CHARACTERISATION OF THE GRAVELS IN THE MAJOR SOIL SERIES OF TRIVANDRUM DISTRICT

By

SURAJ JOHN B.Sc. (Ag.)

THESIS
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DEPARTMENT OF SOIL SCIENCE AND
AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
VELLAYANI, TRIVANDRUM
1996

DECLARATION

I hereby declare that this thesis entitled **"Characterisation *of the gravels in the major soil series of Trivandrum district*"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Suraj John

Vellayani,
24.06.1996.

SURAJ JOHN

CERTIFICATE

Certified that this thesis entitled **"Characterisation of the gravels in the major soil series of Trivandrum district"** is a record of research work done independently by **Mr. Suraj John** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

M. Subramonia

Vellayani,
24.06.1996.

Dr. M. SUBRAMONIA IYER
(Chairman, Advisory Committee)
Associate Professor, Department of
Soil Science & Agricultural Chemistry

Approved by

Chairman :

Dr. M. SUBRAMONIA IYER

13/12/96

Members :

1. Dr. (Mrs.) P. PADMAJA

2. Dr. THOMAS VARGHESE

3. Dr. V. MURALEEDHARAN NAIR

External Examiner :

13/12/96

Dr. V. MURUGAPPAN
Professor of Soil Science,
Tamil Nadu Agricultural University,
Coimbatore

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127.	Fine sand mineralogy of soil - (0-20cm) - light fraction - Thonnackal series - under crossed nicols - Mgf: x 63.	94-95
128.	Fine sand mineralogy of soil - (20-70cm) - heavy fraction - Thonnackal series - in plane light - Mgf: x 63.	94-95

No.	Title	Between pages
129.	Fine sand mineralogy of soil - (20-70cm) - light fraction - Thonnackal series - in plane light - Mgf: x 63.	94-95
130.	Fine sand mineralogy of soil - (70-113cm) - heavy fraction - Thonnackal series - in plane light - Mgf: x 63.	94-95
131.	Fine sand mineralogy of soil - (70-113cm) - light fraction - Thonnackal series - under crossed nicols - Mgf: x 63.	94-95
132.	Fine sand mineralogy of soil - (113-150cm) - heavy fraction - Thonnackal series - in plane light - Mgf: x 63.	94-95
133.	Fine sand mineralogy of soil - (113-150cm) - light fraction - Thonnackal series - under crossed nicols - Mgf: x 63.	94-95
134.	Fine sand mineralogy of soil - (150+cm) - heavy fraction - Thonnackal series - in plane light - Mgf: x 63.	94-95
135.	Fine sand mineralogy of soil - (150+cm) - light fraction - Thonnackal series - in plane light - Mgf: x 63.	94-95
136.	Fine sand mineralogy of soil - (0-14cm) - heavy fraction - Trivandrum series - under crossed nicols - Mgf: x 63.	94-95
137.	Fine sand mineralogy of soil - (0-14cm) - light fraction - Trivandrum series - in plane light - Mgf: x 63.	94-95
138.	Fine sand mineralogy of soil - (14-57cm) - heavy fraction - Trivandrum series - in plane light - Mgf: x 63.	94-95

No.	Title	Between pages
139.	Fine sand mineralogy of soil - (14-57cm) - light fraction - Trivandrum series - in plane light - Mgf: x 63.	94-95
140.	Fine sand mineralogy of soil - (57-150cm) - heavy fraction - Trivandrum series - in plane light - Mgf: x 63.	94-95
141.	Fine sand mineralogy of soil - (57-150cm) - light fraction - Trivandrum series - under crossed nicols - Mgf: x 63.	94-95

INTRODUCTION

INTRODUCTION

Soil is a heterogenous three dimensional continuum consisting of mineral matter, organic matter, water and air. Mineral particles lower than 2mm in diameter are the proper fine earth fraction of soil, while the fractions greater than 2mm in diameter are classified based on shape and size into rounded or flattened particles. Rounded particles are the gravels, cobbles, stones and boulders; flattened particles are the channers, flag stones, stones and boulders. Gravels in soil can range from a size of 2mm to 7.5cm. It is often described that there is a layer of ferruginous gravel on the surface of the laterite soil. But on closer examination it is seen that besides the typical ferruginous gravels, there are other types also scattered on the surface. They are the laterite gravels, weathering parent material gravels and the quartz gravel. They do not differ much in their fertility but contribute significantly to the silicon dioxide and iron oxide content.

Soil texture determination in the laboratory disregards the presence of any component greater than 2mm. In some soils, such inclusions make

- To characterise the morphological, physical, chemical and mineralogical properties of the soil gravel fractions in the major soil series of Trivandrum district.

- To gather details on the genesis of soil gravels.

- To evaluate the fertility contribution of soil gravel fractions.

up a considerable part of the matrix. The presence of gravel in soil has an important bearing on the land use as they interfere with the cultivation operations, reduce effective soil mass, change soil physical behaviour and affect the quantity of water that the soil can supply to crops.

The major soil series of Trivandrum district are gravelly laterite in nature. Close examination on the surface and within the profile reveals the presence of different types of gravels (Soil Survey Staff, 1978). The earlier genetic studies on the gravelly laterite and lateritic soils of Kerala were conducted by Koshy (1962), Satyanarayana and Thomas (1962), Gopalaswamy (1969), Gowaikar and Dutta (1971), Subramonia Iyer (1979), Venugopal (1980), Varghese (1981), Sankarankutty (1986), Sivadasan (1989) and Varghese and Byju (1993). Gopalaswamy (1969) and Schmidt-Lorenz (1979) were the pioneers in the micromorphological studies on laterite soils of Kerala. Schmidt-Lorenz (1979) proposed the theory of plinthisation, wherein kaolinitic clay minerals with absorbed amorphous ferric hydroxide are in-situ transformed to haematite, optionally to gibbsite and not seldom goethite.

The present study was taken up for an integrated characterisation of the soil gravels which will help to reveal their genesis, role in soil hardening, contribution to the soil fertility and management. The specific objectives of the study are :

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Soil gravel content and distribution affect the soil characteristics in the crop root zone and are critical to soil water and nutrient availability to rainfed crops, thus affecting crop production in coarse textured soils. (Grewal *et al.*, 1984; Driessen, 1986 and Sys *et al.*, 1993) In the standard procedures for soil charactersation, gravimetric estimation of gravel alone is made and the detailed analysis is done only on the non-gravel sieved soil fraction (less than 2mm in size).

Specific studies on gravel characterisation, genesis and their contribution to soil fertility are limited.

2.1. Gravel morphology

2.1.1. Size

Depending on their size, soil gravels have been categorized as follows: Fine gravels have a size range of 0.2 to 0.5cm, medium gravels : 0.5 to 2cm and coarse gravels : 2 to 7.6cm (USDA 1981).

The size range of fine gravel is 0.2 to 0.6cm, medium gravel : 0.6 to 2cm and coarse gravel : 2 to 6cm (FAO, 1990).

Four distinct coarse fragment size classes can be identified as fine gravels (2mm to 2.5cm), coarse gravels (2.5 to 7.5cm), cobbles (7.5 to 25cm) and stones (above 25cm) (Sys *et al.*, 1993).

2.1.2. Shape

Shape is commonly defined by two parameters; roundness and sphericity. Roundness is defined as the description of the relative sharpness of the particle corners and can be classed as angular, subangular, subrounded, rounded and well-rounded. Sphericity refers to the overall form of the particle irrespective of the sharpness of the edges or corners (Bullock *et al.*, 1985).

2.2. Content and distribution of gravels

The coarse fragments in the profile showed a tendency to decrease down the slope and consisted mainly of ferruginous laterite gravel in Varkala. The gravel content was lowest in the valley profiles (Venugopal, 1980).

The granulometric composition of soils in the upland and mid-upland laterites of Kerala had shown that the upland profiles are highly gravelly with 38 to 83 per cent gravels (Sankarankutty, 1986).

The soil gravel content from different locations in South Kerala showed a wide variation and ranged from 5.8 in Anchal to 82 per cent in Punalur. It was significantly higher in the samples from upper profiles when compared to the corresponding lower profiles (Wilfred, 1986).

The proportion of soil gravel was significantly high in the six profiles observed in Trivandrum district. In the forest profiles it ranged from 17.46 to 52.75 per cent while it was 24.73 to 50.48 per cent in plantation profiles. In the forests, gravel content was more in subsurface soil and it showed an uniform increase with depth except in the case of shola forest where the increase was only upto a depth of 67cm and thereafter a sudden decrease was noticed in its content (Sivadasan, 1989).

The soil gravel content of Trivandrum series ranged between 67 and 71 per cent. Concretionary gravels were comparatively more in Nedumangad, while non concretionary gravels are seen more in Trivandrum and Palode series. (Ashraf, 1992).

Studies at Vellayani showed that the gravel content of a red loam profile varied from 16.7 to 23.89 per cent with slight decrease with depth while in the case of the laterite profile the gravel content varied from 49.9 to 56.7 per cent (Bindukumari, 1993).

2.3. Gravels and their composition

The laterite horizons may be ferruginous, aluminous or siliceous in chemical composition (Gopalaswamy, 1969; Subramonia Iyer, 1979; Nair and Mathai, 1981).

There are different types of gravels met with in laterite soils. On visual observation, four morphologically different types were separated. They are the laterite gravel which are broken laterite stones, irregular in shape, reddish-brown and hard; the ferruginous gravel which are spherical in shape, shiny black with smooth surface and are very hard; the weathering parent material gravel which are irregular in shape but almost round, yellow, mottled with black and white colour and the quartz gravel (Nair *et al.*, 1973).

The chemical composition of gravel showed a depletion of SiO_2 and accumulation of Fe_2O_3 and Al_2O_3. Between the sesquioxides, accumulation of Fe_2O_3 appeared to be more compared to Al_2O_3 (Stella and Venugopal, 1987).

2.4. Fine sand mineralogy

The fine sand mineralogy of the east coast laterites in India showed a pattern of mineral distribution, containing, quartz, iron minerals, zircon, garnet, rutile, anatase, ilmenite and pyroxene (Manickom, 1977).

Quartz was found to be the most dominant light mineral in laterite-red soil association in Kerala. Ilmenite and ferromagnesian minerals constituted 20 to 25 per cent and 5 to 15 per cent respectively. Mica was present in traces and zircon was also identified. Resistant minerals were found to occur abundantly in coastal and midland laterite soils but the high land laterite soils contained few weatherable minerals (Subramonia Iyer, 1979; Varghese, 1981; Sivadasan, 1989 and Bindukumari, 1993).

Magnetite alters to haematite without intermediate phase while feldspars alters to gibbsite. Quartz is chemically stable showing little evidence of dissolution (Gilkes and Sudhiprakaran, 1981).

Profiles of a yellow quartzitic ferralitic soil contained ilmenite, tourmaline, disthene and sphene in the heavy fraction and quartz and mica in the light fraction (Fundora *et al.*, 1985).

Fine sand mineralogy of selected soils of South Kheri forests of Uttar Pradesh revealed that the dominant minerals were quartz, followed by muscovite. There is very little feldspar and only traces of tourmaline, zircon and iron-oxides (Raina *et al.*, 1986 and Banerjee *et al.*, 1988).

Soils of Assam contained quartz, micas and feldspars in their fine sand fraction (Bhattacharyya and Sidhu, 1987).

In the South Balaghat forest division Madhya Pradesh, sand fractions contained quartz, hornblende, biotite, tourmaline, garnet, staurolite, kyanite, epidote, chlorite and opaques as the major minerals (Dhar *et al.*, 1989).

Soils of Kerala showed varied proportion of heavy mineral fraction from 0.31 to 2.30 per cent in forest soils to 0.47 to 2.79 per cent in plantation soils. The light mineral fraction varied from 5.93 to 13.68 per cent in forest soil to 6.03 to 16.69 per cent in plantation soils (Sivadasan, 1989).

In the Padalur series, Tamil Nadu (fine loamy Typic Ustorthent) the light minerals predominated because of their relative resistance to weathering. Quartz was the dominant light mineral and there was very little feldspar. Plinthite fragments predominated in the heavy fraction. The only variation with depth was a slight decrease in the light minerals content, probably due to the begining of profile development (Mayalagu and Paramsivam, 1990; Mayalagu *et al.*, 1992 and Paramasivam, 1995).

Fine sand mineralogy of Alfisols and Oxisols in Orissa indicated the dominance of quartz and orthoclase feldspar. A combined ilmenite and limonite content of 41 per cent was observed in one pedon (Sahu *et al.*, 1990).

Alfisols, Ultisols, Vertisols, Oxisols and Entisols of Nigerian savanna contained quartz as the dominant mineral followed by potassic feldspar. Oxisols contained appreciable amounts of ilmenite, magnetite and other iron oxide minerals (Moberg and Esu, 1991).

Hapludalfs, Ustochrepts and Chromusterts of the Rajmahal trap of North Bihar revealed that both the light and heavy mineral fractions contained weatherable minerals (Tiwary and Mishra, 1993).

2.5. Micromorphology and pedogenesis

The kaolinite present in the soft soil material of hardened laterite possessed the property of absorbing and immobilising iron (Fripiat and Gustuche, 1952).

The ferruginous skeletons of the hardened laterite showed a high degree of crystallinity and greater continuity of crystalline phase than the associated soil materials (Alexander *et al.*, 1962).

A detailed micromorphological study on the laterite soils of Kerala showed the presence of angular quartz grains in a scattered state in Varkala. Crystalline materials like goethite, haematite, gibbsite, quartz and some kaolinite were present. Most of the gibbsite had no regular shape (Gopalaswamy, 1969).

Iron formed a vascular network in indurated laterite concretions, the vacuoles being composed of original kandite. The network was formed by closely crystallising goethite which gave the form and hardness of petroplinthite (Eswaran and Raghumohan, 1973).

Intraaggregate void space contributed to the higher water holding capacity of Oxisols and Ultisols (Tsuji *et al.*, 1975).

The Ultisols of Goa (Plinthult) developed from Pink Phyllities showed an S-matrix of reddish brown to dark reddish brown plasma and skeleton grains mostly quartz and few weatherable minerals. Booklets of mica are common (Raghumohan, 1978).

Kaolinitic clay minerals with absorbed amorphous ferric hydroxide are in-situ transformed to hematite, optionally to gibbsite and not seldom goethite in the laterites of Kerala (Schmidt Lorenz, 1979).

Iron occured principally as coatings rather than discrete mineral entities in soil matrix in B horizons (Elliott and Sparker, 1981).

The accumulation of iron and alumina and the depletion of silica in laterites is stronger than merely kaolinised products (Schellmann, 1981).

The laterite soil of a footslope in Trivandrum district studied was pre-weathered prior to deposition. Runic quartz and rounded lateritic microaggregates were also observed clay illuviation (Subramonia Iyer and Gopalswamy, 1982).

The presence of a variety of minerals and rock fragments at different stages of weathering and at different depths were observed in Dystochrepts of Kerala. Thin argillans are observed in the groundmass as well as in the voids, while in the strongly altered rock fragments in the lower horizons these argillans are often associated with thin ferrans or mangans (Kooistra, 1982).

A study of Inceptisols revealed that the matrix consists of a variety of minerals, rock fragments and sesquioxide nodules which are highly weathered. The plasmic fabric ranges from skel-masepic to lattisepic and the related distribution is porphyric. The common pedological features are voids, filled with mineral excrements, mangans and papules. (Raghumohan, 1982)

The primary birefringent clay cutans and matrans increased with increase in the amount of rainfall (Manchanda and Hilwig, 1983).

The petroplinthite gravels of skeletal soils in Malaysia were of different types. In the first they were subangular to rounded with well defined boundaries and contained runic quartz in undifferentiated or concentric plasma. In another type, the quartz skeletal grains were angular and showed grains which were angular and showed highly fractured features. In the last type, quartz skeletal grains were subrounded and showed cracks invaded by iron oxyhydrates (Zauyah *et al.*, 1984).

The active petroplinthite formation is normally observed at the foot slope. A petroferric contact may also form on the exposed iron stone gravel which were brought to the surface through uplift and erosion (Blume *et al.*, 1987).

In the Acri-great group of Oxisols, with increasing iron content, the plasma tends to aggregate giving an agglutinic distribution pattern. The larger grains are not affected by this aggregation until the microstructure coalesces to a pellety form (Cardoso and Eswaran, 1987).

Clay illuviation and homogenization by biological activity in the Mollisols of Argentina resulted in an abrupt textural change and the development of an agric horizon (Pazos and Stoops, 1987).

The deposition of organic mineral compounds in the B horizon would give different kinds of microstructures depending upon the intensity of podzolisation process and on the texture and mineralogical composition of the mineral mass of the horizon. In sandy quartzitic materials, strong podzolisation process led to a coated microstructure; if a weak podzolisation process occurred a microaggregated microstructure of biological origin would form. In loamy materials rich in weatherable minerals such as biotite, vermiculite or chlorite, a micronodular structure of physico-chemical origin was formed (Righi, 1987).

Modifications in the fabric from the the bottom to the top of the soil sequence was observed in an Oxisol. In deep horizons of Oxisols sequence, the fabric was continuous and muscovite crystals were transformed into large kaolinite crystals. In the upper part kaolinite crystals became smaller and oxides were completely diffused into the clay matrix forming micropeds (Tandy *et al.*, 1988).

In Sierra Leone soils, ironstone gravels are of two main types, one derived from rock fragments and the other from hardened, plinthite glaebules (Sutton *et al.*, 1989).

The petroplinthic nodules are composed of closely packed goethite crystals. The formation of the petroplinthite nodule is the last stage in the development of the crust, the rigidity of which is due to the perpendicular alignment of the vesicular crystals to the surface (Eswaran *et al.*, 1990).

A micromorphological study of soil-saprolite transition zone revealed the presence of considerable amounts of oriented clay in the argillic horizons, strong to moderate subangular blocky microstructure, porphyric relative distribution pattern, low (less than 0.5) coarse/fine ratios separated at 20 µm and many planar voids. Oriented clays are absent from C horizons and microstructure was termed rock controlled to describe the apedal nature of these horizons (Stolt *et al.*, 1991).

Thin sections of ferruginous soils from Bangalore showed that the coarse fraction below 150 cm differed from that of the surface in that it was more angular, primary minerals were more altered and light minerals coarser. The lower horizon represented weathered granitic gneiss while the surface layer was derived from transported material (Venugopal, 1992).

2.6. Influence of gravel in crop production

The coarse fragments present in the form of gravel has deleterious effect on root development in a sandy soil but were useful for air and water movement in a clayey soil (Lutz and Chandler 1946; Lutz, 1962).

Soil profile gravel concentration upto 10 per cent was beneficial for maize but beyond this limit, it decreased available water holding capacity and checked root development (Babalola and Lal, 1977a).

Murram within 50-60 cm from the surface was less suitable for irrigation than murram-free soils or soils with murram at greater depth (D'costa and Katyal, 1982).

In a gravelly Udic Ustocrepts, the grain and forage yield of summer crops decrease with increasing gravel concentration. The dilution of the soil mass with increasing gravel concentration and the corresponding decrease in nutrient and water holding capacity of the soil appears to have depressed crop yields (Grewal *et al.*, 1984).

MATERIALS AND METHODS

MATERIALS AND METHODS

The objective of the present study is to characterise the morphological, physical, chemical and mineralogical properties of the soil gravel fraction, to gather details on the genesis of soil gravels and to evaluate their fertility contribution in the major soil series of Trivandrum district.

In order to obtain the required information to fulfill the above objectives, the following soil sampling and analysis were done.

3.1. Site selection, profile digging and description

Five representative sites, one each from Palode, Nedumangad, Varkala, Thonnackal and Trivandrum series were selected.

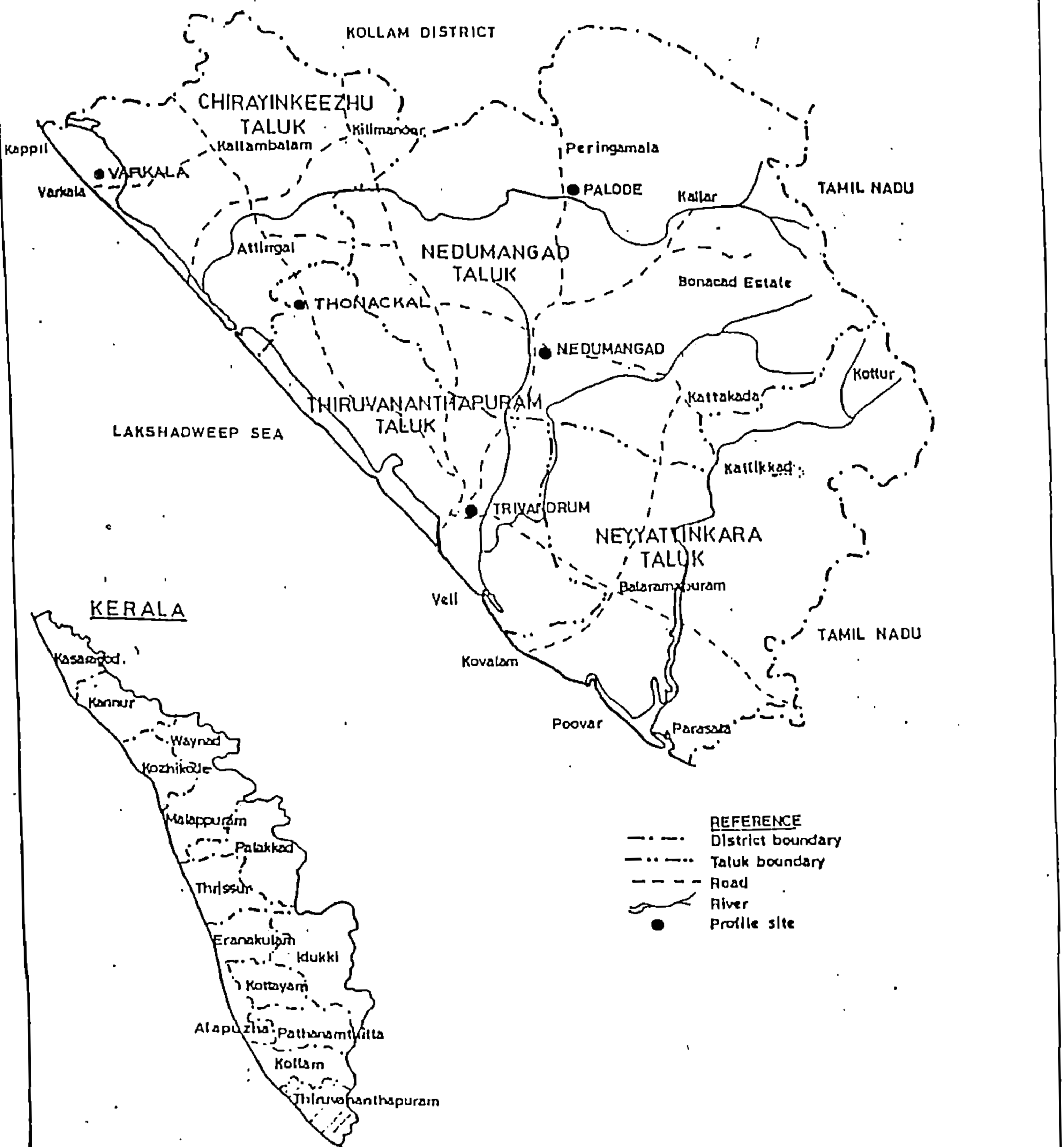
At each site, profile pits of 1.5 x 1.5 x 1.5 m were dug. Profile features and *in situ* observations were recorded as per F.A.O guidelines (1990) and Van Waveren and Bos (1990).

Bulk samples were collected from each of the horizons. The colour of the soil in the field moist condition was recorded using a Munsell Soil Colour Chart (1975).

FIG.1

MAP OF THIRUVANANTHAPURAM DISTRICT SHOWING PROFILE SAMPLE SITES

SCALE - 1:400000



3.2. Sample preparation

3.2.1. Soil

The bulk soil samples were air dried. The clods were broken with a wooden mallet and the samples were sieved with a 2 mm sieve. The less than 2mm and greater than 2mm fraction were stored separately for analysis.

3.2.2. Gravel

The coarser fraction (greater than 2mm) were further sampled into fine gravels (2 mm to 2.5 cm), coarse gravels (2.5 to 7.5cm) and cobbles (7.5 to 25cm) as suggested by Sys *et al.* (1993). These gravel fractions thus obtained were weighed and stored separately for further analysis.

3.3. Characterisation of gravel

3.3.1. Physical properties

3.3.1.1. Weight

Representative gravel samples were drawn from the gravel fractions separated and their weights were recorded.

3.3.1.2. Size and shape

Size and shape of the representative gravel samples were described as per the procedure outlined by Bullock *et al.* (1985).

3.3.1.3. Colour

The representative gravel samples were broken and the colour was described using Munsell Soil Colour Chart (1975).

3.3.1.4. Bulk density

Bulk density of the representative gravels samples were calculated using the procedure outlined by Black (1965).

3.3.1.5. Moisture content

Air dry and oven dry moisture content of gravel samples were determined as per standard procedure (ISRIC, 1992).

3.3.2. Chemical properties

The gravel fractions were ground and analysed for organic carbon and total nutrients.

3.3.2.1. Organic carbon

Organic carbon was determined by Walkey and Black's rapid titration method (Jackson, 1973).

3.3.2.2. Total analysis

Hydrochloric acid extract was prepared from the ground gravel samples. From the hydrochloric acid extract, (AOAC, 1960) acid insolubles, acid soluble silica, sesquioxides, iron, phosphorus, potassium, calcium and magnesium were determined (AOAC, 1960; Jackson, 1973).

Total nitrogen was estimated using the Micro- Kjeldhal method (Jackson, 1973).

3.3.2.3. Available nutrient analysis

Available nitrogen, phosphorus and exchangeable potassium were estimated as per the procedure outlined by Jackson (1973).

Exchangeable calcium and magnesium were determined by the titrimetric method using EDTA (Hesse, 1971).

Gravel fractions as such, without grinding were used for the determination of available nutrients.

3.3.3. Mineralogical analysis of the fine sand fractions

The fine sand separation of the gravel fractions after grinding was done as described by ISRIC (1992). The dried samples were used for the separation of light and heavy minerals using bromoform of specific gravity 2.8 (Carver, 1971) and mounted on microscopic slides using Canada balsam. The slides were observed under Leitz ortholaux petrological microscope and the identification and quantitative estimations were carried out (Black 1965).

3.3.4. Micromorphology

Representative gravel samples were drawn from each of the gravel fractions and micromorphological analysis was carried out as described in the Soil Survey Investigation Report No. I., Soil Conservation Service, USDA (1967). The individual samples were cooked separately in Canada balsam (Refractive index 1.54) taking care to avoid overheating. The impregnation was continued till bubbles almost ceased to appear indicating the filling of voids with the resin. The sample was cured in an oven for 24 hours and a small chip was sawn off.

The sample chip was then ground and polished one side smooth manually on a ground glass plate and fixed on a flat microscopic slide with Lakeside cement - 70. The chip was ground with Carborandum 60, 120, 400 and 600 grade powders till the thickness was 20 μ. A cover glass was fixed on the thinned section using Canada balsam. Excess Canada balsam was removed.

The slides were observed under Leitz ortholaux petrological microscope. Photomicrographs were taken and interpretations were made (Black, 1965; Brewer, 1976; Bullock *et al.*, 1985).

3.4. Characterisation of soil

3.4.1. Physical properties

3.4.1.1. Soil colour

The colour of the soil was described by the help of a Munsell Soil Colour Chart (1975).

3.4.2. Chemical properties

3.4.2.1. Soil reaction

Soil pH was determined using a 1:2.5 soil-water suspension with a Perkin Elmer pH meter (Jackson, 1973).

3.4.2.2. Electrical conductivity

Electrical conductivity of a 1:2.5 soil-water suspension was measured using a conductivity bridge (Jackson, 1973).

3.4.2.3. Organic carbon

Organic carbon was determined by Walkley and Blacks rapid titration method (Jackson, 1973).

3.4.2.4. Total analysis

The hydrochloric acid extract (AOAC, 1960) was used in the determination of acid insolubles, acid soluble silica, sesquioxides, iron, phosphorous, potassium, calcium and magnesium (AOAC, 1960; Jackson, 1973).

Total nitrogen was determined by the Micro-Kjeldhal method (Jackson, 1973).

3.4.2.5. Available nutrient analysis

Available nitrogen, phosphorous and exchangeable potassium were determined by the procedure by Jackson (1973).

Exchangeable calcium and magnesium were determined by the titrimetric method using EDTA (Hesse, 1971).

3.4.3. Mineralogical analysis of the fine sand fraction

Fine sand was separated (ISRIC, 1992) and the dried samples were used for the separation of light and heavy minerals (Carver, 1971). The minerals were mounted on microscopic slides and observed under a Leitz ortholaux petrological microscope. Identification and quantitative estimation of the minerals were carried out (Black, 1965).

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

A study was conducted to characterise the morphological, physical, chemical, mineralogical and micromorphological properties of soil gravel fractions to understand the pedogenesis of soil gravels and to evaluate their fertility contribution in the major soil series of Trivandrum district namely Palode, Nedumangad, Varkala, Thonnackal and Trivandrum.

4.1. Profile morphology

Profile features and in-situ observations of the representative profiles were made as per FAO (1990) and the guidelines for the description and coding of soil data (van Waveren and Bos, 1990) and brief record of the profile morphology is given below :

Profile 1	:	Palode
Date	:	17-10-1994
Country	:	India
Author	:	Suraj John
Location	:	Palode(TBGRI), Semideciduous forest, Trivandrum, Kerala
Latitude	:	8° 45'N Longitude 77° 02'E

Plate 1. Profile site of Palode series

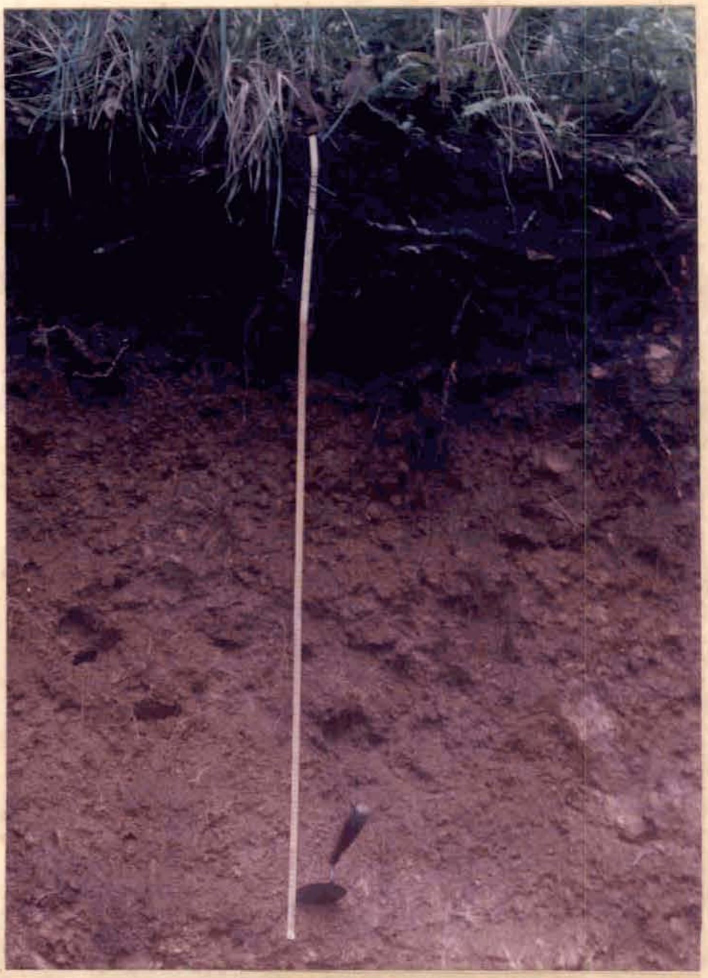


Plate 2. Profile of Palode series

Altitude	:	150 meters above MSL
Classification	:	Humic ferralsol (FAO/UNESCO)/ Argiustoll (USDA)
Parent material	:	Residual material, acidic gneiss stony
Landform	:	Hill
Physiography	:	Undulating to rolling
Drainage	:	Well
Landuse	:	(Semi) natural vegetation
Vegetation	:	Semideciduous woodland
Annual rainfall	:	2602mm (6 years average)
Temperature (max.)	:	32.5°C (6 years average)
Temperature (min.)	:	20.7°C (6 years average)
Average temperature	:	26.6°C (mean annual)

Profile :

Horizon	Depth	Soil colour	Soil texture	Soil structure
A_0	0-14	10YR 2/2 (very dark brown)	Gravelly sandy clay loam	Granular
A_h	14-51	10YR 2/2 (very dark brown)	Gravelly clay loam	Granular
B	51-106	7.5YR 6/4 (light brown)	Gravelly clay	Subangular blocky
C	106-150	5YR 7/3 (pink)	Gravelly clay	Subangular blocky

Profile 2	:	Nedumangad
Date	:	17-10-1994
Country	:	India
Author	:	Suraj John
Location	:	Nedumangad, Pazhakutty-Shencotta road, Kerala
Latitude	:	8° 36'N
Longitude	:	76° 59'53"E
Altitude	:	60 meters above MSL
Classification	:	Plinthic ferralsol (FAO/UNESCO)/ Typic plinthustult (USDA)
Parent material	:	Residual material, acidic gneiss mixed
Land form	:	Hill
Physiography	:	Undulating terrain
Drainage	:	Moderately well
Landuse	:	Medium level mixed farming
Vegetation	:	Semideciduous woodland
Annual rainfall	:	2602mm (6 years average)
Temperature (max.)	:	32.5°C (6 years average)
Temperature (min.)	:	20.7°C (6 years average)
Average temperature	:	26.6°C (mean annual)

Plate 3. Profile site of Nedumangad series

Plate 4. Profile of Nedumangad series

Profile :

Horizon	Depth	Soil colour	Soil texture	Soil structure
A_p	0-11	5YR 5/2 (reddish grey)	Gravelly sandy clay loam	Granular
AB	11-53	10YR 6/3 (pale brown)	Gravelly sandy clay	Subangular blocky
B_t	33-62	7.5YR 6/4 (light brown)	Gravelly sandy clay	Subangular blocky
BC	62-150	7.5YR 8/6 (reddish yellow)	Gravelly sandy clay	Subangular blocky

Profile 3	:	Varkala
Date	:	18-10-1994
Country	:	India
Author	:	Suraj John
Location	:	Kaithakonam, via. Sivagiri, Kerala
Latitude	:	8° 43'55"N
Longitude	:	76° 44'9"E
Altitude	:	40 meters above MSL
Classification	:	Plinthic ferralsol (FAO/UNESCO)/ Typic plinthustult (USDA)
Parent material	:	Residual material, acidic gneiss mixed
Land form	:	Hill
Physiography	:	Undulating

Plate 5. Profile site of Varkala series

Plate 6. Profile of Varkala series

Plate 7. Bhorizon eroded phase of Varkala series

Drainage : Well

Landuse : Coconut, tapioca

Vegetation : Grasses, herbs, shrubs

Annual rainfall : 1686mm

Temperature (max.) : 32.5°C

Temperature (min.) : 20.7°C

Average temperature : 26.6°C (mean annual)

Profile :

Horizon	Depth	Soil colour	Soil texture	Soil structure
Bt_2	0-8	5YR 6/6 (reddish yellow)	Gravelly clay loam	Moderate, medium subangular blocky
Bt_3	8-150	5YR 5/8 (yellowish red)	Gravelly clay	Strong, coarse, subangular blocky

Profile 4 : Thonnackal

Date : 18-10-1994

Country : India

Author : Suraj John

Location : Near Kerala Industrial PolymersLimited, China clay mines, Thonnackal, Trivandrum, Kerala

Latitude : 8° 39'7"N

Plate 8. Profile site of Thonnackal series

Plate 9. Profile of Thonnackal series

Plate 10. Last horizon of Thonnackal series

Longitude : 76° 51'01"E

Altitude : 40 meters above MSL

Classification : Humid ferralsol (FAO/UNESCO)/ Ustoxic Dystropepts (USDA)

Parent material : Colluvial sediments

Land form : Footslopes of low hills

Physiography : Undulating

Drainage : Well

Landuse : Coconut, tapioca

Vegetation : Grasses, herbs, shrubs

Annual rainfall : 1686mm

Temperature (max.) : 31.79°C

Temperature (min.) : 23.54°C

Average temperature : 27.6°C (mean annual)

Profile :

Horizon	Depth	Soil colour	Soil texture	Soil structure
A_p	0-20	5Y 6/3 (pale olive)	Sandy clay loam	Weak medium, subangular blocky
Bt_1	20-70	10YR 8/4 (very pale brown)	Sandy clay loam	Moderate medium, subangular blocky
B_3	113-150	10YR 7/3 (very pale brown)	Gravelly clay	Massive
B_{31}	150 +	10YR 7/3 (very pale brown)	Gravelly clay	Massive

Profile 5	:	Trivandrum
Date	:	19-10-1994
Country	:	India
Author	:	Suraj John
Location	:	Mannanthala, Trivandrum, Kerala
Latitude	:	8° 29'N
Longitude	:	76° 57'E
Altitude	:	30 meters above MSL
Classification	:	Plinthic ferralsol (FAO/UNESCO)/ Typic plinthustult (USDA)
Parent material	:	Residual material, acidic gneiss mixed
Land form	:	Low hill
Physiography	:	Enriched by wet land valleys
Drainage	:	Well
Landuse	:	Low level mixed farming
Vegetation	:	Shrubs
Annual rainfall	:	1840mm (50 years average)
Temperature (max.)	:	30.7°C (50 years average)
Temperature (min.)	:	23.5°C (50 years average)
Average temperature	:	27°C (mean annual)

Plate 11. Profile site of Trivandrum series

Plate 12. Profile of Trivandrum series

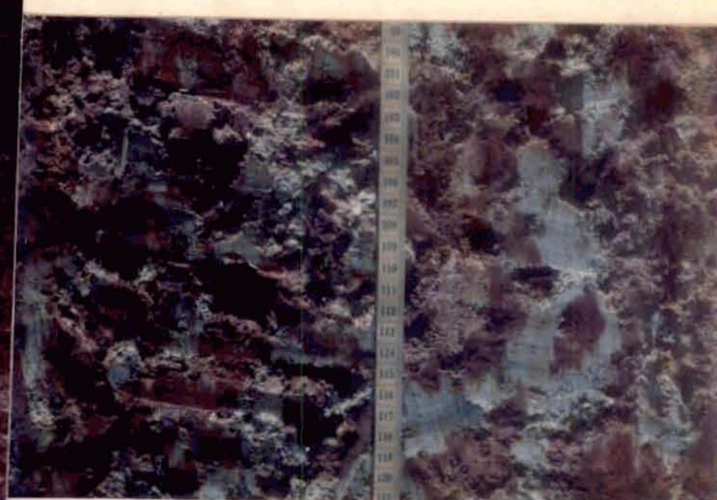


Plate 13. Bt_1 horizon of Trivandrum series

Profile :

Horizon	Depth	Soil colour	Soil texture	Soil structure
A_p	0-14	5YR 6/4 (light reddish brown)	Gravelly sandy clay loam	Granular
AB	14-57	5YR 6/4 (light reddish brown)	Gravelly sandy clay	Subangular blocky
Bt_1	57-150	5YR 6/4 (light reddish brown)	Gravelly sandy clay	Subangular blocky

4.1.1. Comparative morphology

The major soil series investigated for gravel characterisation, genesis and soil fertility contribution of the Trivandrum district namely Palode, Nedumangad, Varkala, Thonnackal and Trivandrum series fall within 8°29' to 8°45'N latitude and 76°2' to 77°59'E longitude. It is a uniform related geological material with less variation in geogenesis. They fall within the altitude of 30 meters to 150 meters above mean sea level and are located in the toe-slope, mid-slope and crest of a hill transect from Palode to Trivandrum with the Varkala profile in the bordering cliff towards the coast having narrow altitudinal variation.

The diagnostic surface horizon at Nedumangad, Varkala, Thonnackal and Trivandrum are ochric with low hue. At Palode, it is mollic epipedon associated with cambic horizon. Subsurface diagnostic horizons at Nedumangad, Varkala and Trivandrum are argillic to fragic. At Varkala, it is irreversibly hardened resulting in an iron stone consistency ie., with petroferric contact and exposed B horizon. At Palode, the argillic horizon is in the early stages of development while the argillic horizon at Thonnackal is with oxic features.

According to FAO/UNESCO system (1988), the Palode profile comes under humid ferralsol while the others are accommodated in the plinthic ferralsol indicating the presence of a compact plinthite layer within a depth of one meter.

As per USDA (1994), Varkala, Trivandrum and Nedumangad profiles are Typic Plinthiustults in which the plinthite forms a continuous phase occupying more than half the volume. The Thonnackal profile which is unique is accommodated in Ustoxic Dystropepts.

The parent material of Palode series is characteristically stony, acidic gneiss residual material. Similar parent materials are observed in Nedumangad, Varkala and Trivandrum but with a mixed mineralogy. The Thonnackal series are developed on colluvial sediments.

The landforms of the profiles vary from footslopes of a low hill (Thonnackal) and low hill (Trivandrum) to others in the hill.

Irrespective of the profiles, the soils are well drained. At Palode, the land is under semi-natural vegetation while at Nedumangad and Trivandrum, it is low level mixed farming. Varkala and Thonnackal series are dominantly under coconut and tapioca cultivation. The natural vegetation at Palode and Nedumangad are of semi-deciduous nature while in the other series studied, shrubs, herbs and grasses dominate.

This geographical area receives an annual rainfall of 1686 to 2602mm. The mean annual temperature of all the profile sites are above 22°C, with little variation from 26.6 to 27.6°C.

All the profiles are well developed except Thonnackal. Laterisation is maximum in the eroded BC profiles of Varkala series and is noticeable even in the Palode series.

The soil colour is with high hue in the darker profile of Palode series and is more red in the other series except Thonnackal. The surface layers of Thonnackal series indicate a low hue value depicting the reduced environment. The lower layers of the series strengthens the colluvial nature of the deposit.

The profiles studied were gravelly throughout except the surface layers of Thonnackal. The surface horizons are granular in the Palode, Nedumangad and Trivandrum series while it is weak to medium subangular blocky at Thonnackal and moderate medium subangular blocky at Varkala.

The soil climate irrespective of the series are with ustic moisture and isohyperthermic temperature regimes.

Ustic soils can be efficiently utilised for rainfed plantation crops which flourish well in the isohyperthermic temperature regime. The performance of vegetables in this moisture and temperature regime are also reported to be economical (Ikawa, 1978).

4.2. Physical properties of gravels

The physical properties of gravels are presented in Tables 1 and 2.

4.2.1. Gravel content

The content and distribution of gravels and their fractions are presented in Table 1 and Plate 14. The gravel content ranges between 65.51 to 77.44, 27.94 to 34.55, 76.04 to 90.91, 6.76 to 49.41 and 49.51 to 76.59 per cent in Palode, Nedumangad, Varkala, Thonnackal and Trivandrum series respectively. The profile pattern of the distribution of gravels at Palode, Varkala and Trivandrum shows an increase with depth

Table 1. Gravel distribution of soil profiles

Series name	Profile site	Depth of horizon (cm)	Gravel content (%)	Gravel fractions and content (%)	Moisture content (Air dry) (%)	Moisture content (Oven dry) (%)
		0-14	65.51	I 45.40	29.84	3.31
				II 20.11		
				I 30.44		
		14-51	72.18	II 14.78	11.54	1.88
				III 26.96		
Palode	TBGRI,			I 33.53		
	Palode	51-106	77.44	II 35.09	14.29	2.11
				III 8.82		
				I 32.43		
		106-150	74.76	II 31.77	15.75	2.03
				III 10.56		
		0-11	33.34	I 24.67	15.49	3.65
				II 8.67		
		11-33	32.45	I 28.77	10.94	2.11
				II 3.68		
Nedumangad	Pazhakutty-	33-62	27.94	I 18.53	12.82	3.53
	Shencotta			II 9.41		
	road,	62-150	34.55	I 33.09	15.38	4.87
	Nedumangad			II 1.46		
Varkala	Kaithakonam	0-8	76.04	I 68.60	7.63	2.95
	via. Sivagiri,			II 7.44		
	Varkala	8-150	90.91	I 51.14	9.28	3.42
				II 39.77		
	Near	0-20	6.76	I 6.76	10.84	1.41
	KIPL	20-70	15.39	I 15.39	12.36	1.54
Thonnackal	china clay	70-133	8.24	I 8.24	14.61	1.66
	mines,	113-150	49.41	I 49.41	12.37	2.35
	Thonnackal	150+	49.39	I 48.19	13.99	1.74
				II 1.20		
		0-14	49.51	I 47.57	14.88	2.72
				II 1.94		
Trivandrum	Mannanthala,	14-57	53.62	I 50.73	14.81	3.03
	Trivandrum			II 2.89		
		57-150	76.59	I 59.57	14.55	5.26
				II 17.02		

Note : Gravel/Coarser soil fraction : I — Fine gravels (2mm-2.5cm)
II — Coarse gravels (2.5 -7.5cm)
III — Cobbles (7.5-25cm)

Table 2. Physical properties of gravels

Series name	Profile site	Depth of horizon (cm)	Gravel fractions	Weight (g)	Bulk density (g cm^{-3})	Shape	Mean Size (cm^2)	Colour
		0-14	I	1.77-9.11 (4.72)	2.31	smooth rounded - undulating subangular (undulating subrounded)	1.02-3.61 (2.16)	10 R 6/4 (pale red), 2.5 YR 2/4 (dark reddish brown), 5 YR 3/4 (dark reddish brown), 7.5 YR 6/8 (reddish yellow), 10 YR 6/8 (brownish yellow)
			II	10.94-56.04 (23.04)	2.12	smooth rounded - undulating subangular (undulating subrounded)	3.40-19.00 (9.41)	10 R 2/2 (very dusky red), 2.5 YR 2/4 (dark reddish brown), 5 YR 6/8 (reddish yellow), 7.5 YR 6/8 (reddish yellow), 10 YR 6/8 (brownish yellow), 5 Y 6/8 (olive yellow)
			I	1.70-12.55 (6.61)	2.38	smooth rounded - undulating subangular (undulating rounded)	1.80-6.30 (4.18)	10 R 3/3 (dusky red), 2.5 YR 2/4 (dark reddish brown), 5 YR 6/8 (reddish yellow), 7.5 YR 6/8 (reddish yellow), 10 YR 5/8 (yellowish brown), 2.5 Y 6/8 (olive yellow)
Palode	TBGRI, Palode	14-51	II	9.49-71.33 (26.59)	2.23	smooth rounded - undulating subangular (undulating rounded)	5.13-17.20 (9.95)	10 R 3/6 (dark red), 2.5 YR 2/4 (dark reddish brown), 5 YR 3/3 (dark reddish brown), 7.5 YR 5/8 (strong brown), 10 YR 8/8 (yellow)
			III	227.38-314.21 (270.79)	2.11	undulating rounded - undulating subrounded (undulating subrounded)	37.62-96.80 (64.05)	2.5 YR 2/4 (dark reddish brown), 10 YR 5/8 (reddish brown), 2.5 Y 6/8 (olive yellow)
			I	1.02-9.96 (5.04)	2.22	smooth rounded - undulating subrounded (smooth rounded)	1.54-7.74 (4.07)	10 R 4/8 (red), 2.5 YR 2/2 (very dusky red), 5 YR 5/8 (strong brown), 7.5 YR 5/8 (strong brown), 10 YR 6/8 (brownish yellow)
		51-106	II	5.22-54.74 (19.76)	2.08	smooth rounded - undulating subrounded (undulating subrounded)	5.25-19.68 (9.20)	10 R 3/3 (dusky red), 2.5 YR 2/4 (dark reddish brown), 7.5 YR 4/4 (dark brown), 10 YR 6/8 (brownish yellow)
			III	(196.10)	2.01	(undulating rounded)	(39.6)	2.5 YR 2/4 (dark reddish brown), 2.5 Y 6/8 (olive yellow)

(Contd ...)

Table 2. (Contd...)

Series name	Profile site	Depth of horizon (cm)	Gravel fractions	Weight (g)	Bulk density (g cm^{-3})	Shape	Mean Size (cm^2)	Colour
			I	1.60-7.76 (4.99)	2.31	smooth rounded - undulating subangular (undulating rounded)	1.60-7.92 (4.17)	10 R 3/3 (dusky red), 2.5 YR 2/4 (dark reddish brown), 7.5 YR 5/8 (strong brown), 10 YR 5/8 (yellowish brown)
		106-150	II	6.95-50.36 (17.06)	2.25	smooth rounded - undulating subangular (undulating rounded)	3.99-24.20 (9.08)	10 R 3/3 (dusky red), 2.5 YR 3/4 (dark reddish brown), 5 YR 5/8 (yellowish red), 7.5 YR 5/8 (strong brown), 10 YR 7/8 (yellow)
			III	(306.12)	2.21	(undulating subrounded)	(88.2)	2.5 YR 4/8 (red), 10 YR 7/8 (yellow)
		0-11	I	1.85-8.45 (4.56)	2.29	smooth rounded - undulating subangular (smooth rounded)	1.68-6.27 (3.72)	10 R 3/3 (dusky red), 2.5 YR 4/4 (reddish brown), 5 YR 5/8 (yellowish red), 7.5 YR 5/8 (strong brown), 10 YR 5/8 (yellowish brown)
			II	5.02-136.34 (29.47)	2.14	smooth rounded - undulating subangular (undulating subrounded)	3.96-39.05 (9.79)	10 R 6/2 (pale red), 2.5 YR 3/4 (dark reddish brown), 5 YR 6/4 (light reddish brown), 7.5 YR 6/8 (reddish yellow), 10 YR 6/8 (brownish yellow)
		11-33	I	1.13-6.78 (4.08)	2.36	smooth rounded - undulating subangular (undulating rounded)	1.53-7.13 (3.62)	10 R 3/6 (dark red), 2.5 YR 2/4 (dark reddish brown), 5 YR 5/8 (yellowish red), 7.5 YR 6/8 (reddish yellow), 10 YR 6/8 (brownish yellow)
			II	5.47-22.95 (11.29)	1.73	smooth rounded - undulating subangular (undulating rounded)	4.18-11.44 (6.88)	10 R 4/2 (weak red), 2.5 YR 2/4 (dark reddish brown), 5 YR 5/4 (reddish brown), 7.5 YR 5/8 (strong brown), 10 YR 5/8 (yellowish brown)
Nedumangad	Pazhakutty - Shencotta road, Nedumangad	33-62	I	0.86-8.94 (4.24)	2.22	smooth rounded - undulating subangular (smooth subrounded)	1.82-6.20 (3.63)	10 R 3/6 (dark red), 2.5 YR 3/4 (dark reddish brown), 5 YR 6/8 (reddish yellow), 7.5 YR 7/4 (pink), 10 YR 8/3 (very pale brown), 2.5 Y 8/6 (yellow)
			II	9.08-63.13 (19.06)	1.61	smooth rounded - undulating subrounded (undulating rounded)	6.00-25.50 (9.67)	10 R 3/4 (dusky red), 2.5 YR 4/6 (red), 5 YR 7/4 (pink), 7.5 YR 5/8 (strong brown), 10 YR 6/8 (brownish yellow)

(Contd...)

Table 2. (Contd...)

