

**INFLUENCE OF TOPOSEQUENCE ON THE GENESIS OF
MINERALS IN CLAY FRACTION OF SOILS DERIVED
FROM GRANITE-GNEISS**

A Thesis

by

T BHATTACHARYYA

**Submitted to the faculty of the Post-Graduate School ,
Indian Agricultural Research Institute, New Delhi,
in partial fulfilment of the requirements
for the degree
of**

MASTER OF SCIENCE

In

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

New Delhi

1980

**Division of Soil Science and Agricultural Chemistry
Indian Agricultural Research Institute
New Delhi 110 012
1980**

AUTHOR'S NOTE

I was thinking about my research and writing- writing research articles, other popular articles, different anecdotes, books, etc. Then I remembered that I had penned quite a few books, but interestingly, my first book was my M.Sc. thesis, which challenged my efforts and capabilities. But then I could do it. I could complete that by using hard labour and cooperation from many people.

My guide was a rigorous person. Unlike other M.Sc. students in IARI, I had to start my research work in the laboratory in the first trimester. No respite and no mercy. There was reason, of course. For clay mineralogy research, the starting materials are clays, not soils. And it takes a lot of time to separate clay from soil.

I completed my work. But right now, I have only a hard copy of it. And there's no soft copy. During 1980, the thesis used to be typed mostly on a Remington machine. And there was no scope for saving files as is a standard practice today.

So, I embarked on this new venture. I started typing my MSc thesis. It was a terrific feeling, you know. I was typing my thesis myself, and it is after nearly 45 years! So many people came flashing up: Mr. Aurora, the typist, my hostel colleagues, laboratory attendants, library staff, and many others. It wasn't easy at that time.

But now, sitting in my cosy study room, I am typing my first book. While typing, I realized how much pain my guide must have taken in assembling the thoughts of many researchers and their ideas on this aspect of my research work. Amazing! I also realized that, compared to my many project reports, my MSc thesis appears to be the most important and close to my heart.

I thought this work of mine should not be kept with me. I should share it with others. And hence this modest attempt.

Tapas Bhattacharyya

Nagpur, Maharashtra

18.04.2024

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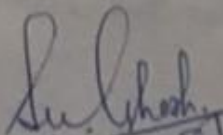
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CERTIFICATE

I hereby certify that the thesis entitled, "Influence of toposequence on the genesis of minerals in clay fraction of soils derived from granite-gneiss" submitted to the Faculty of Post-Graduate School, Indian Agricultural Research Institute, New Delhi-110012, in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE in Soil Science and Agricultural Chemistry by Shri Tapas Bhattacharyya, embodies the results of a bonafide research work carried out by him, under my guidance and supervision. No part of this study reported here has so far been submitted anywhere for any publication or for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of investigation has been duly acknowledged by him.


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My special thanks are due to my friends for their generous help.

I shall be failing in my duty if I do not express my regards to my parents, other relations and my school teachers for their love and encouragement.

The award of Junior Research Fellowship by the Indian Agricultural Research Institute is gratefully acknowledged.

New Dehi

Tapas Bhattacharyya

(T. Bhattacharyya)

August, 8th, 1980

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1. Introduction

The reactions leading to soil development are essentially an interaction of climatic factors of weathering on the reactant part of the soil material. The reactant part of the soil material complexes the unconsolidated primary minerals of parent rock and constitutes the mineral composition of the coarser soil fractions, namely sand and silt. The resultant effect of this pedogenic process is the production of clay fraction, which accumulates in some stable form under a given weathering condition.

Therefore, the soil clays bear the impression of climatic factors of weathering and that of parent material provided that the former has not overshadowed the latter's effect. The weathering reaction is a function of time, and the reactant material of the soil changes its character over time so that at a certain point in time, the parent material may be entirely different from what it was initially during the process of soil development. The climate thus becomes ultimately the major determinant of the soil character. The physically weathered rock fragments constituting the coarser soil materials continue to feed the reactable soil material to weathering. Hence, though climate is the dominating factor in determining process of weathering, formation and accumulation of minerals in clay fraction is still the function of both the climate and the water stable primary minerals of the sand and silt fractions.

The role of the skeletal materials of soil is to maintain on supply the requisite ionic environment and to stabilize the minerals in the clay size fractions. The denudation of the proper ionic environment may bring about instability of minerals in the clay. The minerals in the clay fraction then would act as reactant material under the weathering stress and would itself undergo further decomposition or alteration to other types of minerals which is stable

under the changed environment. The proper role of ionic environment as determinant of clay mineralogy of soil has been fully discussed elsewhere (Grim, 1968). The other possible role of the primary minerals is its ability to directly change into clay minerals under the hydrolytic action of weathering processes. Hydrolytic decomposition of primary aluminosilicate minerals has amply been demonstrated by others (Grunner, 1944; Brindley and Radoslovich, 1956; Garrels and Howard, 1959; Meyer and Hemley, 1959).

The effect of topography or configuration of land in the formation of soil profile is an already established fact. In an undulating landscape where the parent material and the climate do not change appreciably very conspicuous difference in the soil profiles on the ridgetop, on the slope and in the valley, floor may result from their situations. This is due to the differential drainage and run off conditions which affect the amount of water that reaches the site of the reaction and the various coarse and fine materials and also soluble matter that might be carried by the water moving through or over the soil. In such microrelief, therefore, local types of soils are formed that differ in their morphological, physical and chemical properties from those of the prevailing types (Bushnell, 1942).

Weathering of rocks, resulting into different types of products is governed by different factors as outlined in the state factor equation (Jenny, 1941, 1961)

$$S = f(r, cl, o, p, t, \dots),$$

where S denotes any of the soil properties, which is a function of the state factors like relief, climate, organisms, parent material and time and also other unspecified factors like erosion, dust storms etc. Furthermore, the contribution of any state factor to the variation of any soil property in a chosen landscape becomes negligibly small either if the range of the state factor is narrow (constancy of the factor in that area) or if its effectiveness is small. The latter

case becomes important for field studies as here the factor need not be kept constant. It is always possible to select in a region a series of soil profiles for which the contribution of one single state factor outranks the combined contribution of all the factors. Such systems provide pedogenic functions that are valuable and most effective in studying soil genesis and in understanding the behaviour of soils in relation to plant growth.

In fact, topographic position in combination with other factors of soil formation greatly influence the pedological processes that cause the soil differences. Variations in soil properties between the landscape units are related to taxonomic soil classes and have significant meaning in terms of land use and land management. Study of the topo-sequence may be a usual tool in developing mapping legends for soil surveys. Potential soil map units which may correspond to landscape units in a topo-sequence can be predicted with a certain degree of accuracy by characterising and classifying selected pedons in each landscape unit. This is achieved by careful interpretation of the pedological expressions and classification in relation to landscape and the other soil forming factors prevailing in the area. In this regard. Topo-sequence studies may be a useful aid in designing more realistic soil mapping legends in order to facilitate soil survey maps better and more diversified technical groupings of soil mapping units (Valmidiano et al., 1977).

In the present study, however, an attempt has been made to classify the pedons, to elucidate the nature of minerals and amorphous constituents in clay-sized fraction, their genesis with necessary physical, chemical and physico-chemical characterization. The soil samples were collected from red soil area of Bangalore district (Karnataka) selecting three situations, one from 2900 ft above msl (Pedon 1), other from 300-350 ft msl (Pedon 2) and the last one from 270 ft above msl (Pedon 3).

Keeping in view the importance in pedogenic investigation, the present study was oriented to achieve the following objectives:

- i. to classify the pedons in the topo-sequence on the basis of their morphological, physical and chemical characteristics according to Soil Taxonomy (1978),
- ii. to study the effect of relief on the genesis and transformation of minerals in soil derived from granite-gneiss, and
- iii. to study the genesis of amorphous constituents in these soils as influenced by relief and parent material.

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2. REVIEW OF LITERATURE

The red soils, comprising red loams yellow earths, occupy about 2,00, 000 square miles. These soils cover large parts of Madras, Mysore, north-east Andhra Pradesh (old), the tract running along the eastern part of Madhya Pradesh to Chhotonagpur and Odisha. They are also commonly found in the Santhal Parganas of Bihar, Birbhum, Bankura, and Midnapur districts of West Bengal; Khasi, Jaintia, Garo and naga Hills of Assam; Jhansi, Banda and Hamirpur districts of Uttar Pradesh (old); and the territory east of Aravali Hills in Rajasthan (Handbook of Agriculture, 1969).

On a rough estimate Mysore state has about 21500 square miles under red soils. There may be rich soils as is observed in Bangalore and Tumkur districts or the gravity type as found in parts of Mandya and Tumkur districts or pale brown types as found in the Kolar district, red sandy loams as found in Mysore and Hassan districts. The colour of these soils changes from place to place, bright red to yellowish brown and is dependent on the presence of hydrated oxides of iron. These soils permit free lateral and downward movements of water. The depth of these soils vary much as is observed in parts of Mandya district where it is only few inches, while it extends to several feet as in the Bangalore district (from where the profile samples were collected for the present study) (Raychaudhuri et al., 1963).

Parvathappa and Durairaj (1968) studied the profile characteristics of red soils of Mysore state with the elevation varying from 1100-3750 ft and rainfall varying from 56-147 cm. The demarcation between different horizons was clear and smooth in most of the cases. The depth of the profile varied from 23 to more than 100 inches. The average depth of first, second and third horizon was 11. 15

and 26 inches respectively. A fourth horizon, they could find only in two profiles which was kaolinitic. The colour of the profile was red, although it slightly varied from profile to profile. Texture of first horizon was mainly loamy tending towards sandy or clayey textures predominating in the lower horizons. The soil reaction indicated these soils to be neutral to slightly acidic.

All the red soils are classified as Alfisols as they satisfy the conditions laid out i.e. i) they are all mineral soils that have no spodic or oxic horizon overlying an argillic horizon; that have no mollic epipedon; that have no surface and an upper sub-horizon or natric horizon; ii) they have no fragipan but have an argillic horizon; iii) all horizons have base saturation > 35 % throughout the profile.

Krishnamoorthy (1969) classified the soils of Mysore state, he studied as Typic Rhodustalfs and Typic Natrixeralf on the basis of information obtained by him. The data obtained by Murali et al. (1974) from the well-drained, reddish and very deep soils of Mysore State led to classify the soils as Udic Paleustalf.

Some relevant literature on the following aspects of red soils is reviewed.

- A) Physical, chemical and physico-chemical characteristics
- B) Clay mineral formation during weathering of granitic parent material under tropical condition.
- C) Mineral distribution in clay, silt and sand fractions.
- D) Genesis and transformation of clay minerals as related to topography.

2.1. Physical, chemical and physico-chemical characteristics

Robinson (1936) stated that the red soils with low $\text{SiO}_2/\text{R}_2\text{O}_3$ ratios are formed under condition of free drainage and low base status. He reported black and red soils developed on coral limestone in Barbados and pointed out that red soils occur in districts of highest altitude and greatest rainfall, whilst the black soils occur in the drier low lands.

Ramaih (1937) reported that the red soils are rarely rich in clay and possess a $\text{SiO}_2/\text{R}_2\text{O}_3$ molar ratio of about 2 in their clay fraction. These soils correlate well with the nature of clay minerals present in the respective soils. They are also poor in organic carbon and C/N ratios are somewhat lower than the corresponding black soils.

According to the Annual Report of research and experimental work carried out by Hyderabad State Department of Agriculture (1940), $\text{SiO}_2/\text{R}_2\text{O}_3$ ratios for clay fractions of red soils were between 2.3 and 2.5. A study of the ratio in soils indicated a great variation, quite likely due to the varying amounts of fine sand in the samples taken for analysis. Hence, comparison of the ratios in clay fractions gives a true picture.

Desai (1942) reported that although equally high in silica content the red soil is more ferruginous and is higher in alkali content, especially potash.

The per cent of clay fractions were reported to be less in red soils than in the black soils at corresponding depths (Raychaudhuri et al., 1943). They also reported the low ratio of $\text{SiO}_2/\text{Al}_2\text{O}_3$ (2.10-2.96) and $\text{SiO}_2/\text{R}_2\text{O}_3$ (2.08-2.24), both of which increase with depth.

The red soils have generally neutral in reaction, with a tendency to develop acidity than alkalinity. The soluble salt content is low. They are poor in organic matter and nitrogen but are moderately supplied with potash. The nitrogen content is rarely below 0.1 % and, in some cases, up to 0.5% or more. They are rich in total and available K_2O (Raychaudhuri et al., 1963).

Gawande et al. (1967) reported low $\text{SiO}_2/\text{R}_2\text{O}_3$ and $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios in the clay fractions of upland soils in Chhattisgarh basin, exhibiting highly weathered character.

Chemical analysis of the soils studied by Roonwal et al., (1968-69) indicated the accumulation, in the lower horizons, of iron oxides, aluminium oxides and

silica and this is a feature of high leaching processes. Thus, the accumulation of Al_2O_3 and Fe_2O_3 in the lower horizons appears to be due to the downward movement, rather than the weathering of silicates.

The two soils of the Mysore state studied by Murali et al. (1974) were slightly acid, had low content of organic matter, low cation exchange capacity and had high amounts of clay and sand.

The different morphological characteristics as affected by topography of six profiles in a topo-sequence were described by Manickam et al. (1973). The profiles in the upper reaches exhibited dark colour, shallow depth, coarse texture, massive structure, absence of CaCO_3 , good permeability, poor plasticity and stickiness while the profiles of the lower reaches exhibited comparatively light colour, heavy texture, weakly developed prismatic structure, presence of CaCO_3 and poor permeability. Thus, the differences in the various morphological properties observed were attributed to the change in the morphology or relief.

Three soil profiles representing a topo-sequence developed under warm and per-humid climatic conditions in Himachal Pradesh were studied by Sehgal (1974) and their physico-chemical characterisations were made. It was revealed that the soils on the uplands have attained a higher degree of weathering as indicated by red colours, deep textural B horizon and low base status than those in the valleys where the soils have greyish colours and high base status. The soil on slope slopes has brown colours, shallow textural B horizon and relatively high base saturation.

Adams et al. (1975) reported an initial increase in profile silt and clay content which was followed by a decline in both fractions with a corresponding increase in the sand fraction.

2.2. Clay mineral formation during weathering of granitic parent material under tropical condition

Boul (1978) in discussing the weathering of acidic rocks stated,

“Granites and granite-gneiss average approximately 25% quartz, 65% or less orthoclase (potassium feldspar, with lesser amounts of hornblende. These rocks may show slight differences in weathering pattern due to differences in structure-the gneissic being banded, with mineral segregation in the bands. Basically, though, they tend to produce the same kinds of soils. Soils formed from saprolite derived from these rocks by geochemical weathering tend to be coarse (coarse-loamy), especially in surficial horizons. Clay mineralogy in these soils tends to be highly kaolinitic in warmer, more humid climates.”

The mineral at first and direct formation from the plagioclase feldspars is gibbsites. Under tropical conditions, acidic rocks, such as granites and granite gneisses, do not undergo primary laterisation, but gradually change through katamorphism into pipe or pot-clays, or more or less quartziferous and impure kaolins. Granites or other rocks dominated in composition by feldspars, hydrolyse inherently at a lower abrasion pH than those containing mafic inosilicates; this would predispose them towards kaolinization rather than direct bauxitisation. Another factor which may be highly significant is the common presence of K in the feldspars of granite. Apparently, the presence of K in reacting alumina-silica gels facilitates the formation of muscovite mica, which appears to weather preferentially to kaolinite (Harrison, 1934).

Hough and Byres (1937) found that with low rainfall of 500 mm, the weathering was not sufficient to hydrolyse silicates to halloysites type while between 2000-2500 rainfall range, the hydrolysis extended to the end member of the series or the allophane type.

Hosking (1940) stated that granite type of parent material will weather to kaolinite or halloysite under very wide range of climatic conditions. Soils with

good internal drainage, whether formed on granite or basic rocks, are both characterized by kaolin mineral formation. Granite gives creamy colour while basic rocks yield a distinctive red-brown shade to the clay.

When sufficient silica is available, under the influence of wetting and drying, silica reorients unidirectionally to form a hexagonal silicate sheet coordinated with the sheet structure of gibbsite resulting in a kaolin type mineral (Tamura and Jackson, 1953).

That gels (with narrow $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio at pH 3 and later become high about 11 at pH or above) become allophane and then pass through the sequence metahalloysite to kaolinite in soil clays derived from weathering of rhyolitic or andesitic ash, has been reported by Fields (1955) New Zealand.

Watson (1954) observed amorphous material (probably allophane) and gibbsite to be predominant constituents in the clay fractions at early weathering stage of granite, while kaolinite was the dominant clay mineral in later stages of weathering. Kaolinite, according to him was probably formed either by resilication of gibbsite or by alterations of amorphous material to halloysite and then to kaolinite. The earlier development of gibbsite and later formation of kaolinite may be due to differential rate and independent course of synthesis of the two minerals.

2.3. Mineral distribution in clay, silt and sand fractions

Very little information is available on the mineralogy of the soils of Mysore. The data available for the classification of these soils are little. Studies on the mineralogy of Indian soils hitherto reported have generally been qualitative based on X-ray diffraction and DTA.

Bagchi (1951) found that the clay fraction of red and lateritic soils in India are dominated by minerals of kaolinitic nature. Red soil clays from Coorg in Mysore State derived from acid igneous rocks were studied by Ghosh et al.

(1962). They found kaolinitic to be dominant with halloysite and the associated minerals were 14 A⁰ mineral and hematite. In some cases of Shimoga district of Mysore the clay of the red soil developed on blue granite was described to be dominantly montmorillonitic in association with chlorite (possibly chloritized montmorillonite), illite, and kaolinite (Das and Das, 1966).

Ghosh and Das (1963) observed that in addition to kaolinite and hydrous mica some amount of 2:1 lattice type mineral interlayered with iron and aluminium hydroxide was present in the red soils of Ranchi (Bihar, *now Jharkhand*). Presence of montmorillonite in red soils (Mysore) was supported by Anjaneyulu et al. (1965).

Biswas et al. (1966) found illite as the dominant mineral in the soils on the upper and the middle slopes in the catenary sequence of soils developed on granite-gneissic parent material in Kurnool district, whereas montmorillonite predominated in the dark grey soils at the base. Montmorillonite content increased and kaolinite content decreased down the slope.

Kaolinite was found to be dominant mineral in soil clays from Bankura, and Birbhum districts of West Bengal (Ghosh and Datta, 1972). Red sandy soils of Odisha were mainly kaolinitic (Datta and Adhikari, 1972; Sahu and Nanda, 1972; Das, 1972). The red soils of Mysore State were reported to contain mostly little with some amount of kaolinite (Ramkrishnayya, 1971).

Among other minerals. Quartz was found to be dominating in the sand fractions of soils studied by Raychaudhuri et al. (1943) near Coimbatore. Iron oxide minerals were also present in the sand fractions.

Murali et al. (1974) studied the quantitative mineralogical composition of the clay fractions of two red soil (Alfisols) profiles developed on the gneissic rocks in Mysore. Data on the mineralogy of their silt and sand fractions were also

presented. both the silt and clay fractions were kaolinitic and contained considerable amount of amorphous materials.

Mineralogy of clay, silt and sand fraction of two acid soil profiles was investigated to elucidate the genesis of minerals in clay fraction by Ghosh and Das (1976). Data provided in their study indicated that the clays from both the soils were characterised by dominance of kaolinite and halloysite in them. A non-expanding 14A⁰ mineral and hematite were constituents in both the clays. Quartz was the dominant mineral in the silt fraction of both the soils. Chlorite and 7 A⁰ group of minerals were the other constituents. Hematite was an additional component in the silt of the laterite soil. The fine sand and silt mineralogy indicated the intense weathering of the profiles. The authors concluded that the kaolinite in the clay appeared to be the product of feldspar weathering in general and halloysite that of plagioclase weathering. The non-expanding 14 A⁰ minerals seemed to be a product of hydrolysis mica and its subsequent diagnostic change to chlorite and further degradation in a weathering environment rich in iron and magnesium.

The clay fractions of the soils of two topo-sequence derived from gneissic rocks in Southern India consist chiefly of kaolinite and amorphous ferro-aluminosilicates (AFAS). Considerable amounts of smectite were present in the clays of soils on the toe slopes (Murali et al., 1978).

Pal and Roy (1978) characterized some red and laterite soils in topo-sequence and concluded that the clay of these soils was a mixture of illite and kaolinite in the ridgetop but more of smectite was present in the lower part of the slope and in the valley.

The coarse sand fraction of a red earth consisted mainly of quartz and feldspars, with quartz predominating. The feldspars were highly decomposed and strongly stained. Iron oxides, hornblende and rock particles were also

present. The feldspars content was much higher than in the black soil. The fine sand fraction consisted largely of quartz. Feldspars, both oligoclase (including microcline) and plagioclase varieties, brown mica which is slightly bleached, decomposed hornblende, iron oxides, zircon, and black grains from nodules were the other minerals present (Desai. 1942).

Light fractions of sand in red soils derived from gneissic complex parent material are quartz-dominant. Feldspars are in slightly greater quantity than in the associated black soils with orthoclase feldspars dominating in the red soils. Mica content is similar in both the soils. Surface layer of red soil is characterized by total absence of hornblende; hypersthene being present in higher quantities than in bottom layer. Plagioclase feldspars is completely absent in the bottom layer of red soils. Red soil is also characterized by a high per cent of limonite (Parthasarathy, 1959).

2.4. Genesis and transformation of clay minerals as related to topography

That the topography or configuration of the land plays an important role in the formation of a soil profile is a well-known fact. Topography (relief) implies relative elevation and it includes land features such as slope, exposure, position in the landscape etc. It influences soil formation through its effects upon drainage, run-off and erosion and secondarily through variations in exposure to the sun and wind.

In an undulating where the climate and parent material do not alter appreciably a very significant differences may be encountered in the soils at ridgetop, mid pediment and in the valley. This occurs due to the differential run off and drainage pattern in that area owing to the position in the landscape and the different types of materials, soluble salts and other ions moving through or over the soils. As such, due to localised effects of micro-relief soils are formed

that differ in their morphological, physical, and chemical properties from those of the prevailing types (Bunshell, 1942).

Hardy (1935) studied soil genesis from different rocks under humid tropical conditions. He pointed out that granite gives rise directly kaolinitic earth, containing detrital quartz grains together with varying amounts of hydrous oxides of iron, which if abundant may cause the mass to closely resemble red earth derived indirectly from basic rocks.

That the laterite soils develop under wet and dry periods and red loam is supposed to be formed under more or less dry weather with evenly distributed rainfall was the concept given by Sen (1938).

Under high temperature conditions a loose porous material continuously leached with warm water without organic matter in solution gives rise to the products usually termed 'laterite' or 'lateritic' soils. In this type of weathering iron and aluminium hydroxides are left behind and with alternating wet and dry periods these are irreversibly oxidised and thus impart to the soil its red colour which is mainly due to the iron oxide (Mohr, 1933).

Desai (1942) studied the red soils situated at slopes and in well-drained position of the plateau (Medlicott et al., 1893; Menchikovsky, 1932; Morison, 1935; Basu et al., 1938; Viswanath. 1939) and the associated black soils and stated that the red soils are strongly leached and this progressive leaching will eventually lead to introduction of exchangeable hydrogen into the exchange complex.

The importance of efficient, effluent drainage was shown by the observation of Mohr and van Baren (1954) that lateritic and montmorillonite were formed a short distance from each other from the same parent volcanic material and in the same climate, except that the laterite site was well drained, while the montmorillonite site was water logged and silica and metal ions were not

removed. Good drainage may high relief of the land, steep slope and high permeability of soil.

Biswas et al., (1966) in studying the characteristics of catenary soils of granite-gneiss parent rock in the Kurnool district of Andhra Pradesh (old) emphasised the importance of topography in creating differences in external and internal drainage conditions resulting in the variation in soil properties. They observed illite as dominant clay mineral in the upper and middle profiles of the slope while montmorillonite was dominant in the profile at the base. Montmorillonite content increases and kaolinite decreases down the slope. Similar conclusions were drawn by Gawande et al., (1968) from studies of catenary soils of sedimentary formation in Chhattisgarh basin in Madhya Pradesh. They, however, observed that in these soils illite in the upland profiles was mostly degraded, which was considered to be due to excessive leaching condition encountered in the upland.

Goss et al. (1968) studied two soils developed in granite in Texas, one excessively drained (Click) and the other somewhat poorly drained (Bauman) to determine the effects of topography upon their genesis and resulting mineralogy. Heavy mineral data indicated that the soils were developed from relatively homogeneous parent materials. Clay mineralogy of both soils was mixed but that the fine clay of the Bauman soil is dominated by montmorillonite that increases with depth in the profile. The fine clay of Click soil apparently contained near equal portions of kaolinite, illite, montmorillonite and X-ray amorphous materials. Appreciable exchangeable sodium was present in the sub-soil of Bauman profile but was essentially absent in the Click soil. Soluble weathering products from surrounding slopes have moved laterally at the soil unweathered granite interface and accumulated in the Bauman soil thereby

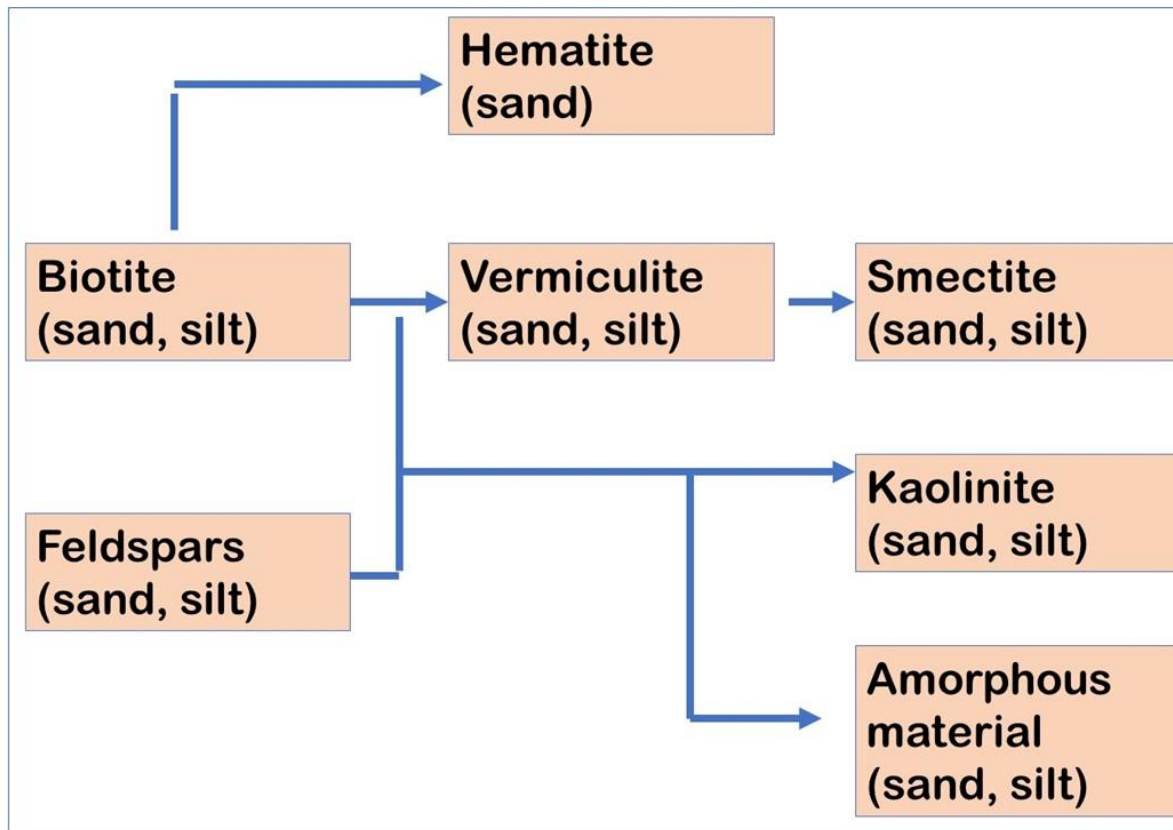
causing its morphology and clay mineralogy to differ markedly from that in the better drained soil.

Nettleton et al, (1968) studied a topo-sequence of soils in Southern California and the differences observed in the soil properties and in the pathways of mineral weathering were explained by the effect of topography on soil moisture relations in a climate of marked alteration of wet and dry seasons.

