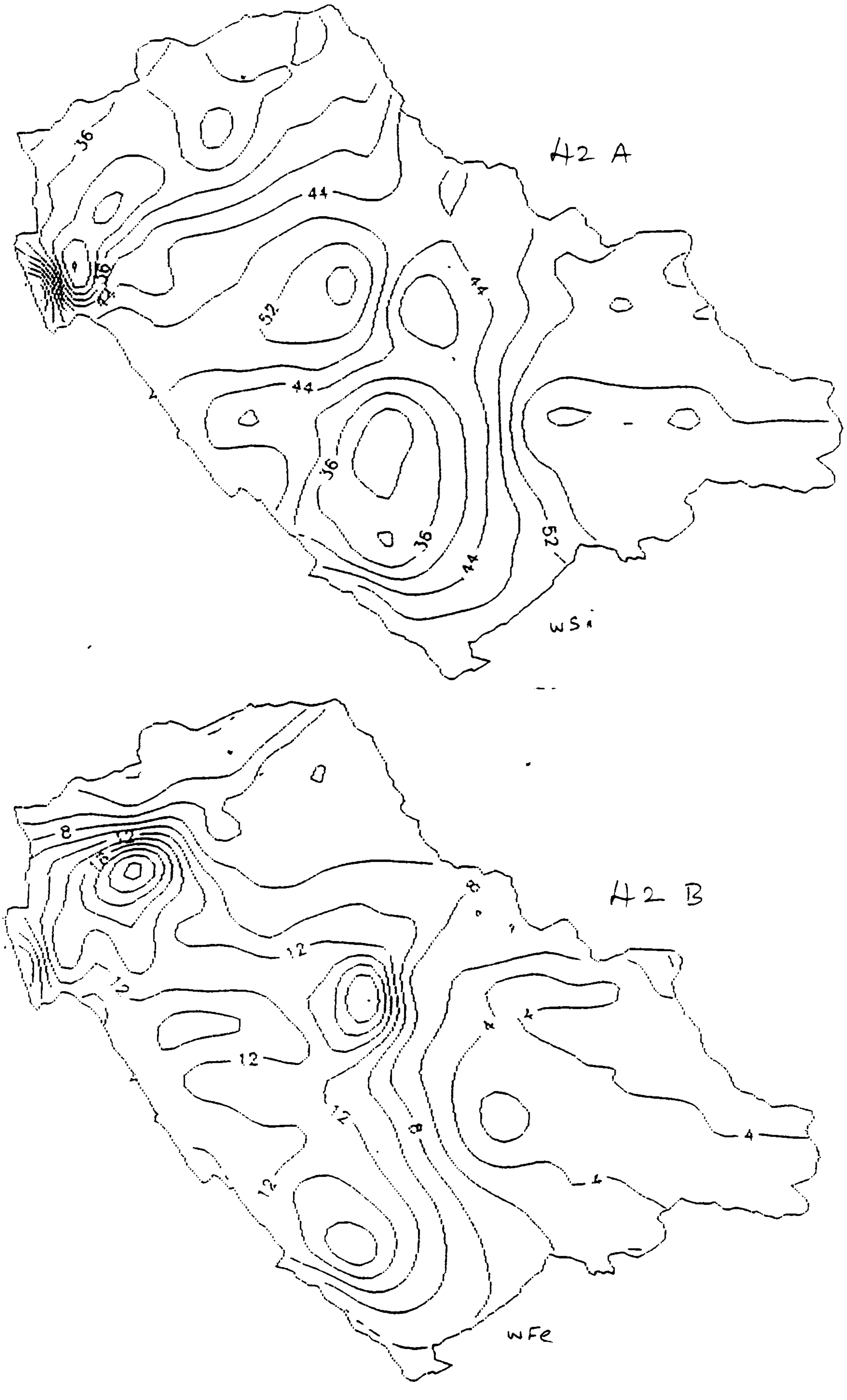
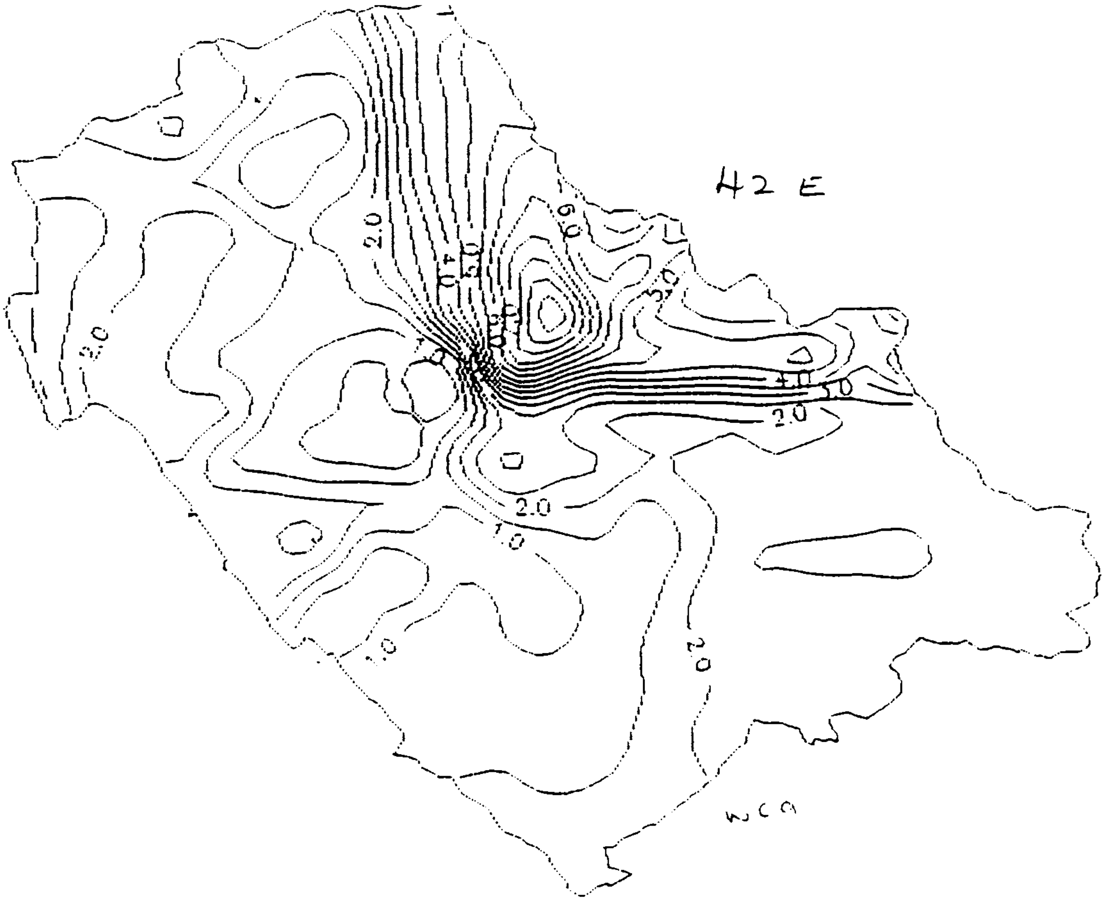
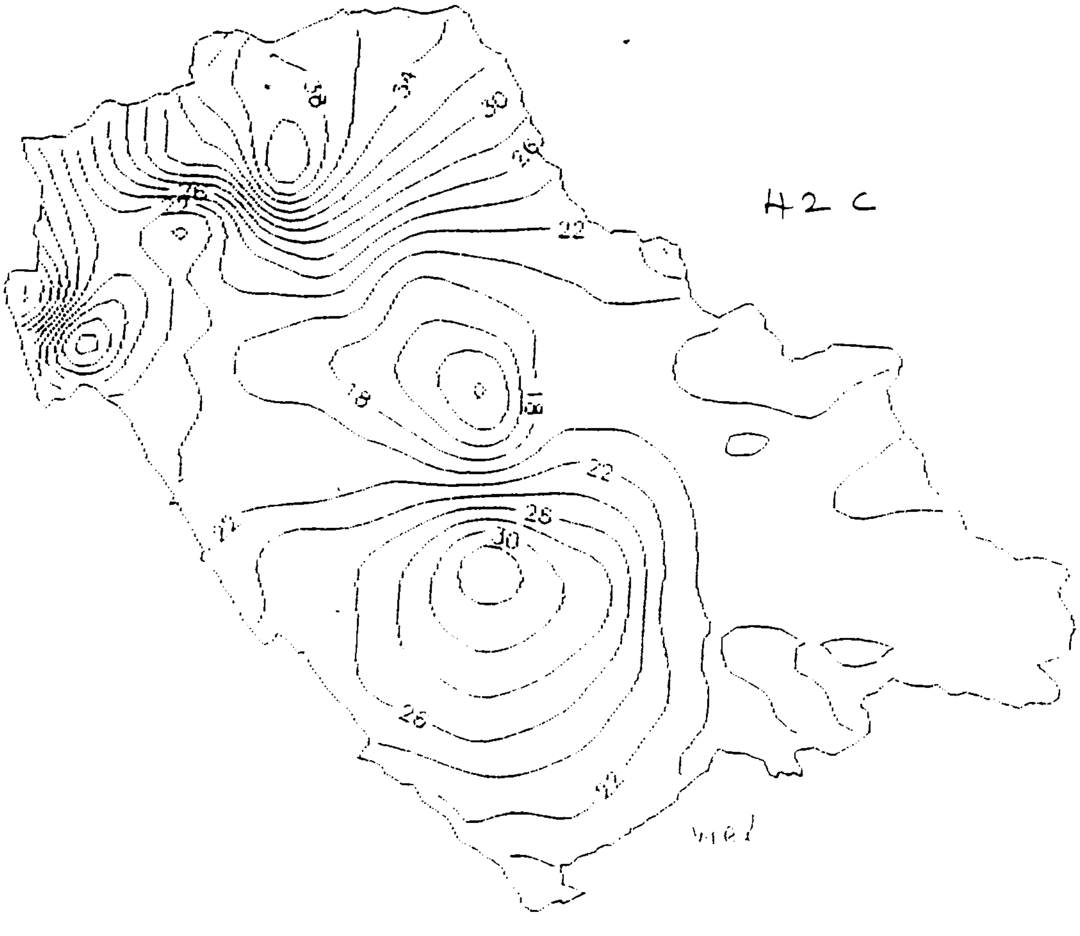


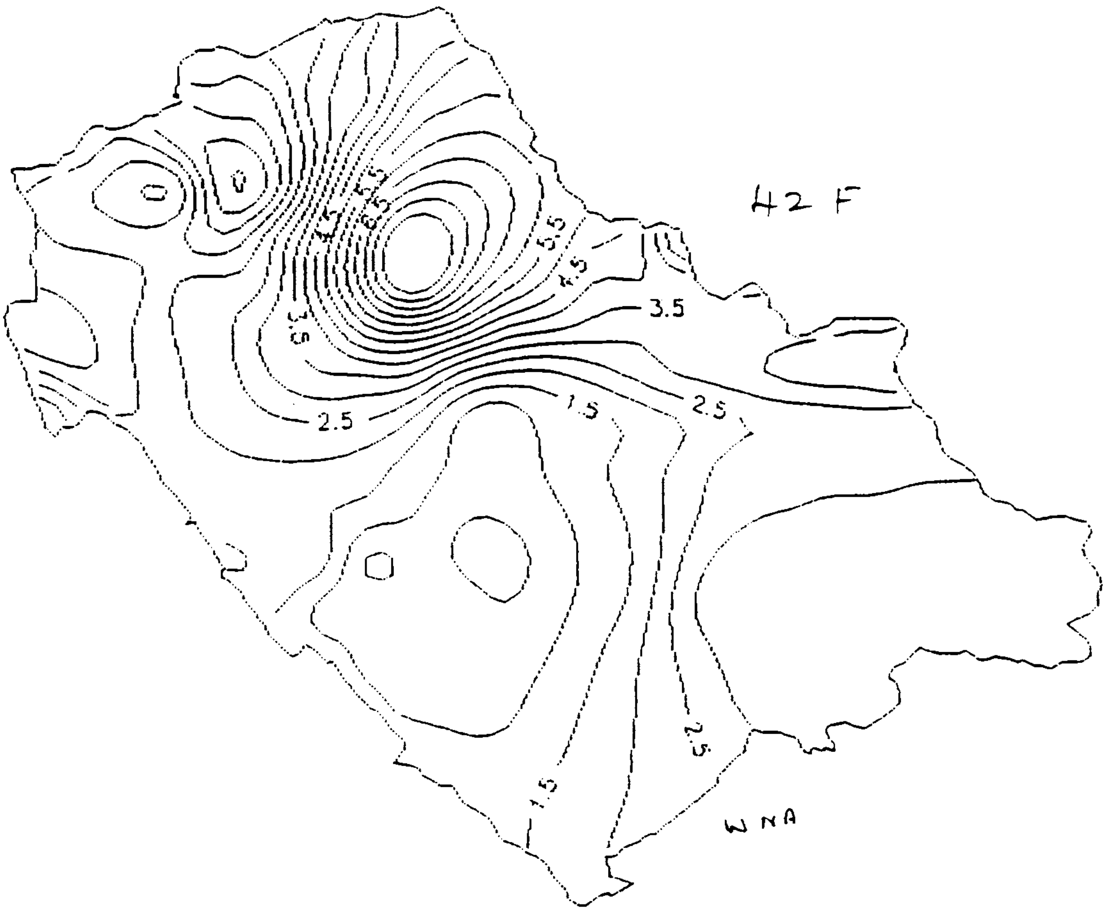
Fig.42 Major element distribution contour maps of Cannanore district based on weathered rock data (42 A : SiO_2, B : Fe_{203} C : Al_2O_3, D : MgO, E : CaO, F : Na_2O G : K_2O, H : TiO_2, I : LOI.