Series name	Profile site	Depth of horizon (cm)	Gravel fractions	Weight (g)	Bulk density (g cm^{-3})	Shape	Mean Size (cm^2)	Colour
		62-150	I	1.26-6.21 (4.02)	2.05	smooth rounded - undulating subrounded (smooth rounded)	2.43-5.46 (3.80)	10 R 3/6 (dark red), 2.5 YR 2/4 (dark reddish brown), 5 YR 6/8 (reddish yellow), 7.5 YR 4/4 (brown), 10 YR 6/8 (brownish yellow), 2.5 Y 7/8 (yellow)
			II	8.81-11.66 (9.97)	1.91	smooth rounded - undulating subrounded (undulating rounded)	6.08-7.59 (6.88)	10 R 3/3 (dusky red), 2.5 YR 2/4 (dark reddish brown), 2.5 Y 6/8 (olive yellow)
		0-8	I	3.57-11.31 (6.46)	2.65	smooth rounded - undulating subangular (smooth rounded)	2.04-6.20 (3.89)	10 R 3/2 (dusky red), 2.5 YR 2/4 (dark reddish brown), 5 YR 4/2 (dark reddish grey), 7.5 YR 6/6 (reddish yellow), 10 YR 5/6 (yellowish brown)
			II	7.18-52.09 (15.18)	2.03	smooth rounded - undulating subangular (smooth rounded)	3.95-16.00 (7.39)	10 R 3/2 (dusky red), 2.5 YR 2/4 (dark reddish brown), 10 YR 5/6 (yellowish brown)
Varkala	Kaithakonam via. Sivagiri, Varkala	8-150	I	3.81-8.26 (5.99)	2.71	smooth rounded - undulating subangular (smooth rounded)	3.74-8.19 (5.12)	10 R 3/4 (dusky red), 2.5 YR 4/4 (reddish brown), 5 YR 4/2 (dark reddish grey), 7.5 YR 5/8 (strong brown), 10 YR 6/8 (brownish yellow)
			II	7.18-24.70 (14.69)	2.19	smooth rounded - undulating subangular (smooth subrounded)	5.25-11.70 (8.51)	10 R 3/3 (dusky red), 2.5 YR 2/4 (dark reddish brown), 5 YR 5/4 (reddish brown), 7.5 YR 5/6 (strong brown), 10 YR 7/8 (yellow)
		0-20	I	0.13-0.87 (0.36)	2.16	smooth rounded - undulating subangular (smooth rounded)	0.24-0.90 (0.57)	10 R 3/3 (dusky red), 2.5 YR 3/4 (dark reddish brown), 5 YR 5/8 (yellowish red), 10 YR 5/8 (yellowish brown)
		20-70	I	0.22-0.98 (0.48)	2.12	smooth rounded - undulating subangular (smooth rounded)	0.53-1.17 (0.93)	10 R 3/4 (dusky red), 5 YR 6/8 (reddish yellow), 10 YR 6/3 (pale brown)
Thonnackal	Near KIPL china clay mines, Thonnackal	70-113	I	0.18-1.02 (0.41)	2.28	smooth rounded - undulating subangular (smooth rounded)	0.43-1.54 (0.76)	10 R 3/4 (dusky red), 2.5 YR 3/4 (dark reddish brown), 7.5 YR 5/8 (strong brown), 10 YR 6/3 (pale brown)

(Contd...)

Table 2. (Contd...)

Series name	Profile site	Depth of horizon (cm)	Gravel fractions	Weight (g)	Bulk density (g cm^{-3})	Shape	Mean Size (cm^2)	Colour
		113-150	I	1.17-6.64 (3.22)	2.36	smooth rounded - undulating subrounded (smooth rounded)	1.00-3.91 (2.57)	10 R 3/4 (dusky red), 2.5 YR 5/4 (reddish brown), 5 YR 5/8 (yellowish red), 7.5 YR 6/4 (light brown), 10 YR 7/8 (yellow), 2.5 Y 7/8 (yellow)
		150 +	I	1.84-6.67 (3.87)	2.45	smooth rounded - undulating subangular (smooth rounded)	1.80-5.27 (3.19)	10 R 3/3 (dusky red), 2.5 YR 3/4 (dark reddish brown), 5 YR 5/4 (reddish brown), 7.5 YR 5/8 (strong brown), 10 YR 5/8 (yellowish brown)
			II	9.70-9.73 (9.72)	2.17	(undulating rounded)	5.20-5.60 (5.40)	10 R 3/6 (dark red), 2.5 YR 2/4 (dark reddish brown), 5 YR 5/8 (yellowish red), 7.5 YR 6/8 (reddish yellow)
Trivandrum	Mannanthala, Trivandrum	0-14	I	1.46-6.52 (3.36)	2.33	smooth rounded - undulating subangular (smooth subrounded)	1.60-5.70 (3.28)	10 R 3/4 (dusky red), 2.5 YR 5/4 (reddish brown), 5 YR 6/8 (reddish yellow), 7.5 YR 6/8 (reddish yellow), 10 YR 6/8 (brownish yellow)
			II	12.25-29.24 (20.75)	2.21	(undulating rounded)	6.27-12.00 (8.94)	2.5 YR 2/4 (dark reddish brown), 5 YR 4/6 (yellowish red), 7.5 YR 4/4 (dark brown)
		14-57	I	1.11-5.97 (3.65)	2.14	smooth rounded - undulating subrounded (smooth rounded)	1.30-7.00 (3.39)	10 R 3/2 (dusky red), 2.5 YR 4/2 (weak red), 5 YR 6/8 (reddish yellow), 7.5 YR 5/8 (strong brown), 10 YR 5/8 (yellowish brown)
			II	11.44-14.24 (13.06)	2.03	smooth rounded - undulating rounded (undulating rounded)	7.20-9.62 (8.57)	10 R 3/6 (dark red), 5 YR 5/8 (yellowish red), 7.5 YR 6/8 (reddish yellow)
		57-150	I	1.30-6.15 (3.45)	1.97	smooth rounded - undulating subangular (undulating subrounded)	1.87-7.82 (3.79)	10 R 4/6 (red), 2.5 YR 4/4 (reddish brown), 5 YR 6/8 (reddish yellow), 7.5 YR 5/8 (strong brown), 10 YR 7/8 (yellow)
			II	7.38-40.41 (15.27)	1.62	smooth rounded - undulating subangular (undulating subrounded)	5.13-19.24 (9.42)	10 R 3/6 (dark red), 2.5 YR 3/2 (dusky red), 5 YR 5/8 (yellowish red), 7.5 YR 6/8 (reddish yellow), 10 YR 6/8 (brownish yellow)

Note : Gravel/Coarser soil fraction :
I — Fine gravels (2mm-2.5cm)
II — Coarse gravels (2.5-7.5cm)
III — Cobbles (7.5-25cm)

while the profile at Nedumangad and Thonnackal behaves differently. The third horizon of Nedumangad shows a marked drop in the gravel content indicating an active aggillisation by clay migration. At Thonnackal, the formation of gravels are inherently disturbed by the siliceous nature of the sediment, lesser enrichment of iron, poor drainage and stratification of the alluvio-colluvial deposits, indicated in the irregular pattern of loose and friable gravel distribution.

4.2.2. Gravel fractions and their distribution

Three size fractions were considered and the whole soil gravels of the series were fractioned. The size ranges of the gravels considered were 2mm to 2.5cm, 2.5 to 7.5cm and 7.5 to 25cm. Palode series is unique with three gravel fractions. The gneissic cobbles present in the subsurface horizons were constituted by weathering quartzitic boulder fragments and were classified under cobbles. The cobbles were absent in all the other series. Fine gravels are more than the coarse gravels in all the profiles. In the Thonnackal series, fine gravels were distributed in all the horizons but were stratified in the last horizon, where there is a patchy tendency of localised iron enrichment and precipitation and coarse gravels developed to a lesser extent. The maximum content of fine and coarse gravels were present in the surface and subsurface horizons of Varkala and the minimum content in the surface and fifth horizon of Thonnackal series respectively.

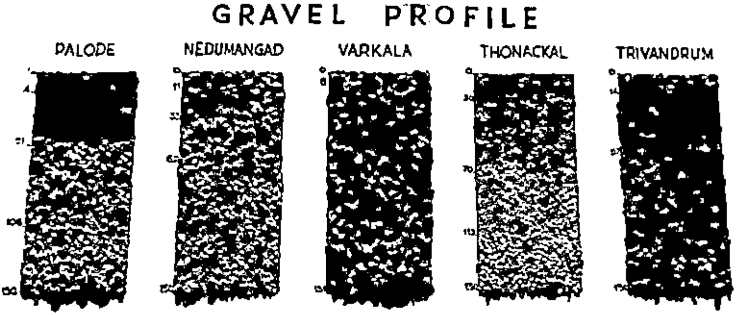


Plate 14. Gravel profiles of the series investigated

The fine and the coarse gravels at Palode exhibited an alternate pattern of decrease and increase down the profile. The coarse gravels exhibited a similar profile pattern at Nedumangad while the fine fraction exhibited an alternate pattern of increase and decrease with depth. While the content of fine gravels decreased with depth at Varkala, the coarse gravels increased with depth (indicating progressive petroplinthisation with depth). Thonnackal series is unique in that the coarse gravels could be found only in the fifth horizon, the fine gravels however showed an alternate pattern of increase and decrease with depth. A vectorial increase in the content of both gravel fractions could be seen in the Trivandrum series.

All the soil series of Trivandrum district under study except Thonnackal series contained four morphological types of gravels in the increasing order, quartz gravel < weathering parent material gravel < laterite gravel < ferruginous gravel. The uniqueness of the Palode series is the subsurface ferruginous gravel layer. Varkala series has a preponderance of laterite gravel followed by ferruginous gravel in the surface layers. The peculiarity of the Nedumangad series is the prominence of weathering parent material and laterite gravels. Quartz gravel, though present in all the series is comparatively more at Nedumangad and maximum at Thonnackal. At Thonnackal, the consolidation of quartz nucleus with iron enrichment is weak and discontinuous while the same at Nedumangad and other series are well developed.

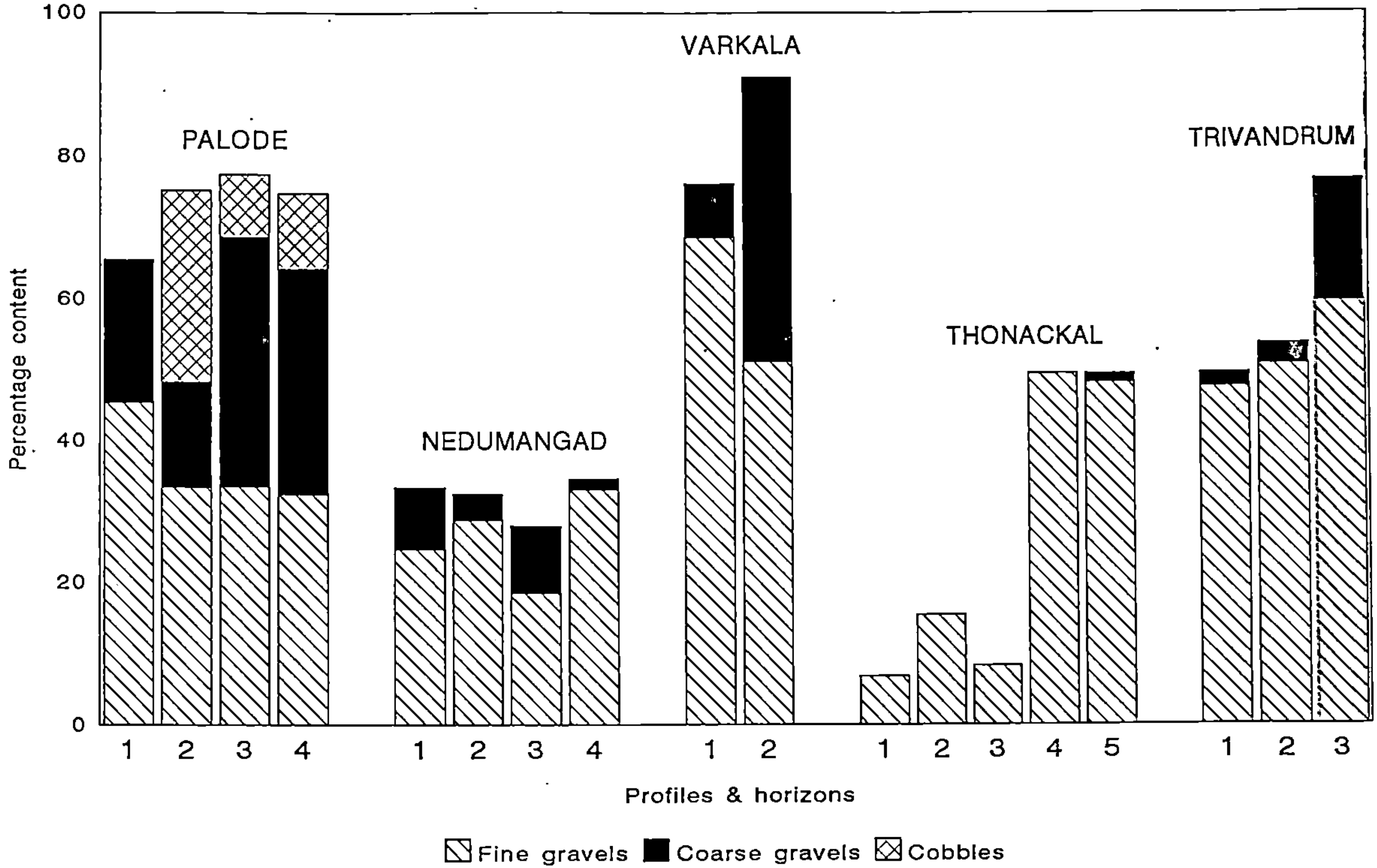


Fig. 2. Distribution of gravel fractions

4.2.3. Colour

At Palode, fine gravels at all depths except the third horizon are dark reddish brown in colour. In the first and second horizons, the fine gravels of brownish yellow and reddish yellow colour are also seen. The dominant colour of coarse gravels at all depths are dark reddish brown followed by brownish yellow. The cobbles seen in the series are of dark brown or olive yellow colour. Fine gravels of Nedumangad series at the surface horizons are yellowish red while at subsurface horizons are dark reddish brown to dark red. Coarse gravels in the surface and subsurface horizons are dark red in colour followed by brownish yellow. The fine gravels of the Varkala series are dusky red to dark reddish brown throughout the profile. The prominent gravel fraction in Thonnackal series are the fine gravels. Dusky red coloured gravels are present in all the horizons, dark reddish brown in alternate horizons, pale brown in the subsurface horizons and yellowish brown present in the first and fifth horizon. The coarse gravels present only in the fifth horizon are dark red, dark reddish brown, reddish brown or yellowish red. The fine gravels of the Trivandrum series are reddish brown, dusky red or reddish yellow in the first, second and third horizons; it may also be strong brown in the second and third horizons. Dark red, yellowish red and reddish yellow coloured coarse gravels are distributed in the second and third horizons with little of yellowish red ones in the surface layers. Within the profile, between fractions, marked difference in colour was not observed at all the sites.

Among the various colours of gravels, the hues between red and yellow are most wide spread caused by various forms and concentrations of Fe (iii) ion (Taylor, 1982; Torrent *et al.*, 1983). The grey colours of gravels above the hard impervious saprolite or last horizon and below the free geogenic surface gravel layer is because of the prevalent reduction environment and subsequent removal of iron.

4.2.4. Weight

Mean weight of soil gravels ranges between 4.72 to 6.61g, 17.06 to 26.59g and 196.10 to 314.21g respectively in the fine, coarse and cobble fractions of the Palode series. The maximum and minimum weights of the fractions were observed in the second and third horizons respectively. Fine and coarse gravels exhibited similar profile patterns of decrease with depth except in the second layer where a marked increase is observed. The cobbles which were absent in the first horizon shows an alternate decrease and increase.

The weight of fine gravels does not differ significantly at Nedumangad with the mean value ranging from 4.02 to 4.56g while the coarse gravels ranged in weight from 9.97 to 29.47g. The maximum weight of the fractions were observed in the surface horizon. The profile pattern of the weight of gravels are uniform in both the fractions with an alternate decrease and increase down the profile.

The shallow profile of the series of Varkala resulted in the maximum weights of the gravels being observed in the surface horizon though the subsurface horizon does not differ much in the gravel fraction weights. The fine gravels showed a weight of 6.46 and 5.99g and the coarse gravels indicated a weight of 15.18 to 14.69g in the two horizons respectively. Both the fractions decreased with depth in their weights.

When compared to other series, in the Thonnackal series, the fine gravel fraction does not differ significantly in their weights in the first three horizons but an abrupt increasing trend is noticed from the fourth horizon onwards. The mean weight ranged from 0.36 to 3.87g for fine gravels and the coarse gravels present only in the fifth horizon recorded a mean weight of 9.72g.

The fine and coarse gravel fractions of the Trivandrum series exhibited distinctly different profile patterns. Fine fraction indicated an alternative increase and decrease with depth while a reverse pattern was observed in coarse gravels. Maximum weights were observed in the second and surface horizons for fine and coarse gravels respectively. Within the profile, though there is significant weight difference in the coarse gravels, the difference in weight of fine gravels is too narrow. The mean weight of fine and coarse gravels ranged from 3.36 to 3.65g and 13.06 to 20.75g respectively.

The weight distribution of the gravel fractions and their proportion indicate that the Palode, Nedumangad, Trivandrum and Thonnackal series are 'members' of the same geological formation and period while the Varkala series is a member of a different geological formation and period.

4.2.5. Size

Mean size of the fine gravels ranges between 2.16 and 4.18 cm^2 with the maximum in the second horizon for Palode series. These values indicated an alternate pattern of increase and decrease with depth. A different profile pattern is observed for the size of coarse gravels with the mean size ranging from 9.08 to 9.95cm^2. The unique cobble fraction which was absent in the surface horizon exhibited an alternate pattern of decrease and increase down the profile, their values ranging from 37.62 to 96.80cm^2. Maximum size of fine and coarse gravels were observed in the second horizon while the minimum size was observed in the first horizon. The cobbles had a maximum size in the fourth horizon and minimum size in the third horizon.

At Nedumangad, the fractions exhibited a different profile pattern. The size of fine gravels increased with depth with a drop in the second horizon. Their mean value ranged between 3.62 and 3.80cm^2. Coarse gravel size exhibited an alternate decrease and increase down the profile with the mean values ranging from 6.88 to 9.79cm^2. Fine gravels indicated maximum size in the fourth horizon while the same for coarse gravels were in the surface horizon.

The size of both the gravel fractions increased with depth at Varkala with the mean value ranging from 3.89 to 5.12 and 7.39 to 8.51cm^2 in the fine and coarse gravels respectively.

At Thonnackal, the size of the fine gravels increased with depth except a decrease in the second horizon. Their mean size ranged between 0.57 and 3.19cm^2. The coarse gravels present only in the fifth horizon had a mean size of 5.40cm^2.

Fine gravels increased in mean size down the profile while the coarse gravels exhibited an alternate pattern of decrease and increase down the profile at Trivandrum. The mean size ranged between 3.28 and 3.79 and 8.57 and 9.42cm^2 in fine and coarse gravels respectively.

The proportion of the gravel fractions indicated similarity in the formation and period of formation of Palode, Nedumangad and Trivandrum series. Varkala series remains odd from the consolidation of gravel size. In the case of Thonnackal, the proportion of size of gravel fractions indicates restricted localised enrichment of iron and aggregation leading to gravel formation indicated by the sharp localised mottling observed in the subsurface horizons.

4.2.6. Shape

Fine, coarse gravels and cobbles were undulating subrounded to undulating rounded, in the Palode series. There were no definite profile pattern for the shape of the coarser soil fractions.

At Nedumangad, the fine gravels were dominantly smooth rounded while the coarse gravels were undulating rounded.

Both the fine and coarse gravels at Varkala were smooth rounded. Similar observations were also recorded in the case of fine gravels of Thonnackal series with undulating rounded coarse gravels in the last horizon. The uniqueness of the fine gravels of the Thonnackal series is that they remain smooth rounded throughout the profile.

The fine gravels were smooth rounded and the coarse gravels were undulating rounded in the Trivandrum series.

4.2.7. Bulk density

Mean bulk density in the Palode series ranged between 2.22 and 2.38, 2.08 and 2.25 and 2.01 and 2.21 g cm^{-3} for fine, coarse gravels and cobbles respectively. Both the gravel fractions exhibited a profile pattern of alternate increase and decrease with depth while the cobbles showed an alternate pattern of decrease and increase.

The mean bulk density in the Nedumangad series of fine and coarse gravels, ranged between 2.05 to 2.36 and 1.61 to 2.14 g cm^{-3} respectively. They exhibited a profile pattern of decrease with depth except in the fourth horizon of coarse gravels.

At Varkala, the mean bulk density of gravels exhibited an uniform profile pattern of increase with depth. It ranged between 2.65 to 2.71 and 2.03 to 2.19 g cm^{-3} respectively for fine and coarse gravels.

The mean bulk density of fine gravels at Thonnackal series increased with depth except in the second horizon where a slight decrease is observed. The values ranged between 2.12 to 2.45 g cm^{-3}. The coarse gravels which were observed only in the fifth horizon had a mean bulk density of 2.17 g cm^{-3}.

The Trivandrum series showed a decrease in mean bulk density for both gravel fractions with depth, the range being 1.97 to 2.33 and 1.62 to 2.21 g cm^{-3} for fine and coarse gravels respectively.

Irrespective of the series, the fine gravels are with higher bulk density than their respective coarse fractions. The tendency of 'consolidation' is still confirmed in the 'dilution' of bulk density in the progressive size range fraction of gravels and cobbles in the Palode series.

4.2.8. Moisture content

Air dry moisture content of these gravelly soils (soil with gravel) ranged between 11.54 to 29.84, 10.94 to 15.49, 7.63 to 9.28, 10.84 to 14.61 and 14.55 to 14.88 per cent respectively in the Palode, Nedumangad, Varkala, Thonnackal and Trivandrum. Similarly, the oven dry moisture content of the respective samples ranged from 1.88 to 3.31, 2.11 to 4.87, 2.95 to 3.42, 1.41 to 2.35 and 2.72 to 5.26 per cent.

The moisture retained by these gravelly soils investigated after air drying and ovendrying clearly indicates that gravel content significantly reduces the moisture retained by these soil series. Both the fractions, irrespective of the series, play a significant role in reducing the moisture retained by these gravelly soils. At Palode, even the cobbles of weathering gneiss also significantly reduced the soil volume and moisture retained from the second horizon onwards.

4.3. Chemical properties

The chemical properties of gravels namely the organic carbon, acid insolubles, acid soluble silica, sesquioxides, iron, total nitrogen, total phosphorus, total potassium, total calcium and total magnesium are presented in Table 3.

4.3.1. Organic carbon

Irrespective of the soil series, organic carbon content of fine, coarse gravels and cobbles exhibited a uniform profile pattern of decrease down the profile. Organic carbon content ranged from 0.14 to 2.61, 0.03 to 0.26 and 0.05 to 0.23 per cent respectively in the fine, coarse gravels and cobbles in the Palode series. At Nedumangad, it ranged between 0.15 to 1.65 and 0.02 to 1.60 per cent respectively for fine and coarse gravels. The range values for fine and coarse gravels of Varkala, Thonnackal and Trivandrum were respectively 0.14 to 0.21 and 0.08 to 0.09; 0.06 to 0.54 and 0.03 and 0.41 to 0.45 and 0.14 to 0.15 per cent.

The organic carbon content of gravel fractions decreased with increase in size. This trend was noticed in all the soil series.

4.3.2. Acid insolubles

Distribution of acid insoluble content of the gravel ranged from 38.31 to 40.26, 37.21 to 41.03 and 37.16 to 39.21 per cent respectively in the fine, coarse gravels and cobbles in the Palode series. Fine and

Table 3. Chemical properties of gravels

Series name	Profile site	Depth of horizon (cm)	Gravel fraction	Organic carbon (%)	Acid insolubles (%)	Acid soluble silica (%)	Sesqui-oxides (% R_2O_3)	Iron (% Fe_2O_3)	Total nitrogen (%)	Total phosphorus (% P_2O_5)	Total potassium (% K_2O)	Total calcium (Cmol kg^{-1})	Total magnesium (Cmol kg^{-1})
Palode	TBGRI, Palode	0-14	I	2.61	40.26	2.38	38.25	24.36	0.172	0.732	0.273	0.92	3.82
			II	0.26	41.03	2.42	38.71	24.47	0.009	0.793	0.292	0.98	3.71
		14-51	I	1.26	39.93	3.18	36.77	25.82	0.113	0.136	0.216	0.51	4.21
			II	0.19	38.17	3.12	36.82	25.21	0.009	0.122	0.253	0.36	4.13
			III	0.23	38.03	3.53	36.99	25.96	0.007	0.138	0.272	0.82	4.52
		51-106	I	0.33	40.17	3.29	35.63	25.93	0.019	0.262	0.193	0.86	5.83
			II	0.18	39.91	3.13	35.82	25.96	0.013	0.211	0.176	0.83	5.91
			III	0.08	39.21	3.29	36.03	25.99	0.002	0.219	0.189	0.92	6.21
		106-150	I	0.14	38.31	3.52	36.28	26.58	0.011	0.113	0.235	0.83	5.52
			II	0.03	37.21	3.72	36.39	26.71	0.006	0.126	0.257	0.89	5.72
			III	0.05	37.16	3.88	36.81	26.82	0.003	0.103	0.361	0.97	5.93
Nedumangad	Pazhakutty-Shencotta road, Nedumangad	0-11	I	1.65	39.26	2.31	35.36	26.21	0.137	0.081	0.183	1.91	3.81
			II	1.60	39.28	2.19	35.69	26.34	0.130	0.073	0.231	2.09	3.98
		11-33	I	0.93	37.22	3.21	38.23	27.13	0.112	0.079	0.236	1.84	2.99
			II	0.19	35.83	1.27	37.92	28.26	0.030	0.062	0.376	2.01	1.76
		33-62	I	0.41	37.10	2.31	38.97	27.92	0.039	0.059	0.328	2.92	3.81
			II	0.12	36.11	2.74	39.66	29.29	0.008	0.065	0.422	2.93	2.72
		62-150	I	0.15	37.86	2.92	39.28	28.02	0.031	0.072	0.277	2.73	4.83
			II	0.02	37.73	2.73	40.08	29.93	0.002	0.063	0.363	2.82	3.63

(Contd...)

Table 3. (Contd...)

Series name	Profile site	Depth of horizon (cm)	Gravel fraction	Organic carbon (%)	Acid insolubles (%)	Acid soluble silica (%)	Sesqui-oxides (% R_2O_3)	Iron (% Fe_2O_3)	Total nitrogen (%)	Total phosphorus (% P_2O_5)	Total potassium (% K_2O)	Total calcium (Cmol kg^{-1})	Total magnesium (Cmol kg^{-1})
Varkala	Kaithakonam via. Sivagiri, Varkala	0-8	I	0.21	38.61	1.23	62.36	53.21	0.035	0.082	0.316	2.36	3.21
			II	0.09	37.95	1.16	63.72	54.38	0.019	0.091	0.329	2.81	3.33
		8-150	I	0.14	32.16	1.86	65.31	56.33	0.008	0.069	0.426	2.93	3.03
			II	0.08	31.84	1.74	65.98	57.88	0.008	0.077	0.493	3.02	3.60
Thonnackal	Near KIPL china clay mines, Thonnackal	0-20	I	0.54	43.26	0.94	33.81	9.82	0.035	0.059	0.243	4.21	13.77
		20-70	I	0.39	44.93	0.82	38.02	9.12	0.012	0.083	0.136	4.59	6.82
		70-113	I	0.21	43.91	0.78	31.54	8.89	0.009	0.113	0.139	6.41	10.53
		113-150	I	0.14	60.28	0.62	30.83	16.24	0.007	0.739	0.392	4.89	9.45
		150 +	I	0.06	58.19	0.91	29.89	9.53	0.003	0.049	0.763	5.77	6.73
			II	0.03	57.03	1.84	30.78	9.93	0.001	0.043	0.821	5.83	7.85
Trivandrum	Mannanthala, Trivandrum	0-14	I	0.45	39.26	3.82	48.21	36.20	0.039	0.193	0.436	0.15	0.49
			II	0.14	35.88	2.37	47.83	37.50	0.016	0.134	0.531	0.09	0.52
		14-57	I	0.42	37.36	5.28	44.63	38.30	0.015	0.112	0.396	0.23	0.36
			II	0.15	38.23	3.26	45.27	36.20	0.011	0.126	0.402	0.18	0.48
		57-150	I	0.41	32.31	4.22	46.81	39.60	0.003	0.096	0.433	0.13	0.31
			II	0.14	33.28	4.09	49.26	42.90	0.002	0.043	0.421	0.16	0.39

Note : Gravel/Coarser soil fraction : I — Fine gravels (2mm-2.5cm)
II — Coarse gravels (2.5-7.5cm)
III — Cobbles (7.5-25cm)

coarse gravels exhibited an uniform profile pattern of alternate decrease and increase. Cobbles which were absent in the surface horizon showed an alternate profile pattern of increase and decrease down the profile.

The acid insoluble content of the fine and coarse gravels of the Nedumangad series ranged from 37.10 to 39.26 and 35.83 to 39.28 per cent respectively. The profile distribution of the acid insoluble content of gravels showed a reverse pattern among the fractions.

The acid insoluble content of both the fractions in the Varkala series decreased with depth. It ranges from 32.16 to 38.61 and 31.84 to 37.95 per cent respectively for fine and coarse gravels.

In the Thonnackal series, the content of acid insolubles of the fine gravels ranged from 43.26 to 60.28 per cent and showed a profile pattern of alternate increase and decrease with depth. Coarse gravel content of the fifth horizon was 57.03 per cent.

Acid insoluble content of fine gravels of Trivandrum series exhibited a similar profile pattern as that of Varkala series. The coarse gravels remain unique among the series and between fractions of all the series, it exhibited an alternate increase and decrease with depth. The content varied from 32.21 to 39.26 and from 33.28 to 38.23 per cent respectively for fine and coarse gravels.

The mean content of acid insolubles of fine and coarse gravels and cobbles exhibited similarity in the distribution in Palode, Nedumangad, Varkala and Trivandrum series because of the uniformity in the ferruginous nature of the gravels. Thonnackal series remains unique with higher acid insoluble content in both the gravel fractions indicating the operation of silicification; pedogenetic process which restricts the enrichment of iron and formation of concretionary gravels. The localised restricted concretionary gravel fractions in the fifth horizon of the Thonnackal series is indicative of the above mentioned restricted pedogenesis of ferruginisation (Table 2 and 3). The extent of laterisation is in the increasing order at Thonnackal < Palode < Nedumangad < Trivandrum < Varkala.

4.3.3. Acid soluble silica

Acid soluble silica content in the Palode series of both the fractions of gravels exhibited an uniform profile pattern of increase with depth but for cobbles an alternate pattern of decrease and increase pattern was noticed. Acid soluble silica content ranged from 2.38 to 3.52, 2.42 to 3.72 and 3.29 to 3.88 per cent in fine, coarse gravels and cobbles respectively.

While an alternate pattern of increase and decrease was noticed in the acid soluble silica content of fine gravels of Nedumangad series, a pattern of decrease and increase was noticed in the case of coarse gravels.

The content ranged from 2.31 to 3.21 and 1.27 to 2.74 per cent in fine and coarse gravels respectively.

The acid soluble silica content of both fractions of gravels showed a pattern of increase with depth at Varkala with the content ranging from 1.23 to 1.86 and 1.16 to 1.74 per cent in fine and coarse gravels respectively.

Acid soluble silica content of fine gravels in the Thonnackal series exhibited a vectorial decrease down the profile except an abrupt increase in the fifth horizon where the coarse gravels were noticed. The content in fine gravels ranged from 0.62 to 0.94 per cent while it was 1.84 in coarse gravels of the fifth horizon.

In the Trivandrum series, acid soluble silica content of fine gravels exhibited an alternate increase and decrease down the profile while the same increased with depth for coarse gravels. The content ranged from 3.82 to 5.28 and 2.37 to 4.09 per cent respectively in fine and coarse gravels.

Acid soluble silica distribution of the series under study indicated the uniform laterisation in the Palode series, over a prolonged geological period protected by the forest canopy. The residual accumulation of soluble silica indicated that the extent of laterisation is in the decreasing order Palode > Nedumangad > Varkala > Thonnackal > Trivandrum series (Table 3).

4.3.4. Sesquioxide content

The sesquioxide content of both the gravel fractions in the Palode series exhibited a uniform profile pattern of decrease in the second and third horizons followed by an increase in the fourth horizon while for the cobbles the content exhibited an alternate pattern of decrease and increase with depth. The content ranged from 35.63 to 38.25, 35.82 to 38.71 and 36.03 to 36.99 per cent respectively for fine, coarse gravels and cobbles.

In Nedumangad and Varkala series, the content of sesquioxides in fine and coarse gravels increased with depth with the values ranging from 35.36 to 39.28 and 35.69 to 40.08 per cent in Nedumangad and from 62.36 to 65.31 and 63.72 to 65.98 per cent in Varkala.

The profile distribution of the sesquioxides content remained unique in the Thonnackal series with an increase in the second horizon and then decreased down the profile. The sesquioxides content in the fine gravels ranged form 29.89 to 38.02 per cent and 30.78 per cent in the coarse gravels of the fifth horizon.

Both the gravel fractions at Trivandrum exhibited an uniform profile pattern of alternate decrease and increase down the profile with the sesquioxide content ranging from 44.63 to 48.21 and 45.27 to 49.26 per cent respectively.

As in the case of acid soluble silica content, a similar pattern was indicated by the sesquioxides content irrespective of the series indicating similar pattern of ferruginisation among the soil series investigated. It also indicated that the gravel formation irrespective of the size range had taken place simultaneously in the same pedogenic period.

4.3.5. Iron

The coarser fractions of the soil at Palode, Nedumangad and Varkala series showed a progressive increase in content down the profile in their iron content irrespective of their size. The iron content of fine coarse gravels and cobbles ranged from 24.36 to 26.58, 24.47 to 26.71 and 25.96 to 26.82 per cent in Palode, 26.21 to 28.02 and 26.34 to 29.93 per cent in Nedumangad and from 53.21 to 56.33 and 54.38 to 57.88 per cent in Varkala.

The fine gravels of the Thonnackal series showed a pattern of decrease down the profile in the iron content except an abrupt increase in the fourth horizon, the content ranging from 8.89 to 16.24 per cent. The coarse gravels of the fifth horizon had a content of 9.93 per cent.

In Trivandrum, although the iron content of fine gravels showed a progressive increase down the profile with the content ranging from 36.20 to 39.60 per cent, the coarse gravels exhibited an alternate profile pattern of decrease and increase down the profile with the content ranging from 36.20 to 42.90 per cent.

As in the case of acid solubles and sesquioxides, the iron content also indicated similarity in the pedogenesis in the Palode and Nedumangad series with comparatively more laterisation in the later series. Ferruginisation was maximum at Varkala series followed by Trivandrum and was least at Thonnackal series. The extent of ferruginisation in the soil series were in the increasing order, Thonnackal < Palode < Nedumangad < Trivandrum < Varkala.

4.3.6. Total nitrogen

At Palode, although the fine gravels showed a decreasing pattern down the profile in their total nitrogen content with their values ranging from 0.011 to 0.172 per cent, the coarse gravels and cobbles behaved differently. The coarse gravels had similar values in the first two horizons and then alternately increased and decreased down the profile ranging from 0.006 to 0.013 per cent. The cobbles showed a profile pattern of decrease and increase, the value ranging from 0.002 to 0.007 per cent.

In Nedumangad, Varkala, Thonnackal and Trivandrum series, the total nitrogen content of gravels showed a pattern of decrease down the profile. At Nedumangad, the range of total nitrogen content for the fine and coarse gravels were 0.031 to 0.137 and 0.002 to 0.130 per cent, at Varkala it was 0.008 to 0.035 and 0.008 to 0.019 per cent, at Thonnackal it was 0.003 to 0.035 and 0.001 per cent and at Trivandrum it was 0.003 to 0.039 and 0.002 to 0.016 per cent.

Organic matter association/adsorption on gravels were less irrespective of the series. The fine gravels contributed more nitrogen than the respective coarse gravels and cobbles. The comparatively low nitrogen content of the gravels of the Palode series indicates its paleoplinthic nature. This is clear from the laterite gravels of Trivandrum series, especially the fine gravels. The least amount of nitrogen is contributed by the gravel fractions of the Thonnackal series.

4.3.7. Total phosphorus

The total phosphorus content of fine and coarse gravels of the Palode series showed a profile pattern of alternate decrease and increase with depth, with the content ranging from 0.113 to 0.732 and 0.122 to 0.793 per cent respectively. The content of total phosphorus in cobbles showed an alternate pattern of increase and decrease with depth ranging from 0.103 to 0.219 per cent.

In Nedumangad, the total phosphorus content of fine gravels showed a decreasing pattern down the profile until the fourth horizon where an increase in content was noticed. The content in coarse gravels showed an alternate pattern of decrease and increase with depth. The content in fine and coarse gravels ranged from 0.059 to 0.081 and 0.062 to 0.073 per cent respectively.

In Varkala and Trivandrum series, the content of total phosphorus showed a decrease with depth in both the fine and coarse gravels, the content ranging from 0.069 to 0.082 and 0.077 to 0.091 per cent at Varkala and 0.096 to 0.193 and 0.043 to 0.134 per cent at Trivandrum.

The content of total phosphorus at Thonnackal in fine gravels showed an increase down the profile except in the fifth horizon where a decrease was noticed the content ranging from 0.049 to 0.739 per cent. The content in the coarse gravels of the fifth horizon was 0.043 per cent.

Estimation of the total phosphorus content of the gravels irrespective of the series were seen dependent on the relative content of silica and iron. Hence, a negative profile pattern in their distribution was observed in relation to the profile pattern of silica and iron content of gravels.

The total phosphorus content of fine gravels are in the increasing order in Nedumangad < Varkala < Trivandrum < Thonnackal < Palode while in the case of coarse gravels it is in the increasing order in Thonnackal < Nedumangad < Varkala < Trivandrum < Palode.

4.3.8. Total potassium

The total potassium content of fine and coarse gravels showed a decreasing trend till the third horizon and then increased to the fourth horizon, the content ranging 0.193 to 0.273 and 0.176 to 0.292 per cent respectively. The cobbles showed an alternate pattern of decrease and increase with depth, the content ranging from 0.189 to 0.361 per cent.

Both fractions of gravels in the Nedumangad series exhibited a pattern of increase till the third horizon and then a decrease in their content of total potassium, the content ranging from 0.183 to 0.328 and 0.231 to 0.422 per cent respectively for fine and coarse gravels.

The Varkala profile showed a profile pattern of increase with depth in both fractions of gravels. The values ranged from 0.316 to 0.426 and 0.329 to 0.493 per cent respectively.

The content in the fine gravels of Thonnackal showed an increase with depth except in the second horizon. The values ranged from 0.136 to 0.763 per cent for fine gravels and 0.821 per cent in coarse gravels of the fifth horizon.

Both fractions of gravels showed an alternate pattern of decrease and increase with depth in their total potassium content at Trivandrum. The content ranged from 0.396 to 0.436 and 0.402 to 0.531 per cent respectively in fine and coarse gravels.

The total potassium content of fine gravels was in the increasing order in Palode < Nedumangad < Thonnackal < Varkala < Trivandrum while in the case of coarse gravels the potassium content was in the increasing order in Palode < Nedumangad < Varkala < Trivandrum < Thonnackal.

4.3.9. Total calcium

The fine gravels and cobbles showed an alternate pattern of decrease and increase with depth in their total calcium content. The content ranged from 0.51 to 0.92 and 0.82 to 0.97 Cmol kg^{-1} respectively. Coarse gravels showed a decrease in total calcium content in the second horizon and thereafter increased, the content ranging from 0.36 to 0.98 Cmol kg^{-1}.

In Nedumangad, the total calcium content showed an alternate pattern of decrease and increase with depth in both the fractions of gravels, the content ranging from 1.84 to 2.92 and 2.01 to 2.93 Cmol kg^{-1} in fine and coarse gravels respectively.

A profile pattern in the total calcium content which increased with depth was observed for fine and coarse gravels, the content ranging from 2.36 to 2.93 and 2.81 to 3.02 Cmol kg^{-1} respectively.

The total calcium content of the fine gravels of the Thonnackal series increased with depth except in the fourth horizon where a decrease was noticed, the content ranging from 4.21 to 6.41 Cmol kg^{-1}. The coarse gravels observed in the fifth horizon had a content of 5.83 Cmol kg^{-1}.

Both fractions of gravels in the Trivandrum series showed an alternate pattern of increase and decrease with depth in their content of total calcium, the content ranging from 0.13 to 0.23 and 0.09 to 0.18 Cmol kg^{-1} in fine and coarse gravels respectively.

Total calcium content of fine gravels was in the increasing order in Trivandrum < Palode < Nedumangad < Varkala < Thonnackal, while in the case of coarse gravels, it was in the increasing order in Palode < Nedumangad < Varkala < Trivandrum < Thonnackal.

4.3.10. Total magnesium

The fine and coarse gravels of the Palode series showed a profile pattern of increase with depth in the content of total magnesium except in the fourth horizon where a decrease was noticed. The content ranged from 3.82 to 5.83 and 3.71 to 5.91 Cmol kg^{-1} respectively. The cobbles showed a profile pattern of alternate increase and decrease with depth, the content ranging from 4.52 to 6.21 Cmol kg^{-1}.

The content of total magnesium in the Nedumangad series showed a profile pattern of decrease to the second horizon and thereon increased down the profile for both fractions of gravels. The content ranged form 2.99 to 4.83 and 1.76 to 3.98 Cmol kg^{-1} in fine and coarse gravels respectively.

In the Varkala series, while the fine gravels showed a profile pattern of decrease with depth down the profile, the coarse gravels showed an increase with depth in the content of total magnesium, the content ranging from 3.03 to 3.21 and 3.33 to 3.60 Cmol kg^{-1} respectively.

The total magnesium content of Thonnackal series showed a pattern of decrease down the profile except in the third horizon for fine gravels, the content ranging from 6.73 to 13.77 Cmol kg^{-1}. The content in the coarse gravels of the fifth horizon was 7.85 Cmol kg^{-1}.

In the Trivandrum series, the total magnesium content showed a decrease down the profile in both fractions of gravels, the content ranging from 0.31 to 0.49 in fine gravels and 0.39 to 0.52 Cmol kg^{-1} in coarse gravels.

Total magnesium content of the fine gravel fractions were in the increasing order in Trivandrum < Varkala < Nedumangad < Palode < Thonnackal while the content of coarse gravels was in the increasing order in Trivandrum < Nedumangad < Varkala < Palode < Thonnackal.

The comparatively higher content of magnesium to calcium in Thonnackal indicates the detrital deposition of calcium and magnesium materials.

4.4. Primary mineral assemblage of gravels

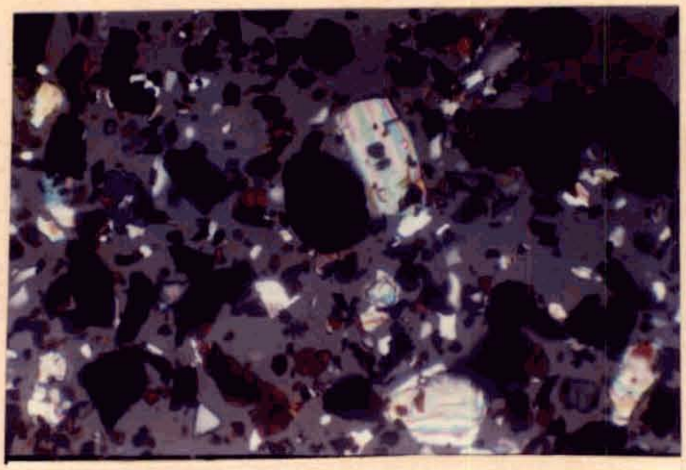
The content of primary minerals in gravels are presented in Photomicrographs 1 to 70 and Table 4.

4.4.1. Heavy fraction

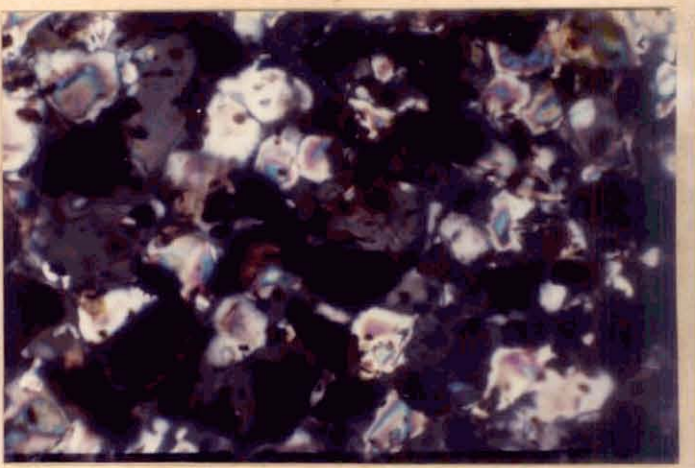
4.4.1.1. Ilmenite

Ilmenite was absent in the coarser fractions of the soils of Palode, Nedumangad and Varkala.

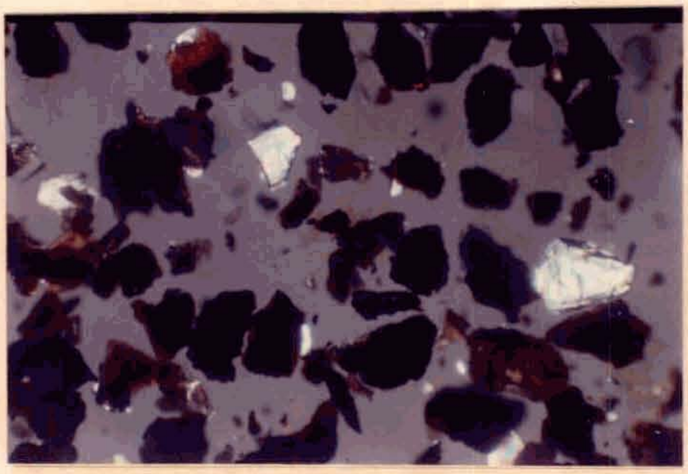
Photomicrographs on primary mineral assemblage of soil gravels



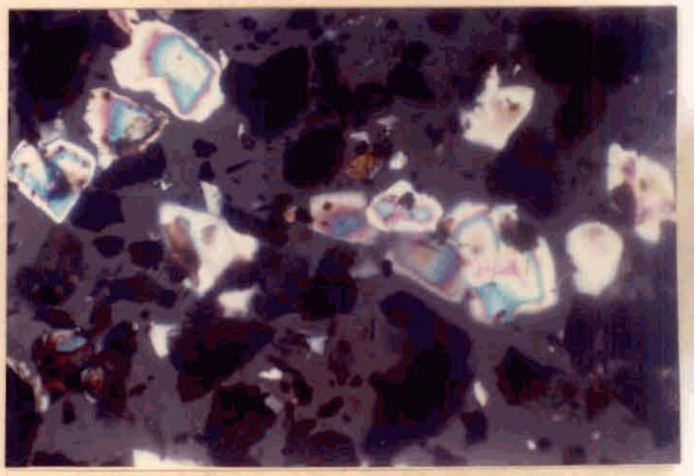
1. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm) - (0-14cm) - heavy fraction - Palode series - under crossed nicols - Mgf: x 63.



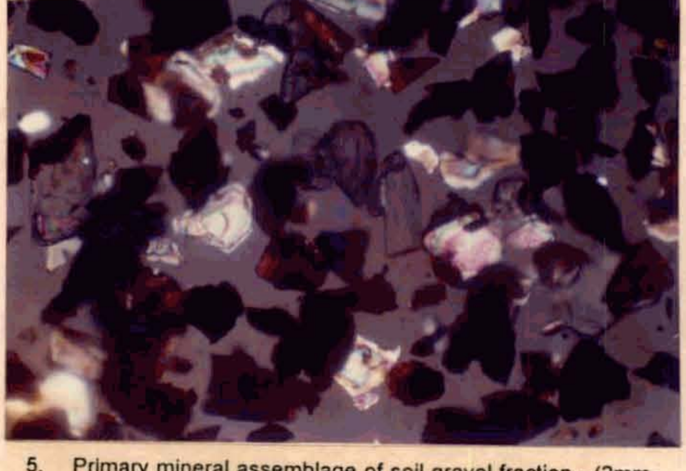
2. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm) - (0-14cm) - light fraction - Palode series - under crossed nicols - Mgf: x 63.



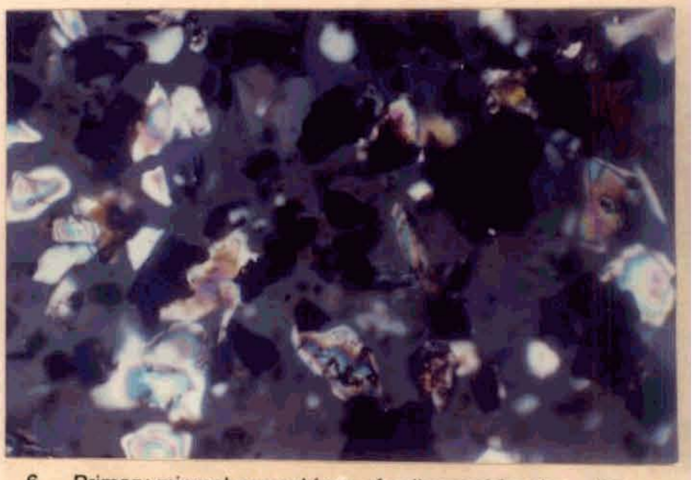
3. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm) - (0-14cm) - heavy fraction - Palode series - under crossed nicols - Mgf: x 63.



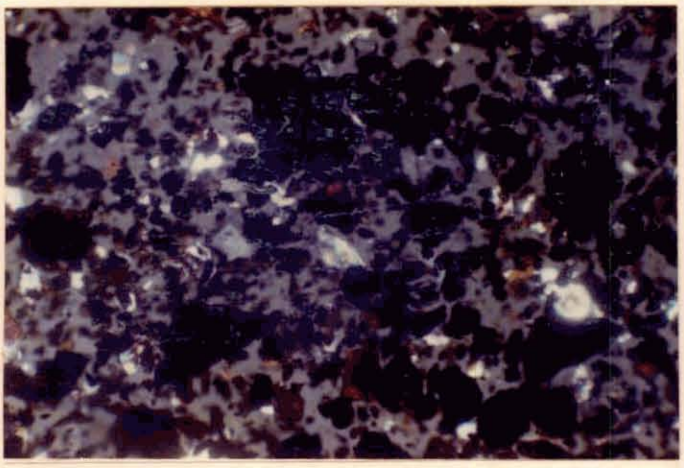
4. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm) - (0-14cm) - light fraction - Palode series - under crossed nicols - Mgf: x 63.



5. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm) - (14-51cm) - heavy fraction - Palode series - under crossed nicols - Mgf: x 63.

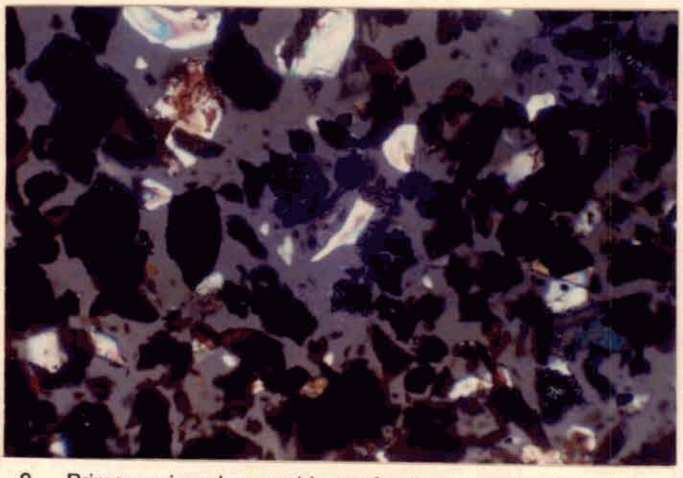


6. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm) - (14-51cm) -light fraction - Palode series - under crossed nicols - Mgf: x 63.

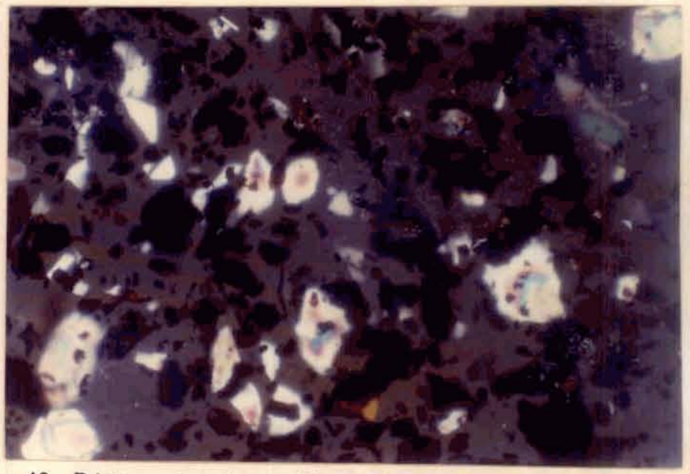


7. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm) - (14-51cm) - heavy fraction - Palode series - under crossed nicols - Mgf: x 63.