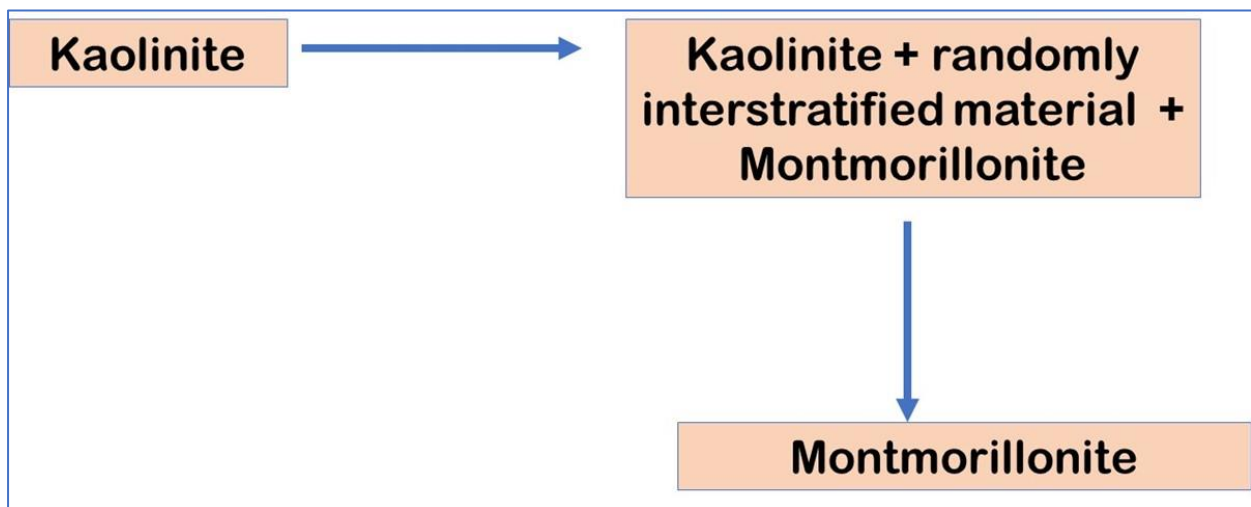
Four profiles of a topo-sequence were studied by Escobar et al. (1972). Two profiles (developed on sandstone on the lower part of the sequence) were reported to be less weathered containing less kaolinite with vermiculite, montmorillonite, allophane and mica; while the other two profiles (on igneous basic rock in the upper part of the sequence) contained high amounts of kaolinite and gibbsite together with allophane, mica and vermiculite.

Ghosh and Das (1973), while discussing the mineralogy of red and laterite soils from Coorg, stated that intense weathering of gneisses syenite and mica schists under humid tropical condition in a weathering condition low in basic cations, led to the formation of kaolinite and halloysite as dominant mineral in soil profile. They could also show the almost extinction of both the feldspars in the profile in such a weathering environment. The similar, idea one could get from the work of Datta and Adhikari (1968a, 1969).

Murali et a. (1974) from a study of the mineralogy of Alfisols profiles developed on the gneissic rocks in Mysore, suggested a possible weathering sequence and transformation of the minerals.



Deep weathering in the upper layer of basalt floors have given rise to lateritic profiles with a surface cover of leached red clay soils overlying ferruginous and mottled zones. A soil catena of six zones with associated plant communities developed in this landscape. Soli differences are related to differences in intensity of weathering, leaching, translocation and precipitation of differentially soluble and mobile constituents of the parent rock. The clay mineral sequence is below. Plant community distribution is closely associated with variations in soil properties (Gunn, 1974)



A topo-sequence of soils on the plateau and slope of the 'Planatto Medio' of Rio Grande do Sul was described by Klam (1972). The soils of the plateau have developed from basic igneous rocks and sandy material, while those on the slopes are derived from the basaltic substratum and stored materials from the uplands. The slope soils were reported to be less highly weathered and more fertile than the plateau soils.

Clay mineral analyses of Caribbean soils were illustrated with the differences in composition that can arise from differences in topography and parent material. Main differences that the alluvial soils do not contain montmorillonite whereas in the soils of Central range and Southern Lowlands which are residual materials, montmorillonite is usually the major constituent. A few profiles showed little or no change in mineralogy with depth suggesting that differences between profiles are due to different parent material and are not a result of weathering in situ. They concluded that in the alluvial environment there may be clay minerals weathered to kaolinite; even taking samples from old alluvium they found only kaolinite and quartz suggesting more maturity of the soil (Beaven, 1966).

A chrono-topo-sequence of five soils formed in strongly weathered granite in the South Island of New Zealand was described on the basis of soil profile morphology, landscape position and the degree of weathering of the underlying granite (Adams et al., 1975). Changes in a number of chemical and physical soil properties were described with the increasing soil development (i.e. increasing weathering and leaching) represented in the sequence properties. An initial increase in profile silt and clay content was followed by a decline in both fractions with a corresponding increasing in the sand fraction. Proportions of kaolinite/metahalloysite initially increased and 2:1 -2:2 Al-intergrades decreased, but in the final these sequence profiles had similar clay mineralogies with kaolinite/ metahalloysite being the main component.

Prasad et al. (1977) further that in the soils of Junagadh area influences of differential parent material has been counteracted by the physiography of the area and bioclimatic forces, resisting in the intermixing of soils obliterating the characteristics inherited from the parent rock.

Three types of topo-sequence are predominant in Togo, consisting of ferrallitic/ferruginous soils, ferruginous/poorly differentiated montmorillonite soils and the later soil type only. These sequences occur on slopes varying in steepness and altitude and their development is discussed in terms of the migration and kaolinite downslope, surface mixing, caused mainly by termites, has affected all soils and led to marked contrast of the B_{fe} concreted horizon. Removal of fine fractions from the upper horizons, structural reorganisations of weathering products and improved drainage in the upper part of the profile (Leveque, 1976).

Krishnamoorthy et al. (1977) studied the associated red and black soils of Andhra Pradesh (old) and stated that in spite of constancy of climate and parent material (granite-gneiss) the developed soils behaved differentially so far, their

different properties are concerned and hence attributed these differences to minor differences in parent material mineralogy and topography.

Topography or more specifically micro-relief alone was observed to influence soil development to the extent that the soil profiles on a single slope were classified differently (Gawande and Biswas, 1977). They observed that the depth of solum increases with decreasing slope. In this trend of decreasing slope black colour intensity increases, structure changes from granular to cloddy, texture from clay loam to heavy clay and also soils at the bottom of slope have poor drainage.

Valmidiano et al. (1977) studied the soil-landscape relationships in a volcanic zone of Philippines. The upper part of the landscape contained large amounts of amorphous materials, as indicated by their swery consistency, have high CEC, low base saturation, low bulk density and exceedingly high water retention properties that are attributed to the nature and age of the parent material and to the prevailing high rainfall. None of the soils in the broad river flood plain were reported to have properties suggesting an abundance of amorphous materials. These soils as described, had a higher base saturation, higher CEC and lower moisture retention than soils of the upper parts of the plain. Authors explained that the allophanic materials might have undergone weathering and synthesis prior to their redeposition on the lower elevation landscape units. Topographic position in combination with other factors of soil formation greatly influenced the pedological processes that brought out the soil differences.

Pal and Roy (1978) studied the characteristics and genesis of some red and lateritic soils occurring in topo-sequence in eastern part of India. With climate and parent material (granite-gneiss) remaining more or less same they could trace the effect of drainage and topography so far as the formation of soil in that

zone is considered. From ridgetop through mid-slope to the valley floor there is a gradual change in all the soil properties due to the topographic situation which has also influenced the genesis of the clay minerals.

2.5. Weathering sequence and clay minerals

Jackson et al. (1948), by introducing the concept of weathering sequence hold the view that a primary mineral is weathering directly to a secondary particle being a more or less closed system. Observation of secondary colloidal pseudo morphosis after primary parent crystals are assumed to establish this binary transformation is a fundamentally sound view. The weathering sequence as given by Jackson is as follows

Weathering Stage	Symbol	Typical clay-size mineral's
1.	Gp	Gypsum (also halite, NaNO ₃ , NH ₄ Cl etc)
2.	Ct	Calcite (also dolomite, aragonite, apatite)
3.	Hr	Olivine-hornblende (also pyroxenes, diopside)
4.	Bt	Biotite (also glauconite, nontronite etc)
5.	Ab	Albite (also microcline)
6.	Qr	Quartz (also cristobalite)
7.	Il	The 10 A ⁰ zones of illite and sericite (also muscovite and other dioctahedral micas)
8.	Vr	Vermiculite (also 2:1, 2:1 to 2:2 layer silicates where the brucite component is primarily ferromagnesian)
9.	Mt	Montmorillonite (also beidillite)
9.	Ig	Pedogenic 2:1 to 2: 2 intergradient mintmorillonite-vermiculite-chlorite
10.	Kl	Kaolinite (also halloysite)
11.	Gb	Gibbsite (also boehmite)
11.	Alo	Allophane
12.	Hm	Hematite (also goethite, limonite)
13.	An	Anatase (also zircon, rutile etc)

With each stage is associated a group of minerals (as shown in brackets above) having similar though not identical weathering stabilities. Indices like different molar ratios namely SiO₂/R₂O₃, SiO₂/Al₂O₃, SiO₂/Fe₂O₃, silica: different bases etc

have been used in the past for evaluating and characterising different soil for weathering stage (Harrassowitz, 1926; Jenny, 1931; Marbut, 1935). But a weathering mean based on the weighted average of the weathering stage of minerals present, offers a sensitive measure of the degree of weathering of soil minerals, and it is particularly more sensitive in stages 4-9 than are molar ratios (Hseung and Jackson, 1952; Jackson, 1948). This weathering mean is sensitive to changes in layer silicate weathering stage wherein, as pointed out by Marshall (1935), the silica: sesquioxide ratio is not. It is well to reemphasize that in both the geographic and the soils are still the products of chemical weathering. Although the colloidal minerals present in a soil or soil parent material must certainly be a function of the weathering to which the material has been subjected, that weathering need not necessarily have taken place in its present site or present environment, nor need it necessarily be correlated with present soil formation. Thus, the field of chemical weathering of soil minerals involves many aspects which are distinct from the field of soil formation, though the two fields have some aspects in common (Jackson et al., 1953).

Ghosh et al. (1974) reported the frequency distribution curves of minerals in clay fraction for two lateritic soil profile and one red soil profile from Midnapore, West Bengal. All the curves were characterized by two distinct peaks, one at 7th stage and the other at 10th stage of weathering. The weathering means in these profiles varied from 8.86 to 9.82.

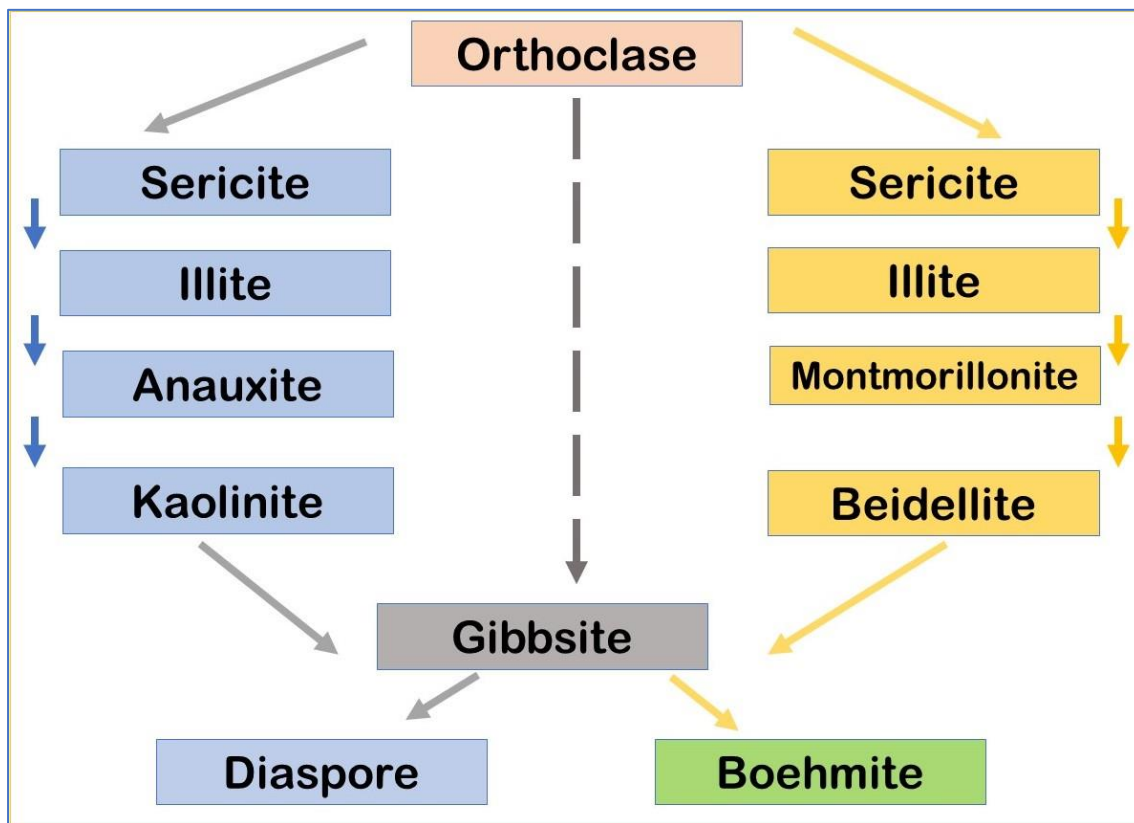
Murali et al. (1974) studied mineralogy of two red soil profiles of Mysore State and the frequency distribution curves obtained for both the profiles were characterized by a weathering mean of 9.70. Murali et al, (1978) studied clay mineral distribution in two topo-sequences of Mysore soils and the frequency distribution curves of all samples showed a dominant peak at 10 except for the

profile on foot slope where smectite was a dominant mineral rather than kaolinite, The weathering means were in a narrow range of 9.16-9.74.

One of the most important observations of Campbell (1971) is that iron oxide accumulates in that position of the soil which is alternately dry and wet owing to the oscillation of the water table. The hydrated aluminium silicates and possibly free alumina accumulates in the zone which is continuously wet. Thus, in the equilateral regions which have alternating wet and dry conditions, one would expect to find the ferruginous laterite and in the tropical rain forest one would expect to find the tropical soils rich in aluminium. This has been suggested by Sherman (1952b) in his report on the genesis of alumina-rich clays of the tropical regions.

Marel (1947) has made extensive observations on the relative stability of magmatic minerals, when weathering conditions and particle size are kept equal. He found that rhyolitic tuft contained 42% of amphibole in the heavy fraction, the slightly weathered material contained 32%, the moderately weathered contained 14%, the strongly weathered 5% and the very strongly weathered revealed 0% amphiboles.

A sequence of orthoclase weathering in acid and alkaline environments is give below:



The broken arrow was inserted to represent the accumulation of gibbsite crusts on weathered rocks (Jackson et al., 1953).

3. Materials and Methods

3.1. Materials

In the present study the materials consist of three pedons collected from South Taluk of Bangalore district of Karnataka. These three pedons were selected from a physiographic unit of the Ustalfs soil area; one from the plateau (Pedon 1), one from the mid pediment (Pedon 2) and the other from the valley (Pedon 3) [Plate 1]. Constancy of the parent material over the area of collection and the position in the physiographic unit were the main criteria for selection of such profiles. It may be mentioned that the valley is narrow and serves as seasonal streams or run off channels leading to streams at lower levels. Such valleys in this area are either sandy or rocky.

3.1.1. Physiography and relief of the area

Bangalore is situated between North latitude $12^{\circ}13'$ - $13^{\circ}23'$. And East longitudes $77^{\circ}07'$ - $78^{\circ}04'$. Bangalore district comprising a total area of 7894.43 sq. km is spread over eleven Taluks of which Bangalore South is 579.78 sq. km, The centra, northern, north-eastern and eastern parts of the district are open lands with undulating to gently sloping topography. The low-lying areas and valleys in this part are covered by a net-work of tanks. In the extreme north west are broken chains of rocky hills extending from North west of Nalamangala Taluk, passing through Magadi, Ramanagaram and Kanakpura Taluks and terminating in lofty peaks such as Sivaganga and Savandarga.

The topography of the upland is hilly to rolling with steep slopes intercepted by narrow valleys and seasonal streams which are either sandy or rocky. The general level of the land declines further south where the hills are closer and surrounded by thick forest. Westward the ruggedness decreases where gently to very gently sloping land forms can be seen with broad valleys of colluvic plains, practically extending to south western limits of the district.

The average altitude in the district ranges from 1859 ft (near Sangam in extreme south) to 4550 ft.

Shivaganga in the north west). Some important elevated places in the districts are 3067 ft in the central part, 2856 ft at Kadagodi in the east, 2994 ft at Bettadapasur in the north, 3088 ft at Sompur in the west. The land in general is sloping from north to south.

3.1.2. Climate

The climate is warm and semi-arid with mean annual precipitation of about 790 mm which is fairly well distributed over seven months in the year. The mean maximum temperature recorded ranges from 300 to 320 during the months of April and May and mean minimum temperature of 160 c during November-December. The distribution of rainfall and temperature records are illustrated in Figure 1. A major portion of the rain is received during south west monsoon, which breaks by the end of May or early June. It continues with some interval till the end of September. The north east monsoon commences in October and ceases by the end of the December.

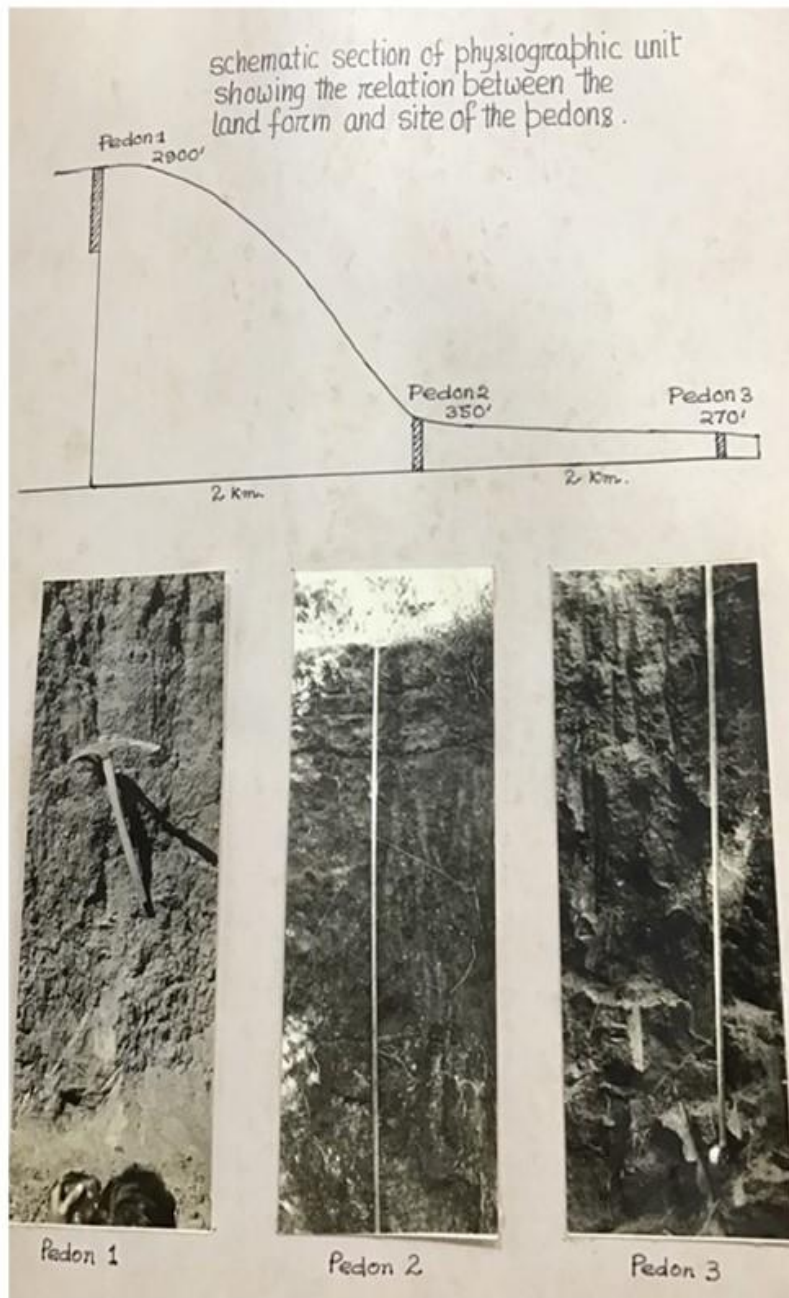
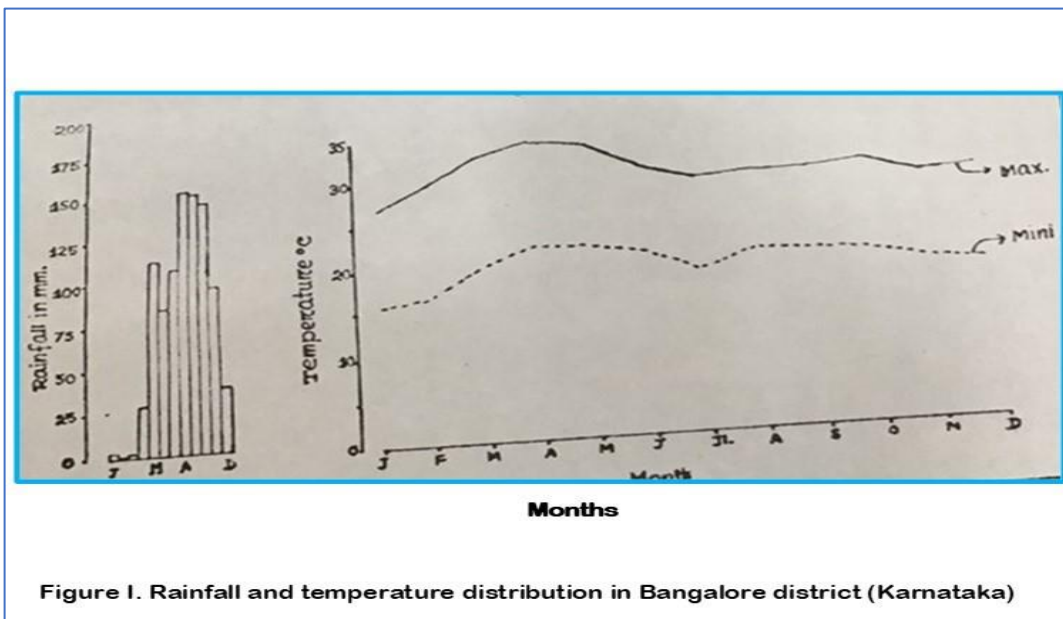


Plate 1. Schematic section of physiso graphic unit showing the relation between the land form and the site of the pedons.



3.1.3. Geology

The geology of the area dates back to the Achaean which consist of the oldest rock formations. The area from where the pedons were collected have gneiss as the common rock, also known as Peninsular gneiss in Indian geology, which lacks uniformity in structure and composition. At times the rock is highly foliated. In other places the rock exhibits granitoid structure. The common gneissic rock types are light to dark gray biotite gneiss that vary in structure, texture and relative abundance or scarcity and mode of decomposition of ferromagnesian minerals. The common minerals of the gneissic rocks are orthoclase, quartz, biotite and muscovite micas, hornblende and other accessory minerals. Bangalore north and south Taluks are dominated by laterites and gneissic rocks with thin strings of amphibolites.

3.2. Methods

3.2.1. Profile Study

The pits were dug for collecting soil samples after proper selection of sites. In case of Pedon 2, however, road-side cut was taken facing the sun. All necessary morphological data in each pedon were collected in the fields and others were accomplished in laboratory using standard methods.

The soil samples were air-dried, sieved through 2 mm sieve and stored for laboratory analysis.

3.2.2. Physico-chemical analysis

- i. Soil pH: pH in soil suspension (1:2.5 soil: water and 1:2.5 soil: MKCl) was measured by a glass electrode pH meter after equilibrating for 30 minutes with occasional stirring (Jackson, 1973).
- ii. Cation exchange capacity: Schollenberger's ammonium acetate (pH 7.0) method was followed for the determination of CEC (piper, 1950).
- iii. Exchangeable cations: The NH_4OAc (pH 7) extract was evaporated and the organic portions by treatment with HNO_3 . The residue was dissolved in 6N HCl and Ca, Mg, Al, Fe, K and Na were determined in the extract, the former two by atomic absorption spectrophotometer, aluminium by aluminon method (Jackson, 1973), iron by 1,10-orthophenanthroline method (Jackson, 1973), and sodium and potassium were determined with a flame photometer (Jackson, 1973).

Physical characteristics

i. Particle size distribution: The known amount of air-dried was treated with 1N NaOAc buffer (pH 4.50). After oxidising organic matter with 30 per cent H_2O_2 , the sample was given citrate-bicarbonate-dithionite treatment for the removal of free iron (Mehra and Jackson, 1960). 95 % ethanol washing was given for removing excess salts. Dispersion and particle size fractionation were

accomplished by Jackson's procedure (1956). Percentages of different soil separates were on the basis of above determination.

Mineral composition of clay, silt and sand of all the samples was determined by X-ray diffraction technique.

3.2.3. Chemical analysis

- i. **Organic carbon:** Oxidisable organic was determined following the method of Walkley and Black (1934).
- ii. **Total nitrogen:** Total nitrogen was determined by modified Kjeldahl method (Jackson, 1973).
- iii. **Total soluble salts:** Electrical conductivity (EC) was determined in 1: 56, soil: water extract (Jackson, 1973; USDA Handbook no. 60, 1968).
- iv. **Elemental chemical analysis:** Silica was determined gravimetrically by Na_2CO_3 fusion. The fused cake was dissolved in 6N HCl and evaporated to dryness. The baking of the sample was done on hot plate using HClO_4 , till fuming of the excess acid ceased. The residue was dissolved in hot water, filtered, washed with acidulated hot water and weighed for SiO_2 after ignition at $900\text{ }^\circ\text{C}$ (Jackson, 1973). The fusion extract after removal of silicon was analysed for the following elements:
 - a. Calcium and magnesium were determined by atomic absorption spectrophotometer as per Jackson's (1973) procedure.
 - b. Potassium was determined with the help of a flame photometer (Jackson, 1973).
 - c. Iron was determined colorimetrically using Klett-Sumerson colorimeter by 1,10-orthophenanthroline method (Jackson, 1973).
 - d. Total sesquioxides were determined in the extract gravimetrically after precipitation by ammonium hydroxide (Jackson, 1973).

- e. Aluminium was estimated by subtracting iron content from total R_2O_3 obtained from the above estimation (Jackson, 1973).
- v) **Selective dissolution analysis:** The sample was first treated with 30% H_2O_2 and citrate-bicarbonate-dithionite as described earlier, before flash boiling and the CBD extract was kept for estimating iron, aluminium and silicon. The sample was added to 400 ml 0.5 N NaOH and boiled for exactly 2.5 minutes for determining amorphous materials. In flash boiling extract silicon and aluminium were determined colorimetrically; the residue was given another CBD treatment and iron was estimated in the last extract (Hashimoto and Jackson, 1960). The following determination were done:
- a. **Iron:** Iron was determined by the method described by Jackson (1973).
 - b. **Aluminium:** Aluminium was estimated colorimetrically with aluminon (Krishna Murti et al. 1974).
 - c. **Silicon:** Silicon was determined colorimetrically (Jackson, 1973) using ammonium molybdate.

3.2.4. Mineralogical analysis by X-ray diffractometry

The clay ($< 2 \mu$), silt ($< 2-20 \mu$) and sands ($20- 50 \mu$ and $> 50 \mu$) fractions of each layer of these pedons were analysed for qualitative mineralogy by X-ray diffraction. 200 mg clay and silt fractions were taken and saturated with Mg and K (only in case of silt) and taken in 10 ml of distilled water to get a 2 per cent suspension.

Parallel oriented aggregate specimens of clay and silt were prepared on a glass slide (4.5×2.5 cm) taking 1 ml suspension in each case. Slides were dried at room temperature and then subjected to X-ray analysis.

For 20- 50 μ fraction, the slides were prepared with dried powder, taking into account the evenness of the surface of the prepared slide. Light fractions of

> 50 μ sand were taken in Philip's powder sample holder after separating the heavier counter parts by bromoform (specific gravity of 2.84) for X-ray analysis.