2.0
4.0
5.0
6.0
3.0
4.0
3.0
2.0
2.0
1.0
1.0
2.0
2.0
wca

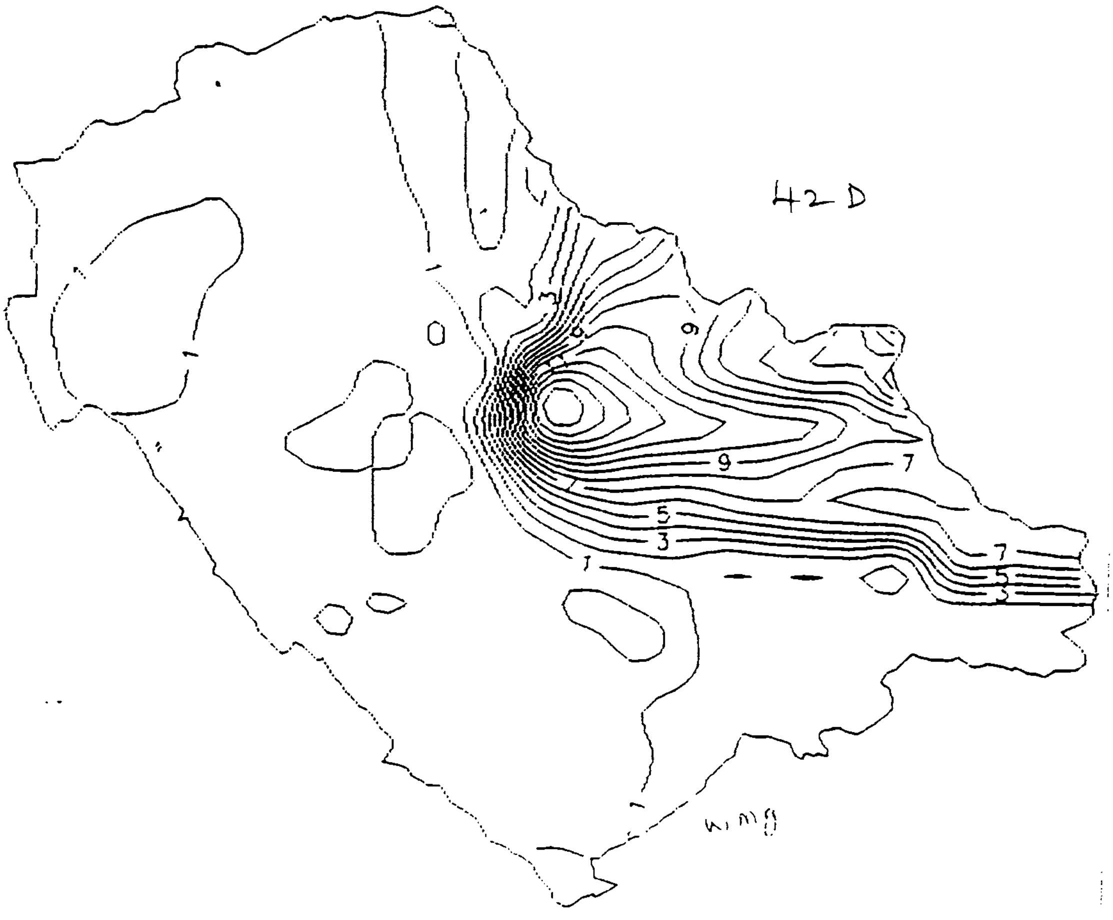
H2 E


38
34
30
26
26
22
18
18
22
22
26
30
26
22
wel

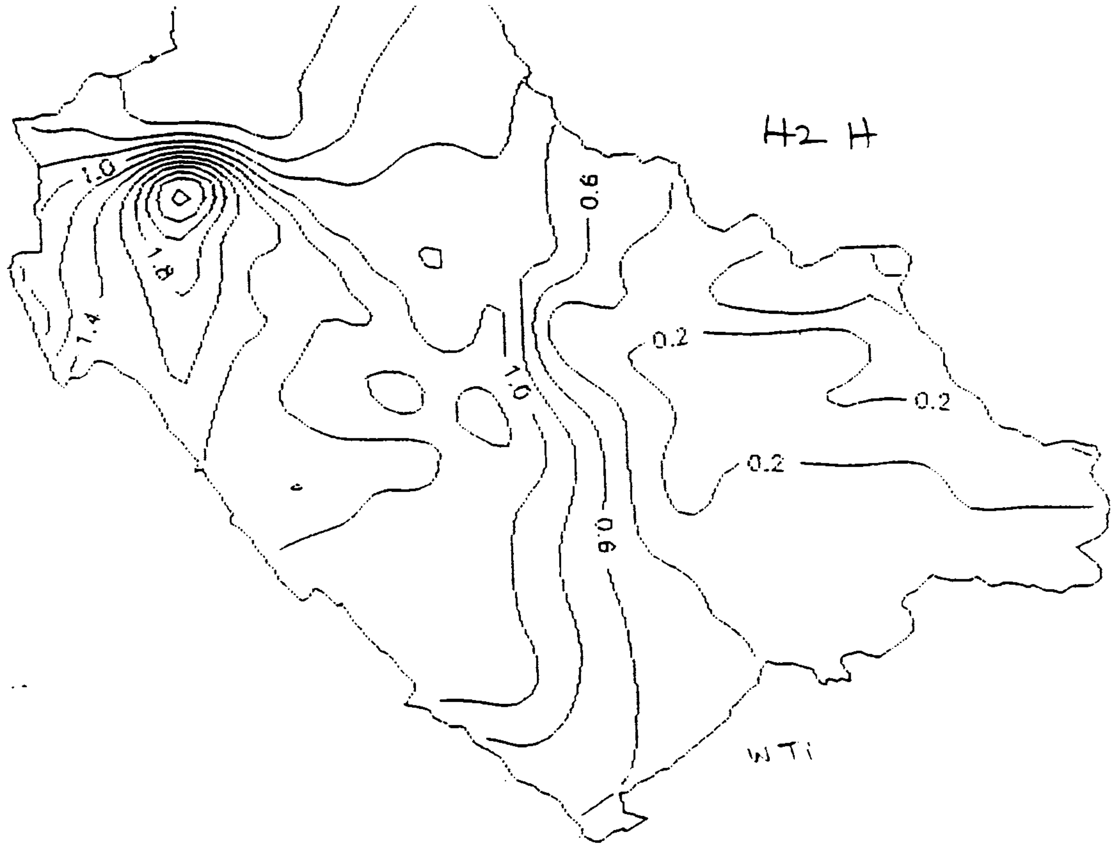
H2 C

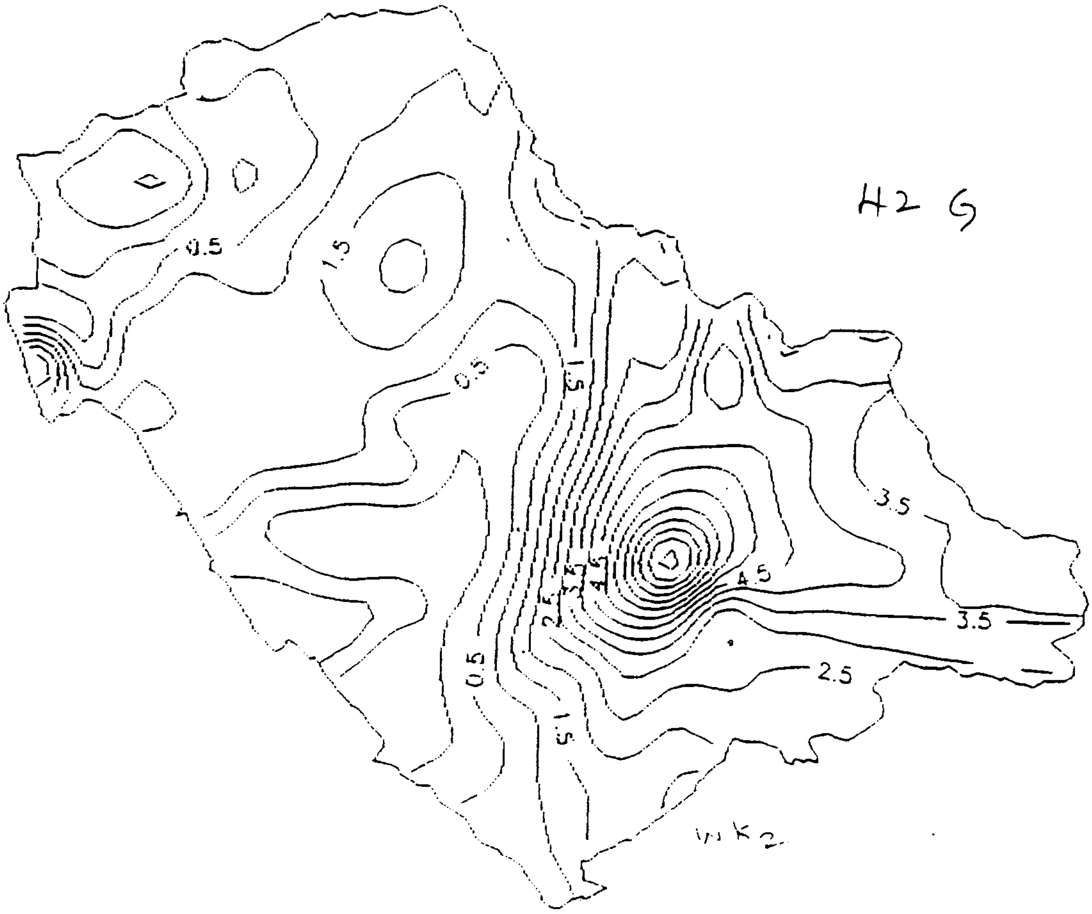


42 F

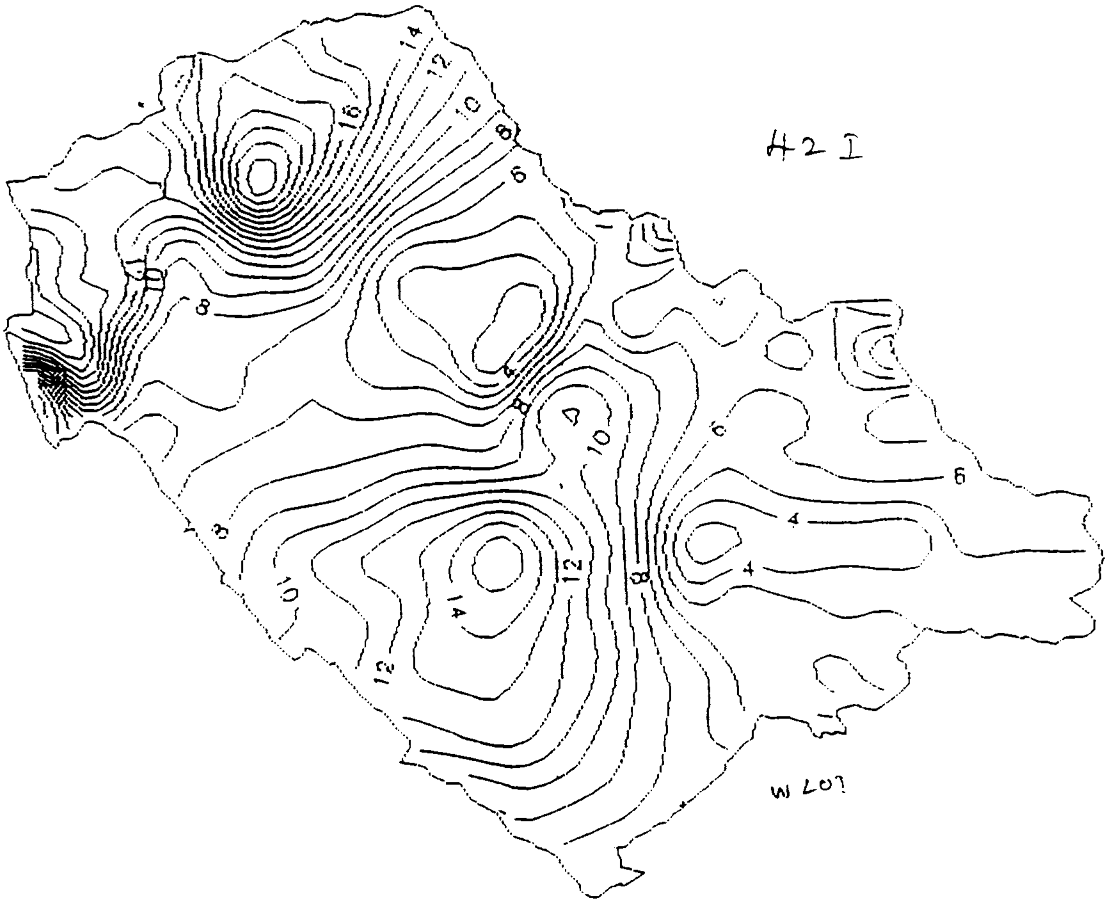


42 D


H2 H
1.0
1.8
1.4
0.6
1.0
0.2
0.2
0.2
0.6
WTi


H2 G
0.5
1.5
0.5
1.5
3.5
4.5
3.5
2.5
3.5
4.5
3.5
2.5
0.5
1.5
1.5
WK2

H2I



W L07

sedimentaries the ratio is 1.34 occasionally leading to the formation of bauxite pockets, as observed in the Palayangadi profile. Lower alumina enrichment in the upper parts of the profiles, as different from the Fe_2O_3 trends, is partly explained by the prevailing lower pH values (acidic), rendering alumina potentially mobile (Loughnan, 1960) and facilitating its migration to lower levels and precipitation there. Occurrence of "bauxitic clay" pockets in the lower portion of the laterite over sedimentaries in the Palayangadi profile, as well as in the weathered portion of the china clays of the same profile can be explained by this mechanism. In anorthosite, Al_2O_3 enrichment is 1.68 and lateritisation could lead to the development of nearly bauxitic patches with Al_2O_3 content of 39.76 wt% and 9.38 wt% of SiO_2.

4. Comparison of the enrichment and depletion of the major constituents during lateritisation leads to the following generalisations (i) The more the content of the mobile elements in the parent rock (Si, Mg, Ca, K & Na), the greater is the depletion during weathering and the concentration ratio of the less mobile element Fe is greater if their content is less in the parent rock suggesting that the concentration mechanism also included absolute enrichment. However, in the prevailing acidic environments, Al_2O_3 enrichment leading to the formation of bauxite in the weathering crust is possible if the bed rock has a high alumina content.

5. From the present studies, it is noticed that lateritisation is mostly a two stage process in the study area involving (1) the breaking down of alumino - silicate minerals to kaolin and rapid removal of alkalies and bases with corresponding enrichment of iron and alumina, and (2) gradual depletion and enrichment of these elements towards the upper part of the profiles. Iron enrichment is rather faster in the second stage in Fe-poor parent rocks.

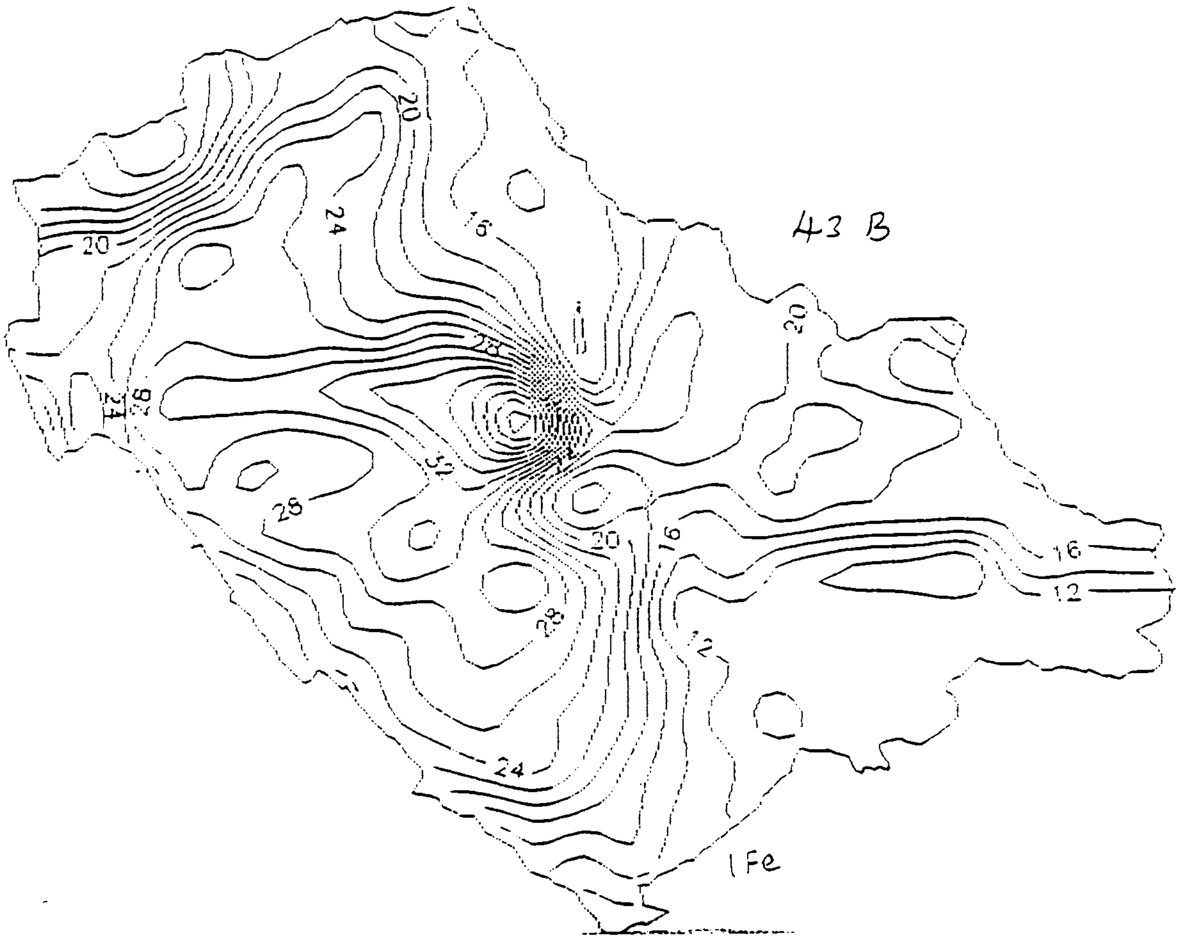
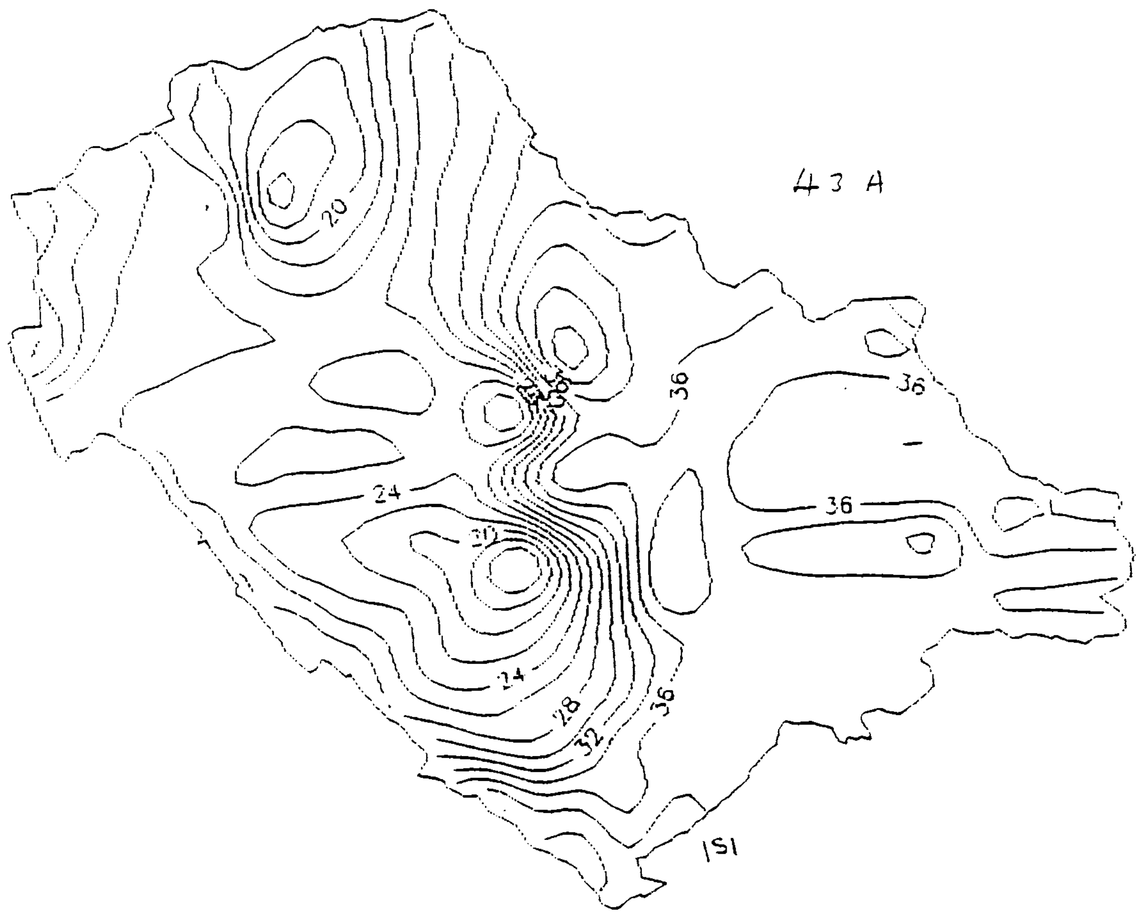
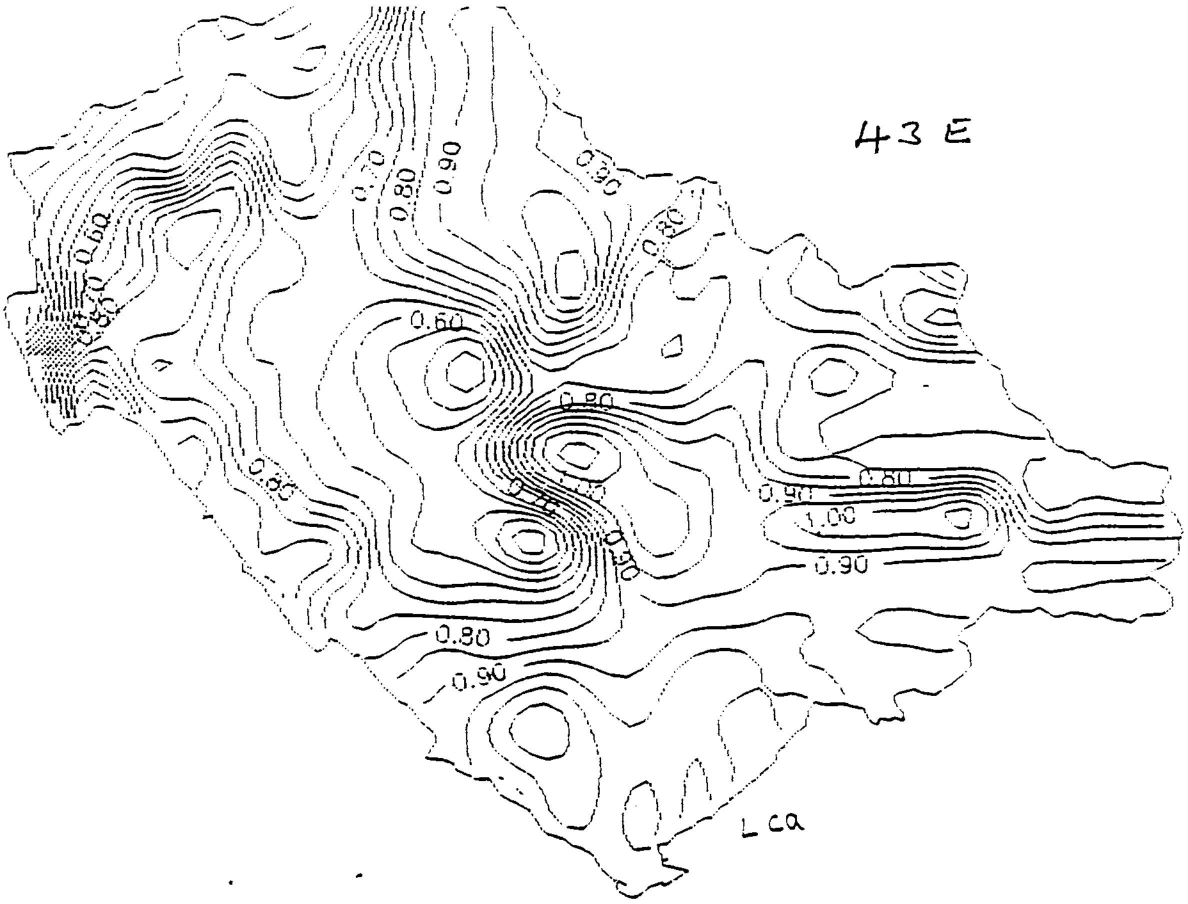
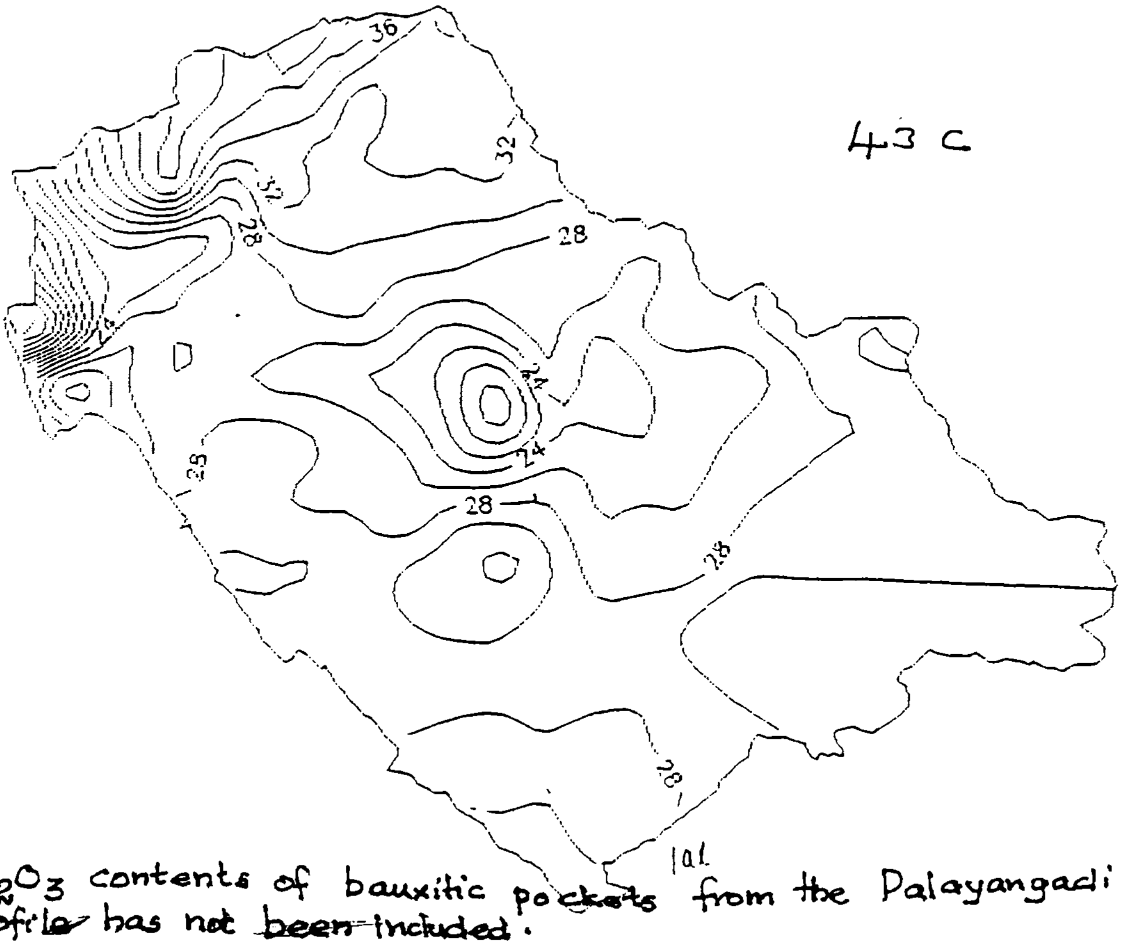