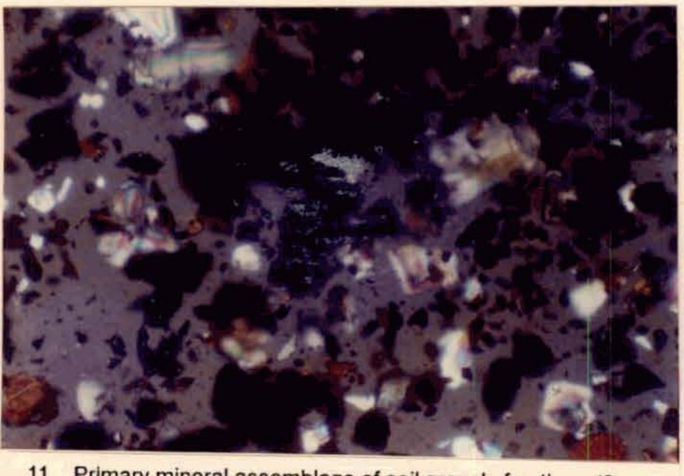
8. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm) - (14-51cm) - light fraction - Palode series - under crossed nicols - Mgf: x 63.



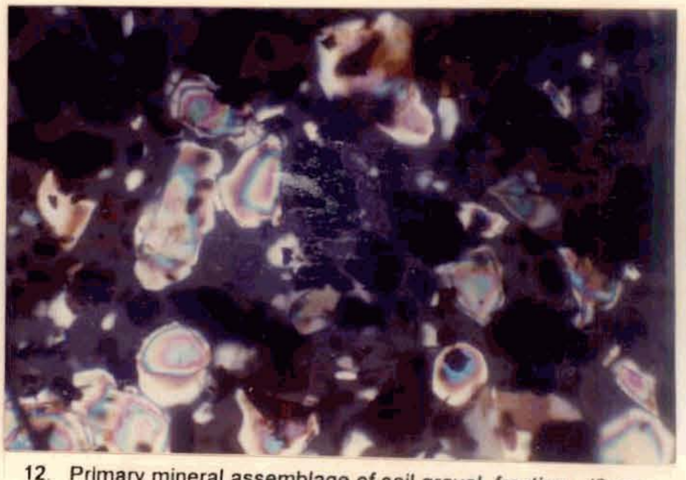
9. Primary mineral assemblage of soil gravel fraction - (7.5-25cm) - (14-51cm) - heavy fraction - Palode series - under crossed nicols - Mgf: x 63.



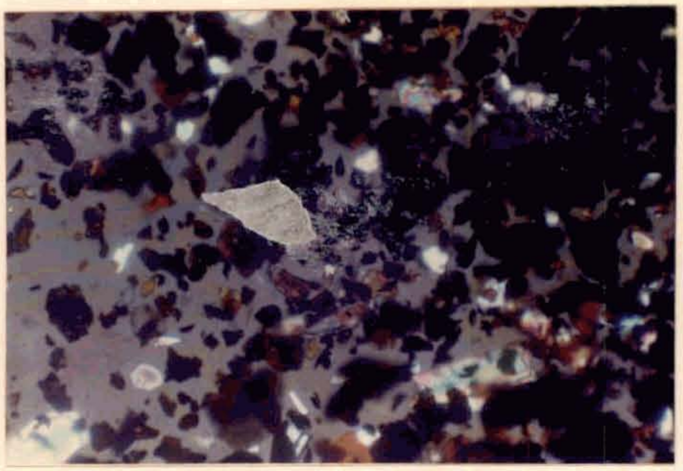
10. Primary mineral assemblage of soil gravel fraction - (7.5-25cm) - (14-51cm) - light fraction - Palode series - under crossed nicols - Mgf: x 63.



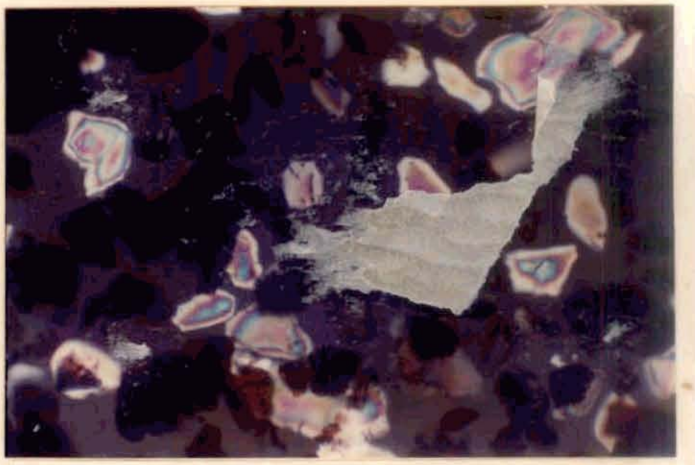
11. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm) - (51-106cm) - heavy fraction - Palode series - under crossed nicols - Mgf: x 63.



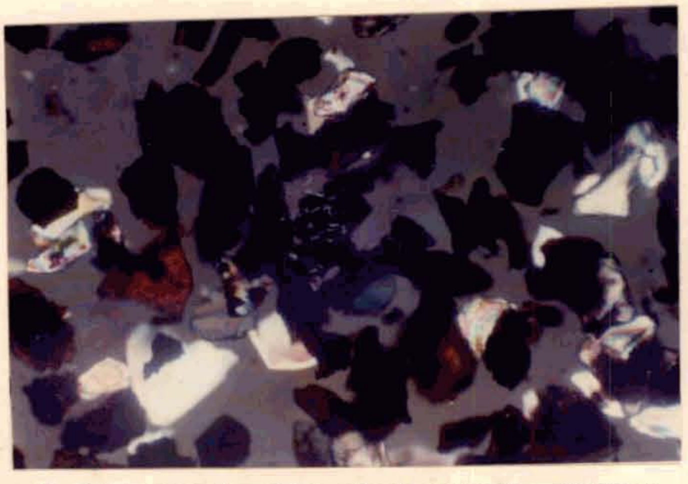
12. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(51-106cm) - light fraction - Palode series - under crossed nicols - Mgf: x 63.



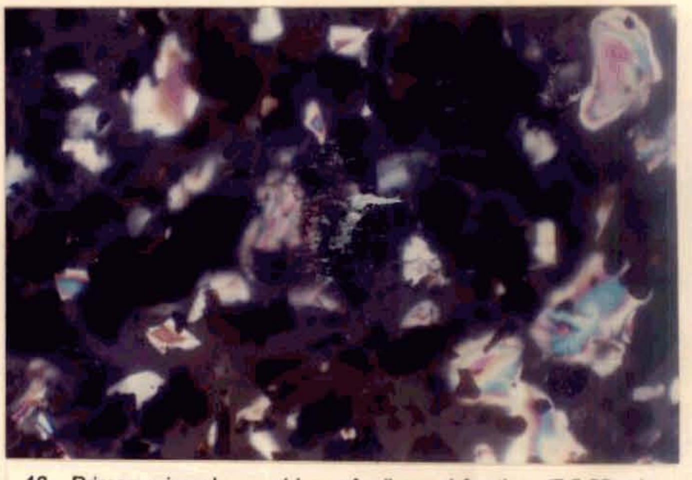
13. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(51-106cm) - heavy fraction - Palode series - under crossed nicols - Mgf: x 63.



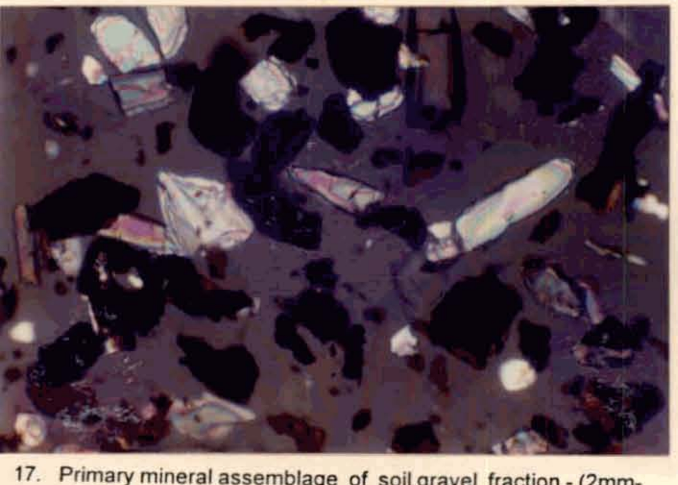
14. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(51-106cm) - light fraction - Palode series - under crossed nicols - Mgf: x 63.



15. Primary mineral assemblage of soil gravel fraction - (7.5-25cm)-(51-106cm) - heavy fraction - Palode series - under crossed nicols - Mgf: x 63.



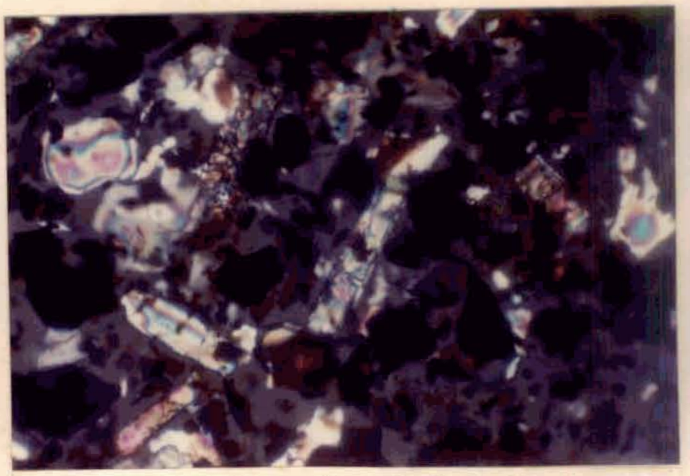
16. Primary mineral assemblage of soil gravel fraction - (7.5-25cm)-(51-106cm) - light fraction - Palode series - under crossed nicols - Mgf: x 63.



17. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(106-150cm) - heavy fraction - Palode series - under crossed nicols - Mgf: x 63.

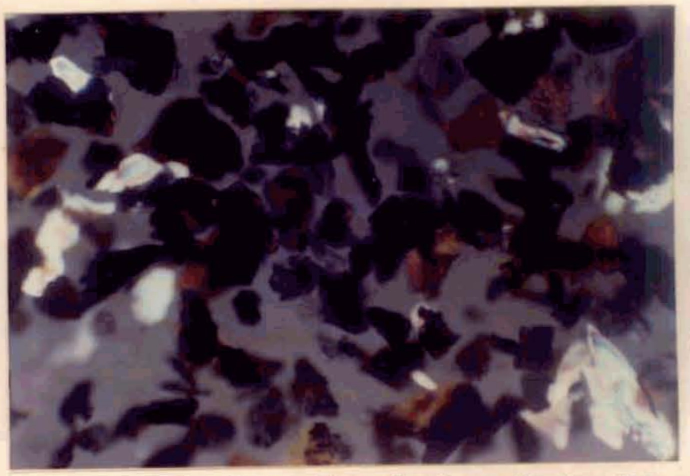
17a. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(106-150cm) - heavy fraction - Palode series - under crossed nicols - Mgf: x 400.

18. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(106-150cm) - light fraction - Palode series - under crossed nicols - Mgf: x 63.

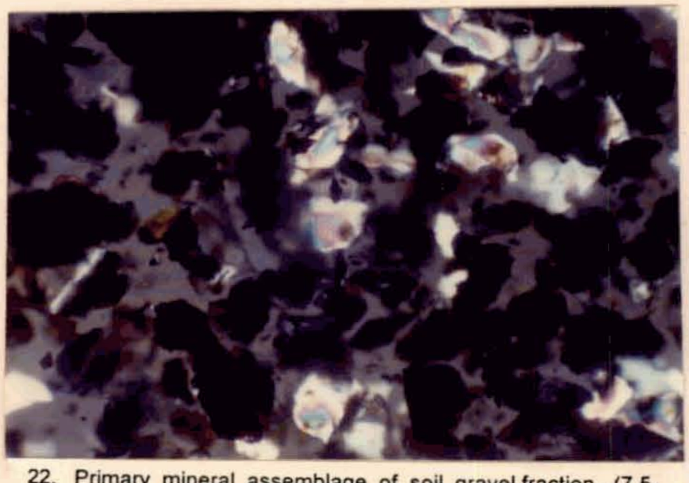


19. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(106-150cm) - heavy fraction - Palode series - under crossed nicols - Mgf: x 63.

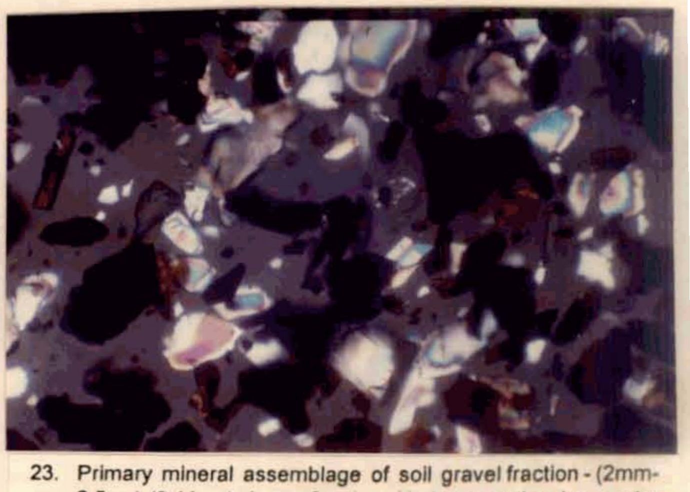
20. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(106-150cm) - light fraction - Palode series - under crossed nicols - Mgf: x 63.



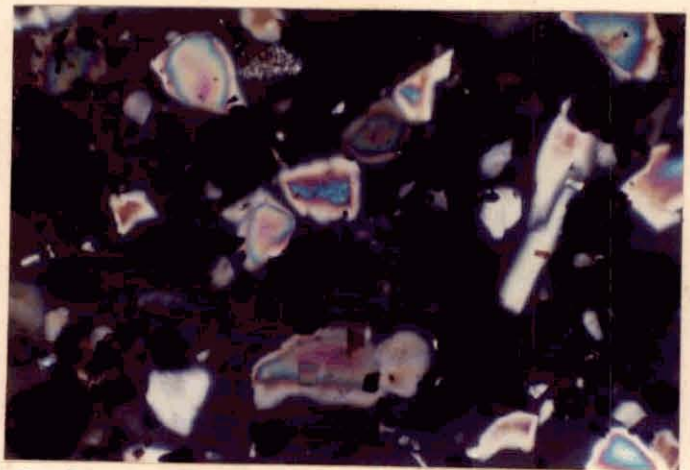
21. Primary mineral assemblage of soil gravel fraction - (7.5-25cm)-(106-150cm) - heavy fraction - Palode series - under crossed nicols - Mgf: x 63.



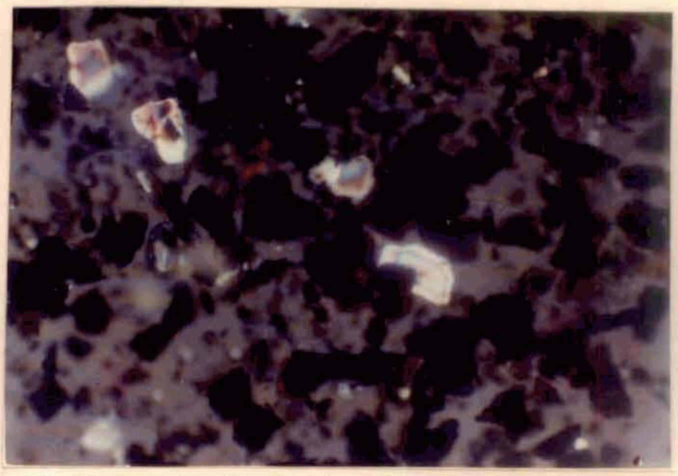
22. Primary mineral assemblage of soil gravel fraction - (7.5-25cm)-(106-150cm) - light fraction - Palode series - under crossed nicols - Mgf: x 63.



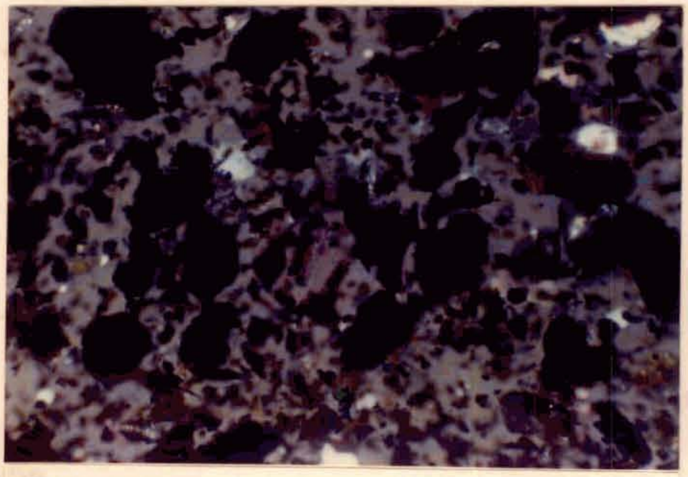
23. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(0-11cm) - heavy fraction - Nedumangad series - under crossed nicols - Mgf: x 63.



24. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(0-11cm) - light fraction - Nedumangad series - under crossed nicols - Mgf: x 63.

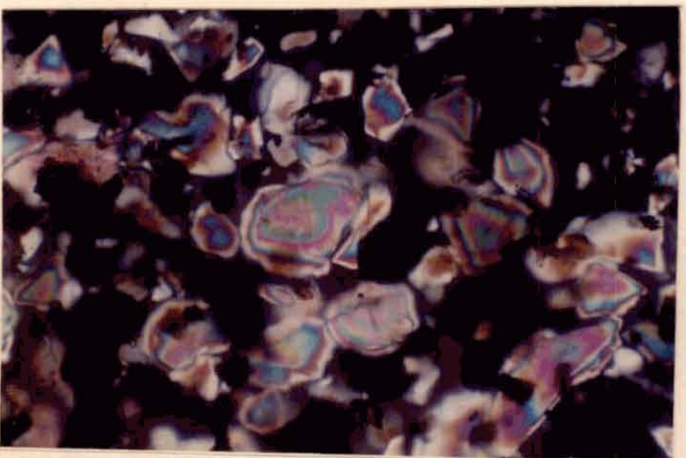


25. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(0-11cm) - heavy fraction - Nedumangad series - under crossed nicols - Mgf: x 63.

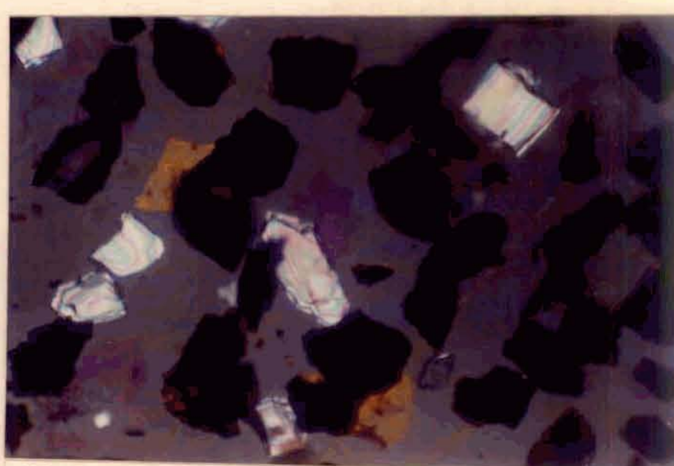


26. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(0-11cm) - light fraction - Nedumangad series - under crossed nicols - Mgf: x 63.

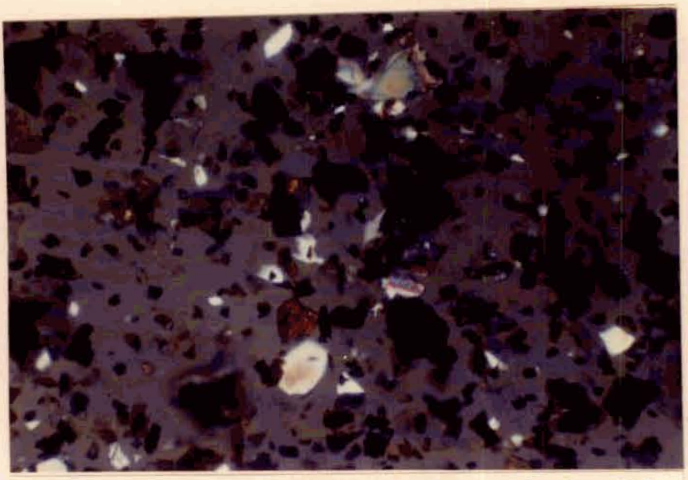
27. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(11-33cm) - heavy fraction - Nedumangad series - under crossed nicols - Mgf: x 63.



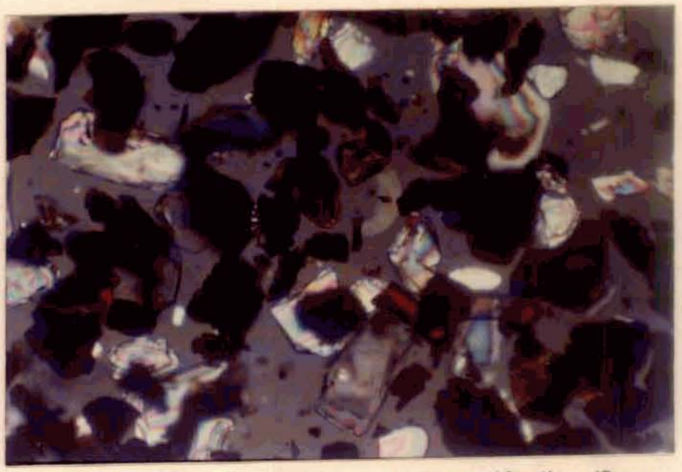
28. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(11-33cm) - light fraction - Nedumangad series - under crossed nicols - Mgf: x 63.



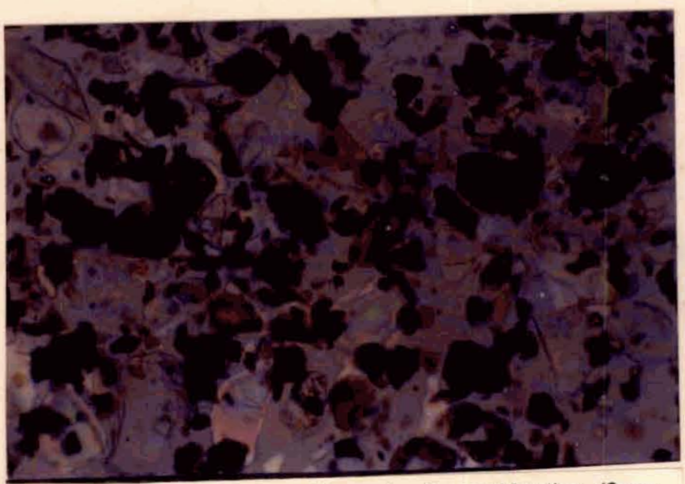
29. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(11-33cm) - heavy fraction - Nedumangad series - under crossed nicols - Mgf: x 63.



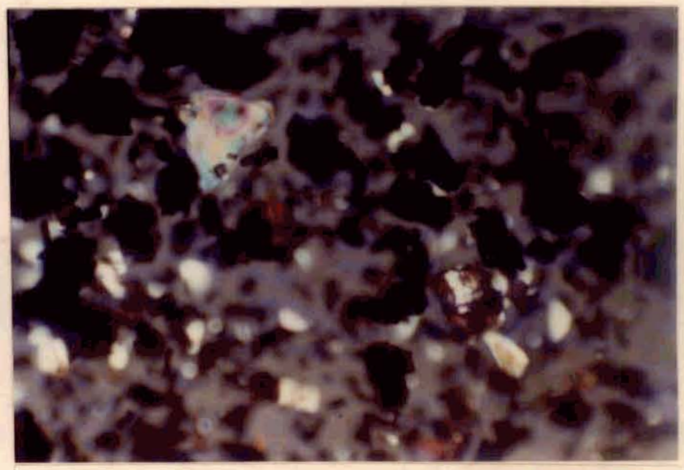
30. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(11-33cm) - light fraction - Nedumangad series - under crossed nicols - Mgf: x 63.



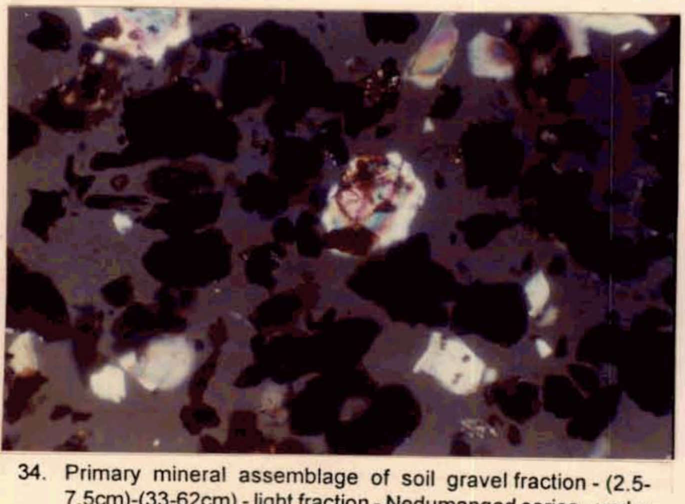
31. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(33-62cm) - heavy fraction - Nedumangad series - under crossed nicols - Mgf: x 63.



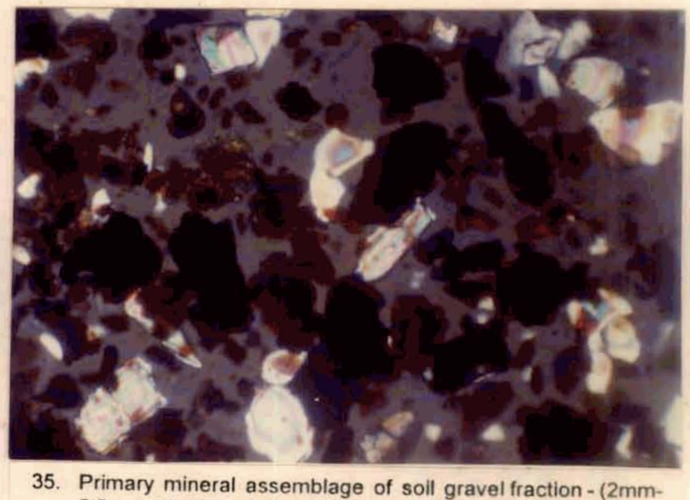
32. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(33-62cm) - light fraction - Nedumangad series - in plane light - Mgf: x 63.



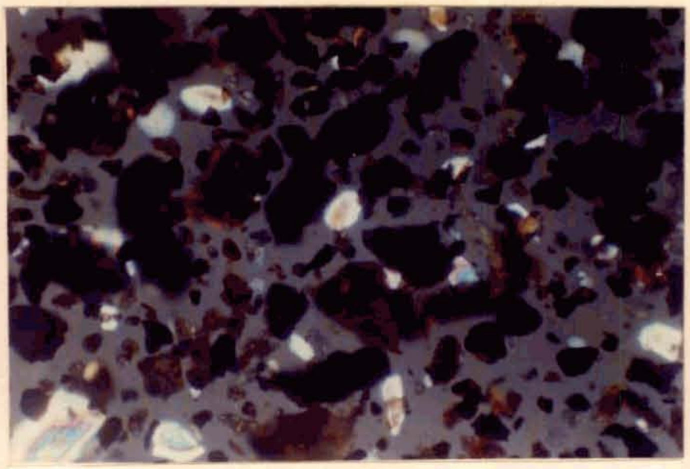
33. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(33-62cm) - heavy fraction - Nedumangad series - under crossed nicols - Mgf: x 63.



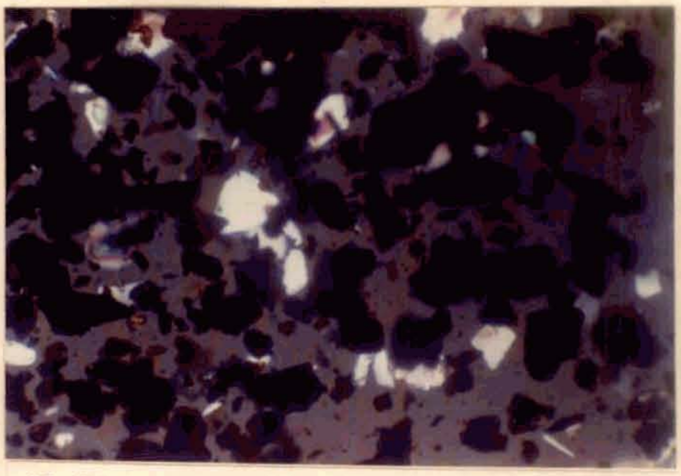
34. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(33-62cm) - light fraction - Nedumangad series - under crossed nicols - Mgf: x 63.



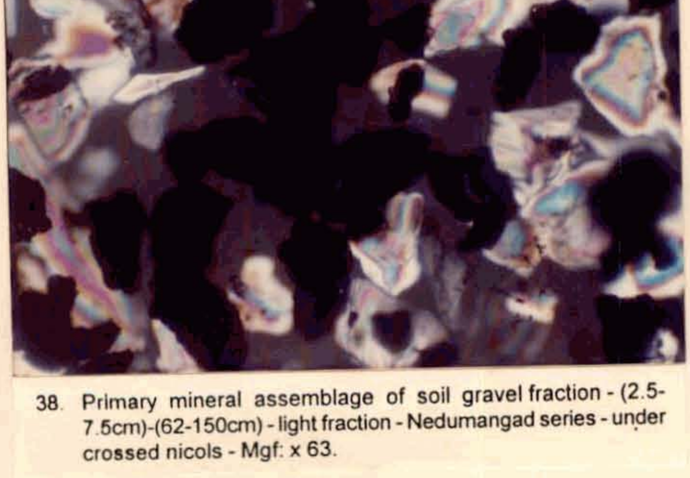
35. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(62-150cm) - heavy fraction - Nedumangad series - under crossed nicols - Mgf: x 63.



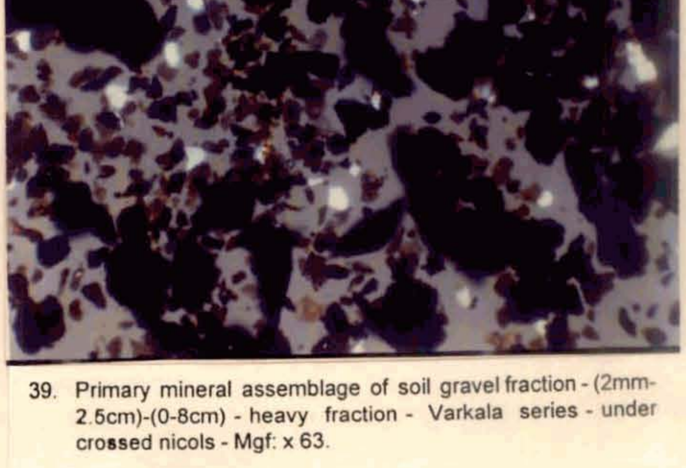
36. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(62-150cm) - light fraction - Nedumangad series - under crossed nicols - Mgf: x 63.



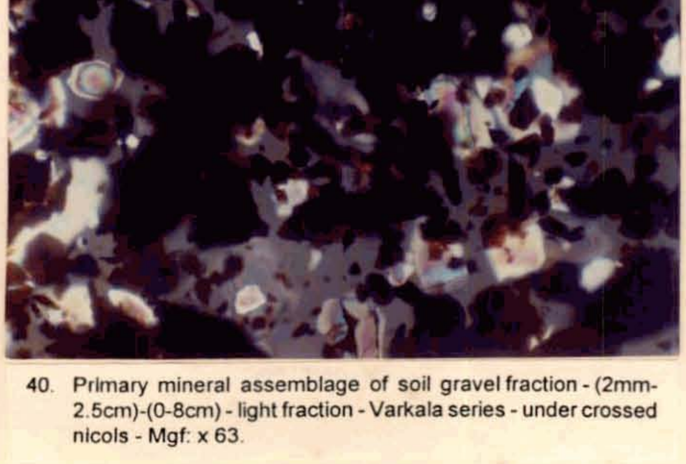
37. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(62-150cm) - heavy fraction - Nedumangad series - under crossed nicols - Mgf: x 63.



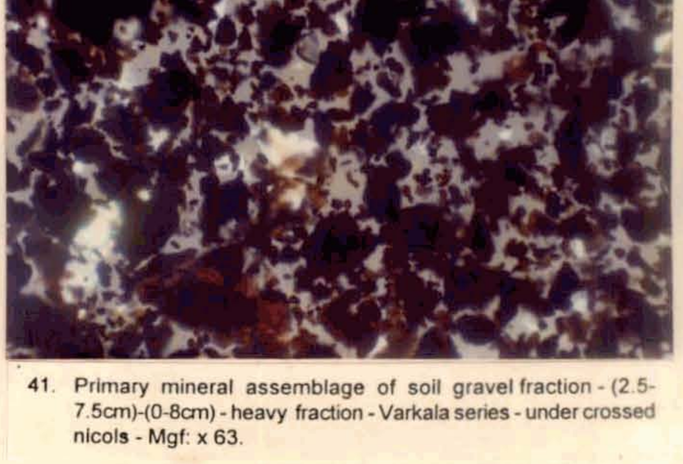
38. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(62-150cm) - light fraction - Nedumangad series - under crossed nicols - Mgf: x 63.



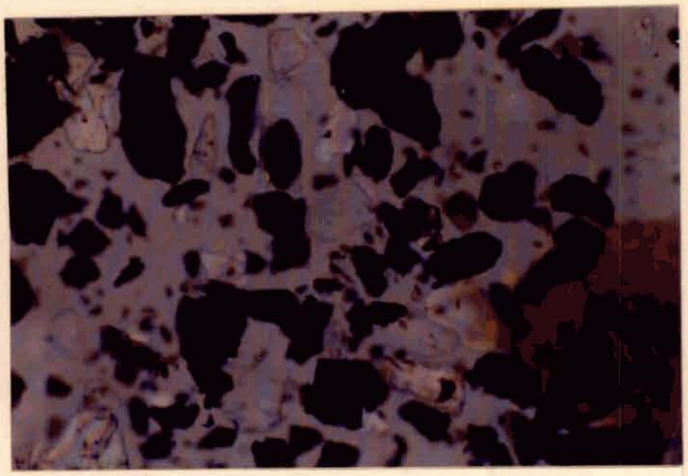
39. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(0-8cm) - heavy fraction - Varkala series - under crossed nicols - Mgf: x 63.



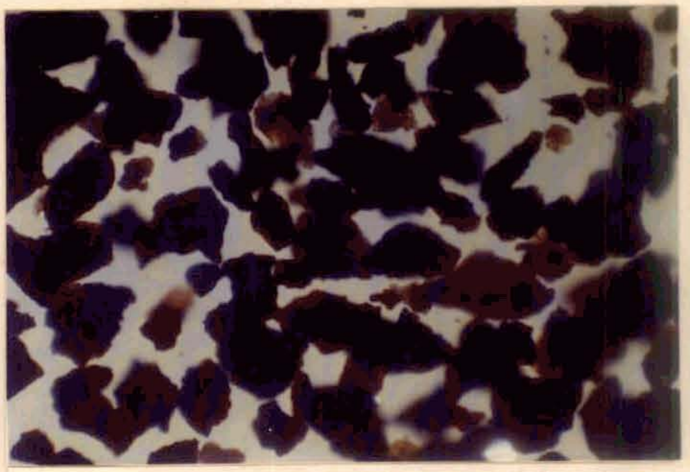
40. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(0-8cm) - light fraction - Varkala series - under crossed nicols - Mgf: x 63.



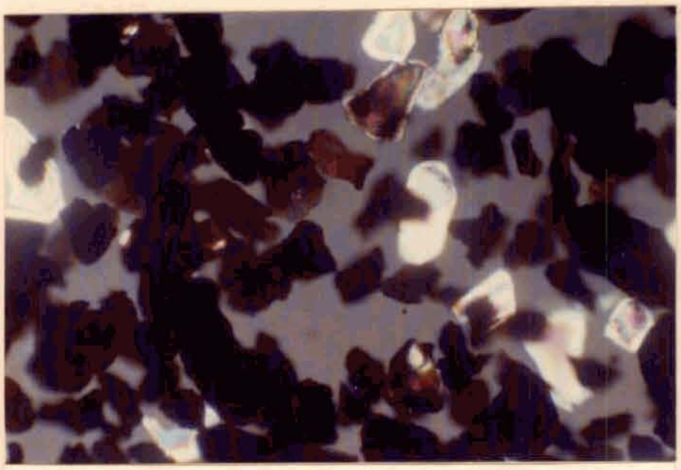
41. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(0-8cm) - heavy fraction - Varkala series - under crossed nicols - Mgf: x 63.



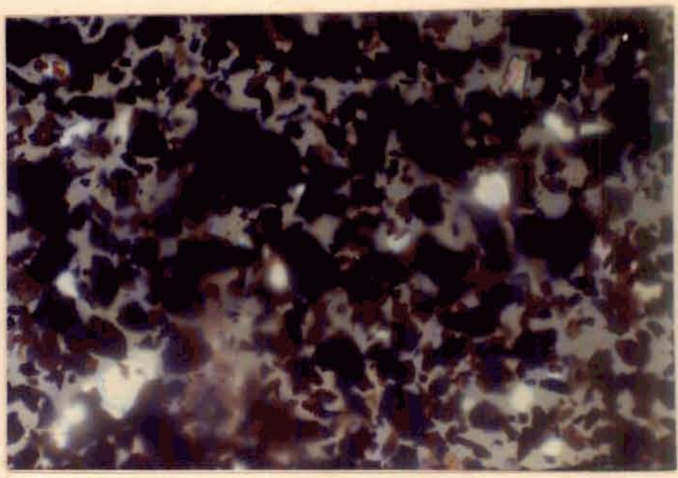
42. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(0-8cm) - light fraction - Varkala series - in plane light - Mgf: x 63.



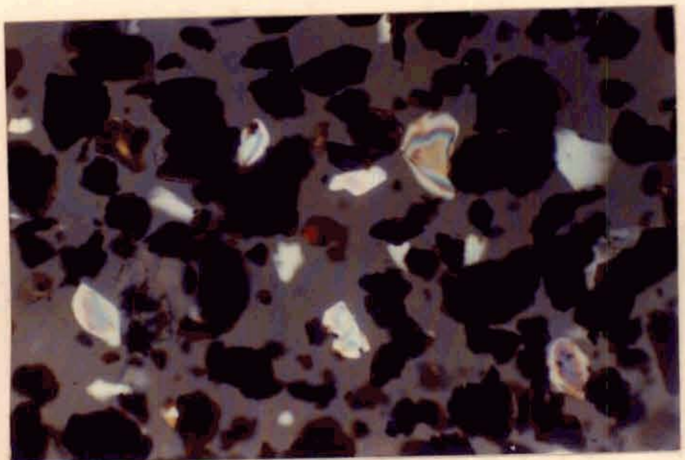
43. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(8-150cm) - heavy fraction - Varkala series - under crossed nicols - Mgf: x 63.



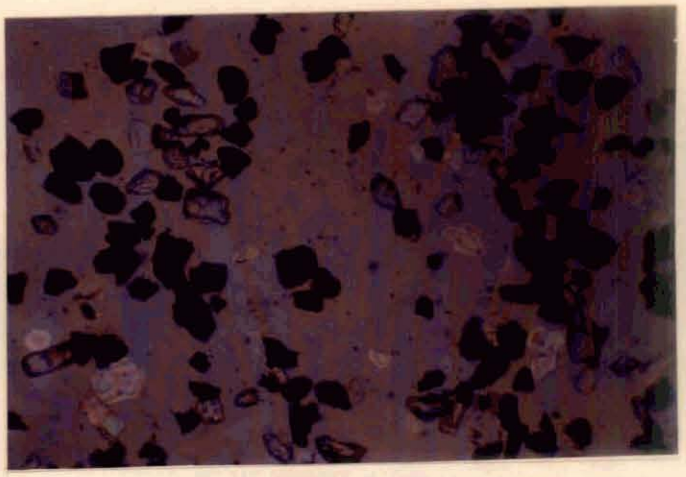
44. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(8-150cm) - light fraction - Varkala series - under crossed nicols - Mgf: x 63.



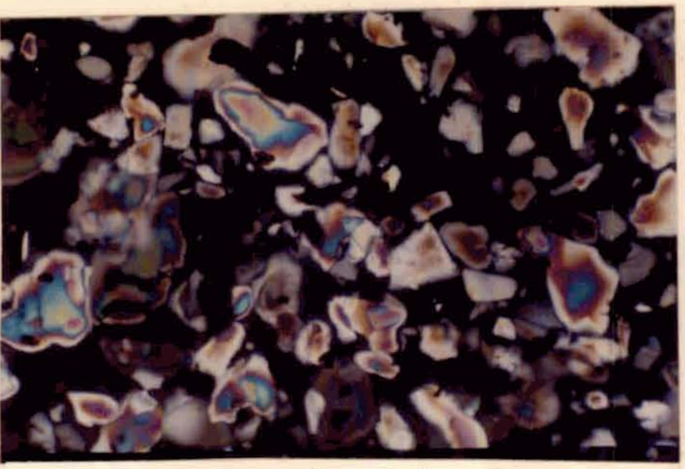
45. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(8-150cm) - heavy fraction - Varkala series - under crossed nicols - Mgf: x 63.



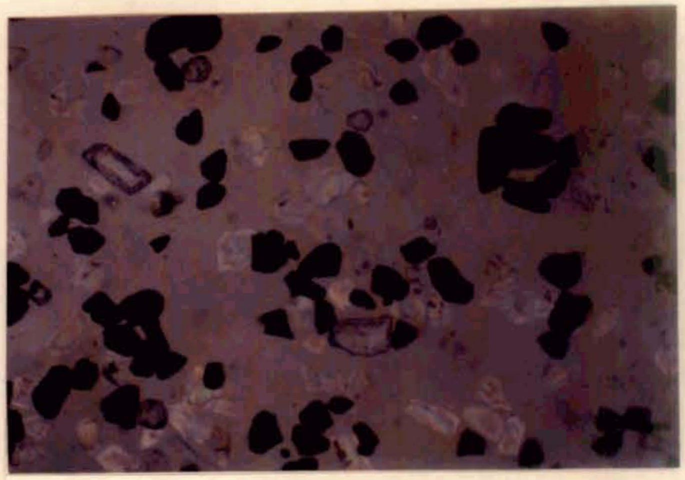
46. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(8-150cm) - light fraction - Varkala series - under crossed nicols - Mgf: x 63.



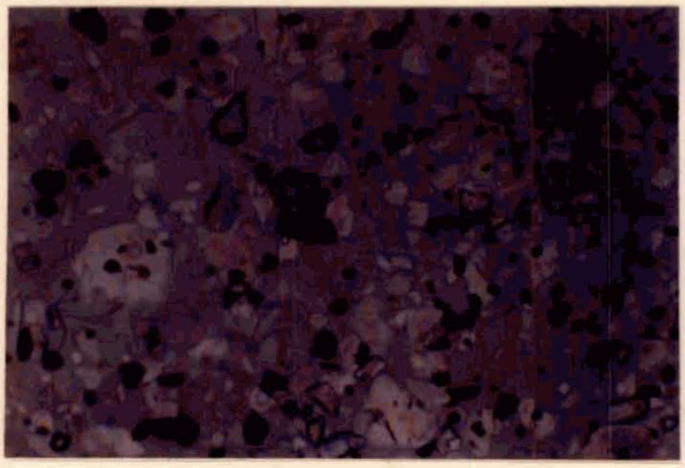
47. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(0-20cm) - heavy fraction - Thonnackal series - in plane light - Mgf: x 25.



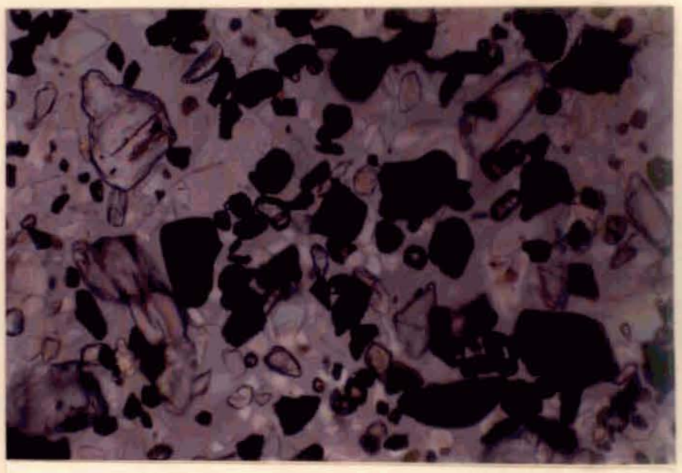
48. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(0-20cm) - light fraction - Thonnackal series - under crossed nicols - Mgf: x 63.



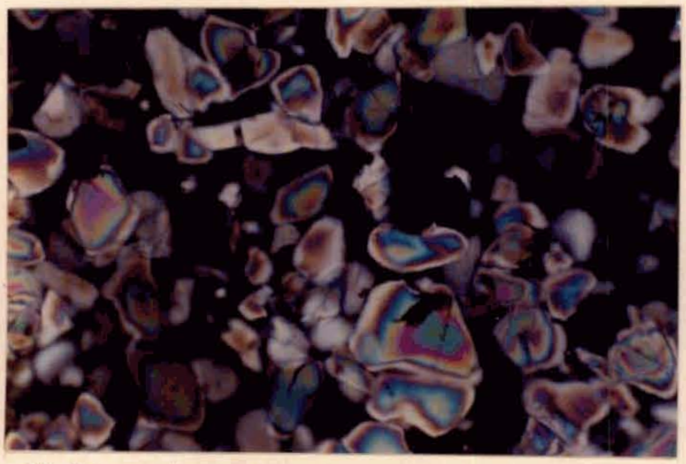
49. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(20-70cm) - heavy fraction - Thonnackal series - in plane light - Mgf: x 25.



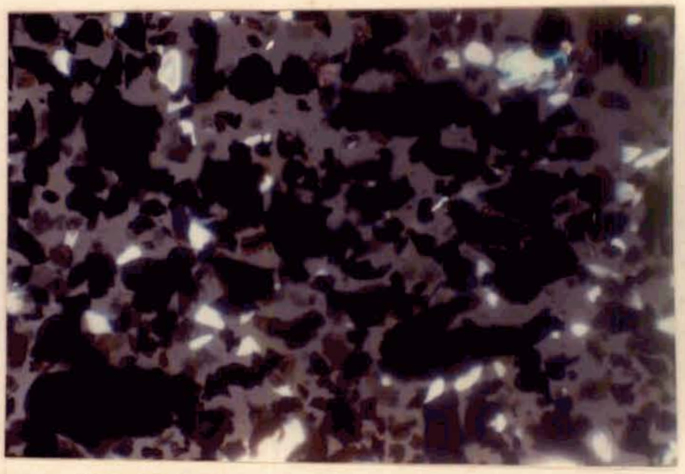
50. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(20-70cm) - light fraction - Thonnackal series - in plane light - Mgf: x 63.



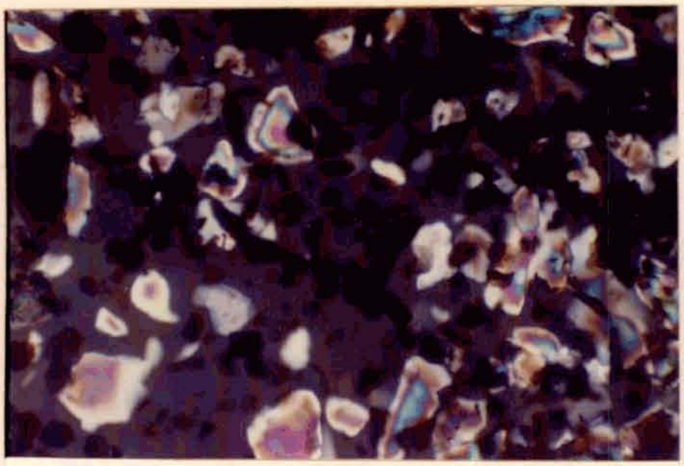
51. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(70-113cm) - heavy fraction - Thonnackal series - in plane light - Mgf: x 63.



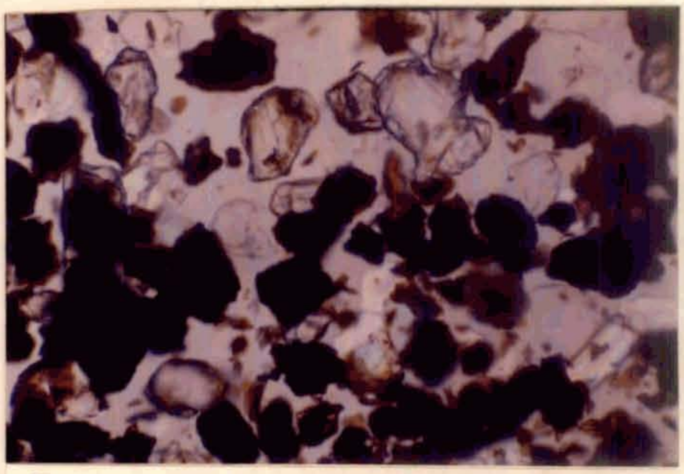
52. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(70-113cm) - light fraction - Thonnackal series - under crossed nicols - Mgf: x 63.



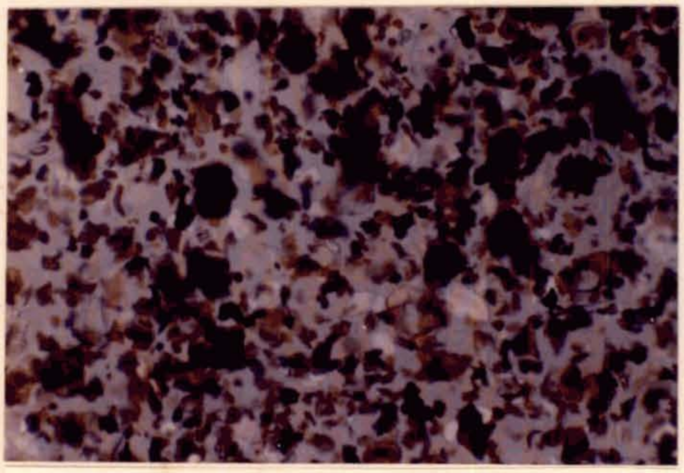
53. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(113-150cm) - heavy fraction - Thonnackal series - under crossed nicols - Mgf: x 63.



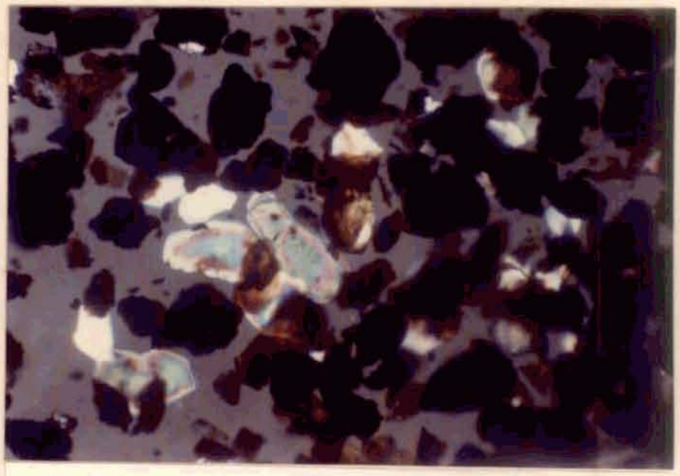
54. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(113-150cm) - light fraction - Thonnackal series - under crossed nicols - Mgf: x 63.