Identification of each crystalline mineral species present in the sample is the purpose of the qualitative interpretation of a diffraction pattern (Jackson, 1956). The identification of different minerals is accomplished by comparing the d-spacings and intensities with that given in ASTM X-ray powder data file published by American Society Testing Material, Philadelphia. The basal diffraction spacings vary according to the nature of cation with which the saturation is accomplished and the type of minerals present were identified in the sample. Different thermal pretreatments as required were given to distinguish and confirm the type of minerals present. Normally, as a routine method the following five treatments were followed:

1. Mg-saturation,
2. Mg-glycerol solvation,
3. K-saturation,
4. K-heating up to 300 °C, and
5. K-heating up to 550 °C.

The quantitative estimation of clay minerals in sample was done according to Gjems (1967) with some modification as used by Ghosh and Datta (1972).

Weathering mean of each horizon of the pedons were calculated from the quantitative clay mineral data as per Jackson and Sherman (1953) from the following formula:

$$\text{Weathering mean (m)} = \frac{\sum (pS)}{\sum (p)}$$

Where, p= percentage of the mineral,

S = weathering stage of that mineral.

3.2.5. Transmission electron microscopic examination of clays ($\leq 2 \mu$)

Clays were separated by ultrasonic vibration from a selected horizon of each of the three profiles. Each of this separated clay was subjected to two separate treatments, 30% H_2O_2 treatment for organic matter removal and other of 30% H_2O_2 + CBD treatment for free iron oxide removal. Each of these treated samples were thoroughly dispersed and a 0.03% suspension was prepared. One drop of this suspension was mounted on a copper grid covered with *Formvar* film for examination in a Philips EM 300 model electron microscope.

4. RESULTS AND DISCUSSION

The results obtained from the present study are presented and discussed under the following heads:

4.1. Pedon 1

4.1.1. Physical, chemical and physico-chemical characteristics

4.1.1.1. Physical properties

4.1.1.1.1. **Morphological properties:** A general description of the area under study, other relevant information and profile morphology are presented below:

- **Location:** The soil profile was selected from Konankunte, 3 km east of Kanakpura-Bangalore Road and 1 km east of Konankunte village.
- **Landscape:** Plateau with sub nominal relief and excessive erosion.
- **Elevation:** About 2900 feet above msl
- **Natural vegetation:** *Pongamia sp.*, *Galbure sp.*, *Lantana sp.* and perennial grasses.
- **Drainage:** Well, drained internally
- **Parent material:** Granite-gneiss
- **Land Use:** Fallow
- **Profile morphology:** as shown below

Horizon	Depth, cm	Description
A1	0-17	Pale brown (10 YR 6/3, dry), clay loam, fine granular structure with abundant fine roots and gradual smooth boundary, no effervescence.
Bt1	17-51	Light brown (7.5 YR 6/4, dry), clay loam, fine blocky structure with medium fine roots and gradual smooth boundary, no effervescence.
B2	51-100	Light yellowish brown (10 YR 6/4, dry), loam, subangular blocky structure with few fine roots and sharp boundary, no effervescence.
B3	100-113	Yellow (2.5 Y 7/6, dry), clay loam, fine granular structure with quartz vein present in the horizon, roots are few, sharp boundary, no effervescence.
C1	113-145	Very pale brown (10 YR 7/4, dry), clay, highly weathered granite-gneiss, fine granular structure, smooth boundary, no effervescence.
C2	145-207	Pale yellow (2.5 Y 7/4, dry), clay, highly weathered granite-gneiss with mottles, smooth boundary, no effervescence.
C3	207-223	Yellow (2.5 Y 8/8, dry), clay, highly weathered rock with gneissic structure and mottles, fine granular structure, with sharp boundary, no effervescence.

The solum depth was found to be 223 cm deep with colour changing from pale brown to yellow as the depth increases. Absence of effervescence in all the

horizons was in agreement with the expected absence of CaCO₃ as the soils were developed from non-calcareous parent material. Structure was granular to subangular blocky. Mottlings were found in the lower horizon along with gneissic structure.

4.1.1.1.2. Mechanical composition: Table 1 shows that the clay content increases down the profile; except in B2 horizon. The clay percentage increases from 23.75% in the surface to 34.87% in C1 horizon after that the value is more or less constant. As the soil in profile 1 is medium textured and percentage of clay in the first layer of B is 1:2 times greater than that in A, the horizon can be designated as a textural B or Bt (Soil Taxonomy, 1978). Silt content has an increasing trend with depth and the reverse was found in case of the sand distribution with 53.11% in the surface layer and 23.70% in the lower layer (C3). These trends for silt and sand are in conformity with findings of Raychaudhuri et al. (1963) with Kanakpura soils, Mysore.

Table 1. Particle size distribution of soils

Depth, cm	Particle size distribution (%)				Textural Class
	Coarse sand (>50 μ)	Fine sand (20-50 μ)	Silt (2-20 μ)	Clay (<2 μ)	
Pedon 1 (Kanhaplic Hapustalf)					
0-17	53.11	7.05	5.00	23.75	clay loam
17-51	33.55	5.27	4.38	28.43	clay loam
51-100	28.75	5.50	6.25	17.81	loam
100-113	39.10	5.06	6.90	31.25	clay loam
113-145	22.85	5.64	11.25	34.87	clay
145-207	23.08	5.79	17.50	33.56	clay
207-223	23.70	7.95	16.25	33.12	clay
Pedon 2 (Typic Kandiuustalf)					
0-13	66.80	7.26	5.00	6.25	loamy sand
13-28	55.80	6.42	7.50	13.75	loam
28-104	60.00	5.54	7.50	17.50	Loam
104-146	60.00	6.00	5.62	3.75	loamy sand
>146	50.00	13.54	25.62	9.16	silty loam
Pedon 2 (Udic Ustochrepts)					
0-15	75.52	5.22	1.25	5.00	loamy sand
15-61	78.35	6.14	5.63	7.08	loamy sand
61-98	76.31	4.00	3.75	10.83	sandy loam
98-152	70.85	4.09	2.50	11.66	sandy loam

4.1.1.2. Chemical properties

4.1.1.2.1. **Organic matter:** The organic matter content was found to be decreasing down the profile and in the last three horizons it gives similar values as presented in Table 2. The maximum organic content is in the Bt horizon (17-51 cm).

4.1.1.2.2. **Total N and C/N ratios:** Total N (Table 2) decreases with depth with 0.17% at the surface and 0.020% in the lowermost horizon. C/N ratio, however, has no general trend and it ranges from 2.5 to 9.5. Leaving the first layer, the trend of C/N ratio values (is decreasing) observed up to 113 to 145 cm is similar to the observed values of Raychaudhuri et al. (1963). The lower C/N ratio in the upper layers may be ascribed to the different excreta and wastes deposited on the ground from different sources.

Table 2. Some physico-chemical properties of the soils

Depth, cm	pH			Organic carbon (%)	Total Nitrogen (%)	C/N ratio	EC*10 ³ (1: 5 water) Mmhos/cm	Organic matter (%)
	1:2.5 water	1:2.5 KCl	Δ pH (water pH-KCl pH)					
Pedon 1 (Kanhaplic Hapustalf)								
0-17	7.40	5.80	1.60	0.96	0.173	5.5	1.39	1.66
17-51	7.35	5.95	1.40	1.02	0.117	8.7	1.09	1.76
51-100	7.40	5.90	1.50	0.76	0.097	7.8	1.09	1.31
100-113	7.30	5.85	1.45	0.44	0.073	6.0	0.79	0.75
113-145	7.50	5.90	1.60	0.19	0.076	2.5	1.24	0.33
145-207	7.10	5.70	1.40	0.19	0.040	4.7	1.24	0.33
207-223	7.55	5.70	1.85	0.19	0.020	9.5	1.31	0.33
Pedon 2 (Typic Kandiustalf)								
0-13	6.00	5.60	0.40	0.98	0.134	7.2	0.99	1.70
13-28	6.25	5.40	0.85	0.96	0.066	14.5	1.12	1.66
28-104	6.40	4.80	1.60	0.53	0.043	12.3	1.08	0.92
104-146	6.25	4.40	1.85	0.15	0.043	3.7	0.59	0.27
>146	5.75	5.25	0.50	0.11	0.033	3.3	0.84	0.20
Pedon 3 (Udic Ustochrepts)								
0-15	5.00	4.30	0.70	0.55	0.033	16.6	0.26	0.95
15-61	5.30	4.10	0.80	0.34	0.030	11.3	0.15	0.59
61-98	5.45	4.15	1.30	0.27	0.043	6.2	0.21	0.46
98-152	5.75	4.35	0.90	0.28	0.056	5.0	0.22	0.46

4.1.1.2.3. **Soluble salts and CaCO₃ content:** Values of electrical conductivity (EC* 10³ mmhos/cm at 25 °C, USDA hand Book No, 60, 1968) as determined in 1: 5, soil: water extracts, are presented in Table 2. The EC values decrease from 1.39-0.79 in the 100-113 cm layer after that it increases again.

4.1.1.2.4. **Elemental composition:** The elemental chemical composition of soils and clays are presented in Tables 3 and 4. Loss on ignition (900 °C) was

found to be more or less similar in the seven layers from 7-10 % in soil and 11.8-15.6% in the clay. The high values of loss on ignition indicates possible presence of allophane particularly when the organic matter content is low and clay contains little or there is no smectite. Silica was found to be dominant over all other elements both in the soil and the clay.

Table 3. Chemical composition of soils (on oven-dry basis, %)

Depth, cm	Loss on ignition	SiO ₂	R ₂ O ₃	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	Molar Ratios	
									SiO ₂ /R ₂ O ₃	SiO ₂ /Al ₂ O ₃
Pedon 1 (Kanhaplic Hapustalf)										
0-17	7.0	63.8	28	22.0	5.9	1.9	0.94	1.32	8.90	4.43
17-51	8.8	61.8	29	21.1	7.8	1.4	1.19	0.86	8.50	4.53
51-100	9.8	50.0	38	29.0	8.9	1.8	0.75	0.77	5.21	2.66
100-113	8.4	66.6	20	11.5	8.4	1.8	0.63	0.50	13.25	8.91
113-145	9.2	56.1	31	22.0	8.9	1.8	0.73	0.79	7.18	3.94
145-207	9.6	51.6	36	25.0	10.9	1.7	1.47	0.45	5.69	3.18
207-223	10.0	53.8	37	25.3	11.6	3.3	2.77	0.84	5.77	3.28
Pedon 2 (Typic Kandiuistalf)										
0-13	3.4	79.2	12	8.5	3.4	3.0	3.08	1.08	26.62	14.43
13-28	18.6	62.8	18	13.5	4.4	1.7	1.37	1.87	13.97	7.19
28-104	6.7	64.0	19	12.3	6.6	1.7	0.82	1.81	13.44	8.06
104-146	4.3	66.0	20	14.2	5.7	3.0	0.65	1.80	13.13	7.18
>146	1.2	64.0	33	26.0	6.4	5.5	0.38	2.57	7.68	3.79
Pedon 3 (Udic Ustochrepts)										
0-15	2.2	87.0	11	9.3	1.6	3.3	4.92	0.92	31.30	14.46
15-61	2.0	80.6	19	17.0	1.9	2.2	1.06	0.80	16.93	7.21
61-98	3.4	78.8	18	16.0	1.9	1.4	0.97	0.83	17.52	7.64
98-152	3.6	77.6	10	7.1	2.8	1.4	0.87	0.64	30.89	17.01

Table 4. Chemical composition of clay (on oven-dry basis, %)

Depth, cm	Loss on ignition	SiO ₂	R ₂ O ₃	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	Molar Ratios	
									SiO ₂ /R ₂ O ₃	SiO ₂ /Al ₂ O ₃
Pedon 1 (Kanhaplic Hapustalf)										
0-17	13.2	31.8	44	39.26	4.7	0.1	1.33	0.482	3.15	1.37
17-51	13.0	45.6	46	40.64	5.3	0.8	--	0.506	4.33	1.90
51-100	13.8	39.8	39	33.01	5.9	0.5	1.03	0.464	4.44	2.05
100-113	13.4	48.8	34	28.01	5.9	0.8	2.65	0.361	6.29	2.96
113-145	13.2	45.2	24	17.30	6.6	1.4	0.75	0.308	8.27	4.45
145-207	11.8	43.4	22	17.24	8.7	0.8	1.19	0.247	8.59	5.59
207-223	15.6	47.2	31	18.49	12.5	1.4	1.70	0.174	6.65	4.34
Pedon 2 (Typic Kandiuistalf)										
0-13	12.4	52.6	24	16.72	7.2	1.9	2.65	1.138	9.61	5.33
13-28	13.2	50.2	22	15.75	6.2	1.4	1.42	0.945	9.94	5.42
28-104	15.6	42.4	30	23.39	6.6	0.5	1.31	0.801	6.18	3.08
104-146	14.0	41.6	22	14.56	7.4	1.3	0.87	0.602	8.24	4.87
>146	14.4	42.0	32	24.76	7.2	1.4	1.33	0.686	5.72	2.88
Pedon 3 (Udic Ustochrepts)										
0-15	13.8	46.8	29	23.64	5.3	1.7	1.83	0.855	7.07	3.36
15-61	13.6	46.2	44	38.01	5.9	1.7	1.53	0.939	4.57	2.06
61-98	13.4	42.2	35	30.26	4.7	0.8	1.31	0.759	5.77	2.59
98-152	14.4	50.8	21	16.26	4.7	1.1	2.16	0.638	10.56	5.31

4.1.1.2.4.1. Silica: Silica content ranges from 50-66.65 and the content being highest at a depth of 100-113 cm which correspond to the presence of quartz vein in this layer. A look at the Table 3 suggests a decreasing trend of the value down the profile. In case of the value down the particle. In case of clay composition (Table 4), silica content ranges from 31.8-48.8% and increases from the surface layer down the depth of the profile.

The distribution of silica as observed in this pedon is in conformity with distribution of silica in the weathering of gneissic parent material. Under tropical conditions, acidic rocks such as granite and granite gneisses, do not undergo primary laterisation, but gradually change, through the katamorphic process into more or less quartziferous and impure kaolin (Mohr and van Baren, 1954). The data obtained here are also supported by the high leaching process as described by Roonwal et al. (1968-69).

4.1.1.2.4.2. Total sesquioxides: Total sesquioxides range from 20-37% in soil. The values increase from surface to the third layer (28-36%) and then decrease to 20, after which the value increases up to 37% in the lowermost horizon. In clay, on the other hand, a decreasing order was observed from top downward up to the last-but-one layer. It ranges from 44-22% and in the 207-223 cm layer the value is 31%.

The data presented in Table 3 clearly signify that the sesquioxides have been eluviated to a lesser or greater extent from surface horizon down to a zone of accumulation and then the R₂O₃ content decrease in the next layer.

4.1.1.2.4.3. Al₂O₃: The alumina content in the seven horizons follows similar trend as the R₂O₃ distribution. The values of the first three layers are 22, 21 and 295 while from the fourth layer the Al₂O₃ content increases from 11.5-25.3% (Table 3). But in case of clay (Table 4) Al₂O₃ content clearly indicates a

decreasing order from 39-40% in the surface and sub-surface layers to 17-18% in the lower layers.

4.1.1.2.4.4. Fe_2O_3 : Total iron oxide distribution in soil has also get a trend similar to the distribution of sesquioxide. It increases from 5.9-8.9% in the third layer showing eluviation and subsequent accumulation in the lower horizons, after which the value registers slight decrease and again increasing, attaining a value of 11.6% at the bottom layer. The transition between the middle layers is perhaps the demarcation of the illuviation zone (Table 3). The quartz vein in the B3 appears to hinder the eluviation process as is evident by formation of an illuvial horizon in B2 and also removal of Fe_2O_3 and Al_2O_3 from the horizon lower to B3 i.e. C1.

In case of clay, the values start increasing right from the first layer and keeps this increasing trend up to the bottom layer. The ranges were 4.7-12.5% from top downward (Table 4). The values observed for Al_2O_3 are in conformity with the findings of Pal and Roy (1978) in two of the three catena studied by them.

The distribution of iron oxide shows the leaching and subsequent accumulation of it in the lower layers. But the increasing trend of the values after third layer and the attainment of a value even greater than the zone of accumulation cannot be due to the leaching phenomenon from surface layer. Low organic matter content of the surface layers, neutral to slightly acidic pH etc are not likely to permit high degree of solubilization of Fe and Al. Therefore, the eluviation of these constituents to vary great depth in high quantities can be ruled out. The reason for higher values of $\text{Fe}_2\text{O}_3/\text{R}_2\text{O}_3$ at lower layers may be due to other pedogenic factors leading to the in-situ weathering of the rock mass and subsequent precipitation of the released Fe and Al in the site of weathering. Besides, the groundwater table fluctuation in the lower layers may also be one of the reasons of precipitating the weathering products (Campbell, 1917).

4.1.1.2.4.5. Silica, alumina and silica/sesquioxide ratios: The silica, alumina ratio does not show any definite order in this profile. It ranges from 2.66 to 8.91 in soil. The surface layers have low $\text{SiO}_2/\text{Al}_2\text{O}_3$ molar ratio as normally found in red soils (Raychudhuri et al., 1943; Gawande, 1968). But quartz content increases appreciably down the profile leading to a wider silica: alumina molar ratios which is quite in conformity with the weathering of granite-gneiss type of rock (Mohr and van Baren, 1954); Harrassowitz, 1926). Such wide ratios under tropical weathering conditions have also been reported by Pal and Roy (1978) in red and laterite soils of West Bengal. The clay fractions have low $\text{SiO}_2/\text{Al}_2\text{O}_3$ molar ratio in the surface layers as expected for kaolinite dominant clays (c.f. X-ray analysis) of these soils, but at lower layers the ratios were as high as 5.59. This is primarily due to higher content of allophane with wider silica/alumina ratio in the clays of the lower layers (Table 4). Besides the clays in the lower layer also contain some amount of smectite.

The silica sesquioxide ratios are still higher ranging from 5.21-13.25 in soil and 3.15-8.59 in clay which are not in accordance with the data earlier reported (Ramiah, 1937; Annual Report Research, 1940; Raychaudhuri, 1943; Gawande, 1967). In examining the wide $\text{SiO}_2/\text{R}_2\text{O}_3$ ratio of these soils it may be borne in mind that these soils have developed from granite-gneiss parent material which has very low content of ferromagnesian minerals. Higher values for this ratio were, however, found after recalculating the data reported by Pal and Roy (1978).

4.1.1.2.4.6. CaO and MgO: In soil the CaO ranges from 1.4-3.35 but the value of 1.8 or 1.7% is obtained throughout the profile layers excepting second layer where it is 1.4%. In clays, however, the values are much lower, ranging from 0.1-1.4% from top downward. The layers in between give the values of 0.8% and 0.5%.

The MgO content in soil has no definite trend. The range is 0.63-2.77%. The MgO content of clay is more than soil. The values are 0.75-2.65%. Similar data are reported by Pal and Roay (1978).

4.1.1.2.4.7. K₂O: The potash content in soil indicates maximum values in the surface soil layer and then starts decreasing up to the fourth layer, then downwards the values are 0.79, 0.45 and 0.84%, respectively. Higher potash content of the surface layer of the soil is in conformity with the earlier findings of Desai (1942) and Pal and Roy (1978) and can be well correlated to mica and K-fertilizers content of the soil (c.f. silt and sand mineralogy). The clay K₂O, however, varies from 0.174-0.506%.

4.1.1.2.5. Free iron, aluminium and silicon

The free iron oxide and silica contents follow the same trend as observed in case of total sesquioxides and Fe₂O₃. Here, the values start increasing and after attaining the highest value in the fourth starts decreasing; from that layer Fe₂O₃ content decreases downward, but becomes uniform in case of silica. Free iron oxides values range from 2.39-4.14% with more or less uniform values (nearly 4%) from second in sixth layer. Silica ranges from 4.95-5.91% (Table 5).

Table 5. CBD, extractable iron, aluminium and silicon in soil

Depth, cm	Fe ₂ O ₃	Al ₂ O ₃	SiO ₂
Pedon 1 (Kanhaplic Hapustalf)			
0-17	3.39	0.078	4.95
17-51	4.14	0.080	5.02
51-100	4.14	0.269	5.38
100-113	4.39	0.064	5.91
113-145	4.14	0.039	5.27
145-207	4.00	0.198	5.77
207-223	2.39	0.100	5.48
Pedon 2 (Typic Kandiuistalf)			
0-13	1.40	0.049	3.92
13-28	1.78	0.130	4.63
28-104	2.60	0.090	4.63
104-146	2.03	0.170	4.63
>146	1.39	0.081	4.10
Pedon 3 (Udic Ustochrepts)			
0-15	0.88	0.094	3.92
15-61	1.14	0.009	4.49
61-98	1.40	0.052	4.01
98-152	1.53	0.118	3.81

4.1.1.2.6. Allophane

Table 6 gives the data obtained for allophane content. Same trend (as observed in case of free oxide) is followed here. The allophane content (23.22%) increases from the surface layer up to fourth layer (25.58%), then decreases to 24.14% and continues up to the bottom layer (22.46%). High content of allophane in soils derived from granite-gneiss under tropical condition of weathering is quite expected. Murali et al. (1978) have also reported similar allophane content in these soils of Bangalore.

**Table 6. Allophane content of the soils
(by selective dissolution analysis of Hashimoto and Jackson, 1960)
(values in per cent)**

Depth, cm	SiO ₂	Al ₂ O ₃	Released Fe ₂ O ₃ after flash boiling	SiO ₂ / Al ₂ O ₃ Molar	AFAS
Pedon 1 (Kanhaplic Hapustalf)					
0-17	3.029	0.6375	0.557	8.33	23.22
17-51	3.600	0.6375	0.400	9.83	23.63
51-100	3.670	0.9445	0.800	6.77	24.41
100-113	5.097	1.1097	0.378	8.40	25.58
113-145	3.172	1.3317	0.643	4.00	24.14
145-207	3.279	1.0389	0.600	5.40	23.91
207-223	2.173	0.8217	0.464	4.50	22.46
Pedon 2 (Typic Kandistalf)					
0-13	2.460	1.3223	0.442	3.33	23.22
13-28	2.780	1.2278	0.421	3.83	23.43
28-104	3.600	1.1097	0.514	5.90	24.22
104-146	3.172	1.4734	0.442	3.71	24.08
>146	2.316	0.8972	0.378	4.75	22.59
Pedon 3 (Udic Ustochrepts)					
0-15	2.387	0.7556	0.335	5.57	22.47
15-61	2.601	0.8311	0.314	5.37	22.74
61-98	3.290	1.1428	0.335	4.90	23.76
98-152	2.601	1.1239	0.314	3.90	23.03

The percentage Fe₂O₃ released after flash boiling ranges from 0.4-0.8% and no definite order of distribution can be found out for this constituent (Table 6). The Fe content in these allophanic material characterise them as amorphous ferro-aluminosilicates (AFAS).

4.1.1.3. Physico-chemical Characteristics

4.1.1.3.1. Soil reaction (pH): The pH of the soil in different horizon was found to be similar with only a slight variation and ranges from 7.10-7.55. pH (MKCl) as is

seen from **Table 2** does not show appreciable changes in different horizons, the values range from 5.70-5.95. Similar results were reported by Raychaudhuri et al. (1963), and Murali et al. (1974, 1978).

4.1.1.3.2. Cation exchange capacity: The CEC of the soil (**Table 7**) was found to be increasing from 16.1 me/100 g in the surface soil to 37 me/100 g in the bottom layer. The trend is, however, not uniform. The mineralogy of the soil showed kaolinite to be the dominant mineral along with some amount of mica as discussed in the section on “mineralogical analysis”. Both the minerals along with the lower organic matter content in the soil cannot account for such a high CEC value for these samples. The presence of allophanes in the soil perhaps may explain the higher CEC values of these soils. The CEC of the last two layers in this pedon is much higher as compared to that of the other layers. It may be noted that in addition to allophanes, smectite is also a constituent mineral which will adequately explain the higher CEC of the soils in these two layers.

Table 7. Cation exchange capacity and exchangeable bases of soils

Depth, cm	Exchangeable cations (meq/100g)								Fe/Al ratio	Base saturation (%)
	Ca	Mg	Fe	Al	Na	K	CEC	Exchangeable bases		
Pedon 1 (Kanhaplic Hapustalf)										
0-17	11.72	3.45	0.1560	0.0072	0.332	0.025	16.1	2.16	15.69	97.45
17-51	13.80	4.59	0.0094	0.0072	0.339	0.025	19.0	1.30	18.77	98.78
51-100	13.54	4.86	0.0094	0.0261	0.346	0.025	19.1	0.36	18.80	98.42
100-113	9.89	3.56	0.0094	0.0900	0.280	0.025	14.0	0.10	13.85	98.92
113-145	12.24	4.86	0.0156	0.0261	0.234	0.025	19.6	0.59	17.40	88.77
145-207	23.18	7.50	0.0236	0.0072	0.266	0.025	31.0	3.27	30.98	99.93
207-223	27.87	8.10	0.0236	---	0.332	0.034	37.0	----	36.39	98.35
Pedon 2 (Typic Kandiuustalf)										
0-13	4.30	2.80	0.0165	---	0.168	0.055	9.4	---	7.35	78.19
13-28	4.09	2.48	0.0094	0.0018	0.087	0.025	6.8	5.22	6.68	98.23
28-104	4.48	2.77	0.0118	---	0.105	0.025	8.6	---	7.40	86.04
104-146	3.54	2.80	0.0041	--	0.133	0.012	6.6	--	6.49	98.33
>146	2.35	2.10	0.0041	0.0018	0.087	0.012	4.8	2.29	4.55	94.79
Pedon 3 (Udic Ustochrepts)										
0-15	2.19	2.16	0.0236	0.0582	0.220	0.025	4.8	0.40	4.67	97.29
15-61	2.29	2.37	0.0197	--	0.105	0.017	5.6	--	4.81	85.89
61-98	2.98	2.81	0.0094	0.0180	0.115	0.034	7.0	0.52	5.97	85.28
98-152	4.30	3.38	0.0094	0.0540	0.133	0.034	8.6	0.17	7.91	91.97

4.1.1.3.3. Exchangeable bases: Values of exchangeable Ca and Mg have the same trend as that of CEC. Exchangeable Ca content ranges from 9.89-27.87 me/100 g and exchangeable Mg 3.45-8.10 me/100 g. The values of exchangeable

Fe and Al are very low. Sodium, however, constitutes fairly high proportion, ranging from 0.234-0.346 me/100 g in the exchange phase. Such trend in the exchangeable bases is observed in the red soils studied by Pal and Roy (1978).

4.1.2. Mineralogical Analysis

4.1.2.1. Interpretation of X-ray diffractograms

4.1.2.1.1. Clay fraction (<2 μ): The X-ray diffractograms showed the dominance of kaolinite in all the horizons, along with it mica was the other mineral present. In the last two horizons smectite was also present in addition to kaolinite and mica. X-ray diffractograms of the clay of surface and bottom layers are presented in **Figures 1 and 2**, respectively while **Table 8** gives the diagnostic lattice spacings of the clay of all the horizons. Kaolinite, with 7.2 \AA and 3.57 \AA spacings dominate throughout the profile with appreciable amount of mica (10, 4.99 and 3.33 \AA). In last two horizons, presence of smectite was confirmed by treating the Mg samples with glycerol when the 14 \AA peak shifted to low angle values.