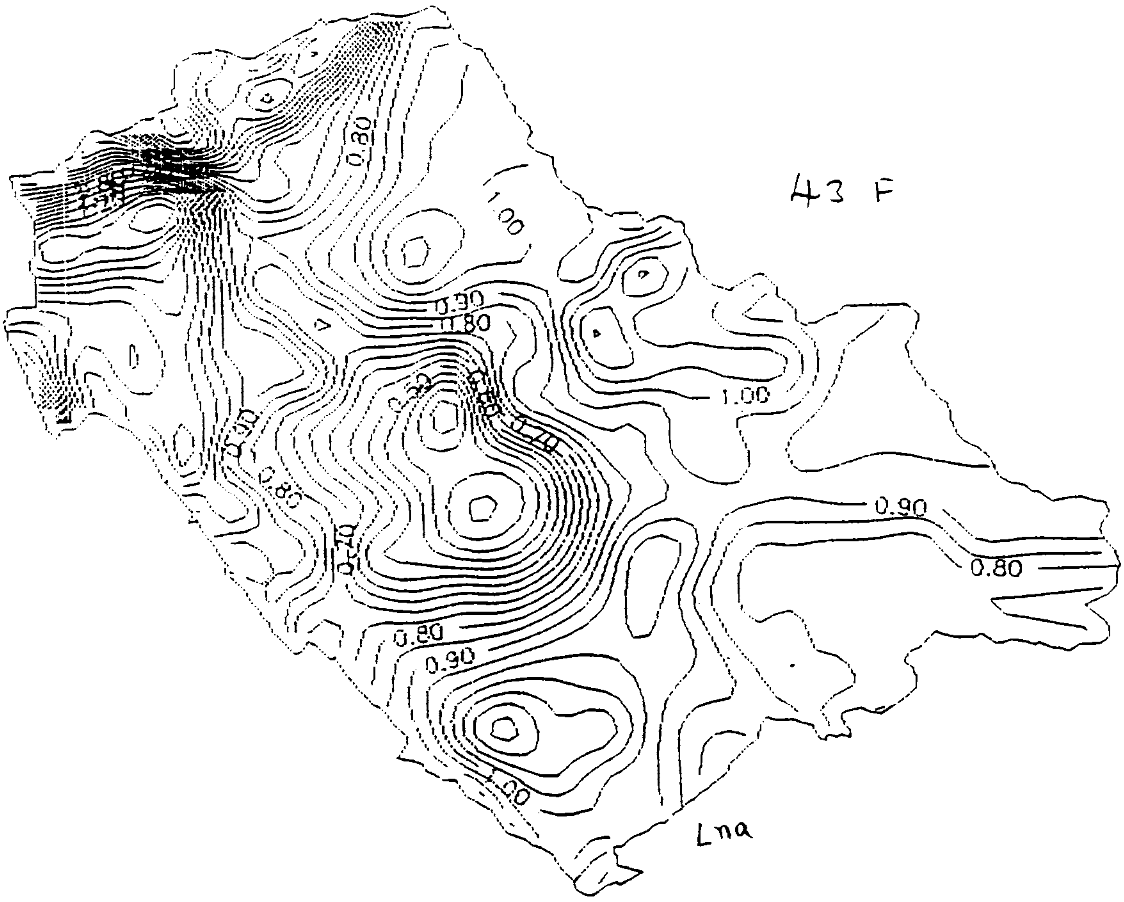
Fig.43 Major element distribution contour maps of Cannanore district based on laterite data (43 A : SiO_2, B : Fe_{203} C : Al_2O_3, D : MgO, E : CaO, F : Na_2O G : K_2O, H : TiO_2, I : LOI.




43 E

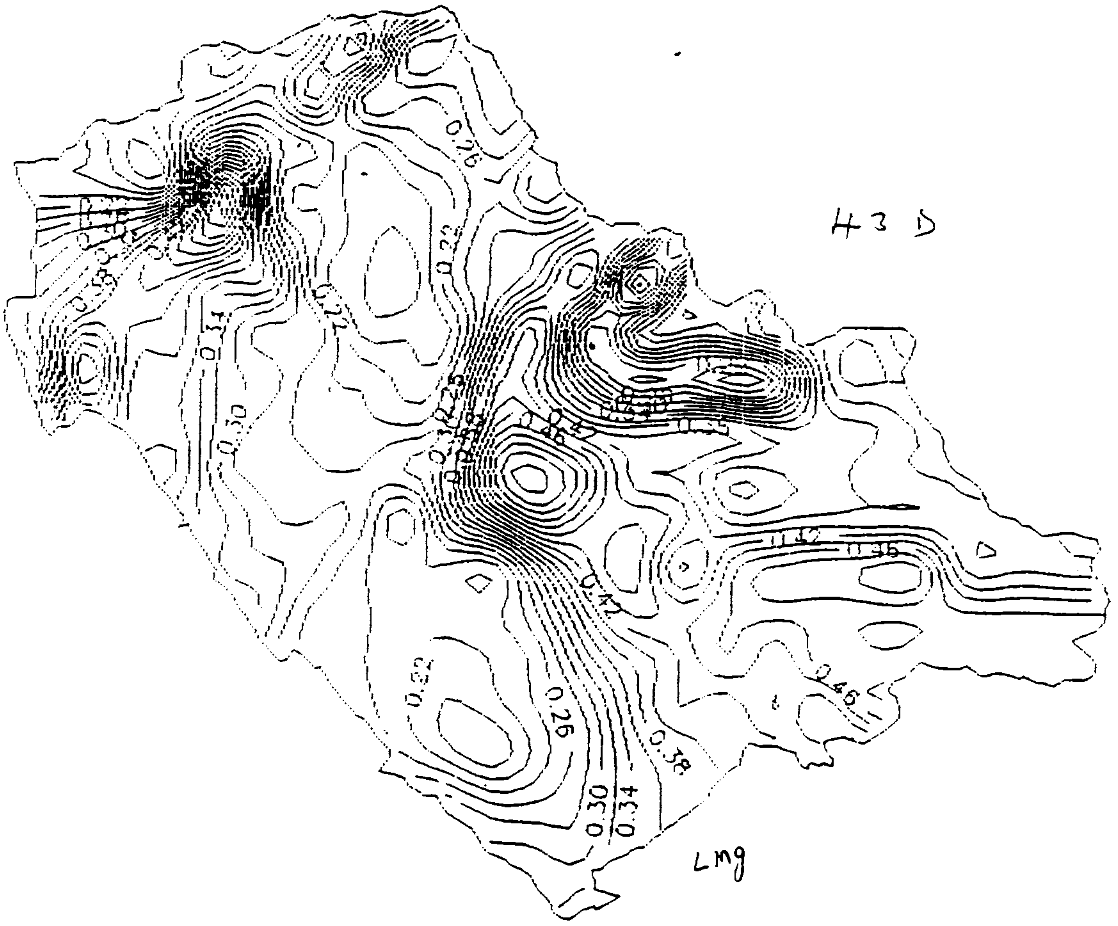

43 C

Note: Al_2O_3 contents of bauxitic pockets from the Palayangadi Profile has not been included.