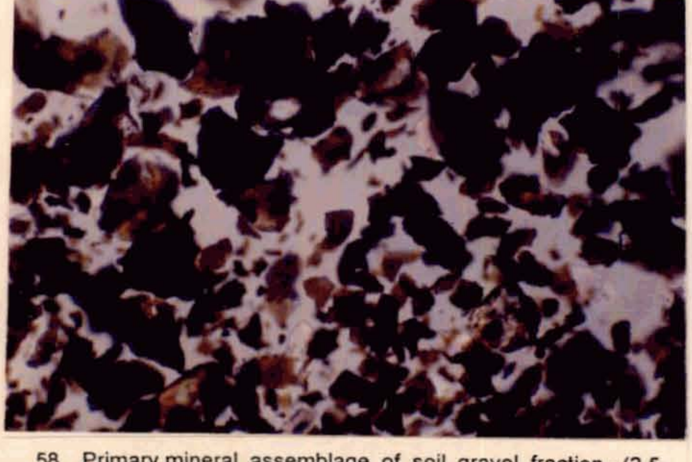
55. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(+150cm) - heavy fraction - Thonnackal series - in plane light - Mgf: x 63.



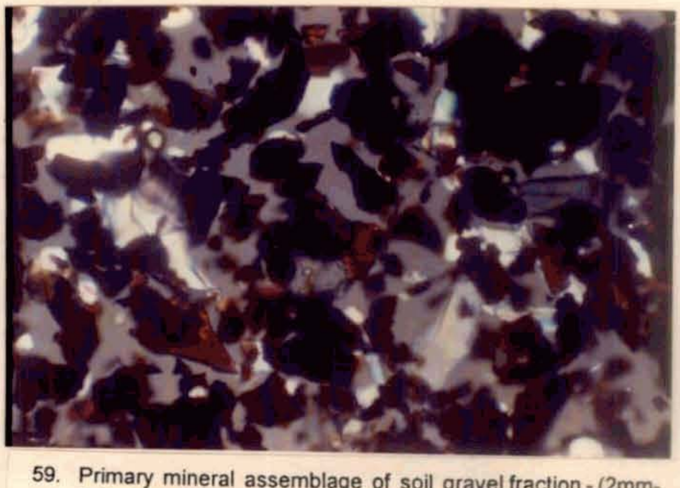
56. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(+150cm) - light fraction - Thonnackal series - in plane light - Mgf: x 63.



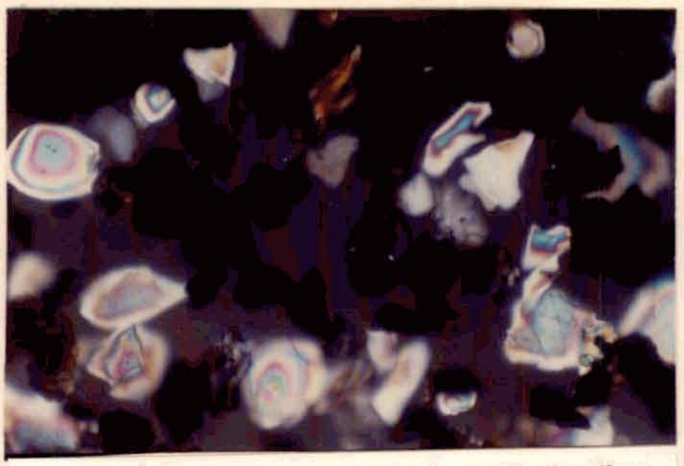
57. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(+150cm) - heavy fraction - Thonnackal series - under crossed nicols - Mgf: x 63.



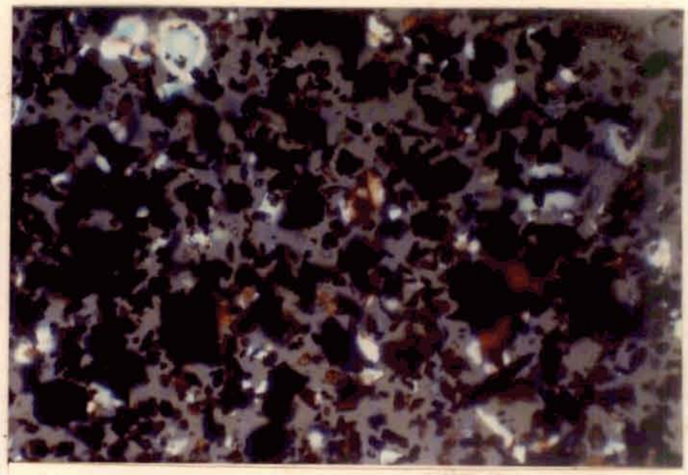
58. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(+150cm) - light fraction - Thonnackal series - in plane light - Mgf: x 63.



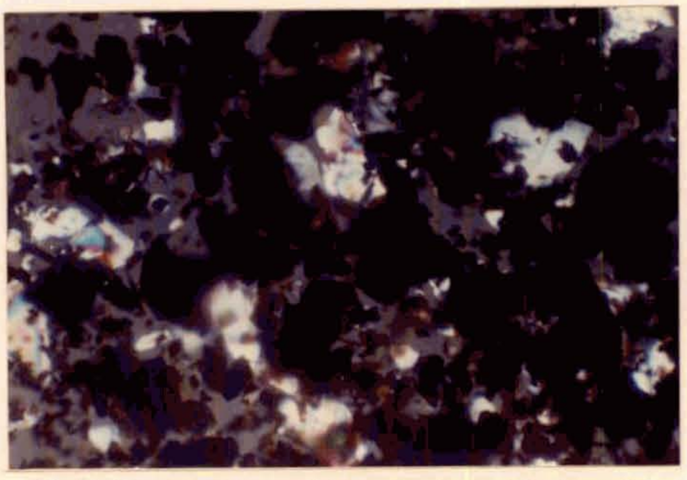
59. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(0-14cm) - heavy fraction - Trivandrum series - under crossed nicols - Mgf: x 63.



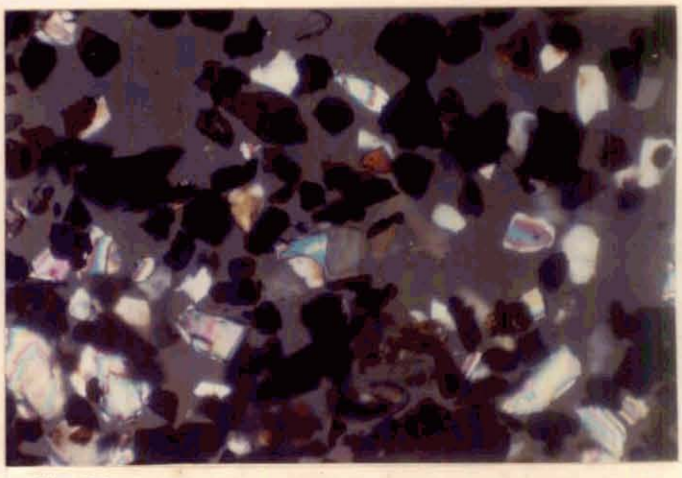
60. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(0-14cm) - light fraction - Trivandrum series - under crossed nicols - Mgf: x 63.



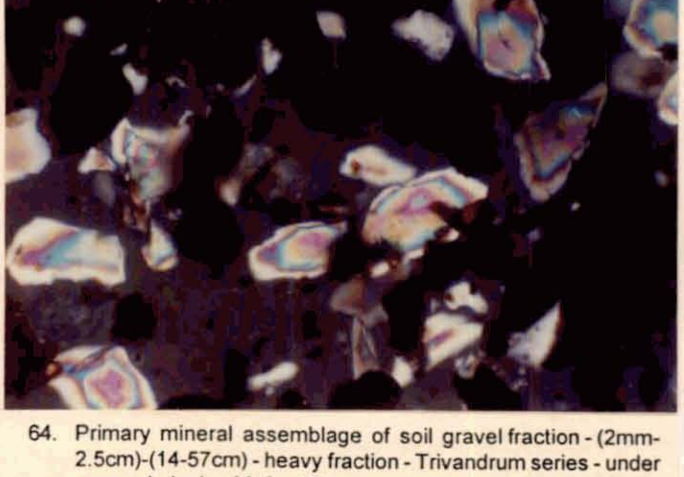
61. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(0-14cm) - heavy fraction - Trivandrum series - under crossed nicols - Mgf: x 63.



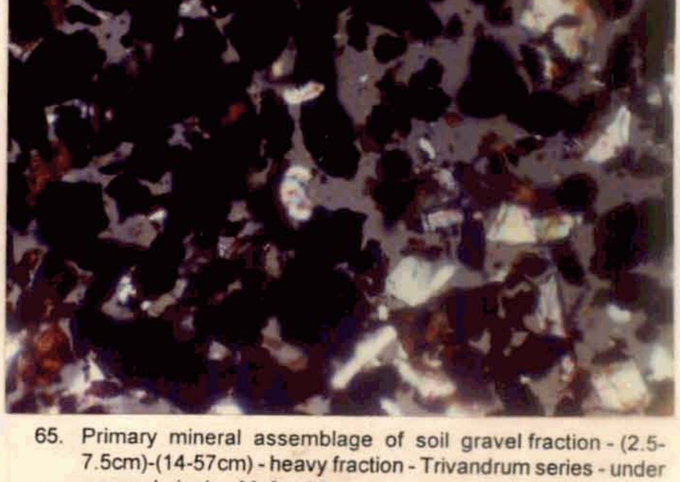
62. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(0-14cm) - light fraction - Trivandrum series - under crossed nicols - Mgf: x 63.



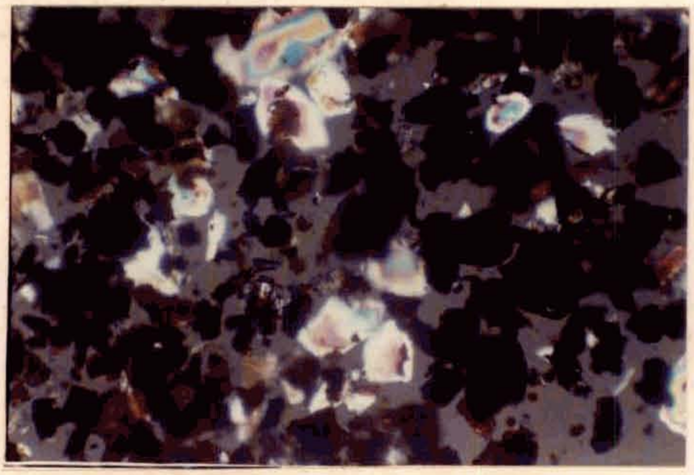
63. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(14-57cm) - heavy fraction - Trivandrum series - under crossed nicols - Mgf: x 63.



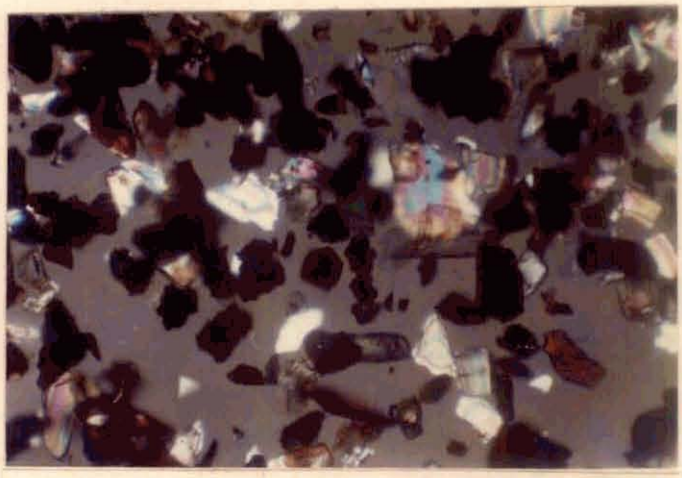
64. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(14-57cm) - heavy fraction - Trivandrum series - under crossed nicols - Mgf: x 63.



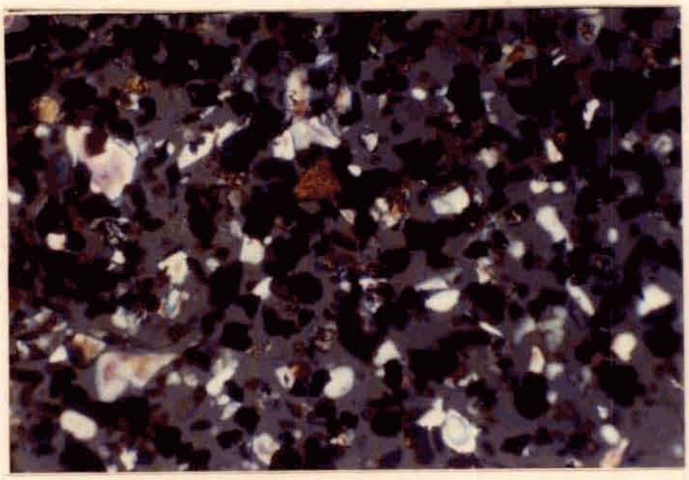
65. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(14-57cm) - heavy fraction - Trivandrum series - under crossed nicols - Mgf: x 63.



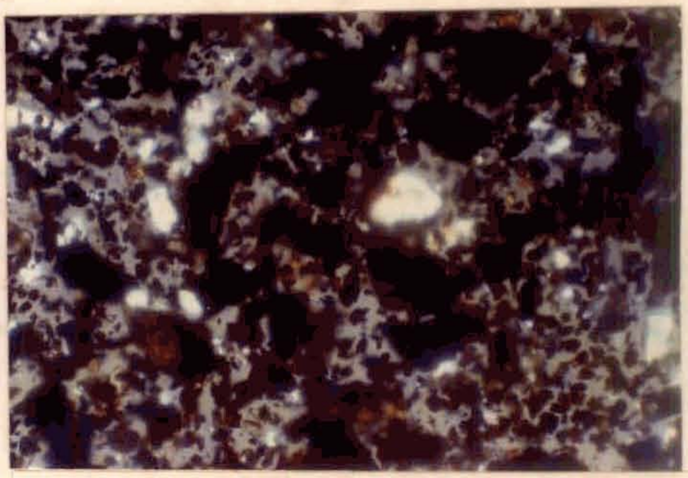
66. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(14-57cm) - light fraction - Trivandrum series - under crossed nicols - Mgf: x 63.



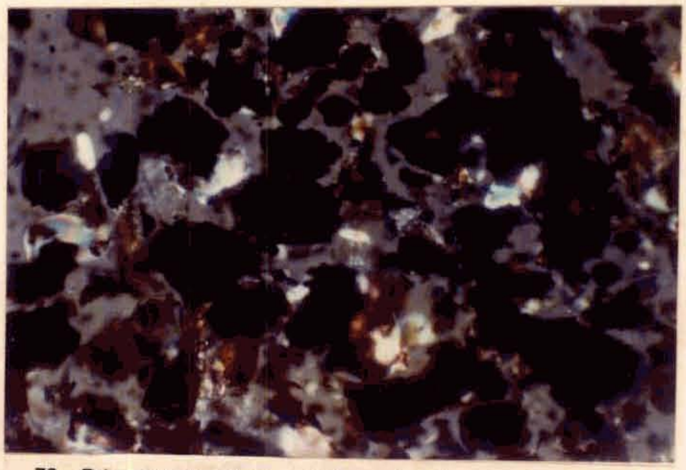
67. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(57-150cm) - heavy fraction - Trivandrum series - in plane light - Mgf: x 63.



68. Primary mineral assemblage of soil gravel fraction - (2mm-2.5cm)-(57-150cm) - light fraction - Trivandrum series - under crossed nicols - Mgf: x 63.



69. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(57-150cm) - heavy fraction - Trivandrum series - under crossed nicols - Mgf: x 63.



70. Primary mineral assemblage of soil gravel fraction - (2.5-7.5cm)-(57-150cm) - light fraction - Trivandrum series - under crossed nicols - Mgf: x 63.

Table 4. Primary mineral assemblage of gravels

Series name	Profile site	Depth of horizon (cm)	GRAVEL FRACTION	Percentage content														
				Heavy minerals								Light minerals						
				ILMENITE	KYANITE	SILLIMANITE	ZIRCON	PLINTHITE GRANULES	HEMATITE	GOETHITE	QUARTZ	QUARTZ	ILMENITE	SILLIMANITE	PLINTHITE GRANULES	HEMATITE	GOETHITE	MAGNETITE
Palode	TBGRI, Palode	0-14	I	-	-	2.35	-	65.73	-	-	31.92	48.81	-	-	51.59	-	-	-
			II	-	-	-	-	76.92	-	-	23.08	27.55	-	-	72.45	-	-	-
		14-51	I	-	-	2.47	-	67.90	-	-	29.63	48.96	-	-	51.04	-	-	-
			II	-	-	-	-	84.69	-	-	15.31	45.31	-	-	54.69	-	-	-
			III	-	-	-	-	72.50	-	-	27.50	24.25	-	-	75.75	-	-	-
		51-106	I	-	-	-	-	80.51	-	-	19.49	48.72	-	-	51.28	-	-	-
			II	-	-	-	-	86.83	-	-	13.17	38.98	-	-	42.37	-	-	18.65
			III	-	-	-	-	33.96	22.65	-	43.39	34.15	-	-	65.85	-	-	-
		106-150	I	-	2.56	-	-	74.36	-	-	23.08	37.10	-	-	50.00	12.90	-	-
			II	-	-	-	-	63.06	9.55	-	27.39	44.93	-	-	55.07	-	-	-
			III	-	-	-	-	62.50	10.58	6.73	20.19	26.21	-	-	73.79	-	-	-
Nedumangad	Pazhakutty - Shencotta road, Nedumangad	0-11	I	-	-	1.77	-	53.98	-	-	44.25	31.53	-	0.90	67.57	-	-	-
			II	-	-	-	-	68.85	17.39	5.79	7.97	7.74	-	-	83.17	9.09	-	-
		11-33	I	-	1.83	6.42	1.83	33.04	19.27	-	37.61	51.08	-	-	48.92	-	-	-
			II	-	-	-	-	54.84	-	29.03	16.13	29.52	-	-	56.02	3.62	10.84	-
		33-62	I	-	-	6.17	-	43.21	25.93	-	24.69	27.35	20.00	-	37.55	-	15.10	-
			II	-	-	-	-	58.82	10.46	-	30.72	25.56	-	-	67.78	-	6.66	-
		62-150	I	-	-	-	-	27.68	53.68	-	18.64	15.47	-	-	42.54	41.99	-	-
			II	-	-	-	-	84.08	-	-	15.92	60.87	-	-	39.13	-	-	-

(Contd...)

Table 4. (Contd....)

Series name	Profile site	Depth of horizon (cm)	GRAVEL FRACTION	Percentage content														
				Heavy minerals								Light minerals						
				ILMENITE	KYANITE	SILLIMANITE	ZIRCON	PLINTHITE GRANULES	HEMATITE	GOETHITE	QUARTZ	QUARTZ	ILMENITE	SILLIMANITE	PLINTHITE GRANULES	HEMATITE	GOETHITE	MAGNETITE
		0-8	I	-	-	-	-	92.71	-	-	7.29	18.63	-	-	81.37	-	-	-
Varkala	Kaithakonam		II	-	-	-	-	88.74	-	-	11.26	25.00	-	-	66.38	-	8.62	-
	via. Sivagiri,	8-150	I	-	-	-	-	33.33	66.67	-	-	22.98	-	-	39.19	37.83	-	-
	Varkala		II	-	-	-	-	89.51	-	-	10.49	14.16	-	-	43.36	30.97	11.51	-
		0-20	I	57.69	-	16.92	1.54	-	-	-	23.85	83.12	10.63	-	-	6.25	-	-
	Near	20-70	I	62.89	-	5.15	-	-	-	-	31.96	79.59	15.92	4.49	-	-	-	-
	KIPL	70-113	I	70.19	-	18.27	-	-	-	-	11.54	94.25	5.75	-	-	-	-	-
Thonnackal	china clay	113-150	I	-	-	-	-	75.44	-	-	24.56	43.45	-	-	56.55	-	-	-
	mines,	150+	I	81.58	-	-	-	-	-	-	18.42	10.61	-	-	31.51	-	57.88	-
	Thonnackal		II	-	-	-	-	17.20	61.29	-	21.51	5.26	25.27	-	10.53	-	58.94	-
		0-14	I	-	-	-	-	40.95	33.07	-	25.98	40.91	-	-	59.09	-	-	-
			II	-	-	-	-	39.41	26.38	19.23	14.98	22.40	-	-	77.60	-	-	-
Trivandrum	Mannanthala,	14-57	I	-	-	-	-	37.29	20.34	5.93	36.44	55.56	-	-	19.05	25.39	-	-
	Trivandrum		II	11.36	-	-	-	12.50	-	52.28	23.86	28.93	-	-	33.88	-	37.19	-
		57-150	I	-	-	-	-	49.55	22.52	-	27.93	44.34	-	-	27.15	-	28.51	-
			II	-	-	-	-	39.06	27.95	20.87	12.12	30.11	-	-	47.31	-	22.58	-

Note : Gravel/Coarser soil fraction :
I - Fine gravels (2mm-2.5cm)
II - Coarse gravels (2.5-7.5cm)
III - Cobbles (7.5-25cm)

At Thonnackal, the fine gravels showed an increasing pattern in the ilmenite content, the range being 57.69 to 81.58 per cent. Ilmenite was absent in the fine gravels of the fourth horizon and coarse gravels of the fifth horizon.

In the Trivandrum series ilmenite was observed only in the coarse gravels of the second horizon, the content being 11.36 per cent.

Among the series, ilmenite were noticed in the Thonnackal and Trivandrum series with the higher content in the Thonnackal series indicating the highly weathered oxic nature of the sedimentary deposit.

4.4.1.2. Kyanite

Kyanite was absent in the soil gravels except in the finer fractions of Palode and Nedumangad, the content being 2.56 per cent in the fourth horizon of Palode and 1.83 per cent in the second horizon of Nedumangad.

The distribution of kyanite in the Palode and Nedumangad series indicates the localised operation of weathering and sedimentary process of the respective horizons. As seen, the process of transformation is completed and the sharpness of the boarders of the minerals indicates accidental inclusion of these minerals by lateral erosion from the surrounding higher landscapes.

4.4.1.3. Sillimanite

Sillimanite was present in the fine gravels of the Palode, Nedumangad and Thonnackal series. At Palode, the content ranged from 2.35 to 2.47 per cent.

The content at Nedumangad showed an alternate profile pattern of increase and decrease with depth, but was absent in the fourth horizon. The content ranged from 1.77 to 6.42 per cent.

The content of sillimanite showed an alternate pattern of decrease and increase with depth at Thonnackal; however it was absent in the coarse and the fine gravels of the fourth and fifth horizons. The content ranged from 5.15 to 18.27 per cent.

Sillimanite was absent in Varkala and Trivandrum series and among the coarse gravels and cobbles of the series investigated.

The distribution of sillimanite in the Palode, Nedumangad and Thonnackal series indicates the acidic nature of the parent material (gneiss) which is highly weathered. It also indicates its accumulation in sedimentary formations as comparatively higher content is noticed in the Thonnackal series.

4.4.1.4. Zircon

Zircon was present only in the second horizon of Nedumangad series and the first horizon of Thonnackal series among the finer fractions of gravels, the content being 1.83 and 1.54 respectively. It was absent in the Palode, Varkala and Trivandrum series and the coarse gravels of Nedumangad and Thonnackal series.

Minor content of zircon in Nedumangad and Thonnackal series indicates the high rate of weathering operating in the these series. Among the series, zircon was significantly unnoticeable in the other soil series indicating comparatively less weathering intensity leading to their apparent accumulation.

4.4.1.5. Plinthite granules

In the Palode series, an increasing pattern was seen in the content in the case of fine and coarse gravels except in the fourth horizon where a decrease was noticed. The content ranged from 65.73 to 80.51 and 63.06 to 86.83 per cent respectively. The content in cobbles showed an alternate pattern of decrease and increase down the profile with the content ranging from 33.96 to 72.50 per cent.

The plinthite granules exhibited a progressive decrease in content down the profile at Nedumangad except in the third horizon where an increase was noticed. The content in coarse gravels increased down the profile except in the second horizon where a decrease was noticed. The content ranged from 27.68 to 53.98 and 54.84 to 84.08 per cent in fine and coarse gravels respectively.

In Varkala series, the content in fine gravels decreased down the profile while the same increased down the profile in coarse gravels, the range being 33.33 to 92.71 and 88.74 to 89.51 per cent respectively.

The plinthite granules at Thonnackal series were present only in the fourth horizon in fine gravels and fifth horizon in coarse gravels, the content being 75.44 and 17.20 per cent respectively.

A uniform pattern of alternate decrease and increase was noticed down the profile for both fine and coarse gravels at Trivandrum. The content ranged from 37.29 to 49.55 and 12.50 to 39.41 per cent respectively.

The plinthite granules are dense, very fine, compact mass of ferric iron neoformations. They can be categorised based on their composition as hematite or red opaques. It lacks the crystallinity, but with continuity of deposition, it results in a reinforced cutanic material of the nucleus minerals in gravels. The sharpness of the granules confirms its maturity. Among the series, except Thonnackal, it is maximum in the increasing order in Nedumangad < Trivandrum < Varkala < Palode for fine gravels while the same for coarse gravels is in the increasing order in Trivandrum < Nedumangad < Palode < Varkala. The Thonnackal series behave uniquely with the plinthite granules in the fine gravels of the fourth horizon and coarse gravels present in the fifth horizon. This can be attributed to lithological discontinuity resulting in lateral leaching and lessivage of iron containing fine minerals of amorphous nature from nearby higher landscapes with deforested area. The maximum content in the Thonnackal fine gravels indicates specific lateral migration of iron containing minerals. Difference in plinthisation is in the increasing order at Palode < Trivandrum < Varkala < Nedumangad < Thonnackal. Restricted localised ferruginisation is indicative of the marked difference of plinthic granule composition of gravels in the Thonnackal series. Amorphous iron-rich minerals is indicated by the loose and friable nature of the Thonnackal coarser fragments.

4.4.1.6. Hematite

The Palode series showed no hematite in the fine gravels; in the coarse gravels, hematite could be seen in the fourth horizon, the content being 9.55 per cent. The cobbles showed a decreasing pattern in the hematite content down the profile, the content ranging from 10.58 to 22.65 per cent in the fourth and third horizon respectively.

The fine gravels of the Nedumangad series showed an increasing trend in the hematite content down the profile, the content ranging from 19.27 to 53.68 per cent. The coarse gravels showed a decreasing pattern down the profile, the value ranging from 10.46 to 17.39 per cent. There was no hematite in the second and fourth horizons of the coarse gravels.

Hematite was absent in the gravels of the Varkala series except in the fine gravels of the second horizon, the content being 66.67 per cent.

In the Thonnackal series, hematite could be seen only in the coarser gravels of the fifth horizon, the content being 61.29 per cent.

The fine gravels of the Trivandrum series showed a pattern of alternate decrease and increase down the profile with values ranging from 20.34 to 33.07 per cent. In the coarse gravels the hematite content showed an increase down the profile with the content ranging from 26.38 to 27.95 per cent. There was no hematite in the coarse gravels of the second horizon.

The content of hematite indicates the iron retained in an intense weathered environment irrespective of the series. It also confirmed the age of the ferruginisation process operated in these soil series. Comparatively, the process of ferruginisation and their age is in the increasing order Trivandrum < Nedumangad < Varkala and Palode < Nedumangad < Trivandrum < Thonnackal series respectively in the fine and coarse gravels. Among the gravel fractions, there is no definite pattern exhibited in the enrichment of hematite. Considering the profiles of Palode, Nedumangad and Trivandrum its content increased with size at Palode and Trivandrum and decreased at Nedumangad.

The comparative distribution of plinthite granules and the hematite indicates that the plinthite granules are more of amorphous iron organisation.

4.4.1.7. Goethite

At Palode, the fine and the coarse gravels did not contain goethite; however, the cobbles of the fourth horizon contained 6.73 per cent goethite.

The fine gravels of the Nedumangad series did not contain any goethite but the coarse gravels of the first and second horizons contained 5.79 and 29.03 per cent goethite.

Goethite was absent in the heavy fraction of gravels in Varkala and Thonnackal series.

The fine gravels of Trivandrum series contained goethite in the second horizon (5.93 per cent). The coarse gravels showed an alternate profile pattern of increase and decrease with depth, the content ranging from 19.23 to 52.28 per cent.

Goethite is seen in the horizons of well drained, oxidised low organic matter containing horizons which favour the establishment of persistent environment of hydroxylation / hydration. Their absence in the Varkala series is because of the advanced stage of ferruginisation without room for reduction. At Thonnackal, the nature of the sedimentary deposit rich in quartz and silicate clay prevents its neoformation, even by the present day process of lateral enrichment of iron observed in the fourth and fifth horizons. This confirms that the iron enrichment of the horizons are specifically due to iron oxide migration rather than leaching. Hematite formation from goethite by dehydration is an ecodependent process. It is a process of dehydration through ferrihydrite which is a precusor of hematite (Chukhrov *et al.*, 1973; Schwertmann, 1986).

4.4.1.8. Quartz

The fine and coarse gravels showed a decrease in quartz content with depth except in the fourth horizon. The content ranged from 19.49

to 31.92 and 13.17 to 27.39 per cent respectively. The cobbles showed an alternate pattern of increase and decrease with depth, the content ranging from 20.19 to 43.39 per cent.

In Nedumangad series, the content of quartz in the fine gravels showed a decreasing pattern down the profile, the content ranging from 18.64 to 44.25 per cent. In the case of coarse gravels, a pattern of increase was seen down the profile, except in the fourth horizon where a decrease was noticed, the content ranging from 7.97 to 30.72 per cent.

Quartz could be seen only in the fine gravels of the first horizon at Varkala with a content of 7.29 per cent. In the coarse gravels, the content decreased down the profile with values ranging from 10.49 to 11.26 per cent.

The quartz content of fine gravels at Thonnackal showed an alternate pattern of increase and decrease down the profile with the content ranging from 11.54 to 31.96 per cent. The quartz content of coarse gravels of the fifth horizon was 21.51 per cent.

Both the gravel fractions of the Trivandrum series showed an alternate pattern of increase and decrease down the profile in their quartz content. The content ranged from 25.98 to 36.44 and 12.12 to 23.86 per cent respectively.

Except the Varkala series and the cobbles of Palode series, the quartz content increased with the size. The difference in the quartz distribution between gravel fractions were in the increasing order Thonnackal < Varkala < Palode < Trivandrum < Nedumangad. The observed difference indicates the relative extent of quartz enrichment. The uniform behaviour of fine and coarse gravels and the cobbles of Palode series indicates the uniformity of the pedogenic process and the lack of weathering and leaching / lessivage of the weathered products respectively in the Thonnackal and Palode series. Thonnackal series indicated a quartzitic gneiss parent material. The gneissic cobbles observed in the field with rock relic features indicate localised arrested laterisation in the cobbles. In the present investigation, quartz is seen in the bromoform separated heavy fraction indicating wide difference in the density of quartz.

4.4.2. Light minerals

4.4.2.1. Quartz

In the Palode series, the fine gravels showed a pattern of decrease down the profile except in the second horizon where there was an increase. The coarse gravels and cobbles showed an alternate pattern of increase and decrease down the profile. The quartz content ranged from 37.10 to 48.96, 27.55 to 45.31 and 24.25 t 34.15 per cent respectively in fine, coarse gravels and cobbles.

The fine gravels of the Nedumangad series showed a decreasing pattern down the profile in the content of quartz except in the second horizon where an increase was noticed, the content ranging from 15.47 to 51.08 per cent. In coarse gravels, the profile pattern showed an alternate increase and decrease down the profile, the value ranging from 7.74 to 60.87 per cent.

At Varkala, while the fine gravels showed an increase down the profile, the coarse gravels showed a decrease down the profile in the quartz content, the range being 18.63 to 22.98 and 14.16 to 25.00 per cent respectively.

The fine gravels showed a pattern of decrease in quartz content at Thonnackal except in the third horizon, the content ranging from 10.61 to 94.25 per cent. The coarse gravels of the fifth horizon had a content of 5.26 per cent.

In the Trivandrum series, the fine gravels showed an alternate pattern of increase and decrease with depth, the content ranging from 40.91 to 55.56 per cent. Coarse gravels showed a pattern of increase with depth, the content ranging from 22.40 to 30.11 per cent.

Quartz content of the light fraction of fine gravels is in the increasing order, Varkala < Nedumangad < Palode < Trivandrum < Thonnackal while their content in the coarse gravels were in the increasing order, Thonnackal < Varkala < Trivandrum < Nedumangad < Palode. Higher quartz content was noticed in the fine gravels. The differences in quartz content were in the increasing order Varkala < Palode < Nedumangad < Trivandrum < Thonnackal. The least difference found at Varkala indicates the uniformity of the pedogenesis namely petroplinthisation and the maximum difference noticed at Thonnackal indicates the accommodation of more silicate clay minerals in the fine gravels. The quartz distribution of gravels indicates more quartz in lighter fraction and less in the heavier fraction indicating the relative weathering.

4.4.2.2. Ilmenite

Ilmenite was absent in the coarse fractions of soils of Palode, Varkala and Trivandrum.

In Nedumangad series, an ilmenite content of 20.00 per cent was recorded in the fine gravels of the third horizon.

The Thonnackal series showed a profile pattern of alternate increase and decrease until the third horizon, the content ranging from 5.75 to 15.92 per cent. It was absent in the fine gravels of the fourth and fifth horizons. A content of 25.27 per cent was recorded in the coarse gravels of the fifth horizon.

The relative occurrence of ilmenite in the primary mineral assemblage indicates the extent of weathering and sedimentation. The sedimentary nature of formation or the process operating is indicated by the ilmenite content at Nedumangad and Thonnackal. It's absence in the Palode, Varkala (though residual) and Trivandrum strengthens its autochonous formation. The non-alteration of ilmenite to leucoxene indicates the lesser weathering intensity.

4.4.2.3. Sillimanite

Sillimanite was absent among the coarse fractions of soils of Palode, Varkala and Trivandrum series.

In Nedumangad series, a content of 0.90 per cent was recorded in the fine gravels of the first horizon.

The fine gravels of the second horizon of the Thonnackal series had a sillimanite content of 4.49 per cent.

The absence of sillimanite in the lighter fraction of gravels, irrespective of the series, except the surface horizons of Nedumangad and Thonnackal indicates acidic hydrolysis prevalent in the well-drained lateritic horizons of slope physiographic position which is well expressed more in sedimentary formations.

4.4.2.4. Plinthite granules

An alternate pattern of decrease and increase was recorded in the fine gravels and cobbles of the Palode series. The coarse gravels, however, showed a decrease in plinthite granules with depth except in the fourth horizon where an increase was recorded. The content ranging from 50.00 to 51.59, 42.37 to 72.45 and 65.85 to 75.75 per cent in fine, coarse gravels and cobbles respectively.

At Nedumangad, the fine gravels showed a decrease down the profile in the content of plinthite granules except in the fourth horizon where an increase was recorded. In coarse gravels, an alternate pattern of decrease and increase was recorded, the content ranging from 37.55 to 67.57 and 39.13 to 83.17 per cent respectively.

Both the gravel fractions of the Varkala series showed a decrease down the profile in the content of plinthite granules, the content ranging from 39.19 to 81.37 and 43.36 to 66.38 per cent respectively in fine and coarse gravels.

Plinthite granules were absent in the fine gravels of the first three horizons at Thonnackal but the content decreased from 56.55 per cent in the fourth horizon to 31.51 per cent in the fifth horizon. A content of 10.53 per cent was observed in the coarse gravels of the fifth horizon.

At Trivandrum, both the gravel fractions showed an alternate pattern of decrease and increase with depth, the content ranging from 19.05 to 59.09 and 33.88 to 77.60 per cent respectively in fine and coarse gravels.

Plinthite granules of the lighter fraction of gravels were in the increasing order Trivandrum < Thonnackal < Nedumangad < Palode < Varkala and Thonnackal < Trivandrum < Varkala < Palode < Nedumangad in the fine and coarse gravels respectively. Considering their relative distribution in the fine, coarse gravels and cobbles, they were comparatively high in finer gravels than the coarser ones, except Varkala and Thonnackal where a reverse trend is observed. At Thonnackal, the proportion of fine gravels to coarse gravels is about three times. The difference in plinthite granules between fractions is in the increasing order Palode < Varkala < Nedumangad < Trivandrum < Thonnackal. Comparatively, the difference in petroplinthisation between gravels were in the increasing order Palode < Trivandrum < Varkala < Nedumangad < Thonnackal.

4.4.2.5. Hematite

A content of 12.90 per cent Hematite could be identified in the fine gravels of the fourth horizon of the Palode series.

In the Nedumangad series, hematite could be found only in the fourth horizon in fine gravels, the content being 41.99 per cent. In the coarse gravels, it showed decrease with depth from 9.09 in the first to 3.62 per cent in the second horizon. It was absent in the third and fourth horizon.

Hematite could be seen only in the second horizon of Varkala series in fine and coarse gravels, the content being 37.83 and 30.97 per cent respectively.

In the Thonnackal series, hematite could be seen only in the fine gravels of the first horizon, the content being 6.25 per cent.

Hematite could be seen only in the fine gravels of the second horizon in Trivandrum series, the content being 25.39 per cent.

The content of iron in the fine gravels are comparatively more than the coarse gravels. Among the fine gravels, the content of iron were in the increasing order Thonnackal < Palode < Trivandrum < Varkala < Nedumangad while among the coarse gravels noticed in the Nedumangad and Varkala series, the iron content was maximum at Varkala. Lack of marked difference in the iron distribution of Varkala gravels indicates its similarity in the ferruginisation while the marked difference observed at Nedumangad indicated that the coarse gravels may be dominantly concretionary in nature with amorphous oxides of iron.

4.4.2.6. Goethite

Goethite could not be observed in the coarse fractions of soil of Palode series.

In Nedumangad series, the fine gravels showed a goethite content of 15.10 per cent in the third horizon but was absent in all other horizons. In coarse gravels, the content showed a decrease down the profile ranging from 6.66 to 10.84 per cent, goethite was absent in the first and fourth horizons.

Goethite was seen only in the coarse gravels of the Varkala series, the content ranging from 8.62 to 11.51 per cent.

At Thonnackal, goethite was seen only in the fine gravels of the fifth horizon, the content being 57.88 per cent. The coarse gravels of the fifth horizon showed a content of 58.94 per cent.

In the Trivandrum series, goethite could be seen only in the third horizon in fine gravels, the content being 28.51 per cent. In the coarse gravels, the content decreased with depth, the value ranging from 22.58 to 37.19 per cent, but it was absent in the coarse gravels of the first horizon.

Goethite is absent in the gravels and cobbles of Palode and fine gravels at Varkala. The goethite content among the other three series in the fine gravels were in the increasing order Nedumangad < Trivandrum < Thonnackal, while the same in the coarse gravels except Palode were in the increasing order Nedumangad < Varkala < Trivandrum < Thonnackal. Between size fraction, marked difference in the goethite content was noticed at Nedumangad and Varkala only indicating the same intensity / extent of dehydration of the ferrihydrite.

The observation of lack of goethite in the Palode series indicates the absence of hydration of hematite to goethite favoured by organic matter and associated soil pH. The absence of even hematite confirms the probability that except the gravels of the surface which are petroplinthised, the iron in the other coarse fractions are dominantly amorphous nature.

Hematite apparently required ferrihydrite precursor for its formation. It is reported to be present in better drained soils of tropical areas since rapid decomposition of organic matter seems to be essential for its formation. (Schwertmann and Taylor, 1977). Persistant environment of dehydration is required for the conversion of goethite to hematite. The thick forest canopy and near hypothermic soil temperature regime prevalent in the Palode series prevent the interconversion of goethite to hematite or even the crystallisation of goethite.

4.4.2.7. Magnetite

Among the soil series studied, magnetite could be seen only in the coarse gravels of the third horizon in Palode series the content being 18.65 per cent.

The odd observation of magnetite in the coarse gravels of the third horizon of Palode indicates comparative high drainage and less weathered magnetite rich parent material inclusion or random neoformations. The dominant parent materials of the Palode and Nedumangad series are garnetiferous, feldspathic leptinite or gneiss. The chance of odd inclusion of magnetite is also reported elsewhere in similar geomorphic position (Sivadasan, 1989). But, its absence cannot be generalised in other series.

The light minerals dominated markedly over heavy minerals probably due to the resistance of the former to weatherability (Ghabru and Ghosh, 1983 and Mayalagu *et al.*, 1992). The presence of plinthite granules now recalled as plinthic granules in these soil series have been reported by Ashraf (1992) and in lateritic soils of Tamil Nadu by Mayalagu *et al.* (1992). These were earlier termed as broken laterite by Nair *et al.* (1973). They are relic features of fossil laterite of paleoclimate.

4.5. Micromorphology of gravels

The detailed micromorphological description (Bullock *et al.*, 1985) of the different sized gravels observed in the different horizons of the major soil series of Trivandrum district are presented below and in Photomicrographs 71 to 105.

The comparative micromorphological evaluation of the gravels and their variability down the profiles are described in Table 5.

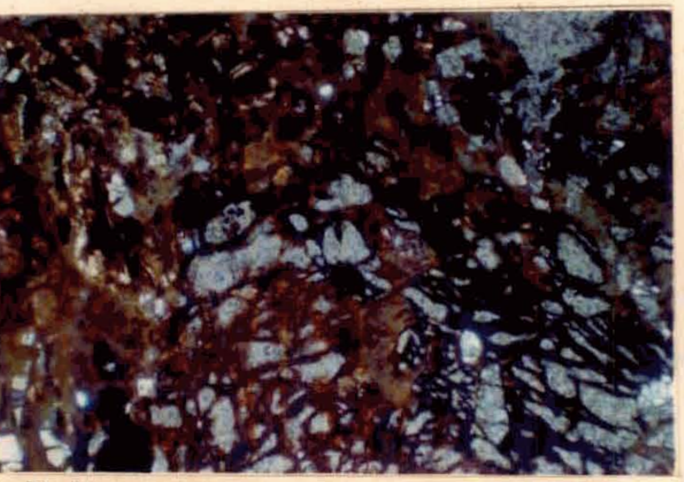
4.5.1. Palode

Except in the first horizon, gravels of fine, coarse and cobble sizes were recognised. The fine gravels of the surface horizon is with sand sized quartz and hematite inclusions with advanced internal weathering, while the coarse gravels are less weathered, opaque, porous, organised; with microgravels, less quartz and few ilmenite.

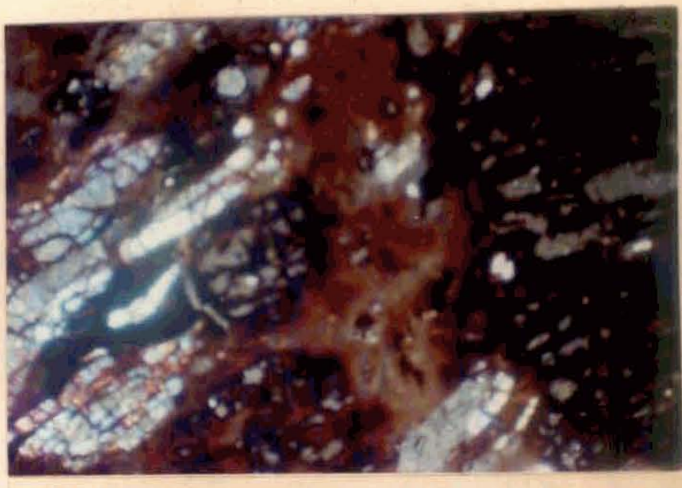
Progressively, the quartz content in the fine sand becomes smaller in size and fractured. It changes to goethitic, non-skeletenous, manganous and ferranic gravels with high relief to fractured non-coated low reliefed quartz with few hematite in highly opaque plasma towards lower horizons.

Though the coarse gravels initially retains the vosepic fabric, iron oxide composite glaebular structure with high reliefed skeletons and noticeable weathering, progressively becomes manganic and ferranic gravels with angular to subrounded, sand to silt-sized, iron coated quartz to highly opaque ferranic to ferri-argillanic plasma with less than sand-sized fractured quartz with few lithorelics.

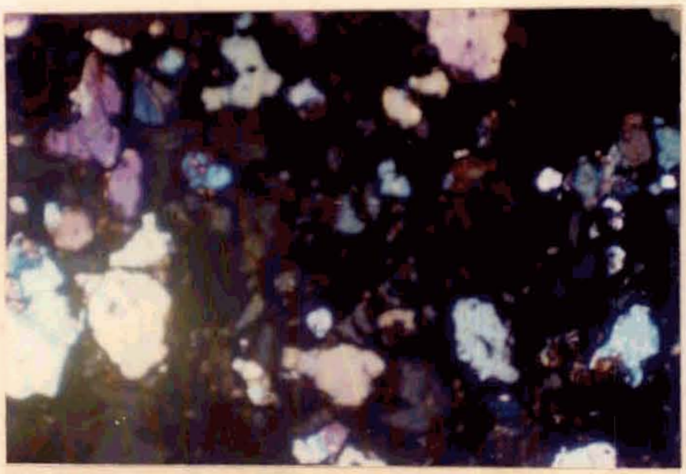
Photomicrographs on soil gravel micromorphology



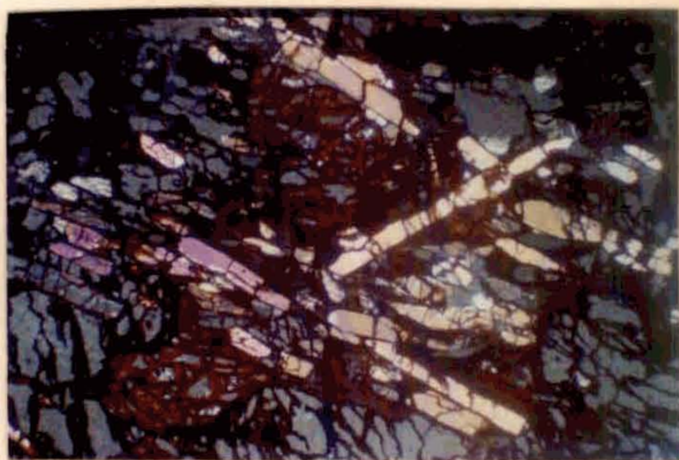
71. Micromorphology of soil gravel - (2mm-2.5cm)- (0-14cm) - Palode series - under crossed nicols - Mgf: x 25.



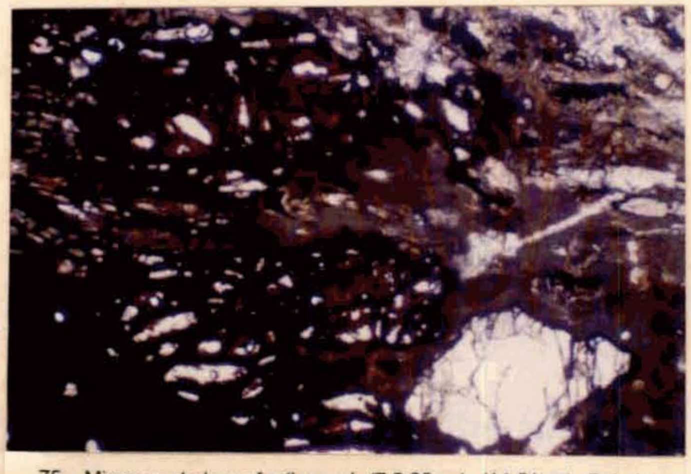
72. Micromorphology of soil gravel - (2.5-7.5cm)- (0-14cm) - Palode series - under crossed nicols - Mgf: x 25.



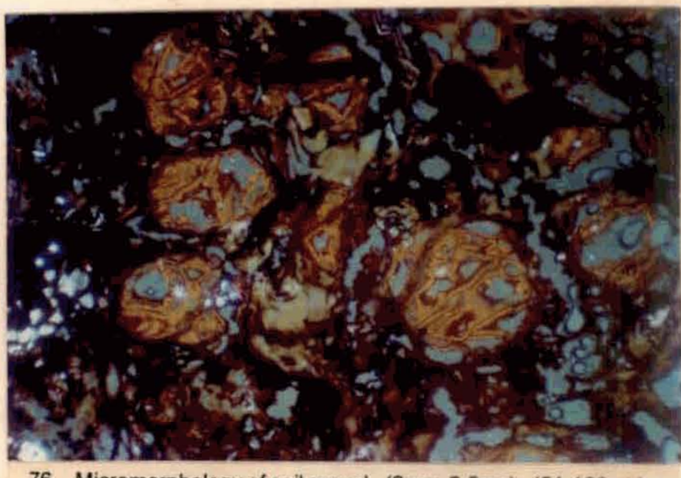
73. Micromorphology of soil gravel - (2mm-2.5cm)- (14-51cm) - Palode series - under crossed nicols - Mgf: x 25.



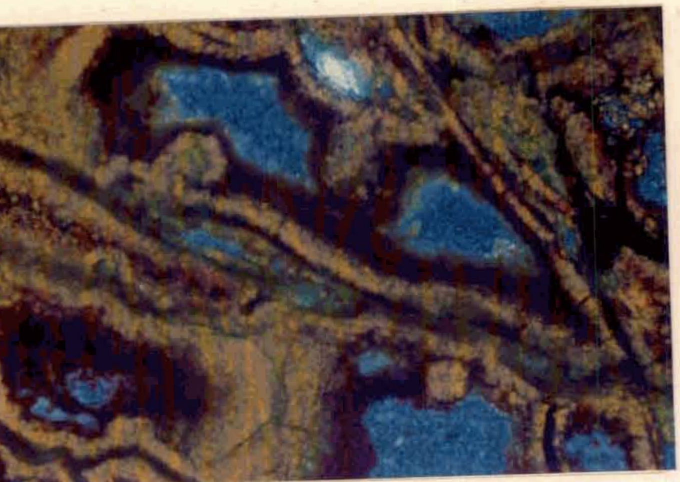
74. Micromorphology of soil gravel - (2.5-7.5cm)- (14-51cm) - Palode series - under crossed nicols - Mgf: x 25.



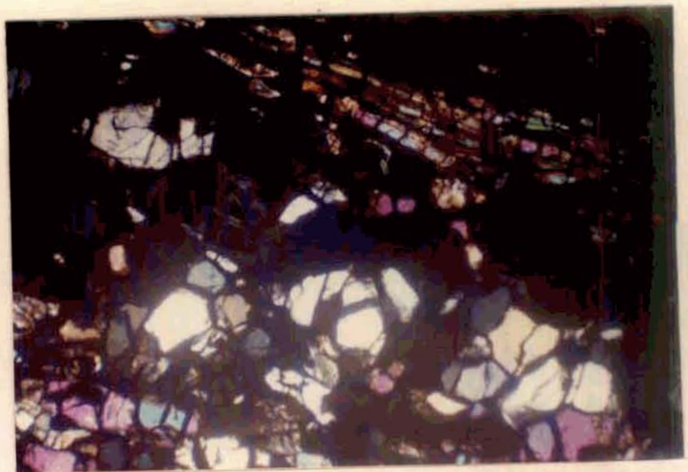
75. Micromorphology of soil gravel - (7.5-25cm)- (14-51cm) - Palode series - in plane light - Mgf: x 25.



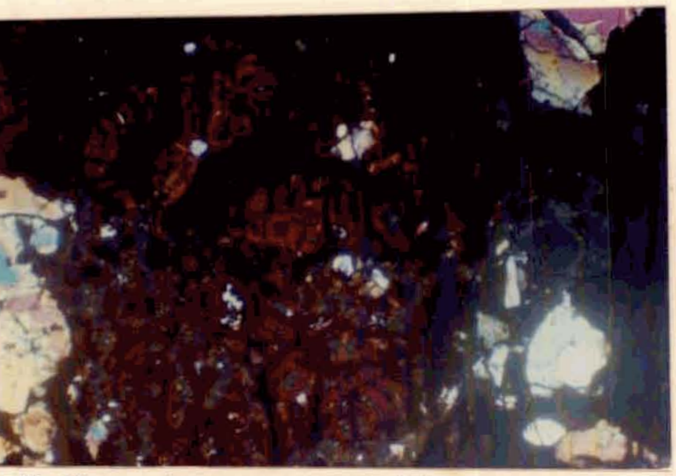
76. Micromorphology of soil gravel - (2mm-2.5cm)- (51-106cm) - Palode series - under crossed nicols - Mgf: x 25.