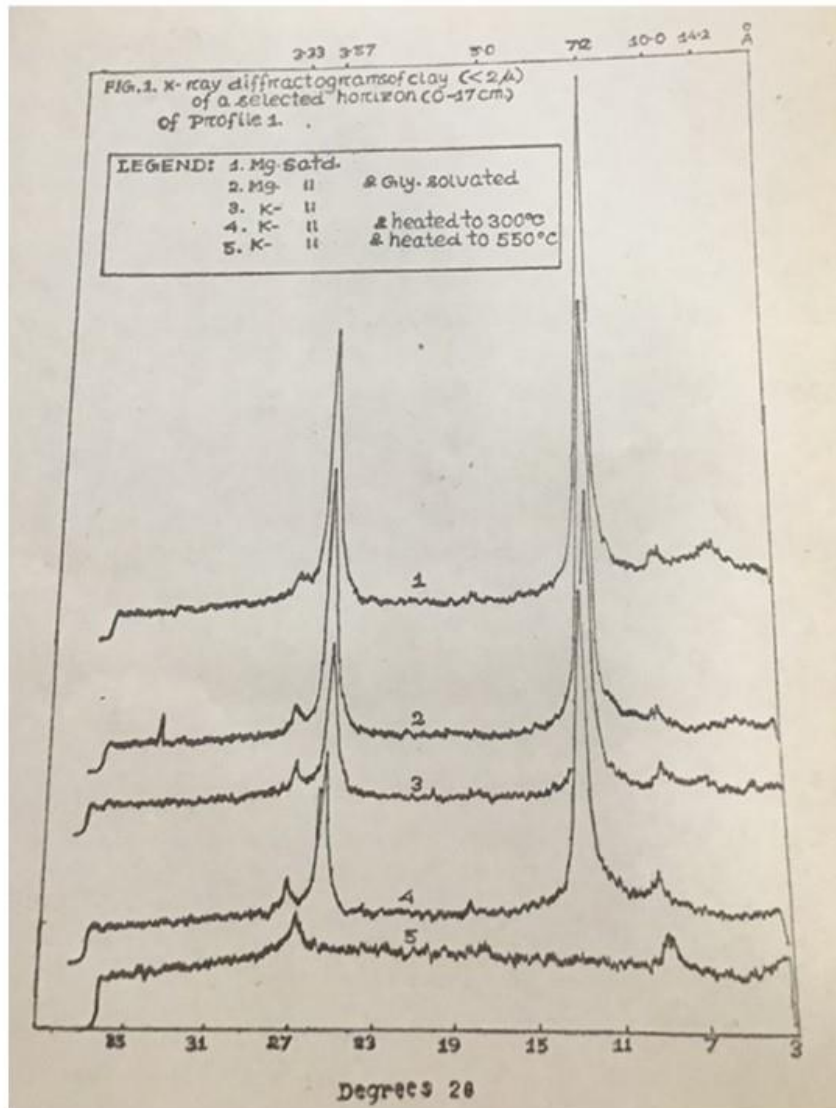


Figure 1. X-ray diffractograms of clay of Profile 1 (0-17 cm)

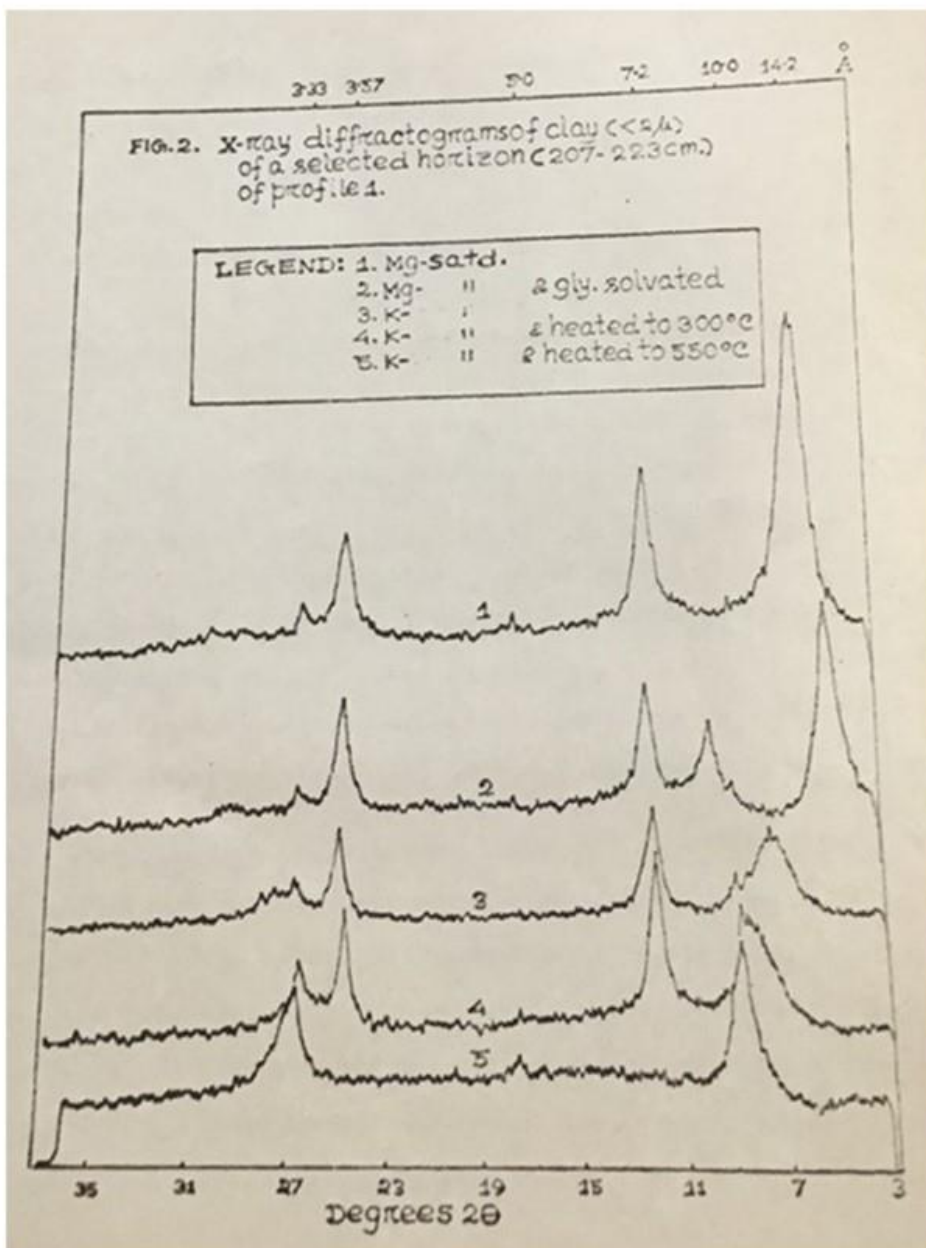


Figure 2. X-ray diffractograms of clay of Profile 1 (207-223 cm)

Table 8. Diagnostic lattice spacings (d_{hkl}) in A^0 observed in the X-ray diffractograms

of clay fractions (<2 μ) of different horizons of Pedon 1

Depth, cm	Treatment of samples					Mineral(s) group corresponding to the observed d_{hkl} (A^0)
	Mg saturated	Mg-glycerolvated	K saturated	K saturated and heated to 300°C	K saturated and heated to 550°C	
0-17	10.00	10.00	10.10	10.00	10.10	Mica
	4.98	4.99	4.98	4.99	4.98	
	3.33	3.33	3.33	3.33	3.33	
	7.20	7.20	7.20	7.20	--	Kaolinite
	3.59	3.59	3.59	3.59	--	
17-51	10.00	10.00	10.10	10.00	10.10	Mica
	4.98	5.00	5.00	5.00	5.00	
	3.33	3.33	3.33	3.33	3.33	
	7.20	7.20	7.20	7.19	--	Kaolinite
	3.59	3.59	3.50	3.50	--	
51-100	9.90	10.00	9.90	10.00	10.10	Mica
	4.98	4.98	4.98	4.98	5.00	
	3.33	3.33	3.33	3.33	3.33	
	7.20	7.20	7.20	7.20	--	Kaolinite
	3.59	3.59	3.59	3.59	--	
100-113	10.10	9.93	10.00	10.00	10.10	Mica
	4.99	4.98	5.00	4.98	4.98	
	3.33	3.33	3.33	3.33	3.33	
	7.20	7.20	7.20	7.20	--	Kaolinite
	3.57	3.57	3.59	3.59	--	
113-145	10.00	10.00	10.00	10.00	10.10	Mica
	4.98	4.98	5.00	4.98	4.98	
	3.33	3.33	3.33	3.33	3.33	
	7.20	7.20	7.20	7.20	--	Kaolinite
	3.57	3.59	3.57	3.59	--	
145-207	15.20	16.99	12.10	10.00	10.10	Smectite
	--	8.62				
	10.10	10.00	10.10	10.00	10.10	Mica
	4.99	4.98	4.98	4.98	5.00	
	3.33	3.33	3.33	3.33	3.32	
	7.20	7.20	7.20	7.20	--	Kaolinite
	3.57	3.59	3.57	3.59	--	
207-223	15.23	18.40	12.10	10.10	10.10	Smectite
	--	9.10				
	10.10	10.00	10.10	10.10	10.10	Mica
	5.00	5.00	5.00	5.00	5.00	
	3.33	3.33	3.33	3.33	3.32	
	7.20	7.20	7.20	7.20	--	Kaolinite
	3.57	3.59	3.57	3.59	--	

The dominance of kaolinite can be well explained in the light of the findings on granite and granite-gneiss weathering under tropical condition as reported by Harrison (1934), Hosking (1940), Watson (1964). That kaolinite dominates the

clay fractions of these red soils is an observed fact supported by Bagchi (1951), Ghosh et al. (1962), Murali et al. (1974) and others. The presence of kaolinite in a fairly high quantity perhaps signifies that the soil is mature, with the process of kaolinization still going on as suggested by the presence of amorphous materials (already discussed) in the weathering environment (Watson, 1964).

Presence of smectite in the lower horizons may be due to the transformation of kaolinite with the presence of leached bases owing to the oscillation of water table in the weathering environment. Besides, the smectite formed in the very earlier stages of weathering may, due to pedogenic processes, be stagnant in the lower horizons aided by the continuous supply of bases leached from surface layers or may come from any pockets in the profile with high base status. And that this mineral (smectite) is still present resisting the present weathering condition, is probably due to the coating of sesquioxides present in fairly high amount of these two horizons. Both the possibilities may be responsible for presence of smectite. Presence of smectite, however, was reported by Anjaneyulu et al. (1965) in red soils of Mysore State. A close look at the **Table 9** (explained later) will suggest that in the bottom layers the kaolinite content decreased as smectite mineral comes to picture. It can be correlated with the kaolinite transformation by resilication in these two layers forming smectite at the cost of the former mineral.

4.1.2.1.2. Silt fraction (2- 20 μ): The **Figure 3** shows the diffractograms of two representative samples and **Table 10** represents the basal spacings observed in the diffractograms. Like clay, kaolinite dominates with two characteristics peaks and other low angle peaks (2.38 and 2.28 A°). Presence of smectite was confirmed in last two horizons in a similar way described in last two horizons in

Table 9. Mineralogy of clay fractions (<2 μ) of the different pedons

Depth, cm	Kaolinite	Mica	Smectite	Weathering mean
Pedon 1 (Kanhaplic Hapustalf)				
0-17	77	23	--	9.31
17-51	75	25	--	9.25
51-100	75	25	--	9.25
100-113	75	25	--	9.25
113-145	76	24	--	9.28
145-207	65	25	10	9.15
207-223	48	32	20	8.84
Pedon 2 (Typic Kandiuustalf)				
0-13	66	31	3	9.04
13-28	69	31	--	9.07
28-104	73	26	--	9.12
104-146	72	28	--	9.16
>146	68	32	--	9.04
Pedon 2 (Udic Ustochrepts)				
0-15	67	33	--	9.01
15-61	69	29	--	8.93
61-98	73	27	--	9.19
98-152	75	22	3*	9.31

*Interstratified minerals

a similar way described under clay. Among other minerals quartz (4.28 A⁰) and feldspars (3.27, 3.24 and 3.20 A⁰) were identified.

In general, kaolinite dominates over mica in this fraction. Smectite was identified in the last two horizons. Other minerals like chlorite, quartz and feldspars were either absent or present in traces. Table 11 gives the necessary information. The data obtained here find support in the work of Murali et al. (1974).

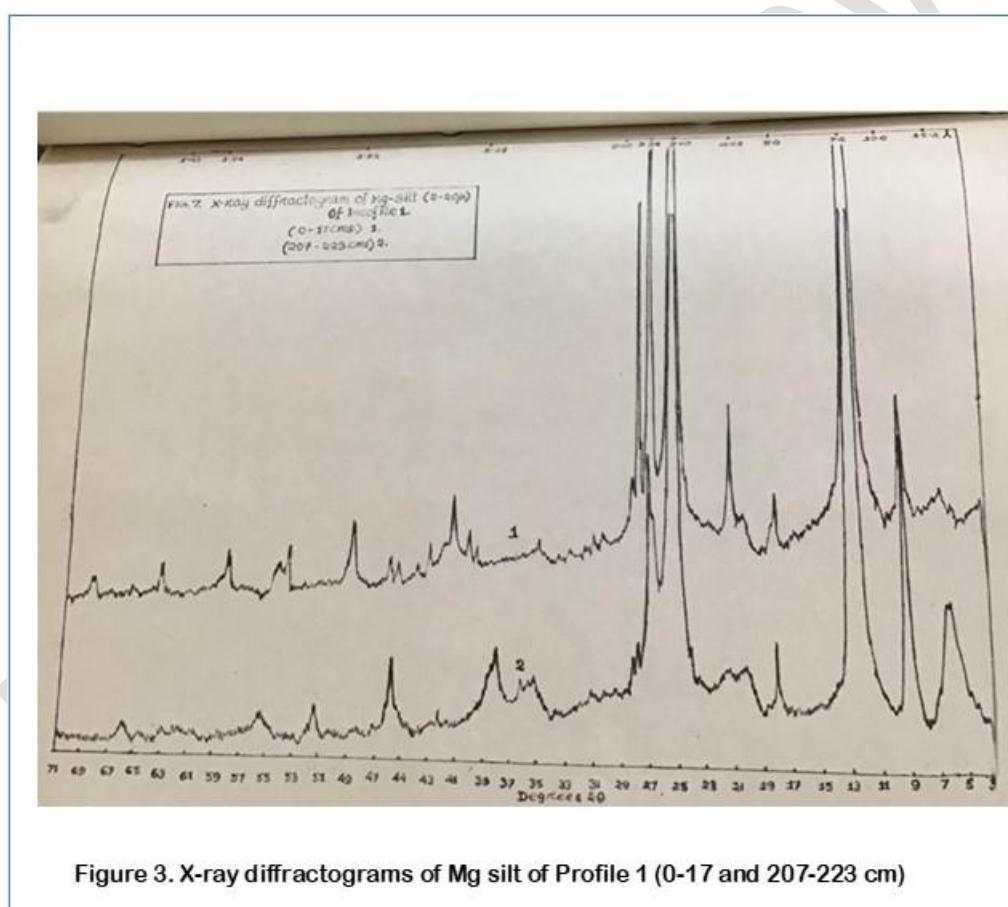
Table 10. Diagnostic lattice spacings (d_{hkl}) in A^0 observed in the X-ray diffractograms of silt fractions (2 – 20 μ) of different horizons of Pedon 1

Depth, cm	(d_{hkl}) in A^0 corresponding to various minerals					
	Kaolinite	Smectite	Mica	Chlorite	Quartz	Feldspars
0-17	7.20	--	10.10	14.94	4.23	3.27
	3.60		5.00	7.20	3.37	3.20
			3.37	3.60	2.43	
					2.30	
					2.15	
17-51	7.20	--	10.00	14.60	4.27	3.24
	3.57		5.00	7.20	3.35	3.20
	2.38		3.35	3.57	2.46	
	2.28				2.28	
					2.24	
					2.13	
51-100	7.20	--	10.00	14.60	4.27	3.24
	3.57		5.00	7.20	3.35	3.20
	2.38		3.35	3.57	2.46	
	2.28				2.28	
					2.24	
100-113	7.20	--	10.00	14.60	4.27	3.24
	3.57		5.00	7.20	3.33	3.20
	2.38		3.33		2.46	
	2.28				2.28	
					2.24	
					2.13	
113-145	7.20	--	10.00	14.60	4.27	3.24
	3.57		5.00	7.20	2.46	3.20
	2.38		3.33	3.57	1.82	
145-207	7.20	14.60	10.00	--	4.27	---
	3.57	18.80*	5.00		3.33	
	2.38		3.33			
207-223	7.20	14.60	10.00	--	4.27	3.24
	3.57	18.40*	5.00		3.33	3.20
	2.38		3.33			

*Spacings for Mg-glycerolvated samples

Table 11. Relative abundance of different minerals in silt fractions (2-20 μ) of different horizons of Pedon 1

Depth, cm	Minerals					
	Kaolinite	Smectite	Mica	Chlorite	Quartz	Feldspars
0-17	+++++	--	+	Traces	+	Traces
17-51	+++++	--	++	+	+	+
51-100	+++++	--	++	+	+	Traces
100-113	+++++	--	++	+	+	Traces
113-145	+++++	--	++	Traces	+	Traces
145-207	+++++	+	+++	--	Traces	--
207-223	+++++	++	+++	--	Traces	Traces



4.1.2.1.3. Fine sand fraction (20- 50 μ): Quartz was found dominating over feldspar and other minerals. Kaolinite, quartz and feldspars were identified with the characteristic lattice spacings as shown in **Table 12**. Mica (10. 4.98, 3.34 A⁰), chlorite (15.50 A⁰), diaspore (2.34 A⁰), hematite (2.69 A⁰) and amphibole (8.7/8.5 A⁰) were the other minerals identified in this fraction.

Quartz is the dominating mineral throughout the profile, followed by feldspars and kaolinite which, however, in the last horizon outranks the relative amount of feldspars and quartz (**Table 13**).

Table 12. Diagnostic lattice spacings (d_{hkl}) in A⁰ observed in the X-ray diffractograms of fine sand fractions (20 – 50 μ) of different horizons of Pedon 1

Depth, cm	Kaolinite	Mica	Chlorite	Quartz	Feldspars	Diaspore	Hematite	Apatite	Amphibole
0-17	7.20	10.00	15.50	4.29	6.53	2.35	2.69	2.85	8.50
	3.60	4.98	1.82	3.34	4.00	2.08	1.48	2.76	
	2.06	3.34	1.72	2.47	3.93	1.89	1.45	2.64	
	1.98	2.58	1.67	2.29	3.73	1.81	1.43	2.16	
	1.89	1.98		2.24	3.26	1.71		2.04	
	1.86			2.13	3.21	1.57		1.95	
	1.71			1.98	3.03	1.48		1.81	
	1.66			1.82	2.95	1.43		1.61	
	1.61			1.67	2.91	1.42			
	1.54			1.54	2.53	1.40			
	1.45			1.38		1.37			
	1.43			1.37					
	1.40								
1.37									
17-51	7.20	10.00	15.50	4.29	6.53	2.35	2.69	2.79	8.50
	3.60	3.34	4.50	3.34	4.00	1.81	1.60	2.76	
	1.98	2.79	3.60	2.47	3.93	1.60	1.45	2.64	
	1.81	1.98	2.43	2.29	3.73	1.57		2.16	
	1.55	1.82	2.03	2.24	3.26	1.37		2.04	
	1.45	1.49	1.87	2.13	3.21			1.96	
	1.40		1.72	1.98	3.03			1.91	
	1.37		1.67	1.82	2.95			1.81	
			1.38	1.67	2.91			1.60	
				1.54	2.53				
				1.38					
				1.37					
51-100	7.20	10.00	14.70	4.29	6.53	2.38	2.69	3.90	8.70
	3.60	3.49	4.50	3.34	4.00	1.90	2.07	3.80	
	1.98	3.34	3.60	2.47	3.93	1.81	1.69	2.76	
	1.81	3.32	2.03	2.29	3.86	1.60	1.60	2.63	
	1.57	2.13	1.87	2.24	3.73	1.57	1.45	2.16	
	1.45	1.98	1.67	2.13	3.26	1.52	1.34	2.04	
	1.40		1.38	1.98	3.21	1.47		1.69	
	1.37			1.82	3.03	1.43			
				1.81	2.95	1.37			
				1.67	2.91	1.34			
			1.38	2.53	1.32				

100-113	7.20	10.00	15.50	4.29	6.50	1.89	2.51	2.16	8.80
	3.60	3.49	4.50	3.34	4.00	1.63	1.69	2.04	
	1.98	3.34	3.60	2.47	3.86	1.47	1.63	1.91	
	1.45	3.32	2.03	2.29	3.73	1.40	1.45	1.69	
	1.40	2.13	1.87	2.24	3.26	1.37			
	1.37	1.98	1.67	2.13	3.21				
		1.49	1.38	1.98	3.03				
				1.82	2.95				
					2.91				
				2.57					
113-145	7.20	10.00	15.50	4.29	6.50	2.08	2.70	2.63	8.0
	3.60	3.49	3.60	3.34	4.00	1.91	2.08	2.16	
	1.66	3.34	1.67	2.47	3.86	1.71	1.60	1.91	
	1.43	2.13	1.66	2.27	3.73	1.57		1.60	
	1.37	1.98		2.13	3.26	1.47			
				1.98	3.21	1.43			
				1.82	3.03	1.40			
				1.67	2.95	1.37			
				1.38	2.91				
			1.37	2.53					
145-207	7.20	10.00	15.50	4.29	4.00	2.55	2.07	3.92	8.58
	3.60	3.34	3.60	3.34	3.73	2.38	1.68	2.86	
	2.55	2.78	2.58	2.29	3.26	2.35	1.45	2.76	
	2.38	2.58	2.43	2.27	3.21	2.07		2.55	
	1.54	2.13	2.38	2.19	2.91	1.47		2.32	
	1.37	1.98	1.67	1.98	2.58	1.37		1.85	
				1.82	2.49			1.68	
				1.67					
				1.54					
			1.37						
207-223	7.20	10.00	13.19	4.29	4.00	3.21	3.67	2.86	8.58
	3.60	3.49	3.60	3.34	3.73	2.55	2.07	2.76	
	2.55	3.34	2.58	2.29	3.21	2.35	1.63	2.55	
	1.93	2.58	2.05	2.27	2.91	2.13	1.45	2.05	
	1.81	2.46	1.67	2.13	2.58	1.81		1.95	
	1.66	1.98	1.66	1.98				1.85	
	1.54			1.82				1.81	
				1.67					
				1.54					

Table 13. Relative abundance of different minerals in fine sand fractions (20-50 μ) of different horizons of Pedon 1

Depth, cm	Minerals								
	Kaolinite	Mica	Chlorite	Quartz	Feldspars	Diaspore	Hematite	Apatite	Amphibole
0-17	++	+	Traces	+++++	+++	Traces	+	+	Traces
17-51	++	Traces	Traces	+++++	++	+	Traces	Traces	+
51-100	+	Traces	Traces	+++++	++	Traces	+	Traces	+
100-113	++	Traces	Traces	+++++	++	Traces	Traces	Traces	Traces
113-145	++	Traces	Traces	+++	+	Traces	Traces	Traces	Traces
145-207	+++	Traces	Traces	+++	++	Traces	Traces	Traces	Traces
207-223	++++	+	+	++	++	+	Traces	Traces	Traces

4.1.2.1.4. Coarse sand fraction (> 50 μ): As shown in **Table 14** kaolinite, mica, chlorite, quartz, feldspars and amphibole were identified in this fraction. Quartz was found dominating (4.29 A⁰) over feldspars (6.53, 3.98 and 3.22 A⁰). In this bottom layer kaolinite was found to be the major mineral (**Table 15**).

Table 14 Diagnostic lattice spacings (d_{hkl}) in A⁰ observed in the X-ray diffractograms of coarse sand fractions (>50 μ) of different horizons of pedon 1.

Depth, cm	d_{hkl} (A ⁰) corresponding to various minerals					
	Kaolinite	Mica	Chlorite	Quartz	Feldspars	Amphibole
0-17	7.20	10.00	14.60	4.29	6.53	8.70
	3.57	3.38	7.20	3.38	3.98	
	1.98	1.98	3.57	3.25	3.83	
	1.54			2.46	3.80	
	1.45			2.28	3.22	
	1.37			1.98	3.04	
				1.82	2.94	
				1.67	2.90	
				1.54	2.57	
				1.45		
113-145	7.20	10.00	14.60	4.29	6.53	8.70
	3.57	3.49	7.20	3.38	4.04	
	1.98	3.38	3.57	2.46	3.83	
	1.45	1.98		2.28	3.70	
	1.37			1.98	3.22	
				1.82	3.04	
				1.67	2.94	
				1.45	2.90	
				1.38		
				1.37		
207-223	7.20	10.00	14.60	4.29	3.98	8.54
	3.57	3.38	7.20	3.38	3.22	
	1.54	1.98	3.57	2.46		
	1.45			2.28		
	1.37			1.54		
				1.45		
			1.37			

Table 15. Relative abundance of different minerals in coarse sand fractions (>50 μ) of different horizons (Pedon 1)

Depth, cm	Minerals					
	Kaolinite	Mica	Chlorite	Quartz	Feldspars	Amphibole
0-17	Traces	Traces	Traces	+++++	+++	Traces
113-145	Traces	Traces	Traces	+++++	+++	Traces
207-223	+++	+	Traces	++	Traces	Traces

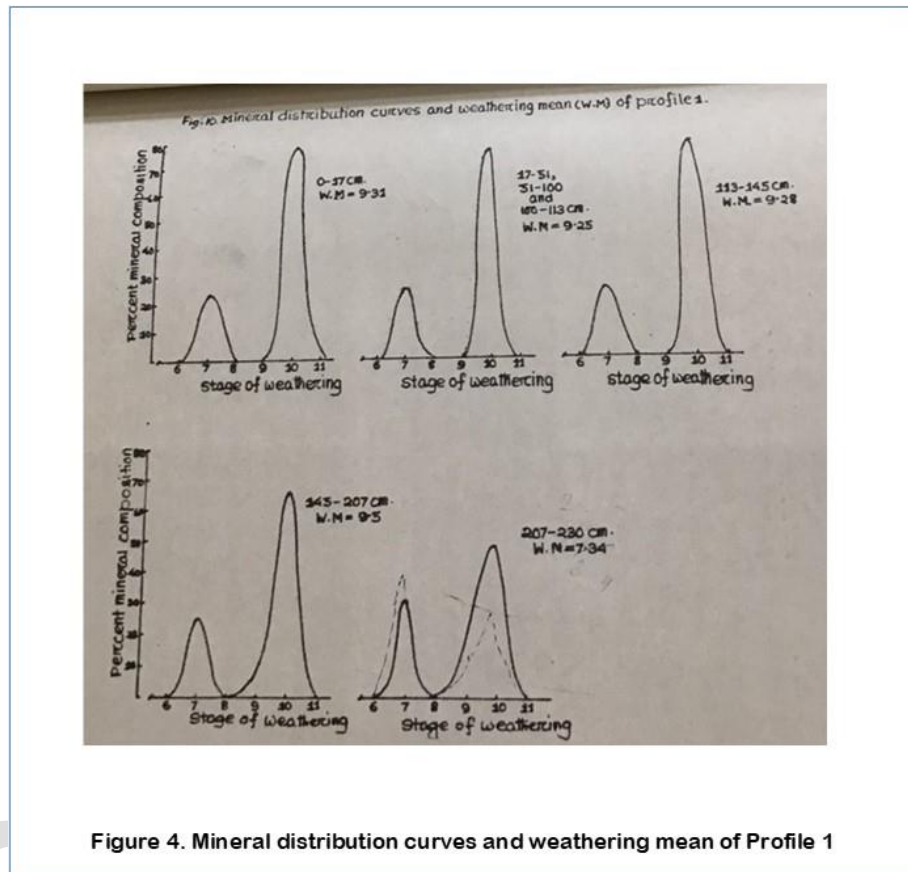
The dominance of quartz in the coarse fractions was well in line with the observations of Desai (1942) and Parthasarathy (1959). Presence of iron oxide minerals was also reported by Raychaudhuri et al. (1943). That the kaolinite is present in a fairly large amount in the bottom layer is in tune with the detailed description of the weathering phenomenon connected with soil formation

(Basairie 1937). He found that the feldspars were completely altered, so much so in fact, that they could be crushed between the fingers, yielding a powder which felt rather sharp in touch. The new product consisted entirely of hexagonal flakes of gibbsite. Basairie also mentioned that the same type of breakdown, leading to the formation of gibbsite, had been observed as being inherent in the katamorphism of granites, basalt, and the amphibolites containing feldspars. It could be added that the same author also pointed out that certain basalts had decomposed into clays which contained no free alumina. In fact, the bottom layer of this profile consisted of a large rock mass which was completely weathered and transformed into clay in situ, so much so that it could be scrapped out with fingers. That kaolinite is the dominant mineral from granitic parent material was also supported by Harrassowitz (1978) and Harrison (1934). The amphibole mineral with very low resistance to weathering (weathering stage 3) is surprisingly present in coarser fractions. The small pockets of these minerals inside the profile may be the reason, resisting the transformation after being coated with sesquioxides.

4.1.2.2. Semi-quantitative distribution of clay minerals (<2 μ): Kaolinite, the dominating mineral, was found to be uniformly distributed throughout the profile (74-77%) except in the last two horizons, where it is 65% and 48%, respectively. Mica places second in abundance and is also more or less uniformly distributed (23-25%) excepting the last horizon (31%). The sixth and seventh layers are, however, characterized by the presence of a third mineral (smectite) whose content is of the order of 10 and 20%, respectively.

The calculated values of weathering mean in this profile ranges between 9.15-9.31. The last horizon, however, is characterized by a relatively low weathering mean (7.84). It is evident from the data (Table 9) that weathering intensity decreased downward from the surface attaining lower value at the zone

of accumulation and the next layer gives value. Higher intensity of weathering is also evident in C1 which is possibly due to the action of subsurface katamorphic activities. The mineral distribution curves are shown in **Figure 4**. It may be noted that the distribution is characterized by the dominant peak at 10th stage and a medium peak at 7th stage and there is break in the curve in the surface layers.