43 F

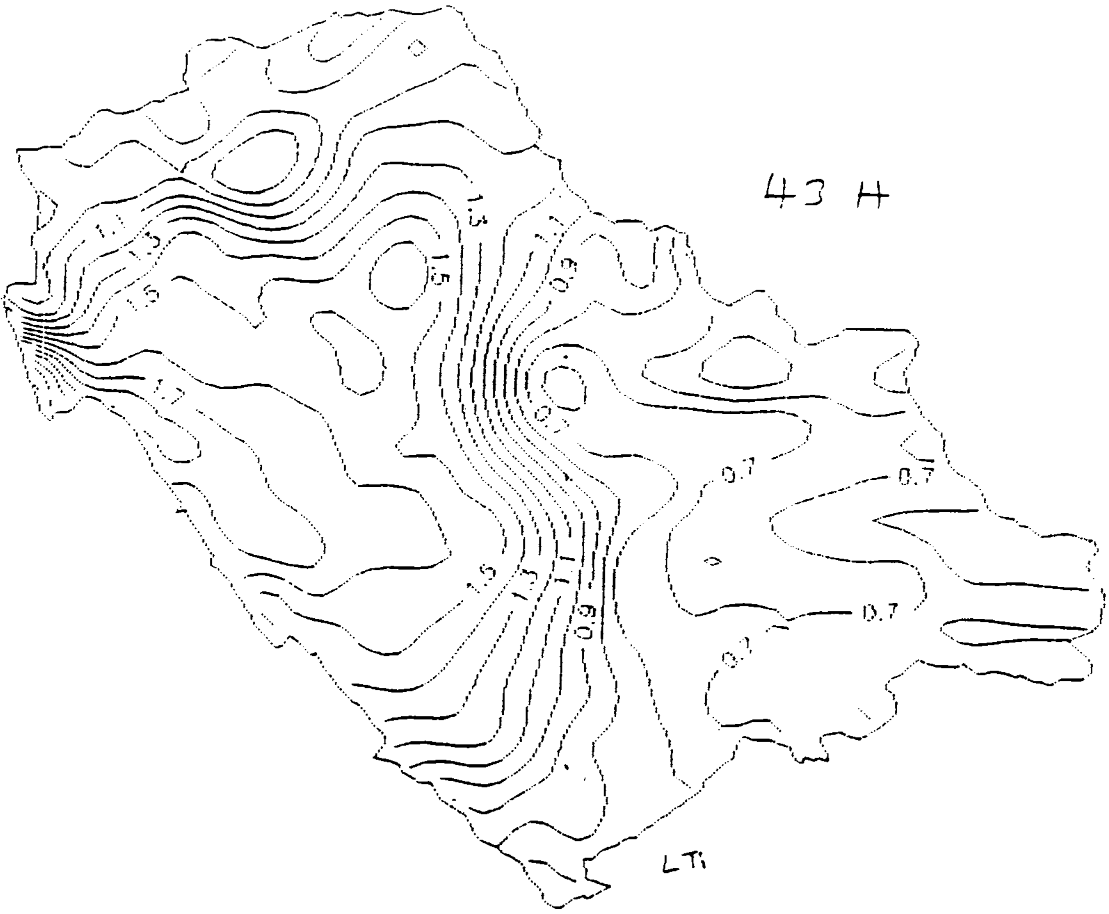
Lna



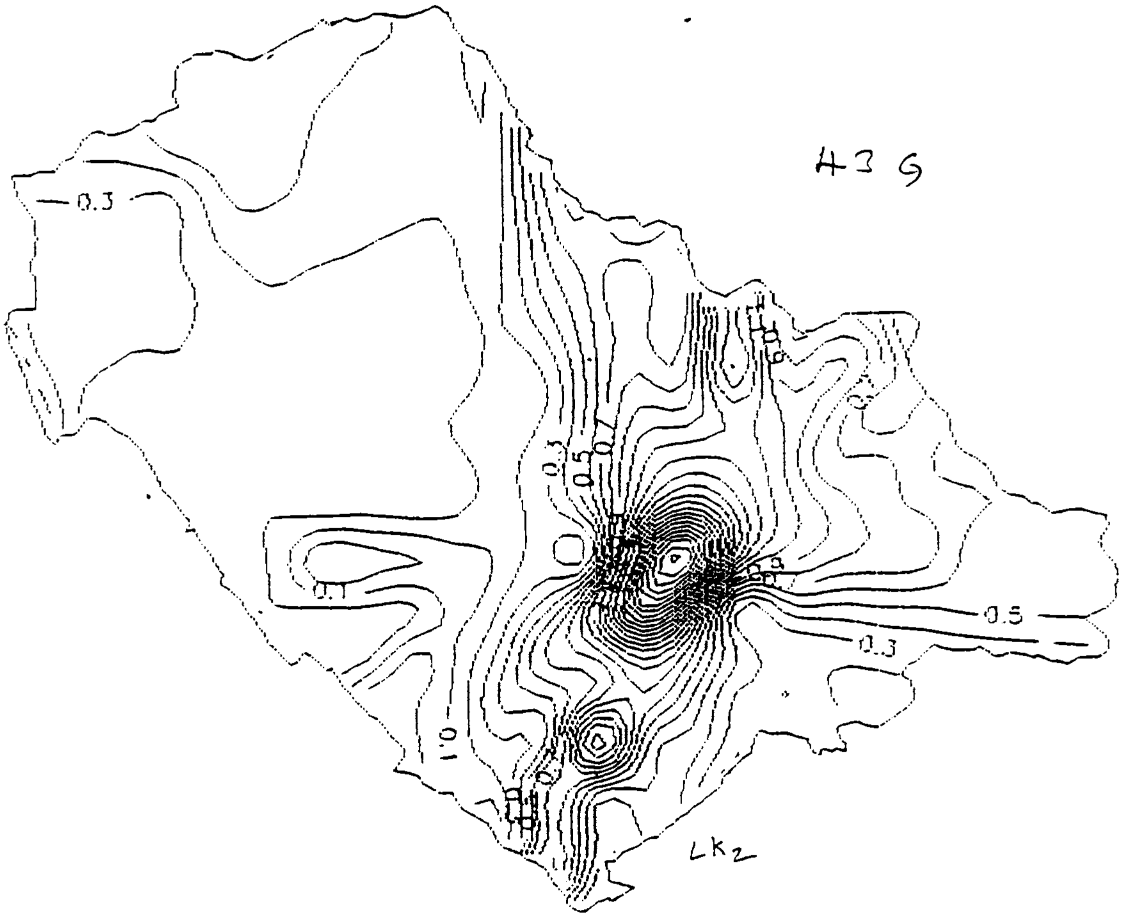
43 D

Lmg

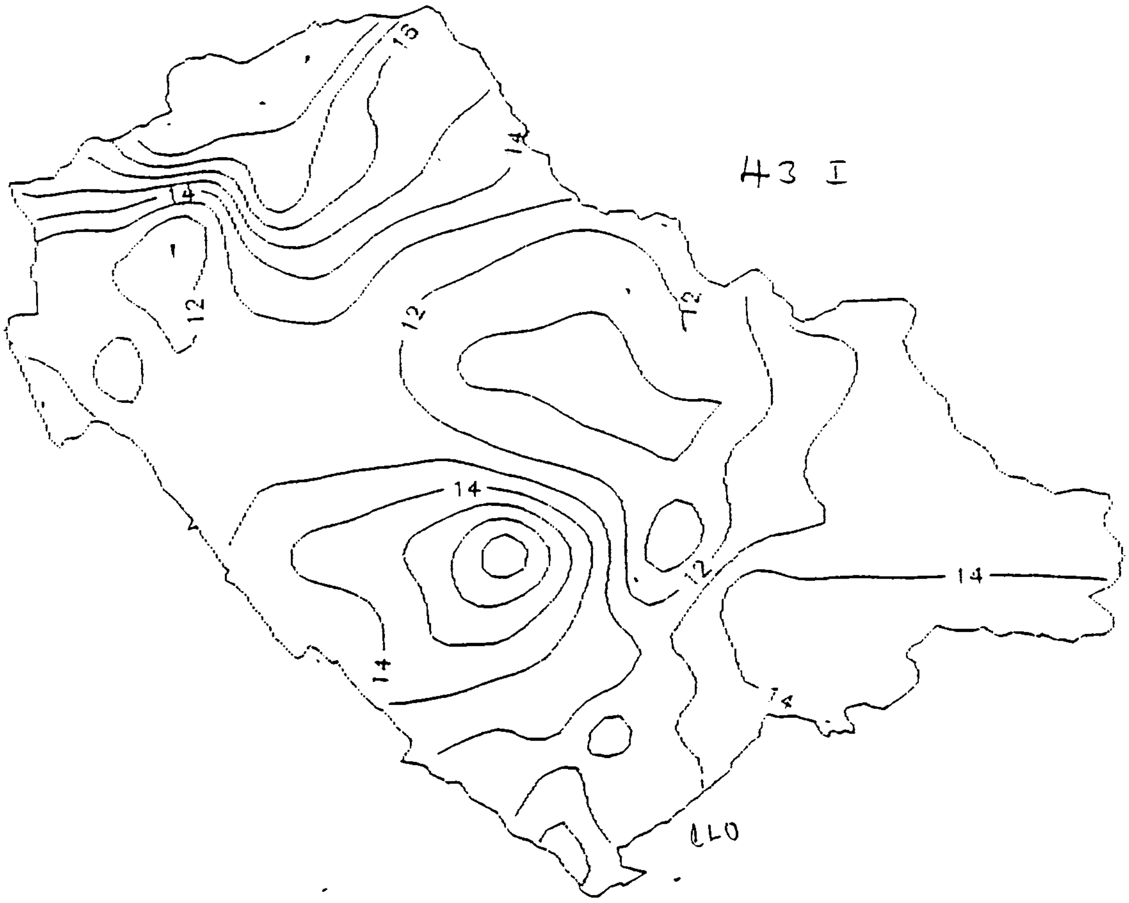
43 H


1.1
1.3
1.5
1.7
1.3
1.5
1.1
0.9
0.7
0.7
0.7
0.7
1.5
1.3
1.1
0.9
LTi

43 G


0.3
0.1
0.3
0.5
0.7
0.5
0.3
0.1
LK2

43 I



It is also noted that the bauxitic mineral, gibbsite is formed due to desilication of kaolinite as revealed from the profiles over anorthosite at Perinthatta and sedimentary formation at Palayangadi. Clays in the laterite act as absorbents for most of the trace elements. A third stage is also decipherable in profiles over anorthosite and sedimentary rocks.

4.4. RARE EARTH ELEMENT GEOCHEMISTRY OF LATERITES

Rare earth elements (REE) have similar chemical properties and are considered to be resistant to fractionation in supracrustal environments. This, coupled with their low solubilities, has resulted in REE distributions being used as a 'fingerprint' to help identify the parental materials of supracrustally altered rocks and sediments (Nesbitt, 1979). In this study, an attempt has been made to investigate the REE distribution patterns of the important units of the weathering profile (namely the vermiform laterite zone and the parent rock) over different parent rocks with the prime object of characterising the laterites based on their parent rock affinity.

4.4.1. Samples and methods

Samples from 3 profiles covering charnockite, alkali syenite and granophyre were chosen for the studies. 0.5 of the finely powdered sample was digested in HF/H_2SO_4 (3 drops) and evaporated off the HF completely. The residue was further digested using 1:1 HCl and made upto 100 ml.

50 ml of this solution was taken up for chromatographic separation using DOWEX[R] 50 AGWX-8 ion exchange resin preequilibrated with 1N HCl.

The column is eluted using 2N and 8N HCl acid. the 8N elutent was taken up for REE determination using ARL 3410 ICP with mini torch Nebiliser (Type K) with RF frequency 27.12 Mzh , RF power 650 watt. at the Regional Sophisticated Instrumentation Centre (RSIC), IIT, Madras. Results are given in Table-7.

4.4.2: Results

a) Chondrite normalised REE distribution patterns of charnockite and the overlying laterite are shown in Fig.44. The fractionation trends of REE in charnockite are more or less in agreement with the trends observed for charnockite from Kerala and Tamil Nadu (Chakraborthy *et al.,* 1983; Chacko *et al.,* 1992), showing flat to slight LREE enrichment with a characteristic negative Eu anomaly. REE pattern in laterite show resemblance to parent rock pattern and general REE depletion during weathering. However, Eu is higher in laterite (0.8 ppm) compared with (0.2 ppm) value in the parent charnockite.

b) Laterite profile over alkali syenite also yields sympathetic REE distribution pattern (Fig.45). The parent syenite depicts LREE enrichment and HREE depletion patterns which are characteristic of syenite in general (Kronberg *et al.,* 1987). Laterite REE value shows general depletion, possibly due to dissolution of the REE host minerals during weathering.

c) REE patterns of profile over granophyre are characterised by broad LREE depletion and HREE enrichment and display a positive Ce and negative Eu anomalies (Fig.46). In laterite REE shows general depletion except in Ce values.

Table 7 REE abundances in laterite profiles.

Profiles over	Sample No.	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Charnockite	1	60.4	315.0	154.4	84.0	25.2	0.2	14.4	11.6	20.6	0.0	58.2	0.6	40.2	15.0
	2	110.3	171.8	48.2	132.5	18.4	5.6	15.9	5.3	43.4	5.9	98.6	0.5	64.0	7.5
	3	34.4	171.6	135.0	59.6	0.0	0.8	7.2	5.4	2.2	0.0	169.4	0.6	32.6	34.8
Alkali Syenite	4	12.6	0.0	0.0	29.8	0.0	1.6	8.2	4.2	17.2	1.6	40.2	0.0	60.2	10.0
	5	10.8	0.0	0.0	22.4	6.8	0.0	2.0	4.2	6.8	0.0	32.2	0.0	12.6	15.0
	6	0.0	143.0	0.0	3.8	0.0	0.0	3.0	5.4	3.4	0.6	64.6	0.0	2.6	25.0
Granophyre	7	5.2	171.6	0.0	13.0	0.0	0.0	6.2	2.2	0.0	0.0	98.8	0.6	10.0	0.0
	8	2.4	42.8	0.0	5.6	0.0	0.0	3.1	0.5	18.3	0.0	5.6	0.3	7.5	10.0
	9	0.0	114.2	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	140.8	0.0	5.0	10.0

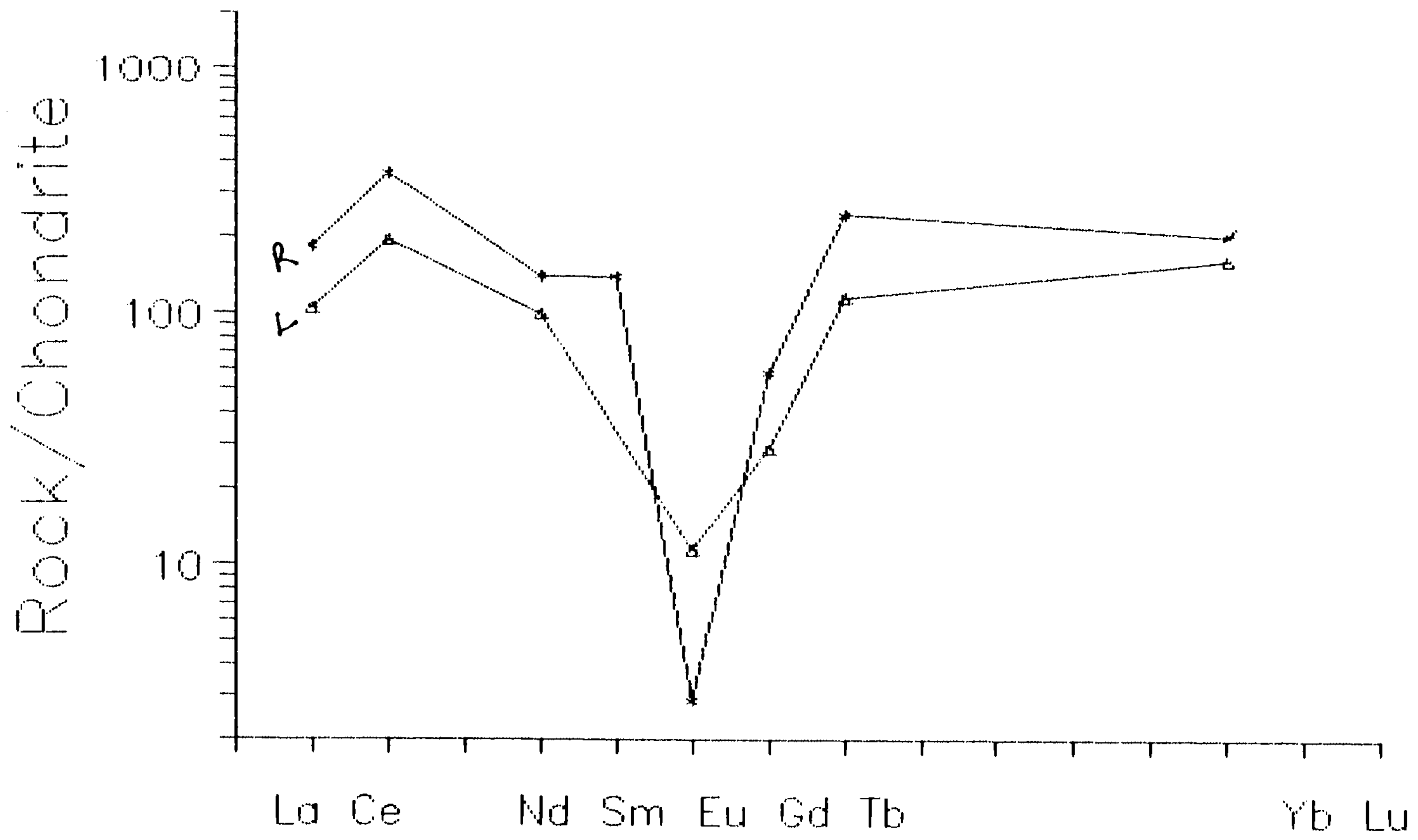


Fig.44 REE plots of laterite and parent charnockite (R = bed rock , L = laterite).

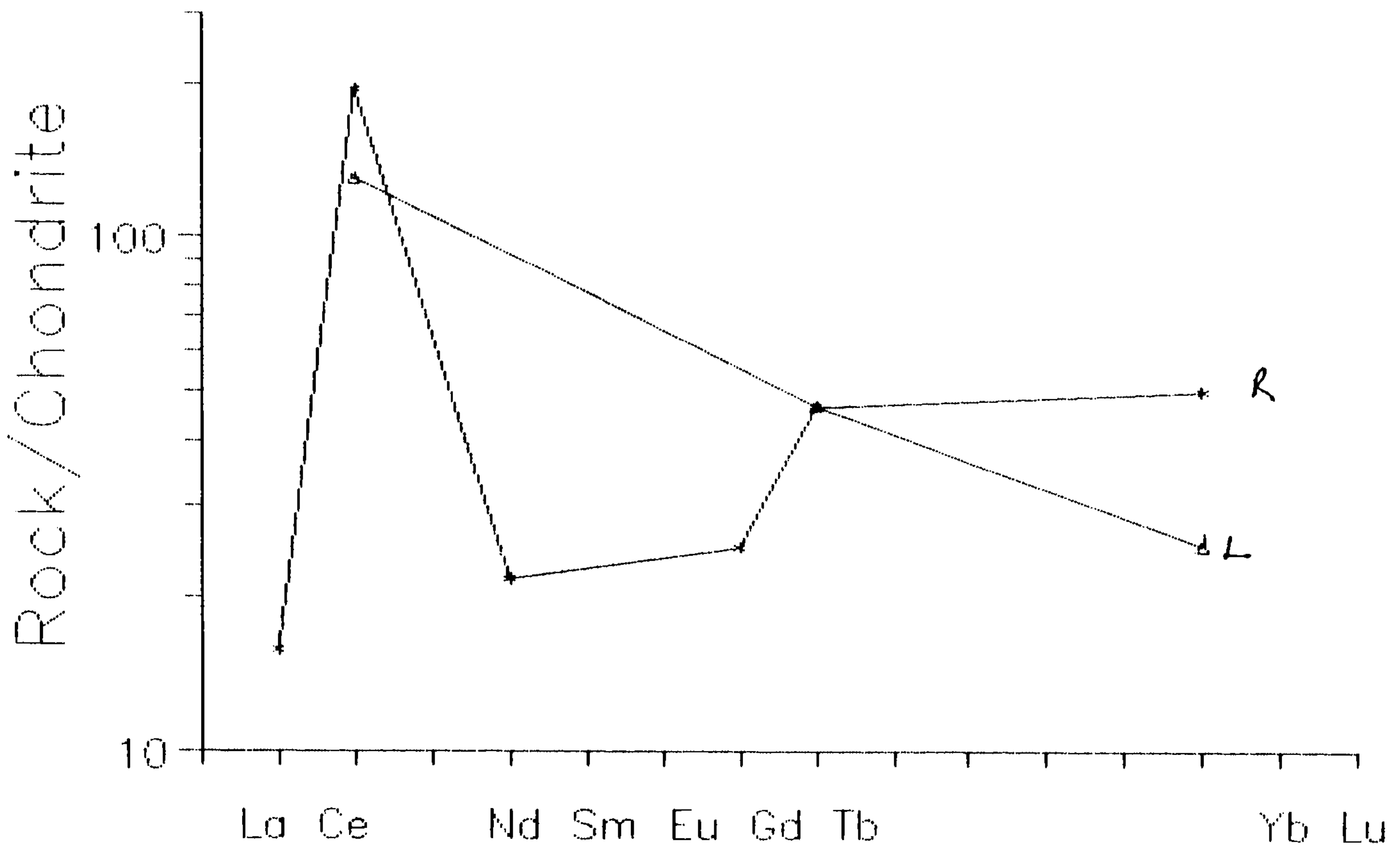


Fig.45 REE plots of laterite and parent alkali syenite (R = bed rock, L = laterite).

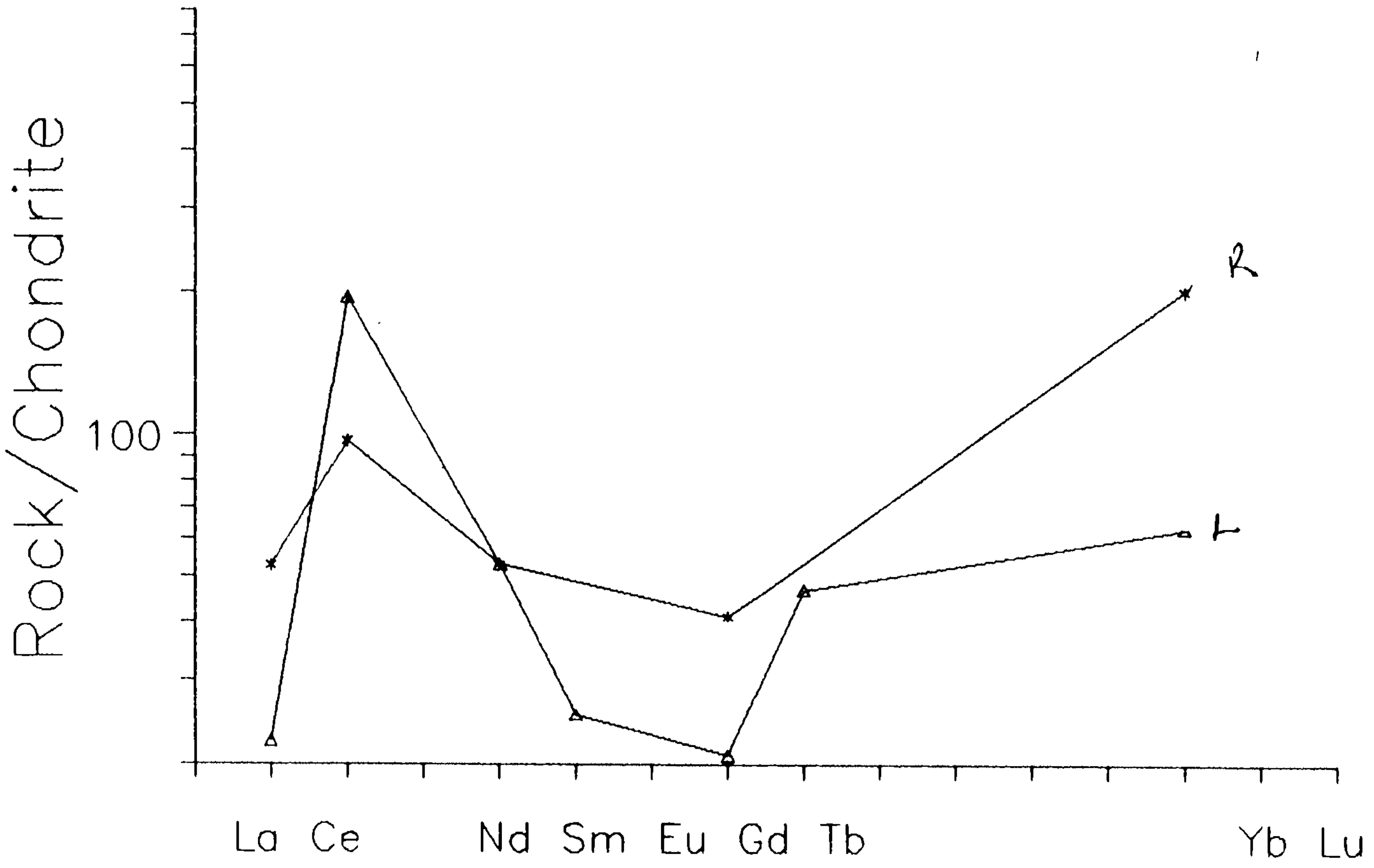


Fig.46 REE plots of laterite and parent granophyre (R = bed rock , L = laterite).

4.4.2. CONCLUSION

Based on the available REE data the following conclusions can be arrived at:

1) In all the three profiles investigated the parent rocks and the overlying laterite show sympathetic trends, resembling the known trends of the respective parent rocks.