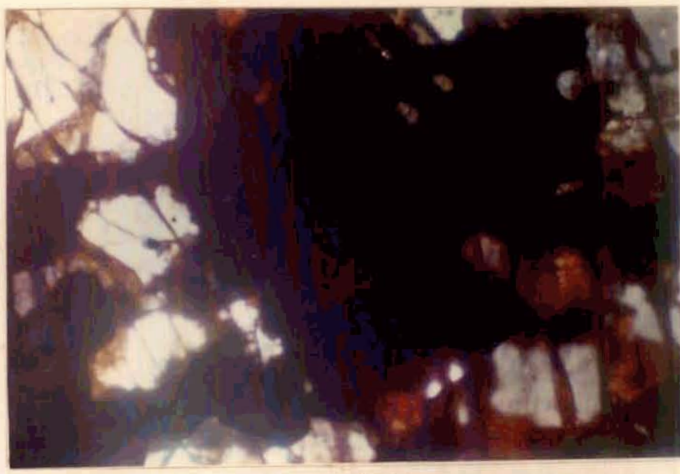
76a. Micromorphology of soil gravel - (2mm-2.5cm)- (51-106cm) - Palode series - under crossed nicols - Mgf: x 160.



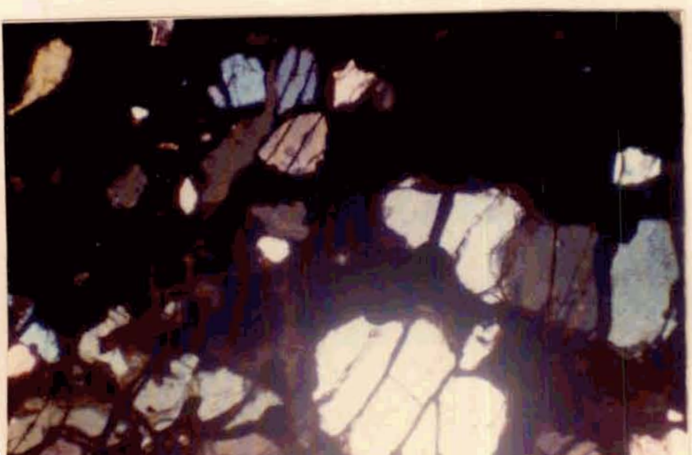
77. Micromorphology of soil gravel - (2.5-7.5cm)- (51-106cm) - Palode series - under crossed nicols - Mgf: x 25.



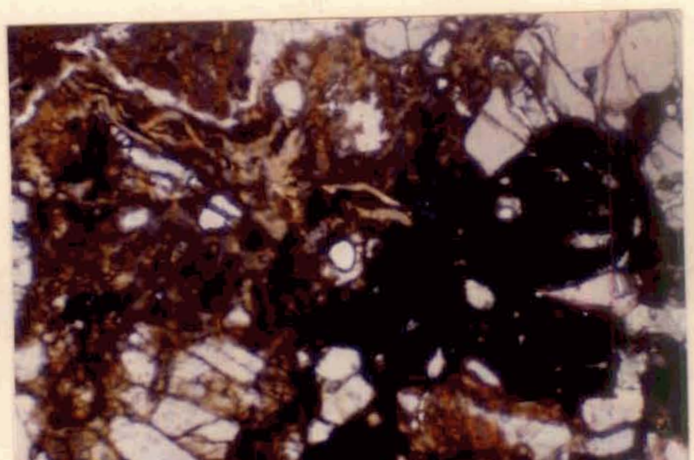
78. Micromorphology of soil gravel - (7.5-25cm)- (51-106cm) - Palode series - under crossed nicols - Mgf: x 25.



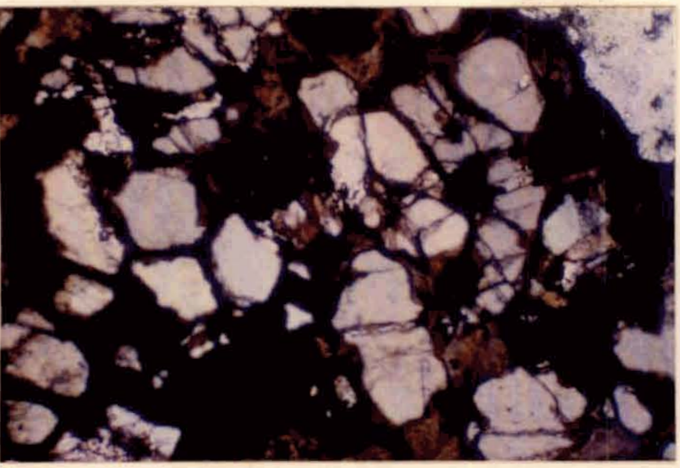
79. Micromorphology of soil gravel - (2mm-2.5cm)- (106-150cm) - Palode series - under crossed nicols - Mgf: x 25.



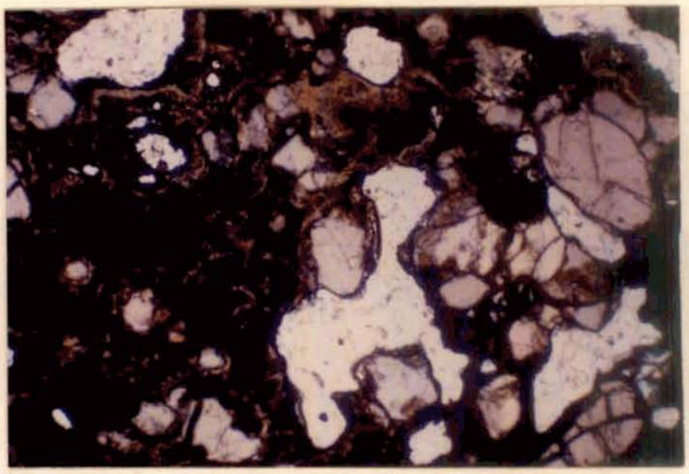
80. Micromorphology of soil gravel - (2.5-7.5cm)- (106-150cm) - *Palode series* - under crossed nicols - Mgf: x 25.



81. Micromorphology of soil gravel - (7.5-25cm)- (106-150cm) - Palode series - in plane light - Mgf: x 25.

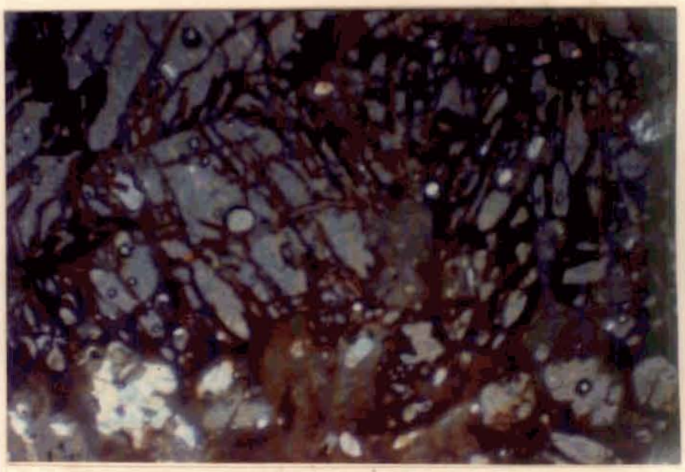


82. Micromorphology of soil gravel - (2mm-2.5cm)- (0-11cm) - Nedumangad series - in plane light - Mgf: x 25.

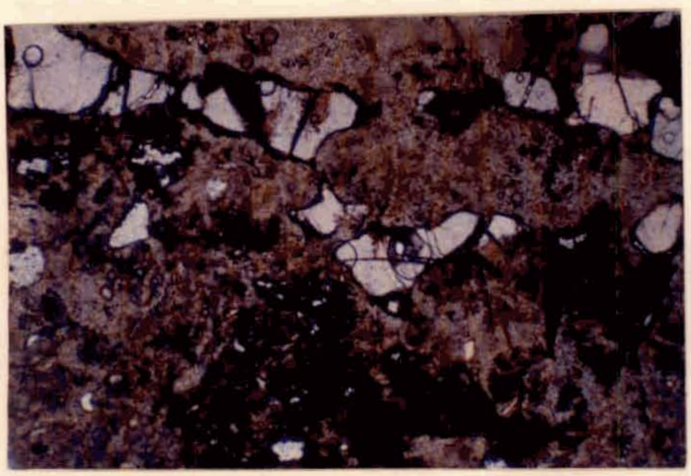


83. Micromorphology of soil gravel - (2.5-7.5cm)- (0-11cm) - Nedumangad series - in plane light - Mgf: x 25.

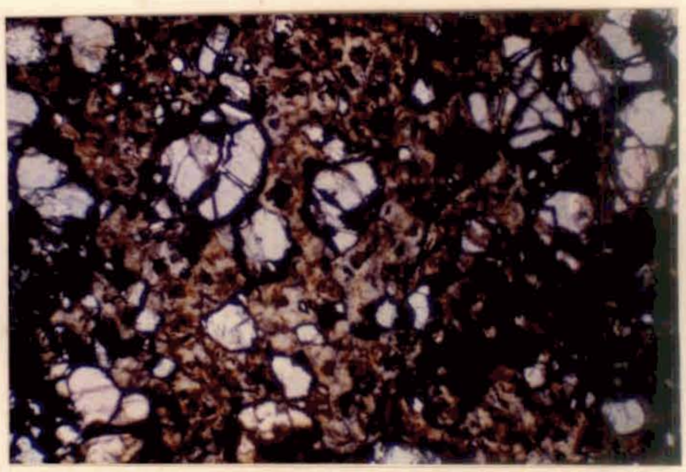
84. Micromorphology of soil gravel - (2mm-2.5cm)- (11-33cm) - Nedumangad series - in plane light - Mgf: x 25.



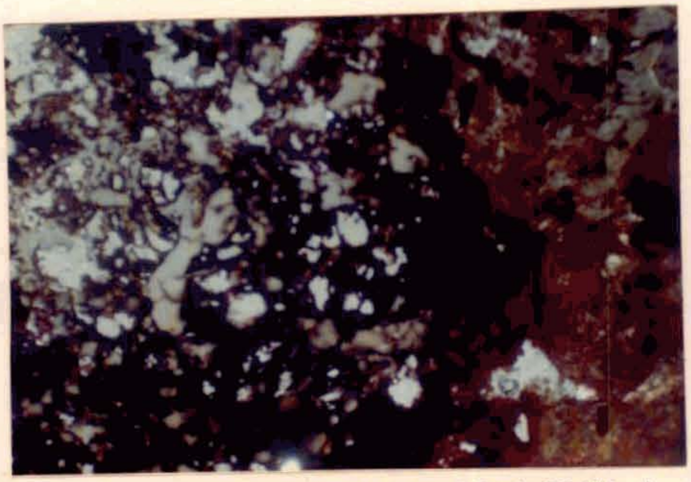
85. Micromorphology of soil gravel - (2.5-7.5cm)- (11-33cm) - Nedumangad series - under crossed nicols - Mgf: x 25.



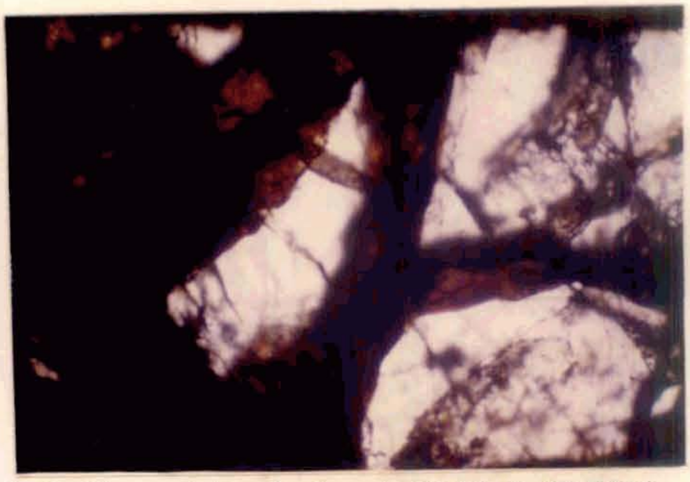
86. Micromorphology of soil gravel - (2mm-2.5cm)- (33-62cm) - Nedumangad series - in plane light - Mgf: x 25.



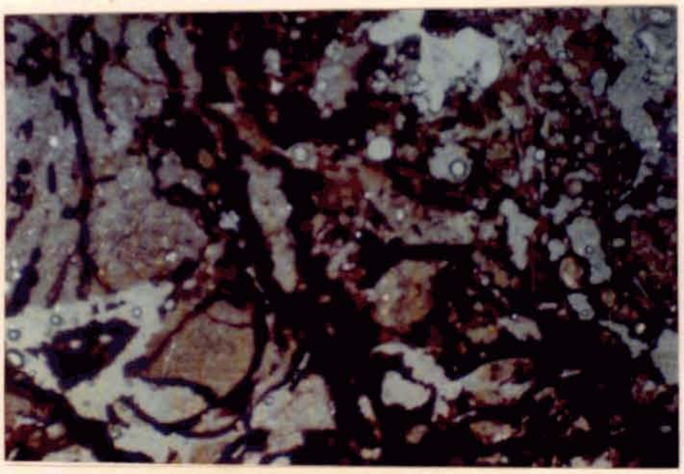
87. Micromorphology of soil gravel - (2.5-7.5cm)- (33-62cm) - Nedumangad series - in plane light - Mgf: x 25.



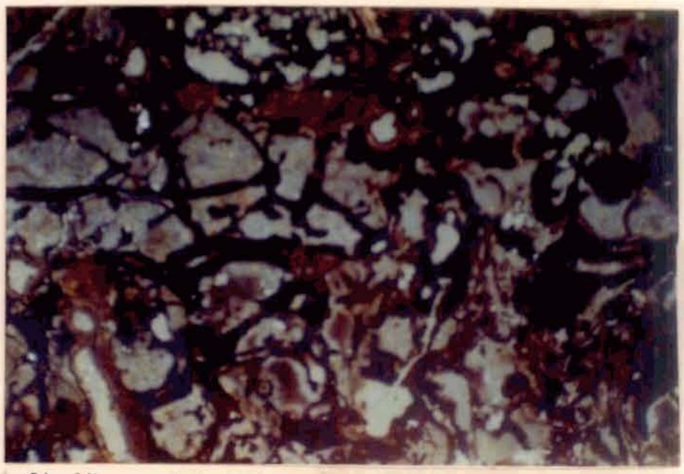
88. Micromorphology of soil gravel - (2mm-2.5cm)- (62-150cm) - Nedumangad series - in plane light - Mgf: x 25.



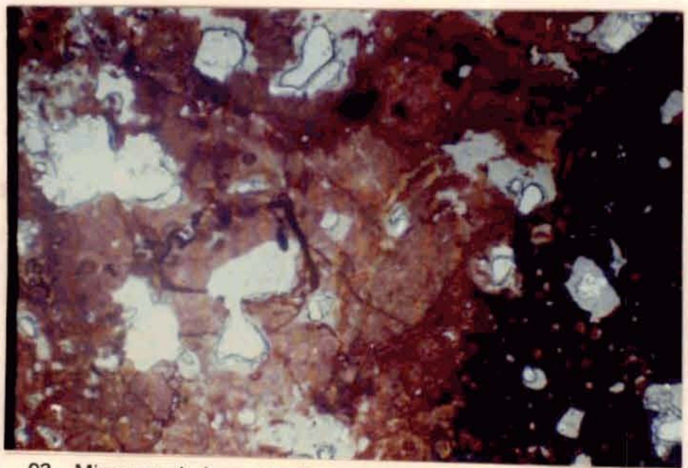
89. Micromorphology of soil gravel - (2.5-7.5cm)- (62-150cm) - Nedumangad series - in plane light - Mgf: x 25.



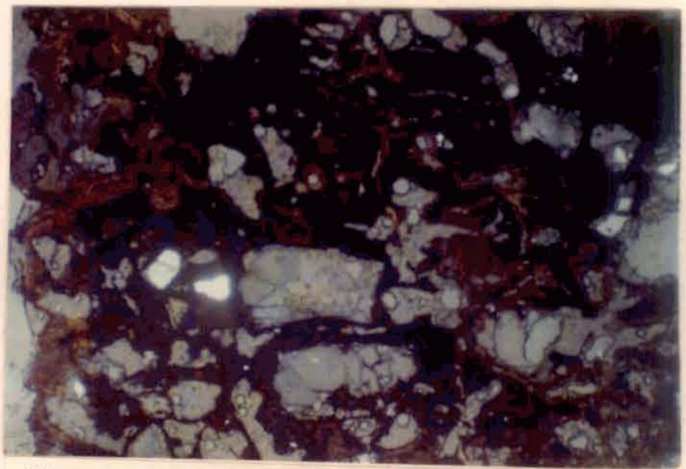
90. Micromorphology of soil gravel - (2mm-2.5cm)- (0-8cm) - Varkala series - under crossed nicols - Mgf: x 25.



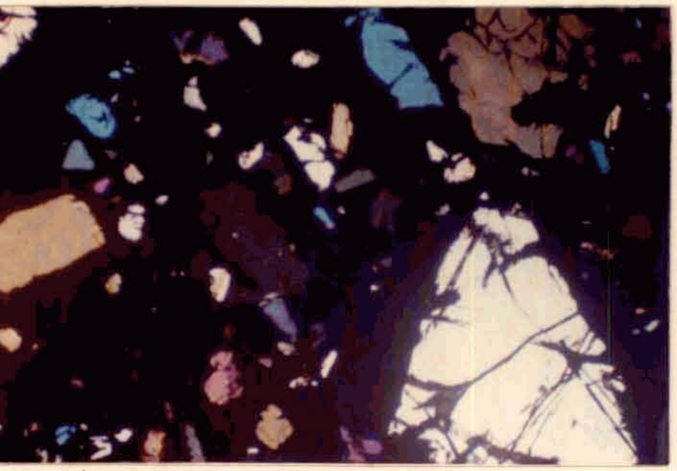
91. Micromorphology of soil gravel - (2.5-7.5cm)- (0-8cm) - Varkala series - under crossed nicols - Mgf: x 25.



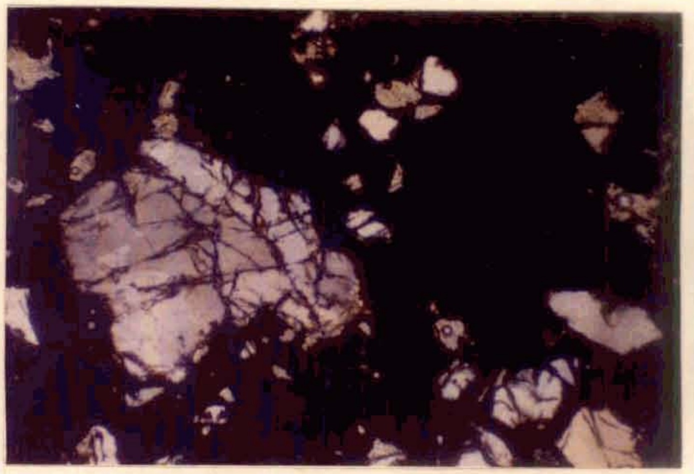
92. Micromorphology of soil gravel - (2mm-2.5cm)- (8-150cm) - Varkala series - under crossed nicols - Mgf: x 25.



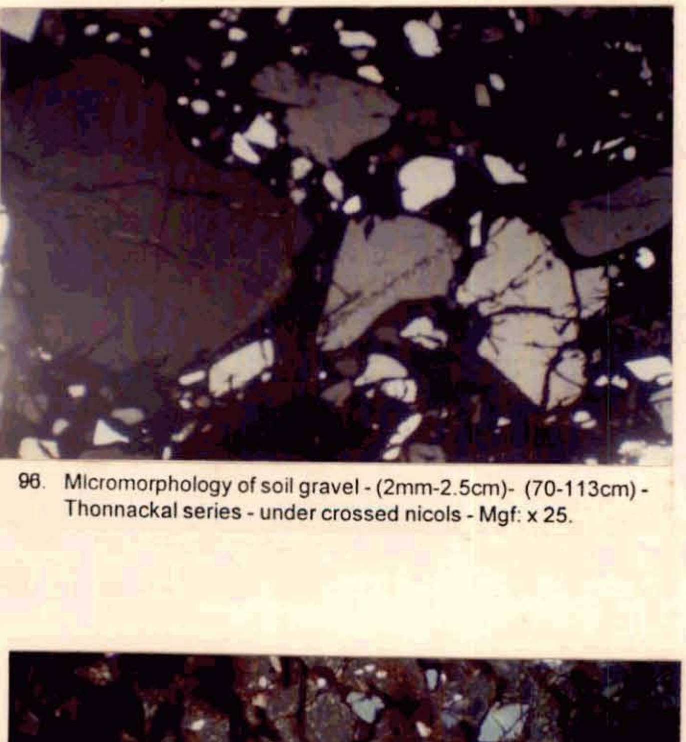
93. Micromorphology of soil gravel - (2.5-7.5cm)- (8-150cm) - Varkala series - under crossed nicols - Mgf: x 25.



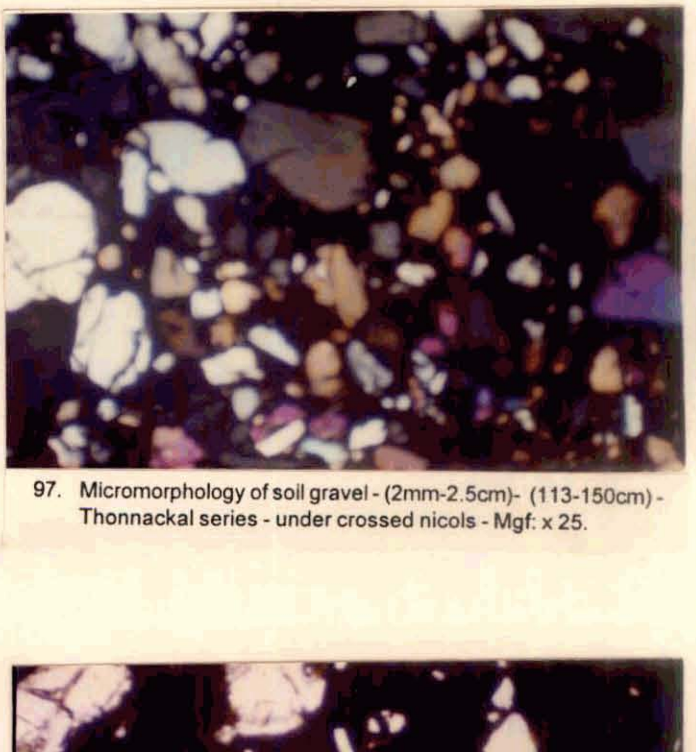
94. Micromorphology of soil gravel - (2mm-2.5cm)- (0-20cm) - Thonnackal series - under crossed nicols - Mgf: x 25.



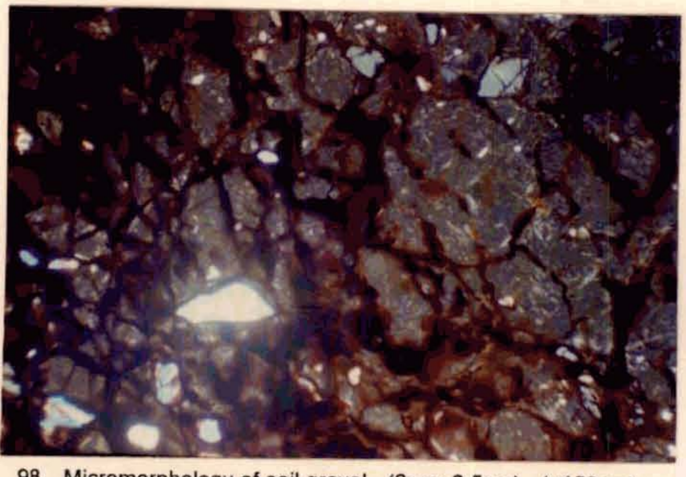
95. Micromorphology of soil gravel - (2mm-2.5cm)- (20-70cm) - Thonnackal series - in plane light - Mgf: x 25.



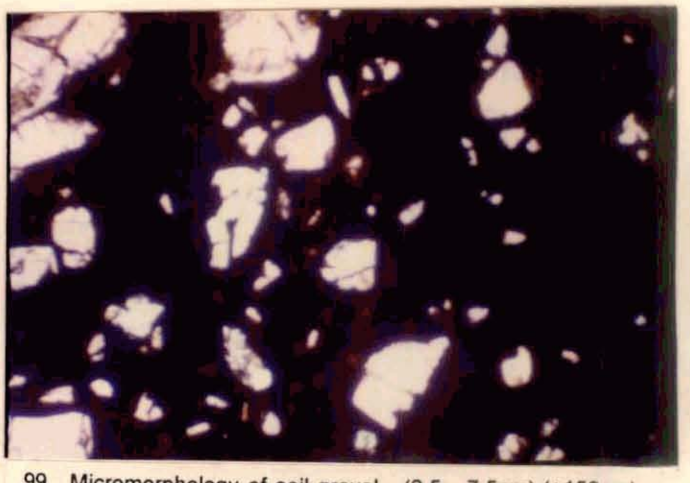
96. Micromorphology of soil gravel - (2mm-2.5cm)- (70-113cm) - Thonnackal series - under crossed nicols - Mgf: x 25.



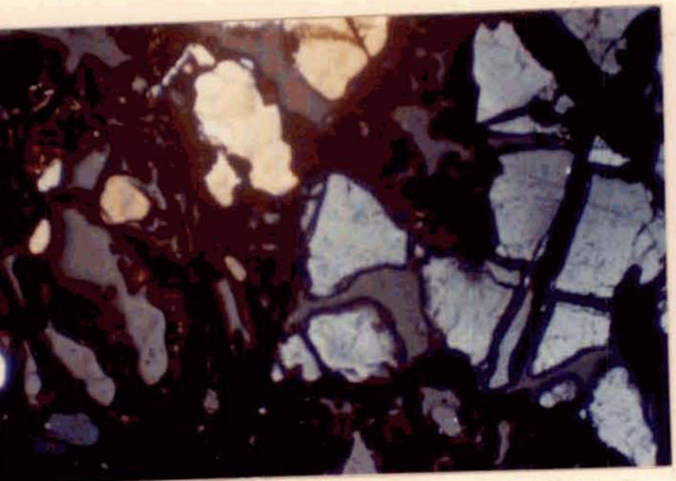
97. Micromorphology of soil gravel - (2mm-2.5cm)- (113-150cm) - Thonnackal series - under crossed nicols - Mgf: x 25.



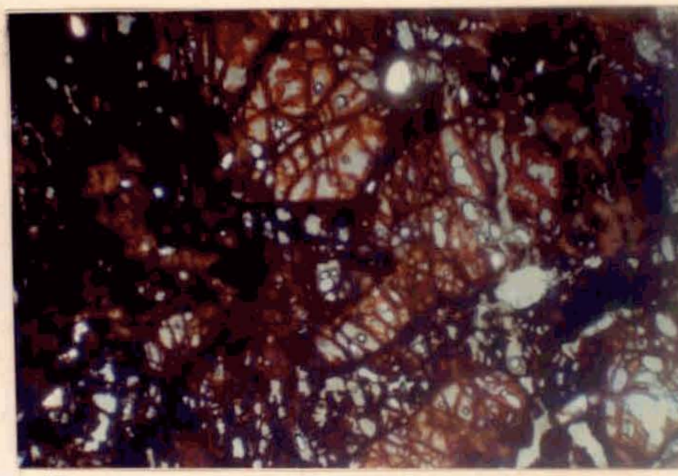
98. Micromorphology of soil gravel - (2mm-2.5cm)- (+150cm) - Thonnackal series - under crossed nicols - Mgf: x 25.



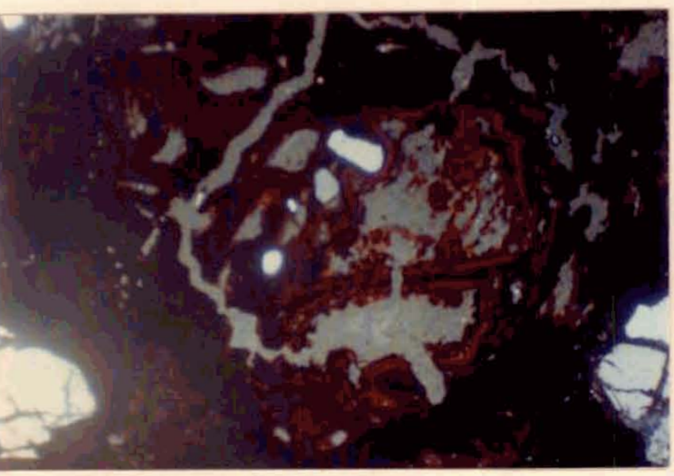
99. Micromorphology of soil gravel - (2.5- 7.5cm)-(+150cm) - Thonnackal series - in plane light - Mgf: x 25.



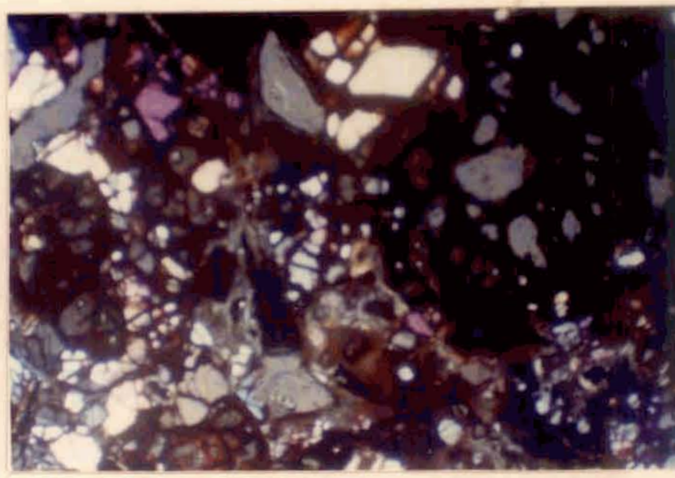
100. Micromorphology of soil gravel - (2mm- 2.5cm)-(0-14cm) - Trivandrum series - under crossed nicols - Mgf: x 25.



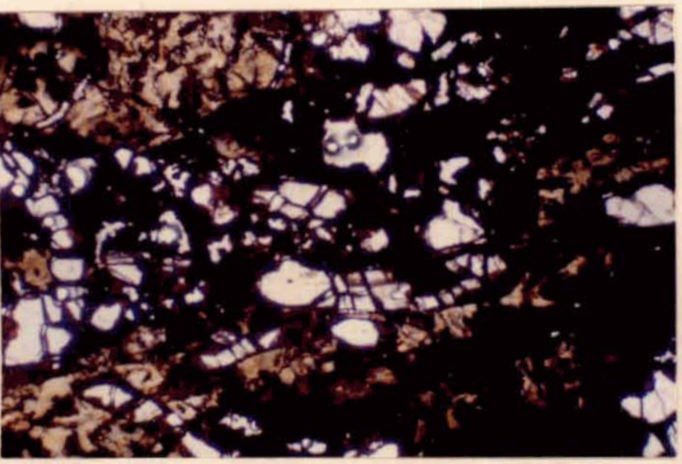
101. Micromorphology of soil gravel - (2.5- 7.5cm)-(0-14cm) - Trivandrum series - under crossed nicols - Mgf: x 25.



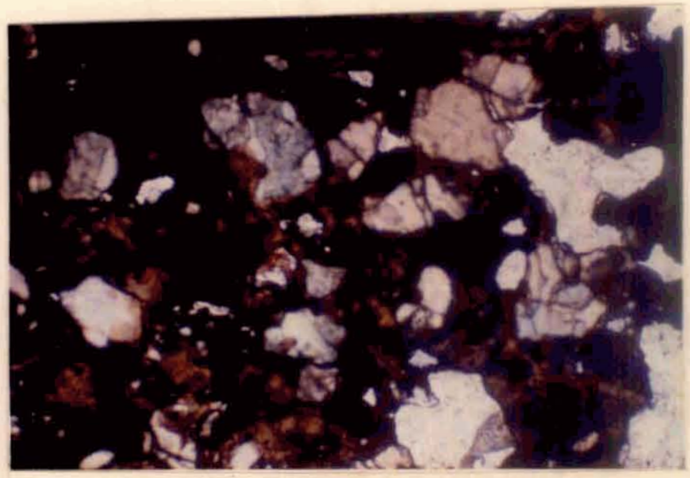
102. Micromorphology of soil gravel - (2mm- 2.5cm)-(14-57cm) - Trivandrum series - in plane light - Mgf: x 25.



103. Micromorphology of soil gravel - (2.5- 7.5cm)-(14-57cm) - Trivandrum series - under crossed nicols - Mgf: x 25.



104. Micromorphology of soil gravel - (2mm- 2.5cm)-(57-150cm) - Trivandrum series - in plane light - Mgf: x 25.



105. Micromorphology of soil gravel - (2.5- 7.5cm)-(57-150cm) - Trivandrum series - in plane light - Mgf: x 25.

Table 5. Micromorphology of soil gravels

Profile name : Palode

Horizon no. 1

Gravel fraction :	I	II
Plasma	Dominantly yellowish red followed by reddish yellow, yellow and violet, forms about 50 per cent of the gravel mass	Opaque to reddish yellow, clay sized haematite and goethite materials present as a webbing mesh of structural feature, glaebules present, more than 50 per cent
Fabric	Skelsepic	Skelvosepic
Skeleton	Angular to subangular, low relief, at places fractured, less than silt sized quartz, very few ilmenite, runic-quartz; at places, the quatrz is highly fractured with iron coating completely surrounding the grains. About 50 per cent of quartz grains are coated with yellow, yellowish red, yellowish brown goethite, bohemite and haematite finer minerals	Less than fine sand sized subangular to subrounded comparatively high reliefed quartz grains with haematite and goethite chlamydomorphic coating. The skeleton grains are oriented diagonally as lathshaped grains interconnected with iron oxide coatings
RDP	Chlamydomorphic to intertextic	Chlamydomorphic and at few places porphyroskelic
NRDP	Granic	Granic

Coarser/fine fraction	50/50 per cent	Coarser, 60/40 per cent
Voids	Compact with interconnected channels and planes, completely filled with manganese oxyhydrate, magnetite, haematite, bohemite and goethite finer mineral	Vughs and chamber shaped with bigger interconnected vugh and vessicles as an area of iron oxide removal by gradual leaching
Humus	Absent	Absent
Chlamydomorphic coatings	Continuous, surface spots or smeared thick repeated goethite (yellowish) bohemite (orangish yellow) red haemetite, purple opaque magnetite and manganese oxyhydrate	Repeated, opaque iron oxide mesh of high relief and hardness in the cluster of microgravels with few quartz. Certain microgravels are without any mineral
Lithorelics	Absent	Absent
Cutans	Mangan, ferran, goethan as chlamydomorphic and intertextic coatings with specific feature of limpidity in cutans	Ferran, mangan, highly opaque with repeated deposition
Special observation	The gravel is in the advanced stage of internal weathering by moist environment under the forest conopy along the slope. A few sand sized quartz grains has surfacial haematite inclusions Photomicrograph : 71	The gravel is an organised composite structure of highly opaque porous less quartzitic (0.5mm dia) glaebules/micro gravels in a speckled orientation. Limpidity, inclusions and surface coating absent, lath shaped fine sand sized quartz present. Content of quartz less. Very few ilmenite. Comparitively less weathered, initial stages of internal weathering Photomicrograph : 72

Horizon no. 2

Gravel fraction :	I	II	III
Plasma	Highly opaque, brownish red, iron oxide, clay sized	50 per cent, yellowish red to opaque composed of goethite, haematite, magnetite and maganese oxihydrate, dominant one being opaque magnetite and manganese oxihydrate	Opaque to brownish red, clay sized
Fabric	Vosepic and at few places skelsepic	Voskelsepic	Vosepic and very few skelsepic
Skeleton	Sand sized 30 per cent comparatively high reliefed fractured, (vesicular), sub-rounded. The skeletons are embedded on thick vacuolar mesh of iron oxide coating. Limpidity is a peculiar feature of the gravel	Less than fine sand sized long jointed, fractured quartz oriented diagonally, speckled orientation very few, magnetite and ilmenite (clay sized, opaque) present. Cracks or sutures of the grain are filled with ferran	Quartz angular to sub angular, few less than clay sized and very few sand sized, fractured
RDP	Intertextic	Chlamydomorphic to intertextic	Intertextic
NRDP	Granic	Granic	Plasma and at few places granic
Coarser/finer fraction	Finer, 30/70 per cent	Finer, 40/60 per cent	Coarser, 75/25 per cent
Voids	Vughs and vesicles – not interconnected	Non–interconnected vughy and vesicular	Vughs, vesicles
Humus	Absent	Absent	Absent

Chlamydomorphic coatings	Absent, coatings are porphyroskelic	Absent	Absent
Lithorelics	Absent	Absent	Absent
Cutans	Opaque, ferran, mangan, ferri-argillan	Mangan, ferran, goethan	Mangan, ferran
Special features	Vesicular shape, fractured fine sand sized quartz, porphyroskelic coating, limpidity of clay sized quartz, highly opaque, voids dominantly non inter-connected vughs and vesicles Photomicrograph : 73	Highly vosepic, iron oxide meshed porous composite glaebular (0.3mm dia) microfabric. Tendency of weathering is indicative. Skeletons are high reliefed and long with speckled orientation Photomicrograph : 74	Composite glaebular, (0.5mm dia), aged opaque to brownish yellow cutanic micro-structure with many clay sized vughy or vesicular voids with few clay sized quartz glaebules Photomicrograph : 75

Horizon no. 3

Gravel fraction :	I	II	III
Plasma	60–70 per cent, 70 per cent ferranic to manganic and 30 to 40 per cent limonitic and goethitic clay sized	30 per cent opaque to brownish red less than clay sized ferranic material	80 per cent composed of ferriargillan, ferran, goethan and at few places (10 per cent) faint-margined manganic plasma.
Fabric	Vosepic	Skelsepic	Asepic to Voskelsepic (10 per cent)
Skeleton	Very few less than clay sized subangular to subrounded quartz	Angular to subangular and very few subrounded, fractured, low reliefed quartz (0.04mm dia) with no surface cutanic coating and many obliquely packed iron oxide coated long high reliefed fractured quartz (0.004mm dia)	Less than silt sized, angular to subangular, fractured, low reliefed, faint margined quartz with marginal and surficial manganese coating and fillings
RDP	Chlamydomorphic to intertextic	Porphyroskelic to intertextic	Porphyroskelic and at few places without any cutanic coating
NRDP	Plasmic and at micolocations	Granic	Plasmic to ferriargillasepic slightly granic with about 10 per cent granic
Coarser/finer fraction	Finer, 5/95 per cent	Coarser, 80/20 per cent	Finer, 10/90 per cent

Voids	Voids within the glaebules are vughy and vesicular and that between the glaebules are chamber and channel shaped but not much interconnected. The margins of voids are sharp, organised by ferranic and manganic cutanic material in the surroundings with limonitic and goethite in the glaebules	Few vughy and vesicular of less than 0.04mm dia	Non-connected and inter-connected planar vughy, vesicular and chamber type of voids with thickned margins of mangan and ferran
Humus	Absent	Absent	Absent
Chlamydomorphic coatings	Absent. Finer mineralo-clay accumulation as complete coating or infillings in the interangular spaces defined as dermatic. At places where their aggregation is dominant, it is termed as agglutinic	Absent, but it in porphyroskelic to intertextic	Absent
Lithorelics	Very few	Few, lithorelics of less than silt size, iron coated	Few present but with faint margins, low reliefed
Cutans	Ferran, mangan, goethan	Opaque, manganic and ferric	Ferri-argillan, mangan, ferran and goethan
Special features	Composite goethitic non-skeletonous glaebular microstructure with non-interconnected vughs of dimension 0.2mm. The special feature characteristic of the gravel is manganous and ferranic	Angular to subrounded fractured low reliefed quartz and many less than silt sized long, iron coated, obliquely packed fractured quartz grains with surrounding opaque	Composite cluster of sand sized (0.5mm dia) porous repeated, high reliefed ferranic and goethitic margin (meshed), micrograves

surrounding plasmic material with characteristic non-interconnected chambers and channels with clear margins. At micro locations the cutans and the plasmic materials are well oriented. The black projecting line is indicative of the extinction and high relief of the deposition. They are concretionary in nature
Photomicrograph : 76

manganic to ferranic plasmic material, few vughs of less than fine sand sized present
Photomicrograph : 77

with very few fractured subangular to subrounded low reliefed, faint margined quartz. At micro locations the cutans and the plasmic materials are well oriented. The black projecting line is indicative of the extinction and high relief of the depositon
Photomicrograph : 78

Horizon no. 4

Gravel fraction :	I	II	III
Plasma	Opaque to reddish yellow clay sized plasmic material of high relief (thicker) with few ferriargillanic material, less than 5 per cent	Opaque to blackish brown ferric and few ferriargillic plasmic material occupying an area of 70 per cent	Plasmic material occupy 85 per cent with yellowish brown ferriargillan to opaque ferranic clay sized limpid material
Fabric	Skelsepic to Asepic	Skelsepic to Asepic and at few places vosepic	Skelsepic and at few places asepic to vosepic
Skeleton	Less than 15 per cent angular to sub-rounded, low reliefed, fractured, faint margined, sand sized quartz grains and and few less than sand sized haematite grains. Quartz grains are embedded on thick plasmic material	Fractured and cracked low reliefed non-coated less than fine sand sized quartz (0.1mm dia) with the cracks completely filled with opaque ferranic materials	Sand sized to less than sand sized, angular to subangular, radially cracked and fractured quartz with ferri-argillanic cutan on the surface and surrounding the skeletons. The cracks or fractures are not significantly filled with cutanic materials indicating the recent nature of the cracking
RDP	Porphyroskelic and at few places intertextic	Intertextic to porphyroskelic	Intertextic to porphyroskelic
NRDP	Granic	Granic	Granic

Coarsal /finer fraction	Finer, 15/85 per cent	Finer, 40/60 per cent	Coarser, 60/40 per cent
Voids	Interconnected chambers and few vughs accomodating less than 5 per cent	Vughs and vesicles	Interconnected channels, chambers and few vughs
Humus	Absent	Absent	Absent
Chlamydomorphic coatings	Absent, but is dominantly porphyroskelic	Absent, but it is asepic and at few places intertextic to posphyroskelic	Absent, but is intertextic to porphyroskelic
Lithorelics	Not noticeable due to thick plasmic material	Few present but coated with opaque brownish red iron oxide cutans	Few present and smeared with ferriargillan
Cutans	Opaque, ferran and goethite and few ferri-argillan	Ferran, ferri-argillan	Ferri-argillan, ferran and argillan
Special features	Fractured angular to subangular non-coated, low reliefed quartz and few haematite embedded on thick and opaque plasmic material occupying 80 per cent Photomicrograph : 79	Highly opaque, ferranic thick plasmic material with few ferri-argillan and less than fine sand sized fractured and cracked low reliefed quartz and few lithorelics, embedded Photomicrograph : 80	Non-coated sand to less than sand sized radially cracked medium to low reliefed quartz and opaque, non-quartzitic vesicular glaebules with few inter-connected chambers and channels with the plasmic materials dominantly ferri-argillan in nature Photomicrograph : 81

Profile name : Nedumangad

Horizon no. 1

Gravel fraction :	I	II
Plasma	Opaque to yellowish brown and at very few micro-locations reddish yellow, occupy 30 to 40 per cent.	Opaque to greyish yellow ferri-argillanic oriented thick plasma material, 50 per cent.
Fabric	Skelsepic	Voskelsepic
Skeleton	Subangular to subrounded, fractured and cracked, moderate reliefed, slightly coated quartz of less than fine sand size embedded on thick opaque to yellowish brown ferranic to ferri-argillanic plasmic material	Subrounded slightly fractured, slightly coated moderately reliefed quartz 50 per cent of less than fine sand size (0.04mm dia)
RDP	Porphyroskelic	Intertextic to porphyroskelic
NRDP	Granic	Granic
Coarse/fine fraction	Coarser, 60/40 per cent	50/50 per cent
Voids	Few interconnected channels, chambers and vesicles 10 to 15 per cent.	Interconnected channel and chambers obliquely oriented, coated with opaque to greyish yellow ferri-argillan.
Humus	Absent	Absent
Chlamydomorphic coatings	Absent	Few present but dominantly porphyroskelic

Lithorelics	Absent	Absent
Cutans	Mangan, ferri-argillan and few ferran. Limpidity is noticed in all the cutans dominatly in ferri-argillan with less than fine silt sized quartz	Opaque to greyish yellow coloured ferri-argillan and ferran, highly oriented indicated by their extinction lines
Speical features	Opaque to yellowish brown thick plasma with fractured and cracked subangular to subrounded moderately reliefed, fine sand sized quartz Photomicrograph : 82	Opaque to greyish yellow thick oriented limpid plasma with moderately reliefed slightly fractured, slightly coated fine sand sized quartz grains and interconnected channels and chambers with ferri-argillanic margins Photomicrograph : 83

Horizon no. 2

Gravel fraction :	I	II
Plasma	Highly thickened, slightly oriented nonlimpid, opaque, greyish brown and yellowish brown colour (30 per cent)	Brown to yellowish brown as organised oriented mesh structured (40 per cent)
Fabric	Skelvosepic	Vosepic
Skeleton	Highly fractured sand sized (0.2mm dia), slightly coated, angular, subangular to subrounded, high reliefed quartz grains embedded on thick opaque to yellowish brown slightly oriented plasma	Very few find sand sized and less than silt sized quartz grains and magnetite
RDP	Porphyroskelic to intertextic	Chlamydomorphic to intertextic
NRDP	Granic	Plasmic but SRDP is dermatic and DRDP is agglutunic.
Coarse/fine fraction	Coarser, 70/30 per cent.	Coarser, 60/40 per cent
Voids	Interconnected channels and chambers, few vughs and vesicles completely filled with opaque to yellowish brown ferri-argillans	Yellowish brown to browinsh cutan margined dominantly vughy followed by vesicular and spherical shaped without infillings and clay sized magnetite and quartz granules
Humus	Absent	Absent

Chlamydomorphic coatings	Absent	At micro locations thou dominantly voids are cr seperations
Lithorelics	Few less than silt size ferri-argillan coated present.	Very few, less than clay identified
Cutans	Opaque ferran, yellowish brown goethan and ferri-argillan	Ferran and ferri-argillar obliquely and specifical of the voids
Special features	Thick, opaque to yellowish brown plasma with embedded slightly coated highly fractured sand sized quartz grains, few coated lithorelics and characteristic interconnected channels and chambers filled with cutans Photomicrograph : 84	Skeletonless, highly vo: voids with ferran and fe oriented margins, tende is observed Photomicrograph : 85

Horizon no. 3

Gravel fraction :	I	II
Plasma	Brownish red, greyish brown, patchy plasma of varied thickness with clear limpidity. The plasma is ferranic and ferri-argillanic	Highly aggregrated, browinish red, ferranic and slightly ferri-argillanic, 45 per cent
Fabric	Asepic to skelsepic	Skelsepic
Skeleton	Find sand sized to silt sized chalamydomorphic coated cracked or fractured, angular to subangular quartz, few lithorelics, magnetite and ilmenite	Highly fractured variable sized chalamydomorphic coated quartz - dominantly sand to fine sand sized
RDP	Intertextic to porphyroskelic and at microlocations chalamydomorphic	Chalamydomorphic to intertextic
NRDP	Granic	Granic
Coarse/Fine fraction	Coarser, 85/15 per cent	Coarser, 55/45 per cent
Voids	Faint margined to dark margined interconnected big vesicles and narrow chamber shaped voids	Interconnected vesicles and vughs
Humus	Absent	Absent
Chalamydomorphic coatings	Present	Present

Lithorelics	Very few less than silt sized present	Very few less than silt sized present
Cutans	Ferran and ferri-argillan (brownish red)	Ferran and ferri-argillan as patchy plasmic material and as opaque chalamydomorphic coatings of skeletons
Special features	Patchy, ferranic to ferri-argillanic plasma with limpidity and with chalamydomorphic ferran coated fine sand sized to silt sized angular to subangular quartz Photomicrograph : 86	Prominently chalamydomorphic coated highly fractured skeletons and highly patchy, ferranic to ferri-argillanic plasmic material with faint margined interconnected vesicles and vughs Photomicrograph : 87

Horizon no. 4

Gravel fraction :	I	II
Plasma	Opaque, brownish red, reddish yellow, patchy to granular limpid plasma with mangan, ferran and ferri-argillan, tendency of iron migration towards voids observed	Opaque, red and reddish yellow coloured thick plamsic material of ferranic and slightly ferri-argillanic composition
Fabric	Skelsepic and at microlocations skelvosepic	Skelsepic
Skeleton	Irregular shaped, slightly fractured less than fine sand sized to clay sized quartz grains and granules chlamydomorphic to intertextic ferranic coated	More than sand sized angular to subangular, fractured and cracked quartz and less than silt sized haematite
RDP	Chlamydomorphic, intertextic and at microlocations, porphyroskelic	Porphyroskelic
NRDP	Granic	Granic
Coarse/Fine fraction	50/50 per cent	Coarser, 70/30 per cent
Voids	Dominantly vesicular with few angular and spherical voids	Very few vughy and spherical voids filled with ferrans
Humus	Absent	Absent
Chlamydomorphic coatings	Present	Absent

Lithorelics	Few less than silt sized ferran coated present	Absent
Cutans	Ferran, ferri-argillan and goethan	Ferran
Special features	Irregular shaped slightly fractured chlamydomorphic coated, composite sized group of quartz grains and granules with opaque to brownish red, red, reddish yellow ferranic, ferri-argillanic, goethanic plasmic material with predominantly vesicular voids Photomicrograph : 88	More than sand sized, angular to subangular non-coated, non-weathered quartz on opaque, red, reddish yellow, ferranic plasma with very few vughy and spherical voids with ferran infillings Photomicrograph : 89

Profile name : Varkala

Horizon no. 1

Gravel fraction :	I	II
Plasma	Red, reddish yellow, yellowish brown, oriented plasma composed of ferran, goethan and ferri-argillan and conspicuosly limpid, 60 per cent	Moderately aggregated indicating an agglutinic SRDP of a former oxic material, reddish brown opaque to reddish yellow coloured, 70 per cent, highly vacuolated thick and clear, moderately limpid with faint margined of granules comparatively more kaolin, aggregates of clay to silt sized present
Fabric	Vosepic to voskelsepic	Vosepic to voskelsepic
Skeleton	Few less than fine sand sized, subangular slightly fractured quartz.	Subangular to subrounded fine sand sized to sand sized fractured quartz filled with manganiferous cutans in cracks.
RDP	Thick, clear, continous chlamydomorphic to intertextic	Chlamydomorphic to intertextic and at microlocations porphyroskelic
NRDP	Ferritic with tendency to granic at microlocations	Granic
Coarse/Fine fraction	Finer, 40/60 per cent	Finer, 30/70 per cent
Voids	Interconnected chambers, vughs, vessicles which are moderately filled with ferran or ferri-argillan	Non interconnected vessicles and vughs and few interconnected channels and chambers

Humus	Absent	Absent
Chlamydomorphic coatings	Present, but tending to thick, clear intertextic	Present, tending to intertextic and porphyroskelic
Lithorelics	Few, less than fine sand sized with quartz inclusions	Absent
Cutans	Mangan, ferran, ferri-argillan, goethan	Mangan, ferran, ferri-argillan
Special features	Plasma is dominantly thick clear manganiferous, limpid oriented obliquely as margins of interconnected bigger chambers and moderate to micro sized vughs and vesicles. Coated less than fine sand sized slightly cracked chlamydomorphic coated few quartz grains (0.01 mm dia) and clay sized many quartz granules and kaolin Photomicrograph : 90	Highly thick, opaque, oriented, reddish brown manganiferous plasma with marginal halo region of ferri-argillan and goethan, limpid with fine quartz granules, kaolin microaggregates indicating agglutinic SRDP Photomicrograph : 91