4.1.2.3. Electron microscopic examination of clays ($\leq 2 \mu$): The general morphological features of CBD treated clay is presented in Plate 2a. It is evident from this electron micrograph that most of the kaolinite particles are present as broken pieces still remaining coated with amorphous material. Few particles of mica and structureless masses with diffused boundaries (allophane) are easily discernible in this micrograph. Some of the allophanic constituents when examined at much higher magnification revealed characteristic features of mixtures of silicic acid, aluminium hydroxides and iron oxides (Plate 2b) as

described by Beutelspacher and van der Marel (1968). Such allophanes and the coatings on the crystalline clay particles persisted even after three successive CBD treatments thereby suggesting that these are stable allophanes of the types described by Jackson (1956) forming under intense weathering conditions of tropics and subtropics.

4.2. Pedon 2

4.2.1. Physical, chemical and physico-chemical characteristics

4.2.1.1. Physical properties

4.2.1.1.1. Morphological properties: A general description of the area under study is given below:

- **Location:** The soil profile was selected from Kanakpura Road, about 400 m north-east of Talaghattapura State Silk Farm in village Talaghattapura.
- **Landscape:** Undulating upland with a normal relief and south-west slope. Surface gravelly with moderate erosion.
- **Elevation:** About 300-350 feet above msl
- **Natural vegetation:** *Pongamia sp.*, *Agave*, *Lantena sp.* and tall grasses.
- **Drainage:** Well drained soil with 10-12 m deep ground water table.
- **Parent material:** Granite-gneiss.
- **Land Use:** Mango, Horse gram and ragi.
- **General description of pedon:** Colour is brown with ochric epipedon; moderately well drained with moderate permeability. Soil has a paralithic contact at 146 cm depth with well-developed argillic horizon. The horizon B2t has a platy clay domain which are discontinuous.
- **Profile morphology:** as shown below

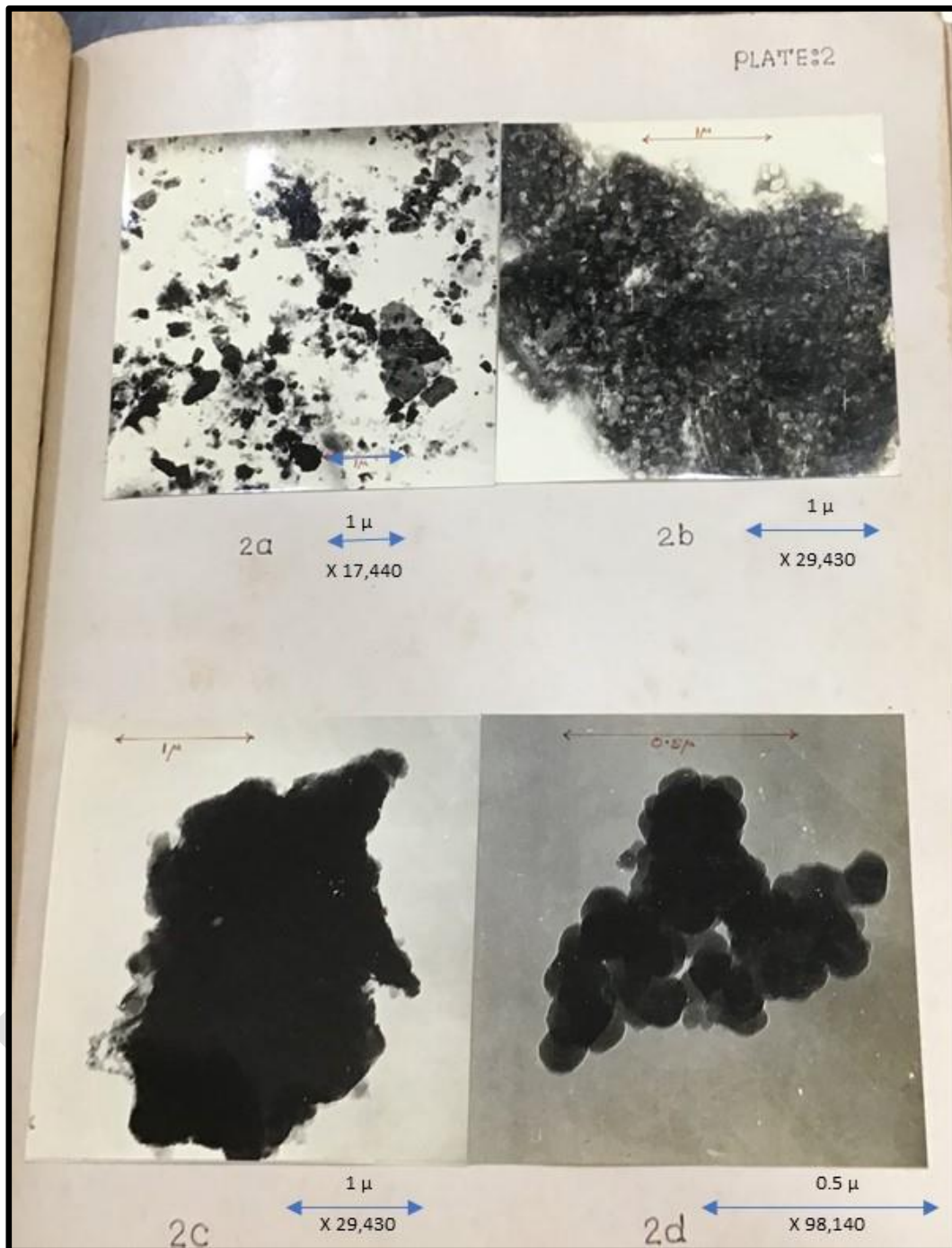


Plate 2: Electron micrographs of Clays, a) General morphological features of CBD treated clay in Pedon 1, b) characteristic features of mixtures of silicic acid, aluminium hydroxides and iron oxides persisted even after consecutive CBD treatments in Pedon 1, c) Microaggregates formed with clay minerals, humus, sesquioxides and allophanic materials in Pedon 2, d) Domain of allophanic aggregate in Pedon 2.

Horizon	Depth, cm	Description
A	0-13	Light olive brown (2.5 Y 5/4, dry), loamy sand, coarse boundary, subangular blocky structure with many fine roots and rapid permeability; no effervescence.
B1	13-28	Brown (7.5 TY 5/4, dry), loam, clear smooth boundary; subangular blocky structure with many roots and continuous clay cutans and moderately rapid permeability; no effervescence.
B2t	28-104	Light yellowish brown (10 YR 6/4, dry), loam with gradual smooth boundary subangular blocky structure with continuous and very thick clay cutans; few fine roots and moderately slow permeability; no effervescence.
B3	104-146	Yellow (10 YR 7/6, dry), loamy sand, weathered granite-gneiss mixed with the soil, gradual wavy boundary, coarse subangular blocky structure with discontinuous and thick cutans, slow permeability, no effervescence.
C	>146	Variable mixture of colours, silty loam; weathered granite-gneiss; coloured white gravels, no effervescence.

Among the morphological features solum depth was 146 cm with 5 horizons. Soil colour changed from light olive brown to yellow as the depth increases. The colour in the last horizon, however, is variable mixture. CaCO₃ was absent throughout the profile. Soil structure was subangular blocky.

4.2.1.1.2. Mechanical composition: A close look at the Table 1 will show that the clay distribution is in an increasing order after which it decreases. The value, however, ranges between 3.75-17.50% in the five horizons. The third horizon (17.50%) contains 3% more clay than surface horizon and as the soil is sandy, that horizon can be designated as B2t (textural B). The silt content, in general, decreases down the profile with sudden rise (up to 25.62%) in the lowermost horizon.

The coarse sand distribution decreases with depth.

4.2.1.2. Chemical properties

4.2.1.2.1. Organic matter: The organic matter content is maximum in the surface soil (1.70%) and decreases with depth uniformly. The range is 0.20-1.70% in lowermost and surface layers respectively (Table 2).

4.2.1.2.2. Total N and C/N ratios: table 2 gives the data obtained for total N and C/N ratios. Total N has a decreasing trend from top downwards ranging from 0.033-0.134%.

C/N ratios do not follow any definite trend as shown in Table 2. The range is, however, from 3.3-14.5. The reason for very narrow C:N ratios of the surface layers appears to be the same as suggested for Pedon 1.

4.2.1.2.3. Soluble salts and CaCO₃ content: Values of electrical conductivity (EC*10³ mmhos/cm at 25 °C) were determined by the method described with the first profile. In general, the values are lower than the previous profile described. The range is from 0.59-1.12% without any order of decrease or increase down the profile. CaCO₃ was found to be absent in this profile.

4.2.1.2.4. Elemental composition: As the Table 3 shows, loss on ignition is found to be 3.4, 6.7, 4.3 and 1.2% in the four layers. The loss on ignition in clays is much higher and ranged from 12.4 to 15.6%. Such high values are, as described earlier, suggestive of presence of allophane in these clays which was confirmed by other analysis including electron microscopy.

4.2.1.2.4.1. Silica: The silica was found to give higher values in the soil of this profile than its content in Pedon 1. Its range is 62.8-79.2% with a trend to decrease down, although not uniformly (Table 3).

The same trend was observed in the clay though the clay fractions has much lower content of SiO₂. The range here was from 41.6-52.6% and the higher limit is more than what was found in the first pedon on the plateau.

4.2.1.2.4.2. Total sesquioxides: Total sesquioxide contents are low in comparison with pedon 1, in both soil and clay. In soil, the range is 12-33% in an increasing order from top downwards. In the case of clay, the values show a decreasing trend downward but not uniformly. In third horizon it stops increasing and then after decreasing becomes maximum its last horizon. The range is 22-32%. The same explanation as given in case of pedon 1 also holds good here. Comparing pedons 1 and 2 appears that pedon 2 presents evidence of lower degree of weathering.

4.2.1.2.4.3. Al₂O₃: The alumina content in soil and clay at first increases with depth and then again increases giving low values in between. The range is 8.5-26% (in soil) and 14.5-24.7% (in clay).

4.2.1.2.4.4. Fe₂O₃: The Fe₂O₃ content of soil increases up to third horizon (6.6%) and then again increases after decreasing to 5.7% in the 4th horizon (Table 3). But in clay, it decreases from 7.2% to 6.6% at third layer and after that Fe₂O₃ contents are 7.4% and 7.2% for 4th and 5th horizons respectively. Similar reasoning as given in pedon 1 perhaps holds good in explaining the data obtained for this pedon.

4.2.1.2.4.5. Silica, alumina and silica, sesquioxide ratio: Unlike pedon 1, the ratios are very much high in this pedon. In soil, SiO₂/Al₂O₃ ratio ranges from 3.79-14.43 with a decreasing trend with depth. SiO₂/R₂O₃ ratio has the range of 7.68 - 26.62 with same trend. Such wide ratios are the result of high proportion of coarser fraction viz. sand and silt, particularly sand dominated by quartz.

In clay the values are, however, less. SiO₂/Al₂O₃ ratio ranges from 2.88-5.42 and for SiO₂/R₂O₃ it is 5.72-9.94. The low values are supported by Raychaudhuri et al. (1943) and others; while higher values do find support from Harrassowitz (1926) and Pal and Roy (1978) after recalculating the value of SiO₂, Al₂O₃ and R₂O₃ given by them. It has already been explained in discussing the results of pedon 1 that wider SiO₂/Al₂O₃ molar ratios are caused by allophane content in the clay and also possibly SiO₂ which has not been determined separately. It is worthwhile mentioning here that the elemental analysis of the clays was carried out after removal of free Fe-oxides by CBD method and, therefore, contain much less iron than was reported by earlier workers (Raychaudhuri et al., 1943; Gawande, 1967, 1968) for such soil clays. Whatever Fe₂O₃ or R₂O₃ are present in the clays are present as part of amorphous ferro-alumino-silicates (AFAS) which are retained in appreciable amount even after the CBD treatment as coatings of

“stable allophane” on the clay mineral surface (c.f. transmission electron microscopic photographs). This fact will explain, why $\text{SiO}_2/\text{R}_2\text{O}_3$ ratios are much wider in the soil clays than reported by most workers on the basis of analysis of clays not freed from free oxides.

4.2.1.2.4.6. CaO and MgO: The CaO content in soil is 1.7% in 3rd horizon after decreasing from 3 and 5.5%, respectively. The MgO content right from the surface layer (3.08%) decreases down the profile and gives the value of 0.38% in last horizon (Table 3).

The values for clay are not at all uniform. The CaO content ranges from 0.5-1.9% MgO content, however, decreases from 2.65-0.87% up to 4th layer uniformly. In the last horizon it is 1.33%.

4.2.1.2.4.7. K₂O: The potash contents in both soil and clay are higher than the first pedon which can be explained by higher proportion of mica present in this profile as will be clear in the subsequent discussion on mineralogy. In soil (Table 3), the content of K₂O increases (not uniformly) in the last horizon ranging from 1.08-2.57%. In clay (Table 4) the values uniformly decline from 1.138-0.686% with depth. The higher values for potash in soil than clay is in conformity with the results of Desai (1942) and Pal and Roy (1978) and are related to silt and sand mineralogy which is characterized by the presence of mica and potash feldspars (c.f. mineralogy of silt and sand fraction).

4.2.1.2.5. Free iron, aluminium and silicon: The free iron increases down the profile, then increases and again records a decreasing trend. Maximum content of Fe_2O_3 is associated with the third layer perhaps suggesting the zone of accumulation. The range is 1.39-2.60%. Free Al_2O_3 content is not at all uniformly distributed in the profile and ranges from 0.049-0.17%, Silica (free) content is 3.92% and 4.10% in the first and last horizon with the value of 4.6% in between these two layers.

In general, the values for free Fe₂O₃, Al₂O₃ and SiO₂ are less in comparison to what was observed in the first pedon (Table 5).

4.2.1.2.6. Allophane: The allophane content in the different horizons is presented in Table 6. Allophane content increases from surface layer (23.33%) to the third horizon (24.22%). Thus, the highest content of allophane coincides with the zone of accumulation. The percentages in the last two horizons are 24.08 and 22.59, respectively. The high limit of allophanic material in this pedon, however, is less than that in the pedon 1. The data on free oxide content as well as the allophane content also provide supporting evidence regarding lower weathering intensity in pedon 2.

In general, the values obtained for released Fe₂O₃ after disintegration of allophanes by the Hashimoto and Jackson's (1960) procedure in this pedon (ranging from 0.378-0.514%) is less than what obtained in pedon 1.

4.2.1.3. Physico-chemical characteristics

4.2.1.3.1. Soil reaction (pH): The pH (in water) indicates that this profile is slightly acidic, values ranged from 5.75-6.40. In *N* KCl, the values obtained are ranging from 4.40 to 5.60. In 1 N KCl, the values obtained are ranging from 4.40 to 5.60. The pH values as shown in the Table 2 are less than that in pedon 1. Similar results on soil reaction of such soils were reported by Raychaudhuri et al. (1963) and Murali et al. (1974, 1978).

4.2.1.3.2. Cation exchange capacity of soils (CEC): Cation exchange capacity declines from maximum value (9.4 me/100g) in the surface layer to a minimum (4.8/100g) in the last horizon. The values in the other horizons (1st, 2nd and 3rd) are 6.8, 8.6 and 6.6 me/100g, respectively. Although the CEC values as shown in Table 7 are less in comparison to that of pedon1, are still higher for soils with low content of clay dominated by kaolinite. Therefore, contribution from amorphous materials cannot be ignored in this soil also.

4.2.1.3.3. Exchangeable bases: Exchangeable Ca (ranging from 2.35-4.48 me/100g) dominates over exchangeable Mg (2.1-2.8 me/100g) and other bases like Fe, Al, Na and K. Exchangeable Al in three layers could not be traced. Exchangeable Na was found to be more in comparison to exchangeable K (Table 7).

4.2.2. Mineralogical Analysis

4.2.2.1. Interpretation of X-ray diffractograms

4.2.2.1.1. Clay fraction (<2 μ): The **Figures 5 and 6** show the diffractograms of two representative horizons and Table 16 gives the basal spacings of different minerals.

All the layers contain kaolinite (7.20 and 3.59 A^0) and mica (10, 5.0 and 3.38 A^0) minerals. The first horizon along with kaolinite and mica also contains smectite as was confirmed by 18.4 A^0 peak in Mg glycerolvated sample. The reasons for kaolinite dominance are the same as that extended in case of pedon 1. The presence of smectite may be due to its formation in earlier stage of weathering and its subsequent stabilization by coating with sesquioxides rendering it resistant to further breakdown.

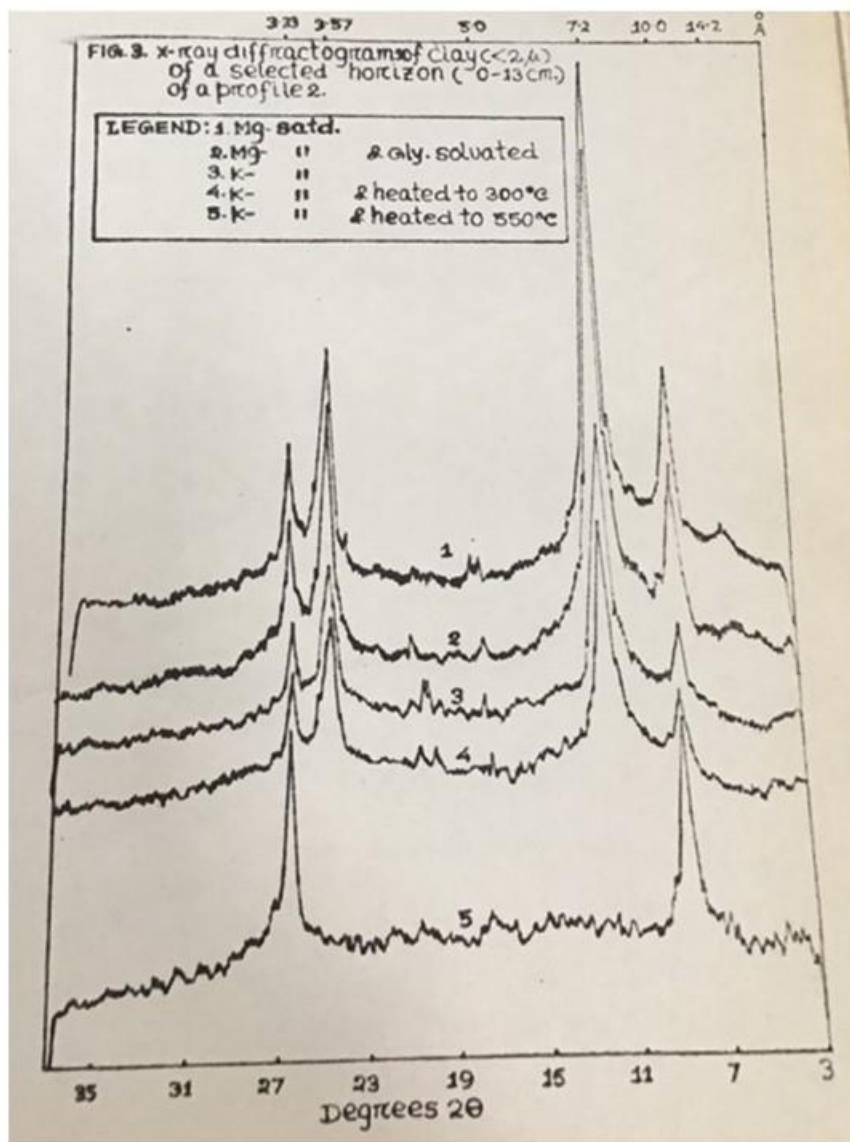


Figure 5. X-ray diffractograms of clay of Profile 2 (0-13 cm)

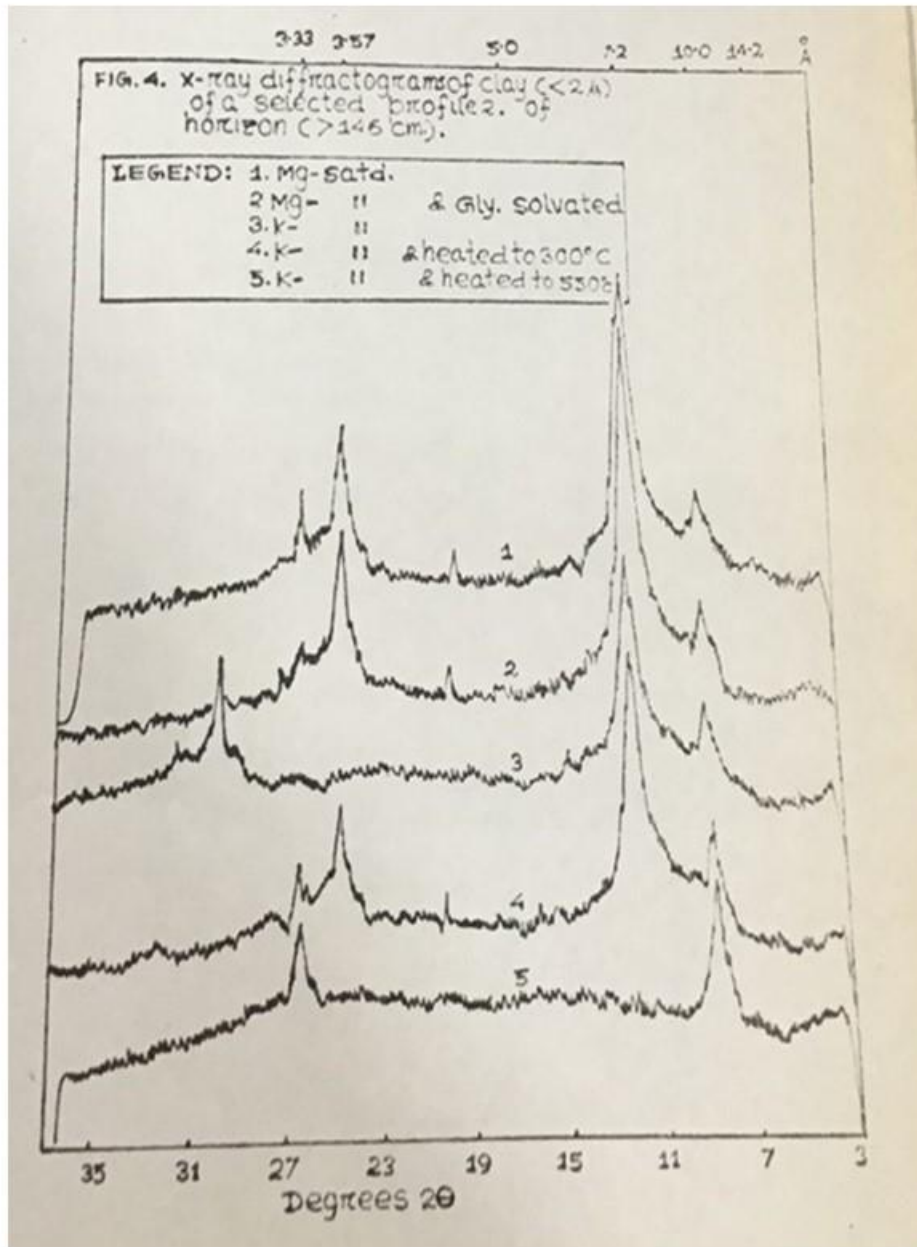


Figure 6. X-ray diffractograms of clay of Profile 2 (>146 cm)

Table 16. Diagnostic lattice spacings (d_{hkl}) in A^0 observed in the X-ray diffractograms of clay fractions ($<2 \mu$) of different horizons of Pedon 2

Depth, cm	Treatment of samples					Mineral(s) group corresponding to the observed d_{hkl} (A^0)
	Mg saturated	Mg-glycerolvated	K saturated	K saturated and heated to 300°C	K saturated and heated to 550°C	
	14.20	18.40	10.10	10.00	10.10	Smectite
0-13	10.10	10.10	10.10	10.10	10.10	Mica
	5.00	5.00	5.00	5.00	5.00	
	3.35	3.35	3.35	3.34	3.34	
	7.20	7.20	7.20	7.20	--	Kaolinite
	3.59	3.57	3.60	3.57	--	
13-28	10.00	10.10	10.10	10.10	10.10	Mica
	5.00	5.00	5.00	5.00	5.00	
	3.33	3.33	3.33	3.33	3.33	
	7.20	7.20	7.20	7.20	--	Kaolinite
	3.57	3.57	3.59	3.59	--	
28-104	10.20	10.10	10.10	10.10	10.10	Mica
	5.00	5.00	4.99	4.99	5.00	
	3.33	3.33	3.35	3.36	3.35	
	7.20	7.20	7.20	7.20	--	Kaolinite
	3.59	3.59	3.59	3.57	--	
104-146	10.10	10.00	10.00	10.10	10.10	Mica
	4.99	4.99	5.00	4.98	5.00	
	3.33	3.33	3.33	3.33	3.33	
	7.20	7.20	7.20	7.20	--	Kaolinite
	3.57	3.57	3.57	3.57	--	
>146	10.10	10.10	10.10	10.00	10.10	Mica
	5.00	4.98	5.00	4.98	4.98	
	3.33	3.33	3.33	3.33	3.33	
	7.20	7.20	7.20	7.20	--	Kaolinite
	3.59	3.59	3.60	3.59	--	

All the layers contain kaolinite (7.20 and 3.59 A^0) and mica (10, 5.0 and 3.38 A^0) minerals. The first horizon along with kaolinite and mica also contains smectite as was confirmed by 18.4 A^0 peak in Mg glycerolvated sample. The reasons for kaolinite dominance are the same as that extended in case of pedon 1. The presence of smectite may be due to its formation in earlier stage of weathering and its subsequent stabilization by coating with sesquioxides rendering it resistant to further breakdown.

4.2.2.1.2. Silt fraction (2-20 μ): Mg-treated silt samples are dominated by kaolinite with the characteristic basal spacings and mica, chlorite, quartz and feldspars were detected in smaller quantity as shown in **Table 17** with the d-spacings. **Figure 7** shows the diffractogram of two representative samples of this profile. Feldspars were found dominant in the fourth horizon. Other minerals like chlorite and amphibole were found in traces (**Table 18**). The data obtained on silt mineralogy are supported by the findings of Murali et al. (1974).