2) Laterite shows general depletion trends except in Eu value over charnockite and Ce value over granophyre. This is in agreement with the finding of Burkov and Podporina (in Nesbitt, 1979), in which they obtained lower concentrations of REE in residual materials developed over granite. Similar findings have been reported by Nesbitt (1979) also on residual materials over granodiorite. Similar to their findings, the studied profiles also display higher concentrations of REE in the weathering front (partly weathered parent rock) than the parent rock (see Table no 7, not shown in Figure).

3) Mobilisation of REE probably results from pH changes as suggested by Nesbitt (1979).

4) It is therefore possible to use this technique for the elucidation of the bed rock character under laterite, wherever they are not exposed. However, more detailed investigation as to the behaviour of REE during weathering is required.

4.5. HYDROGEOCHEMICAL CHARACTERISTICS IN THE STUDY AREA

Water chemistry data and their evaluation are useful in determining the rate of leaching and the total amount of elements lost from the profiles due to water-rock interaction. As a part of the present investigation, water samples from a number of wells in the weathering profiles of the study area were collected and analysed. Since dissolved species in natural waters vary in different seasons due to water-rock interaction/aquifer-mineral interaction characteristics, samples were collected in two seasons. Results of the samples collected from 17 wells and 1 spring from the study area (for locations and rocks types see Table-8) are discussed here.

4.5.1. Samples and methods

Water samples were collected during December, 1981/January, 1982 when the water table was between 3.0 and 14.1 m, during November, 1982 when the water table was between 4.5 and 19.6 m and during July, 1983 (water table 1.8 - 12.4 m).

The samples were collected in polythene bottles in two sets. The polythene bottles were flushed with the well-water before sampling. pH was measured directly in the field using portable water quality analyser. Of the two sets, one set of samples was acidified to determine the cations. The other set was kept as such for determining TDS, CO_3 , HCO_3 , SO_4 , PO_4, and Cl^- .

From the acid treated samples, Si, Al, Ti, Fe, Ca, Mg, Na, and K were determined using Atomic Absorption Spectrophotometer (Perkin Elmer Model 4000). $CO3^{=}$, Cl^- , $SO4^-$, were determined by titration and TDS by loss on

Table 8 Trace element composition (ppm) of ground water from lateritic terrain, Cannanore district.

Profile Sl.No.	Sample No.	ph 1981	ph 1982	ph 1983	HCO3 1981	HCO3 1982	HCO3 1983	Cl 1981	Cl 1982	Cl 1983	K 1981	K 1982	K 1983	Na 1981	Na 1982	Na 1983	Ca 1981	Ca 1982	Ca 1983	Mg 1981	Mg 1982	Mg 1983	Fe 1981	Fe 1982	Fe 1983	Si 1981	Si 1982	Si 1983	Al 1981	Al 1982	Al 1983	Ti 1981	Ti 1982
1	1	6	-	6.11	3.66	-	10.98	8	-	16	0.38	-	.20	.38	-	6.06	0.22	-	6	0.08	-	2.43	0.03	-	0.44	1.5	-	2	.2	-	.15	nd	-
2	2	6.1	-	5.46	3.66	-	4.27	6	-	10	.38	-	.57	2.59	-	4.27	.81	-	2	.29	-	1.22	.15	-	.62	2.6	-	1.1	nf	-	.08	nd	-
3	3	5.9	-	5.46	6.1	-	6.1	6	-	10	.33	-	.11	1.95	-	2.96	1.21	-	1.2	.42		1.22	.13	-	.74	1.6	-	.6	nf	-	.42	nd	-
4	4	6	-	5.84	3.66	-	3.66	6	-	8	.53	-	.05	1.88	-	1.65	.52	-	.8	.25	-	.73	.24	-	.09	1.7	-	nf	nf	-	.10	nd	-
5	5	-	6.3	5.67	-	4.88	4.88	-	4	8	-	1.28	.1	-	6.33	1.96	-	1.6	1.2	-	.49	.73		.49	.37	-	3.1	.6	-	-	.12	-	nf
6	6	-	6.7	6.27	-	6.1	4.88	-	10	8	-	.05	.16	-	13.47	1.73	-	1.6	.8	-	.37	.43		.47	.28	-	3.7	nf	-	-	.09	-	nf
8	7	-	6.9	6.7	-	51.24	25.62	-	10	10	-	.68	.37	-	6.76	5.97	-	8	8.8	-	6.83	6.6		.37	.28	-	14.6	15.7	-	.2	.06	-	.1
9	8	-	7.3	5.77	-	10.98	9.76	-	10	8	-	.93	.39	-	4.96	4.31	-	3.21	2.4	-	1.35	2.7	-	.12	.31	-	7	5.1	-	.3	.13	-	.1
11	9	-	4.9	5.39	-	14.64	4.88	-	8	8	-	.7	.92	-	4.17	2.07	-	3.21	1.6	-	1.51	.43		.19	.28	-	9.6	.4	-	.1	.04	-	.2
12	10	-	7	5.29	-	8.54	6.1	-	10	12	-	.21	.57	-	2.96	9.77	-	3.21	2.4	-	.81	1.7		.41	.37	-	4.2	1.5	-	.1	.08	-	nf
13	11	6.5	-	5.8	6.1	-	7.32	6	-	16	.21	-	.39	2.95	-	1.9	1.34	-	2.4	.2	-	1.2	.12	-	.38	5.4	-	.7	.1	-	.44	nd	-
17	12	-	6.6	5.39	-	8.54	4.88	-	24	30	-	1.12	.15	-	12.81	19.4	-	4.81	4.4	-	.37	1.7		.59	.08	-	3.3	1.3	-	-	.1	-	.1
21	13	6.5	-	5.68	4.88	-	3.05	8	-	8	.64	-	.14	4.11	-	3.62	1.19	-	1.2	.31	-	.37	.01	-	.09	4.4	-	1.1	nf	-	.08	nd	-
22	14	-	7.6	6.7	-	2.44	3.66	-	10	10	-	.16	.13	-	3.42	2.03	-	nf	1.2	-	5.35	.24		.37	.02	-	3.7	2.1	-	1.7	nf	-	nf
23	15	-	7	6.75	-	4.88	7.32	-	8	14	-	.69	.9	-	4.09	2.22	-	2.49	4.8	-	0.32	0.73	-	.14	1.79	-	.4	2.2	-	.2	2.57	-	nf
27	16	-	6.6	5.5	-	7.32	4.88	-	10	8	-	1.37	.36	-	4.58	3.56	-	1.6	1.6	-	.37	.37	-	.31	.31	-	7.9	3	-	-	nf	-	.1
28	17	-	7	5.36	-	7.32	6.1	-	10	6	-	1.57	1.23	-	2.92	2.52	-	1.6	1.6	-	.23	.43	-	1.7	.31	-	5.6	2.1	-	-	nf	-	.1

Water samples from Laterite profiles
(Profile No. as per table 5; locations given in Index 1)

Profile No. 1 to 4 : Charnockite
Profile No. 5 & 6 : Gneiss
Profile No. 8 & 9 : Ultamafite
Profile No. 11 & 12 : Quartz-mica schist
Profile No. 13 : Anorthosite
Profile No. 17 : Gabbro
Profile No. 21 to 23 : Granophyre
Profile No. 27 & 28 : Alkali Syenite

weight.

4.5.2..Results and discussion

The chemical composition of water samples collected during different seasons from laterite profiles developed over 7 rock types are given in Table. Results do not show any marked variation in their water chemistry depending on the bed rock or on the geomorphic units. However, water samples collected from the vermiform zone of ultramafic rocks, gabbro, mica schist, granophyre and charnockite have subtle differences in chemical composition. The analyses of water samples collected during December, 1981/ January, 1982 and June/July, 1983 have pH values ranging from 5.02 to 6.75, while the samples collected during November, 1982 have pH values ranging from 6.6 to 7.6.

The acidity of water is expected because of the absence of bases in the upper horizons of laterite. The respiration of microbes, decay of plant material (reaction 1) and activity of roots (reaction 2) which will all release CO_2 increasing the partial pressure of CO_2 , all make the water acidic. Hydrolysis reaction of ferric and aluminium ions (reaction 4) will also decrease the P .

$CH_2O + O_2 = CO_2 + H_2\,O = H_2CO_3$ --(1)

$CO_2 + H_2O = H_2\,CO_3$ --(2)

$H_2CO_3 = H^+ + HCO3^-$ --(3)

$Al^{3+} + 3H_2O = Al(OH)_3 + 3H^+$ --(4)

Anionic composition of the water consists of $HCO3^-$, $C1^-$, and PO4- . There is a total absence of NO_3, SO_4 and CO_3. The relative concentration of HCO3- is caused by the low pH range where majority of the dissolved carbonate species will be in the form of H_2CO_3 (Krauskoff, 1979). The low levels of Cl^- and PO_4 contents are due to absorption and complex formation of ferric and aluminium compounds with them.

Table 8 shows the concentration of cations in the water samples of laterite profiles. There are several possible sources of these ions in the water. They are (i) the relict A1 - silicate minerals such as K - feldspar, plagioclase etc, which are not yet completely weathered (2) break down of newly formed minerals such as kaolinite and hematite or goethite in the top horizons (3) decay of plant materials and (4) fertilizers used for agriculture. As the samples were collected after four months of the cessation of the monsoon and just during the beginning of the monsoon, the contribution of elements from the last two sources may be assumed to be negligible or nil.

The source then may be ascribed to the minerals either remnant or newly formed ones. This leads us to consider the equilibrium relationship between the minerals which may be used in defining the stability relationship. Although a number of mineral phases may be utilised for such exercises, the relationship, between feldspars, kaolinite, and gibbsite (Garrels and christ 1965) are considered here.

$$3KAlSi_3O_8 + 2H^+ + 12H_2O = KAl_3Si_3O_{10}(OH)_2 + 6H_4SiO_4 + 2K^+ \quad (5)$$

(K- Feldspar) (Mica)

$$2KAl_3SiO_8 + 2H^+ + 9H_2O = H_4Al_2Si_2O_9 + 2K^+ + 4H_4SiO_4 \quad (6)$$

(kaolinite)

$H_4Al_2Si_2O_9 + 5H_2O = Al_2O_3 + 3H_2O + 2H_4SiO_4$ (7)

(Gibbiste)

Likewise, for plagioclase, similar relationship can also be written in terms of Na^+ and Ca^{++} . Considering these, it is clear that only dissolved species namely H^+ , K^+ and H_4SiO_4 need be considered to define the relationships. These diagrams are presented in Figures.47 A to C and the respective log Na/H, log K/H and log H4 SiO4 were plotted in the diagrams. The plots fall mostly in the stability field of kaolinite, and rarely in the field of gibbsite, indicating that these are the solid phase in equilibrium with the groundwaters.

It is apparent from the plots of analytical data, that the most stable phase in these profiles is kaolinite.

Dissolved silica in the form of H_4SiO_4 is also present in an amount ranging from 1.4 to 5.4 ppm. In the absence of any aluminium in the water sample, this tends to support the finding that desilication of gibbsite takes place in the laterite horizons.

The relatively higher amount of Fe in water (Table 8) indicates that ferric hydroxide or hematite/goethite are being actively leached by ground water. Fe in the water samples is derived from the dissolution of the minerals present in the lower laterite horizons in contact with acidic water in an environment deficient in oxygen. However, the mode of the Fe in water in form of organic metal chelate as transport of iron as free Fe2+ or Fe3+ is unlikely in this environmental mileu.

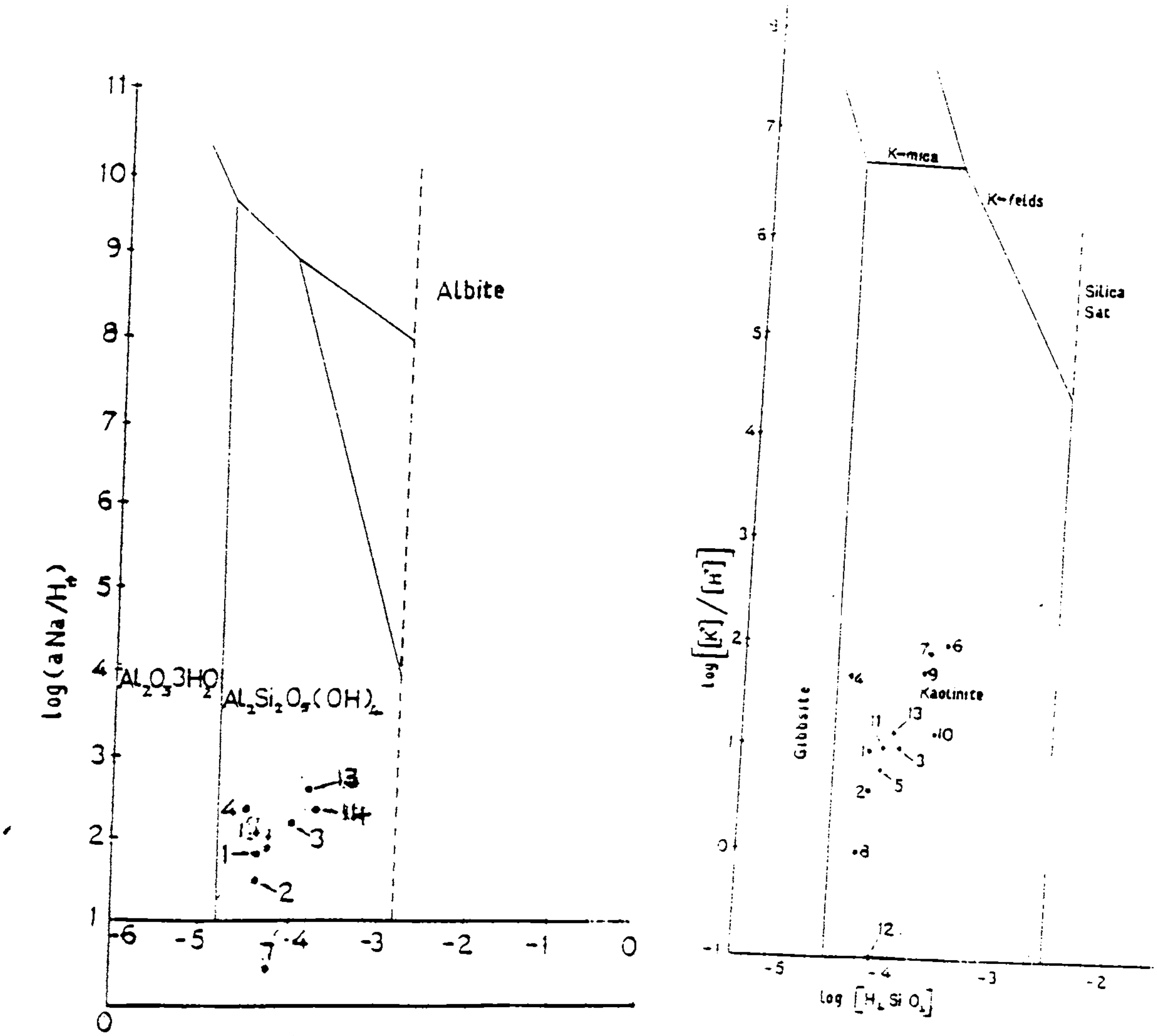
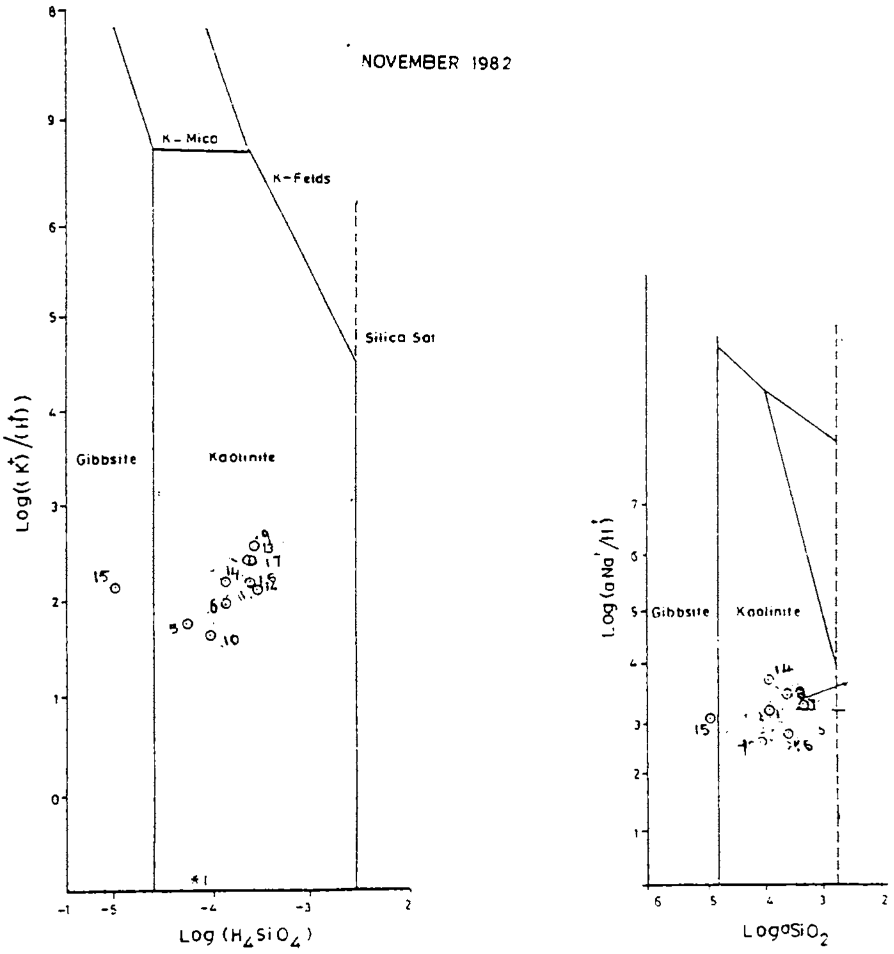


Fig. 47A. December 1981/January 1982

(i). plots of water chemistry data in the system plg-kaol- gibb (after Loughnan, 1969).