Horizon no. 2

Gravel fraction :	I	II
Plasma	Opaque, red, reddish brown, yellowish red, yellow, 80 per cent. Partially obliquely oriented, composed of mangan, ferran ferri-argillan and goethan	Opaque, brownish red, reddish brown, reddish yellow thick, sharp moderate to well oriented manganic and ferranic, restricting ferri-argillans in the obliquely oriented interconnected channels and chambers, 60 per cent
Fabric	Skelvosepic	Skelsepic and skelvosepic
Skeleton	Less than fine sand sized, low reliefed subangular to sub-rounded clear margined non-coated quartz, very few less than silt sized iron coated lithorelics. Non coated quartz granules are seen in vesicular and vughy voids of faint margins. Few sand size gravels with less than silt sized to clay sized innumerable subangular quartz granules embedded on manganiferous opqaue plasma	Non coated sand sized to fine sand sized many slightly fractured clear margined angular to sub-angular quartz grains with very few less than silt sized runic quartz
RDP	Porphyroskelic	Porphyroskelic
NRDP	Granic and tending to agglutinic SRDP	Granic to agglutinic tendency
Coarse/Fine fraction	Finer, 20/80 per cent	Finer, 40/60 per cent

Voids	Vesicular, less than 0.02 mm dia., vesicular non-interconnected voids with few criss-crossing curved skew planes	Vesicular with many interconnected chambers and channels filled with ferri-argillan and ferrans
Humus	Absent	Absent
Chlamydomorphic coatings	Absent	Absent
Lithorelics	Very few, less than silt sized iron coated lithorelics	Absent
Cutans	Ferri-argillan, mangan, ferran.	Mangan, ferran, ferri-argillan.
Special features	Ferri-argillanic, maganic, ferranic, less limpid plasma with faint margined vesicles retaining clear margins, subangular to subrounded non-coated less than fine sand sized quartz grains, few criss-crossing skew planes, sand sized thick manganiferous quartzitic gravel Photomicrograph : 92	Comparatively bigger (sand sized to fine sand sized) slightly fractured clear margined non-coated moderately reliefed quartz, many vesicles, interconnected chambers and channels with ferri-argillan and ferran fillings, obliquely oriented with very few runic quartz Photomicrograph : 93

Profile name : Thonnackal

Horizon no. 1

Gravel fraction	I
Plasma	Opaque to dark brownish red thick limpid ferranic plasma, 85 per cent
Fabric	Skelvosepic
Skeleton	Sand sized to clay sized, angular to subangular, subrounded, non-coated cracked and fractured quartz, very few ferran variable reliefed coated lithorelics
RDP	Porphyroskelic
NRDP	Granic
Coarse/Fine fraction	Finer, 15/85 per cent
Voids	Few vughs and vesicles
Humus	Absent
Chlamydomorphic coatings	Absent
Lithorelics	Very few less than silt sized and ferran coated, subangular
Cutans	Thick opaque brownish red ferran
Special features	Sand sized to clay sized, non coated, variable reliefed, cracked and fractured quartz and very few less than silt sized ferran coated lithorelics, few vughs and vesicles on thick opaque to brownish red limpid plasma Photomicrograph : 94

Horizon no. 2

Gravel fraction	I
Plasma	Opaque dark blackish grey to greyish yellow thick plasma with slight limpidity, 80 to 90 per cent
Fabric	Skelsepic
Skeleton	Very few highly fractured and cracked subangular to subrounded non coated, clear margined quartz with many less than silt sized to clay sized coated and non coated subangular to subrounded quartz granules with very few coated fragmented lithorelics
RDP	Porphyroskelic
NRDP	Granic
Coarse/Fine fractions	Coarser, 90-85/10-15 per cent
Voids	Few vughs and vesicles
Humus	Absent
Chlamydomorphic coatings	Absent
Lithorelics	Less than silt sized coated, subangular to subrounded
Cutans	Thick, opaque, blackish grey to greyish yellow ferran. Thin illuviation argillans are present mainly associated with silt sized quartz grains on their surface. In bigger grains the argillan coatings are partly stripped off
Special features	Thick, opaque, blackish grey to greyish yellow, ferranic plasma with few subangular to subrounded non coated or partially coated quartz grains ranging from sand sized to clay sized. Silt sized and less than silt sized are not fractured with full or partial argillan coatings Photomicrograph : 95

Horizon no. 3

Gravel fraction	I
Plasma	Brownish red to brownish black, thick ferranic limpid plasma, 30 per cent
Fabric	Skelsepic
Skeleton	Many sand sized medium reliefed subangular to subrounded fractured non coated quartz and many less than silt sized silica aggregate and few silt sized plinthic quartzitic glaebules
RDP	Porphyroskelic
NRDP	Granic
Coarse/Fine fraction	Coarser, 70/30 per cent.
Voids	Few less than silt sized vughs
Humus	Absent
Chlamydomorphic coatings	Absent
Lithorelics	Absent
Cutans	Ferrans
Special features	Sand sized subangular non coated to subrounded comparatively with more reliefed fractured quartz and few plinthic glaebules with clay sized quartz and many less than silt sized angular to subangular gibbsite on opaque to brownish red thick plasma Photomicrograph : 96

Horizon no. 4

Gravel fraction	I
Plasma	Brownish yellow, brownish red thick non limpid, 50 per cent
Fabric	Argillasepic to skelsepic
Skeleton	Few soubrounded, fine sand sized and many angular to subangular silt sized and round to subrounded clay sized quartz. The fine quartz are with ferran coatings completely on the surface while the bigger quartz grains are non coated. Many fine sand sized to silt sized subangular to sunrounded gibbsite is also noticeable
RDP	Porphyroskelic to intertextic
NRDP	Granic to agglutinic
Coarse/Fine fraction	50/50 per cent
Voids	Few ferran filled faint margined vughs
Humus	Absent
Chlamydomorphic coatings	Absent
Lithorelics	Very few less than silt size fractured, plinthic present
Cutans	Ferran and thin ferri-argillan
Special features	Dominantly fine sand sized to clay sized slightly fractured subangular to subrounded, coated quartz grains, non-coated gibbsite and few fine sand sized non-coated slightly fractured quartz grains on thick brownish red to reddish yellow or brownish yellow plasma and very few voids Photomicrograph : 97

Horizon no. 5

Gravel fraction :	I	II
Plasma	Very fine, limpid non-oriented greyish white kaolin, plasma is with opaque to reddish brown ferranic oblique oriented staining	Opaque to brownish yellow thick uniform plasma, 80 per cent
Fabric	Insepic, argillasepic and locally vosepic	Argillasepic plasmic fabric
Skeleton	Very few less than silt sized to clay sized, marginal coated moderately reliefed quartz grains, subangular non-coated runic quartz, less than silt sized well aggregated coated kaolin	Fine sand to silt sized runic quartz common with few illuviation argillans towards the margins of less than silt sized grains
RDP	Agglutinic to argillasepic	Argillasepic
NRDP	Plasmiporphyric	Granic
Coarse/Fine fraction	Finer, 5/95 per cent	Finer, 20/80 per cent
Voids	Very few less than clay sized vesicular and chamber shaped present	Very few less than clay sized, ferran filled vughs
Humus	Absent	Absent
Chlamydomorphic coatings	Absent	Absent
Lithorelics	Absent	Absent

Cutans	Opaque to reddish brown obliquely oriented ferran as staining on the plasma in a vacuolar or cellular pattern	Thick ferri-argillan towards the margins of less than silt sized runic quatz
Special observations	Skeletons very few fractured marginal coated silt sized to clay sized quartz and runic quartz, gibbsite on greyish white kaolin plasma. The plasma is stained with opaque to reddish brown oriented cellular, vacuolar shaped ferran Photomicrograph : 98	Opaque to brownish yellow argillasepic plasmic fabric with fine sand sized to silt sized non-coated slightly fractured runic quartz. Very few voids Photomicrograph : 99

Profile name : Trivandrum

Horizon no. 1

Gravel fraction :	I	II
Plasma	Opaque to reddish brown, yellowish brown, ferran and ferri-argillan present as voidal seperation and as marginal coatings of skeleton grains, 60 per cent	Opaque brownish red, yellowish red plasma which are limpid, 30 per cent
Fabric	Skelvosepic and at locations argillasepic	Argillasepic to agglutanic
Skeleton	Sand sized, geometrically fractured, subangular to sub-rounded marginal ferran coated quartz with few fine sand sized ferri-argillan coated subangular to subrounded and irregular shaped quartz	Runic quartz of less than silt sized to clay sized
RDP	Chlamydomorphic to porphyroskelic	Argillasepic to agglutinic
NRDP	Granic to agglutinic	Agglutinic
Coarse/Fine fraction	Finer, 40/60 per cent	Coarser, 98 per cent
Voids	Dominantly non interconnected vesicles with thick opaque reddish brown ferran margins, few clustered fine vessicles and chambers filled with ferri-argillan indicating the previously oxic material	Highly porous, non interconnected, less than silt sized many to abundant vughs, few vessicles and interconnected channels
Humus	Absent	Absent

Chlamydomorphic coatings	Present	Absent
Lithorelics	Absent	Absent
Cutans	Thick opaque to reddish brown, yellowish red ferran and ferri-argillan	Rich in highly oriented opaque to reddish brown, reddish yellow ferran, ferri-argillan resulting in a porous mesh of cutans creating abundant less than silt sized vughs
Special observations	Plasma less, thick aggregated oriented, opaque to reddish brown, yellowish red, ferran and ferri-argillan material as margins of sand sized, angular to subangular non-coated geometrically fractured high reliefed quartz grains and characteristic bigger vesicles and smaller clusters of chambers and vesicles, all non connected Photomicrograph : 100	Skeleton very less, plasma less highly thick opaque to reddish brown, reddish yellow ferran and ferri-argillan, geometrically oriented as net work of cutan mesh resulting in abundant less than silt sized vughy, porous structure Photomicrograph : 101

Horizon no. 2

Gravel fraction :	I	II
Plasma	Opaque dark red reddish brown, ferranic cutan stained plasmic material	Opaque thick brownish red, yellowish brown, ferranic and ferri-argillanic plasma material
Fabric	Argillasepic to agglutinic	Argillasepic to polyplinthicmicroglaebular fabric
Skeleton	Very fine sand sized to silt sized subangular, subrounded, rounded runic quartz	Less than silt sized to clay sized subrounded to rounded non coated, cracked, few fine sand sized non coated, non cracked quartz, ferran coated, high reliefed opaque lithorelics, fine quartz are runic quartz
RDP	Agglomeroplasmic to agglutinic	Agglomeroplasmic to agglutinic
NRDP	Agglomeroplasmic to agglutenic slightly granic to argillasepic	Granic to agglutinic
Coarse/Fine fraction	Finer, 3/9-97 per cent	Coarser, 70/30 per cent
Voids	Chambers, channels, interconnected, non interconnected vesicles macrosized	Vughs in the microgravels, chambers and channels in the intermicrogravel space
Humus	Absent	Absent
Chlamydomorphic coatings	Absent	Absent

Lithorelics	Absent	Present, few opaque subangular silt sized high reliefed and ferran coated
Cutans	Reddish brown, red oriented repeateadly deposited forming the mesh of plinthic microgravels	Opaque brownish red, yellowish brown ferran and ferri-argillan forming plinthic mesh of micro-gravels
Special features	Dark red, reddish brown, opaque ferran, geometrically oriented as a mesh of microgravels with few silt sized fine sand to silt sized runic quartz, non fractured, non-coated with agglomeroplasmic to agglutinic SRDP Photomicrograph : 102	Opaque brownish red, yellowish brown ferraniferous to ferri-argillaceous cutan mesh, plinthic microgravels with many less than silt sized to clay sized cracked, subrounded to rounded runic quartz with clear margined vughs and vesicles in the micrograves. Plasma very less Photomicrograph : 103

Horizon no. 3

Gravel fraction :	I	II
Plasma	Opaque highly aggregated brownish red to yellowish brown ferranic to ferri-argillinanic slightly limpid plasma, 50 per cent	Opaque to yellowish and at very few micro locations reddish yellow occupying 30-40 per cent
Fabric	Skelsepic to argillasepic	Skelsepic
Skeleton	Highly fractured, cutan filled non coated to slightly coated subangular to subrounded fine sand sized to silt sized quartz, less than silt sized to clay sized magnetite	Subangular to subrounded, fractured, sand to fine sand sized, moderate reliefed quartz, embedded in thick opaque to yellowish brown ferranic to ferri-argillanic plamic material
RDP	Porphyroskelic to argillasepic	Porphyroskelic
NRDP	Aggulitinic to argillasepic	Granic
Coarse/Fine fraction	50/50 per cent	Coarser, 60/40 per cent
Voids	Broken, interconnected ferri-argillan and ferran filled chambers, vesicles and channels	Few interconnected channels, chambers and vesicles 10-15 per cent
Humus	Absent	Absent
Chlamydomorphic coatings	Absent	Absent

Lithorelics	Absent	Absent
Cutans	Opaque brownish red, reddish brown, brownish yellow ferran and ferri-argillan as infillings of interangular spaces of grains, skeletons and voids	Oriented opaque ferran, oriented ferri-argillan less than silt sized ferri-argillan filled vessicles and chambers
Special features	Opaque, brownish red, yellowish brown aggregated plasma as infillings of voids dominantly vesicles. Skeletons fine sand sized, cracked and highly fractured non-coated to slightly coated embedded on thick opaque plasma. Ferri-argillan accounts about 10-15 per cent of the voidal infillings Photomicrograph : 104	Opaque to yellowish brown ferri-argillanic, thick plasma with fractured and cracked subangular to subrounded moderately reliefed, fine sand sized quartz Photomicrograph : 105

Note : Gravel/Coarser soil fraction : I — Fine gravels (2mm-2.5cm)
II — Coarse gravels (2.5-7.5cm)
III — Cobbles (7.5-25cm)

Cobbles are present only in the subsurface horizons and are characteristically with composite glaebular internal structure. They are aged and opaque with few vughs and vesicles and less than clay sized quartz in the surface. The ferranic and goethitic plasma content and the large sized high reliefed quartz with orientation tendency increases down the profile to non-coated, less than sand-sized radially cracked quartz rich gravels with opaque glaebules with few interconnecting channels. Plasma becomes dominantly ferriargillanic.

Surface fine and coarse gravels are less weathered to highly weathered and are materials transported from nearby higher landscape of similar soil material comparatively aged subjected to repeated plinthisation. The increase in size fraction down the profile is because of the gneissic cobbles present in the subsurface horizons. Laterally transported fine to coarse gravel clustering leads to multiglaebular microgravels and multimicrogravelly coarse gravels and cobbles down the profile. Clay migration and enriched ferruginisation favours the progressive organisation and distribution of higher sized gravels down the profile. Surface gravels are plinthic to petroplinthic while the subsurface gravels are concretionary, ferruginous to plinthic indicating active laterisation in the profile with a forest canopy. The dry semideciduous nature of the forest vegetation, higher slope, older landscape, high rainfall and long dry spell favour the active laterisation even to deeper layers. These observations further strengthen the tendency of mollic to argillic diagnostic horizon conversion in the advanced stage.

4.5.2. Nedumangad

The unique feature of the Nedumangad series is the absence of cobbles, although the coarser gravels are approaching the lower size limit of cobbles indicating an associate soil series to the Palode series where the gneissic cobbles nucleate the ferruginisation and rubefaction by lateral enrichment of iron. Comparative low relief, flat to gentle slope, well-drained profile located in a toe-slope facilitate the active clay migration, ferruginisation both by plinthorhodofication and rubefaction (Schmidt Lorenz, 1964) leading to the development of more of the slightly plinthic gravels. The opaque to yellowish brown plasma with fractured slightly coated subrounded fine sand-sized quartz, voids of chamber and channel type with ferriargillanic margins irrespective of the gravel size fraction is indicative of their allothonous nature of formation. The gravels in the subsurface horizons are more of pedogenic and autothonous orgin. Like the Palode series, the surface gravels are more of geogenic origin. Similar nature of fine and coarse gravels in the subsurface horizon with few lithorelics, leached and broken ferri-argillan indicate the restricted migration of the components of the gravel. This restriction of drainage is noticeable by the presence of patchy cutanic variegated coloured limpid plasma, angular same sized quartz, with few faint margined cutan coated vughs and vesicles, irrespective of the gravel fraction. The non-weathered angular skeletons, variegated coloured patchy plasma and argillans confirm the retention of the same environment even down the profile.

4.5.3. Varkala

Plasma of both fine and coarse gravels of the surface are highly thick manganeferous, limpid, opaque and oriented. The orientation is oblique in the fine gravels as margins of interconnected bigger chambers, vughs and vesicles. The coarser gravels are less porous. The skeletons present in the fine gravels are less than fine sand -sized few slightly cracked quartz and many clay sized quartz granules and kaolin flakes. Instead, in the coarse gravels, the cutan present are ferriargillan and goethan giving a reddish-brown colour with fine quartz skeletons. Kaolin is present as microaggregates resulting in agglutinic SRDP.

Down the profile, the finer gravels become ferriargillanic to ferranic and at microlocations manganic, less limpid with angular to subangular less than fine sand-sized quartz, few sand-sized quartz, few criss-crossing skew planes giving thick manganeferous quartzitic composition. As in the case of fine gravels, the coarse gravels also contain bigger skeletons, sand sized to fine sand-sized slightly fractured, non-coated quartz. The unique feature of the coarse gravels in the subsurface horizons is the presence of vesicles, interconnected channels and chambers filled with ferriargillan and ferran with oblique orientation and few runic quartz.

The gravel development down the profile is more of pedogenic than geogenic. Surface gravels are a result of repeated plinthisation over geological periods resulting in angular heavier opaque gravels. The lack of opaque colour, presence of yellowish brown, reddish brown and red colour indicate the progressive ferruginisation of recent geological period with heavy rainfall and short span of dry spell. It is indicative that the surface gravels are related eroded material of a nearby higher landscape. As compared to the gravels of the Palode series, there is little difference in the gravel morphology of the profile at Varkala. The observed lack of difference in the morphology of gravels down the profile is due to the less weathering, leaching and lessivage because of the dense ill-drained plinthite layer. Gravels are hence more of a nodular nature than concretionary, indicating the autothonous weathering dominantly by plinthorhodofication (Schmidt Lorenz, 1964).

4.5.4. Thonnackal

Plasma of the fine gravels are opaque to brownish red and limpid in the surface horizon which becomes richer with vareigated colours down the profile. Skeletons of wide difference in size, sphericity, coating, relief and cracking, is the feature observed in the surface horizons indicating the role of the prevalent lesser slope and restricted drainage. They become rounded, subangular to subrounded down the profile except the last horizon, indicating the influence of the lateral movement of water leading to the chances of mutual attrition. Non-fractured, non-coated finer skeletons with higher relief and angularity on gibbsitic, plinthic and kaolinitic plasma indicate their geogenic formation at lower depths. Even at the compact lower depths, at microlocations, the chances of lateral lessivage are indicated by cellular and vacuolar ferran mesh with faint - margined gibbsitan and kaolin infillings with fine runic quartz limpidity.

The coarse gravels, observed in the last horizon, are similar in composition to the respective fine gravels in the nature of plasma colour, fabric, size of skeletons, coating, facturing and even the compactness with lesser voids. The unique feature is the presence of runic quartz as seen in the respective fine gravels.

Except in the surface and sub-surface horizons, the gravels are of geogenic formation with slower but active detrital processes of leaching and lessivage resulting in the lateral patchy expression of rubefaction. The rubefaction observed in the lower layers irrespective of the size of gravels are unique and different from that reported by Schmidt Lorenz (1964). The difference is the restricted drainage resulted by the presence of a dense layer constituted of finer quartz and kaolin. Iron segregates are more of goethitic and bohemitic composition rather than the reported hematite. The uniqueness of the series is the rubefied less hard kaolinitic gravels with goethitic islands having runic quartz limpidity confirming its detrital genesis.

4.5.5. Trivandrum

Less plasma, thick and aggregated opaque to reddish-brown, yellowish-red coloured ferran and ferriargillanic material are present as marginal cutans on sand-sized, angular to sub-angular geometrically fractured high reliefed quartz. Vesicles are bigger and the pressure of smaller clusters of non-connected chambers and vesicles are unique features of the fine gravels of the surface horizon. The plasma colour becomes redder and at places opaque as geometrically oriented mesh of microgravels with the unique presence of few silt-sized to fine sand-sized runic quartz. They are also non-fractured and non-coated and these features result in and agglomeraplasmic to agglutinic SRDP in the subsurface fine gravels which finally becomes aggregated but retains the same colour and are present as infillings of vesicles. Skeletons are different from the ones of the layers above, constituted of fine sand-sized, cracked and highly fractured non-coated to slightly coated quartz. Plasma is thick and opaque. The uniqueness of these fine gravels is the presence of ferriargillan as infillings of voids.

In the case of coarse gravels of the surface horizon, nature and colour of plasma, their orientation, quantity and the nature of skeletons are similar to the respective fine gravels. The uniqueness of these gravels are the abundance of less than silt-sized vughy porous structure.

As in the case of fine gravels, the plasma of the coarse gravels is less and becomes redder with plinthic mesh of microgravels. Skeletons are cracked, subrounded to rounded runic quartz and are less than silt-sized to clay-sized. The microgravels present are unique with clear margined vughs and vesicles. These gravels are with yellowish-brown coloured thick plasma. Similar nature of skeletons are observed but are of fine sand-size. As in the case of the respective fine gravels, few runic quartz are also noticed.

Opaque, thick, less plasma, angularity of bigger skeletons though cracked and fractured, gravels with microgravels, clear margined vughs and vesicles are indicative features of 'soil fossil' ie. of non contemporaneous origin. Mohr and Van Baren (1954) have reported such features in the laterite soils and they have grouped them as 'senile material' of older Ejecta (pliocene to miocene). It also indicates that these gravels are nodular in nature - plinthic to petroplinthic.

4.6. Soil properties

The soil properties are reported in table 6.

4.6.1. Soil content

The soil content of the Palode series showed a decrease with depth except in the fourth horizon where an increase was noted, the range being 22.56 to 34.49 per cent.

Table 6. Soil properties

Series name	Profile site	Depth of horizon (cm)	Soil content after gravel seperation (%)	Soil colour Dry	Soil colour Moist	pH water (1:2.5)	Eletrical conductivity water (1:2.5) (dsm^{-1})	Organic carbon (%)	Acid insolubles (%)	Acid soluble silica (%)	Sesquioxides (%) (R_2O_3)	Iron (%) (Fe_2O_3)	Total N (%)	Total P (%) (P_2O_5)	Total K (%) (K_2O)	Total Ca ($Cmol\ kg^{-1}$)	Total Mg ($Cmol\ kg^{-1}$)
Palode	TBGRI, Palode	0-14	34.49	10 YR 2/2 very dark brown	5YR 2/1 black	4.50	0.19	3.70	79.91	0.35	17.13	1.93	0.314	0.092	0.120	1.83	1.87
		14-51	27.82	10 YR 2/2 very dark brown	5YR 2/1 black	4.87	0.21	2.60	79.97	0.41	16.25	2.09	0.221	0.054	0.107	1.60	2.08
		51-106	22.56	7.5 YR 6/4 light brown	7.5 YR 5/8 strong brown	4.77	0.21	0.89	80.10	0.49	15.40	2.53	0.079	0.032	0.118	1.84	5.61
		106-150	25.24	5 YR 7/3 pink	7.5 YR 5/8 strong brown	3.92	0.20	0.72	78.17	0.16	15.31	2.42	0.068	0.031	0.145	1.72	5.32
Nedumangad	Pazhakutty-Shencotta road, Nedumangad	0-11	66.66	5 YR 5/2 reddish grey	10YR 4/2 dark greyish-brown	4.81	0.20	2.20	76.23	0.26	18.26	2.89	0.213	0.079	0.136	1.74	3.38
		11-33	67.55	10 YR 6/3 pale brown	5YR 4/2 dark reddish-grey	4.49	0.21	1.70	75.87	0.31	18.39	2.43	0.160	0.076	0.113	1.63	2.92
		33-62	72.06	7.5 YR 6/4 light brown	7.5 YR 5/8 strong brown	4.50	0.21	0.92	73.11	0.31	17.25	3.52	0.121	0.062	0.208	2.47	3.83
		62-150	65.45	7.5 YR 8/6 reddish yellow	5 YR 6/8 reddish yellow	4.83	0.21	0.86	75.26	0.30	17.29	4.29	0.103	0.057	0.168	2.36	4.11
Varkala	Kaithakonam via Sivagiri, Varkala	0-8	23.96	5 YR 6/6 reddish yellow	5 YR 4/6 yellowish red	4.93	0.19	0.39	73.23	0.34	22.99	9.21	0.054	0.083	0.290	4.28	3.97
		8-150	9.09	5 YR 5/8 yellowish red	2.5 YR 4/8 red	4.58	0.20	0.18	66.31	0.38	27.13	9.83	0.032	0.052	0.312	5.13	3.41

(Contd.....)

Table 6. (Contd...)

Series name	Profile site	Depth of horizon (cm)	Soil content after gravel seperation (%)	Soil colour		pH water (1:2.5)	Eletrical condu-ctivity water (1:2.5) (dsm^{-1})	Organic carbon (%)	Acid insol-ubles (%)	Acid soluble silica (%)	Sesqui-oxides (%) (R_2O_3)	Iron (%) (Fe_2O_3)	Total N (%)	Total P (%) (P_2O_5)	Total K (%) (K_2O)	Total Ca ($Cmol\ kg^{-1}$)	Total Mg ($Cmol\ kg^{-1}$)
				Dry	Moist												
Thonnackal	Near KIPL china clay mines, Thonnackal	0-20	93.24	5 Y 6/3 pale olive	10 YR 5/2 greyish brown	4.07	0.20	0.60	88.51	0.22	4.83	1.73	0.057	0.042	0.198	3.98	2.51
		20-70	84.61	10 YR 8/4 very pale brown	10 YR 4/3 brown	3.94	0.21	0.48	61.26	0.29	7.32	1.71	0.033	0.032	0.431	4.19	2.48
		70-113	91.76	10 YR 7/3 very pale brown	10 YR 6/6 brownish yellow	4.74	0.19	0.44	61.38	0.35	13.93	1.99	0.035	0.033	0.256	3.56	6.94
		113-150	50.59	10 YR 7/3 very pale brown	10 YR 7/8 yellow	4.42	0.19	0.42	63.19	0.23	19.62	3.57	0.040	0.038	0.232	5.83	11.43
		150+	50.61	10 YR 7/3 very pale brown	10YR 7/4 very pale brown	4.35	0.19	0.09	50.27	0.16	20.97	3.13	0.011	0.021	0.183	4.59	7.93
Trivandrum	Mannanthala, Trivandrum	0-14	50.49	5YR 6/4 light reddish brown	5YR 5/8 yellowish red	4.96	0.20	0.63	80.61	0.17	15.56	4.30	0.053	0.087	0.124	5.89	13.52
		14-57	46.38	5 YR 6/4 light reddish brown	5 YR 5/8 yellowish red	4.98	0.20	0.57	81.17	0.51	15.98	4.83	0.041	0.063	0.138	4.39	11.73
		57-150	23.41	5 YR 6/4 light reddish brown	5 YR 5/8 yellowish red	4.85	0.22	0.54	83.08	0.32	15.39	5.26	0.037	0.051	0.133	4.83	10.36

In the Nedumangad series, the soil content showed an increase down the profile except in the fourth horizon where a decrease was noted, the content ranging from 65.45 to 72.06 per cent.

In Varkala and Trivandrum, the profile pattern was, decrease with depth,the content ranging from 9.09 to 23.96 and 23.41 to 50.49 per cent respectively.

An alternate pattern of decrease and increase with depth was observed at Thonnackal, the content ranging from 50.59 to 93.24 per cent.

4.6.2. Soil colour

The colour of field moist soil down the profile varies from black to strong brown at Palode, dark greyish-brown to reddish yellow at Nedumangad, yellowish red to red at Varkala, greyish brown to very pale brown at Thonnackal and yellowish red to red at the Trivandrum series.

4.6.3. Soil pH

In Palode, the pH showed a decrease with depth except in the second horizon where an increase was noted, the value ranging from 3.92 to 4.87.

The Nedumangad series showed a profile pattern of increase with depth except in the second horizon where a decrease was noted, the value ranging from 4.49 to 4.83.

The pH of the Varkala series showed a decrease with depth, the value ranging from 4.58 to 4.93.

A decreasing trend down the profile was observed in the pH of the Thonnackal series except in the third horizon where an increase was noticed, the value ranging from 3.94 to 4.74.

The soil pH of the Trivandrum series showed an alternate pattern of increase and decrease with depth, the value ranging from 4.85 to 4.98.

4.6.4. Electrical conductivity

The electrical conductivity of the soils investigated showed that the values remained more or less near the 0.20 dS m^{-1} with little change within the profile.

4.6.5. Organic carbon

The organic carbon content showed a decrease with depth at all the sites.. The content varied from 0.72 to 3.72 per cent at Palode, 0.86

to 2.20 per cent at Nedumangad, 0.18 to 0.39 per cent at Varkala, 0.09 to 0.60 per cent at Thonnackal and 0.54 to 0.63 per cent at Trivandrum.

4.6.6. Acid Insolubles

In the Palode series, the acid insoluble content showed an increase down the profile except in the fourth horizon where a decrease was recorded, the content ranging from 78.17 to 80.10 per cent.

The acid insoluble content of the Nedumangad series showed a decrease with depth except in the fourth horizon where it showed an increase, the content ranging from 73.11 to 76.23 per cent.

The content showed a decrease with depth in the Varkala series, the content ranging from 66.31 to 73.23 per cent.

In the Thonnackal series, the acid insoluble showed a decrease in the second and fifth horizons, the content ranging from 50.27 to 88.51 per cent.

An increase in the acid insoluble content was observed in the Trivandrum series, the content ranging from 80.61 to 83.08 per cent.

4.6.7. Acid soluble silica

The acid soluble silica content of the Palode series showed an increase down the profile except a decrease in the fourth horizon, the content ranging from 0.16 to 0.49 per cent.

In the Nedumangad series, the content showing a decrease down the profile except in the second horizon where there was an increase, the content ranging from 0.26 to 0.31 per cent.

The content showed an increase down the profile in Varkala series ranging from 0.34 to 0.38 per cent.

In Thonnackal series, the content of acid soluble silica increased till the third horizon and then decreased down the profile, the content ranging from 0.16 to 0.35 per cent. An alternate pattern of increase and decrease down the profile was observed in the Trivandrum series, the content ranging from 0.17 to 0.51 per cent.

4.6.8. Sesquioxides

The sesquioxide content of the Palode series showed a decrease down the profile, the content ranging from 15.31 to 17.13 per cent.

The content showed an alternate pattern of increase and decrease with depth in the Nedumangad and Trivandrum series, the content ranging from 17.25 to 18.39 and 15.39 to 15.98 per cent respectively.

In Varkala and Thonnackal series the content showed an increase down the profile, the value ranging from 22.99 to 27.13 and 4.83 to 20.97 per cent respectively.

4.6.9. Total iron

The total iron content in the Palode series showed an increase down the profile except in the fourth horizon where it decreased, the content ranging from 1.93 to 2.53 per cent.

In the Nedumangad series, the profile pattern was an increase down the profile except in the second horizon where a decrease was noticed, the content ranging from 2.43 to 4.29 per cent.

In the Varkala and Trivandrum series, the content showed an increase down the profile, the content ranging from 9.21 to 9.83 and 4.30 to 5.26 per cent respectively.

In the Thonnackal series, the content of iron decreased in the second horizon, then increased till the fourth horizon and decreased to the fifth, the content ranging from 1.71 to 3.57 per cent.

4.6.10. Total nitrogen

The content of total nitrogen decreased down the profile in all the series except Thonnackal; where it decreased in the second horizon, then increased till the fourth and decreased to the fifth horizon. The content ranged from 0.068 to 0.314 per cent in Palode, 0.103 to 0.213 per cent at Nedumangad, 0.032 to 0.054 per cent at Varkala, 0.011 to 0.057 per cent at Thonnackal and 0.037 to 0.053 per cent at Trivandrum.

4.6.11. Total phosphorus

The content of total phosphorus decreased down the profile in all the series except at Thonnackal where a decrease was found in the second horizon, then an increase till the fourth horizon from where it decreased in content. The content varied from 0.031 to 0.092 per cent at Palode, 0.057 to 0.079 per cent at Nedumangad, 0.052 to 0.083 per cent at Varkala, 0.021 to 0.042 per cent at Thonnackal and 0.051 to 0.087 per cent at Trivandrum.

4.6.12. Total potassium

The content showed an increase with depth except in the second horizon in the Palode series, the content ranging from 0.107 to 0.145 per cent.

In the Nedumangad series, the content showed a decreasing trend except in the third horizon; the content ranged from 0.113 to 0.208 per cent.

At Varkala, the content increased with depth ranging from 0.290 to 0.312 per cent.

The total potassium content showed a decrease with depth except in the second horizon at Thonnackal, the content varying from 0.183 to 0.431 per cent.

An alternate pattern of increase and decrease was observed in Trivandrum series, the content ranging from 0.124 to 0.138 per cent.

4.6.13. Total calcium

In Palode, Nedumangad and Trivandrum series, the content showed an alternate pattern of decrease and increase down the profile, the values ranging from 1.60 to 1.84, 1.63 to 2.47 and 4.39 to 5.89 Cmol kg^{-1} respectively.

A profile pattern of increase with depth was observed at Varkala, the content ranging from 4.28 to 5.13 Cmol kg^{-1}.

At Thonnackal, an alternate pattern of increase and decrease down the profile was observed, the content ranging from 3.56 to 5.83 Cmol kg^{-1}.

4.6.14. Total magnesium

The total magnesium content at Palode showed an increase with depth till the third horizon and then decreased to the fourth horizon, the value ranging from 1.87 to 5.61 Cmol kg^{-1}

At Nedumangad, the profile pattern was an increase with depth except in the second horizon, the values ranging from 2.92 to 4.11 Cmol kg^{-1}.

In Varkala and Trivandrum, the total magnesium content decreased with depth; the content ranged from 3.41 to 3.97 and 10.36 to 13.52 Cmol kg^{-1} respectively.

The total magnesium decreased in the second horizon, then increased till the fourth horizon and then showed a decrease in the fifth horizon at Thonnackal, the values ranging from 2.48 to 11.43 Cmol kg^{-1}.

4.7. Fine sand mineralogy of soil

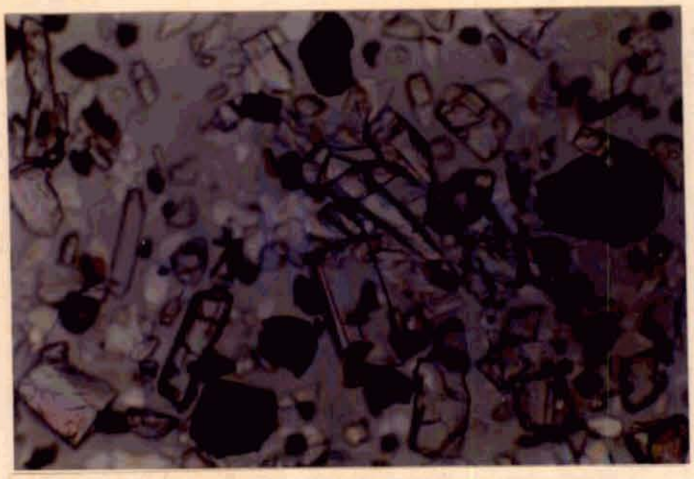
Fine sand mineralogy of soil is presented in Photomicrographs 106 to 141 and Table 7.

4.7.1. Heavy fraction

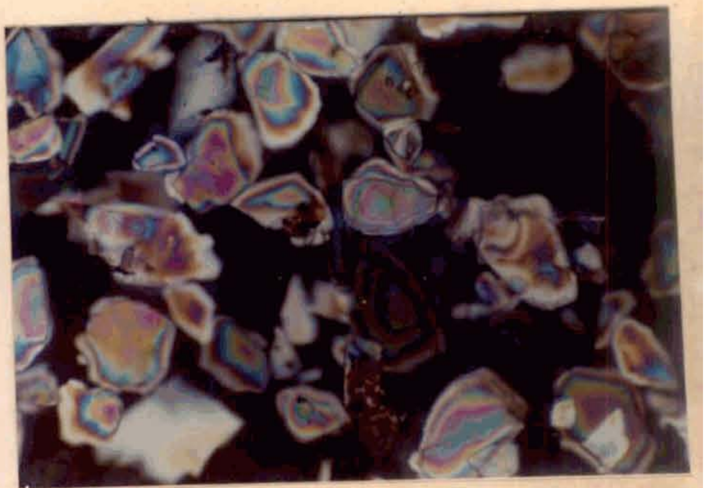
4.7.1.1. Ilmenite

In the Palode series, the ilmenite content showed an increase with

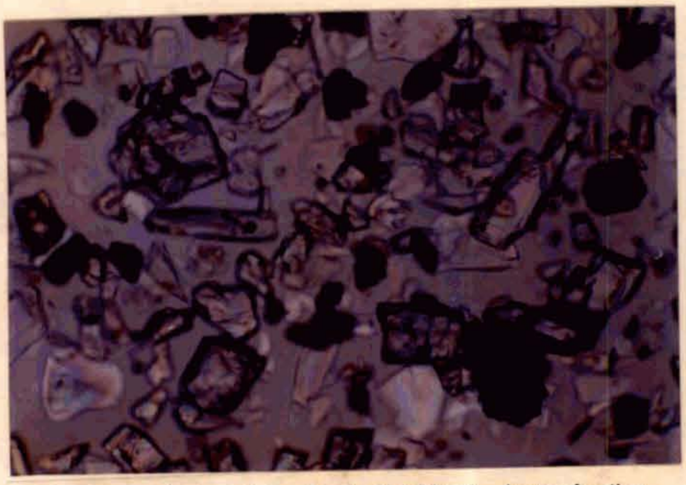
Photomicrographs on soil mineralogy



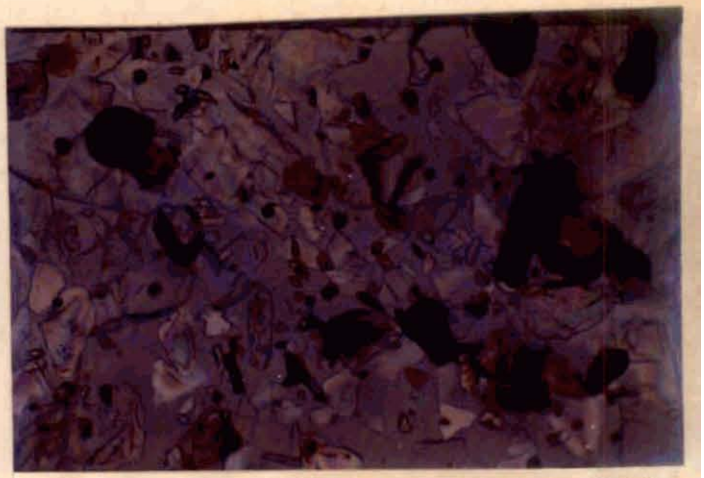
106. Fine sand mineralogy of soil - (0-14cm) - heavy fraction - Palode series - in plane light - Mgf: x 63.



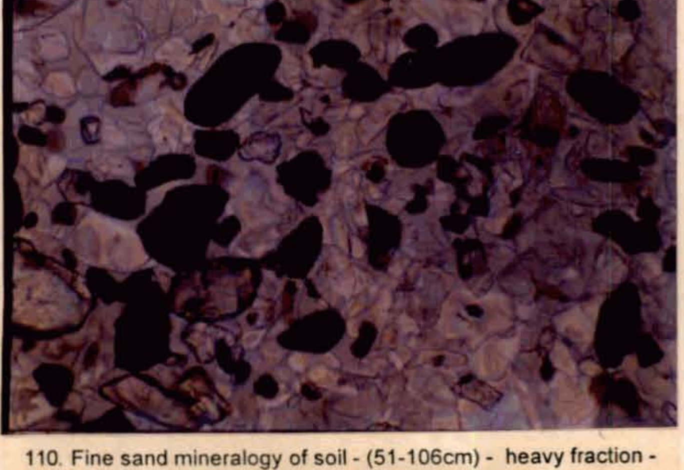
107. Fine sand mineralogy of soil - (0-14cm) - light fraction - Palode series - under crossed nicols - Mgf: x 63.



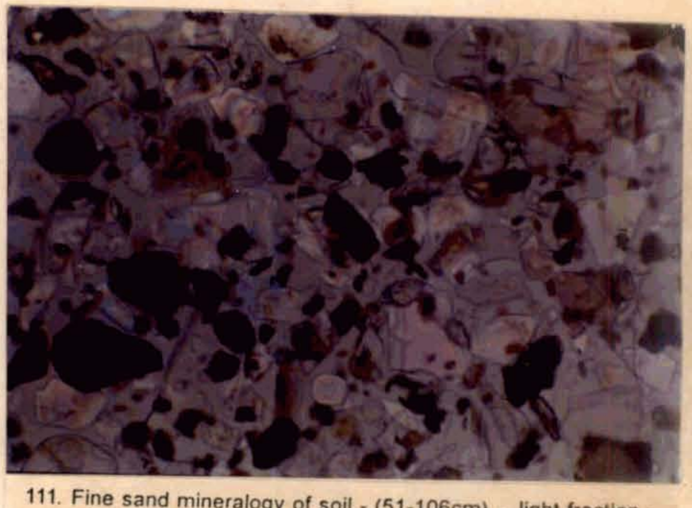
108. Fine sand mineralogy of soil - (14-51cm) - heavy fraction - Palode series - in plane light - Mgf: x 63.



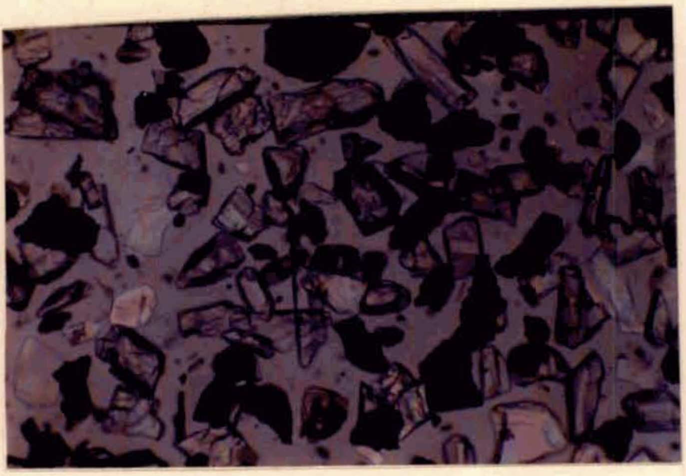
109. Fine sand mineralogy of soil - (14-51cm) - light fraction - Palode series - in plane light - Mgf: x 63.



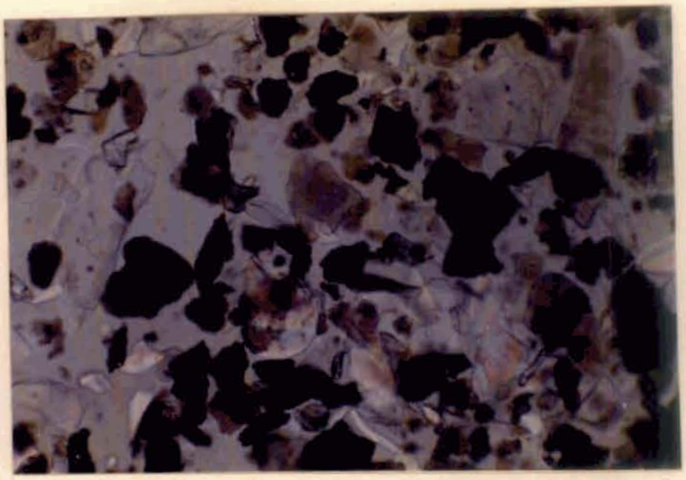
110. Fine sand mineralogy of soil - (51-106cm) - heavy fraction - Palode series - in plane light - Mgf: x 63.



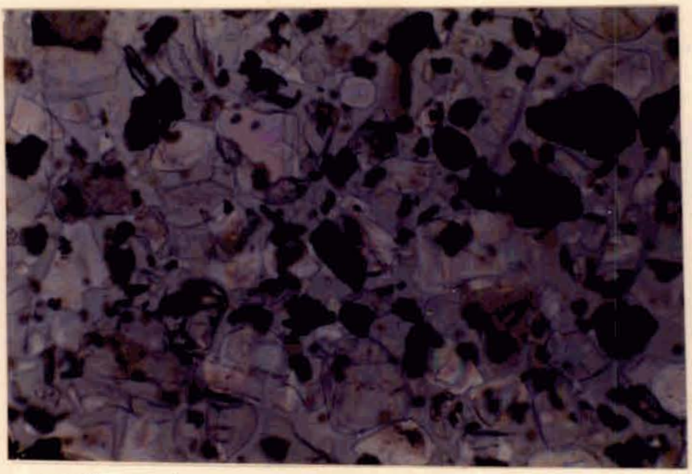
111. Fine sand mineralogy of soil - (51-106cm) - light fraction - Palode series - in plane light - Mgf: x 63.



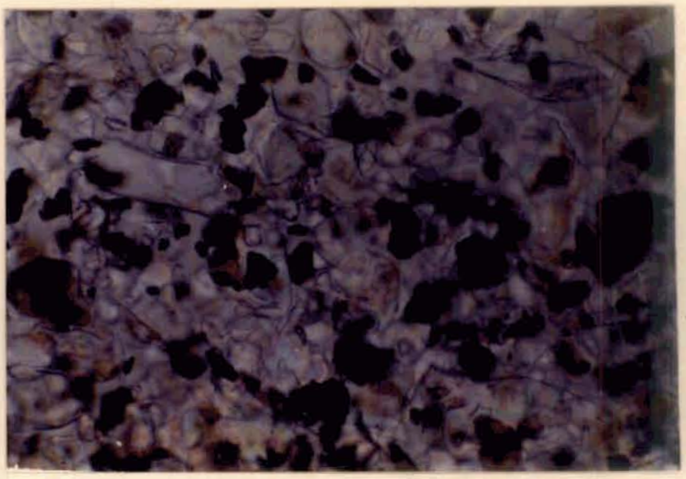
112. Fine sand mineralogy of soil - (106-150cm) - heavy fraction - Palode series - in plane light - Mgf: x 63.



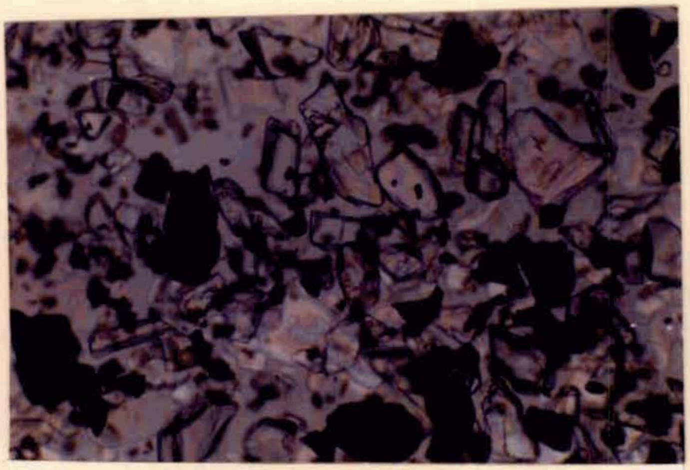
113. Fine sand mineralogy of soil - (106-150cm) - light fraction - Palode series - in plane light - Mgf: x 63.



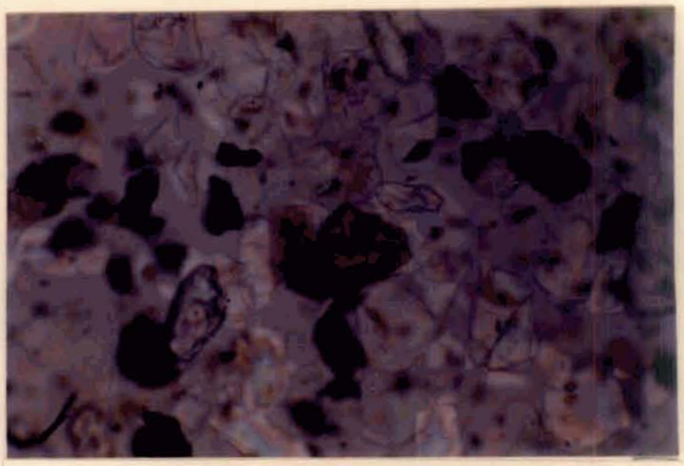
114. Fine sand mineralogy of soil - (0-11cm) - heavy fraction - Nedumangad series - in plane light - Mgf: x 63.



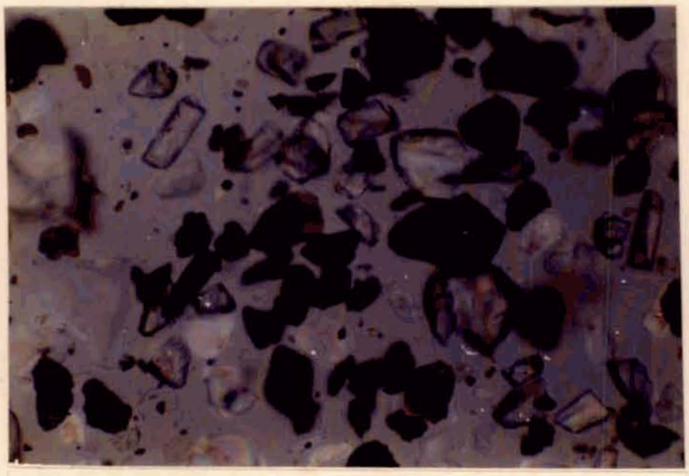
115. Fine sand mineralogy of soil - (0-11cm) - light fraction - Nedumangad series - in plane light - Mgf: x 63.



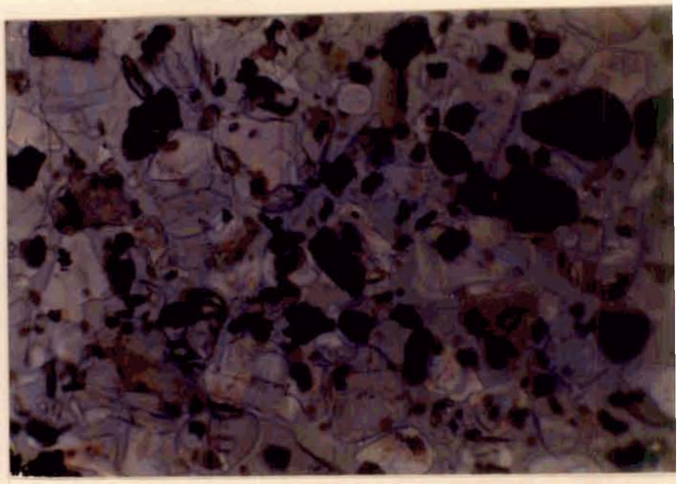
116. Fine sand mineralogy of soil - (11-33cm) - heavy fraction - Nedumangad series - in plane light - Mgf: x 63.



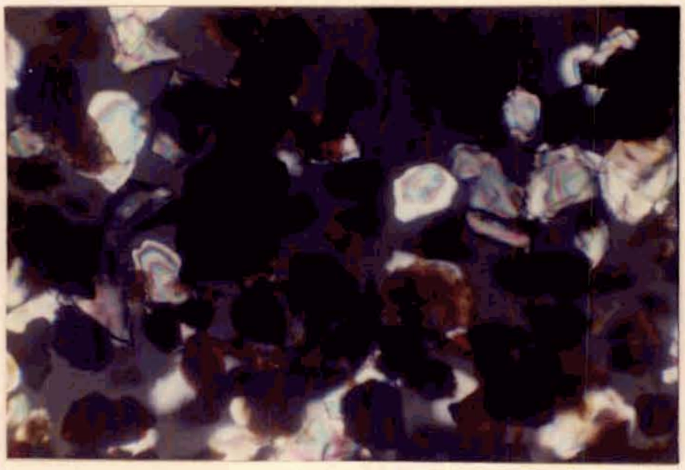
117. Fine sand mineralogy of soil - (11-33cm) - light fraction - Nedumangad series - in plane light - Mgf: x 63.