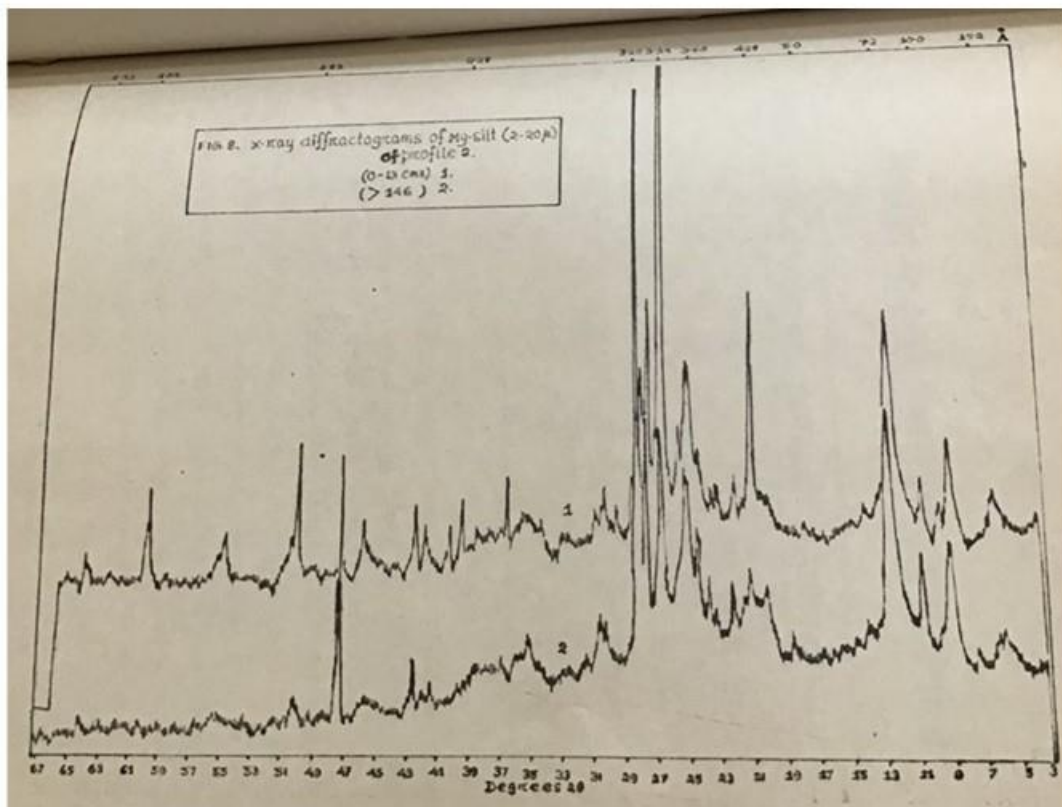


Figure 7. X-ray diffractograms of Mg silt of Profile 2 (0-13 and >146 cm)

Table 17. Diagnostic lattice spacings (d_{hkl}) in A⁰ observed in the X-ray diffractograms of silt fractions (2 – 20 μ) of different horizons of Pedon 2

Depth, cm	(d_{hkl}) in A ⁰ corresponding to various minerals						
	Kaolinite	Smectite	Mica	Chlorite	Quartz	Feldspars	Amphibole
0-13	7.20	--	10.40	14.02	4.34	3.61	8.67
	3.57		5.00	7.20	2.29	3.42	
	2.29			3.57	1.98	3.22	
	2.25				1.82	3.16	
	1.98					2.93	
13-28	7.20	--	10.00	15.20	4.27	3.80	8.67
	3.57		5.00	7.20	2.46	3.67	
			3.33	3.57	2.13	3.24	
					1.82	3.20	
28-104	7.20	--	10.00	15.20	4.27	3.24	8.67
	3.57		5.00	7.20	2.46	3.20	
			3.35	3.57	2.13		
					1.82		
104-146	7.20	--	10.00	15.20	4.27	3.80	8.67
	3.57		5.00	7.20	2.46	3.67	
			3.33	3.57	2.13	3.24	
						3.20	
					1.82	2.57	
>146	7.20	--	10.00	15.20	4.27	3.80	8.67
	3.57		5.00	7.20	2.46	3.67	
			3.33	3.57	2.13	3.24	
					1.82	3.20	
						2.57	

Table 18. Relative abundance of different minerals in fine silt fractions (2-20 μ) of different horizons of Pedon 2

Depth, cm	Minerals					
	Kaolinite	Mica	Chlorite	Quartz	Feldspars	Amphibole
0-13	+++	+	+	++	Traces	Traces
13-28	+++	++	Traces	++	+++	Traces
28-104	++++	+	Traces	+	Traces	Traces
104-146	++	+	+	++	+++	+
>146	++++	+	Traces	++	++	Traces

4.2.2.1.3. Fine sand fraction (20-50 μ): The basal spacings of different minerals are shown in **Table 19**. The minerals identified in this fraction are kaolinite, mica, chlorite (14.2, 4.6, 3.6 A°), quartz (4.29 A°), feldspars (6.46, 3.21 A°). Diaspore (2.38, 2.35, 1.37 A°), hematite (2.69, 1.84 A°), apatite (2.76 A°), and amphibole (8.67 A°) with their characteristic spacings. Feldspars were found dominating in all the four layers except in surface where quartz dominates. In first, fourth and fifth horizons amphibole were found to be present in relatively higher amount. The minerals present in traces or almost traces are kaolinite. Mica, chlorite, diaspore, hematite and apatite. Amphiboles and kaolinite were also present in traces in a few layers as shown in **Table 20**.

Table 19. Diagnostic lattice spacings (d_{hkl}) in A^0 observed in the X-ray diffractograms of fine sand fractions (20 – 50 μ) of different horizons of Pedon 2\

Depth, cm	Kaolinite	Mica	Chlorite	Quartz	Feldspar	Diaspore	Hematite	Apatite	Amphibole
0-13	7.20	9.93	14.20	4.29	6.46	2.38	1.84	2.84	8.67
	3.60	4.98	3.60	3.34	3.26	2.35	1.70	2.76	
	3.13	3.34	2.58	2.47	3.21	2.31	1.60	2.31	
	2.38	2.58	2.38	2.29	3.03	1.61	1.45	2.16	
	2.18	2.38	1.66	2.24	2.91	1.57		2.04	
	1.86	2.18	1.39	2.13	2.53	1.43		1.95	
	1.66	1.98		1.98		1.37		1.84	
	1.54			1.90				1.61	
	1.46			1.82					
	1.39								
	1.37								
13-28	7.20	10.00	14.20	4.29	6.46	2.55	2.69	2.79	8.67
	3.60	3.49	4.60	3.34	4.73	2.38	1.83	2.30	
	3.13	3.34	3.60	2.47	4.07	2.08		1.88	
	2.55	2.79	2.58	2.29	4.00	1.74		1.86	
	2.38	2.58	2.43	2.24	3.85	1.60		1.80	
	2.18	1.98	2.38	2.13	3.70	1.54		1.58	
	1.93	1.83	2.03	1.98	3.26	1.51			
	1.80	1.50	1.88	1.82	3.21	1.37			
	1.66		1.72	1.67	3.13				
	1.62		1.67	1.54	2.57				
	1.58		1.66	1.38	2.43				
	1.54		1.39	1.37					
	1.46								
	1.42								
1.39									
1.37									
28-104	7.20	10.00	14.20	4.29	6.46	2.35	2.69	3.90	8.67
	3.60	3.49	3.60	3.34	4.07	2.05	2.07	3.80	
	2.18	3.34	2.43	2.47	3.70	1.81		2.76	
	1.93	3.32	1.72	2.29	3.26	1.60		2.63	
	1.62	2.13	1.67	2.24	3.21	1.57		2.16	
	1.54	1.98		2.13	3.03	1.47		2.04	
	1.37			1.98	2.94	1.43		1.69	
				1.82	2.91	1.37			
				1.81	2.43				
				1.67					
				1.38					
				1.37					
104-146	7.20	10.00	14.20	4.29	6.46	2.08	1.61	2.85	8.67
	3.60	3.49	2.03	3.34	4.00	1.89		2.76	
	1.98	3.34	1.72	2.47	3.86	1.63		2.16	
	1.45	3.32	1.66	2.29	3.73	1.47		2.05	
	1.40	2.13		2.24	3.26	1.40		1.95	
	1.37	1.98		2.13	3.21	1.37		1.77	
				1.98	3.03			1.61	
				1.82	2.95				
					2.91				
					2.57				
> 146	7.20	10.00	14.20	4.29	6.46	2.08	2.08	2.85	8.67
	3.60	3.49	2.03	3.34	4.07	1.61	1.61	2.76	
	2.18	3.34	1.67	2.47	3.85	1.57	1.48	2.64	
	1.93	2.13	1.66	2.27	3.73	1.48		2.16	
	1.80	1.98		2.13	3.26			2.04	
	1.66			1.98	3.21			1.61	
	1.43			1.82	3.03				
	1.62				2.95				
	1.46				2.91				
				1.37	2.53				

Table 20. Relative abundance of different minerals in fine sand fractions (20-50 μ) of different horizons of Pedon 2

Depth, cm	Minerals								
	Kaolinite	Mica	Chlorite	Quartz	Feldspars	Diaspore	Hematite	Apatite	Amphibole
0-13	Traces	Traces	Traces	++++	+++	Traces	Traces	Traces	+
13-28	Traces	Traces	Traces	++++	++++	Traces	Traces	Traces	Traces
28-104	+	Traces	Traces	+++	+++++	Traces	Traces	Traces	Traces
104-146	+	Traces	Traces	++	+++++	Traces	Traces	Traces	+
>146	+	Traces	Traces	+++	+++++	Traces	Traces	Traces	+

4.2.2.1.4. Coarse sand fraction (> 50 μ): Table 21 shows the different basal spacings characterizing different minerals. The minerals identified are kaolinite, mica, chlorite (all in traces), quartz, feldspars and amphiboles (8.54 \AA). Amphiboles were present in quite a good amount in last horizon, which is dominated by feldspars and quartz. In the other two horizons quartz dominates over feldspars. Kaolinite, mica, chlorite and amphiboles were, in general, in traces (Table 22). Similar mineral association was found in pedon 1 with only difference that amphibole was present in pedon 2 even in silt fractions again providing evidence of relatively low degree of weathering of pedon 2.

4.2.2.2. Semiquantitative distribution of Clay mineral (<2 μ)

Table 9 shows the semiquantitative mineral distributions. Kaolinite dominates throughout the profile from 66-73% followed by mica (26-32%). Only in surface horizon 3% of smectite was detected. The weathering mean varies from 9.04-9.16 and the values are less in comparison to what was obtained in pedon 1. The trend of the values in Table 9, however, is similar to that observed in pedon 1. The mineral distribution curves are shown in Figure 8. These curves are characterized by breaks which possibly is a peculiarity of tropical weathering condition.

Table 21. Diagnostic lattice spacings (d_{hkl}) in A^0 observed in the X-ray diffractograms of coarse sand fractions ($>50 \mu$) of different horizons of pedon 2.

Depth, cm	d_{hkl} (A^0) corresponding to various minerals					
	Kaolinite	Mica	Chlorite	Quartz	Feldspars	Amphibole
0-13	7.20	10.00	14.60	4.29	6.53	8.54
	3.57	3.38	7.20	3.38	3.98	
	1.98	1.98	3.57	3.25	3.83	
	1.54			2.46	3.80	
	1.45			2.28	3.22	
	1.37			1.98	3.04	
				1.82	2.94	
				1.67	2.90	
				1.54	2.77	
				1.45		
				1.39		
				1.38		
	28-104	7.20	10.00	14.60	4.29	6.53
3.57		3.38	7.20	3.38	4.04	
1.98		1.98	3.57	2.46	3.83	
1.45				2.28	3.70	
1.37				1.98	3.22	
				1.82	3.04	
				1.67	2.94	
				1.45	2.90	
				1.39	2.85	
				1.38	2.77	
					2.65	
					2.57	
> 146		7.20	10.00	14.60	4.29	6.53
	3.57	5.00	7.20	3.38	4.04	
	1.54	3.38	3.57	2.46	3.83	
	1.45	1.98		2.28	3.70	
	1.37			1.54	3.22	
				1.45	3.04	
				1.39	2.94	
				1.38	2.90	
					2.85	
					2.77	
					2.65	
					2.57	

Table 22. Relative abundance of different minerals in coarse sand fractions ($> 50 \mu$) of different horizons of Pedon 2

Depth, cm	Minerals					
	Kaolinite	Mica	Chlorite	Quartz	Feldspars	Amphibole
0-13	Traces	Traces	Traces	++++	+	Traces
28-104	Traces	Traces	Traces	+++	+	+
>146	+	+	Traces	+++	++++	++

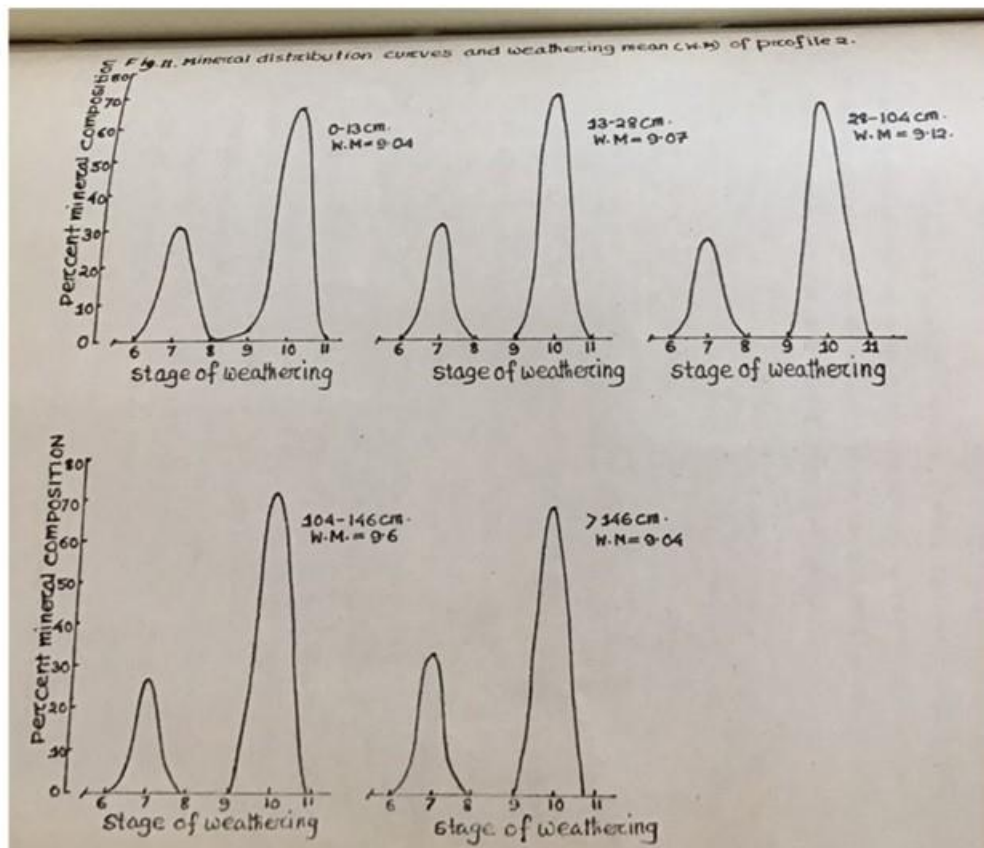


Figure 8. Mineral distribution curves and weathering mean of Profile 2

4.2.2.3. Electron microscopic examination of clays (2μ)

The clays were isolated without using any chemical treatment by dispersing the soil with ultrasonic vibrations. Clays thus separated are mostly found to be microaggregates formed with clay minerals, humus, sesquioxides and allophanic materials. One such microaggregate is presented in **Plate 2c**. That some particles remain uncoated and free from complex aggregation can be seen from the tiny particles forming ringlike structure at one corner of the

microaggregate. The allophanic materials not only participate in aggregate formation, but also form domains of their own, one such aggregate of only allophane is shown in Plate 2d, which is characterized by aggregated and almost spherical particles. Such spherical allophanic particles are very characteristic of strongly weathered volcanic tuffs and ashes as reported in West Town, New Zealand (Beautelspacher and van der Marel. 1968). It is obvious from this finding that similar alumino silicic allophanes ($XAl_2O_3 \cdot YSiO_2 \cdot ZH_2O$) may also originate during the weathering of granite-gneiss under tropical weathering condition.

The clays were re-examined after removal of organic matter with 30% H_2O_2 . An electron micrograph of one such sample is presented in Plate 3a. It can be clearly seen that after organic matter removal, individual clay particles consisting mainly of kaolinite got dispersed to a large extent but microaggregates heavily coated with iron oxides and AFAS appearing as dark aggregates persisted. The clay also contained amorphous silica which as a result of sonification got dispersed and appeared as a tiny spherocolloids forming small aggregates mixed with dispersed hematite particles which appeared on the electron micrographs as tiny dots. Occurrence of such amorphous silica are common in red earths, latosols, gley soils and weathered sediments (Plate 3b). SDA by Hashimoto and Jackson's method (1960) method of soils of all the three pedons studied has revealed presence of high percentage of amorphous materials rich in silica. It is now obvious from electron micrographs that part of this allophanic silica participate in aggregate formation also. Plate 3c shows few microaggregates of clay particles in which amorphous silica, hematite and other AFAS are also involved. Microaggregates formed by allophanes and domains of allophanic aggregates are also observed

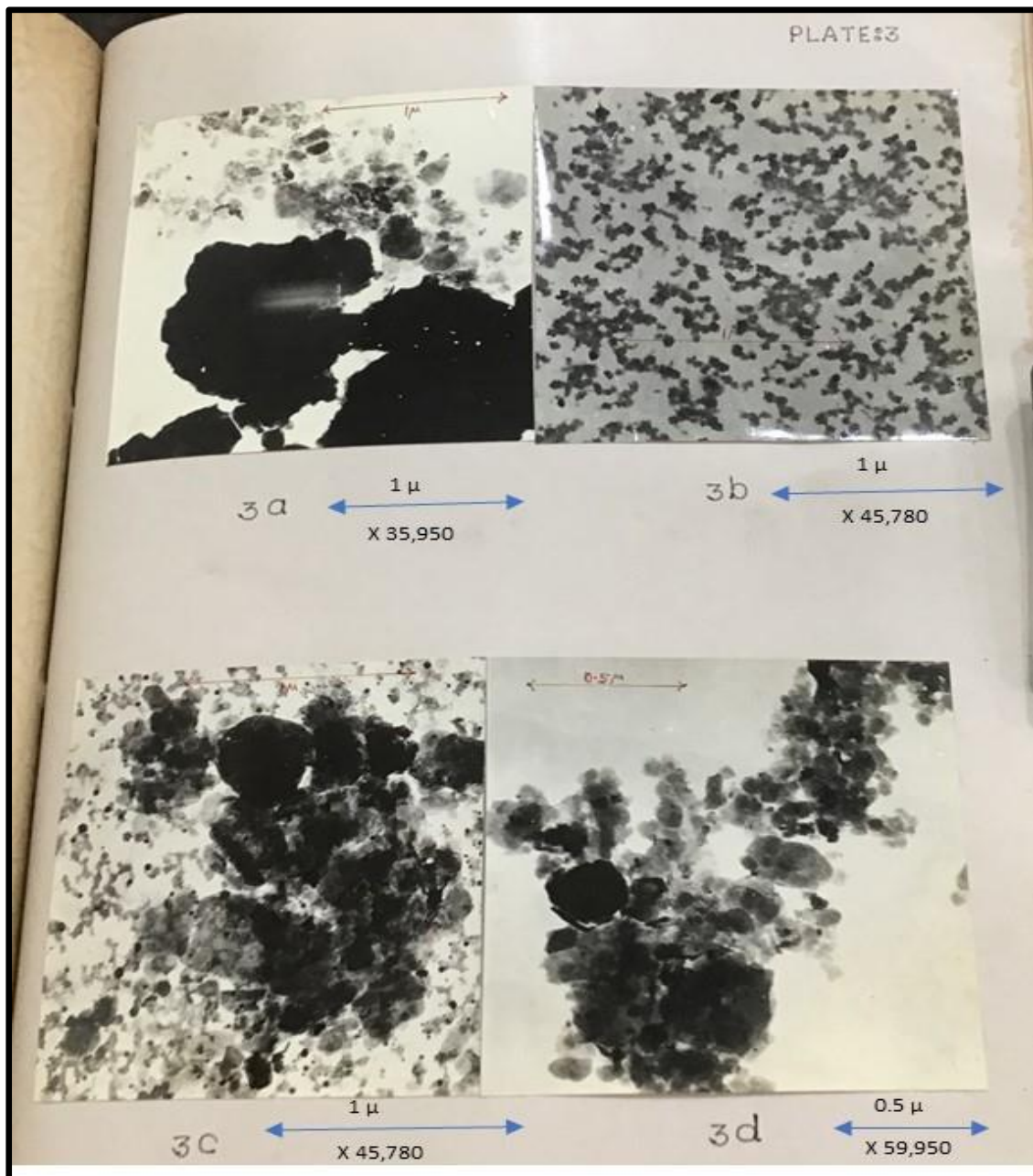


Plate 3: Electron micrographs of Clays, a) General morphological features of H_2O_2 treated clay in Pedon 2 showing kaolinite particles heavily coated with iron oxides and AFAS, b) Dispersed tiny spherocolloids forming small aggregates mixed with hematite particles in clay of Pedon 2, c) Few microaggregates of clay particles involving AFAS, hematite and silica even after CBD treatments in Pedon 2, d) Microaggregates formed by allophanes and domains of allophanic aggregates in Pedon 2.

in these clays (Plate 3d). In areas where particles are well separated at a very high magnification the surface coatings on individual particles can be seen as consisting of mixtures of silicic acids, aluminium and iron hydroxides (Plate 4a). The clays were then examined after giving repeated CBD treatments. The general morphological feature of clay after such treatments is shown in Plate 4b. It is evident that it has been possible to get much better degree of dispersion after these treatments but the clay surface continues to be coated with AFAS. The morphological kaolinite particles are now better discernible from their hexagonal morphological features although in many cases the edges appear smooth and rounded because of the coating on the surface and edges. Mica flakes were also found to remain heavily coated. When these individual particles were examined under very high magnification, the typical coating by AFAS on surfaces and edges of the particles were very clearly seen. The spheroidal allophanic particles joined themselves to form chain like structure between coated particles (Plate 4c). Amorphous materials, having no shape were also found to occur as separate domains. The persistence of these allophanic materials has separate entities and also has coating on the clay mineral surfaces (Plate 4d) qualify them to be described as stable allophanes as described earlier. Occurrence of such stable allophanes as coatings on kaolinite surfaces has also been reported by Raghu Mohan (1978) in laterite soils of Goa and Brinkman (1977) in Thailand.

4.3. Pedon 3

4.3.1. Physical, chemical and physico-chemical characteristics

4.3.1.1. Physical properties

4.3.1.1.1. Morphological properties

A general description of the area under study, other relevant information and profile morphology are presented below:

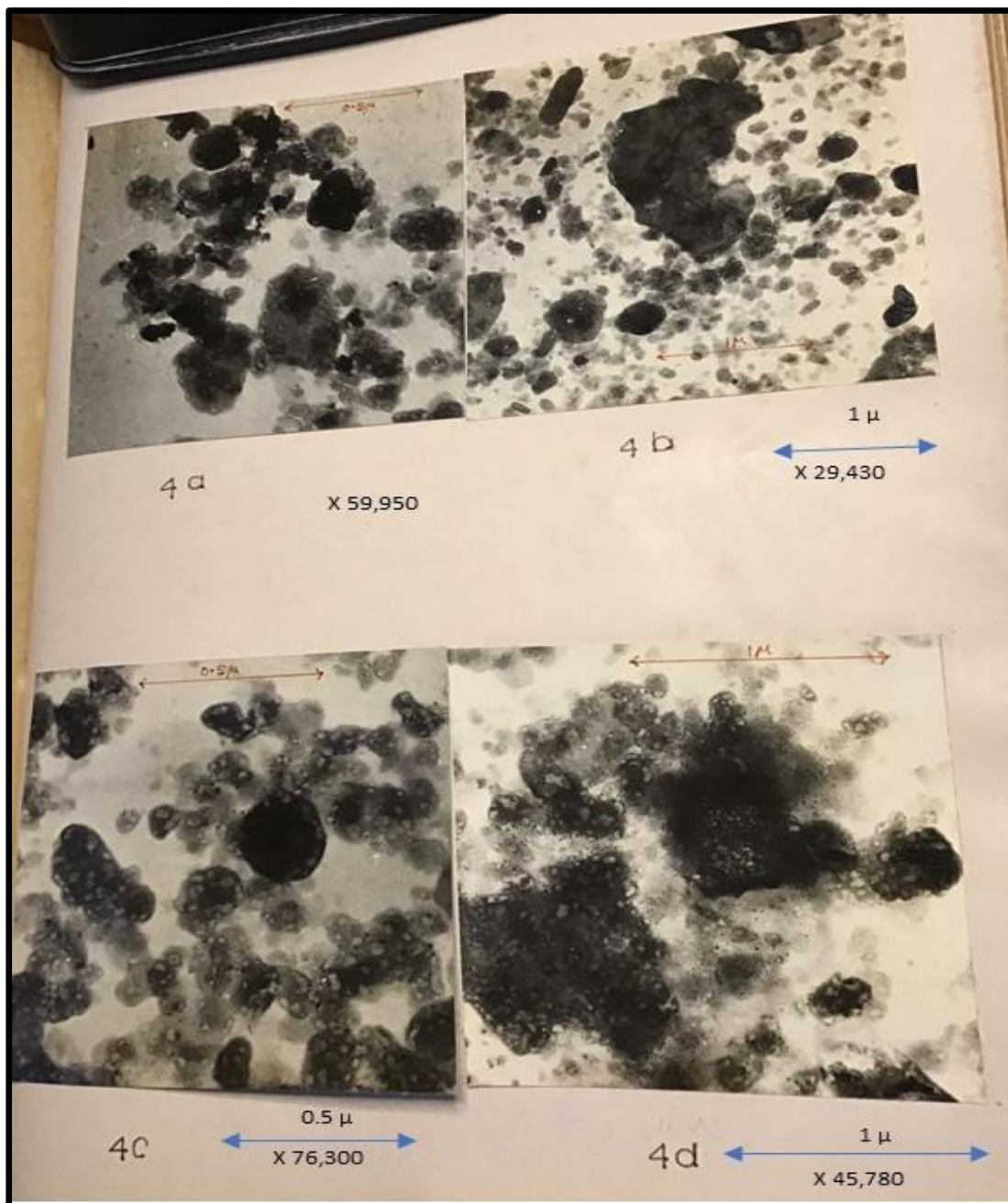


Plate 4: Electron micrographs of Clays, a) Surface coatings on individual particles in clay fractions in Pedon 2, b) General morphological features after CBD treatments in clay of Pedon 2, c) Spheroidal allophanic particles to form a chain in clay of Pedon 3, d) Persistence of allophanic particles in red soil clays of Pedon 3.

- Location: The soil profile was selected from 100 m south of Talaghattapura village on Bangalore-Kanakpura Road.
- Landscape: Very gently sloping narrow valley, with normal relief and moderate erosion.
- Elevation: About 270 feet above msl.
- Natural vegetation: *Pongamea sp.*, Shikakai, *Lantena sp.* and tall grasses.
- Drainage: Well drained soil with 10-12 m deep groundwater table.
- Parent material: Granite-gneiss.
- Land use: Ragi, mixed crops and jowar.
- Profile morphology

Horizon	Depth, cm	Description
A	0-15	Light brown (7.5 YR 6/4, dry), loamy sand; granular structure and plenty fine roots; no effervescence; gradual smooth boundary.
B1	15-67	Brown (10 YR 5/3, dry), loamy sand; plenty fine roots, sub-angular blocky structure; no effervescence; gradual smooth boundary.
B2	67-98	Reddish brown (5 YR 5/4, dry), sandy loam, few fine and coarse roots; weak sub-angular blocky structure; no effervescence; clear and smooth boundary.
C	98-152	Dark yellowish brown (10 YR 4/4, dry), sandy loam, few fine and coarse roots; massive structure; no effervescence.

Among the morphological feature solum depth is 152 cm, soil colour is light brown to dark yellowish brown, CaCO₃ is absent throughout the profile, structure is granular to sub-angular blocky and mottlings are not present.

4.3.1.1.2. Mechanical composition: A close look at Table 1 will reveal that clay distribution has been increased from 5% to 11.66%. Silt content varies from 1.25-5.63% without any uniform order of increase or decrease. The coarse sand fraction, however, decreases down the profile. Fine sand ranges from 4-6.14%. The light texture of the valley is due to that it is situated in a run off plain and does not allow the light fractions to be accumulated in this position.

4.3.1.2. Chemical properties

4.3.1.2.1. Organic matter: Organic matter content decreases from 0.95-0.46% with depth. The percentage values in this profile are less than that observed in pedons 1 and 2.

4.3.1.2.2. Total N and C/N ratio: Total N values are 0.033, 0.030, 0.043, and 0.056% in the four layers, respectively which are low in comparison to other two pedons (Table 2). C/N ratio declines from 16.6-5.0 down the profiles. These values are, however, more than in pedons 1 and 2.

4.3.1.2.3. Soluble salts and CaCO₃ content: Soluble salts are very low in this profile from 0.15-0.26 mmhos/cm, which decrease down the profile.

4.3.1.2.4. Elemental composition: Tables 3 and 4 give the observed values for different elements. The loss on ignition (900 °C) values for soil is comparatively low ranging 2-3.6%. That in clay is almost similar with minor fluctuation in values (13.4-13.8%).

4.3.1.2.4.1. Silica: The soils seem to be highly siliceous as the silica content is very high (amongst all the pedons). The values, however, have a decreasing trend with depth ranging from 87-77.6%. In general, silica content in clay fraction was found to be lower than other profiles and more or less uniform, it ranges from 42.2-50.8%. The increasing order of silica in clay is in line with the general trend of granite weathering as discussed under pedon 1.

4.3.1.2.4.2. Total sesquioxides: Throughout the profile the total sesquioxides keep up the increasing trend with depth ranging from 11-19%, lowest content being in the surface layer and highest one in the bottom (Table 3). Percentages R₂O₃ in clay is more than the soil. The values are 29, 44, 35, and 21 from top downwards.

4.3.1.2.4.3. Al₂O₃: Alumina content in soil gradually increases from the surface layer (9.3%) to the bottom (17%). The values for clay are higher ranging from 16.26-38.01%.