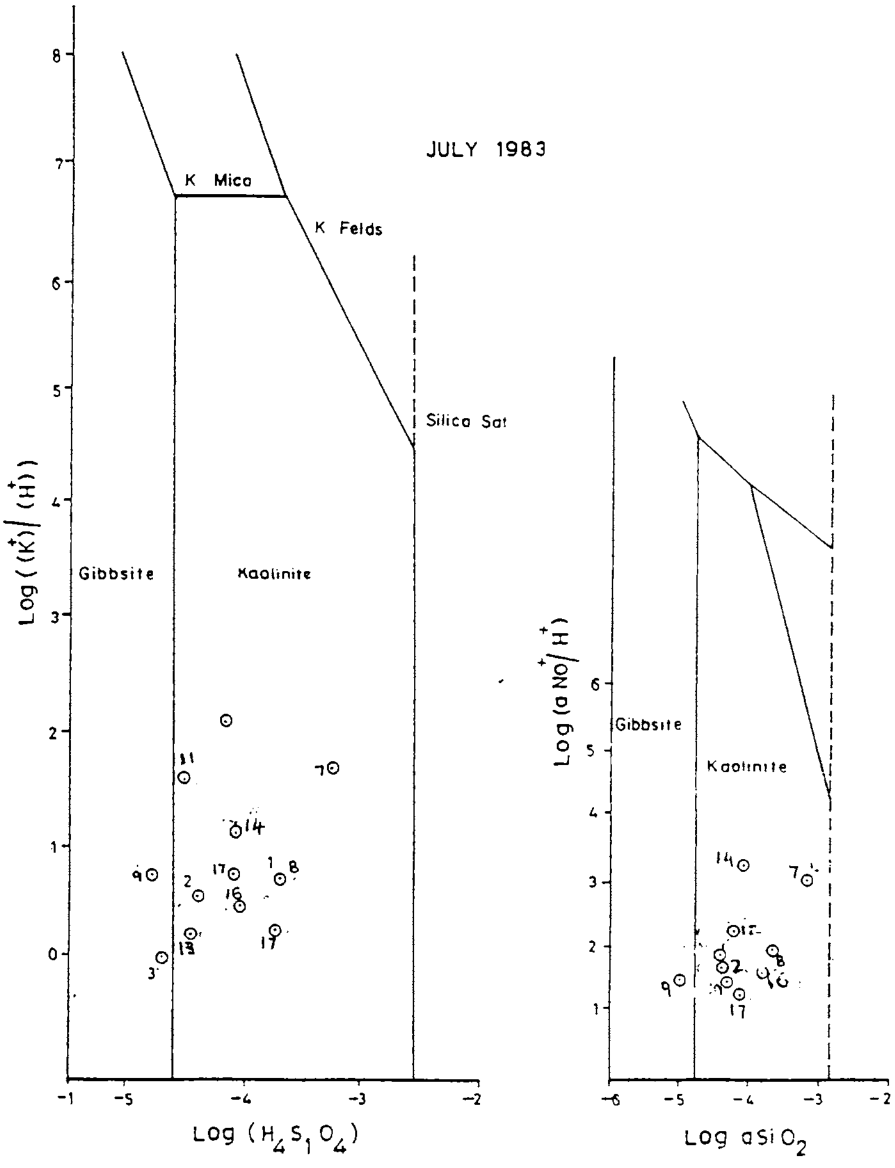
(ii). plots of water chemistry data in the system K-felds-kaol-gibb-K-mica (after Garrels and Christ, 1965)



47B Nov. 1982

(i). plots of water chemistry data in the system plg-kaol- gibb (after Loughnan, 1969).

(ii). plots of water chemistry data in the system K-felds-kaol-gibb-K-mica (after Garrels and Christ, 1965)



47C July 1983

(i). plots of water chemistry data in the system plg-kaol- gibb (after Loughnan, 1969).

(ii). plots of water chemistry data in the system K-felds-kaol-gibb-K-mica (after Garrels and Christ, 1965)

4.6.CONCLUSIONS

1) The acidity of water in the studied laterite profiles is due to respiratory activity, decay of plant materials and hydrolysis reaction leading to the formation of Al and Fe hydroxides.

2) The alkalinity of the water in the studied laterite profiles during post monsoon season is due to prolonged contact with silicate minerals.

3) Cl, HCO_3 are present in low concentration in the water.

4) Considering the phase relationship, kaolinite seems to be the most stable Al - mineral. Gibbsite in the lower horizons may be resilicated to form kaolinite.

5) There is an indication that Fe is being leached from the profiles, which may ultimately lead to the formation of Al rich horizon.

Chapter 5

GENESIS AND GEOMORPHIC SIGNIFICANCE

Laterite and bauxite, products of intense sub-aerial weathering under tropical conditions are noticed throughout the world and have been found to be derived from a variety of rocks. This process of chemical weathering involving removal of large quantities of silica, alkalies, lime and magnesia, with concomitant residual enrichment of alumina and iron along with certain trace elements, takes place in a strongly oxidising and leaching environment under conditions of planation

Ionic potential, p^H and e^H are the principal chemical factors that affect the behaviour of the chemical constituents during lateritisation. As shown in Fig. 48 the alkaline and alkaline earth cations with a small ionic potential are highly soluble, and consequently leached out. Fe^{+2} behaves similar to the alkaline cations. The elements of intermediate ionic potential such as Al^{3+} and Ti^{4+} precipitate as insoluble hydroxides. Finally, silicon with its high charge forms soluble complex and tends to be leached out.

The aluminium content in the laterite/bauxite mainly come from the decomposition of the feldspars. A direct alteration of K-feldspar to gibbsite is possible only if the P of the leaching solution is above 4.3 and the concentration of dissolved silica is less than $10^{-4.6}$ moles/litre (Gardner, 1972). Kaolinite is metastable under the conditions of laterite/bauxite formation and is consequently dissolved either congruently or incongruently (Garrels and Christ, 1965; Gardner, 1972; Kittrick, 1969; Norton, 1973).

The following are the important factors that control the composition of the final residue resulting from the formation of bauxite/laterite as per Norton (1973).

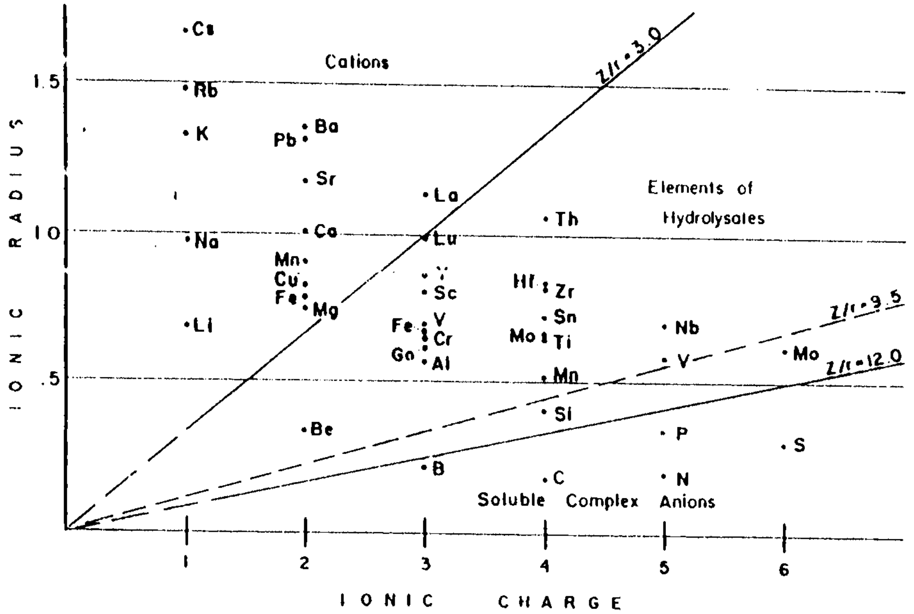


Fig.48 Grouping of certain elements according to their ionic radii and charges (after Mackenzie et al., 1952)

1. Climate, rainfall and temperature
2. Period upto which the solutions act on the bedrock and the neoformed minerals
3. Topography
4. Groundwater movement
5. Drainage
6. Relative rates of chemical and mechanical erosion
7. Type and amount of vegetation and
8. The bedrock character

Of these factors that facilitate the chemical weathering (Norton, 1973), bed rock character and mainly and topographical features to some extent are different for the various laterite cappings in the Cannanore district. Vegetation features have not been included in the present study, and hence the genesis of the Cannanore laterites are basically approached from the angle of bed rock characteristics and their topographical features.

Major element geochemical trends indicate mostly a two stage development of laterite profiles in the area with the exception of anorthosite and sedimentary rock units. The first stage is marked by break down of alumino-silicates and rapid depletion of certain elements (K,Na,Ca,Mg,Fe^{2+},Si et.) with concomitant enrichment of Al_2O_3, TiO_2 and Fe_2O3 followed by a gradual depletion of the former set of elements during the second stage.

Among the trace elements V, Co and Ni generally show enrichment, whereas Ba and Zn show general depletion consistent with their geochemical affinities with feldspars. In laterites over ultramafites, nickel is getting concentrated (see Table 6) which is also supported by the presence of garniearite in the XRD (Fig. 21D).

The calculated geochemical mobilities for various elements in charnockites and pyroxenites of the ultramafites show that Mg is more mobile than other elements, and Na and Ca are relatively less mobile. This is supported by petrographic findings in these rocks types, where alteration of pyroxenes precedes that of feldspars. Alteration of pyroxenes in the beginning of the weathering process is attributed to its-relatively less stable structure. In quartz-mica schists also Mg is more mobile than Na, which is also substantiated by earlier alteration of hornblende than the feldspars or muscovite. The measured values of Mg in groundwater from wells in these rock localities further substantiate these findings (also ref. Table 8). The relatively higher mobility of Fe^{2+} in these rocks types results in less iron-enrichment ratios varying from 2.48 in charnockite though 3.28 in quartz-mica-schist to 3.34 in ultramafites.

Fuchsite-quartzite rock type, in contrast, is characterised by lesser mobility of Fe^{2+} and Mg compared to other elements including, K, Ca and Si and displays very high iron-enrichment ratios (64.22). Occurrence Fe-rich laterites over the schistose rocks in the Western Ghats region may be attributed to this peculiarity in the geochemical transformation to laterite.

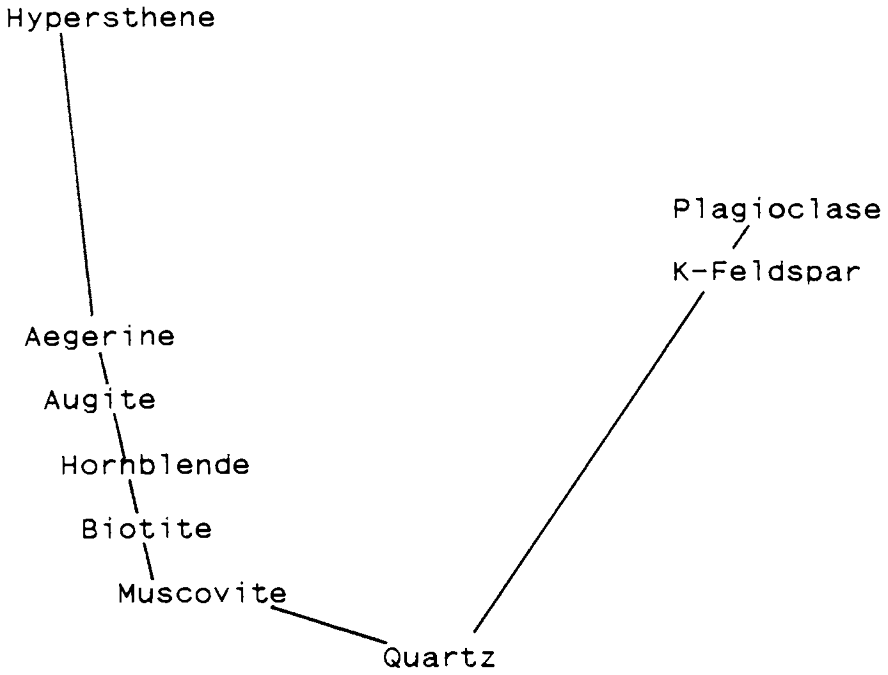
In anorthosite and gabbro Ca and Fe^{2+} are more mobile than rest of the elements and K and Mg are less mobile. This trend is consistent with their bulk geochemistry and the measured Ca and Fe values in groundwater from the gabbro/anorthosite terrains. However, iron-enrichment is more in anorthosite (Fe_2O_3 enrichment ratio is 25.11 than in gabbro (3.7), possibly suggesting an absolute enrichment of iron in anorthosite through capillary action. Alumina enrichment is also high in anorthosite, leading to the formation of bauxite patches in the weathering profile. Desilication of kaolinite to gibbsite (as observed in thin sections) is responsible for the appearance of bauxite.

Granophyre and partly alkali syenite, with the exception of Fe^{2+}, are characterised by mobility series, comparable to those typical of normal acidic rocks, with higher mobility for potassium and lesser mobility for silica, and the alteration process starts with the feldspars. Fe_2O_3 enrichment ratios in these rock types are 7.24 and 11.09 respectively.

Quartz appears to be the stablest mineral among all others. When it occurs as large crystals in the parent rock it is retained sometimes as small fragments in the laterite zone. Smaller crystals are almost totally removed due to leaching.

Based on petrographic, geochemical and water geochemistry data the following stability series can be attributed for the rock-forming minerals of the study area.

Low Stability



(High stability)

Water geochemistry data indicate that Fe is being leached out from the profiles, further facilitating relative Al_2O_3 enrichment. The higher p^H values due to prolonged water-rock interaction at lower levels in certain rock areas is also conducive for the precipitation of alumina in the lower horizons. Phase relations indicate kaolinite and partly gibbsite as stable phases, and resilication of gibbsite is suspected.

Most of the rare-earth elements are also mobilised and removed during weathering, as reflected in the lower REE abundances in the laterite.

The relatively higher p^H values measured in ground waters from the alkali syenite, anorthosite and granophyre (also refer Table 8) areas shall explain the higher iron enrichment rates in those rocks, since Fe^{2+} gets precipitated as Fe^{3+} under alkaline environment towards the upper parts of the profiles. This may be the case with fuchsite quartzite areas also, where the iron-enrichment ratio is maximum compared to other rock types.

Consequently, differential mobility and enrichment of various elements in the various rock types of the study area during weathering is explained as due to the prevailing p^H conditions, influenced and brought about by rock-chemistry and rock-water interaction.

5.1. LATERITE GENESIS AS RELATED TO GEOMORPHOLOGY OF THE REGION

Weathering has led to widespread development of extensive laterite surfaces/lateritic mesas in the study area, in sharp contrast to the narrow incised valleys and inter-fluvial terraces/surfaces developed in south Kerala.

Geomorphic features ranging from coastal beaches of negligible relief in the west to the high hills with conspicuous relief (>600m) in the east are discerned in the area. In broad geomorphic terms, the area can be divided into 7 units such as(1)coastal plain,(2) fluvio-tidal channels and swamps,(3) flood plain and terraces, (4) flat to rolling plains, (5) denudational hills and slopes,(6) lateritic mesas and (7) denudational hills and mountains (Fig.49). The lateritic mesas have been separately marked from the landsat images and aerial photographs on account of their significance in landscape development. It is possible to mark a number of subunits or morphological features under each unit. Thus the coastal plain itself can be divided into beaches, cliffs, dunes and plains with or without laterites.

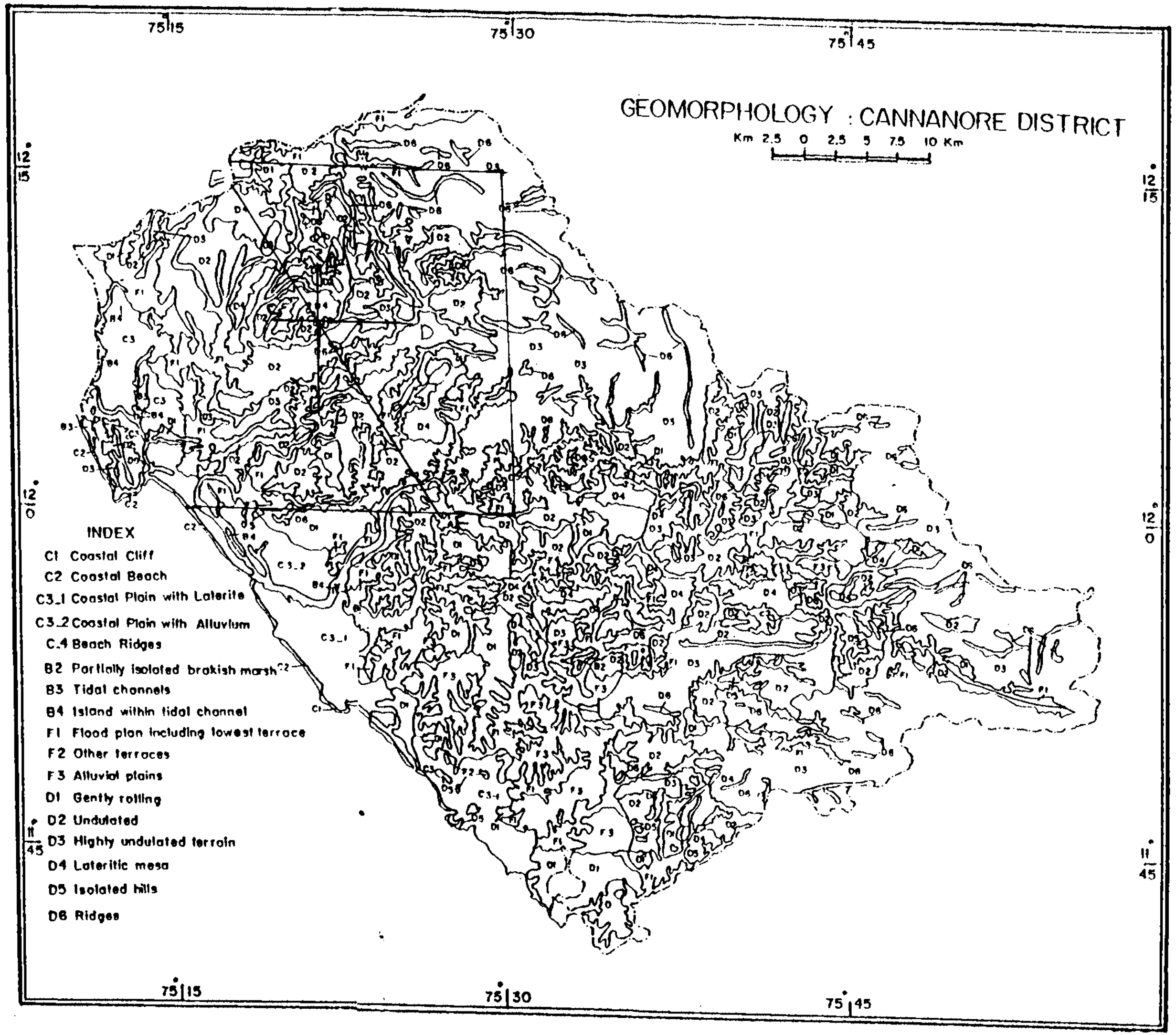


Fig: 2

Fig.49 Geomorphological map of Cannanore district.