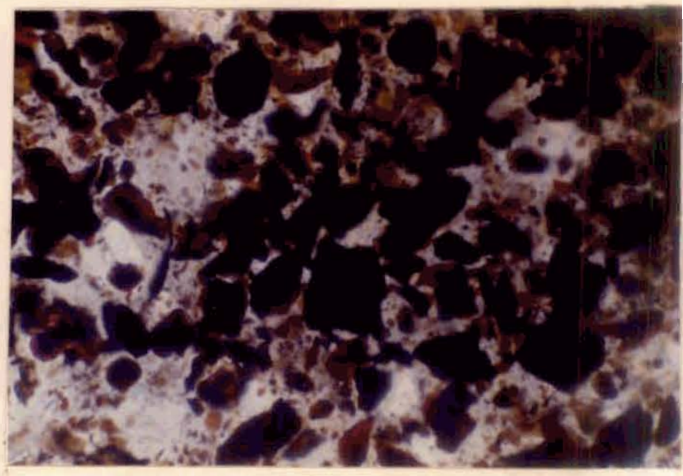
118. Fine sand mineralogy of soil - (33-62cm) - heavy fraction - Nedumangad series - in plane light - Mgf: x 63.



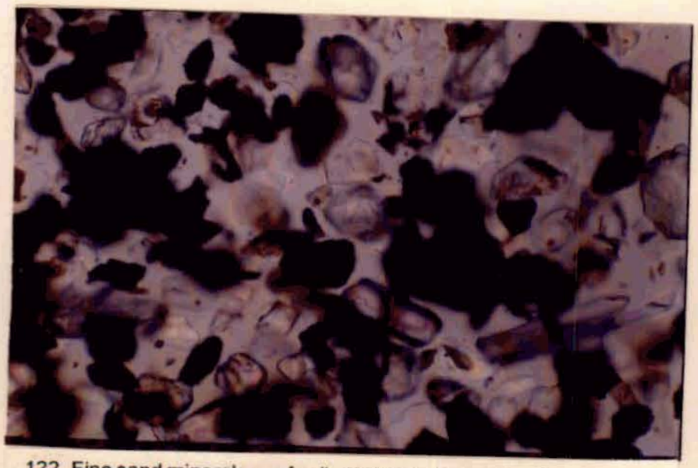
119. Fine sand mineralogy of soil - (33-62cm) - light fraction - Nedumangad series - in plane light - Mgf: x 63.



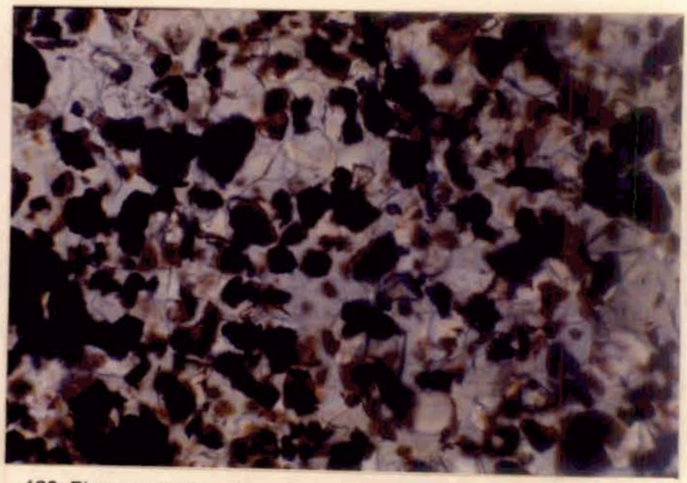
120. Fine sand mineralogy of soil - (62-150cm) - heavy fraction - Nedumangad series - under crossed nicols - Mgf: x 63.



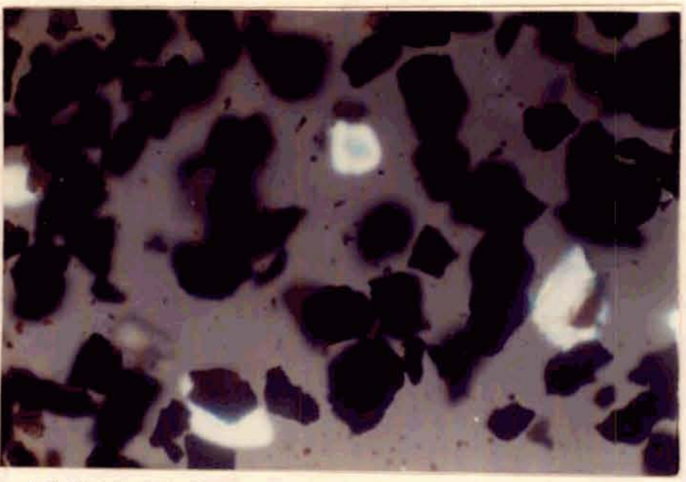
121. Fine sand mineralogy of soil - (62-150cm) - light fraction - Nedumangad series - in plane light - Mgf: x 63.



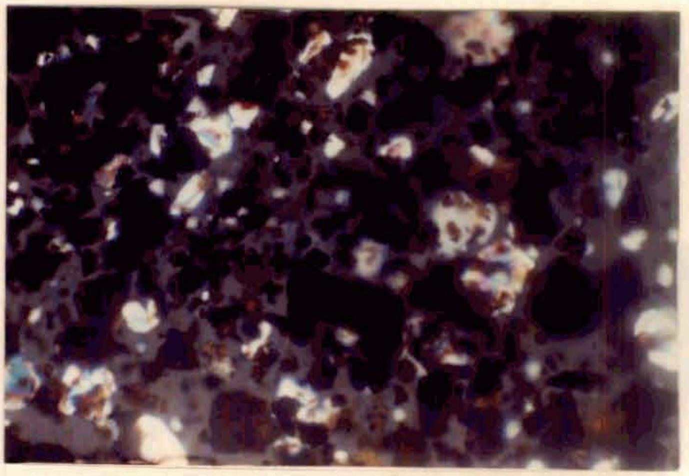
122. Fine sand mineralogy of soil - (0-8cm) - heavy fraction - Varkala series - in plane light - Mgf: x 63.



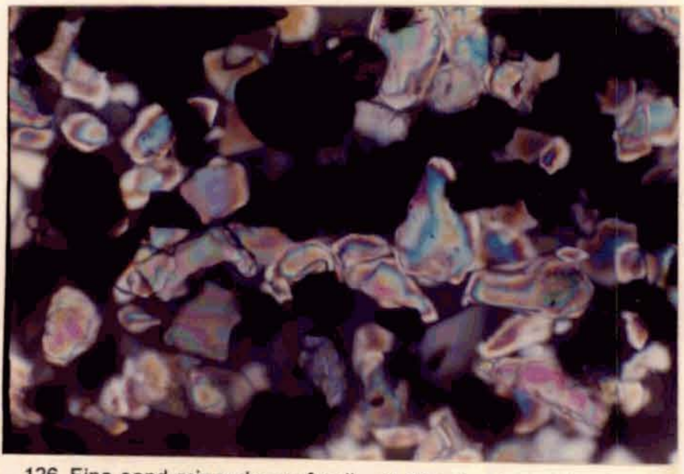
123. Fine sand mineralogy of soil - (0.8cm) - light fraction - Varkala series - in plane light - Mgf: x 63.



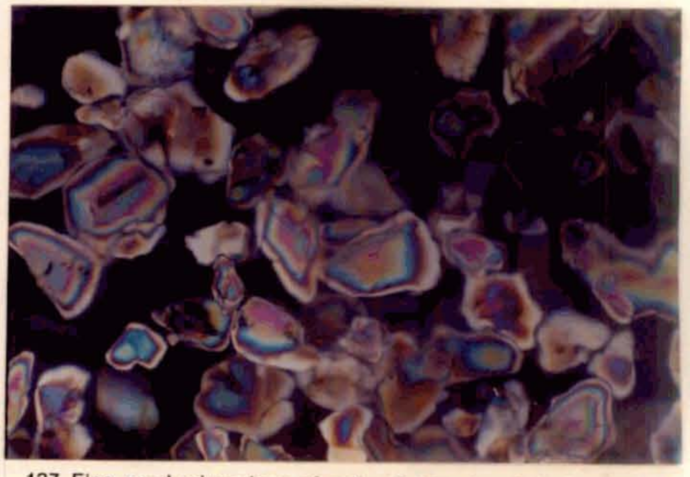
124. Fine sand mineralogy of soil - (8-150cm) - heavy fraction - Varkala series - under crossed nicols - Mgf: x 63.



125. Fine sand mineralogy of soil - (8-150cm) - light fraction - Varkala series - under crossed nicols - Mgf: x 63.



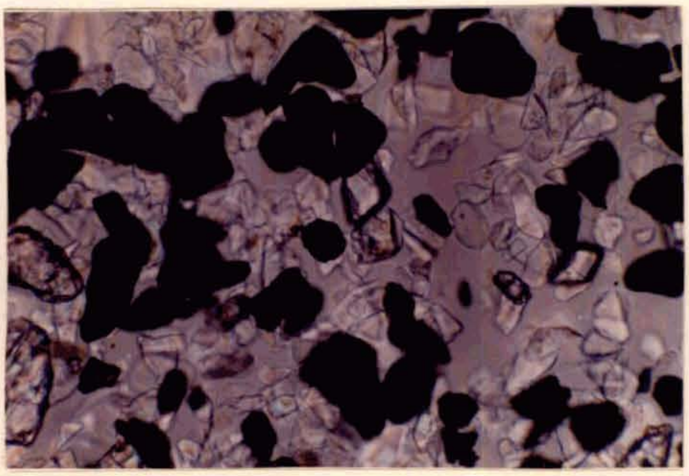
126. Fine sand mineralogy of soil - (0-20cm) - heavy fraction - Thonnackal series under crossed nicols - Mgf: x 63.



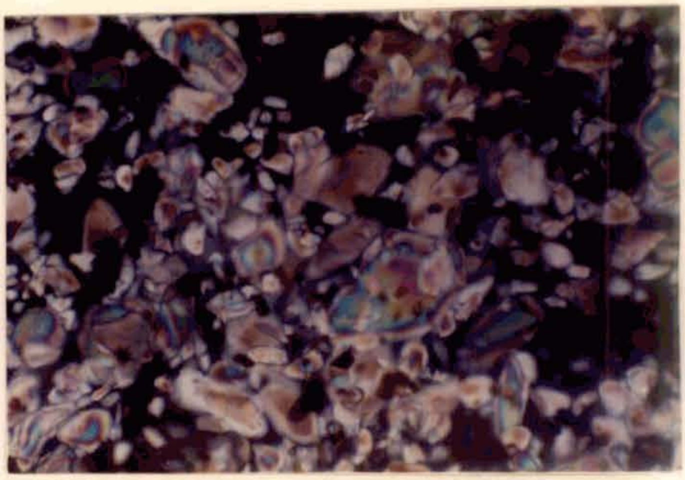
127. Fine sand mineralogy of soil - (0-20cm) - light fraction - Thonnackal series - under crossed nicols - Mgf: x 63.

128. Fine sand mineralogy of soil - (20-70cm) - heavy fraction - Thonnackal series - in plane light - Mgf: x 63.

129. Fine sand mineralogy of soil - (20-70cm) - light fraction - Thonnackal series - in plane light - Mgf: x 63.

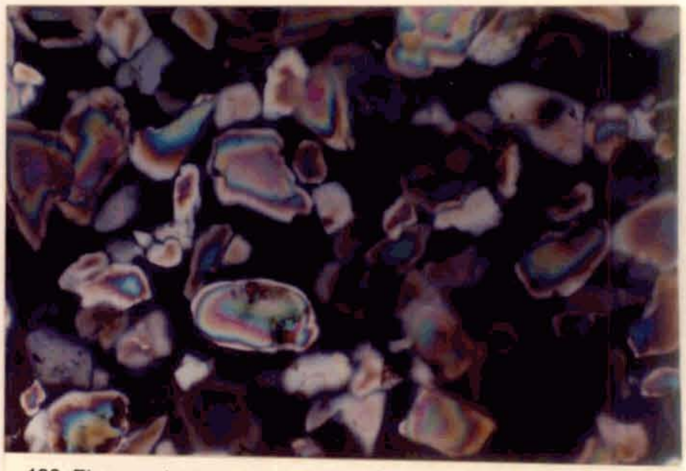


130. Fine sand mineralogy of soil - (70-113cm) - heavy fraction - Thonnackal series - in plane light - Mgf: x 63.

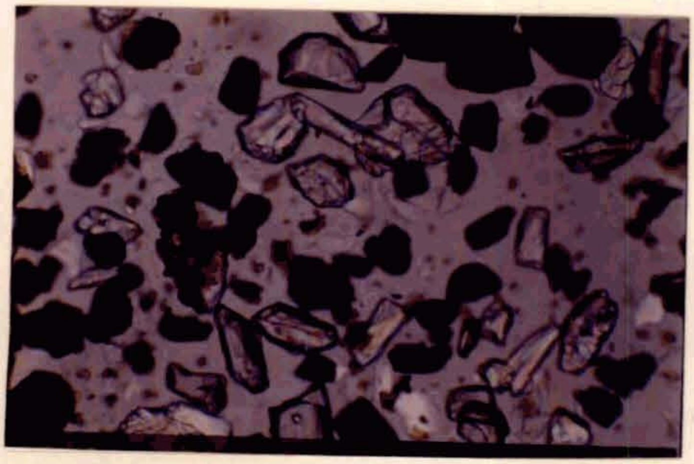


131. Fine sand mineralogy of soil - (70-113cm) - light fraction - Thonnackal series - under crossed nicols - Mgf: x 63.

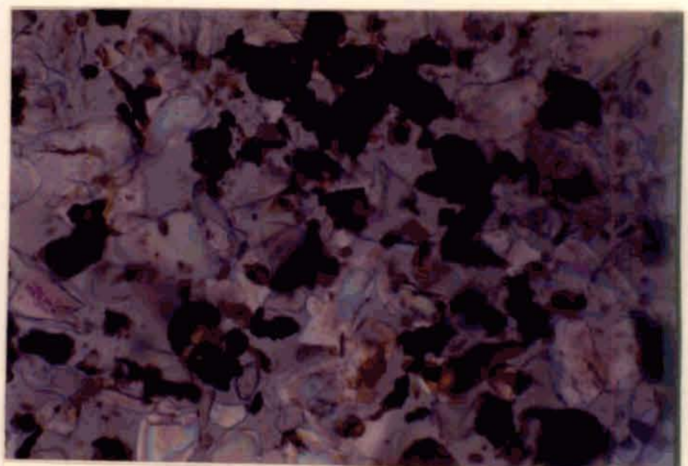
132. Fine sand mineralogy of soil - (113-150cm) - heavy fraction - Thonnackal series - in plane light - Mgf: x 63.



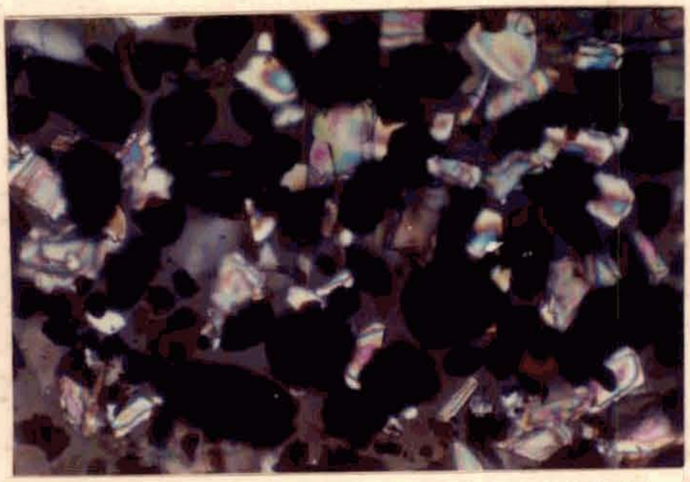
133. Fine sand mineralogy of soil - (113-150cm) - light fraction - Thonnackal series - under crossed nicols - Mgf: x 63.



134. Fine sand mineralogy of soil - (150+cm) - heavy fraction - Thonnackal series - in plane light - Mgf: x 63.

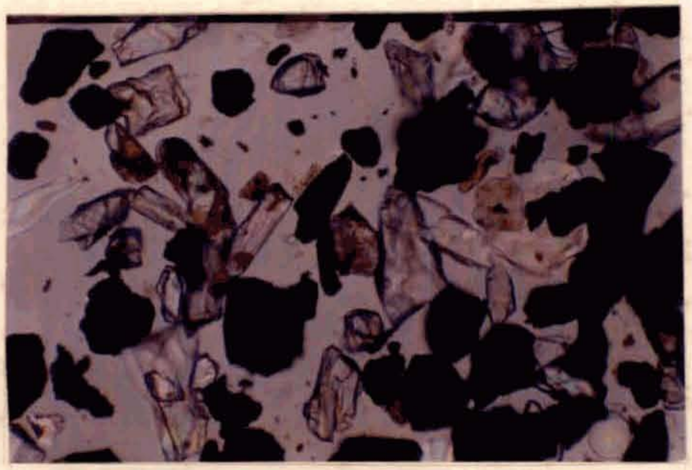


135. Fine sand mineralogy of soil - (150+cm) - light fraction - Thonnackal series - in plane light - Mgf: x 63.

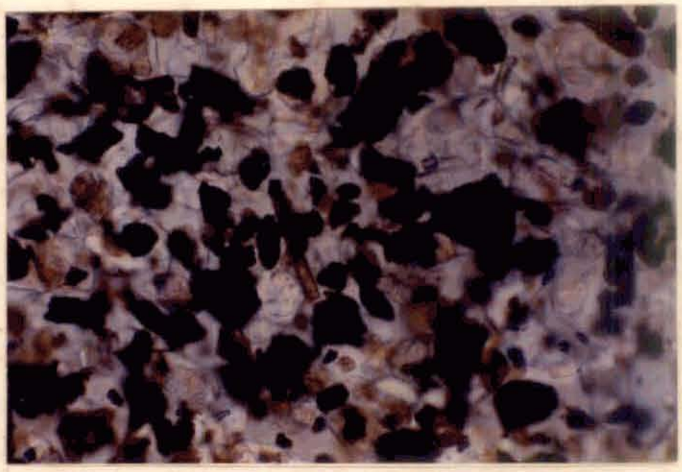


136. Fine sand mineralogy of soil - (0-14cm) - heavy fraction - Trivandrum series - under crossed nicols - Mgf: x 63.

137. Fine sand mineralogy of soil - (0-14cm) - light fraction - Trivandrum series - in plane light - Mgf: x 63.



138. Fine sand mineralogy of soil - (14-57cm) - heavy fraction - Trivandrum series - in plane light - Mgf: x 63.



139. Fine sand mineralogy of soil - (14-57cm) - light fraction - Trivandrum series - in plane light - Mgf: x 63.

140. Fine sand mineralogy of soil - (57-150cm) - heavy fraction - Trivandrum series - in plane light - Mgf: x 63.

141. Fine sand mineralogy of soil - (57-150cm) - light fraction - Trivandrum series - under crossed nicols - Mgf: x 63.

Table 7. Fine sand mineralogy of soil

Series name	Profile site	Depth of horizon (cm)	Percentage content														
			Heavy minerals								Light minerals						
			ILMENITE	KYANITE	RUTILE	SILLIMANITE	ZIRCON	HEMATITE	MAGNETITE	QUARTZ	QUARTZ	ILMENITE	SILLIMANITE	ZIRCON	PLINTHITE GRANULES	HEMATITE	MAGNETITE
Palode	TBGRI, Palode	0-14	20.86	6.75	1.84	–	–	–	–	70.55	100.00	–	–	–	–	–	–
		14-51	19.18	6.85	–	9.59	–	–	–	64.38	6.16	19.18	–	74.66	–	–	–
		51-106	23.25	–	–	76.75	–	–	–	–	53.42	46.58	–	–	–	–	–
		106-150	27.18	–	–	22.34	3.88	–	–	46.60	54.78	43.48	–	1.74	–	–	–
Nedumangad	Pazhakutty - Shencotta road, Nedumangad	0-11	31.48	2.78	–	7.40	–	–	–	58.34	63.49	36.51	–	–	–	–	–
		11-33	11.83	2.15	2.15	16.13	–	–	–	67.74	70.65	22.83	–	–	–	–	6.52
		33-62	44.55	–	–	15.84	1.98	–	–	37.63	51.96	48.04	–	–	–	–	–
		62-150	24.19	–	–	–	–	–	–	75.81	38.76	10.07	–	–	–	33.33	17.84
Varkala	Kaithakonam via. Sivagiri, Varkala	0-8	24.32	–	–	9.46	–	–	–	66.22	25.62	18.72	2.46	–	–	32.02	21.18
		8-150	–	–	–	–	–	18.37	14.28	67.35	34.09	–	–	–	22.26	43.65	–

(Contd....)

Table 7. Contd....

Series name	Profile site	Depth of horizon (cm)	Percentage content															
			Heavy minerals								Light minerals						
			ILMENITE	KYANITE	RUTILE	SILLIMANITE	ZIRCON	HEMATITE	MAGNETITE	QUARTZ	QUARTZ	ILMENITE	SILLIMANITE	ZIRCON	PLINTHITE GRANULES	HEMATITE	MAGNETITE
		0-20	18.18	–	–	7.79	–	–	–	74.03	96.36	3.64	–	–	–	–	–
		20-70	17.24	–	–	13.79	–	–	–	68.97	84.11	5.61	10.28	–	–	–	–
Thonnackal	Near KIPL china clay mines, Thonnackal	70-133	24.03	–	–	3.88	–	–	–	72.09	72.12	–	–	–	–	16.97	10.91
		113-150	50.00	–	–	12.00	–	–	–	38.00	75.76	4.55	–	–	–	12.12	7.57
		150+	39.13	–	–	23.91	–	–	–	36.96	36.73	–	–	–	–	33.33	29.94
		0-14	37.93	–	–	2.59	–	–	–	59.48	37.71	21.31	–	–	–	27.86	13.12
Trivandrum	Mannanthala, Trivandrum	14-57	41.77	–	–	37.97	–	–	–	20.26	35.76	25.17	–	1.99	–	29.80	7.28
		57-150	37.15	–	–	42.85	–	–	–	20.00	76.25	–	–	–	–	12.50	11.25

depth except in the second horizon where a decrease was noticed, the content ranging from 19.18 to 27.18 per cent.

The content showed a decrease with depth except in the third horizon where an increase was noticed in the Nedumangad series, the value ranging from 11.83 to 44.55 per cent.

Ilmenite was present only in the first horizon of the Varkala series where a content of 24.32 per cent was recorded.

At Thonnackal, the content decreased in the second horizon, then increased till the fourth and again decreased in the fifth, the content ranging from 17.24 to 50.00 per cent.

In the Trivandrum series, the ilmenite content showed an alternate increase and decrease down the profile, the values ranging from 37.15 to 41.77 per cent.

4.7.1.2. Kyanite

Kyanite was present only in the first two horizons of Palode and Nedumangad series; at Palode it increased with depth and at Nedumangad it decreased with depth. The value ranged from 6.75 to 6.85 and 2.15 to 2.78 per cent at Palode and Nedumangad respectively.

4.7.1.3. Rutile

Rutile was observed only in the first horizon of Palode and second horizon of the Nedumangad series, the content being 1.84 and 2.15 per cent respectively.

4.7.1.4. Sillimanite

In Palode and Nedumangad, the content of sillimanite showed a pattern of alternate increase and decrease with depth, the content ranging from 9.59 to 76.75 and 7.40 to 16.13 per cent respectively. There was however no sillimanite in the first horizon of Palode and the fourth horizon of Nedumangad series.

At Varkala series, sillimanite could be seen only in the first horizon, the content being 9.46 per cent. The sillimanite content at the Thonnackal series showed an increase with depth except in the third horizon where a decrease was noticed, the content ranging from 3.88 to 23.91 per cent.

A pattern of increase with depth was observed in the content of sillimanite in the Trivandrum series, the value ranging from 2.59 to 42.85 per cent.

4.7.1.5. Zircon

Zircon was present only in the fourth horizon of Palode and the third horizon of Nedumangad series the content being 3.88 and 1.98 per cent respectively.

4.7.1.6. Hematite

Hematite was present only in the second horizon of Varkala series, the content being 18.37 per cent.

4.7.1.7. Magnetite

Magnetite was present only in the second horizon of Varkala series, the content being 14.28 per cent.

4.7.1.8. Quartz

In Palode and Trivandrum series the content of quartz decreased with depth, the content ranging from 46.60 to 70.55 and 20.00 to 59.48 per cent respectively. There was no quartz in the third horizon of Palode.

In Nedumangad series, an alternate pattern of increase and decrease with depth was noticed, the content ranging from 37.63 to 75.81 per cent.

A pattern of increase with depth was observed in the Varkala series, the content ranging from 66.22 to 67.35 per cent.

The quartz content in the Thonnackal series showed a decrease with depth except in the third horizon, the content ranging from 36.96 to 74.03 per cent.

4.7.2. Light fraction

4.7.2.1. Quartz

The quartz content of the Palode series showed an increase with depth except in the second horizon where a decrease was noticed, the content ranging from 6.16 to 100.00 per cent.

In the Nedumangad series, the quartz content showed a decrease with depth except in the second horizon where an increase was noticed, the content ranging from 38.76 to 70.65 per cent.

The content of quartz in the Varkala series increased with depth, the value ranging from 25.62 to 34.09 per cent.

In the Thonnackal series, the quartz content showed a decrease with depth except in the fourth horizon, the value ranged between 36.73 to 96.36 per cent.

In Trivandrum series, the content showed an alternate pattern of decrease and increase with depth, the value ranging from 35.76 to 76.25 per cent.

4.7.2.2. Ilmenite

The content of ilmenite at Palode showed an alternate pattern of increase and decrease down the profile, the value ranging from 19.18 to 46.58 per cent. There was no ilmenite in the first horizon.

In the Nedumangad series, an alternate pattern of decrease and increase was noted, the content ranging from 10.07 to 48.04 per cent.

At Varkala, ilmenite could be seen only in the first horizon, the content being 18.72 per cent.

In the Thonnackal series, ilmenite content showed and increase to the second horizon but no ilmenite could be seen in the third and fifth horizons; the content in the profile ranged from 3.64 to 5.61 per cent.

The ilmenite content showed an increase down the profile at Trivandrum, the value ranging from 21.31 to 25.17 per cent. Ilmenite could not be observed in the third horizon.

4.7.2.3. Sillimanite

Sillimanite was noticed in the first horizon of Varkala and second horizon of Thonnackal series, the content being 2.46 and 10.28 per cent respectively.

4.7.2.4. Zircon

Zircon was present only in the second and fourth horizons at Palode, the content being 74.66 and 1.74 per cent respectively.

In Trivandrum, a content of 1.99 per cent was recorded in the second horizon.

4.7.2.5. Plinthite granules

Plinthite granules were seen only in the second horizon of the Varkala series, the content being 22.26 per cent.

4.7.2.6. Hematite

In Palode and Nedumangad series, hematite was absent except in the fourth horizon of Nedumangad where a content of 33.33 per cent was recorded.

The content at Varkala increased from 32.02 per cent in the first horizon to 43.65 per cent in the second.

In the Thonnackal series, hematite was absent in the first two horizons, then the content showed an alternate pattern of decrease and increase with depth, the content ranging from 12.12 to 33.33 per cent.

The hematite content of Trivandrum series showed an alternate pattern of increase and decrease with depth ranging from 12.50 to 29.80 per cent.

4.7.2.7. Magnetite

Magnetite was absent in the Palode series. At Nedumangad, it was present only in the second and fourth horizons, the content being 6.52 and 17.84 per cent.

In the Varkala series, magnetite was present only in the first horizon, the content being 21.18 per cent.

Magnetite could not be observed in the first two horizons of the Thonnackal series, then the content showed an alternate pattern of decrease and increase with depth, the value ranging from 7.57 to 29.94 per cent.

The magnite content showed an alternate pattern of decrease and increase with depth at Trivandrum, ranging from 7.28 to 13.12 per cent.

Heavy minerals present in the fine sand fraction were ilmenite, kyanite, quartz and rutile at Palode series. The light minerals fraction is occupied by quartz and plinthite granules. At Nedumangad, the heavy mineral fraction is contituted by ilmenite, kyanite, sillimanite and quartz while quartz and ilmenite are the only minerals present in the respective light mineral fraction. At Varkala, quartz, sillimanite and ilmenite are present in both heavy and light mineral fractions. In addition, the light mineral fraction also contain hematite and magnetite. At Thonnackal, quartz and ilmenite are present both in the light and heavy mineral fractions. The heavy mineral fraction also contains sillimanite. The primary mineral assemblage of the fine sand fraction of Trivandrum series is constituted of ilmenite and quartz. The additional minerals present in the heavy fraction is sillimanite and those in the light fraction is hematite and magnetite.

It is seen that the heavy mineral fraction of the soil is in general lacking in zircon, plinthite granules, hematite, goethite, rutile and magnetite. At Varkala, Thonnackal and Trivandrum, kyanite is also absent. Similarly, in the light mineral fraction, irrespective of the series, plinthite granules, goethite and zircon are absent in all the series.

At Palode, ilmenite is absent while sillimanite is present in the light fraction of Varkala series; hematite and magnetite are present in the light fraction of Varkala and Thonnackal series.

Irrespective of the series, quartz occupies 40 to 90 per cent of the primary mineral assemblage of soil fraction indicating highly weathered and leached weathering environment. The resistant mineral zircon is absent in all the series except the Thonnackal series. The preponderance of ilmenite and other opaque minerals in both fractions is also an universal observation in these series indicating the primary mineral source solely to the parent material of the region which are minerals of residual geological formations related to the Warkalli formations. Another unique observation is the presence of plinthite granules in the soil fine sand fraction.

Comparatively, considering the preponderance of quartz, the resistant index mineral, the weathering of the soil is in the increasing order at Thonnackal < Nedumangad < Palode < Varkala < Trivandrum. Palode, Varkala and Trivandrum are with more of geogonic relic quartz minerals while Thonnackal and Nedumangad are with more of pedogenic quartz material of detrital origin. Among the series, the ferruginisation and plinthisation is observed only at Varkala series and is confirmed by their total iron content indicating ferruginous parent material. This is still reinforced by the presence of hematite. Subangular to subrounded, moderately faint margined hematite and magnetite at Varkala and

Thonnackal respectively indicate their detrital genesis also. The presence of zircon at Nedumangad and Palode in the lower layers and their absence in the other series indicate its detrial origin by later migration. Earlier workers have also reported the fine sand mineralogy of these series (Gopalaswamy, 1969; Subramonia Iyer, 1979; Venugopal, 1980; Sankarankutty, 1986; Sivadasan, 1989; and Ashraf, 1992). Presence of kyanite and rutile in the Palode and Nedumangad series indicates it's metamorphic parent material. This is in agreement with the observations of Sehgal *et al.* (1985).

4.8. Genesis of gravels

4.8.1. Comparative chemical composition of gravels and soils

Irrespective of the series, acid insolubles, total nitrogen, calcium and magnesium of the gravels are less than the corresponding soil fraction while acid soluble silica, sesquioxides, iron, total phosphorus and potassium of the gravels are higher than the respective soil fraction. This is indicative of the comparative weathering of gravels and corresponding soil fractions. The unique observation of lesser acid insolubles of gravels than the corresponding soil fraction indicates the resistance of soil gravels as composite minerals towards weathering. The pattern of distribution of chemical parameters of both soils and gravels clearly establishes that all are members of related geological formations, though located in different geomorphic positions and representative of the different soil series. The uniformity of the composition of the gravels and soils thus confirms similarity of the parent materials and the extent of weathering intensity.

The higher content of acid soluble silica and sesquioxides in gravels indicates the repeated process of plinthisation. The observation of higher total phosphorus and potassium content of gravels is an important information as a potential source of phosphorus and potassium for crop production, especially for coarser rooted perennial crops. This is to be further established by conducting trials in actual field situation.

The comparative contribution to potential fertility by gravels for nitrogen is $1/4^{th}$ of the soil while in the case of phosphorus and potassium, it is about 1 1/2 to 2 times. The contribution of calcium by gravels are about half of the contribution by the respective soil fraction. In the case of magnesium it even indicates that the contribution is about uniform by the soil and gravel fraction when we generalise the mean contribution of magnesium irrespective of the series.

The comparative distribution of acid soluble silica, sesquioxides and iron of gravels and soil pin-point the main chemical and mineralogical reaction in their origin to be saprolitisation and laterisation respectively ie., a process of kaolinisation and formation of iron oxides in gravels with an on-going decrease in silica and increase in alumina. It dosen't satisfy the enriched iron requirement of laterisation indicating highly ferruginised gravels and highly aluminous soils. They together constitute the inseparable processes of saprolitisation and laterisation.

4.8.2. Micromorphology and pedogenesis of gravels

In the Palode series, based on external morphology amiboidal and disjointed gravels are seen in the surface, while in the progressive argillic horizon, it is digitate or aggregate. The internal morphology of these gravels are pseudomorphic in the first two horizon except in the cobbles of the second horizon, where they are sepatric. The gravels of the third horizon is compound pseudomorphic while in the fourth horizon, it is typic to geodic.

At Nedumangad, in the surface horizons the external morphology of gravels are disjointed, digitate and even amiboidal while at progressive argillic horizons, they are dominantly disjointed to aggregate. The gravels are of the pseudomorphic internal morphology, except the coarse gravels of the fourth horizon which tend to become geodic.

The external morphology of gravels are disjointed to amiboidal in the surface and subsurface horizons of Varkala. The fine gravels of the first horizon are of the pseudomorphic type while the coarse gravels are crossed concentric, but all the gravels of the second horizon are geodic when considering the internal morphology.

The gravels of the Thonnackal series are more of digitate to disjointed and in the interspace, aggregate in external morphology. The gravels of the first two horizons are of nucleic internal morphology while they are pseudomorphic downwards, except the coarse gravels of the fifth horizon which are nucleic.

The surface gravels of the Trivandrum series are disjointed to amiboidal while in the progressive argillic subsurface horizons they are dominantly disjointed and at microlocations digitate. The fine gravels of the first horizon are of the geodic internal morphology while the coarse ones are crossed concentric. The second and third horizons however has geodic and pseudomorphic gravels respectively.

Comparatively, all the series are with gravels of amiboidal, disjointed and digitate morphological types in the surface with pseudomorphic internal fabric except typic to geodic at Palode, Nedumangad, Varkala and Trivandrum and nucleic at Thonnackal. In the lower horizons, they are digtate or aggregate in Palode and Nedumangad series with typic, geodic and psendomorphic to geodic internal fabrics. At Varkala and Thonnackal, they are disjointed with geodic to nucleic internal fabric. The gravels at Trivandrum are disjointed and digitate with pseudomorphic internal fabric.

Gravels are both geogenic and pedogenic (Brewer, 1976) features of past or present pedological processes which can be differentiated as discrete fabric units with difference in granulometric fractions, organic matter, crystals, chemical components or an internal fabric (Bullock *et al.*, 1985). Gravels may be crystalline, amorphous and cryptocrystalline and fabric pedofeatures. Gravels are pedofeatures unrelated to voids, grains and aggregates, classified under the group nodules. They do not consist of single crystals or crystal outgrowths. They are similar in concept to the glaebules of Brewer (1976). Glaebules are logically microgravels present in soils and gravels.

The presence of the morphological types and internal fabric typical of gravels in the series investigated confirm the above discussion on the genesis of gravels. The internal fabric types is a direct expression of both the geogenic and pedogenic origin of gravels (Bullock *et al.*, 1985). This is generalised by the preponderance of geodic internal morphology in the lower horizons and pseudomorphic in the surface horizons. The pseudomorphology of the surface gravels are the effect of the current pedogenic processes and accelerated erosions. The observation of nucleic type of gravels in the lowest horizon of Thonnackal series is indicative of it's detrital origin from microgravels of nearby higher landscapes with geodic relic gravels. The relic nucleic internal fabric is markedly observed because of the recent rubefaction.

Soils with pediment gravels at shallow depth are widespread in West Africa, in areas where the underlying country rock is precambrian granite and metamorphic, mainly paragneiss, quartzite and quartzschist (Babalola and Lal, 1977b).

Gravel horizons occur in most soil profiles of middle and upper slopes (Smyth and Montgomery, 1962). The thickness of this horizon as well as the concentration and size of the coarse fraction vary even for short distances.

In the whole of Kerala, the surface graveliness with less than 15 percent of gravel is occupied by 70 per cent, 15-40 per cent gravel in 19 per cent and 40-70 per cent gravel in 1 per cent of the area (NBSS and LUP, 1993). The gravel content of the soil series investigated is with 7 to 90 per cent gravel.

Most wide-spread iron oxides in soils and gravels are goethite (alpha FeOOH) and hematite (alpha Fe_2O_3). Their coexistence as observed in the progressive argillic horizons of the soil series investigated reflects their similar thermodynamic stability. The important factors which influence the quantitative relationship between goethite and hematite are soil temperature, activity of soil water, soil pH, soil organic matter and also the release rate of iron during weathering.

Hematite formation is not the direct result of dehydration of goethite ($2\ \alpha\ FeOOH \rightarrow \alpha\ Fe_2O_3 + H_2O$). Ferrihydrite is the precursor of hematite ie: goethite → ferrihydrite → hematite (Schwertman, 1966 and Chukhrov *et al.*, 1973). Ferrihydrite is only a recently discovered Fe (iii) oxide mineral of bulk composition $5Fe_2O_3 . 9H_2O$ with disordered structure : defect hematite-like structure.

The isohypertherrmic temperature regime of the series with little variation in soil temperature contributes to lesser formation of hematite by the above pedogenic process in the above soil series.

As seen in the present investigation, primary mineral assemblage fine sand mineralogy of gravels and soil respectively indicate higher goethite content with increasing organic carbon percentage (Schwertman, 1985).

Carbon preserving pedoclimate favours goethite over hematite. Organics, complexes iron and lower the activity of Fe (iii) iron in solution and hence prevent the solubility product of ferrihydrite and not the much lower one of goethite from being exceeded. As ferrihydrite is considered as a necessary precursor of hematite, this will prevent hematite formation and only goethite will be formed.

As in the soil redoxmorphic features, gravels also exhibit such morphology as a result of heterogeneous distribution of iron oxide.

The hardened plinthite gravel (iron stone gravel) observed at Palode, Nedumangad, Trivandrum and Varkala in the decreasing order is believed to be the result of more of geogenic than of active pedogenic origin. The hardened plinthite gravel ie., the petroplinthite gravel is to be proposed in the soil taxonomy to differentiate Entisols and Inceptisols from Oxisols and Ultisols, after a detailed further study. Already , plinthite is important in the separation of Oxisols from Inceptisols and Ultisols in Soil Taxonomy (USDA, 1994). The term petroplinthic is suggested in place of skeletal at the family level when the more than 2 mm fraction is dominantly petroplinthic in nature. If there are 30 per cent or more in the upper 1.25 m of the profile the term petroplinthic would reflect the genetic nature of the greater than 2 mm fraction as opposed to skeletal, which refers mainly to the residual primary rock or mineral fragments more than 2mm.

The presence of a variety of gravels represents relict and polygenetic formation. Pal *et al.* (1989) reported that the red and lateritic soils of peninsular India represent relict and polygenetic soils. Similar remnant laterite features were also reported by Venugopal *et al.* (1987) in Karnataka.

Sehgal *et al.* (1992) have reported the presence of porphyric related distribution pattern in the soils of Southern India with plinthite classified as plinthudults and plinthustults. The present investigation of the soil series of Nedumangad and Trivandrum confirms the above report.

The results of the gravel morphology, mineralogy, micromorphology and chemical composition in relation to soil fine sand mineralogy and chemical composition throw light on the possible genesis and their pathway leading to different types of gravels. The higher content of iron oxide and relatively lower soluble silica in the gravels indicate repeated impregnation of iron, smearing relict parent material, plinthite granules and quartz as the nucleus of gravels. The possibility of forming a ferruginous gravel now described as compound pseudomorphic gravel with microgravel in the gravel fabric is also confirmed.

The probability of forming ferruginous gravels with iron oxide and with occluded silica in these soil series reported by Nair *et al.* (1973) is confirmed in the present investigation especially in the Nedumangad and Thonnackal series with kaolinite occlusion rather than pure silica. This is in agreement with petroplinthite micromorphology of Bangalore reported by SEM studies of Eswaran and Raghumohan (1973).

A common geogenic rather pedogenic feature in the major soil series of Trivandrum district is the presence of opaque angular hard coarser free gravels (nodules) in the surface and in the argillic, texturally different subsurface horizon with diameters of 2mm to 7.5cm. The nature of these gravels above and below 2 mm diameter and their variability by physical, chemical, mineralogical and micromorphological analysis from the major soil series of Trivandrum district indicate that the nodule microstructure is mainly of bridged grain type compared to dominantly peculiar type for the soft friable concretionary gravels. The basis components are coarser : quartz, feldspar, opaques, lithogenic hematite, goethite and bohemite; finer : variegated mottled kaolin, mica, quartz and even organic matter. The similarity in the mineral suites between size fractions and within the profiles and the thus observed retention of porphyric RDP especially in the subsurface gravels indicate even authigenic origin of micrograves through an eluviation/illuviation process as reported by Arocena and Pawluk (1991). Micromorphological analysis of redder to opaque concretions indicates that they are dominantly goethite alone or in association with hematite. These concretions are pedological features observed in all the soil series investigated and they are present in the increasing order Thonnackal < Nedumangad < Palode < Trivandrum < Varkala. Similar is the tendency of ferruginisation both by phinthorhodofication and rubefaction. Instead of skeletic phase or skeletal materials, plinthic or petroplinthic is proposed accommodating its genesis. Plinthic gravels are dominantly pedogenic while petroplinthic are dominantly geogenic in origin. The other variability is the size, nature, weathering of quartz infillings, coatings, orientation, nature and composition of denser pedological features. Micrograve in gravel is an unique feature observed in Palode, Trivandrum and Nedumangad series.

Though it is easier to differentiate concretions of pedogenic and geogenic origin by external morphology, it is difficult to differentiate between concretions of pedogenic and detrital origin. This differentiation is made easier in the present investigation from the internal fabric observed from micromorphology. The higher content of silica in the soil gravels is due to the greater utilisation of sand fraction as the nuclei for the precipitation of iron oxides. The similar pattern of distribution of sesquioxides in soil and gravel indicates their direct effect in the formation of gravels. It is evident from the total chemical composition of the essential plant nutrients like potassium, calcium and magnesium in the gravels and the respective soils that irrespective of the series, potassium is fixed in the concretions; while in the case of calcium and magnesium, similar observations are seen at Nedumangad and Thonnackal series. This is in agreement with the observations leading to nutrient deficiency as reported by Diwakar and Singh (1993).

The preponderance of quartz, both in the soil and gravels is obviously due to the acid igneous and metamorphic parent rock. The higher content of quartz, specifically indicates granite gneiss parent rock (Clarke, 1924 and Pettijohn, 1957) and their variation in distribution at Thonnackal and Varkala indicates more of detrital influence in their soil pedogenesis.

4.8.3. Gravel and soil hardening

Total iron, sesquioxides, acid insolubles and micromophology of the soil gravels of the series indicated (Table 3, plates 1 to 13 and photomicrographs 71-105) that iron is the common and important agent and sole contributor to the rapid soil hardening. The soil hardening by the consolidation of soil gravels especially by the geodic, nucleic and compound type are in the increasing order at Thonnackal < Nedumangad < Palode < Trivandrum < Varkala series. Irreversible hardening by the consolidation of petroplinthic gravels and compound gravels are more of a saprolitisation process rather than kaolinisation process. It is even seen that these are not separable process as observed in the argllic horizons. The webbing of kaolin by goethite resulting in absorption and immobilisation of iron indicates that goethite crystallisation hardens soil gravels rather than kaolinite impregnated with feruginous solution. The kaolin deposit of Thonnackal series with little iron is found to harden but not with the same degree and rapidity of the extreme situation of true ferruginous gravels of Varkala series. Concentration of gravels and the hardening is resulted from a close packing of microgravels. Petroplinthic gravels are with closely packed goethite crystals when compared to the plinthic gravels. Closely packed goethite results in the formation of closely packed macrocrystals responsible for the hardening. The present investigation also confirms both the relative accumulation and absolute accumulation of iron in gravels leading to it's hardening. These observations of the micromorphological evidences of soil hardening are in agreement with the earlier reports (Fripiat and Gustuche, 1952; Alexander *et al.*, 1962; Sivarajasingham *et al.*, 1962; Eswaran and Raghumohan, 1973; Schmidt Lorenz, 1979 and Eswaran *et al.*, 1990.

4.9. Comparative fertility contribution of soil and gravels

4.9.1. Gravel fertility

The nutrient status of gravels are presented in table 8.

4.9.1.1. Available nitrogen

Available nitrogen content of gravels and cobbles decreases within the profile irrespective of the series.

In the Palode series, it ranged from 44.88 to 111.82 kg ha^{-1}, 4.26 to 9.39 kg ha^{-1} and 3.28 to 4.21 kg ha^{-1} in fine coarse gravels and cobbles respectively.

In the Nedumangad series, it ranged between 27.94 to 103.42 kg ha^{-1} and 4.68 to 21.00 kg ha^{-1} in the fine and coarse gravels respectively.

The fine and course gravels of the Varkala series exhibited an available nitrogen content of 17.47 to 73.02 and 11.65 to 41.72 kg ha^{-1} respectively.

The available nitrogen content of the fine gravels of the Thonnackal series ranged from 13.89 to 81.26 kg ha^{-1} and that of the coarse gravels of the fifth horizon was 5.02 kg ha^{-1}.

Table 8. Nutrient status of gravels

Series name	Profile site	Depth of horizon (cm)	Gravel Fraction	Available nitrogen (kg ha^{-1})	Available phosphorus (kg ha^{-1})	Exch. potassium (kg ha^{-1})	Exch. calcium (Cmol kg^{-1})	Exch. magnesium (Cmol kg^{-1})
		0-14	I	111.82	12.23	39.67	0.13	0.08
			II	9.39	9.31	26.50	0.07	0.03
			I	77.73	11.21	40.90	0.16	0.03
		14-51	II	6.32	8.36	23.13	0.09	0.02
			III	4.21	5.21	10.37	0.05	0.02
Palode	TBGRI,		I	63.18	9.36	34.48	0.93	0.06
	Palode	51-106	II	5.34	5.29	32.67	0.27	0.03
			III	4.02	3.31	8.48	0.09	0.01
			I	44.88	5.23	34.32	0.89	0.05
		106-150	II	4.26	2.31	25.43	0.26	0.02
			III	3.28	1.96	17.45	0.08	0.01
		0-11	I	103.42	10.78	29.79	0.28	0.25
			II	21.00	8.23	17.94	0.11	0.13
		11-33	I	83.13	9.33	39.09	0.08	0.29
Nedumangad	Pazhakutty-		II	12.62	7.27	25.76	0.02	0.21
	Shencotta	33-62	I	45.25	8.29	23.70	0.25	0.49
	road,		II	9.19	5.88	10.37	0.13	0.38
	Nedumangad	62-150	I	27.94	7.22	22.96	0.21	0.33
			II	4.68	3.26	8.97	0.19	0.21
		0-8	I	73.02	11.97	49.71	0.19	0.18
Varkala	Kaithakonam		II	41.72	8.31	43.04	0.08	0.09
	via. Sivagiri,	8-150	I	17.47	10.88	39.42	0.27	0.04
	Trivandrum		II	11.65	9.13	19.01	0.15	0.01
	Near	0-20	I	81.26	20.11	67.57	0.82	1.01
	KIPL	20-70	I	75.08	18.36	166.74	1.93	0.73
Thonnackal	china clay	70-113	I	61.39	18.29	126.00	1.02	3.02
	mines,	113-150	I	20.34	21.52	40.08	1.99	4.81
	Thonnackal	150+	I	13.89	13.31	8.39	3.01	1.93
			II	5.02	8.19	8.07	2.15	0.23
		0-14	I	83.31	9.28	40.82	0.42	0.19
			II	13.26	8.26	26.42	0.13	0.09
Trivandrum	Mannanthala,	14-57	I	76.20	10.82	52.26	0.37	0.33
	Trivandrum		II	8.31	9.83	34.81	0.18	0.09
		57-150	I	66.41	8.39	46.91	0.29	0.52
			II	2.62	7.21	26.83	0.16	0.22

Note : Gravel/Coarser soil fraction : I — Fine gravels (2mm-2.5cm)
II — Coarse gravels (2.5-7.5cm)
III — Cobbles (7.5-25cm)

The Trivandrum series had fine and coarse gravels which had available nitrogen content ranging from 66.41 to 83.31 and 2.62 to 13.26 kg ha^{-1} respectively.

Fine gravels of the contributed comparatively more available nitrogen than coarse gravels. Among the series, the available nitrogen contribution is in the increasing order Varkala < Thonnackal < Nedumangad < Palode < Trivandrum in the case of fine gravels while the same for coarse gravels is in the increasing order Thonnackal < Palode < Trivandrum < Nedumangad < Varkala. The difference in contribution of available nitrogen is in the increasing order Varkala < Thonnackal < Nedumangad < Palode < Trivandrum.

4.9.1.2. Available phosphorus

The available phosphorus content of all the coarse fractions of the soil at Palode and Nedumangad series showed a decrease with depth. The content ranged from 5.23 to 12.23, 2.31 to 9.31 and 1.96 to 5.21 kg ha^{-1} in the fine coarse gravels and cobbles respectively at Palode and 7.22 to 10.78 and 3.26 to 8.23 kg ha^{-1} in the fine and coarse gravels at Nedumangad.

Fine gravels of Varkala and Thonnackal showed a decreasing trend down the profile except in the fourth horizon of the Thonnackal series, the content ranging from 10.88 to 11.97 and 13.31 to 21.52 kg ha^{-1} respectively. The coarse gravels present in the fifth horizon of the Thonnackal series showed a content of 8.19 kg ha^{-1} and the coarse gravels of the Varkala series showed a decrease with depth the content ranging from 8.31 to 9.13 kg ha^{-1}.

The available phosphorus content of the gravels at Trivandrum series showed an alternate pattern of increase and decrease with depth, the content ranging from 8.39 to 10.82 and 7.21 to 9.83 kg ha^{-1} respectively in fine and coarse gravels.

As in the case of available nitrogen, the available phosphorus content contributed by fine gravels are more than the coarse gravels. The contribution by finer gravels was in the increasing order Trivandrum < Palode < Nedumangad < Varkala < Thonnackal while in the case of coarse gravels it was in the increasing order Nedumangad < Palode < Thonnackal < Trivandrum < Varkala. Except in Varkala and Thonnackal, the comparative contribution of available phosphorus in fine and coarse of available phosphorus in fine and coarse gravels does not differ significantly. The maximum difference is exhibited by the Thonnackal series and the least by the gravels of the Trivandrum series. The difference in contribution by the fraction is in the increasing order Trivandrum < Varkala < Nedumangad < Palode < Thonnackal.

4.9.1.3. Exchangeable potassium

In the Palode series, the profile pattern for exchangeable potassium in the fine gravels showed a decrease down the profile except in the second horizon where an increase was noticed, the content ranging from 34.32 to 40.90 kg ha^{-1}. In the case of coarse gravels and cobbles an alternate pattern of decrease and increase was observed down the profile, the content ranging from 23.13 to 32.67 and 8.48 to 17.45 kg ha^{-1}.

Both the gravel fraction of the Nedumangad series showed a similar profile pattern of decrease with depth in the content of exchangeable potassium except in the second horizon where there was an increase. The content ranged from 22.96 to 39.09 and 8.97 to 25.76 kg ha^{-1} respectively for fine and coarse gravels.

The Varkala series showed a profile pattern of decrease with depth in the exchangeable potassium content, the content ranging from 39.42 to 49.71 and 19.01 to 43.04 kg ha^{-1} respectively for fine and coarse gravels.

The exchangeable potassium content in fine gravels of the Thonnackal series showed a decreasing trend down the profile except in the second horizon where an abrupt increase was noticed, the content ranged from 8.39 to 166.74 kg ha^{-1}. The content in the coarse gravels of the fifth horizon was 8.07 kg ha^{-1}.

An alternate pattern of increase and decrease with depth was observed for both fraction of gravels in the Trivandrum series, the content ranging from 40.82 to 52.26 and 26.42 to 34.81 kg ha^{-1} respectively for fine and coarse gravels.