4.3.1.2.4.4. Fe₂O₃: The values for iron oxides in soil is ranging from 1.6-2.8% and increase with depth. In clay, however, the content is still higher and here the range is 4.7-5.9%. The higher percentage in clay may be due to the presence of

iron bearing minerals. Similar explanations for sesquioxides and iron oxides distribution can be cited as discussed in pedon 1.

4.3.1.2.4.5. Fe₂O₃: Silica, alumina and silica sesquioxide ratio: The values are observed still higher in this pedon. The SiO₂/Al₂O₃ ratio ranges from 7.21-14.46 and SiO₂/R₂O₃ ranges from 16.93-31.30. Such high values are obviously due to more than 70% sand content of this soil which is dominated by quartz. In clay, values are lower ranging from 2.06-5.31 (SiO₂/Al₂O₃) and 4.57-10.56 (SiO₂/R₂O₃). The reasons for wider SiO₂/Al₂O₃ and SiO₂/R₂O₃ molar ratios have been explained in connection with discussion of the data obtained for pedon 2 and the same reasonings hold good for this pedon also.

4.3.1.2.4.6. CaO and MgO: CaO content in both soil and clay is less than MgO content. The former varies from 1.4-3.3% (soil) and 0.8-1.7% (clay) and the later from 0.87-4.92% (soil) and 1.31-2.16% (clay).

4.3.1.2.4.7. K₂O: The potash content decreases with depth ranging from 0.64-0.92% in soil. The values for clay are still higher (0.602-1.138%) probably due to the contribution from mica present in clay fraction. Higher potash content of surface layer of the soil is in conformity with the earlier findings of Desai (1942) and Pal and Roay (1978) and can be well correlated to mica and K feldspars content of the soil (c.f. silt and sand mineralogy).

4.3.1.2.5. Free iron, aluminium and silicon: The iron oxide content decreases gradually down the profile. The values obtained are 0.88, 1.14, 1.40 and 1.53%. Free Al₂O₃ content is very low ranging from 0.009-0.118%. Silicon content is, however, more and the range is 3.81-4.49% (Table 5). Free Al₂O₃ and SiO₂ values are not as uniform as Fe₂O₃.

4.3.1.2.6. Allophane: Allophanic materials are comparatively low in this profile, and are distributed with an increasing order down the profile. It ranges from 22.42-23.76%. Similar values were obtained for two soils in Mysore State as

reported by Murali et al. (1978). The percentage of released Fe_2O_3 was also found to be low as compared to that found for the other two pedons although the values are similar throughout the profile. It ranges from 0.314-0.335% (Table 6). Free Fe_2O_3 , Al_2O_3 and allophane contents suggest lower weathering intensity in this pedon.

4.3.1.3. Physico-chemical characteristics:

4.3.1.3.1. Soil reaction (pH): The soil reaction is slightly acidic. The pH (water) ranges from 5.75 to 6.40. In *NKCl* the values are 4.40-5.60. Similar results were reported by Raychaudhuri et al. (1963) and others.

4.3.1.3.2. Cation exchange capacity of soils (CEC): The CEC (me/100 g) was found very low in this profile which may be due to the low content of clay present in this profile. The values gradually increase from 4.8 in the surface layer to 8.6 in the bottom which is perhaps due to the increase in percentage clay in the same order (Table 7).

4.3.1.3.3. Exchangeable bases: Ca and Mg were found to be the major exchangeable bases and the results in the Table 7 show that the values of these two are more or less similar throughout the profile. In other two profiles Ca was in higher proportions than Mg. The range for Ca is 2.19-4.30 me/100 g and for Mg 2.16-3.38 me/100 g, increasing in both the cases down the profile. Among other bases, iron, aluminium and potassium were in less amount while Na was relatively higher ranging from 0.105-0.220 me/100 g in exchange phase.

4.3. 2. Mineralogical Analysis:

4.3.2.1. Interpretation of X-ray diffractograms

4.3.2.1.1. Clay fraction (<2 μ): All the four layers contain two minerals in this fraction namely kaolinite (7.2, 3.59 A°) and mica (10.1, 4.99, and 3.33 A°). The fourth layer appears to contain an interstratified mineral giving a 14.5 A° peak in Mg clay and 15.2 A° peak on glycerolvation. The peaks, however, are absent in

K 550 °C treatment. The Figures 9 and 10 show the diffractograms of two representative layers and **Table 23** represents the basal spacings as observed in the X-ray diffractograms.

4.3.2.1.2. Silt fraction (2-20 μ): The minerals identified in this fraction are kaolinite, mica, chlorite, quartz, feldspars and amphibole with their characteristic lattice spacings as tabulated in **Table 24**. The **Figure 11** shows the diffractograms of top and bottom layer of this profile. The data obtained here are supported by Murali et al. (1974). Kaolinite also dominates (like clay fraction) although mica and quartz are in good amounts. The other minerals like, feldspars and amphiboles are in traces (**Table 25**).

4.3.2.1.3. Fine sand fraction (20-50 μ): The minerals identified in this fraction are kaolinite, mica, chlorite, quartz, feldspars, diaspore (2.55, 2.38 and 2.35 Å⁰), hematite (3.67, 1.45 Å⁰), apatite (3.92, 2.76 and 1.61 Å⁰) and amphibole (8.5 Å⁰) as shown in the **Table 26**. The second horizon in this fraction is dominated by feldspars; while in other layers quartz contributes the major portion. In first two layers both kaolinite and amphibole are in relatively higher amount. Mica, quartz, diaspore, hematite, apatite are in lesser quantities throughout this profile (**Table 27**).

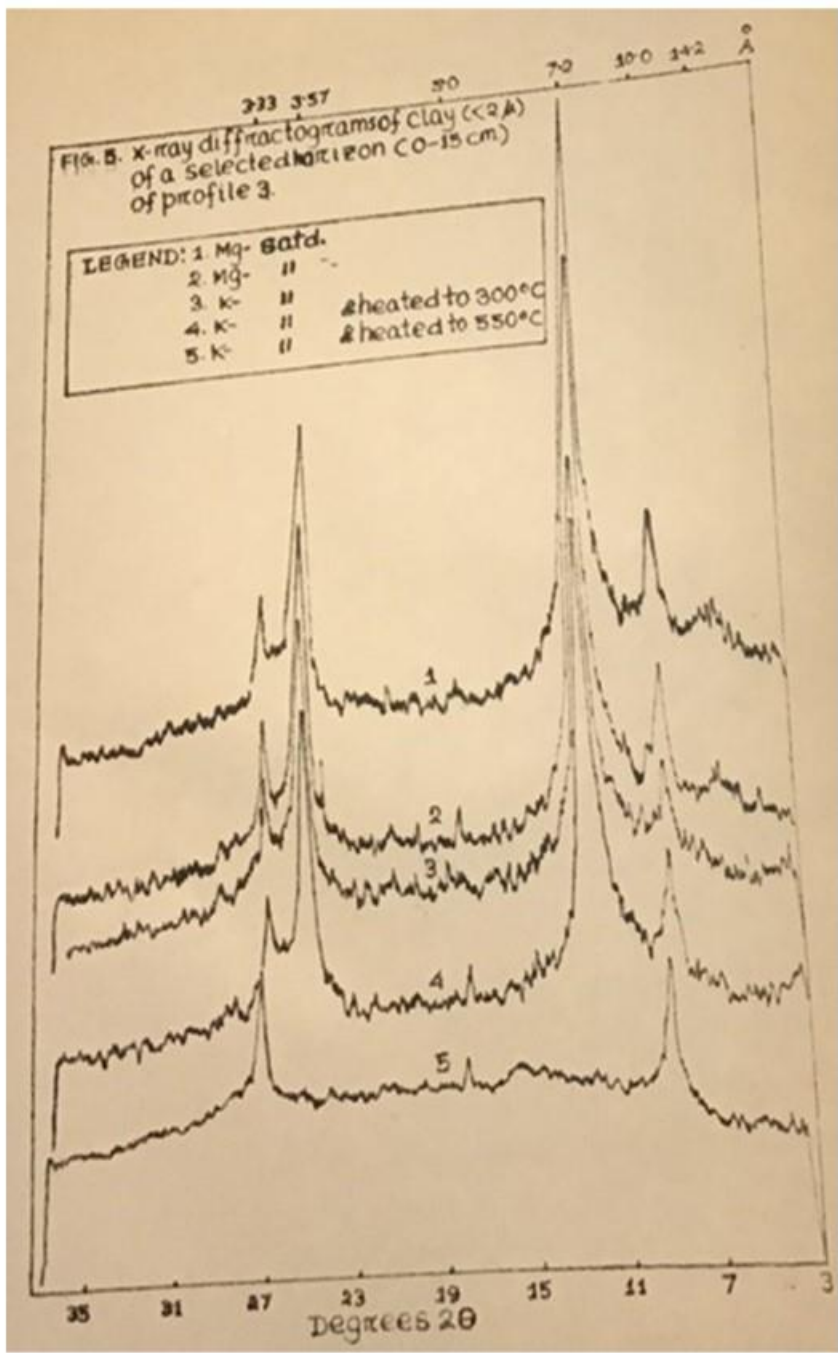


Figure 9. X-ray diffractograms of clay of Profile 3 (0-15 cm)

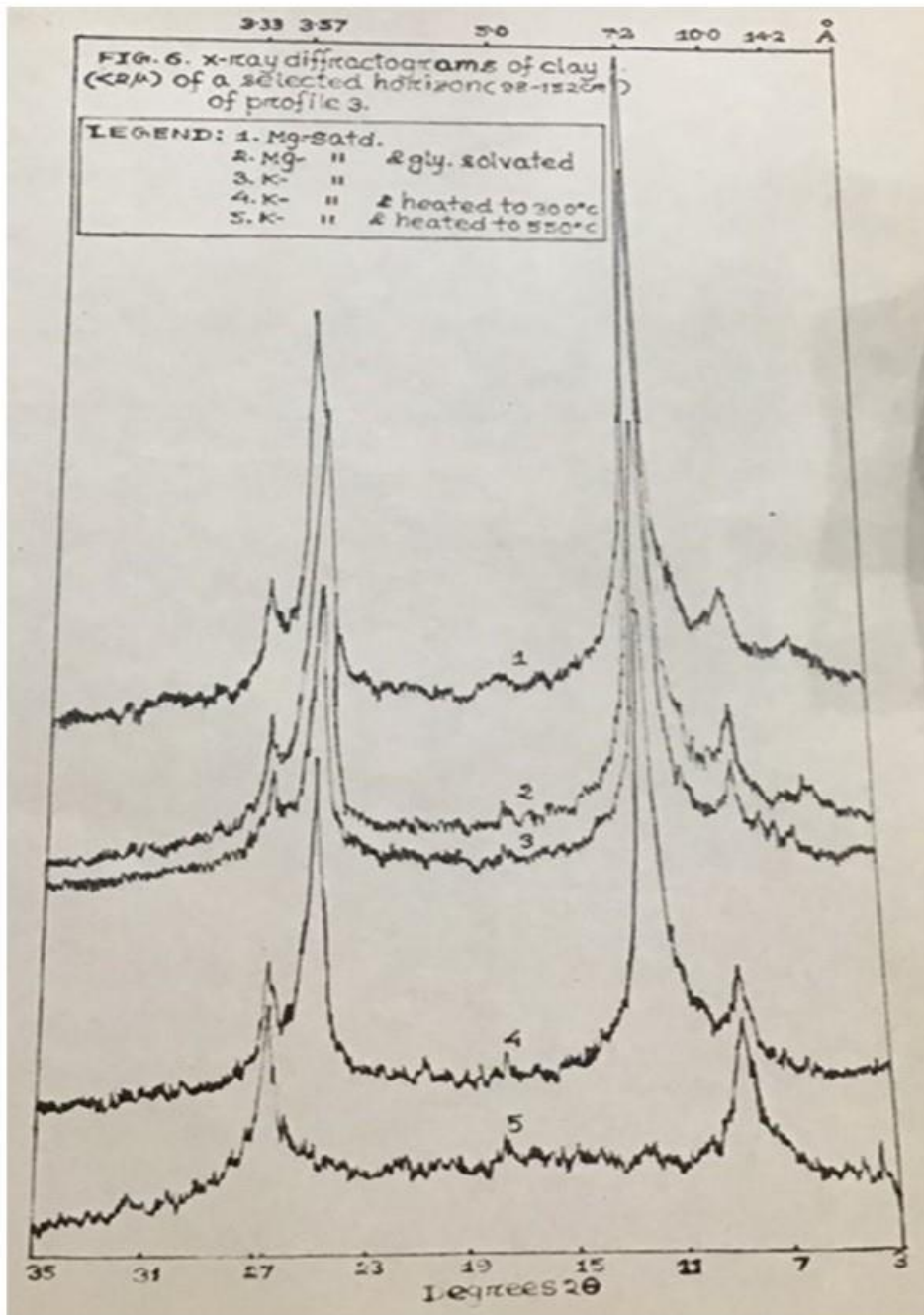


Figure 10. X-ray diffractograms of clay of Profile 3 (98-152 cm)

Table 23. Diagnostic lattice spacings (d_{hkl}) in A^0 observed in the X-ray diffractograms of clay fractions ($<2 \mu$) of different horizons of Pedon 3

Depth, cm	Treatment of samples					Mineral(s) group corresponding to the observed d_{hkl} (A^0)
	Mg saturated	Mg-glycerolvated	K saturated	K saturated and heated to 300°C	K saturated and heated to 550°C	
0-15	10.10	10.10	10.10	10.10	10.10	Mica
	4.99	4.99	4.99	5.00	5.00	
	3.35	3.35	3.35	3.35	3.34	
	7.20	7.20	7.20	7.20	--	Kaolinite
	3.59	3.57	3.60	3.59	--	
15-61	10.20	10.10	10.10	10.10	10.10	Mica
	5.00	5.00	5.00	5.00	5.00	
	3.36	3.34	3.33	3.33	3.35	
	7.20	7.20	7.20	7.20	--	Kaolinite
	3.59	3.57	3.59	3.59	--	
61-98	10.10	10.00	10.10	10.10	10.10	Mica
	5.00	4.98	5.00	4.98	5.00	
	3.33	3.33	3.33	3.33	3.33	
	7.20	7.20	7.20	7.20	--	Kaolinite
	3.59	3.59	3.59	3.59	--	
98-152	14.48	15.20	14.20	14.02	--	Interstratified mineral
	7.20	7.20	7.20	7.20		
	3.59	3.59	3.59	3.59		
	10.10	10.10	10.10	10.10	10.10	Mica
	4.98	5.00	5.00	4.99	5.00	
	3.33	3.33	3.33	3.33	3.33	
7.20	7.20	7.20	7.20	--	Kaolinite	
3.59	3.59	3.59	3.59	--		

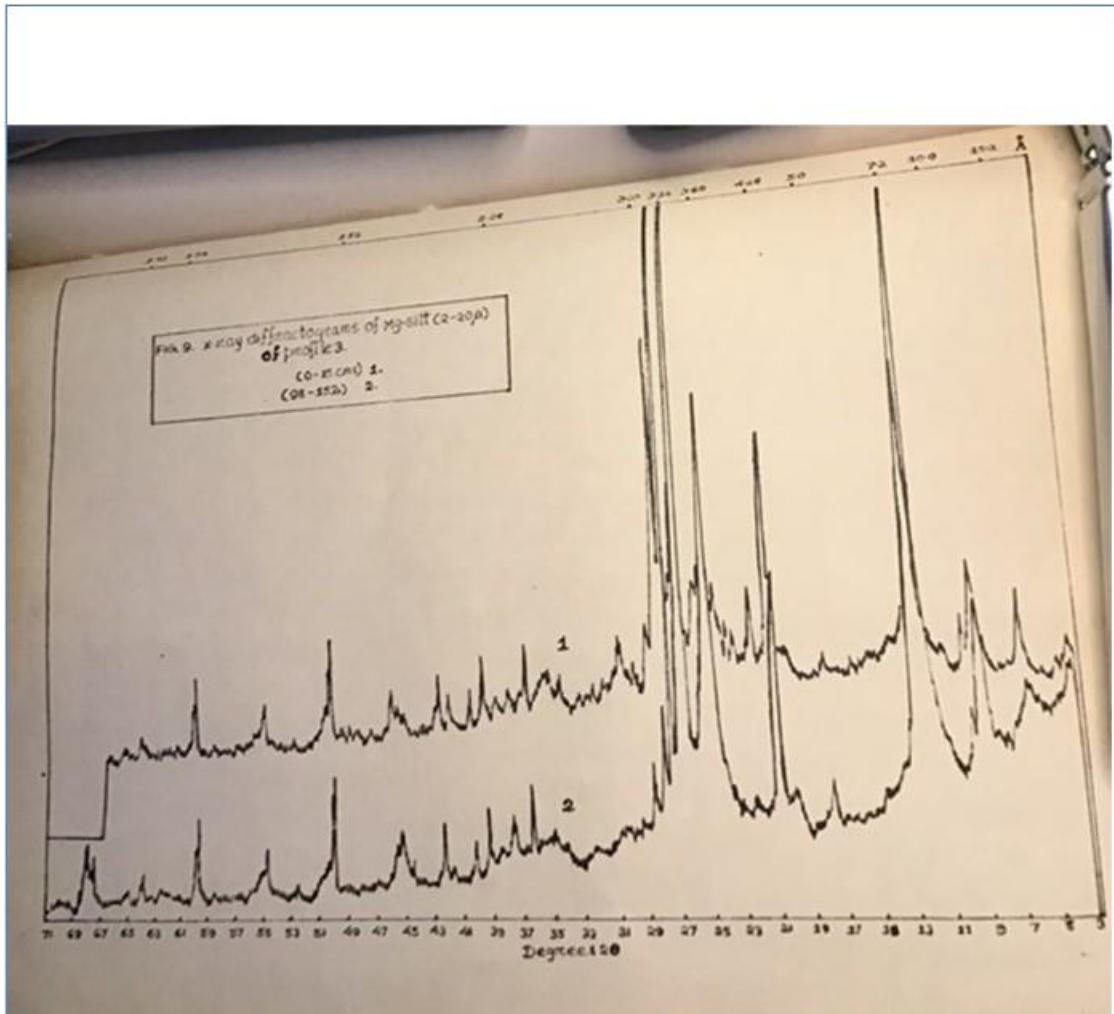


Figure 11. X-ray diffractograms of Mg silt of Profile 3 (0-15 and 98-152 cm)

Table 24. Diagnostic lattice spacings (d_{hkl}) in A^0 observed in the X-ray diffractograms of silt fractions (2 – 20 μ) of different horizons of Pedon 3

Depth, cm	(d_{hkl}) in A^0 corresponding to various minerals						
	Kaolinite	Smectite	Mica	Chlorite	Quartz	Feldspars	Amphibole
0-15	7.20	--	10.00	14.40	4.27	4.04	8.67
	3.57		5.00	7.20	3.33	3.85	
	2.28		3.33	3.57	2.46	3.78	
					2.24	3.67	
					2.13	3.26	
					1.82	3.24	
					3.20		
15-61	7.20	--	10.00	14.40	4.27	4.04	8.67
	3.57		5.00	7.20	3.33	3.78	
	2.28		3.33	3.57	2.46	3.26	
					2.24	3.24	
					2.13	3.20	
					1.82		
61-98	7.20	--	10.00	14.20	4.27	4.04	8.67
	3.57		5.00	7.20	3.33	3.78	
	2.28		3.35	3.57	2.46	3.26	
					2.24	3.24	
					2.13	3.20	
					1.82		
98-152	7.20	--	10.00	14.02	4.29		8.67
	3.57		5.00	7.20	3.33	3.61	
	2.28		3.33	3.57	2.46	3.22	
					2.13	3.18	
					1.82		

Table 25. Relative abundance of different minerals in silt fractions (2- 50 μ) of different horizons of Pedon 3

Depth, cm	Minerals					
	Kaolinite	Mica	Chlorite	Quartz	Feldspars	Amphibole
0-15	++	+	Traces	++	++	Traces
15-61	+++++	+++	Traces	++	+	Traces
61-98	+++	++	Traces	+++	Traces	Traces
98-152	++	+	Traces	Traces	++++	+

Table 26. Diagnostic lattice spacings (d_{hkl}) in A^0 observed in the X-ray diffractograms of fine sand fractions (20 – 50 μ) of different horizons of Pedon 3

Depth, cm	Kaolinite	Mica	Chlorite	Quartz	Feldspar	Diaspore	Hematite	Apatite	Amphibole
0-15	7.20	10.00	14.60	4.29	6.44	2.55	3.67	3.90	8.50
	3.60	5.06	4.59	3.34	3.26	2.38	1.71	2.84	
	1.98	3.49	3.60	2.47	3.20	1.81	1.45	2.76	
	1.71	3.34	2.38	2.29	3.04	1.71		2.55	
	1.61	2.38	2.03	2.24	2.96	1.57		2.32	
	1.54	2.13		2.13		1.37		2.16	
	1.37	1.98		1.98				2.04	
				1.82				1.91	
				1.67				1.84	
				1.54				1.81	
				1.38				1.76	
				1.37				1.71	
								1.61	
15-61	7.20	10.10	14.60	4.29	6.46	2.55	3.67	3.92	8.50
	3.60	5.06	4.59	3.34	4.00	2.38	2.07	2.84	
	2.55	3.49	3.60	2.47	3.85	2.35		2.64	
	2.38	3.34	2.43	2.29	3.70	2.07		2.55	
	1.93	2.38	2.38	2.24	3.26	1.61		2.05	
	1.80	2.13	2.05	2.13	3.20	1.57		1.94	
	1.66	1.98	2.03	1.98	3.16	1.43		1.61	
	1.58	1.50	1.88	1.82	3.04	1.42			
	1.42		1.66	1.67	2.96	1.37			
	1.37			1.54	2.43				
				1.38					
				1.37					
	61-98	7.20	11.05	15.20	4.29	6.46	3.21	2.20	3.92
3.51		3.34	3.51	3.34	4.00	2.55	1.59	2.84	
3.13		2.79	2.04	2.47	3.95	2.35	1.48	2.55	
2.18		2.46	1.72	2.29	3.86	1.71		2.16	
1.93		2.28	1.67	2.24	3.24	1.61		2.04	
1.66		2.24	1.66	2.13	3.20	1.48		1.95	
1.62		2.13		1.98	3.04	1.43		1.61	
1.54		2.00		1.82	2.96	1.42			
1.46		1.82		1.81	2.43	1.40			
1.37				1.67	1.67	1.37			
				1.38					
				1.37					
98-152		7.20	11.05	15.20	4.29	4.07	2.35	2.08	2.76
	3.51	3.34	3.51	3.34	4.00	2.08	1.61	2.16	
	3.13	2.79	2.04	2.47	3.86	1.81	1.45	2.05	
	2.18	2.46	1.72	2.29	3.73	1.47		1.95	
	1.93	2.28	1.67	2.24	3.26	1.43		1.77	
	1.66	2.24	1.66	2.13	3.21	1.40		1.61	
	1.62	2.13		1.98	3.03	1.37			
	1.54	2.00		1.82	2.95				
	1.46	1.82		1.67	2.94				
	1.37			1.38	2.58				
				1.37					

Table 27. Relative abundance of different minerals in fine sand fractions (20-50 μ) of different horizons of Pedon 3

Depth, cm	+								
	Kaolinite	Mica	Chlorite	Quartz	Feldspars	Diaspore	Hematite	Apatite	Amphibole
0-15	+	Traces	Traces	++++	+++	Traces	Traces	Traces	+
15-61	+	Traces	Traces	+++	+++++	+	Traces	Traces	+
61-98	Traces	Traces	Traces	++++	+++	Traces	Traces	Traces	Traces
98-152	Traces	Traces	Traces	+++	++	Traces	Traces	Traces	Traces

4.3.2.1.4. Coarse sand fraction (>50 μ): Table 28 gives the basal spacings of different minerals namely kaolinite, mica, chlorite, quartz, feldspars and amphibole (8.54 and 8.7A⁰). The 61-98 cm layer has feldspars as the dominant mineral; in other two horizons, quartz is the major mineral present. Kaolinite, mica, chlorite and amphibole are found in traces in this fraction (Table 29). The dominance of quartz in all the layers can be explained in a similar fashion as discussed in connection with pedon 1.

4.3.2.2. Semiquantitative distribution of clay minerals (<2 μ): Kaolinite is the dominant mineral with the percentage distribution (ranging from 67-75) gradually declining with depth. Mica was the other mineral with the range of 22-33% and follows the same order as kaolinite. The bottom layer, however, contains 3% interstratified mineral (smectite and chloritized-smectite interstratification). The percentages of kaolinite in this profile and pedon 2 are more or less same while that in pedon 1 is relatively higher (Table 9). A close look at the Table 23 suggests that formation of interstratified mineral may be at the cost of mica, the contents of which in the bottom layer decreases (22%). The calculated values for weathering mean ranges from 8.93-9.31. The mineral distribution curves are shown in Figure 12.

Table 28 Diagnostic lattice spacings (d_{hkl}) in A^0 observed in the X-ray Diffractograms of coarse sand fractions ($>50 \mu$) of different horizons of pedon 3.

Depth, cm	d_{hkl} (A^0) corresponding to various minerals						
	Kaolinite	Mica	Chlorite	Quartz	Feldspars	Amphibole	
0-15	7.20	10.00	14.60	4.29	6.53	8.54	
	3.57	5.00	7.20	3.38	3.98		
	1.98	3.38	3.57	3.25	3.83		
	1.54			2.46	3.80		
	1.45			2.28	3.22		
	1.37			1.98	3.04		
				1.82	2.94		
				1.67	2.90		
				1.54	2.65		
				1.45	2.57		
				1.39			
				1.38			
	15-98	7.20	10.00	14.60	4.29	6.53	8.54
		3.57	3.38	7.20	3.38	4.04	
1.98		1.98	3.57	2.46	3.83		
1.45				2.28	3.70		
1.37				1.98	3.22		
				1.82	3.04		
				1.67	2.94		
				1.45	2.90		
				1.39	2.85		
				1.38	2.77		
					2.65		
					2.57		
98-152		7.20	10.00	14.60	4.29	6.53	8.70
		3.57	3.38	7.20	3.38	4.04	
	1.98	1.98	3.57	2.46	3.83		
	1.54			2.28	3.70		
	1.45			1.54	3.22		
	1.37			1.45	3.04		
				1.39	2.94		
				1.38	2.90		
					2.85		
					2.77		
					2.65		
					2.57		

Table 29. Relative abundance of different minerals in coarse sand fractions (> 50 μ) of different horizons of Pedon 3

Depth, cm	Minerals					
	Kaolinite	Mica	Chlorite	Quartz	Feldspars	Amphibole
0-15	Traces	Traces	Traces	+++++	++	Traces
61-98	Traces	Traces	Traces	+++	++++	Traces
98-152	Traces	Traces	Traces	+++++	+	Traces

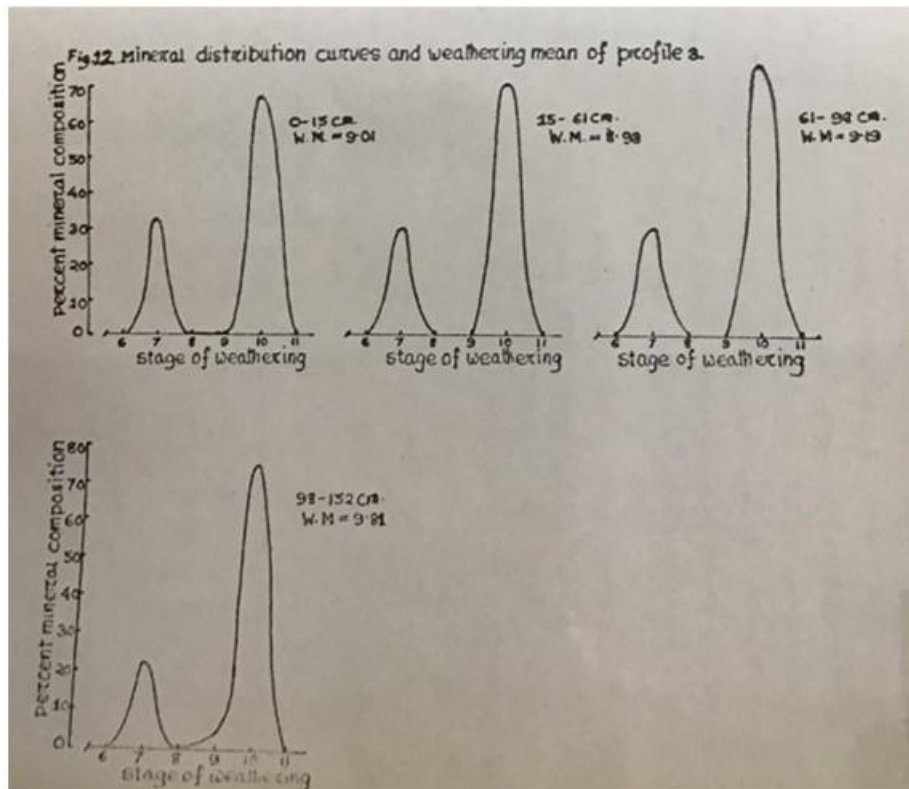


Figure 12. Mineral distribution curves and weathering mean of Profile 3

4.3.2.3. **Electron microscopic examinations of clays (<2 μ):** Similar information as described earlier were also obtained in the electron microscopic examinations of the clays of this pedon. It can be seen from Plate 5e that after several CBD treatments as in the other two pedons, the clay particles still remain to be heavily coated with AFAS. Plate 5b presents few kaolin and mica particles on the surfaces. All these particles, although show clearly their morphological

outline have coatings of AFAS on their surface. Domains of shapeless amorphous materials were fairly common in this clay (Plate 5c). Allophanes with spherical morphology and coatings of AFAS on kaolin and mica surfaces are common features in this clay (Plate 5d).