Comparing geology and morphologic units, it can be observed that the eastern and south-eastern parts are dominated by undulating terrain, hills, and mountains comprising granulites, gneisses, granites and high grade schists. All the above lithounits are lateritised and in a number of places hard crust- mesa like landforms have been developed. Extensive laterites mesa -like landforms have been identified in the northern parts, underlain by granulites, schists and sedimentaries. Geochemical features of laterites over these rock units indicate more of iron-enrichment trends, facilitating to the formation of hard crust. The river valleys that mostly follow the lineaments cutting across the laterite are narrow, steep but flat bottomed. This indicates the dominance of scarp retreat in landform development. This has been possible only due to the presence of hard laterite cap at the top and soft clayey material below it, consistent with the observations in the studied profiles. Similar features are also reported in the lateritic terrain in Australia (Brook and Twidale, 1984).

Studies of cross profiles and projected profiles (Fig.50) show that the planation surfaces are traceable at the altitudes of 160 to 220m, 60m to 160m and 20 to 60m. Above 220m the only notable surface is at an altitudinal range of 750m to 900m. This surface represents the Wynad plateau. Even though the hard crust laterite surfaces are confined to less than 300m altitude towards the coast, they are observed even below 10m. Therefore the entire stretch of land below 220 under the extensive laterite crust cannot possibly be considered as a single planation surface. Retreat of Wynad plateau scarp is evident from the longitudinal profiles of the rivers. Due to weathering it may be possible that the surface expression of uplift, leading to truncation of the extensive planation surface might have been obscured from the profiles.

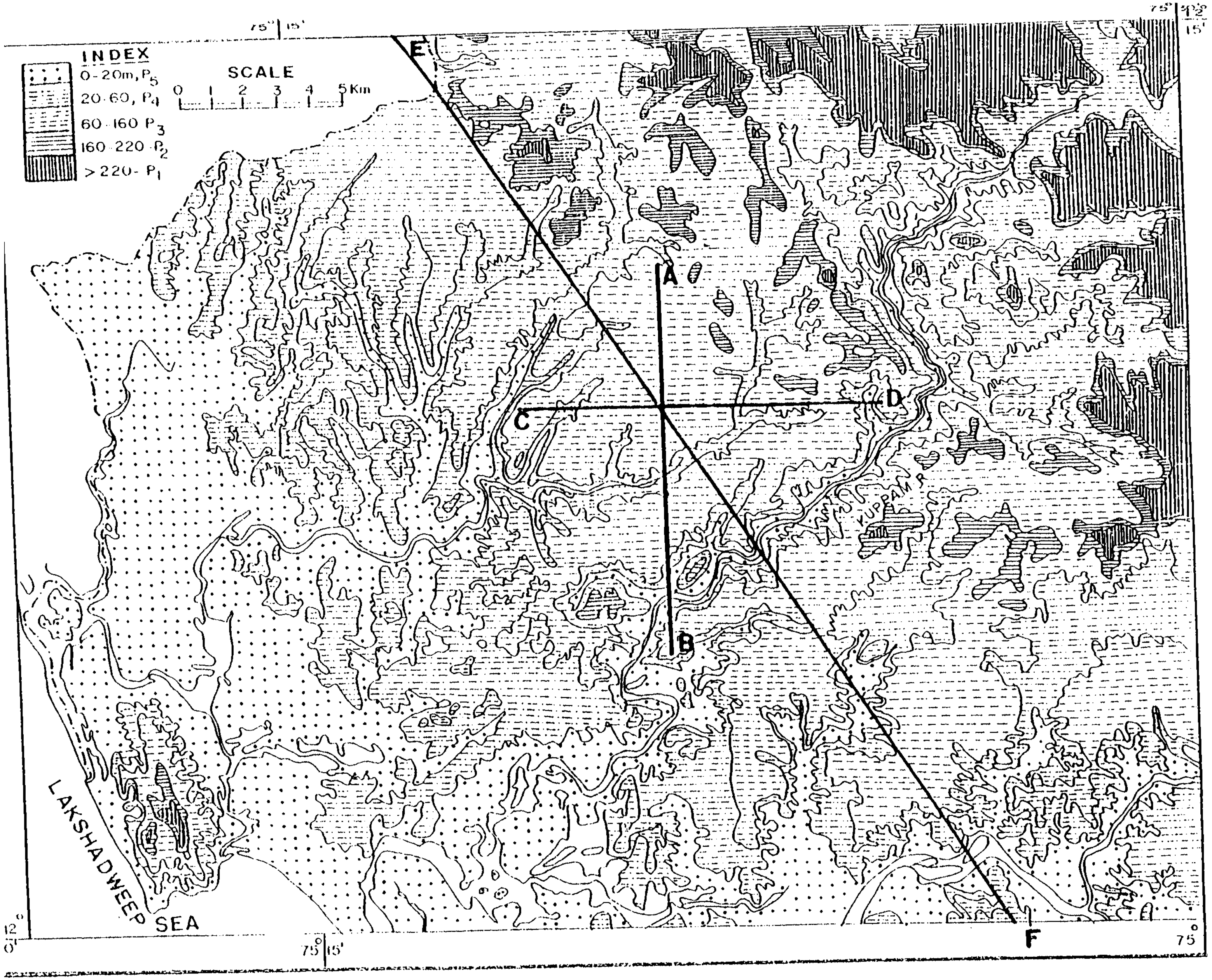


Fig.50 Geomorphological map of a part of Cannanore district showing planation surfaces.

The drainage lines are largely controlled by lineament pattern except in the coastal plain. The distribution of existing mesas parallel to the channels in a linear fashion can be taken as a structurally controlled feature. Narrow width of the basin, particularly Kuppam, in the mesa dominated areas also indicates structural control.

In order to characterise the mesas properly, a sample area covering Kuppam and parts of Valapatanam catchments has been selected and the planation surfaces are demarcated (Fig.51) and cross profiles across a mesa are given in figure 52. Five surfaces P_1 to P_5 are enumerated in the younging order (oldest to recent). P_3 surface (60-160) is well preserved with laterite mesas and covers major part of the area (Fig.52). The P_1 surface (> 220m), being preserved as ridges, forms the interfluves of P_3 surface. The P_1 surface is mostly stripped of the laterite cover in the upper slope and some laterite remnants are observed in the shoulder slope. The P_2 surface also with laterite cover, mostly occurs as bounding slope to the P_1 surface and gradually merges with the next P_3 surface. P_4 surface occurs as valley bottom, incised on the P_3 surface along the rivers. P_5 surface is generally the aggradational plain consisting of coastal deposits in the western part and alluvial and colluvial deposits in the eastern valley bottom. These two surfaces also show laterite cover in some cases, particularly in the western part. Along the coast, P_5 surface exhibits hard laterite cover, which in some areas (Cannanore coast) is exposed as laterite flats resembling marine terraces (Fig. 53). Evidences to assign specific geological ages to these surfaces are not conclusive; however, the sequence of events leading to the evolution of these planation surfaces can be summarised as given below:

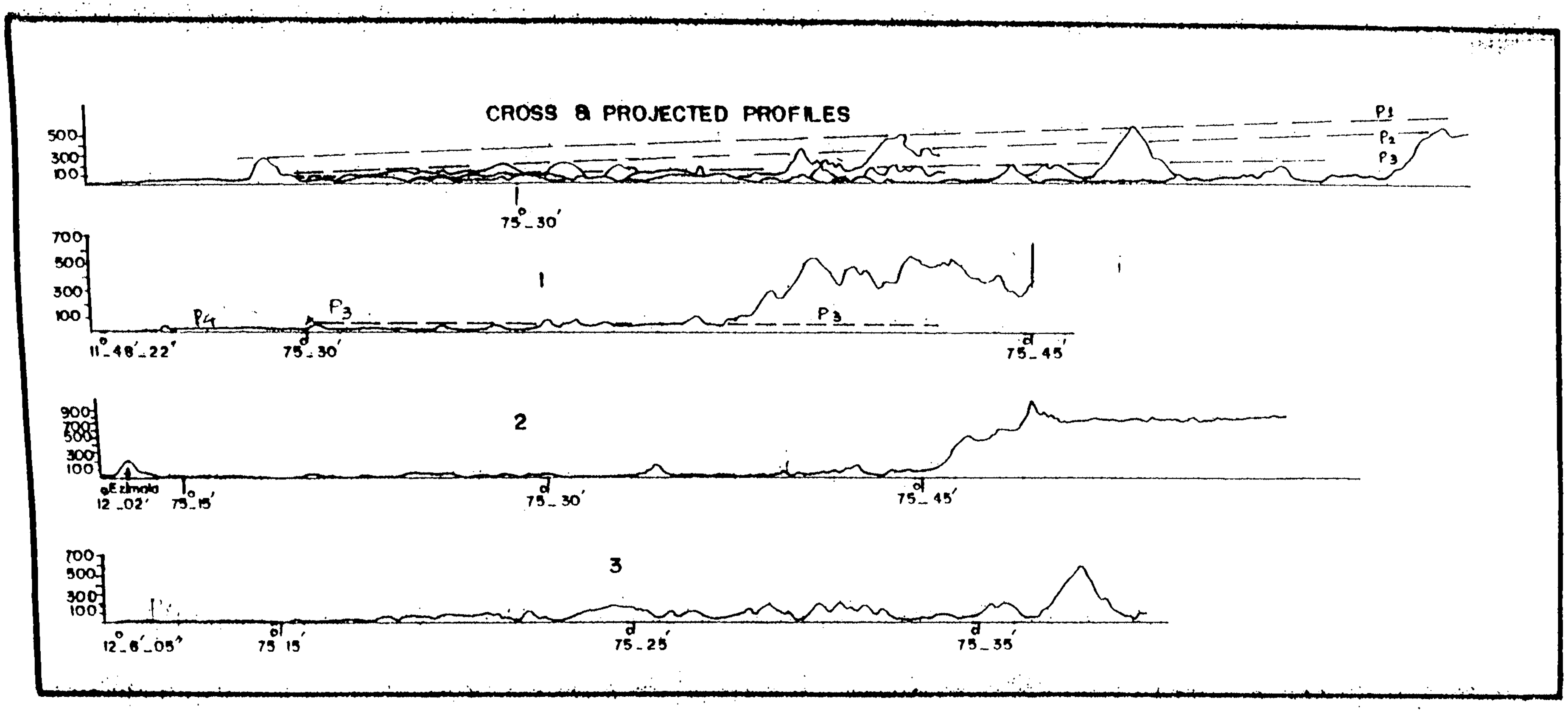
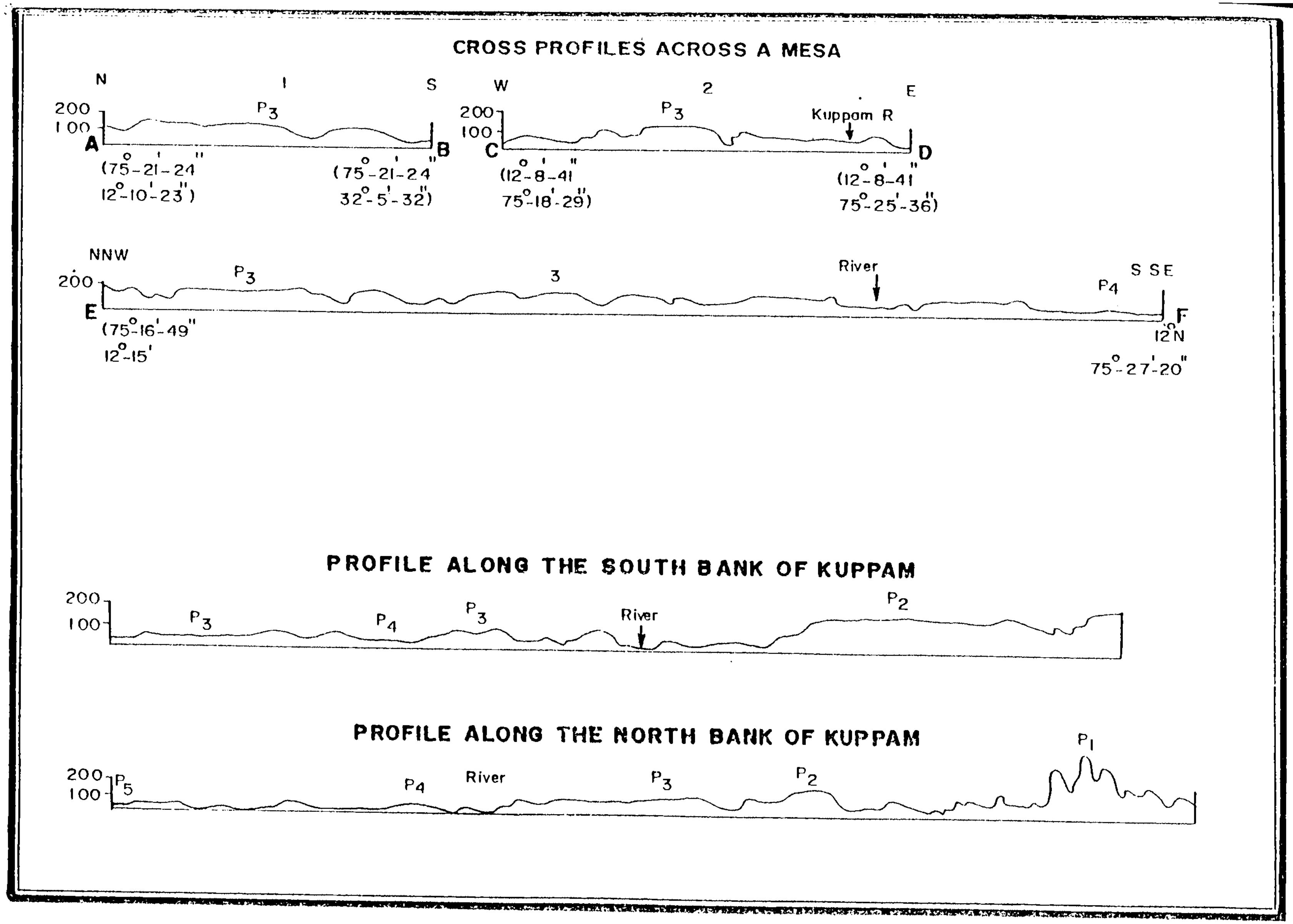


Fig.50A Cross and superimposed profiles showing various planation surfaces.



CROSS PROFILES ACROSS A MESA

PROFILE ALONG THE SOUTH BANK OF KUPPAM

PROFILE ALONG THE NORTH BANK OF KUPPAM

Fig.51 Cross profiles across Fig.50.

FIGURE·51

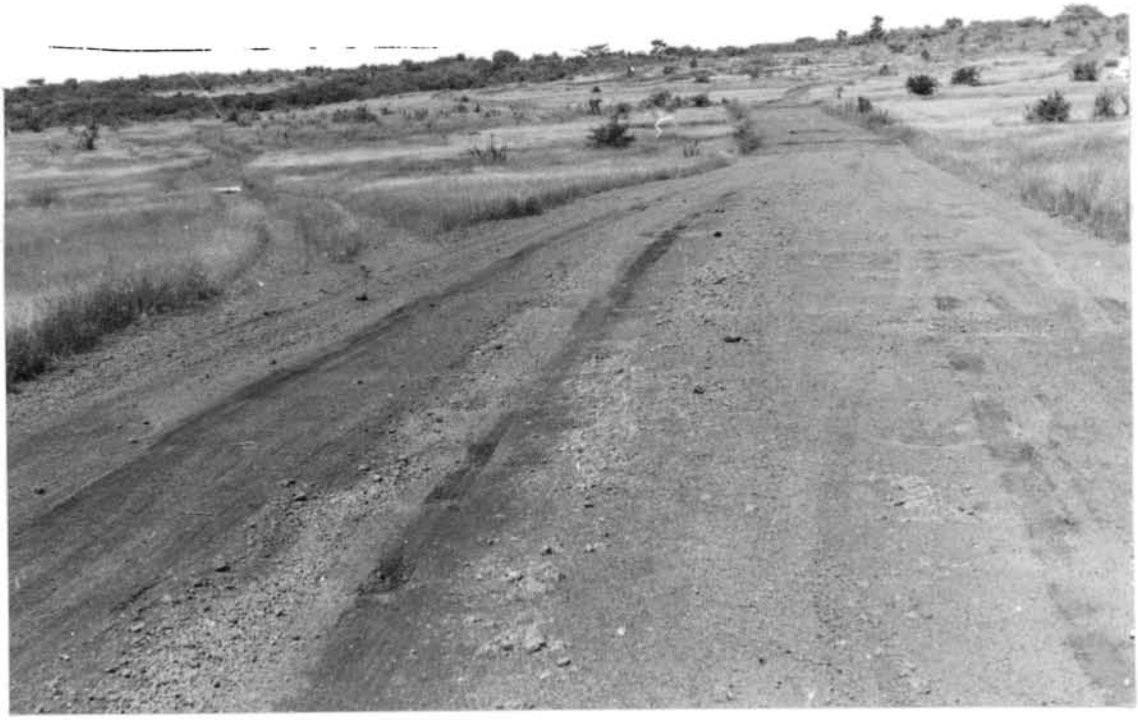


Fig.52 An areal view of the extensive laterite surface near Chimeni area, Cannanore district.

Fig.53 Laterite flat resembling marine terrace at Cannanore section

Geomorphic event	Planation surfaces
Emergence of coastal plain, Pediment formations and widening of valley bottoms.	P_5
Erosion predominated with initiation of new cycle - reduction of P_3 surface	P_4
Development of P_3 surface	P_3
Upliftment of the region, flexuring and widespread dissection of peneplains	P_2
Major phase of peneplanation and lateritisation	P_1

The presence of laterite cap on the erosional surface has implications on denudational processes. The erosional intensity is considerably less due to the hardness and impermeability of the hard laterite surface. Examination of a mesa reveals that the top surface is flat to gently rolling with no significant drainage line. Sections across a number of mesas in the Kuppam drainage basin have been plotted (Fig. 51) and these sections in different directions indicate that the surfaces are encircled by steep slopes and the intervening valleys are mostly flat. The surfaces also show gentle inclination towards the major valleys. Field investigation brings out that the process of valley formation in the mesa dominated areas conforms more to the scarp retreat model.

Another important aspect in the laterite morphology of this area is the formation of 'soup plates'. These are the colluvial - alluvial basins of various dimensions over the laterite sur -alluvial basins of various dimensions over the laterite surfaces. Paulose (1965) had also marked these features as part of geological mapping programme of GSI. McFarlane (1976) reported this type of feature, and dealt with the possible causes of its formation. Twidale (1987), however, has considered it as a 'sinkhole' on laterites. These basins present almost permanent wet land condition. is beyond the scope of the present study.

5.2. CONCLUSION

1. The cause and consequence of laterite genesis in Cannanore district has been influenced mostly by the bed rock character and partly by geomorphic features.

2. Stability of minerals during weathering of various rock types in Cannanore district and rock-water interaction, influencing the p^H values have been attributed to the differential mobility and concentration of elements in the weathering profiles.

3. Extensive laterite mesa development in the study area is concentrated mostly in the northern parts below 300m. altitude. These areas are underlain by granulites, schists, sedimentary rock etc. Geochemical features of laterite in these rocks units were also conducive for the formation of hard laterite crusts.