The exchangeable potassium contribution by the fine gravels are comparatively more than coarse gravels at all the series. This difference is marked in the increasing order at Palode < Nedumangad < Varkala < Trivandrum < Thonnackal. The contribution of fine gravels were in the order at Nedumangad < Palode < Varkala < Trivandrum < Thonnackal, while the contribution of the nutrient by coarse gravels were in the increasing order at Thonnackal < Nedumangad < Palode < Trivandrum < Varkala.

4.9.1.4. Exchangeable calcium

The exchangeable calcium content of the fine and coarse gravels of the Palode series showed a progressive increase down the profile except in the fourth horizon where the content decreased. The values ranged from 0.13 to 0.93 and 0.07 to 0.27 Cmol kg^{-1} in fine and coarse gravels respectively. In the cobbles, the content ranged from 0.05 to 0.09 Cmol kg^{-1} with an alternate increase and decrease pattern with depth.

In the Nedumangad series, the fine gravels showed a decrease down the profile except in the third horizon where a marked increase was noticed. In the coarse gravels, a pattern of increase with depth was observed except in the second horizon where a decrease was noticed. The content ranged from 0.08 to 0.28 and 0.02 to 0.19 Cmol kg^{-1} for fine and coarse gravels respectively.

Both fraction of gravels showed an increase down the profile in their exchangeable calcium content in the Varkala series the content ranging from 0.19 to 0.27 and 0.08 to 0.15 Cmol kg^{-1} in fine and coarse gravels respectively.

In the Thonnackal series, there was a progressive increase in the content of exchangeable calcium down the profile except in the third horizon where a decrease was noticed. The content ranged from 0.82 to 3.01 Cmol kg^{-1} in fine gravels while the content in coarse gravels of the fifth horizon was 2.15 Cmol kg^{-1}

The exchangeable calcium content of the fine gravels at Trivandrum showed a decrease down the profile while the same showed an alternate pattern of increase and decrease with depth in the case of coarse gravels. The content ranged from 0.29 to 0.42 and 0.13 to 0.18 Cmol kg^{-1} in fine and coarse gravels respectively.

Irrespective of the series, the exchangeable calcium contribution of fine gravels was more than the respective coarse gravels except in the

Thonnackal series where the exchangeable calcium content of coarse gravels were higher than the respective fine gravels. They were in the increasing order with respect to the content at Nedumangad < Varkala < Trivandrum < Palode < Thonnackal for both fraction of gravels. Difference in contribution by the gravel fraction of exchangeable calcium was in the increasing order at Nedumangad < Varkala < Trivandrum < Palode < Thonnackal.

4.9.1.5. Exchangeable magnesium

The exchangeable magnesium content in the Palode series of all the coarser fractions of soil showed an alternate pattern of decrease and increase with depth. The content ranged from 0.03 to 0.08, 0.02 to 0.03 and 0.01 to 0.02 Cmol kg^{-1} in fine, coarse gravels and cobbles respectively.

In the Nedumangad series, the profile pattern was an increase down the profile, except in the fourth horizon where a decrease was noticed. The content ranged from 0.25 to 0.49 and 0.13 to 0.38 Cmol kg^{-1} in fine and coarse gravels respectively.

A decrease in content was observed in both the gravel fraction of the Varkala series, the content ranging from 0.04 to 0.18 and 0.01 to 0.09 Cmol kg^{-1} in fine and coarse gravels respectively.

The content of exchangeable magnesium in the fine gravels showed a decrease to the second horizon, then increased till the fourth, before decreasing in the fifth horizon; the values ranged from 1.01 to 4.81 Cmol kg^{-1}. The content in the coarse gravels of the fifth horizon was 0.23 Cmol kg^{-1}.

The exchangeable Magnesium content showed a progressive increase down the profile in both fractions of gravels. The content ranged from 0.19 to 0.52 and 0.09 to 0.22 Cmol kg^{-1} in fine and coarse gravels respectively.

Exchangeable magnesium contribution of fine gravels was in the increasing order at Palode < Varkala < Nedumangad < Trivandrum < Thonnackal, while the same in coarse gravels was in the increasing order at Palode < Varkala < Trivandrum < Nedumangad < Thonnackal. As seen in the content of exchangeable calcium, fine gravels contributed more than coarse gravels. The maximum contribution was by the fine gravels of the Thonnackal series. Difference in contribution by the gravel fraction was in the increasing order at Palode < Varkala < Nedumangad < Trivandrum < Thonnackal.

4.9.2. Soil fertility

The nutrient status of soils is reported in Table 9.

Table 9. Nutrient status of soils

Series name	Profile site	Depth of horizon (cm)	Available nitrogen (kg ha^{-1})	Available phosphorus (kg ha^{-1})	Exch. potassium (kg ha^{-1})	Exch. calcium (Cmol kg^{-1})	Exch. magnesium (Cmol kg^{-1})
		0-14	282.31	45.26	270.19	0.89	0.28
Palode	TBGRI,	14-51	210.68	43.72	281.55	1.08	0.24
	Palode	51-106	147.74	39.31	249.20	1.33	0.38
		106-150	126.63	30.23	240.81	1.41	0.41
	Pazhakutty-	0-11	182.59	40.29	209.29	1.26	1.67
Nedumangad	Shencota	11-33	175.56	39.18	264.68	0.40	1.83
	road,	33-62	108.85	38.73	168.63	1.33	3.33
	Nedumangad	62-150	103.23	38.24	163.45	1.28	2.50
	Kaithakonam	0-8	103.93	42.33	339.16	1.02	1.10
Varkala	via. Sivagiri,	8-150	78.65	41.38	295.37	1.53	0.20
	Varkala						
	Near	0-20	89.89	26.31	76.96	0.93	1.11
	KIPL	20-70	82.87	22.87	323.11	2.29	0.93
Thonnackal	china clay	70-113	78.65	21.36	157.03	1.26	3.22
	mines,	133-150	74.44	27.89	51.85	2.19	5.23
	Thonnackal	150+	54.07	20.12	12.18	3.10	2.31
Trivandrum	Mannanthala,	0-14	152.32	39.26	277.84	2.71	1.13
	Trivandrum	14-57	129.13	42.29	339.73	2.31	2.32
		57-150	120.17	38.11	331.01	1.26	3.36

4.9.2.1. Available nitrogen

The available nitrogen content of soils decreased with depth in all the soil series investigated. The content ranged from 126.63 to 282.31, 103.23 to 182.59, 78.65 to 103.93, 54.07 to 89.89 and 120.17 to 152.32 kg ha^{-1} at Palode, Nedumangad, Varkala, Thonnackal and Trivandrum. However there was a slight increase in the content in the third horizon of Trivandrum.

4.9.2.2. Available phosphorus

The available phosphorus content showed a decrease with depth in the soils of Palode, Nedumangad, Varkala and Thonnackal, except in the fourth horizons of Thonnackal where there was an increase. The content ranged from 30.23 to 45.26, 38.24 to 40.29, 41.38 to 42.33 and 20.12 to 27.89 kg ha^{-1} in the respective soil series.

At Trivandrum the available phosphorus content showed an alternate pattern of increase and decrease with depth, the content ranging from 38.11 to 42.29 kg ha^{-1}.

4.9.2.3. Exchangeable potassium

The exchangeable potassium content of soils at Palode, Nedumangad, Thonnackal and Trivandrum showed a decrease except an increase in the second horizon, the content ranging from 240.81 to 281.55, 163.45 to 264.68, 12.18 to 323.11 and 277.84 to 339.73 kg ha^{-1} respectively.

In the Varkala series, the profile pattern showed a decrease down the profile with the content ranging from 295.37 to 339.16 kg ha^{-1}.

4.9.2.4. Exchangeable calcium

The Palode and Varkala profile showed a profile pattern in exchangeable calcium of increase with depth, with the values ranging from 0.89 to 1.41 and 1.02 to 1.53 Cmol kg^{-1} respectively.

In Nedumangad, the profile pattern showed an alternate pattern of decrease and increase with depth, the content ranging from 0.40 to 1.33 Cmol kg^{-1}.

A profile pattern of increase with depth, except in the third horizon was observed in the Thonnackal series in the content of exchangeable calcium with the values ranging from 0.93 to 3.10 Cmol kg^{-1}.

The exchangeable calcium content of the Trivandrum series showed a decrease down the profile with values ranging from 1.26 to 2.71 Cmol kg^{-1}.

4.9.2.5. Exchangeable magnesium

The profile pattern for exchangeable magnesium for the Palode series showed an increase with depth except in the second horizon where a decrease was noticed, the content ranging from 0.24 to 0.41 Cmol kg^{-1}.

In the Nedumangad series, the exchangeable magnesium showed an increase with depth except in the fourth horizon, the content ranging from 1.67 to 3.33 Cmol kg^{-1}.

The exchangeable magnesium content showed a decrease with depth in the Varkala series, the content ranging from 0.20 to 1.10 Cmol kg^{-1}.

The Thonnackal series, showed a profile pattern of decrease to the second horizon and thereon increasing till the fifth horizon where a decrease was noticed, the content ranging from 0.93 to 5.23 Cmol kg^{-1}.

In Trivandrum, there was an increase in the content of exchangeable magnesium with depth, the content ranging from 1.13 to 3.36 Cmol kg^{-1}.

4.9.3. Comparative fertility contribution

Comparatively, the available nitrogen, available phosphorus, exchangeable potassium, calcium and magnesium contribution by the fine

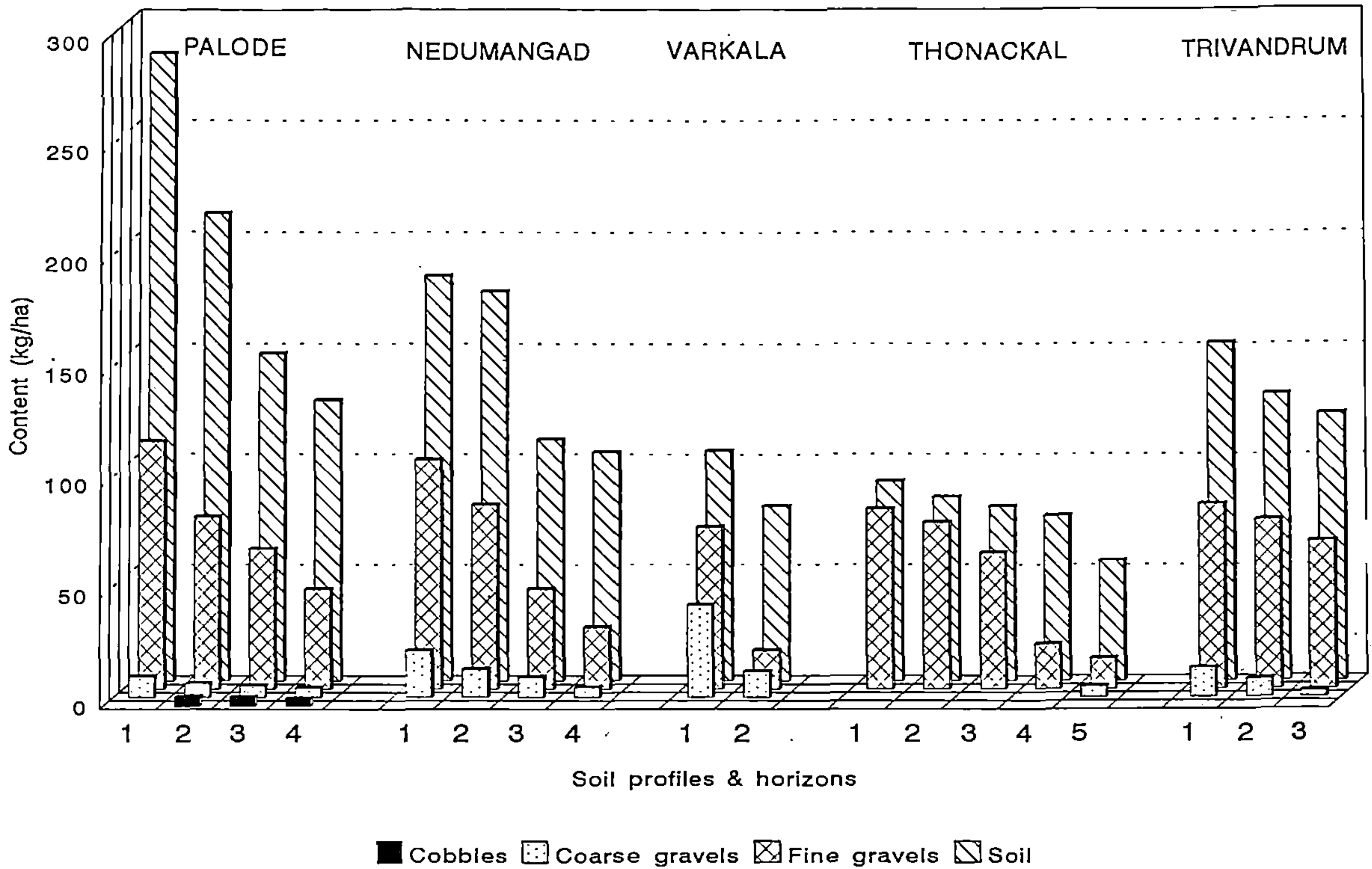


Fig. 3. Nutrient status of soils and gravels - available nitrogen

earth fraction (soil) is higher than the different sized coarse fragments (gravels and cobbles) in all the series investigated. In the case of gravels their contribution decreases with increase in size except the Thonnackal series in which the coarse gravels gave a higher calcium content than the respective finer fraction. This can be attributed to detrital calcium rich gravel migration and their entrapment.

Comparative and relative contribution of soil and gravel fraction to the available and exchangeable status is clearly shown in Figures 2 to 6 and Table 10.

Among the series, the comparative gravel contribution to soil available nitrogen is in the increasing order at Palode < Nedumangad < Thonnackal < Varkala < Trivandrum. Varkala, Thonnackal and Trivandrum indicate a pattern of residual detrital soils while Palode and Nedumangad are comparatively with less *in-situ* weathering and release of available nitrogen. The trend of other nutrients among the series are different. In the case of phosphorus it is in the order at Nedumangad < Trivandrum < Varkala < Palode < Thonnackal; for exchangeable potassium, it is Nedumangad < Varkala < Trivandrum < Palode < Thonnackal; for calcium it is Trivandrum< Varkala < Nedumangad < Palode < Thonnackal; for magnesium, it is Trivandrum < Nedumangad < Varkala < Palode < Thonnackal. The proportional contribution by the gravels for phosphorus and potassium is higher for Thonnackal series and

Table 10. Comparative fertility contribution of soil and gravels

Series name	Profile site	Depth of horizon (cm)	Fertility contribution (Soil + Gravel) Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Ex. K (kg ha^{-1})	Ex. Ca (Cmol kg^{-1})	Ex. Mg (Cmol kg^{-1})	Fertility contribution by soil (%) Av. N	Av. P	Ex. K	Ex. Ca	Ex. Mg.	Fertility contribution by gravel (%) Gravel fractions	Av N	Av. P	Ex. K	Ex. Ca	Ex. Mg
Palode	TBGRI, Palode	0-14	403.52	66.80	336.36	1.09	0.39	69.96	67.75	80.33	81.65	71.79	I	27.71	18.31	11.79	11.93	20.52
													II	2.33	13.94	7.88	6.42	7.69
		14-51	298.94	68.50	355.95	1.38	0.31	70.48	63.82	79.09	78.26	77.42	I	26.00	16.37	11.49	11.60	9.68
													II	2.11	12.20	6.49	6.52	6.45
													III	1.41	7.61	2.93	3.62	6.45
		51-106	220.28	57.27	324.83	2.62	0.48	67.07	68.64	76.72	50.76	79.17	I	28.68	16.34	10.62	35.49	12.50
													II	2.42	9.24	10.05	10.31	6.25
													III	1.83	5.78	2.61	3.44	2.08
		106-150	179.05	39.73	318.01	2.64	0.50	70.72	76.09	75.73	53.41	82.00	I	25.07	13.16	10.79	33.71	10.00
													II	2.38	5.81	7.99	9.85	5.00
													III	1.83	4.94	5.49	3.03	3.00
Nedumangad	Pazhakutty-Shencotta road, Nedumangad	0-11	307.01	59.30	257.02	1.65	2.05	59.47	67.94	81.43	76.36	81.46	I	33.69	18.18	11.59	16.97	12.10
													II	6.84	13.88	6.98	6.67	6.44
		11-33	271.31	55.78	329.53	0.50	2.33	64.71	70.24	80.32	80.00	78.54	I	30.64	16.73	11.86	16.00	12.45
													II	4.65	13.03	7.82	4.00	9.01
		33-62	163.29	52.90	202.70	1.71	4.20	66.66	73.21	83.19	77.78	79.29	I	27.71	15.67	11.69	14.62	11.66
													II	5.63	11.12	5.12	7.60	9.05
		62-150	135.85	48.72	195.38	1.68	3.04	75.99	78.49	83.66	76.19	82.24	I	20.57	14.82	11.75	12.50	10.85
													II	3.44	6.69	4.59	11.31	6.91

(Contd....)

Table 10. (Contd....)

Series name	Profile site	Depth of horizon (cm)	Fertility contribution (Soil + Gravel)					Fertility contribution by soil (%)					Fertility contribution by gravel (%)					
			Av. N (kg ha-1)	Av. P (kg ha-1)	Ex. K (kg ha-1)	Ex. Ca (Cmol kg-1)	Ex. Mg (Cmol kg-1)	Av. N	Av. P	Ex. K	Ex. Ca	Ex. Mg.	Gravel fractions	Av N	Av. P	Ex. K	Ex. Ca	Ex. Mg
Varkala	Kaithakanom via. Sivagiri, Varkala	0-8	143.37	62.61	431.91	1.29	1.37	72.50	67.61	78.52	79.07	80.29	I	18.29	19.12	11.51	14.73	13.14
													II	9.21	13.27	9.97	6.20	6.57
		8-150	107.77	61.39	353.80	1.95	0.25	72.98	67.41	83.49	78.46	80.00	I	16.21	17.72	11.14	13.85	16.00
													II	10.81	14.87	5.37	7.69	4.00
Thonnackal	Near KIPL china clay mines, Thonnackal	0-20	171.15	46.42	143.53	1.75	2.12	52.52	56.68	52.92	53.14	52.36	I	47.48	43.32	47.08	46.86	47.64
		20-70	157.95	41.23	489.85	4.22	1.66	52.47	55.47	65.96	54.27	56.02	I	47.53	44.53	34.04	45.73	43.98
		70-113	140.04	39.65	283.03	2.28	6.24	56.16	53.87	55.48	55.26	51.60	I	43.84	46.13	44.52	44.74	48.40
		113-150	94.78	49.41	91.93	4.18	10.04	78.54	56.45	56.40	52.39	52.09	I	21.46	43.55	43.60	47.61	47.91
		150+	72.98	41.62	28.64	8.26	4.47	74.09	48.34	42.53	37.53	51.68	I	19.03	31.98	29.31	36.44	43.18
													II	6.88	19.68	28.16	26.03	5.14
Trivandrum	Mannanthala, Trivandrum	0-14	248.89	56.80	345.08	3.26	1.41	61.20	69.12	80.52	83.13	80.14	I	33.47	16.34	11.83	12.88	13.48
													II	5.33	14.54	7.65	3.99	6.38
		14-57	213.64	62.94	426.80	2.86	2.74	60.44	67.19	79.59	80.77	84.67	I	35.67	17.19	12.25	12.94	12.04
													II	3.89	15.62	8.16	6.29	3.29
		57-150	189.20	53.71	404.75	1.71	4.10	63.51	70.96	81.78	73.68	81.95	I	35.10	15.62	11.59	16.96	12.68
													II	1.39	13.42	6.63	9.36	5.37

Note : Gravel/Coarser soil fraction : I — Fine gravels (2mm-2.5cm) II — Coarse gravels (2.5-7.5cm) III — Cobbles (7.5-25cm)

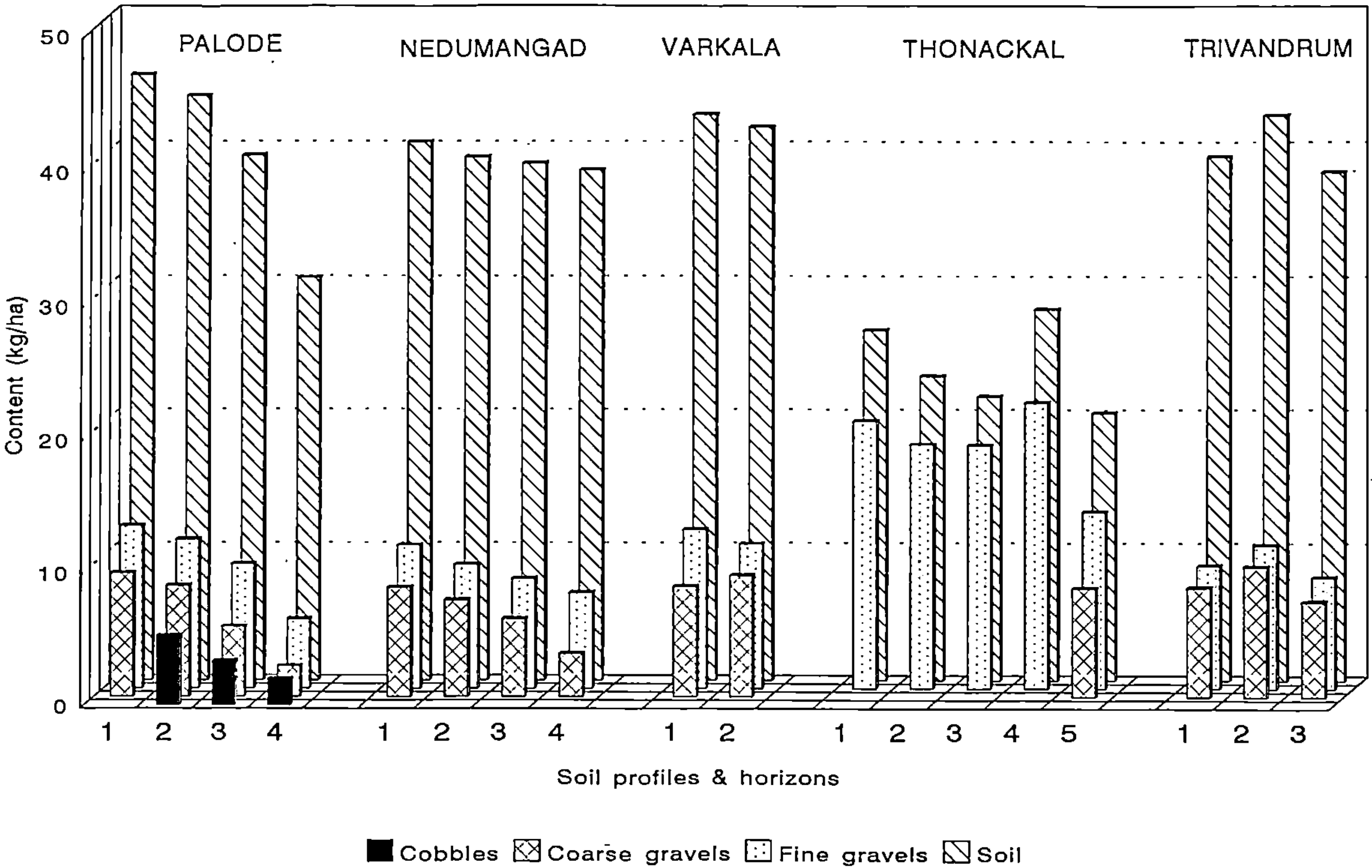


Fig. 4. Nutrient status of soils and gravels - available phosphorus

least for Nedumangad series. But for calcium and magnesium, it is least for Trivandrum and maximum for Thonnackal.

Among the nutrients, the maximum value is reported for Thonnackal series, except nitrogen where it is for Trivandrum series. Higher total Mgo and Cao was reported earlier to be for soil and gravels of Thonnackal series (Stella and Venugopal, 1987). Similar trend is also seen for phosphorus, potassium, calcium and magnesium of the Palode series in the presnt investigation. The least proportion of nutrients by the gravels of Palode, Nedumangad and Trivandrum was for nitrogen; phosphorus and potassium and calcium and magnesium respectively. This is due to the dominance of more of relict less weathered geogenic gravels and lesser active current weathering.

Soil texture determination, both in the laboratary and in the field disregard the presence of any component with a diameter in excess of 2mm. In the soil series investigated, such "inclusions" make up a considerable part of the matrix, except the Thonnackal series where it was found to be less than 7 per cent. The pressure of gravel reduces the volume of soil material that can be explored by the roots and consequently the quantity of water that the soil can supply to a crop.

The coarse fragments in the soil have an important bearing in land use as they interfere with the cultivation operation, reduce effective soil mass and change soil physical behaviour (Soil Survey Staff, 1951)

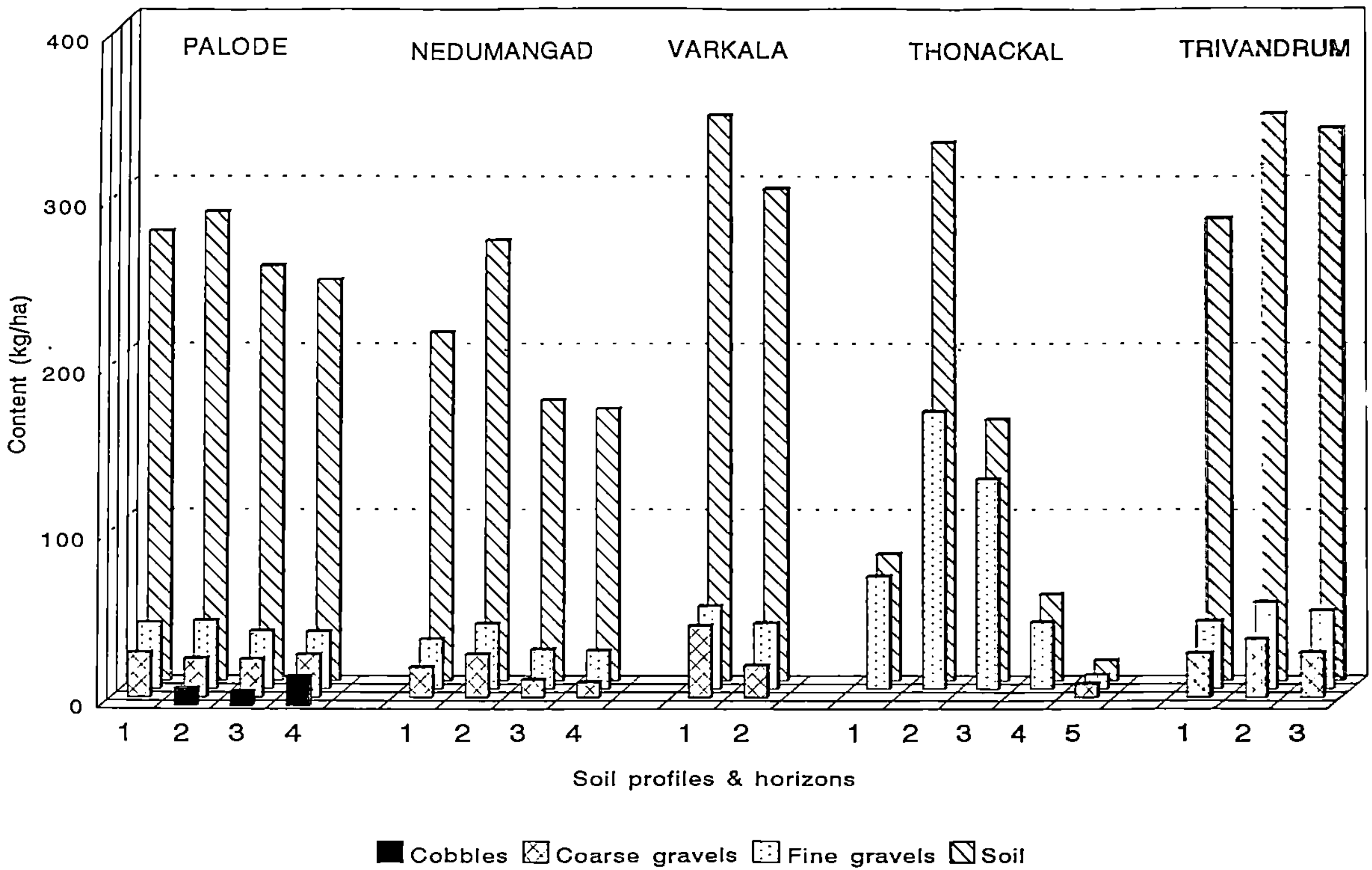


Fig. 5. Nutrient status of soils and gravels - exchangeable potassium

Lutz and Chandler (1946) and Lutz (1962) reported that the coarse fragments present in the form of gravel had deleterious effect on root development in a sandy soil but were useful for air and water movement in a clayey soil.

Laboratory observations made by Ungar (1971 a&b) showed that soil above a gravel layer in the soil column retained more water than uniformly packed soil column in light frequent showers but permittted considerable water loss during extended dry periods. He also reported that the presence of gravel on the soil surface reduced soil erosion and conserved profile water.

From the present study it is seen that the effect of soil profile gravel content may vary according to its concentration, location in the profile, soil type and rainfall behaviour. The foot hill soil series of Palode and even Nedumangad contain varying concentration of gravel in the profiles.

In the case of the Palode series with higher content, the distribution in the profile is some what uniform and the maximum contribution occurred at 50-110 cm depth interval.

The soil series investigated differed not only in the total amount of gravels but also in their size, nature distribution and location in the profile.

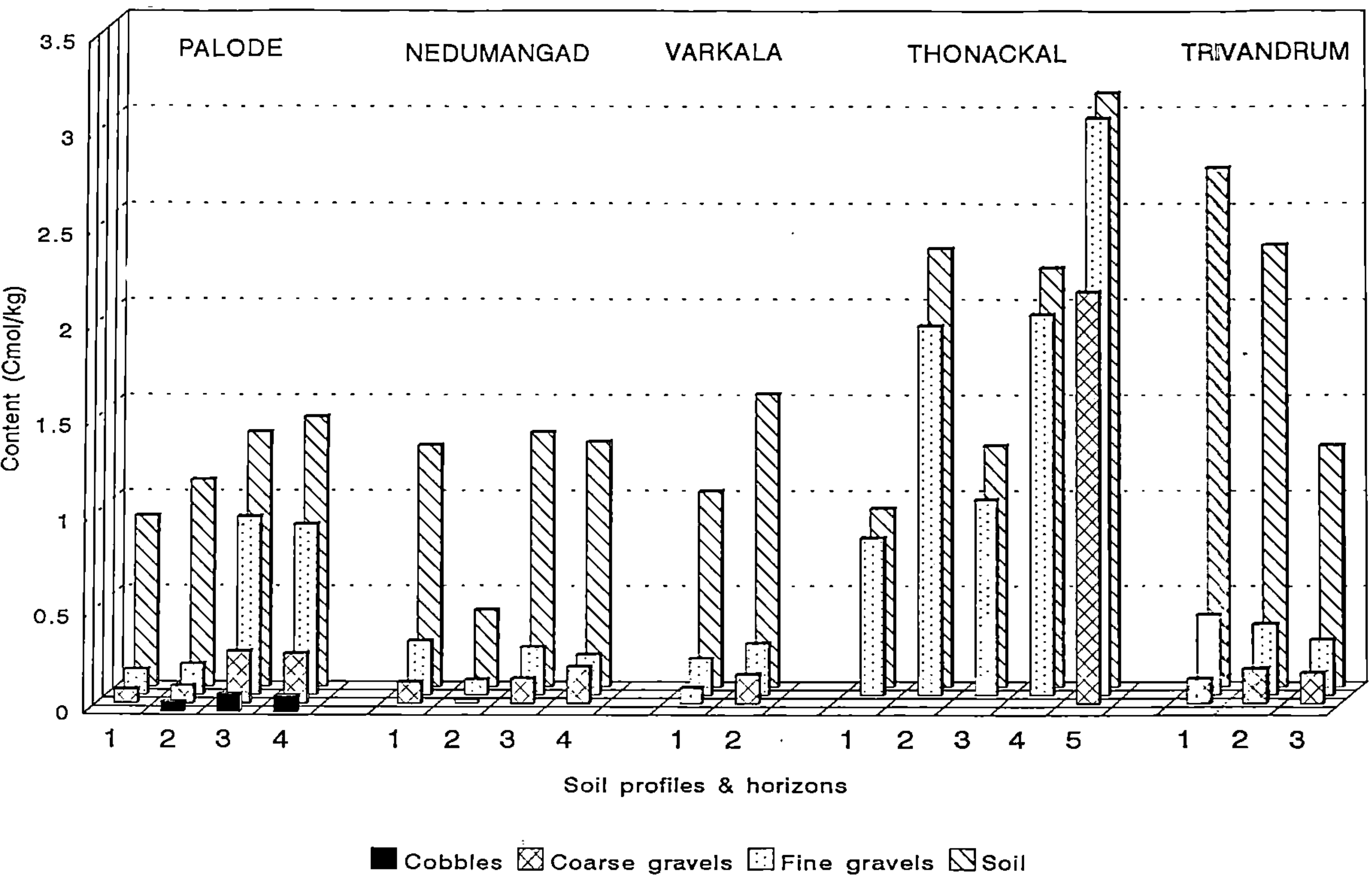


Fig. 6. Nutrient status of soils and gravels - exchangeable calcium

Grewal *et al.* (1984) reported a fast decline in the yield of sorghum fodder, slow decline in oil seeds and pulse crops, sesamum and cowpea with increasing gravel content. Maize was in between these two extremes. There was more than 50 per cent reduction in gross returns in all crops at higher gravel content as compared with low gravel content, except cowpea. His data indicate that sorghum and cowpea were relatively better crops in economic terms in inferior gravelly soils.

The yield of horticultural crops and strawberries were also inversely related to gravel content in the profile (Kongsrud, 1978).

The present studies pinpoint that the dilution of the soil mass due to gravels will result in low nutrient and water holding capacity thus causing reduction in rainfed crop yields. Some of the earlier workers (Babalola and Lal, 1977 a&b; Lamb and Chapman, 1943, Malmgren, 1960) have also confirmed that gravel dilutes both water and nutrient content of soils.

It can be inferred from the present study and the survey of literature that the leguminous crops with dense canopy like cowpea or drought resistant crops having vigorous fibrous root system like sorghum are likely to perform better on light textured gravely soils.

Nair *et al.* (1973) reported the lack of difference in the contribution by the gravel type to soil fertility. Present studies clearly establishes the

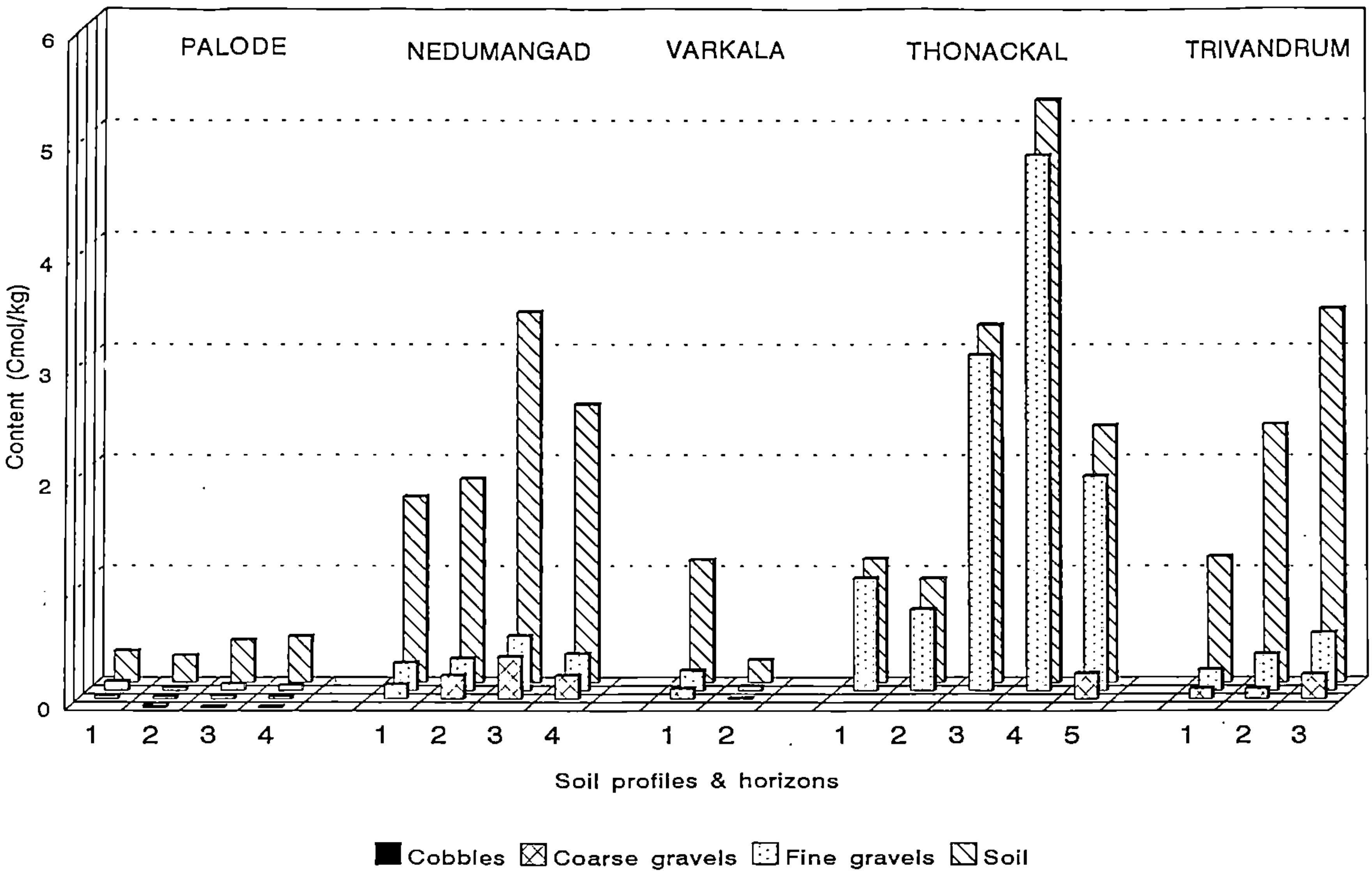


Fig. 7. Nutrient status of soils and gravels - exchangeable magnesium

size relational contribution to soil fertility, relative contribution by detrital gravels than pedogenic and geogenic ones and even differences in morphological types and internal fabric subtypes.

Takijima and Sakuma (1967) found that rice growth was depressed by a mixture of coarse sand and gravel and the roots were bent and thickened. Gravels depressed root growth up to 40 per cent and coarse sand upto 70 per cent.

Bouchard and Damour (1971) reported that subsurface gravel horizons in the Eastern Malagasy did not appear to limit the development of oilpalm roots.

Babalola and Lal (1977 a) reported that maize leaf nutrient concentration of nitrogen, phosphorus and potassium decreased with decreasing depth to the gravel layer.

The interaction of gravel size and matrix texture on plant growth in general and root growth in particular is not well understood. There are conflicting reports in the literature concerning the effect of gravels in soil on root development. Literature on leaf nutrient concentration with gravel content and depth to the gravel layer is limited.

The inhibitory effect of gravel size on root development was more pronounced for small rather than for large gravel size.

Based on the baseline information on the nature, distribution and fertility contribution of gravels, representative field experiments with the preferred crops of the area are to be conducted in these soil series to gather actual field situation and interaction of soil and gravel in the crop production.

SUMMARY AND CONCLUSIONS

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Soil gravels are geogenic and pedogenic features of ferruginous soils. The gravels present are different not only in their origin but also in their morphological, physical, chemical, and mineralogical properties. It is generally considered that the fertility contribution to crop production is by the fine earth fraction of the soil and usually the gravel or the coarser fraction contribution to soil fertility is ignored. They interfere with cultivation operations, reduce effective soil mass and available water.

The present study was undertaken to characterise the morphological, physical, chemical, mineralogical and micromorphological properties of the soil gravel fraction to reveal the pedogenesis and fertility contribution of the gravels in the Palode, Nedumangad, Varkala, Thonnackal and Trivandrum series.

The salient findings and observations of the investigation are presented below :

1. All the profiles studied were gravelly throughout, except the surface layers of Thonnackal.

2. The profile pattern of the distribution of gravels at Palode, Varkala and Trivandrum series shows an increase with depth while no specific profile pattern was observed at Nedumangad and Thonnackal.

3. The size ranges of the gravels considered were 2 mm to 2.5 cm, 2.5 to 7.5 cm and 7.5 to 25 cm. Palode series is unique with all the three gravel fractions and the cobbles seen were gneissic in nature. Cobbles were absent in all the other series.

4. Irrespective of the series, fine gravels are more than the coarse gravels.

5. All the soil series, except Thonnackal contained four morphological types of gravels in the increasing order quartz gravel < weathering parent material gravel < laterite *gravel* < ferruginous gravel.

6. Laterite gravel / ferruginous gravel, weathering parent material gravel and quartz gravel are the uniqueness of Varkala, Nedumangad and Thonnackal series respectively. Combinations of gravels different in genesis and morphology are present both at Palode and Trivandrum series.

7. The hardened plinthite gravel ie; the petroplinthite gravel is proposed in the soil taxonomy to differentiate Entisols and Inceptisols from Oxisols and Ultisols.

8. The proportion of the gravel fractions indicated similarity in their formation at Palode, Nedumangad and Trivandrum series with gravel consolidation at Varkala and their localised enrichment and aggregation in the lower layers of Thonnackal.

9. Gravels make up a considerable part of the matrix of the soils, except in the Thonnackal series where it was found to be less than seven per cent.

10. Due to the restricted pedogenesis and ferruginisation, gravels present in the Thonnackal series are concretionary.

11. Acid insolubles of the gravels are in the increasing order at Varkala < Trivandrum < Nedumangad < Palode < Thonnackal.

12. Acid soluble content increases in the finer fraction of gravels in the order Thonnackal < Varkala < Nedumangad < Palode < Trivandrum while in the coarse fraction, the maximum content was observed in Varkala and the least at Trivandrum.

13. Sesquioxide and total iron content of gravels were in the increasing order at Thonnackal < Palode < Nedumangad < Trivandrum < Varkala.

14. The gravel fractions of all the series investigated differ in their total nitrogen and phosphorus and potassium content.

15. The least content of total nitrogen was at Thonnackal and Trivandrum for the fine and coarse gravels, while their respective maximum was recorded at Nedumangad and Palode.

16. Though the maximum content of total phosphorus was recorded at Palode the minimum values were observed in the fine and coarse gravels of the Nedumangad and Thonnackal series respectively.

17. Maximum content of total potassium was observed in the gravels of the Palode series and the least content by the fine and coarse gravels of the Trivandrum and Thonnackal series.

18. Total calcium contribution of gravel fraction are similar and they are in the increasing order at Trivandrum < Palode < Nedumangad < Varkala < Thonnackal.

19. Higher values of total magnesium were reported by gravel fractions of the Thonnackal series and the least content by the Trivandrum series.

20. In all the series, acid insolubles, total nitrogen, total calcium and magnesium of the gravels are less than the corresponding soil fraction while acid soluble silica, sesquioxides, iron, total phosphorus and potassium of the gravels are higher than the respective soil fraction. This indicates the resistance of soil gravels as composite minerals towards weathering.

21. The observation of higher total phosphorus and potassium content of gravels is an important information as a potential source of phosphorus and potassium for crop production respectively for the coarser rooted perennial crops.

22. The comparative contribution to potential fertility by gravels for nitrogen is 1/4 th of the soil, while in the case of phosphorus and potassium it is about 1 1/2 to 2 times. The contribution of calcium by gravels are about half of the contribution by the respective soil fraction. However, the mean contribution of magnesium by both soil and gravel fraction is uniform in all the series.

23. The preponderant primary minerals of the soil and gravel fraction namely quartz and plinthite granules differ in their content among the different gravel fraction.

24. Quartz content of the fine gravels are in the increasing order at Varkala < Nedumangad < Palode < Trivandrum < Thonnackal, while that of the coarse gravels are in the increasing order at Thonnackal < Varkala < Trivandrum < Nedumangad < Palode.

25. The plinthite granules of the fine gravels are in the increasing order at Trivandrum < Thonnackal < Nedumangad < Palode < Varkala, while that of the coarser gravels are in the increasing order at Thonnackal < Trivandrum < Varkala < Palode < Nedumangad.

26. Goethite content of the gravel fractions were maximum at Nedumangad and least at Thonnackal series.

27. The quartz distribution of the soil fine sand fractions are in the increasing order at Varkala < Trivandrum < Palode < Nedumangad < Thonnackal.

28. In the soils plinthite granules were observed only in the soil fine sand fraction of second horizon of Varkala.

29. The other fine sand mineral of importance is ilmenite which are in the increasing order at Palode < Varkala < Nedumangad < Thonnackal < Trivandrum.

30. Palode and Nedumangad series contain multiglaebular coarse gravels and cobbles. Surface gravels are plinthic to petroplinthie while the subsurface gravels are concretionary and ferruginous to plinthic. There is little difference in the gravel morphology at Varkala, where it is dominantly nodular than concretionary.

31. The uniqueness of the Thonnackal series in the presence of rubefied less hard kaolinitic gravels with goethitic islands having runic quartz limpidity indicating its detrital genesis.

32. The gravels of the Trivandrum series are nodular, plinthic to petroplinthic with bigger angular skeletons and clear margined voids indicating them as fossil features.

33. Comparatively, all the series are with gravels of amiboidal, disjointed and digitate morphological types in the surface with pseudomorphic internal fabric except typic to geodic at Palode, Nedumangad, Varkala and Trivandrum and nucleic at Thonnackal. In the lowest horizons, they are digitate or aggregate in Palode and Nedumangad series with typic, geodic and pseudomorphic to geodic internal fabrics. At Varkala and Thonnackal, they are disjointed with geodic to nucleic internal fabric. The gravels at Trivandrum are disjointed and digitate with pseudomorphic internal fabric.

34. The preponderance of geodic internal morphology in the lower horizons and pseudomorphic in the surface horizons are direct expressions of geogenic and pedogenic origin of gravels. The observation of nucleic type of gravels in the lowest horizon of Thonnackal series is indicative of its detrital origin from microgravels of nearby higher landscapes.

35. The preponderance of quartz, both in the soil and gravels is obviously due to the acid igneous and metamorphic parent rock.

36. Comparatively, the available nitrogen, available phosphorus, exchangeable potassium, calcium and magnesium contribution by the fine earth fraction is higher than the different sized coarse fragments (gravels and cobbles).

37. Among the series, the comparative gravel contribution to soil available nitrogen is in the increasing order at Palode < Nedumangad < Thonnackal < Varkala < Trivandrum.

38. Varkala, Thonnackal and Trivandrum indicate a pattern of residual detrital soils while Palode and Nedumangad are comparatively with less *in-situ* weathering and release of available nitrogen.

39. The trend of other nutrients among the series are different. In the case of available phosphorus, exchangeable potassium, calcium and magnesium, they are in the increasing orders at Nedumangad < Trivandrum < Varkala < Palode < Thonnackal; Nedumangad < Varkala < Trivandrum < Palode < Thonnackal ; Trivandrum < Varkala < Nedumangad < Palode < Thonnackal and Trivandrum < Nedumangad < Varkala < Palode < Thonnackal.

A multilocational field experiment based on the nature, distribution and fertility contribution in these series is to be taken up to gather details in the actual field situation on the growth and performance of the preferred crops in the area.

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TRIVANDRUM DISTRICT

By

SURAJ JOHN B.Sc. (Ag.)

ABSTRACT OF A THESIS
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COLLEGE OF AGRICULTURE
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ABSTRACT

Soil gravels are different in their morphological, physical, chemical and mineralogical features; as well as in their origin. In the major soil series of Trivandrum district, soil gravel inclusions make up a considerable part of the soil mass. Presence of soil gravels interferes with the cultivation operations, reduce soil volume and quantity of available water. In soil textural determinations and the soil fertility evaluation, presence of soil component greater than 2mm is usually disregarded and ignored. In order to gather information on the nature and properties of soil gravels, their genesis and distribution and their specific contribution to soil fertility; an integrated and systematic morphological, physical, chemical, mineralogical and micromorphological characterisation and interpretation of soil gravels of the representative profiles of the major soil series of Trivandrum district namely Palode, Nedumangad, Varkala, Thonnackal and Trivandrum series were attempted.

All the series except Thonnackal were gravelly throughout; Palode, Varkala, and Trivandrum series showed an increase in gravel content with depth but no specific profile pattern was observed at Nedumangad and Thonnackal. Palode series is unique with all the different gravel fractions

(2mm to 2.5 cm, 2.5 to 7.5 cm and 7.5 to 25 cm). Another uniqueness of the Palode series is the presence of gneissic cobbles. Cobbles were absent in all the other series. Combination of grayels different in morphology and genesis are present at Palode and Trivandrum series. Gravel consolidation and soil hardening were observed maximum at Varkala series and least at Thonnackal series. Higher total phosphorus and potassium content of gravels indicate that gravels are the potential source of phosphorus and potassium for crop production.

Acid insoluble content of gravels are in the increasing order Varkala < Trivandrum < Nedumangad < Palode < Thonnackal. Acid solubles increase in fine fraction in the order Thonnackal < Varkala < Nedumangad < Palode < Trivandrum, while in the coarse fractions, the maximum content was reported in Varkala and the least by the Trivandrum series. Sequioxide and total iron content were in the increasing order Thonnackal < Palode < Nedumangad < Trivandrum < Varkala. The potential of gravels to supply nitrogen is $1/4^{th}$ of the soil while in the case of phosphorus and potassium it is about 1 1/2 to 2 times. The contribution of total calcium by gravels are about half the contribution by the respective soil while the mean contribution of total magnesium by both the soil and gravels are uniform throughout.

Quartz content of the finer gravels are in the increasing order at Varkala < Nedumangad < Palode < Trivandrum < Thonnackal while those for coarse gravels are in the increasing order at Thonnackal < Varkala < Trivandrum < Nedumangad < Palode. The plinthite granules of the finer gravels are in the increasing order at Trivandrum < Thonnackal < Nedumangad <Palode < Varkala, while that of coarse gravels are in the increasing order Thonnackal < Trivandrum < Varkala < Palode < Nedumangad. Goethite content of gravels fraction was maximum at Nedumangad and least in the Thonnackal series. Investigations on the soil fine sand mineralogy reveal that the quartz content is increasing in the soils of Varkala < Trivandrum < Palode < Nedumangad < Thonnackal. Plinthite gravels were observed only in the soil of the second horizon of Varkala. Ilmenite content increased in the order Palode < Varkala < Nedumangad < Thonnackal < Trivandrum.

Palode and Nedumangad series contain multiglaebular microgravels and multimicrogravelly coarse gravels and cobbles. The gravels of Varkala are dominantly nodular than concretionary. The uniqueness of the Thonnackal series is the presence of rubefied less hard kaolinitic gravels. The gravels of the Trivandrum series are nodular, plinthic to petroplinthic with bigger angular skeletons.

The preponderance of gravels with geodic internal morphology in the lower horizons and pseudomorphic in the surface horizons are direct expressions of geogenic and pedogenic origin of gravels. The observation of nucleic type of gravels in the last horizon of Thonnackal series is indicative of its detrital origin from microgravels of nearby landscapes. The preponderance of quartz both in the soil and gravels is obviously due to the acid igneous and metamorphic parent material. The hardened plinthite gravel ie., the petroplinthite gravel is proposed in the soil taxonomy to differentiate Entisols and Inceptisols from Oxisols and Ultisols.

The comparative gravel contribution to available nitrogen content of the soil is in the increasing order Palode < Nedumangad < Thonnackal < Varkala < Trivandrum; for available phosphorus, it is in the order Nedumangad < Trivandrum < Varkala < Palode < Thonnackal; for exchangeable potassium, in the order Nedumangad < Varkala < Trivandrum < Palode < Thonnackal; for exchangeable calcium, in the order Trivandrum < Varkala < Nedumangad < Palode < Thonnackal and for exchangeable magnesium, in the order Trivandrum < Nedumangad < Varkala < Palode < Thonnackal.

A multilocational field experiment based on the information gathered in the present study is desired to be taken up to reveal the effect of gravels on the performance of crops in the actual field situation.