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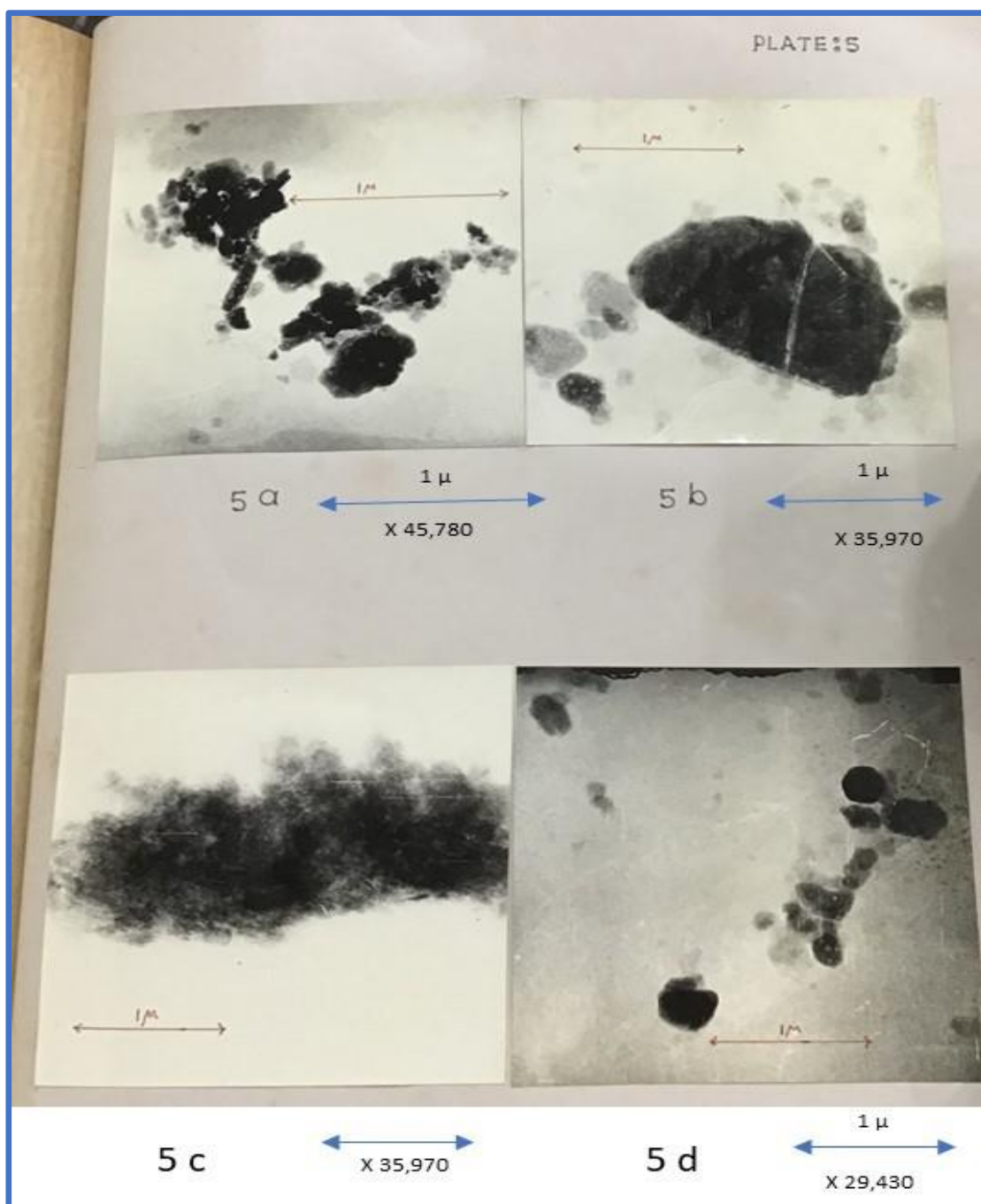


Plate 5: Electron micrographs of Clays, a) Heavily coated clay particles CBD treated samples in Pedon 3, b) Kaolinite and mica particles after CBD treatments in clay of Pedon 3, c) Shapeless amorphous materials common in clay of Pedon 3, d) Spherical Allophanic particles with AFAS coatings in clay of Pedon 3.

5. GENERAL DISCUSSION

The profile morphology and the analytical data presented in the previous chapter help classifying the soil according to Soil Taxonomy (1978) as shown in **Table 30**.

Table 30. Soil Classification

Diagnostic horizon/category	Pedon 1	Pedon 2	Pedon 3
Epipedon	Ochric	Ochric	Ochric
Subsurface diagnostic horizon	Argillic	Argillic	Albic
Order	Alfisols	Alfisols	Inceptisols
Suborder	Ustalfs	Ustalfs	Ochrepts
Great group	Haplustalfs	Haplustalfs	Ustochrepts
Sub group	Rhodic Haplustalfs	Lithic Haplustalfs	Udic Ustochrepts
Family	Fine loamy, kaolinitic, non-acid, hyperthermic Rhodic Haplustalfs	Coarse loamy, kaolinitic, non-acid, hyperthermic Lithic Haplustalfs	Loamy, kaolinitic, non-acid, hyperthermic Udic Ustochrepts

All the three pedons under study have ochric epipedon. As discussed earlier excepting pedon 3, other two have clear argillic subsurface horizons. Figure 1 help characterising the area under ustic moisture regime leading to classify the soil under Ustalfs as these two pedons show the characteristics of Alfisols. The hue redder than 5 YR led the pedon 1 to be classified under Rhodic Haplustalfs up to the subgroup level. In case of pedon 1 presence of paralithic contact led it to be classified as Lithic Hapustalf at subgroup level.

Unlike these two pedons, the third one, however, fitted best in the Inceptisols (order) due to the very light textures of this profile. It should be mentioned here that pedon 3 is situated in a run off plane and any light materials (clay) coming from higher elevations of the landscape cannot accumulate there and hence leave only the coarser materials. The brown colour or colour B or albic B helps designing the pedon with an albic horizon; ochric, like other two pedons, is the epipedon here. Soils are free of carbonates. These were the basis for classifying pedon 3 under Udic Ustochrepts up to subgroup level. The soil reaction, mineralogy, textures and temperature of the area of soil collection helps classifying the soil up to family level (Table 30).

The three pedons studied show clear evidence of the effect of topography.

It can be noted that pedon 1 occurring on the plateau is rather deep (solum depth = 113 cm) whereas the pedon on the valley has much lower depth of solum (98 cm). The pedon 2 on the mid-slope, however, has maximum solum depth 146 cm. It appears that the solum depth of pedon 1 was restricted due to the presence of a thick quartz vein below the highly weathered parent material to a greater than 207 cm still maintained its structural characteristics. If the solum depth of pedon 1 and 2 are compared is the light of the above fact, it is understandable why pedon 1 has lower solum depth than pedon 2. Thus, it appears that in this physiographic unit the solum depth tend to decrease with decreasing elevation.

The change in soil colour from the plateau to the mid-pediment and to the valley is also a distinctive feature of the effect of topography on soil characteristics in this physiographic unit. The soil on the plateau has a hue redder 5 YR, whereas in the mid-slope the soil colour changes to less red hue (2.5 Y). The colour of the soil in the valley is light brown (7.5 YR 6/4). The change

in redox condition, hydration level, and also free iron oxide content from upper slope to lower slopes (Table 5) account for the colour variation. The valley soil has a lower oxidation state, higher hydration level and low content of free Fe_2O_3 . As a result, the colour is also light brown (7.5 YR 6/4).

It has already been pointed out while presenting data on individual pedons that distribution of free Fe_2O_3 , allophane, $\text{SiO}_2/\text{R}_2\text{O}_3$ ratio, base content etc. all clearly points to the fact that the weathering intensity in the three pedons is in the order pedon 1 > pedon 2 > pedon 3. All chemical, physico-chemical and morphological data provide evidence of much higher degree of weathering in the two pedons at plateau and mid-slope as compared to the one at valley level.

Pedon 2, located at much lower elevation in comparison to pedon 1, is less weathered as is evident from chemical and physico-chemical data on the two pedons. The weathering means calculated on the basis of semi-quantitative clay mineralogical data further confirm this. Thus, these two pedons developing on exactly similar parent material in the same climatic zone reveal differences in weathering intensity which appears primarily due to the difference in weathering in their location in the landscape. Both the pedons, however, show characteristic features of Alfisols and qualify themselves to be classified as Haplustalfs at the great group level. They differ at subgroup and family levels.

The differences of pedon 3 with the other two are so great that it can be classified under the same order as the other two pedons. It has already been pointed out that this pedon is in a narrow valley representing a run off channel. The deposited material is, therefore, highly weathered material from the uplands on this physiographic unit. The weathering mean values which are very similar to that of pedon 2 also indicate the highly weathered character of the deposited material. But the morphological features clearly indicate the low level of pedogenic activity in this profile.

Though there is slight increase in clay content in the subsurface layer (B1) there has not been the development of characteristic argillic horizon as is found in the other two pedons. The location of this pedon is such in the landscape that deposition of finer particles (e.g. clay) is restricted as is evident from the coarse texture of the deposited material throughout the profile depth. The pedon was classified as belonging to the order Inceptisols. The effect of topography thus appeared to be more conspicuous on this pedon.

The present material of all the three pedons is granite-gneiss. As already stated, granites and granite-gneiss average approximately 25% quartz, 65% or less orthoclase with lesser amounts of mica and small amounts of hornblende and other accessory minerals. The area represents old landform and, therefore, has been exposed to weathering for a very long time under tropical conditions. It is a well-known fact that weathering of granite-gneiss under such conditions leads to formation of laterites as an end product with the formation of kaolinite, halloysite, gibbsite, allophanes, hydrated iron and titanium oxide and dehydrated iron and titanium oxides in various proportions at various stages of weathering.

The pedons under study do not appear to have attained the laterite stage of weathering as is evident from the absence of “plinthite layer” and presence of weatherable primary mineral though pedons have developed in neighbouring areas of Bangalore South Taluk with “plinthite” and “petroplinthite” layers. Pedon 1 on the plateau represent fairly advanced stage of weathering. In the C horizon of this profile the intense argillation process has proceeded to great depth, but the gneiss has still maintained its megascopic and external structures. The rock at the lowest depth examined is so soft and clayey that a nail or the pick point of a hammer penetrates it easily. Most of the orthoclase feldspars appeared to have weathered to white kaolin while some weathered

orthoclase feldspar grain still retained its light pink colour. Pseudomorphism in weathered crystalline rocks in such grand scale has been found in kaolinization, at depth, of Cornwall granite (Holmes, 1950).

Total kaolinization of gneiss and retention of the structure of the rock in Mangalore, Malabar Coast of India was reported as early as in 1926 by Harrassowitz. The argillation process in the C horizon of pedon 2 was much less vigorous. The rock though had a weathered appearance was not sift, there was less evidence of intense kaolinization of feldspars and even some dark coloured ferromagnesian minerals were easily detectable. These observations are in these two pedons already outlined in the foregoing discussion.

Kaolinite is the dominant mineral together with appreciable quantity of mica in the clay fraction of all the pedons. In the weathered C horizon of pedon 1, the clay also contains smectite. The silt fraction is also dominantly kaolinitic, with mica, quartz, feldspars, traces of secondary chlorite and amphiboles. The persistence of amphibole in this fraction is noteworthy, The mineral assemblage in 20-50 μ fraction clearly shows decline in kaolinite content and dominance of either quartz or feldspars; mica appears only in small quantities, traces of chlorite and amphiboles are also present, minerals like diaspore and hematite which may be considered as being formed during the course of weathering (parent rocks do not contain these minerals) show their appearance and apparently concentrates in this particles size fraction (20-50 μ).

The coarse sand fraction (>50 μ) contains mainly quartz and feldspar with traces of mica, kaolinite, chlorite and amphibole. Besides, these crystalline minerals in the various particle size fraction of the soils contain free silica, free iron oxide, free alumina, amorphous ferro-alumino-silicates as has been brought out by selective dissolution analysis and electron microscopic examination of the clays after various pretreatments.

The dominance of kaolinite in the clay and silt fraction and its occurrence in the coarser fractions of the soils in various proportions clearly indicates that kaolinization was the major process operated during the weathering of the granite-gneiss. Kaolinite formation requires, relatively high ratio of Al to Si, high H^+ , low base content and under laboratory condition synthesis is generally restricted to low pH of 4.5 (De Kimpe et al. 1961) or 2.5 (De Kimpe et al. 1964). Under natural weathering condition these factors may be met by the alteration of aluminium silicate parent material under condition if efficient effluent drainage so that Ca, Mg, Na, K are removed from the weathering zone and Fe is either removed in solution or deactivated by precipitation.

The importance effective drainage condition has also been shown by the early observation of Mohr and Van Baren (1054) that laterite (kaolinite) and montmorillonite were formed a short distance from each other from the same parent material in the same climate, except that the laterite site was well drained, while the montmorillonite site was waterlogged and hence silica and metal ions were not removed. The area under study is well drained and, therefore, provide congenial weathering condition for kaolinization of granite-gneiss. But the present day warm semi-arid climatic conditions in this area (Bangalore) cannot be considered severe enough for transformation and weathering to the kaolinite stage and the neutral to slightly acidic pH values of the soil are not conducive to the transformation of 2:1 mineral to kaolinite.

Studies on soils of neighbouring regions of the Mysore plateau (Brunner, 1968; Rengaswami, 1973; Murali et al. 1974) have suggested that kaolinite was formed in an earlier geological period with more rainfall and greater fluctuations in temperature. A relatively high ratio of Al with respect to Si, as indicated by the composition of kaolinite and its laboratory synthesis (De Kimpe et al. 1961) seems to have arisen as a result of differential removal of silica particularly in the

presence of K and Na liberated during the decomposition of feldspars. It is well known industrial practice in the preparation of soluble colloidal silica to add low concentration of alkali metals to stabilise such colloidal solution i.e. keeping the silica in solution.

These effects suggest that weathering of K and Na feldspars would lead to the loss of silica by solution and consequent enrichment with alumina. Therefore, granite-gneiss rocks having very high content of orthoclase feldspar are susceptible to ready kaolinization. The high degree of kaolinization observed in the pedons studied are in conformity with the inference drawn on the basis of argument presented above.

Establishing the fact that kaolinization is the natural consequence of granite-gneiss weathering in the area of study, let us examine the genesis of other products of other products of weathering found in various particle size fractions. The process of kaolinization is characterised by an amorphous gel phase, intermediate in stage of alternation between parent silicate (primarily feldspar in this case) and the neo formed product (kaolinite group of minerals). The weathering reaction starts at the silicate-water interface. The proportion of such reaction zones and the products formed at the silicate surfaces have been studied by several workers (Correns, 1963; DeVore, 1959; Hemley, 1959; Garrels and Howard, 1959; Nash and Marshall, 1956; Morey and Chen, 1955).

Garrels and Howard (1959) concluded on the basis of the study of feldspar and mica with water that the first result of the reaction of mica and feldspar is the formation of a surface layer that gradually form an outer portion which is structurally disrupted to an inner portion and it retains the original silicate structure but with H substituted for K. Correns (1961, 1963) on the basis of the study on laboratory decomposition of feldspars concluded that the components of framework silicates entered the solution as ions that there were formed on the

particles, a very thin residue layer, the thickness of which does not increase during the course of decomposition.

The composition of the residue layer is such that the $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio does not correspond to formation of either kaolinite or montmorillonite or any such minerals in this layer. In fact, the residue layer proves to be amorphous on X-ray examinations. Thus alumino-silicic sols are bound to form during weathering of feldspars. The simultaneous weathering of biotite mica and other ferromagnesian minerals present in the rock provides Ca, Mg, and Fe ions in the solution. Ca and Mg have destabilizing affect particularly on the silica and iron leading to precipitation of both as amorphous silica and iron hydroxide which may subsequently crystallize on aging to quartz and iron minerals, respectively.

The occurrence of amorphous silica, free iron oxide, hematite and diaspore in these pedons are results of such neofomation reactions. Harrassowitz (1926) has also reported the formation of diaspore during kaolinization of gneiss in the Malabar Coast of India. With changing conditions of weathering over long period precipitation of mixed alumino-silicic and also ferro-alumino-silicic gels are quite likely, which with long ageing developed into allophane. Though there are no direct proofs for such inference, the occurrence in the pedons of AAS and AFAS as evident from the electron micrographs and the data on the content of allophanic material (table 6) strongly suggests that the weathering reaction followed such a course. Fieldes (1955) has also concluded that silica-alumina gel pass through the stage allophane, halloysite and then kaolinite. In these pedons halloysite, however, did not form.

Another course of formation of kaolinite from K feldspar is known to be through the intermediate stage of mica formation (K feldspar.....mica..... kaolinite). Sand (1956) found that kaolinite was pseudo morphous after the mica and the basal plane of the kaolinite oriented, in general, parallel to those of the

mica. De Vore (1959) has suggested an interesting mechanism by which rearrangement of the atoms exposed on the broken surface of feldspar might give rise to similar 2:1 clay mineral. Keller (1964) commented that this possibly is one of the mechanisms resulting in the direct transformation of feldspars to mica and then to kaolinite.

Considering the intense kaolinization process that operated in this profile it is logical to infer that mica, particularly biotite mica, which is major mica component in the rocks of this area, has completely weathered and only some muscovite mica may persist the severe weathering as a result of formation of coatings of stable allophane on their surfaces, which might have protected the inner core i.e. the mica crystal. But the appreciable quantity of mica (23-31%) that is found in the clay fraction and its occurrence in small to trace quantities in other coarser fractions suggest that even if small amount of mica is inherited from parent rocks, there must have been neo formation of mica during the course of weathering.

It, therefore, appears that feldspar weathering in these pedons possibly has also passed through the intermediate stage of mica as suggested by Sand (1956) and Bates (1960) and led to its accumulation in the clay fraction. The traces of mica in the fine and coarse sand fractions are in all likelihood has been inherited from the rock minerals. The mica in the clay and other fraction has been stabilized under the present-day weathering conditions, by the presence of K-feldspars in fairly high amounts in silt and sand fractions.

Weathering of K-feldspar keep the weathering environment rich in K ions and thereby retarding transformation of mica. Though K release from mica is relatively easier than from K-feldspars the relative abundance of K-feldspar and its high concentration in silt size fraction may account for higher k release from the feldspars and thereby effectively stabilising the mica in the clay. Datta (1960)

from study of mineralogy of clay, silt and sand fractions of soils in per-humid regions (Assam State) has also concluded that under intense weathering conditions mica in the clay have been stabilised by presence of K-feldspars in silt and sand fractions.

At this stage it may be pointed out that the clay mineralogy of the C2 and C3 horizons of pedon 1, which showed signs of intense argillation is likely to throw light on what other minerals were formed at various stages of weathering. It is evident from the clay mineralogy data of these two horizons that appreciable amounts of smectite has also been formed during the argillation of this rock. This points to the fact that mica might have weathered in these pedons following the course:

Mica.....> Smectite.....> Kaolinite

Part of the smectite might have been originated by other mechanisms as the lower layers are likely to be rich in silica and bases which are carried in solution from the upper layers. Diagenetic changes of kaolinite by resilication under such condition cannot be ruled out. Rateev (1957) concluded that kaolinite disappears particularly or completely in marine sediments owing to diagenetic transformation. In pedon 1 smectite content in lower layers is associated with decrease in kaolinite content whereas mica content does not show much change (Table 23). This relationship also points to diagenetic change of kaolinite to smectite.

The chlorite like mineral that was detected in these pedons are either derived by chloritization of smectite i.e. aluminum or sesquioxides interlayering of smectite lattice or during the weathering of mica. Such chlorotic mineral are fairly stable and have weathering index of 9 (Jackson, 1963). Thus, occurrence of such minerals is association with kaolinite (weathering index of 10) either in clay or other coarse fraction is quite expected.

Jackson (1953) have suggested that continuity of weathering function is indicated by the occurrence of minerals of successive weathering stages in the soil colloidal fraction and thereby giving a continuous mineral distribution curve. In these pedons clear breaks are observed in the mineral distribution curves of almost all the horizons. In most of the horizons minerals of 7th, 9th, and 10th stages are found whereas 8th stage mineral is not detectable. In fact, 9th stage mineral also occurs in very small quantity except in the C2 and C3 horizons of pedon 1. Similar results were reported for other red and lateritic soil clays by Ghosh et al. (1974). It, therefore, appears that under conditions of intense weathering in tropical climate, Jackson's weathering sequence may show discontinuity.

Occurrence of hornblende in trace quantities in coarser fractions are quite interesting phenomenon. Harrison (1934) reported the occurrence of hornblende in adherent layer of primary laterites derived from hornblende-schist. The traces of hornblende that persist in the pedons under study seems to have resisted their extinction as a result of sesquioxidic coatings on their surfaces. In Earlier investigations such coated grains of primary minerals escaped proper identification because rarely the coatings were thoroughly removed or whenever attempts were made for removal of coatings such drastic methods (e.g. Tamm's acid oxalate method) were that the mineral itself got disintegrated. In the present study it has been possible to detect hornblende by X-ray diffractions only after removal of free oxide by CBD method.

Comparison of the mineral distribution in the three pedons also bring out some interesting features which are related to the topo-sequence of the pedons. Kaolinite in the clay fraction decreases and mica content increases down the slope i.e. from pedon 1 to pedon 2. Amphibole was not detected in the silt fraction of pedon 1 whereas it was present in the silt fraction of the other two pedons. The sand fraction of the pedon 1 has much higher kaolinite content than that of

the other two pedons. All these facts clearly points to the more advanced stage of weathering of the pedon 1 as compared to the other two. Increase in kaolinite content in soil mineral colloid indicate an increasing weathering intensity (Jackson et al. 1948; Tanda, 1950).

The pedon at the valley level shows weathering stage as high as that of pedon 2. It may be recalled that the material deposited in the narrow valley is a mixture of the weathered product brought from the higher elevations. Therefore, though the pedogenic processes have not produced much differentiation in this profile, the overall weathering index of the clay remained fairly high. The content of minerals in the various subfractions of all the three pedons are similar but their relative proportions vary considerably bearing the impress of the effect of toposequence.

The overall sequence of the genesis and transformation of the minerals in these pedon appears to have followed the model as shown in Figure 13.

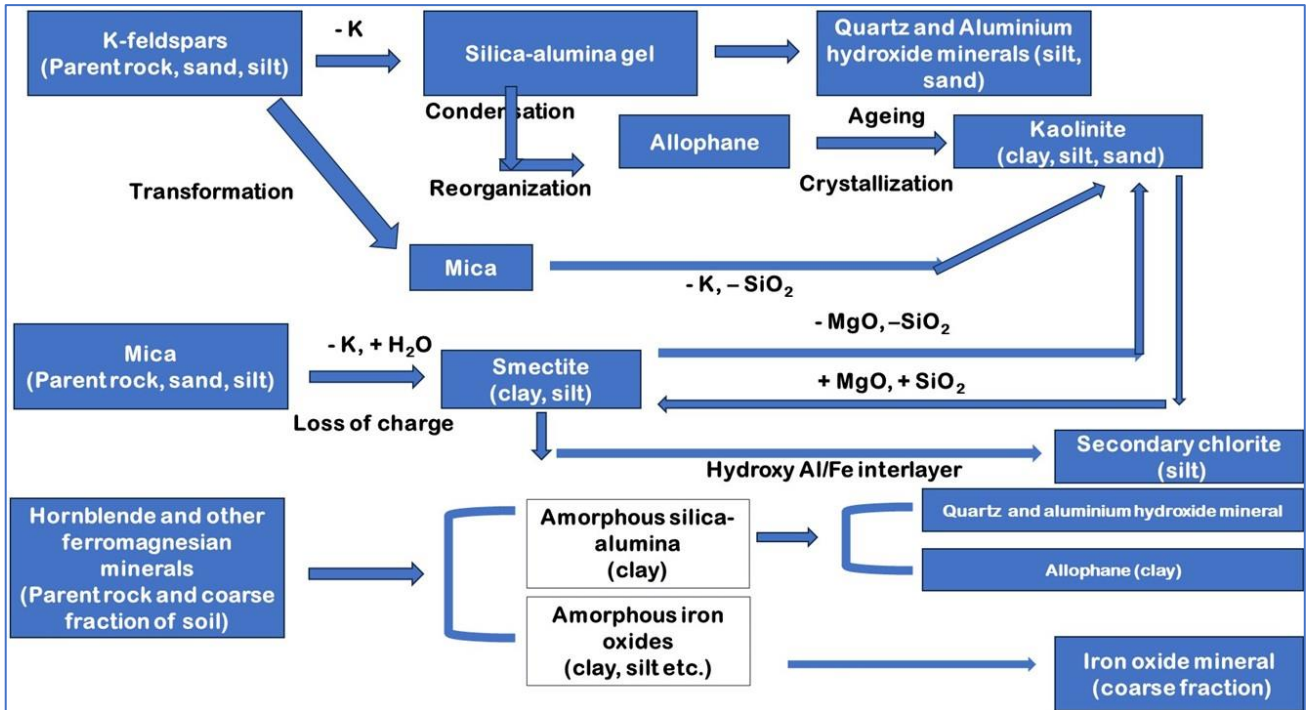


Figure 13. Genesis and transformation of minerals in soils of the study area: a model understanding

7. SUMMARY

The investigation was carried out with three pedons collected in a topo-sequence, one on plateau, another on the mid slope and the third one in the valley from Bangalore South Taluk of Karnataka State to

1. Classify the pedons on the basis of their morphological, physical, chemical and physico-chemical characteristics,
2. Study the effect of relief on the genesis and transformation of minerals in soil derived from granite-gneiss, and
3. Study the genesis of amorphous constituents in these soils as influenced by relief and parent material.

The profile morphology was studied in the field. Other characterisations of the soils were elucidated in the laboratory using standard methods. The X-ray diffraction analysis of different fractions of soil suggested the presence of kaolinite as the dominant mineral in clay and silt while in coarser fractions mostly quartz and feldspars dominate and diaspore, hematite, apatite, amphibole minerals occur almost in trace quantities.

The effect of topo-sequence was conspicuous as with decreasing elevations solum depth decreases, colour of the soils becomes less red. Pedon 2, located at much lower elevation in comparison to pedon 1, is less weathered than the later. The weathering mean data and also the chemical and physico-chemical data further confirm this. Both the pedons, however, was classified as Alfisols and they differ in the subgroup and family level. The pedon 3 shows more pronounced effect of topography as it fitted best in the Inceptisols.

Kaolinite is the dominant mineral together with appreciable quantity of mica in the clay fraction of all the pedons. In the weathered C horizon of pedon 1 the clay also contains smectite. The dominance of kaolinite in the clay and silt

fractions clearly suggest that kaolinization was the major process during the weathering of granite-gneiss. Kaolin appears to have been formed following two pathways: 1) Feldspars.....> Allophane..... Kaolinite, and 2) Feldspar.....> Mica.....> kaolinite. Part of the mica in the pedons also appeared to have been formed by the second pathway. Occurrence of various amorphous constituents were found to characterize these pedons. Topographic influence was also observed in the content of free iron and aluminium oxide, but the content of allophane was apparently not so much affected.

So far, the quantity of the minerals in clay fraction is concerned, pedon 1 contains much greater amount of kaolinite than other two pedons. The gradual decrease in the amount of clay minerals is suggestive of the fact that topography has got an important role to play during the weathering processes in these soils. It also confirms that the pedon 1 is in much more advanced stage of weathering than the pedons in lower elevations.

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