4. Scrap retreat and formation of flat bottomed valleys in the laterite mesa-areas have also been facilitated by the composition of the lower zones of the weathering profiles.

Chapter 6

SUMMARY AND CONCLUSIONS

The study area is characterised by extensive development of laterites over rocks belonging to different lithological/chemical affinities and different age relations. Weathering has affected the granulites and related gneisses, schistose assemblages belonging to the Sargur (Manantoddy schist belt) and Dharwar (Vengad Group) groups, acidic, basic, and alkaline intrusive phases and Tertiary sedimentary formations. The available age data indicate that the lateritised parent rocks belong to Archean, late Proterozoic and late Tertiary epochs. Results of the present investigations are summarised below:

(1) Laterite profiles studied in the area generally consist of a humus zone, followed by a pebbly layer. Further below vermicular laterite is observed. In some of the profiles, pallid zone, consisting of kaolinitic clay is observed. This is followed by completely weathered and partly weathered zones. Fresh parent rock is seen further below. Contacts between the various zones are gradational. In some of the profiles all these units are not seen. Maximum thickness of the weathering profiles in the area is 17 m over anorthosite near Perinthatta. In this profile, the vermicular laterite and the overlying hard crust zones together occupy 8.2 m. The laterites have brick red to purplish colour with cavities completely or partly filled with greyish white clay often passing into ochreous. specific gravity of the laterites in the area range from 1.72 to 2.41.

(2) Occurrence of in situ laterites developed over different lithologies in the area and laterites seen over Precambrian at the base of the Tertiary sedimentary formations suggest that two lateritisation cycles (pre-Warkalli and post-Warkalli) have affected the region. Maturity indices calculated for laterites of the Tellicherry and Palayangadi

profiles (over Tertiary sediments and over the underlying Precambrians) show that the laterite over Precambrians are relatively less mature than that over the sedimentaries. It may therefore be suggested that the first spell of lateritisation lasted for a shorter duration than the second spell.

(3) The laterites are mostly composed of goethite, hematite, kaolinite, quartz, gibbsite and vermiculite. In laterites of the alumina-rich rock types, proportion of gibbsite is more than in other varieties. In thin sections, desilication of kaolinite to gibbsite is observed. In rocks of ultramafic affinities, XRD data indicate presence of garnierite, maghemite and illite also. The primary clay observed at the base of the Tertiary formations at Palayangadi consists of well-crystalline kaolinite, as indicated by XRD, DTA, IR spectroscopy and SEM. The overlying sedimentary kaolin consists of relatively poor crystalline kaolinite. A leached portion of the sedimentary kaolin consists of kaolinite with traces of gibbsite.

(4) Petrographic observations and calculations of mobility-series of elements during weathering suggest that minerals/elements of various lithological units behave differently. pH measurements indicate varying values and elemental abundances in different rock provenances. Consequently it is concluded that differential mobility and enrichment of various elements are due to the prevailing pH conditions brought about by prolonged rock-water interaction.

(5) Iron enrichment ratios in different rock types calculated from geochemical data vary from 2.48 in charnockite to 64.2 in fuchsite quartzite. Further the relatively iron-poor rock types show higher

Fe_2O_3 enrichment ratios than the iron-rich varieties. The relatively higher pH values measured in ground water from alkali syenite, anorthosite and granophyre localities may explain the higher enrichment ratios in these rocks, as under alkaline conditions Fe^{2+} tends to get precipitated towards the upper portions of the laterite profiles. This mode of Fe enrichment is suggested for the fuchsite quartzite also.

(6) Concentration ratios of Al_2O_3 range from 0.99 in fuchsite quartzite to 3.22 in gabbro. Water-geochemistry data suggest that Fe is being leached out from the profiles, facilitating relative enrichment of alumina. Lower alumina enrichment in the uppermost parts of the studied laterite profiles is attributed to the prevailing lower pH values (acidic), rendering alumina potentially mobile, and facilitating its migration towards lower horizons. The higher pH values prevailing in the lower horizons of some of the profiles due to prolonged water-rock interaction facilitated precipitation of alumina there. This explains the formation of bauxitic patches in profiles over anorthosites and in the lower portions of the profile at Palayangadi. Consequently, alumina enrichment leading to the formation of bauxitic patches is more feasible in relatively Al-rich parent rocks of the study area, such as anorthosite and sedimentary formations. Hence it is suggested that future research for bauxite in Cannanore area may be concentrated on laterite profiles developed over Al-rich rocks.

(7) Water geochemistry data indicate that kaolinite in the stable mineral phase in the weathering milieu of the study area. The primary kaolin developed over Precambrians underlying the Tertiary sedimentary rocks displays better crystallinity than that of the sedimentary formations,

pointing to its relatively superior physical properties (Grim, 1968).

8) Trace element data indicate concentration of Ni in laterite profiles over ultramafites, which is also substantiated by the presence of garnierite in XRD. Laterite profiles over ultramafites of these schistose rocks may be further investigated for Ni concentration. The fuchsite quartzite from the area also contains barite

(9) Rare Earth Element (REE) data on laterite and the parent bed rock indicate similarity in their patterns, and the laterite shows broad REE depletion trends. However, in laterite developed over charnockite Eu shows enrichment, while Ce is enriched in Laterite over granophyre. The sympathetic REE pattern in laterite and the corresponding parent rock may be used to elucidate the bed rock character of the laterite in areas where the parent bed rock is not exposed. However, in the weathering front, unlike in laterite, REE concentration is more. This may be due to the pH changes.

(10) From the available geochemical data, it is evident that lateritisation in the study area is mostly a two-stage process over charnockite, gabbro, granophyre, ultramafites, gneisses, alkali syenite and fuchsite quartzite, while three stages are discerned over anorthosite and sedimentary formations. The first stage is marked by rapid depletion of silica, lime, magnesia and alkalies and enrichment of Fe_2O_3, Al_2O_3 and TiO_2. The second stage marks a gradual depletion trend for SiO_2, CaO, MgO, Na_2O_3 and K_2O with corresponding enrichment of Fe_2O_3, Al_2O_3 and TiO_2. Rapid depletion of silica and partial leaching out of iron (as also indicated by water geochemistry data) with residual enrichment of alumina

characterise the third stage, discernible over anorthosite and sedimentary rocks. The latter also explains the occurrence of bauxitic patches in these rock types.

(11) Comparison of the enrichment and depletion of the major chemical constituents during weathering indicates the following also: (a) the more the content of the mobile elements (Si, Mg, Ca, K and Na) in the parent rock, the greater is the depletion and (b) the concentration ratio of the less mobile element iron is greater if its content is less in the parent rock which suggest that the concentration mechanism also includes absolute enrichment. This is further corroborated by water geochemistry data.

(12) Extensive development of laterite over various lithological units under favourable terrain conditions has given rise to a laterite planation surface in the area at an altitudinal range of less than 300 m. The more pronounced hard laterite crust of this landform is developed in the northern parts of the study area, underlain by granulites, schists and sedimentary formations. The laterite are hard, as also indicated by their geochemical features.

(13) Dissection of the extensive laterite surface has given rise to the present day mesa-like landform. Scrap retreat, facilitated by the loose nature of the lower horizon of the laterite profiles led to the formation of flat-bottomed valleys in the area.

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APPENDIX

INDEX TO THE STUDIED PROFILE LOCATIONS

	Location	Laterite Profile over	Lat.	Long.
1.	Olayampadi	Charnockite	12°10'55"	75°20'53"
2.	Kukanam	-do-	12o11'28"	75o16'35"
3.	Kuttumukkam	-do-	12°2'55"	75°30'32"
4.	Vesala	-do-	12o56'0"	75o30'52"
5.	Muttannor	Gneiss	12°57'38"	75°31'12"
6.	Near Kelakam	-do-	12o54'28	75o43'12"
7.	Tumbeni Hill	Fuchsite Quartzite	12° 1'59"	75°29'59"
8.	Vayakara	Ultramafite	12o1'57"	75o30'38"
9.	Madamapam	-do-	12°2'10"	75°31'35"
10.	Mapini	-do-	12o2'0"	75o32'12"
11.	Nellunni	Quartz-mica-schist	12°55'1"	75°35'8"
12.	Kuyilur	-do-	12o57'38"	75o32'35"
13.	Perinthatta	Anorthosite	12°10'10"	75°16'48"
14.	Vattapara	-do-	12o8'30"	75o13'25"
15.	Kuruveli	-do-	12°9'18"	75°12'22"
16.	Near Vattapara	-do-	12o9'50"	75o12'50"
17.	Near Ettikkulam	Gabbro	12°2'2"	75°12'50"
18.	Ettikkulam	-do-	12o2'25"	75o12'32"
19.	Palkkod	-do-	12°2'4"	75°12'48"
20.	Near palakkod	-do-	12o1'38"	75o12'50
21.	Ezhimala	Granophyre	12°3'40"	75°10'50"
22.	-do-	-do-	12o3'58"	75o11'0"
23.	-do-	-do-	12°2'0"	75°11'40"
24.	-do-	-do-	12o12'25"	75o11'50"
25.	-do-	-do-	12°3'30"	75°11'50"
26.	-do-	-do-	12o1'55"	75o13'3"
27.	Shivapuram	Alkali Syenite	12°54'20"	75°39'40"
28.	Peralimala	-do-	12o55'1"	75o37'52"
29.	Palayangadi	Sedimentary Formation	12°1'58"	75°15'59"
30.	Tellicherry	-do-	12o44'51"	75o28'20"

APPENDIX - II

METHODS USED FOR LABORATORY TREATMENT FOR SAMPLE PREPARATION AND FOR THE CHEMICAL ANALYSES

Accurate determination of chemical composition is essential for their detailed characterisation hence care was taken to crush the samples for mineralogical (XRD) studies and chemical analysis (Major, trace and REE determinations), to avoid contamination a Hard Steed Pestly and mortar made out of imported stainless steel material with super alloy tungsten and iridium suitable for geochemistry powdering was used. Samples from each zone of the laterite profile was taken in sufficient quantity (7-8 kg.) for geochemical and mineralogical studies. Since laterite is hetrogenous in nature, care was taken to select heterogeneous parts proportionately and representatively for crushing as suggested by Schorin and Labrequ (1980). The grain size chosen is 0.1 -- 1 cm and 1 kg. by weight (Final quantity). This sample was crushed to -80 mesh, 20gms. of the sample was finally taken after cone and quartering from which mineralogical (XRD) of laterite, IR, SEM studies of clays were carried out, -420 mesh, and used for major and trace elemental wet chemical analyses follows the procedures at Sapiro (1985) Vogel(1978), Fritz, & Schenck (1974).

MRG, Sy1, Sy2, Canadian soil, Venezuelan laterite and bauxite were used as reference studies. REE analyses:

APPENDIX - IIA

Chemical analyses of samples from the laterite profiles.

1. By AAS

Preparation of sample solution

The method prescribed by Sapiro 1975 was followed for analyses. (2 solution procedure) Preparation of solution - A for determination of SiO_2 and Al_2O_3. It is prepared by fusing 50 mg of the finely powdered sample with NaOH in a Nickel crucible. This way decomposition was obtained very quickly and at a comparatively low temperature. These standard solutions and a reference blank solution were also prepared simultaneously with solution - A. The reference blank solutions were prepared in the same way as solution - A except that sample powder is omitted. Solution - B is used in the determination of TiO_2 total iron MnO, P_2O_5 , MgO CaO, Na_2O, K_2O. to prepare this solution 50 mg of the sample is digested overnight with HF(40ml) and H_2SO_4 (5 drops) in A large cover platinum crucible on a steam bath. HF is then removed by heating until copious fumes of the SO are given off, and the residue dissolved in water and made to 100ml volume. Major and trace elements compositions were determined using Perkin Elmer 4000 AAS following the methods suggested by Shapiro (1975).

2. Wet chemical method

Decomposition of sample and determination of SiO_2

Ignite a clean platinum crucible of 25ml capacity with well-fitting platinum cover gasped with platinum tipped crucible tongs above the blue or green inner zone of the non luminous flame of a merker burner for some minutes and place the crucible and cover inside a desiccator. As soon as cool, transfer 0.5 gm of accurately weighed sample (W) to the crucible, add 2 to 3gm of anhydrous sodium carbonate, mix well with a platinum rod and cover the mixture with a layer of 1gm anhydrous sodium carbonate. Heat over a Merker burner till an almost viscous liquid is obtained and cool.

Transfer the fusion cake from the crucible into a 300ml procelain basin, add some water and add a few drops of ethyl alcohol. Cover the basin with a watch glass and add 50ml 1+1 Hcl. place the basin over a water bath and evaporate the content until the residue is free from fumes of hydrochloric acid. Transfer the basin and contents to an oven and bake for 1 hour - at 110°C cover the basin, add cautiously to the dry cool residue 10ml of Hydrochloric acid and 100ml hot water. Heat on steam bath for 10 minutes stir well until the salts are in solution.

Filter through a whatman No.42 Filter paper and collect the solution in a 250 ml standard flask. Transfer the precipitate to the filter paper by means of a jet of hot water and wash the paper and precipitate 10-12 times with hot water until the filtrate free from chloride. Reserve the paper and residue (I) and also the combined filtrate and washings (II).

Transfer the residue to a platinum crucible and incinerate. Place the crucible with cover in a furnace and heat the crucible at 1000°C for 15 to 20 minutes. Allow to cool in a desiceator and weigh (A). Carefully moisten the content with water, add some drops of 1+1 H_2SO_4. (H_2SO_4 converts all the contaminating bases to sulphates and prevent loss of titanium or Zirconium as fluorides). Add 10ml Hydrofluoric acid and evaporate slowly upon a stem bath. Carefully expel the sulphuric acid and ignite the crucible at 1000 C for 1 or 2 minutes. Allow to cool in a desiceator and weigh without delay (B).

The weight difference (C=A-B) given the weight of silica.

Percentage of silica = (A-B) x 100/W

Add a little pot. pyrosulphate to the crucible and melt the residue left behind in the crucible. Cool add a little water and dissolve the contents by heating in a low flame. After dissolution add it to the main filtrate (II). Make up the solution to 250 ml.

Determination of total iron

Pipette out 25 ml filtrate to a 250ml beaker, dilute to 40ml add 10ml Con. HCl to oxidise all iron to Fe state. Boil the solution and add stannous chloride solution till the solution becomes colourless. The solution is then rapidly cooled to about 20°C with protection from air. Add 10ml saturated Mercuric chloride solution to remove the excess stannous chloride. The solution is allowed to stand for five minutes, add 20ml 1:1 H_2SO_4, 5cc orthophosphoric acid and a few drops of Barium diphenylamine indicator. Titrate with standard 0.01 N potassium dichromate solution until the pure green colour changes to grey-green. Then add dichromat dropwise until the first tinge of blue-violet, which remains permanent on shaking, appears.

Fe_2O_3 (Total)= vol. of $K_2Cr_2O_7$ x Factor x 100/W

FeO

Take 0.2g, sample in a 250 ml conical flask and 10ml add 10ml 80% H_2SO_4 5ml HF and heat the flask for w minutes in an atmosphere of carbondioxide. Cool the flask in ice cold water. Add 15 ml saturated Boric acid solution and 5ml orthophosphoric acid. Add a few drops of Barium diphenylamine sulphonate indicator and titrate with standard 0.01 N potassium dichromate solution until the colour changes to blue violet.

FeO = vol. of $K_2Cr_2O_7$ x Factor x 100/W

Net Fe_2O_3 = Fe_2O_3 (Total) - FeO x 1.1113

Aluminium

Pipette out 25ml solution of the filtrate from the separation; of SiO_2 to a 250 ml beaker add a few drops of phenolphthalein indicator and add 20% NaOH till just alkaline and 5ml more and boil for a few minutes.s Cool and filter the solution through a whatman No. 40 filter paper and waste the residue with hot water. Collect the filtrate and washings in a 400ml beaker.

Neutralise the filtrate by adding 1:1 Hcl till the solution becomes colourless. Add very dilute NaoH in drops to the solution to change it just alkaline. Add 15 ml Ammonium acetate and 10ml 0.1M EDTA cover the beaker and boil in a low flame for 30 minutes. Cool in ice add 1ml acetic acid 1 or 2 drops xylanol orange indicator and titrate with 0.1M Zn solution until the colour changes from Lemon-yellow to red colour.

1ml. 0.1M EDTA = 2.697mg Al = 5.095 mg Al_2O^3

Al_2O_3 % = (B-V) x Factor x 100/W

CaO and MgO

Pipette out 25 ml solution of the filtrate from the solution of SiO to a 250ml beaker. Add 1gm Ammonium chloride and 10 to 15ml NH_3. Boil a few minutes Filter through a whatman No.40 Filter paper and collect the filtrate in a 100 ml Standard flask wash with hot water and collect the washing also in the same flask. Make up the solution to 100 ml.

Pipette out 25 ml solution in to a 100ml china dish and 2ml ammonium chloride-Ammonia buffer and 1 or 2 drops Eriochrome Black T indicator and titrate with standard 0.0s1M EDTA till the colour changes from wine red to blue. The volume of EDTA (A) corresponds total Ca and Mg. Take another 25ml add 2ml 5% NaoH solution and 2 drops Murexide indicator. Titrate with 0.01 EDTA till the colour changes to violate. The volume of EDTA (B) corresponds to Ca. Volume of (A-B) corresponds to Mg.

CaO = B ml x Factor/W

MgO = (A-B) ml x Factor/W

Solution for Trace

Take 0.5 gm sample to a platinum dish add a few drops H_2SO_4 and 25 ml HF. Evaporate to dryness. Add 30ml 1:1 HCl and heat to boil. Transfer the solution to a 100ml standard flask and make upto the mark. Trace elements are determined by Atomic Absorption Spectrophotometer. Na_2O and K_2O are determined by flame photometer using the solution for trace elements determination.

Moisture and LOI

Weigh a clean heated, cooled platinum crucible with lid accurately (A) Add about 1gm sample and weighed again the weight of sample. Place the crucible with lid in an oven for 1 hour at 105-110°C. Cool in a desiceator and weigh(C). B-C gives the loss of weight.

Moisture% = (B-C) X 100/Weight of sample

After the moisture determination place the crucible in a muffle furnace at 1000°C for 30 minutes cool and weight (D). Loss of weight on ignition is (C-D)

LOI % = (C-D) x 100/weight of sample

P_2O_5

Take 0.5 gm sample and 2gm potassium pyrosulphate in a test tube fuse well and cool. Add 10ml 1:1 HNO_3 and boil in a water bath. Filter and collect in a 50ml standard flask. Take a suitable volume of the solution add 5 ml vanadate molybdate reagent and compare the colour with a standard using spectrophotometer between 460 and 480 nm.

P_2O_5 % = Factor x 2.20